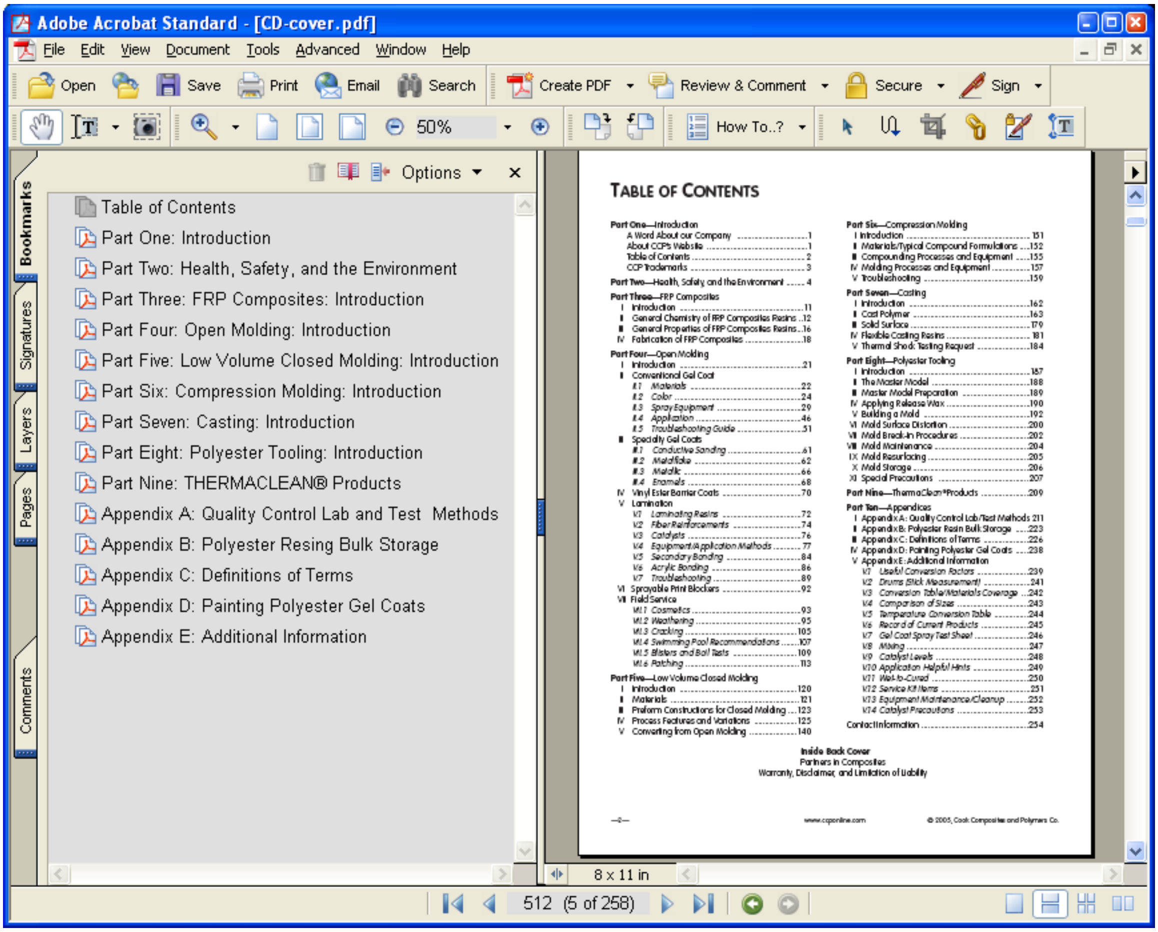
To aid in navigating the 2005 Composites Application guide, this PDF has links in the Table of Contents as well as selected chapter and section pages. Bookmarks also exist for all chapters and appendices as shown in the sample screen below.

Feel free to click on the Table of Contents as well as any chapter and section headings. Many of the chapter headings that are in the “In Part XXX” are also links.

Click here to go directly to the Table of Contents.



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COMPOSITES
APPLICATION GUIDE
10th edition

CCP
COOK COMPOSITES & POLYMERS

With you from start to finish

10th edition

A WORD TO OUR VALUED CUSTOMERS . . .

As your partner in the composites products industry, CCP is committed to supporting your success by providing the latest in composites technology.

We believe that commitment goes beyond researching, developing, and making the best products on the market. By publishing this tenth edition of the CCP Composites Application Guide, our technical staff also provides those critical how to's—that is, expert advice and information to assist you with product selection, application techniques, processes, equipment, troubleshooting, and environmental regulations, as well as other considerations.

Over these ten editions of the Application Guide, the products we make—and the products you make—have seen many changes.

With the implementation of new standards and regulations, you are challenged with making the transition to new processes and new materials. We want that experience to be smooth and trouble-free for you. From low HAP materials to no-HAP processes, this manual will provide you with detailed information on emerging markets and technologies.

Customer satisfaction and product quality are the highest priority at CCP. It is our goal to more than meet the expectations of our customers. We hope this manual will serve you not only as a tool in support of the products you make, but as an important element in our ongoing business relationship.

As always, we welcome your comments and suggestions.

ABOUT CCP'S WEBSITE . . .

Please pay a visit to CCP's website, www.ccponline.com, where you will find a wealth of valuable information, any day, any time. Composites product data sheets and MSDS's are all available in printable PDF format. You'll also find a handy interactive map with contact information for product distributors in your area. And, under *What's New,* you can track CCP's participation in industry trade shows, and keep up with other announcements pertinent to your business operations.

As always, we value your input regarding our website and appreciate your ideas on how we may make the site even more useful to you. E-mail your comments to **feess@ccponline.com.**

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CCP TRADEMARKS

Listed below are trademarked CCP products designed specifically for the composites market. The CCP logo and trademarked product name assure optimum quality backed by a tradition of commitment to research.

ACPOL®—acrylic modified polymers.

AQUA*CLEAN*™—machine-designed for cleaning tools used in composite parts manufacturing.

AQUA*WASH*™—water-based resin emulsifier cleaner.

ArmorCast®—casting resins designed for a wide variety of casting applications.

ArmorClear®—lower emission gel coat with improved flexibility and good weathering resistance.

ARMORCOTE®—in-mold coating with durability that far exceeds basic gel coat.

ArmorFlex®—gel coat with improved flexibility over standard gel coats.

ArmorGuard®—vinyl ester barrier coat designed for reducing osmotic blistering.

ArmorShield PB™—syntactic foam designed to reduce fiber print in a bulk laminate.

ArmorStar®—epoxy-modified skin and bulk-laminating resins designed for the marine industry.

BUFFBACK®—gel coat with excellent gloss recovery in the repair process.

EASY*CLEAN*™—machine designed for cleaning tools used in composites parts manufacturing.

MARBLE*CLEAN*™—cleaning machine for cultured marble and solid surface.

MARBLE*WASH*®—non-hazardous solvent-based cleaner for use in MARBLE*CLEAN*™ machine.

NUPOL®—thermosetting acrylic resin.

OPTIMOLD®—mold construction system that includes a filled tooling resin mix for rapid mold production.

***OptiPLUS*™**—mold construction system for non-filled shrink controlled tooling resin.

PATCHAID®—additive designed for gel coat and in-mold coating to improve patching results.

POLYCOR®—products of UPR, gel coats, and polymer systems.

REPLACETONE®—water-based resin emulsifier.

STYPOL®—products of UPR, gel coats, and polymer systems.

THERMA*CLEAN*®—non-hazardous cleaning products.

UNI*SOLVE*™—universal solvent.

UNI*WIPE*™—low NVR surface cleaner.

Wipe-Bright™—surface cleaner.

XYCON®—family of hybrid polymers based on polyester (or other unsaturated polymers) and urethane chemistries; also considered an inter-penetrating polymers network.

HEALTH, SAFETY, and the ENVIRONMENT

Part Two

In This Section

1. INTRODUCTION—Health, safety and the environment are of prime importance to all manufacturers, especially those handling hazardous materials and chemicals. This has become a very complex issue with numerous Federal, State and Local regulations. Each user of a chemical product, such as polyester resin and gel coat, must comply with Federal, State and Local laws that regulate production, employee exposure, emissions, and shipping hazardous materials and waste.

The following information is of a general nature only. Compliance requirements must be determined by the user of the product. Information concerning the hazards of these products can be found in the Material Safety Data Sheet (MSDS) and label for each product. These documents must be read. Polyester resins and gel coats can be handled safely when proper precautions are taken to protect workers, facilities, and the environment.

CCP products are intended for industrial users only. Sales to private individuals and home consumers is not recommended nor endorsed. CCP does not sell products (nor recommend that they be sold) to private individuals for repairing their boats, tubs/showers, lawn furniture, swimming pools, spas or saunas, farm implements or equipment, automobiles, etc. There are plastic supply firms and automotive retail outlets that have products available for fiberglass repair.

Information concerning health and safety regulations can be obtained from OSHA, EPA, State and Local governing offices or their websites. At the end of this chapter is a list of references including websites where more detailed information can be obtained.

2. REGULATIONS—

A. Federal Regulations—The OSHA Hazard Communication Standard, 29 CFR 1910.1200, requires employers to evaluate chemicals used in their workplaces to determine if they are hazardous and to transmit information on hazardous chemicals to employees by means of a comprehensive training and in-plant hazard communication program.

OSHA establishes permissible exposure limits (PELs) for certain chemicals, such as styrene, which has an industry voluntary standard for permissible exposure of 50 ppm, and an OSHA PEL of 100 ppm.

SARA TITLE III (EPA, 40 CFR 355) requires emergency planning, chemicals inventory reporting and toxic chemical release reporting.

The Resource Conservation Recovery Act (RCRA) includes 'cradle to the grave' regulations, governing the generation of storage, treatment, and disposal of hazardous waste.

The Clean Air Act Amendments of 1990 (CAAA) regulate emissions of hazardous air pollutants (HAP) and volatile organic compounds (VOCs).

The Department of Transportation regulates shipment of hazardous materials and wastes.

B. State Regulations—State and/or Local regulations must be at least as stringent as the Federal requirements.

California regulations place limits on VOC emissions of resins and gel coats by limiting monomer content and requiring specific application methods.

California also requires the label or data sheet to state the amount of any VOCs in that product.

California Proposition #65 prohibits releases of certain chemicals into drinking water and requires 'clear and reasonable' warning to persons potentially exposed to carcinogens and reproductive toxins.

Other states, such as New Jersey and Pennsylvania, have regulations concerning hazardous materials.

Federal, State and Local regulations are constantly changing. Publications and trade organizations, such as the ACMA or NMMA, are good sources for tracking regulatory information.

3. SAFETY—CCP encourages its customers to develop a Safety Management System. Safety is the responsibility of every employee. Fire losses and worker illnesses and injuries have occurred where good work practices were not established or enforced.

The Safety Management System should designate the person(s) responsible for the written safety programs (Hazard Communication, Personal Protective Equipment, Lockout/Tagout, Confined Space Entry, Exposure Control, Disaster Control, etc.) and employee training. Supervisors and employees should be aware of hazards (see MSDS), necessary precautions, and incident reporting responsibilities.

Periodic safety inspections are recommended. Material Safety Data Sheets (MSDS) and other safety data for all hazardous materials found in the work place must be kept on-site. All employees, supervisors and workers, should be aware of proper handling and cleanup directions when handling any hazardous material.

CCP strongly recommends that its customers establish an Emergency Action Plan or Emergency Response Plan for each facility.

4. FIRE HAZARDS—A fire is dangerous, destructive and costly. It can start from a simple cause or a complicated one. Knowing how fires start is the foundation to knowing how to prevent one.

To sustain a fire, there must be:

- Fuel
- Oxygen
- Heat or an ignition source.

If you remove any one of these factors, a fire cannot occur.

A. Fuel—Quantities of a fuel source are required for a fire. Resins or gel coats, in the liquid state, are flammable fuel sources. Resins or gel coats can also be combustible fuel sources when cured, or as a dust. Most cleanup solvents, catalysts, and waxes are fuel sources. Composites plants have the usual fuel sources of paper, rags, wood, cardboard boxes, trash, etc. All fuel sources must be carefully controlled and minimized.

Resins and gel coats are found in four states in a plant:

- Liquid
- Vapor
- Solid
- Dust.

Vapors and dust are typically the most dangerous. Excess vapors and dusts must be avoided. Keep containers closed or covered when not in use. Controlled dust should be reduced and not allowed to accumulate.

Vapors are created from spraying, heating from curing parts, evaporation, etc. Vapors from resin and gel coat are heavier than air (sink to the floor) and may collect in low spots. Vapors and dust can normally be removed from a plant by effective mechanical ventilation.

NOTE: Check for Federal, State, and Local codes on exhausting and/or discharging any materials directly into outside air. These regulations must be followed.

Flammable liquid resin and gel coat are also dangerous. It is essential to keep uncatalyzed resin and gel coat in closed containers when not in use, and stored in a separate area away from the work area until needed. Do not store in direct sunlight or where excess heat is present. Wipe up or remove all spills or over spray as soon as possible.

Liquid catalysts (peroxides) must be handled according to the manufacturer's recommendations. Organic peroxides can be explosive and are the most dangerous fuel in a plant, because they provide oxygen and fuel to a fire. They should be kept in their original containers, out of direct sunlight, not exposed to heat, free from contamination, and closed when not in use.

Catalysts are oxidizing materials which will react (at times explosively) with reducing agents, such as cobalt accelerators, metals, and strong acid. A catalyst should never be diluted with acetone. If a diluted catalyst is necessary, use catalysts obtained from a catalyst manufacturer or those diluents recommended by the catalysts' manufacturer.

Catalyst must always be kept or used in containers which will not react with the catalyst. See the catalyst manufacturer's MSDS for specific recommendations. Over-spray and catalyst mist must be minimized. Over-spray must be wiped up and removed immediately according to the manufacturer's recommendations.

Special care must be taken with catalyzed resin or gel coat (e.g., over sprays and gun flushings, as these mixtures have the individual hazards of all the combined materials of resins or gel coats, catalyst, solvent, etc.). In addition, the chemical reaction between the resin or gel coat and catalyst produces heat which can possibly cause ignition of solvents, unmixed or high concentrations of catalyst, and other flammable materials. The amount of heat generated will depend on the amount of catalyst, the degree of mixing, the temperature, the mass, and the reactivity.

Catalyzed resin or gel coat must not be allowed to accumulate. Gelled masses and sanding dust should be removed at once or temporarily immersed in water until they can be removed.

Plant solid waste must be handled carefully. Trimmings, over-spray and trash have thin ragged sections which can be ignited. Trash should not be allowed to accumulate. The cured parts are harder to ignite, but will burn.

Likewise, any finely divided solid material may present a fire or explosion hazard when dispersed and ignited in air if the following conditions are met:

- The dust is combustible.
- A cloud is formed exceeding the minimum explosive concentration.
- A source of ignition is present. Dusts should be minimized and not allowed to accumulate.

Wax mold release agents are also fuel sources. Care and caution must be used with these materials and the materials used in their application and removal. See the manufacturer's MSDS for instructions for handling, use and storage.

B. Oxygen—Oxygen is necessary for any fire. There are two main sources of oxygen: air and chemically combined oxygen in the material itself. All volatile materials must be within certain ratios with air or oxygen to burn or explode. With polyesters (resins or gel coats), good mechanical ventilation can dilute the fuel below its explosive limit.

Peroxides are a special case. Peroxides contain chemically combined oxygen which can be easily liberated for combustion by heat, chemical reaction, decomposition, contamination, etc. Since peroxides are also fuels, all that remains for a fire is heat or a source of ignition.

Because of this, peroxides require additional care to be used safely. Storage should be separate from other flammable or combustible materials. Close containers when not in use. Spills, gun flushings, and over-sprays should be removed immediately. See the manufacturer's MSDS for recommendations.

C. Heat—Heat or a source of ignition is necessary for a fire. This can be a match, cigarette, flame, hot filament, exotherming resin or gel coat, heater, pilot light, spark (metal or hard surface or static), arcing of an electric motor or wires, etc.

Dusts and vapors require a smaller ignition source than liquids or cured parts to start a fire.

To avoid these hazards, ignition sources must be removed from spray areas, working and storage areas.

One source of heat that must not be overlooked is from the chemical reaction of resin or gel coat and/or peroxides. Polyesters produce heat when they gel and cure. The amount of heat produced depends on the amount of catalyst and its degree of mixing, the temperature, the mass, the resin to filler ratio, and the reactivity.

Trimmings, over-spray, flushed material from spray guns, and dust from sanding and grinding should be removed at once or temporarily dispersed in water until they can be removed.

A good safety program works to remove, control or minimize all three elements.

The following results indicate that closed cup flash points are lower than open cup flash points. This data also shows that the addition of acetone to a gel coat significantly lowers the flash point.

FLASH POINT DATA

Material	Closed Cup & Flash Point (Approx.)
Acetone	0°F
Methyl Ethyl Ketone	20°F
Ethyl Acetate	24°F
Styrene	88°F
Polyester Gel Coats	79 to 88°F
Methyl Methacrylate	51°F

CCP does not recommend the addition of acetone or any other solvent to resins or gel coats.

The following extinguishing agents may be used on resin or gel coat fires:

- Foam
- Dry chemical
- Water fog
- Carbon dioxide.

If electrical equipment is involved, the use of foam or water should be avoided.

NOTE: Direct streams of water may spread a fire involving solvents or monomers due to incompatibilities and density differences. The burning material often floats on water.

By properly handling catalysts and accelerators, controlling vapors, and keeping the shop safely clean, much can be done to reduce the risk of fire. With these factors controlled, a composites operation is relatively safe.

5. GENERAL HAZARDS OF MATERIALS USED—

A. Catalysts (Initiators)—Read the MSDS for all catalyst products. The catalysts required for curing resins and gel coats are usually organic peroxides, such as methyl ethyl ketone peroxide (MEKP) and benzoyl peroxide. By their nature, organic peroxides are usually highly flammable and may decompose explosively.

Initiators are tested for heat sensitivity, shock sensitivity, burning rate, flash point, storage stability, and reaction to blasting caps to determine their relative hazards.

Obtain the manufacturer's MSDS and product information to learn more about how to safely dispose of unwanted or old initiators.

According to NFPA 43B, incompatible materials (such as accelerators) and flammable liquids should not be stored within 25 feet of organic peroxides. The effective separation distance should be maintained by floor slope, drains, dikes, two-hour fire wall, or detached storage building to prevent flammable liquid leaks from entering the organic peroxide storage area.

Only closed containers should be permitted in the storage areas. No more than a one day inventory quantity of initiator should be brought from storage into the work area.

Initiators should never be added or allowed to contact accelerator which has not been added and well mixed with large, diluting quantities of resin or gel coat. The best procedure is to first mix accelerator in the resin until a homogenous mix is obtained, then add the initiator. See manufacturer's handling precautions.

A very small amount of peroxide initiator can make drastic changes in the physical properties of a resin or gel coat. CCP emphasizes the importance of following the proper procedures in handling the commercial forms of these products. Failure to do so can lead not only to poor performance of the initiator but also, in some instances, to a violent polymerization or decomposition.

Storage conditions and contamination are potential sources of risk in handling peroxide initiators:

1) Heat—Do not expose organic peroxides to any form of heat, such as direct sunlight, steam pipes, radiators, open flames or sparks. Heat may cause organic peroxides to decompose violently and they will burn if ignited. Never exceed the peroxide manufacturer's recommended storage temperature or conditions.
2) Metals—Do not let organic peroxides come in contact with easily oxidized metals such as copper, brass, and mild or galvanized steel. If replacement parts must be installed on peroxide handling equipment, use the same materials of construction as specified by the manufacturer of the equipment.

   Metal contamination, such as dust from grinding, can produce serious consequences. For example, installation of a brass relief valve on a catalyst pressure pot or a brass connector in a catalyst line could cause the peroxide that comes in contact with the brass to decompose. Under such confined conditions, the decomposing peroxide could develop enough pressure to burst the pressure pot or the initiator line.
3) Promoters and Accelerators—Never mix organic peroxides directly with promoters or accelerators. Such mixtures can be explosive. In addition, never contaminate initiators with resin or resin over-spray because the resin may contain enough promoter to decompose the peroxide. A small amount of promoter goes a long way. Promoters are not consumed; they just continue to decompose the peroxide. The peroxide decomposition produces heat. This heat speeds up the action of the promoter, which then produces more heat; and so the cycle can continue until the point is reached where the remaining peroxide decomposes violently.
4) Solvents or Diluents—If a solvent is used to clean organic peroxide handling equipment, be sure to dry off the solvent before using. Some solvents, such as acetone, can react with peroxides to form unstable peroxides of their own. Small amounts of these unstable 'solvent peroxides' can cause the explosive decomposition of commercial peroxides.

   If it is necessary to dilute an organic peroxide, be sure to consult with the peroxide manufacturer for compatible solvents. Never use contaminated solvents. Never use reclaimed solvents unless they have been tested by the peroxide manufacturer. For greatest safety, obtain the manufacturer's diluted organic peroxides.
5) Always store an organic peroxide in its original container. If it is necessary to transfer or measure out some peroxide, use clean polyethylene, polypropylene, Teflon® or stainless steel containers, funnels, etc.
6) Other—Other types of contaminants to be avoided when working with organic peroxides are dirt, resin or gel coat sanding dust, acids, bases, and styrene. Further information on the proper handling of peroxides is available on request from catalyst manufacturers.

Basic guidelines regarding organic peroxides include:

1) Read the MSDS (Material Safety Data Sheet).
2) NO SMOKING around peroxides (or any polyester or associated materials).
3) Organic peroxides and promoter (for example, MEKP and cobalt) should NEVER be mixed directly with each other—a violent reaction will occur!
4) Organic peroxides should always be stored separately from promoters. Consult local insurance inspection bureau and fire authorities for guidance.
5) Organic peroxides should not be allowed to 'sit around.' Take only as much as will be used during each shift. If the peroxide is transferred into another container, use a container made of a suitable material such as polyethylene.
6) Always wear eye protection. Rubber gloves and face shields are also recommended.
7) Organic peroxides should not be stored in a refrigerator that also contains food or water, nor should they be poured into or stored in containers that could be mistaken for other items, such as a soda pop bottle, baby bottle, etc.
8) Dilution of organic peroxides by the end user is not recommended.
9) Although the flash point of some organic peroxides is higher than other chemicals usually found in the typical composites operation, it is misleading to think that peroxides are 'safer' with regard to fire. While it will take a hotter temperature to get them to burn, they will decompose and auto-ignite sooner than the other chemicals. The decomposition temperature is 145°F to 170°F.
10) Do not expose organic peroxides to any form of heat such as direct sunlight, steam pipes, radiators, open flames, or sparks.

11) Do not let organic peroxides come in contact with easily oxidized metals such as copper, brass, and mild or galvanized steel.
12) Most organic peroxide suppliers have safety programs available (including videos or CD's). Contact the supplier to request a Product Stewardship visit.
13) Always store organic peroxides at or below the recommended temperature as specified by the manufacturer.
14) 'Red' organic peroxides are believed by some to be less stable than clear. Rotate inventory of red organic peroxides frequently.
15) These safety considerations are not all inclusive. The organic peroxides supplier should be contacted for specific safety recommendations.

B. Accelerators—Read the MSDS. Some of the accelerators commonly used are extremely hazardous. Diethylanaline (DEA) and dimethylanaline (DMA) are particularly hazardous since even small splashes may be absorbed through the skin, resulting in contact dermatitis. Headache, nausea, breathing irregularities, or fainting may occur soon after breathing vapors of these materials. If excessive quantities are inhaled, even more severe reactions, including poisoning or death, may occur.

C. Styrene and Solvents—Read the MSDS. Some monomers and cleanup solvents used may have health effects. Physiological health problems may occur from overexposure. For specific information regarding the health hazards of specific products, consult the manufacturer's Material Safety Data Sheet.

The accumulation of styrene and solvent vapors provides one of the conditions for an explosion or flash fire. A static charge or simple spark ignition source is all that is needed. Vapors should be immediately removed by a good ventilation system.

California Air Quality Management District rules require that the maximum loss of volatile organic compounds (VOCs) of all VOC-containing products packaged in quarts or larger be reported. This includes CCP's gel coat and resin product lines.

As a result, a series of tests were performed according to the Standard Method for Static Volatile Emissions on catalyzed polyester resins and gel coats. The maximum quantity of VOCs not consumed during polymerization was found to be 40 grams per liter (or 230 grams per meter considering surface area exposed to air) for all catalyzed CCP resins and gel coats measured in a gallon can lid. For all uncatalyzed CCP resins and gel coats, the maximum VOC content is 600 grams/liter.

Copies of this VOC content information should be retained and available for compliance inspections.

Depending on the application equipment, the temperature, and gel time, gel coats may lose 20 to 25 percent of the pounds sprayed, or up to 65 percent of the monomer(s) present.

Styrene, a typical monomer, can be lost from gel coats in two ways. When gel coat is atomized, styrene evaporates as the gel coat travels from the end of the gun to the mold. The loss of styrene at this point is controlled by temperature, method of atomization, spray distance, and the degree of breakup (atomization).

The second loss occurs as the gel coat cures on the mold. During this time period, the loss is governed by the evaporation rate of styrene. Once the surface film is gelled, the evaporation rate drops off dramatically. This loss of styrene is influenced by the gel time, temperature, film thickness, surface area, mold configuration, and air movement.

Styrene monomer is flammable and forms explosive mixtures with air:

- The lower explosive limit is: 1.1 percent.
- The upper limit is: 6.1 percent (percent by volume).

When styrene vapor is present in concentrations between these limits, any source of ignition can cause an explosion.

Styrene Ignition Temperatures	
Flash point is the lowest temperature at which a substance gives off enough vapors to form a flammable or ignitable mixture with air near the surface of the substance being tested.	Flash point of styrene is 31°C (87.8°F)
Fire point is the lowest temperature at which a liquid in an open container will give off enough vapors to continue to burn when ignited. Fire points are generally slightly above flash points.	Fire point of styrene is 34°C (93.2°F).
Auto-ignition temperature is the lowest temperature required to initiate or cause self-sustained combustion in the absence of a spark or a flame.	Auto-ignition temperature of styrene is 490°C (914°F).

Adequate ventilation (especially the use of fume hoods) is recommended. Open flames, local hot spots, friction, and static electricity must be avoided.

D. Disposal of Cured Unsaturated Polyester—Discarded solid plastic materials from a manufacturing process utilizing unsaturated resins or gel coats cured with organic peroxides, like methyl ethyl ketone peroxide, constitute an industrial solid waste. As required by 40 CFR 262.11 (and corresponding applicable state regulations), the generator of this waste is required to determine if it is a hazardous waste.

This process would involve the determination if the solid waste is classified as a listed hazardous waste, either as a discarded commercial product (40 CFR 261.33), as a specific source waste (40 CFR 261.32), or as a nonspecific source waste (40 CFR 261.31). The generator must then determine whether the waste meets the characteristics of hazardous waste defined in 40 CFR 261, Subpart C. These defined characteristics are:

Defined Characteristics of Hazardous Waste			
Ignitability	Corrosivity	Reactivity	Toxicity

Since the waste is not a liquid with a flash point of less than 140°F, a non-liquid which may ignite spontaneously or by friction, an ignitable compressed gas, or an oxidizer, it does not exhibit the characteristics of 'Ignitability.' Likewise, the waste does not exhibit the characteristics of 'Corrosivity' (aqueous pH less than two or greater than 12.5 or corrodes steel) or of 'Reactivity' (i.e., normally unstable, violently water reactive, or capable of generating toxic gases, vapors or fumes in contact with water). Depending on the level of methyl ethyl ketone peroxide used, the solid waste may be classified as hazardous because of toxicity. Methyl ethyl ketone is listed in Table 1 of 20 CFR 261.24.

All generators of solid wastes of this nature should retain a written determination in their records with documented data or generator knowledge on waste profiles for all wastes which they generate. This is required by Federal and State regulations.

6. HEALTH HAZARDS—Read the MSDS for health hazard warning information for all materials used in the workplace. Most materials used in a manufacturing facility may be hazardous if not properly or carefully handled. Each chemical should be considered separately, and looked at in reference to other chemicals with which it can come in contact or react with to produce new chemicals. Chemicals may enter the body through several routes of entry including inhalation, ingestion, absorption, or injection. Consult the MSDS (Material Safety Data Sheet) to determine acceptable exposure levels and emergency response procedures.

Both the OSHA Hazard Communication Standard and certain state regulations require that manufacturers place precaution labels on containers of manufactured products, and provide to each customer Material Safety Data Sheets that list the acute (immediate) and chronic (delayed) hazards of their products.

Contact with hazardous materials must be minimized. Resins, gel coats, solvents, initiators, etc., should not come in contact with the body. Where contact is unavoidable, protective equipment (clothing, gloves, etc.) should be used and all spills cleaned up at once.

Safety glasses or goggles must be worn at all times in all working areas.

If the possibility of vapor or dust is present, adequate ventilation is necessary. NIOSH-approved 'hood type' supplied air respirators are recommended for applications with high vapor or dust levels. *NOTE: Air supplied to the hood must be absolutely clean and separate—no exhaust vapors or compressor oil. All dusts should be removed by adequate ventilation and with an adequate face mask being worn. Do not use air to blow dust off a person. Remove by washing with cool water.*

Pigments used by some gel coat suppliers may contain lead and hexavalent chromium compounds. OSHA regulations require workplaces with lead containing materials to monitor worker exposure. Because of the number of recognized health hazards associated with the use of lead and heavy metal pigments, CCP does not use lead or heavy metal pigments in its resin or gel coat products.

Two types of lead/chromium pigments used by some gel coat suppliers are described as:

CHROME YELLOW

- Classified as Light and Primrose
- Contains Lead Chromate
- Lead is a reproductive toxin and affects various body systems and organs adversely.
- Hexavalent Chromate is considered a respiratory carcinogen.

MOLY ORANGE

- Bright Orange and Scarlet shades
- Is a compound of Lead Chromate, Lead Molybdate and Lead Sulfate
- Has the same lead and chromate hazards as Chrome Yellow.

Many states have regulations to control the use and waste disposal of mixtures containing lead and hexavalent chromate. The OSHA Occupational Exposure to Lead Standard, 29 CFR 1910.1025, defines requirements of workplaces with employees who may be exposed to lead. Compliance procedures required by this standard include:

A. Make an initial determination of employee exposure by monitoring the work space in which lead may be present.

B. Employee exposure is that exposure which would occur if the employee were not using a respirator.

C. Notify employees within five days of the receipt of monitoring results that represent that employee's exposure.

D. If monitoring results show employee exposure to be at or above the action level of 30 micrograms of lead per cubic meter, additional monitoring is required.

E. If monitoring results show employees are exposed to lead above the permissible exposure level of 50 micrograms per cubic meter, periodic monitoring, medical surveillance, engineering controls, employee notification and respirators may be required.

If the decision is made to monitor for lead or chromium, qualified industrial hygiene consultants for monitoring and testing services may be obtained by contacting:

American Industrial Hygiene Association
2700 Prosperity Ave., Suite #250
Fairfax, VA 22031
Ph: 703-849-8888
Fax: 703-207-3561
www.aiha.org

7. ELECTRICAL HAZARDS—The two main hazards from electrical equipment are sparks and shock. All equipment, power lines, lights and connectors should be explosion-proof and effectively grounded.

All possible sources of static discharge should be eliminated through adequate grounding or other measures. This includes spray guns, holding tanks, transfer lines, etc.

8. EQUIPMENT HAZARDS—A composites operation may use many power tools. All tools which have exposed turning parts should have guards to prevent hands and clothing from being caught in them. All persons should be properly trained in the use of power tools. Spray guns should be grounded, worn fittings and hoses replaced.

NOTE: Airless spray equipment develops enough pressure to force material through the skin. Safeguards must be taken to prevent this. Any person who sprays, regardless of equipment type, must be adequately trained and be made aware of how to protect himself and others from these hazards.

Before starting repairs on spray equipment or any equipment with moving parts or internal pressure, turn off and disconnect all power sources and bleed off ALL internal pressures. Care must be taken with chopper guns because cutting blades and glass roving cut anything with which they come in contact.

Well-run housekeeping and order programs that include trash removal, spill cleanup, and regular equipment and building maintenance, will reduce fire and health hazards in the workplace. Such programs save money, promote efficiency, and increase job satisfaction.

9. HEALTH, SAFETY, AND ENVIRONMENTAL INFORMATION—The references listed below are given as a guide only. This is not meant as a recommendation or endorsement of any of these references or services. They are listed as a sample of the type of information that is available.

There are many sources of information and guidance on health, safety and environmental matters, for example:

- Company insurance carrier
- Local Fire Marshall
- Suppliers (product stewardship)

Other sources of information are:

REGULATIONS/COMPLIANCE

United States Environmental Protection Agency (EPA)
www.epa.gov

United States Department of Transportation (DOT)
www.dot.gov

Occupational Safety and Health Administration (OSHA)
www.osha.gov

American Composites Manufacturing Association
1010 Glebe Rd., Ste 450
Arlington, VA 22201
Ph: 703-525-0511
Fax: 703-525-0743
www.acma.org

National Marine Manufacturer's Association (NMMA)
200 E. Randolph Drive, Ste 5100
Chicago, IL 60601
Ph: 312-946-6200
www.nmma.org

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www.nfpa.org

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No. 68 — Explosion Venting Guide
No. 69 — Explosion Prevention System
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CHEMICAL HEALTH HAZARDS

National Toxicology Program (NTP)
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FRP COMPOSITES: Introduction

Part Three, Chapter I

In Part Three:

Chapter I: **Introduction**
Chapter II: **General Chemistry of FRP Composites Resins**
Chapter III: **General Properties of FRP Composites Resins**
Chapter IV: **Fabrication of FRP Composites**

A composite material is an engineered product made by combining dissimilar materials that remain separate and distinct from each other on a macroscopic level. The resulting material has a unique set of characteristics and qualities that is more useful than any of its individual constituent materials.

Any composite consists of a matrix material and a reinforcing material. The matrix surrounds the reinforcement, maintaining the relative positions of the reinforcements. The matrix serves to transfer loads from the surface of the part into the reinforcement material and between reinforcements. Almost any material can fulfill the matrix role. A few examples of broad categories of matrix are:

- Mud
- Pitch
- Plastic
- Carbon
- Glass
- Cement
- Rubber
- Ceramic
- Metal.

The reinforcement can take numerous forms such as:

- Powdered or aggregate minerals
- Whiskers (very short fibers)
- Chopped fibers
- Continuous fibers.

Fibers can be fashioned into textile products such as felts or cloths, or fabrics of various constructions. Fiber materials can be composed of a wide variety of materials such as glass, carbon, silicone carbide, boron, mixed ceramics, a number of different polymers, and naturally occurring materials such as hemp.

Composite materials are different from conventional materials in many ways. Most significantly, they achieve their properties and characteristics only after being successfully processed in the manufacturing facility. They are composed of truly 'raw' materials. Age of materials, their storage, and processing temperatures are only three of the variables that must be managed and controlled.

In contrast, a so-called raw material such as aluminum sheet arrives on a skid with all of its properties and characteristics intact, and it keeps them indefinitely, barring some very extreme exposure conditions. The handling and usage of composite materials is not unlike the handling and usage of food items. Quality requires freshness, while consistency requires adherence to 'the recipes' and attention to process details. It is no surprise that this application guide has become known throughout the world as the 'Cook Book.'

Composite materials consisting of Glass Fiber Reinforced Polyester (GFRP) resin are in widespread use throughout the world. These are generally considered 'commodity' type composite materials. Applications range from fiberglass bathware to solid-surface counter tops to decorative statues to vehicular body parts to windmill blades and more. Almost anything can be molded using GFRP.

Glass fibers are composed of a mixture of inorganic metal oxides. The principle constituent is silicone dioxide with smaller amounts of aluminum oxide, calcium oxide, magnesium oxide, boron oxide, and zirconium oxide. Exact composition determines the end-use performance. There are at least seven commercially available glass types with the most common being E glass, followed by A glass and then C and S glass. Quartz fiber is essentially pure silicone dioxide and features one of the lowest dielectric constants of commercial materials.

The class of resin chemistry determines the end-use suitability for any application. Unsaturated polyester resins provide a good balance of properties for a modest cost. Vinyl ester resins offer improvements in certain properties such as strength and heat resistance, but at a cost premium.

Fiber Reinforced Plastic (FRP) parts are molded to the design shape by using a cure tool and a molding protocol. Most cure tools are called molds, although not all molds are curing tools. The most common exception is a fiber pre-forming mold. A cure tool can consist of several elements. At its very minimum, a cure tool consists of a mold skin which mirrors the cured part about its external surface. Larger molds incorporate bracing to reinforce local areas and framing to distribute the mold weight onto concentrated load points such as casters, which also provide for mobility.

This guide pertains to one specific type of composite known as Fiber Reinforced Plastic (FRP). The major subcategory of FRP is Glass Fiber Reinforced Plastic (GFRP or GRP). All three terms are sometimes used interchangeably.

FRP COMPOSITES: General Chemistry of FRP Composites Resins

Part Three, Chapter II

In This Chapter

1. INTRODUCTION—Thermoset polyester and vinyl ester polymers are the starting point for most CCP resins and gel coats. They are the basis for RTM, marble, casting, laminating and molding resins.

These resins are very versatile and are used in a broad spectrum of applications, including:

- Building and construction
- Corrugated and flat paneling
- As reinforcement for acrylic sheet
- In shower stalls, tubs and marble vanities
- In both interior and exterior auto body panels
- In polymer concrete and mine bolts
- In electrical components
- In boat and other marine laminates
- In corrosion-resistant tanks and components.

They are the major component in buttons, simulated wood castings and bowling balls. They can be formulated from rigid to flexible (or anywhere in between) and can be corrosion and water resistant. They can be used unfilled, filled, reinforced, or pigmented. Fabricators can cure polyester resins at temperatures that range from ambient up to 400°F.

When armed with a knowledge of how polyester and vinyl ester resins are made and how they cure, the fabricator will more readily understand some of the things that affect them. This will support good use techniques with fewer problems. Knowledge and experience together provide the foundation for efficient production methods and high quality parts.

This chapter of the Applications Guide offers a brief description of the chemistry of thermoset polyester and vinyl ester resins. It is a guide to how they are made and how they cure. Further information is available in the references listed at the end of this chapter.

2. SYNTHESIS OF POLYESTER AND VINYL ESTER POLYMERS—The building blocks for synthesis of polyester and vinyl ester polymers generally come from the petrochemical industry. Their ultimate source is oil and/or natural gas. They are primarily composed of carbon, hydrogen and oxygen. For unsaturated polyesters, they fall into three types of compounds: dibasic acids, glycols, and monomers/diluents. For vinyl esters, the building blocks are diepoxides, monofunctional acids, and monomers or diluents.

For polyester chemistry, the acids and glycols join together under heat to form a long chain called a polymer. Because the acids and glycols react together to form an ester in what is called an esterification reaction, the resulting polymer is called a polyester (literally 'many esters'). Some of the dibasic acids are unsaturated and for this reason the polyester is said to be an unsaturated polyester. To form the polymer, the acids and glycols are 'cooked' together in a kettle. Cooking time can vary from 14 to 24 hours at temperatures up to 430°F. The progress of the cooking process—or 'cook'—is followed by measuring the reduction in acidity and the increase in viscosity. A by-product of the reaction is water that boils out of the reaction kettle as it is formed.

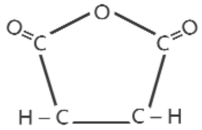
Vinyl esters also form similar unsaturated esters via an addition reaction between the epoxy function and acids. The unsaturated part typically comes from the methacrylic acid rather than maleic acid as is the case with unsaturated polyesters. Processing conditions are typically eight to 14 hours at temperatures up to about 246°F. Processing parameters are very similar to unsaturated polyesters, however, no water is eliminated as this is an addition rather than condensation reaction.

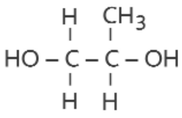
The polyester or vinyl ester polymer is generally a hard solid, similar to a chunk of glass. To make it readily usable by the fabricator, it is dissolved in a monomer, usually styrene, which also has an unsaturated portion. When the fabricator adds a peroxide catalyst, the unsaturated portion of the monomer reacts with the unsaturated portion of the polymer. The resulting material is a hard solid that will not soften or melt even when heated to very high temperatures. For this reason, the resin is said to be a thermoset resin.

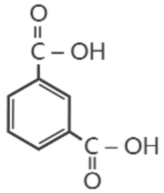
3. TYPES OF POLYESTER AND VINYL ESTER RESINS—The final properties of the polyester resin depend on the acids, glycols, and amount of unsaturated acid used in making the polyester polymer. The most common unsaturated acid is maleic anhydride. Maleic anhydride converts to maleic acid and then finally to fumaric acid during the cooking process. Saturated acids include phthalic anhydride, isophthalic acid, and adipic acid. Glycols include ethylene glycol, diethylene glycol, propylene glycol, dipropylene glycol, and neopentyl glycol.

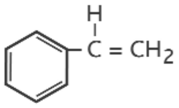
Styrene monomer is nearly always used, but other monomers that can be used are vinyl toluene, alpha-methyl styrene, and methyl methacrylate. The structures of some of these components are shown on the following page.

Each of these components contributes to the final properties of the resin. Isophthalic acid and neopentyl glycol increase moisture, chemical and corrosion resistance. To improve resistance to weathering, neopentyl glycol, methyl methacrylate, and stabilizing additives that protect against ultraviolet rays of the sun, are used. Addition of adipic acid plus reducing the amount of unsaturated acid results in a softer resin with increased flexibility. In contrast, to increase rigidity, higher amounts of unsaturated acid are used, sometimes with higher-functionality monomers such as divinylbenzene. These materials result in greater hardness and rigidity by increasing the number of chemical bonds of the resin as it cures. To alter the flammability characteristics of a resin, acids such as chlorendic anhydride and tetrabromophthalic anhydride are used.


MALEIC ANHYDRIDE

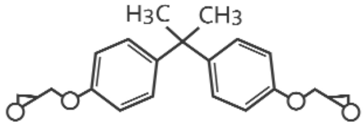

PROPYLENE GLYCOL

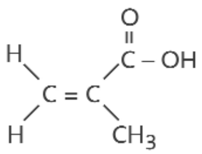

ISOPHTHALIC ACID


STYRENE MONOMER

Another building block, generally used in laminating resins, is dicyclopentadiene (DCPD). It replaces some of the glycol and contributes a faster tack free time with lower apparent shrinkage and a smoother surface on cure. These resins are primarily used in structural applications which require an excellent cosmetic appearance and reduced fiber print-through.

As with unsaturated polyester, the final properties of vinyl ester resins are very dependent on the choice of polymer constituents. The most common and basic vinyl ester resins employ the diglycidyl ether of bisphenol-A as the diepoxy, and methacrylic acid as the unsaturated mono-acid. The structures of these components are shown below:


DIGLYCIDAL ETHER OF BISPHENOL – A


METHACRYLIC ACID

Modifications of this basic structure may include using a novalac epoxy (a multi-functional epoxy), maleic acid, bisphenol-A or other monofunctional acids in addition to the basic ingredients. The modifications can impart either increased strength, increased flexibility, or modified cure behaviors depending on the choices made.

The choice of monomers for vinyl esters is very similar to that of unsaturated polyesters. Vinyl esters are selected for application where mechanical strength, and/or chemical or water resistance demands are greater than can typically be obtained by conventional unsaturated polyester resins.

In addition to unsaturated polyester and vinyl ester resins, CCP markets resin systems that are a combination of both polyester and urethane; that is, the CCP XYCON® hybrids. The properties of these hybrids reflect these two chemistries. They have excellent toughness, adhesion, water resistance, and speed of cure. They are used as a barrier coat in marine applications to reduce fiber print-through and increase blister resistance. In addition, they can be formulated for use in structural applications.

4. CURING MECHANISM—As previously noted, after the polyester or vinyl ester polymer is cooked, it is dissolved in monomer (usually styrene) so that it is a readily pourable fluid that can be easily used by the fabricator. The ratio of polyester polymer to monomer ranges from 75:25 to 50:50 parts by weight. At this point, additives called inhibitors are added to the solution to prevent the monomer and the unsaturated acid in the polymer from reacting together until the fabricator adds a peroxide catalyst.

Gel and cure of a polyester or vinyl ester solution takes place by a free radical reaction. In this procedure, a peroxide catalyst is added to the polymer solution. The peroxide catalyst splits apart into highly energized free radicals which attack the unsaturated portions of the polymer and monomer. The presence of the free radicals together with the unsaturated functionalities of the polymer and monomer permit the formation of new chemical bonds to 'crosslink' the resin system.

Once crosslinking starts, movement of the solution is highly restricted. After a small fraction of the unsaturated groups have linked together, the solution is gelled. Eventually the polymer chains are crosslinked by the monomer into one solid, infusible mass that will not soften or melt on exposure to heat. Typically in laminating and casting applications, 80 to 90% of the unsaturated groups (which ultimately react) will have joined together by the time the part is demolded. The parts will reach 95 to 97 percent cure in two to four months if kept above 70ºF. Curing is accompanied by the development of large amounts of heat, commonly referred to as exotherm. This is the result of the new chemical bonds forming and makes the reaction proceed even faster.

Inhibitors are used to delay crosslinking until the appropriate peroxide catalyst is added. Free radicals can form naturally in the resin, and can form faster if the polymer solution is exposed to heat and/or sunlight, or is contaminated with metals or other materials. The inhibitors seek out the free radicals and destroy them. For this reason it is important to store polyester resins in a cool, dark place as recommended on CCP data sheets.

Factors that affect the curing reaction are:

- Temperature of the resin—the rate of gel and cure will double with each increase in temperature of 18ºF. Conversely, it will halve if the temperature decreases by 18ºF. If the temperature is too low, the polyester may never cure properly.

- Mass—the amount (mass) of resin and its shape will affect the rate of cure. A large, thick casting will cure faster than a thin laminate because the casting will hold the exothermic heat better than the laminate. Very thin laminates may require a source of external heat to cure properly.
- Catalyst—the type and amount of peroxide catalyst are based on the resin and curing conditions. CCP data sheets specify recommended types and amounts. Peroxide catalysts are discussed in the following section.
- Accelerators—addition of accelerators speeds up the curing mechanism greatly. CCP adds accelerators (promoters) to its resins. Accelerators are discussed in a following section.

5. PEROXIDE CATALYSTS—The function of the peroxide catalyst is to crosslink the resin, at first causing a gel and then a complete cure. When a peroxide catalyst is added to a resin, heat and/or the accelerators in the resin split the peroxide catalyst into free radicals. The free radicals first consume the inhibitor present in the resin and then attack the unsaturated portions of the polyester polymer and monomer. These activated unsaturated groups become free radicals themselves, and then add onto other unsaturated groups until long polymer chains are formed. The whole process stops when the free radicals are no longer mobile enough to contact other unsaturated groups. This happens when the viscosity of the curing system becomes very high. The remaining groups slowly crosslink as the part ages or when it is heated in a postcure step by the fabricator.

The catalysts used with polyesters and vinyl ester resins are called peroxides. Some are very unstable at room temperature and must be stored under refrigeration. Because peroxides and accelerators react explosively, they should never be mixed together directly. For this reason, resins for use at room temperature generally come pre-accelerated (or pre-promoted). If additional accelerator or promoter is needed, it should be mixed thoroughly into the resin before the peroxide catalyst is added. The precautions listed in the Material Safety Data Sheet for the peroxide catalyst should be strictly observed.

Curing of polyester and vinyl ester resins can be divided into two groups: room temperature (65 to 95°F) and elevated temperatures. Curing at elevated temperatures generally takes place in heated tools or molds at temperatures of 180°F to 320°F. Peroxides chosen for use at these temperatures include t-butyl perbenzoate, t-butyl peroctoate, benzoyl peroxide, peroxyketals, and other specialty peroxides designed by catalyst manufacturers. Accelerators are not generally needed to activate these peroxides. Heat is enough to break them down into free radicals. These peroxides are generally liquids or are dissolved in diluents to make them easy to use.

Room temperature is generally used in casting and laminating applications. Methyl ethyl ketone peroxide (MEKP); cumene hydroperoxides (CHP); 2,4-pentanedione peroxide (2,4-P); or combinations of these peroxides are generally used. To make them usable, they are diluted with various plasticizers to an active oxygen content of four to nine percent. Accelerators in the resins split these catalysts into the free radicals necessary for the gel and cure process.

MEKP is made from methyl ethyl ketone and hydrogen peroxide. These materials can combine to form different peroxides called isomers. The MEKP supplied by most manufacturers is a mixture of these isomers and depends on the manufacturing process. Thus MEKP's from different manufacturers react differently and should be checked before switching from one to another. There are also small amounts of water and hydrogen peroxide in MEKP. These can also change the reactivity of the MEKP.

Some of the factors governing peroxide catalyst usage are:

- Amount—An adequate amount of peroxide must be used to start the process and bring it to final cure. Resins and peroxide catalysts are formulated so that from 0.75 to three percent catalyst solution is enough to generate the free radicals needed. If too much catalyst is used, too many polymer chains will start growing. In addition, they will all be short chains and the cured resin will be weak and have poor physical properties. If too little peroxide catalyst is used, the gel time will be very long and the growing polymer chains may die out before all the unsaturated groups are reacted. The resin may never cure properly even if post cured. It will tend to be physically weak and possibly rubbery.
- Heat—Enough heat must be supplied to properly cure the resin. It can come from an external source such as an oven, heat lamps or a heated mold. The heat can also come from the exotherm of the resin itself. Exotherm is the heat given off as the resin cures. If the exotherm is more concentrated, such as in a thick casting, the part will get hotter and cure faster. If the part is a thin laminate the exothermic heat will be dissipated through the large surface area of the laminate and cure will be slower.

Shop conditions are very important. If temperatures are below 60°F, cure will be greatly extended. However, if the temperature is in the 90's, gel and cure will be faster. Cutting back on the peroxide catalyst may result in enough working time, but there may not be enough free radicals to properly cure the resin.

6. ACCELERATORS—Resins formulated for cure at room temperature contain accelerators (also called promoters). They increase the breakdown rate of the peroxide catalyst into free radicals. The amount of both accelerators and peroxide catalyst must be such that the fabricator has enough working time to form the part, and, at the same time, enough speed of cure to make the process economically practical. CCP adds accelerators to its gel coats and resins (i.e., pre-promotes them). Gel coat and resin data sheets contain information on the type and amount of peroxide catalyst to use. CCP's resins are tailored to meet fabricators' needs; i.e., fast gel and cure, fast gel with slower cure for longer trim time, longer gel with fast cure, etc.

Accelerators used in CCP products are generally metal salts (sometimes called metal soaps) and amines. They include cobalt, calcium, copper and potassium salts and amines such as dimethyl aniline and diethyl aniline.

Some of these accelerators are described as follows:

- Cobalt—Solutions of cobalt contain from six to percent metal. They impart a pink to red color to the resin depending on the amount used. Cobalt acts on most peroxide catalysts to form free radicals. Cobalt also affects perbenzoate and peroctoate catalysts that are used at intermediate temperatures (140°F to 180°F). Cobalt does not act as an accelerator for benzoyl peroxide.
- Amines—Amines generally color polyester resins yellow to brown depending on the amount present. They also can cause accelerated yellowing of cured parts. Dimethyl aniline (DMA) and diethyl aniline (DEA) do not act directly on MEKP or on 2,4-P. They increase the ability of cobalt to split these peroxides into free radicals. They are very effective in shortening the cure time and hardness development of MEKP-catalyzed resins.

DMA and DEA act directly with benzoyl peroxide so that this catalyst can be used at room temperature. Without an amine present, BPO is too slow in generating free radicals at ambient temperatures for use in polyester or vinyl ester resins.

7. SUGGESTED REFERENCES

BOOKS

Plastics Engineering Handbook of the Society of the Plastics Industry
Society of the Plastics Industry, Inc. (SPI)
1667 K Street NW, Ste 1000
Washington, DC 20006
Ph: 202-974-5200
Fax: 202-296-7005
www.socplas.org

Plastics Handbook
McGraw-Hill, Inc.
2 Penn Plaza
New York, New York 10121-2298
Ph: 877-833-5524
www.books.mcgraw-hill.com

Reinforced Plastics Handbook
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www.modplas.com

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P.O. Box 78
Brooklin, ME 04616
Ph: 207-359-4651
Fax: 207-359-8920
www.proboat.com

FRP COMPOSITES: General Properties of FRP Composites Resins

Part Three, Chapter III

In This Chapter

1. INTRODUCTION—Fiber Reinforced Plastic (or Glass Reinforced Plastic) is an adaptable material. The uses of FRP cover a broad range of applications. This chapter offers a brief outline of the properties that make FRP such a useful material.

In the past, the comparison of physical properties of one manufacturer's laminating resin to another, based on suppliers' data sheets, has been used to make many material selections. This practice, though common, is flawed and can lead to poor material selection decisions.

In general, most manufacturers report the physical properties of products as measured in both a casting and a laminate. ASTM methods are followed during the preparation and testing of the sample at all resin manufacturers. However, within ASTM guidelines, variations are allowed in the construction of the samples (e.g., catalyst type and level, post-cure cycle, and the use of glass panels versus Mylar®). These variations can cause fairly drastic differences in the properties reported on the data sheets.

In addition, other variances can occur while testing the materials. If the test samples are not prepared in the same way, differences can occur. CCP participated in a double blind round robin study where liquid samples of five competitors were provided to one another. Each company made castings and laminates based on their own protocols for following ASTM methods. Then, each company ran physical properties and reported results. In general, relative performance differences between the materials were discernible by all laboratories involved. In addition, in comparison of results for any given material it was observed that some laboratories tend to report higher physical properties than others.

Therefore, comparing physical properties as listed on data sheets can lead to incorrect assumptions that one material is better than another. To avoid such inaccurate comparisons, it is advisable to prepare and run side-by-side samples on the same piece of equipment in the same laboratory. This will narrow the number of variances and yield numbers that can be compared.

In general, data sheets should only be used as general guidelines for suitability of a material for a given application, and to compare materials manufactured by a single supplier.

2. MECHANICAL PROPERTIES—The tensile, compressive and flexural properties depend on the reinforcement material (cloth, roving, woven roving, mat, etc.), the reinforcement to resin ratio, and how the reinforcement is oriented to the direction of the stress. The reinforcement fibers can be arranged, during fabrication, in the direction of known stresses so that the strength of the reinforcement is used more economically and better performance is achieved.

For instance, reinforcement roving can be used in areas where direct tension occurs, and reinforcement mat where isotropic (random) compression stresses occur. A rod made of parallel glass roving strands can have a tensile strength of 150,000 psi whereas a sprayup laminate (made of chopped glass fibers) may have a tensile strength of 15,000 psi. A combination mat and woven laminate will have tensile and flexural strengths from 30,000 to 50,000 psi.

Impact strength of FRP is high because it has no yield point (as contrasted with metal). This property eliminates denting, gives the structure dimensional integrity and makes it easy to repair (since it does not lose shape, even when ruptured).

3. PHYSICAL PROPERTIES—The specific gravity of FRP is low in relation to other structural materials (about 1.7 depending on glass-to-resin ratio). An extremely high strength-to-weight ratio is available (important to the aircraft industry).

The thermal conductivity is very low for a solid material (2BTU/(hr/ft2)°F/ft) which is not only important to insulated structures, but makes the surface pleasing to the touch in hot or cold ambient conditions.

A Barcol 934-1 Impressor is used in measuring hardness of an FRP laminate. A Barcol 934 Impressor should show a reading of 35 to 45 when the laminate has cured. More rigid resins will give a higher Barcol reading while resilient and flexible resins, of course, will give a lower reading.

Because of thin and inconsistent gel coat films, the use of the Barcol Impressor is not recommended.

The heat distortion point of the laminate depends on the type of resin and reinforcement used. General purpose polyesters run about 200°F where a high heat distortion polyester runs up to 275°F. Continuous operating temperatures should not exceed 160°F for general purpose room-temperature-cured polyester resins.

The thermal coefficient of expansion is slightly higher than steel and about the same as aluminum: 13 x 10-6in./in/°F.

4. CHEMICAL PROPERTIES—Although some chemicals can attack FRP rather rapidly, FRP has excellent resistance to aqueous solutions (salts, acids, etc.). General purpose polyesters have poor resistance to strong alkalies and do not stand up to certain strong acids (such as nitric) or high temperature solutions (over 140°F). Special polyesters are used in these applications.

This generally high degree of chemical resistance of FRP makes it particularly useful for tanks, hoods, covers, pipes, ducts and other structures in paper, textile, fertilizer, sewage disposal and petroleum chemical plants.

Certain solvents such as ketones (acetone) and those having chlorine (carbon tetrachloride and chloroform) solvate all polyester resins rapidly.

5. ELECTRICAL PROPERTIES—A unique property of FRP is that it is electrically transparent. This is particularly useful in the manufacture of radomes, Doppler systems, etc. Polyester resins generally have a low dielectric constant making them good potting materials for capacitors and other electrical equipment. FRP is an exceptionally good insulator, having a dielectric strength of 300 to 500 volts/mil. Polyesters can be made (if desired) to be electrically conductive.

6. FIRE RESISTANCE—All resins, being organic, will burn. However, most fire codes call for a certain maximum burning rate or certain characteristics which are available in special halogenated polyester resins or through the addition of alumina trihydrate.

7. OPTICAL PROPERTIES—Most general purpose polyester fiberglass laminates are translucent, although up to 90 percent light transmission can be achieved in a 1/16 inch to 1/8 inch FRP laminate through the use of special resins and mat.

However, an opaque laminate can also be made by incorporating pigments and fillers in the resin. Color can be molded into the product so that painting is unnecessary.

8. WEATHERING PROPERTIES—The outdoor weathering properties of FRP are generally good. However, there is a certain susceptibility to ultra violet rays which require that ultra violet absorber be specified for translucent laminates. Normally, UV absorbers are not required for gel coat because the pigments and fillers act as absorbers. In addition, all exposed laminates should either have a gel coat or a glass surfacing mat specified for the exposed surfaces to prevent fiber 'blooming' or surface exposure of the fibers. See also the chapter on ' Weathering.'

9. POLYESTER SHRINKAGE—Polyesters will shrink approximately six to nine percent by volume. A glass reinforced laminate may have only 0.25 percent linear shrinkage.

FRP COMPOSITES: Fabrication of FRP Composites

Part Three, Chapter IV

In This Chapter

1. **Introduction**
2. **Process Descriptions**
3. **Process Selection**

1. INTRODUCTION—Fiber reinforced plastics can be fabricated using a number of processes. Some examples are as follows:

- Hand layup lamination
- Sprayup lamination
- Continuous lamination
- Resin transfer molding and numerous variations of this process
- Infusion
- Pultrusion
- Fiber placement
- Spin casting
- Filament winding
- Compression molding
- Injection molding.

This book will not cover each of these processes in depth. However, three main categories of these processes will be examined further. These categories are:

- Open molding
- Low volume closed molding
- Compression molding.

A brief description of each of these process categories follows. Table 1 shows a comparison of the major features of each category.

2. PROCESS DESCRIPTIONS

A. Open Molding—Open molding is the simplest and most widely used process to produce FRP parts. Open molding is done in ambient shop conditions. The mold itself is generally fabricated from FRP and is one-sided. It can be male (part is molded onto) or female (part is molded into). The cosmetic surface of the part is fabricated next to the mold. The back side of the mold is open.

In contrast to many other fabrication processes where the exterior coating is applied after the main structure of the part has been built, open mold parts are built from the exterior to the interior. The first step in open molding is to apply the gel coat (the exterior coating of the part) to the mold. The remaining layers of the laminate design, which will include some but not all of the following, back the gel coat:

1) Barrier Coat—An additional coating that is applied behind the gel coat. A barrier coat improves part cosmetics, reduces cracking and improves osmotic blister resistance in marine parts.
2) Skin Laminate—A relatively thin glass fiber reinforced laminate fabricated behind the gel coat. Skin laminates improve cosmetics and osmotic blister resistance.
3) Print Blocker—A sprayable syntactic foam material used behind a skin coat to improve laminate cosmetics.
4) Coring Materials—Light weight materials used to build part thickness and stiffness without adding weight.
5) Bulk Laminate—The main portion of the laminate that provides most of the structural properties.

Glass fiber reinforcement used in skin and bulk laminates can be applied by hand layup or sprayup. Hand layup is used when applying roll good reinforcements such as chopped strand mats, and textile constructions that are stitched or woven. Brushes, rollers or wetout guns can be used to apply the resin.

Sprayup is used when the laminate reinforcement is chopped roving. Chopped roving and catalyzed resin are sprayed onto the lamination surface with a chopper gun. The glass is wet out and compacted with lamina-

Table 1. PROCESS COMPARISON

Part Characteristic	**Open Molding**	**Low Volume Closed Molding**	**Compression Molding**
Maximum Part Size	Any Size	Any Size	Up to 100 Square Feet
Factors Limiting Part Size	Mold and Part Handling	Mold and Part Handling	Press Size
Part Surface	One Side	Two-Sided, Smooth or Textured	Two-Sided, Smooth or Textured
Part to Part Consistency	Fair	Good to Excellent	Excellent
Cross Section	Completely Variable	Better if Uniform	Easily Varied
Number of Parts Per Year	<1000	<10,000	>5,000
Parts Per 8-Hour Shift Per Mold	1-2	16-90	100-500
Mold Construction	Composite	Aluminum Nickel Shell, or Composite	Chrome Plated Tool Steel
Mold Lead Time	2-4 Weeks	4-8 Weeks	16 Weeks or More
Tons of Composite Per Tons of Emissions	37[1]	135-1630[2]	135-1630[2]

[1] Numbers taken from unified emissions factors; 35 percent styrene content resin; mechanical non-atomized application; and 30 percent fiberglass.

[2] Numbers taken from EPA AP-42 emission factor; 35 percent styrene content resin; compound paste (25 to 100 percent resin); and 30 percent fiberglass.

tion rollers. Hand layup and sprayup can be combined within the same part or laminate.

The part size for open molding is restricted only by part and mold handling considerations. Open molding is labor intensive in comparison to some other processes. Part-to-part consistency is dependent on operator skill and is generally variable. Emissions from open mold processes are significant and are regulated by Federal NESHAP standards and, in some cases, State and Local regulations.

More detailed information on open molding can be found in Part Four of this book.

B. Low Volume Closed Molding—The category of low volume closed molding processes includes processes in which liquid resin is transferred into a closed cavity mold containing reinforcing materials. Over time, many variations of low volume closed molding processes have evolved. Some examples are:

- Vacuum infusion
- Seamann Composites Resin Infusion Manufacturing Process (SCRIMP®)
- Conventional RTM
- Light RTM (shell laminate RTM)
- Silicone bag RTM
- Closed Cavity Bag Molding (CCBM®)
- Multiple Insert Tooling (MIT®) RTM
- Zero Injection Pressure (ZIP®) RTM.

Parts fabricated using these processes may or may not have gel coat on the exterior surface. For parts fabricated with gel coat, the gel coat is applied to one half of the mold using the same techniques as used for open molding. The mold is then loaded with reinforcing materials and closed. Catalyzed resin is transferred into the mold. After the part is sufficiently cured, the mold is opened and the part demolded.

The part size for these processes is limited by mold and part handling considerations. Part-to-part consistency is better than with open molding due to less dependence on operator skill. Also, two-sided cosmetic parts can be produced. Emissions from these processes are still regulated; however, they are much lower than with open molding due to the closed portion of the process. Emissions from the gel coat application, if used, are the same as for open molding.

More detailed information on low volume closed molding can be found in Part Five of this book.

C. Compression Molding—Compression molding is another closed molding process that uses clamping force during mold closure to flow a pre-manufactured compound through a mold cavity. A hydraulic press generally provides the clamping force. Compression molds are generally made from chrome plated tool steel. Sheet molding compound, bulk molding compound and wet molding compound are examples of pre-manufactured compounds.

If an external coating is needed on a compression molded part, it is generally post applied; however, in-mold coatings are available. Part size is limited by press platen size. Part-to-part consistency is excellent. Emissions from compression molding are still regulated; however, they are much lower than with open molding due to the closed nature of the process.

More detailed information on compression molding can be found in Part Six of this book.

3. PROCESS SELECTION—The best process to use for fabrication of a specific part may be obvious. However, when the best process is not obvious, process selection is best accomplished through a process trade study.

A process trade study involves comparing the part fabrication costs and part performance factors for a specific part fabricated by various processes. Part fabrication costs include but are not limited to equipment costs, tooling costs, material costs, and labor costs. Part performance factors are dependent on the specific part being studied but can include, weight, strength requirements, and appearance requirements. Emissions of Hazardous Air Pollutants (HAP) or other regulated materials vary by process and may also factor into process selection. An example trade study follows.

The subject part is from the deck of a run-about boat. It is a hinged hatch cover that provides access to an under-deck storage compartment or cooler. The step face features a non-skid profile on the external surface. The step face comprises glass skins over foam filled honeycomb core. The part measures 11 inches by 25 inches with a 1.5-inch tall perimeter flange. The design criteria include an impact of 300 pounds from a three-foot elevation. The part is shown in Figure 3/IV.1.

Processes considered in the trade study were open molding and several low volume closed molding processes including vacuum infusion, silicone bag RTM, light RTM, and conventional RTM. Equipment costs, tooling costs, material costs and labor costs were calculated for each process on a per part basis. Costs are based on typical values in the year 2005, and are presented as relative costs with open molding at 100 parts produced as the baseline.

The number of parts to be produced varied from 10 to 9,000. Parts were to be produced over a three-year time frame with an equal number of parts per year. Process trade study cost results are shown in Figure 3/IV.2 on the following page. The cost per part decreases as the number of parts produced increases. However, the amount of decrease depends on the process, meaning that different processes are the most cost-effective at different production rates.

Conventional RTM is not a cost-effective option for hatch cover production at production run sizes of less than 1000

Figure 3/IV.1—Trade Study Hatch Cover

parts. For production run sizes greater than 1,000 parts this process becomes competitive with light RTM, but does not become cheaper than light RTM even at production run sizes of 9,000 parts due to the need for a gel coated surface.

The cost comparison could be different for large production runs of a non-gel coated part.

While competitive with light RTM, silicone bag RTM is never the cost-effective process for hatch cover production. This is due to the cost of the materials needed to fabricate the silicone bags. However, silicone bag RTM can be an excellent process selection for parts with closed contours that are not easily fabricated by other processes.

Light RTM is the low cost process for hatch cover production at production run sizes greater than 100 parts.

Vacuum infusion is competitive with open molding as the low cost process for hatch cover production runs of less than 100 parts. At higher production rates vacuum infusion is not cost-effective due to the cost of the consumable materials (vacuum bag film, sealant tape, etc.) needed for each part.

Open molding is the low cost process for hatch cover production runs of less than 100 parts. But is not cost-effective for production runs greater than 100 parts.

Overall process trade study results including part appearance, strength, cost and emissions, for the hatch cover are shown in Table 2.

Use of closed a closed molding process reduces emissions by 50 percent in comparison to open molding with low VOC materials. The emissions differences as well differences in part appearance could influence process selection for hatch cover production.

This trade study is provided as an example of the type of evaluation that can be done to make an informed decision on process selection. The conclusions reached are not valid for all part types, sizes, complexity and specific combinations of labor, material and capital costs.

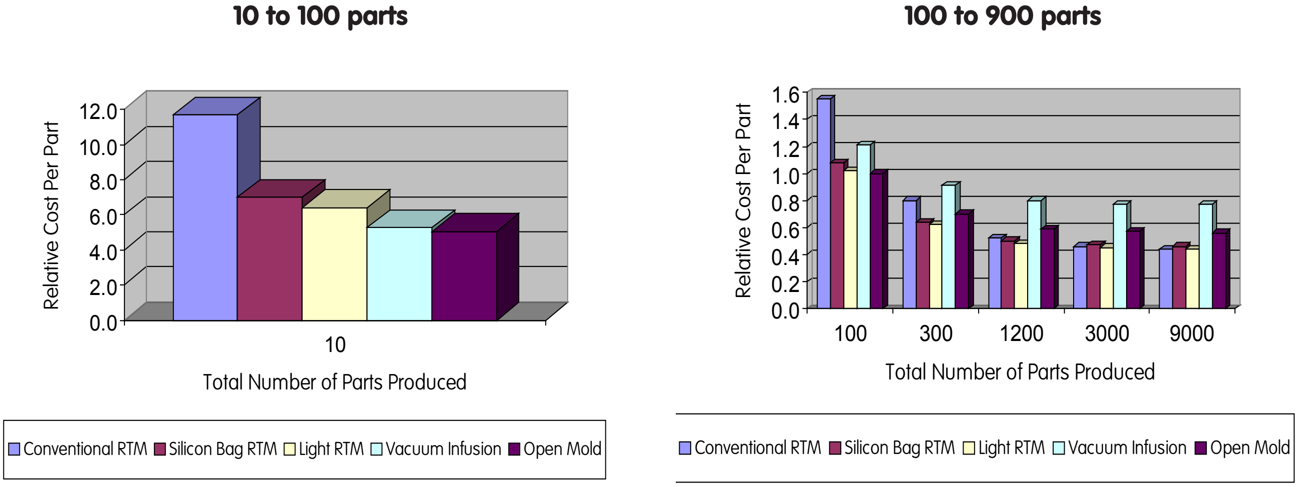


Figure 3/IV.2—Process Trade Study Cost Results

Table 2. COMPARISON OF RTM PROCESSES

Property	Open Molding	Vacuum Infusion	Light RTM	Silicone Bag RTM	Conventional RTM
Part Appearance	Part back side is rough	Part back side is matte	Part back side is smooth	Part back side is matte	Part back side is smooth
Strength	Acceptable	Comparable to open molding	Comparable to open molding	Comparable to open molding	Comparable to open molding
Cost Effective Production Run Size	<100 parts	<200 parts	100 to 9,000 parts	100 to 9,000 parts	>1000 parts
Emissions	0.126 lbs/part	0.064 lbs/part	0.064 lbs/part	0.064 lbs/part	0.064 lbs/part

OPEN MOLDING: Introduction

Part Four, Chapter I

In Part Four

Chapter I: **Introduction**
Chapter II: **Conventional Gel Coat**
Chapter III: **Specialty Gel Coats**
Chapter IV: **Vinyl Ester Barrier Coats**
Chapter V: **Lamination**
Chapter VI: **Sprayable Print Blockers**
Chapter VII: **Field Service**

Open molding is the most widely used process for fabrication of FRP parts. The basic open molding process involves applying gel coat to a one-sided mold, and then backing the gel coat with the remainder of the laminate design. Open molding is generally done in ambient conditions. Some of the materials commonly used in open molding are:

- Gel Coat—The exterior coating of the part, the gel coat serves several purposes. During manufacturing, the gel coat protects the mold from abrasion and chemical attack. It also provides a releasable coating. After manufacture, the gel coat becomes the exterior cosmetic coating of the part, and also provides protection against water exposure and weathering. Most, though not all, open-molded parts are gel coated. Examples of non-gel coated open molded parts include spas, bathtubs, and shower stalls where acrylic or ABS is used in place of gel coat as the exterior coating.
- Barrier Coat—An additional coating that is applied behind the gel coat, the barrier coat improves part cosmetics, reduces cracking, and improves osmotic blister resistance in marine parts.
- Skin Laminate—A relatively thin glass fiber reinforced laminate fabricated behind the gel coat, the skin laminate is specially formulated to cure completely as a thin laminate and to improve part cosmetics. Skin laminate resins are also typically formulated with high performance polyester or vinyl ester polymers to improve osmotic blister resistance.
- Print Blocker—A sprayable syntactic foam material, the print blocker is used behind a skin laminate to improve laminate cosmetics.
- Coring Materials—These light-weight materials are used to build part thickness and stiffness without adding weight.
- Bulk Laminate—This component is the main portion of the laminate that provides most of the structural properties.

The following chapters cover the various gel coat and resin materials used in open molding, application techniques, troubleshooting guidelines, and field service issues.

OPEN MOLDING: Conventional Gel Coat—Materials

Part Four, Chapter II.1

In This Chapter

1. **Introduction**
2. **Materials**
3. **Quality Control**

1. INTRODUCTION—A conventional gel coat is a pigmented, polyester coating that is formulated for use in ambient temperature, open mold processes. The gel coat is applied to the mold surface and becomes an integral part of the finished product. The gel coat provides a durable, cosmetically appealing finish and also protects the part from environmental exposure.

2. MATERIALS—Conventional gel coats are formulated from several components including the polymer, reactive monomer, pigments, fillers, thixotropic agents, promoters, inhibitors, and specialty additives. Proper selection of raw materials and the amounts of those materials will result in a gel coat that has good spray characteristics and will not sag on the mold when applied at the recommended film thickness, typically 18 ± 2 mils wet. The gel coat should cure in a reasonably short period of time to meet production requirements and—when properly cured—will offer good color retention with resistance to water, weathering and other environments.

A. Polymer—Polyester polymers can have a wide range of properties depending on the raw materials (acids and glycols) used to produce them. All polyester polymers have an unsaturated acid component, typically maleic anhydride. The unsaturation in the polymer provides a site for reaction with the monomer, also known as cross-linking. Polyester polymers used in gel coats also have a saturated acid component. In some cases the saturated acid has been orthophthalic acid, but the most commonly saturated acid is isophthalic. Polyester polymers containing orthophthalic acid have been used in gel coats for general purpose applications. Polyester polymers containing isophthalic acids impart superior weathering, water resistance, and chemical resistance properties to the gel coat. (See Part Three, Chapter II, General Chemistry of FRP Composites for more information.)

B. Monomer—The monomer fulfills two roles in the gel coat. The first role is to react and cross-link with the unsaturation sites in the polymer to form the cross-linked thermoset material. Secondly, it reduces the viscosity of the polymer to workable levels for application. Some common monomers used in gel coats are styrene and methyl methacrylate (MMA). The amount and combination of these monomers affect the flash point and evaporation rate. Emissions regulations limit the type and/or amount of monomers that can be used in gel coats.

C. Fillers—Fillers are used to achieve the proper spray properties. Fillers influence the cured physical properties of the gel coat, as well as resistance to water and other environments that may change color or influence chalking. Commonly used fillers are calcium carbonate, talc, and aluminum trihydrate.

D. Thixotropic Agents—Gel coats are formulated to be thixotropic, i.e., have a viscosity that is dependent on shear rate. A gel coat should have a low viscosity during spraying, which is a high shear operation. Once on the mold and under low shear, the gel coat should recover to a high viscosity to prevent sag. This thixotropic behavior is obtained through use of thixotropic agents. These materials form a network with the polyester polymer through hydrogen bonding. During high shear this network breaks down and lowers the viscosity of the gel coat. After the high shear is completed, the network reforms, or recovers, and the viscosity of the gel coat increases. The faster the rate of recovery the lower the risk of sag but the higher the risk of air entrapment.

The thixotropy of a gel coat is determined by measuring the low shear and high shear viscosity of the product. The ratio of these two values is reported as the Thixotropic Index (TI).

Two major classes of thixotropic agents are fumed silica and organoclays. Other thixotropic agents called synergists are used to further enhance the thixotropic network.

E. Promoters and Inhibitors—The types and levels of promoters and inhibitors used in gel coats determine the cure behavior. The most important cure parameter for gel coats is cure rate. The gel time must be long enough to allow for spraying, air release and leveling, but short enough to meet desired production rates. Short gel coat cures also reduce the possibility of under cure issues including 'alligatoring,' caused by styrene solubility of the gel coat. Rapid cure also improves gloss and facilitates release of the part from the mold.

Most gel coats are cured under ambient conditions with peroxide catalysts. Promoters, also called accelerators, split the peroxide catalyst into free radicals. These free radicals attack the unsaturation sites in the polyester polymer, preparing them for reaction with the monomer. The most common promoter used in gel coats is cobalt. However, cobalt by itself does not typically result in proper cure behavior. Other materials called co-promoters are used to further enhance the cure behavior. Co-promoters enhance the ability of promoters to split the peroxide catalyst into free radicals. They are very effective in shortening the gel time and accelerating the cure or barcol development rate. Typical co-promoters are amines such as dimethyl aniline or diethyl aniline.

Inhibitors provide shelf life stability to gel coat, as well as help control the gel time. Free radicals generated in the gel coat during storage or after addition of peroxide catalyst react preferentially with the inhibitors. Only after all the inhibitors are consumed does the cross-linking or curing process begin.

F. Specialty Additives—In addition to the above materials, a number of other additives can be used in gel coat formulations to effect properties. Some examples include air release agents to reduce porosity and UV absorbers and light stabilizers for weathering performance.

G. Pigments—Pigments are used to produce gel coats in a wide variety of colors. The specific pigments used determine not only the color of the gel coat and fabricated part, but also significantly affect performance characteristics of the coating.

Pigment type and concentration affect the hiding capacity (opacity) of the gel coat. Bright yellows, oranges, reds and dark blues will have slightly less hiding capacity than pastels. The high pigment loads necessary to achieve better hide with these bright colors can cause spray and cure problems. Careful pigment selection can also slow chalking that occurs with outdoor exposure and provide an abrasion resistant coating that can be readily cleaned, waxed and buffed to a high gloss.

The most commonly used pigment in gel coats is titanium dioxide. Titanium dioxide is the primary pigment in white gel coats and is also used in combination with other pigments in non-white colors.

3. QUALITY CONTROL—When producing gel coats, manufacturers run a variety of quality control tests to ensure that the product being produced will meet the end-users needs. Standard quality control tests for gel coat are gel time, viscosity, Thixotropic Index, weight per gallon, color, sag, porosity, pigment separation and hide. Each of these tests is briefly described below.

A. Gel time—The gel time is a measure of the time required from catalyzation for the gel coat to turn from a liquid to a solid. With few exceptions, gel time tests are run at 77°F on a 100 gram sample of gel coat using 1.8 percent of a standard 9.0 percent active oxygen MEKP catalyst. The 100 gram mass cup gel properties are a standard in the FRP industry for characterizing gel coat cure. These parameters are valuable to the resin manufacturer when producing the product and to the end-user for verifying that the product will be suitable for use in their process. However, it is important to the fabricator to understand that 100 gram mass cup gel parameters will not correspond to the those observed in the actual application. Specifically, the 100 gram mass cup gel time is faster than the gel time in the sprayed film.

B. Viscosity—Viscosity is a measure of the fluidity of a material. The higher the viscosity, the less fluid the material. For example, water has a lower viscosity than molasses. Unless otherwise specified, viscosity is measured using a Brookfield RV model viscometer with a RVF #4 spindle at 4 RPM. Viscosity is measured at 77°F and reported in centipoises (cps).

C. Thixotropic (Thix) Index—The Thix Index indicates the dependence of the gel coat's viscosity on shear rate. (See Section 1.D on the preceding page on thixotropic agents.) It is typically reported as the ratio of the Brookfield viscosity readings with an RVF #4 spindle at two and 20 RPM at 77°F.

D. Weight per gallon—The weight per gallon is the density of the gel coat and is reported in pounds per gallon. It is measured at 77°F.

E. Color, Sag, Porosity, Pigment Separation—A color panel is prepared for each batch of gel coat and compared against a color standard. (See Chapter II.2 in this Part of the manual for a discussion of color.) This color panel is also used to visually check sag resistance, porosity/pinholes, and pigment/resin separation.

F. Hide—Hide is evaluated by drawing down the gel coat sample on a gray and white patterned paper. The draw down bar is tapered creating a variable gel coat film thickness. Gel coat film is visually inspected to determine the point at which the pattern on the paper is no longer visible. The gel coat thickness at this point is measured using a mil gauge (this mil gauge thickness is the hide). The thickness required for hide is generally less than the recommended gel coat thickness.

Typical properties of POLYCOR® gel coats are shown in the table below.

TYPICAL PROPERTIES OF POLYCOR® GEL COATS	
Gel Time	10 - 16 minutes
Viscosity (Brookfield)	9,000 to 22,000 cps—varies according to color and pigmentation levels
Thixotropic Index	4 to 8
Weight per Gallon in Lbs.	9 to 12
Sag Resistant	18 mils
Hiding Complete	18 mils
Sprayability	Excellent
Shelf Life	4 months @ 73°F or below
Coverage	60 sq. ft./gallon at 18 ± 2 mils (includes waste)

Quality control values typically reported on a certificate of analysis (COA) include the gel time, viscosity, Thix Index and weight per gallon. See Appendix A for additional information on quality control testing procedures.

OPEN MOLDING: Conventional Gel Coat—Color

Part Four, Chapter II.2

In This Chapter

1. INTRODUCTION—This chapter deals with color and polyester gel coats. It includes a brief description of color, how it is judged and by what standards, tinting and color matching (visually and instrumentally).

2. COLOR IN GENERAL—Color is all around. It directly or indirectly affects an individual's interpretation of everything he or she sees. Color is used to please, motivate, sell, amuse, and instruct. It is used to judge the freshness of an apple or a piece of meat. It can affect how people feel; consider the difference between a bright sunny day, and one that is gray and overcast. The human eye can differentiate among 300 colors from memory and about ten million colors when placed side-by-side; yet color is very hard to define or explain.

Color is a psycho-physical reaction to how the mind interprets what is seen. Since color is an interpretation by the brain, the ability to see color differences is learned. It is subject to the whims of the observer and his or her past experiences. If several people are shown a yellow-green panel and are asked to name the color, there will be several different responses. Some will say the color is green, while an artist may describe it as chartreuse, and a farmer may say 'John Deere green.'

Since light and color are sensed by the eye, the condition of the eye is important. Naturally, if a person is color-blind (partially or fully), there will be problems with color distinctions. Anything that affects vision (e.g., fatigue, eye glasses, lighting, inflammation, alcohol, or disease), will affect color perception. As a person ages, there is less sensitivity to violet and blue light due to a build up of yellow pigment in the eye.

Texture and gloss of the substrate will also affect color perception. These will cause a color change with viewing angle. In general, the glossier something is, the darker and more saturated (less gray) it appears. An example of this may be seen by sanding an area of a dark gel coated panel. The sanded area and sanding dust will appear to be whiter than the unsanded panel. This effect is due to how light is reflected from that roughened area.

The type and amount of light under which an object is viewed affects its color. If sunlight is passed through a prism, a rainbow of colors appears. This display of color is the visible spectrum. Visible light is measured by wavelengths using 'nanometers' as the unit of measure. A nanometer is equal to one billionth of a meter. Violet is 400 to 430 nanometers; blue—430 to 485; green—485 to 560; yellow—560 to 585; orange—585 to 610; and red—610 to 700. Wavelengths of light outside this range are not seen by the human eye. As each wavelength group has its own energy and as light passes through the prism or raindrops, the groups are separated due to energy differences.

When all the light is reflected back from a panel, the color is called 'white.' If the panel surface absorbs all the light, it is called 'black.' If the panel absorbs all the wavelengths except the red length, it is called 'red.' But if a red light is shone on a white panel, the only wavelength of light it can reflect is red and the panel appears to be red.

To review a color properly requires a light source which has all the visible wavelengths of light. North daylight is considered the classic standard for color viewing. But even daylight changes from day to day. Artificial lights are strong or different in one area. Tungsten A lights are strong in the yellow-red range, giving a yellow-red cast to an object. Incandescents are rich in red. Mercury vapor is deficient in red, giving a greener cast to objects.

This difference in light sources accounts for why one may buy an item of a particular color in a store and then, on unwrapping it at home, discover it is quite a different color. The color has not changed, but the light source has. This can even happen when a color standard is taken to the store. The coloring agents (pigments) in the standard and the final product may be different. This is especially true when the standard is made of a different substance (paint versus cloth, plastic versus paint). Each pigment or dye has unique absorption and reflection characteristics in the visible light spectrum and is dependent upon the light source as well. For this reason, one type of yellow pigment used in a color chip appears different than another yellow pigment used on a chair. They may not always appear to be the same color depending on the light. Under one light source (perhaps in a store), the yellows may appear to be the same color, but in another type of light, they will appear to be different (the paint may appear redder, the chair greener). This is called color flip, or metamerism. The amount of light also affects color. It is difficult to determine color differences in a darkened room or in a very bright light.

Color is quantified instrumentally using three pairs of antagonistic color contrasts. The contrast pairs are:

- Light-dark
- Red-green
- Yellow-blue

Using these pairs, the eye determines all colors. When someone is color-blind, he or she usually cannot make a distinction in one or more of these areas. There are a number of color-blindness tests (Holmgen, Wood Test, Nagel Charts, Stilling and Ishihara), but these are not foolproof. Usually, a color-blind person is revealed by errors in color work.

3. DESCRIBING COLORS—Three terms must be used to describe any color:

- Hue
- Chroma
- Contrast

It must be assumed that the observer recognizes the primary colors—red, blue and yellow. These are hues. Chroma refers to brightness or intensity of a particular color, and contrast refers to lightness or darkness.

4. JUDGING COLOR MATCHES AND STANDARDS

A. Criteria—Judging a color match is like any other test: All variables must be held constant except the object being tested. Or, in simpler terms, one wants to judge colors under the same conditions and using the same standard.

B. A number of things can affect color. These must be held constant in order to judge color. These items are:

1) The Observer—The person who is judging color must be free from any type of color blindness. Many times the opinion of two or three people is used as a safeguard. Instrument type and accuracy will influence measurement values. See Section 5. , Instrumentation in this chapter for details.
2) The Light Source—The type of light affects the color. Therefore, the best judgment of color is made when two or more different types of light are used for viewing. The classic standard is north light. To use this method, the tester stands with his or her back to a north light, holding the panels to be judged out in front at a 135 degree angle. The color is checked again under an incandescent or fluorescent light. When color judgments are critical, a light booth is used. These booths have multiple light sources—typically, daylight and horizon (yellowish) are included.
3) Background—Color is influenced by the background or surroundings. Best color judgments are made when the background is a neutral dull gray. Color booths have a light gray viewing background.
4) Viewing Angle—The standard and test panel should be positioned side-by-side at the same angle. Best color viewing is at 135 degrees. Best viewing of gloss is at the same, but opposite angle from the light source. Switch the panels from side to side to prevent bias.
5) Size and Texture—The object size affects color perception. A larger area observed provides a broader color sample. The smaller the area observed, the more limited or restricted the perception. Texture and gloss also affect color perception. Higher gloss is perceived as darker, while lower gloss appears lighter.
6) Temperature and Humidity—Pigments are subject to color change depending upon conditions. When temperature alters the color, then the object is considered to be 'thermochromatic.'
7) Standard— The choice of a standard is very important. It should:
    - Not change on aging
    - Be uniform in color
    - Be of the same material as the test panel
    - Measure at least three inches by five inches.

C. There are three types of standards:

1) Master Standards—This type is used to set the original color. It is stored in the dark when not in use, and should be refrigerated to prevent color change. It is only used as a final color check or as a reference for what the absolute color should be.
2) Working Standards—These standards are the ones which are used in the preliminary comparison for color. They can be sections of the master standard or the agreed upon 'perfect match.' As these standards are handled daily, exposed to light and general wear, they will drift in color. These standards must be checked periodically against the master and discarded when they drift too far from the original.
3) Electronic Standards—These standards are spectral measurements by instrument stored on a color computer. Master and working standards can be replaced. Color drift is limited by the instrument accuracy.

Once the standard method of viewing and variances are established, there are still a few things to remember:

- When a new standard is selected, it must match the old one perfectly and the supplier must also change his standard at the same time.
- All standards for that color must be changed accordingly. Also, the supplier must be provided adequate time and a target date to switch over to the new standard. When compar-

ing batch to batch, always refer to the standard. It is possible to obtain a batch on the light side of the standard (good match) and a second batch on the dark side of the standard (good match), but the batches might be poor matches to each other.

5. **INSTRUMENTATION**—Although there are instruments to help in color matching and judgments, these will not solve color problems. There are two types of instruments: Those that measure color magnitude differences (tristimulus colorimeter) and those that measure color wavelength differences (spectrophotometer). Each instrument has its own limitations. They are still dependent on a consistent reference standard and a good test panel with the same gloss as the standard.

If the standard used to set the reference point is mottled or distorted, the reference point will vary. If the test panel is distorted or different in gloss, it will provide different readings in different viewing areas. In some wavelengths of color, one instrument will be more accurate than others. Usually, dark colors are more difficult. Some of these instruments include:

A. The Colorimeter—It views color differences using three color filters in groups of wavelengths. A standard is placed under a view port and the machine reference points are set. Then the sample is inserted and color difference is read from the four following scales:

dL scale	(- is dark, + is light)
da scale	(- is green. + is red)
db scale	(- is blue, + is yellow)
DE	Total color difference

This instrument is good for determining in which direction a batch is off, and can be used for tinting.

B. Spectrophotometer coupled with a computer system—These newer and more expensive systems provide more (and more useful) information. These instruments use a monochromator that measures wavelength by wavelength, detecting the amount of light reflected by the standard versus the test sample. Multiple light sources are used with four readings for each light as follows:

DL	(-dark, +light)
DCRG	(-green, +red)
DCYB	(-blue, +yellow)
DE	Total color difference

These readings can be given in various color systems, such as MacAdam, CMC, CIE, or Hunter Units. One MacAdam Unit is normally considered as the minimum amount of color difference to be detectable by the normal human eye. This instrument will spot metamerism (color flip), aid in tinting batches and pigment selections for best possible color match, and final color match.

NOTE: These instruments are of great aid, but the final decision on suitability of a color match should always be made with the trained eye. These instruments can produce numbers that indicate a good match, while visually it is not.

6. **DETERMINATION**—Now that the conditions are set for viewing a color match, the hardest part involves judging the color. Does the test panel match the standard or is it just an acceptable match? It is nearly impossible to make a product over and over so that each batch perfectly matches the standard.

It can be a challenge to set up allowable limits of color differences. To set up allowable color variances, first determine how important color differences are. If the final product is sold as one item part and will rarely be next to another part of the same color, a wider variance is more acceptable. If parts are used side-by-side or need to match the color of another part, the variance in color must be kept at a minimum. Usually, reasonable allowable color variations are set by trial and error and are not absolute. Keeping samples of acceptable batches is one way to get a feel for allowable variance.

NOTE: Tighter color control will take more time and therefore cost more.

In comparing color, there are two possible approaches:

- Visual—subjective, but usually the final determining method.
- Instrumentation—quantifiable and easily defined, but may be misleading if numeric values are not properly interpreted.

Before covering the specifics of these individual approaches of color comparison, some general considerations must be given:

A. Rating system—Whether comparing the color with the unaided eye or by instrumentation, a rating system is useful. (At CCP, color matches are rated as A, B, or C in quality.)

B. Color standards made with gel coat products—These standards can drift in color. Whites and off-whites can drift the most. To slow this color drift, storing the gel coat standards in a freezer is recommended. The life of a standard may be extended to a year or more by this method.

C. Sample—For this discussion, 'sample' refers to a cured gel coat film. This film may be laminated or simply 'taped' (gel coat film backed with masking tape). The preparation of the sample is important to standardize. Factors which influence the final color are:

1) Agitation—That is the amount of mixing prior to application and the application method (drawdown, conventional spray, airless spray, etc.)

2) Catalyst Level—The gel coat color typically becomes darker and greener with more catalyst.
3) Curing—The gel coat will differ depending on the temperature at which it is cured. Higher curing temperatures will make the color darker. *NOTE: Gel coat castings made for color comparisons are not reliable since the exotherm of a gel coat in a mass may cause color variations.*
4) Thickness of the gel coat film and type of substrate—Thin gel coat films will present different color appearances depending upon the color of the substrate. Gel coats typically will hide at 15 mils cured film thickness. Bright colors, like reds and yellows, typically require 20 to 25 mils cured film thickness for appropriate coverage. Films thinner than this might allow the substrate to show through the gel coat film. Tape-backed samples usually read lighter than laminated samples. *NOTE: There is a color difference between the front and back of a gel coat film. Color comparison of the gel coat versus the standard should be of the 'mold side.'*
5) Low gloss samples will appear lighter. Obtaining the same color on a re-spray of a particular gel coat is limited by the above factors. Generally, the variations are hardly noticeable (if at all) to the unaided eye; however, for tight color control, all factors must be considered when Class A color matches are required. Once a suitable sample panel has been prepared, a color comparison may be made by one of the two methods mentioned previously.

D. Visual comparisons—Visual comparisons are, by far, the most common method. No matter what instrumental readings may show, the color match must 'look' good. *NOTE: Generally, three-inch by five-inch color panels are compared under a standard light source in a light booth. Panels are placed side-by-side at a 135 degree angle. Viewing colors under more than one light source is important in identifying the metamerism.*

Visual comparisons are usually the final determining factor in acceptance of a color match. The light source, background and observer influence the decision. There is no way to eliminate the subjectiveness created by the observer; however, the other factors can be standardized.

E. Instrument comparisons—CCP uses only high accuracy spectrophotometers. With this type of equipment, CCP can accurately correlate data generated from one instrument to another and from one day to another. Without this type of equipment, accurate color comparisons against stored or absolute values are not possible. Also, because of the variation of instruments, coordinating the readings of two different models of instruments (even from the same manufacturer) is not possible when Class A color matches are desired.

CAUTION: Taking a single instrumental reading of a large panel may not provide a representative reading of the overall panel. When possible, CCP suggests taking multiple readings of the standard and sample, using the average color values for determining color differences.

7. COLOR MATCHING TECHNIQUES—CCP be-lieves the following method of color matching provides the most accurate and reproducible production color matching in the industry. The electronically stored value provides a consistent standard regardless of the CCP manufacturing site, and eliminates the inherent color drift of 'master standards' that are based on FRP polyesters (even under freezer storage), or from damage to standards due to day-to-day handling.

CCP does not recommend matching to the 'last batch' panel or by side-by-side drawdown since these techniques lead to a color drift from the standard. This is particularly true for whites and off-whites where there is a natural tendency of the observer to approve the current batch on the light and clean (red and yellow) side of the 'last batch.' There is also a natural shift of color, in the container, for whites and off-whites to the light and clean side due to the interaction of promoters and fillers/thixotropes over time.

A. Equipment—Datacolor's Spectroflash 600 Plus CT (Close Tolerance) series spectrophotometer with Chroma-Calc software.

B. Calibration/verification—Calibrate instrument at initial set-up, after repair, or at any time where output is in question. Individual instruments are verified by a 'color tiles' test on a weekly basis. Agreement between instruments is confirmed by a BCRA (British Ceramic Research Association) color tiles test at initial set-up.

C. Color standards—Electronically stored spectrophotometric values as determined on a master instrument maintained in CCP's Kansas City Corporate Research facility. These electronically stored values are shared between all CCP plants through a common electronic network.

D. Color sample preparation—Catalyze and spray out onto a freshly waxed glass mold. Cure for 30 to 40 minutes at 150°F . Apply masking tape to the back side and demold. (Note that mold preparation, the amount of catalyst added, spraying and cure cycle have a dramatic influence on color. These parameters must be controlled carefully.)

E. Tolerances and measurement methods—Color readings are Specular Included (eliminates influence of gloss and distortion of the color sample) and color differences are computed by the CMC (1.00:1.00) method.

OPEN MOLDING: Conventional Gel Coat—Color

Typical color match tolerance is 0.30 DE (barely detectable visually). Other DE tolerances are used depending on product, color and customer requirements. (A visual reference to the 'last batch' or 'a master standard' may also be required as an additional precautionary step.)

8. TINTING—At times, tinting in the field is required (for example, for a part made several years previously which must now be patched, or for a one-time small job). To do well, and to do quickly, tinting requires skill and experience. CCP normally does not recommend tinting in the field, but for those who must do this, there are a few rules:

A. Use only pigment concentrates designed for polyester.

B. Tint at least one-half gallon of gel coat at a time. It is much harder to work with small quantities.

C. Make small additions, mixing well and scraping down the sides of the container between adds. These additions should get smaller as the color comes in closer.

D. To determine the undertone of a concentrate, it is helpful to check that concentrate in white.

E. Obtain the basic color shade first (yellow, blue), then look for minor differences—reddish, greenish, etc.

F. If the match is not good at the start, put a wet spot of the batch on the solid part or next to the wet sample. As the color gets closer, it will be necessary to switch to catalyzed sprayouts because some colors change from wet to cured.

G. Once a match is made, record what pigments and amounts were used to obtain the color, in case it has to be matched again. Listed below are the approximate effects of adding the following pigment concentrates:

COLORANT	**COLOR EFFECT**	
	PRIMARY	**SECONDARY**
Titanium Dioxide or TiO_2	Lighter	Chalky in dark colors
Carbon Black	Darker	Gray in pastels
Phthalo Green	Green	Darker
Phthalo Blue	Blue	Darker
Iron Oxide Red	Red	Darker; pink in pastels
Ferrite Yellow	Yellow	Red

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

Part Four, Chapter II.3

In This Chapter

1. INTRODUCTION—The application of gel coat is a critical operation with its success dependent on the material, the equipment, and the operator. These are the three main factors that determine the quality of parts, none of which can be overlooked or taken for granted.

The information compiled in this chapter is designed to help in the selection of spray equipment and to determine initial starting settings. Because each shop is different, these are general recommendations. The plant, the part, production speed and the spray person will ultimately determine the exact equipment, spray guns and settings to be used. Obtain and read spray equipment manufacturer manuals, parts lists, and safety guides before using.

2. EQUIPMENT NEEDED FOR OPERATION OF A SPRAY GUN—To use a spray gun efficiently and safely, the following items should be the proper size and type, and be in proper working condition.

A. Ventilation—A spray booth is required to spray polyester resins and gel coats. The size and the air makeup will depend on the size and the air makeup of the parts being sprayed. General rules of thumb include:

1) Measurement of the largest part to be sprayed.
    a) Height—add minimum of two feet.
    b) Width—add minimum of four feet.
    c) Length—add minimum of six feet.
2) CFM requirements are figured with the following formula: width x height x 125. The average air velocity required to expel fumes is 125 FPM.
3) Disposable filters only.
4) Contact equipment supplier for recommendations.

B. Lights and electrical switches—Explosion proof.

C. Manifolds and regulators

1) Manifolds and regulators should have a CFM capacity at least one and 1/2 times the sum required by the equipment they supply.
2) The atomizing air should be on a separate regulator with a water trap.
3) All gauges must be readable and working and should be permanently attached.

D. Moisture and oil traps—Moisture and oil traps should be installed and drained daily on all air lines at the spray booth. These not only keep contaminants out of gel coats but also protect and lengthen spray equipment life. Do not install within 25 feet of compressor. Traps should be located at the lowest point in the line.

E. Band heaters—CCP does not recommend using band heaters because of the possibility of creating localized heat spots, which will cause the material to gel solid.

F. Quick disconnect—If quick disconnects are used, use the largest size possible. Quick disconnects can reduce the volume of air and fluids that pass through them. If a quick disconnect is used on fluid lines, a ball valve may be installed in front of it to help reduce leaking.

Table of Air Pressure Drop

Size of Air Hose	Air Pressure Drop at Spray Gun in Lbs.		
(Inside Diameter)	20 Ft. Length	25 Ft. Length	50 Ft. Length
1/4 inch			
At 60 lbs. pressure	16 ¾	19	31
At 70 lbs. pressure	19 ½	22 ½	34
At 80 lbs. pressure	22 ½	25 ½	37
5/16 inch			
At 60 lbs. pressure	5 ½	6	11 ½
At 70 lbs. pressure	6 ¾	7 ¾	13
At 80 lbs. pressure	8	8 ¾	14 ½

G. Hoses—Hoses should only be used for delivery of air and fluid from a regulator on a main air line or fluid pump to the gun. The length should not exceed 50 feet (normally only 25).

Hoses should be large enough to deliver the proper volume of material at the proper pressure that the gun demands when the trigger is pulled. A pressure drop will always occur between the source of the air or fluid and the exit.

NOTE: Catalyst and airless hoses are made of special material—consult the equipment manufacturer about replacement parts.

H. Main air lines—The main air lines should be made of steel pipe and should meet the following requirements:

1) Be large enough to supply air to all facilities with no CFM or pressure drop.
2) Be capable of supplying the pressure and volume of air to run all air-powered equipment used at the same time.
3) Be laid out as straight as possible.
4) Have minimal fittings.
5) Have drop lines that come off the top of main air lines.
6) Have slant lines to drain any water to one end, with a low end drain.
7) Have air lines off drop lines that are not taken off the end but at least 12 inches above. A drain valve should be on the bottom.

Air lines should be pressure tested for leaks yearly.

MINIMUM PIPE SIZE RECOMMENDATIONS

COMPRESSING OUTFIT		MAIN AIR LINE	
Size (HP)	**Capacity (CFM)**	**Length**	**Size**
3 & 5	12 to 20	Up to 200 ft. Over 200 ft.	¾ inch 1 inch
5 to 10	20 to 40	Up to 100 ft. Over 100 to 200 ft. Over 200 ft.	¾ inch 1 inch 1 ¼ inch

CFM'S REQUIRED FOR VARIOUS AIR TOOLS

TOOL	CFM REQUIRED
Air motor	4
Polisher	2
Sander	5
Dusting gun	2.5
Nailers & staplers	6

I. Compressor

1) The compressor must supply the volume of air required by all air tools in the plant (total draw plus 50 percent).
2) If a compressor is to be purchased, estimate future requirements for all air tools in the plant and match the compressor size to the estimate.
3) Rule of thumb: one (each) horsepower delivers approximately four cubic feet per minute of air.

J. Pump accumulators—An often overlooked but VERY important aspect of regularly scheduled equipment maintenance is the fluid pump accumulator (also called surge chamber).

1) The accumulator is typically on the pressure side of the fluid delivery system and is an integrated part of the filtering system.
2) The accumulator is a cylinder that is designed to act like an air shock to dampen or minimize pressure drop when the pump changes direction.
3) If the accumulator is ignored, and not cleaned on a regular basis, material will gel inside it. When this material breaks loose, it will cause filter and tip plugging, leading to part defects and lost production time.
4) The accumulator may gel to the point where it no longer is doing its intended job.
5) Accumulators used on most equipment are not easily cleaned; this is believed to contribute significantly to problems. *NOTE: If equipment is cleaned when changing from one color to another, the accumulator must also be thoroughly cleaned.* Care should be taken to thoroughly flush the accumulator to remove any residual material that could contaminate the next material. After cleaning, dry the inside of the accumulator to remove any cleaning material that may be trapped inside.
6) Some equipment manufacturers have started to design and distribute accumulators that can be easily disassembled for cleaning. If the accumulator in use is old and difficult to clean, it may be cost-effective to invest in a new, more easily cleanable model. In addition to time saved, and therefore better productivity, a reduction in part defects should result.

3. GENERAL CONSIDERATIONS FOR SELECTION OF SPRAY EQUIPMENT—Before selecting a particular spray gun, determine the following:

A. What type of part is going to be sprayed? Is it a small, large, flat, curved, simple or complicated part?

B. How many parts are going to be sprayed per day and will they be sprayed all at once, spaced out evenly during the day, or at several different times?

C. How many different colors are going to be sprayed through this gun?

D. What are the future requirements for this spray gun and will it be adaptable to other operations? Is it a temporary or permanent installation?

E. How much physical labor is involved in this spray application, including the distance the gun must be moved to spray the part, time required to spray one part, dragging of hoses, setting up and cleanup?

F. What type of a maintenance program is in place or can be set up to protect this investment?

G. What are the safety precautions that must be considered?

H. Do local air quality regulations require or disallow a particular type of gun?

After answering the above questions, determine, in general, what type of gun is needed by looking at the characteristics of spray guns on the market.

4. DESCRIPTION OF TYPES OF SPRAY EQUIPMENT—Spray guns can be classified in a number of ways:

A. Material delivery—This refers to how the material is delivered to the gun. This can be done in three ways:

1) Gravity—The material, which is delivered from above the gun, flows to the gun. This process is not commonly used for gel coats; it is sometimes used for metal flake and very heavy (viscosity) materials.
2) Siphon—The material is picked up by passing air over a tube inserted into the material (no direct pressure on the material). This process is not commonly used for making production parts due to slow delivery rates; it can be used in patching.
3) Pressure—The material is forced to the gun by direct air pressure (pressure vessel) or by a pump. If a pump is used, it has a rating usually from two to one up to 33 to one. The air motor is from two up to 33 times larger than the fluid section. This rating means that if a pump is rated four to one, for every one psi of air pressure put into the air motor, the fluid section develops four times that pressure on the material (in theory). For example:

> A four-to-one pump at 30 psi is, in theory, delivering material at 120 psi (four times 30). In actual practice, the delivery pressure is lower than theoretical. The increase in pressure (four times) is the result of the air motor volume being four times larger than the fluid volume. Pressure feed systems (mainly pumps) are the systems most commonly used with gel coats.

B. Method of catalyzation

1) 'Hot Pot'—Catalyst is measured into a container (pressure pot) and mixed in by hand. This is the most accurate method but requires more cleanup.
2) Catalyst Injection—Catalyst is added and mixed at (or in) the gun head, requiring separate lines and a means of metering catalyst and material flow.

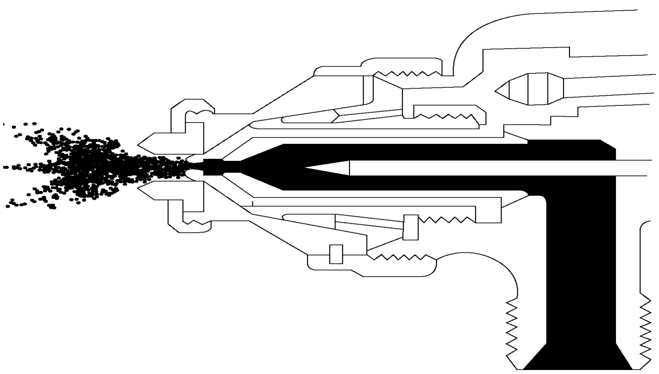


Figure 4/II.3.1—Binks spray gun.

3) Catalyst Slave Pump—A small slave pump is driven by the master fluid pump. It is engineered to deliver (by volume) ratios of one percent to three percent catalyst to the volume of gel coat/resin that is being delivered. Since the catalyst slave pump is more foolproof, it is the most common system used today for both gel coating and laminating. See Section 10. Calibration, I. (the letter) in this chapter.

C. Atomization—With a conventional air-atomized system, the material is 'broken up' by direct contact with an air stream (60 to 90 psi). This can be done in several ways:

1) Internal (see Figure 4/II.3.1.) — Air and gel coat meet inside the gun head and come out a single orifice. This system is not recommended for gel coats except for one or two special type products as it has a tendency to cause porosity and produce a rougher film. It also requires a solvent flush system.

   The internal mix nozzle is often employed in high production applications of materials where fine finish is not required. The internal mix air nozzle can be used only with pressure feed systems. Only low air and fluid pressures are necessary, and these must be regulated so as to be about equal at the nozzle.

   Less air volume is required than with external mix nozzles and this, coupled with the lower air pressure minimizes amount of over-spray and rebound. For this reason, internal mix may be referred to as semi-airless.

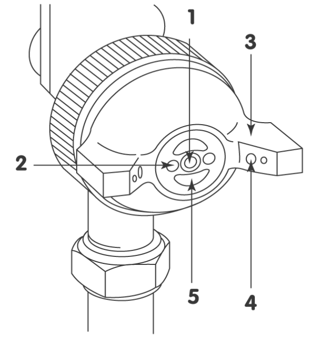
   Disadvantages of the internal mix air nozzle are few but important: the spray pattern size and shape is controlled by the air cap; a relatively coarse atomization is produced (not suitable for fine finishes); nozzles are subject to considerable wear (although replacement is easy and low in cost); certain types of materials, such as 'fast driers,' clog the exit slot or hole and film porosity is worse. The gun must be flushed after each use.

2) External (see Figure 4/II.3.2 on this page)—Air and gel coat meet outside of the gun head or nozzle. This is the most common system. The gel coat is atomized or broken up in three stages:
   a) First stage atomization—As the fluid being sprayed leaves the orifice of the nozzle, the fluid stream is immediately surrounded by an envelope of pressurized air emitted from the annular ring around the fluid nozzle tip. The resulting turbulence mixes or coarsely atomizes the fluid with the air.
   b) Second stage atomization—Immediately past the first stage atomization, the fluid stream is intersected by jets of air from converging holes on each side of the annular ring. Two straight holes indexed 90 degrees are containment holes which keep the stream from spreading. The turbulence occurring at the intersecting point of the material stream and air jets results in a finer atomization.
   c) Third stage atomization—The angular projections on the nozzle (often called 'wings,' 'ears,' or 'horns') contain passageways for the air jets. These jets intersect the stream just after second stage atomization, and at 90 degrees to the two sets of converging holes. The primary purpose of these jets is to form or shape the round cross section of the fluid stream into an elongated one referred to as 'fan' shaped. Additional turbulence occurs at this point, resulting in additional atomization. The spray pattern size is determined by the design of the air nozzle, the fan control, the method of feeding the spray gun, and the cohesive nature of the material being sprayed.

3) Airless atomization—In an airless system, the gel coat does NOT come in direct contact with compressed air nor is it atomized by air. Instead, a high ratio pump (22:1-33:1) puts the gel coat under high pressure (1000-3000 psi) and forces it through a small orifice (0.015 inch to 0.26 inch).

   As the material passes through the orifice, the material is atomized, similar to water as it exits a garden hose with a spray nozzle. Airless systems are used where high volumes of gel coat can be handled by the operator on large, essentially flat or open parts. It is cleaner and more efficient than conventional air-atomized.

   Contrary to what may be assumed, airless atomization does not atomize more monomer than conventional air spray. Tests have shown that a sprayed film will retain more monomer (harmful to yellowing and chalk) under these conditions:
   a) Airless atomization retains more styrene than conventional air-atomized.
   b) Airless atomization retains more styrene than 'properly' atomized air-assist airless equipment.
   c) The closer the gun is to the mold, the more styrene is going to be retained.
   d) The fewer the number of spray passes, the greater the amount of styrene retained. Typically, a 'finer atomization' (small particles/droplets) will provide a finer orange peel, and therefore better gel coat film/surface/laminate, which will also offer better resistance to yellowing/chalking.



1. Annular ring around the fluid nozzle tip.
2. Containment holes.
3. Wings, horns or ears.
4. Side-port holes.
5. Angular converging holes.

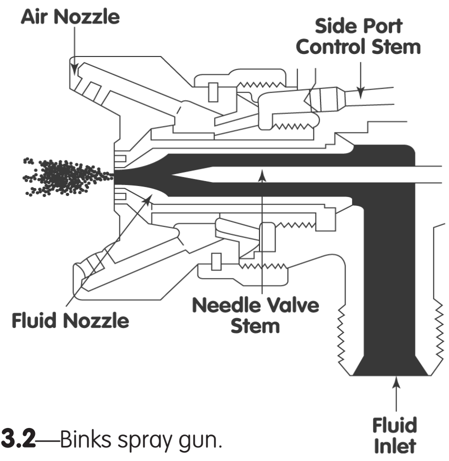


Figure 4/II.3.2—Binks spray gun.

4) Air-Assist Airless—This equipment is a combination of conventional air atomization and airless techniques.

Material is supplied to the airless tip at much lower pressure (400 to 1000 psi) than for standard airless spraying, (1000 to 3000 psi). At this low pressure, however, the spray pattern is coarse and has poor atomization. Atomizing air is now introduced to the spray pattern at low pressure, (three to 30 psi), to refine the spray pattern.

Excess atomization would return the operation back to the state of conventional air atomization.

Many of the pumps used are in the 10-to-12-to-one ratio range which will do a good job on lower viscosity and weight per gallon gel coats, but will not do the job when pumping high viscosity, high weight per gallon (white) gel coat, or MACT compliant gel coats. In many cases, even when pumps are run at line pressure of 100 psi or more, not enough pressure is developed for adequate breakup.

With the low pressure, a very coarse orange peel pattern is developed due to larger than normal droplets of gel coat hitting the mold. This causes a wide range of film thicknesses, as high as 20 mils at the high point and 11 at the low point. This wide variance causes problems such as:

a) Blister resistance on a 20/11 orange peel type situation would only be as good as the 11 mils area, but with much more material actually used.

b) Quick sand through in thin areas of orange peel.

c) Roll out of skin coat over coarse orange peel is often more difficult and will contribute to a defect customers call shot gunning or buck shot, which is small air bubbles trapped in the low areas of coarse orange peel. These small air bubbles show up on the finish after buffing or after the parts are heated in the sun. A 22-to-one or higher pump ratio is recommended to achieve a good breakup with pump pressures in the 30-to-75 psi range. This reduces wear and tear on seals, minimizes the effect of plant air fluctuations, and allows for adjustments due to wear on the tip.

5) High Volume Low Pressure (HVLP)—This type of equipment is not new to the paint industry but is relatively recent to the gel coat industry. California customers especially are using it in an attempt to cut down on emissions (use of the gun is intended to cut down on emissions, or monomer loss). This method of spraying results in larger droplets, a film with very coarse orange peel (causing rollout to be more difficult), and its wetter, more styrene-rich film is more prone to sag.

A typical HVLP gun is manufactured so that no more than 10 psi of atomizing air is at the gun for atomization. Gel coat is atomized by the higher volume (cfm) of air. Results (application and monomer retention) similar to the HVLP have been obtained by merely turning atomizing air way down with the conventional air-atomized gun (see Test Five on the chart on this page).

Note also that airless and air-assist airless retain more styrene in the film than conventional air-atomized equipment.

PERCENT MONOMER IN GEL COAT FILM

Control (material not sprayed)	Conventional Air Spray		Airless		Air-Assist Airless	HVLP**
Test 1						
			(Tip 2140)			
38.3%	32.9%		34.4%		—	—
Test 2						
			(Tip 1750)	(Tip 2640)	(Tip 2640)	—
35.8%	—		20.7%	27.4%	24.9%	—
34.6%	—		—	28.0%	23.1%	—
36.4%	—		22.6%	28.6%	24.7%	—
Test 3						
41.8%	—		(Tip 2140)		—	—
2 to 3 ft.*	—		34.7%		—	—
6 ft.*	—		30.8%		—	—
Test 4						
47.0%	—		(Tip .021 inch)		—	—
1.5 Ft.*	41.4%		43.8%		—	—
3.0 ft.*	32.5%		41.7%		—	—
4.5 ft.*	—		40.0%		—	—
6.0 ft.*	—		37.4%		—	—
Test 5						
34.3%	(60 psi)	(20 psi)	—		—	29.0
	26.6	28.9				

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

ITEM	Hot Pot A	Hot Pot B	Hot Pot C	Air-Atomized Catalyst Injection	Airless Catalyst Injection	Air-Assist Airless	FIT or Convergence
Material supply	1 quart	2 quart	1 or 2 gallon	1 to 20 gal. pressure pot or pump	Pump	Pump	Pump
Part size	Small up to 20 sq. ft.	Small to medium up to 40 sq ft.	Medium to large 150 sq. ft.	Various	Various	Various	Various
Number of parts	One or two	One or two	One or two	Any number	Any number	Any number	Any number
Use	Intermittent	Intermittent	Intermittent	Constant	Constant	Constant	Constant
Switching colors	Easy	Easy	Fair (hose must be cleaned)	Fair (separate pressure pots normally used)	Pump and lines must be cleaned	Pump and lines must be cleaned	Pump and lines must be cleaned
Future use	Very flexible, tooling prototype small runs	Tooling, small jobs	Tooling, small jobs	Large production	Large production	Medium to large production	Large production
Portability	Easy to move	Easy to move	Easy to move	Fixed or cart mounted	Fixed or cart mounted	Fixed or cart mounted	Fixed or cart mounted
Number of hoses	One	Two	Two	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom	2 to 4 hoses may be on a boom
Catalyst Measurement	Weight or volume	Weight or volume	Weight or volume	Metered (requires calibration)	Metered (requires calibration)	Metered (requires calibration)	Metered (requires calibration)
Mixed by	Hand	Hand	Hand	By gun	By gun	By gun	By gun
Cleaning	After each use	After each use	After each use	Wipe gun off intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump	Wipe off tips intermittently. Clean pots or pump

6) Non-atomized Spraying, Fluid Impingement or Convergence—With this method, new to the polyesters industry, gel coat is sent through two orifices in the head which converge or impinge on each other. When this happens, a fan occurs. This is accomplished at lower pressures than with the other systems. Larger tips are used with less over-spray. Note that the fan pattern will have a different appearance than with current systems (large droplets and slightly more orange peel.)

5. SPRAYING MACT COMPLIANT GEL COATS WITH AIR-ASSIST AIRLESS AND NON-ATOMIZED EQUIPMENT—With the emphasis on reducing the emissions of Hazardous Air Pollutants (HAP), Maximum Achievable Control Technology (MACT) Compliant (MC) gel coats have been introduced to the industry. MC gel coats—because they have less monomer—will pump, spray, and flow differently than standard gel coats. Also, new spray equipment with Non-atomized Application Technology (NAT) uses a different principle than conventional equipment to break up gel coat.

Because MC gel coats are high solids gel coats, they do not flow through hoses or pipes as easily as non-MC gel coats, and there is a greater pressure drop at the end of small hoses or pipes while spraying.

Since lower spraying pressures are needed and there are fewer monomers in MC gel coats, material temperature and fluid line size become more critical.

A. Temperatures—*NOTE: The viscosity of MC gel coat increases more than that of standard gel coats as the temperature drops, due to less monomer.* For good spray characteristics, the temperature of the MC gel coat should be 75°F or higher. Fewer problems will be encountered if the work area is temperature controlled (preferably 80°F), rather than reliance on the use of band heaters or in-line heaters.

Use of band or drum heaters is not recommended because gel coat is an insulator and can be over-heated very easily, which will cause premature gellation. Also, malfunctioning thermostats or heaters left on overnight can cause the whole drum to gel.

Use of an in-line heater will allow use of smaller tips as well as lower flow rates.

While in-line heaters present fewer problems than band or drum heaters, gellation can occur. If an in-line heater is used, make sure it can be disassembled and bored out if/when gellation occurs.

Also, when using in-line heaters, the lines should be insulated. A bypass valve near the gun can be used to draw off material until heated gel coat reaches the gun. This valve should be of the locking type, so it cannot be accidentally bumped on. The material coming out of the gun should be 90 to 95°F. Do not heat gel coat over 100°F, as stability is greatly decreased as the temperature rises.

B. Fluid line size—For standard (non-MACT-compliant) gel coats, a 3/8-inch hose with a three- or four-foot 1/4-inch whip works well, but a 1/2-inch diameter hose with a 3/8-inch whip works better because lower pump pressure can be used.

For MC gel coats, a 1/2-inch hose with a three-foot 3/8-inch whip is recommended for up to 30 feet.

For up to 75 feet, use a 3/4-inch hose for the first 50 feet, and then drop down to a 1/2-inch hose with a three-foot 3/8-inch whip. Runs of more than 75 feet should be hard-piped with large lines, one-inch or larger. For recommendations, contact your equipment supplier.

C. Spraying the film—Film build is quicker with an MC gel coat due to less over-spray. Film build speed increases even more when non-atomized application technology (NAT) equipment is used, as the spray is softer (less atomization). Also, it is important to keep in mind that multi-pass spraying of MC gel coats can be counter-productive; the more passes that are used to apply a given thickness of film, the more emissions will go into the air. The fewer the spray passes, the fewer emissions released.

Film should be sprayed in at least two passes. The first pass should be the thinnest continuous wet film possible, somewhat around eight to 10 mils. The second pass can be another eight to 10 mils, for a total film thickness of 16 to 20 mils. If the second pass is thinner than eight mils, then a third pass can finish from 16 to 20 mils. If spraying below the water line, another four mils can be added for a total of 20 to 24 mils for better water blister resistance.

NOTE: Do not spray a dry film. Each pass must be developed through a wet film and perpendicular to the previous film. Gel coats should not be sprayed more than four feet from the mold because they can go dry.

Use of a constantly recirculating system is not recommended because it can cause viscosity to drop or can introduce large amounts of air into the gel coat.

6. SPRAYING WITH NON-ATOMIZED APPLICATION TECHNOLOGY (NAT) EQUIPMENT—Fluid Impingement Technology equipment uses two streams of gel coat which hit (collide) with each other to form the gel coat fan pattern. This is done under low pressure (11:1 pump) and produces larger droplets than an air-assist airless or airless setup. The lower pressure and larger droplet size account for the lower emissions and reduced over-spray. These factors will alter the appearance of the spray pattern.

Gun pressure settings will need to be adjusted, sometimes to settings that will be the opposite of those used with air-assist airless or airless systems.

The impingement tip will have two holes angled so that the fluid streams will meet (impinge) each other within an inch of the tip. Usually the first two numerals of the tip number will indicate the size of each hole (in thousandths of an inch). The third and fourth numerals doubled will indicate the approximate fan angle. The larger these last two numbers, the wider the fan pattern will be.

Tips are available in orifice sizes of 15, 17, 20, 22, 25, 27 and 30 (tip size below 17 is not recommended as plugging can occur). Fan angle sizes are 17, 20, 22, 25, 27 and 30. Starting tips for standard gel coats (non-MC) are 1720 or 2520, with a 40 to 60 psi pump pressure.

While larger tips are used with whites and colors, smaller tips may be appropriate for both colors and clears.

The chart below gives examples of pressure drops for an MC white gel coat.

TIP	PRESSURE at PUMP (PSI)	FEET of ¾-INCH HOSE or PIPE	FEET of ½-INCH HOSE	PRESSURE DROP at GUN
2520	700	20	0	0
2520	600	20	20	0
2520	650	0	40	-400
2320	500	70	0	-150
2320	700	70	0	-100

As a startup procedure, start the pump at zero, then increase the pressure in five-psi increments until the fan droplets are all about the same size. This uniformity will appear immediately following the disappearance of the 'fingers.' *NOTE: The droplets will be larger in size than when using air-assist airless or airless equipment.*

With impingement technology, spray will be more coarse with a rougher pattern, but will have fewer tendencies for porosity.

Do not adjust to achieve a finer particle size as porosity can occur, emissions may increase, and fan edges may be ragged. To clean up edges, use a small amount of refinement air.

Some adjustments will be opposite those normally used with air-assist airless and airless equipment. For example, with impingement technology, better breakup can be achieved by using a larger tip at a lower pressure. (Air-assist is not used for breakup; it is turned on only slightly to clean up fan edges. If turned too high, emissions go up and porosity occurs.) If breakup is not achieved, or if pump pressure is running above 80 psi, try a larger tip and/or a larger hose (the opposite of the action to take with air-assist airless). Catalyst air should be 10 to 15 psi.

In cases where flow rates are slightly higher and more material is going into the mold, only two passes will be needed to achieve proper film build. *NOTE: Do not dust coat. Use a thin continuous film for the initial coat.*

Because the fluid velocity is lower, the maximum spray distance from the mold is three feet. Tight areas may be more challenging to spray.

The chart on the following page shows flow rates using impingement equipment with 25 percent HAP white gel coat:

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

TIP	NO HEAT— Lbs./Minute	HEATER— Lbs./Minute	BREAKUP
1925	2 to 3	2 to 3	Fair
2120	2.5 to 3	2 to 3	Good/Fair
2520	4 to 5.5		Good

NOTE: With the heater off, pump pressure must be increased for good breakup; therefore, the flow rate is higher.

For smaller, more intricate parts, use a smaller tip. Use larger tips for large, wide open, easy-to-spray parts.

Because impingement equipment operates at lower pressure, there may be a very slight 'wink' in the fan pattern; however, it should not be pronounced. If that is the case, use a larger surge chamber or warm the material (if it is cold).

Due to the larger droplets, the pattern will be rougher looking; the final film backside may also appear slightly rougher than it would with an airless or air-assist gun. However, adjusting to a finer droplet may create porosity and increased emissions.

It is important to USE A MIL GAUGE.

Adjusting pump pressure (1/2-inch hose with a 3/8-inch whip) for proper breakup, using various tips and without heat, yielded the results shown in the chart below:

HEATER	TIP	PRESSURE (PSI)	BREAK-UP	FLOW RATE Lbs./Minute
OFF	2120	90	POOR	NA
OFF	2520	75	OK	5.7
ON*	2520	40	OK	3.4
ON*	2120	45	OK	2.1
ON*	1925**	50	OK	1.8

7. SPRAYING MC GEL COATS THROUGH STANDARD AIR-ASSIST AIRLESS OR AIRLESS EQUIPMENT—Because MC gel coats contain less monomer, emissions are reduced. However, this also alters how the gel coats flow and break up.

MC gel coats are harder to spray than standard gel coats through air-assist airless and standard airless equipment, but this can be achieved.

Because MC gel coats flow differently, CCP recommends a 22:1 pump to ensure that air pressures can be kept in the 40 to 75 psi range for better control and less wear on the pump. Pump pressure should be adjusted with the air assist turned on just enough to produce proper breakup. Always use minimum pump and air assist pressure.

Spray the gel coat on in a continuous film thickness of eight to 10 mils per pass. Rely on a mil gauge, as the backside will have a different appearance than non-MC gel coats.

Use a 0.018-inch tip for clears and small parts; the flow rate will be about two and a half pounds per minute. For decks or complex parts, use a 0.21-inch or 0.023-inch tip; flow rate will from two and a half to three and a half pounds per minute. With 0.26-inch tip, used on large flat or open parts (hulls), flow rate will be about four pounds per minute.

8. SPRAY SYSTEM SELECTION—There are a number of spray guns that can be used for polyester. See the charts on the following pages for basic characteristics of these tools.

9. SPRAY SELECTIONS AND SETTINGS—Once a spray system has been selected, the next step is to determine the recommended starting pressure settings and spray procedures. These settings may have to be changed slightly to match a part and spray operator. Also check with the equipment manufacturer for setup procedures and handling precautions.

10. CALIBRATION—Since polyesters require the proper amount of catalyst to be added and mixed in to achieve desired properties, it is necessary to calibrate catalyst injection spray equipment.

Because wear on equipment, temperature and the differences of flows between materials will change the catalyst ratio, it is not possible to rely on setting pressure readings once and then using them continuously day after day.

Different colors produce different flow rates (at equal pressures) and present another reason to be concerned with calibration. Calibration should be done weekly or for each batch change. Setting up a calibration routine—such as the first thing every Monday morning—is an easy and worthwhile habit to establish.

Consult the equipment manufacturer and their literature for recommended calibration methods and procedures.

A. Safety considerations

1) Always wear eye protection.
2) Never point the spray gun at self or others.
3) Always ground spray equipment.
4) Before working on equipment, depressurize by turning the air supply off and then pulling the trigger of the spray gun and bleeding the bypass at the filter.
5) Never trust spray equipment even if all the gauges say zero pressure. If there is any doubt that the equipment is still pressurized, and it must be dismantled to relieve the pressure, keep protection between the operator and the equipment (such as a piece of cardboard or rag), and always wear eye protection.
6) Airless (high pressure) systems can create enough pressure to force the material through human skin—BEWARE!
7) Read all Material Safety Data Sheets and Equipment Safety Sheets.
8) Always turn valves on slowly to avoid sudden surges of pressure that can rupture hoses.

B. General procedures for determining flow rates and percent catalyst of gel coat include:

1) With X grams of material collected in 30 seconds and a desired flow rate expressed in pounds per minute:

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

X grams times 2 = Grams Per Minute (GPM).
GPM = Pounds Per Minute (PPM)
454
(1 lb. = 454 grams)
Example: 300 grams in 30 seconds
300 x 2 = 600 GPM
GPM = 1.32 PPM
454

2) With X pounds of material collected in 30 seconds and a desired flow rate expressed in GPM:

X pounds times 2 = Pounds Per Minute (PPM)
PPM x 454 = GPM
Example:
0.66 pounds in 30 seconds
0.66 x 2 = 1.32 PPM
1.32 x 454 = 600 GPM

3) To determine the amount of catalyst needed for a flow rate, multiply the grams per minute of gel coat by percent catalyst desired.

Example:
Flow rate is 600 GPM
Percent catalyst desired is 1.8%
600 x 1.8% = 10.8 grams or cc's
Percent catalyst desired is 1.8%
600 x 1.8% = 10.8 grams or cc's

NOTE: This test can also be run for a 15-second collection time; then, to calculate the grams per minute, multiply by four instead of two.

HOT POT				
Items Needed	**DeVilbiss JGA-502**		**Binks 2001**	
	1 Quart	2 Quarts to 20 Gallons	1 Quart	2 Quarts to 20 Gallons
Container	Attached	Remote	Attached	Remote
Catalyst	Hand mixed	Hand mixed	Hand mixed	Hand mixed
Air atomization	External	External	External	External
CFM	17 @ 70 psi	17 @ 70 psi	17 @ 70 psi	17 @ 70 psi
Air cap	AV-1239-704	AV-1239-704	67 PB	67 PB
Fluid nozzle	AV-601-E	AV-601-E	67	67
Needle	JGA-402-E	JGA-402-E	67	67
Pressure				
Air*	60 - 90	60 - 90	60 - 90	60 - 90
Fluid	10 - 25	15 - 45	10 - 25	15 - 45
Delivery (lbs./minute)	1 to 2.5	1 to 2.5	1 to 2.5	1 to 2.5
Spray distance	18 to 24 inches	18 to 24 inches	18 to 24 inches	18 to 24 inches
Number of passes	3	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7	5 to 7

CONVENTIONAL AIR-ATOMIZED CATALYST INJECTION			
Spray Gun	**Binks 18N Catalyst Injection**	**Binks 18C Catalyst Side Injection**	**Glas-Craft ISD C-20 Gel Coat Nozzle Kit**
Air cap	A63 PB	63 PB	Stage 2
Fluid orifice	66SS	66	.078 orifice
Needle	65	65	External
Atomization	External	External	60 to 90 psi
Air atomization*	60 to 90 psi (carries catalyst)	0 to 90 psi	—
Catalyst	Std MEKP	As required	As required
Catalyst pressure	—	As required	As required
Ball setting (top)	As required	As required	As required
Material supply			
Pump pressure (4:1)	25 to 35	25 to 35	25 to 35
Pot pressure	20 to 45	20 to 45	20 to 45
CFM	17 @ 90 psi	17 @ 90 psi	17 @ 90 psi
Delivery (lbs./minute)	1 to 2.5	1 to 2.5	1 to 2.5
Spraying distance	18 to 24 inches	18 to 24 inches	18 to 24 inches
Number of passes	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7
Calibration (material & catalyst)	Gel times	Flow and gel times	Gel times

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AIRLESS CATALYST INJECTION A

		Binks Mavrick		
TYPE	**Binks 43 PL**	**with ACI**	**with 3400**	**STAR**
Catalyst	*Diluted MEKP	MEKP Standard	MEKP Standard	MEKP Standard
Catalyst atomization and mix	Airless Pressure External	Air External	Air External	Air External
Catalyst tip	0.011 to 0.013	0.052	0.015	Fixed
Catalyst injector pressure	25 to 60 psi	25 to 35 psi	As required	As required
Catalyst atomizing pressure	—	3 to 5 lbs. lower	At least 60	15
Gel coat pump	33:1	33:1	33:1	24:1
Pump pressure	50 to 90	50 to 90	50 to 90	50 to 90
Material tip	0.015 to 0.026	0.015 to 0.026	0.015 to 0.026	0.015 to 0.026
CFM	40 CFM max.	40 CFM max.	40 CFM max.	—
Delivery (lbs./minute)	2 to 4 lbs.	2 to 4 lbs.	2 to 4 lbs.	2 to 4 lbs.
Passes	3	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7	5 to 7
Spraying distance	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches
Calibration	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time
Fan pattern	Vertical	Horizontal or vertical	Horizontal or vertical	Vertical

* See catalyst and equipment manufacturers for proper diluents and instructions.

AIRLESS CATALYST INJECTION B

TYPE	**Glas-Craft LPA**	**Venus Internal Mix**	**GS Manufacturing**	**Polycraft G555**
Catalyst	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard
Catalyst atomization and mix	Air External	— Internal	Airless External	Air External
Catalyst tip	External	—	.011 to .013	Fixed
Catalyst injector pressure	35 to 50 psi	Same as material	100 (catalyst regulated by fluid regulator)	30 to 40
Catalyst atomizing pressure	At least 2 psi below catalyst pressure	—	—	3 to 5 Lbs. lower
Gel coat pump	33:1	11:1	20:1	30:1
Pump pressure	50 to 90	60 to 90	50 to 90	50 to 90
Material tip	0.015 to 0.026	0.015 to 0.026	0.015 to 0.026	0.015 to 0.026
CFM	—	—	—	—
Delivery (lbs./minute)	2 to 4 lbs.	2 to 4 lbs.	2 to 4 lbs.	2 to 4 lbs.
Passes	3	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7	5 to 7
Spraying distance	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches
Calibration	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time
Fan pattern	Horizontal or vertical	Horizontal or vertical	Horizontal or vertical	Horizontal

C. Binks—18-N

1) Select and install correct air cap, nozzle, and needle in gun.
2) Attach fluid hose to gun.
3) Check pump filter and lines.
4) Put pump in gel coat container.
5) Back out regulator and make sure pressure is off. To pump, turn on air to pressure gauge. Then slowly increase pressure until pump starts.
6) Adjust pressure to 30 psi on pump (four to one) and check for leaks.
7) Run flow rate 30 seconds (catch in a previously weighed container); adjust to one to 2.5 pounds per minute. *NOTE: Gel coats must be weighed, as volume measurements will not be accurate due to density differences.*
8) Check catalyst level in tank (#5200) and fill if necessary.
9) Attach and check catalyst lines.
10) Back out regulator to make sure it is off. Turn on air to catalyst pressure gauge. Then slowly turn to 30 psi. STOP. Check for leaks. Then adjust injector pressure to 70 to 90 psi. A T-gauge must be used (Binks Part #73-125) to check pressure at the gun. If flow rate is at maximum two and

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

AIR-ASSIST AIRLESS CATALYST INJECTION						
TYPE	**Binks 118-AC/ Vantage 11C**	**Magnum ATG 350**	**Polycraft G-755**	**GS Mfg**	**Glas-Craft LPA II**	**Binks 102-2400**
Catalyst	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard
Catalyst atomization and mix	— External	Air External	Air External	Air External	Air External	— External
Catalyst tip	.013	Fixed	Fixed	Fixed	Fixed	.013
Catalyst injector pressure (psi)	10 to 15 (Plug groove valve at the gun)	60	25 to 45	As required	As required	10 to 15
Gel coat pressure (psi)						
clears	400 to 600	400 to 600	400 to 600	400 to 600	400 to 600	400 to 600
colors	600 to 1000	600 to 1000	600 to 1000	600 to 1000	600 to 1000	600 to 1000
Pump pressure (psi)	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump
Material tip	018 to .026	.018 to .026	.018 to .026	.018 to .026	.018 to .026	.018 to .026
Air-assist air*	5 to 30	5 to 30	5 to 30	Fixed	5 to 45	5 to 30
CFM	—	—	—	—	—	—
Delivery (lbs./minute)	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.
Passes	3	3	3	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7	5 to 7	5 to 7	5 to 7
Spraying distance	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches
Calibration	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time
Fan pattern	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical

* As low as possible.

a half pounds, 60 psi is required (with fan full open) to properly atomize the gel coat. *NOTE: 100 psi maximum on Binks injector; 80 psi maximum on Glas-Craft I injector.*

11) Check atomization and adjust as necessary (either air or fluid). *NOTE: If adjusting downward, relieve pressure in lines as the check valve may retain the original pressure until relieved by pulling the trigger.*
12) Calculate amount of catalyst necessary for the flow rate.
13) **CAUTION: Do not rely on catalyst charts. Confirm the flow rate manually.**
14) Adjust the ball to this reading. Turn top knob all the way open, then one and a half turns in; adjust ball with bottom knob to the right side.
15) Spray the catalyzed material onto a glass panel and collect by scraping about 100 grams into a paper cup. Note the gel time.
16) For gel time comparisons, take gel coat from the container and weigh out 100 grams. Add the same amount of catalyst as calculated in C.12 and run the gel time.
17) Compare gel times and adjust catalyst injector if necessary. The catalyst ball can be adjusted in five-unit steps until desired gel time is reached, but stay in the 1.2-to-three percent range.
18) Wipe off gun after each use.

D. Binks—18-C

1) Select and install correct air cap, nozzle and needle in gun.
2) Attach fluid hose to gun.
3) Check pump filter and lines.
4) Put pump in gel coat container.
5) Back out regulator and make sure pressure is off. Turn air on to pressure gauge at pump. Then slowly increase pressure until pump starts.
6) Adjust pressure to 30 psi on pump (four to one) and check for leaks.
7) Run flow rate 30 seconds; adjust to two to two and a half pounds per minute. Catch in a previously weighed container. *NOTE: Gel coats must be weighed, as volume measurements will not be accurate due to density differences.*
8) Release pressure on pump, and bleed at gun and bypass valve.
9) Calculate amount of catalyst necessary for the gel coat flow rate.
10) **CAUTION: Do not rely on catalyst charts. Confirm the flow rate manually.**
11) Check catalyst level in tank (#5202) and fill if necessary.
12) Attach and check catalyst lines.
13) Back out regulator to make sure it is off. Turn air on to catalyst pressure gauge.
14) Adjust the ball for appropriate reading.

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

AIR-ASSIST AIRLESS SLAVE ARM CATALYST					NON-ATOMIZED	
TYPE	**MAGNUM ATG 3500**	**Venus Pro Gel Coat**	**Glass Craft AAC**	**Binks 102-2400**	**FIT MAGNUM**	**POLYCRAFT**
Catalyst	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard	MEKP Standard
Catalyst atomization and mix	5 to 30 External	Internal Mix*	35+ External	— External	5 to 30 External	5 to 30
Catalyst tip	Fixed	Internal	Fixed	0.013	Fixed	Fixed
Catalyst slave arm	Set as desired	Set as desired	Set as desired	Set as desired	Set as desired	Set as desired
Gel coat pressure Clears Colors	 400 to 600 600 to 1000	 400 to 600 600 to 1000	 400 to 600 600 to 1000	 400 to 600 600 to 1000	 300 to 600	 300 to 600
Pump pressure	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump	Dependent upon size of pump	30 to 60	30 to 60
Material tip	0.018 to 0.026	0.018 to 0.026	0.018 to 0.026	0.018 to 0.026	0.19 to 27	0.19 to 27
AAA (psi)	5 to 30	5 to 30	10 to 15	5 to 30	Low	Low
CFM	—	—	—	—	—	—
Delivery (lbs./minute)	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.	2 to 3 lbs.
Passes	3	3	3	3	3	3
Mils per pass	5 to 7	5 to 7	5 to 7	5 to 7	5 to 7	5 to 7
Spraying distance	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches	24 to 36 inches
Calibration	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time	Flow rate and gel time
Fan pattern	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical

* Solvent flush requires 30 to 40 psi.

15) Collect catalyst for one minute and figure percent.
16) Adjust catalyst ball if required and run catalyst flow rate again.
17) Turn on gel coat pump to previous pressure setting and run gel time comparison (see C.15, C.16, C.17).

E. Airless with airless atomized catalyst system (Binks 43 PL and GS)

1) Select fluid material tip and put on gun.
2) Check fluid lines and pump filter.
3) Put pump in gel coat. (If catalyst slave pump, disconnect. See Section 10. Calibration, I. (the letter) in this chapter.)
4) Back out regulator and make sure pressure is off. Turn air on to pump gauge. Then slowly turn pressure up until it starts. Check for leaks.
5) Turn pressure up to approximately 60 psi and slowly adjust pressure until tails are eliminated at 24 inches from the gun head.
6) Take flow rate in pounds per minute, two to four. Use no more than three pounds for small/intricate molds, no more than four pounds for large/open molds.
7) Release pressure off pump, bleed at gun and bypass valve.
8) Wipe off gun.
9) Check catalyst level in tank. Fill if necessary (If catalyst slave pump, reconnect.) *NOTE: May require special viscosity MEKP. Consult catalyst manufacturer.*
10) Check fitting and lines and install catalyst tip. Start with .011.
11) Back off regulator and make sure it is off. Turn on air to catalyst gauge. Slowly adjust pressure to catalyst supply. Stop at 15 psi. Check for leaks.
12) Adjust catalyst pressure for proper atomization.
13) Run flow on catalyst in graduated cylinder. Calculate percent catalyst and adjust if necessary. Check gel time, adjust as desired but remain in the 1.2 to three percent catalyst range. If diluted catalyst is used, the percent of diluent must be taken into consideration.
14) Turn on gel coat pump to previous setting and run gel time comparison (see C.15, C.16, C.17).

F. Airless with internal air-atomized catalyst and external mix (Binks Maverick ACI, Glas-Craft, Polycraft, Star, Magnum).

1) Select correct tips and put on gun.
2) Check pump filter and material lines.
3) Put pump in gel coat. (If pump is a catalyst slave pump, disconnect. See I. in this section).
4) Back out regulator and make sure pressure is off. Turn air on to pump gauge; then slowly increase pressure on pump until it starts. Check for leaks.
5) Turn pressure up to approximately 60 psi and slowly adjust until tails are eliminated at 24 inches from the gun head.
6) Take flow rate, two to four pounds per minute.

Use no more than three pounds for small/intricate molds, and no more than four pounds for large/open molds.

7) Release pressure off pump, bleed at gun and bypass valve.
8) Wipe off gun.
9) Check catalyst level in tank. Fill if necessary.
10) Check catalyst and air line. (Reconnect catalyst slave pump if used).
11) Back off regulators.
12) Adjust catalyst atomizing air and catalyst pressure, and check for leaks.
13) Calculate amount of catalyst necessary for the gel coat flow rate.
14) Check catalyst atomization and adjust ball for the required amount of catalyst.
15) Run catalyst flow. Compare to gel coat flow. Adjust if necessary. If catalyst pressure is to be decreased, the catalyzer pot pressure will need to be bled before calibrating.
16) Turn on gel coat pump to previous setting and run gel time comparisons (see C.15, C.16, C.17).

G. Airless with external air-atomized catalyst system and external mix (Binks Maverick-3400).

1) Select correct tips and put on gun.
2) Check pump filter and material lines.
3) Put pump in gel coat.
4) Back out regulator and make sure pressure is off. Turn air on to pump gauge; then slowly increase pressure on pump until it starts. Check for leaks.
5) Turn pressure up to approximately 60 psi and slowly adjust until tails are eliminated at 24 inches from the gun head.
6) Take flow rate, two to four pounds per minute. Use no more than three pounds for small/intricate molds, no more than four pounds for large/open molds.
7) Release pressure off pump, bleed at gun and bypass valve.
8) Wipe off gun.
9) Check catalyst level, fill if necessary.
10) Calculate amount of catalyst necessary for the gel coat flow rate.
11) Turn on catalyst pot or pump slowly. Check for leaks.
12) Run catalyst flow rate and adjust pressure up and down to achieve catalyst desired.
13) Adjust catalyst pressure as required for fine atomization of catalyst—no catalyst droplets.
14) Turn on gel coat pump to previous setting and run gel time comparisons (see C.15, C.16, C.17).

H. Air-assist airless (Binks 118-AC/Vantage II-C, Polycraft G755, Magnum ATG3500, GS Manufacturing, Glas-Craft LPA, Binks 102-2400).

1) Select correct tips and put on gun.
2) Check pump filter and material lines.
3) Put pump in gel coat. If catalyst slave pump disconnect. See Section 10, Calibration, I. (the letter) in this chapter.
4) Back out regulator and make sure pressure is off. Turn air on to pump gauge; then slowly increase pressure on pump until it starts. Check for leaks.
5) Turn pressure up to approximately 30 to 50 psi (largely dependent upon pump ratio). Do not exceed 600 psi gel coat pressure with clear gel coat, nor more than 1000 psi with color gel coat. The pressure will vary according to tip size, gel coat viscosity and temperature. Ideally, gel coat pressure should be as low as possible while still maintaining a good fan and flow rate. Do not be concerned with fingers or tails because the air-assist will refine them.
6) Take flow rate; do not exceed 3 pounds per minute.
7) Release pressure off pump, bleed at gun and bypass valve.
8) Check catalyst level, fill if necessary (if catalyst slave pump, reconnect).
9) Run catalyst flow:
   If 118AC, Vantage II-C or 102-2400 as in D.9 through D.17.
   If G-755, ATG-3500, GS or Glas-craft LPA II, as in F.12 through F.16.
10) Adjust air-assist air. Use only as little pressure as possible so as to minimize the fingers and tails.

I. Do not assume that a catalyst slave pump is delivering the correct amount of catalyst.

The catalyst delivery can be off due to inaccurate slave pumps, wear, leaks, clogged filters or atomizing pressure that is too high.

If the slave pump is suspected to be inaccurate, calibrate the pump according to the manufacturer's recommendations. Equipment manufacturers offer calibration kits for checking slave pump calibration.

In addition, slave settings are based on volume percentages. CCP's catalyst specifications are based on weight percentages. There is an inherent error introduced due to the variation of the weight per gallon of the gel coat:

Weight/Gallon of Gel Coat	Slave Pump Setting	Actual Weight %
8.8 (Clears)	1.8	1.9
9.8 (Colors)	1.8	1.7
10.8 (Whites)	1.8	1.5
11.8 (Low VOC)	1.8	1.4

An alternative, but not quite as accurate procedure, to a calibration kit is to use the stroke counting method. The stroke counting method is to count the pump strokes while checking the flow rate. After the flow rate is determined, disconnect the gel coat supply to the gun. Open the bypass valve on the pump and adjust the valve so the pump is stroking the same number of strokes per minute as when the flow rate was checked. Collect catalyst out of the tip of the gun while allowing the pump to pump gel coat through the bypass at the determined stroke per minute rate. Divide the catalyst flow rate by the gel coat flow rate to get percent of catalyst. Catalyst percent should be approximately ± 0.10 percent of the slave pump setting. Confirm by running gel time comparisons (see C.15, C.16, C.17).

In addition, the pump must be checked and primed each day because gas pockets can form, causing cavitation.

Monitor the filter to ensure it is not plugged or restricted.

11. CLEANUP PROCEDURES

A. Relieve all pressure from pump and lines.

B. Place pump in container of wash solvent.

C. Wipe down outside of pump.

D. Remove and clean spray tips.

E. Turn up pressure slowly until pump just starts with trigger pulled.

F. Run two to three gallons of solvent through pump and lines, then relieve all pressure. Spray into bucket for disposal. Do not let the pump cycle (both strokes) more than one per second.

G. Carefully open bypass at filter.

H. Remove and clean filter; replace if necessary. Every two weeks check and/or clean surge chamber.

I. Put pump in container of clean solvent.

J. Repeat steps F to G.

K. Wipe hoses and gun down.

L. Grease or lubricate necessary parts.

M. Inspect for worn parts and order replacements.

N. Make sure pump is stopped in down position to prolong packing life (make sure lubricant cup in pump shaft is full).

O. Relieve all pressure and back regulators out to zero.

12. MAINTENANCE—The spray gun and support equipment represent a considerable investment. To protect the investment, it is important to implement a planned maintenance program. It should include the following:

A. An inventory of spare parts for all spray guns, pumps, hoses, catalyst injector or catalyst slave pump to include:

1) Air cap, nozzle and needle.
2) Packings and gaskets.
3) Extra hoses—fittings.
4) Extra gauges.

B. Be in constant awareness of the following:

1) Catalyst flow.
2) Condition of all hoses, both gel coat and catalyst. No kinks or frayed hoses.
3) Spray pattern and technique.
4) Contamination. If present, remove.
5) Use of proper protective equipment.

C. The daily checklist for the beginning of each shift should include:

1) Drain water traps morning, noon and afternoon (more if needed).
2) Mix gel coat (just enough to keep resin and styrene mixed in). Do not over-mix gel coats. Over-mixing breaks down gel coat viscosity, increasing tendencies to sag, and causes styrene loss, which could contribute to porosity. Gel coats should be mixed once a day, for 10 minutes. The gel coat should be mixed to the sides of the container with the least amount of turbulence possible. Do not use air bubbling for mixing gel coat. It is not effective and only serves as a source for possible contamination.
3) Inventory gel coat for day's use. Check catalyst level. Always add catalyst which is at room temperature. If using a slave arm catalyst system, check for air bubbles in the catalyst line. Disconnect catalyst pump and hand pump until resistance is felt on both up and down strokes, or until proper pressure is reached on catalyst gauge (if the system has one).
4) Start pumps with regulator backed all the way out. Open valve and charge air slowly, checking for leaks. Do not let the pump cycle (both strokes) more than 1 per second.
5) Shut down.
   a) Turn off all air pressures and back regulator out.
   b) Bleed lines.
   c) Store pump shaft down to keep it wet.
   d) Check for material and catalyst leaks.
6) Clean up. Remove spray tips, clean, then store safely. Lightly grease all threads. If the tips and cap are placed in solvent overnight, make sure it is clean solvent.
7) Secure the area. Remove all solvents and check for hot spots. Remove and properly dispose of any collections of catalyzed material or catalyst/materials combinations.

D. Weekly checklist should include:

1) Calibrate each spray gun for material flow.

2) Calibrate each catalyzer or catalyst slave pump for catalyst flow.
3) Check gel time of gel coat through the gun versus gel time of known control.
4) Clean filter screens.

13. EQUIPMENT TROUBLE SHOOTING—The majority of polyesters used today are sprayed or pumped through semi-automatic equipment. The care and operation of this equipment will determine whether or not the polyester will achieve its maximum properties and performance. Fabrication equipment operators must be trained in how to use and maintain their equipment.

Anyone who uses spray equipment should have (and read) all the literature available from the manufacturer of the equipment. This includes warnings, parts diagrams, set up instructions, operating instructions, maintenance requirements, safety and trouble shooting guides.

If this information has not been obtained or if a question arises, call or write both the company from whom the equipment has been purchased and the manufacturer. They will help because they want the equipment used efficiently, correctly and safely. Also, they will have general literature on spraying, and technical service people to help.

Always remember the investment in the equipment and that it was purchased to do an important job. If it is not maintained and if worn parts are not replaced, the investment will be lost and the equipment will not do the job for which it was selected and purchased.

One way to determine if a cure-related problem is caused by material or equipment is to make a small test part where the catalyst is mixed directly in the gel coat. If this part does not exhibit the problem, then the cause is more likely in the equipment or operator. Another way to check is to run a different batch of material through the equipment; however, this could generate bad parts, making the first test method preferable.

A list of some of the more common problems that can occur with fabrication equipment follows. Since there are many different types of equipment in use, it is impossible to cover each one individually or to list all the possible problems or solutions. See the manufacturer's literature for the particular type of equipment in use, or contact the manufacturer.

EQUIPMENT TROUBLESHOOTING—SUGGESTED CAUSES AND REMEDIES

PROBLEM—GEL COAT/SPRAY	SUGGESTED CAUSES AND REMEDIES
Atomization poor (large droplets)	Check air pressure, length of hose, hose diameter (which may be too small), clogged or worn nozzle or air cap, check if valves are stuck, too much fluid flow, regulator not working properly.
Catalyst injector balls drop	Bottom needle valve almost closed and vibrates, filter plugged, not enough CFM's.
Catalyst injector balls overshoot	Top valve wide open, turn 1½ turns in—(Binks Injector)
Catalyst injector ball goes out of sight when pressured	Catalyst level too low—insert special gasket with .013 hole over delivery tube (Binks injector), air in flow tube.
Catalyst injector balls fluctuating	Catalyst needle valve vibrating or too close to seat—open or tighten packing, not enough or fluctuating CFM's, dirty catalyst filter.
Catalyst valve—burst of catalyst	Weak spring due to aging. If Binks, use Plug Groove valve at the gun. If hose within a hose, check for broken catalyst line.
Cavitating pump—sucks air	Remove siphon tube, put pump directly into resin—if pumps okay—cavitating due to siphon system leak, pump too small, cold or high viscosity.
Check ball stuck	Residue after flushing, vapor lock. Use piece of wood to free ball or tap side of pump.
Drips (Gun):	
Fluid	Worn, clogged, or bent needle, seating adjustment of needle, over-spray on gun, worn packings or seals, loose connection.
Catalyst	Worn seat or seals, damaged air valve, trigger out of adjustment, over spray on gun, loose connection, clogged valve or seat, gun head not aligned to gun body, fan control may trap catalyst in dead air space and drip catalyst out of air horns.
Solvent	Clogged or worn valve, worn seals, sticking needle or button.
Gelled hose	Bad fluid nozzle, bad seat.
Material (none on downstroke)	Foot valve, spring, spring retainer, or foot valve ball worn or dirty.
Material (none on upstroke)	Piston cups, piston ball or pump cylinder worn.
Pattern of spray off to one side	Partial clogged air cap, damaged nozzle, worn nozzle or air cap, bent or worn fluid needle.
Plugged filter screen	Seedy or partial gelled batch, trash from material falling off pump when placed in new drum; due to normal buildup, screens and pumps must be cleaned periodically; dirty surge chamber.
Pump cycles when gun not in use	Worn piston cups, bottom check ball not seating.
Shaft of pump drops an inch or two—shudders	Starved pump—check filters or worn internal packings. Check for worn packing by stopping pump at top of stroke—if with no material flow shaft creeps down, packing is worn.

OPEN MOLDING: Conventional Gel Coat—Spray Equipment

EQUIPMENT TROUBLESHOOTING (continued)

PROBLEM—GEL COAT/SPRAY	SUGGESTED CAUSES AND REMEDIES
Shaft of pump (material coming up around)	Loose or worn seals—clean and tighten, stop pump in down position when system not in use, worn shaft.
Siphon wand jumps	Dirt on check ball in pump.
Slow gel time and/or cure	Check catalyst and material flow, oil or water contamination. Check gun trigger for proper activation. If slave pump, check for air bubbles.
Surging:	
Material	Inconsistent or low air pressure on pump, worn or loose pump packing, out of material, sucking air through loose connection, balls not seating in pump (dives on down stroke—bottom ball; fast upward stroke—top ball; flush pump), filter plugged, siphon line has air leak, screens plugged, too much material flow, cold or high viscosity, plugged surge chamber.
Catalyst	Inconsistent or low air pressure, out of catalyst, check valve sticking in gun or catalyzer, loose connection, screen plugged. If Binks equipment install Plug-Groove valve at the gun, keep hoses straight rather than coiled.
Tails (airless):	
Material	Pump pressure too low, worn tip, too large of tip, viscosity too high.
Catalyst	Worn tip, low pressure, wrong tip, viscosity too high, too large a fan.
Tips spitting or trigger will not shut off	Worn seat or worn needle or weak spring, check packing.
Trigger stiff	Bent needle, bent trigger, worn needle guide.
Water in air lines	No extractor, extractor too close to compressor—should be no closer than 25 ft, all take off's from main line should come off the top.
Worn packings	Pump overheating from being undersized, high pressure or pumping without any material, do not let pumps jackhammer—no more than 1 cycle (both strokes) per second—use glass reinforced Teflon® packings. Keep idle pump shaft in down position to keep dried material from damaging packings.
Fan pattern width varies on the up stroke versus the down stroke	Worn inner packing—replace.
Chunks in the filter larger than the mesh of the strainer on the pickup tube	Gelled material in the surge chamber or pickup hose—clean or replace.
Tails (non-atomized)	Use larger tip or hose; use inline heater.
Catalyst pump feels spongy when hand pumping	Trapped air pocket—open and close bypass, or pull trigger and pump up again.
Catalyst gauge pressure drops when gun not in use	Catalyst leak—find and repair.

14. ADDITIONAL INFORMATION ON EQUIPMENT

A. **If pump packing** is too tight it will cold flow and there will be strings at the edges of the packing.

B. **Always put catalyst tip** on bottom so catalyst does not spray on glass.

C. **Pre-orifice or insert**—softens spray (less force); in some cases requires less pressure for proper breakup. *NOTE: Use same size (or smaller) insert than tip.*

D. **To tighten** upper packings, relieve pressure, tighten 1/8 turn at a time, run pump five strokes and repeat, until no leak under pressure.

E. **Catalyst condenses** out of atomizing air in the hose in 10 to 15 minutes, (system at rest).

F. **When ordering gun**, specify nozzle and air cap.

G. **Transfer pumps** go through bung four to one, eight to one only.

H. **Binks pump**—lower screen: 30 mesh; upper filter: 50 mesh. Upper filter is half the orifice size.

I. **Starting pump**—open bypass until flow is steady.

J. To prevent leaks, avoid swivel fittings.

K. **Compressor electric**—one horsepower is approximately four CFM.

L. **Quick disconnect** restricts air flow.

M. **Catalyst tip angle**—same as material—want equal fan pattern.

N. **When spraying**—pull trigger all the way (it's all or nothing—no partial flow).

O. **Lubricant**—can use Vaseline.

P. **Never insert** a sharp object or probe into tip orifices. Blow out with compressed air from the front of the tip to prevent lodged particle from becoming more deeply lodged in orifice.

Q. **Ask the equipment manufacturer** about glass filled fluid packings for pumping polyesters.

R. **Always install** shut off valves in combination with fluid quick connects.

S. **Always flush** a filled system (resin/styrene) with unfilled resin, then solvent. Then always clean the filter.

T. **Use water soluble** grease in between chevron packings to reduce resin buildup between them.

15. EQUIPMENT SUPPLIERS—Following is a partial list of equipment suppliers. They have many detailed booklets on spraying and equipment. Write to (or call) these suppliers and ask for their literature and recommendations.

A. Complete systems

ITW-Binks-Polycraft
195 International Blvd.
Glendale Heights, IL 60139
Ph: 630-237-5006
Fax: 630-248-0838

Glas-Craft, Inc.
5845 West 82nd St., Ste 102
Indianapolis, IN 46278
Ph: 317-875-5592
Fax: 317-875-5456
www.glascraft.com

GS Manufacturing
985 W. 18th Street
Costa Mesa, CA 92672
Ph: 949-642-1500
Fax: 949-631-6770
www.gsmfg.com

Magnum Venus Products
5148 113th Ave. North
Clearwater, FL 33760
Ph: 727-573-2955
Fax: 727-571-3636
www.mvpind.com

B. Pumps only

The ARO Corporation
One ARO Center
Bryan, OH 43508
Ph: 419-636-4242
www.hydraulic-supply.com

GRACO
P.O. Box 1441
Minneapolis, MN 55440
Ph: 612-623-6000
www.graco.com

OPEN MOLDING: Conventional Gel Coat—Application

In This Chapter

1. INTRODUCTION— Proper application of gel coat is critical to producing cosmetically appealing and durable parts. Improperly applied gel coat increases the cost of the part. The amount of additional cost incurred depends on the number of rejected parts as well as the effort required to rework the parts. Making the investment of properly applying the gel coat can pay big dividends by reducing rework and scrap. Proper gel coat application includes material preparation, equipment calibration, use of trained spray operators and appropriate spray methods.

2. OVERVIEW—A conventional gel coat is applied with spray equipment as described in Chapter II.3 of this Part of the Guide. Brushing of gel coats is not recommended. The following information assumes that the proper gel coat spray equipment has been selected and that equipment is being properly maintained.

The ideal catalyst level for most gel coats is 1.8 percent at 77°F. However the catalyst level can be varied between 1.2 percent and three percent to compensate for specific shop conditions. Catalyst levels below 1.2 percent or above three percent should not be used as the cure of the gel coat can be permanently hindered. Refer to product data sheets for specific catalyst recommendations. Environmental factors that may require catalyst range variation include temperature, humidity, material age, and catalyst brand or type. Manufacturers should always verify gel times under specific plant conditions prior to gel coat usage.

The gel coat should be applied in three passes to a total wet film thickness of 18 ± 2 mils thickness. A coating that is too thin (under 12 mils) could cause under-cure of the gel coat, while a film that is too thick (over 24 mils) could crack under flexing. Gel coat that is spray-applied on vertical surfaces (using this multiple pass procedure) will not typically sag due to the gel coat's thixotropic properties. The gel coat is also resistant to entrapping air (porosity) when spray-applied per instructions.

Under normal conditions, gel coats are ready for lamination 45 to 60 minutes after catalyzation. The actual time is dependent on temperature, humidity, catalyst type, catalyst concentration, and air movement. Low temperatures, low catalyst concentrations, and high humidity retard gel and cure, meaning that longer times will be required before the gel coat is ready. A reliable test to determine whether the gel coat is ready for lamination is to touch the film at the lowest part of the mold. If no material transfers, it is ready for layup.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, problems can occur due to poorly atomized catalyst, surging problems with the gel coat or catalyst, contamination and poor application procedures. These problems will quickly negate all benefits of calibration. The equipment and application procedures must be monitored on a routine basis to ensure proper application and cure of the gel coat. Inquire about and adhere to all equipment manufacturers' recommendations.

3. MATERIAL PREPARATION—Gel coat materials are supplied as completely formulated products. No additional materials other than catalyst should be added.

Prior to use, gel coats should be mixed for 10 minutes to ensure product consistency. The agitation level should allow for product movement all the way to the walls of the container, but with the least amount of turbulence possible. Do not over mix. Over-mixing can break down the thixotropy, increasing the tendency to sag. Over-mixing can also cause styrene loss that may contribute to porosity. Do not use air bubbling for mixing. Air bubbling is ineffective and only serves as a potential source for water or oil contamination.

Gel coats are designed for use at temperatures above 60°F. Below 60°F, the viscosity, thixotropy, and cure of the gel coat are affected.

- The lower the temperature the higher the viscosity.
- The lower the temperature the lower the thixotropy.
- The lower the temperature the longer the gel time.

Catalyst viscosity also increases with decreasing temperatures. This can influence catalyst injector readings.

These factors combine to affect flow rates and atomization as well as make sagging a possibility. In addition, the affect of cold weather on cure can result in poor part cosmetics. The slower gel times and cure times of gel coats in cold conditions can lead to post-cure that can be seen as print-through and/or distortion.

CCP has developed a few helpful hints to facilitate gel coat usage during cold weather; these include:

- Calibration of the spray equipment, while always important, is especially so during cold weather due to the increase in viscosity of the gel coat and catalyst.
- Allow ample time for warming and make sure to check material temperature prior to use. Drums can take two to three days to warm, even inside a warm shop. In extremely cold weather, even longer warming periods may be needed (three to four days). A cold floor will extend the warming time.

- If the plant has a cement floor, there should be insulation (such as a wooden pallet) underneath the material container. This procedure will keep the material warmer by preventing the heat from being drawn out by the concrete.
- Review inventory very carefully and place orders well in advance.

4. EQUIPMENT CALIBRATION—General equipment calibration procedures for material delivery rate and catalyst concentration are discussed below. See Chapter II.3 of this Part of the Guide for more detailed information. Always consult the equipment manufacturer for proper calibration of a particular type of equipment.

A. Batch Mix (Hot Pot)

1) Material Delivery Rate or Fluid Supply—The material delivery rate or fluid supply is the rate that the gel coat flows from the spray gun. For optimum spray application, the material delivery rate should be between 1.5 to 2.5 pounds per minute. Determine the material delivery rate as follows:
    a) Back out the fluid needle adjustment, allowing maximum material delivery through the gun with the trigger pulled.
    b) Weigh (in pounds) the container that will be used to capture the gel coat .
    c) Spray gel coat into the container for 30 seconds.
    d) Reweigh the container and gel coat in pounds.
    e) Calculate material delivery rate in pounds per minute by subtracting the original weight of the container from the container and gel coat weight and multiply this figure by two.

    Adjustment is made by changing the air pressure on the pressure pot or pump or by changing the orifice size. Material delivery rate checks must be done by weight, not volume, as gel coat densities vary.
2) Atomizing Air—Correct air pressure is essential for proper material atomization. To measure, read the pressure gauge attached to the spray gun when the trigger is pulled (dynamic pressure) and the fan is fully open. Adjust as necessary to a minimum of 60 psi. This will help product a porosity free film. *NOTE: Long air lines, small inside diameter air lines, or a number of fittings within the line can reduce the volume of air supplying the gun and can create erroneous results. Adjust as necessary for a minimum of 60 psi.*
3) Catalyst—Proper catalyst level is accomplished by accurate weight or volumetric measurement, so that the catalyst level is exact as well as consistent. Always maintain the catalyst level between 1.2 and three percent, as needed based on specific plant conditions. *NOTE: Catalysts used to cure polyester resins are very reactive chemicals. Contact with many materials can cause decomposition that can present real fire hazards. Good housekeeping practices need to be maintained at all times.*

B. Catalyst Injection—With most catalyst injection equipment, the peroxide catalyst is mixed externally with the gel coat. If sprayed alone, it can travel several feet or more, eventually settling onto surrounding surfaces. Accumulation of materials or other substances that can react with the catalyst have been the direct cause for fires in fiberglass shops. Cleanliness and constant removal and proper disposal of waste catalyst and contaminated materials are the only safe ways to deal with this potential hazard. Also, spraying only catalyst should be avoided.

Solvent, either from diluting the catalyst as required for some equipment, or from cleanup operations, acts to increase the chances of an undesirable reaction.

Consult catalyst supplier, as well as Part Two on 'Health, Safety, and the Environment' and CCP Material Safety Data Sheets for further information.

1) Material Delivery Rate or Fluid Supply—calibrate same as for batch mixing.
    a) Air-atomized—1.5 to 2.5 pounds per minute.
    b) Airless—1.5 to three pounds per minute for smaller, intricate molds; 1.5 to 4.0 pounds per minute for large, open molds.
2) Atomizing Air (Air Volume)—Calibration is the same as described for batch mixing with one exception: the catalyzer has a safety valve that will only allow 80 to 100 psi static air pressure (no air flowing through the gun). The maximum pressure allowed by the safety valve varies with the specific equipment. When maximum static pressure is reached, changing inside hose diameter, using a shorter hose, and minimizing restrictions will permit more air volume.

    Airless systems have no air atomization of material so there is no calibration of air pressure needed, or possible. Some airless systems do have air-atomized catalyst which must be calibrated.

    Air-assist airless systems require additional atomizing air. It is important that air-assist air be kept as low as possible.
3) Catalyst—Specific equipment manufacturer's recommendations should be followed.

Calibration methods work as follows:

a) The intent is to collect some catalyzed gel coat just as it leaves the gun, and time it to see how long it takes to gel. Comparing this gel time to that of a sample that has been catalyzed by accurately weighing the catalyst gives a basis of comparison for adjusting catalyst settings. This should be done at two different catalyst settings.

The procedure is to collect about 100 grams of catalyzed gel coat in a small cup, recording fluid pressure, setting level of the catalyst ball (or balls), and the time. Similarly, collect 100 grams that is uncatalyzed, and then weigh in the specified amount of catalyst, noting the time of catalyzation. Adjust catalyzer by the recommended method specific to the equipment until the two gel times are equal. It should be noted that ball settings are only relative guides and do not read in percent catalyst.

b) After gel coat has been calibrated (delivery rate), turn gel coat off. Then run delivery rate on the catalyst. Compare catalyst delivery to gel coat delivery (percent catalyst) and adjust catalyst percent as required to stay in proper range.

4) Do not assume a catalyst slave pump is working properly. These can be calibrated also and should be monitored continually. See Chapter II.3 on 'Gel Coat Spray Equipment' in this Part of the Guide for additional calibration information.

CCP's gel coat (944-L-A72) contains catalyst indicator which is used to show efficiency of catalyst atomization and mix.

5. SPRAY OPERATOR—A spray gun is a precision tool. It requires a skilled operator to efficiently apply the material. Many defects can be traced back to how the gel coat was applied. A poor spray application can be very costly, so it is in the shop's best interest to select the proper person as the spray operator and to follow through with good training. A good spray operator should:

- Be conscientious
- Have good coordination
- Desire to do good work
- Have some mechanical skill
- Be patient
- Possess good vision with no color blindness.

Good training is important for there are techniques that must be mastered correctly—from the beginning—to avoid use of bad techniques and costly shortcuts.

New spray operators should start out under direct supervision from competent personnel. They should be assigned to spraying easy, noncritical parts. Progression to more difficult parts should be made in conjunction with the experience and ability of the individual.

Free informational literature is available from suppliers of raw materials and equipment manufacturers. Training schools are offered by most vendors.

6. GENERAL SPRAY METHODS—

A. Check gun and lines for contamination such as solvent, water, or oil. Clean and correct as necessary before spraying. Drain water from pressure regulator and traps daily; more often if necessary. If water is a constant problem, a temporary solution is to leave the bleed off valve on the water extractor open slightly. Water in the air lines can lead to expensive repairs to equipment and affect the performance of the gel coat. It is best to avoid the problem (and less costly in the long run) by investing in a good drying system.

B. Check air pressures before spraying and adjust to achieve proper flow and breakup. Droplets should be no larger than 1/16 inch.

C. Always start spraying nearest the exhaust fan to minimize over-spray that could be pulled on to the mold.

D. If catalyst injection is used, make sure catalyst is flowing properly. Do not let raw catalyst fall onto the mold or sprayed gel coat.

E. Check temperatures; adjust catalyst as necessary (1.2 percent to three percent). Under extremely warm conditions, working times may become very short, necessitating the addition of inhibitor to allow for enough working time. Consult a CCP representative regarding what to add and the amount. Do not go below 1.2 percent catalyst, or higher than three percent.

F. Keep the spray gun perpendicular to the mold during each stroke.

G. Hold the spray gun 18 to 24 inches from the mold when using conventional air-atomized equipment; if using airless equipment, 24 to 36 inches is the proper distance.

H. Do not arc the gun while spraying.

I. Keep the speed of each stroke such that a full and constant wet coat is applied.

J. The first spray pass should be a thin continuous film (five to eight mils, dependent upon temperature, gel coat viscosity and mold wax). Use of this technique helps to prevent porosity, resin tearing, and mottling. About three passes are needed to achieve a total thickness of 18 ± 2 mils. Spraying is a two handed operation—a spray gun in one hand, and mil gauge in the other.

K. Overlap strokes 50 percent.

L. Do not reach with a stroke. Stroke length should be comfortable for the operator. Normally this is 18 to 36 inches.

M. Begin spraying near an edge in a continuous stroke towards the opposite side. Each pass should be parallel to the former, developing a uniform thickness. Subsequent passes should be perpendicular or diagonal to the preceding pattern to insure proper uniform coverage.

N. When practical, spray in sections from one end, working continuously to the other. Avoid (as much as possible) over-spray onto other parts of the mold. Time lapse between spray passes or in spraying overlapping sections on large molds should not be excessively delayed. Maintain a wet line (I.e., cover up spray edges and over-spray as soon as possible).

O. Do not flood the gel coat on, or spray with the fan sideways.

P. Use a mil gauge and touch up the tested area afterwards.

Q. Clean the gun immediately after using. This includes any part of the equipment that may have received over-spray, such as hoses and gauges.

R. Inspect the gun regularly and replace worn parts.

S. Lubricate the gun and packings with light machine oil daily. Do not contaminate the gel coat with oil.

T. Accidental contact with gel coat or catalyst can be hazardous. In the event of contact involving body or clothing, clean the affected area immediately. See appropriate data sheets and labels for proper precautionary steps to follow.

U. Know the fire and toxic hazards of polyesters, catalyst, and the particular cleaning solvent being used.

V. Have a regular preventive maintenance program.

W. Place only one mold in the spray booth at a time. This prevents over-spray onto other molds.

X. For all around end performance properties, a wet film thickness of 18 ± 2 mils is recommended as ideal. Films less than 12 mils may not cure properly, may be hard to patch, have more print-through, and be more susceptible to water blisters. Films above 24 mils may pre-release, trap porosity, or crack, and are more subject to weathering discoloration. If water blisters are of a great concern (boat hulls), 20 to 24 mils would perform better than a thinner film, but resistance to sag, porosity and cracking could suffer. If weathering (yellowing from sunlight) is of great concern, then thinner films of 12 to 16 mils would perform better, but patchability, and resistance to print-through and blister could suffer.

Y. Never reduce gel coat with a 'conventional' paint or lacquer thinner.

Z. Disperse catalyst thoroughly. Poor distribution causes uneven cure, color variation, blister potential, and premature release from mold before layup.

AA. Do not over-catalyze or under-catalyze. Excess catalyst plasticizes gel coat, thus degrading its water resistance and accelerating chalking and erosion. Poor cure also results from under-catalyzation. A poorly cured gel coat is weak and will be degraded by weather.

Recommended catalyst level is: 1.2 to three percent (1.8 percent at 77°F ideal) MEKP (9.0 percent active oxygen).

BB. Apply a minimum of 16 mils of gel coat if glass fiber pattern is to be suppressed appreciably. Never apply less than 12 mils, as under-cure may take place. The degree of protection against the outdoor elements is directly dependent on the amount of gel coat deposited and its quality.

CC. Atomize the gel coat thoroughly when spraying. Low spray pressures will result in poor breakup and leave entrapped air in the gel coat. Entrapped air causes blistering and high water absorption.

To check atomization, spray gel coat over glass to a film thickness of 16 to 20 mils and hold over strong light. Looking through the deposited gel coat will reveal any entrapped air.

DD. Do not apply gel coat over wet Polyvinyl Alcohol (PVA) Parting Film. Residual water in the film will retard gel coat cure and also cause 'alligatoring.'

EE. Use the catalyzed gel coat within its working life with a proper allowance of time for cleanup of equipment.

7. SPRAY METHODS FOR PARTICULAR PARTS—The shape and contour of each mold will dictate how it can best be gel coated. This should be considered in planning where to start, where to finish and how everything in between will be handled. Unfamiliar parts should be given serious consideration as to how they will be sprayed before the actual application begins. Experience will show how it can be done better and more efficiently.

Suggestions on spraying different configurations in a mold follow:

A. Try to spray the most difficult area first and work continuously out from it.

B. Keep over-spray to a minimum.

C. Use a series of passes perpendicular or diagonal to each other for more uniform thickness.

D. Keep laps (stroke) wet. This is called 'maintaining a wet line.' Do not let a lap stay on the mold more than five minutes without covering with a 'fresh' lap. Alligatoring, and/or resin tearing, and 'splotches' could occur when the part is sanded and buffed.

E. Flat areas—These are easy to spray. Begin spraying near an edge in a continuous stroke toward the other side. Each spray pass should be parallel to the previous pass until a uniform thickness is achieved. Subsequent spray passes should be perpendicular or diagonal to the preceding pattern to insure proper uniform coverage.

F. Corners—Spray a pass down each side through the corner and work out about 12 inches from the corners. Use short strokes, then spray adjacent areas.

G. Gentle Curves—Spray by arcing the gun to keep it perpendicular to the working surface.

H. Channels—Spray the sides first. Most of the time, over-spray will cover the bottom.

I. Deep or Narrow Channels—Turn the fluid control in to cut the flow down and narrow the fan. If using airless or air-assist airless equipment, consider a smaller fan. Less fluid and air pressure may be necessary, requiring more passes. Spray the sides first. Do not spray with the fan directly parallel to the channel. Keep the fan perpendicular to the channel (or as much as is possible).

NOTE: If using catalyst injection, cutting back on material flow will change the percent catalyst supplied to the gel coat. Adjustment for proper catalyst level will be necessary.

Use a one quart pot gun to spray very difficult areas.

J. Use a rotating platform for round or small parts.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

Part Four, Chapter II.5

In This Chapter

1. **Introduction**
2. **Problem Diagnosis**
3. **Common Gel Coat Problems and Solutions**

1. INTRODUCTION—Even under the best of conditions, problems can occur due to accidents, mistakes and unanticipated changes. Listed are some of the various problems that can occur and how to solve them. Also remember that the gel coat is affected by the laminate, and good gel coat will not compensate for a poor laminate.

2. PROBLEM DIAGNOSIS—To isolate and diagnose the problem, give consideration to the following:

- **A. What does** the defect look like?
- **B. Where does** it occur? All over, random, isolated side or section?
- **C. Is it on all parts,** some of the parts, or just one?
- **D. When did** it first occur? Or when was it first observed?
- **E. Does it match up** to a defect in the mold?
- **F. When were** the defective parts sprayed?
  - 1) Did it occur during a particular shift? Or from a particular spray operator?
  - 2) Was it during a particular part of the day—when it was hot, cold, damp, or other?
- **G. Did the problem** occur through all spray stations or just one in particular?
- **H. Where does** it occur? In the gel coat film? Against the mold? On the back side? Within the film?
- **I. What is** the code, batch number, and date of the gel coat with which the problem is occurring? Were good parts sprayed from this batch or drum?
- **J. Was anything** done differently, such as a change in catalyst level, spray operator, method of application, or weather conditions?
- **K. How would** someone else identify or describe the defect?
- **L. What were** the weather conditions at the time the part was sprayed?
- **M. What corrective steps** were taken and were they effective?
- **N. Check the material** or laminate that was applied to or on the gel coat.

Listed on the following pages are common gel coat problems and their usual solutions.

Photographs illustrating many of these problems are also included.

COMMON GEL COAT PROBLEMS AND SOLUTIONS

PROBLEM	CAUSE	SOLUTION OR ITEMS TO CHECK FOR
Air Bubble (see Photo #1, page 57)	Air pockets	Check rollout procedures.
Alligatoring—a wrinkling of the gel coat, resembling alligator hide (see Photo #2, page 57)		
Before laminating	Raw catalyst	Check for leaks or over-spray.
	Solvent	Do not reduce with solvents.
	'Cured' over-spray	Check for contamination. Maintain a wet line.
	Thin gel coat	Use a minimum of 12 mils, wet. Discontinuous gel coat film.
After or during lamination, or a second application of gel coat	Insufficiently cured gel coat	Catalyst level too high or too low. Temperature too low. Gel time too long. Time between coats or lamination insufficient. Moisture or contamination in the mold.
Bleeding—one color shows on another, typically when color striping (see Photo #3, page 57)	Striping gel coat sagging over 'cured' gel coat	Check sag resistance of 'striping' gel coat. Spray stripe coat as soon as possible. Spray thin film of stripe color over the 'wet' base coat.
Laminate Bleed (cosmetic problem only)	Monomer in laminating resin	Check for excessive monomer in laminating resin.
	Gel coat back side cure	Change gel coat.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

COMMON GEL COAT PROBLEMS AND SOLUTIONS

PROBLEM	CAUSE	SOLUTION OR ITEMS TO CHECK FOR
Blisters (see Photos #4, 5, 6, page 57) —		
Appear shortly after part is pulled, especially when put in sun	Unreacted catalyst or under-cure	Check percent catalyst, catalyst over-spray, mixing, and leaks.
	Solvent, water, or oil	Check air lines, material, and rollers.
	Air pockets	Check rollout.
Appear after part in field	Unreacted catalyst	Check catalyst levels and distribution, film thickness—18 ± 2 mils.
	Solvent, water or oil	Check air lines, materials, and rollers.
Water blisters	Various	See Part Four, Chapter VII.5 on 'Blisters and Boils' tests.
Chalking (gel coats will oxidize/chalk over an extended period of time; degree of chalking is related directly to the environment (see Photo #7, page 58) —		
Dry, chalk-like appearance or deposit on surface of gel coat (premature) (see Part Four, Chapter VII.2 on 'Weathering')	Cure	Under- or over-catalyzation, producing incomplete cure. Check air lines, material, and rollers. Check catalyst level, film thickness, water and solvent contamination.
	Contamination	Surface soil picked up from atmosphere.
	Insufficient buffing	Wipe buffed area with solvent rag. If gloss remains, area is okay. If gloss dulls down, part needs more buffing.
	Poor mold condition	Reduce sanding and buffing requirement on parts by keeping molds in good condition.
Checking (mud cracking)—		
Single or groups of independent or crescent-shaped cracks	Poor integrity of the gel coat film	Trapped vapor or incompatible liquid which blows through the gel coat film on aging. Check catalyst level. Check for water, solvent, etc. Chemical attack. Temperature extremes.
Craters—while spraying	Chunks in the gel coat	Dirt in the gun or material. Material old and starting to gel; rotate stock. Strain (filter) the gel coat.
	Equipment	Clogged gun (clean). Improper atomizing air setting (too low).
Cracks (see Photos #8, 9, 10, page 58)—		
Spider cracks radiating out from a central point or in circles (reverse impact)	Impact from laminate side	Check on handling and demolding procedures. Caution people about hammering on parts.
	Excessive gel coat film thickness	Use a mil gauge and do not go over 24 mils.
	Mold mark	Defect in the mold.
Frontal impact	Impact	Be careful.
Stress cracks (cracking in parallel lines)	Stress due to flexing	Excessive gel coat thickness. Laminate too thin. Pulled too green; laminate under-cured. Demolding or handling procedure. Sticking in the mold.
	Mold mark	Defect in the mold.
Delamination—		
In spots	Contamination	Check for dust, solvents, moisture, catalyst getting onto the gel coat surface. Excess mold release wax floating through to the gel coat surface, creating areas that will not adhere.
Large area	Gel coat too fully cured	Check for high catalyst level. Letting the gel coat cure too long, such as overnight; skin coat, rather than leave on the mold for long periods of time. Excess mold release wax or wax in the gel coat.
	Contamination	Solvent wiping, then waxing (around taped off areas),
	Unbalanced laminate	Dry fiberglass.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

COMMON GEL COAT PROBLEMS AND SOLUTIONS		
PROBLEM	**CAUSE**	**SOLUTION OR ITEMS TO CHECK FOR**
Dimples—in the gel coat surface ((see Photo #11, page 58)	Contamination	Check for water, solvent, or improperly mix catalyst. Over-spray. Seedy resin. Excess binder on the glass mat.
	Other	Thin laminate or gel coat. Very dry laminate. Pin air entrapped. Post-curing of the laminate.
Dull gloss—on the gel coat— When part is pulled	Rough mold	Polish out mold.
	Mold buildup	Wax and buff with cleaner. In most instances, what is called wax buildup is actually polystyrene buildup and should be treated as such.
	Polystyrene buildup	Sand or scrub with brush and strong solvent; read precaution on solvent before using. DO NOT USE STYRENE.
	Dirt or dust on mold	Clean the mold. It is best to clean in the spray booth just prior to gel coating. Time span should be as short as possible between cleaning and gel coating. Use a tack rag.
	Solvent or water	Check for solvent or water. Drain water traps regularly.
	Raw catalyst	Start catalyst flow from gun away from the mold. Only catalyzed gel coat should be sprayed into the mold.
	Rough PVA or wet PVA	Check spray technique.
When and after part is pulled	Insufficiently cured gel coat or laminate	Correct excessive or insufficient catalyst level in gel coat and laminate. Wait longer before pulling. Check for low temperature (minimum of 60°F). Check for contamination: water, air or solvent.
Dull or soft spots—at random	Gel coat uneven	Poor breakup; use three passes.
	Catalyst poorly mixed into either gel coat and/or laminate	Mix catalyst thoroughly or make equipment adjustments for good catalyst mix. Equipment surging (material pump and/or atomizing air). Improper catalyst settings (high or low). Gun held too close to mold.
	Trapped solvent in gel coat and/or laminate	Check cleaning procedure. Check catalyst level with equipment using solvent reduced catalyst.
	Trapped water in gel coat and/or laminate	Drain lines and correct the problem.
	Insufficient catalyst	Confirm correct catalyst concentration.
Fading—see also water spotting (see Part Four, Chapter VII.2 on 'Weathering')	Poorly cured gel coat	Check catalyst levels and film thickness (18 ± 2 mils).
	Improper cleaners or chemicals	Do not use strong alkaline or acidic cleaners.
Fiber pattern and distortion—in parts (see Photos #12 and #13, pages 58 and 59)	Insufficient cure	Correct excessive or insufficient catalyst level in gel coat and/or laminate. Wait longer before pulling, Do not pull while laminate still has heat. Check for low temperature. Check for contamination by water, oil, or solvent.
	Transferred from mold	Refinish mold.
	Glass cloth	Too close to the gel coat. Should have two layers of cured 1.5 oz. mat or equivalent chop between gel coat and cloth.
	Woven roving	Too close to the gel coat. Should have three layers of cured 1.5 oz. mat or equivalent chop between gel coat and woven roving.
	Gel coat too thin	Use 18 ± 2 mils, wet.
	High exotherm of laminate	Cure laminate more slowly. Laminate in stages. Use lower exotherm laminating resin.
Fisheyes (see Photo #14, page 59)	Water, oil, or silicone contamination	Drain air lines. Check mold release wax. Excess and/or fresh coat of wax is worse.
	Dust/dirt on mold	Check lubricating materials used within the equipment. Use tack rag.
	Gel coat film too thin	Use 18 ± 2 mils in three passes.
	Low viscosity material	Old material—rotate stock.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

COMMON GEL COAT PROBLEMS AND SOLUTIONS

PROBLEM	CAUSE	SOLUTION OR ITEMS TO CHECK FOR
Material gelled—in container	Age	Use partial container first; keep covered.
	Storage condition	Use within storage limitations.
Jagged tape lines	Gel coat starting to gel	Use less catalyst (do not go below recommended minimum). Use double tape process. Use good tape recommended for fine lines.
Pigment darting or specks (see Photo #15, page 59)	Contamination	Clean pump and lines.
	Foreign particles	Strain and keep material covered. Keep over-spray minimized; be sure molds are clean; spray perpendicular to mold surface.
Pigment separation or mottling (see Photo #16, page 59)	Pigments separate from each other	Check for contaminants such as water or solvent. Dirty equipment.
	Other	Dry over-spray. (Keep a wet line.) Excessively applied gel coat causing sagging. Excessively high delivery rates causing flooding onto the mold surface.
Pinholes (see Photo #17, page 59)	Insufficient atomization	Too high gel coat delivery rate. Not enough atomizing pressure.
Porosity (see Photo #18, page 59)	Entrapped air	Wrong air pressure. Too high tens to yield fine porosity; too low will produce larger, surface porosity.
	Wrong catalyst	Check gel coat vendor for recommendation.
	No catalyst	Check catalyst supply and alignment.
	Gel coat film thickness	Applied too thick; use 18 ± 2 mils wet. Apply in two to three passes.
	Formulation	Improper viscosity and/or resin solids. Check with vendor.
	Water or solvent	Check for contamination.
	Pump cavitation	Check pump for air leaks.
	Excessive mixing	Mix once a day for 10 minutes only.
Pre-release of the gel coat— During cure, causing obvious surface distortion and low gloss (see Photos #19, 20, page 60)	Wrong catalyst	Refer to CCP recommended catalyst list.
	High catalyst level	Calibrate equipment and decrease catalyst.
	Low catalyst level	Calibrate equipment and increase catalyst.
	Uneven and/or too thick film	Check thickness, not to exceed, not to exceed 24 mils, wet. Ensure a consistent film thickness.
	Gel coat allowed to cure too long	Gel coat should not be allowed to set on the mold for more than a few hours without laminating at least a skin coat. Varies with temperature—should be laminated same day.
	Gel coat resin solids too low	Check with manufacturer; do not add styrene without their approval.
	Uneven cure	Improperly dispersed catalyst.
	Mold release	Type and amount on the mold.
	Clay	Some clays cause an oily residue and pre-release. Change type of clay, dust the clay with a very fine powder or over-spray with PVA.
Occurring after cure; observed as visible sharp distinct line (will not necessarily feel line) with increased fiber pattern on the side of the line that pulled away—sometimes referred to as 'heat' or 'shrink' marks	Too long of cure	Laminate sooner—don't lap or jar the mold.
	Laminate curing too fast	Check for proper catalyst level. Build laminate in stages.
	Wrong type resin	Too high in exotherm.
	Laminate curing uneven	Low resin solids. Uneven laminate thickness. Check resin to glass ratio. Resin drain-out or puddling.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

COMMON GEL COAT PROBLEMS AND SOLUTIONS		
PROBLEM	**CAUSE**	**SOLUTION OR ITEMS TO CHECK FOR**
Resin tearing—or resin separation (see Photo # 21, page 60)	Pigments separate from resin Application	Check for sources of water contamination. Avoid over-spray. Improper spray techniques create excessive over-spray, droplets and flooding. Can be aggravated by long gel time and sagging. Do not allow over-spray to dry; keep a wet line.
Sags and runs	Excessive gel coat Spray techniques Low viscosity Mold wax Other	Apply 18 ± 2 mils, wet. Atomizing air is pushing and blowing the gel coat. Not enough styrene is being volatilized. Check viscosity and thixotropic properties. Over-agitated. Material was reduced, but should not have been. Silicone content too high. Jarring the mold before gelation.
Softness	Soft gel coat film which be easily matted	Incomplete cure of gel coat. Check catalyst levels, contaminants and film thickness.
Splotches after demolding (see Photo #22, page 60)	Solvent contamination	Ensure that all solvent has been flushed out of spray equipment lines. For internal mix equipment, ensure that solvent flush line is not leaking.
Splotches after parts are sanded and buffed—also referred to as 'leathery,' pebbly,' 'chicken skin'	Over-spray Not maintaining a wet line Cure	Do not allow over-spray to accumulate. Spray laps within five minutes. The total film must cure as a total homogenous film rather than several independently cured thin films.
Water spotting—see also fading (see Photo # 23, page 60)	Usually caused by exposure with a combination of excessive heat and moisture Poorly cured gel coat Certain chemical treatments such as chlorine and/or cleaners Exposure of parts to moisture too quickly after fabrication	Use only a product recommended for the particular application. Improper shrink-wrap. Use only a product (and recommended procedures) applicable to gel coats. Check for both over- and under-catalyzation. Misuse of these chemicals. Allow one week ambient cure before service.

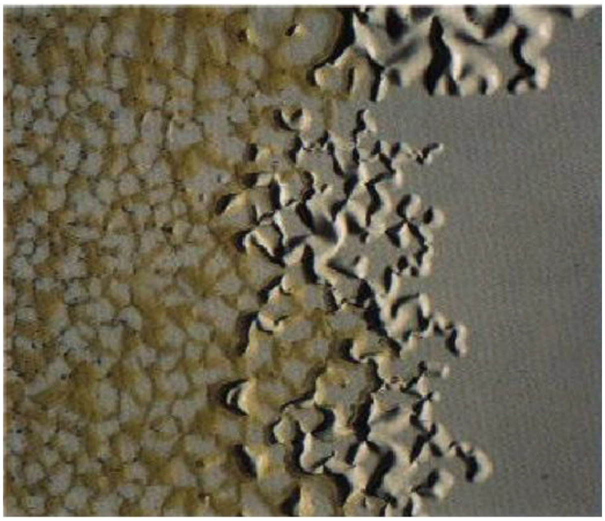
OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

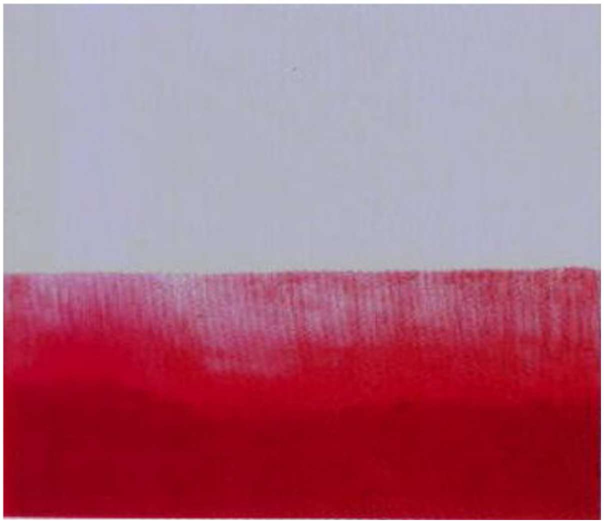
COMMON GEL COAT PROBLEMS AND SOLUTIONS

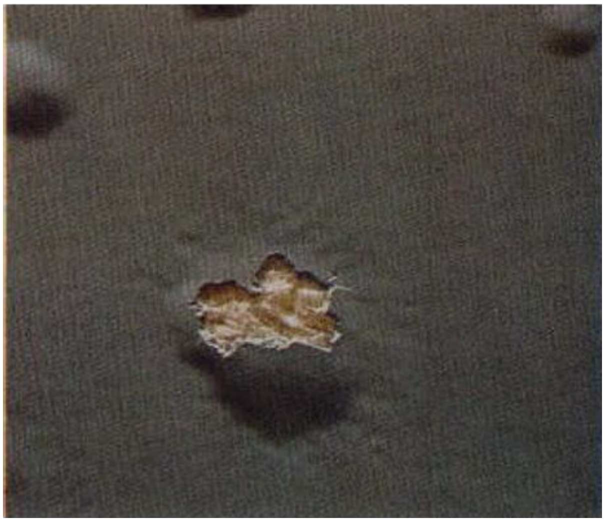
PROBLEM	CAUSE	SOLUTION OR ITEMS TO CHECK FOR
Yellowing of gel coat—gel coat yellows rapidly and unevenly when exposed to sunlight and/or heat and moisture; see Part Four, Chapter VII.2 on 'Weathering' (see Photo # 24, page 60)	Polystyrene/wax buildup on the mold which has transferred to the part during molding	Perform regular mold-cleaning program. Do not clean mold with styrene or used, dirty, or reclaimed solvent.
	Inadequate gel coat cure:	
	Improper catalyzation which results in inadequate cure of gel coat	Check catalyst (bad or old lot batch) and catalyst level. Use only a recommended catalyst and maintain the proper level of catalyzation. (See the product data sheet.)
	Contamination such as solvent, moisture, or oil	These contaminants will affect the gel coat's cure. Look for moisture or oil in air lines, moisture or other contaminants in solvents used to cut the catalyst or other sources of contamination.
	Improper or unauthorized adjustment of the gel coat	Do not add any material (other than the recommended methyl ethyl ketone peroxide catalyst) to the gel coat without the advice of a CCP representative. The addition of solvents or excessive additions of styrene, inhibitors, accelerators, etc., will adversely affect the gel coat's cure and therefore its resistance to yellowing. Contact a CCP representative if adjustment seems necessary.
	Cold temperature during application	Do not apply gel coat at temperatures below 60°F; permanent under-cure of gel coat may result.
	Old material	Old material may be slow in gel and cure and will need adjustment. Consult a CCP representative.
	Film cure inhibited by styrene vapors	Provide adequate air circulation for 'deep well' areas where styrene vapors may collect.
	Pre-release	Most of the conditions which cause pre-release will also result in unusual gel coat yellowing, i.e., uneven gel coat thickness, uneven catalyzation, uneven film gel and cure, etc. Check for and eliminate any pre-release causes.
	Excessively hot resin-rich laminates	Good laminating techniques must be followed. This is especially true in deep well areas where the gel coat is not likely to cure adequately. Unusually 'hot' laminates at this point in the gel coat's cure may result in permanent under-cure and more yellowing of the gel coat.
	Resin tearing	Over-spray, excessive film build, flooding or contamination, all of which can result in vehicle/pigment separation. A concentration of the gel coat vehicle on the surface of the part will result in more rapid yellowing of the finished part.
	Uneven gel coat film thickness	Avoid flooding the gel coat or applying excessively thick gel coat. Maintain the recommended 18 ± 2 mils wet film coverage. Excessively thick gel coat films will yellow more.
	Cleaning the finished part with an alkaline cleaner	Do not use any strong alkaline cleaner (such as ammonia or other cleaner having a pH greater than nine) for cleaning a gel coat surface. A weathered gel coat can be yellowed by such cleaners.
	Holding gun too close to the mold	Maintain proper distance.
	Spraying in one pass	Spray in multiple passes.
	Insufficient atomization	Gel coat must be atomized to fine particles.

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide

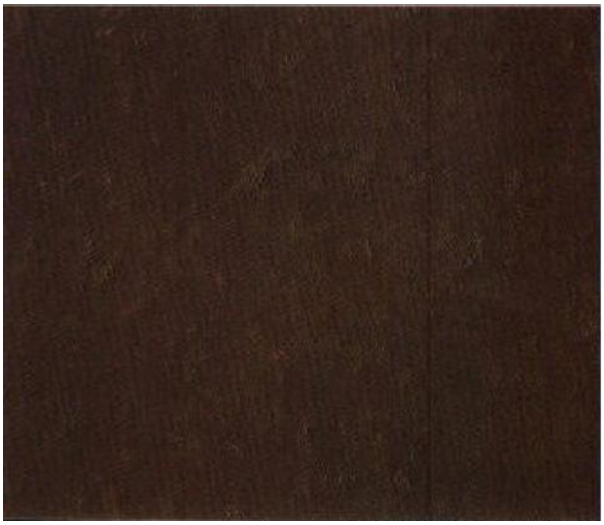

1. Air Bubble


2. Alligatoring
(Yellow area indicates resin)

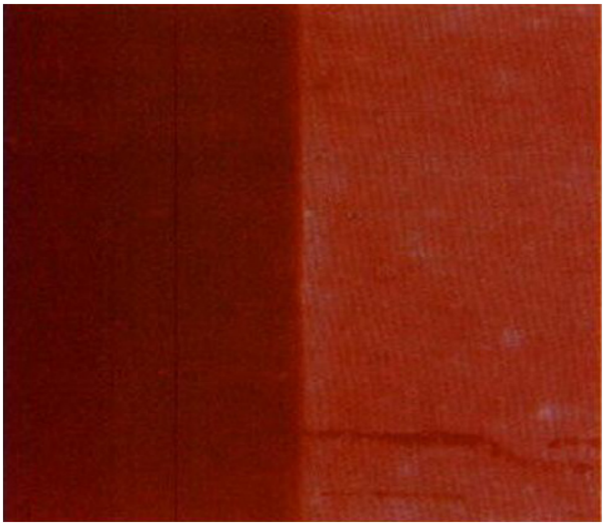

3. Bleeding


4. Blisters
(Caused by catalyst drop)

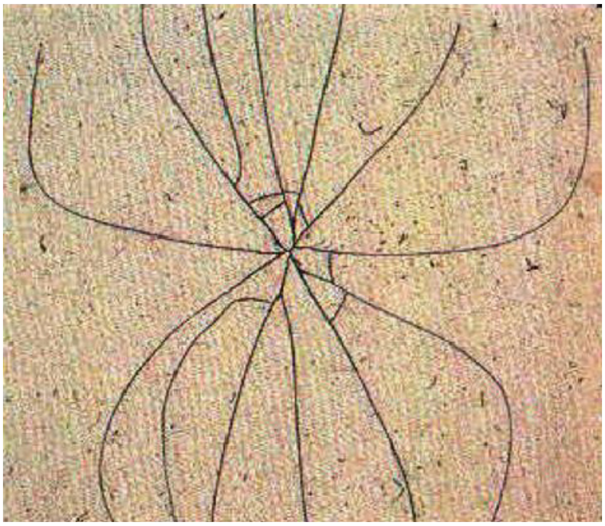

5. Blisters—Osmotics
(Small blisters—gel coat; large—laminate)


6. Catalyst Drop Gassing
(Can likely blister as in Photo #4)

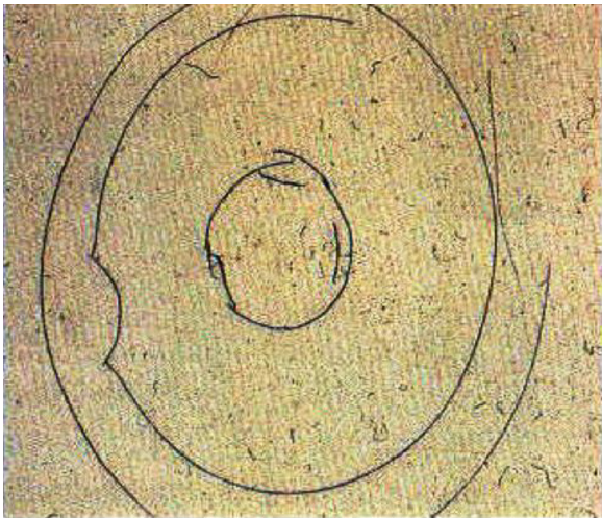
OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide



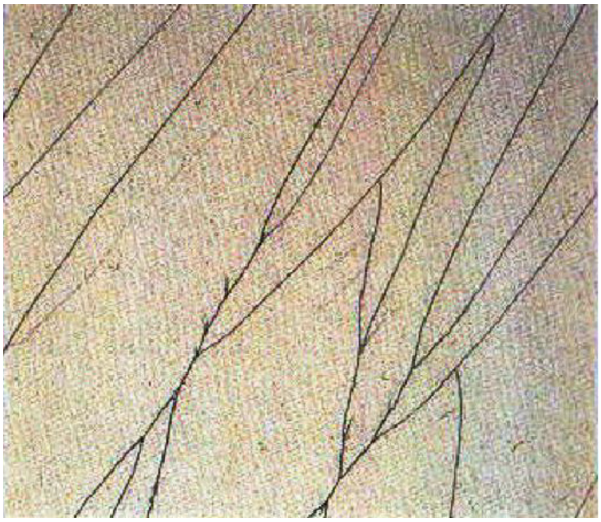
7. Chalking



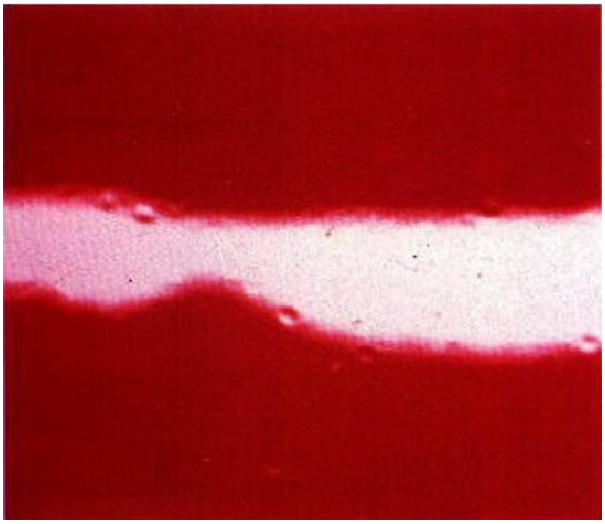
8. Cracks—Reverse Impact
(Spider/star)



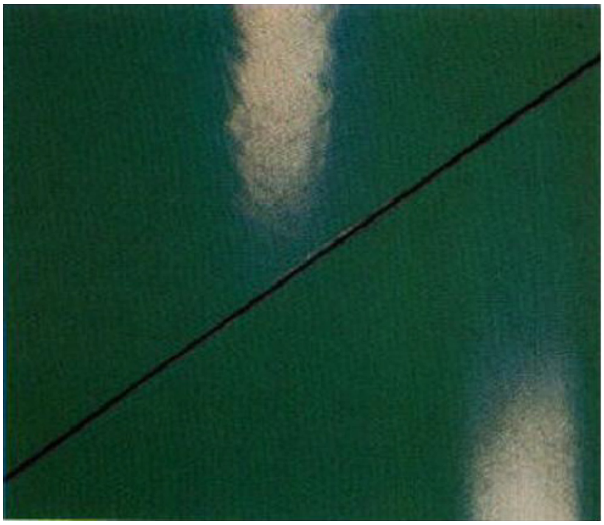
9. Cracks—Frontal Impact



10. Cracks—Stress

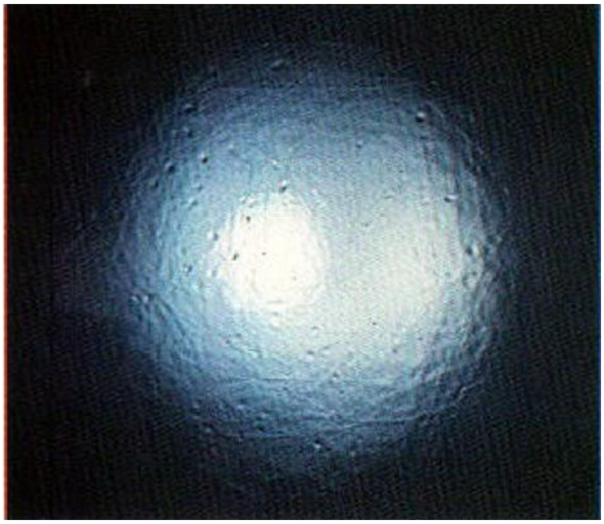


11. Dimples

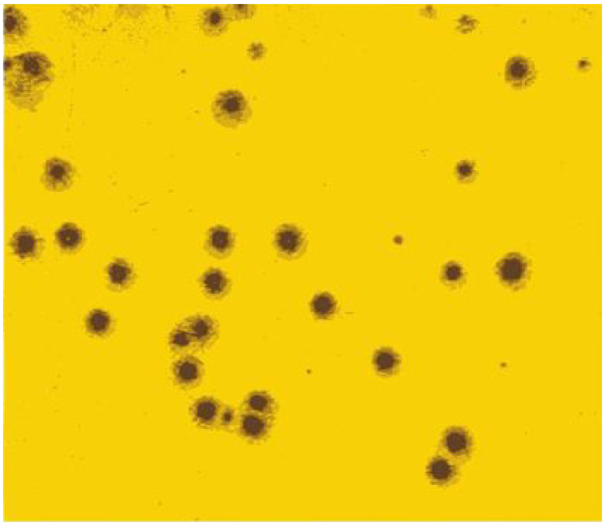


12. Distortion
(Top panel shows distortion)

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide



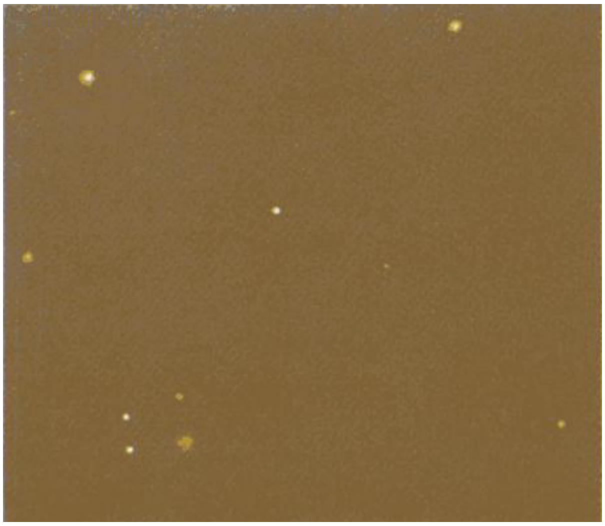
13. Fiber Pattern & Distortion
(Note: also exhibits dimples)



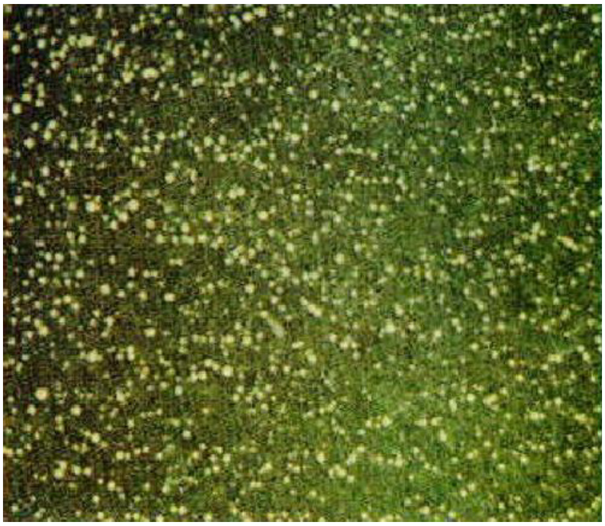
14. Fisheyes

15. Pigment Darting

16. Pigment/Color Separation

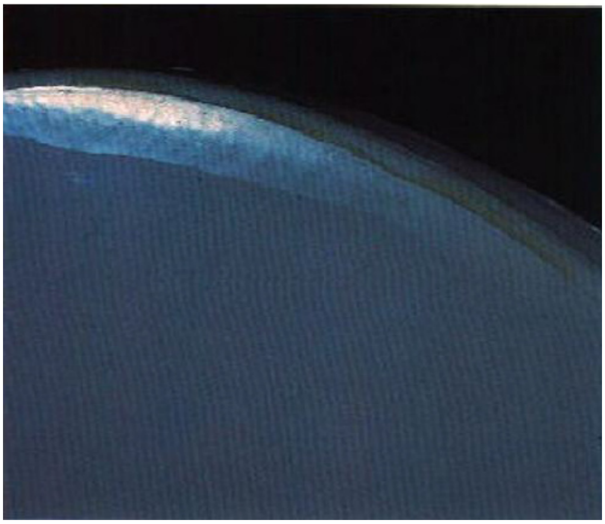


17. Pinholes



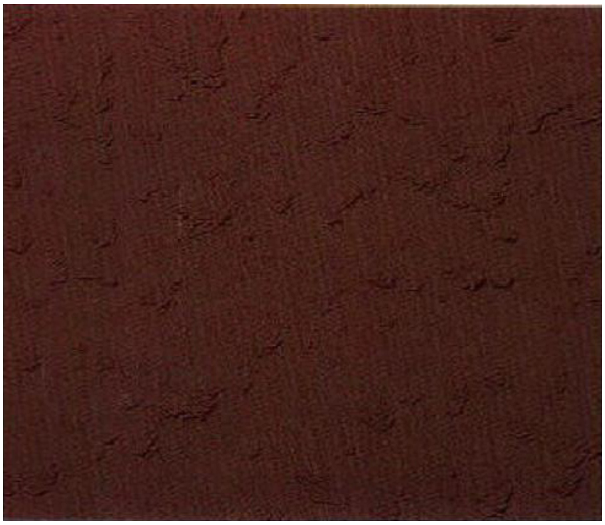
18. Porosity
(Magnified 10x)

OPEN MOLDING: Conventional Gel Coat—Troubleshooting Guide



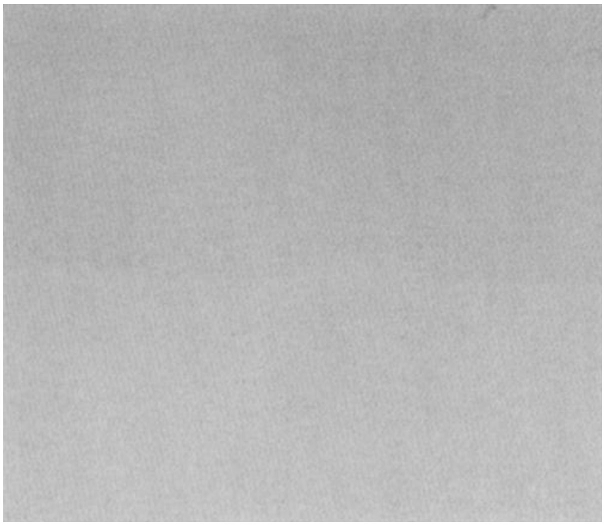
19. Pre-Release
(Gel coat, before lamination)

20. Pre-Release
(Gel coat, during or after lamination)



21. Resin Tearing

22. Solvent Contamination



23. Water Spotting

24. Yellowing Caused by Thick Gel Coat
(Inset shows 55 mil thickness of white gel coat)

OPEN MOLDING: Specialty Gel Coats—Conductive Sanding

Part Four, Chapter III.1

In This Chapter

1. **Description**
2. **Application**

1. DESCRIPTION—CCP conductive sanding gel coats have been used for several years in composite construction to enable electrostatic post painting of FRP parts. They are offered for both open mold and RTM processes. They may also be used as a gel coated surface to facilitate static electricity drain off (with proper grounding provided).

These products are available only in black. Conductivity comes from carbon particles which are black. The liquid material will normally yield a maximum resistance of 0.10 megohms when tested by an ITW Ransburg #76634 meter. Users should determine that the product's conductivity meets the intended use.

These conductive sanding gel coats are made from resilient isophthalic polymers to meet normal flexing/fitting demands after paint baking. They allow quick powdering-sanding and surface preparation. They exhibit good chemical resistance and are considered very serviceable in a saltwater environment.

While the gel coat is only part of the composite/laminate structure, it must participate in the processing and service conditions of the total composite. Parts made with these conductive gel coats can withstand temperature elevations to 180°F, but normal operating temperature range is considered 0°F to 120°F. The cured gel coat will endure the lower temperatures of this range but can crack if stressed significantly. Temperatures as high as 285°F for 30 minutes are withstood, but customers should expect some pinhole blowing and accompanying spew from trapped air pockets within the sanded composite.

These gel coats are ready to use and require only the addition of an appropriate methyl ethyl ketone peroxide (MEKP) to cure.

These gel coats will chalk when exposed to direct sunlight and are not designed (nor recommended) for constant water immersion parts.

Conductive surface coats (or enamels) can be made from these products by adding 2.5 percent 970-C-949 wax solution.

2. APPLICATION—Conductive sanding gel coats are generally formulated for both airless and conventional spray application. Brushing or rolling is not recommended. Refer to Part Four, Chapter II Conventional Gel Coat, sections on 'Application,' and 'Spray Equipment,' for additional specific recommendations.

Pits, pinholes, and porosity are, of course, very detrimental in a sanding gel coat which is to be post painted. It is important not to spray any of these defects into the film. Keeping the equipment properly calibrated (gel coat delivery/atomization and catalyst delivery/atomization) is important as is maintaining a minimum temperature of 60°F (material, mold, and ambient) and applying the gel coat in at least three smoothly sprayed six mil coats using the appropriate spray distance.

CCP recommends a gel coat delivery rate of no more than 2.5 pounds per minute with conventional air-atomized equipment, and no more than four pounds per minute with airless equipment.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, potential problems can occur due to: poorly atomized catalyst; surging problems (gel coat or catalyst); poor tip alignment (catalyst to gel coat mix); contamination; and poor application procedures, which will quickly negate all benefits of calibration. The equipment (and application procedures) must be monitored on a routine basis to ensure proper application and cure of the gel coat. Ask about and adhere to most equipment manufacturer's recommendations.

For best overall end performance properties, a wet film thickness of 18 ± 2 mils is recommended as ideal. Films less than 12 mils will have less conductivity, may not cure properly, may be hard to patch, have more print-through, and are more susceptible to water blisters. Films above 24 mils may pre-release, trap porosity and crack.

Proper mold maintenance is important. Although conductive gel coats have excellent patching properties, minimal repair work is always desirable.

OPEN MOLDING: Specialty Gel Coats—Metalflake

Part Four, Chapter III.2

In This Chapter

1. INTRODUCTION—There is a unique appeal to a metalflake finish. When done right, it is eye-catching. The colors glisten, changing with shadows or light. On close examination, there is a distinctive richness and depth of luster.

Use of a metalflake finish will require increased investment in materials and labor, but if the design of the part warrants such an unusual finish, then the extra time and care should be taken to insure the quality of the final product.

Metalflake suppliers recommend epoxy coated aluminum and polyester flakes for use with polyesters. There are polyester flakes coated with epoxy or acrylic. Polyester flake generally makes a better looking, more brilliant part than aluminum metalflake, but also costs more.

Polyester flake density is closer to that of clear gel coat. However, an advantage of aluminum flake is its solubility in muriatic acid, which is a help on patching. Muriatic acid will not dissolve polyester flake.

Questions about metalflake should be directed to the metalflake supplier.

2. SELECTING THE RIGHT GEL COAT—The gel coat must be clear so that the full brilliance of each metal particle is visible in the final product. Clear gel coats are formulated for various specific applications, which include use with metalflake. Always specify a marine clear (rather than marble clear).

Cook Composites and Polymers Company produces several marine clear gel coats suitable for metalflake application. CCP's marine clear gel coats are formulated for superior UV resistance and flexibility. Gel coats with flexibility and lower viscosity are preferred for metalflake applications. Contact a CCP sales representative for more specific recommendations.

3. RECOMMENDED APPLICATION PROCEDURE

A. Clear gel coat should be catalyzed at the recommended level; consult individual data sheets for these specifications. Over- or under-catalyzation can cause premature yellowing, cracking, or crazing, or physical deficiencies in surface gloss or general surface appearance.

Spraying uncatalyzed clear gel coat is not good practice. If sprayed too thick, the result can be an under cured film that will contribute to a distorted surface. In addition, an uncatalyzed film can be prone to porosity.

B. To ensure an enriched depth of metalflake, catalyzed clear gel coat should be applied 12 to 14 mils, wet, in two to three passes, allowing sufficient time for air release between each pass. This coat of clear helps prevent a rippled surface and protects the metalflake particles from the elements. Less than 12 to 14 mils can result in an under cured film, which will have greater alligatoring potential. Also, it is much harder to patch metalflake when there is little or no clear. More than 12 to 14 mils can interfere with clarity and produce a heavy gel coat thickness, which is more susceptible to cracking, crazing and poor weathering.

C. Once the clear coat is ready, the metalflake coat may be applied. Opinions vary on how much metalflake to use. Normal range is 10 to 20 percent by weight. If greater hide or more brilliant color is desired, these may be achieved by mixing proportions of fine and coarse flake. It is important to remember when catalyzing clear and metalflake mixtures to subtract the weight of the metalflake; for example, with a 1000 gram total mixture, if 20 percent is metalflake, then only 800 grams of the total mix will require catalyst. It should be noted that sufficient residual chemicals may remain on the metalflake, so that if higher percentages are used, gel and cure of the clear gel coat may be retarded. Normally, a reduction in metalflake can help correct this problem. Also, if pressure pot equipment is used, gel coat and flake mix should not be allowed to sit more than 60 minutes before being used. Longer contact time can cause gel/cure extension. Poor cure results from this extension. Poor cure will be observed as a grainy or rippled distortion. Reduced gloss may also be observed.

Catalyzation of the metalflake gel coat should meet material specification, with application at 12 to 20 mils, wet.

D. Generally, regardless of how much metalflake is added to the gel coat, it will not (and should not) produce complete, total hide. Orientation of the flakes will always produce small voids in the color.

If not addressed, these voids can distract from the total effect, leaving a flatness in the finish. This can be overcome with a procedure that further enhances the final appearance. The procedure is to apply a pigmented layer directly behind the metalflake. Not only is complete hide assured with this procedure, but use of a contrasting color (usually black), will provide greater depth and eye-catching appeal.

If everything has been done correctly to this point, about 30 mils of gel coat have been applied to the mold. More gel coat could create problems of cracking and crazing due to excess of total gel coat thickness.

Two methods are commonly used. The most common is wet-on-wet.

1) Wet-On-Wet Procedure—although CCP recommends that each coat cures before the next coat is applied, metalflake has been sprayed successfully using the 'wet-on-wet' technique. The advantage is in time saved. The procedure consists of spraying all coats on top of one another without waiting for each coat to cure. There should be no lag time once spraying is started. The following problems can occur:
    a) Alligatoring.
    b) Blow through (blowing the metalflake through the first clear, or blowing the backup through the flake coat).
    c) Metalflake rippling may increase.
    d) Checking (occurs when edges of the flake are within the clear coat and immediately next to the mold surface).
    e) Stretch marks (occurs when the backup coat cures much more quickly than the flake coat; worsened if the back up coat sags).

   Proper catalyst levels must be maintained in all three coats.
2) Cured Procedure
    a) Allow the clear to cure adequately before applying the metalflake coat. Time will vary, depending upon a number of conditions, including catalyst type and concentration, temperature and humidity. Cure should be such that the metalflake coat does not cause the clear coat to alligator.
    b) Once the initial coat of clear is ready, the metalflake coat can be applied.
    c) After the metalflake coat has cured, the backup coat is applied.

Laminate and allow a good cure before pulling. No pull should be made until after the part has exothermed and cooled to room temperature. Provide adequate heat, or an under cured part can induce some surface rippling in the final part. Overnight cure is best.

4. EQUIPMENT—Conventional air-atomized spray equipment (the kind suitable for spraying regular gel coats) is sufficient, but some changes will be necessary. The metalflake tends to clog, so larger fluid tips and nozzles will be required. Fluid tip sizes in the range of 0.090 inches to 0.110 inches should be sufficient.

High percentages of metalflake or larger metalflake particles can become trapped between the fluid nozzle and the needle. This can prevent the gun from shutting off properly. To prevent this, Binks has a 'Metalflake Nozzle Kit' (#102-530) to fit their 7N gun.

Pressure pots are used instead of pumps for delivery to the gun. The metalflake particles can be damaged by pumping action. In addition, these particles can create problems with the pump and existing filters. Usually more than one specific color metalflake is used, so small batch mixing of up to several gallons each proves to be the most practical means of application. Mixed batches should not be allowed to sit for more than one hour before use.

Alternatively, metalflake can be applied using standard airless air-assist gel coat equipment, using a separate container of metalflake that is fed to the gun head.

To use airless air-assist gel coat equipment, some modifications are required. Gel coat and catalyst tips must be rotated 90 degrees, creating a horizontal rather than vertical spray pattern, similar to the fan pattern in chopped fiberglass. The gun head must be fitted with a top-mounted tube, allowing directional control of the metalflake, again similar to a chop chute. The bulk dry metalflake is in a hopper at the spray booth or carried with the operator in a backpack. If using a backpack, the two most common types are hard cylinders or soft pouches. The gel coat gun must be modified with an air line, which can be fed to the backpack. Air from the gel coat gun to the backpack 'fluidizes' the metalflake and creates a pressure differential that forces flake down the delivery tube, normally 3/8 inch to 1/2 inch in diameter to the gun head. This method allows for coverage of a much greater surface area than would using a pressure pot, allows the same tips to be used for clear coat and metalflake coat, and is also a more efficient method requiring no premixing.

5. UNIQUE PROBLEMS—Color change and blistering of the metalflake film can be caused by a combination of:

- Metalflake
- Catalyst (the higher the catalyst level, the greater the problem)
- Water.

In the initial stages, the flake darkens and at the same time exhibits less brilliance. As the color change progresses, the flakes seem to disappear. Since the flakes become transparent, the backup color will begin to show through. The ultimate and final stage has been reached when all flakes seem to disappear (they are actually transparent), when there is no luster or brilliance, and when there is a dramatic color change. Magnification, about 10X, is very helpful to observe this process.

This problem seems to occur only with epoxy-coated polyester flake. Construction of this flake starts with a polyester film such as Mylar®. Pure aluminum is deposited onto the polyester film, providing an opaque, mirror-like surface.

An epoxy coating is then applied. This coating contains colorants.

The visible change results when the aluminum is dissolved from the flake. At first, light corrosion of the aluminum causes darkening and loss of luster. With a lighted magnifying glass, this can be seen as a more random diffraction of light. In final stages, when all of the aluminum is dissolved, the flakes are transparent and of a color representative of the colorant used in the epoxy coating and the color of the backup gel coat.

Continued exposure to water makes this problem show up. High humidity can be worse than immersion. Pure or distilled water is more corrosive and worse than tap water. With elevated temperatures, corrosion occurs sooner.

MEK Peroxides are corrosive in the presence of both water and metalflake. Excessive amounts of catalyst speed the rate at which corrosion occurs. Raw catalyst spots can cause dramatic and rapid changes. Catalyst injection equipment may not always provide even catalyst dispersion, resulting in areas of concentrated catalyst that will increase susceptibility to corrosion.

Maintaining recommended catalyst level with properly functioning equipment is one precautionary step the fabricator can use to control and minimize this problem. The recommendation is that metalflake should be catalyzed and applied via the hot pot system (i.e., a known amount of catalyst mixed into the gel coat).

If a particular operation will not allow use of the hot pot, then equipment should be calibrated weekly, or more often if:

- A new batch of gel coat is used
- A new batch of catalyst is used
- A new pump is used
- A rebuilt pump is used
- Any equipment malfunction has occurred
- An extreme temperature change has occurred
- New equipment is placed on the same air line
- Pressures are changed
- Tips are changed.

Key people—such as the supervisor, lead person and spray person—should be advised of this potentially damaging problem occurring due to a high catalyst level. They should be knowledgeable about calibration and be watchful for catalyst drops, excess catalyst, or a sudden decrease in gel coat flow.

6. pH TEST FOR METALFLAKE—The pH test can be helpful. This can be a standard incoming quality control test, or specifically used to confirm problem lots of metalflake.

The procedure is simple. Mix an equal volume of metalflake with distilled water and let stand for 30 minutes. Check with pH meter (preferred), or pH paper (available from chemical supply houses). Also check pH of the distilled water, which should show a pH of seven. Any pH less than seven indicates an acid solution. Stronger acid solutions are indicated by lower pH, or simply a smaller number.

Solutions with a pH of five to seven are generally trouble free. Batches of metalflake that show pH from two to five are more likely to have gel/cure problems, and can be subject to field discoloration.

7. PATCHING METALFLAKE—Metalflake is difficult to patch and requires more expertise and patience than regular pigmented gel coats.

The clear coat is very important. The main problem with patching metalflake is that when flake is sanded, color is removed and the flake turns a bright silver. If a clear has been applied, minor scratches can be sanded or buffed out. If the first clear is not used, no sanding can be done until a clear spray patch is applied. It is the clear coat that can be worked and sanded, not the flake coat.

Use only the same clear gel coat (marine type) that was used to make the part. Do not use a gel coat intended for the manufacture of cultured marble.

CCP offers special patching thinners developed specifically for patching metalflake. See the patching thinners data sheet for product selection and specific instructions.

A. Small spot patch.

1) Prepare the area by routing, sanding to feather and washing with solvent.
2) Brush with catalyzed accent color. Let dry.
3) Apply a small amount of catalyzed flake and clear (approximately 15 percent flake and 85 percent clear). Cover with a sweep made of waxed paper or cellophane. Strike across the sweep as smoothly as possible.
4) Let cure overnight (due to inhibition tendencies of the flake).
5) Sand with 600 grit paper.
6) Buff.
7) Wash with HYDROCHLORIC or MURIATIC acid to dissolve any exposed flake (only if working with metalflake rather than polyester flake). **CAUTION: Hydrochloric (Muriatic) acid is very toxic and can be harmful if not properly handled. Always wear gloves and protective glasses.**
8) Wax.

B. Very small spot patch with no sanding.

1) Route area. Do not sand surrounding area.
2) Brush with catalyzed accent color. Let dry.
3) Apply a small amount of catalyzed flake and clear. Cover with a sweep made of waxed paper or cellophane. Strike across the sweep as smoothly and nearly flush as possible.
4) Let cure overnight and remove paper.
5) Trim and clean with knife blade.
6) Wax.

C. Spot patch with clear over-spray.

1) Prepare the area as for regular spot patch.
2) Brush with catalyzed accent color. Let dry.
3) Apply a small amount of catalyzed flake and clear mix. Cover with a sweep made from waxed paper or cellophane. Strike across the sweep as smoothly and nearly flush as possible.
4) Let set overnight and remove paper.
5) Scuff and solvent wash the area to prepare for spray patch.

6) Over-spray with catalyzed clear gel coat.
7) Let cure minimum of two hours. Sand, buff, and wax.

D. Spray patch.

1) After damaged area has been prepared, wash with solvent.
2) Mask off a large area around the repair.
3) Spray with catalyzed flake and clear mix (see patching thinner data sheet for product selection and specific instructions). Let cure for two hours.
4) Over-spray with clear, making sure to go beyond the perimeter of the flake coat. Spray PVA or catalyzed PATCHAID® on top of the clear for better surface cure. Let dry overnight.
5) Sand, buff and wax.

If clear gel coat was not used for the part, then clear must be sprayed to provide a base coat to feather into. Scuff an area larger in size than the actual repair area. Use 600 grit sandpaper and be careful not to sand hard enough to turn the flake silver. Spray this area with catalyzed clear and proceed with step D.3, previously.

OPEN MOLDING: Specialty Gel Coats—Metallic

Part Four, Chapter III.3

In This Chapter

1. **Description**
2. **Application**
3. **Precaution**
4. **Exposure Performance**
5. **Metallic Effects**

1. DESCRIPTION—Cook Composites and Polymers Company offers a line of metallic gel coats for the FRP industry. These gel coats are used in passenger, camper, utility and recreation vehicles of the transportation industry, as well as for decorative structural components and marine vehicle surfaces.

These gel coats produce the small metallic sparkle common in the automotive industry. These metallic particles are smaller than typical metalflake and provide a subtle brilliance and elegant appearance.

Normally the colors and effects will not be quite as dramatic or as appealing as many of the automotive-type metallic finishes.

True metal (metallic) pigments can cause very dramatic results in a polyester such as a gel coat. The aluminum pastes can be used but usually cause the resin to gel overnight, so they must be added just prior to use. Copper containing pigments can cause real problems, permanently inhibiting gel and/or cure. Percentages are limited to about 10 percent by weight, and may exhibit some gel and cure inhibition. Colors will be duller and their durability may be substantially harmed.

The other type of pigments capable of producing a metallic effect are pearlescent pigments such as Afflair Flake pigments from E.M. Industries, Inc., or the Luster pigments from Engelhard. Both achieve similar results; they differ mainly in color.

Usually pearlescent pigments can be added in the range of 0.2 percent to five percent by weight to a neutral or clear gel coat. Neutral gel coats tend to work better than clears because they have less tendency to mottle when sprayed.

Some really exciting colors can be achieved by adding just enough pigment concentrate to get a specific color. Of the tinted colors, black, blue, and maroon seem to offer the more appealing shades in metallics.

Patching this type of gel coat can be difficult. Sags and pregel disturbance of the metallic film causes obvious distortions in the surface appearance. Contact local FRP distributors for metalflake, metallic, and pearlescent supplies.

2. APPLICATION—Metallic gel coats are formulated for spray application. Brushing or rolling is not recommended. (See also Part Four, Chapter II.4 on 'Application.')

Changes in the setup of the spraying equipment and/or application technique lead to variances in metallic color shades and patterns. To reproduce a metallic color, it is essential that the following be kept constant: spray equipment, pot pressure, atomization pressure, and distance from which the spray is applied.

A Binks 7N spray gun can be used. Setup should include a 63 PB air cap, 66 fluid nozzle and 36 needle. The rate of delivery should be no more than 1.5 pounds of gel coat per minute. Forty pounds of air pressure (measured at the gun) is necessary to properly atomize the gel coat. Equipment suppliers offer container pots that will continually mix the gel coat to insure proper dispersion. Keep the spray gun two to three feet from the molds.

If the patterns of the metallic on the finished part are not satisfactory, a dust coat approach may be used. Whether it is a 'heavy dust' or a 'light dust' is not as important as getting the dust coat consistent and uniform. A heavy dust will provide a different ultimate effect than a light dust. If the gel coat is sprayed to an extremely inconsistent dust coat, these different effects will be noticeable.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, problems can occur due to: poorly atomized catalyst; surging problems (gel coat or catalyst); poor tip alignment (catalyst to gel coat mix); contamination; and poor application procedures which will quickly negate all benefits of calibration. The equipment (and application procedures) must be monitored on a routine basis to ensure proper application and cure of the gel coat. Inquire about and adhere to all equipment manufacturers' recommendations.

For best overall performance properties, a wet film thickness of 18 ± 2 mils is recommended as ideal. Films less than 12 mils may not cure properly, may be hard to patch, have more print-through, and may be more susceptible to water blisters. Films that exceed 24 mils may pre-release, trap porosity, or crack, and are more subject to weathering discoloration. If water blisters are of a great concern (boat hulls), 20 to 24 mils thickness would perform better than a thinner film, but sag, porosity and cracking resistance could suffer. If weathering (yellowing from sunlight, decks) is of great concern, then thinner films (12 to 16 mils) would perform better, but patchability, print-through and blister resistance could suffer.

Proper mold maintenance is important. Minimal repair work is always desirable. Sanding and compounding can hasten the chalking and loss of gloss of all gel coats.

Patching metallic gel coats is very difficult and patches are likely to be more noticeable than those for solid colors. Fabricators may have to be content with some color and appearance differences between the patch and surrounding area, due to the sanding/polishing disturbance of the metallic pigments.

3. PRECAUTION—Metallic gel coats may contain aluminum pigments. Precautions for products that contain aluminum pigment must be exercised. All equipment should be well grounded. Chlorinated solvents in contact with aluminum can cause an explosion; refrain from cleaning the metallic spray equipment with such solvents.

4. EXPOSURE PERFORMANCE—Metallic gel coats expose similarly to conventional solid gel coat colors. Chalk development and gloss loss will vary with metallic content. High metallic content gel coats may demonstrate more rapid chalk development than other gel coats. Consult a CCP representative about specific formulations.

5. METALLIC EFFECTS—Flakes of aluminum, bronze, coated mica, copper, glass, iron oxide, and thermoplastic or thermoset plastic are used to impart metallic effects. Type, size, concentration, orientation, transparency and opacity of the flakes, along with the presence of dyes or pigments, contribute to the overall color and appearance of metallic gel coats.

OPEN MOLDING: Specialty Gel Coats—Enamels

Part Four, Chapter III.4

In This Chapter

1. **Introduction**
2. **Surface Preparation**
3. **Applications**
4. **Cure**
5. **Availability**
6. **Cleanup**

1. INTRODUCTION—POLYCOR® enamels are formulated to be used as topcoats (surface coats, interior gel coats) for FRP. They are very similar to gel coats except that they cure tack-free.

Enamels are used like paint on FRP surfaces—a topcoat to seal and hide a substrate. Normally, enamels are used as interior finishes or to cover a laminate to provide a colored surface. Enamels cannot be used like mold contact gel coats because they contain wax and cure tack-free, which could cause delamination. Along with providing a tack-free surface, the wax in enamels helps to suppress styrene evaporation. This reduces the volatile organic content (VOC) emitted into the air.

Enamels can be made from isophthalic, ISO/NPG or orthophthalic base resin. Consult a CCP sales representative for more information about a particular product.

Enamels are multi-mil surface coatings formulated for use in boat and camper shell interiors.

Standard enamels should not be used for water immersion service. Contact a CCP sales representative for recommendations if water immersion is required.

POLYCOR® enamels produce a hard, tough, durable, flat finish with good water resistance characteristics when applied correctly.

2. SURFACE PREPARATION—With fiberglass laminates such as boat and camper shell interiors:

> **A. POLYCOR® enamel** should be sprayed after the laminate has cured and while it has a tacky surface. Beware of glossy laminates which could cause the enamel to separate, sag, or provide poor adhesion.
>
> **B. While still wet,** the POLYCOR® enamel can be flecked or cobwebbed.
>
> **C. When using laminates** that contain a 'wax surface' or 'mold release,' remove this surface before coating with POLYCOR® enamel. Sand with rough sandpaper to remove all indications of wax or mold release. Then wipe with solvent.

In all cases, before applying POLYCOR® enamels to any surface, be sure the surface is clean, dry and free from asphalt, dirt, dust, grease, oil, form oil, soap or cleaning agents, disinfectants and deodorants.

3. APPLICATION—Enamels should NOT be applied to surfaces when the temperature is below 70°F; inadequate cure can result.

Normally, enamels are applied with spray equipment, but they can be rolled. Brushing is not recommended due to poor flow and leveling. Refer to Part Four, Chapter III.4 on 'Application' for additional specific recommendations. Equipment, settings, and techniques for spraying gel coats are the same for enamels.

CCP recommends a delivery rate of no more than 2.5 pounds per minute with conventional air-atomized equipment, and no more than four pounds per minute with airless equipment.

For optimum results, uniform catalyst mix must be achieved. Even with the equipment properly calibrated, problems can occur due to: poorly atomized catalyst; surging problems (gel coat or catalyst); poor tip alignment (catalyst to gel coat mix); contamination; or poor application procedures. Any of these conditions will quickly negate all benefits of calibration. The equipment (and application procedures) must be monitored on a routine basis to ensure proper application and cure of the gel coat. Inquire about and adhere to all equipment manufacturers' recommendations.

Equipment, pot pressure, temperature, and length of hoses will vary the spraying; therefore, it is necessary to adjust equipment to obtain a good surface.

One gallon of POLYCOR® enamel will cover approximately 60 to 80 square feet, depending on the film thickness of the coating. A wet film thickness of 18 ± 2 mils is recommended for proper hiding, cure and performance properties. A film below 12 mils may not cure properly. Excessive millages above 24 may pre-release, are more prone to cracking and tend to trap porosity. If a 'fleck coat' of POLYCOR® enamel is desired over the base coat of enamel, it should be applied while the base coat is wet.

CAUTION: Enamels are not compatible in the liquid state with gel coats or resins. Equipment must be completely clean of these gel coats or resins before enamels can be used.

Do not over-mix enamels. Over-mixing breaks down viscosity, increasing tendencies to sag, and causes styrene loss, which could contribute to porosity. Enamel should be mixed once a day for 10 minutes. The enamel should be mixed to the sides and bottom of the container with the least amount of turbulence possible. Air bubbling should not be used for mixing. It is not effective, and only serves as a potential for water or oil contamination.

Do not add any material, other than a recommended methyl ethyl ketone peroxide, to these products without the advice of a representative of the Cook Composites and Polymers Company.

4. CURE—It is recommended that gel time be checked in the customer's plant because age, temperature, humidity and catalyst will produce varied gel times. Refer to CCP Product Data Sheets for specific catalyst recommendations.

The catalyst level should not exceed three percent or fall below 1.2 percent for proper cure. Recommended range is 1.2 percent to three percent with 1.8 percent at 77°F being ideal. Cure characteristics are dependent on material temperature, room temperature, humidity, air movement, and catalyst concentration. Special fast-cure versions are available but must be requested. These products offer lay up times of 30 minutes or less depending on gel times. Fast cure products have shorter stability and should not be inventoried over 45 days.

These products (standard or fast cure) should not be used when temperature conditions are below 70°F, as curing may be adversely affected.

5. AVAILABILITY—POLYCOR® enamels are available in clear, white, or any of the colors listed in the standard gel coat color deck.

Special colors are available upon request. Economy enamels are available also.

6. CLEANUP—Clean all equipment upon completion of the application, as it will be impossible to clean equipment if the POLYCOR® enamel sets up and is allowed to cure in the hoses and gun.

OPEN MOLDING: Vinyl Ester Barrier Coats

In This Chapter

1. **Introduction**
2. **Materials**
3. **Application**
4. **Performance**

1. INTRODUCTION—Vinyl ester (VE) barrier coats are specialized gel coat formulations designed to enhance the performance of composite laminates. Barrier coats are primarily used in the marine industry, but can be used in any application where improved osmotic blister resistance and part cosmetics are desired. Use of barrier coats can also reduce production cycle times in some applications.

2. MATERIALS—Barrier coats are formulated from the same types of materials as used in gel coats. (See Part Four, Chapter II.1) However, barrier coats are generally formulated with vinyl ester polymers. Other polymer types such as isophthalic polyesters and isophthalic polyester/polyurethane hybrids have been used in barrier coat formulations, but their usage is limited. Another difference between barrier coats and gel coats is that barrier coats are not formulated for use as an exterior coating. Barrier coats rapidly chalk and fade when used in this application.

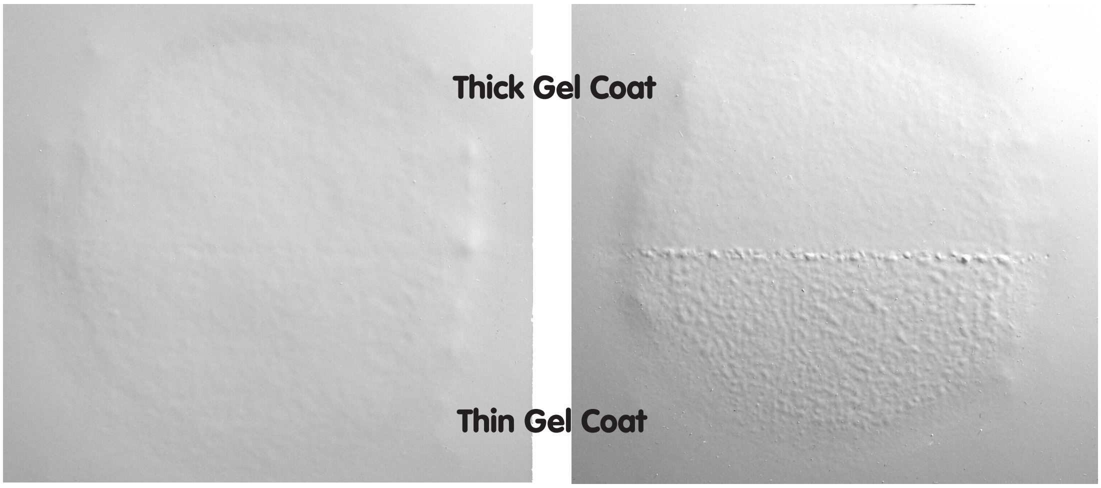
3. APPLICATION—A barrier coat is applied directly behind the gel coat prior to application of the structural laminate. Application of vinyl ester barrier coats is similar to that of gel coats. Vinyl ester barrier coats should be mixed prior to application to ensure homogeneity of the material and to break down the viscosity in preparation for spraying. MACT compliant barrier coats are generally high in viscosity and should be at least 75°F when sprayed. In colder shops, in-line heaters may be necessary to raise the temperature of the material. Larger angle tips and larger diameter hoses may be required.

Vinyl ester barrier coats can be applied through conventional and low emission spray equipment. The preferred method of spray application is either conventional or air-atomized, air-assisted airless, or airless. See Part Four, Chapter II.3 for additional information on spray equipment and Chapter III.4 for additional application information. Always refer to the product data sheet for specific application information.

The vinyl ester barrier coat must be applied correctly to realize the performance benefits. In particular the thickness of the vinyl ester barrier coat is critical. Thin application will result in under-cure, causing poor cosmetics and osmotic blister resistance. Thick application can lead to increased cracking.

4. PERFORMANCE—Composite parts fabricated with a correctly applied barrier coat will have significantly reduced blistering in comparison to parts fabricated without a barrier coat. The pictures below show the comparison of laminates that have been exposed to boiling water for a minimum of 100 hours. Each laminate was fabricated with two gel coat thicknesses.

Laminates after 100 hour Boiling Water Exposure



Laminate with VE Barrier Coat
(No blisters)

Laminate without VE Barrier Coat
(Heavily blistered)

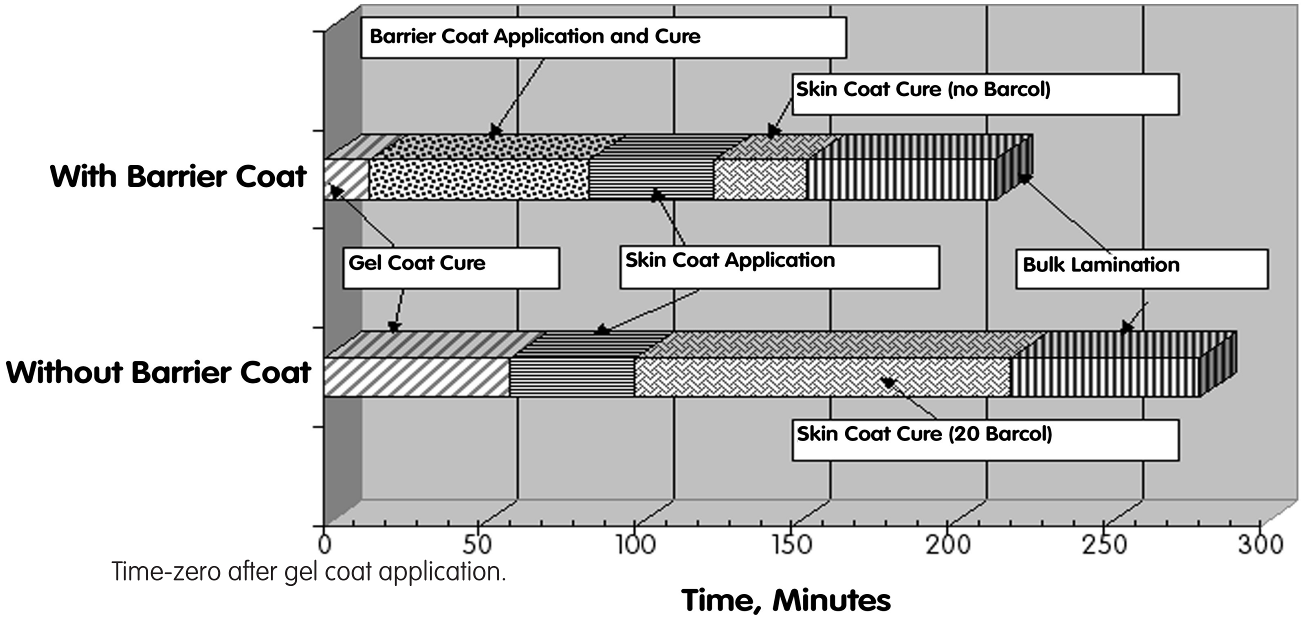
OPEN MOLDING: Vinyl Ester Barrier Coats

Reduction of osmotic blistering is accomplished by two mechanisms. First, the vinyl ester polymers used to formulate the gel coat have inherently low water absorption properties. Second, use of a barrier coat moves laminate porosity or air voids away from the gel coat. Laminate porosity at the gel coat-laminate interface is a source of blistering and cosmetic defects.

Vinyl ester barrier coats also improve laminate cosmetics by reducing fiber print-through and distortion. Use of a barrier coat increases the distance of the laminate's reinforcing fibers, balsa and other structural parts from the gel coated surface, reducing the impact of these features on laminate cosmetics. Vinyl ester barrier coats also provide protection against dimensional changes (shrinkage) of the laminating resin during post demold curing. Vinyl ester barrier coats are two to three times tougher than typical pigmented gel coats, so the increased thickness can be added without increasing the risk of cracking that is associated with thick gel coat applications.

In addition to the performance benefits, fabricators have found that the use of a vinyl ester barrier coat accelerates the production cycle compared to laminates fabricated using a conventional skin coat. To realize the cosmetic benefits of a skin coat, it must be allowed to cure thoroughly prior to laminate application. However, a vinyl ester barrier coat needs only to cure to a tack-free condition prior to proceeding with lamination. The barrier coat reaches a tack-free condition much more quickly than the skin coat achieves a thorough cure. This cycle time savings is illustrated below for a high volume boat manufacturing operation.

Cycle Time Comparison for Typical (High Volume) Boat Manufacturing



Time-zero after gel coat application.

Over *ONE HOUR* time savings per unit using a barrier coat.

OPEN MOLDING: Lamination—Laminating Resins

Part Four, Chapter V.1

In This Chapter

1. **Introduction**
2. **Laminating Resin Formulation**
3. **Laminating Resin Specifications**

1. INTRODUCTION—Laminating resins are polyester or vinyl ester resins that are formulated for use in ambient temperature, open mold, sprayup or hand layup processes. Laminating resins can be formulated for use in the neat form or filled with inorganic fillers.

2. LAMINATING RESIN FORMULATION—Laminating resins are formulated by resin suppliers from several components including the polymer, reactive monomer, thixotropic agents, promoters, inhibitors and specialty additives. The specific components and amounts used are dictated by the end-user's processing requirements, requirements for finished part performance, and cost considerations. Emissions regulations also effect the resin formulation. Processing requirements typically include spray ability, wetout, sag, working time, trim time, cure or Barcol development time and peak exotherm temperature. Finished part performance requirements can include part appearance, physical properties, water resistance, weathering resistance, corrosion resistance, bond strength, flame retardancy among others.

A. Polymer—Unsaturated polyester and vinyl ester polymers are the basis for most laminating resins. The type of polyester or vinyl ester used depends on processing requirements, emissions requirements, finished part requirements and cost. Vinyl ester polymers typically offer better finished part performance than polyesters, but are also generally more expensive. Vinyl ester resins have superior physical properties, water resistance and corrosion resistance.

Polyester polymers can have a wide range of properties depending on the raw materials (acids and glycols) used to produce them. All polyester polymers have an unsaturated acid component, typically maleic anhydride. The unsaturation in the polymer provides a site for reaction with the monomer also known as crosslinking. The most common polyester polymers used in laminating resins are orthophthalics, isophthalics and DCPD's. Orthophthalics are good general purpose resins and are used in a wide variety of applications. Orthophthalics typically have good bonding properties either for secondary bonding applications or for bonding to other substrates such as acrylic. Isophthalic resins are used in applications requiring good thermal properties or corrosion resistance. DCPD's offer good cosmetics, but can be brittle and are not ideal for bonding applications. DCPD polymers are often used to formulate products to meet emissions regulations. Blends of various types of polyesters and vinyl esters can capitalize on the properties of each of the individual polymers. (See Part Three, Chapter II on General Chemistry of FRP Composites Resins for more information.)

B. Monomer—The monomer fulfills two roles in the laminating resin. First, it is reactive and crosslinks with the unsaturation sites in the polymer to form the crosslinked thermoset material. Second, it reduces the viscosity of the polymer to workable levels for the laminating application. Some common monomers used in laminating resins are styrene, vinyl toluene, methyl methacrylate (MMA) and alpha methyl styrene. The amount and combination of these monomers effect the exotherm temperature reached during curing, glass fiber wetout, cure rate, and mechanical properties. Emissions regulations limit the type and/or amount of monomers that can be used in the laminating resin.

C. Thixotropic Agents—Laminating resins are formulated to be thixotropic or have a viscosity that is dependent on shear rate. A laminating resin should have a low viscosity during high shear operations such as spraying and wetout. After these high shear operations are completed, the resin should recover to a high viscosity to prevent sag and/or draining. This thixotropic behavior is obtained through use of thixotropic agents. These materials form a network with the polymer through hydrogen bonding. During high shear this network breaks down and lowers the viscosity of the material. After the high shear is completed the network reforms or recovers and the viscosity of the resin increases. The faster the rate of recovery the lower the risk of sag or drainage, but the higher the risk of air entrapment.

The thixotropy of a resin is determined by measuring the low shear and high shear viscosity of the resin. The ratio of these two values is reported as the Thixotropic Index (TI). For unfilled laminating resins, the high shear viscosity generally ranges from 400 to 700 cps. TI's are typically between two and four. Filled laminating resins typically have lower TI's. In filled systems the thixotropy not only helps prevent sag and draining, but also helps hold the filler in suspension.

Two major classes of thixotropic agents are fumed silica and organoclays. Other thixotropic agents called synergists are used to further enhance the thixotropic network.

D. Promoters and Inhibitors—The types and levels of promoters and inhibitors used in laminating resins determine the cure behavior. Typical cure behavior concerns formulation of a laminating resin, including the gel time or the working time available to the lamination operator, the Barcol development rate which determines when part can be trimmed and demolded, and the peak exotherm temperature achieved during the part fabrication processes. Low peak exotherm temperatures can be a sign of under-cure. High peak exotherm temperatures can result in mold damage. Promoters and inhibitors can also affect the color of the cured resin. This effect must be considered when formulating low color or pigmented systems.

Most laminating resins are cured under ambient conditions (65 to 95°F) with peroxide catalysts. Promoters, also called accelerators, split the peroxide catalyst into free radicals. These free radicals attack the unsaturation sites in the polymer, preparing them for reaction with the monomer.

The most common promoter used in laminating products is cobalt. However, cobalt by itself does not typically result in proper cure behavior. Other materials called co-promoters are used to further enhance the cure behavior. Co-promoters enhance the ability of promoters to split the peroxide catalyst into free radicals. They are very effective in shortening the gel time and accelerating the cure or Barcol development rate. Typical co-promoters are amines such as dimethyl aniline or diethyl aniline.

Inhibitors provide shelf life stability to laminating resins as well as help control the working time or gel time. Free radicals generated in the laminating resin during storage or after addition of peroxide catalyst react preferentially with the inhibitors. Only after all the inhibitors are consumed does the crosslinking or curing process begin.

E. Speciality Additives—In addition to the above materials, a number of other additives can be used in laminating resin formulations to effect properties. These include processing aids such as air release agents, wetting agents, color change dyes to show catalyst addition, and odorants. Additives can also be used to affect part performance such as UV absorbers and light stabilizers for weathering performance and a variety of additives to impart flame retardant properties.

3. LAMINATING RESIN SPECIFICATIONS—When producing laminating resins, resin manufacturers run a variety of quality control tests to ensure that the product being produced will meet the needs of end users. Final results of these tests are reported to the end user via the Certificate of Analysis (COA). Typical test results reported on a COA include:

- High shear viscosity
- Thixotropic Index (TI),
- 100 gram mass cup gel time, time to peak exotherm and peak exotherm
- Laminate gel time and peak exotherm
- Laminate Barcol development.

See Part Ten, Chapter I, Appendix A on Quality Control Lab and Test Methods for information on the equipment and procedures used to run these tests.

The 100 gram mass cup gel properties are a standard in the FRP industry for characterizing resin cure. These parameters are valuable to the resin manufacturer when producing the product, and to the end user for verifying that the product will be suitable for use in their process. However, it is important to the fabricator to understand that 100 gram mass cup gel parameters will not necessarily correspond to those observed in the actual application. For example, the 100 gram mass cup gel time is generally faster than the gel time in a laminate and the 100 gram mass cup peak exotherm is much higher than that of the laminate.

OPEN MOLDING: Lamination—Fiber Reinforcements

Part Four, Chapter V.2

In This Chapter

1. **Fiber Reinforcement**
2. **Laminate Thickness vs. Layers of Glass Reinforcement**

1. FIBER REINFORCEMENT—Reinforcement is no longer limited to fiber arrangements of glass. It may be synthetic polymer in roving, mat, or entangled sheet form. It may also be fiber forms of inorganic elements or compounds such as boron, carbon (graphite), minerals, or silica in rovings or mat. This discussion will primarily refer to fiberglass because it is the most common reinforcement.

A. Surfacing Mat (Veil)—Veil is a thin (usually 10 mils) layer of fine, soft fiberglass or synthetic fiber that is used next to the gel coat. It is used to reduce the transfer of fiber pattern through the gel coat from the coarser glass mats. It is also used in corrosion work as the last layer next to exposed surfaces, where it yields a resin-rich surface.

B. Chopped Strand Mat—Chopped strand mat is a roll goods material available in weights from 3/4 ounce to three ounces per square foot. Structurally, it has multi-directional strength, rather than the bi-directional strength of woven roving. It is made up of chopped strands up to two inches long that are held together with a binder, which is soluble in the polyester resin. (Excess binder can cause a dimpling of the gel coat surface.) Tear the mat and inspect it for the particles, (small and crystalline). Normally, there is more binder on one side of the mat than the other. Some mats are made with an insoluble binder and cannot be used in the hand layup process. Mat is used to inexpensively build up bulk and to increase strength and stiffness.

C. Roving—Roving is a loose twine of glass fibers (usually 60) wound up into a cylindrical package weighing about 35 pounds. It is the least costly form of fiberglass. It is used mostly in the sprayup process where it is chopped and fed with converging streams of catalyzed resin onto the mold surface. Sometimes the continuous roving is used as a wrap-around (for circumferential strength), in special configurations such as tanks, fishing rods, vaulting poles and stiffening ribs. Roving is available with one red strand (out of 60) called a tracer, to help gauge the uniformity of thickness and distribution. The glass fibers become transparent when wet with resin.

The ideal roving for use in sprayup has good compatibility with the resin, good cutting characteristics, easy rollout, fast wetout, low water sensitivity, and minimal buildup of static electricity. Handling properties vary, notably to the extent that the sizing on the roving renders it 'hard' or 'soft.' Hard roves cut well and have good strand integrity. Soft roves tend to filamentize (i.e., open up) when cut; however, they can be compacted into sharp corners, such as the strakes of boat hulls, without spring back.

D. Woven Roving—This material costs about the same or a little less than mat, but is twice as strong in tensile and flexural strength, so most structural laminates have some woven roving in their makeup. It is a coarse weave and is available in weights from 13 to 27 ounces per square yard; 18 and 24 ounces are most common. It is shifty and conforms to contours better than mat or cloth. However, its coarse weave is sometimes problematic since its outline is 'telegraphed' through the gel coat when it is positioned too closely behind it. It is best to have at least 3/16 inch of mat or chopped roving between the woven roving and gel coat to minimize the print-through. Its strength is bi-directional (like cloth), so that multiple plies are laid at different angles to each other. Isotropic mat is used between plies.

E. Cloth (Hand Layup and Sprayup)—Cloth is the most expensive form of fiberglass and the strongest woven material on an equivalent weight basis. It is available in weights from two to 40 ounces per square yard. Although most production parts utilize four to 10 ounce material, the heavier weights such as 40 ounce cloth, can be used in tooling to build up strength and thickness quickly. It is available in different types of weaves such as twill, crowfoot and satin style where the satin is stronger and conforms more easily to compound curves. Cloth is used principally as a finishing layer (for better appearance) or a skin layer (just behind the gel coat) for extra strength. It will 'telegraph' through the gel coat as does the woven roving, but with less 'profile.'

F. Core Materials—When the fabricator needs to build in stiffness and strength without significant increases in weight, core materials are sandwiched between layers of fiberglass. These core materials may be metal or paper honeycomb, cardboard, wood, foam, composites of hollow bubbles and fiberglass, or combinations thereof. Also, core material can be in sprayable form. Consideration must be given to the resin demand of core materials, and their impact on cure and on subsequent print/distortion. Their placement in order of construction must also be studied for optimum results. The angles, ribs, and tie-ins created during sandwiching add sturdiness, stiffness, strength and bulk to the FRP structure. Reinforcement is usually specified by the type of material, number of ounces per unit area, and location in the laminate. The first layer is important in that it must reinforce the gel coat and be free of air pockets. Reinforcing is best insured by a thin layer (skin coat) of binder-free glass.

Studies have shown that laminate construction has an important effect on the performance of the gel coat. To reduce cracking, blisters, and crazing in gel coats, best results are obtained by using a thin coat of chopped glass and resin behind the gel coat; then, continue with one and 1/2 ounces glass mat layup. Proper roll out of the skin coat is important to remove all air voids at the gel coat surface.

The next layer or two should be a heavier mat (one and 1/2 ounces), or chopped roving depending on the ultimate thickness desired. This provides for fast laminate buildup. Another advantage of starting the laminate with mat layers is that it positions the fabric layers, which show a greater fiber pattern, further from the surface.

The third or fourth layer, if it is the final layer, can be woven roving or cloth. Woven roving should be used where strength is critical. Otherwise, six or 10 ounce cloth is used for a better finished surface (than the mat) and a little extra strength. Another advantage of cloth as a final layer is that the laminator can squeegee hard on the surface to remove trapped air bubbles and excess resin. For best strength, succeeding layers should be alternating mat and woven roving (24 ounce standard). It is not usually good practice to face two woven layers because of poorer inter-laminate bond and a higher chance for porosity (air bubbles entrapped in the cloth or woven roving, usually extending the entire thickness of the fabric).

Nine total ounces of mat per square foot will result in a 1/4 inch laminate (at 30 percent glass content). Glass content is usually specified to prevent resin-rich areas (too low glass content) which would crack and craze, or resin-starved areas (too high glass content) which would cause porosity. An all-mat or chop laminate should have a tolerance of 30 percent glass (low) to 35 percent glass (maximum) for best results. When woven roving is used in conjunction with mat, the range of glass content can be as high as 80 percent for the ultimate in strength. Bag molded parts should have a glass content of 60 to 65 percent.

2. LAMINATE THICKNESS VERSUS LAYERS OF GLASS REINFORCEMENT—The following table is offered as an aid toward estimating approximate laminate thickness of various glass reinforcing materials and typical laminating resins. The values given are averages and will vary according to application technique. It is noteworthy that a material's multiple layer thickness is not in direct proportion to its single layer thickness.

REINFORCEMENT	NUMBER OF LAYERS	LAMINATE THICKNESS	PERCENT GLASS CONTENT
1.5 OZ. MAT[1]	1	0.041 inch	36
	2	0.070 inch	34
	3	0.107 inch	33
7.5 OZ. CLOTH[2]	1	0.017 inch	41
	2	0.031 inch	40
	3	0.045 inch	43
24 OZ. WOVEN ROVING [3]	1	0.043 inch	54
	2	0.069 inch	55
	3	0.092 inch	59
Alternating layers of mat and cloth	3 (m,c,m)	0.106 inch	30
	5 (m,c,m,c,m)	0.145 inch	34
	7 (m,c,m,c,m,c,m)	0.207 inch	31
Alternating layers of mat and woven roving	3 (m,r,m)	0.110 inch	36
	5 (m,r,m,r,m)	0.163 inch	42
	7 (m,r,m,r,m,r,m)	0.226 inch	44

DRY GLASS THICKNESS		
1	1.5 oz. mat	0.022 inch
2	7.5 oz cloth	0.011 inch
3	24 oz. woven roving	0.024 inch

OPEN MOLDING: Lamination—Catalysts

Part Four, Chapter V.3

In This Chapter

1. **Function and Types**
2. **Usage Levels**

1. FUNCTION AND TYPES—The function of a catalyst or initiator is to crosslink the resin. The most common type of catalyst used in open mold, ambient temperature lamination is called organic peroxide. For more general information on peroxide catalysts, refer to Part Three, Chapter II, on General Chemistry of FRP Composites Resins. Laminators can choose from many types of organic peroxide catalysts. Each one affects the gel and cure behavior of the resin differently.

A. Methyl ethyl ketone peroxide (MEKP) catalysts are the most commonly used catalysts for ambient temperature open mold lamination. These catalysts are actually solutions of various MEKP isomers and hydrogen peroxide in plasticizers. The plasticizer, also known as a phlegmatizer, serves to stabilize the peroxides. The same resin catalyzed with different MEKP catalysts may show significantly different gel and cure behavior due to differences in overall peroxide levels and peroxide combinations. The recommended MEKP catalyst usage level is between 0.75 and 2.5 percent based on weight.

B. Cumene hydroperoxide (CHP)/MEKP blends are specialized catalysts that should be considered by laminators needing to reduce laminate peak exotherm temperatures in comparison to those obtained when using MEKP catalysts. Like MEKP catalysts, CHP/MEKP blends are solutions of peroxides (CHP, various MEKP isomers and hydrogen peroxide) in plasticizers. The overall peroxide content and the levels of the each of the various peroxides will affect the catalyst performance. In general, CHP/MEKP blended catalysts result in longer gel times, longer cure times, lower peak exotherm temperatures, and slower initial Barcol hardness development. When used appropriately, the ultimate cure of laminates produced with CHP/MEKP blended catalysts is equivalent to or better than those produced with MEKP catalysts. CHP/MEKP blended catalysts are not recommended for thin laminates or skin coats since reduced exotherm temperatures may not allow for complete cure. Use of MEKP/CHP catalyst blends in cooler temperatures should be carefully reviewed by the laminator and used only when required due to excessive peak exotherm temperatures. Recommended usage levels of CHP/MEKP blended catalysts are typically higher than for MEKP catalysts, 1.5 to 2.75 percent by weight.

C. Acetyl acetone peroxide (AAP) or 2,4 Pentadione catalyst is another specialized catalyst that should be considered by laminators needing faster cure and demold times at similar gel times obtained with MEKP catalysts. AAP catalysts are solutions of 2, 4 Pentadione peroxides in plasticizers. Use of AAP catalysts is somewhat limited since the faster cure rate also results in higher peak exotherm temperatures. The faster cure rate also results in a narrower trim window. Recommended usage levels of AAP catalysts are similar to MEKP catalysts, 0.75 to 2.25 percent.

Many catalysts are available with a red dye. These red catalysts can be used in applications that are not sensitive to color to provide a visual indication of catalyst level and dispersion.

2. USAGE LEVELS—The recommended usage levels for catalysts are generally expressed as a range. The starting point for catalyst usage level is typically the level used by the resin manufacturer during quality control testing. Resin suppliers produce resins to meet gel and cure behavior specifications agreed to by the customer. An important part of these specifications is the catalyst type and level to be used during quality control testing as well as the test temperature. Unless directed otherwise by the customer, resin suppliers typically perform quality control tests using 1.25 to 1.5 percent by weight MEKP catalyst. The test temperature is typically 77°F.

Deviations from this usage level occur based on shop conditions and part geometry:

A. Shop Conditions—The most important shop condition factor effecting catalyst level is temperature. The higher the ambient temperature the faster the gel and cure of the resin will occur. In warmer conditions, it may be necessary to reduce the catalyst level to allow appropriate working time for the lamination operator. In cooler conditions, it may be necessary to increase the catalyst level to maintain desired production line speeds.

B. Part Geometry—The most important part geometry factor effecting catalyst level is thickness. When using the same resin and catalyst to fabricate parts having a variety of thicknesses, the laminator may need to adjust the catalyst level. Higher catalyst levels may be required in thinner parts to ensure complete cure. Lower catalyst levels may be required in thicker parts to limit the exotherm temperature.

When selecting a catalyst and determining a usage level, it is highly recommended that the laminator discuss options with their resin and catalyst suppliers.

OPEN MOLDING: Lamination—Equipment and Application Methods

Part Four, Chapter V.4

In This Chapter

1. INTRODUCTION—Lamination is the process of combining resin and reinforcing materials on an open mold. Use of proper lamination equipment and techniques are critical to producing structurally sound parts that meet design requirements as well visually appealing parts that meet cosmetic requirements. Improperly applied laminates add cost to the part due to scrap and rework. Making the investment in proper equipment, equipment maintenance and calibration, and operator training can pay big dividends by reducing rework and scrap. This chapter provides an overview of the lamination process, lamination equipment, equipment calibration procedures, key factors affecting laminate quality and lamination methods. A list of equipment, tools and supplies that should be available in the lamination shop is also provided.

2. PROCESS OVERVIEW—Lamination of glass fiber reinforcements can be accomplished by hand layup or sprayup methods. Hand layup is used when applying roll good reinforcements such as chopped strand mats and textile constructions that are stitched or woven. The roll good reinforcement is cut to the desired shape and manually placed in the mold. Brushes, rollers or spray guns can be used to apply the resin. Sprayup is used when the laminate reinforcement is chopped roving. Continuous strands of fiberglass roving are pulled through a chopper and cut into short lengths (1/4 to one inch lengths are typical) called chopped roving. Chopped roving and catalyzed resin are combined and applied onto the lamination surface with a spray gun or a flow chopper. In both hand layup and sprayup, the glass is manually wet out and compacted with lamination rollers.

Selection of sprayup or hand layup methods for a particular part depends on the part configuration, mechanical property requirements, thickness tolerances and cost considerations.

- Complexity of shape often favors sprayup over hand layup since complex shapes require time consuming and labor intensive trimming and tailoring of roll goods plies. However, small and deep drafted parts cannot generally be produced by sprayup for economic reasons.
- Hand layup laminates can be significantly stronger than sprayup laminates due to higher glass contents of some roll goods.
- Laminate thickness is more easily controlled with hand layup than sprayup. In hand layup the laminate thickness is based on the type of roll goods used, the areal weight of the roll goods and the number of layers of roll goods. In sprayup, the laminate thickness is dependent on the operator's skill in evenly depositing the required amount of resin and glass over part surface.
- The sprayup process is generally the lower cost process when compared to hand layup. Roving is generally less expensive than roll goods. Also, waste from over-spray will typically be less than waste from trimming roll goods particularly when an experienced spray operator is used. Labor costs are also generally lower for sprayup since no trimming or tailoring of roll goods plies is required. Also, resin and reinforcement can be deposited faster with sprayup than hand layup, particularly on contoured surfaces.

Hand layup and sprayup are often combined within the same part or laminate to realize the advantages of both processes.

3. EQUIPMENT—Numerous types of lamination equipment are available to FRP fabricators. The equipment can be as simple as a paintbrush or as complex as a robotic unit programmed to select, meter, mix and apply the reinforcements and resin. Several key features can categorize lamination equipment: catalyst metering and incorporation method, resin application method and glass application method.

A. Catalyst Metering and Incorporation—Slave arm systems have become the industry standard for catalyst metering. The advantage of slave arm systems over other catalyst metering systems is that catalyst flow rate is tied to the resin flow rate. This helps to ensure consistent catalyzation at the desired level. In slave arm systems, the air motor for the resin is used to pump the catalyst, thus the resin and catalyst are connected to the same air motor (hence, slaved together). To prevent excess pressure being put on the catalyst, a pressure relief valve is incorporated. The slave pump may be set either by specific intervals or on a dial-adjusted scale, generally ranging from 0.5 to four percent. Incorporation or mixing of the catalyst with the resin can either be accomplished internally or externally depending on the specific type of equipment being used.

Other types of catalyst metering and incorporation systems include catalyst injection and split batch or dual nozzle spray gun system. In catalyst injection systems, a small pressure vessel with a flow meter is used to inject a metered quantity of catalyst into the resin stream. The catalyst is then mixed with resin either internally or externally. In catalyst injection systems, the control of the catalyst content is dictated by multiple variables including resin flow rate and air pressure to the catalyst pot.

Split batch or dual nozzle spray gun systems utilize two streams of resin. One stream is unpromoted but contains enough catalyst to cure both streams. The other stream is promoted but uncatalyzed. The two streams of resin are delivered to the spray gun so that the two streams intermix. The intermixing may occur internally or externally. These systems require the use of two separate resin systems. The catalyst resin stream must be used within its pot life.

Neither catalyst injection nor split batch systems are in widespread use today.

B. Resin Application Method—Historically, atomized spray has been the most common method of resin application particularly in sprayup operations. However, EPA and OSHA requirements to reduce styrene emissions has resulted in the emergence of new resin application techniques such as non-atomized spraying and non-spray methods.

Atomized spray involves the use of high fluid pressure or compressed air (up to 100 psi) to create a finely divided or atomized spray pattern. The small size of the particles in the spray pattern means large exposed surface area. Evaporation of monomers from this surface area creates high emissions. Catalyst incorporation can be either internal or external.

In non-atomized spray, the resin exits the gun in low-pressure streams. The impingement technique uses two low-pressure streams that cross each other. The collision of these streams creates a spray pattern. Flow coatings (another technique) uses multiple, fine diameter orifices to produce parallel streams. Non-atomized spray results in less exposed surface area than atomized spray, and therefore lower emissions. Catalyst incorporation can be either internal or external.

Flow coaters utilize internal catalyst mixing so the mixing chamber must be periodically flushed to prevent the accumulation of gelled resin. Resin distribution with flow coaters is also not as even as with other spray techniques. This can lead to thickness and glass content variations, particularly in thin laminates.

Pressure-fed rollers, a non-spray technique, are used for hand layup applications. The roller system also utilizes internal catalyst mixing and must be periodically flushed. Pressure is used to push catalyzed resin out of a roller similar to a typical paint roller. Roller size and length can make resin application by this method difficult in tightly contoured areas.

C. Glass Application Method—Glass fiber reinforcements can be either hand laid or sprayed. For sprayup, an air powered roving chopper is combined with the spray or flow coater resin application head. The resin application head and roving chopper are suspended from a carrying boom to allow the operator freedom of movement. One or more strands of roving are guided from spools along the boom to the chopper. Ceramic guides are recommended to reduce fuzzing and static electricity generated by friction of the glass.

When the trigger on the chopper gun is pulled, two tangent rollers pull the rovings into the chopper, cut the rovings to the desired lengths and propel the chopped roving toward the mold surface. Razor-like blades mounted in one of the rollers chop the roving. Spacing of the razor blades determines the strand length (typically one inch). Shorter strands will be easier to roll out, but will reduce overall part strength. Longer strands increase strength, but may not conform to tight radii during rollout and cure. Outside the chopper, the glass fiber chop converges with the resin and is partially wet before reaching the mold surface.

4. EQUIPMENT CALIBRATION—Calibration of equipment is important to ensure laminate quality. Equipment should be calibrated with each use, or at the very least daily. When calibrating sprayup equipment, the main areas of concern are resin flow rate, glass flow rate, resin to glass ratio, catalyst flow rate, and catalyst content. For hand layup, the resin to glass ratio is controlled by the operator; however, spray guns and pressure fed flow rollers should be calibrated for resin flow rate, catalyst flow rate, and catalyst content. Always consult the equipment manufacturer for proper calibration of a particular type of equipment.

A. Resin Flow Rate, Glass Flow Rate and Resin to Glass Ratio—For sprayup equipment, determine the resin and glass flow rates in pounds per minute as follows:

- Adjust the pump to the desired pressure.
- Weigh two containers individually in pounds.
- Direct the resin head and glass head of the chopper gun into the separate containers.
- Spray resin and glass into the containers for 10 seconds.
- Individually weigh the containers in pounds.
- Determine the resin weight by subtracting the empty weight of the resin container from the container weight after spraying.
- Determine the weight of glass by subtracting the empty weight of the glass container from the container weight after spraying.
- Calculate the resin flow rate by multiplying the resin weight by six.
- Calculate the glass flow rate by multiplying the glass weight by six.

For example if the resin weight is 2.33 pounds the resin flow rate will be 14 pounds per minute. If the glass weight is one pound, the glass flow rate will be six pounds per minute.

Total laminate output or the sum of the resin and glass flow rates can vary, but are typically between six and 30 pounds per minute. Some of the factors to consider when adjusting the total laminate output of a chopper gun are:

- Part size
- Available manpower for roll-out
- Desired laminate thickness
- Gel time or working time of the resin.

If the total laminate output or the resin or glass flow rates are not within the desired range, adjust the equipment per the supplier's recommendations.

Calculate the resin content in percent by dividing the resin weight by the sum of the resin and glass weights and multiplying by 100. Calculate the glass content in percent by dividing the glass weight by the sum of the resin and glass weights and multiplying by 100. The resin to glass ratio is then expressed as resin content (percent) : to glass content (percent).

For example, if the resin weight is 2.33 pounds and the glass weight is one pound, the resin content will be 70 percent and the glass content will be 30 percent. The resin to glass ratio is then 70:30.

If the resin to glass ratio is not within the part and process design requirements, adjust the equipment as necessary.

For hand layup processes using spray guns or flow coaters, follow the procedures above to determine resin flow rates. Resin to glass ratios are controlled by the operator.

B. Catalyst Flow Rate and Catalyst Content—Determine catalyst flow rate and resin flow rate in pounds per minute as follows:

- Attach a resin/catalyst splitter (available from the equipment manufacturer) to the spray equipment.
- Weigh two containers individually in pounds.
- Spray the resin and catalyst streams into the separate containers for 30 seconds.
- Individually weigh the containers in pounds.
- Determine the resin weight by subtracting the empty weight of the resin container from the container weight after spraying.
- Determine the catalyst weight by subtracting the empty weight of the catalyst container from the container weight after spraying.
- Calculate the resin flow rate, by multiplying the resin weight by two.
- Calculate the catalyst flow rate, by multiplying the catalyst weight by two.

For example, if the resin weight is seven pounds the resin flow rate will be 14 pounds per minute. If the catalyst weight is 0.1 pound, the catalyst flow rate will be 0.2 pound per minute. If the resin or catalyst flow rates are not within equipment supplier's recommendations, adjust the equipment as necessary.

Calculate the catalyst content in percent by dividing the catalyst weight by the sum of the resin and catalyst weights and multiplying by 100. For example, if the resin weight is seven pounds and the catalyst weight 0.1 pound, the catalyst content will be 1.4 percent.

Catalyst content may also be checked by comparing the gel time of resin catalyzed with a known catalyst amount versus the gel time of catalyzed resin from the lamination equipment.

- For the control sample, obtain 100 grams of uncatalyzed resin. Weigh the appropriate amount of catalyst into the resin. For example, if a catalyst content of 1.5 percent is desired, weigh 1.5 grams of catalyst into the resin. Start a timer and thoroughly mix the catalyst into the resin. Stop the timer when the resin reaches a physical gel.
- Obtain catalyzed resin from the lamination equipment. Pour 100 grams into a container similar to the one used for the control sample. Start a timer at the time of catalyzation. Stop the timer when the resin reaches a physical gel.

The gel time of the material from the lamination equipment should be within ± 5 percent of the gel time of the control sample.

5. KEY FACTORS AFFECTING QUALITY—Key factors affecting laminate quality are discussed below.

A. Temperature—Temperature during laminate fabrication is the most important process variable in open molding lamination shops. Many quality problems are traced to excessive temperature variations, and this can further be complicated by variations in humidity and airflow. The resin and catalyst viscosity and the resin gel and cure times are all related to temperature. The temperature of the reinforcing materials, mold surface and shop can affect the temperature of the resin and catalyst during application. Therefore, the temperature of the resin, catalyst, reinforcing materials, mold surface and shop should all be regulated.

Most polyester and vinyl esters are formulated for use at temperatures between 60°F and 95°F. Consult the product data sheet for the specific usage temperature range for each product.

Catalysts and resins increase in viscosity with decreasing temperature. Cold, high viscosity catalysts and resins are difficult to spray and distribute on the mold surface. Cold, high viscosity resins are slow to wet strands of glass and other reinforcements. Poor spray and wetting can result in increased void content that significantly lowers the mechanical properties of the laminate.

Catalysts and resins decrease in viscosity with increasing temperature. Use of hot, low viscosity resins can result in drain-out from reinforcements that can increase void content and reduce mechanical properties.

Resin gel time and cure rate increase with decreasing temperature. A good rule of thumb is that the gel time and cure rate will double with every 20°F reduction in temperature and will be cut in half with every 20°F increase in temperature. The slower gel times and cure times of resins in cold conditions can lead to post-cure that can be seen as print-through and/or distortion. The faster gel times and cure times in warm conditions may not allow enough working time for proper wet out.

Within the recommended temperature usage range, the catalyst level can be varied to adjust the gel and cure time of the resin to compensate for specific shop conditions. Higher catalyst levels are used at lower temperatures and lower catalyst levels are used at higher temperatures. Catalyst levels should be maintained within a range specified by the resin manufacturer. This range is typically between 0.75 percent and 2.5 percent for most laminating resins.

Use of unsaturated polyester and particularly vinyl ester laminating resins at temperatures below the specified minimum (typically 60°F) can result in permanently under-cured parts. Under-cured parts will have poor physical properties and cosmetics. Extremely high temperatures can also be detrimental to the cure of laminating resins. The monomer content may be lowered due to evaporation at elevated temperatures. Resins that are cured too quickly tend to be brittle.

In colder weather, removing parts from the temperature controlled application area too quickly after application can cause cure retardation. Even drafts of cold air should be avoided during application and until a sufficient degree of cure has been achieved.

To help compensate for seasonal temperature variances, the same resin can be supplied in summer and winter versions. Summer versions have longer gel times to allow for more working time in hot weather. Winter versions have shorter gel times to improve cure. Changes in viscosity can also be incorporated to provide the viscosity desired at the application temperature.

B. Catalyst Level—Low catalyst concentration and poor catalyst distribution are two more leading causes of problems in FRP composites. Peroxide catalysts initiate the crosslinking reactions in unsaturated polyesters or vinyl ester resins. All peroxide-initiated resins specify a minimum catalyst level as well as a maximum. A typical range for a nine percent active oxygen methyl ethyl ketone peroxide catalyst is 0.75 percent to 2.5 percent. Always consult the product datasheet for specific recommendations on catalyst type and usage range recommendations.

The minimum range limit is necessary to ensure that enough catalyst is available to achieve a suitable reaction rate and complete cure. Even small amounts of peroxides, or other free radical sources, will start the cross linking reaction; however catalyst starved resin will be permanently under-cured and the resulting laminate will have poor mechanical properties and cosmetics.

The maximum limit is necessary due to the diluents used in the peroxide initiator products. These diluents are non-reactive and high levels can 'plasticize' the resin. 'Plasticized' resins have poor stiffness and hardness. High catalyst levels can also cause an increase in the monomer-to-monomer side reactions that further weaken the laminate.

C. Catalyst Mixing—Even if an appropriate catalyst level is specified and equipment has been properly calibrated, faulty equipment may fail to mix the catalyst in the resin evenly or consistently. Parts made with poorly mixed catalyst may not show any symptoms during fabrication, or at demold. In fact, parts with uneven catalyst may only present problems after the parts are put in service. Common indications of poorly mixed catalyst include print, distortion and delamination in laminates. Due to the severity of these problems, proper catalyst dispersion should be ensured.

D. Resin to Glass Ratio—The resin to glass ratio is the amount of resin (by weight) versus the amount of glass (by weight) in the total laminate. The appropriate resin to glass ratio depends on the type of glass fiber reinforcement being used. For laminates that are fabricated with sprayup chopped roving, the resin-to-glass ratio is typically between 70:30 and 60:40. For laminates fabricated with roll goods, the resin-to-glass ratio may be as low as 40:60. Always check the data sheet for the reinforcement being used to determine the recommended glass content.

The resin to glass ratio affects the finished parts' mechanical properties, appearance, and weight. Resin-rich laminates, or laminates with high resin-to-glass ratios, have a glossy or wet appearance on the open side of the laminate. These laminates will have lower mechanical properties than laminates with appropriate glass contents and may crack or fail in service. Resin richness will result in additional shrinkage that may affect the finished part's dimensions and cosmetics due to pre-release, distortion and fiber print. Resin richness will result in higher laminate peak exotherms that can also contribute to pre-release. High peak exotherms can also damage tooling and degrade the cosmetics of subsequently produced parts. Resin-rich laminates are also heavier than laminates fabricated with proper glass contents.

Resin-poor or resin-starved laminates will have a dull, dry appearance on the open side and may have significant porosity. In extreme cases, resin-poor laminates will have dry fibers. These laminates will have lower mechanical properties than laminates with appropriate glass contents and may crack or fail in service. Resin-poor laminates may also be under-cured and print or distort.

E. Thickness Control—Laminate thickness control is required to ensure a quality laminate. Thick laminates will have higher peak exotherms during laminate cure than thin laminates. High exotherm temperatures can contribute to pre-release and can also damage tooling, resulting in degradation of cosmetics for subsequently produced parts. During sprayup, slow pass speeds and excessive overlap of strokes are two sources of excess laminate thickness. During hand layup, overlaps in roll goods can create excess laminate thickness.

Thin laminates can also result in poor laminate quality. Thin laminates may not cure properly, resulting in poor cosmetics and mechanical properties. During sprayup, fast pass speeds and minimal overlap of strokes can result in thin laminates.

F. Laminate Construction—Laminate construction or design has a significant impact on the field performance of the end part. To reduce cracking, blisters and crazing, the best results are obtained by using a barrier coat behind the gel coat. (See Part Four, Open Molding, Chapter IV for more information on Barrier Coats.) Skin laminates are also used for this purpose, although they are not as effective as barrier coat. A skin laminate is a thin laminate applied directly behind the gel coat. Ideally, skin laminates are fabricated using chop and a high performance laminating resin such as a vinyl ester, isophthalic polyester or blends of these resins with DCPD's. Proper roll out of the skin coat is important to remove all air voids at the gel coat surface. The skin laminate must also be allowed to cure thoroughly prior to subsequent lamination to realize cosmetic benefits.

Print blockers can be used behind the barrier coat and/or skin coat to provide further protection against print through from subsequent layers. See Part Four, Open Molding, Chapter VI for more information on Print Blockers.

The next layer or two should be a heavier mat or chopped roving, depending on the ultimate thickness desired. This provides for fast laminate buildup. Another advantage of starting the laminate with mat versus woven roving or cloth is that it distances the fabric layers from the laminate surface, minimizing fiber pattern.

The next layers can be fabric layers such as woven roving or cloth. Woven roving should be used where strength is critical. Otherwise, six to ten ounce cloth is used for a better-finished surface than roving. Use of fabric in the final layers of the laminate allows the operator to squeegee hard on the surface to remove trapped air bubbles and excess resin. For maximum strength, succeeding layers should alternate mat and woven roving. It is not usually good practice to use consecutive layers of woven material because of poor interlaminate bond and a higher chance for porosity.

G. Workmanship—The workmanship of the lamination operator is also a key contributor to laminate quality.

6. LAMINATION METHODS—General preparation for lamination is as follows:

- Check all equipment and lines for contamination such as flushing solvent, water, or oil.
- Check the temperature of the shop, mold, resin, catalyst and reinforcing materials to ensure that they are within the appropriate range (typically 60°F to 95°F).
- Completely calibrate the equipment as described previously in this chapter.
- Mix the resin as needed, according the manufacturers direction.

When using spray equipment, it is recommended to make a test spray to check the spray pattern. When using sprayup equipment, the test spray should also be used to check glass dispersion and wetting.

Before laminating behind gel coat or barrier coat, check the film to make sure that it is ready for lamination by touching it. If no material transfers, it is ready for lamination. Due to its high vapor density, styrene vapors tend to accumulate in low portions of the mold. High styrene vapor concentration tends to retard the cure of a gel coat film. Monitor initial film curing by checking a well-ventilated area like the trim flange, but the final film cure should be checked in low areas.

When laminating behind a skin coat, check the skin coat to make sure that it is thoroughly cured. The skin coat must be thoroughly cured prior to subsequent lamination to realize cosmetic benefits. The approximate extent of cure can be measured with a Barcol impressor. The Barcol impressor measures the hardness of the resin. Resin hardness is related to cure. The further the cure progresses, the harder the resin becomes. Typically, skin laminate resins should reach a minimum Barcol hardness of 20 prior to subsequent lamination.

A. Sprayup Methods—

1) Spray a thin mist coat of resin on the mold to help with fiber wetout at the surface.
2) Next, spray the first layer of chop. The layer should be sprayed in two passes with the second pass being at right angles to the initial pass. Overlap strokes by approximately 50 percent. Keep the gun perpendicular to the mold to ensure a uniform fan pattern. Maintain

a constant speed throughout the spraying to ensure even material distribution. A quick roll out of material between passes may help prevent sagging or sliding on vertical surfaces.

3) After spraying, completely wet out and compact the glass with lamination rollers or brushes. Brushes often work best in corners or areas with complex geometry. Pay special attention to removal of air bubbles or voids particularly at the gel coat surface. Voids at the gel coat surface can create cosmetic defects and lead to blistering.
4) After rollout, verify that the thickness of the laminate is within the design range by using a mil gauge.

Larger parts may need to be sprayed in sections. The size of each section will depend on the available working time and manpower. Sections should be sized so that they can be thoroughly wet out prior to resin gelation.

B. Hand Layup Methods—

1) Trim the required number of roll goods plies to the desired size and shape.
2) Wet the surface of the mold with a sufficient amount of resin.
3) Position the first ply on the mold. Trim the ply as required to fit the mold.
4) Wet out the glass and remove air bubbles with lamination rollers, brushes or squeegees. Brushes often work best in corners or areas with complex geometry. Add additional resin as required to sufficiently wet out the ply.
5) Repeat this procedure until all plies are in-place and wet.
6) Carefully inspect the laminate for wetting and air voids. Touch up with rollers or brushes as needed. Remove any excess resin with a paint roller or brush.

For best control of resin-to-glass ratio and for minimizing air voids, textile constructions should always be back wet. Resin is applied to the mold surface, the dry ply is placed in the liquid resin, and the ply is wetted by working the resin through from the backside.

Some laminate designs utilize coring materials to increase the laminate stiffness while minimizing the additional weight. Coring materials can be incorporated into the laminate by bedding them prior to resin gelation. The bedding layer should be thick enough for adequate bonding, but thin enough to prevent print-through.

1) Laminate the bedding layer using the methods discussed above.
2) Wet the side of the core material that will be applied to the laminate with a thin coat of resin.
3) Position the core on the laminate and roll over the surface, applying pressure to ensure good surface contact.

After lamination is complete, the laminate must be allowed to cure adequately prior to demolding. The definition of adequate depends upon the part and process design criteria. The amount of time required to achieve adequate cure depends on the resin, the type and amount of catalyst used, and the temperature. Premature demolding of a laminate can lead to print or distortion as the laminate continues to cure outside the mold. As previously discussed, the Barcol hardness can be used as an indicator of cure.

After gelation and the peak exotherm temperature have occurred, it is possible to accelerate the remainder of the cure by exposing the part to elevated temperatures. This process is commonly known as post-curing. There are many benefits of post-curing composites. The ultimate mechanical properties are more easily achieved through post-cure. If the post-cure is done while the part is still in contact with the mold surface, the parts will be more dimensionally stable and resistant to print and distortion during service. Post-curing can also drive off unreacted monomer to reduce odors in the finished part.

7. EQUIPMENT, TOOLS, AND SUPPLIES—The following is a list of equipment tools and supplies that should be readily available in the lamination shop:

A. Equipment needed includes:

1) Spray booth with filter, exhaust fan, metal lined sliding doors, ample walking space around molds, good lighting.
2) Air compressor (don't skimp on size—specify an air dryer; use accumulators with large water extractors). It is recommended that all hand tools be air operated for operating costs and for safety reasons (non-sparking).
3) Cutting table for glass reinforcement (not needed for sprayup), 60-inch wide rack on one end for mounting rolls of glass, two rolls.
4) Lamination equipment (as discussed earlier in this chapter and per manufacturers' guidelines).
5) Monorail and hoists for heavy parts, like boats and shower stalls.
6) Dollies or conveyor track for moving molds around plant.
7) Air hose, additional water traps, connectors, air regulators.
8) Air powered gear driven mixer for mixing resin.
9) Storage bin—heated or dehumidified for glass materials.
10) Fire extinguishers around plant; consult insurance carrier and local safety officials for proper type and location.

11) Scales for weighing ingredients (ounces and gram).

B. Tools needed include:

1) Large scissors for cutting roll goods and smaller ones for individual tailoring during layup.
2) Paint brushes—three-inch and four-inch, solvent-resistant.
3) Rollers—plastic and aluminum, such as one inch by three inches and two inches by 12 inches, and corner rollers. Nap rollers are used to redistribute resin.
4) Squeegee material.
5) Hand grinders for smoothing exposed surface and edges.
6) Buffers for applying rubbing compound, cleaner and glaze.
7) Putty knives for bonding, filling, repairing.
8) Air powered drills for hardware, trim, other attachments.
9) Linoleum knives for trimming edges of part in mold.
10) Wrenches for bolting molds together.
11) Clamps for holding inserts to wet laminate while curing.
12) Measuring container for measuring catalyst.

C. Auxiliary supplies:

1) Sandpaper—80 to 600 grit, wet or dry.
2) Solvent for cleanup.
3) Covering for floors under laminating area.
4) Cans—one gallon and five gallon, for resin and solvent of appropriate type.
5) Sponges for washing molds.
6) Mold cleaner, mold sealer and mold wax.
7) Wash basins—for cleanup.
8) Solvent dispenser can.
9) Rags.

OPEN MOLDING: Lamination—Secondary Bonding

Part Four, Chapter V.5

In This Chapter

1. INTRODUCTION—Secondary bonding is defined as fabrication of a new laminate (secondary laminate) onto a previously cured laminate (primary laminate). The term secondary bond refers to the chemical and/or mechanical interaction between the primary and secondary laminate. Although chemical bonds are stronger than mechanical bonds, both types of bonds are necessary to optimize secondary bond strength.

A chemical bond is formed when the resin from the secondary laminate reacts with available sites on the primary laminate. Available (or unreacted) sites on the surface of the primary laminate can result from an under-cured laminate surface, otherwise known as an air inhibited surface. The amount of chemical bonding that occurs depends upon the number of available sites.

A mechanical bond is formed when resin from the secondary laminate flows into and cures in rough areas or keyways on the primary laminate's surface. This interaction creates an interlocking force holding the two laminates together. The open sides of most open molded laminates have some keyways. More uniform and extensive keyways can be created by mechanical abrasion.

Generally, shops with slower turnover of parts have the greatest concern with secondary bond adhesion. In such circumstances, parts are either large customer yacht hulls and decks, or smaller, more intricate FRP parts that are laminated over extended periods.

2. CONDITIONS AFFECTING SECONDARY BONDING—There are many conditions that can affect the ability of a secondary laminate to form a strong bond with the primary laminate. These conditions include:

A. Temperature—Exposing a cured laminate to elevated temperatures allows the laminate to obtain a greater degree of cure. This greater degree of cure is good for the overall properties of the laminate, but not good for secondary bonding. This greater degree of cure reduces the number of unreacted sites on the surface of the primary laminate thus limiting the amount of chemical bonding that could occur with the secondary laminate.

B. Humidity—High relative humidity has the opposite effect on the primary laminate. Humidity slows down the surface cure and increases the number of unreacted sites. These unreacted sites are then available to form secondary chemical bonds.

C. Surface Contamination—On the primary laminate, surface contamination can affect both chemical and mechanical bond strength. If the primary laminate is not cleaned properly, the secondary bond can be compromised, and the secondary laminate cure could be affected as well.

D. Ultra Violet Radiation or Exposure to Sunlight—Exposure to sunlight has the same effect as exposure to elevated temperatures. The laminate surface obtains a greater degree of cure thus reducing the number of unreacted sites on the surface to obtain a chemical bond with the secondary laminate.

E. Time—The time between cure of the primary laminate and application of the secondary laminate also effects secondary bonding. In general, the shorter the time between these steps the better. The more time that elapses between primary laminate cure and secondary laminate application, the further the cure of the primary laminate will progress. Also the chance of exposure to elevated temperatures, contamination and sunlight is greater.

3. RESIN CHEMISTRY AND SECONDARY BONDING—The type of resin used by the fabricator significantly influences the degree of secondary bonding that can be obtained. As mentioned in the previous section, there are numerous conditions that can affect secondary bonding regardless of resin type. However, resin type plays a major role and must be considered. For the purpose of this discussion, the resin types that will be compared for secondary bonding are orthophthalic and DCPD resins.

A. Orthophthalic Resins—Orthophthalic resins have proven to be very forgiving in secondary bonding applications. Orthophthalic resins are air-inhibited, which means that they have poor cure in the presence of oxygen. The poor cure is manifested as tackiness on the open side of a laminate. Poor surface cure is a benefit for secondary bonding since there are a relatively large number of unreacted sites on the primary laminate that are available to react with the secondary laminate. In addition, the poor surface cure characteristics of orthophthalic resins means that the degree of surface cure will not progress as quickly with time or exposure to heat and sunlight as for other resin types.

Primary laminates made with orthophthalic resins that are stored in a cool, dark location and kept free from contamination can be used successfully in secondary bonding applications without extensive surface preparation for several weeks.

Fabricators need to be aware that some orthophthalic resins contain additives to reduce the surface tack. These additives form a film on the open side surface of the laminate and can be detrimental to secondary bonding. The most common additive used is paraffin wax.

B. DCPD Resins—DCPD resins have been widely accepted by FRP composites fabricators for reasons such as tack-free cure, good cosmetics, low shrink, low costs and emissions compliance. However, the tack-free cure means that DCPD resins are non-air inhibited and have poor secondary bonding characteristics since there are relatively few unreacted sites on the open side of the laminate. Exposure to heat and sunlight further cure the surface, resulting in even fewer unreacted sites for secondary bonding.

Primary laminates made with DCPD—containing resins that are stored in a cool, dark location and kept free from contamination can be used successfully in secondary bonding applications without extensive surface preparation for only one to three 3 days. After this time period, the primary laminate must be mechanically abraded and use of structural adhesives is recommended to achieve a good secondary bond.

4. SURFACE PREPARATION— Mechanical abrasion of the primary laminate surface is the best approach to ensuring a good secondary bond. Primary laminates meeting the following conditions should always be mechanically abraded prior to application of the secondary laminate:

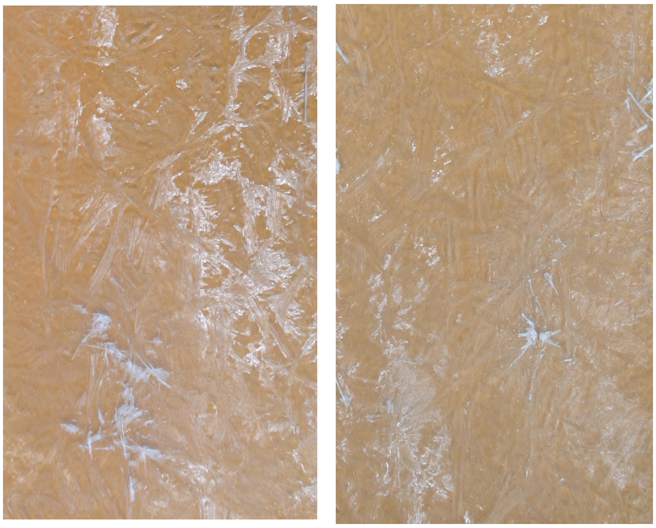
- Laminates made using resins containing wax or most other additives to reduce surface tack.
- Laminates that have been exposed to elevated temperatures.
- Laminates that have been exposed to UV light
- Laminates made using DCPD-containing resins that have been cured for more than three days.
- Laminates with glossy resin-rich surfaces.

Mechanical abrasion by sanding or grinding should remove all visible gloss and expose a fresh laminate surface. It is advisable to sand down to expose some fiberglass.

5. SECONDARY BOND EVALUATION—It is recommended that each fabricator experiment with secondary bonding using their materials and specific shop conditions. The most common method for evaluating secondary bonding is to perform a pull test. This type of testing does not quantify secondary bond strength, but allows for assessment of secondary bond integrity by evaluation of the failure location and failure mode. Users may want to perform several pull tests to evaluate various materials, storage conditions, storage times and/or surface preparation procedures. Testing should be repeated when changing any materials (e.g., glass, resin or catalyst). The testing procedure is outlined below.

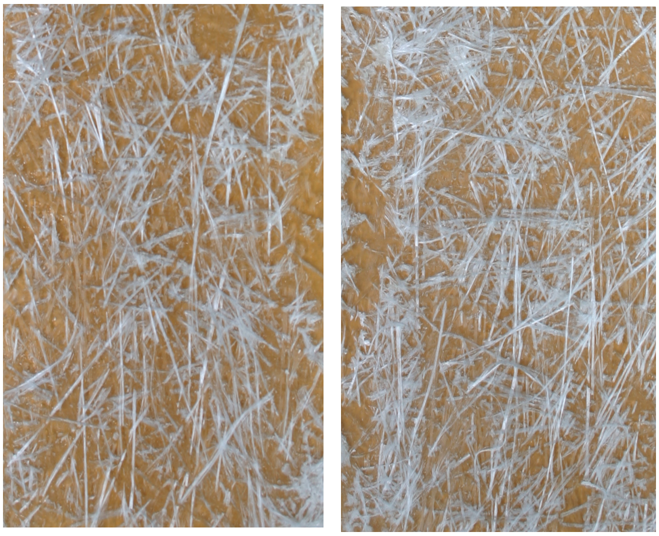
- Fabricate a primary laminate and store it under the desired conditions and for the desired time frame.
- Prepare the surface of the primary laminate. Place a strip of Mylar® film or other release material at one edge of the laminate to act as a failure initiation point.
- Apply the secondary laminate. The secondary laminate should have the same dimensions as the primary laminate. Allow the secondary laminate to cure for at least 24 hours.
- Using the Mylar® film location as a failure initiation point, pull the two laminates apart.

If the failure occurs between the two laminates without fiber tear, the secondary bond is considered poor. If the failure mode is within either of the two laminates as evidenced by fiber tear, then the secondary bond is considered acceptable. See the following pictures for examples of poor and acceptable secondary bonds.



Primary Laminate **Secondary Laminate**

Poor Secondary Bonding



Primary Laminate **Secondary Laminate**

Acceptable Secondary Bonding

OPEN MOLDING: Lamination—Acrylic Bonding

Part Four, Chapter V.6

In This Chapter

1. INTRODUCTION—Acrylic plastics were introduced in 1936 and because of some distinguishing properties, have become a widely accepted liner material for the fabrication of tubs, showers and spas. Acrylic plastics offer the fabricator a variety of colors, and outstanding weathering characteristics, chemical resistance, and a durable, easy-to-clean surface for both the fabricator and end-user. Acrylic liners are typically backed with FRP laminates made with polyester or vinyl ester resins. These laminates, when properly bonded to the acrylic liner, provide strength and stiffness to the finished part.

2. ACRYLIC THERMOFORMING PROCESS—The process for creating the desired acrylic part shape is called 'thermoforming.' Thermoforming is the shaping of a polymer sheet by the use of heat. This process can be broken down into three stages: heating, forming, and cooling.

A. Heating—The first stage of the thermoforming process (i.e., heating) varies, depending on the specific type of acrylic sheet being used. In general, a source of heat is applied to the acrylic sheet. After the heat application at a predetermined temperature and length of time, the sheet becomes soft, and can then be molded into the desired shape.

B. Forming—Forming creates the desired shape. This is accomplished by taking the heated acrylic sheet, laying the sheet over the mold, and by some mechanical and/or pneumatic means, molding the acrylic into the desired shape.

C. Cooling—The process of cooling returns the acrylic sheet back to its original stiffness but now in the desired part shape and dimensions. For specific details regarding the thermoforming process, the fabricator should contact one of many suppliers of thermoforming machines. The suppliers of these machines can thoroughly discuss all parameters and options related to the thermoforming process.

3. RESIN MATRIX MATERIAL SELECTION—Numerous options for backing thermoformed acrylic sheeting are now available from resin suppliers. The resin types typically used for backing up acrylic are either polyester or vinyl ester resins.

A. Polyester Resins—The majority of acrylic backup laminates are fabricated with polyester resins. Orthophthalic resins are common, but other types of resins can be used as well. Not all polyester resins adhere to all types of acrylics. Resins selection is significantly influenced by adhesion considerations.

Polyester resins can be used unfilled or filled. Unfilled or neat resin application generally provides better adhesion than filled application, but is also more expensive.

1) Neat resin is defined as applying only the pure resin and fiberglass behind the acrylic. Better adhesion properties are one advantage to applying a neat resin layer behind the acrylic. A disadvantage to using neat resin is cost to the fabricator.

2) Filled resin systems use inorganic materials such as, alumina trihydrate, calcium sulfate and/or calcium carbonate added to the resin. There are many advantages to using a filled resin system such as lower matrix cost, increased flame retardancy and reduced volatile organic emissions. However, fillers can detract from the adhesion of the resin to the acrylic substrate. Because fillers vary, the type and amount used (typically between 30 to 60 percent) can affect the resin viscosity, and cure characteristics. Fabricators should work with the resin supplier in order to develop a resin system suitable for the fabricator's specific process. Another parameter that must be considered when using a filled resin system is the type and amount of fiberglass reinforcement applied to the part. Typical glass contents range from 15 to 30 percent and can be the chopped roving applied by sprayup, or chopped strand mat applied by hand layup. The type and amount of glass reinforcement directly affects mechanical properties of the finished part. The fabricator is ultimately responsible for determining the amount of reinforcement required to obtain the desired end use engineering design.

B. Vinyl Ester Resins—Vinyl ester resins are typically used as acrylic backup resins when superior water resistance or thermal properties are required. Spas are an example of such a requirement. The vinyl ester resins are typically applied as a thin laminate next to the acrylic, and the remainder of the backup laminate thickness is built with a more economical polyester resin. As with polyester resins, not all vinyl ester resins adhere to all acrylics. The value of the vinyl ester resin us lost if the product does not adhere to the acrylic.

4. GENERAL APPLICATION GUIDELINES—Once the acrylic shell has been properly clamped and supported to the laminating stand, the acrylic should to be cleaned to remove contaminants such as dust, moisture and other liquid materials. These contaminants can interfere with the resin's ability to adhere to the acrylic or affect the curing characteristics of the resin matrix. Possible methods for cleaning the acrylic include:

- Use of compressed air to remove unwanted dust
- Use of an approved cleaner (recommended by the acrylic sheet supplier to remove moisture and/or other liquid contaminants).

Before any resin matrix material is applied to the acrylic shell, the fabricator should make sure all manufacturing process parameters have been checked. These parameters include but are not limited to:

- Filler is mixed properly into resin
- Resin and shop temperatures within the resin supplier's recommended guidelines
- If using a chopper gun, the gun is in proper working condition.

When the fabricator is ready to apply the resin matrix, a good recommendation is to either spray or brush on a thin layer or mist coat of resin directly to the acrylic shell. The mist coat helps to ensure that there is sufficient resin next to the acrylic to provide adhesion.

After application of the mist coat, the first layer of resin and glass reinforcement can be applied. This layer needs to be completely and carefully wet and rolled out. All air voids must be removed to ensure a complete bond between the laminate and the acrylic. At this point, the fabricator can continue with the next layer of reinforcement or allow this layer to cure before continuing.

Each fabricator must determine a preferred specific lamination sequence. Some factors to consider are:

- Resin cure characteristics
- Filler loading
- Acrylic draw thickness

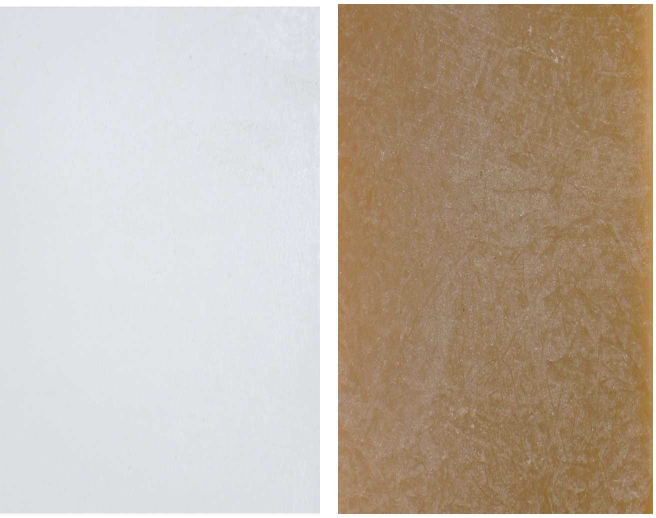
All these factors affect the laminate exotherm temperature. Low exotherm temperatures can be an indicator of poor cure. Poorly cured laminates will have low physical properties and poor adhesion. High exotherm temperatures can cause cosmetic issues, especially in areas where the acrylic is relatively thin.

This testing should be repeated on a regular basis to ensure that proper fabrication procedures are being followed. This testing should also be done when any material change is made, including changes in cleaners, acrylic, resin, filler, catalyst, and glass fiber.

The final stage of the process is the trimming and addition of any plumbing or external hardware. It is recommended that the resin matrix be allowed to properly cure and cool down before any such work is performed. A good indicator of resin cure is to check the Barcol hardness of the backup resin. Ideal Barcol hardness is a minimum of 20 HB. Performing such work before the resin has been allowed to cure properly can result in stress fractures in the part and minimize the resin's adhesion properties to the acrylic. It is the sole responsibility of the fabricator to determine when these types of operations can be performed (see the following section on adhesion testing).

5. ADHESION TESTING—Before Cook Composites and Polymers makes a resin recommendation for an acrylic backup application, CCP offers to perform adhesion testing for the fabricator. However, CCP cannot duplicate all of a fabricator's conditions. Each fabricator should design a suitable internal method to periodically check adhesion, using their specific materials and conditions.

The perfect time for the fabricator to check adhesion is when



Acrylic **Laminate**

Poor Acrylic Adhesion

Acrylic **Laminate**

Acceptable Acrylic Adhesion

the part is trimmed. The excess flange material can be observed for proper laminate rollout and wetting. Good adhesion can be determined by breaking a piece in half. Good adhesion is characterized by the appearance of resin and fiberglass left behind on the acrylic. This indicates laminate failure and not failure at the acrylic and laminate interface. Caution should be taken if using this method because the flange acrylic area is typically thicker than the remainder of the part. It is easier to obtain a good bond over a thick acrylic than over thinly drawn sections of acrylic, partly because of less change to the acrylic polymer structure during the thermoforming process.

The most common method for evaluating acrylic bonding is to perform a pull test. This type of testing does not quantify secondary bond strength, but allows for assessment of secondary bond integrity by evaluation of the failure location and mode. The testing procedure is:

A. Prepare a thermoformed section of acrylic per standard production procedures. It is important to use thermoformed acrylic since the thermoforming operation influences adhesion. Place a strip of Mylar® film or other release material at one edge of the laminate to act as a failure initiation point.

B. Apply the backup laminate per standard production procedures.

C. Allow the backup laminate to cure to a Barcol hardness of at least 20.

D. Physically separate the laminates at the failure initiation point.

If the failure occurs between the acrylic and laminate with little or no fiber tear or pullout, the adhesion is considered poor. If the failure occurs within the laminate with significant fiber tear or pullout, the adhesion is considered acceptable. See the pictures on the previous page for examples of poor and acceptable acrylic adhesion.

Finally, fabricators have the option of quantifying the adhesion by performing ASTM C297 for flat-wise tensile strength. For more information on this type of testing, please contact a third party mechanical testing facility or CCP representative.

OPEN MOLDING: Lamination—Troubleshooting

Part Four, Chapter V.7

In This Chapter

1. LAMINATION TROUBLESHOOTING—Even under the best of conditions, problems can occur due to accidents, mistakes, and unanticipated events.

Listed on the following pages are some of the more common laminate problems, although other problems can occur (it is impossible to anticipate every plant circumstance that can cause problems).

COMMON LAMINATE PROBLEMS, CAUSES, AND SOLUTIONS

Problem	Cause	Solution or Items to Check for
Color variation in the laminate	Hot/cold laminate	Mix in catalyst well; reduce percentage of catalyst; resin puddles; moist glass.
	Uneven laminate	Check spray pattern.
Cure time—long or short	Various	Check percentage of catalyst and type; temperature; laminate thickness; gel time; contaminations.
Delamination		
a) From gel coat	Contamination	Dust on gel coat; mold release buildup dissolved by gel coat; used enamel instead of gel coat.
	Under-cured/over-cured	Timing for gel coat layup.
b) Between laminates	Application	Poor impregnation, resin rich.
	Resin	Too much wax in resin; weak resin; check grade and physicals.
	Cloth against cloth	Use mat or chopped glass between plies.
	Uncured	Check percentage of catalyst; temperature; pulling green.
Dimples in gel coat	Particles in laminate	Check for excessive binder on mat (one side may be worse than the other). Trash or dust between gel coat and laminate; gel particles in resin.
Drain-out		
a) No dry glass	Resin-rich	Reduce resin-to-glass ratio; avoid 'after-wet.'
	Resin too thin	Use a higher thixotropy resin.
b) Dry glass	Long gel time	Increase catalyst where allowed; check temperature.
Gel time—too long or short	Various	Check percentage of catalyst and type; temperature; laminate thickness; gel time; contaminations.
Glass pattern or waviness found in gel coat		
a) When part is pulled	Resin shrinkage or heat	Check catalyst level, temperature, use lower exotherm resin, avoid resin puddling, thin gel coat, under-cured gel coat.
	Thin gel coat	Use a minimum of 18 mils.
	Under-cured gel coat	Use a minimum of 1.2 percent MEKP; temperature should be at least 60°F.
	Laminating process	Too much laminate at one time (use a skin coat); woven roving or cloth too close to gel coat.
b) After part is pulled	Post cure	Too low a catalyst level; temperature too low; liquid contaminated; resin exotherm too low; demolding too soon; gel coat too thin.
Glass pickup on roller	Rolling near gelation	Adjust gel time.
	Styrene evaporation	Dip roller in styrene or fresh catalyzed resin. Keep air movement across laminate to a minimum.
	Rolling too fast	More deliberate rolling.
	Glass percentage too high	Increase resin.
	Dirty rollers	Change solvent.
Hot spots	Over-catalyzing	Check equipment; catalyst and resin sides for clogs, surging, drips; purge catalyst line.
	Resin-rich areas	Reduce resin content.
	Unbalanced laminate	Check thickness of different areas.
Resin crack	Pulling too soon	Do not pull under-cured parts.
	Too hot	Resin puddles; excessive catalyst; resin too high in exotherm.

OPEN MOLDING: Lamination—Troubleshooting

COMMON LAMINATE PROBLEMS, CAUSES, AND SOLUTIONS		
Problem	**Cause**	**Solution or Items to Check for**
Strength (low impact) or cracking	Insufficient glass	Check glass-to-resin ratio.
	Demolding	Rough demolding; too much twisting and flexing.
	Part too thin; weak resin	Increase thickness; check grade and physicals.
Soft spots	Unmixed catalyst	Check equipment; catalyst and resin sides for clogs, surging, drips; purge catalyst line.
	Water, solvent or oil (may appear as whitish areas)	Check air lines and solvent; rollers must be free of solvent.
Voids (air bubbles)	Entrapped air	Poor rollout; slow wetting glass; resin-starved areas; resin viscosity high; filler level high; resin drainout.
Warpage of parts	Unbalanced laminate	Use symmetrical layup; back spray laminate with gel coat or enamel.
Wetting (poor)	Viscosity too high	Check viscosity; cold resin; moisture contamination. High resin solids.
	Glass type or wetting properties	Check type and grade of glass.

2. EQUIPMENT TROUBLESHOOTING—The majority of lamination today utilizes semi-automatic equipment. The care and operation of this equipment will determine whether or not the laminate will achieve its maximum properties and performance.

Fabrication equipment operators must be trained in how to use and maintain their equipment.

Anyone who uses spray equipment should have (and should read) all the literature available from the manufacturer of the equipment. This includes parts diagrams, set up instructions, operating instructions, maintenance requirements, safety and troubleshooting guides. If this information has not been obtained or if a question arises, call or write both the company from whom the equipment has been purchased and the manufacturer. They will be happy to help because they want the equipment used efficiently, correctly and safely. Also, they will have general literature on spraying, and technical service people to provide assistance.

Always remember the investment in the equipment and that it was purchased to do an important job. If it is not maintained and if worn parts are not replaced, the investment will be lost and the equipment will not do the job for which it was selected and purchased.

One method that can be used to determine if a cure related problem is caused by material or equipment is to make a small test part where the catalyst is mixed directly in the resin. If this part does not exhibit the problem, then the cause is more likely in the equipment or operator. Another way to check is to run a different batch of material through the equipment; however, this could generate bad parts, making the first test method preferred.

A list of common problems that can occur with lamination equipment follows. Since there are numerous types of equipment in use, it is impossible to cover each one individually or list all possible problems or solutions. See manufacturer's literature for the type of equipment in use, or contact the manufacturer.

EQUIPMENT TROUBLESHOOTING—SUGGESTED CAUSES AND REMEDIES	
Problem—Resin/Chopper/Laminate	**Suggested Causes and Remedies**
Atomization poor (large droplets)	Check air pressure, length of hose, hose diameter (which may be too small), clogged or worn nozzle or air cap, stuck check valves, too much fluid flow, regulator not working properly.
Balls in the catalyst flow meter drop	Bottom needle valve almost closed and vibrates, filter plugged, not enough CFM's (cubic feet per minute).
Balls in the catalyst flow meter overshoot	Top valve wide open, turn 1 and 1/2 turns in—(Binks Injector)
Catalyst ball goes out of sight when pressured	Catalyst level too low—insert special gasket with .013 hole over delivery tube (Binks injector), air in flow tube.
Catalyst injector balls fluctuating	Catalyst needle valve vibrating or too close to seat—open or tighten packing, not enough or fluctuating CFM's, dirty catalyst filter.
Catalyst valve—burst of catalyst	Weak spring due to aging. If Binks, use Plug Groove valve at the gun. If hose within a hose, check for broken catalyst line.
Cavitating pump—sucks air	Remove siphon tube, put pump directly into resin—if it pumps okay—cavitation is due to the siphon system leak, pump too small, cold or high viscosity.
Check ball stuck	Residue after flushing, vapor lock. Use piece of wood to free ball or tap side of pump.
Chopper will not run or runs slowly	Loss of air, not cfm's; regulator not on; rubber roller adjusted too tight.

OPEN MOLDING: Lamination—Troubleshooting

EQUIPMENT TROUBLESHOOTING—SUGGESTED CAUSES AND REMEDIES	
Problem—Resin/Chopper/Laminate	**Suggested Causes and Remedies**
Drips (Gun):	
Fluid	Worn, clogged, or bent needle, seating adjustment of needle, over spray on gun, worn packings or seals, loose connection.
Catalyst	Worn seat or seals, damaged air valve, trigger out of adjustment, over spray on gun, loose connection, clogged valve or seat, gun head not aligned to gun body, fan control may trap catalyst in dead air space and drip catalyst out of air horns.
Solvent	Clogged or worn valve, worn seals, sticking needle or button.
Gelled hose	Bad fluid nozzle, bad seat.
Glass (chopped) not uniform in length	Worn or damaged blades; worn rubber roller; incorrect roller adjustment.
Glass pattern narrow	Chopper angle wrong; chopper air too low.
Glass off to one side	Chopper out of alignment; fluid nozzle worn or clogged.
Glass to resin ratio varies	Chopper air not regulated; pressure dropping before compressor kicks on—install regulator and set below the compressor's kick-on pressure; pre-wetting and extra wetting not accounted for.
Hot spots	Uneven laminate thickness, catalyst or resin surging, purge catalyst line before starting, catalyst drops.
Shaft of pump drops an inch or two—shudders	Starved pump—check filters or worn internal packings. Check for worn packing by stopping pump at top of stroke—if with no material flow shaft creeps down, packing is worn.
Shaft of pump (material coming up around)	Loose or worn seal—clean and tighten, stop pump in down position when system not in use, worn shaft.
Siphon kit jumps.	Dirt on check ball in pump.
Slow gel time and/or cure.	Check catalyst and material flow, oil or water contamination. Check gun trigger for proper activation. If slave pump, check for air bubbles.
Surging:	
Material	Inconsistent or low air pressure on pump, worn or loose pump packing, out of material, sucking air through loose connection, balls not seating in pump (dives on down stroke—bottom ball; fast upward stroke—top ball; flush pump), filter plugged, siphon line has air leak, screens plugged, too much material flow, cold or high viscosity, plugged surge chamber.
Catalyst	Inconsistent or low air pressure, out of catalyst, check valve sticking in gun or catalyzer, loose connection, screen plugged. If Binks equipment install Plug-Groove valve at the gun, keep hoses straight rather than coiled.
Tails (airless):	
Material	Pump pressure too low, worn tip, too large of tip, viscosity too high.
Catalyst	Worn tip, low pressure, wrong tip, viscosity too high, too large a fan.
Tips spitting or trigger will not shut off	Worn seat or worn needle or weak spring, check packing.
Trigger stiff	Bent needle, bent trigger, worn needle guide.
Water in air lines	No extractor, extractor too close to compressor—should be no closer than 25 feet, all take-off's from main line should come off the top.
Worn packings	Pump overheating from being undersized, high pressure or pumping without any material, do not let pumps jackhammer—no more than one cycle (both strokes) per second—use glass reinforced Teflon® packings. Keep idle pump shaft in down position to keep dried material from damaging packings.

OPEN MOLDING: Sprayable Print Blockers

Part Four, Chapter VI

In This Chapter

1. INTRODUCTION—Sprayable print blockers are used to protect the gel coat surface from the effects of heat and shrinkage of the bulk lamination layers. Print blockers thermally insulate the gel coat and skin coat from the rest of the laminate during manufacturing. Parts made using a print blocker have less print-through from cloth, overlaps, or underlying structural elements in the laminate.

2. MATERIALS—Sprayable print blockers are formulated from the same types of materials as gel coats (see Chapter II, Section II.2 of this part of the Guide), except that sprayable print blockers are syntactic foams. Syntactic means that these products incorporate various types of microspheres or microballons to enhance the properties. Glass, ceramic and thermoplastic spheres all provide specific properties in the syntactic foam. Selection of the proper mixture of spheres increases hardness, improves durability, and reduces the density of the finished print blocker.

Early versions of print blockers were formulated with low strength and low heat distortion flexible resins, such as putty resins. These products have not been very successful since they distort when exposed to high temperatures like those seen on dark colored gel coats exposed to the sun. Also these print blockers can fatigue in service and cause catastrophic delaminations. Some of these early print blockers continue to persist in the marketplace. More recent products such as CCP's ArmorShield PB™ are formulated with higher-grade resins to resist distortion and fatigue failure.

3. APPLICATION—Application of ArmorShield PB™ is similar to gel coat application. (See Chapter II, Section II.4 of this part of the Guide.) As with gel coats, ArmorShield PB™ should be mixed prior to use. ArmorShield PB™ is a very viscous material. Mixing is required to break down the viscosity for adequate fluid movement and sprayability. Mixing will also ensure homogeneity of the material. A paddle type mixer is recommended. The motor speed should be such that mixing extends to the side of the drums with no dead spots. A minimum mixing time of 30 minutes is recommended. Air bubbling should not be used for mixing. It is not effective and only serves as a potential for water or oil contamination. Due to its high viscosity, ArmorShield PB™ should not be used at temperatures below 70°F. While in use, the material should be mixed for five minutes every four hours to ensure material homogeneity.

ArmorShield PB™ is a fully formulated product. No other materials, other than the recommended methyl ethyl ketone peroxide (MEKP), should be added. When using a nine percent active oxygen MEKP peroxide, the recommended catalyst range is 1.5 percent to three percent with two percent at 77°F being ideal.

The preferred method of application for ArmorShield PB™ is spray. Spray procedures are similar to gel coats except that a larger orifice tip is required. A transfer pump to move the material from the drum to the spray equipment is also needed. Typical flow rates are between four and 5.25 pounds per minute.

For marine applications, ArmorShield PB™ is applied behind the barrier coat or skin coat at a thickness of 60 mils. In transportation applications ArmorShield PB™ is applied directly behind the gel coat at a thickness of 30 to 60 mils.

Normally, ArmorShield PB™ is ready for layup within 30 minutes. However, the time is dependent on temperature, humidity, air movement and catalyst concentration.

4. PERFORMANCE—Use of sprayable print blockers can reduce application and cycle times. Sprayable print blockers are more cost-effective to use than sheet goods print blockers due to reduced application time. Use of sprayable print blockers also reduces cycle times in applications using skin coats. Since the print blocker provides protection against print and distortion, fabricators using print blockers do not need to wait for skin coat Barcol development before proceeding with lamination. The skin coat now only provides strength and toughness near the gel coat surface.

Print blockers should only be applied at the minimum thickness necessary to stop print. They should not be used as cores or as stiffeners. Syntactic print blockers contain fairly friable materials, like glass spheres. Thick applications will have poor shear strength. Flexural fatigue testing of ArmorShield PB™ at a thickness of 60 mils shows no loss of properties up to one million cycles. If additional panel stiffness is required, alternate coring materials should be used.

OPEN MOLDING: Field Service—Cosmetics

Part Four, Chapter VII.1

In This Chapter

1. **Defining Cosmetic Surface Quality for FRP**
2. **Sources of Cosmetic Flaws and Strategies for Preventing Print and Distortion**

1. DEFINING COSMETIC SURFACE QUALITY FOR FRP—Cosmetic surface flaws go by many different names: print-through, distortion, heat lines, orange peel, dimples, waviness, glass print, pock marks, puckered, poor profile, glass pattern, balsa print, woven roving checks, rough surface, and heat distortion.

There are various types of surface distortions that are caused by different mechanisms. While not all types can be neatly classified, all print distortion can be grouped grossly into two sets:

- Small-term distortion (less than 0.05 mm)
- Long-term distortion (greater than 0.5 mm).

Small term distortions (orange peel, fish eyes, etc.) are generally found in the coating film thickness (paint or gel coat) but also include distortions that show through the individual fibers of the layer of reinforcement directly behind the film.

Long-term distortions are those flaws that are larger and may even disrupt the surface enough to be felt. Larger flaws seen in application of the coating film such as sag lines or curtaining are long-term distortions. Other common examples are the transfer to the surface of patterns of the reinforcing fabrics and cores.

2. SOURCES OF COSMETIC FLAWS AND STRATEGIES FOR PREVENTING PRINT AND DISTORTION—

A. Tooling—The quality of the mold surface is the primary source for print. A smooth, flawless part CANNOT be made from a distorted tooling surface. The surface quality of the part is only as good as the surface quality of the mold. Every copy fabricated in a flawed tool will cost more in labor to restore than fixing the tooling surface (see Part Eight on Polyester Tooling for more information).

B. Gel Coat—While gel coat is only designed to provide color and gloss, distortions also occur in the gel coat film. Most gel coat cosmetic flaws are due to application mistakes. Heavy or uneven application can cause the ripples and sags that show through to the finished surface. Under-catalyzed (less than 1.2 percent) gel coats do not cure properly and have heat distortion temperatures. Poorly cured gel coats are easily distorted by the substrate laminate and by exposure to high temperatures.

Along with under-cure, thin gel coat application is the leading cause of small-term fiber print-through. Because the fiber bundles of the glass are closer to the surface, the shrinkage of the laminate around the fiber also pulls the gel coat film. Thicker films of gel coat are more resistant to showing the fiber print-through. There are trade-offs, however, with thicker application of gel coat, as sagging, porosity, cracking and weathering problems are more likely to occur.

C. Barrier Coats—Use of a barrier coat is an effective method of increasing the distance of the reinforcing materials from the surface of the gel coat without the problems associated with thicker gel coat. Barrier coats like CCP's ArmorGuard® are made with vinyl ester resins, which are two to three times tougher than typical pigmented gel coat, and add an unreinforced layer to the gel coat, which is not prone to cracking. Besides fiber print blocking, barrier coats offer increased resistance to osmotic blistering.

D. Print Blockers—Use of a print blocker is another method of distancing reinforcing materials from the gel coat surface. Sprayable print blockers like CCP's ArmorShield PB™ that are formulated with high-grade resins will thermally insulate the gel coat from bulk lamination layers.

E. Reinforcement—Fibers used for reinforcing FRP must have the correct sizing for the matrix resin used. Fiber sizing for epoxy does not dissolve in styrenated polyester and vinyl ester resins. If the fiber is not compatible with the resin, the resultant composite will have prominent fiber print. When the fibers are not thoroughly wetted by the matrix resin, micro voids along the fiber axis are left behind. During cure, these voids expand and cause the fiber print pattern to be enhanced.

The type of reinforcement architecture also influences cosmetics. Laminates made with woven, stitched cloth, continuous roving reinforcements or coring materials close to the gel coat surface show pronounced long-term print. Laminates made with coring materials close to the gel coat surface without bedding into a random fiber layer or a veil also show pronounced long-term print. The resin rich areas between fibers and bundles shrink more than fiber rich areas. The pattern of this shrinkage transfers through to the surface.

The laminate sequence and cure cycle can also influence surface cosmetics. The heat of exotherm of each lamination step must be controlled to prevent distortion caused by excessive shrinkage at high temperatures.

F. Resins—Polyester and vinyl resins generate heat as they cure. This heat of reaction is mass sensitive, meaning the larger the volume cured, the higher the exothermic temperature.

There are several strategies for controlling the exotherm in a laminate. The most basic is to control the thickness applied during one cure cycle. This is the time it takes for the resin in the laminated layer to gel and exotherm. The best example of controlling exotherm by ply thickness is in the traditional mold building process. Using a conventional polyester resin to build a tool, thin layers (less than 90 mils) are laminated over several days. This process allows the shrinkage to occur in small, controlled steps while very little exotherm is generated resulting in a distortion-free surface. Most production schedules do not allow for this extended cure time as in tool building.

Other strategies for exotherm control include:

- Resins formulated to suppress exotherm are designed to moderate the peak exotherm of the reaction by extending the duration of the exotherm phase of reaction. This results in a longer time to reach the ultimate cure. There is some penalty on speed of cure in thin sections with these versions.
- Catalyst level and types can be used to control exotherm of each ply. Lowering the catalyst to the minimum limit for the specific resin can help moderate exotherm. Lower catalyst levels lower exotherm, but also extend gel time and cure and may be detrimental to surface cosmetics.
- Methyl ethyl ketone peroxide (MEKP) catalysts blended with cumene hydroperoxide (CHP) are available, such as Arkema KC-70. These catalysts provide exotherm control by diluting the MEKP with an alternative peroxide initiator. The CHP and resin have a lower heat reaction. Used properly, these systems can provide exotherm control with negligible delay of the final cure.

G. Process Factors—Faster production rates in an FRP fabrication process can be detrimental to good surface cosmetics. Faster gel and cure cycles increase the percentage of shrinkage. A part spending less time in contact with the mold increases the chance for shrinkage to happen after the part is demolded (commonly referred to as post-cure). Parts that are demolded earlier in the cure cycle are also at risk for other problems such as cracking and dull finish.

Hot, cold, or uneven temperatures in the fabrication shop can cause a host of cosmetic issues. If the temperature is too high (more than 95 to 100°F), parts may demold in sections during lamination. This is known as secondary pre-release and leaves the areas of smooth finish where the part remained in contact with the mold adjacent to areas of fiber print. Uneven temperatures, such as one side of the part near a heat source, and the other side near an open door, can also cause secondary pre-release. Lamination in cold temperatures (less than 60 to 65°F) risks retarding the cure of the laminate. On demold, these parts may distort as they warm and finish curing later, producing a warped distorted surface. If the temperature is too low, the cure may be permanently retarded. In this case the under-cured part will have a low heat distortion temperature. Depending on the color of the exposed surface, sunlight may be enough to distort the surface.

OPEN MOLDING: Field Service—Gel Coat Weathering

Part Four, Chapter VII.2

In This Chapter

1. INTRODUCTION—Gel coated FRP parts have a shiny finish when new but, regardless of quality, over time the gel coat can dull and fade. The following is an explanation of what has occurred, how it can be prevented or slowed down, and what needs to be done to restore the gel coat.

Gel coats have evolved over many years. They provide very durable, water and weather resistant surfaces. Normally, gel coats are applied 10 to 20 times the typical thickness of paints. Even though these surfaces are very durable, they are not indestructible.

Synthetic and natural materials, when placed outside, slowly deteriorate. The part is exposed to sunlight, heat/cold, water, wind, dust and chemicals in the air. When something is used, it will eventually show wear and tear. How much wear and tear depends on how the product is treated and maintained. If a car isn't washed and waxed, its surface will deteriorate and it will have a poor appearance. If a product is allowed to deteriorate, it will require a good deal of costly repair work to restore its appearance. It is nearly always easier and cheaper in the long run to do a little maintenance periodically.

Aside from the quality of material used and careful procedures to make the fiberglass part, the only secret in keeping fiberglass looking like new is maintenance.

2. WEATHERING PROBLEMS

A. Chalking—Chalking results from a breakdown of a part's top surface into an extremely fine powder. When this happens, the color of the part whitens. The chalk is strictly on the surface. Most house paints are designed to chalk and then wash clean when it rains. Gel coat chalk, however, does not simply wash off.

B. Fade—Fade means that the color has changed uniformly. Fade can be interpreted as an unrecoverable change in color, less brightness/intensity, washed out appearance, changes in hue (red, blue, yellow), chroma (brightness or intensity) and value (lightness and darkness). Since chalking causes a color to appear lighter, it is easily interpreted as fade, but really stems from the whitish oxidation powder at the very surface. Because of differences in pigment and polymer, not all gel coats fade to the same degree; for example:

- Chalking makes the gel coat look lighter.
- Pigments used in the system may have actually changed in color. In this case, a high gloss persists but the color has changed.
- The gel coat is bleached or stained by something.

C. Yellowing—Yellowing occurs when the gel coat has actually started to exhibit a yellow cast, which can be uniform or streaked. Usually non-uniform yellowing can be attributed to application. Streaks can be caused by chemical stains, residues, or by a covering that was left on the gel coated surface which, therefore, shielded the surface from the environment.

D. Gloss—Gloss refers to the gel coat's shine. Any change in the surface (be it a light sanding, chalking, or dirt) will alter the gloss. CCP has found that parts restored after weathering will lose gloss faster upon re-exposure than will a new surface weathered for the first time.

Most of the changes are cosmetic. They appear on the surface of the gel coat and do not affect its strength. The surface is sound, but does not look as it did originally.

Once a part is made, it begins to change because it is immediately and inevitably attacked by the environment. The attack is from:

- Light
- Water
- Pollutants
- Temperature.

These are strong forces which cause wooden boat owners to repaint and recaulk almost every year, and which cause cars to rust, vinyls to crack, and virtually every synthetic material to need repainting.

A fiberglass laminate must be protected by a thick coating to prevent the fibers from protruding through the surface (fiber bloom). In most cases, this thick protective coating is a gel coat.

Gel coats must retain their original color and gloss as long as possible.

1) Light—Light is a form of energy. The energy in light is made up of different components or wavelengths. A rainbow displays light separated into its individual wavelengths. Some of these components are stronger than others. Ultraviolet (UV) is considered to be the most destructive wavelength, when it comes to weathering, but the others cannot be ignored.

   The energy in light attacks materials by breaking down their molecular or polymer structure (degradation). This energy can cause a chemical reaction to take place. This reaction is oxidation, chain splitting, or atomic extraction, and is noticed as color change (yellowing, chalking, or bleach fading).

2) Water—Water is called the universal solvent. It will dissolve more things than any other chemical.

Water attacks parts by dissolving or reacting with them. It penetrates materials and leeches out impurities or degraded materials. It can also contribute pre-dissolved chemicals which can cause stains or degradation. It can change a non-corrosive material into a corrosive material.

3) Pollutants—The environment is not sterile. The atmosphere contains many foreign materials. Some of these are natural: pollen, mold spores, dust, aquatic grasses, organisms and dirt. Others are man-made: smog, acids, oxides, etc., as in exhaust from manufacturing plants. Some are harmless, some stain, and some attack whatever they land on.

4) Temperature—Sunlight generates heat and will raise the temperature of a part. How much the temperature will escalate depends on color. White reflects most of the sunlight and warms up only slightly (e.g., in 100°F air, white can be 120 to 130°F). Dark colors absorb more sunlight and warm up more (e.g., in 100°F air, black can be 150 to 170°F).

As the part warms up, three things happen:

- The material softens slightly.
- Additional cure can take place.
- Chemical attack and water penetration rates are increased (see the chart below).

EFFECT OF COLOR CHOICE ON SURFACE TEMPERATURE UNDER SUNLIGHT

	Surface Temperature (°F)	
Panel Color	**Unbacked**	**Foam Backed**
White	120	127
Light Blue	127	137
Medium Blue	137	157
Dark Blue	144	174
Medium Red	128	142
Dark Red	137	169
Black	148	173

These panels were exposed to outdoor sunlight with unrestricted ventilation of 100°F air.

3. INFLUENCES ON WEATHERING—When a change in a gel coat product is noticed, the owner may ask the following questions:

- Does my part have a structural problem?
- Why is my part faded and yellowed?

The answer to the first question is: No—not if the proper application procedure was used in making the part. Fading and yellowing happen on the surface and do not affect strength. A good cleaning may restore the finish.

Yellowing is caused by the reaction of light, water, air pollutants and heat with any reactive sites in the gel coat which can include aromatic structures, unpolymerized maleic or styrene, or by-products. Some of these 'sites' always exist. Achieving a good cure is necessary to reduce these to a minimum.

Fading and chalking are the breakdown of the surface resin and pigment on a microscopic level. This breakdown, which is also caused by exposure to light and water, is so fine it appears to be white in color.

The effectiveness of UV absorbers and UV stabilizers is dependent on pigmentation and product series. For instance, UV absorbers are of significant benefit in clear or nonpigmented gel coats. However, UV absorbers do not generally improve the weatherability of white pigmented gel coats. UV stabilizers can be of significant value in certain colors.

Light absorbers work by absorbing the harmful sunlight and converting it into non-destructive energy. Light absorbers eventually are used up. They only slow down and even out yellowing. The part will change in color with time.

Light stabilizers (HALS) can be effective in improving weatherability of pigmented gel coats. Light stabilizers work by scavenging free radicals formed in the photo-oxidation process, and inhibit degradation. Light stabilizers are not used up, but instead are regenerated in a cyclic process.

Certain end-use specifications may require that UV absorbers be specifically added to the gel coat. In these cases it is CCP's policy to add UV inhibitors and/or UV stabilizers to gel coat products upon the customer's written request. Since the effectiveness of such additives is not always known in a particular circumstance, CCP cannot make any claims or warranties as to their effectiveness in a particular product or with a particular color.

A. Gel Coat Types

1) General

a) Resins—The weather and water resistance of polyesters can be related to the resin type used. Certain glycols and acids impart better yellowing, chalking, and blister resistance to a polymer than do others.

b) Other Ingredients—The other ingredients used in gel coats can improve or reduce the weathering characteristics of the base resin. Application, weathering, and blister resistance have to be balanced. These ingredients are:

- Fillers—type and amount
- Pigments
- Additives

2) Clears—Clear gel coats are the most susceptible to yellowing because of the absence of pigment. Because of this, UV light absorbers are useful in clears.

The use of light absorbers in clears is a compromise. They add to the initial yellow color of the clear (as the better light stabilizers are yellow themselves) but this is balanced against slower yellowing upon aging.

Clears have greater gloss retention than standard gel coats due to the absence of pigments and fillers.

3) Metalflakes—A metalflake system is a clear backed by the metalflake in clear. The weathering on the surface is the same as a clear, but now the effect of environment on the flake itself must be considered. Some metalflake is made by coating an aluminum foil or aluminized Mylar® sheet with a dyed epoxy. The aluminum reflects the light back through the dyed epoxy coating, giving it the color of the dye. If the epoxy is not properly cured and the gel coat is not cured, the aluminum can be corroded and the color is changed.

4) White and Off-White Gel Coats—The weathering of whites and off-whites is partly controlled by the amount and grade of titanium dioxide (TiO_2) used. High exterior durability grades of TiO_2 are the best and also the most expensive. Whites are very forgiving as they do not show changes in gloss easily, but will yellow. White gel coats are highly pigmented and will chalk more than clears. The chalking is not as noticeable because it is white on white, but gloss will suffer. Chalking is more noticeable on dark colors.

5) Colored Gel Coats—A wide variety of pigment types are used to make colors. All pigments do not weather equally. Normally, medium to dark colors do not yellow, but will chalk and fade. Color pigment must be checked out carefully. Colors that weather well in paints may not work in polyesters.

Accelerated weathering must be compared against actual outdoor exposure (i.e., some colors look good in the weatherometer, but after six months in Florida will have faded badly). Many pigments will bleach out when subjected to either acids or bases. Blues and greens fade in color, while yellows and reds turn brown or go darker.

NOTE: The durability, cost and hide of bright yellows, maroons and reds are changing due to EPA regulations. At CCP, lead, chromate and other heavy metal pigments have been discontinued.

6) Deep Colored Gel Coats—Blacks, blues, reds, burgundies and greens chalk as they weather. They may do so at the same rate as other colors, but the whitish chalking is more visible. This is due to the fact that deep colors highlight any chalking, making it stand out. Some colors absorb more sunlight, becoming hotter and weathering faster. In general, as they weather, clears, whites and off-whites will yellow; colors will fade; and black and deep colors will chalk.

Colored gel coats, whether lighter or darker, have a greater tendency to discolor (lighten) and develop osmotic blisters when exposed to water than white or off-white gel coats. The severity of water-spotting or blushing will depend on the length of time of the exposure, the temperature of the water, chemical make up of the water, the darkness of the color, degree of cure, etc. Also note that continuous use is more detrimental than intermittent use. For example, boats stored on trailers or in dry dock are less likely to display the problem than boats left in the water continuously.

B. Fabrication—The durability of a part is related to the care that is taken in making it. Good materials used poorly will produce a poor part. Poor materials used well will also produce a poor part.

Today's increased production rates leave very little margin for error. Training and tight controls are a must.

Beware of making parts rapidly with the intention of fixing them later. Repairs are costly and take away from the ultimate quality of the part. Sanding and buffing can hasten the chalking and loss of gloss of gel coats. The ideal approach is to build quality in, rather than add it on (by patching).

CAUTION: Patches will not weather (chalk and change color) at the same rate as the original gel coat. This phenomenon may be most noticeable with bright whites, but is not necessarily limited to just this color. Because of the different weathering characteristics of a patch versus original gel coat, it is advised that patches be taken to a break point on the part, such as an edge, tapeline, or where hardware may be attached later, etc. If a patch must be made in a flat area with no break line, the customer is advised to determine if the different weathering characteristics of the patch versus the original gel coat is a significant cosmetic problem. To make this determination, perform an exposure test on parts made and patched in the production area, using the exact same patching technique and materials proposed.

Molds and equipment will get dirty and wear quickly; good maintenance is a must to assure production of a quality part.

1) Molds—Weathering takes place at the surface of the part which mirrors the mold. If a mold has any dirt, dust or a buildup on it, some will be transferred to the part. For example, polystyrene slowly builds up on the molds. Polystyrene yellows badly. If the molds are not properly cleaned, the polystyrene is transferred to the part and will yellow. Do not use styrene to clean a mold for three reasons:

    a) Fumes can cause more polystyrene to form.

    b) It can leave a thin residue of polystyrene on the mold.

    c) The styrene may contain polystyrene, leaving it on the mold. Pure styrene starts to form polystyrene after only 30 days. Styrene, as it ages, will turn yellow, thicken, and eventually gel.

    Excessive wax left on the molds can also be transferred to the part which may yellow later.

2) Additions to Gel Coat—If the gel coat is modified before spraying, its weathering properties can be changed.

    Do not thin the gel coat without authorization from the gel coat supplier. Do not add anything except catalyst without the supplier's permission, as the initial color and resistance to weathering may suffer.

3) Calibration—Inadequate calibration will affect the weathering of parts. Too high (or too low) catalyst levels can cause parts to prematurely yellow or chalk. Refer to the product data sheet for type and amount.

    Poorly atomized gel coat will retain more monomer, resulting in more yellowing.

4) Technique—The gel coat must be applied as evenly as possible because inconsistent film thicknesses will cause non-uniform weathering. Also, apply in at least two passes. One-pass spraying of thicker films will cause yellowing. Thinner films yellow less than thicker films. For high visibility areas such as boat decks, 12 to 16 mils might be considered; however, resistance to print-through and blistering would be reduced.

5) Cure—Poorly mixed catalyst will make various sections of a part weather differently. Over-catalyzed parts or areas will bleach, fade, and chalk worse than an under-catalyzed part. Ambient and mold temperatures in the plant must be 60°F or above to insure proper cure.

C. Part Maintenance—Weathering can be influenced by the care the finished part receives.

Weathering starts immediately. It does not depend on whether the part is immediately sold or if it sits at a dealer.

FRP parts need to be washed, waxed and taken care of like a car. They do not need repainting and caulking each year like wooden boats, but they do need care. A car dealer will wash his cars once a week to keep them looking good. A professional FRP dealer should do the same.

Chemicals and dirt can collect during storage. The gel coat can be attacked or stained when chemicals combine with rain or dew. They then can attack or stain the gel coat.

Following are some general instructions for keeping fiberglass parts looking almost like new (for further information, contact the manufacturer or suppliers of cleaning materials):

- Wash monthly or more frequently, if needed. Wash with mild soap such as dishwashing soap; avoid using strong alkaline cleaners or abrasives.
- Wax the part once or twice a year with a good grade paste wax formulated for gel coat surfaces.
- Cover the surface with an appropriate breathable material or shelter from sunlight when not in use.

For parts that have weathered and chalked:

- Wash
- Try a little wax in one area to see if this is sufficient to restore luster. If not, use a fine glaze, followed by wax.

If the part has weathered for some time and has developed a very severe chalk, rubbing compound alone may not be strong enough to remove the chalking. Sand lightly with 600 (or finer) 3M™ Wetordry™ paper, following with a fine rubbing compound, glaze, and wax. Use finer paper or preferably use finest obtainable compound/glaze to remove less severe chalking.

1) Cleaners—Polyester gel coats are very resistant to water and other chemicals, but the number of overly harsh cleaners that are available on

the market is alarming. Avoid any strong alkaline (such as trisodium phosphate) or highly acidic cleaners. Avoid bleach and ammonia. These materials, if left in contact with polyester, may attack or change the color. Any cleaner that is used should be in contact with the polyester the minimum amount of time required to do the job. All cleaners are meant to attack dirt and remove it. The longer they remain in contact, the more they attack the dirt and the finish. It is best to use mild detergents such as hand dishwashing soap, which will work for a majority of stains and dirt accumulations. If unsure about using a cleaner, do two things:

a) Read the label and instructions. Also, look at the precautions. CCP found one material, recommended for fiberglass, that casually mentioned 'keep off of aluminum parts.' The reason for this statement was that the material contained HCL, more commonly known as hydro-chloric acid. Read the label to see if the product is recommended for specific surfaces only. Using them on surfaces other than those intended could be damaging. Cleaners normally used for wood or teak also may not be appropriate for fiberglass.
b) Run a test spot. Try it in an inconspicuous spot. If it discolors, or dulls this area, do not use it.

2) Sanding and Buffing—The process of sanding and compounding a new part surface can cost three to six months of finish life. For weatherability's sake, it is advantageous to operate with defect-free, high gloss molds (and good procedures) so that minimal finishing is required on the part.

The reason this causes a reduction in weatherability is that sanding and compounding removes the thin, resin rich surface which protects the part's surface and imparts higher gloss.

Glazes give gel coats a glossy appearance when first applied. This is a temporary shine that may disappear as it wears or evaporates. It is easy to be deceived with this false gloss and fooled into thinking the gel coat is rapidly losing gloss when it is really fugitive glaze. Again, the best approach is to build the gloss into the part through the mold surface finish.

3) Rubbing Compounds—There are a wide variety of rubbing compounds. Some are faster cutting (more abrasive); some are slower. A rubbing compound is a fine, gritty material that is used to take off part of the top surface. Compounds come in a number of different types of grits, like sandpaper.

The coarser grits are faster cutting compounds, which have larger particles and remove more of the surface more quickly. Stay with the fine grits. These grits are carried in a variety of liquids (lacquer, mineral spirits, water and other vehicles). General tips are:

a) Read directions on use.
b) Do not use in direct sunlight. This makes the rubbing compound dry out.
c) Use clean pads to apply. Apply rubbing compound liberally. Do a small area, (usually three feet by three feet) at a time. If using a power buffer, use low RPM (1,700 to 3,000 RPM range). Keep the buffer moving at all times. Do not apply heavy pressure. Heavy pressure will make the rubbing compound cut quicker, but will also leave gouges, pits, scratches, and swirl marks, and will produce heat. If using the power buffer, keep the buffing pad wet with material. Do not allow the pad to dry out. Gradually lighten up on pressure as a high gloss appears. Several applications may be necessary. If the pad dries out, coarser particles scratch rather than cut. After a rubbing compound has been used, apply a 'glaze,' then wax the part.

4) Waxes—There are a number of waxes on the market. Try to use one specifically designed for fiberglass. Apply a thin coat of wax. Do not leave a large residue because excess wax can yellow, causing a streaking pattern later on.

General instructions on waxes:

a) Read the directions on the can.
b) Do not use in direct sunlight.
c) Use clean cloths.
d) Work a small area (about three feet by three feet) at a time.

Normally, the harder the wax in the can, the higher the wax content. Softer waxes have a higher proportion of silicones and solvents in them. If a power buffer is used, use a low RPM with light pressure. Keep it moving at all times to prevent heat buildup.

Waxes formulated specifically for gel coat/ fiberglass surfaces are handled by many boat dealers, shower stall dealers, and automotive retail stores.

5) Sealants—While sealants may provide a wet luster or slick surface when applied to a new or sanded and/or compounded/exposed gel coat surface, CCP has not found them to sig-

nificantly extend the gloss or color retention life of that surface. If applied frequently during the use of the FRP item, a sealant will make the surface look better during that use; however, a one time application will not protect or add durability to the gloss or color of the surface. Waxes designed for exterior surfaces perform similar benefits as sealants. One system may last longer than another before reapplication is needed to achieve a slick feel and luster. Again, neither has been found to be a one-time application solution to weathering.

6) Stains—Many fiberglass parts, as they age and are used, eventually pick up stains. These stains can come from dust, dirt accumulation, road tar, plant sap and pollen, rust from fittings, material that has leaked out from caulking or sealing compounds, covers, other fittings, and accessory parts.

Materials which stain can be broken down into two very general type substances: soluble and nonsoluble in water. The majority will be water soluble. Stains can be difficult to remove. It requires a lot of trial and error to determine the fastest and easiest method to remove the stain. The best practice is to begin with the easiest method and then work up to the more complicated. Before trying to remove stains, materials used should be pretested in an inconspicuous area. Some materials not only remove the stain, but also deteriorate the gel coat or change its color.

The majority of stains will be caused by water soluble materials. Pre-wet the area and wash with a mild detergent. Beginning with a small portion of the stain, apply the cleaner, making sure it is no more than a fine abrasive as it will also remove some of the surface. It may be necessary to come back with rubbing compound and wax to restore the luster. If the soap and water solution does not remove the stains, a solvent might be necessary.

Water insoluble materials are often organic based substances. There are two general classes. One is called aliphatic, and the other is aromatic. It is a general rule in chemistry that 'like dissolves like.' Before using any solvent, read directions and the warning label.

CAUTION: If using cleaning solvents, contact must be limited. Leaving a solvent-soaked rag on the part can cause deterioration of the gel coat. Also, many solvents are flammable.

The accepted procedure is to apply a small amount of solvent to the area that is being cleaned, and then promptly wipe it dry. Repeat if necessary, but do not soak an area. Different types of solvents can be used; test areas are recommended.

The most common removers for aliphatics are acetone, methyl ethyl ketone (NOT CATALYST, which is methyl ethyl ketone peroxide), ethyl acetate, and rubbing alcohol. Acetone is a principal ingredient in fingernail polish remover and is also found in lacquer thinners. Lacquer thinners also contain some alcohols and other solvents. To remove aromatics, try xylene or toluene. These are commonly used as paint thinners. If these materials do not remove the stains, or if the stain has gone deeper into the material, then surface abrasion will be necessary. In mild cases, rubbing compound works for a small spot. If this does not remove the stain, then use 400 to 600 sandpaper, followed by rubbing compound, glaze, then waxing.

7) Scratches and Nicks—Scratches can occur with normal use. To repair scratches, try the simplest method first. Work on a small area of the surface (as small as possible). First try a little rubbing compound. This may not completely remove the scratch, but may make it hardly noticeable. If rubbing compound does not do a satisfactory job, move on to wet sandpaper. Again, both these procedures must be followed by waxing to retrieve the original sheen.

If the scratch has penetrated the gel coat, a repair will have to be done. For instructions on repairs, see the chapter on 'Patching,' or contact the manufacturer of the part. Minor repairs can be done easily with the knowledge of how to work with polyesters. A good repair is almost invisible. Major repairs should be done by a professional.

In cases where there is extensive damage, it may be necessary to paint or refinish the fiberglass part. In all cases, read the coatings manufacturer's literature and directions on the container. Recommendations should be read and followed. Two-component polyester or acrylic urethanes find best acceptance.

8) Shrinkwrap—Boat manufacturers, marinas and dealers are being encouraged to 'shrink-wrap' boats by those who sell the wrap and heat guns. This practice is suggested to keep boats clean during storage and transit. As a manufacturer of gel coats for the marine and fiberglass industry, CCP believes it is important to alert our customers to the complications and risks associated with this practice.

Of course, a clean boat is preferable to a dirty boat. However, those who choose to shrinkwrap boats need to consider the possible adverse side effects as well as viable alternatives.

CCP's concern centers on two primary issues:

- Heat applied to the laminate
- Moisture trapped next to the gel coat.

Shrinkwrapping involves heat being applied against a plastic film. The heat causes a reaction and the film 'shrinks to fit.' This heat—if/when applied to a laminate—can have an adverse effect. Heat can bring about fiber print and postcure distortion.

These wraps may not 'breathe.' If these films trap water or condensed moisture next to the gel coat surface for prolonged periods, the possibility of blistering or color fading is likely. Boats are obviously constructed to sit in water. However, lakes, rivers, oceans, etc., have moderate temperatures compared to heat trapped inside plastic. It is somewhat analogous to rolling up the windows of a car on a hot day; it is hotter in the car with the sun beating through the window than on the outside. The length of time and the temperature at which the FRP article is stored with the plastic wrap, as well as the color of the gel coat and the shrinkwrap, are major factors influencing the severity of this possible problem.

Breathable materials which would allow moisture to escape are preferred. Less heat is preferred to more heat and no heat is the best option when covering a fiberglass part.

If it is the customer's decision to continue the shrinkwrap practice with the full knowledge of the risk involved, then CCP encourages adoption of certain techniques which can reduce the severity of these potential problems:

a) Use white or light colored shrinkwrap for less heat generation.

b) Taping of shrinkwrap to rails or to the white or off-white gel coat surface or an area not affected by the moisture, will place the condensed moisture in an area less sensitive to these problems.

c) Seal or tape the shrinkwrap to a position of the hull in such a way that collected moisture does not rest against an area that is highly visible.

d) Place a barrier of foam or fabric between the plastic film tape and the gel coat surface to prevent heat released plasticizers from reacting with the gel coat surface.

Removal of the discoloration depends on severity. Mild cases have been removed to a limited extent by use of a heat gun. The procedures must be conducted cautiously and at lower heat settings to avoid heat discoloration as well as laminate print.

D. Pro-Active Minimization—Now that the causes of weathering have been addressed, the next question is: What can be done to minimize these effects of weathering?

Here is a simple, ten-step procedure that has shown to positively influence the problem of weathering:

1) Keep the molds in good condition.
    a) Do not let polystyrene, wax or dirt accumulate on them, and pay particular attention to radii and nonskid areas.
    b) Do not clean molds with styrene.
2) Choose a gel coat optimized for durability and application.
3) Choose colors with weathering in mind.
4) Do not thin gel coats.
5) Contact the gel coat manufacturer before adding anything (except catalyst) to the gel coat.
6) Calibrate the gel coat equipment.
7) Use the proper type and amount of catalyst with complete mixing.
8) Keep film thickness as uniform as possible and not excessively thick.
9) Clean and wax the finished part at least twice per year.
10) Ship a 'care package' of instructions with the manufactured part.

4. WEATHERING TESTS—The principal environmental elements causing the deterioration of gel coat include light energy, heat, and moisture. The only way to evaluate the weathering characteristics of a gel coat is to test it.

A. Outdoor Exposure—The best test is outdoor exposure. The ideal location should have lots of sun, moisture and warm temperature, (e.g., southern Florida). The only problem is time; usually it takes one year or more to achieve results.

Several configurations for outdoor testing are currently in operation, primarily in Florida. Test options include open or closed back sample. The test panels are placed at either five, 26, or 45 degrees facing south. The panel angle affects the amount of UV radiation striking the surface. Integrated energy taken from Florida readings is presented in the chart that follows at the top of next column:

OPEN MOLDING: Field Service—Gel Coat Weathering

VARIATION IN RADIATION WITH PANEL ANGLE		
Panel Angle	Total Radiation * (MJ/M^2)	UV Radiation * (MJ/M^2)
5 degrees	6453	300
26 degrees	6480	271
45 degrees	6458	260
* Mega joules per meter^2		

B. Artificial Weathering—The brief chronology that follows details the significant milestones in artificial weathering technology:

- 1918—first enclosed carbon arc (used to test fabrics for the Navy)—Atlas Electric.
- 1930's—introduction of the source for the open flame Sunshine carbon arc.
- Late 1950's—first xenon arc source—Heraus (Atlas quickly followed).
- 1968—the 6500 W xenon power source currently in use became available; a quartz/borosilicate filter combination was widely used by the automotive industry.
- 1970—FS40 fluorescent bulb (B bulb) weatherometer introduced.
- 1984—the 313 B fluorescent bulb, a more powerful version of the FS40 bulb is introduced.
- 1987—The 340 A fluorescent bulb is introduced; more realistic UV cut-on frequency.
- 1980's-90's—enhanced filter technology to provide better spectral simulation of sunlight (xenon units); feedback/data acquisition technology to control the irradiance intensity (all units).

There are two fundamental issues which must be considered when selecting an accelerated weathering method. These two issues, which must be considered in sequence, are:

> Correlation and Acceleration. The term correlation refers to the ability of the accelerated test to produce results which agree with real-time outdoor test results. Acceleration is a measure of how rapidly the test can be conducted using an accelerated weathering device compared with outdoor weathering. If agreement exists with outdoor results it is valid to estimate the acceleration of the laboratory test.

The single most significant component of simulated weather is the nature of the light (radiation). Light energy varies in intensity throughout the ultraviolet, visible, and infrared components of the spectrum. The most energetic, and therefore most damaging, portion of the spectrum is the ultraviolet region, with wavelength less than 400 nanometer (nm). The ultraviolet portion of the spectrum has been further divided by ASTM (G113) into three regions, UV-A, UV-B, and UV-C.

The UV-A region consists of wavelengths (400-315 nm); this type of light causes polymer damage. The UV-A light will transmit through window glass and is therefore relevant to interior materials. The next section of the ultraviolet region is the UV-B which consists of wavelengths (315-280 nm). UV-B light is highly energetic and will result in polymer deterioration. UV-B light is the shortest wavelength light reaching the Earth's surface. UV light is filtered by common window glass and is therefore relevant for components used outdoors. The most energetic section of the ultraviolet region is UV-C light (wavelength below 280 nm). This region of the solar ultraviolet spectrum is filtered by the atmosphere and is found only in outer space.

Testing protocols have been established by several standards organizations including ASTM (American Society for Testing and Materials), SAE (Society of Automotive Engineers, ISO (International Organization for Standardization), as well as other groups (DIN, GM, AATCC, FLTM, NSF, VW, Ford, Renault).

The four basic options to accelerated weathering of exterior materials are:

1) Light source based on electrified xenon gas (modified via optical filters).
2) Light source based on the arc produced between carbon rods (filtered).
3) Light produced by fluorescent bulbs.
4) Sunlight concentrated using a Fresnel (outdoor) reflector.

C. Weathering Instruments

1) Xenon Arc Weatherometer—The xenon lamps are the closest match to solar power distribution throughout the UV/visible/IR spectrum. The Ci65 xenon unit fitted with a quartz inner filter and borosilicate outer filter has been the industry standard. Recently, data has been published comparing other filter combinations. The borosilicate inner/borosilicate outer filter combination has been shown to provide higher correlation with Florida exposure results than the quartz/borosilicate combination.

   The Xenon exposure is based on kilojoules of energy per meter area (kJ/m2). CCP's unit yields 200 kJ/m2 per week. A 1400 kJ/m2 test (equal to about 1 year South Florida exposure) will take seven weeks to run. This method of expressing exposure (kJ/m2)) allows for accurate comparison of one test series to another. Measurements in just 'hours' do not compensate for variation in lamp intensity as the bulb ages.

2) Carbon Arc Weatherometer—Graphing of the spectral power distribution for the carbon arc weatherometer shows the Sunshine carbon arc to be an improvement over the older enclosed carbon arc. The spectral cut-on (appreciable energy) frequency of the Sunshine unit approximates sunlight near 300 nm. Neither the Sunshine nor enclosed carbon arc provides a good representation of sunlight over the entire UV/visible spectrum.

3) Fluorescent Bulb Unit (QUV or UVCON)—The older FS40 B bulb and the UVA-313 bulb produce significant irradiance in the UV light region. These bulbs are particularly harmful to aromatic unsaturated polyester which have light sensitivity in the spectral region emitted. The UVA-340 bulb has a peak irradiance wavelength which is much closer to sunlight. The UVA-351 bulb is intended for testing interior materials. The fluorescent bulbs do not contain significant levels of infrared radiation which is responsible for the different temperature reached by different colored panels in sunlight.

4) Fresnel Reflector—Fresnel-type reflectors—such as the EMMAQUA (DSET Laboratories) and SUN10 (Atlas Electric Devices)—use multiple flat mirrors to concentrate the sunlight onto samples mounted on a target plane. The radiant light concentration varies with wavelength, but is approximately equal to 'eight suns.' An air blower is used to control the specimen surface temperature.

   The Atlas Ci65 weatherometer (Type 'S' borosilicate/borosilicate inner and outer filters) consistently produces relatively high correlation with Florida exposure over a range of colors and appearance characteristics. The EMMAQUA device provides good overall correlation for gloss retention, but it does not fare quite as well at correlating with Florida on some important color change characteristics. The smaller xenon unit (DSET CPS) and the carbon arc weatherometer perform similarly, showing high correlation in some respects and low correlation in others. The UVA-313 bulb consistently exhibits poor gloss and overall color change correlation with the Florida data set. The UVA-340 bulb produces a significant improvement in correlation at the expense of time (acceleration factor of approximately three). Issues of correlation and acceleration must be considered sequentially.

   The Atlas Ci65 xenon arc weatherometer and the EMMAQUA+NTW device provided the highest level of correlation with high acceleration. The UVA-340 bulb unit represents a significant improvement in correlation over the UVA-313 bulb although the test is significantly slower than the Ci65 or the EMMAQUA+NTW. Significant differences exist in purchase price, operational cost, and capacity among the weathering devices.

Features of Weathering Devices

Device	Light Source	Moisture	Max. Temp.
QUV B 313 bulb	Unrealistic— UV below that of sun	Dew cycle	60°C
QUV A 340	UV component only	Dew cycle	60°C
Carbon Arc	UV/Visible— poor match	Water spray	63°C
DSET CPS Xenon	UV/Visible— good match	None	44°C
Atlas Ci65 Xenon	UV/Visible— excellent match	Water spray	70°C
EMMAQUA+ *NTW	Magnification of sunlight	Water spray	—

*Night Time Wetting—

D. Methods to Assess a Material's Response to Weather—The traditional methods to monitor deterioration due to weathering focus on the changes in appearance. The gloss meter and color computer form the basis to evaluate appearance changes. The gloss meter measures the specular reflection (shine) of the gel coat on a scale of zero to 100 (zero = dull and 100 = perfect reflection). The color computer quantifies the color related changes such as yellowing, fading and milkiness of the gel coat. The Wave Scan unit can measure long and short range surface attributes such as fiber print or surface distortion. The haze meter measures haze (light diffusion) rather than gloss.

Changes in appearance of the gel coat during exposure include gradual reduction in gloss as well as potential change in color. When the part is demolded the gloss will register in the high 80's to low 90's depending on the gloss of the mold surface. The part continues to be visually acceptable until the gloss reaches a value at or below 50. As the gloss value continues to drop, the surface appears increasingly dull, and eventually chalking is evident. Changes in color of the gel coat are highly system dependent, being influenced by initial color. Light colors (white, off-white) are generally evaluated for yellowing or overall color change. Medium and darker colors are frequently evaluated for fading or overall color change. The surface may have more print-through and distortion as well as a haze.

1) Gloss Change—Gloss is determined by measuring the amount of specular light reflected from a surface. Typically, the measurements are taken at 20, 60 and/or 85 degree angles from the light source. The 20 degree and 60 degree angles show the most change, and the 85 degree angle the least.

2) Color—Reference the Instrumentation and Determination Sections in the chapter on Color. *NOTE: As the degree of gloss drops during the weathering process, the gloss influence on color measurement will increase.*
3) Surface Profile—The Wave Scan can measure print-through and distortion. It measures long term as well as short term waviness. Long term waviness typically can still be seen at distances of up to six to 10 feet. Short term waviness is most obvious at a close distance of about 20 inches.
4) Haze—Diffusely scattered light (haze) can be caused by long and short term waviness. Surfaces that exhibit haze will have a sharp reflected surface that is surrounded by a halo. For measurement with the Byk-Gardner haze-gloss reflectometer, two additional apertures are used on either side of the 20-degree aperture, which allows for the measurement of the diffusely scattered light.

5. ADDITIONAL READING—For a complete review of gel coat weathering correlation, ask a CCP representative for a copy of 'Evaluating the Durability of Gel Coats Using Outdoor and Accelerated Weathering Techniques: A Correlation Study,' L. Scott Crump, Cook Composites and Polymers Co., Reinforced Plastics/Composites Institute SPI, 51st Annual Conference, 1996.

OPEN MOLDING: Field Service—Cracking

Part Four, Chapter VII.3

In This Chapter

1. OVERVIEW OF GEL COAT CRACKING—A gel coat acts as a thin (less than thirty thousandths of an inch) cosmetic shell to protect the composite and add color to fiberglass parts. However, gel coats are not designed to contribute any structure to a fiberglass part. In designing laminates, the mechanical strength of the gel coat is usually not included in the composites strength calculation.

NOTE: Gel coat cracks are always caused by movement due to stresses upon the laminate. The sources and reasons for gel coat cracking are complex and can involve every element of a fiberglass part's life cycle, from design to production to usage. An analysis of some of the typical sources for these stresses on fiberglass parts can be helpful in determining the root causes of gel coat cracking.

During the life of a fiberglass part, cracking can occur in two places:

- In-plant: The fabrication or production of the part can introduce cracks in a variety of ways that involve the composite materials, and/or stresses that involve the handling of the parts.
- Post-Production: The end-use or final destination of a fiberglass composite part can introduce stresses that might exceed the design and production quality of the parts.

2. IN-PLANT SOURCES OF GEL COAT CRACKING—Possible sources and contributing factors for gel coat cracking that can occur during typical production of fiberglass parts are:

A. Gel Coat Thickness—Over-application of gel coat is the number one reason for gel coat cracking. Gel coats, like all coatings, are designed to be used in a narrow range of thicknesses. If the gel coat is applied too thin, the part could have cure and coverage issues. If the gel coat is applied too thick, yellowing or cracking could occur.

B. Demolding—The process of demolding a fiberglass part can generate, in most parts, greater stresses than the part will encounter throughout the rest of its life cycle.

C. Handling Before Assembly—A fiberglass part without its structural support elements (ribs, stiffeners, etc) is extremely fragile. Even small mishaps in handling these parts can stress the laminate beyond its design parameters and thereby initiate cracks that may not appear until later in the part's life.

D. Design of the Part—The design of a fiberglass part is critical to the short-term and long-term durability of any gel coated part. Marginal designs that do not consider the range of possible stresses are likely to produce cracks.

E. Complex Part Geometry—While fiberglass fabrication does offer the versatility to combine many complicated shapes into one larger part, there are practical limits to these unitized designs. Complex part shapes are more difficult for gel coat application (deep draws are hard to gel coat with a consistent thickness), for lamination layout and especially for demold.

F. Cure/Green Strength—Under-cure at the point of demold of any of the polymeric materials in a fiberglass composite can lead to cracking. The mechanical strength of a fiberglass composite builds with time as the thermoset polymers in the resins, gel coats, cores, and putties cure. If the cure is slowed either by low temperatures or incorrect catalyst levels, or if the part is de-molded too quickly, cracking can occur because the 'green strength' of the part is not sufficient to protect the part from stresses at demold.

G. Glass Content—The fiberglass adds the stiffness to a composite part. Cracks can occur if the glass content is too low, too high or inconsistent, or if the glass reinforcements are oriented incorrectly.

H. Joining/Fitting Parts/Pinning Boat Decks—Fitting fiberglass parts together is a great source of stress on the laminate. While composite parts will flex to some degree to allow for fitting and joining, stresses will be built into the parts that may later produce cracks.

I. Metallic Pins of Screws—Use of metallic pins or screws to join fiberglass parts can also be a source of cracking due to differences in thermal expansion coefficient between the metallic material and the composite. Drilling and counter-sinking pilot holes can significantly reduce cracking at fastener locations.

J. Jigging Stresses—Using jigs while bonding structural elements such as ribs and stiffeners can deform fiberglass parts beyond their designed limits. Cracking can arise from placing the part in the jigs or from shrinkage during the cure of the adhesives or putties.

K. Voids in Laminate—Voids left in the laminate can cause cracking by allowing parts of the laminate to move more than the designed limits or by causing separations in the laminate cross-section.

L. Temperature—The temperatures that fiberglass parts are exposed to can lead to cracking during processing. Temperature not only affects the cure of the laminate but low temperatures can also contribute to cracking in 'fully' cured parts. The stiffness of fiberglass parts increases as the temperature decreases.

3. POST-PRODUCTION SOURCES OF GEL COAT CRACKING— Among factors that affect gel coat cracking after parts are assembled and have left the production plant are:

A. Handling During Shipping—Proper cradling and use of supports are critical when transporting all types of fiberglass composite products. It is relatively easy to over-stress a composite part during shipping (i.e., boat hulls are designed to be supported by water on all sides, not by two fork lift tongues, and storage tanks are designed to carry a static load, not swing from a crane, etc.).

B. Misuse in Final Application—Unintended usage, misuse, and abuse are oftentimes the sources for cracking once the fiberglass part is put in service.

C. Environmental—Temperature extremes and other weather-related issues are often determined to be causes for gel coat cracking.

D. Design Flaws—Repeated cracking in the same area on multiple copies of a composite part might be an indication of either a laminate construction deficiency or a design flaw that is concentrating stresses in that area. Parts can also be under-engineered for stresses in 'normal' usage, leading to gel coat cracking.

OPEN MOLDING: Field Service—Swimming Pool Recommendations

Part Four, Chapter VII.4

In This Chapter

1. INTRODUCTION—The look, feel, durability and strength of fiberglass makes this unique material an ideal candidate for the construction of swimming pools. With proper selection of materials, good workmanship by the manufacturer, and reasonable maintenance by the consumer, a fiberglass unit will provide many years of trouble free service; however, if these criteria—material selection, workmanship, and maintenance —are not met, problems affecting the appearance of the fiberglass unit can be encountered. In fact, problems such as blistering, staining and color fading can occur after a unit has been placed in service for only a short period of time.

2. MATERIAL SELECTION—Swimming pools are exposed to continuous water contact of 50 to 100°F. This factor, coupled with the use of a variety of chemicals in the treatment of pool water, provides for severe operating conditions. It is important to select the proper materials for these demanding applications.

To reduce and minimize potential problems, CCP has formulated specific gel coats for making pools.

A. Specific Products—These products are listed below. All are MACT compliant for the swimming pool industry.

960-L-293SW Medium Blue
960-L-826SW Aqua
960-LF-214SW Light 'Baby' Blue
960-W-016SW White

B. Swimming Pools Only—These products are not recommended for spas or saunas or any application where the composites will be exposed to continuous moisture contact in excess of 100°F. These products should also not be used for any other MACT compliant application.

CAUTION: Do not use any other products for a pool without consulting with a CCP representative.

CCP does not recommend or sell any materials for repair or refinishing of swimming pools to the post coating markets.

Each of the materials used in constructing a fiberglass unit has an influence on the performance of the finished product. This includes the laminating resin, reinforcement glass, gel coat, and catalyst. The manufacturer should carefully select all materials and then test the entire system by a suitable test method.

One such test method is the 100 hour boiling water test per ANSI Z124.

A major concern in regard to proper material selection should be the avoidance of gel coat blistering. Blistering is a severe cosmetic problem which is expensive to repair. It can also lead to another problem unique to pools. That problem is called 'Black Plague.'

Black Plague is a black or brown staining of the gel coat surface and will form around a blistered area. Chemically, the source of Black Plague appears to be a reaction of the cobalt accelerator found in all room-temperature-cured polyester, and the chlorine compounds used in treating pool water.

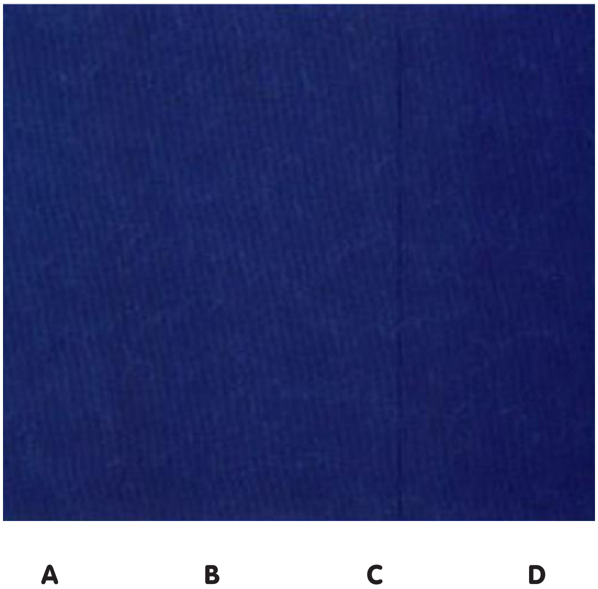
To prevent Black Plague, eliminating blistering is essential (see also the chapter on 'Blisters and Boil Tests'). Blistering is best minimized by using ISO/NPG gel coats, vinyl ester barrier coats, and isophthalic or vinyl ester laminating resins. The gel coat must be applied to at least 20 mils wet film thickness and good spray procedures should be followed.

Glass selection must also be carefully considered. Because of the wide variety of reinforcement glass available (i.e., the glass type, sizings and binders used), a specific recommendation is not given here.

Generally, a chopped glass laminate is superior to a mat laminate. Some surfacing veils can be used to improve a mat laminate's resistance to blistering. However, not all surfacing veils and glass mats (or even rovings) will give the same blistering resistance. Therefore, the manufacturer is encouraged to test the complete resin, glass, gel coat and catalyst system before entering production.

3. APPLICATION—Proper application is necessary for good field performance of the finished unit. Even if the best materials are used, poor application techniques can result in an inferior unit. One important manufacturing concern is proper catalyzation. Improper catalyzation can lead to poor gloss, blistering and color fading.

OPEN MOLDING: Field Service—Swimming Pool Recommendations



The picture above shows color change on a panel that was made in the field and then exposed in CCP's lab.

- **A:** Control—no exposure.
- **B:** Exposed in water at room temperature that contained pool chemicals.
- **C:** Exposed in water at room temperature.
- **D:** Exposed in warm water that contained pool chemicals.

The white splotches are caused by excess catalyst or catalyst drops from poorly atomized catalyst. Poor catalyst/gel coat tip alignment can cause this also, which will be evidenced by a 'spray' pattern in the gel coat surface.

Gel coat color fading in particular can be extreme if the unit is exposed to unusual chemical treatment by the owner. Some color fading of the gel coat surface is expected over a period of time. Also, certain colors are more inclined to fading than others. The color fade is usually slow and not to a degree which is objectionable to the unit owner. However, this fade can be accelerated to the point of being objectionable when any two of three factors exist. These factors are:

- Over-catalyzation of the gel coat during application
- Excessive use of chlorine compounds in water treatments
- Elevated temperatures.

If all three factors are present, the fade will occur most rapidly.

Excessive use of chlorine compounds in water treatment can attack the gel coat even if it has been properly applied. But the discoloration will be increased if good manufacturing techniques are ignored.

Over-catalyzation is known to accelerate the gel coat color fading. The manufacturer can encounter units which have faded in spots, patches, or even stripes. These are usually symptoms of over-catalyzation.

4. OWNER MAINTENANCE—Owner care of the unit is the least controllable factor in assuring good field performance and yet mistreatment by the owner may be the source of many field failures. A variety of chemicals are used in pool water treatment and in marine cleaning. When used in excess (especially the chlorine compounds or acid cleaners), color fade can result.

The unit manufacturer should select gel coat colors which are resistant to fading in a chlorine environment. It is important to remember that chlorine is a bleaching agent and that no pigmentation system is completely resistant to chemical attack.

The unit manufacturer should offer recommendations for water treatment. Those guidelines listed on pool chemical containers quite often are standard for concrete pool construction and may not be applicable for fiberglass units.

Many conditions can influence the performance of FRP pools. Evaluation of all components together is the key to successfully servicing the finished article.

OPEN MOLDING: Field Service—Blisters and Boil Tests

Part Four, Chapter VII.5

In This Chapter

1. Introduction
2. Causes of Blistering
3. Boil Tests
4. Troubleshooting Blisters

1. INTRODUCTION—In the manufacture of fiberglass parts, sooner or later blisters occur.

A blister is a raised surface area behind which there is either a hollow area (generally referred to as an air bubble) or a liquid area (swelling). Blisters normally appear on the surface of the part. They are very seldom caused by the gel coat.

An analogy may be seen in the condition of an old car. Generally, rusted areas around which the paint has blistered will be noted. Many of these blisters are not due to the paint failing, but rather to rusting of the metal.

When looking for the source of blisters, it is important to consider not only the gel coat, but all the ingredients that make up the total composite.

2. CAUSES OF BLISTERING

A. Air Pockets—Air, trapped beneath gel coat, can cause a blister to form when the surface is heated enough to cause the entrapped air to expand. A part in sunlight can reach temperatures greater than 150°F. The darker the color of the part, the higher the temperature. If the surface above the air void is weaker than the force generated by expansion, a blister will form. These voids can also serve as a collecting point for liquids, such as water or residues.

An air pocket is a common cause of blistering and can be easily located by tapping the part with a plastic or wooden stick. Air voids generally are indicated by a difference in sound; usually that sound will be dead or muffled. Air pockets such as these are generally detected and repaired in the plant. They will vary in size and are more commonly found in radii (corners).

Most of these air pockets are caused by poor roll out, too much glass and/or filler, or poor wetout of the glass or glass spring back. Some air pockets are caused by debris that has fallen into a mold, trapping air or affecting bonding between layers due to contamination. These voids, however they are formed, will also cause the gel coat to crack more easily.

B. Entrapped Liquids—Entrapped liquids are another common cause of blisters. An entrapped liquid can expand with heat. Heat can cause some materials to form gas or to become a reactive/corrosive liquid. These blisters will normally show up a few hours after the part is pulled and placed in the sun. Some will take longer to appear. Bubbles of entrapped liquids are generally random and about the size of a quarter or smaller. If punctured, they are sticky and contain fluid.

Any non-reacted liquid, such as catalyst, can be self-sealing or encapsulated. The outer edge of the drop will react with the polyester to form a tight gelled skin that entraps the rest of the unreacted catalyst. The catalyst can cause a blister by simple expansion, or by breaking down to form gasses and/or solvent-like material that slowly weakens the surrounding area.

An entrapped solvent can also expand, change into a gas, and then weaken the area around it.

Uncatalyzed resin entrapped between cured layers can cause blisters. Some of the more common entrapped liquids and their characteristics are found in the table on the following chart:

LIQUID	COMMON SOURCE	DISTINGUISHED CHARACTERISTICS
Catalyst (main cause)	Over-spray; drips due to leaks or malfunctioning valves and tips.	Usually emits vinegar-like odor when punctured; if in a laminate, will appear brown or burnt in color. If part is less than 24 hours old, wet starch iodine test paper will turn blue.
Water	Air lines, improperly stored material, perspiration.	No real odor when punctured; area surrounding blister will be whitish or milky. More print/distortion is exhibited.
Solvents	Leaky solvent flush system; over-spray; carried in by wet rollers.	Odor; area will sometimes be white in color; more print/distortion.
Oil	Compressor seal leaking.	Very little odor; fluid feels slick and does not evaporate; more print distortion.
Uncatalyzed Resin	Malfunctioning gun or catalyst runs out.	Styrene odor and sticky; more print/distortion.

C. Attack by Chemical—This type of problem occurs when a corrosive agent literally breaks up the part from the outside or from within.

When polyesters are attacked by a chemical, the first signs are swelling and blisters.

The general types of materials than can break up polyesters are: alkaline (such as lye, caustic, trisodium phosphate); certain solvents (such as acetone, ethyl acetate, or methyl ethyl ketone, if in contact long enough before evaporation); chlorinated liquids (such as methylene chloride). Typically, these solvents will also cause delamination of the gel coat.

If chemical attack is suspected, it is important to check for signs of attack on metal fittings, trim and wood attachments. This agent can be airborne from water sources.

D. Creation of an Osmotic Pressure Cell—Osmosis is a very common natural phenomenon. This mechanism involves a membrane and liquids or liquid mixtures that can or cannot pass through that membrane. In the case of laminates, the gel coat acts as a membrane. Water permeates through the gel coat to saturate it, but also to saturate the laminate behind it. The hydrolysis of the laminating resin, (i.e., the depolymerization of the unsaturated polyester polymer), generates decomposing molecules. Those molecules are dissolved in the water, saturating the laminate and the osmotic pressure cell created. Indeed, on one side of the gel coat, (i.e., the membrane), there is water, and on the other side there is a blend of water and decomposition products that are too large to pass through the gel coat. When the pressure created becomes higher than the critical stresses the materials can withstand, (e.g., when the water attack of the laminating resin has been extensive and the concentration of decomposition products has become very high), the structure weakens and blisters are formed.

The blister resistance is therefore affected by all the parameters that affect the overall hydrolytic stabilities (i.e., the chemical resistance to water) of the components (gel coat, laminating resin), and the strength of each of the components in the laminate (geometry, degree of cure) as well as the presence of impurities such as unreacted species (unreacted catalyst, synergist, etc.).

The ability of a laminate to resist osmotic blistering can be greatly improved through the use of vinyl ester barrier coats or skin laminates. Of course, the degree of improvement is dependent on the quality of the materials and the application techniques used. A vinyl ester barrier coat or skin laminate is recommended for fiberglass parts that will be exposed to continuous moisture, such as boat hulls, swimming pools, waterslides, etc.

3. BOIL TESTS (ANSI WATER RESISTANCE TEST)—The boil test consists of exposing the gel coated surface of a laminate to 100°C water for 100 hours. Caution must be taken when interpreting the results of this test.

This test is one section of the ANSI-Z124 standard for fiberglass plastic bathtub units. It was developed to set up a material standard for shower and tubs. The rating applies to five separate areas:

- Blister (size and number)
- Change in surface profile (fiber prominence)
- Cracks
- Loss of visible gloss
- Color change.

The rating scale for each area is subjective. The scale is 'zero to five' with 'zero' being no change and 'five' being the maximum change possible.

Values one, two, three, and four are increasing gradations of change. A panel is independently rated by three experienced people. A panel is failed if any one area has a rating of four or over, or the total of all area averages is over nine. The ANSI standard also lowers the severity of the test for thermoplastic sheet material by lowering the test temperature to 82°C. It is important to note that blisters do not necessarily mean failure by themselves; rather, it is the combination of all factors.

The question has been posed as to whether the boil test can be related to actual use. Several factors have instigated such questioning:

- Different test temperatures are used for different materials.
- The thickness of gel coat and type of substrate is not specified, but both are major influences on the success or failure of the specimen.
- Test conditions are extremely severe and are not found in normal field application.
- Some materials which fail this test have been used successfully for years in certain field applications.
- Test results are very dependent on types of glass and resin and their application.

However, it is important to remember that in the production of shower stalls, which must meet FHA requirements, these criteria must be met, as well as the other requirements listed in ANSI-Z124.

This test, if performed with proper controls, can be helpful in choosing or comparing materials.

Since the boil test is required by the shower stall industry and is referred to by other segments of the FRP industry, a good understanding of what affects this test is a must.

The purpose of the boil test is to create conditions that will accelerate the attack of the water and therefore obtain results much quicker than at room temperature.

The following factors will affect the performance of gel coats on boil tests:

A. Type of Resin Used in the Gel Coat—The more resistance the gel coat has to the attack of water and to permitting the water to pass through it, the better the test results. In general, gel coat systems rank as follows:

1) Orthophthalic systems (fair)
2) ORTHO/NPG systems (fair to good)
3) Straight isophthalic systems (good)
4) ISO/NPG systems (best)

B. Water Resistance of Other Gel Coat Components

C. Cure of the Gel Coat—If the gel coat is under-cured, it will have poorer water resistance. Major factors affecting cure are:

1) Temperature—if parts are made below 60°F, poor cure will result.
2) Percent catalyst—If the catalyst is too low or too high, under-cure can occur. Too high appears to be a greater problem than too low because excess catalyst remains that can act as an osmotic agent. It can simultaneously chemically attack the gel coat and weaken it further.
3) Type and grade of catalyst—different brands and types of catalyst will have different ratios of ingredients and produce different cures.
4) Thickness—if a gel coat is less than 12 mils, the possibility of under-cure is increased due to insufficient mass and to excessive styrene loss due to surface evaporation. *NOTE: A thin film (or over-spray) sprayed on to cured gel coat will cause water blisters. Areas that receive extended water immersion (boat hulls, swimming pools) should not be back sprayed with a thin film/over-spray onto cured gel coat.*
5) Contaminants—these consist of agents such as water, solvent, and intentionally or unintentionally introduced materials.

D. Thickness of Gel Coat—The thicker the gel coat, the better the results will be. This is because a thicker gel coat can withstand a higher pressure, and slows water penetration.

E. Barrier Coat—Use of a properly applied vinyl ester barrier coat such as CCP's ArmorGuard® will reduce blistering (see Part Four, Open Molding, Chapter IV.)

F. Quality of the Laminating Resin—In general, orthophthalic resin yields poorer results than isophthalic resin or vinyl esters.

G. Fillers—Certain fillers can increase or decrease blistering and color change.

H. Laminate Cure—The cure of the laminate is important because it is more susceptible to attack if under-cured (see 'C' for factors involved).

I. Type and Sizing of Glass (Layer Next to Gel Coat)

1) A layer of surfacing veil yields good results when used as a skin coat for either chopped glass or mat.
2) Cloth yields better results than mat or chopped glass. *NOTE: Layers of cloth next to each other show sporadic large blisters due to poor bonding between layers.*
3) Roving (chopped laminate), in general, yields better results than chopped mat. *NOTE: There is a difference between types and brands of roving. Some yield poorer results than mat, others better. This may be related to the type of glass binder and sizing.*
4) Mat is generally a worse choice than any other type of fiberglass due to binder deposits.

J. Layup Time—The more time that passes beyond layup readiness, the poorer the boil/blister resistance will be due to weaker bonding between gel coat and laminate.

Clearly, there are many factors that affect the boil test. If this test is used to compare gel coats or other materials used in making a part, it is important to make sure that nothing else overrides the material being tested. For example, in comparing two gel coats, the following should occur:

1) Proper fabricating temperature should be maintained above 60°F, preferably 77°F. Maintain proper cure.
2) Proper amount and type of catalyst should be used. Refer to the data sheet on each product.
3) Uniform thickness is desirable. Strive for a normal film thickness (18 ± 2) and a higher film thickness (25 to 30 mils). Side-by-side draw-down comparison is most accurate.

Use the same gel coat, laminating resin, glass and amount of proper catalyst consistently throughout all systems to be compared, allowing for only one variable at a time.

4. TROUBLESHOOTING BLISTERS—When blisters are encountered, do not assume a particular cause. Do the following:

A. Examine the Blistered Part

1) Where does the blister occur on the part?
2) What is the number of blisters, and what is the size of each blister?

3) Were water and/or heat involved?
4) How soon did the blister develop after demold?

B. Puncture and Observe the Blister—Make cross section cut and note the following:

1) How deep is the blister or where did it occur (gel coat, skin coat, bulk laminate or between layers)?
2) Does it contain fluid or is it dry?
3) Does it have a different color?
4) Does it have an odor? *NOTE: Decomposed catalyst will not smell like pure catalyst.*
5) Is there any discoloration around or near the blister on wood or fittings? What color is the discoloration?

C. Selection of Most Probable Blister Mechanism—Select the most probable mechanism and list materials, equipment and procedures that are involved.

Now comes the hard part: Try to determine what material, process, or combination caused the blister. Sometimes the cause will be obvious. In other instances, testing will be required.

It is impossible to guarantee that even one of the parts will never develop blisters. Too many materials, types of equipment and people are involved. However, CCP can provide guidance on the best methods to reduce the occurrence of blisters. These strategies are:

- Apply proper types of gel coat; refer to data sheets. *NOTE: Some gel coats, such as orthophthalics and some ORTHO/NPG's, develop blisters within themselves that cause failure regardless of laminate construction.*
- Apply the proper type of gel coat. CCP's isophthalic or ISO/NPG gel coats are recommended.
- Use proper equipment and procedures to apply; refer to the Equipment Selection section. If catalyst injection equipment is used, make sure it is properly calibrated.
- Make sure temperature is above 60°F.
- Avoid contamination in any part of the system.
- Use a high-quality laminating resin.
- Use the right catalyst and its proper amount in all polymer portions of the composites. See data sheets.
- Assure that the laminate is applied and cured properly, especially the skin coat.
- Choose a suitable glass; refer to the data sheet on that glass.

OPEN MOLDING: Field Service—Patching

Part Four, Chapter VII.6

In This Chapter

1. INTRODUCTION—This section of the manual is designed as a guide for the repair of a fiberglass part.

No matter how much care is taken in making fiberglass parts, some parts will require repair. The need for repair may be prompted by: defects in the mold, operator error, contamination, rough demolding, impacts during handling, storage, or use.

The first step to take when a defect is found is to try to determine the cause. If possible, steps should be taken to correct the cause, and then proceed to repair the affected part.

2. GENERAL WORKING CONDITIONS—Fiberglass repairs should be made with the same type of gel coat and/or laminating resin used to make the original part. The same chemical reactions that gel and cure the materials used to make the original part take place during repair. Considerations of safety, temperature, catalyst levels, and calibration to make a good part are also important to achieve a good repair. In fact, they are more critical since additional heat from other steps is not available, and the repair does not set up for hours in the mold until sanded and buffed.

A. Safety—Many of the materials used in fiberglass repairs can be hazardous. Therefore, before any repairs are started, obtain and read all MSDS's on ALL materials (gel coats, resin, catalysts, solvents, etc.). Make sure all safety requirements are met before proceeding.

B. Cure—

1) Temperature—Repairs should not be attempted when material, ambient, or substrate temperature is below 60°F as poor cure may result. Poor cure can cause the repair to change color, be dull and/or prematurely fail. Note that at 60°F, repairs will be slow and will have long cure times.

   It is best to have temperatures above 75°F since small masses of materials (thin films of gel coat) are being used. Air and part temperatures are critical as cold air, or draft, and cold parts will greatly influence small masses of materials. If this happens, poor cure can result.

2) Catalyst—Since small amounts of gel coats are used and additional heat from the laminate is not available, the catalyst levels should be kept on the high side, normally two percent but no more than three percent. Refer to CCP product data sheets for catalyst recommendations.

   To achieve good cure, the ratio of catalyst to material should be calibrated (measured) to be within proper limits.

   Many repairs are small and require small amounts of patching materials. One method of catalyzing is to use the 'drop' method (example: for a two percent catalyst level for a teaspoon of gel coat, add four to six drops of catalyst). This method can work but the margin of error is great because of the small amounts used. A better method is to use larger amounts (50 grams at a minimum) and measure material and catalyst using grams. Even if 95 percent of catalyzed material is discarded, it is cheaper than redoing a repair due to error in using small amounts of materials. It is less costly in the long run if the materials are accurately measured.

   The next best method is to measure by volume (50 ml or cc of gel coat, 1 ml or cc of catalyst).

   Low cost measuring devices can be purchased from scientific apparatus suppliers, or from laboratory/hospital supply firms (see Yellow Pages) or local pharmacies. (Also see J under Helpful Hints.)

C. Visibility—Most repairs are done on areas that are visible. It is necessary that the repair area be well lighted to insure the defect is removed, to see what is being done, and to make sure the repair is acceptable.

D. Mixing—To assure uniformity, all materials must be mixed before use.

NOTE: Material used in repair is taken from larger production containers. The larger container must be mixed before repair supplies are obtained.

3. MINOR SURFACE REPAIRS—SPOT PATCHING—The following procedure is recommended for small areas which have damage to the gel coat only, or which have a blemish (hole, gouge, or scratch) that is deep enough to penetrate through the gel coat to the fiberglass, but not deep enough to go completely through the laminate (less than 1/32 inch or 30 mils deep).

A. Roughen up the surface of the damaged area using a hand-held router, power drill with burr bit attachment, or coarse sandpaper. Feather the edge surrounding the blemish with finer grit sandpaper. Do not undercut this edge.

B. Be sure that the area to be patched is clean and dry, and free of wax, oil, or other contaminants. Solvents (see Warning G under Helpful Hints in this chapter) such as ethyl acetate and methyl ethyl ketone are suitable for this purpose.

C. Measure out 50 grams, ml or cc of gel coat in a suitable container such as an eight ounce cup. By adding five percent (2.5 g, ml or cc) 970-C-940 Wax Solution to the gel coat, good surface cure can be obtained without other coverings.

NOTE: Always make the patch with material from the same batch of gel coat that was used to make the original part. Failure to comply with this rule will almost certainly result in an off-color patch. (See K under Section Eight, Helpful Hints.)

Thoroughly mix the proper amount of MEK Peroxide into the mix. The addition of two percent (one g, ml or cc) catalyst to mix should yield a gel time of about that of the gel coat itself.

D. Work the catalyzed gel coat into the damaged area with a knife or spatula. Slightly overfill the blemish, including the area around and above, to allow for shrinkage. Puncture and eliminate any air bubbles that may be trapped within the gel coat.

E. If wax solution is not added to the gel coat, cover the repaired area with cellophane, waxed paper, or parting film (PVA) while the patch cures. *NOTE: PVA can be difficult to spray, but in order for it to provide an efficient barrier, it must be sprayed as a film rather than a dust coat, but do not flood it on or spray it too thickly.*

CAUTION: Patches will not weather (chalk and change color) at the same rate as the original gel coat. This phenomenon may be most noticeable with bright whites, but is not necessarily limited to just this color. Because of the different weathering characteristics of the patch versus the original gel coat, it is advised to take a patch to a break point on the part, such as an edge, tapeline, or where the hardware may be attached later, etc. If a patch must be made in a flat area with no break line, the customer is advised to determine if the weathering characteristics of the patch compared with those of the original gel coat constitute a significant cosmetic problem. This can be done by performing an exposure test on parts made and patched with production area gel coats, using the exact patching technique and materials proposed.

F. The patch should be allowed to cure thoroughly before any further action is taken; cure time should be approximately two to three hours. The patch has not cured sufficiently if a thumbnail leaves an impression in the gel coat.

G. Sand the patched area with 220 grit wet or dry sandpaper. Change to 320 or 400 grit, then to 600 grit wet or dry paper. If the patch shrinks to a point where the surface is not level with the adjoining areas, repeat the preceding process. Complete the finishing process by buffing with rubbing compound to a smooth surface. Then wax and buff the surface to a high gloss. (See Section Seven in this chapter on Finishing Techniques.)

If this spot patch does not match the part in color, double check to see if the same batch of gel coat was used in the patch as was used for the original part. It might be necessary to make a spray patch (see following directions) over this spot patch or over an entire section. As with bodywork on automobiles, it is sometimes necessary to spray patch an entire section at a time, using edges or corners as boundaries for difficult-to-match situations.

4. AREA PATCHING—SPRAY PATCHING

A. Sand the area to be patched using 220 grit sand paper. Feather the edges, using finer grit paper in hard-to-match situations.

B. Clean the surface with a suitable solvent as described under Item B in Section Three on Minor Surface Repairs—Spot Patching.

C. Always make the patch with material from the same batch that was used to make the original part. Not using the same batch will almost certainly result in an off-color patch. (See K under Section Eight, Helpful Hints.)

For best color match and weathering considerations, the best method is to use the material as is with no diluents or additions except catalyst. CCP, however, offers several products as aids for reducing the viscosity for better spray characteristics and leveling (less orange peel), and/or for accelerating patch cure time for quicker sanding. See individual data sheets on each of the following for mixing and application instructions:

1) 970-X-900, Fast PATCHAID® for reducing viscosity and when repairs need to be sanded

quickly. Typically, the patch can be sanded in 45 minutes dependent upon catalyst, temperature and air movement.

2) 970-X-901, Slow PATCHAID® is used to lower the viscosity and when repairs do not need to be sanded quickly, such as mold resurfacing and when initial gel times are already very short. Also, 970-X-901 is formulated to yield better dilution; therefore, it works better when using aerosol cans or air brushes.
3) 970-XJ-037 is a fast PATCHAID® version of 970-X-901.
4) Ten percent of a two percent wax solution can be used as a diluent also. Typically, the patch can be sanded approximately two hours after catalyzation.

CCP does not recommend solvents (acetone, MEK, ethyl acetate, or any of the replacement solvents or cleaners) for diluting gel coat. If they are used, it is important to remember: do not use a replacement solvent or cleaner.

Solvents are more flammable and reduce the flash point of the gel coat. Always use high purity solvents.

Use high atomization and do not spray too close to the part, or too quickly; do not apply too thickly.

Retained solvent in the patch will deteriorate patch quality by retarding cure, creating porosity, changing the color, lowering gloss, reducing hardness, and compromising weatherability.

D. Using a Binks 115 type spray gun, spray the catalyzed gel coat over the entire sanded and feathered area. Thickness should be approximately eight to 12 mils for good cure. If spraying an area where gel coat has been completely removed, thickness must be at least 12 mils for good hide.

E. Let the patch cure thoroughly.

F. Sand the patched area with 400 grit wet or dry sandpaper; then change to 600 grit wet or dry paper. Buff with rubbing compound, then wax and buff to a high gloss for the final finish. See Section Seven on Finishing Techniques, and the Spray Patching Wall Chart in this chapter.

5. HOLES OR CRACKS IN THE GEL COAT THAT REQUIRE A PUTTY PATCH—There are two aspects to putty patching. If only a 'thick' gel coat is required, use about two percent fumed silica. If a reinforcing or strengthening putty is required, use 1.0 percent fumed silica and about 10 percent of a glass filler such as milled fibers, micro glass, or glass bubbles. Reinforcing putty should be used to resist patch cracking if the laminate is weak or flexible.

Preparation and procedure are the same as those given for minor surface repairs. Normally, spray patches have to follow a putty patch because air bubbles are entrapped in the patch or there is a slight color change due to the filler added. Coarse sandpaper, such as 100 grit, can be used to level the putty patch. Masking tape can be placed alongside the patch to keep from sanding the surrounding gel coat.

Finish with a spray patch.

6. PATCHING OF HOLES, PUNCTURES AND BREAKS—The following repair method is used for damage which penetrates completely through or deeply into the entire laminate.

A. Repairs from the inside—

1) Prepare the affected area by cutting away the fractured portion of the laminate to the sound part of the laminate. A keyhole or saber saw works well to cut away these ragged edges.
2) Roughen up the inside edges of the affected area, using a power grinder. Feather out the backside at least half the diameter of the hole to be patched.
3) Clean the surface and remove all paint or foreign substances as previously described in spot patching.
4) Use a template to give 'shape' to the part. Tape cellophane in place over a piece of cardboard (or aluminum) large enough to completely cover the affected areas with the cellophane toward the inside of the part. Aluminum is used when contour is present.
5) Cut glass fabric and mat to the shape and size of the hole. Cut another set of reinforcement material one half diameter larger than the hole. Materials and total thickness of each set should approximate that of the part being repaired.
6) Mix an ample amount of resin (approximately one pint per square foot) and catalyst (6.5 gm, ml or cc) thoroughly. Using the hole-sized set of reinforcement, daub catalyzed resin onto the glass mat to thoroughly wet it out. Wet out the fabric in a similar manner. Apply the mat against the surface inside the hole. Then apply the fabric.
7) Roll out or squeegee out all air bubbles. Allow the area to cure well. Build this laminate up to the same thickness or greater than the thickness of the original laminate.
8) Apply catalyzed resin and the larger reinforcement over the hole patch and the surrounding surface.
9) After the laminate has cured, remove the cellophane and backing from the outside of the hole. Rough up this surface from outside, feathering the edge with a power grinder.
10) Now follow procedures 3.A. through 3.F.

B. Repairs from the outside:

1) If it is not possible to access the backside (blind

hole) of the part, a template will not be used. Cut a piece of cardboard slightly larger than the hole. Then cut the fiberglass mat and cloth along the same outline as the cardboard insert, only slightly larger. Thread a wire or wires through the center of the cardboard insert; follow with the fiberglass.

2) Roughen up the inside edges of the hole to at least half the diameter of the hole. If a power grinder cannot be used, thoroughly sand by hand with coarse sandpaper.
3) Wet out the fiberglass with catalyzed resin. Force the plug through the hole. (Don't worry about neatness; the first concern is a structurally sound repair.) Use the wire to pull back and secure the plug until the resin cures. When cured, check adhesion of the plug and proceed.
4) Mask the area with tape and paper to protect the surrounding surface. Then, if a large void is present, repeat Steps A.6 and A.7. Smaller voids could be patched with putty material.
5) Using 80 grit sandpaper, smooth and blend the surface to be coated into the surrounding surface.
6) Follow Steps A. through F. in Section Four on Area Patching—Spray Patching to complete the patch and to obtain a high gloss color matching patch.

7. FINISHING TECHNIQUES—The frequency of complaints related to cosmetic finish problems has increased dramatically in the last several years. These defects are most often referred to as pits or comet tails. It is highly likely that increased customer demand for contact molded FRP parts accounts for these problems. This problem is not exclusive to Cook Composites and Polymers gel coats; it is industry-wide. CCP's research staff has observed such problems at one time or another on all products in the field or in lab testing.

Production process techniques have changed to help manufacturers keep up with increased customer demands. To meet production demands, molds are sometimes run in poor condition and turned faster. This in turn causes more sanding and buffing to remove mold defects on production parts caused by over use.

Parts are not allowed to sit in the mold as long as previously, and are not well cured when sanded and buffed, which worsens problems. Dual action sanders are replacing hand sanding. These sanders are fast, but the sanding area is a minimum of four inches regardless of the size of the defect. Polishing is accomplished with 10 inch buffers which further increases the size of the finish area. Finishers often stop sanding with 320 grit DA paper and use high speed electric buffers along with coarse buffing compound to take out the scratches. High RPM's (more than 3000) and excessive buffing pressure can cause excessive heat build up. Buffing should not heat the gel coat to a level greater than 'just warm.'

Intense finishing of the gel coat creates comet tails, burns the gel coat, and causes the resin to post cure, producing print through. Higher RPM buffers in conjunction with heavy pressure can definitely induce finishing problems. Sanding to the finest possible grit is highly recommended so that the least amount of buffing is required.

A. Review safety procedures for using DA's and power buffers. Be aware that these tools can 'kick out' and spin off particles.

B. Determine if sanding is necessary to smooth out the defect or patch. If not needed, go to Step F.

C. Start sanding with 400 grit sandpaper. When finished, wipe off sanding dust and any loose grit.

NOTE: If a coarser type paper is necessary to speed sanding the area, work step-by-step back up to 400 grit. Follow each grit by wiping off to remove any loose grit. Example: 220 paper was necessary, wipe off; 320, wipe off; 400, wipe off.

TIP: If a paper coarser than 400 is constantly required, review patching techniques to minimize orange peel and/or surface roughness. For quick, better and more economical patches, do the least amount of work to get a good repair.

D. Wet sand with 600 wet/dry paper.

E. Wash off (using water) all loose dust and grit.

F. Start buffing using a wool pad with a medium grit rubbing compound. CCP has found that either 3M™ Super Duty #05954 or #06025 quickly removes 600 scratches with the least amount of buffing and residual haze. Use this type of compound or its equivalent. Ideal buffing speeds are from 1700 RPM to 3000 RPM.

1) Always precondition a new/clean pad by prebuffing with compound at low RPM's in order to 'wet' the fibers of the pad.
2) Do not use excessive buffing pressure. Let the weight of the buffer do the work.
3) Use plenty of compound to lubricate and cool the gel coat surface. As the compound begins to dry out, lighten up on the buffer.
4) 'Spur' the buffing pad when it starts to glaze over or change to a new preconditioned pad.
5) Always keep the pad tilted just slightly to the surface being buffed. Do not tilt the buffer so the pad edge only is being used.
6) Wipe or wash off all loose compound and grit.

7) Gel coats may leave some 'coloring' on the buffing pad. This is a function of the pigment used, and is not an indication of the degree of cure.

G. Using a separate, pre-wet synthetic pad, buff with a fine finishing glaze such as 3M's™ Finesse-It II (#05928) or equivalent.

H. Thoroughly wipe the area to remove all traces of finishing glaze and residue.

I. Wax using a light-stable, exterior-protective paste wax.

8. HELPFUL HINTS

A. To speed up the patching process and for patching in cold working conditions, use heat lamps, heat guns, or space heaters or prebuff before sanding. **CAUTION: Overheating may cause blistering and poor color matching. Patching materials are flammable; be careful.**

B. Spray patches generally match better than spot or putty patches.

C. Different colors behave differently in patching.

D. Additional additives to the gel coat may cause a color change.

E. As a general rule, keep any patch as small as possible.

F. If the patch is not cured thoroughly on the surface, wiping with a suitable, fast evaporating solvent will clean the surface sufficiently to allow sanding without clogging the paper.

G. WARNING: Acetone and many other fast evaporating solvents are highly flammable and can be toxic. Consult suppliers, individual MSDS's, and literature such as the book of Dangerous Properties of Industrial Materials, published by Reinhold Publishing Corporation, New York, for physical hazards of these materials.

H. Check technical literature for the correct catalyst levels on all materials used.

I. Do not use excessive buffing pressure. Excessive pressure creates heat; this heat may cause print-through and distortion. This heat and pressure can actually abrade the cured film of gel coat away down to the laminate.

J. CCP's experience has shown that one of the biggest factors that contributes to patching problems is lack of a method for measuring gel coat, PATCHAID® and catalyst. The method CCP has developed for mixing patching material in the shop is quick, accurate, and inexpensive. The effort required to accurately measure gel coat, PATCHAID® and catalyst is often the difference between a patch matching or having to start over again.

1) Apply mold release in three or five ounce cups to be used for molds. *NOTE: Do not use paraffin-lined cups. The paraffin can be scraped loose during mixing and contaminate the batch.*
2) Obtain samples of gel coat to make castings. Use a 70:30 ratio. Catalyze enough gel coat to make two castings. Catalyze gel coat at 0.5 percent so that castings are less likely to get too hot and crack. Weigh catalyzed gel coat into waxed cups, and set on a level surface to cure.

   If using five ounce cups, a 100 gram standard patch mix will allow plenty of room for mixing. Use 100 grams in one cup and 70 grams in the other. Allow the castings to cure and cool, then remove from the cups.
3) When preparing to make a patch, use the castings to mark lines in the mix cup. Gel coat should be filled to the bottom line, then PATCHAID® to the top line. Stir PATCHAID® and gel coat together thoroughly and then catalyze at two percent for best cure. A 10 cc graduated cylinder should be used to measure catalyst. For a 100 gram mix, use two cc's of catalyst.

K. Tinting—At times, tinting in the field is required, such as for a part which was made several years ago and must be patched, or on a one-time small job. Tinting is a talent that requires experience to do it well and quickly. CCP normally does not recommend tinting in the field, but for those who must, here are a few rules to follow:

1) If the part is weathered, buff out the area to be patched to achieve the real color.
2) Use only pigment concentrates designed for polyester.
3) Tint at least one-half gallon of gel coat at a time. The smaller the batch, the harder it is to tint.
4) Make small additions (adds), mixing well and scraping down the sides of the container between adds. Subsequent adds should get smaller as the color is approached.
5) Sometimes it is helpful to test each concentrate with 50 percent white gel coat before hand, because it is easier to see shades.
6) Get the basic color shade first (yellow, blue) then look for the minor differences, such as reddish, greenish, etc.
7) If the color match is not close, put a wet spot of the batch on the solid part or next to the wet sample. As the true color approaches, it will be necessary to go to catalyzed sprayouts because some colors change from wet to cured.
8) Once color match is reached, record what pigments and amounts were used to get the color in case it has to be matched again.

OPEN MOLDING: Field Service—Patching

The chart below shows the approximate effects of adding the particular pigment concentrates.

NOTE: Use only pigment concentrates designed for polyesters.

Colorant	Primary Color	Secondary Color
White	Lighter	Chalky in dark colors
Black	Darker	Gray in pastels
Green	Green	Darker
Blue	Blue	Darker
Red	Red	Darker, pink in pastels
Gold Yellow	Yellow	Red

9. TROUBLESHOOTING GUIDE

PROBLEM	ITEM TO CHECK
Color does not match	Wrong batch used for patching; fillers added; too many accelerators added; catalyst level off; patch under-cured; trapped solvent; dirty spray gun; buffer developed too much heat.
Patch is dull	Under-cured; catalyst level off; low temperature; sanding too quickly; trapped solvent; PVA sprayed too wet.
Comet tails	Too coarse a sandpaper used on last sanding; buffing too hard; dry pad.
Low gloss	Excessive buffing pressure; coarse compound.
Sand marks	Too coarse a sandpaper used in last step—work up through 600 wet.
Ring around patch (halo)	Edge not feathered; not sanded properly; porosity in original gel coat, may have to over-spray; under-cured patch; improper level of PATCHAID®.
Crack reappears	Crack was not fully ground out; weak laminate.
Patch is glossy, part dull	Original gel coat under-cured; buffer developed too much heat; too much PATCHAID®.
Porosity or void in patch	Not sprayed or leveled properly; filler not mixed in properly; trapped solvent; air not worked out.
Patch is depressed/ shallow	Patch will shrink—allow for this by overfilling. Do not sand and finish until patch is cured. 'Hot' buffing can cause patch to shrink. Condition patch by prebuffing before sanding.

10. ASSOCIATED DATA—See Chapter III.2 Specialty Gel Coats—Metalflake, and CCP's PATCHAID® Data Sheet DS-70D.

11. WALL CHART PATCHING GUIDE

SPRAY PATCHING GUIDE

Average gel coat weight per gallon is 10 pounds.	There are 128 fluid ounces in a gallon.	At 10 pounds per gallon each fluid ounce would have a weight of approximately 35 grams. One cc/ml of catalyst is equal to 1.1 grams (for shop use, one gram per cc/ml acceptable).

For best color match, always use the same batch of gel coat the part was made from.

Use recommended level of PATCHAID® to reduce the gel coat for spray patching.

These patching materials are formulated to:

#1—Help the patch spray smooth.	#2—Speed cure of the patch.	#3—Surface cure the patches for ease of sanding.

For each color, establish a level of patching additive that gives the best patching results.
Usually 30% PATCHAID®
works well.

Make a master mix of gel coat and PATCHAID® for patchers to use. The idea here is if the mix works for one patch, it should work for all,
if catalyzed with
the proper amount of catalyst.

Important: The gel coat patching mix must be mixed thoroughly prior to each use.

Use 2% of approved 9.0% Active Oxygen catalyst.

Three fl oz of gel coat patching mix = 35 g; use 0.5 g/cc/ml to catalyze	Two fl oz of gel coat patching mix = 70 g; use 1.5 g/cc/ml to catalyze	Three fl oz of gel coat patching mix = 105 g; use two g/cc/ml to catalyze	Four fl oz of gel coat patching mix = 140 g; use three g/cc/ml to catalyze
NOTE: g/cc/ml are rounded to nearest .5 g/cc/ml			

LOW VOLUME CLOSED MOLDING: Introduction

Part Five, Chapter I

In Part Five

Closed molding is a broad category of fabrication processes in which the composite part is produced in a mold cavity formed by the joining of two or more tool pieces.

Examples of closed molding processes include matched metal die molding of SMC and/or BMC, RTM, VARTM, and vacuum infusion. These processes are generally regarded as higher technology than open-mold processes because they require more planning, and often, more sophisticated and costly equipment. They do offer a number of significant advantages over open molding, including higher production rates, reduced labor, two-sided finish, greater design latitude, and reduced emission of Hazardous Air Pollutants (HAP). Consequently, the interest and usage of closed molding processes is beginning to increase from its current level of about 10 percent of today's UPR market.

Increased awareness of environmental impact on the part of composite fabricators, combined with governmental regulatory pressures, has led to the study and control of two aspects of composites fabrication. First, fabricators are concerned with the rate of HAP emissions. Second, there is concern with the absolute level of overall HAP emitted, which is determined by both the rate of emissions and the production volume. The following table shows the volume of composite that can be manufactured by the various processes using estimated emission rates.

Closed molding processes can be used to reduce emissions as well as increase production relative to open molding.

There are many variations of the closed molding process, each having a unique or distinctive aspect. For the purposes of this technical discussion, these variations are categorized into two types: Resin Transfer Molding and Compression Molding.

- Resin Transfer Molding (RTM)—Resin Transfer Molding (RTM) processes are those in which liquid resin is transferred into a closed cavity mold. The reinforcing fiber, any embedded cores, and inserts are placed into the cavity before the resin is introduced. Over time, a number of RTM variations have been developed. Common examples are Conventional Resin Transfer Molding (CRTM), Vacuum Assisted Resin Transfer Molding (VARTM) and Vacuum Infusion (VI). Figure 5/II.1 illustrates schematically some features of a typical RTM process.
- Compression Molding—Compression molding processes use clamping force during mold closure to flow a pre-manufactured compound throughout the mold cavity. The clamping force is typically delivered to the system by some type of press. Sheet molding compound (SMC), bulk molding compound (BMC), and wet molding compound are examples of pre-manufactured compounds used in compression molding.

LOW VOLUME CLOSED MOLDING: Materials

Part Five, Chapter II

In This Chapter

1. **Introduction**
2. **Resins**
3. **Reinforcement**
4. **Cores**
5. **Filler**

1. INTRODUCTION—In general, the materials used in Resin Transfer Molding processes are the same as those used in ordinary open molding, with the most significant differences in reinforcement technology. The process production rate determines many of the requirements for materials. Higher production rates require the use of pre-made reinforcement preforms and resins with short gel and cure times. Lower production rates use materials that more closely resemble typical open mold material systems.

2. RESINS—All varieties of polyester and vinyl ester polymers are used in the Resin Transfer Molding process. Polymer choice depends on end use. Most are formulated as low viscosity, non-thixotropic resins. Ideal viscosities range from 50 to 150 centipoise before adding any filler. Cure properties depend strongly on cycle times and can be adjusted either by the resin manufacturer or by the molder. Adjustments to gel time, cure time and peak exotherm can be made by adding promoters, co-promoters and inhibitors. These adjustments are not a trivial matter because they require very accurate measurements. In addition, some materials are toxic. Many molders prefer to buy pre-promoted, ready to use resins.

Resin gel times must be long enough for the mold to fill before gelation, and short enough to meet production rate goals. For high production rates of small parts, fill times are less than a minute, gel times are two to three minutes, and cycle times are less than 15 minutes. Exotherm control is very important for such rapid processes in order to maximize mold life. Molds can have provisions for cooling to remove exotherm heat. For large parts, fill times can approach 45 minutes, with gelation at 90 minutes, and at least overnight cure.

Selection of peroxide initiators depends on the production rate. Various MEKP initiators are common. In some cases, different peroxide initiators are preferred. When a quicker gel and cure is desired, acetyl acetone peroxide (such as 2,4-pentanedione peroxide) is used. To extend the gel, blends of MEKP and cumene hydroperoxide or blends of acetyl acetone peroxide and cumene hydroperoxide are used.

3. REINFORCEMENT—Glass fiber is a typical type of reinforcement; it is available by pattern cutting of roll goods or preform fabrication. A preform is a construction of glass fiber that has been shaped to fit into the mold cavity. A preform can lower cycle times two ways: first, the preform fabrication time is not a part of cycle time; second, the preform construction is easily placed into the mold. Glass forms that are not shaped to fit the mold require more care when they are placed in the mold. Preform fabrication can utilize either roving and conventional glass forms or conformable constructions. For a more complete discussion of preform technology, see the Chapter III in this Part on 'Preform Constructions.'

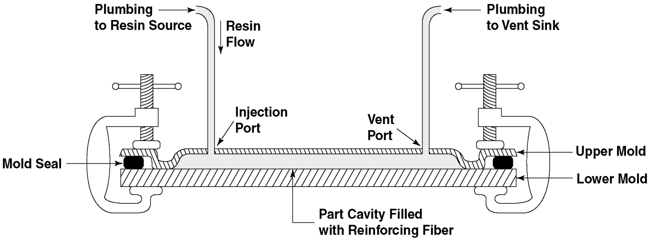


Figure 5/II.1—In a typical RTM process, resin is transferred to a mold cavity that contains dry fiber reinforcement.

In closed molding, continuous filament mat (CFM) is used instead of the chopped strand mat (CSM) that is commonly used in open molding. CFM will conform to the mold shape more reliably than CSM, which also has a tendency to tear and wash in the resin flow, leaving un-reinforced areas. Special constructions have been developed specifically to improve conformability by using special knits. Other constructions provide a sandwich style laminate with a low density core fiber and glass skins on either side.

CFM is a non-woven mat of continuous fiber that generally contains some binder. CFM is very lofty (much thicker for the same weight until compressed) compared to CSM. Weights for this glass form use the units ounces per square foot (osf). Typical weights are 1.5 osf and 2.0 osf.

Cored glass constructions are available under a variety of trademark names. They share a common architecture having three distinct layers. Outermost skin layers are glass fiber, while the inner layer is a polymer fiber. The cored construction adds considerably to bending stiffness without adding the weight of additional glass. This is because the polymer fiber core material is much less dense than the glass fiber and because bending stiffness increases greatly with an increase in thickness. Stitched molding mat (SMM), a product of Owens Corning, and Rovicore, a product of Chomarat, are examples of core mats with skin weights varying from 1.5 to 2.0 ounces of glass and from five to seven ounces of core.

CSM is generally not used by itself in pressure injection processes. This material is held together with a binder that is soluble in styrene. When used alone in a pressure injection process, the material has a tendency to wash and leave unreinforced areas. Also, during mold closure, the material can tear easily. For these reasons, other mats are more frequently selected. CSM is relatively inexpensive and is added locally to increase glass skin thickness, but generally in combination with CFM or stitched mat (SM).

The weights for this glass form use the units ounces per square foot (osf), with typical weights ranging from 0.75 osf to three osf.

Stitched mat (SM) is a special chopped strand mat that is produced without any chemical binders. The strands are held together mechanically with a polymer stitch yarn. This mat is available in weights ranging from one to four osf. This mat is considerably more conformable than ordinary CSM.

Surfacing veil (SV) is a non-woven mat of either glass or polymer fibers. These materials range between three mils and 40 mils thick. They provide a resin rich layer adjacent to the part surface. This improves both cosmetic appearance and corrosion resistance. Reduced fiber blooming after sanding is another benefit.

4. CORES—There are a variety of reasons for molding cores into the laminate. Some provide section thickness (therefore bending stiffness) without adding a lot of weight. Others provide hard points for locating screw or bolt installations. Cores can range from plywood to PolyVinyl Chloride (PVC) foam or urethane foam-filled honeycomb. There is a large variety of embedded materials in common use. Even strips of metal have been sandwiched between fiber layers. Some cores are not compatible with the liquid injection process because they will simply fill up with resin and add too much weight. One example is open cell honeycomb.

5. FILLER—Some resins are designed for use in filled systems in which fillers are used to replace some resin, resulting in both cost savings and improved cosmetic appearance. The peak exotherm temperature is also lowered which, as an added benefit, contributes to long mold life. Calcium carbonate, calcium sulfate and aluminum trihydrate are commonly used. Filler use increases both the resin viscosity and the finished part weight and commonly varies from 15 percent to 45 percent by weight. In general, the filler size is in the six to 10 micron range to keep the glass pack from filtering the filler. A nominal eight micron particle size is commonly used. Finer filler, as low as three micron, is also used.

LOW VOLUME CLOSED MOLDING: Preform Constructions

Part Five, Chapter III

In This Chapter

1. **Introduction**
2. **Preforming Process Description**
3. **Characteristics of the Various Binders**

1. INTRODUCTION—The preforming process can vary from fairly simple to rather complex. Briefly, this process consists of the manufacture of a reinforcing mat, which has the shape of the part to be molded. This process accommodates molding those parts that have complex shapes, deep draws, and sharp radii, which are not easily moldable with commercial flat reinforcing mats. Because of the uniform distribution of the fibers, parts made using preforms generally have higher physical properties compared to parts made by other processes. Preforms are traditionally used in the compression wet molding process but are also very useful in other processes such as cold press molding, RTM (resin transfer molding), SRIM (structural reaction injection molding), and Vacuum Infusion (VI).

Preforms are usually made of chopped fiber glass roving strands or fiber glass mat reinforcement. However, the reinforcing fibers may be glass, carbon, graphite, aramid or other polymers. Preforms are made in a separate step and delivered to the mold as needed, allowing for more efficient use of resources.

Polymeric binders are used during the manufacture of preforms. A binder is a bonding resin applied to the reinforcing fibers to hold them in position so that shapes are maintained as needed for even fiber distribution in a mold.

Binders are available in various forms, including aqueous emulsions, aqueous solutions, 100 percent reactive liquids, solvent solutions, and reactive powders. Thermosetting binders usually cure or set up through polymerization caused by the action of heat on peroxide initiators and/or melamine cross-linking agents. Some binders are designed to cure by UV or visible light energy. Preferred binders also have reactive sites that can form a chemical bond with both the fiber glass reinforcement and the matrix resin, thus producing composites with superior mechanical properties.

2. PREFORMING PROCESS DESCRIPTION—Three main methods are used in making preforms; these are:

- Directed fiber
- Thermoformable mat
- Conformable reinforcement

Some of the characteristics of each of these three processes follow:

A. Directed Fiber Preforming—When this method is employed, chopped fiber roving (along with binder) is sprayed onto a screen made in the shape of the part to be molded. A vacuum is drawn from the back side of the screen. This serves to hold the fiber/binder in place. The screen, still under vacuum, is then placed in a high volume forced-air oven where the water or other carrier solvent(s) are removed and the binder is cured. Cure/bake cycle is generally 350 to 400°F for one to five minutes. With some binders, lower temperatures can be used; however, if they are aqueous based, lower temperatures require increased time for water removal. Directed fiber preform binders are usually in liquid form, but solid powdered binders have also been used.

A variation of this method is the use of a string binder. In this variation, some strands of the roving are precoated with a binder resin that is either a high melting point thermoplastic, or a thermosetting resin that is solid at room temperature and cures at elevated temperature. Like the standard directed fiber method described above, the roving is chopped onto a screen, but without the need for a liquid binder spray. It is then baked as described above. In a variation of string binder, a thermoplastic strand is chopped along with standard fiber glass roving. When indexed into an oven, it partly melts and adheres to the glass strands it bridges.

Some comments on directed fiber preforming are:

- Best method to obtain uniform glass distribution and excellent part definition over complicated, three-dimensional shapes.
- Molded parts are stronger than those made by SMC/BMC at the same reinforcement content.
- Lowest cost method of preforming.
- Poorest in housekeeping requirements.

B. Thermoformable Mat Preforming—With this method, a fiber mat is made with or treated with a thermoplastic binder. The mat is heated, usually in an oven, and then placed in a cold mold made in the shape of the part. The mat is pressed to conform to the mold. After cooling, the mat retains the shape of the part. Comments on this method are:

- Less housekeeping problems compared to directed fiber method.
- Lower energy requirements than directed fiber method.
- Not recommended for making complex, deep draw parts.
- More expensive than directed fiber method because of the higher cost of using mat and because of cutting waste of mat.

C. Conformable Reinforcement Preforming—With this method, a mat made of chopped fibers is placed on the mold. It can be easily made to conform to the shape of the part to be molded. One can cut the mat to the general shape of the mold, place it in the mold, and then press on it to conform it to the shape of the mold.

Comments on this method are:

- Relatively clean, easy-to-use method of glass placement.
- Some mats are more filamentized than conventional reinforcing mats, restricting flow through them.
- May result in areas of low/no reinforcement in parts with deep draws.
- Much more expensive than other methods of preforming materials.
- Low or no capital investment to make preforms.
- Good material to add to other preforms to increase glass content in resin rich areas.

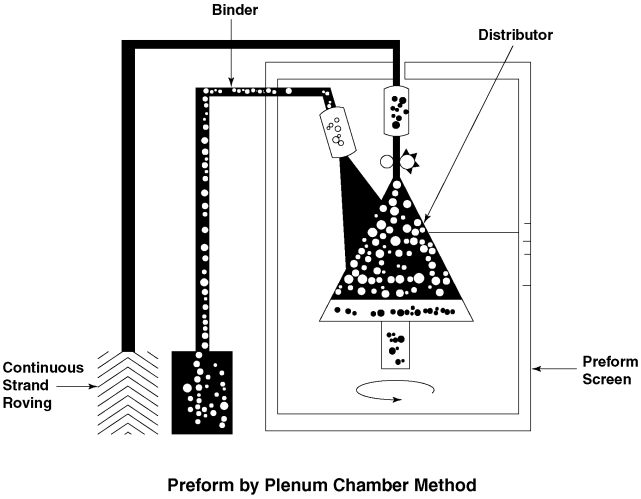


Figure 5/III.1—Preform by Plenum Chamber Method

3. CHARACTERISTICS OF THE VARIOUS BINDERS—Each type of binder has its advantages and disadvantages, and is briefly described in the chart that follows.

Binder Characteristics		
Binder Type	**Advantages**	**Disadvantages**
Aqueous emulsion binders	No VOC's Excellent preform stability Thermosetting/rapid cure Good glass compaction with good flow-through properties Chemically bonds to matrix resins and to glass Excellent part moldability	Energy needed to remove water.
Aqueous solution binders	Low or no VOC's Thermosetting/rapid cure Good glass compaction with good flow-through properties	May contain formaldehyde. Energy needed to remove water. May be pH dependent.
100% reactive powder	Pre-catalyzed No VOC's Fast cycle time No water/solvent removal Lower energy required	Housekeeping problems (dusty).
UV curable 100% reactive liquids	No solvent removal No VOC's Very fast cycle time Lower energy required	Need double screen or two-sided clear mold for good compaction.
String binder	No solvent removal Fast cure Lower energy required	Requires very high suction or double screen for compaction. Emerging technology; expensive.

LOW VOLUME CLOSED MOLDING: Process Features and Variations

Part Five, Chapter IV

In This Chapter

1. **Process Features**
2. **Variations**

1. PROCESS FEATURES—To facilitate understanding and communication when discussing the various RTM process variations, a process description and naming convention is presented in this section. All resin transfer molding processes can be characterized by five basic process features:

- Resin pressure head
- Resin transfer scheme
- Upper mold type
- Mold clamping method
- Mold open-close method

For each of these process features, there are at least four variations that are commonly used. These variations are presented in table form, followed by a basic description of each feature variation, examples of commonly known variations, and finally, a detailed description of each feature.

A. Resin Pressure Head—The first and most significant feature, this is the state of pressure across the resin from injection point to vent point; it is the driving force that causes the resin to flow through and saturate the fiber pack. The resin pressure head is described by first stating the condition at the injection location and then stating the condition at the vent location. The variations are: (1) Pressure to Pressure; (2) Pressure to Atmosphere; (3) Pressure to Vacuum; (4) Atmosphere to Vacuum; and (5) Vacuum to Vacuum These scenarios form the basis for the differences between the common definitions for vacuum assisted resin transfer molding (VARTM), resin transfer molding (RTM) and vacuum infusion processing (VIP), among others.

B. Resin Transfer Scheme—This describes the plumbing pathway used to transfer the resin into the fiber pack. The first method is discrete port injection in which the resin is introduced at specific points called ports or injectors. The second pathway is edge manifold in which a channel along the part edge (or entire perimeter) provides the resin pathway into the fiber pack. The third pathway is interlaminar manifold, whereby a layer of high-permeability material is placed midway through the laminate thickness. Fourth is face manifold, in which the resin is introduced below or (usually) above the fiber pack using some form of resin distribution manifold. Often times, this resin distribution manifold is nothing more than ordinary bubble wrap packing material.

C. Upper Mold Type—This describes the materials and construction used for the mating mold. The terms 'upper' and 'lower' are used to describe the mold halves, due to the fact that gravity acts vertically and gravity is most often used to assist in separating mold halves. Although many prefer to consider molds male or female, many molds have elements that are in some areas male and other areas female. In addition, it is possible to have either one as the upper or lower. Therefore, upper and lower mold halves are the more general description.

Variations for the upper mold type are: (1) rigidized laminate, which is the conventional RTM mold; (2) shell laminate which is a thin glass reinforced laminate; (3) multi-use, otherwise known as a silicone vacuum bag; and (4) bag film single use, which is a vacuum bag constructed from rolls of vacuum bag film.

D. Mold Clamping Method—The means for holding mold pieces together. Variations are: (1) mechanical clamps, (2) vacuum clamps; (3) pneumatic clamps; and (4) hydraulic clamps. These variations have a significant impact on capital requirements and cycle time.

E. Mold Open-Close Method—The method for separating mold pieces to allow inserting the dry glass and removing the finished part. Variations are: (1) hand lift; (2) mechanical hoist; (3) pneumatic actuators; and (4) hydraulic actuators. These variations have a significant impact on capital requirements and cycle time.

Resin Pressure Head	Resin Transfer Scheme	Upper Mold Type	Clamping Method	Open-Close Method
Pressure to Pressure	Discrete Port	Rigidized Laminate	Vacuum Clamps	Hand Lift
Pressure to Atmosphere	Edge Manifold	Shell Laminate	Mechanical Clamps	Mechanical Hoist
Pressure to Vacuum	Interlaminar Manifold	Silicone Multi-Use	Pneumatic Clamps	Pneumatic Actuators
Atmosphere to Vacuum	Face Manifold	Bag Film, Single Use	Hydraulic Clamps	Hydraulic Actuators
Vacuum to Vacuum	—	—	—	—

2. VARIATIONS

A. Resin Pressure Head—The Resin Pressure Head is the state of pressure across the resin from the point of injection to the vent location. This pressure drop causes the resin to flow through the fiber pack. At some point in the mold cavity's boundary, the resin enters the mold; this location is called the injection port. As the mold fills, the resin displaces the air. This air escapes through a vent; this location is called the vent port. The resin pressure head is the difference in pressure between these two points.

At the injection port, when resin pressure is higher than normal atmospheric pressure, injection is under pressure. When pressure is normal atmospheric, injection is under atmospheric pressure. At the vent port, when pressure is normal atmospheric, venting is to atmospheric pressure. When pressure is lower than normal atmospheric, venting is to vacuum.

The resin pressure head is described by first describing the condition at the injection location and then describing the condition at the vent location. As outlined previously in Item 1.B. Resin Transfer Scheme, there are five combinations that are used in RTM.

- Pressure to Pressure
- Pressure to Atmosphere
- Pressure to Vacuum
- Atmosphere to Vacuum
- Vacuum to Vacuum

Conventional RTM uses Pressure to Atmosphere. VARTM uses Pressure to Vacuum. Vacuum Infusion uses Atmosphere to Vacuum. These are significant differences that greatly impact the remainder of the process features and variables. The following schematics illustrate the Pressure to Vacuum, Pressure to Atmosphere and Atmosphere to Vacuum resin pressure heads.

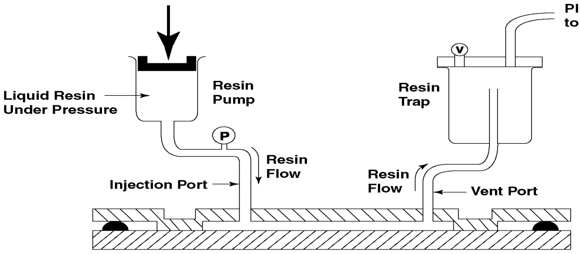


Figure 5/IV.1—For the Pressure to Vacuum Head, a pump supplies the injection port with resin under pressure and a vacuum is applied to the vent port.

In the Pressure to Vacuum or Atmosphere to Vacuum or Vacuum to Vacuum processes, the vent port must be attached to a resin trap of some sort. Otherwise the resin will enter the vacuum system and plug it up.

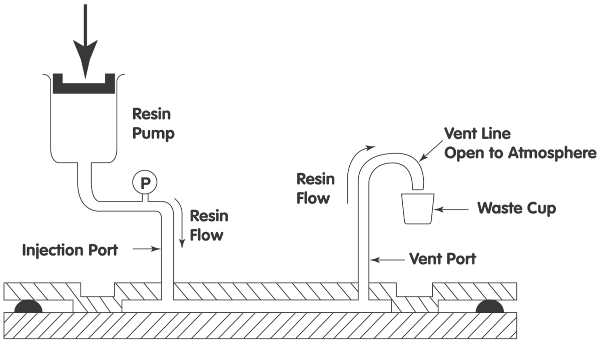


Figure 5/IV.2—For the Pressure to Atmosphere Head, a pump supplies pressurized resin to the injection port and the vent port is open to the atmosphere.

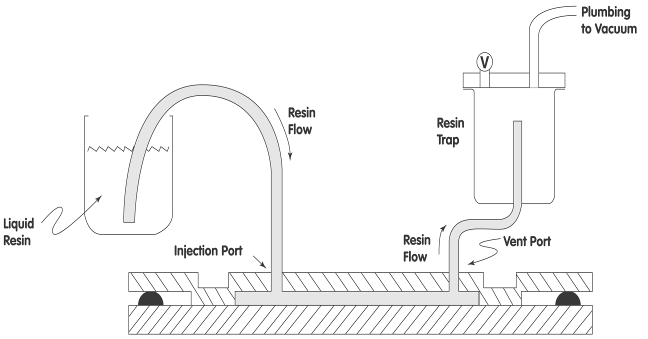


Figure 5/IV.3—For the Atmosphere to Vacuum Head, a vacuum source applied to the vent port draws the resin from an unpressurized container through the injection port and into the part.

B. The Resin Transfer Scheme—It is very important to consider the molding process at the very beginning of part design. The part must be designed not only to be the part, but also to be successfully molded. This is necessary to ensure that the fiber pack creation and mold filling processes are economically viable.

In all variations of resin transfer molding the objective is to transfer the resin into the fiber pack. Pressure forces must be generated in some fashion to drive the resin throughout the part. Once there is pressure on the resin, it will flow. The resin will prefer to follow the path of least resistance. The position of the resin as it advances into an unfilled area is called the resin flow front. This flow front moves throughout the mold until the mold is completely filled. The control and management of this resin flow front is the heart of the RTM process. The sections that follow discuss flow in general terms and then discuss the various types of resin transfer schemes.

1) General Considerations to Controlling Flow—The glass within the mold cavity is compressed somewhat by the mold. The more the glass is compressed, the more resistance there is to resin flowing through it. The less the glass is compressed, the less resistance there is to resin flowing through it. The ability of the resin to flow through a fiber pack is called its permeability. The easier it is for resin to flow, the more permeable the fiber pack is.

   There are two main resin flow situations, diverging flow and converging flow. Diverging flow starts at a point or area and the resin flow front goes outward until it meets some boundary condition. One example of diverging flow is Discrete Port when there is only one port. The following schematic depicts one type of diverging flow field.

   Converging flow starts at several points or around the perimeter and multiple resin flow

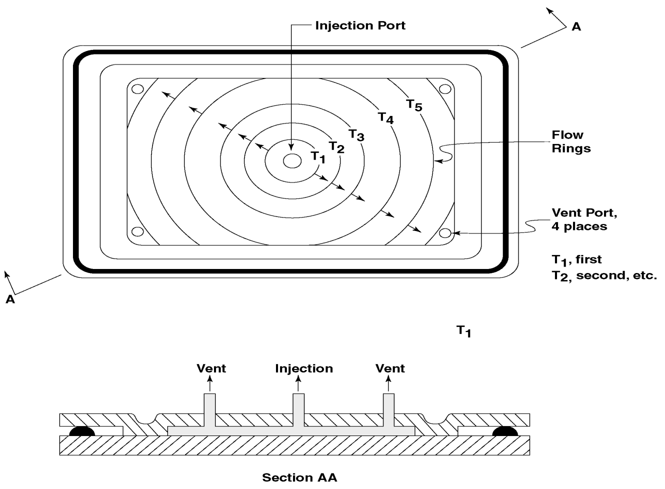


Figure 5/IV.4—In diverging flow, resin enters the mold cavity at a point and flows outward. Here, discrete port injection is used.

fronts meet (converge upon) each other. Examples of converging flow are the Edge Manifold when the manifold spans either opposite sides or the entire perimeter and Discrete Port when there are two or more injection ports. The following schematic depicts one type of converging flow field.

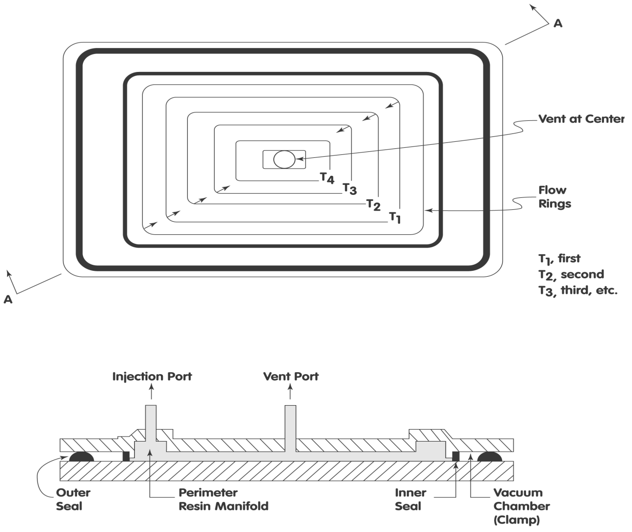


Figure 5/IV.5—In converging flow, resin enters the mold cavity at multiple points and flows to a single point. Here, an edge manifold supplies resin to the entire perimeter.

If the fiber flow front gets out of control, it gets ahead of itself, closes upon itself and seals in a dry spot. To avoid dry spots, one must determine where the resin front is getting ahead of itself, and then slow it down in these areas or speed it up in other areas. These strategic areas are located by producing a series of parts with short shots of resin, so that the parts are filled to various amounts. Like a time-lapse camera, this set of specimens will clearly show where the resin is travelling too quickly and too slowly.

Sometimes a dry spot can be percolated out of the part. This is accomplished by allowing resin to continue to flow out the vent port. Depending on where the dry spot is in relation to the vent, a considerable amount of resin may need to be released. If the dry spot occurs in a consistent place, adding a vent port at the center of the dry spot will let the air out and allow the dry spot to fill.

Special cases can be constructed when there are mixtures of the two types of flow. Generally, this should be avoided by carefully considering the fill process before the upper mold is designed and built. In terms of broad generalizations, diverging flow vents to the perimeter and converging flow vents in the center of the part. For the converging flow, the flow fronts probably don't converge right at the vent location. So, the vent must be kept open until all the air works its way out of the part. For this reason, converging flow may waste more resin. The amount wasted depends strongly on the management of the resin flow front.

Special attention must be paid to the distance that the resin flow front must move. If one path is farther, it will take more time to get there. If there is an open channel pathway, the resin will prefer to follow the channel. If the fiber pack is less permeable, the resin flow front will move more quickly. If there is a vent to atmosphere or vacuum draw to an area, the flow front will tend towards the draw more quickly. These are the fundamental principles of resin flow front management. Trial and error usually produces an arrangement that fills properly.

2) Discrete Port Injection—The resin enters the part cavity at a specific point called a discrete port. The injection port is plumbed directly into the part cavity. Usually, only one port is preferred. This method always uses a diverging flow front; any converging flow fronts will seal in a dry spot. It is best to vent at the farthest reaches of the perimeter. The reinforcement is placed in the mold. The mold halves are closed. Resin is injected until it fills the fiber pack and flows out of the vents. As the resin reaches each vent, that vent tube is sealed off. Once the last vent is sealed, the injection tube is sealed off.

A schematic of discrete port injection can be found in Figure 5/IV.4 for an example of a diverging flow field.

3) Edge Manifold Injection—A resin injection channel along the part edge characterizes the Edge Manifold Injection process. The reinforcement is loaded and the mold halves closed. The resin is plumbed to the channel through the injection port. Since the channel is an open space, resin prefers to flow down the channel rather than flowing into the fiber pack. Once the channel fills, flow into the fiber pack begins, if not somewhat beforehand. When the manifold follows only a small portion of the perimeter, the flow is diverging and venting is performed on the far sides of the part. When the manifold runs completely around the perimeter, the flow is converging and the vent is positioned at the flow center of the part. If the flow fronts do not converge simultaneously at the vent location, resin flow is continued until any air bubbles work their way out. This adds to resin waste. A schematic of edge manifold injection can be found in Figure 5/IV.5 for an example of a converging flow field.

4) Face Manifold Injection—The Upper Mold contains numerous resin channels. This can be as simple as bubble wrap packing material under a Single-Use vacuum bag or as complex as a Laminate Rigid Upper Mold with resin channels molded in. The resin is plumbed to these channels through the injection port. The resin prefers to flow down the channels rather than flowing into the fiber pack because empty space is more permeable than a compressed fiber pack. Once the channels are full, the resin saturates the fiber pack. A peel ply may be necessary on the top of the laminate if the resin ridges that remain on the part due to the manifold pathways must be removed. Usually, multiple perimeter vents are used for the resin. A good perimeter vent is necessary to vent the air as the fiber pack is wet out.

5) Flow with Rigidized Laminate Upper Mold—For the this variation, the mold cavity is discretely the same every time the molds are closed. If one were to add an extra layer of glass, it would be squeezed down to the same height as the glass pack with one less layer. Since the amount that the glass is compressed affects its permeability, this affects the resin flow front. For this reason, it is very important to have good dimensional accuracy in the mold cavity thickness. Large variations in the cavity can cause the fiber flow front to behave erratically.

   Glass compression and the resulting loss of permeability may also be used as an advantage to control the flow front. An extra layer in strategic locations will slow the front. Similarly, one less layer would speed the front.

6) Other Features—A visual method of determining when the mold is full involves using witness holes. A polyethylene tube through a fitting into the mold is often used. When the resin fills the tube, that vent is closed. This is repeated until all vents are closed, injection is halted and the injection tube is closed. Simple clamps can be used to pinch the hoses. Bending the hose and sticking the bent end into a large washer is an economical method for sealing the port. When the polyethylene hose does not go entirely through the injector or vent fitting, one must drill out the cured resin before the next part is made.

   Permanently mounted thermocouples can be used to monitor part exotherm. This information can be used by the operator to determine the demold point. Generally, the part is not removed before the peak exotherm temperature is reached. The demold point strongly depends on the production rate and the part requirements. Surface profile is compromised by rapid demold because the part is still curing. When the resin is curing and shrinking without being in contact with the mold surface, the lack of support results in more fiber print and profile.

   Dielectric sensors can be used to monitor resin flow and cure. The simplest dielectric sensors will measure at only one point, such as a resin trap at a vent location. These sensors can provide the signals to close the vent valves automatically, alert the operator to gelation and indicate the approximate part demold time. This can greatly reduce the likelihood for operator error.

   When a series of dielectric sensors are used, a computer model displayed on a screen can show, with color changes, the mold fill process and cure event throughout the part. Since it can take a bit of time to fill a mold, and the resin cure starts at catalyzation, the computer controller can even increase the catalyst level slightly towards the end of the fill process so that the entire part cures more simultaneously. This can decrease the cycle time for large parts.

C. Tooling—For the purposes of this discussion, a closed mold set contains the following items:

- Lower Mold
- Upper Mold

The terms Upper and Lower are used to describe the mold halves. This is generally due to the fact that gravity acts vertically and gravity is most often used to assist in separating mold halves. Although many prefer to consider molds male or female, many molds have elements that are in some areas male and other areas female. In addition, it is possible to have either one as the upper or lower. Therefore, upper and lower mold halves are the more general description. While there may be more than two physical tooling pieces, these pieces incorporate all of the following features:

- Part Cavity
- Mating Flange
- Flange Seal
- Injection Port
- Vent Port
- Alignment Device

The part cavity is the physical space between the upper and lower molds in which the part is produced. The mating flanges are the portions of the lower and upper molds which come into contact with each other when the mold is assembled. The flange seal (sometimes omitted) is a rubber extrusion placed in a special recess between the mating flanges. Some compression of the seal rubber is produced by the mating flanges when the mold pieces are assembled. The injection port is that location in the resin plumbing where the resin enters the assembled upper and lower mold set. The vent port is that location in the boundary for the part cavity where air escapes when the resin is being transferred to the glass pack. The alignment device (sometimes not present, sometimes accomplished with the part shape itself) is the mechanism for aligning the upper and lower molds.

Particular requirements for the molds depend largely upon the pressures that are generated during the molding process. For laminate molds, all of the ordinary requirements for open mold polyester tooling apply. There are, however, additional requirements for molds that are subject to either injection pressures or large closing forces. In general, the processes that generate large resin pressures require a robust framing system and a high grade polyester or vinyl ester resin and gel coat. For higher temperature processes, epoxy resins and vinyl ester gel coats are preferred. Upper molds also have special requirements that are not described in the section on polyester tooling. These special requirements will be described in the sections that follow.

When Shell Laminate and Rigidized Laminate upper molds are used, special consideration must be given to orient the pattern to provide a mold parting flange that is both planar and horizontal (or very nearly so). This allows the mold to release from the part by separating due to a true vertical motion. If the parting flange is not in a single plane, or not very close to a single horizontal plane, great difficulties in sealing the mold will be encountered during mold closure. This is because the mold seal rubber is dragged along the non-horizontal mating flanges as the flanges come together in a vertical motion. This will most likely result in two things: a leaky mold that is a housekeeping challenge; and a mold that produces unfilled parts. Certain rubber sealed extrusions will be more tolerant of non-planar flange geometries.

Sometimes, the part boundary is extended so that the mating flange is more nearly planar and horizontal. The extended portion is trimmed during post-mold finishing operations.

1) Lower Mold—The Lower Mold construction falls into one of following three categories:
    - Lower Mold Conventional
    - Lower Mold Conventional with a Wide Flange
    - Lower Mold Robust

   When the upper mold is the Bag Film, Single-Use mold, the lower mold is a conventional open mold with a conventional flange. For both the upper mold Shell Laminate and Elastomer Multi-Use processes, the lower mold is a conventional open mold with a wide flange to accommodate sealing the upper mold to the lower mold. Flange details will be covered in the sections that describe the associated upper molds. The third category, Lower Mold Robust, is discussed in the next section.

2) Lower Mold, Robust—There are a few cases in which the resin pressures are considerable. When this is the case, the lower mold must be robust to resist these pressures without excessive deflection and subsequent fracture. When the RTM process uses pressure to fill the mold and when the Upper Mold is Rigidized Laminate, the lower mold must be robust. This is the conventional RTM mold. Another case where significant resin pressures are generated is when resin is Hand Applied and Hydraulic Clamps close the mold, causing the resin to flow throughout the fiber pack. This is the conventional wet mold. (See the section on Compression Molding.)

   The flange is typically four to five inches wide. It must be wide enough to accommodate both a primary and secondary seal, as well as resin traps at the locations of the vents, but narrow enough to resist excess deflections. The resin traps allow some amount of air to percolate out after the resin first reaches it and before the vent must be closed. It is very important to clearly establish the filling, venting, alignment and clamping issues prior to the start of lamination. See associated sections for more information.

   The gel coat is either polyester or vinyl ester; the laminating resin is either a high grade polyester or a vinyl ester. If a polyester gel coat is used with a vinyl ester or epoxy laminating resin, a special adhesion coat should be applied. A surfacing veil, generally 10 mils thick, is placed in the tooling gel coat when it reaches the tack stage and brush laminated to a low glass content (10 to 20 percent) , while carefully avoiding entrapped air. Entrapped air must be removed and the veil replaced in a second lamination stage. The skin coat is typically one layer of 1.5 osf CSM at 35+ weight percent glass. The laminate is as much as 12 osf CSM at 35+ weight percent glass, laminated two layers of 1.5 osf CSM in each lamination step.

The framing is very robust. The particular frame design depends on the means of clamping. Individual hydraulic cylinder clamps and mechanical clamps, either screws or toggle style, require the most robust frame. This is because clamping forces are localized only at the clamp location. Mold frames for pneumatic clamps or a hydraulic platen press can be somewhat lighter since the clamping force is more evenly distributed across the frame. However, these frames must have planar and parallel contact surfaces to be used successfully in a press. If they don't, the press forces will crush sections of the mold. For additional press mold requirements, see the section on Pneumatic Clamps.

The frame is built about 1/4 to 3/4 inch offset from the mold using two by four, two by two, one by two, and 1/2 by two square tubular steel with typically 0.063 to 0.125 inch wall thickness. The mold panel size between framing members is generally no larger than four inch by six inch to six inch by eight inch. The frame is tacked together and then removed from the mold for final welding. In a properly constructed frame, all the steel elements are carefully fitted and welded on all sides. End caps are placed over all open ends.

The completed frame is fitted onto the mold, filling the gap between the frame and the mold with a bedding mixture of resin and either glass or ceramic microspheres. Before doing this, the mold is covered with release film. This allows the bedding mixture to bond to the steel frame but not to the mold laminate. The steel frame should be thoroughly cleaned on the contact surfaces, and a brush coat of resin should be applied before installation. This will help the steel bond to the bedding mixture. After cure, the assembly of frame and bedding mixture is removed. Grinding on the edges of the bedding mixture provides a neater, cleaner appearance. Finally, silicone sealant is applied to the bedding material contact surface, and the frame assembly is installed permanently on the mold.

3) Tooling, Upper Mold Type—The upper mold can take many forms depending on the particular process. Most closed mold sets use a silicone rubber seal for process reasons related to mold filling, and for housekeeping purposes. Resin leaks, drips, and puddles during the mold fill process should be avoided through mold design features. This is important because once the resin has cured, a chisel and hammer is often used to clean off the resin debris. There is no greater threat to a mold's long and productive life than a hammer and chisel. Any place that is likely to collect resin should be coated with a layer of silicone, about 1/4 inch thick. This will allow the molder to pry out the cured resin rather than using a grinder or chisel.

   Many upper molds have two seals, inner and outer. In some cases, this is a primary and a backup seal. With some separation between the seals, a vacuum chamber can be made around the part perimeter. This chamber can have two functions: providing the mold clamping force in Vacuum Clamping processes; and porting vacuum to the part perimeter in Pressure to Vacuum or Vacuum to Vacuum processes. These vacuum ports can be point vents, made by placing a vacuum venting material through the inner seal. Or, the entire perimeter can be vented by careful design and construction of the pinch-off area.

4) Creating the Mold Cavity—The Upper Mold is usually constructed using the Lower Mold as a platform. There are various cavities that will exist between the upper and lower molds. To produce these cavities, two major methods can be used.

   For the upper mold Rigidized Laminate, considerable cost is incurred during construction of the upper mold. The other re-usable upper mold types are either less expensive to remake (Shell Laminate) or somewhat forgiving (Elastomeric Multi-Use) with respect to cavity variations. However, for the upper mold Rigidized Laminate, it is very important to know what part thicknesses and glass loadings are required. Once the upper mold is made, these cannot be changed without going to considerable expense. Simply adding glass will change the flow characteristics making the mold filling process difficult or impossible. It is preferable to demonstrate a sound part design before building the upper mold.

Using the lower mold, a complete part should be carefully hand laminated. Thorough attention to glass loading and glass/resin ratio should be exercised. Cores or inserts, if present in the design, should be installed during the lamination process. The part should be tested sufficiently to prove out the design before proceeding with designing and building the upper mold pattern.

5) Dimensional Waxing—Dimensional waxing is probably the most economical and accurate means for producing the part cavities. Starting with the lower mold, the dimensional wax is applied to mimic the part thickness. Wax stock is currently available in a wide range of thicknesses and several temperature ranges. It is important to use the high temperature variety due to the exotherm heat generated during mold cure. The adhesive backing helps keep the wax in position. Dimensional waxing is very much an art requiring skill and finesse for accurate thickness control.

Dimensional waxing is most successfully accomplished in a temperature controlled environment. Sometimes, dimensional wax is applied in two layers. The first layer is thinner and placed as tiles with channels between pieces. These channels form a vacuum manifold. This vacuum manifold serves to hold the second, thicker layer in place. This configuration can reduce the likelihood of pre-release during the gel and lamination stages of mold building. In general, it contributes to higher accuracy in the mold cavity dimension. Clay can be used to produce fillets in tight radii and to fill the seams between adjacent courses of wax. The preferred clays are very stiff at room temperature. A hard clay produces a better gel coat surface on the cured mold. A heat lamp or other kind of hot box is usually required to condition the clay so it can be easily molded. Once it cools, the clay becomes very stiff and provides a good molding surface. Some clays can inhibit the gel coat cure during mold fabrication, so the clay should be checked to ensure this does not occur.

The surface quality of the upper mold half depends critically on the quality of the dimensional wax and clay installation. Careful attention to detail will result in the least re-work to the upper mold.

Prior to constructing the upper mold half, paste wax is applied over the clay and dimensional wax. Then PVA is sprayed over the paste wax to serve as a parting film between the pattern and the mold. When the upper mold is Elastomeric Multi-Use, a soap solution is instead sprayed on the pattern to facilitate release of the silicone bag material. It is important to test new combinations of materials on a small scale before expecting them to work on a large scale.

6) Master Part—The mold cavity can also be patterned by building a master part. In general, cavity thicknesses have greater variation when using the master part versus the dimensional waxing method. In the lower mold, a complete part should be carefully hand laminated. Very careful attention to glass loading and glass to resin ratio should be exercised. Any cores or inserts should be installed during the lamination process. The entire top surface is then sanded smooth. Body putty is used to fill major imperfections. The top surface is covered with a high quality surfacing primer followed by tooling gel coat which is sanded and buffed to a high gloss. This preparation adds to the cavity size, so careful planning and execution is necessary to end up with the proper cavity. Also, keep in mind that female edges and corners have greater thickness variations; this results in resin rich areas on the production part. See the section on Polyester Tooling for more information on building patterns and plugs.

7) The Pinch-Off—The pinch-off is a mold feature that can serve several functions. The pinch-off is that certain part of the mold cavity at the edge of the part where the two mold halves come together. The mold mating flange is just outside the pinch-off. There is still a gap between mold halves in the pinch-off. Generally, the same or smaller gap is carried onto the mating flanges. In the pinch-off, the separation distance is much less than in the cavity area. In general, 0.015 inches of pinch-off space is allowed for every 1.5 osf of CFM. In comparison, 0.045 inch of cavity space filled with one 1.5 osf of CFM provides a laminate with 30 weight percent glass (zero filler load)). The pinch-off compresses the CFM to roughly one third its original height. This makes the glass pack less permeable and the liquid resin cannot easily penetrate this area. This prevents the resin from wetting out the laminate in or past the pinch-off area.

Immediately after molding, while the part is still not fully cured, the flashing can be torn off the part by hand or cut off with a hook knife. The flashing and the part separate at the pinch-off area. This type of part edge is adequate for some applications. For many applications, the part edge will need to be a high quality cut edge.

The pinch-off also provides a vent path for the fiber pack. Air will vent through the pinch-off while the glass is still dry. A vacuum plenum must be provided outside the pinch-off area, in either the lower or upper molds. Once the resin arrives and wets the glass, air will no longer vent through the pinch-off. At the vent locations, the pinch-off is interrupted by making a channel from the part to the vent. This improves the effectiveness of the vent.

8) The Rigidized Laminate Upper Mold—The Rigidized Laminate upper mold is used whenever there are substantial resin pressures and/or large mold closing forces. This mold type is typically used in RTM.

In general, this mold is a glass laminate fitted to a heavy steel frame. See the Lower Mold Robust section for a typical mold description. Generally, the mold flange has two rubber perimeter seals. In the Pressure to Vacuum process, the space between the seals serves as a perimeter vacuum manifold.

The upper mold Rigidized Laminate mold set is the heaviest of all. For example, a part larger than two square feet will have a mold too heavy for people to Hand Lift apart. This system has the potential for the fastest production rates in very sophisticated processes. The upper mold Rigidized Laminate mold set is the most durable of the various molds and can be expected to have the longest life.

Parts that require gel coat present a special challenge for the Rigidized Laminate mold process. The extra process time for spraying and curing the gel coat extends cycle time. In addition, there are often cosmetic requirements for gel coated parts that demand excellent surface profile without distortion or fiber print. Rapid cycle times and quick demold events allow the part to cure without being in contact with the mold surface; this compromises cosmetic quality. To address both of these issues, the lower mold can incorporate two features: a dish and a pan. The dish contains the actual mold surface but no support frame whatsoever. The pan is a lower support mold that holds the dish. This lower support mold is a glass laminate mold with a very robust steel frame. Vacuum between the pan and the dish ensures that they nest perfectly. As a result, the supporting pan mold reacts the injection pressures during the mold fill process. Several of these dishes can be fabricated for each pan.

These dishes can be gel coated off line from the molding station. The gel coated dishes would then be processed, in sequence, through the mold station. After the part is molded, it can remain in the dish for some period of time. This will improve surface cosmetics in addition to throughput.

9) The Shell Laminate Upper Mold—The Shell upper mold will probably enjoy the most widespread use for small production run parts. This is largely because existing open mold assets can be readily converted to accept this type of upper mold. In addition, this upper mold is both the least expensive to fabricate and uses no new chemistry. This upper mold is a thin glass laminate with a special flange detail. The flange detail usually has two seals. A vacuum applied to the cavity between the two seals usually provides the clamping force (Vacuum Clamps). In addition, vacuum venting to the part cavity can provide clamping forces across the entire part.

The Shell Laminate upper mold is similar to the Rigidized Laminate upper mold in that both are made with glass laminate. But, the Shell Laminate is much thinner and has little or no framing.

The Shell Laminate upper mold generally is one of two types based on the flange detail. Both provide for a clamping force but they differ in resin transfer functions. One applies a vacuum to the part perimeter for a diverging flow fill from the part center to the edges. The other provides an Edge Manifold that serves as the resin pathway into the fiber pack for a converging flow fill to a vent at the part's flow center. Schematic diagrams for diverging and converging flow fields can be found in the section on General Considerations to Controlling Flow.

A typical flange detail is presented in Figure 5/IV.6. There are two popular ways to develop the flange detail. The preferred method is to pattern the flange detail around the perimeter of the mold using dimensional waxing and other conventional pattern building techniques. In this method, the flange is laminated when the upper mold is laminated, except the flange is usually thicker. The other method is to miter and butt prefabricated stock lengths of a flange detail around the part perimeter. When the upper mold is laminated, narrow strips of wet glass are placed across the flange butt joints, and the laminate in the part cavity is lapped over the flange pieces, thus forming a one piece upper mold and flange.

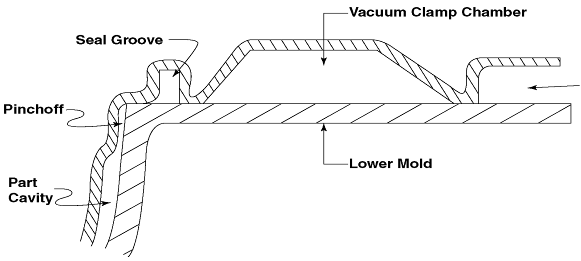


Figure 5/IV.6—A flange detail for the upper mold shell laminate type incorporates two seals and a vacuum clamp chamber to hold the upper mold to the lower mold.

The Shell Laminate upper mold can be built by spraying clear gel coat over the prepared and properly released pattern, followed by laminating the mold. Clear gel coat provides an upper mold that is translucent so that one can watch the fill process when the upper mold is used. The laminate thickness is generally four to 12 osf CSM over the part cavity and four to 18 osf CSM over the flange. The thickness is strongly dependent upon the part geometry. Lamination stages are limited to 1.5 osf for skin coat, and three osf per lamination operation to avoid excess heat generation.

The flange detail commonly has some provision for alignment. Sometimes the lower mold will have an upturn flange at its outermost perimeter that is matched correspondingly by the upper mold flange. Sometimes, it is a downturn flange. The dimensions needed for successful locating will depend on the overall part area and depth. If no provision is made for locating, then the overall part shape will try to locate the two mold halves. However, slight misalignments will cause fractures in edge and corner locations of the upper mold that result in reduced mold life.

The Shell Laminate upper mold is a durable mold that will endure many molding cycles when properly built and properly cared for. Mold failure is generally characterized by fracture of the laminate in edges and corners. This is aggravated by a poor fit in the corner and/or inadequate alignment features in the molds.

10) The Elastomer Multi-Use Upper Mold—The Elastomer Multi-Use systems generally use silicone vacuum bags. Be advised that silicone is a chemical class just like polyester, and there are many different formulations from single component to two component, and either addition cure or condensation cure varieties. It is important to demonstrate compatibility between the silicone and the molding resin. The cure of polyester resin can be inhibited when in contact with certain materials.

There are two types of multi-use bags, typically designated as conformal or non-conformal. Non-conformal bags are fabricated from flat sheets of calendered silicone. These are limited to parts with a flat profile and mild curvature. The typical technique for joining adjacent pieces usually involves butt splices of calendered material covered with a lap of uncured rubber. Heat curing is accomplished under a Single-Use vacuum bag.

Conformal bags are molded to the part's upper mold line. They can be molded from calendered sheet stock that is partially cured or from bulk silicone material. For the calendered stock, pieces are applied to cover the pattern, a Bag Film Single-Use vacuum bag is applied, and it is cured in an oven. For the bulk silicone, it is applied to the pattern surface by brushing or other means. Often, a polypropylene mesh or some other flexible reinforcement is embedded in the silicone to provide strength and durability. Some varieties of silicone will cure at room temperature.

The flange detail can range from a tacky rubber seal tape to an aluminum or fiberglass flange detail with EPDM, silicone, or neoprene rubber seals. The flange detail may provide a vacuum chamber around the part perimeter. For small parts, this type of bag is easily handled. For large parts, handling becomes difficult and it becomes easy to tear or damage the bag. Improper storage can result in damage and premature bag failure.

A 'V' or 'C' groove in the lower mold flange can also serve as a seal for the elastomer multi-use upper mold. When the upper mold is fabricated, this groove in the lower mold is filled with elastomer. The elastomer extends beyond the groove as well. Simply placing the upper mold in place around the lower mold flange provides the seal once vacuum is applied. In some cases, a vacuum plenum (groove) in the lower mold flange (which is not replicated in the upper mold), located just inboard of this seal groove must be used to ensure the upper mold seal integrity.

11) The Bag Film Single-Use Upper Mold—The Bag Film Single-Use systems use the classic vacuum bag constructed from roll stock material. This method enjoys widespread use both in the aerospace industry and with very large fiberglass parts. Each time the part is built, a new vacuum bag is constructed. This method is typically used for parts that have small production runs and low production rates.

There are two fundamental approaches to vacuum bagging, surface bagging and envelope bagging. In surface bagging, the vacuum bag is sealed to the tool face. The tool should not contain any penetrations that would cause leaks. The tool laminate can also leak vacuum if it has porosity. This porosity can be repaired by using a vacuum bag to draw a vacuum on one side of the mold face while painting an elastomeric seal material on the back side. Vacuum forces will draw the seal material into the porosity and seal the mold face. Several applications may be necessary. In envelope bagging, the vacuum bag completely encapsulates the tool. This is only practical on smaller, somewhat flat parts.

There are a few items which are commonly used to construct vacuum bags, although not all of them are always used. These items are: Peel Ply; Release Film; Breather Material; Bleeder Material; and Bagging Film. All of these items are considered expendable goods. In other words, one buys them for each part and throws them away once the part is cured. This is practical for low production run products, but is too expensive for higher volume applications.

Peel ply is a nylon, polyester or fiberglass fabric that is laminated into the part surface. The fibers in the peel ply are treated (or left untreated) so that no bond occurs with the laminating resin. Some time after the part is laminated, the peel ply is removed by peeling it off, hence the name. This leaves a clean, slightly textured surface that can be bonded to or painted on without further surface preparation, provided it is not left open to the air for an extended time.

Release film is a film that doesn't bond to resin. It is used to ensure a part does not bond to another item, such as vacuum breather or vacuum bag. It can be perforated to allow resin or vacuum to pass through, or non-perforated which prevents resin or gasses from passing through. Release film is always in contact with the laminate. It forms the border between the part and the vacuum bag system.

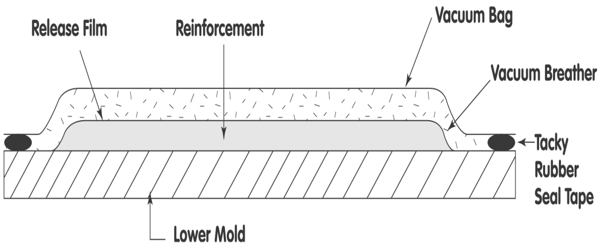


Figure 5/IV.7—A vacuum bag system may incorporate the vacuum bag, vacuum breather, and a release film. No resin transfer plumbing is shown in this view.

Breather is a key element of the vacuum bag system. Without breather, the forces on the vacuum bag are not consistent from one spot to another. In fact, some areas of the vacuum bag may have no force whatsoever. This is because the vacuum bag, in contact with either a mold surface or a wet laminate, will tend to seal off and not pass the vacuum. A breather works to vent vacuum under the bag everywhere the breather material is. Breather is usually a spun mat made from a polymer fiber. A non-woven paper product such as handy wipes is an example of a low cost breather.

Bleeder is used to extract (soak up) excess resin that exits a part. It generally is used in conjunction with perforated release film. The release film prevents the bleeder stock from becoming part of the laminate. The bleeder can be any type of fibrous material. Polymer fiber such as spun polyester fiber is common. Glass stock can also be used at a greater expense.

Bagging film is the last layer. It is the layer that the atmospheric pressure acts upon.

In general, this is a nylon film that is carefully selected for its good elongation properties. It forms the boundary between the vacuum and the atmosphere. This pressure difference results in a compaction force. Many types of nylon film are plasticized by moisture. The ambient humidity has a strong effect on the bag material's softness and elongation. If a roll of bag film dries out, it becomes very crinkly and hard to work. The bag stock can be restored to usable form by putting it in a tent with an ordinary vaporizer. Once the film absorbs some moisture, its desired properties will return.

The bag is sealed to the flange using a sealing tape that is a rubber based material with high tack. A common size is 1/8 inch x 1/2 inch in 25 foot rolls. Since the bag is made from flat roll stock, numerous pleats are used to fit the bag into and onto edges and corners.

All the items mentioned above are considered disposable items and are consumed during each molding cycle.

12) Mold Seals—Most molds for Resin Transfer Molding have rubber extrusions for seals. Many times, a double seal arrangement is used. Various synthetic elastomers are used such as polysiloxane (silicone), polychloroprene (neoprene) and ethylene-propylene-diene monomer (EPDM) rubber. Numerous cross sections are available. The seal and its geometry has a strong effect on the design of all upper mold flanges that are re-usable. Silicone seals are almost always used at the part boundary. Resin doesn't stick to the silicone, making mold maintenance easier. The backup seal is generally EPDM rubber, which is much less expensive than silicone. Some processes use neoprene rubber seals.

D. Clamping Method—The Clamping Method has a cost in terms of capital requirements with a corresponding benefit in cycle time. Part size strongly influences the choices of clamping method, but the biggest driver is the way the resin pressure head is developed. The general clamping types are Vacuum Clamps, Mechanical Clamps, Pneumatic Clamps and Hydraulic Clamps.

1) Vacuum Clamps—Vacuum Clamps are a very useful and practical way to clamp molds together. In general, vacuum clamps consist of two rigid shells that come into contact with a rubber seal between them. These shells form the boundary of a cavity. When vacuum is applied to the cavity, atmospheric pressure forces the shells together. The size of the cavity and the level of vacuum will determine the magnitude of the clamping force.

   A schematic for a perimeter vacuum clamp can be found in Figure 5/IV.6. See the example of a typical flange detail for Shell Laminate upper molds.

   Sometimes, a vacuum clamp arrangement consists of a single seal that surrounds the part cavity. Vacuum is applied in a wholesale fashion to the part cavity to provide the clamping function as shown in Figure 5/IV.8.

2) Mechanical Clamps—Mechanical clamps are generally very robust and located at approximately 18 inch intervals around the perimeter. Clamp locations are generally reinforced with 3/8 inch or 1/2 inch thick steel plate. Generally the clamps provide for the alignment of the upper and lower molds. Screw clamps are typically two machined pieces that provide alignment. Generally, a one inch diameter bolt through the top piece and a replaceable nut in the bottom piece provide the clamping force. Toggle Clamps include a pair of hooks with a lever arrangement like a break-over clamp to provide the clamping force. One of the hook elements has a provision for length adjustment. Welding of the final clamp elements usually doesn't occur until the upper mold frame is constructed. At that time, the clamp/alignment elements are held in the tightly closed position while they are welded in place to ensure their alignment.

3) Pneumatic Clamps—Pneumatic Clamps generally consist of two horizontal and essentially parallel platens and an air bag. In a pneumatic press, the platens don't need to be perfectly parallel, but they do need to be very flat. The platens are held a fixed distance apart by a number of large threaded rods with heavy duty nuts positioned above the upper platen, and some holding nuts below the upper platen. This allows for some variation in the height of the closed mold set. It is not a trivial matter to adjust this height, so limited production runs should be made with molds that are nearly the same height. The closed mold set is shuttled into position between the platens. There is only a small empty space between the mold set and the top platen. An air bag built into the lower platen inflates and lifts the mold set upward against the upper platen. Since the air bag inflates quite a bit, and since it inflates until it closes the gap, it compensates for the fact that the platens may not be exactly parallel, as long as they are truly flat. This is not the case

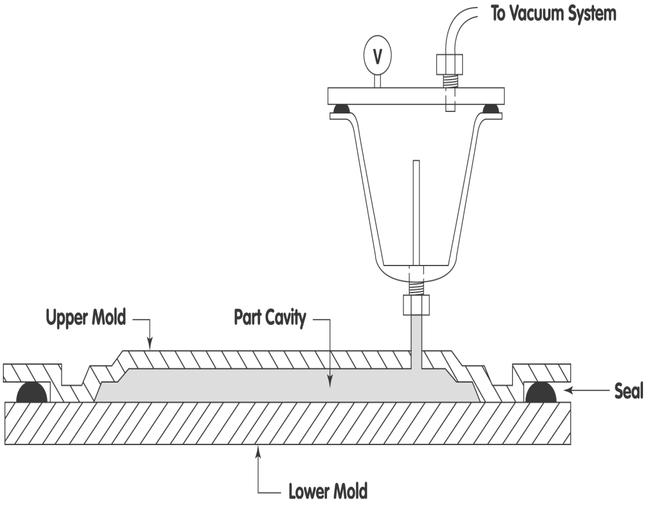


Figure 5/IV.8—In the RTM configuration, vacuum applied to the mold cavity results in a clamping force across the entire part. Here the resin is applied before the upper mold is installed.

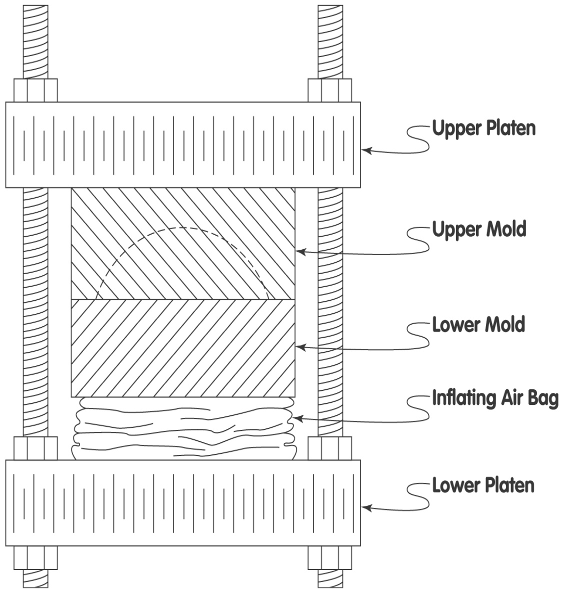


Figure 5/IV.9—A pneumatic press uses compressed air to inflate an airbag. This forces the assembled mold set upward against the upper platen, clamping the upper and lower molds together.

for a hydraulic press; the quality of a hydraulic platen press is directly determined by how parallel, in addition to how flat, its platens are.

4) There are two types of hydraulic clamping systems. The first is a platen press. The second type uses a number of hydraulic cylinders placed around the mold perimeter. One design uses offset geometry to move the clamp's claw out of the way during the opening motion. The closing motion moves the clamp into position for applying the clamping force. In this way, the upper mold can be lifted clear of the lower mold. A second design uses pneumatic cylinders to swing the hydraulic clamp elements out of the way so the mold can be opened, and back in place so the clamping force can be applied. Unless a mold set is run non stop, the cost of hydraulic systems limits the flexibility of this system. This can be addressed by the use of a clamping frame device. This clamping frame can be used with similarly sized closed molds. A particular closed mold set is installed in the clamping frame and a brief production run is then executed.

G. Mold Set Open-Close Method—The Open-Close Method has a cost in terms of capital requirements with a corresponding benefit in cycle time. The size and weight of the mold is the biggest driver for selecting the Open-Close method. The cycle time is the next biggest driver.

For small molds and moderate production rates, the Hand Lift method is frequently used. In general, if it takes more than two people to lift and handle a mold, another method becomes preferred.

There are several variations of Mechanical Hoist. A winch is the least expensive and most cumbersome to use. A manual chain hoist is generally only used for limited production rate, mold building or research and development processes. Most often, the electric chain hoist is used. Often times, two or three hoists are used simultaneously on one mold. This method has the greatest flexibility at the lowest cost, but only provides moderate production rates.

When the desired production rate is faster and when the mold is large and heavy, a custom manipulator is used to open and close the mold. The controls for a manipulator can vary in sophistication. For a simple control system, there is a greater likelihood for operator error. A very complex control system can use a Programmable Logic Controller (PLC) to apply logic in process operation. In general, a manipulator is a large steel structure with actuators to move the mold halves. Some actuators may separate the mold halves while others may shuttle a mold half to the loading or gel coating station. The cylinders can be Pneumatic Actuators or Hydraulic Actuators. In general, pneumatic actuators cost less and hydraulic actuators can apply greater forces.

H. Equipment—The equipment for Resin Transfer Molding can range from a few C-clamps, paper tubs, wooden stir sticks and a catalyst bottle to upwards of hundreds of thousands of dollars in facilities and equipment. We will discuss some of the general items below.

1) Pressure Systems—There are two methods of providing resin under pressure. A pressure pot is the least capital intensive method. A standard injection machine is the more capital intensive. For the pressure pot, the pickup tube is one end of the polyethylene tubing that directs the resin to the mold. Catalyzed resin is placed in a disposable tub inside the pressure pot so that valuable solvent is not expended on cleaning functions. Compressed air provides the pressure head that forces the resin through the system.

The injection machine is generally a dual positive displacement pump arrangement driven by an air motor. Different pump configurations and lever arrangements provide settings for varying catalyst ratio. Conceptually, it is the same system that is used for modern choppers and gel coat units although variations in pumps and provisions for ratios may vary.

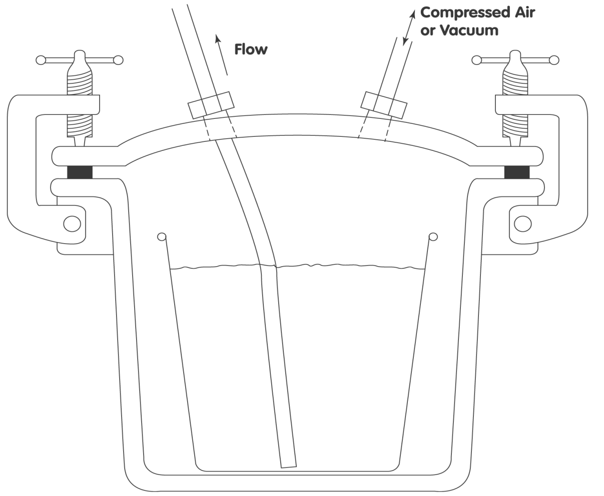


Figure 5/IV.10—A standard pressure pot can be modified to deliver resin under pressure or vacuum.

2) Vacuum Systems—There are two basic means of providing a vacuum source: a venturi or a mechanical vacuum pump. A venturi uses compressed air to produce a vacuum. This is the lowest capital investment option, but the vacuum flow rates are small and the compressed air requirements are large. It is not the most economical source of vacuum for large demands, but it is an excellent source of vacuum for R&D functions, for mold making, and for limited production. A venturi vacuum system can be pieced together for less than fifty dollars in parts cost. An assembled system will cost from $300 to $500.

A moderate-sized industrial style vacuum pump system can be purchased for less than $5000. Such a system has a vacuum cutoff switch, to provide a preset range of vacuum, and a tank similar to an air compressor system. The compressor and tank size should be chosen based on current and near term projected vacuum needs. The plumbing throughout a plant does contribute to the tank size. Ordinary 4 inch diameter, Schedule 40 PVC pipe is commonly used to plumb vacuum throughout a facility. This can add considerably to the volume of the vacuum storage tank and improves draw-down capacity.

Vacuum regulators are approximately ten times the cost of conventional compressed air regulators. In some instances, separate low and high vacuum systems are economical. The very low vacuum system can use a shop vac. This is useful for evacuating large amounts of air to a slight vacuum. This is especially valuable in the Bag Film Single-Use processes. Once the low vacuum evacuation is complete, one can switch to the higher vacuum system for the resin injection process.

3) Resin & Vacuum Plumbing—Once the resin is catalyzed, it is plumbed to the mold. The resin enters the mold through an injection port, the mold fills, and the resin may exit the mold through a vent port. If the resin is allowed to cure in the plumbing, some provision for removing it will be needed. In simple systems, the injection and vent ports can be drilled out between parts. Another method uses disposable polyethylene tubing that lines the metal injection or vent port. It is discarded between parts. A third method uses a valve body that directs catalyzed resin into the mold. When flow is complete, the valve body seals the mold. Solvent is used to flush the lines and valve body. The solvent and resin waste is then plumbed into a covered waste container. Such a valve body can also be fitted to the vent ports.

When vacuum is applied to the vent port, a resin trap is placed in the plumbing between the mold and the vacuum system. This trap is a reservoir that catches resin and prevents it from entering the vacuum system. A resin trap is shown schematically in Figure 5/IV.11.

An air ejector is a device that is molded into the closed mold. It is used to blow (not push) the part out of the mold. It consists of a cylindrical housing with a cylindrical piston device at its center. It works by using two compressed

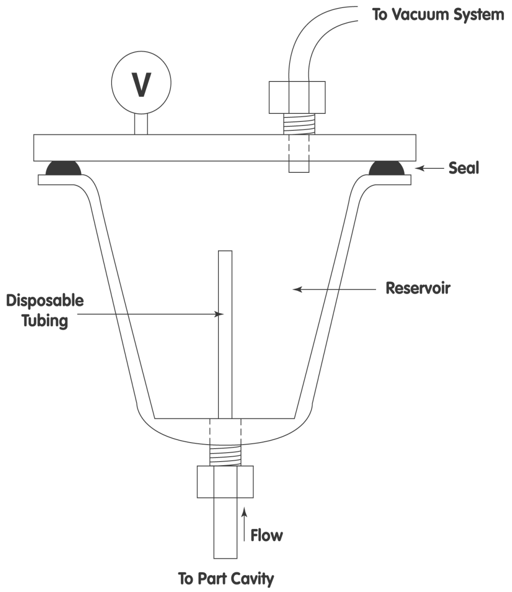


Figure 5/IV.11—Resin trap separates the vacuum system from the part cavity in Pressure to Vacuum and Atmosphere to Vacuum resin transfer schemes.

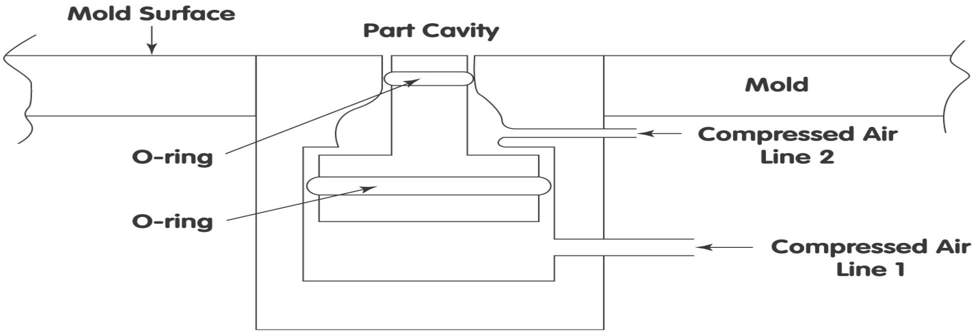


Figure 5/IV.12—When compressed air is applied to Line 1, the ejector piston is held in contact with the part surface. When compressed air is applied to Line 2, the ejector piston moves away from the part surface, allowing compressed air to release the part from the mold.

air lines. While the part is being molded, one of the compressed air lines applies air pressure to hold the piston to keep the ejector port closed. To demold, the other compressed air line is used to move the piston away from the part surface. This causes a gap between the piston and the part surface. Compressed air flows into this gap and releases the part. A schematic is shown in Figure 5/IV.12.

4) Hydraulic Pressure Systems—Hydraulic systems can be used to clamp molds in high rate production processes. A small system, with a pump, cooler, accumulator, valves, hoses, and 8 hydraulic cylinders would cost about $10,000. They tend to be durable systems. Pumps can be rebuilt, as can most cylinders. This type of equipment can be used on a clamping frame that will accommodate a variety of similarly sized molds. Such a configuration is like a mini hydraulic platen press. Hydraulic platen presses are very expensive and quickly run into the hundreds of thousands of dollars. Hydraulic clamping systems are only used on the highest production rate processes.

LOW VOLUME CLOSED MOLDING: Process Features and Variations

I. Troubleshooting

PROBLEM	POTENTIAL CAUSES	POTENTIAL SOLUTION
Laminate shell mold cracks in edges and corners	Mold too thick	Reduce thickness and use aligned fiber reinforcement.
	Mold not aligning well during closing	Alignment devices must engage before part features force alignment.
	Mold cavity too thick in edges and corners	During patterning, dimensional wax should not bridge corners and/or the master part must not be too thick.
Mold does not fill	Injection location(s) not in best spot	Try new locations.
	Vent location(s) not in best spot	Try new locations.
	Part cavity too thin for the glass loading	Redesign part cavity and/or glass loading.
Dry spots in part	Resin flow front splits in two at start of dry spot and rejoins at end of dry spot	Put vent at dry spot to allow air to escape. Modify injection location.
Mold leaks resin	Mold seal not compressed	Add spacer to mold seal groove under mold seal rubber to shim it outward.
	Mold pieces don't fit well	Redesign geometries.
Warpage or distortion of molded part	Cure and shrinkage after demolding	Cool parts in jigs to maintain shape. Delay demold point to allow more cure.
	Incomplete cure	Increase molding temperature. Increase catalyst level. Switch to hotter catalyst.
	Unsymmetric laminate	Change resin promoter package. Correct unsymmetry.

LOW VOLUME CLOSED MOLDING: Converting from Open Molding

Part Five, Chapter V

In This Chapter

1. INTRODUCTION—The term 'Best Practices' describes the actions and considerations that produce a sort of optimum set of results. Many times, these actions are arguable depending upon which 'optimum' is desired. Some things depend upon the specific part design and production plan. For the purposes of this section of the manual, the 'Best Practices' are those actions and considerations that contribute to successful production of gel-coated cosmetic parts with high as-molded quality for production runs of hundreds to thousands of parts.

Closed molding presents some unique challenges to the established open molder. It is most important to focus on the product development process from part design through production scale-up. Figure 5/V.1 presents this process in the context of 'Best Practices' for minimum cost.

Large quantities of small, non-gel coated parts are best produced using conventional, High-Pressure RTM. Rapid cycle times are necessary to offset the high tooling costs. Rapid cycles are achieved with a combination of High-Pressure injection, heated molds to drive the cure, and hydraulic actuation to rapidly open and close the mold set. The upstream process of gel coat application/cure can easily double the cycle time, challenging the economics and applicability of high-pressure RTM. It is the most expensive process for large parts.

Shell Laminate (Light RTM) is the process of choice for most parts without any negative draft. The process uses low-pressure injection to vacuum venting with vacuum clamping. The upper molds should be considered semi-disposable for optimum economics. There is very little benefit from flow media because the upper mold is rigid enough to prevent the glass pack from becoming completely compressed, and a positive displacement resin pump provides a suitable pressure drop.

Silicone Bag RTM, with low-pressure injection to vacuum venting, is the process of choice for die-locked geometries or parts with exceptionally deep draws. Some shops appreciate the ability to fold the upper molds and store them in a pigeon-hole shelf unit. Flow media provide little benefit because the resin transfer operation inflates the cavity and resin flows quickly across the glass pack top surface in the manner of a temporary face manifold. The high cost of silicone relative to fiberglass will always make this process slightly more costly than Shell Laminate RTM.

Vacuum Infusion is the process of choice for limited production runs or for parts that require high glass contents. Some means of bulking the laminate is necessary to hit thicknesses common to open mold designs. Extremely large parts are also good candidates for vacuum infusion, although these are usually limited-production parts anyway. Flow media are absolutely required. Under vacuum and without a resin pump, the flexible bagging film compresses the glass pack considerably, reducing permeability and flow velocity below practical limits. Surface flow media are often removed and discarded after molding. Interlaminar flow media are becoming more popular, although they do provide lower interlaminar shear strength than a glass-reinforced ply. The high cost of bagging film recurs with each part manufactured.

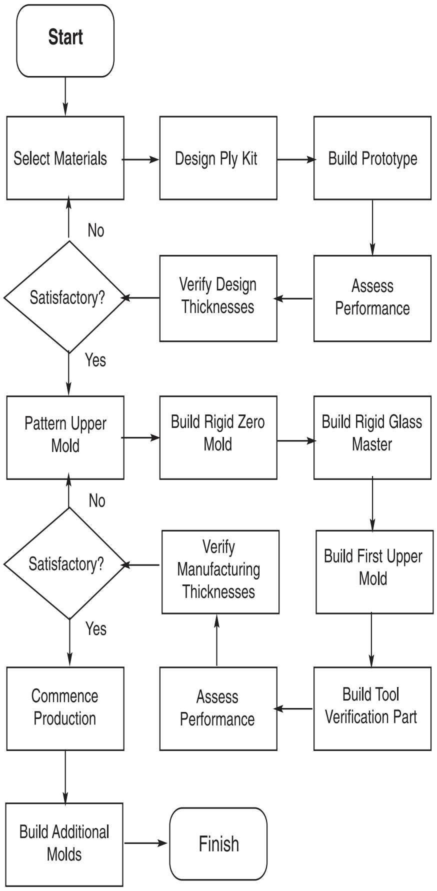


Figure 5/V.1—'Best Practices' product development evaluates a prototype prior to mold fabrication and verifies manufacturing thicknesses prior to production.

2. DESIGN AND PROTOTYPING—A prototype is a necessary step in a product's development. The prototype serves to validate the design's fit, form and function. Many times, the process is abbreviated by not addressing function. Fit and form are evaluated for the prototype, but function is not evaluated until further down the product development cycle where it is usually discovered via a product failure. In open molding, the solution manifests itself in changes to the laminate schedule. A part is designed, a pattern is prepared, a mold is constructed and a part is produced. The part is evaluated for fit and form and the design is certified as acceptable. If function is later found to be lacking, additional reinforcement materials can be added to an open molded part without much concern for the mold design.

When the upper mold comprises vacuum bag film or silicone rubber, adding additional plies of material to increase part strength and stiffness is equally non-consequential. But, when the upper mold is rigid, adding additional plies of material becomes problematic. The part cavity remains the same. Thus, the plies must be compressed to a greater extent, with a corresponding decrease in their permeability. At some point, the plies become so compressed that they don't wet out properly and don't exhibit their normal strength. White fiber bundles visible at the part surface are evidence of inadequate wet out. Further ply compression can even prevent resin from flowing through the region, resulting in dry spots.

Many variables work towards or against proper and consistent mold filling. The biggest factor is the consistency of the glass fiber pack. Best results are achieved by controlling the type and amount of reinforcement, as well as the location and extent of ply overlaps. This is achieved by designing the ply kit before the mold cavity is designed. This requires material selection prior to ply kit design, and includes not only the type of glass reinforcement, but the specific form (usually width) for that glass type. The benefits of this approach are two-fold: Minimizing material waste; and, ensuring consistent mold-fill performance.

3. DESIGNING THE REINFORCEMENT PACKAGE—There are various methods of preparing the reinforcing pack, including:

A. Preforming—This method produces the reinforcing pack in a upstream operation known as preforming. The preform is placed dry in the empty mold, the mold set closed, and the resin injected. The most rapid cycle times are achieved using the preform approach. The reinforcement pack can also be assembled in the empty RTM mold. The lower mold is engaged during this process, which adds directly to cycle time.

B. Continuous Filament Mat (CFM)—The most common reinforcement, Continuous Filament Mat (CFM) is also the least expensive. Its architecture results in resin-rich and fiber-rich areas that result in more fiber print than other materials. It is not very conformable and requires cutting and darting for complex geometries. CFM is the most commonly used reinforcement for conventional RTM processes.

C. Stitched Chopped Strand Mat (Stitched CSM)—Offers much greater conformability that CFM, the polymer fiber cross-stitches in Stitched CSM prevent the fiber wash that would be seen during the fill process with ordinary Chopped Strand Mat.

D. Other Options—Other stitched materials are used as structural materials. These are available in a wide variety of configurations, often with three or more distinct layers. A common example is 1808 material. This is a three layer material. The first layer is aligned glass fiber in the warp direction, while the second layer is aligned glass fiber in the weft direction, and the third layer is chopped mat.

E. Special Constructions—One interesting product comprises two layers of glass reinforcement separated by a layer of polymer fiber core. The polymer fiber core adds thickness, and thus bending stiffness, without the full weight of a glass ply. Available from several sources, these materials tend to be very conformable and provide good cosmetics. They do suffer from reduced inter-laminar shear strength due to the low strength of a polyethylene or polypropylene fiber ply.

A spun-bound polymer fiber ply works effectively as a print blocker when placed against the gel coat layer. With this approach, there is a trade-off between the cosmetic quality and the tendency of the gel coat layer to crack.

In vacuum infusion, the flexible bag film upper mold tends to compress the glass reinforcement so much that the permeability becomes very low, and therefore, the resin flows very slowly. Certain materials have been designed that resist compression and provide a ready flow path for the resin. These can be placed within the laminate thickness, or above the laminate for subsequent removal.

The ply kit must be designed and proven before designing the mold cavity. Material types and forms are selected by fiber architecture, areal weight and width, respectively. The ply kit is designed by determining the minimum number of lineal feet required of that width material to build the part thickness. This usually requires ply splices to be located somewhere on the part. Figure 5/V.2 illustrates how intentional ply splices can be used to minimize roll goods usage. Any overlap areas are designed in the part cavity in the form of additional thickness. This approach ensures consistent filling during the resin transfer operation by eliminating highly compressed areas in the reinforcement pack that serve as flow restrictions.

Nesting plies in a ply kit is another method of minimizing material usage. Nesting refers to the operation of

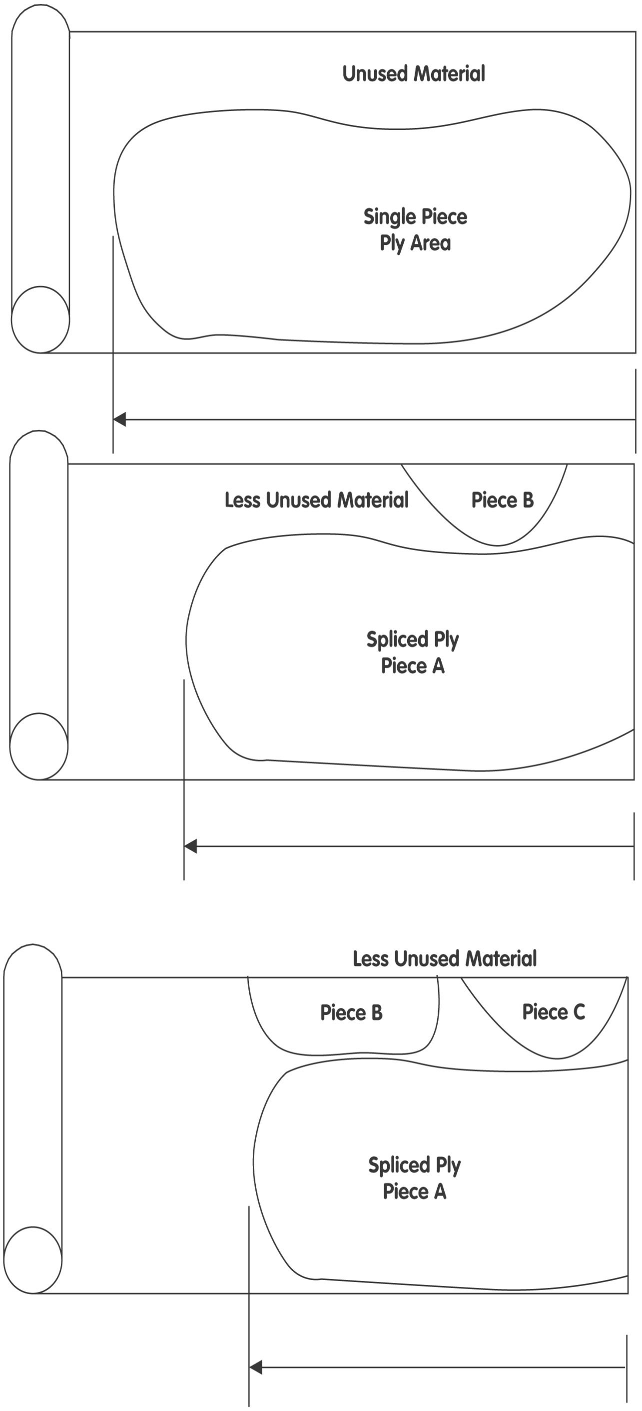


Figure 5/V.2—

orienting different ply details so that the greatest fraction of material is utilized. Plies from different parts should never be co-mingled in a single nest for the same reason that different parts should not be ganged together in a single mold; it leads to higher material usage. Replacing any one scrap part requires production of all the parts nested or ganged together. Nesting is common for aerospace designs in which individual ply details are precisely designed. Nesting is not the low cost approach to minimizing material usage unless the design is a minimum weight design. For a minimum weight design, ply splices must be precisely controlled in order to ensure design integrity. Ply splices are weak spots that must be accounted for in strength analysis. Seldom are glass fiber polyester resin composites designed to minimum weight. More likely, they are designed to minimum cost. Usually, ply splices can be located with concern for assembly fit tolerance and without regard for part strength provided that basic splice rules are followed. Above all, splices should never be superimposed through the thickness.

There are two types of splices: butt splices and overlap splices. These are described as:

1) The butt splice comprises two ply details oriented so that the edge of one ply is adjacent to the other. A butt splice should be avoided when the ply constitutes a significant fraction of the part thickness. Since the reinforcement is discontinuous across the splice, the joint is significantly weaker than the area away from the splice.
2) The overlap splice comprises two ply details oriented so that some portion of the end of one ply lies on top of the other. Overlap splices provide greater strength than butt splices. Overlap splices almost always require additional part thickness to accommodate the extra reinforcement material. Overlaps should never be less than 10 times the ply thickness. For good load transfer, the overlap ratio should be 20 times the ply thickness or better.

Butt splices are preferred when assembly fit tolerance requirements preclude additional part thickness.

Once the ply kit is designed, the materials should be used to hand laminate or vacuum infuse a part for prototype testing. This testing should evaluate part functionality and verify that the part thicknesses and reinforcements are adequate for the design. Careful attention to glass content and part thickness is imperative to a successful structural evaluation. Once the laminate schedule is proven, the prototype part should be cut into pieces to verify design thicknesses. Then and only then should the part cavity be designed and patterned.

4. CLOSED MOLD DESIGN DETAILS—Certain design details can greatly impact the performance of a mold set on the factory floor. While they are not critical for success, they can contribute to the robustness of the process.

A. Closed Mold Features that Add Robustness—The mold set should be designed so that the upper mold cannot be accidentally installed at the wrong clocking relative to the lower mold. If the lower mold is oriented at 12 o'clock, it should not be possible to close the mold at any orientation other than 12 o'clock.

The mold halves should separate with a true vertical motion. Many times, open mold parts are designed with some negative draft that requires the part to be pulled somewhat horizontally prior to being moved vertically out of the mold. This should be avoided in closed molding unless a device is fashioned to align and move the mold pieces into the mated configuration. This will also require special seal extrusions for proper functioning.

For both the Shell Laminate and Silicone Bag RTM processes, the mold assembly procedure should require only moderate hand pressure and the vacuum clamps, without resorting to mechanical clamps.

B. Closed Mold Framing and Thickness—For the three process variations, laminate thickness, structural reinforcement and construction materials vary considerably. A conventional RTM process minimizes fill times with high injection pressures. Its mold frame must not only support the weight of the mold laminate, but also the injection pressures. The frame itself must be structurally tied to the mold laminate. Both the lower and upper mold must be held to shape, and clamped together. The highest pressures are at the injection point, which is usually at the part center. This area needs to be adequately reinforced to prevent mold cavity deformation.

In contrast, an open mold frame only serves to support the weight of the mold laminate. The open mold frame acts as a cradle to support the mold laminate, with flexible glass laminate ties that don't couple the mold and frame structurally. This cradle design is much more tolerant of thermal shock than is a structural RTM framing system because thermal expansion differences between the steel reinforcement and glass laminate are absorbed by deflections of the light ties.

The shell laminate upper mold must be thin to resist cracking. This thinness allows the mold to bend and flex without generating a great deal of interlaminar shear stress. The laminate schedule should include one 20-mil layer of tooling gel coat, a 10-mil conformable glass veil directly against the gel coat, a chopped glass skin coat and one layer of a structural material such as 1708 or 1808. These are non-crimp fabrics with chopped mat stitched into a three layer assembly. Additional thickness should be used over the vacuum clamps, edge manifold and alignment devices. Vinyl ester should be the minimum grade resin material.

C. Closed Mold Alignment Devices—Problems with aligning the mold halves can show up in various ways. The simplest feature is a thickness variation in the part's vertical walls. One side is thinner while the opposing side is correspondingly thicker. In other cases, certain geometric features work to align the molds after the outermost vacuum seal is established. When this happens, the mold is not free to float into position. The interference that occurs at these geometric features can cause stresses that fracture a shell laminate upper mold. The resulting vacuum leaks will introduce air into the mold cavity, displacing resin and resulting in voids and/or dry spots in the part.

Extending the lower mold flange beyond the outer seal can provide a simple alignment feature. Any alignment device must engage itself prior to those features on the part. Figure 5/V.3 shows an alignment device that does not engage before part interference occurs. A better design is shown in Figure 5/V.4. In this sketch, the height of the diagonal surface is slightly greater than the height of the part features that otherwise would align the molds.

Three or four of these details are required to provide mold alignment. These details also serve as wedge points when the upper mold needs additional force to effect release, without causing damage to the rubber seal extrusions.

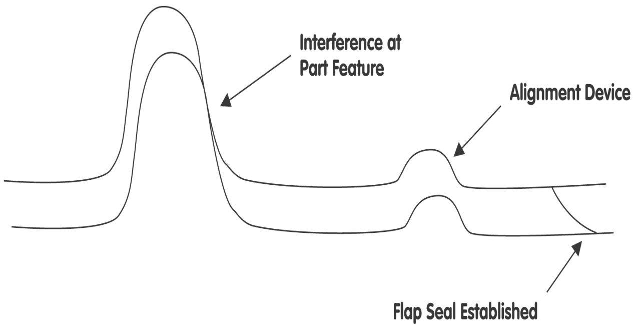


Figure 5/V.3—In the upper and lower mold line sketch above, the alignment device is ineffective. For clarity, not all mold features are depicted.

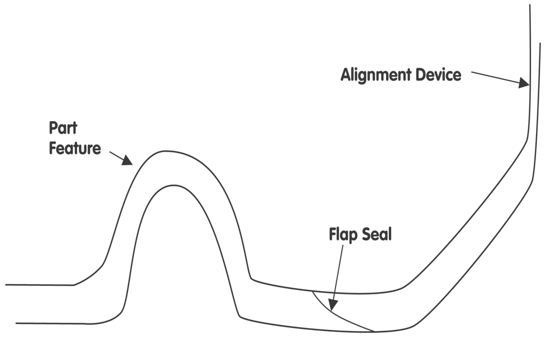


Figure 5/V.4—In the upper and lower mold line sketch above, the alignment device engages prior to flap seal contact or part feature interference. For clarity, not all mold features are depicted.

D. Closed Mold Demold Devices—A common problem when converting from open mold lamination to closed molding occurs when a lower mold is designed according to the criteria 'simply an open mold with a wide flange.' For the open mold, the part edge is often located on a vertical but drafted surface. The open molded part is commonly laminated with the glass reinforcement lapping over the flange inside edge, extending sometimes beyond the outside edge. This 'flange laminate' is subsequently trimmed from the part. However, this material provides a convenient demolding tab. Wedge tools are inserted between the mold flange and this offage, producing a lifting force that serves to begin the demolding event.

When the newly designed closed mold system features reinforcement that ends at the flange inside edge, there is no longer a 'flange laminate' that can be used as a demolding tab. When mold release requires mechanical assistance, wedges placed between the mold flange and the resin that filled the edge manifold easily break off the unreinforced resin without generating adequate lifting force to effect the part removal. Then, when wedges are placed between the mold sidewall and part, the forces are mostly in the horizontal direction, not in the vertical lifting direction. Although demold can be achieved in this manner, the more common result is gel coat scarring near the boundary of the edge manifold. This becomes progressively worse throughout the mold service life.

A fiber reinforced demolding tab can be incorporated in the molded part by extending the part surface upwards and outwards as shown in Figure 5/V.5. A simple bevel at 45 degrees from vertical accomplishes this with little added cost to tooling and part manufacture. The upper transition, from the diagonal to the horizontal, also provides an accurate guide for cutting the dry glass. This provides for consistency in the perimeter edge manifold width, with resultant increases in fill consistency.

E. Closed Mold Sealing Issues—A rubber extrusion seals against a physical surface by being compressed against the surface. One way to achieve this is to use a solid rubber profile that is compressed by moving the mold pieces together. This contact is best accomplished by moving the surfaces together in purely a perpendicular fashion. The initial contact occurs before the mold pieces are completely together. As the mold pieces are brought into contact, the seal is compressed.

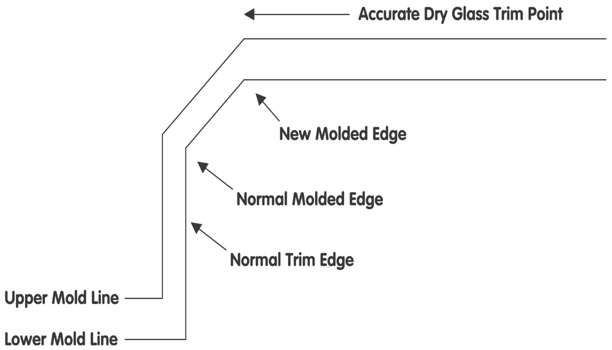


Figure 5/V.5—Extend the part so that there is a one inch long bevel at 45 degrees. This replaces the open mold flange laminate with a reinforced tab that assists in demolding when wedges are used.

When two mold pieces come together, there are two components to the motion. One is perpendicular to the surface while the other is parallel to the surface. Problems arise when bringing the surface and the extrusion into contact by motion that includes a parallel component. From the time when contact is first established until the seal is compressed, the parallel motion serves to drag the seal extrusion. Best results are obtained when the contact surfaces move together in purely a perpendicular fashion. Another method uses a hollow rubber profile that fits in a seal groove and is expanded by pressure once the mold pieces are assembled. Tucked inside the seal groove, the parallel motion cannot drag the seal extrusion.

F. Resin Transfer Ports, Manifolds and Vents for Shell Laminate RTM—Proper, symmetric mold filling is almost always best achieved with two injectors and one vent. These injectors will be called the 'primary' injectors. The resin is supplied to the entire part perimeter via the edge manifold. The resin flow will converge on the vented flow center. The flow center depends on the planform (the outline of an object when viewed from above) and the thickness. For a single cavity thickness, the flow center is in the planform center. If half the part is twice as thick, the flow center is skewed towards the thick area, because it takes more resin to fill up the greater thickness. The vent should always be located at the flow center.

The injectors are positioned by finding the 'longest straight line distance across the part.' For certain odd part shapes, this 'straight' line may be 'bent' at one or more locations. Measure a path across the part with a cloth tape measure (available in the sewing aisle at grocery or discount stores) until you identify the longest straight line path. The vent is almost always along this path. If the thickness is not constant, or if there is more part to one side of this line, the line will move in a parallel sense towards the 'thicker' or 'bigger' area. 'Thicker' is relative to 'longer' when it comes to the path because it takes more resin to fill up the thicker cavity. The two primary injectors are positioned at the part perimeter at these points.

For large parts, or extremely odd shapes, two secondary injectors may be used. These injectors are located midway between the primary pair of injectors. With a consistently thick part, the secondary injectors would be placed exactly between the two primary injectors. For parts with varying thickness, the secondary injector would be skewed towards the thicker portion of the part.

If parts are much longer than they are wide, secondary injectors are not used until later in the fill process. The delay time depends on the length to width ratio. The longer it is to wide, the longer the secondary injectors are delayed.

Certain part designs require a second resin manifold, a portion of the way from the edge manifold to the flow center. The edge manifold is used to fill the part until the resin reaches the inner manifold. Then, resin flow is directed through the inner manifold until the part is completely full. This is necessary for large parts, parts with high glass contents, or parts with heavy filler loadings and thus, higher viscosity matrix material.

G. Examples of Injector and Vent Locations—

1) Example Part #1 is a perfect square of uniform thickness. The longest straight-line path across the part is on the diagonal. Two injectors are located on opposite corners. The vent is located midway between the injectors, at the center of the square. Most often, the injectors are mistakenly placed at the middle of a side.
2) Example Part #2 is a long rectangle of uniform thickness. The longest straight-line path across the part is on the diagonal. Two injectors are located on opposite corners. The vent is located midway between the injectors, at the center of the rectangle.
3) Example Part #3 is a perfect circle of uniform thickness. The longest straight-line path is any one of the diameters. The injectors are located at both ends of the diameter and the vent is in the center.

5. PATTERNING THE UPPER MOLD—There are three methods of patterning the Upper Mold geometry. Each can produce the necessary upper mold, although with varying results.

A. Machining from Tooling Block—The highest degree of accuracy is achieved with a computer controlled cutting machine. Solid modeling techniques are used to produce a computer aided design (CAD) /computer aided manufacturing (CAM) data file that is used to control a numerically controlled (NC) cutting machine. A plug blank is first constructed from tooling block or other pattern materials.

B. Calibrated Sheet Pattern Materials—The lower mold can also provide the basis for the upper mold geometry. Pattern materials are placed into the lower mold to simulate the part thickness. Calibrated thickness sheet wax provides a high degree of accuracy. Other pattern materials can be used, particularly in thick areas. Mold features such as the edge manifold and vacuum clamps are also patterned upon the lower mold. This master plug then provides the surface definition for the upper mold.

C. The Master Part—A master part can be constructed using either hand lamination or vacuum infusion. The lower mold is used for this method. Careful attention to glass content is required to ensure accurate mold cavity thickness. Inside edges tend to be thicker than intended for hand laminated parts. Some amount of grinding may be necessary to achieve back side radius requirements. The entire part surface must be coated with a filler type primer material and finished smooth for molding the upper mold. This method does not provide the same accuracy as the other methods presented.

6. CLOSED MOLD FABRICATION—Most patterns are not durable and are suitable for only one pull. The demold process usually imparts sufficient forces to destroy the pattern. As a result, two options present themselves for consideration. Either one accurate upper mold can be built from the pattern, or a robust master with accurate upper mold geometry can be built that can yield any number of high accuracy upper molds.

In almost all cases, a Zero mold should be made from the pattern. This Zero mold is so named because it is used as a step in the production of tooling. It has the geometry of the upper mold, but is not the same construction. The Zero mold should be constructed in a manner similar to a conventional open mold. Steel framing is preferred but wood is acceptable when encapsulated in glass laminate. A fiberglass Master Mold is made from the Zero mold. The production molds are made from the fiberglass Master Mold. In this method, accurate upper mold geometry has been maintained through the successive moldings.

A common mistake is to forgo the master building step and build the upper mold directly from the pattern. The shell laminate upper mold can be easily warped or cracked during use as an RTM mold. When this happens, geometric accuracy is lost. Any master produced from a warped/cracked shell laminate upper mold will not have the correct geometry, consistent mold fill performance or accurate part thicknesses and weights. The only recourse is to re-pattern the upper mold using the lower mold as a basis. This requires that the lower mold be taken out of production for one to two weeks for the mastering process. With a high quality fiberglass master, a new shell laminate upper mold can be produced in two days time while the current mold set is still in production.

7. UPSTREAM PROCESSES—Processes that occur upstream of the liquid injection procedure reduce lower mold productivity when the mold is engaged in that activity. These processes can include taping/masking, applying and curing gel coat and loading the reinforcement materials. Multiple lower mold pieces can be used to address the need for Work In Process (WIP) at each operation.

For conventional RTM, the lower mold tooling cost becomes prohibitive when gel coat is an upstream operation. The benefits of rapid cycling disappear, and the need for high pressure injection wanes.

8. EXECUTING THE CLOSED MOLD PROCESS—During the course of building parts, certain actions can have undesirable effects. These effects can go unnoticed, or their causes can be unknown. Regardless, bad habits during process execution usually adds production cost.

A. Resin Transfer—The proper amount of resin must be transferred to the closed mold cavity. This is best accomplished with a resin pump that automatically shuts off after pumping the desired quantity of resin. For both the Shell Laminate RTM and Silicone Bag RTM processes, the mold cavities are full before they appear to be full. Resin pressure lifts the upper mold slightly as the mold fills. When the proper amount of resin is transferred, the vent vacuum causes the upper mold to return to its design height as the resin reaches the vent location. Properly executed, very little resin exits the mold cavity at the vent location.

Transferring the proper amount of resin is particularly important for Shell Laminate RTM. The resin flows from the perimeter edge manifold and converges on the vacuum vent at the flow center. As the fill process begins, there is no hydrostatic pressure on the resin flow front in the unobstructed flow channel. As the resin begins to move into the glass pack, the pressure increases according to the distance traveled through the glass pack and the rate of resin delivery. The pressure is highest at the edge of the part and lowest at the flow front. The pressure forces the upper mold to move upwards, producing a thicker mold cavity that requires more resin to fill. If resin pumping continues until the resin enters the vent trap, the pressures rise very quickly due to the small vent diameter relative to the large injector diameter. Usually, the higher exotherm temperatures experienced in the greater mass will cause the upper mold to take a permanent set. When this occurs, part thickness is permanently impacted for this mold set.

B. Vacuum Leakage—Whenever vacuum is applied to the mold vent, the mold set must be vacuum tight. Minor vacuum leaks are the root cause of most problems encountered when developing a closed mold system that features vacuum venting. These problems produce parts with dry spots and air voids. Vacuum integrity is one of the more difficult concepts for open mold technicians to appreciate, particularly when the vacuum leakage is through the mold laminate. On the other hand, technicians working with high pressure (i.e. autoclave) lamination processes quickly learn to respect leakage through the mold laminate.

1) Measuring Vacuum Leakage for the Closed Mold Set—A vacuum gauge is required to determine minor vacuum leakage rates. First, vacuum is applied to the mold set. The level of vacuum is noted. The vacuum source is interrupted and the time interval is measured. After a prescribed time, the level of vacuum is again noted. The difference between the initial vacuum and the vacuum after five minutes corresponds to the overall vacuum leakage rate.

For a very tight mold, vacuum will hold steady during the entire five-minute test. A leak-down of 0.5 to one inches of mercury is consistent with a well sealed mold. Even this level can make part manufacture difficult for high vacuum processes. For leak-down rates from one to two inches of mercury, most parts can be successfully fabricated. For a leak-down exceeding five inches of mercury in five minutes, successful part manufacture is difficult, if not impossible, even if vacuum is vented before resin gellation.

It is vitally important to have a leak-free mold. To ensure the vacuum integrity, a leak down test must be performed on every new mold set. Since there are two separate cavities in the Light RTM mold, the leak down test should be performed twice: once on the clamp chamber, and once on the part cavity.

First, ensure that both molds have a serviceable coating of release agent. Load the glass and cores into the lower mold. Prepare the upper mold by installing a new injection tube. Position the upper mold upon the lower mold. Install the resin trap at the vent location. Clamp off the injection tube. Apply a full vacuum to the clamp chamber via the clamp fitting. Apply half vacuum to the part cavity via the resin trap. If the mold set does not close and seal, apply a manual force to the upper mold until the flap seal contacts the lower mold flange. Once the flap seal is established, the upper mold will draw towards the lower mold until the inner seal comes into contact with the lower mold flange.

Vent the vacuum connection to the part cavity by disconnecting the line to the resin trap while maintaining the vacuum connection to the clamp chamber. The inner seal should allow the clamp to maintain a closing force between the mold halves.

Interrupt the vacuum supply to the clamp cavity without venting the clamp to atmosphere. Monitor the level of vacuum present in the clamp cavity as time passes. The clamp should maintain enough vacuum to remain clamped for 30 minutes or longer. If the clamp does not maintain vacuum very long, there is a leak. It may be necessary to find and repair this leak.

Once vacuum integrity has been established for the clamp chamber, apply vacuum to the part cavity. At this point, both the clamp and the part cavity are under vacuum. After a few minutes, interrupt the vacuum supply to both the clamp and part cavity. Monitor the level of vacuum present in the part cavity as time passes. The part cavity should maintain vacuum for 30 minutes or longer. If the part cavity does not maintain vacuum very long, there is a leak. It is probably necessary to find and repair this leak.

Some leaks are not harmful. If the clamp leaks, and if that leak is NOT across the inner seal, and if the vacuum system can keep ahead of the leak, successful molding is possible. If the part cavity leaks, and if that leak is right at the resin trap vent location, successful molding is possible.

If, however, the part cavity leaks, and if the leak's location is away from the vent location, the vent vacuum will draw air into the part, and the displaced resin will accumulate in the resin trap. A large leak will allow most of the resin to exit the part via the vent fitting. If the resin trap overflows, resin will enter the vacuum system and require immediate removal.

2) Vacuum Leakage through Laminate Porosity in the Closed Mold Skin—All laminates contain some amount of porosity or micro-porosity. When this porosity is great enough, atmospheric air will leak into the mold cavity by traveling through the porous laminate.

Of all the possible leakage paths, this one is the most difficult for process engineers to comprehend. A simple experiment can be performed to show this phenomenon. The experimenter should build two vacuum bags. One vacuum bag should be on the mold side of a porous laminate. The other vacuum bag should be on a glass plate. Each vacuum bag should be equipped with both a vacuum gauge on the resin feed line, and on the vent line, a vacuum source that can be interrupted without venting the bag to atmosphere.

Perform a vacuum leak-down test on both vacuum bags. The vacuum bag on the glass plate serves to demonstrate that the student can successfully build a good vacuum bag which maintains vacuum for a long time.

If the mold skin porosity is resulting in vacuum leakage, successful part manufacture may not be practical.

3) Resin Outgassing—During resin manufacture, air is introduced into the resin during blending operations. This air dissolves into the resin in the same way that carbon dioxide dissolves into water to form the fizz in carbonated beverages. Reducing the pressure above the solution and increasing its temperature provides a driving force which forces the dissolved gases out of solution in the form of bubbles.

During the resin transfer operation, applied vacuum first acts to de-gas the resin, pulling dissolved air out of the resin solution. It is normal for bubbles to form at the resin flow front. Many times this is mistakenly attributed to 'styrene boil.' Instead, these bubbles are largely due to degassing.

Vacuum does not draw air bubbles 'through' the resin. On a sealed system, vacuum will cause the air bubbles to become larger in accordance with Boyle's Law. Applying vacuum to the vent merely increases the pressure head that forces the resin to flow through the mold cavity. Air bubbles move through the mold cavity by virtue of being carried by this resin flow. Any air in the system must exit during the resin transfer operation. Problems arise when air enters the system late in the fill process. There must be enough resin flow to carry the bubbles to the vent. This requires that more resin enters the mold cavity.

C. Downstream Impacts—Operations that occur downstream from the closed mold process can be affected by changes in the part that directly result from the change to closed molding.

1) Open Mold Tabbing—Open mold tabbing is the process of affixing a secondary structural element to a previously laminated part using open mold laminating techniques. This is a secondary lamination process. Secondary lamination requires that the underlying surface is not fully cured and not extremely smooth. Timing is the key parameter. The underlying part is allowed to gel and cure to some extent. To achieve a good secondary bond, the secondary laminate must be applied before the part cures too much.

If too much time elapses, then the part surface must be mechanically abraded prior to applying the secondary laminate. This procedure removes contaminates as well as provides a mechanical 'keyway' for the secondary laminate adhesion. An alternative to mechanical abrasion is the use of a peel ply. The peel ply produces a textured fracture surface when it is removed from the cured part.

There are two components to secondary laminate adhesion. One is a chemical bond with resin unsaturation in the underlying part. The second is a mechanical bond due to the surface roughness on the underlying part.

To understand the importance of mechanical bonding, consider the following scenario. Select a well-cured substrate comprising a molded surface with exterior gel coat. On one half of the substrate, do not perform any sanding; this will be called the smooth substrate. On the other half of the substrate, lightly sand the gel coated surface with an aggressive sandpaper, such as 60 grit, until the gloss is removed and the surface is covered with sanding scratches; this will be called the sanded substrate. Solvent-wipe the surface to remove all traces of dirt and contaminants from both halves of the substrate. Apply a nominal thickness (1/4 to 1/2 inch thickness) of catalyzed polyester bonding putty to each half of the substrate. Allow the bonding putty to cure. Evaluate the bond quality by using a putty knife to pry the bonding putty from each half of the substrate. The putty on the smooth gel coat substrate will release with much less effort than the putty on the sanded gel coat substrate. The difference is due entirely to the mechanical keyway provided by the sanding scratches. In this case, both pieces were equally well cured and not subject to oxygen inhibition as is the case with a back side open mold laminate.

2) Adhesive Bonding—The substrate surface features will determine the appropriate type of adhesive to use for successful bonding. Some adhesive types contain an etching agent that enhances the adhesion on smooth, gel-coated surfaces. Alternatively, some adhesive systems use a primer wipe to soften the substrate prior to bonding. Methacrylate adhesives are becoming increasingly popular as a replacement for open mold tabbing.

D. Conclusions—Variations of the RTM process are suitable to replace open mold lamination. Attention to detail is a key ingredient to the success of transitioning. Building an accurate mold cavity that is free from vacuum leaks is the pertinent challenge for Shell Laminate RTM and Silicone Bag RTM processes.

For rigid upper mold types, the fabrication of the upper mold must follow successful prototyping to include the ply kit and lamination schedule (not just in regards to fit and form, but also function). Designing the ply kit prior to the upper mold provides for the most economical part material usage. The upstream process of gel coating has a distinct impact on the economics of conventional RTM due to the time involved with applying and curing the gel coat. The downstream processes of secondary lamination and adhesive bonding must also be examined for suitability with a given closed mold process due to the different nature of smooth, molded surfaces.

E. Appendices—The following sections provide additional information that many consider useful.

1) Flow Theory—Flow through porous media can be described mathematically. A French civil engineer in the mid 1850's formulated a relationship known as Darcy's Law. This relationship is:

$Q = -KA\,dh/L$ Rate of Fluid Flow
Q is the rate of fluid flow
K is the hydraulic conductivity
A is the cross sectional area of the porous medium
dh is the change in pressure over the length L
L is the path length

This equation shows that which is intuitively obvious. The flow is quicker when the hydraulic conductivity is greater, when the flow area is greater, when the pressure drop is greater and when the fill path is shorter. Rapid fluid flow requires greater hydraulic conductivity, larger flow area, larger pressure drops and shorter fill lengths. The flow is slower when the hydraulic conductivity is lower, the flow area is smaller, the pressure drop is lower and the path length is longer.

The hydraulic conductivity is also known as the permeability. This permeability is greater when the fiber is less compacted. Conversely, when the fiber is highly compacted, the permeability is low, and flow is reduced. The orientation and arrangement of fibers in the reinforcing pack will also affect the permeability. These features are referred to as the fiber pack architecture.

To expand on Darcy's Law further and define the hydraulic conductivity K:

K = (Intrinsic permeability)*(fluid density)*(Acceleration due to gravity)/(fluid viscosity)

The intrinsic permeability of the porous media is the property determined by the reinforcement form and its degree of compression. A lower fluid viscosity causes an increase in the hydraulic conductivity with a corresponding increase in the rate of fluid flow.

The two resin properties of interest, density and viscosity, are both functions of temperature and degree of cure. As a mold fills, the viscosity increases until gellation occurs.

2) Shell Laminate Mold Design Checklist—

Lower Mold:

—Does my lower mold have features that allow me to wedge out a stuck part without causing damage to the mold surface?

—Is the boundary of the edge manifold easily identified to enable accurate material trimming?

—Is my flange design appropriate for my seal rubber extrusions?

—Will the upper mold fit in only one clock position?

—Does my mold set come together and separate with a pure vertical motion?

Upper Mold:

—Have I designed and proven my part?

—Have I designed my ply kit so that I know where my overlaps will be?

—Have I chosen cavity thicknesses that correspond to the materials and glass contents specified by the proven design?

—Have I identified the flow center and injector locations?

—Does my mold set have alignment devices that align the mold set before the part features force the molds to align?

—Does my mold set have features that allow me to wedge the upper mold off the part/lower mold without destroying my rubber seal extrusions?

3) Shell Laminate RTM—

Step-by-Step Process Description:

—Mask the lower mold flange at the flap seal for gel-coating. Apply gel coat.

—Load the cavity with specified glass and core.

—Trim reinforcement at the edge manifold.

—Place Upper Mold approximately in position.

—Install and clamp the injector tube(s).

—Install the vent line or resin trap.

—Apply vacuum to the part cavity at the vent first. Apply hand pressure to bring the outer flap seal into contact with the lower mold.

—Apply vacuum to the clamp cavity once outer seal integrity is established.

—Vent the part cavity to check the inner seal.

—Re-apply the vacuum supply to the part cavity. Perform Leak-down Test.

—Transfer the proper amount of resin into the part cavity. Clamp off the injector tube.

—Maintain vacuum on both the part cavity and clamp cavity until the resin gels.

—Once the resin gels, remove the resin trap and clean immediately.

—Maintain vacuum on the clamp chamber until the part cures sufficiently to meet the part and process design requirements.

—Remove the upper mold. Perform mold maintenance immediately.

—Allow the part to continue curing sufficiently to meet the part and process design requirements. Remove the part.

4) What makes a good Shell Laminate RTM mold design?

A properly designed and built Light RTM mold has certain features:

—The mold set is vacuum tight.

—The upper mold cannot accidentally be installed at the wrong clocking relative to the lower mold. If the lower mold is oriented at 12 o'clock, it is not possible to close the mold at any orientation other than 12 o'clock.

—Alignment devices align the mold set before the part's geometry does.

—The mold can be assembled and sealed using only moderate hand pressure and the vacuum clamps, without resorting to mechanical clamps.

—The fill is consistent from part to part.

—The glass is not so compressed as to prevent fiber wet out.

—A known amount of resin is transferred to the part cavity and very little (tablespoons) makes its way into the vacuum trap.

—The molds separate with a true vertical motion.

—It's easy to wedge the upper mold off the lower without damaging the rubber seal extrusions.

—It's easy to wedge the part off the lower mold without damaging the lower mold gel coat surface.

9. A DISCUSSION OF VACUUM—Vacuum bags work by using the Earth's atmosphere to provide a force. The weight of the Earth's atmosphere amounts to approximately 14.7 pounds per square inch. Whenever a vacuum is applied to a closed cavity, the Earth's atmosphere can apply up to 14.7 pounds per square inch against the outside walls of the closed cavity. This 14.7 pounds per square inch is for a full vacuum at standard temperature and pressure (STP). STP is defined by scientists to be 77°F at sea level and will produce approximately 14.696 psi of normal atmospheric pressure.

Vacuum is not an entity or a thing. It is just a pressure that is lower than normal atmospheric pressure. Pressure is a scale much the same as temperature; both indicate how much of something is present. Pressure indicates how many gas molecules are contained in a certain volume at a certain temperature. If there are zero gas molecules in a volume, there is zero pressure. There is no such thing as negative pressure. Pressure can only be positive or zero. The amount of vacuum can vary, but there is a maximum value of 14.7 psi vacuum. This is an average number; the exact maximum depends on one's altitude and weather conditions (current barometric pressure).

Consider an 'empty' open container at 77°F, at sea level on a standard Earth day. Close it and seal it. It would contain some number of gas molecules at one atmosphere of pressure, which is the same as 14.7 pounds per square inch absolute (psia) pressure. Since Earth's atmosphere is one of pressure, 14.7 psi absolute (psia) pressure is considered to be the same as zero psi gauge (psig) pressure. Zero psi gauge pressure means the gas is not compressed any more than it already is in the surrounding air. To convert, take absolute pressure and subtract 14.7 psi to get gauge pressure; conversely, one would take gauge pressure and add 14.7 psi to get absolute pressure. Most times, the word 'gauge' is left off, much the same as the words 'per square inch' are left off when it is said that 'The tire takes 35 pounds of air pressure'; neither is technically correct but both are used widely as an abbreviation.

Taking that same container of air, consider removing some portion of the air molecules. This would cause the pressure in the container to drop lower than the 14.7 psi absolute. For instance, the new pressure in the container might be 9.7 psi absolute. The amount of vacuum is the difference between the normal atmospheric pressure and the actual absolute pressure. In this case the amount of vacuum is 14.7 minus nine = five psi vacuum. In this example, the Earth's atmosphere is now exerting five psi of force on the outside of the container's walls. If one were to pump out all the air, one would have a full vacuum. A full vacuum is zero psi absolute, which is the same as 14.7 psi vacuum, which is the same as minus 14.7 psi gauge pressure. Notice that the gauge pressure is a negative number in this example. It is not a negative pressure. It is a negative number because we took the actual pressure, which was zero psi absolute and subtracted one atmosphere's worth of psi.

The amount of vacuum is generally not expressed in terms of pounds per square inch. Usually, vacuum is referred to as 'inches of mercury.' Even though vacuum is widely used, most people don't care how much vacuum they have as long as they have enough. Originally, most of the people who cared how much vacuum they had were scientists. In the laboratory, scientists can make a very accurate vacuum gauge with ordinary lab items. These simple gauges read vacuum in 'inches of mercury.' Since commercially manufactured gauges were originally sold mainly to the scientists, they used the same 'inches of mercury' scale of vacuum. On the other hand, the earliest compressed air gauges were used by engineers who made tools and other things that work with air pressure. These gauges have the units of pound per square inch because square inches are easy to measure, and calculating the force is simply multiplying the pounds per square inch (psi) times the square inches that the pressure is acting upon.

To understand inches of mercury, consider a U-shaped tube that is filled with mercury, with both ends pointing upward and open to the atmosphere. The mercury in the left side of the U is at the same height as the mercury in the right side of the U. Now, keep the left side of the U open to the atmosphere. Connect the right side of the U to a full vacuum. There is a certain amount of 'pull' to a vacuum. The atmospheric air pressure pushes downward on the mercury in the left side of the U. At the same time, there is a full vacuum pull on the right side. Since there is only a certain amount of vacuum pull, the mercury goes downward in the left tube, upward in the right tube until it balances out. Now the mercury in the right and left tubes are at different heights. If one measured the distance between the two, it would be 30.00 inches of mercury from a full vacuum. A partial vacuum is any amount of vacuum that is less than full vacuum.

COMPRESSION MOLDING: Introduction

Part Six, Chapter I

In Part Six

Compression molding involves molding a pre-manufactured compound in a closed mold under pressure and often using heat.

Typical compression molding applications include:

- Appliance housings
- Automotive body panels and structural parts
- Basketball backboards
- Cafeteria trays
- Door skins
- Furniture
- Electrical circuit boards and boxes
- Personal water craft
- Satellite dishes
- Shower/tubs and sinks
- Utility boxes

A pre-manufactured compound is a combination of some or all of the following: thermoset resin, catalyst, mold release, pigment, filler, various additives, and fiber reinforcement.

Compounds can be produced in several forms including sheet molding compound (SMC), bulk molding compound (BMC), and wet molding compound.

Two additional compound forms are Low Pressure Molding Compound (LPMC) and Low Pressure, Low Temperature Molding Compound (LPLTMC). These compounds can be either in sheet or bulk form but are specially formulated to allow molding at lower pressures and/or lower temperatures than conventional SMC and BMC. Lower molding pressures mean lower press tonnage requirements, which reduces the capital expense for a new press or increases efficiency of an existing press. Lower molding pressures can also mean lower tooling costs since materials other that tool steel can be used. Lower molding temperatures can result in lower tooling costs and lower energy costs.

The table below compares the various types of compounds:

Property	**Sheet Molding Compound (SMC)**	**Bulk Molding Compound (BMC)**	**Wet Molding Compound**
Part cross-section	Complex	Complex	Uniform
Parts per eight-hour shift	100-500	100-1000	50-100
Compounding equipment	SMC machine	BMC mixer	Mixer
Time required for maturation after compounding	2-5 days	0-2 days	None
Glass type	Chopped	Chopped	Preform
Mold charging	Charge weight and geometry are predetermined. Charge cutting and loading is done manually or by computer controlled slitting and loading.	Various (manual, injection or transfer)	Place perform in mold by hand and pour resin over
Molding temperature	Conventional: 270-320°F Low temperature: 180-220°F	Conventional: 270-320°F Low temperature: 180-220°F	Room temperature to 300°F
Molding pressure	Conventional: 500-3000 psi Low pressure: 50-200 psi	Conventional: 500-3000 psi Low pressure: 50-200 psi	<50 psi
Mechanical properties	Good	Low	High

COMPRESSION MOLDING: Materials and Typical Compound Formulations

Part Six, Chapter II

In This Chapter

1. RESINS—Unsaturated polyester resins (UPR) are the basis for most compression molding compounds. The type of UPR used varies depending on the performance requirements for the finished part and cost. Resins used for compression molding can be broken into four broad categories:

- Structural Resins—isophthalics and terephthalics
- Low Profile Resins
- General Purpose Resins—orthophthalic or dicyclopentadiene
- Specialty Resins

Structural resins are used in applications requiring excellent mechanical properties and/or temperature and chemical resistance. Low profile resins are used in applications requiring excellent part appearance or low surface profile such as automotive body panels. Low profile resins are characterized by high reactivity rather than polymer type. General purpose resins are used in applications that are cost-sensitive and have more lenient part performance requirements than structural or low profile applications. Specialty resins are designed for very specific application requirements such as weather resistance or flame retardancy.

2. SHRINKAGE CONTROL ADDITIVES—Unsaturated polyester resins shrink five to seven percent by volume during cure. This shrinkage can create a variety of defects in molded parts such as surface distortion, waviness, fiber print, and warpage. Shrinkage of unsaturated polyester resins can be controlled by the use of shrinkage control additives. However, use of shrinkage control additives reduces mechanical properties. Shrinkage control additives can be divided into two categories: low shrink additives and low profile additives.

A. Low shrink additives minimize shrinkage but do not eliminate it. Low shrink additives are used in applications with lenient surface appearance and dimensional stability requirements. Low shrink additives are especially useful in applications requiring pigmentation. Common low shrink additives are polystyrene, polymethyl methacrylate, and rubber elastomers.

B. Low profile additives, when used at appropriate levels, eliminate shrinkage and can even result in slight expansion. Low profile additives are used in applications requiring excellent surface appearance and dimensional stability such as automotive body panels. Molding compound formulations using low profile additives have limited pigmentability, generally white or light pastel colors. Common low profile additives are saturated polyesters and polyvinyl acetate.

Blends of low shrink and low profile additives are frequently used to impart the benefits of both types of additives to the molded part.

3. CATALYSTS—Catalysts initiate the chemical reaction of the UPR and monomer. For elevated temperature processing the heat from the mold causes the catalyst to decompose initiating the reaction. For ambient or low temperature processing, a promoter or a combination of promoters is needed to accelerate decomposition of the catalyst. Typical promoters are cobalt and amines. Catalyst selection depends on the molding temperature. Some common catalysts and their molding temperature ranges are given in the following chart Two or more catalysts are often used to ensure complete cure.

4. INHIBITORS—Inhibitors are used to control compound shelf life and cure rate. Two commonly used inhibitors are butylated hydroxy toluene (BHT) and para-benzoquinone (PBQ). BHT has little effect on elevated temperature cures but does significantly lengthen room temperature shelf life. PBQ lengthens both room temperature shelf life and cure time.

5. PIGMENTS—Many, but not all, molding compounds are pigmented and a broad range of molded-in colors can be achieved. However, some limitations on color do exist. Fillers used in compression molding compounds can add color to the compound and limit the possible colors of the molded part. Also, the type of shrinkage control additive used can limit color possibilities. Generally, darker and richer colors are more difficult to achieve. Darker colors can shift hue during maturation/aging.

Catalyst Type	Processing Temperature Range °F
Benzoyl peroxide (BPO) and amine promoter	90-120
Benzoyl peroxide (BPO)	180-250
Tert-butyl peroxy-2-ethyl hexanoate (PDO)	220-280
Tertiary butyl perbenzoate (TBPB)	250-320

Pigments are added during compound manufacture in either powder or pre-dispersed paste form. Powder pigments can be difficult to disperse in the compound due to agglomeration. Pre-dispersed pigment pastes are easier to disperse and can be used at lower concentrations than dry powders. Common white pigments are titanium dioxide and zinc sulfide. Carbon black is often used for black pigmentation. Pigment paste dispersions generally consist of the pigment dispersed in an unsaturated polyester grinding vehicle. Pigments can affect the shelf stability and reactivity of molding compounds.

6. MOLD RELEASE—Compression molding compounds generally contain internal mold release. Some of the most commonly used internal mold releases are zinc stearate, and calcium stearate. Liquid mold release additives are also available. Use of these additives result in much lower SMC paste viscosity than that obtained with stearates.

7. FILLERS—Compression molding compounds with the exception of those used to mold parts for structural applications are highly filled. Fillers lower material costs while enhancing molded part appearance, reducing shrinkage, promoting the flow of glass reinforcement during molding, and contributing to a harder, stiffer part. However, fillers increase the viscosity of molding compound paste, limiting the amount of glass that can be used. Glass content is directly related to the mechanical properties of the molded part with higher glass contents yielding superior mechanical properties. Fillers also provide opacity and increased part density. The most common fillers are calcium carbonate, clay and alumina trihydrate. Clay fillers are often used in combination with calcium carbonate fillers to control the compound paste viscosity, promote flow and improve crack resistance in molded parts. Alumina trihydrate is generally used in applications requiring flame retardancy and/or good electrical properties.

8. THICKENERS—Thickeners are used in sheet molding compound (SMC) to transform the material in to a manageable, reproducible molding material. Thickeners chemically react with the resin portion of the compound resulting in an increased viscosity. Thickeners are the last component added to the compound paste and begin to react immediately after addition.

Typical thickeners are alkaline earth oxides or hydroxides such as MgO, Mg(OH)2, CaO and Ca(OH)2. MgO provides the quickest thickening of those listed and is the most commonly used thickener. Thickeners are sometimes used in combination to achieve a particular thickening profile. Thickeners can be added as a powder or pre-dispersed paste. As with pigments, pre-dispersed pastes are easier to disperse in the compound and generally result in more consistent thickening.

A typical thickening profile is described in terms of paste (all ingredients except reinforcement) viscosity. During compounding, the paste viscosity must be low enough to allow for pumping and reinforcement wet out. Compounding is generally accomplished in less than 30 minutes from the time of thickener addition. Initially (immediately after thickener addition), paste viscosities are 10,000 to 60,000 cps (similar to thick pancake batter). The paste viscosity typically increases to 300,000 to 1,000,000 cps (similar to pudding) in the first 60 minutes. After compounding, the material is moved to a maturation room, typically maintained at 90°F, until it reaches its release viscosity. At the release viscosity the compound has the required characteristics to allow it to be molded. These characteristics include the following:

- The compound must be manageable to allow for charge preparation.
- The viscosity must be high enough to carry the fiber reinforcement as the material flows in the mold.
- The viscosity must be low enough to permit sufficient flow for mold filling at reasonable molding pressures.

The release viscosity is typically between ten to 30 MM cps (similar to bread dough) and is achieved in one to four days. The viscosity of the material continues to increase even after it has reached its release viscosity. The rate of this increase determines the molding window of the material. SMC may be moldable up to 100 million cps depending on part complexity and molding pressure. Factors effecting thickening of a SMC formulation include thickener type and level, the acid value of the UPR, molecular weight of the UPR, and water content of the compound.

9. FIBER REINFORCEMENT—Many types of fiber reinforcements including glass, carbon/graphite and aramid can be used in compression molding. The most common fiber reinforcement in compression molding is glass. Various forms of glass fiber are used depending on the type of compression molding compound being produced and molded. Chopped fibers ranging in length from 1/8 inch to 1/2 inch are used in bulk molding compounds. Continuous rovings are used in SMC production. The roving is chopped to 1/2 inch to two-inch lengths during the SMC compounding process. The most common length of glass fiber for SMC is one inch.

Glass fiber preforms, made to the general size and shape of the part, are used for wet molding and cold molding. For these processes, the glass and compound paste are combined during molding rather than during compound manufacturing as for BMC and SMC. Please refer to Part Five, Chapter III for more information on glass fiber preforms.

Surfacing veil is often used in wet or cold molding to provide a resin rich layer. Surfacing veil is a non-woven mat of either glass or polymer adjacent to the part surface. This improves molded part appearance and corrosion resistance. Reduced fiber blooming after sanding is another benefit.

Another factor in glass fiber reinforcement selection is the type and amount of sizing. Sizing is applied during glass fiber manufacture and holds the individual glass filaments together to form glass fiber strands. Glass fiber used in compression molding generally has one to three percent sizing by weight. Sizings can influence fiber characteristics such as choppability, abrasion resistance and resin wetout. Sizings are categorized by their solubility. Sizings that have low solubility are categorized as hard. Fibers with hard sizings have good strand integrity, are easy to chop, and have good strengths. However, fibers with hard sizings can be difficult to wet out during compounding, and can result in fiber print and non-uniform pigmentation in molded parts. Sizings that are highly soluble are categorized as soft. Fibers with soft sizings can be difficult to handle and chop; however, they are easy to wet out during compounding and contribute to good surface profile and uniform pigmentation in molded parts. Fibers with medium sizings have characteristics in between fibers with hard and soft sizings.

10. SPECIALTY ADDITIVES—Other additives used in compression molding compounds include:

- Surfactants to reduce the viscosity of filled systems allowing more filler to be used.
- Additives to improve flame retardancy such as antimony trioxides, tris phosphates, chlorinated paraffins and zinc borates.
- Additives to improve weathering such as ultraviolet (UV) absorbers.
- Additives to improve compatibility between resins and shrinkage control additives

11. TYPICAL COMPOUND FORMULATIONS—Typical formulations for SMC, BMC, wet molding and cold molding compound are shown in the tables on this page:

SMC Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage control additive	Low shrink additive: Polystyrene Polymethyl methacrylate Rubber elastomer Low profile additive: Polyvinyl acetate Saturated polyester	0-45 parts
Catalyst	t-Butyl perbenzoate	1-2 parts
Inhibitor	para-Benzoquinone (PBQ)	0.005-0.05 parts
Pigment	Various	As required
Mold release	Zinc stearate	3-6 parts
Filler	Alumina trihydrate Calcium carbonate	150-250 parts
Thickener	Group II Alkaline earth oxides Hydroxides--MgO, $CA(OH)_2$	0.5-1.5 parts
Glass fiber	Continuous roving chopped during compound production, ½ to 2-inch lengths, commonly I-inch lengths	15-65%

BMC Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage control additive	Low shrink additive: Polystyrene Polymethyl methacrylate Rubber elastomer Low profile additive: Polyvinyl acetate Saturated polyester	0-45 parts
Catalyst	t-Butyl peroctoate (injection or transfer) t-Butyl perbenzoate (manual)	1-2 parts 1-2 parts
Inhibitor	Para-Benzoquinone (PBQ)	0.005-0.05 parts
Pigment	Various	As required
Mold release	Calcium stearate	7-12 parts
Filler	Alumina trihydrate Calcium carbonate	200-400 parts
Glass fiber	Chopped roving 1/8 to 1-inch lengths	10-30%

Wet Molding Formulation Component	Typical Materials	Quantity
Resin	Unsaturated polyester	55-100 parts
Shrinkage control additive	Low shrink additive: Polystyrene Polymethyl methacrylate Rubber elastomer Low profile additive: Polyvinyl acetate Saturated polyester	0-45 parts
Catalyst	Various	Various
Inhibitor	Various	Various
Pigment	Various	As required
Mold release	Fatty acid or stearate	Various
Filler	Alumina trihydrate Calcium carbonate	< 100 parts

COMPRESSION MOLDING: Compounding Processes and Equipment

Part Six, Chapter III

In This Chapter

1. **Sheet Molding Compound**
2. **Bulk Molding Compound**
3. **Wet Molding Compound**

1. SHEET MOLDING COMPOUND—The sheet molding compound process involves three basic steps. First, a compound paste is mixed that includes all the formulation ingredients except for the reinforcement. Second, the compound paste and reinforcement are combined and formed into a sheet. Third, the compound is allowed to thicken or mature.

A. Mixing of Compound Paste—Mixing of the compound paste can be done by batch, continuously or as a combination of batch and continuous mixing called batch/continuous mixing. For all paste mixing processes, the paste must be well mixed to ensure all components are completely dispersed. Highly filled compound pastes will heat during the mixing process and the temperature must be monitored. To control the thickening reaction, the temperature of the paste when delivered to the compounding equipment should be 85°F to 90°F for batch processes. Higher temperatures can be used for continuous processes.

1) Batch Mixing—Batch mixing involves mixing the compound paste in a mixing vessel such as a pail, drum or mixing kettle using a high shear cowles mixer. All formulation components are added to the mixing vessel manually. Batch mixing is an economical method adequate for preparing small amounts of compound paste for short production runs. Batch mixing has some disadvantages for long production runs, including low material efficiencies, batch-to-batch variations and labor requirements for delivering the batch mix to the compounding equipment.

2) Continuous Mixing—Continuous mixing is best for long runs. This method involves pumping liquid ingredients and metering dry ingredients to a continuous mixer. Continuous mixing results in very consistent compound due to accurate pumping and metering of the ingredients. Continuous mixing also results in very little waste. However, the length of setup time makes short runs of multiple formulations impractical.

3) Continuous/Batch Mixing—Continuous/batch mixing is a combination of the batch and continuous mixing processes that uses 'A' and 'B' component batch tanks. The 'A' side generally includes all compound paste ingredients except thickener. The 'B' side consists of thickener or thickener pre-dispersed in a non-thickenable resin mix. The 'A' and 'B' sides are pumped at a predetermined ratio through a static or dynamic mixer to the compounding equipment.

B. Compounding—The compound paste and reinforcement are combined and the compound formed into a sheet using an SMC machine. SMC machines are sized by the width of compound that they produce. SMC machine widths vary from two feet to five feet. The most common width is four feet. A schematic of an SMC machine is shown below:

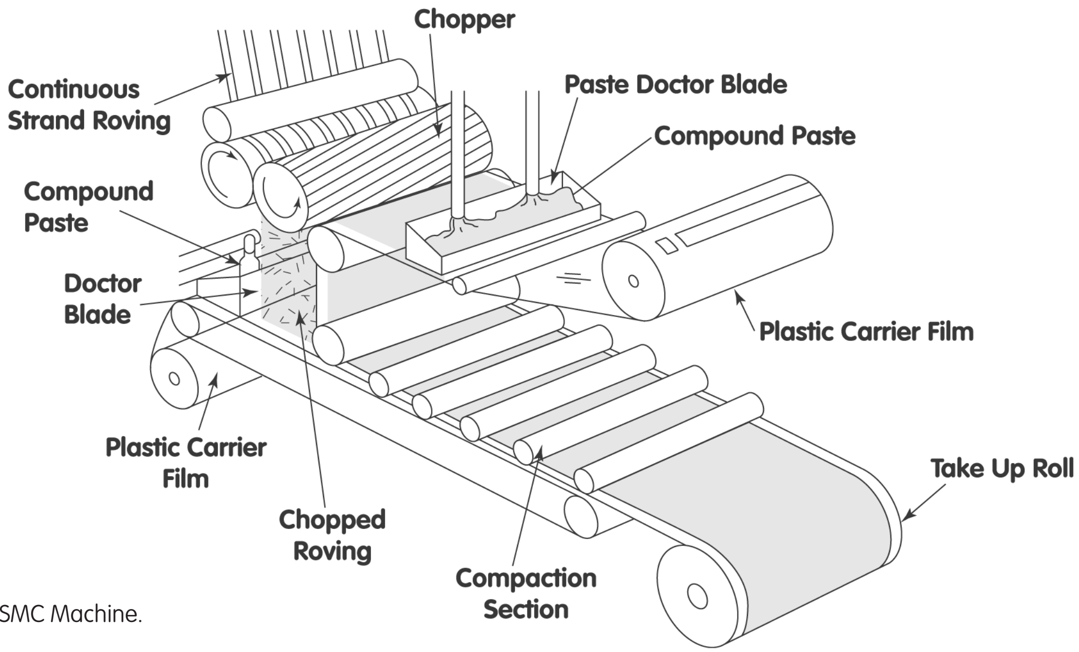


Figure 6/III.1—SMC Machine.

The compound paste is delivered to two reservoirs called doctor boxes; it is deposited on a carrier film that is being pulled through the machine. A metering blade called a doctor box blade that is set to a predetermined height above the film controls the amount and thickness of the compound paste deposited on the film. Continuous strand roving is pulled through a glass chopper and the chopped glass fiber is dropped on the compound paste on the lower film. The upper and lower films meet so that a sandwich is created between the carrier films consisting of two resin layers with chopped glass in the center. The carrier films are pulled through a compaction section in which pressure is applied to accomplish glass wet out. After compaction, the material is either wound on a take-up roll or festooned (folded similar to computer paper) into a box and moved to a thickening or maturation room.

The glass content of the SMC is determined by the height of the doctor box metering blades, the speed of the glass chopper and the speed at which the carrier films are being pulled through the compounding machine. Glass content of the SMC is generally verified during production by comparing the areal weight of the compound being produced with the areal weight of the glass being dropped on the compound. The carrier film is typically a nylon/polyethylene co-extrusion. The nylon prevents monomer loss through the film and the polyethylene can be used to heat seal the compound edges to prevent monomer loss. Film edges can also be folded or taped to prevent monomer loss. The pressure in the compaction section is an important process parameter. The compaction pressure needs to be high enough to wet out the glass, yet low enough to prevent compound from being squeezed out of the film edges.

C. Thickening—The thickening or maturation room is typically controlled at 90°F to provide consistent thickening of the SMC compound. To verify thickening and determine compound readiness for molding, a retain of the compound paste is taken after thickener addition, but prior to glass addition. This retain is stored with the SMC and monitored for viscosity. A Brookfield HB viscometer with T-bar spindles is typically used for these viscosity measurements.

2. BULK MOLDING COMPOUND—During the manufacture of bulk molding compound all formulation components are combined in the mixer. One of the most common mixer types is a sigma blade mixer shown below. Liquid components of the formulation are pumped or manually added to the mixer and agitated until dispersed. Dry components, except for glass fiber, are added next and mixed until thoroughly wet. The glass fiber is the last formulation component added and is mixed in until thoroughly wet. Continued mixing of the compound after glass wet out can result in unnecessary degradation of the reinforcement, which can cause reduced mechanical properties of the molded part. BMC is ready to mold when it is discharged from the mixer.

3. WET MOLDING COMPOUND—Wet molding compound is the oldest and simplest compression molding compound form. Reinforcement is incorporated during the molding process rather during compounding. Manufacture of wet molding compound involves mixing of the formulation components using a simple cowles mixer.

COMPRESSION MOLDING: Molding Processes and Equipment

Part Six, Chapter IV

In This Chapter

1. **Introduction**
2. **Charging**
3. **Part Formation**
4. **Finishing**

1. INTRODUCTION—As stated earlier, compression molding involves pressing and curing a pre-manufactured compound in a closed mold cavity under pressure and often heat.

The compression molding process involves three steps. First, the compound is inserted or charged into the mold. Second, the mold closes and the part is formed. Third, the part is removed from the mold and finished. One to two operators per press are generally sufficient even for rapid cycle times. Additional operators may be required for very large parts. Operators can work on charge preparation for the next part or part finishing of the last part during pressing.

2. CHARGING—Charging of the material to the mold varies based on compound form.

A. SMC—The charge must be prepared by removing the carrier film from the sheet and cutting the sheet to the desired shape. Cutting can be done manually or by computer-controlled slitting. Two major factors influence the configuration of the charge:

1) First, the charge must contain enough material to fill the volume of the closed mold. Since in most cases it is impractical to measure volume, the amount of charge added to the mold is controlled by weight. The standard charge weight for a specific compound and mold are often determined experimentally. Depending on part size and the areal weight of the SMC, several layers of SMC may be needed to achieve the required weight.

2) Second, the surface area of the charge must be sufficient so that the material has time to flow and fill the mold prior to gelation. As the surface area of the charge increases, the chance of trapping porosity in the molded parts also increases. Flow of the material in the mold helps to remove air from compound. Complex parts may require that several separate charges be placed throughout the mold to ensure complete fill. One drawback to multiple charges are that knit lines are created when the material flows and the charges meet. Knit lines are often low in strength and are susceptible to cracking. The shape and surface area of the charge are again generally determined experimentally for a specific compound and mold combination. The surface area of the charge is generally referred to as a percentage of the mold surface area or mold coverage.

After the charge is prepared, it may be loaded into the mold manually or with automatic loading equipment.

B. BMC—Three basic methods are used for charging BMC to the mold:

1) Hand charge placement is similar to charging of SMC in that the charges are controlled by weight. After weighing, the charge is placed in predetermined areas of the mold.

2) Transfer involves the use of a plunger to force material into the mold.

3) Injection involves use of a screw extruder to push material into the mold. For transfer and injection molding, pressure applied to the mold serves to hold the mold together during the compound charging rather than to compress the material into the mold.

Transfer and injection compound charging processes have shorter cycle times and require less labor than hand charging, but also require more capital expense.

For wet molding, a fiber preform is placed in the mold and the compound paste is poured into the mold over the preform. The pressure applied to the mold during closing forces the paste into the preform, wetting the glass.

3. PART FORMATION—Compression molding is done using a matched-die tool. A schematic of a simple compression molding tool is shown below:

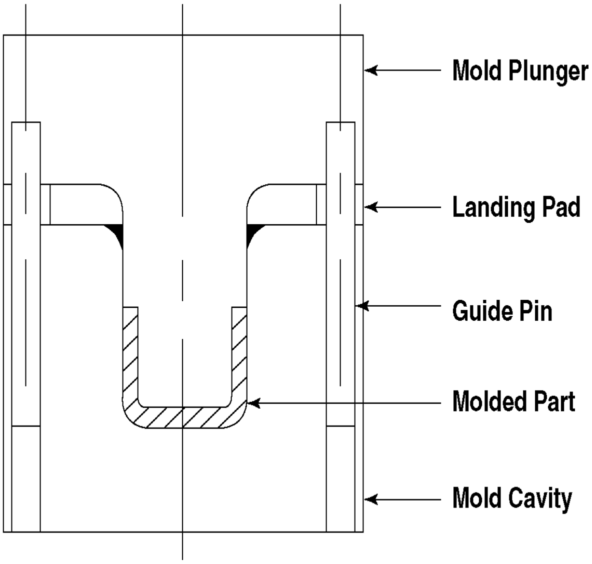


Figure 6/IV.1—Compression molding tool schematic.

COMPRESSION MOLDING: Molding Processes and Equipment

A. The tool consists of a cavity and a plug or plunger. Guide pins maintain the proper relation between the tool members. The tool cavity forms the outer surface of the part. The tool plunger forms the inner surface of the part being molded and serves to compress the compound when the tool is closed. The molding compound is thus confined to the open space between the plunger and cavity while it cures. Numerous features can be incorporated into the molds to facilitate production.

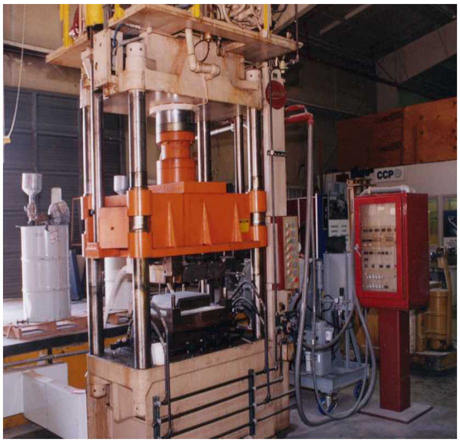


Figure 6/IV.2—Hydraulic press.

B. Elevated temperature molding requires provision for heating in the mold design. Some presses are equipped with heating platens that transfer heat to the molds. In some mold designs, the cavity and plunger are drilled to permit a heating medium to circulate for heating. Common heating mediums are oil or steam. A boiler or hot oil heater is required to heat the steam or oil and circulate it between the mold and heating unit. Knockout or ejector pins are often used to push the piece away from the mold.

C. Conventional compression molds are made from tool steel and are chrome plated. Alternate tool materials such as aluminum, nickel shell and composite can be used for low pressure compression molding. Tools made from these alternate materials are less expensive than tools made from tool steel; however, the production run life of tools made from these alternate materials are generally shorter than for tool steel.

D. Compression molding is done in hydraulic, air, or mechanically operated presses with hydraulic being the most common. A photograph of a hydraulic press is shown on this page. The two general types of hydraulic presses are downstroke and upstroke presses:

1) The downstroke press makes use of an overhead cylinder to move the top platen downward and apply pressure to the mold. This type of press is advantageous for molding large parts since the lower platen remains at a constant level and allows the operator to walk around the mold and on the platen as is sometimes required for charging or demolding large parts.

2) An upstroke press has the cylinder positioned below, and the ram moves the lower platen upward. This type of press provides greater safety for the operator. A malfunction in the hydraulic circuit causes the lower platen to drift downward opening the press. A hydraulic malfunction in a downstroke press could cause an operator to be trapped. The hydraulic press shown in the photograph in Figure 6/IV.2 is a downstroke press.

E. Molds are generally bolted to press platens with clamp bolts at the front and back. Sheets of phenolic or glass bonded mica are often used to insulate the mold from the press platen. Use of insulation reduces the heat transferred from the mold to the press and gives better thermal uniformity within the mold.

F. Mold daylight is the measurement between the upper and lower platens of the press in the open position. This dimension minus the stroke (the maximum platen movement) is the minimum die height to ensure that pressure will be applied to the part. The opening between mold halves must be sufficient to allow charging and part removal.

G. Press controls generally include pressure controls, closing and opening speed controls and a clamp timer. When the clamp time expires the press automatically opens. Safety features such as laser systems, that prevent the press from closing if an operator is too close to the press, can also be incorporated.

H. Molding conditions vary between the different compound forms. Typical molding conditions are shown in the table below:

Compound Forms	Pressure	Temperature	Time
SMC			
Conventional	500 - 3000 psi	270 - 320°F	30 seconds to 5 minutes
Low Pressure	50 - 500 psi	180 - 220°F	
Low Temperature	50 - 500 psi	180 - 220°F	
BMC			
Conventional	500 - 3000 psi	270 - 320°F	30 seconds to 5 minutes
Low Pressure	50 - 500 psi	180 - 220°F	
Low Temperature	50 - 500 psi	180 - 220°F	
Wet Molding Compound	<50 psi	Room temperature to 350°F	2 to 10 minutes

I. Molding pressure is influenced by compound flow characteristics, press tonnage and part complexity. On a particular tonnage press, the larger the part the lower the pressure that can be exerted. More complex parts require high molding pressures to ensure complete fill. Molding temperature and time are influenced by compound flow and cure characteristics and by part size and thickness.

4. FINISHING—Finishing of the part involves flash removal, drilling of any holes required for assembly, and packaging. Flash removal can be accomplished with sandpaper, a file or a box knife.

COMPRESSION MOLDING: Troubleshooting Guide

Part Six, Chapter V

In This Chapter

1. **SMC Compounding**
2. **BMC Compounding**
3. **Molding**

1. SMC COMPOUNDING

Problem	**Potential Causes**	**Suggested Remedies**
Glass content too low..	Doctor box blade too high .... Film speed too fast .... Glass chopper speed too slow	Reduce doctor box blade gap. Reduce film speed. Increase glass chopper speed.
Glass content too high	Doctor box blade too low .... Film speed too slow .... Glass chopper speed too fast	Increase doctor box blade gap. Increase film speed. Decrease glass chopper speed.
Dry fibers in SMC	Low compaction pressure .... Paste viscosity too high	Increase compaction pressure. Reduce paste viscosity or slow thickening rate.
Compound squeezing out edges of film	Compaction pressures too high .... Paste viscosity too low	Reduce compaction pressure. Increase paste viscosity or increase thickening rate.
Compound contains air after compaction	Compaction pressures too high .... Paste viscosity too low .... Glass content too high	Increase compaction pressure. Increase paste viscosity or increase thickening rate. Reduce glass content.
Shelf life stability	Premature gelation	Minimize pigment amounts with carbon black, iron (brown), and cobalt (blue). Use shelf life inhibitor. Do not expose the material to excessive heat (store in a cool room at 60 to 70°F.

2. BMC COMPOUNDING

Problem	**Potential Causes**	**Suggested Remedies**
Dry filler or glass (can result in mold abrasion, blisters, etc.)	Compound viscosity too high .... Mixing times too short	Modify compound formulation to lower the viscosity. Increase mixing times.
Compound too wet (can make compound difficult to charge and can result in blisters, porosity, etc.)	Compound viscosity too low .... Mixing times too long	Modify compound formulation to increase the viscosity. Decrease mixing times.

COMPRESSION MOLDING: Troubleshooting Guide

3. MOLDING

Problem	Potential Causes	Suggested Remedies
Non-fills ((mold not filled completely during pressing)	Charge weight too low	Increase charge weight.
	Compound gels before mold is filled	Decrease molding temperature; decrease mold closing time; increase molding pressure; decrease compound reactivity.
	SMC charge area too small	Increase SMC charge area.
	Tool shift deflection	Move charge toward non-fill area.
	Material discharged from mold	Decrease pressure; reduce clearance of mold-shear edges.
	Trapped air	Remove trapped air from charge prior to compression; decrease area of SMC charge to increase flow.
	Molding on stops and cocked die/platen	Increase charge weight after confirming gap is 0.003 inch to 0.010 inch around all sides of the mold.
Blisters	Trapped air	Remove trapped air from charge prior to compress-ion; decrease area of SMC charge to increase flow.
	Trapped or unreacted monomer	Reduce mold temperature; decrease compound reactivity; reduce styrene content of compound.
	Dry glass in compound	Increase SMC roller compaction; increase mixing time for BMC.
	Weakness at knit line	Modify charge to prevent formation of knit line.
	Incomplete curing	Increase cure time; increase mold temperature; increase compound reactivity.
	Contaminants such as moisture, press oils, lubricants, and external mold release	Check mold, SMC, and raw materials for contaminants.
Cracks	Excessive shrinkage	Modify compound formulation to provide better shrinkage control.
	Weakness at knit line	Modify charge to prevent formation of knit line.
	Sticking to mold surface	Modify mold release in compound; apply external mold release to mold.
	Sticking to flash area	Clean and wax flash area.
	Insufficient shrinkage	Modify compound to increase shrinkage.
	Sever undercuts or ejector pins holding part down, causing fracture	Remove problem undercut.
	Unbalanced ejector pins/plate	Verify ejector pin motion.
	Ejector speed is too fast	Reduce ejection speed.
Surface porosity	Area of charge is too large; air cannot escape because of short flow path	Decrease charge area.
	Pre-gel	Decrease mold temperature; increase closing speed; decrease compound activity.
	Unwet glass or air in compound	Increase SMC compaction pressure; increase BMC mixing times.
	Low viscosity compound	Increase SMC maturation viscosity; increase filler or glass content.
	Contaminants such as moisture, press oils, lubricants, and external mold release	Check mold, SMC, and raw materials for contaminants.
	Air entrapment due to dirty shear edges and vacuum ports	Clean shears or vent ejector pins.
	Mold halves too close in temperature, entrapping air	Maintain temperature differential to keep shears edge open to allow air to escape.

COMPRESSION MOLDING: Troubleshooting Guide

MOLDING (continued)		
Problem	**Potential Causes**	**Suggested Remedies**
Warpage or distortion of molded part	Shrinkage after demolding	Cool parts in jigs having desired shape; modify compound to improve shrinkage control.
	Incomplete cure	Increase cure time; increase mold temperature; increase compound reactivity.
	One mold surface much hotter than the other	Reduce differential between mold surfaces.
	Unbalanced construction	Change laminate design.
	Fiber orientation	Shorten flow path by modifying charge; increase compound viscosity to improve fiber carry.
Wavy surface on flanges or ribs	Interruption of uniform flow	Increase pressure; change mold design; modify charge.
Wavy surface on main part surface	Insufficient shrinkage control	Reformulate compound to improve shrinkage control.
Sink marks at rib or flange locations	Non-uniform shrinkage during molding	Reformulate compound to improve shrinkage control; increase mold temperature on one half of mold; shorten chopped fiber lengths; change mold design; modify charge.
	Charge laid directly over ribs or bosses causes shrinkage	Optimize charge pattern.
	Low temperature differential causes simultaneous curing on core and cavity, increasing shrinkage	Increase temperature differential by 20°F with appearance surface at a higher temperature.
	High molding pressure throughout hold time	Thirty seconds after compression reduce pressure by at least 25 percent.
Laking (areas of low gloss on cooled part)	Pre-gel	Decrease mold temperature; increase closing speed; decrease compound reactivity.
	Insufficient molding pressure	Increase molding pressure.
	Mold contamination	Clean and condition mold.
	Too much shrinkage	Modify formulation to reduce shrinkage.
	Mold temperature is low, or there are hot and cold spots on tool	Adjust tool temperature and heating issues; increase temperature on tool surface.
Dull part surface	Pressure too low	Increase pressure.
	Incomplete cure	Increase mold temperature; increase cure time; increase compound reactivity.
	Dull mold surface	Rework mold surface to a higher polish.
Flow lines (local waviness on part surface)	Long flow path creating fiber orientation	Modify charge pattern.
	Low viscosity creating fiber orientation	Increase viscosity of compound to improve fiber carry.
Burning (dark brown surface stain, generally in non-filled area)	Trapped air and styrene vapors raise temperature to ignition point	Modify charge so material pushes air out of mold as it flows; reduce closing speed.

CASTING: Introduction

In Part Seven:

Casting is the simplest manufacturing process for unsaturated polyester resin. Casting processes are varied, but all involve pouring catalyzed resin, either filled or unfilled, into a mold and allowing it to harden or cure. Once cured, the part retains the shape of the mold. It is then removed or demolded and 'finished,' meaning the surface can be sanded, polished and/or painted.

Casting applications include but are not limited to decorative figurines, polymer concrete, flex trim moldings, furniture, embedment castings (e.g., paperweights) and countertops and bathware. Although the general casting process is the same for all applications, raw materials used vary depending on the performance requirements for each type of finished product.

Three main categories of the casting industry will be covered in this text. These are cast polymer, solid surface and flexible casting resins.

CASTING: Cast Polymer

Part Seven, Chapter II

In This Chapter:

1. Introduction
2. Materials
3. Molds
4. Manufacturing Process
5. Trouble Shooting Guide
6. Supplies for Marble Production

1. INTRODUCTION—This section will focus on the countertop and bathware industry, most commonly referred to as 'Cast Polymers.' Cast polymer products are used in commercial, residential, industrial, and medical areas. The cast polymer product line has extended beyond the original kitchen and bath markets. Examples of cast polymer products are vanity tops, sinks, bathtubs, shower pans, wall panels, countertops, windowsills, flooring, bar sinks, interior and exterior facades, banisters, and furniture, with the list continuing to grow. There are three distinct product lines within cast polymers:

- Cultured Marble—gel coated surface, filled with calcium carbonate, usually pigmented and/or veined, opaque in appearance.
- Cultured Onyx—gel coated surface, filled with aluminum trihydrate, usually veined with a non-pigmented background, and translucent in appearance showing depth like natural onyx.
- Cultured Granite—gel coated surface, filled with specially designed granite filler to produce a multi-colored speckled appearance.

An unlimited variety of colors, cosmetic designs, and shapes that can be manufactured or fabricated provide cast polymer products with distinct advantages over their natural counterparts. In addition, natural products are porous (which can become a source of bacterial growth) and can easily be stained, while cast polymer products are not porous and are stain resistant.

2. MATERIALS

A. Gel Coat—For cast polymer products of cultured marble, onyx, and granite, the use of gel coat is required. Gel coat is not used with solid surface products. It is a polyester coating that is applied to the mold surface and becomes an integral part of the finished product. The function of gel coat is to protect the part from its environment, providing chemical resistance, water resistance, and weathering resistance (UV stability). The gel coat is also accountable for the part's cosmetic surface and durability. It is the gel coated surface that is visible and therefore a critical aspect of the part.

Both pigmented and clear gel coats can be used to produce cast polymer products although clear gel coats are generally more popular.

Pigmented gel coats are mainly used to produce cultured marble. Parts produced with pigmented gel coats are solid colored. The pigmented gel coat forms an opaque coating and hides the color of the matrix poured behind it. Pigmented gel coats used in cultured marble are formulated similarly to those used in open molding.

Clear gel coats add depth and dimension to the part. Artistic colors and designs, such as veining and granite effect of the matrix are viewed through the clear gel coat. Clear gel coat is also used to produce cultured marble where veining patterns are applied. Clear gel coat is required with onyx to accentuate the translucency and depth of the veining to more closely resemble natural onyx. Clear gel coat is also required to show off the multi-colored effect of granite filler.

Cultured granite can be manufactured using one of two methods:

1) Granite effect filler is mixed into the resin and poured behind a clear gel coat.
2) Specially designed spray granite chips are mixed with a specially designed clear gel coat, and then sprayed onto the mold. Standard marble matrix is poured behind it.

Clear gel coats used in the cast polymer industry are specifically formulated for cast polymer applications. Key differences from clear gel coats formulated for other industries are lower color and slower cure rates. Clear gel coats to be used with spray granite chips also have different viscosity and spray characteristics.

To meet performance requirements of bathware products both pigmented and clear gel coats must be based on ISO/NPG polyester resins. Please refer to Part Four Open Molding for additional information on gel coats.

B. Resin—Casting resin is mixed with fillers to make the matrix. The matrix gives the cast part its structural integrity. Resin suppliers formulate casting resins from several components including the polymer, reactive monomer, promoters, inhibitors and specialty additives. The specific components and amounts used are dictated by the end-use application, manufacturing process, required cure behavior, end-use physical properties requirements and manufacturing plant conditions. Plant conditions can dictate that resin gel time and/or viscosity be varied to account for seasonal temperature changes.

Unsaturated polyester polymers are the basis of casting resins. Cultured marble, onyx and granite resins are based on orthophthalic polyesters. (For additional information on resin chemistry see Part 3, Chapter II.)

The monomer fulfills two roles in the polyester resin. First, it reacts and crosslinks with the unsaturation sites in the polymer to form the crosslinked thermoset material. Second, it reduces the viscosity of the polymer to workable levels. The most common monomer used in casting resins is styrene.

Promoters, also called accelerators, split the peroxide catalysts used to cure casting resins into free radicals. These free radicals attack the unsaturation sites in the polymer preparing them for reaction with the monomer. Promoters used in casting resins determine the cure behavior and also have a significant impact on finished part color. In general, the higher the promotion level the darker the cured resin color. As a result the types and amounts of promoters used in casting resins vary depending on the production speed and color requirements for each application.

- For cultured marble, the matrix is usually pigmented or poured behind pigmented gel coat making the cured resin color less important than for some other applications. As a result, marble resins are typically highly promoted for faster cure.
- For cultured onyx and granite, clarity and low cured casting color are critical factors. Cultured onyx cannot be pigmented as heavily as cultured marble because it will reduce its translucency. As a result, onyx and granite resins have very low promoter levels and correspondingly slower cure rates.
- Swing or dual-purpose resins are a compromise between marble and onyx/granite resins. Swing resins contain a higher level of promoters than onyx/granite, but less than marble. The result is lower cured casting color than cultured marble, but faster cure rates than onyx/granite. For most manufacturers, the small sacrifice in cured color is worth the increased speed of production with onyx and granite products. In many cases, the color difference is not noticed. The slower cure of swing resins in cultured marble applications can be addressed with catalyst. Manufacturers that do not want to buy separate resins for marble and onyx/granite applications also use swing resins.

Inhibitors provide shelf life stability to casting resins as well as help control the working time or gel time. Free radicals generated in the polyester resin during storage or after addition of peroxide catalyst react preferentially with the inhibitors. Only after all the inhibitors are consumed does the crosslinking or curing process begin.

In addition to the above materials, a number of other additives can be used in casting resin formulations to affect properties. These include processing aids such as air release agents and wetting agents. Additives can also be used to affect the product's performance such as UV absorbers and light stabilizers for weathering performance.

C. Fillers—The filler is the largest part of the cast polymer composition. The type of filler to be used depends on the cast polymer product.

1) Cultured Marble—

a) Calcium Carbonate (CaCO3)—Typical marble filler is calcium carbonate (ground limestone). CaCO3 is mined and ground into small particles; size is measured in units called mesh. Filler particles are sorted through screens with different size openings. Mesh size is designated by the number of holes per linear inch, with lower numbers indicating a coarse or large particle size, and higher numbers indicating a small or fine particle size. CaCO3 fillers are supplied as 'all coarse' or 'all fine' particles or as pre-blended bags of coarse and fine particles.

A mixture of particle sizes of filler is used to provide maximum loading, with coarse at 40 to 200 mesh, and fine at 325 mesh. Fine particles fill in between coarse particles so that resin rich areas are reduced and higher filler loadings can be achieved. For temperatures below 85°F, a mix ratio of two parts coarse to one part fine provides excellent loading properties while avoiding warpage and cracking problems. For temperatures above 85°F, a mix ratio of three parts coarse to two parts fine will maintain the same matrix viscosity.

b) Dolomite—Just like CaCO3, dolomite is a mined mineral, a mixture of calcium carbonate and magnesium carbonate. It is supplied just like CaCO3. Dolomite is more abrasive than CaCO3 and therefore may require more equipment maintenance.

c) Lightweight Fillers—The use of lightweight fillers in cast polymer products has been steadily increasing. Lightweight fillers are hollow spheres made of glass (silica) or plastic. They occupy space or volume but do not add weight, which effectively reduces the weight of a given part without changing its dimensions. Lightweight fillers are used with CaCO3. They can be bought separately or pre-blended with CaCO3 to a known weight displacement. Typically, these fillers demand a higher resin percentage for wet out and to maintain a flowable viscosity. Also, because of its insulating effect, lightweight fillers cause the exotherm of the curing part to increase.

2) Cultured Onyx
    a) Aluminum trihydrate (ATH)—The filler of choice for cultured onyx, ATH is a by-product resulting from the processing of bauxite minerals in the manufacturing of aluminum. Onyx grade ATH is much brighter white than CaCO3, thus eliminating the necessity of using background pigment. It is a semi-translucent granular filler which provides a visual effect like natural onyx, and has the added feature of acting as a flame retardant. At temperatures of 410°F, ATH releases its water particles, slowing combustion and reducing smoke generation.
    b) Lightweight Fillers—The use of lightweight fillers is not recommended in cultured onyx since this would reduce translucency.
3) Cultured Granite—Granite effect fillers are also gaining in popularity. Filler suppliers have specially formulated colors and particle size distributions to achieve a multi-colored speckled granite appearance, and to give the product a cosmetic textured look. The colored granules may be coarse ground minerals or synthetically made from pigmented resins. The resin demand will vary greatly depending on the granule size(s) and distribution. There is a difference in granite effect filler mixed into the matrix versus spray granite filler mixed into the gel coat and sprayed; therefore, method of application needs to be noted when purchasing these fillers.

While inexpensive initially, if not chosen and checked properly, fillers can become extremely costly. For example, if too much coarse filler is used and subsequently settles, a resin rich area will result on the back side which could cause warpage. If too much fine filler is used, the viscosity will be very high resulting in air entrapment. If the fillers contain too much moisture or become damp, they will affect the gel and cure.

Lot-to-lot variations and contamination of fillers can also affect the cured casting color. There can be significant particle size variations from lot-to-lot as shown in the analysis in the following column.

Each lot should be checked as soon as it is delivered to determine if these factors will affect gel, cure, color and warpage. To make this determination, make a part with the new filler and compare it to parts made with the lot already in use. Do not wait until time to switch to a new lot. Fillers should be checked in conjunction with the resin for their effect on matrix color, gel time, and cure properties.

D. Catalyst/Initiator—Catalyst is the component needed to 'harden' the polyester resin mix into a solid mass. Technically, catalyst causes the reaction but does not participate in the reaction. In the composites industry, the correct term is initiator, which starts the reaction and is consumed by the reaction. There are three common types of room temperature initiators used in cast polymers:

1) Methyl Ethyl Ketone Peroxide (MEKP)—The most widely used initiator, MEKP is a clear liquid that easily mixes into the resin. It is the most cost effective choice, and is available in different 'strengths' to give a variety of curing characteristics. Recommended range is 0.5 percent to three percent catalyst level based on resin amount.
2) 2,4-Pentadione Peroxide (2,4-PDO)—Also known as acetylacetone peroxide (AAP), this initiator offers fast cure time and high peak exotherm. Although it does lengthen gel time, Barcol hardness builds quickly. Typically, 2,4-PDO is used during the colder temperatures It is available separately or pre-blended with MEKP; however, pre-blends are the most popular. In pre-blends, the MEKP controls the rate of the gel time and the 2,4-PDO provides the faster cure rate and higher peak exotherm. Recommended range is one percent to two percent catalyst level based on resin amount. Above two percent, 2,4-PDO peroxide may inhibit cure. The only disadvantage with this initiator is that with some resins, cured casting color may have a yellowish tint.

Sieve Size	**Lot A%**	**Lot B%**	**Lot C %**
40	1.5	1.75	1.5
60	7	6.5	6.5
80	6.5	6.7	7.5
100	7	10	10.5
120	7	7.25	4
150	6	12	6
200	19.5	19.75	30.5
Through 200	45.5	36.75	33.5

(3) Cumene Hydroperoxide (CHP)—CHP lowers peak exotherm and lengthens gel and cure times. Lower peak exotherm reduces cracking, crazing, and shrinkage but also slows down Barcol development. CHP is most popularly used during hotter temperatures and/or on thick parts like shower pans and tubs. It is available separately or pre-blended with MEKP; however, pre-blends are the most popular.

Some control over gel and cure rates can be achieved by changing initiator levels and blending the above mentioned initiators. Initiator level should be maintained between 0.5 percent and three percent with 1.25 percent being the norm. Initiator levels below 0.5 percent may cause curing problems. Levels of 0.5 percent should only be used during hot ambient temperatures where the heat will serve as a secondary catalyst or in large mass products (e.g., tubs) where higher exotherms will be generated because of the part's thickness. Initiator levels above three percent are at the point of diminishing return, with very little improvement seen in relation to the use of the higher amount. If the initiator level is excessive, the initiator will cancel itself out to the extent that the reaction will stall. As the initiator level moves outside the range of 0.5 percent to three percent, change should be made to a cooler or hotter initiator strength. Once this choice has been exhausted, a different gel time version of the resin should be ordered from the resin supplier.

3. MOLDS—The mold determines the shape, texture, and gloss of the finished part. It is a mirror image of the part so any defect in the mold will be reflected in all the castings made from that mold. Simple molds have one size and shape. Custom parts require special dimensions so dividers and moveable bowls provide the flexibility to cast these one-time needs. Holding them in place can be done with double face tape, suction cups, clamps, hot glue or other ingenious methods. Providing cosmetic transitions, such as a small radius where the floating bowl or divider bars meet the deck, can be accomplished using wax fillets or clay.

NOTE: Different clays vary in formulation, and with some there may be technical problems that can show up as fish-eyes, pre-release, or that simply cause cure problems with the gel coat. One way to reduce these problems is to dust the applied clay with baking soda or fumed silica. The make sure to blow off the excess powder before applying the gel coat.

A. Mold Materials—A number of materials can be used to make a mold. The most common are shown in the table at the top of the next column.

B. Mold Configuration— Vanity top molds are modular or custom. Modular molds are fixed size, one piece, seamless construction with bowls, back splash, and any special features built in. Custom molds may have built-in back splash but bowls and dividers are separate parts and positioned as desired.

Vanity top molds include the following accessories:

1) Drain Plug—Usually made of polyethylene, the drain plug measures 1 and 3/4 inches in diameter. It can be permanent or removable. It serves to form the drain hole and attachment point for an overflow assembly (if used). The plug is attached to the bowl during set up before gel coat application.

2) Overflow Assembly—Although not required by the national plumbing codes, overflows may be needed for some specific applications. A permanent plastic drain collar and tube may be encapsulated and remain in the bowl or a reusable flexible tube may be retrieved from the cure part. The tube attaches to the bowl and drain plug and should be installed after gel coat is applied. The end connected to the drain plug should remain unattached until after gel coating for easier gel coat application to the bowl. This will allow the critical area of water impingement to be easily gel coated to the proper thickness. The overflow tube should be spaced at least 1/2 inch from the bowl surface to help prevent cracking.

Mold Type	Advantage	Comments
Fiberglass	Easy to make Long lasting Can be textured Radii can be built in Easy to repair Easy to handle Easily customized	Type most often used
Stainless Steel or Chromed Steel	Durable Hard surface Smooth finish	Expensive Deep scratches and dents not easily removed
Formica or Melamine	Easy to make Can be textured Inexpensive	Not long-lasting Not durable Surface finish is fair
Glass	Perfectly flat Low maintenance	For flat panels only Care must be taken not to crack or scratch the surface

3) Overflow Assembly—Although not required by the national plumbing codes, overflows may be needed for some specific applications. A permanent plastic drain collar and tube may be encapsulated and remain in the bowl or a reusable flexible tube may be retrieved from the cure part. The tube attaches to the bowl and drain plug and should be installed after gel coat is applied. The end connected to the drain plug should remain unattached until after gel coating for easier gel coat application to the bowl. This will allow the critical area of water impingement to be easily gel coated to the proper thickness. The overflow tube should be spaced at least 1/2 inch from the bowl surface to help prevent cracking.

4) Faucet Plugs—These form one-inch diameter holes for faucet installation. Plugs may be solid knockouts (re-usable) or cardboard rings that remain in the part. Plugs may be placed in wet gel coat to be held in position when the gel coat cures. Clay can also be used to hold them in position.

5) Female hat—The hat functions to hold the matrix in place to form the bowl's wall thickness. It is contoured to the male bowl mold and allows for overflow assembly (if used). It is usually constructed with fiberglass, polyethylene, or polystyrene. Fiberglass and polyethylene hats are reusable (removed from part). Polystyrene hats are permanent (remain on the part). Hats may be full or partial. Full hats are usually used with modular molds. Full hats completely cover the mold and can be clamped in place for the one-pour production method. Partial hats are sometimes used with modular molds and always on custom molds since these molds will differ in bowl location. Partial hats cover the bowl only and are used in the two-pour production method.

E. Polyethylene Dividers—These are often used to custom size flat areas, such as wall panels, back splash, and vanity decks, into various shapes or sizes.

4. MANUFACTURING PROCESS

A. Overview—The twelve steps listed in the following table provide a very general outline of the manufacturing procedure for cast polymer:

Step #	Action
1.	Prep and set up molds.
2.	Apply mold release agent to the molds.
3.	Spray gel coat onto the mold.
4.	Remove gel coat overspray from mold flange while gel coat is still wet. This is easily done by applying masking tape on the flange before gel coating and then removing the tape after gel coating.
5.	When the gel coat is 'castable,' apply matrix (resin, filler, catalyst, pigment) to the gel coated mold.
6.	During the process of transferring the matrix into the mold, a variety of veining techniques can be applied to achieve the final cosmetic appearance of the part.
7.	Vibration is added to level the matrix in the mold and remove air bubbles from the gel coated surface.
8.	Remove excess matrix from the mold flanges after the matrix gels but before it shrinks.
9.	When possible, remove the back hat, open the back splash, and eliminate any other constraints on the part.
10.	Demold the part as soon as possible to avoid internal stress fractures.
11.	After demolding, place the part on a supporting surface to retain its shape during cure. If it is a solid surface product, it is recommended the part be postcured.
12.	Once cured, the part is finished (trimmed, sanded, and polished) and repaired (if necessary).

B. Mold Preparations and Maintenance—The mold determines the texture, smoothness, and gloss of the finished part. It is imperative that the mold be kept in optimum condition. New molds must be broken in following the directions of their manufacturer. (If building a mold, refer to Part Eight on 'Polyester Tooling' for suggestions regarding procedure.) Molds for marble will last through the production of many parts and provide maximum performance if good mold maintenance is practiced and good workmanship is used in producing the mold.

A mold maintenance program is essential in a marble shop to insure the long life of polyester molds. While it sometimes suffices to re-wax a mold when it starts pulling hard, CCP has found that problems such as sticking and polystyrene buildup result from neglect of the mold over time. CCP suggests a routine mold prep schedule. It is far better to prevent polystyrene buildup with a good consistent preventive maintenance program than to allow molds to get into bad shape.

To determine the prep schedule, start by determining how many pulls (parts) it takes for the mold to start sticking. Then routinely prep and wax the mold before this number is reached. For example, if the mold starts to pull hard and gloss is diminished after seven parts are pulled, then always prep and re-wax the mold after pulling the sixth part. With careful adherence to such a program, molds will last longer and produce better looking parts with less patching.

The mold prep area should be completely enclosed and away from the production area. There should be isolated stalls for grinding and a separate area for gel coating.

Mold buildup should not be confused with what was once referred to as 'wax buildup.' Wax buildup is more correctly stated as 'wax leave-on" because the buildup occurs when excess wax is not buffed off. In fact, mold buildup is styrene (polystyrene) that has come from the production gel coat. It adheres to the mold mainly for these reasons:

- Wax leave-on
- Pulling parts too soon (the more 'green' a part when pulled, the more susceptible it is for styrene to adhere to the mold)
- Too many parts made in the mold without proper maintenance.

Normal mold preparation involves machine polishing of the mold with a glaze. If the mold is very hazy and has some polystyrene buildup, a coarser compound should be used and followed with the glaze. The mold should be washed and rinsed with cold water to remove compounding dust and compound vehicle.

Some compounds can cause sticking if left on the mold. Six fresh coats of mold wax should follow the water wash. The fish eye and pre-release tendency will always be greater after this fresh wax. However, if the gel coat is sprayed to a thickness of 18 to 20 mils, the fish eyes should be covered and pre-release tendency is minimized.

If the mold has a lot of buildup, it must be removed by scrubbing with a commercial stripper (toluene, methyl

ethyl ketone, ethyl acetate, or 'wax off'). Do not use styrene for cleaning molds. All of these commercial strippers are flammable and health hazardous. Safety precautions should be observed:

- Read the Material Safety Data Sheet (MSDS)
- Wear gloves
- Wear safety glasses
- Make sure the area is well ventilated
- No smoking

After molds have been stripped, if there is still roughness on the mold surface, then the mold should be sanded with sand paper no coarser than 600 grit and polished. If roughness or scum is left on the mold, it will permit quicker mold/polystyrene buildup when put back into production. If using a polymer mold release system, follow supplier's instructions. Too much polymer mold release will cause fish eyes in the gel coat.

For more information, please refer to Chapter VIII, 'Mold Maintenance', in Part Eight on 'Polyester Tooling.'

C. Gel Coat Application—Application of gel coat is the most critical aspect of cast polymer production since it provides the ultimate first impression of the product. Also, performance of the finished product is directly related to how well the gel coat is applied. For information on spray equipment and technique, please refer to Chapter II, 'Conventional Gel Coat,' Section II.4, 'Application,' in Part Four on 'Open Molding.'

Clear marble gel coats, specifically designed for cast polymer, and pigmented gel coats should be used in production of cast polymer. Typically, gel coat is sprayed in a wet film thickness of 16 to 24 mils. For parts that are not as critical (for example, wall panels), the minimum wet film thickness is acceptable. For parts with high exposure to water impingement, the maximum wet film thickness is recommended. It is important that the gel coat is applied evenly throughout the part and therefore, the use of mil gauges is encouraged.

Film gel time must be long enough to allow leveling and air release but short enough to prevent the styrene in the gel coat from attacking the release barrier between it and the mold surface. If the latter situation occurs, it would cause release impairment leading to cracking and edge peeling, or stress and shrink lines. Likewise, if the gel coat thickness is insufficient, the styrene in the marble matrix can penetrate the gel coat into the mold release and cause similar problems. Thin gel coat may also not cure thoroughly.

The gel coat is allowed to partially cure before marble mix is poured. Cure times are normally 30 to 90 minutes depending upon plant temperatures, catalyst level, and air movement. Slight air movement speeds cure by moving styrene vapor off the gel coat surface. Styrene vapor does inhibit gel coat cure. Forced air ovens, set at 100°F to 120°F, can reduce the gel coat cure time to a range of 15 to 20 minutes. Uneven heat, too much heat, extended time, and too little or too much air movement in the oven may cause pre-release.

NOTE: Gel coats are flammable. Ovens used must be designed to accommodate flammable materials.

D. General Matrix Formulation—Listed are general starting points for each product line. As production continues, the matrix formulation becomes customized to each manufacturer.

1) Cultured Marble—

Resin	22 - 26%
CaCO3	74 - 78%
Base Pigment	0.5 - 1.5%
Initiator/Catalyst	0.5 - 3.0% (based on resin content)

2) Cultured Onyx—

Resin	26 - 30%
Onyx Grade ATH	70 - 74%
Initiator/Catalyst	1.0 - 3.0% (based on resin content)

Due to finer particle size ATH filler, cultured onyx requires higher resin content than marble wet out and to reduce matrix viscosity to aid in air release. Due to the translucency of this product, it is necessary to release as much air as possible (unlike opaque cultured marble where it is only critical to remove the air from the gel coat surface). Catalyst level is higher than marble due to the lower promoter level of onyx resin.

3) Cultured Granite—

Granite Matrix (granite mixed into the matrix)

Resin	22 - 30%
Granite Effect Filler	70 - 78%
Initiator/Catalyst	1.0 - 3.0% (based on resin content)

Resin content varies greatly with granite effect fillers depending on the particle size and distribution of the granite particulates. The larger the granite chips, the lower the resin content. The finer the granite chips, the higher the resin content. If the mix is too loose (too high in resin content), the larger particulates will fall to the gel coat surface and not achieve the desired appearance. If the mix is too thick, air bubbles will be trapped in the matrix. Initiator/catalyst level will also vary greatly depending on the granite color(s) being cast. It is advisable to keep a log of initiator/catalyst level versus granite color for reference.

Spray Granite (granite mixed into the gel coat)

Clear Gel Coat	50 - 60%
Spray Granite Effect Filler	40 - 50%
Initiator/Catalyst	1.5 - 2.0% (based on resin content)

Unlike granite filler mixed into the resin and poured behind clear gel coat, spray granite is granite filler mixed with a specially formulated clear gel coat and sprayed as the gel coat. Standard marble matrix is poured behind it. There is a difference in appearance between these two methods of processes. As above, there is a wide range of gel coat/resin content due to the particle size and distribution of the granite particulates. Please refer to the notes written above on 'granite matrix.'

It is a common practice to use marble clear gel coat as the carrier for the spray granite. The advantage is in not having to stock another product. The disadvantage is that gel coat is designed to cure in thin films and therefore is very reactive. To get the coverage or 'hide' of spray granite, 20 to 30 mils film thickness is required. Depending on granite particle size, thicker film thicknesses may be required. If the layer is too thin, the matrix behind it will show through. At 20 to 30 mils film thickness, standard gel coat may cure too fast and exotherm too high, resulting in a variety of problems such as pre-release, excessive shrinkage, distorted surface, etc. Specially formulated gel coat has been developed to resolve this issue. The advantage is that the specially formulated gel coat is very highly thixed to help suspend the granite particulates and will cure at a much lower exotherm than standard clear gel coats. The disadvantage is in having to stock another material.

The typical application process for spray granite is to:

- Apply 20 to 22 mils of wet clear gel coat to the mold (this will give the finished product a smooth glossy surface and add depth to the finish appearance).
- Wait for the gel coat layer to dry to a tacky finish, then spray on 25 to 35 mils of the wet spray granite mix (gel coat or resin plus spray granite effect filler).
- Wait for the spray granite layer to dry to a tacky finish, and then pour on the marble matrix (it is recommended to pigment the background of the marble matrix the same general color as the spray granite for cosmetic purposes).

There are differences between granite effect fillers intended to be mixed into the matrix versus spray granite intended to be mixed into gel coat. Make sure to specify to the supplier which product is needed.

E. Matrix Mixing Methods—There are several different methods for mixing the matrix (incorporating the resin, pigment, catalyst, and fillers). If possible, add and mix the catalyst to the resin first before adding the filler. Mixing in the catalyst first will ensure even distribution of the catalyst throughout the mix. Also, if adding separate fine and coarse fillers, mix in the fine or lightweight fillers first since they are more difficult to wet out before the coarse fillers. When using dry pigment, make sure the pigment is well mixed into the resin before adding catalyst. If dry pigment comes into direct contact with catalyst, it creates a gaseous reaction that will leave many air voids in the matrix.

1) Hand Batching/Small Batching Method—Materials are manually measured and mixed in a batch mixer making 100 to 400 pounds of matrix per batch.
    a) Pre-measure all ingredients first.
    b) Add measured resin into mixing pot.
    c) If adding background color, add pigment to the resin. Mix for one minute. Add a small amount of filler to help disperse the pigment.
    d) Add catalyst to the pigmented resin. Mix for one minute.
    e) If using lightweight filler, add to the mixing pot and mix until all is wet out.
    f) If using separate fine and coarse fillers, add fine fillers first. Mix until all is wet out. Then add coarse filler and mix until all is wet out.
    g) Scrape down sides and mixing blade for unmixed material.
    h) Mix for additional three minutes to ensure thorough mixing.
    i) Add veining pigment(s) if desired.
    j) Pour onto molds.
2) Auto-Dispensing Method—Auto-dispensing equipment is designed to deliver measured amounts of resin and filler into the mixing pot. The primary advantage is that most auto-dispensing units have resin heating capability that allows higher filler loading. This equipment eliminates the labor and time previously required for measuring materials, delivers con-

sistent material quantities, and reduces material costs by heating up the resin to increase filler loading. Maintenance is critical. As for any machine, calibration should be performed regularly to ensure proper delivery of material amounts.

a) Operator chooses preset formulation and enters batch size into the machine.
b) Heated resin is dispensed into the mixing pot.
c) Catalyst may be added by hand or by machine. Mix for one minute.
d) Add background pigment by hand and mix for one minute. May add small amount of filler to help disperse the pigment.
e) Machine dispenses filler into the mixing pot. Mix until all is wet out.
f) Scrape down sides and mixing blade for unmixed materials.
g) Mix for additional three minutes to ensure thorough mixing
h) Add veining pigment(s) if desired.
i) Pour onto molds.

3) Auto-Casting Method—As the name suggests, auto-casting equipment is designed to measure, mix, and dispense matrix directly onto the mold. The machine is programmed with a formulation. It measures the heated resin, filler, catalyst, and background pigment. The materials are dispensed into a tube called the barrel. In the barrel, there is an auger screw that serves as the mixing mechanism and transports the matrix through the tube. Veining pigment, if desired, may be automatically added as the matrix nears the end of the barrel or may be hand applied to the mold. Once the matrix emerges from the barrel, it falls onto the mold or can be put in a bucket and then hand poured onto the mold.

Like the auto-dispensing equipment, auto-casting equipment has resin heating capabilities which allow higher filler loading. The whole process is automated, reducing the labor force. Matrix output is high, greater than 50 pounds per minute, which increases product output. Finished product should be consistent. No need for measuring materials. Keeping the machine calibrated is critical.

F. Veining—Veining is an art that becomes an identifying mark for each manufacturer. Veining techniques vary as widely as the resulting designs. No one method is better than the other; it is purely a subjective preference.

The table below lists some factors that will influence veining results.

G. Pouring Methods—Transferring the matrix from the mixing pot/bucket to the mold can be done using paddles, scoops, gloved hands, or simply pouring out of the bucket. Pouring method, again, is the preference of the manufacturer based on the cosmetic appearance of his product.

In general, the veined matrix is applied on the mold first. Once the vein pattern is established, the remaining matrix is transferred and fills up the mold.

1). Pouring Vanity Tops/Bowls—

a) One-Pour Method—The full hat, in this case with a lip that covers the whole mold, is positioned and clamped into place to stop matrix leakage. The rest of the mold is then filled as necessary. Some techniques utilize overfilling of the mold areas, followed by quickly clamping down the hat to force the extra matrix into the bowl area of the hat. Vibration is continued an additional five minutes to ensure air removal.

b) Two-Pour Method—This method is required with partial hats. It is similar to the one-pour up to the point of adding the hat. Also, the initial pour can be a higher viscosity because the semi-closed mold situation in single pouring, which hampers flow and air release, is not a factor. Crisper veining will result. Once the cavities of the deck are filled, along with a matrix cover of 1/8 to 1/4 inch on the bowl area, a hat with a three to five inch lip is positioned around the bowl area only. This may be removable or permanent. Once the first pour has gelled and has enough strength to hold the hat in place to prevent leakage, the second mix is made to fill the cavity of the hat. This mix can be lower in viscosity to allow it to flow more easily. It may be any color as it will not show through the first layer of marble.

Matrix Viscosity	**Temperature**	**Vibration**
• Thick matrix will produce crisp sharp veins. • Thin matrix will produce blurred veins.	• Hot temperatures will decrease or thin the matrix viscosity. • Colder temperatures will increase or thicken the matrix viscosity.	• Long vibration time will produce blurred or less defined veins. • Short vibration time will produce crisp, sharp veins. • It is important to keep the vibration time constant in order to maintain consistent appearance.

The second pour, to fill the hat, may be added shortly after the first pour gels, or it may be delayed until after the first pour has exothermed. Timing of the second pour is important. If either pour shrinks significantly while the other pour is soft, cracking can result. The catalyst level of the second pour may be reduced to delay and lower exotherm development.

2) Pouring Large Parts (Tubs, Shower Pans, Etc.)—Tub castings can present unique problems because of their mass. The larger the mass, the higher the exotherm during cure. The high exotherm may lead to excessive shrinkage and cracking. Tubs may also vary in wall thickness, which can lead to differential shrinkage and cracking. A thicker area may begin shrinking and create a tear or crack if adjacent to a thinner, less cured area. Tubs are often cast in multiple pours, which are catalyzed at different times.

The following are points to consider in casting tubs:

Catalyst Level
• Catalyzation should be appropriate for the ambient temperature. • Catalyst levels may range from 0.5 percent in the hot summer months to 1.25 percent in the cold winter months. The norm is approximately 0.75 percent (based on resin content). • Low catalyst levels coupled with variable thickness can contribute to cracking due to low green strength development.
Special Formulated Tub Resins
• Tub resins are high viscosity versions of marble resins. (With higher viscosity, there is less styrene monomer in the resin.) • Lower styrene content reduces the amount of shrinkage during the cure. • Also, it is desirable to have thick matrix viscosity for tubs so that the matrix will adhere to the mold during the mold filling process.
Demolding
• Remove the hat as soon as allowable to dissipate the exotherm. • Suspend the mold so that the part is right-side up one inch above the floor to allow gravity to aid in demolding the part. • Demold the part as soon as possible to alleviate any stress on the matrix.

H. Vibration—The effect of vibration is a result of time, frequency, and amplitude. Frequency is the rate at which vibration occurs. Amplitude is the power or energy of the vibration. Ideally, vibration causes the mold and matrix to resonate at the vibration frequency. Heavier parts and mold can dampen the amplitude and make the vibration ineffective. Likewise, the vibrator motor can make loud noises but not actually transfer its power (amplitude) to the mold. It is recommended to periodically check the effectiveness of the vibrator motor.

Vibration is used during the process of filling the mold to help the matrix flow over the mold surface. As the matrix moves, filling the mold, air bubbles are able to come to the surface and break. Once the mold is filled, the vibration continues to help the entrapped air move off the gel-coated side and migrate to the back of the part.

Vibration should commence during the filling of the mold and stop several minutes after the mold is filled. Vibration should never continue once the matrix has gelled. Excess vibration can wash out the vein pattern and cause the filler to settle to the mold side, which can contribute to warping. If air bubbles are seen on the gel coated side, it may be due to ineffective vibration or vibration time that is too short.

I. Demolding—Once the matrix has gelled, the mold should be trimmed. This requires removal of the tape, the overspray gel coat, and the matrix from the mold flange. This helps the gel coat to release from the mold and reduces the potential problem of edge peel. As the part cures and begins to shrink, it is good practice to remove the back hat (of a bowl), open the back splash, remove inserts, and eliminate other constraints as soon as possible. Do not force these parts off because that will stress and possibly crack the part. During the curing process, the matrix will release or shrink away from these parts and its removal should be relatively easy.

Demold the part as soon as possible to avoid developing internal stress as the part shrinks on the male mold. In extreme cases, it is possible for the part to shrink and lock itself onto the male mold. As stated before, do not force the part out of the mold. It should release on its own. If it requires too much energy or pressure, then the part is not cured enough to come off. When working with large parts such as tubs, the mold can be suspended upside down to allow gravity to demold the part.

Once the part is demolded, it should be supported on templates or tables to reduce the possibility of warping while it is completing its cure. This is especially critical if the demolded part is still very ‘green’ (flexible or soft).

J. Finishing and Repairing—Once the part is cured, it will need to be finished. Typical finishing includes:

- Sanding the edges and the back or bottom of the part (smoothing off the surfaces)
- Polishing the top surface (gel-coated side)
- Drilling or smoothing the edges of the faucet and drain holes
- Repair or patching of surface defects.

If the defect is in the gel coat only, patch using the gel coat. If it is deeper, use catalyzed matrix almost to the surface. After it cures, patch with the gel coat. With granite or solid surface, repair using the matrix mix.

K. Influence of Temperature—Gel and cure of the gel coat and matrix are influenced by many factors; for example, catalyst levels, catalyst type, humidity, types of fillers, and pigments can shorten or lengthen gel times. Gel and cure rates can be manipulated by variations of catalyst type and level. The use of higher catalyst levels produces faster gel times but will also produce hotter cures. The use of lower catalyst levels produces slower gel times but will also lengthen total cure times.

The most influential factor and the hardest to control is temperature. Often times, attention is given to the temperature of the resin, but temperatures of the fillers, mold, and room are neglected. If the resin is warmed to 100°F and it is mixed 75 percent with filler at 50°F, the combined matrix temperature will be approximately 60 to 70°F. The gel and cure is further inhibited by pouring the matrix onto a 50°F mold sitting at 50°F ambient temperature.

Heat is another catalyst to the crosslinking reaction. The exotherm generated by the reaction is needed to help drive the cure through. If the ambient temperature and the materials are cold, the exotherm is lost to heating its surroundings. In cold temperatures, viscosity of matrix thickens, cure times are extended, and degree of cure issues and air entrapment problems are predominant. As ambient temperatures go up, matrix viscosity decreases and high exotherms and inconsistent shrinkage become the main problems. As catalyst levels and resin contents are lowered to account for the higher temperatures, the green strength development becomes affected which can lead to cracking or tearing problems.

A crack is characterized by a sharp straight line and is primarily due to excessive shrinkage caused by high exotherms. Cracks can be controlled by reducing catalyst level and optimizing the filler to resin ratio. A tear will have a haphazard direction and is 'whitish' in color and appears in areas of maximum stress. Tears are primarily due to poor green strength development.

A mix will hold significantly more fillers at higher temperatures. For example, a resin adjusted to 1500 cps when used in a mix of 23 percent resin, 26 percent fine and 51 percent coarse fillers has a viscosity of 344,000 cps at 77°F. The same mix at 99°F is only 152,000 cps and is too thin to be workable. Often times, mixing viscosity is fine tuned by adding resin or filler. In this case, adding more filler will bring up the viscosity. As this is done, resin percentage can drop to the point where green strength development is significantly slower, which can result in edge peel, stressing, and possibly tearing of the part.

A recommended procedure would be to alter the coarse-to-fine ratio to maintain proper matrix viscosity while maintaining the original resin content. It is advisable when using a two-component filler system to increase the percentage of fine filler during the hotter temperatures. A standard mix using a two-coarse to one-fine filler ratio will require two percent additional filler at 99°F versus 77°F to keep the same viscosity. At ambient temperatures over 85°F, fine fillers should be increased to a ratio of three-coarse to two-fine fillers. If pre-blended fillers are used, it is suggested to keep bags of fine fillers available for such adjustments.

Another alternative to keeping mix viscosity constant without changing filler ratios at higher temperatures would be to use higher viscosity resins. From the manufacturing side, whatever opportunities to keep materials as cool as possible are available should be used. Problem parts should be cast during the coolest point of the day. Starting earlier and finishing earlier for summer hours to take advantage of cooler mornings deserves strong consideration.

5. TROUBLESHOOTING GUIDE—This section provides some possible causes or explanations for typical problems encountered during production of cast polymer products.

A. Filler Particle Packing—Filler particle packing refers to the distribution of the individual filler particles within the matrix. The looser the distribution, the larger the spaces between particles. The tighter the distribution, the smaller the spaces between particles. Use of all coarse or large filler particles results in the loosest distribution of particles. Use of a combination of coarse and fine fillers results in the tightest particle packing. See the Figure 7/II.1 and Figure 7/II.2 on the following page.

Tight filler particle packing in cast polymer products enhances the performance of the finished part. In cast polymer products, resin fills in the gaps between particles. If the gaps are large enough, the resin may shrink and pull away from the filler particles creating small fissures within the matrix. This is referred to as resin laking. The fissures caused by resin laking may go unnoticed until stress or impact, such as thermal cycling, causes it to open to a visible surface crack.

Filler particle packing and particle size also affect the matrix viscosity. See Figure 7/II.3 on the following page. Use of all coarse filler particles will result in higher viscosity due to poor packing. Use of all fine particles will result in high viscosity due to poor particle packing and high resin usage. Again a blend of coarse and fine particles is ideal. Use of two parts coarse and one part fine fillers will yield the lowest matrix viscosity.

B. Temperature—Temperature affects the viscosity of the resin, which can lead to changes in the resin content of the matrix. The higher the temperature the lower the viscosity and the lower the temperature the higher the viscosity. Examples of viscosity versus temperature relationships for two resins area shown in Figures Seven/

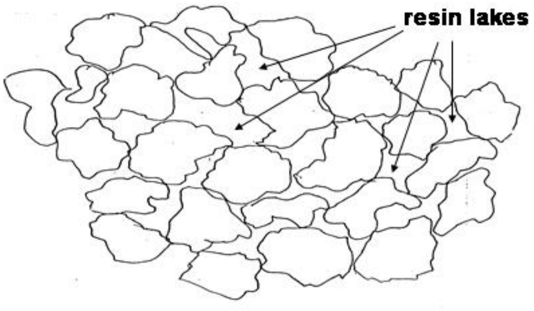


Figure 7/II.1—Poor filler particle packing.

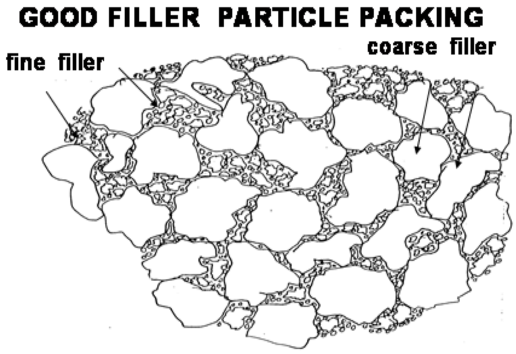


Figure 7/II.2—Good filler particle packing.

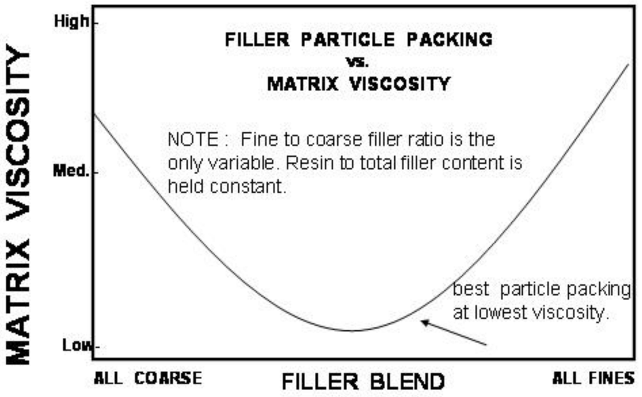


Figure 7/II.3

II.4 and Seven/II.5. Low temperatures affect the viscosity much more dramatically than high temperatures. The higher the original resin viscosity the more temperature changes will affect the viscosity.

Temperature also affects the matrix viscosity. Starting with resin at 1260 cps viscosity and blending 25 percent resin and 75 percent filler, the resulting matrix has a 200,000 cps viscosity. When the temperature increases to 95°F, the 1260 cps resin viscosity can thin down to 600 cps. To get the same 200,000 cps matrix viscosity using the 600 cps viscosity resin, the matrix composition will be ~22.7 percent resin and 77.3 percent filler. This is a 2.3 percent resin reduction in the matrix composition. Low resin content may lower the finished product's performance, such as thermal shock.

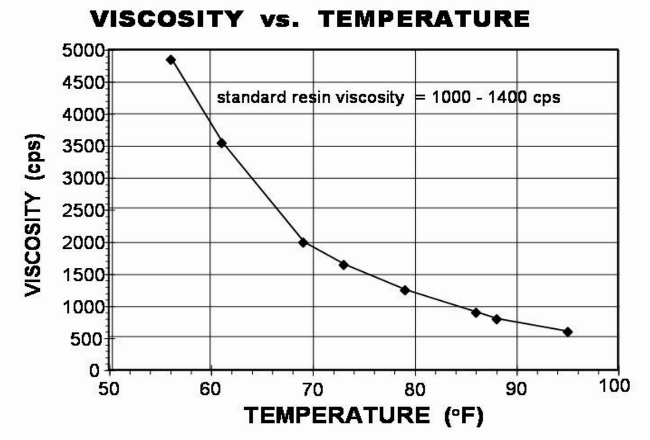


Figure 7/II.4—Viscosity poor filler particle packing data.

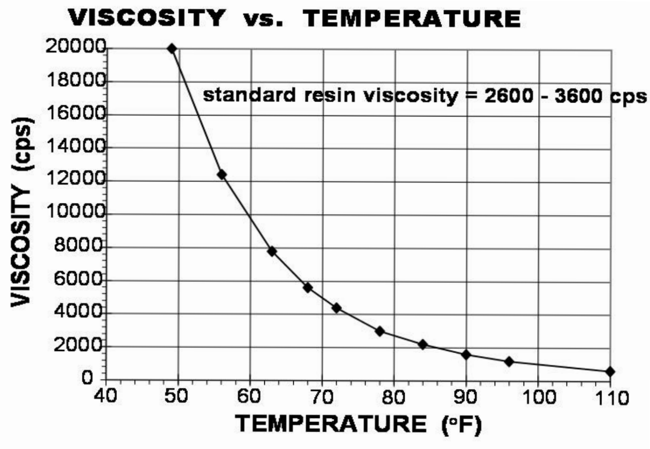


Figure 7/II.5—Good filler particle packing data.

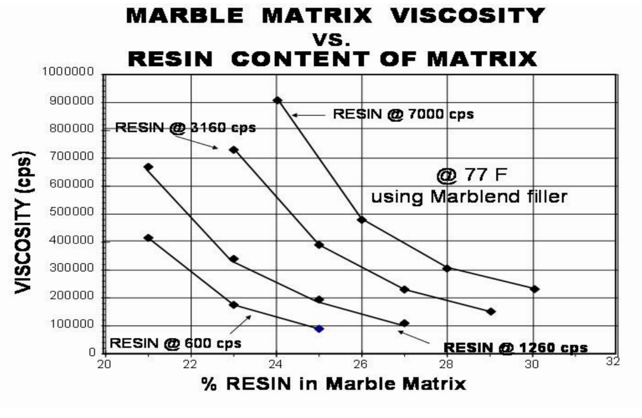


Figure 7/II.6.

C. Cracking and Tearing—As temperatures increase, cracking and tearing problems will also increase.

Cracks (sharp straight lines) are primarily due to excessive shrinkage caused by high exotherm.

Tears (lines which are haphazard or lack direction, and which may have frayed appearance) are primarily due to low green strength* and will appear in areas of maximum stress.

Cracking and tearing can be avoided by adjusting filler ratios in relationship to increases in temperature.

As temperature increases:

DO NOT	Increase filler percent to increase matrix viscosity. - Increased filler percent will lower the resin percent. - Lower resin percent will reduce green strength* development which can lead to tearing.
DO	Maintain resin percent and increase ratio of fine fillers. - Standard filler mix is two parts coarse to one part fine. - At temperatures over 90°F, a ratio of three parts coarse to two parts fine will maintain original viscosity.
DO	Switch to higher viscosity resin. - Allows use of standard filler mix (two parts coarse to one part fine).

D. Gel Coat Delamination—This situation occurs when gel coat adhesion to the mold is so strong that the matrix is not able to pull the gel coat free from the mold as it shrinks; subsequently, the matrix pulls away from the gel coat.

Some possible solutions for gel coat delamination are as follows:

1) Improve the mold release application or change mold release type.
2) Increase in catalyst level of the gel coat to accelerate the cure time. This will prevent the styrene from dissolving the release agent, and improve the cure of the gel coat and increase shrinkage.
3) Take care to ensure the gel coat is sprayed on 20 to 25 mils wet (cures to 18 to 20 mils). Thin films cure slowly.
4) Use a resin with faster green strength development.

E. Gel Coat Delamination on Edges of Part—Gel coat delamination on the edges of a part has two primary causes. These causes along with solutions are described as:

1) Gel Coat Over-Spray—Over-spray tends to be thin, and cures at a slower rate. Flange areas typically are not waxed and gel coat does not easily release from the surface. Adhesion of the gel coat to the unwaxed flange area of the mold is stronger than the adhesion of gel coat to matrix at the edge. Thus, upon demolding, the gel coat will peel off the marble matrix edge.

   To avoid this problem, tape the flange areas to the edge of the marble part. After spraying the gel coat, remove the tape while the gel coat is still wet.

2) Thin Gel Coat on Vertical Edge—Gel coat on a vertical edge may be thin causing it to cure at a slower rate, and therefore not shrink away from the mold.

   To check for this problem, measure the mil thickness on the vertical edge to ensure that it is the same as the rest of the part. Also, increase the catalyst level of the gel coat to accelerate the cure time.

*WHAT IS GREEN STRENGTH?

In a filled polyester system, green strength is the strength development between gelation and the point of peak exotherm (cure rate). This is measured by the time required from catalyzation to a measurable Barcol hardness.

Soon after gelation, the matrix begins to shrink. It is not immediately apparent due to the adhesion of the gel coat to the mold. During the shrinking process, the strength is building up to a point when it is able to sufficiently overcome the adhesion of the gel coat to the mold. Hence, the part releases from the mold. If the shrink rate exceeds the strength development, tearing occurs.

Slow green strength development may be caused by:

1. Slow reactive resin
2. Cold resin, fillers, mold, shop
3. Catalyst level too low or wrong type
4. Filler loading too high
5. Moisture in the fillers
6. Influence of pigment.

F. Pre-release of gel coat on bowl perimeter and edges of parts—Pre-release of gel coat on bowl perimeter and edges of parts has a number of potential causes. These causes along with solutions are described as follows:

1) Uneven Gel Coat Thickness—The gel coat may be too thick in the creases due to drainage. These thicker areas will cure faster and have a higher shrink rate.

   To avoid, check gel coat thickness while spraying. Keep spraying as evenly as possible (20 to 25 mils wet).

2) Motion—If using floating bowls which are not secured, movement or vibration will cause the bowl and gel coat to move and release from the mold surface.

   To avoid, make sure all mold parts and edges are secured.

3) Pre-Release When Using Clay—When using clay around the bowl perimeter and edges, oils from the clay can cause pre-release of the gel coat. Potential for this problem is magnified in the summer months, as hotter temperatures soften the clay and release more oils to the surface. These oils serve as mold releasing agents to the gel coat.

   Take one or more these steps to avoid this problem:

   a) Keep clay as cool as possible. When cold, the oils remain in the clay and are not drawn to the surface.
   b) After placing the clay on the mold, lightly sprinkle talc or powder on it to absorb the oils. Be sure to blow off the excess powder.
   c) After placing the clay on the mold, put a layer of mold release on the clay; this will help seal in the oils.
   d) Before applying the clay onto the mold, draw the oils out of the clay with a microwave oven. Put the clay on an unwaxed paper plate or paper towel and microwave for 30 to 60 seconds. The oils will come to the surface and be absorbed by the paper. **CAUTION: If microwaved too long, the clay will become dry and crumble.**

G. Gel Coat Stress Lines—The main cause of stress lines is high gel coat adhesion to the mold which causes incremental release instead of a smooth continuous release.

To avoid, check the following areas:

1) Mold Release—
   a) Make sure molds have good layer of mold release.
   b) Be sure mold release is applied properly over entire mold, including the edges.
2) Gel Coat—
   a) Make sure gel coat is sprayed evenly over part (20 to 25 mils wet). Remember that thin films cure slowly.
   b) Catalyze gel coat to get reasonably fast gel and cure. Slow gel times will allow gel coat to dissolve release agents. Over-catalyzing will cause too much shrinkage.
   c) Check catalyst line of spray gun to make sure catalyst is not ‘spitting’ and making hot spots. Thick films will cure and shrink more.
3) Matrix Shrink Rate Greater than Gel Coat Shrink Rate—
   a) Reduce catalyst level of matrix to slow down gel and cure rate.
   b) Use lower shrinkage resin.
   c) Reduce lightweight filler amount. Lightweight filler increases peak exotherm, causing higher shrink rate.
   d) Increase filler loading.
   e) Check fine to coarse filler ratio. Too much coarse filler will increase number of resin lakes between fillers and increase shrinkage.

H. Cracking and Delamination of White Gel Coats—White gel coats (as opposed to clear gel coats) are more heavily promoted and contain titanium dioxide (TiO2-white pigment). TiO2 inhibits (slows) the gel time; therefore, higher catalyst levels are required.

Higher catalyst levels can lead to higher exotherm that in turn leads to exothermic cracking. On the other hand, if the catalyst level is not sufficient, the gel coat will cure very slowly. Upon curing of the matrix, insufficiently cured gel coat may tear due to low green strength and fail to release from the mold.

Once the gel process has occurred, because of higher promoter levels and extra catalyst, the cure rate is quicker than with clear gel coats. If the gel coat has over-cured, the matrix will not bond well. Delamination will be further enhanced by the TiO2, which reduces the surface tack of the gel coat.

To avoid this problem, be sure to:

1) Determine the appropriate catalyst level.
2) Be aware of the cure rate of the gel coat.
3) Pour the matrix at the appropriate time.

I. Gel Time Too Fast or Too Slow—There are three main factors that can promote either a too-fast or too-slow gel time.

These influencing factors are:

1) Influence of Fillers and Pigments—
   a) Change of filler sources.
   b) Change from coarse to fine particle ratios (the more fine particles, the slower the gel time).
   c) Moisture in filler (or resin) which will inhibit gel time.
   d) Change in pigment colors and concentration. Dark colored pigments and TiO2 inhibit gel time.
2) Influence of Temperature—
   a) As a rule of thumb, a resin temperature increase of 20 degrees (Fahrenheit), will cut the gel time in half. A decrease of 20 degrees in temperature will double the gel time.
   b) Temperature of filler. If resin is warm and filler is cold, matrix is cold.
   c) Mold temperatures. Cold molds will cool off a warm matrix.

3) Influence of Catalyst—
    a) Change in catalyst supplier.
    b) Change of catalyst ratio.
    c) A change from or blend of MEKP catalyst to 2,4-pentadione peroxide (2,4-PDO) catalyst, (i.e., Azox Trigonox-44). A 2,4-PDO catalyst will have a slower gel time but a faster relative cure.

J. Too fast or too slow cure times have two primary causes. These causes along with solutions are described below.

1) Influence of Pigments, Fillers, Temperature, and Catalyst—
    a) Any influence of the above factors that affect gel time will also affect cure time. *NOTE: Gel and cure times are directly related. The faster the gel time, the faster the cure time.*
    b) Use of lightweight fillers tends to increase peak exotherm and cause a faster cure rate.
2) Casting Size and Thickness (the larger and thicker the part, the faster it cures and the higher the peak exotherm)—
    a) Lower the catalyst level or use a 'cooler' catalyst.
    b) Remove or open molds as soon as possible.
    c) Use air or water to dissipate the heat from the surface of the part.

K. Warpage—Warpage has two basic causes. These causes along with solutions are described below.

1) Filler Settling—This produces resin-rich backs, which cure, shrink, and pull inward causing the parts to warp upwards in the mold. Solutions include:
    a) Increase filler loading to increase or thicken the matrix viscosity.
    b) Reduce vibration time to reduce the chance of filler settling.
    c) Increase the catalyst level to shorten the gel time.
2) Excessive Shrinkage—Excessive shrinkage causes warpage on the decks around the bowl. Solutions are described as follows:
    a) Increase filler loading. The lower the resin content in the composition, the lower the peak exotherm and shrinkage.
    b) Check fine to coarse filler ratio. Too much coarse filler will increase the number of resin lakes and increase shrinkage.
    c) Reduce the catalyst level. The longer the gel time, the lower the peak exotherm.
    d) If back-pouring the bowls, reduce the catalyst level in the second pour. The exotherm of the first pour will help catalyze the second pour.
    e) Remove the parts from the mold while still warm and support it right side up to counter the warpage.
    f) Look for a lower exotherming resin.
    g) Check mold release application to make sure it's not a pre-release problem.
3) Post Demold Warpage—Warpage of parts after demolding due to lack of full cure can be avoided by the following:
    a) Lay the part down so that it is better and fully supported until cured.
    b) Increase the catalyst level to quicken the cure or try a secondary curing catalyst like a 2,4-pentadione catalyst (Azox, Trigonox-44, etc.)
    c) Check the mixing procedure and make sure the catalyst amount is both measurable and a large enough quantity to ensure a good even distribution of catalyst throughout the matrix.

L. Cracking—Cracking is mainly caused by unrelieved cure shrinkage stress which exceeds the green strength of the resin. Solutions to this problem include:

1) Reduce Matrix Shrinkage—
    a) Increase filler loading.
    b) Use lower shrinkage resin or lower exotherming resin.
    c) Cure matrix slower by reducing or changing catalyst.
    d) For tubs and shower pans, use higher viscosity resin.
2) Increase Matrix Crack Resistance—
    a) Increase green strength by doing one of the following:
        a1) Use hotter catalyst or increase catalyst level.
        a2) Use 2,4-Pentadione type catalyst.
    b) Increase matrix elongation.
        b1) Use higher elongation resin.
        b2) If using lightweight fillers, try using lightweight fillers with added elongation or glass fibers (e.g., R. J. Marshall Thermolite 100).
    c) Relieve stress by allowing the part to move as it shrinks.
        c1) Remove hats, open back splashes.
        c2) Check mold release.
        c3) Check gel coat gel and cure.
        c4) Check mold design.

M. Air Bubble Entrapment—Air bubble entrapment has three possible causes. These causes and suggested solutions follow.

1) Matrix Viscosity Too High—
   a) Check temperature of resin, fillers, shop, and mold. The colder it is, the thicker the matrix.
   b) Check for high concentration of fine filler particles. The higher the quantity of fine particles, the thicker the mix.
   c) Increase the resin ratio of the mix.
   d) Use lower viscosity resin.
   e) Add wetting and air release agents to the resin.
2) Ineffective Vibration—
   a) Check for sufficient and uniform vibration force around the table.
   b) Lower catalyst level to decrease gel time and allow more time for vibration.
3) Catalyst Reaction with Pigment and/or Filler Generating Gas Bubbles—
   a) Mix catalyst thoroughly into resin first before adding dry pigment and filler.
   b) Make sure all dry pigment and fillers are thoroughly dispersed (no lumps) before addition of the catalyst.

N. Soft Spots—Soft spots are cause by resin that has not gelled or cured evenly. Possible solutions are:

1) Increase catalyst levels, using lower strength catalyst and increasing volume.
2) Mix catalyst to resin thoroughly before adding filler.
3) Check for moisture in filler (wet filler tends to clump; water retards gel and cure).
4) Check for pockets of unmixed pigment.

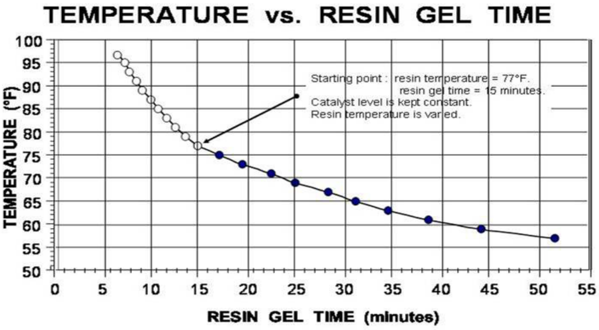
O. Blurred Vein Lines—Blurred vein lines are caused by matrix mix that is too low in viscosity. This problem can by resolved as follows:

1) Increase filler ratio.
2) Increase catalyst level.
3) Reduce vibration time.

P. 'Guesstimating' Resin Gel Time—For example, if a resin gel time at 70°F equals fifteen minutes, what would the gel time be at 60°F or 80°F? The formula is:

Use 60 - 70 = -10
Multiplying factor for -10 = 1.90 (see chart)
15 X 1.90 = 28.5
Gel time at 60°F = 28.5 minutes.

Use 80 - 70 = +10
Multiplying factor for +10 = 0.68 (see chart)
15 X 0.68 = 10.2
Gel time at 80°F = 10.2 minutes.



As a general rule of thumb, for every 11°F decrease in temperature, the gel time doubles (2x).

For every 18°F increase in temperature, the gel time halves (0.5x).

RESIN GEL TIME GUESSTIMATOR

Temperature Difference	Multiplying Factor	Temperature Difference	Multiplying Factor
-2	1.15	+2	0.92
-4	1.31	+4	0.85
-6	1.51	+6	0.79
-8	1.67	+8	0.73
-10	1.90	+10	0.68
-12	2.09	+12	0.62
-14	2.31	+14	0.58
-16	2.59	+16	0.53
-18	2.95	+18	0.50
-20	3.46	+20	0.45

Q. Catalyst Ratio—Remember that increased temperatures can cause high exotherms and increase shrinkage, which will result in cracking. When temperatures increase:

DO NOT	DO
Reduce the catalyst level. - Catalyst amount may be too small to disperse thoroughly in the mix. - This will slow green strength development. - Full cure may not be achieved.	Change to a lower strength catalyst. - This allows an increase in catalyst amount for better mixing and to ensure full cure. Switch to a longer gel time resin. - Allows an increase in catalyst percent or . . . - Maintains 'normal' catalyst percent.

The general rule of thumb for catalyst ratio is that the level should be maintained between 0.5 percent minimum and three percent maximum.

As the catalyst level moves outside this range, change, as appropriate, to a cooler or hotter catalyst type.

6. SUPPLIES FOR MARBLE PRODUCTION—Cook Composites and Polymers supplies gel coats, resins, and cleaners for cast polymer production. Other resources are listed on the following page:

CASTING: Cast Polymer

A. Mold Manufacturers

Gruber Systems
25636 Avenue Stanford
Valencia, CA 91355-1117
Ph: 800-257-4070
661-257-4060
Fax: 661-257-4791
www.gruber-systems.com

J. R. Composites Inc.
1251 GoForth Road
Kyle, TX 78640
Ph: 800-525-3587
512-268-0326

Ken Fritz Tooling & Design, Inc.
1945 Puddledock Road
Petersburg, VA 23803
Ph: 800-426-1828
804-862-4155
Fax: 804-748-2561
www.KFToolDesign@aol.com

B. Filler Suppliers

Alcan Chemicals
3690 Orange Place, Ste 400
Cleveland, OH 44122
Ph: 800-321-3864
Fax: 216-765-2570

Imerys
100 Mansell Court East, Ste 300
Roswell, GA 30076
Ph: 888-277-9636
770-645-3700
Fax: 770-645-3384
www.imerys-perfmins.com

R. J. Marshall Company
26776 W. 12 Mile Road
Southfield, MI 48034
Ph: 800-338-7900
248-353-4100
Fax: 248-948-6460
www.rjmarshallco.com

ACS International
4775 South 3rd Avenue
Tucson, AZ 85714
Ph: 800-669-9214
520-889-1933
Fax: 520-889-6782
www.acstone.com

Huber Engineered Materials
1000 Parkwood Circle Ste 100
Atlanta, GA 30339
Ph: 678-247-7300
Fax: 678-247-2797
www.hubermaterials.com

Sanco Inc.
207 Brookhollow Industrial Blvd.
Dalton, GA 30721
Ph: 800-536-5725
706-729-3773

C. Dry Pigment and Pigment Dispersion Suppliers

American Colors
1110 Edgewater Drive
Sandusky, OH 44870
Ph: 419-621-4000
Fax: 419-625-3979
www.americancolors.com

BroCom Corp.
2618 Durango Drive
Colorado Springs, CO 80910
Ph: 888-392-5808
719-392-5537
Fax: 719-392-5540
www.marblecolors.com

Plasticolors
2600 Michigan Ave.
Ashtabula, OH 44005
Ph: 440-997-5137
Fax: 440-992-3613
www.plasticolors.com

B&H Industries
4171 Legion Drive
Mason, MI 48854
Ph: 517-676-1909
Fax: 517-676-5054

Gruber Systems
25636 Avenue Stanford
Valencia, CA 91355-1117
Ph: 800-257-4070
661-257-4060
Fax: 661-257-4791
www.gruber-systems.com

CASTING: Solid Surface

Part Seven, Chapter III

In This Chapter:

1. **Introduction**
2. **Materials**
3. **Manufacturing Process**
4. **Matrix Formulation**
5. **Post-Curing**

1. INTRODUCTION—Solid surface is a specialized casting application characterized by its homogenous composition and the absence of gel coat. Homogeneity is required for fabrication of solid surface parts since installation may include routing, cutting, surface sanding, creating inlaid designs, and edge shaping. As a result, each side of a solid surface part is potentially a finished side, including the cut edges. Solid surface parts can be pigmented or veined and are slightly translucent.

One of the main defects found in solid surface parts are voids. If the matrix contains voids, some will likely be exposed during the installation process. Exposed voids become visible defects and are susceptible to staining. Materials used, matrix mixing procedures, and matrix formulation all influence void content.

2. MATERIALS—Solid surface resins are based on ISO/NPG polyesters similar to those used in gel coats rather than the orthophthalic type resins used in gel coated casting applications. This higher-grade matrix resin is required since it must provide all the protection that would have been provided by the gel coat. (For additional information on resin chemistry see Part 3, Chapter II.) As with cultured onyx, clarity and low cured casting color are very important factors. Solid surface resins are highly promoted to achieve reasonable cure rates while using the fine particle size ATH fillers. However, the promotion system differs from cultured marble in that the cured casting color is not as dark. Air release and wetting agents are typically added to help release air bubbles from the mix and to reduce or eliminate voids. UV stabilizers are added to improve UV stability.

Aluminum trihydrate (ATH) is the preferred filler for solid surface products. Solid surface grade ATH is a much finer particle size than for onyx grade. Its size is measured in units called microns. The finer or smaller the particle size, the whiter the cured casting color and the tighter the particle packing. Tighter particle packing leads to increased surface hardness and a smoother, glass like surface. ATH is also chemical resistant which adds the stain resistance properties of the part. Because of the ATH particle size, there is a high resin demand to wet out the fillers. Specially formulated granite effect fillers are available for solid surface.

Catalysts/Initiators used in solid surface production are similar to those used in cast polymer applications.

3. Manufacturing Process—The general fabrication process for solid surface production is shown in the chart in the column at right.

Solid Surface Mix Procedure	
1.	Weigh out the ingredients.
2.	Add resin to the mixing pot.
3.	May add catalyst to the resin and mix well for one minute OR add catalyst at a later step.
4.	Add pigment and mix well. May add small amount of filler to help disperse the pigment.
5.	Add filler and mix well.
6.	Stop mixer and scrape down sides and mixing blade for unmixed material.
7.	Mix well for additional 3 minutes.
8.	Apply vacuum; vacuum should be maintained for at least five minutes once 25 to 27 mmHg is reached.
9.	If catalyst has not already been added in Step Three, add catalyst to the mix.
10.	Mix for 30 seconds without vacuum to blend in catalyst.
11.	Apply vacuum and maintain for five minutes.
12.	Pour into molds.

Use of a vacuum mixer is recommended to aid in eliminating entrapped air in the matrix and voids in the finished part. Vacuum mixers have been specifically designed for manufacturing solid surface. A vacuum with 25-27 mmHg is recommended. Less than 23 mmHg vacuum is not effective while more 28 mmHg will cause monomers in the resin to vaporize. Monomer vaporization would result in millions of microscopic air bubbles in the matrix that would be impossible to eliminate.

4. Matrix Formulation—With solid surface, resin content is much higher than other casting forms due to the fine grind of the solid surface ATH filler and the necessity to release air bubbles. Also, because of the fine grind of the ATH filler, a higher catalyst level is needed. A typical solid surface matrix formulation is:

Resin	38-45%
Solid Surface Grade ATH	55-62%
Base Pigment	1.0-1.5%
Initiator Catalyst	1.0-3.5% (based on resin content)

5. Post-Curing—To post-cure is to expose a room temperature cured part to an elevated temperature for a period of time. The theory of post-curing is that the elevated temperature will increase the amount of crosslinking of the polyester resin. All cast polymer products are cured at room (ambient) temperature; however, the room temperature will change depending on the season. If the ambient temperature is cold, the polymer reaction will slow down, resulting in longer gel and cure times. The longer the cure time, the harder it is for the part to reach a complete cure. Even in warmer ambient temperatures, there are numerous factors that will prevent the part from achieving a full cure. Post-curing ensures that all parts consistently achieve a complete cure.

Post-curing is a necessity for solid surface products. Post-curing will optimize the physical properties which are critical to meeting standards and certification testing. Studies have shown that physical properties such as flexural and tensile strengths and heat distortion temperatures improve with post-curing. Also, chemical resistance, water resistance, and UV stability of the final product are enhanced. Post-curing also reduces the amount of residual styrene left in the part.

Recommended post-cure temperature is 180°F to 200°F for two to four hours. Do not allow temperatures above 225ºF since this approaches the temperature at which solid surface begins to degrade and discolor. It is important that the elevated temperature is uniform in the post-curing area. If there are 'hot spots,' there is a risk that a part or a portion of a part will degrade or discolor. Post-curing is more beneficial when parts are postcured immediately after demolding (i.e., while the part is still warm and coming down off the peak exotherm) than post-curing a part that has completely cooled to room temperature. While being post-cured, the part should be well supported. No matter when a part is post-cured—after demolding, the next day, or later—the benefits of post-curing will always exceed not post-curing.

CASTING: Flexible Casting Resins

Part Seven, Chapter IV

In This Chapter:

1. INTRODUCTION—Flexible resin is a special polyester resin formulated to achieve its flexible property. There are several uses for flexible resins:

- Decorative trim molding—flex resin is mixed with various types of fillers and pigments, typically cast in long strips. Required properties for trim molding products include:
    - Flexibility—strips of molding are rolled for packaging. Trim needs to bend around structural curvatures.
    - Nailability—nails are used to secure molding in place.
    - Paintability—once installed, moldings are painted.
- Safety glass—flex resin is poured between glass plates to prevent the glass from shattering upon breaking.
- Blending resin—the most popular usage of flexible casting resins is in blending with another rigid polyester resin to increase the tensile elongation (flexibility) of the rigid resin. The blending ratio is dependent upon the desired flexibility. Increasing the flexibility will improve the 'toughness' by decreasing the 'brittleness' of the part.

General characteristics of flexible resins are as follows:

- Very low shrinkage
- Tacky surface finish
- High tensile elongation
- Low heat distortion temperature (HDT)
- Low Barcol hardness
- Poor UV resistance.

Flexible resin by itself or blended in high ratios is NOT recommended for use in structural parts or for use with gel coats. The high tensile elongation, low heat distortion temperature, and low Barcol hardness will not provide structural integrity. Gel coat is typically rigid and can crack if there is too much movement in the matrix or laminate behind it.

2. MATERIALS—Flex resins are available in pre-promoted and unpromoted versions. The pre-promoted versions require only the addition of catalyst to start the curing process. The curing process can be started for unpromoted versions by either use of heat and a heat-activated catalyst or use of catalyst and promoters at room temperature.

- Benzoyl peroxide (BPO) catalyst is the most commonly used heat activated catalyst and is typically used at temperatures above 200°F.
- BPO may also be used to cure polyesters at room temperature, provided an amine promoter is used. Examples would include diethylaniline (DEA) or dimethylaniline (DMA). DMA yields shorter gel times than DEA. More amine speeds up both gel and cure rates. Castings cured this way tend to be more flexible. Instances where this cure system might be used are in two pot systems where catalyzed resin and promoted resins are mixed just before or during usage. BPO is a paste and therefore less convenient to use than methyl ethyl ketone peroxide (MEKP).
- The most common system used for room temperature cure is MEKP catalyst with a cobalt promoter. Use of a co-promoter amine is frequently desirable to provide faster gel and cure rates for production needs. Typical concentrations would include 0.15 to 0.25 percent of a 12 percent cobalt solution and 0.025 to 0.25 percent DMA. Additional inhibitor may be added to achieve a specific gel time, once the right cure rate has been determined.

CAUTION: When promoting polyester resins, promoters and catalysts must NOT come into direct contact with each other because rapid and violent decomposition may result. The resulting by-product may pose serious health and fire hazards.

Fillers are used to extend the resin, thereby lowering raw material costs. Fillers impart color and opacity to a casting. Many inorganic fillers are white to light gray in a resin system. Organic fillers produce brown colors. Pigments can also be used to produce any desired color.

A. Inorganic Fillers—Typical inorganic fillers are calcium carbonate, talc (magnesium silicate), and aluminum trihydrate. The two primary reasons for using this type of filler are low cost and availability. Some fillers affect the final cured properties and need to be checked by the end user for acceptable results. Since these are heavy fillers, parts will reflect higher densities. Use of this type of filler makes a part harder and less flexible. Aluminum trihydrate can reduce the flammability characteristics of the final casting.

B. Organic Fillers—Organic fillers are usually composed of agricultural by-products that are ground to various particle sizes. Because they are agricultural by-products, availability and consistency may vary relative to geographic area. Typical fillers include ground pecan or walnut shells. Parts made with organic fillers result in a wood-like finish and can be painted. Careful selection of organic fillers is necessary. Many organic fillers inhibit gel and cure—in some cases, very severely. Sawdust is a common material that is not recommended.

C. Lightweight Fillers—Use of lightweight fillers can reduce cured densities close to that of wood. Lightweight fillers are hollow spheres that displace weight but not volume and thereby effectively reduce the part's density. There are various lightweight filler compositions available as well as pre-blended mixtures with calcium carbonate. Be aware that some types of lightweight fillers are fragile and readily break. Once broken, these lightweight fillers become fine particles and advantage of lighter weight is lost.

Chopped fiberglass, milled fibers, wood, or metal rods can be used to reinforce structural parts. Fibers are mixed into the resin to produce a higher physical strength part. Wood, such as particleboard or plywood sheets, can be used as a back support. It is important to make sure the wood is dry. Metal rods inserted into the casting will impart stiffness.

3. PROCESSING INFORMATION—Molds must be flexible and strong for long life and ease in removing the cast part. In addition, they must be resistant to solvents and styrene. Mold materials must be capable of duplicating every detail from the master. Typical mold-making materials are RTV silicone rubber, urethane elastomers, and latex or vinyl rubber. *NOTE: Latex must be non-sulfur based. Sulfur based latex will inhibit the gel and cure of polyester resins.*

Castings pulled from the mold usually will have a slightly tacky surface. This tackiness is mostly unreacted styrene monomer. Hot soapy water or solvent wash will easily remove it. Castings can then be sanded, buffed, and polished to a variety of surface finishes from glossy to matte. Castings can also be painted, stained, lacquered, or varnished.

4. FORMULATIONS FOR FLEX TRIM MOLDING—Typical properties of CCP STYPOL® flexible resin are:

Properties	
Viscosity (Brookfield)	80 cps
Gel Time at 77°F	3.5 minutes
Cure Time	10 minute
Peak Exotherm	330°F
Weight per Gallon	9.4 pounds

The following formulations are starting guidelines:

Flexible Parts	
Resin	91.3%
Pecan Shell	2.2%
Calcium Carbonate	6.5%
Promoters	as needed
MEKP	1% minimum

Semi-Rigid Parts (nailable)	
Resin	80.0%
Pecan Shell	20.0%
Pigments	as needed
Promoters	as needed
MEKP	1% minimum

Light-Weight Parts (semi-rigid and nailable)	
Resin	73.0%
Pecan Shell	19.0%
Lightweight Filler	8.0%
Pigments	as needed
Promoters	as needed
MEKP	1% minimum

Rigid	
Resin	57.8%
Pecan Shell	42.2%
Pigments	as needed
Promoters	as needed
MEKP	1% minimum

5. REFERENCES

Wood Flour
Agrashell
5934 Keystone Drive
Bath, PA 18014
Ph: 610-837-6705
Fax: 610-837-8802

Composition Materials Co.
125 Old Gate Lane
Milford, CT 06460
Ph: 203-874-6500
Fax: 203-875-6505
www.compomat.com

Southern Georgia Pecan Co.
P.O. Box 5366
Valdosta, GA 31603
Ph: 800-627-6630
Fax: 229-247-6361
www.georgiapecan.com

Calcium Carbonate
Imerys
100 Mansell Court East, Ste 300
Roswell, GA 30076
Ph: 888-277-9636
770-645-3700
Fax: 770-645-3384
www.imerys-permins.com

RJ Marshall Company
26776 W. Twelve Mile Road
Southfield, MI 48034
Ph: 800-338-7900
248-353-4100
Fax: 248-948-6460
www.rjmarshallco.com

Lightweight Fillers
3M Glass Bubbles
Specialty Additives
3M Center
St. Paul, MN 55144
Ph: 866-364-3577
651-753-1110
Fax: 651-737-3061
www.3m.com

Lite-Weight Products
1706 Kansas Avenue
Kansas City, KS 66105
Ph: 913-281-0123

RJ Marshall Company
26776 W. Twelve Mile Road
Southfield, MI 48034
Ph: 800-338-7900
248-353-4100
Fax: 248-948-6460
www.rjmarshallco.com

Silicone Rubber
Dow Corning Corp.
P.O. Box 994
Midland, MI 48686-0994
Ph: 989-496-4400
Fax: 989-496-6731
www.dowcorning.com

General Electric
3135 Easton Turnpike
Fairfield, CT 06828
Ph: 203-373-2211
Fax: 203-373-3131
www.ge.com

CASTING: Thermal Shock Testing Request

Part Seven, Chapter V

In This Chapter:

1. **Thermal Shock Testing**
2. **Factors Affecting Thermal Shock Performance**
3. **Thermal Shock Test Request**

1. THERMAL SHOCK TESTING—Thermal shock is an accelerated test designed to measure the longevity of cast and solid surface parts when exposed to water conditions of a typical home. Parts tested for thermal shock are typically kitchen sinks and bathroom sinks and tubs. Thermal shock testing is a required protocol of ANSI standards Z 124.3 for plastic lavatories and Z 124.6 for plastic sinks.

During the thermal shock test, the part is exposed to cycles of extreme hot and cold water. The time exposure, rate of flow, and water temperatures are specific to each standard or test method. During the hot water exposure, the part will expand or contract. Then the cold water will shrink or constrict the part. As a result, the part will continuously 'move' by contracting and constricting throughout the test period.

Eventually, the part will reach a point of fatigue and fail, as indicated by the visible appearance of a crack. If the test is permitted to continue, the crack will grow longer and deeper, and other cracks can appear. Results are generally reported as the number of cycles to failure, along with a description of the failure, including whether the failure occurred in the gel coat or in the matrix. Thermal shock testing results have not been correlated to the actual real time performance of the product.

2. FACTORS AFFECTING THERMAL SHOCK PERFORMANCE—Although thermal shock testing results can be influenced by the quality of materials used to fabricate the part, the manufacturing process used to fabricate the part is the main factor influencing results.

If thermal shock testing is being performed to qualify a new raw material, two parts should be made—one with the 'new' material and one with the 'old' material—using the same manufacturing process. Results should be compared only to each other. If the results, then the difference is most likely influenced by the raw material. However, very significantly different results would indicate a possible manufacturing defect in the part with the lower result. If both results are equal but are very low (not meeting required number of cycles), a manufacturing process issue is indicated.

When performing thermal shock testing to become qualified to a standard, it is assumed that the tested sink or tub is a typical representative of the manufacturer's product. Failure during thermal shock testing can occur in either the gel coat or the matrix. Descriptions of each of these failure modes and possible causes for failure follow.

A. Gel Coat Failure—Short cracks or crazing only in the gel coat layer indicate gel coat failure. If testing continues after gel coat failure has occurred, water will eventually seep under the crazed areas of the gel coat and cause it to peel. The exposed matrix will eventually crack. Gel coat failures can be caused by porosity in the gel coat, or by thick, thin or uneven gel coat.

1) Porosity—When exposed to hot water, porosity or entrapped air in the gel coat layer expands more than the surrounding gel coat. Because the gel coat is such a thin layer, it does not require many cycles of hot water before a crack appears. The size of the air bubble will also make a difference as to how quickly the failure occurs.
2) Thick or Thin Gel Coat—If the gel coat layer is too thin, failures typically occur because the gel coat lacks the strength to withstand the stress of the contraction. It the gel coat layer is too thick, performance is better; however, as a result of the excess thickness, increased movement during contraction/constriction can fatigue the part and cause premature cracking.
3) Uneven Gel Coat—If the gel coat is not applied evenly, areas of thin and thick gel coat will contract and constrict at differing rates, causing the interfaces where thick and thin areas meet to become high stress areas.

B. Matrix Failure—Cracks resulting from matrix failure are deeper, longer and sometimes wider than gel coat failure cracks. Typical matrix cracks radiate straight out from the drain because the drain is the thickest section of the bowl. Matrix failure can be caused by matrix composition, reactivity of the back pour, porosity, misalignment of back (bowl) hats, or improper placement of the overflow tube.

1) Matrix Composition—During the thermal shock test, the resin is the only material in the matrix composition that contracts and constricts. If the matrix is resin-rich, there will be an excessive amount of movement in the contraction and constriction, If the matrix is resin-poor, it will not hold together.

2) Reactivity of the Back Pour—Frequently, matrix resin content is increased for the back pour to make it easier to fill in the hats. High matrix resin content coupled with the thicker mass of the bowl will cause the exotherm of the back pour/hat to be very high. The higher the exotherm, the greater the possibility of building in stress fractures in the matrix during the curing process. The stress fractures will grow during the thermal shock test and eventually become visible on the surface.
3) Porosity—When exposed to hot water, porosity or entrapped air in the gel coat layer expands more than the surrounding gel coat. Because the gel coat is such a thin layer, it does not require many cycles of hot water before a crack appears. The size of the air bubble will also make a difference as to how quickly the failure occurs.
4) Misalignment Back (Bowl) Hats—Misalignment of back (bowl) hats will shift the mass of the matrix. The result will be even greater differences between thick and thin matrix areas. Just like uneven gel coat thickness, there is a difference in the rate of contraction and constriction between thick and thin matrix areas, with the stress being at the interface between the areas.
5) Improper Placement of Overflow Tube—The space under the overflow tube should be consistent from the drain to the connection near the bowl's edge. Matrix fills the gap between the bowl and the tube. If the space under the tube is not consistent, thickness variations will occur and cause failure as described above.

As stated previously, thermal shock testing is an indicator as to how well the part was manufactured. It is an accelerated method of testing with harsh and extreme conditions designed to push the performance of the part. If results are good, then the manufacturer has 'the peace of mind' of knowing that the production process is working well. If results are poor, then it is important information defining the issues that need to be addressed and corrected in the manufacturing process.

3. THERMAL SHOCK TEST REQUEST—CCP provides thermal shock testing as a service to its customers. To request the test, please fill out the following page and send with the item to be tested to:

CCP
Attn: Tony Giordano, Research Dept.
820 East 14th Street
North Kansas City, MO 64116

Inquiries should be directed to:
Ph: 816-391-6088
Fax: 816-391-6215

Testing can be performed to either the ANSI Z 124.3 or the ANSI Z 124.6 standards.

1) ANSI Z 124.3 (Bathroom)—The standard test uses 150°F and 50°F water. One cycle consists of:

1.	90 seconds of 150°F water flowing at one gallon per minute.
2.	30 seconds of drain time.
3.	90 seconds of 50°F water flowing at one gallon per minute.
4.	30 seconds of drain time.

To pass this test, a minimum of 500 cycles without cracks or blisters is required. Typically, bowl test are run until at least two cracks are observed. The bowl is then cut. The cracks are inspected and the gel coat thickness is measured.

2) ANSI Z 124.6 (Kitchen)—This test uses 175°F/45°F water flowing at two gallons per minute.

CASTING: Thermal Shock Testing Request

REQUEST FOR THERMAL SHOCK TEST (MB-218)

IMPORTANT

1. Form must be completed before testing begins. 2. Vanity tops wider than 32 inches cannot be tested.

Company Name: ______________________
Address: ______________________
____
City/State/ZIP: ______________________

Phone: ______________________
Fax: ______________________
E-mail: ______________________
Contact Name: ______________________

Product: ☐ Marble ☐ Onyx ☐ Granite ☐ Solid Surface ☐ Other: ______________

Date of Manufacture:

Shop Temperature (°F):

Bowl: ☐ Round ☐ Oval ☐ Square ☐ Shell ☐ Other: ______________

Overflow: ☐ Yes ☐ No

Thermal Shock Test: ☐ Standard 50/150 ☐ Solid Surface Kitchen 70/190 ☐ Other: ______________

GEL COAT: Manufacturer: Product Code: Batch#:

Spray Type: ☐ Airless ☐ Air-Assisted ☐ Non-Atomized ☐ Other: __________

Method of Catalyzation: ☐ External ☐ Internal ☐ Hot Pot

Catalyst Manufacturer & Product:

Percentage Catalyst:

Wet Film Thickness: ☐ Under 10 mils ☐ 10 – 15 mils ☐ 15 -20 mils ☐ 20 -25 mils ☐ 25 - 30 mils ☐ Over 30 mils

Cure Tunnel: ☐ Yes ☐ No ☐ Tunnel Temperature (°F): __________

Spray Granite Manufacturer: ______________

Product Code: ______________
Color: ______________

Filler Percentage in Gel Coat: __________

RESIN: Manufacturer: Product Code: Batch#:

Catalyst Manufacturer & Product:

Percentage:

FILLER: ☐ CaCO3 ☐ ATH (Onyx) ☐ Granite ☐ Other: __________ ☐ ATH (Solid Surface) ☐ Granite (Solid Surface)

Filler Manufacturer & Product:

MATRIX: Resin Percent: Filler Percent: Matrix Temp. (°F): Ambient Temp. (°F):

FOR RESEARCH USE ONLY

Type of Failure: ☐Gel Coat ☐Matrix ☐Other: ______________ # of Cycles: ______________

Project #:

Date Assigned:

COMMENTS: ______________________
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POLYESTER TOOLING: Introduction

Part Eight, Chapter I

In Part Eight

Fiber reinforced plastic (FRP) parts are molded to the design shape using a cure tool (commonly called a mold) and a molding protocol. At its minimum, a mold consists of a mold skin.

The molding protocol has a large impact on the cure tool design. When a molding process involves high pressures, or whenever any mold deflection must be limited, bracing is used to reinforce the mold skin. This can be accomplished with any combination of increased thickness, the use of cores, and/or shaped stiffener elements like hat-section or c-section laminates. Each case of bracing can be unique in its design.

When a mold skin is larger than a few square feet, a framing system is also used to provide a means of handling the mold skin without causing it to be deformed or fractured. A framing system can be one of two types. The simplest framing system supports the dead weight of the mold and concentrates it on a few load points. The more complex type also provides structural support to react molding forces and restrict mold deformation. Both systems provide a means of grabbing the mold for lifting and transport operations.

Most mold skins used to produce FRP parts are fashioned from FRP type materials. For high production runs, a metal mold skin can be most economical, but at a higher up-front cost. An FRP type mold skin is produced using a master model, also known as a pattern or plug. This master model is a full-scale representation of a part design that incorporates all of the geometry for one of the part surfaces. A model may be geometrically equivalent to the part image or it can be a mirror image about the part's external surface.

There is no quick or easy way to produce quality FRP tooling. Good tooling is a precise, painstaking craft. It begins with careful preparation of the master model and continues through the final building of the production mold. Any defects on the master model will translate onto each subsequent piece of tooling and require extra effort to remove. The highest quality production mold begins with an even-higher quality master model.

The terms master model, pattern and plug are sometimes used interchangeably. Due to recent advancements in computer numerically controlled (CNC) routers, the term pattern generally describes a master model that is machined from a blank constructed of a single material or material type. In contrast, the term plug generally describes a master model that is constructed from a variety of materials and shaped manually. Neither a pattern nor a plug is particularly durable and is suitable for producing only one, or a small number of moldings. When two or more molds are required to meet production requirements, a master mold is used to produce the production molds. This master mold is a durable, robust, full-scale representation of a part image design and is constructed in the same manner as a production mold.

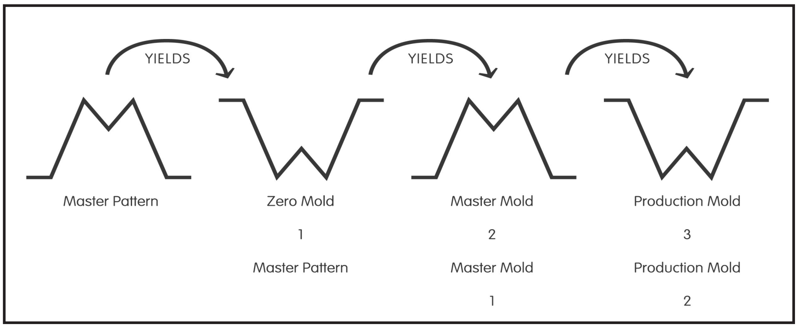
POLYESTER TOOLING: The Master Model

Part Eight, Chapter II

In This Chapter

1. **Introduction**
2. **Number of Moldings**
3. **Surface Quality**
4. **Generator**

1. INTRODUCTION—A wide variety of materials can be used to construct the master model. Some examples are plaster, polyester resin, epoxy resin, urethane foam, polyvinyl chloride (PVC) foam, body filler, FRP materials, wood coated with epoxy or polyester resin, medium density fiberboard (MDF) and certain laminated Melamine®-faced sheet materials like Formica® or bathroom wallboard.



2. NUMBER OF MOLDINGS—The number of moldings expected from the master model will influence the choice of materials and construction methodology. Plaster or foam-board type patterns, or plugs constructed from numerous materials will seldom survive one pull without incurring some damage. If several molds are needed, it is best to build a master mold using FRP materials. A master mold is robust and can be used to produce a large number of production molds.

3. SURFACE QUALITY—The surface quality of the master model is its most important feature. It should be hard, glossy and free of defects. The molding process will reproduce and worsen any defects on the master model. CCP tooling gel coat makes an excellent final coating for the master model. When properly applied, tooling gel coat provides the most fool-proof surface (see DS-45 Tooling Gel Coat Data Sheets for specific information).

Resin shrinkage during the molding process will result in a part that is smaller than the master model. For some parts, the master model may be made slightly larger to offset this. The exact amount will depend on the type of resin and its inherent shrinkage, the glass content, process temperatures and the number of generations between the master model and the production part. A general rule of thumb for conventional room-temperature cured polyesters is 1/32 inch of shrinkage per linear foot when reinforced with 25 weight percent glass content. Gel coat shrinks more than fiber reinforced resin, resulting in parts that are more concave on the gel coat side. For this reason, any large, flat areas should be crowned convex to prevent dishing in the reverse direction. A crown of 1/4 inch per linear foot is typical for small panels.

4. GENERATOR—The term 'generation' refers to the number of successive moldings between the master model and the production part. If a production mold is made on the master model, it is a first generation production mold. If a production mold is made from a master mold that is made from the master model, it is a second generation production mold. A second generation mold requires a master model geometry that is a mirror image about the part design surface as described in the schematic below. Each subsequent generation can be slightly smaller than its predecessor. The exact amount will depend upon the materials and processes involved.

Producing a master mold from the geometry of a master model that is identical to the part design surface requires an intermediate piece of tooling. This intermediate piece is made from the master model and is called a zero mold. The zero mold is used to manufacture the master mold. The master mold yields the production molds one, two, etc. Here, the zero mold is a first generation mold, the master mold is from the second generation, and all of the production molds (one, two, etc) are from the third generation.

When the master model is constructed from certain materials and/or certain combinations of materials, the boundaries between materials may become visible as witness lines in the subsequently molded FRP part. This cosmetic defect, known as mark-off, happens due to a combination of molding exotherm, substrate heat capacity, substrate thermal expansion, cure shrinkage and softening in the gel coat, both on the model and molding. The zero mold presents an opportunity to remove these witness lines by wet sanding, buffing and polishing. This is particularly true for outside edges and corners on the zero mold (convex, or 'male' type features). Outside features are more easily sanded than inside edges and corners (concave, or 'female' type features). Defects at these inside edges and corners are more easily corrected on the next piece of tooling, the master mold, when they become outside edges and corners.

POLYESTER TOOLING: Master Model Preparation

Part Eight, Chapter III

In This Chapter

1. **Sanding**
2. **Polishing and Buffing**
3. **Test for Shine**

1. SANDING—A master model should be surfaced with tooling gel coat that is well-cured and sanded smooth. At a minimum, sanding should be accomplished by using finer grit sandpapers until no scratches are present that are deeper than those made by 600 grit paper. For a higher gloss with less buffing, 800, 1000, 1200 and 1500 grit papers are available. Each grit should be used at a 90 degree angle to the direction of the preceding grit, until all of the transverse scratches are removed. A water-insoluble dye such as steel layout fluid or a dry guide coat can be used to increase the visibility of larger grit scratches, which should be sanded until they are eliminated before changing to the next finer grit paper. When wet sanding, a small amount of dish soap helps to suspend sanding particles in the water. This water should be changed whenever moving to a finer grit paper to avoid subsequently scratching the model surface with the sanding particles from the coarser grit.

2. POLISHING AND BUFFING—After sanding, the model surface should be polished and buffed using a polishing compound formulated for polyesters and a polishing machine equipped with a pile pad. Careful attention is needed in this operation. Poor polishing caused by the high heat of the buffing pad can result in orange peel, fiber print and burn-through. After polishing, wash the model with dish soap and water to remove residues from the buffing compound or polishing medium.

3. TEST FOR SHINE—After final polishing, check to see if the tooling gel coat has a natural shine or an artificial shine. Using a rag lightly dampened with acetone or other suitable solvent, wipe the gel coat surface to remove any residue. The solvent should remove some of the residual compound oil, but the overall natural shine should still be excellent. If the tooling gel coat dulls down a great deal, a lack of natural original gloss is indicated because the compound oil has produced an artificial gloss. Development of a high, natural shine is what separates a tooling gel coat from other surfacing materials. To achieve this high natural gloss, the mold must be adequately sanded and/or buffed.

To prevent damage to the tooling gel coat, do not allow acetone or other solvents to puddle upon, or to remain in contact with the model's surface for very long. Note also that mold release wax should not be used for 'shine power.' A solvent wipe will remove the wax shine also, returning the mold to its natural shine. Wax is used for releasing, not shine.

Once the master model has been surfaced, sanded, buffed, polished and washed with soap and water, a mold release system should be applied.

POLYESTER TOOLING: Applying Release Wax

Part Eight, Chapter IV

In This Chapter

1. INTRODUCTION—Successful mold release with master models, new molds, or resurfaced molds can be very difficult when sanding and/or heavy buffing has taken place. A film-forming agent, such as Poly Vinyl Alcohol (PVA) should be considered for extra release protection on new molds, mold patches, or whenever the mold has been sanded or heavily buffed.

2. TYPES OF MOLD RELEASE—The best results for tooling are achieved by using a good grade of paste wax formulated for FRP. It is imperative that the master model or mold be thoroughly waxed to avoid any sticking during demold of the part. At least six coats of wax should be applied to the master mold. Each layer of wax should be allowed to haze before buffing with clean, soft cheesecloth or terry cloth towels.

If a polymer-based, or semi-permanent mold release system is used, follow the specific directions from the manufacturer. Most polymer mold release systems are designed for multiple pulls without updating the mold release system. This results in less mold maintenance time, and subsequently in increased productivity. For the purposes of mold construction, this benefit is thoroughly outweighed by a specific detriment to polymer mold release. There is an increased risk of gel coat pre-release due to the extraordinarily good release on the first pull. (Usually, only one zero mold is pulled from a master pattern and only one master mold is pulled from a zero mold, eliminating the benefit of multiple releases via a polymer mold release system.) For production molds pulled from a glass master, the cost of applying an additional coat of paste wax between pulls is far less than the cost of correcting gel coat pre-release. It is always a good idea to build a small test panel to be sure the system will produce moldings with the required quality.

3. APPLICATION OF PASTE WAX—Apply the first coat of release wax in a circular motion, taking care not to apply the release wax too heavily. Wait the amount of time recommended by the manufacturer for the wax to haze and the solvents to flash off. Polish thoroughly by hand using clean, soft, lint-free cotton cheesecloth or terry cloth towels. Always use two rags for wax buffing. The first rag is used to remove the bulk of the wax. The second rag is used for final polishing. Avoid using fibrous paper products because they can mechanically abrade and remove the wax release layer. Do not use a machine buffer for polishing, as it may burn through the waxed surface and leave bare areas. Allow each coat of release wax to dry sufficiently. Refer to the manufacturer's instructions for details.

Apply the second, third, fourth, fifth and sixth coats as described above. To help avoid leaving unwaxed areas, begin and end each coat at a different place on the mold. Always wait for hazing before buffing, and always wait between coats. After the final coat has dried sufficiently, hand wipe the entire surface with cheesecloth to remove any dust and dirt.

4. ADDITIONAL RELEASE PROTECTION—To further ensure successful release, a film-forming material that creates a physical barrier can be used in addition to the six coats of wax release. Poly Vinyl Alcohol (PVA) is a water/alcohol solution of water soluble, film-forming materials. PVA is particularly recommended as an additional release agent on new molds, and when molds are resurfaced, repaired or sanded and buffed. Since it is water soluble, it is not recommended as a release film for gel coats or resins that contain water or emit water during cure. The PVA film does impart some degree of surface roughness to the molded article, so some post-molding sanding may be required to meet cosmetic requirements. Upon part removal, the PVA should readily dissolve and wash from the molding with water. If the PVA adheres to the mold rather than the part, the film was probably too thin.

Upon completing the release wax procedure, apply two coats of a non-silicone paste wax such as Ceara, Partall #2, Oscar's 600 or TR108. The non-silicone paste wax will help prevent fisheyes and allow the PVA to flow more smoothly.

Best spray results are obtained with as fine a spray as possible. Use high air pressure (80 to 100 psi) and low PVA fluid flow. Normal spraying distance is 12 to 20 inches. It is essential to apply several thin coats of PVA, and then follow with a 'heavier' wet coat to a film thickness of approximately two to four mils. One gallon will cover approximately 400 square feet. Drying time is 15 to 30 minutes (depending on the temperature, humidity, air movement and film thickness). Do not apply tooling gel coat over wet PVA. When dry, the PVA film should be tack-free, very smooth and glossy. The spray gun should be cleaned with water, and then flushed with solvent to remove the residual water. When using PVA, refer to the table on 'Troubleshooting PVA Application' on the preceding page for suggestions.

5. TROUBLESHOOTING—

Troubleshooting PVA Application		
	Observation	**Suggestion**
1.	Air bubbles in the PVA film	Air pressure too low, use at least 80 psi dynamic at the gun.
2.	Film solution runs	Film sprayed on too wet and too thick.
3.	Dull spots in the film caused by PVA overspray	Spray dried PVA film with water to cause re-wetting and flow out.
4.	Entire film is dull and hazy, grainy looking	Film not thick enough, film not sprayed to a "wet" coat.
5.	Surface on part is rough and dull	See problems above in 3. and 4.
6.	Film won't wet out evenly or fish eyes form	Contaminated surface. Do not use release wax that contains silicone.
7.	PVA etch (a dull, textured pattern on both mold and part surface)	PVA film too thin (dust coat).
8.	Hard, white buildup accumulates on the mold	Laminate too hot or PVA too thin.
9.	Part sticking	PVA film too thin.
10.	PVA stays with the mold, not the part	PVA film too thin.

POLYESTER TOOLING: Building a Mold

In This Chapter

1. MOLD DESIGN CONSIDERATIONS—Molds are usually produced using the contact (open) molding method. The mold fabrication process must be designed, scheduled and executed within a controlled time frame. Gel coat is applied and allowed to cure. Subsequently, the laminate is applied, and it bonds to the previously cured gel coat. This bond is a secondary bond, and a source of potential weakness. For this reason, the gel coat or laminate should never be allowed to cure completely before applying the next layer of material.

There are several options to consider in the design of a mold laminate. A mold laminate can consist of two or more components. At the minimum, tooling gel coat serves as the surface layer and a bulk laminate serves as the structural panel. The tooling gel coat must provide a surface that is hard and has a natural shine, and a very smooth, glossy surface. Isophthalic polyester tooling gel coats provide the highest gloss, but with a modest strength and heat distortion temperature (HDT). Vinyl ester gel coats provide the highest strength and HDT, but at a modest gloss. Review the DS-45 (945 Series) Tooling Gel Coat Data Sheet for specific material, equipment and application information.

One method to achieve synergy within these layers is to use a surface layer of isophthalic polyester gel coat, with the subsequent layer a vinyl ester barrier coat applied in a method similar to that used with the gel coat. This barrier coat serves to strengthen the gel coat and to enhance surface cosmetics. Review the DS-67B 967BJ244 ArmorGuard® MC Vinyl Ester Black Barrier Coat Data Sheet for specific information.

The laminate reinforcement can be any reinforcing fiber. Chopped gun roving at 30 to 35 percent reinforcement provides best cosmetics and overall results. Higher strengths can be achieved using continuous reinforcement, but print-through and distortion will be greater. Chopped strand mat (CSM) contains a binder resin, which can lead to dimples on the gel coat surface. Typically, there is less binder on one side of the CSM. This side should be placed against the gel coat layer. For best cosmetics, any CSM splices in the part area should employ tear joints at the CSM edges.

A skin coat laminate can be used to avoid air entrapment next to the gel coat that would lead to subsequent failure of the gel coat layer. A skin laminate is generally a thin layer, from 0.030 to 0.090 inches, of chopped gun roving at 30 weight percent reinforcement. This corresponds to between one and three ounces per square foot (300-900 grams/square meter).

The bulk laminate is usually made with one of three resin materials: conventional isophthalic laminating resin, OPTIMOLD® II (alumina trihydrate filled zero-shrink) laminating resin, or *OptiPLUS*™ (unfilled zero-shrink) laminating resin. Refer to the subsequent sections for each material.

Mold thickness depends upon the size and shape of the mold. A thickness of 1/4 inch for up to ten linear feet, with an extra 1/8 inch for each additional five linear feet is a 'loose' rule of thumb. Thickness can vary according to different shapes, sizes and needs. The style and type of framing, as well as the mechanical and physical properties for the laminating materials, also influence the design thickness.

Structural considerations are addressed with bracing and framing. Bracing is an element that is integral to the mold laminate. Large molds usually incorporate balsa core materials. A shaped stiffener element, like a hat, or C-section, can also be incorporated. Framing is a structure that surrounds and supports the mold from the back side. Generally steel is used for framing, although sometimes wood is used.

For contact (open) molding, the frame is a cradle that supports the mold laminate, distributing its weight onto concentrated load points (usually casters). For high pressure resin transfer molding, the frame is a structural reinforcement for the laminate that defines the mold cavity.

Once the mold's design and construction methodology are selected, one or more small test panels should be produced to demonstrate suitable process conditions and application techniques. Performance of these tests prior to building molds is very prudent and leads to the highest quality mold for the lowest cost.

2. TOOLING GEL COAT—Before using tooling gel coat to fabricate molds, a gel coat spray-out test panel should be prepared. The spray-out should be made under the same conditions as those that will be used in spraying the actual mold. After evaluation, the spray-out should be retained along with other data as part of the mold's historical record.

Using a clear tooling gel coat for the first coat will help avoid faults or defects. Any porosity and/or pinholes will be quite visible in the clear film. If porosity is evident after the film is gelled, the coat should be removed and the problem corrected. Once the film is clean, with no porosity, pits or pinholes, the second coat can be applied. This second coat should be the color that is preferred for the mold (black, green or orange).

To produce a quality spray-out, first apply mold release wax to a clean glass plate. A common size is 12 inches by 12 inches. Then, using the same equipment, as well as the same lot of gel coat and catalyst, spray a properly catalyzed film of gel coat using the same techniques as used on the production mold. Use a wet-film gauge to ensure the gel coat is applied in a smoothly sprayed layer at 18 ± 2 mils (450 ± 50 microns) wet. Once cured, the gel coat film should be laminated or backed with masking tape for demolding. The gel coat surface should be visually inspected for imperfections. Sanding the surface and wiping with a contrasting dye will reveal any surface and/or internal porosity.

If the sprayout panel looks satisfactory, use the same material lots, equipment and application techniques to produce the mold. If the panel does not look satisfactory, spray adjustments should be made until a high quality panel is produced that is porosity-free with no surface imperfections.

OPTIMOLD® II Catalyst Correction	
Catalyst % by Volume	**Catalyst % by Weight**
0.90	1.27
0.95	1.34
1.00	1.41
1.05	1.48
1.10	1.55
1.15	1.62
1.20	1.69
1.25	1.77

When using Binks pressure pot spray equipment, the 66 fluid orifice, 65 needle and 63 PB air cap combination provides a material flow rate between 1.5 and 2.5 pounds per minute. An air atomization pressure of 60 to 75 psi (at the gun with the fan full open) utilizes 17 CFM of air and normally ensures excellent atomization of the gel coat. Material flow rates in excess of 2.5 pounds per minute can create sags, pinholing, porosity and excessive orange peel. Airless equipment requires a gel coat with suitable properties.

The tooling gel coat should be applied in two smoothly sprayed coats of 18 ± 2 wet mils for each cure. Each coat should be developed through three spray passes, with each pass at right angles to the previous pass. The first coat should be allowed to gel between coats and cure only to the point where it will not alligator when the second coat is applied. Normally, this time period is 90 minutes at 77°F and 1.8 percent catalyst. The second coat may be a different color and can act as a warning when the first coat has been sanded through during the mold's service life.

Lamination should begin only after the second layer of tooling gel coat has cured for 60 to 90 minutes or up to a maximum of three hours. The time element is dependent upon room temperature, air movement, humidity, catalyst type and concentration. If the gel coat cures too completely, it may shrink and pull away from the master. The gel coat should be covered with at least a skin laminate on the same day it is sprayed. Excessive delays can result in dust or dirt accumulation that can prevent proper laminate adhesion.

Spraying tooling gel coat at temperatures less than 77°F can result in under-cure that appears later as distortion and/or dulling of the mold surface.

3. BARRIER COATS IN TOOLING APPLICATIONS—A vinyl ester barrier coat can be used as a print-blocker to provide a smoother gel coat surface. This translates into a mold that yields parts with improved cosmetics. The barrier coat's black color also provides a visual aid to detecting air bubbles during skin coat lamination. For best cosmetics, the barrier coat should be in addition to two layers of tooling gel coat. The barrier coat could also be used as a substitute for the second layer of tooling gel coat, but at a slight cosmetic penalty.

The barrier coat material is applied in the same manner as a gel coat to a thickness of 16 to 20 mils (400-500 microns). This buildup should done in three passes, with each pass at a right angle to the previous pass. Refer to the DS-67B ArmorGuard® MC Vinyl Ester Black Barrier Coat (967BJ244) datasheet for specific application instructions. An MEKP with a low hydrogen peroxide content should be used. Quality control is performed with Arkema Luperox® DDM-9. The ideal catalyst level is 1.8 percent at 77°F, and should always be between 1.2 percent and 2.5 percent for proper cure. This generally requires ambient temperatures in the 70°F to 95°F range. Successful usage is possible at temperatures slightly outside this range, but at an increased risk of pre-release or poor cure. Normally, the barrier coat film is ready for lamination within 60 minutes. This time interval is dependent upon material temperature, room temperature, humidity, air movement and catalyst concentration.

4. SKIN COAT—A chopped glass skin coat laminate using unfilled tooling resin is strongly suggested for complex geometries. The OPTIMOLD® SL (STYPOL®040-4339) is the recommended isophthalic skin resin and the OPTIMOLD® SLSS (ArmorStar® SRX 073-5120) is a higher performance, epoxy-modified polyester skin resin. Use of a skin coat provides the best opportunity to prevent air voids behind the gel coat surface. The skin coat also provides good mechanical properties and impact resistance, both of which directly improve mold life.

Any defects in the skin coat, such as blisters, voids, contamination and/or foreign objects will transfer through to the gel coat surface. These imperfections will not always be visible on a new mold, but can appear as the mold is used in production. Therefore, these defects are usually removed by grinding prior to subsequent laminations. Removing a skin coat defect by grinding can result in scratches, nicks or gouges on the underlying mold or pattern surface. It is often more economical to start over than it is to repair gouges on a fiberglass master mold or production mold. Removing skin coat defects by grinding should not be entrusted to untrained and/or unskilled personnel without accepting the risk of damage to high-value assets.

In general, a skin coat should contain 28 to 32 percent chopped glass fiber by weight. The nominal thickness should fall in the range from 30 mils to 90 mils. A chopped glass skin coat at one ounce per square foot (osf) glass will measure about 30 mils, 1.5 osf will measure about 45 mils, two osf will measure about 60 mils, and three osf will measure about 90 mils. A laminate thickness gauge should be used to verify that the correct thickness is applied. An air-free skin coat is easier to apply thinly rather than thickly. A thinner skin coat should be ± 5 mils, while a thicker skin coat should be ± 10 mils.

When applying a skin coat, the use of a zero-shrink resin such as OPTIMOLD® II or *OptiPLUS*™ should be avoided. These resins require a sufficient mass to produce the exotherm heat needed for shrinkage control. Proper rollout and removal of all air voids becomes very difficult at the thicknesses required for shrinkage control.

For molds that will experience thermal cycling or thermal shock, the glass content should be lower in the layer adjacent to the gel coat than it is in the rest of the laminate. For the greatest durability, a glass veil with a weight of 25 to 50 grams per square meter should be brush laminated right against the gel coat. Glass content should be 10 to 15 percent by weight. Due to the thin nature for a veil layer, the catalyst level should be at the high end of the recommended range for good cure. This resin-rich veil layer should be followed by a more typical 30 percent chopped glass skin coat. The low-fiber-content veil layer provides a transition from the high thermal expansion characteristics in the gel coat layer to the much lower thermal expansion characteristics in the structural laminate. This reduces the stresses imposed by the thermal cycle or shock between the gel coat and laminate, thus extending mold life.

Woven or stitched broadgood materials can be used in a skin coat. However, resin shrinkage usually results in weave print (print-through) that is visible on the final mold surface. The severity of this weave print depends upon the fiber architecture in the material. For example, woven roving has large bundles that undulate (move up and down) at bundle crossovers. This results in a large resin-rich area as a bundle crosses under another. The resin shrinkage at these points will easily telegraph through to the mold gel coat surface. This can be so pronounced that the difference between 18 osy (ounce per square yard) WR (woven roving) and 24 osy WR will be discernible. This weave print may not be visible when the mold is first produced, but may appear as the mold experiences production cycles.

5. CONVENTIONAL BULKING MATERIALS—A conventional bulking material is a thixotropic laminating resin with a high heat distortion temperature (HDT). Historically, an isophthalic polyester resin has been the industry standard. This type of resin shrinks when it cures. This shrinkage causes an overall dimensional change in the molding and cosmetic flaws known as distortion and print-through. Distortion is the surface waviness visible on the panel surface when light is reflected off the gel coat surface. Print-through is more severe and can mimic the architecture of the fiber forms used in the underlying laminate. Mark-off is a cosmetic defect that can appear when something such as a piece of steel framing presses against the laminate back side.

Shrinkage occurs because of two mechanisms: curing shrinkage and cooling shrinkage. The first mechanism, curing shrinkage, occurs in two stages: during cure (before demold) and during postcure (after demold). Curing shrinkage is due to a volume change in the resin that accompanies the cure. This curing shrinkage is inevitable and it is best when all of it occurs prior to demolding from the master. When some portion of the cure occurs after demolding, the additional shrinkage causes cosmetic flaws to appear on the surface. This is commonly called ‘postcure,’ but it is really distortion that is caused by the additional shrinkage that occurs during postcure. The second mechanism, cooling shrinkage, is due to thermal expansion (actually contraction) when the laminate cools from its stress free temperature. The stress free temperature is related to the temperature that is seen by the laminate when the resin solidifies. The greater the difference between the stress free temperature and ambient temperature, the more cooling shrinkage occurs. Therefore, the cooling shrinkage can be managed by minimizing the exotherm temperature during the laminate cure. Postcure shrinkage is minimized by achieving a complete cure and may require elevated temperatures. Cooling shrinkage is minimized by lower exotherm temperatures and minimal exposure to elevated temperatures. As a result, the optimum cure profile is very strongly dependent on the laminate exotherm temperature and resin area weight.

Minimizing shrinkage provides the best cosmetics. Completing the cure prior to demolding provides the most stable cosmetics. For conventional bulking materials, this is achieved by single-ply laminations, one per day, with a resin that is specifically designed to cure in a single ply. Due to the extended nature of this lamination sequence, the secondary bonding window becomes important for scheduling purposes. Usually, a mold is started early on a Monday, and lamination proceeds throughout the week. When lamination pauses greater than 24 hours, as over a weekend, it is best to enhance secondary bonding with thorough mechanical abrasion in addition to normal surface de-burring. For best cosmetics, the completed mold laminate is allowed to cure for an additional five to 10 days prior to demolding. A new mold should always be demolded prior to any elevated temperature postcure.

The most common single ply lamination is 45 mils (1.5 ounces per square foot or 450 grams per square meter) at 30 weight percent reinforcement. Exotherm temperatures will run five to 15°F above ambient, and are seldom tolerated as high as 140°F. Slight concessions in cosmetic quality occur when single-ply laminations are applied twice per day (such as morning and evening). Additional concessions in cosmetic quality occur when double-ply laminations are applied. These concessions are worse for laminations closer to the gel coat surface.

Skin coat resins like STYPOL® 040-4339 or ArmorStar® SRX 073-5120 are designed for single-ply lamination. Optimum cosmetics for double-ply or thicker laminations may require a slightly different resin such as STYPOL® 040-2989 isophthalic polyester tooling resin, which is designed to cure in thicker laminates. Refer to the respective product data sheets for more specific information.

6. OPTIMOLD® II LOW PROFILE TOOLING PRODUCTS— OPTIMOLD® II resin is a two-component, low profile resin system that incorporates alumina trihydrate (ATH) filler. The two resin components are STYPOL® 040-8060 and STYPOL® 040-8070. When mixed, the OPTIMOLD® II resin is a pre-promoted, thixotropic, shrinkage-controlled laminating resin. OPTIMOLD® II is used to produce molds with outstanding cosmetic quality and significant time and labor savings. Laminate thickness can be added quickly without surface distortion. This surface quality is achieved via minimal resin shrinkage during the cure process. The minimal resin shrinkage provides a mold with dimensions nearly identical to the master model. Unlike conventional isophthalic tooling resins, the cosmetic quality is very stable over the life of the mold. The OPTIMOLD® II resins cure at room temperature with a high-dimer MEKP initiator such as Arkema MEKP-925, Luperox® DHD-9 or Chemtura HP 90.

The advantages of OPTIMOLD® II are:

- Excellent cosmetic stability due to controlled-shrinkage technology
- Faster mold building than with conventional isophthalic tooling resin
- Fire retardant characteristics due to the ATH filler
- Good mechanical properties
- Pre-promoted in pre-weighed packages.

When using OPTIMOLD® II to laminate molds, attention to process details is a key element for success. OPTIMOLD® II products are very sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using OPTIMOLD® II in a controlled environment with near ideal process conditions.

OPTIMOLD® II is packaged in a short-filled, open-head drum with a companion pail. This allows the mix to be prepared in the original container. The drum contains 255 pounds of STYPOL® 040-8060. Each companion pail contains 45 pounds of STYPOL® 040-8070. One pail of 040-8070 is added to the drum and mixed, followed by 200 pounds of ATH filler (four 50 pound bags) for a 500 pound batch at the proper mix ratio. For smaller batches, the mix ratio by weight is 40 parts ATH filler added to the pre-mixture of nine parts 040-8070 and 51 parts 040-8060. Recommended fillers are either R. J. Marshall A-208 or J. M. Huber SB-432.

Mixing the filler into the resin requires agitation with a large paddle mixer. High shear mixing is not required nor desired. Over-mixing increases the tendency to sag. The filler should be added slowly under gentle agitation. Avoid mixing air into the batch by using the least amount of turbulence possible. After the filler appears to be mixed in, the sides of the container should be scraped clear of dry filler. Mixing should continue for 30 minutes to allow small particles of filler to completely wet. To prevent filler settling, the mixture should be kept under gentle agitation until it is completely used. The mixture should be used within five days. After five days, extended gel times and loss of shrinkage control may result. It is best to use the entire batch on the same day it is mixed.

A bung hole mixer will not adequately mix in the filler, resulting in clumps of unmixed (dry) filler on the mold. Air bubbling should never be used for mixing. It is not effective and only serves as a potential for water or oil contamination. Use of the mix prior to complete filler wetting can result in localized, soft, filler-rich areas in the laminate. If the material is allowed to sit without proper agitation, the filler will settle to the bottom and be very difficult to re-disperse.

Laminating with OPTIMOLD® II should be performed at temperatures between 75°F and 90°F. Successful application is possible at temperatures outside of this range, but will require specific adjustments in laminate thickness and catalyst level to keep exotherm temperatures within specification. Temperatures of all materials and process items should be between 75°F and 90°F. This includes the master mold, the resin and the glass roving, in addition to the ambient room temperature. When temperatures are outside this range, the likelihood of poor cure, excessive shrinkage or laminate expansion and the resultant substandard cosmetic quality is increased. Prior to building each mold, small test laminates should be prepared to demonstrate suitable process conditions and application techniques.

A chopped-glass skin coat using unfilled, tooling resin is highly suggested for complex geometries. The OPTIMOLD® SL (STYPOL® 040-4339) is the recommended isophthalic skin resin; the OPTIMOLD® SLSS (ArmorStar® SRX 073-5120) is a higher performance, epoxy-modified polyester skin resin. Use of a skin coat results in a modest compromise in surface cosmetic quality and stability, but provides the best opportunity to prevent air voids behind the gel coat surface. The skin coat also provides improved mechanical properties and impact resistance.

For OPTIMOLD® II tooling resins, glass contents should be between 22 percent and 28 percent by weight. The ideal glass content is 25 percent by weight. Lower glass contents will result in excessive exotherm temperatures and could cause expansion of the laminate. Higher glass contents will result in lower exotherm temperatures and may cause poor cure or excessive shrinkage. The recommended glass rovings are Vetrotex #292, OCF 357D, and PPG Hybon 6700.

Nominal uniform laminate thickness of 3/16 inches per lamination is recommended. The laminate thickness and catalyst level can be adjusted for variations in ambient temperature. The laminate thickness can range from 170 to 220 mils. Obtaining a laminate exotherm temperature between 110°F and 140°F produces optimum results.

OPTIMOLD® II quality control testing is performed using Norac MEKP-925 initiator. Chemical equivalents, such as

Arkema Luperox® DHD-9 or Chemtura HP 90, can also be used. Cumene Hydroperoxide (CHP) and MEKP blends are not recommended. Consult a CCP representative for other specific initiator recommendations. Under ideal conditions at 77ºF, use MEKP-925 at 1.5 percent based on resin mix weight. For colder temperatures, as much as 1.75 percent can be used. For warmer temperatures, as little as 1.25 percent can be used. Initiator levels slightly outside the range of 1.25 percent to 1.75 percent may be necessary at the temperature extremes, but this can lead to substandard results and is not recommended.

A standard resin pump with a catalyst slave pump provides catalyst adjustments based upon volume, not weight. Since the OPTIMOLD® II is filled with ATH, and ATH is non-reactive, the true catalyst ratio (by weight) is different from the volume ratio marked on the equipment. The preceding table provides a cross reference between the catalyst percentage by volume and the true catalyst percentage by weight for the OPTIMOLD® II system.

If the laminate has turned uniformly white within 60 minutes of catalyzation, it is most likely properly cured. If the laminate is amber in color, or spotty white and not uniform, it is most likely poorly cured. Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test laminates prior to full-scale mold building activities.

Most chopper guns configured for filled resins can be used to spray OPTIMOLD® II resins. Standard laminating equipment may require specific adjustments to ensure proper application. An increased spray pressure and/or larger tip orifice size may be required due to the viscous nature of an ATH-filled resin.

When using fluid impingement equipment, refer to the manufacturer's recommendations for filled systems. The glass content should be demonstrated by measuring prior to building a test laminate. The test laminate is then used to verify catalyst level and laminate thickness. Mold building should commence only after a test laminate is successfully produced.

OPTIMOLD® II lamination begins with a mist coating of resin on the working area. For the first lamination against the gel coat, apply 40 mils of gun chop in the work zone. This 'air release' layer should be rolled to eliminate all air at or near the gel coat surface. Once rolled and before gellation, another 130 to 170 mils of gun chop is applied to the work zone. This second layer is then rolled for consolidation. A slow-motion rolling approach with a light touch helps to consolidate the material and helps to avoid just pushing the material around. Neighboring work zones should then be covered in a similar manner, maintaining a 'wet edge' between work zones. A typical work zone ranges from 25 to 100 square feet, depending upon the number of laminators and ambient temperature conditions. This nominal 190-mil-thick lamination is allowed to gel and cure, which should occur approximately 30 to 60 minutes from application to each work zone. The laminate should exotherm to 110ºF to 140ºF, and should turn uniformly tan-white at approximately 75 minutes. Times in excess of 90 minutes would suggest a reduced or poor cure, and subsequent warpage and post curing of the mold may occur. An infrared thermometer should be used to monitor laminate exotherm, both for the test laminates and the mold laminates.

Additional OPTIMOLD® II laminations are applied until the design mold thickness is achieved. Each lamination can begin once the mold temperature returns to near ambient temperature (comfortable to touch). Subsequent laminations do not require the 40-mil-thick 'air release' layer, although applying material in two layers does facilitate rolling. The entire 190-mil-laminate thickness can be applied after the mist coating of resin for each subsequent lamination.

For best results, the entire OPTIMOLD® II mold laminate should be applied on the same workday. Spotty interlaminar adhesion may result if one lamination is allowed to cure too completely. When delays are required, the STYPOL® 040-4353 Adhesion Promoter should be used to achieve a good secondary bond. From the time properly catalyzed 040-4353 is applied, the secondary bonding window is six hours. This material is sprayed on the previous lamination in a thin, continuous film, one to four mils in thickness. Typically, it is sprayed similarly to paint or PVA, with fairly low delivery and low atomizing pressure. Refer to the STYPOL® 040-4353 datasheet for specific spray recommendations.

7. *OPTIPLUS*™ LOW PROFILE TOOLING PRODUCTS—*OptiPLUS*™ resins are used to produce molds with outstanding cosmetic quality. This surface quality is achieved with minimal resin shrinkage during the cure process. Unlike conventional isophthalic tooling resins, the cosmetic quality is very stable over the life of the mold. The *OptiPLUS*™ resins are pre-promoted, thixotropic, shrinkage-controlled laminating resins that do not require the addition of fillers or additives. The *OptiPLUS*™ resins cure at room temperature with conventional MEKP initiators.

The advantages of *OptiPLUS*™ are:

- Excellent cosmetic stability due to controlled-shrinkage technology
- Faster mold building than conventional isophthalic tooling resin
- Lower weight molds than OPTIMOLD® II (ATH-filled) tooling resin
- Excellent mechanical properties.

When using *OptiPLUS*™ to laminate molds, attention to process details is a key element for success. *OptiPLUS*™ products are very sensitive to plant airflow, cooling conditions, erratic operating conditions and inconsistencies in application. Best results are obtained by using *OptiPLUS*™ in a controlled environment with near ideal process conditions.

Laminating with *OptiPLUS*™ should be performed at temperatures between 75ºF and 90ºF. Successful application is possible at temperatures as low as 60°F or as high as 100°F, but will require specific adjustments in laminate thickness and catalyst level to keep exotherm temperatures within specification. Temperatures of all materials and process items should be between 75°F and 90°F. This includes the master mold, the resin and the glass roving, in addition to the ambient room temperature. Temperatures outside this range are not recommended due to the high likelihood for poor cure, excessive shrinkage or laminate expansion and the resultant substandard cosmetic quality. Prior to building each mold, small test laminates should be prepared to demonstrate suitable process conditions and application techniques.

A chopped-glass skin coat using unfilled, isophthalic tooling resin is highly suggested for complex geometries. This results in a modest compromise in surface cosmetic quality, but provides the best opportunity to avoid air voids behind the gel coat surface.

For *OptiPLUS*™ tooling resins, glass contents should be between 35 percent and 40 percent by weight. The ideal glass content is 38 percent by weight. Lower glass contents will result in excessive exotherm temperatures and could cause expansion of the laminate. Higher glass contents will result in lower exotherm temperatures and may cause poor cure or excessive shrinkage. Uniform laminate thickness of 0.15 inches per lamination is recommended. The laminate thickness and catalyst level can be adjusted for variations in ambient temperature. Obtaining a laminate exotherm temperature between 130°F to 160°F produces optimum results.

OptiPLUS™ quality control testing is performed using Norac MEKP-9 initiator. Chemical equivalents, such as Arkema Luperox® DDM-9, can also be used. Under ideal conditions at 77°F, use MEKP-9 at 1.5 percent based on resin weight. For colder temperatures, as much as 2 percent can be used. For warmer temperatures, as little as 1.2 percent can be used. Initiator levels outside the range of 1.2 to 2 percent can lead to substandard results. High dimer peroxide initiators, such as Norac MEKP-925, Chemtura HP 90 or Luperox® L-50 can be used, but will provide longer gel times. Cumene Hydroperoxide (CHP) and MEKP blends may also be used if the CHP is less than 35 percent of the blend. Suitable cure should always be tested. Consult a CCP representative for other specific initiator recommendations.

If the laminate has turned uniformly white within 60 minutes of catalyzation, it is most likely properly cured. If the laminate is amber in color, or spotty white and not uniform, it is most likely poorly cured. Reconstruction should be performed under more ideal conditions. Avoiding the need for reconstruction is best accomplished by building test laminates prior to full-scale mold building activities.

Most laminating spray equipment can be used to spray *OptiPLUS*™ resins. The equipment may require specific adjustments to ensure proper glass contents. Two strands of glass roving, reduced spray pressure and/or reduced tip orifice size may be required. For fluid impingement equipment, an orifice of 0.040-inch with a 40 to 50 degree fan pattern at 40 psi is suggested. The glass content should be demonstrated by testing prior to building a test laminate. The test laminate is used to verify catalyst level and laminate thickness. Mold building should commence only after a test laminate is successfully produced.

Mold laminate construction begins with a mist coating of resin on the working area. For the first lamination against the gel coat, apply 0.040-inch of gun chop in the work zone. This 'air release' layer should be rolled to eliminate all air at or near the gel coat surface. Once rolled and before gellation, another 0.11-inch of gun chop is applied to the work zone. This second layer is then rolled for consolidation. A slow-motion rolling approach with a light touch helps to consolidate the material and helps to avoid just pushing the material around. Neighboring work zones should then be covered in a similar manner, maintaining a 'wet edge' between work zones. A typical work zone ranges from 25 to 100 square feet, depending upon the number of laminators and ambient temperature conditions. This 0.15-inch thick lamination is allowed to gel and cure, which should occur at approximately 30 to 60 minutes from application to each work zone. The laminate should exotherm to 130°F to 160°F, and should turn uniformly tan-white at approximately 75 minutes. Times in excess of 90 minutes would suggest a reduced or poor cure, and subsequent warpage and post curing of the mold may occur. An infrared thermometer should be used to monitor laminate exotherm, both for the test laminates and the mold laminates.

Additional *OptiPLUS*™ laminates are applied until the design mold thickness is achieved. Each lamination can begin once the mold temperature returns to near ambient temperature. Subsequent laminations do not require the 0.04-inch thick 'air release' layer. The entire 0.15-inch laminate thickness is applied after the mist coating of resin.

8. BRACING—A mold reinforcing element, bracing is a continuation of the mold skin laminate. For contact (open) molding, bracing is used to react all of the molding forces, including those resulting from the demolding event. Modest thickness increases result in large increases in bending stiffness, and therefore, robustness. Sandwich construction using a core material such as balsa or plywood, is the simplest form of bracing. Sandwich construction provides the added benefit of preventing damage to the mold surface from back-side impacts. Shaped stiffener elements can also be formed over foam, cardboard or wood pattern materials. The most common shapes are hat stiffeners and vertical blade stiffeners. When contact molds develop cracks, the best solution is usually to add bracing in the local areas. Bracing with laminate materials and structural cores does not introduce thermal stresses near as large as those possible with steel framing.

9. FRAMING—A mold reinforcing element that is outside the mold skin, framing falls into two different categories. For high pressure molding, framing must be used to react molding forces. These high pressure processes include conventional RTM and sometimes SMC. For low pressure molding, framing primarily serves as a cradle to distribute the mold weight onto concentrated load points such as casters. The frame also provides a means of grabbing the mold for lifting and transport operations without introducing loads at concentrated points that can lead to laminate fracture.

Most mold frames are made from mild steel tubing. The tubing may be square or round with a wall thickness of approximately 60 to 120 mils. Wood can also be used and usually takes the form of deep-section blade stiffeners that are cut from plywood and entirely encapsulated by the mold laminate. When wood is not encapsulated with laminate, moisture variations cause the wood to swell and contract, and should be avoided for all but small or temporary molds.

The differences in thermal expansion between a steel frame and an FRP mold skin are very significant. A parameter known as the linear coefficient of thermal expansion (CTE) is used to quantify a material's response to a temperature change. For laminated composites, there are three distinct coefficients. AlphaXX is the coefficient in the panel x direction, alphaYY is the coefficient in the panel y direction, and alphaZZ is the coefficient in the panel z thickness direction. The coefficient is defined as the change in unit length for a unit change in temperature at a given temperature. The thermal expansion coefficient for a gel coat or unreinforced resin is between 31 to 55 micro-inches per inch per degree Fahrenheit, while a chopped glass laminate is between 11 to 18 micro-inches per inch per degree Fahrenheit in the laminate plane. For comparison, this laminate CTE is similar to aluminum, which is 13 micro-inches per inch per degree Fahrenheit. Steel, on the other hand, ranges from 5.5 to 9.5 micro-inches per inch per degree Fahrenheit.

Now, consider a temperature change from 70°F to 0°F. A 20-foot long piece of steel will contract (20 foot long)*(12 inches per foot)*(7.5E-6 average inches per inch per degrees Fahrenheit)*(70°F temp change) = 0.126 inches (525 microstrain). As a laminate, that same 20-foot span will contract (20 foot long)*(12 inches per foot)*(14.5E-6 average inches per inch per degrees Fahrenheit)*(70°F temp change) = 0.244 inches (1015 microstrain). The fiberglass panel contracts 1.94 times as much as the steel structure. Structurally tying the two materials together and forcing them to become the same length makes for big thermal stresses. Adding more steel simply compounds the problem.

When thermal stresses are developed rapidly due to a rapid change in temperature, one material can reach its new dimension much more quickly than the other. Within the same material, the same thing can happen at different spots, depending on exactly how quickly it changes temperature, and where. This is a rate-dependent, worst-case type thermal stress known as thermal shock.

To minimize thermal shock effects, the steel frame must be designed to expand and contract, at a rate that is different from the mold laminate, without forcing the mold skin to crack. Therefore, the cradle and the mold laminate must not be structurally coupled. This is best done by leaving a gap between the steel frame and the mold laminate, and bridging this gap with a low-stiffness tie made from a single piece of two osf chopped strand mat and a resin with a low inherent shrinkage. This is often a production resin such as a DCPD (which has a low inherent shrinkage) that will cure in a thin laminate. Isophthalic tooling resin can also be used, but at a higher cost and with higher shrinkage. Zero shrink resins like OPTIMOLD® II and *OptiPLUS*™ should never be used as a frame tie resin because they will not cure properly at the desired tie laminate thickness.

The contact mold frame is usually fabricated on the laminated mold once the design mold thickness has been applied and cured. Sections of tubing are cut and bent to fit while maintaining a gap between the tubing and the mold skin. Thick cardboard or crushable foam (two to four pounds per cubic feet urethane or PVC) is good to use for a spacer. Either material is soft and can crush without marking the mold gel coat surface. Cigarette butt filters are too small in diameter, and crush too easily to work effectively as offset spacers. Once positioned, the pipe sections are welded together into a single unit, and usually fitted with casters and provisions for lifting. One advantage to the OPTIMOLD® II system when welding is the flame retardancy provided by the ATH filler. For unfilled systems, careful attention while welding is important to avoid accidentally setting the mold on fire.

When laminating the ties between the frame and the mold skin, exercise care to avoid saturating the offset spacers with resin, which will harden and defeat the spacers' purpose. Once the ties are cured, the spacers should be pulled out to prevent the future possibility of mark-off.

Spacing between frame elements depends on the tubing size and the thickness of the mold laminate. Small molds less than 20 feet long will commonly use a laminate thickness of 1/2 inch and a tubing diameter from 1.25 inches upwards of two inches. Frame spacing is set to provide an unsupported panel length of 12 to 15 inches. For larger molds, two-inch by four-inch or larger rectangular tubing is used, oriented with the longer direction perpendicular to the mold laminate. Sandwich construction with one-inch balsa core will commonly separate two 3/8 inch thick skins. For this heavier panel section, the unsupported panel length may be as large as 20 to 24 inches. These are 'loose' rules of thumb and should not be construed as better than any frame design that is tried and tested true.

Frame spacing and laminate thickness must also consider the mechanical and physical properties of the mold materials. For instance, the OPTIMOLD® II system utilizes lower glass loadings and a high filler content that produces a heavier mold skin with lower mechanical properties than a conventional isophthalic tooling system. The frame spacing must be smaller and the mold skin must be thicker because of these features.

The frame must be rigid compared to the mold laminate. One way to evaluate frame rigidity is to jack up one caster and see if the frame deforms. Another way is to position the mold so that one caster is hanging over the edge of a loading dock. If it droops down noticeably, the frame is not rigid and is probably not supporting the mold properly. If the frame is not rigid, picking up the mold can cause it to bend and twist, increasing the chance for mold cracks to occur during normal handling and demold operations.

Wherever a steel frame is in contact with a mold laminate, a mark-off may appear on the mold gel coat surface. This mark-off may merely witness the contact, or it may lead to gel coat cracking due to point loading. Regardless, steel frame contact should be avoided for low pressure molding applications.

For high-pressure molding applications, a steel frame must contribute to reacting the molding forces. Any gaps between the steel frame and the mold skin are often filled with a high-compression strength syntactic putty after the frame is constructed. For this reason, rectangular tubing is used instead of round tubing. The frame is then structurally tied to the mold skin by laminating with a heavy material such as woven roving stitched to mat.

When steel framing is structurally coupled to a mold skin and used to react molding forces, normal thermal shocks experienced by moving molds from outside to inside and back in cold climates can result in extensive mold cracking. Additional steel framing does not improve the situation. The only practical solution is to create conditions that slow down the rate of temperature change. One way to accomplish this is to use a partitioned space between the two temperature extremes. As an example, a small area near the door can be partitioned off and separated from the heated shop area. The door to the outside is opened and allowed to remain open long enough for the temperature in the space to become close to outside temperature. At this point, the mold is moved into the space and the outer door is closed. The inner door is opened somewhat, and the space is allowed to slowly come back to the shop temperature, with the mold also slowly increasing temperature. The absolute worst-case scenario is to place a very cold mold directly under a big, forced air or infrared heater running continuously. Unfortunately, these heaters are usually located near the door where cold molds are first brought inside and left until the snow and ice melts off of them.

POLYESTER TOOLING: Mold Surface Distortion

Part Eight, Chapter VI

In This Chapter

1. **Types of Cosmetic Flaws**
2. **Causes**

1. TYPES OF COSMETIC FLAWS—There are three types of cosmetic flaws that can develop on a gel coat surface. The extent of these flaws can vary from minimal distortion up to major fiber print.

A. Distortion—Distortion is the waviness seen in light reflected off the mold surface.

B. Print-through—Print-through is a pattern that mimics the construction architecture of a fibrous reinforcement. Print-through can appear as a fiber bundle known as fiber print, or it can appear as the weave construction known as weave print.

C. Mark-off—Mark-off is a visible witness caused by differences in stiffness and hardness at the boundary from one material to another. This boundary is usually present in the mold or pattern and transfers to the molded article. A common example is a plug constructed using a fiberglass laminate and body filler. The body filler can be softer and can have a lower glass transition temperature than the fiberglass laminate. They also differ in thermal expansion and heat capacity characteristics. Both the heat from exotherm and the forces due to resin shrinkage apply stresses. These stresses are supported and reacted differently by the different regions. At the boundary between them, a mark-off can result. Mark-off can also occur when a mold frame element is in contact with the back side of the mold.

2. CAUSES—The gel coat surface displays these flaws. The root causes, however, are not due to any properties or characteristics of the gel coat layer. By itself, a gel coat film properly cured on a flat, polished master will exhibit remarkable gloss and visual smoothness. This quality will be almost as good as, but not quite as good as, and certainly never better than the surface on which it is molded.

Even when resin is cast behind the gel coat film, the resulting surface will be very glossy, smooth, and free from these cosmetic defects. Cosmetic flaws are caused by how resin shrinkage is affected by different materials. These flaws will magnify when the gel coat is either thin or under-cured.

When a laminate is cured against the gel coat layer, cosmetic flaws will appear. Their severity is directly related to the amount of resin shrinkage experienced during its cure. A resin that shrinks a lot will produce cosmetic flaws to a greater extent than a resin that shrinks negligibly. These flaws are also influenced by the nature of the reinforcing fiber and the architecture of the fiber form in the underlying laminate.

Lack of shrinkage of a fiber doesn't lead to cosmetic flaws. Instead, the flaws result when the fiber resists the resin's shrinkage. Different fibers resist resin shrinkage to different degrees according to the fiber's transverse stiffness. Transverse to the fiber axis, glass fiber has a stiffness of about 10 msi (million pounds per square inch). Resin has a stiffness of about 1/2 msi, which is a factor of 20 less than glass. As the resin shrinks and tries to squeeze the glass fiber, the glass offers 20 times more resistance to being squeezed than the resin can deliver. This results in the image of the fiber being visible on the gel coat surface because the resin rich areas shrink away from the gel coat surface, while the fiber rich areas resist shrinkage away from the gel coat surface.

Carbon, graphite, and polymer fibers achieve a high stiffness in the axial direction due to molecular orientation imparted during the fiber manufacturing process. As a result, their transverse stiffness is low and can be 1/2 to two msi. The lower the fiber transverse stiffness, the less impact the fiber has on cosmetic flaws because it can't prevent the resin from shrinking. Consequently, polymer fiber print blockers provide better cosmetics than glass fiber veils.

In a textile construction such as woven roving, the bundle undulations (overlaps and underlaps) result in resin pockets that alternate with fiber bundles. The unrestrained shrinkage in the resin pocket contrasts markedly with the restrained shrinkage in the fiber bundle, causing the weave print to appear on the surface. Thus, the architecture of the fiber form has a distinct impact on cosmetics.

Resin shrinkage, fiber transverse stiffness, and the architecture of the fiber form are the root causes of cosmetic flaws. For a given fiber and form, such as chopped glass, cosmetic flaws vary in their severity according to resin shrinkage. Most resin shrinkage occurs during the molding process referred to as the curing operation. Any additional curing that occurs after demolding is called post-cure. Post-cure results in additional shrinkage, and this post-cure shrinkage causes cosmetic flaws to develop.

Normal room temperature does not provide enough energy to completely cure an unsaturated polyester resin. At some point in the cure, the crosslink density becomes high enough that the curing reaction stalls. Further curing requires temperatures that are close to the resin's glass transition temperature. This further curing pushes the resin's glass transition temperature closer to its maximum, resulting in a complete cure. Once the cure is complete, no additional cure shrinkage will occur, and the cosmetic quality will stabilize. Usually, the final stages of curing occur when the mold experiences exotherm heat during production of the first few parts.

Instead of allowing the post-cure to occur when the mold is exposed to the exotherm heat generated by parts during production, a new mold can be subjected to a special post-cure operation. The post cure temperature should be chosen to be 20°F above the expected production exotherm temperatures, or the expected maximum glass transition temperature for the gel coat and resin used to manufacture the mold, whichever is less. Four hours at temperature is generally sufficient to complete the cure and achieve the maximum glass transition temperature. Isophthalic tooling gel coats have a maximum glass transition temperature of 200 to 210°F, while vinyl ester gel coats have a maximum of 250 to 260°F.

Any elevated temperature post-cure should always be accomplished with the mold in the free-standing condition, supported to prevent warping due to its own weight. If a mold is post-cured at elevated temperatures while it is still on the master, differences in thermal expansion due to geometry will cause mark-off to appear in various places on the gel coat surface, on both the master and the mold. For best cure results, any elevated temperature post cure operation should be scheduled within three days of the initial cure.

Wet sanding and buffing will remove cosmetic flaws that develop on a mold surface due to cure and post cure. This should sensibly be performed only after the mold has reached its final cure state. Once the cure is complete, no cure related shrinkage will occur regardless of the temperature a mold experiences.

If the mold temperature is near or above its glass transition temperature, however, the mold materials will soften and can acquire a mark-off due to stresses caused by the shrinkage in a production part. If a part contains woven roving, the weave print on a part can transfer to the mold surface when the molding temperatures are near or above the mold's glass transition temperature. If the part is made with a zero-shrink resin, the part does not put shrinkage stresses on the mold surface, and minor excursions above the mold glass transition temperature do not cause print to transfer from the part to the mold surface.

In summary:

- Molds will develop cosmetic flaws due to resin shrinkage during cure and postcure.
- The cosmetic flaws can be sanded out, but may return if the mold is not yet fully cured.
- Parts made with conventional unsaturated polyester resin can print or distort a fully cured mold if the exotherm temperatures approach or exceed the mold glass transition temperature.
- Low profile resins will produce less severe cosmetic flaws because these systems shrink negligibly compared to conventional unsaturated polyester resin.
- Distortion (sometimes called 'orange peel') only appears on a gel coat surface when there is a laminate behind the gel coat. It is caused when a fiber's transverse stiffness is great enough to resist the resin shrinkage. Distortion is not caused by the gel coat's back-side roughness because a smooth draw-down of tooling gel coat develops the same degree of distortion as a sprayed film that features back side orange peel.
- A gel coat film that is sprayed or drawn-down (smooth surface) will not show distortion if there is no laminate behind it or if there is only unreinforced resin behind it.
- If a tooling gel coat has a maximum glass transition temperature of 212°F, post-curing the mold above this temperature will not improve its distortion resistance.
- A 'harder' tooling gel coat does not resist distortion any better. It may polish to a higher gloss, but will exhibit a greater tendency to crack.

POLYESTER TOOLING: Mold Break-In Procedures

Part Eight, Chapter VII

In This Chapter

1. **Introduction**
2. **Conventional Mold Release Waxes**
3. **Semi-Permanent Mold Release Systems**
4. **Poly Vinyl Alcohol (PVA)**

1. INTRODUCTION—A proper break-in procedure maximizes the mold's value by preventing part sticking, promoting gloss retention and lessening fiber print-through. Once the break-in procedure is complete, the mold is considered seasoned and can be treated with normal mold maintenance procedures.

Any mold can, at any point in its life, become permanently bonded to a production part. Inadequately updating the mold release system is the most common reason for part sticking. Porosity in the mold gel coat surface is the second most common reason for sticking. The porosity allows for the part to mechanically attach via the mold pores. This usually occurs after a mold has been sanded and buffed because these operations can expose subsurface porosity.

Gel coat surface porosity and micro-porosity are the reasons that a new mold has a higher likelihood of sticking than a seasoned mold. Porosity that is visible essentially guarantees part sticking. Micro-porosity, which takes at least 60x magnification to see, can be addressed by the proper usage of a mold sealer. Most molds have some degree of micro-porosity. During the break-in procedure, mold release gradually fills mold surface porosity, bonding permanently in place. This is a gradual process that takes several production cycles. Once complete, the mold is considered 'seasoned.'

A new mold, or a mold that has been sanded and buffed, should be inspected for porosity and micro-porosity before determining the appropriate break-in procedure. It may be necessary to repair the porosity before proceeding. Whenever porosity is visible, the use of a Poly Vinyl Alcohol (PVA) film-forming barrier should be used on the first few parts. If porosity is found on a new mold, the mold fabrication history data should be reviewed. In particular, the gel coat 'spray-out' panel described in Part Four, Chapter II, Section 11.3 'Gel Coat Application' should be re-examined. The cause of the porosity should be determined, and procedures to avoid porosity should be implemented in future mold-making activities.

There are a number of approaches to mold break-in. The first, 'wax it and go,' is not recommended for best results. Even though it works much of the time, the costs of failure are too great. For most instances, sealing and waxing the mold is adequate. Best results are realized by also applying a gel coat layer as a 'blow coat' (also known as 'strip coat' or 'peel coat'). To maximize chances for successful break-in, particularly on a porous mold surface, a film-forming barrier should be used on the first few parts, but this imparts some texture on the molded part surface.

The three categories of release systems are:

- Conventional Mold Release Waxes
- Semi-Permanent Mold Release Systems
- Poly Vinyl Alcohol (PVA)

2. CONVENTIONAL MOLD RELEASE WAXES—Long used in the industry, mold waxes contain carnauba as the release agent. The carnauba must bond to the mold surface and be driven down into the mold pores. Carnauba is the hardest and most expensive of waxes in the wax family. In pure form, it is very hard. The melting point of carnauba is 183 to 187°F, whereas the melting point of paraffin (sometimes used as a release wax) is 117 to 150°F. Typically, mold release waxes contain a mix of carnauba, paraffin and silicone (very few release waxes are silicone-free). The carnauba serves as the release agent, the paraffin softens the carnauba, and the silicone serves as a lubricant so the carnauba/ paraffin can be easily wiped on and off. The chemical makeup and proportioning of the carnauba, paraffin, silicone, and solvent content is very proprietary and varies not only from manufacturer to manufacturer, but within each manufacturer's line of products. A sealer glaze should always be used to close mold pores and seal new or reconditioned molds before applying conventional paste wax.

3. SEMI-PERMANENT MOLD RELEASE SYSTEMS—Usually wiped onto the mold surface, these leave a cured resinous film bonded to the mold surface. This film serves as the barrier for release. Under no circumstances should a semi-permanent mold release be poured onto the mold surface and subsequently wiped with a rag. This results in an over-thick polymer film that leaves a visible mark-off at the puddle edge. It may be necessary to polish the mold surface to remove this type of mark-off. Semi-permanent mold release systems should always be used with a compatible surface sealer. On porous mold surfaces, a compatible surface primer should also be used. Surface primers generally produce a much thicker film that is chemically bonded to the mold surface. Primers should always be applied sparingly. Primers generally have no release properties and must always be followed with first a sealer and then the release layers. Semi-permanent release system manufacturers claim many more releases can be completed between update events. A secondary advantage is the ability to tailor the release system to the type of release motion. Release motion describes the physical motion of the two surfaces involved in the release event. For perpendicular release, the surfaces move apart in a purely perpendicular fashion. For parallel release, the surfaces move apart with some component of dragging between the two. This release motion occurs on parts that have a deep draft and benefits from more 'slippage' in the release system than does a purely perpendicular release.

High slip release systems are microscopically thicker which allows for some amount of release film erosion. The high-slip film's greater thickness provides a corresponding decrease in finished part gloss. In contrast, a semi-permanent release film that produces a high gloss is thinner and microscopically smoother and wears more quickly on deep-drafted parts. Semi-permanent mold release systems seem to cause more fisheyes and pre-releases than waxes, particularly on the first pull, and are not recommended when building molds and masters. As always, read and follow the semi-permanent release manufacturer's surface preparation and usage instructions.

4. POLY VINYL ALCOHOL (PVA) is a film-forming barrier. Refer to Part 8 Polyester Tooling, Chapter IV. 'Applying Release Wax.' When applied correctly, PVA forms a physical barrier between the mold and the part. A barrier film is only good for one release event and will have to be applied for each part. It should be sprayed on rather than brushed or wiped. The PVA film will have an orange peel texture. This texture will transfer to the part, so some part rework may be required to meet cosmetic requirements.

The following seasoning procedure should be followed on new molds and whenever a mold surface has been sanded and buffed:

	SEASONING PROCEDURE
1.	Wash the mold surface with a mild detergent solution such as dish soap and water. Allow the surface to dry thoroughly. Inspect the mold surface for porosity and micro-porosity. Apply a mold primer/sealer. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, two coats of a sealer-glaze should be machine buffed, in opposite directions.
2.	Apply the mold release system. Allow each coat to cure. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, six coats are generally sufficient.
3.	Spray a blow coat with a hot pot. This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible. It is best to spray tooling gel coat catalyzed at the high end of the recommended catalyst range, at the high end of the wet-film thickness range. For large molds, divide the area into work zones and work on one section at a time.
4.	Strip the blow coat from the mold when it reaches the 'firm gel' stage. Do not let the blow coat cure without peeling it from the mold. If there is no sticking, proceed with the following step (5). In case of sticking, the mold must be repaired and completely prepared again.
5.	Update the mold release system after the blow coat has been stripped. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, two coats are generally sufficient.
6.	Spray production gel coat with a hot pot. This is preferred over slave pumps or catalyst injection, where uneven catalyzation is possible. Laminate the first production part. If the first part pulls adequately, update the mold release system. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, two coats are generally sufficient. If the part does not pull adequately, the mold must be repaired and completely prepared again.
7.	Build three more production parts. After each part, update the mold release system. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, one coat is generally sufficient after each part.
8.	Build two production parts without updating the mold release system. After the second part is pulled, update the mold release system. Follow the specific recommendations from the release system manufacturer. When using conventional paste wax, one coat is generally sufficient.
9.	Evaluate the release performance for the second pull in the preceding step. If the part pulls adequately on the second pull, gradually increase the number of parts built between update events. The number of parts between updating can vary from one to as many as 10 or more. The exact number depends on a variety of factors such as part geometry, solvent content in the gel coat layer, the gel time of the gel coat, exotherm heat generated in the laminate, the degree of cure of the gel coat and laminate, etc.
10.	Once the release system update interval is known, begin normal mold maintenance procedure. Monitor the mold for ease of pulling and dullness or haze. It is important to update the mold release system before a part sticks, but maximum mold life is obtained by updating the release system at the first sign of dullness or haze. When using conventional paste wax, a non-abrasive build-up remover and a machine buffer will remove the haze without breaking the surface seal. Two additional coats of paste wax are generally sufficient to return the mold to serviceable condition.

POLYESTER TOOLING: Mold Maintenance

Part Eight, Chapter VIII

In This Chapter

1. **Protocol**
2. **Procedure**

1. PROTOCOL—Properly constructed contact laminated molds will produce many thousands of parts. Maximum value, however, will only be achieved if a good mold maintenance protocol is followed. Lack of discipline when executing a mold maintenance protocol always results in excessive costs for reworking, repairing or refinishing the mold. A preventive maintenance program is essential to ensure long mold life. The preventive approach is proactive and prevents damage from occurring to a mold surface. Updating a mold release system after a part sticks is not considered a preventive, proactive approach, and always leads to lower quality and higher costs.

2. PROCEDURE—The mold maintenance area should be completely enclosed and away from the production area. In order to control dust and overspray, there should be isolated stalls for grinding and gel coating.

Residue that forms on a mold surface is not what was once referred to as 'wax buildup'. True wax buildup is more correctly described as 'wax leave on' because this buildup occurs when excess wax is not buffed off. Residue buildup is due to styrene (polystyrene) which has come from the production gel coat and which adheres to the mold usually for one of these reasons:

- Paste wax leave-on or over-application of the semi-permanent release agent
- Inadequate cure of the release system
- Pulling parts too soon. The more 'green' a part is when pulled, the more susceptible it is for styrene (polystyrene) to remain on the mold
- Micro-porosity in a mold surface that has not been adequately sealed.

If the mold is used beyond the proper mold release update interval, the residue will accumulate more rapidly. Eventually, the buildup will require sanding to remove.

Colors appear to haze a mold more (or sooner) than a white or off-white gel coat. This phenomenon has been observed with all gel coats and is not limited to generic types or those from various manufacturers. Colors differ in formulation because of solids and pigmentation. Any dark colored pigments will tend to be more visible than light colored pigments when trapped in the polystyrene buildup. The hazing is usually noticed because colors are used as a striping accent (side by side) next to the white or off-white base coat. Hazing in and of itself is not damaging to the mold, although its removal can reduce mold life. Premature hazing can occur when an under-cured gel coat film is followed by hot laminate that is pulled too green.

When using conventional paste wax, light residue and haze can be removed by machine polishing the mold with a build-up remover such as TR-502 Wax Build-Up Remover. This will not break the surface seal in the release system. Performing this cleaning every three to five pulls for deep draft parts and every six to nine pulls for shallow draft parts eliminates most problems with haze. Two coats of fresh paste wax will return the mold to its serviceable condition. When using a semi-permanent release system, follow the specific cleaning recommendations from the manufacturer.

If the mold is very hazy and has some textured buildup, a coarser compound should be used followed by a wash with a mild detergent solution and a rinse with cold water. Some compounds, if not removed by a detergent wash, will cause sticking by preventing the mold release system from bonding to the mold surface. Compounding will break the surface seal in the release system, so the complete mold seasoning procedure should be performed as described in Part 8, Chapter VII Mold Break-in Procedures.

If the mold has considerable residue buildup, it will have to be removed by scrubbing with a commercial stripper. When using conventional paste wax, toluene, methyl ethyl ketone, or ethyl acetate can be used as a stripper. When using a semi-permanent release system, follow the specific stripping recommendations from the manufacturer. These stripper materials can be flammable and potential health hazards. Refer to the appropriate MSDS sheets for all safety precautions. In general, always wear gloves and safety glasses, ensure the area is well ventilated and most importantly, do not smoke. Do not use styrene for cleaning molds because it initiates and promotes the process of polystyrene buildup.

For molds that have been extensively neglected, removing the polystyrene residue will require dry and wet sanding, followed by compounding and buffing. This erodes a significant portion of the tooling gel coat layer, thus greatly reducing the life of the mold. The entire mold seasoning procedure will return the mold to its serviceable condition, albeit minus some of the gel coat layer.

POLYESTER TOOLING: Mold Resurfacing

Part Eight, Chapter IX

In This Chapter

1. INTRODUCTION—Mold resurfacing is an expensive proposition. Resurfacing a mold involves applying a new layer of tooling gel coat. Since the gel coat is sprayed onto the existing mold surface, the new surface features an orange peel texture. This texture must be sanded smooth in much the same way that a master pattern is sanded and polished. When the resurfaced area is large, the labor required to finish the mold can cost more than building a new mold from the polished master.

Small portions of a mold can be resurfaced fairly economically. If there are cracks in the tooling gel coat or laminate, they can easily reappear on the resurfaced mold. Any cracks must first be completely removed by grinding.

2. GEL COAT CRACKS—Remove only as much material as is necessary to remove the crack. The space can be filled with a putty made from tooling gel coat and fumed silica. The crack should be overfilled, allowed to cure, and postcured with a heat lamp or hot air gun. If this is done before the surface is sanded smooth, the cure shrinkage won't cause the repair to sink below the surrounding surface.

3. LAMINATE CRACKS—Each layer that contains a crack should be ground away several inches either side of the crack, with the edges tapered back to the undisturbed laminate thickness. Then, additional laminate bracing should be applied on the mold back side in the damaged area. This is imperative because the mold was not strong enough and stiff enough to resist the cracks initially. Once the laminate is properly braced on the back side, the front side laminate is replaced.

4. STEPS TO RESURFACE A MOLD—The following procedure describes the steps to resurface a mold once the substrate is repaired and braced to prevent future cracks:

A. The surface should be sanded with a very coarse grit to help remove any release agent and also to provide a mechanical keyway for adhesion. Use sandpaper between 60 and 100 grit.

B. Blow off the mold with compressed air.

C. Wash the mold with acetone (or equivalent) until there are no smear streaks left on the mold. Use several clean cloths so that wax and dust are removed (review the precautions for solvents).

D. Set up the gel coat spray equipment to produce as fine a spray as possible. Typically, lower flow rates and higher atomizing pressure will produce less orange peel on the new gel coat surface.

E. Prepare the tooling gel coat as follows (if spraying with airless or air-assist airless equipment use 945GA104 or 945YA058 only; if spraying with pressure pot, any CCP tooling gel coat can be used):

1) For multi-coating, first (and secondary coats if used) must not contain wax or surfacing agent solutions. Use patching thinner to reduce the gel coat viscosity and improve leveling. Catalyze at 1.2 to two percent dependent on temperature. Spray the gel coat in three passes to a wet film thickness of 14 ± 2 mils. Allow this coat to cure to typical layup time (approximately 90 minutes at 77°F). Follow with the top coat.

2) For the top coat, combine 75 parts tooling gel coat and 25 parts PATCHAID®. Catalyze at 1.2 to two percent depending upon temperature. Spray in 3 passes to a wet film thickness of 14 ± 2 mils. Allow this to cure at least overnight. Postcure with a hot air gun or heat lamp to ensure that all shrinkage is complete prior to finishing.

F. Orange peel should be minimal enough such that no coarser than 320 grit sandpaper can be used to eliminate the orange peel. Finish by wet sanding up through 1000 to 1500 grit sandpaper. Compound and polish using a machine buffer. Wash the mold patch with a mild detergent solution such as dish soap and water. This mold should now be seasoned as if it were a new mold.

POLYESTER TOOLING: Mold Storage

Part Eight, Chapter X

In This Chapter

1. **Preferred Storage Environment**
2. **Condition of the Mold**
3. **Outdoor Storage**

1. PREFERRED STORAGE ENVIRONMENT—Most molds will eventually be stored for use at a later time. As with a classic car, the best storage conditions result in the least wear and tear during the storage period. For a mold, temperature and humidity climate control is an unnecessary expense, but shelter from the outdoor elements is essential to maintaining quality during storage. Uncovered, outdoor storage may be the least expensive from a capital standpoint, but always results in greater rework and mold maintenance costs.

2. CONDITION OF THE MOLD—Any dirt and dust that accumulates on the gel coat surface can cause surface scratches and abrasion that leads to loss of gloss if removed while dry. Best results when removing dirt and grime are obtained using a mild detergent solution such as dish soap and water. The solution lifts the abrasive dirt particles off the surface, preventing scratching and loss of gloss.

Rainwater should never be allowed to stand in a concave mold feature. Standing water provides a breeding ground for mosquitoes, but worse, leads to blistering of the tooling gel coat layer. Gel coat blistering requires complete replacement of the gel coat layer in the affected areas and can be more costly than building a new mold from a polished master. In addition, if the water freezes, its expansion can cause the mold to fracture.

Direct sunlight will cause the gel coat surface to lose gloss, develop chalk, and craze. Tooling gel coats are formulated for long-term gloss retention and release performance, not resistance to ultraviolet radiation. Tooling gel coats based on vinyl ester chemistry are particularly prone to chalking. Applying a gel coat layer and skin coat can provide some protection from the elements. If the laminate releases, however, liquid water can accumulate between the gel/skin and the mold surface, leading to blistering.

3. OUTDOOR STORAGE—If outdoor storage is unavoidable, best results are obtained by orienting the molds upside down on wooden pallets, covered with a light colored tarp above and open to the air below. Dirt and grime will accumulate on the mold surface and require removal with a mild detergent solution, but blistering and ultraviolet degradation will be largely eliminated.

If the back side of the mold will be exposed to sunlight during storage, a layer of white production gel coat will reflect the sun's energy, lowering the temperatures it reaches in summertime. This layer should be applied to the mold's backside just prior to installing its frame. After the frame ties are glassed, PVA can be sprayed over the entire construction to ensure good surface cure.

The ideal storage conditions for FRP molds are indoors, heated during periods of extreme cold, and covered with a sheet such as painter's plastic to avoid dirt and grime accumulation.

POLYESTER TOOLING: Special Precautions

Part Eight, Chapter XI

In This Chapter

1. **Introduction**
2. **Precautions**

1. INTRODUCTION—There is an economic advantage to producing a quality long lasting mold that requires little or no subsequent finishing. This requires strict quality control methods in the application of both tooling gel coat and the mold laminate.

The approach to designing and building molds requires a different mind-set than the approach to building production parts. During production, certain short cuts can provide recurring savings. However, during mold fabrication, short cuts can provide recurring costs because mold flaws translate directly into part flaws on each production part. Extra care and effort during mold fabrication reduces part re-work costs, providing a recurring savings. Many gel coat and laminating defects result from conditions that can easily be corrected.

2. PRECAUTIONS—Please note the following:

A. Do not use more than 2.4 percent initiator in the tooling gel coat. Excess catalyst can cause excessive shrinkage of the gel coat. This leads to pre-release from the master surface. For adequate cure, do not use less than 1.2 percent initiator. Disperse catalyst thoroughly in the gel coat. Poor distribution causes uneven cure, color variation and premature release before layup. While mixing by hand, the material should be poured from one container into another to facilitate top-to-bottom dispersion. Best results are obtained with a small mixer attached to a variable speed pneumatic motor. Best cure is obtained when the ambient, material and mold temperatures are between 70 and 90°F.

B. Tooling gel coat should not be left to cure overnight before at least a skin coat lamination is applied. Excessive film cure results in a loss of tack and reduced bond quality between the gel coat and laminate. In addition, the likelihood for pre-release is greater.

C. Install oil and water traps on the air line leading to the spray gun. These traps will remove lint, rust, oil, other contaminants and liquid water. A water trap will not catch moisture in the form of water vapor. Therefore, the compressed air should be cool when it enters the water trap or else water vapor will pass right through the trap. This can be checked by running a test with an extra 50-foot hose and a tool that consumes a lot of compressed air. A spray gun will not show this fault because the spray gun is designed to atomize high molecular weight gel coat and will vaporize any water that has condensed in the compressed air line. The tool should be run for about as long as one would expect to be spraying the tooling gel coat. If liquid water sputters out the tool exhaust, the water trap is passing vapor that is condensing in the hose or in the tool. Water in the gel coat film will cause problems and should be removed with a compressed air cooler. Compressed air coolers are commercially available. A simple, home-made cooler can be fashioned from a 50-foot coil of 1/2 inch copper tubing that is spiraled to fit inside a plastic tub or drum filled with tap water. Gallon jugs of ice can provide additional cooling when placed in the water within the tubing spiral.

D. Proper spray technique is very important to prevent pinholes and porosity in the gel coat film. Use slow, even strokes, keeping the gun at right angles to the surface. Trigger the spray gun at the end of each stroke to prevent build-up at overlaps. Begin applying gel coat near the booth exhaust in order to avoid over-spray from air-drying on the master. Air-dried over-spray can cause pigment separation and form pinholes once the tooling gel coat is applied. Pigment separation appears like a watermark on the cured gel coat surface. The gel coat must be well atomized and each coat applied to a wet film thickness of 18 ± two mils in three passes. Subsequent passes should always be at right angles to the prior pass. Use conventional air atomization with a minimum of 60 psi dynamic (at the gun, trigger pulled wide open). Low atomizing pressure will result in poor breakup and leave entrapped air (pinholes) in the sprayed film.

E. Do not use internal air atomization spray equipment, catalyst injection or airless spray equipment with standard tooling gel coat. These types of equipment often result in thick films and porosity. See DS-45 tooling data sheet for special instructions regarding gel coat application using airless equipment.

F. Best results when spraying tooling gel coat are obtained by using a pressure pot. This prevents catalyzation problems due to surging in resin or catalyst pumps, lack of calibration and poor mixing. Avoid material delivery rates in excess of 2.5 pounds per minute because more than this is difficult to atomize.

G. Never add acetone or other solvents to tooling gel coat. A compatible patching thinner or PATCHAID® can be used for repair activities. PATCHAID® contains a surfacing agent that prevents air from inhibiting the cure. This surfacing agent can prevent a second layer from adhering. For multiple cured coats, the patching thinner (without the surfacing agent) is recommended.

H. Molds can develop stress cracks due to thermal shock. If molds are stored at cold temperatures and then suddenly brought into a warm building, the rapid heat up can cause stresses that lead to fracture in the gel coat.

POLYESTER TOOLING: Special Precautions

I. Manufacturers of conventional paste wax claim indefinite shelf life as long as the solvents do not evaporate. Keep containers closed except to remove the wax. Do not apply paste wax using the 'sock method.' This involves tying the wax up into a ball with sheeting. The sock allows solvent and oil to pass through, but the waxes remain in the sock.

J. Semi-permanent mold releases do have a shelf life and must be kept closed when not in use. These materials are polymers that require humidity for proper cure. Low humidity conditions will extend the time required for them to cure. Always follow the storage and usage recommendations from the semi-permanent release system manufacturer.

K. Both conventional paste wax and semi-permanent mold release systems must bond to the mold surface. A good bond requires a clean mold surface. The residue from rubbing or polishing compounds must be removed using a mild detergent solution such as dish soap and water. If these residues are not removed prior to mold release application, the first pull may remove the release agent and the second part can stick.

L. Do not be afraid of silicones. Most mold waxes do contain silicone, and non-silicone types are the exception rather than the rule. Excess silicone can and will cause problems, such as fisheye and pre-release. The important thing is to make sure all excess wax is polished from the tooling gel coat surface. Fisheye and pre-release will be more of a problem on fresh wax than on ensuing parts.

M. Do not use high speed buffers (more than 3,000 RPM). High speed buffers cause excessive heat and can lead to burning.

THERMA*CLEAN*® PRODUCTS

Part Nine

In This Section

1. INTRODUCTION—Traditional cleaning solvents for equipment and tools in the composites and casting industries have been acetone, methyl ethyl ketone, ethyl acetate, methylene chloride and toluene. These conventional solvents have been used for every aspect of tool and equipment cleaning as well as personnel skin contact cleaning. These solvents exhibit varying degrees of flammability from 'very' to 'slight.' In the past several years, the toxicological and environmental risk aspects of these cleaning products have caused fabricators to seek alternative cleaners. Objectives or desirable features for such alternative cleaners would be:

- Effective polymer solubility or loosening
- Carrying ability of the cleaner
- Low volatility
- Low/no flammability
- Reasonable cost
- Disposal as a non-hazardous material
- Reduced risk to employees, facility, or environment.

Benefits derived through reduced fire insurance rates have been further encouragement for alternatives. CCP manufactures THERMA*CLEAN*®, a line of replacement cleaners which meet the above listed objectives, and which provide CCP customers with a product support system that addresses technology, application, and waste disposal.

THERMA*CLEAN*® products are effective industrial cleaners with lower environmental impact when used as replacements to solvents. These products are used in a variety of cleaning applications within the composites, industrial, cultured marble/cast polymers and other industries.

2. TECHNOLOGY—The THERMA*CLEAN*® product line consists of two basic technologies:

- Water-based products, including resin emulsifiers and wipe down cleaners
- High flash point, no HAP, low VOC emission, solvent-based products, including a variety of specialized gun flushes.

These products are cost effective compared to low flash point solvents because THERMA*CLEAN*® products have very slow evaporation loss rates, and water-based products are diluted with up to 10 parts of water.

These products also significantly improve personnel and plant safety, since high flash points greatly reduce fire hazards, and low toxicity minimizes employee health risks. THERMA*CLEAN*® products are non-hazardous for flammability and toxicity by EPA and DOT definitions.

3. APPLICATION—To assist customers with the use of THERMA*CLEAN*® products, CCP provides a wide range of application support. This support extends from specialized equipment which improves productivity, such as CCP's MARBLE*CLEAN*™ machine, and its AQUA*CLEAN*™ machine, to specialized application tips for product use, as well as technical consulting by the THERMA*CLEAN*® support group.

4. WASTE DISPOSAL—Water-based products may be sewerable (with prior POTW approval). Solvent-based products must be disposed of through an appropriate waste disposal company. A CCP representative can assist in identifying an appropriate waste disposal company.

CCP customers who choose THERMA*CLEAN*® products not only use the best environmental cleaners available, but gain access to CCP support and resources as well.

THERMACLEAN® products are well-demonstrated as they have been specifically developed in CCP's research laboratories to clean a variety of gel coats and resins.

Product data sheets describing the entire THERMA*CLEAN*® line are available on request through CCP customer service or through CCP's website at www.ccponline.com.

APPENDIX A: Quality Control Lab and Test Methods

In This Chapter

1. **Introduction**
2. **Basic Needs and Equipment**
3. **Basic Testing Methods and Equipment**
4. **Physical Testing**
5. **Sources of Equipment**

1. INTRODUCTION—The fiberglass industry is constantly changing. Parts are made at faster rates, with a demand for higher quality and better durability. There is less latitude for errors that can cause unsatisfactory products and costly downtime. Everything must work properly and be compatible.

Many companies in the fiberglass industry are setting up their own internal quality control (QC) labs to monitor materials, to do in-house process monitoring, and to assure performance of final parts. Qualification for ISO certification requires monitoring of materials and process.

What defines the cost of a control lab is not an easy question to answer. It depends at least partly on what benefits are expected. If a dollar is spent on obtaining information and the information isn't used, too much money has already been spent.

A QC lab (or any laboratory) has one basic function: it collects and reports factual information that should be used to make reasonable decisions. A QC lab can answer the following questions:

- Is the material to be used really what the supplier says it is?
- Does it meet in-house requirements for processing?
- Is consistent material (necessary for optimum production schedules and requirements) being supplied?
- Does a new vendor's different material match the presently used product?
- Can production use the product?
- Is production consistent?
- What amount of material is actually used on each part? Are parts consistent, not only in weight, but in quality?
- Is the process used in making the part cost efficient?
- Does a specific change in production actually bring about a cost or quality benefit?
- Are the products and parts compatible with each other to produce the desired quality?

A QC lab can also perform several other functions:

- Evaluate new products, equipment, or processes
- Run safety testing
- Coordinate samples to be sent out for testing—product testing, environmental testing or analysis work
- Assume responsibility for regulatory activities (Sara III Reports)

A QC lab can also provide:

- Design, testing
- Cost information on parts
- Cost estimates on new parts

Before setting up a quality control lab, it is important for each company to review its expectations and determine the scope of its needs.

A single company's needs will vary greatly (e.g., critical aerospace applications versus non-critical parts), and one company's needs will vary greatly from another. It is not possible for CCP to provide a complete layout or list of equipment for each possible situation. Listed in this chapter, however, are basic equipment and general costs. Final choices are up to each fiberglass manufacturer.

2. BASIC NEEDS AND EQUIPMENT—The most rudimentary quality control lab needs a room that is temperature controlled and that is equipped with good lighting. Other requirements are a sink with hot and cold water, electrical outlets for test apparatus, shelves and a desk.

One of the primary functions of a QC lab is record keeping. Data must be collected, recorded, and put in a form that is usable and accessible for decision-making. The economical way of doing this is with pencil and paper. If large amounts of data must be reviewed, then a small computer may be necessary. A spread sheet program and/or statistical quality control program might be necessary.

NOTE: A computer may not save time for simple day-to-day operations, but it does make handling of large volumes of information easier, particularly in arranging it and sorting it into a meaningful form.

A QC lab should have available a list of all raw materials, with approved suppliers, used in the company's plants. It should have the phone numbers of not only the salespeople but the technical staff of suppliers. A list of industry organizations such as the ACMA and SPI-CI, with phone numbers, should be included. The lab should also retain a selection of references. The first of these should be the business phone directory for the nearest large city. Reference books should be set up for each supplier's data sheets. Material Safety Data Sheets, process bulletins and bulletins on how to use their products. The lab should be on the subscription list of as many industry magazines as possible. Subscriptions to many of these magazines are free to industry people. A binder must be set up that contains all of the test methods that the lab is to use.

The QC lab should have a system for reporting information. Simple forms can be used and should be arranged so that the characteristics and consistency of a batch can be seen at a glance.

APPENDIX A: Quality Control Lab and Test Methods

When a material is logged into the lab, there are a number of QC steps that should be done. The details of the actual test depend on what type of part will be made from the material, and what is required from it. Start with the simplest tests and then move on to the more complicated. First steps must be taken before final steps. It is acceptable to pause anywhere along the process as long as steps are taken in order.

These steps will normally include:

A. Record the following information on a particular product or raw material when received:

- Code number
- Batch number
- Batch date
- Date received
- A part number if available
- Specifications (if set up for a particular raw material) should be listed with their tolerances
- If a spec sheet comes with the material, it should be compared to standard specifications and the typical results of previous batches.

B. Visual Inspection—The simplest inspection is visual and is oftentimes overlooked. This should consist of:

- Examining containers as they are received. Are any damaged? Is there any swelling or buckling? Are there any leaks?
- Opening the container and examining the material. Does it appear like the previous batch? Is it roughly the same color, cloudy, clear, etc.? Are there any visible signs of contamination, water, etc.? *NOTE: The color of resins may vary from batch to batch.* If there seems to be a significant variation, check with the supplier. Results of these visual inspections should be written down.
- Mixing the container's contents and visually comparing it to the inspection report's reference to the unmixed appearance. *NOTE: Some settling may be normal. It is important to be aware of materials that need to be mixed before use.*
- Pulling a sample, putting it in a proper container and marking it with the code number, batch, batch date and date received. Save this for testing or future reference for 90 days. *NOTE: Polyesters should be stored in opaque containers at 73°F or below.*

The following are also required for the preceding procedures: clipboard, paper, paper cups, containers and a marker.

Before initiating a testing program, it is important to obtain a list of all the normal tests and procedures used by the supplier to control the quality of the product.

Review the literature for test methods and decide which test procedure to use. The selected procedure should be written up and filed in a notebook. A copy of the proposed procedure should be sent to the supplier with a request for comments.

Any time a test is run, results should be recorded and compared to the standard and to previous batches.

C. The following general methods and equipment used in testing catalysts may be used to test a variety of materials.

While a very small component, catalyst is a very important one. There are only two basic tests that can be run with catalysts (unless the laboratory is highly sophisticated). These tests are:

- Visual—Check the clarity of the product; look for any seeds, crystals or cloudiness in the material. If found, contact the supplier at once.
- Reactivity—Tests must be run to compare a new lot of catalyst to an old lot of catalyst in the same resin or gel coat. For QC work to be effective, tight controls are required for accuracy. Run gel, cure, and peak.

Equipment needed for catalyst testing includes:

1) A water bath, accurate to within 1°F. An example of this type of bath is Blue Magni Whirl Model MW110A1.
2) A gel meter. CCP uses Sunshine gel meters.
3) A balance accurate to 0.1 gram.
4) A thermometer accurate to within 0.2°F.
5) For a more permanent record of temperature changes or time versus temperature, a strip chart recorder is required.

The equipment mentioned here is provided as an example; other brands may be suitable.

3. BASIC TESTING METHODS AND EQUIPMENT

A. Acid Number (Similar to ASTM D 465-59)— The acid number is the number of milligrams of potassium hydroxide (KOH) necessary to neutralize the free acid end groups in one gram of sample. This test is used on resins to determine how far the reaction has proceeded during cooking; it is also used for batch to batch consistency. The acid number will vary from resin to resin; it may be as high as 60 or as low as three.

NOTE: Acid number can be calculated in either of two ways: On resin solids only (monomer factored out), or on total solution (monomer not factored out). CCP acid numbers are based on resin solution.

APPENDIX A: Quality Control Lab and Test Methods

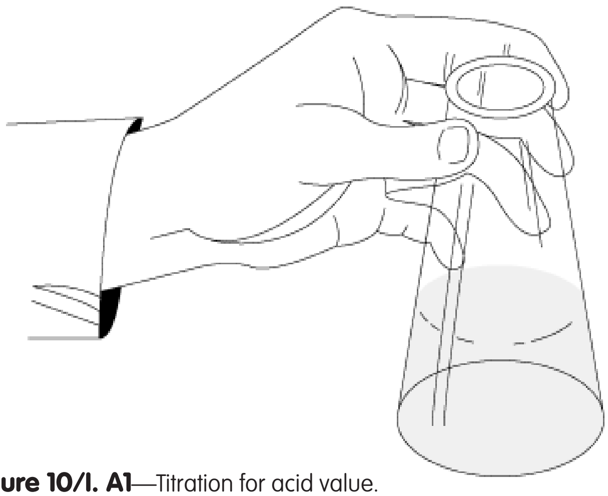


Figure 10/I. A1—Titration for acid value.

1) Procedure:
   a) Weigh 5.6 grams of resin into a 150 ml Erlenmeyer flask (or other similar sized container).
   b) Add about 20 ml of the following solvent mix:

Toluene	33 grams
Xylene...........................	33 grams
Ethanol (denatured)	34 grams
Phenolphthalein	2 grams

   c) Swirl and warm on a hot plate, if necessary, to dissolve the resin.
   d) Titrate, using 0.1 normal KOH solution until the resin solution holds a faint pink color for 30 seconds (the color will tend to fade away).
   e) The acid value (AV) = ml of KOH solution used.

B. Barcol Hardness (similar to ASTM D 2583)—This test is used to determine the hardness of a material as it cures. It also can be used to compare the hardness of different resins and the development of cure.

This test is not recommended for production gel coats, but is appropriate for resins and tooling gel coats.

A Barcol impressor measures the resistance to penetration of a needlelike point on a scale of zero to 100. It requires a mass of material to obtain an accurate reading.

Barber-Colman, manufacturer of the Barcol impressor, is specific regarding instructions (and limitations) for the proper use of the Barcol impressor. Barber Coleman advises:

- For accurate readings, material should be at least 1/32 inch (31 mils) thick.
- The testing area should be smooth and free from mechanical damage.
- As a general rule, the number of readings taken increases with the softness of the materials being tested.

Barber-Colman recommends numbers of readings for the Model 934:

Hardness Scale (934)	Reading Variance	Number of Readings
30	22.4	20
40	17.2	22
50	12.0	16

CCP has observed when checking a rough surface (typical of gel coat pour-outs) that variances will be much greater. Resin castings (because of lower viscosity) show more consistent readings in a quart lid than gel coat castings.

Barcol is not a good indicator of cure for production gel coats. The best indicator is the finished product; (e.g., does the product exhibit good gloss after being pulled from the mold).

A low Barcol will not necessarily indicate decreased cracking, nor does a high number indicate increased cracking. Higher or lower numbers do not affect buff-back capabilities.

Barcol will not indicate print-through or distortion resistance. The primary cause of fiber print through is a thin film of gel coat. Distortion is caused by the laminate shrinkage differential of the resin versus the glass. Hardness of a 16 to 20 mil film can only do so much. It cannot prevent laminate cracking and distortion.

Because results are inconsistent and can be misleading, it is difficult to check Barcol on a film of tooling or production gel coat. The needle of the Barcol impressor is .031 inch (31 mils); therefore, the film must be at least 31 mils thick to obtain an accurate reading.

If tooling gel coats are sprayed to the recommended thickness of 16 to 20 mils in two coats, the wet film thickness will be a total of 32 to 40 mils. This 32 to 40 mil film will shrink and lose about 25 percent monomer, providing a cured film of about 24 to 30 mils. In addition, film thickness will vary within the eight mil range, and 24 mils would provide a different reading than 30 mils.

The needle will penetrate thinner films and start reading Barcol of the laminate beneath the film. Production gel coats are applied at a thickness that measures much less than 31 mils, and thickness of the sprayed film will again vary.

Two different Barcol meters are used in the FRP industry:

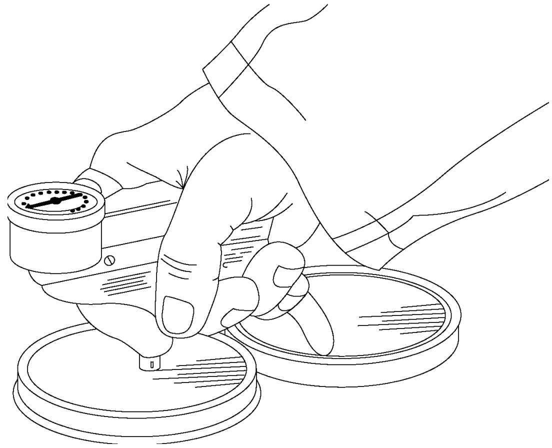


Figure 10/I.A2—Barcol meter.

1) Model 935 (softer materials), normally used for initial readings.
2) Model 934 (hard materials), normally used for ultimate cure or when 935 gives readings of 75 or above.
3) Procedure—Many times, this test is run at the same time as the gel time test. The sample size is increased to either 150 grams or 200 grams and brought to 77°F and catalyzed.
    a) Calibrate Barcol impressor with test discs supplied.
    b) Note the time of catalyzation.
    c) Weigh a specific weight of catalyzed resin into an aluminum weighing dish and place on a non-heated, insulated surface in an area free from drafts. Remainder of sample is used for gel time test.
    d) After the sample has gelled, test sample every five minutes with a pencil. If the pencil dents the resin, do not use Barcol impressor. Note that time starts from moment of catalyzation, and test normally runs one hour or until a reading of 70 or 80 is reached on a 935 Barcol.
    e) If a pencil will not dent the resin, take a reading with the 935 Barcol impressor by pressing needle assembly into the resin, noting the average of at least three readings. Make sure needle assembly is perpendicular to resin surface.
    f) Continue this procedure until 935 Barcol reaches 60 to 70. When this occurs, the 934 may also be used.
    g) Report time and readings. Needle may fade towards zero. Make note if this occurs.
    h) If any resin sticks to the needle, wash needle to prevent blockage. See the following example:

	Time (min.)	935	934
Catalyzed	0	--	--
Gelled	15	--	--
	20-25	--	--
	30	5	--
	35	15	--
	40	50-60	0
	45	70	0-5
	50	80	15
	55	80	20-30
	60	80	40

C. ANSI (American National Standard for Plastic Bathtub Units)—The purpose of this standard is to establish generally acceptable quality standards for plastic bathtub units. Its purpose is also to serve as a guide for producers, distributors, architects, engineers, contractors, home builders, code authorities and users; to promote understanding regarding materials, manufacture, and installation; to form a basis for fair competition; and to provide a basis for identifying bathtub units that conform to this standard. This standard and test procedures deal with the acceptability of a plastic bathtub unit as a plumbing fixture. Building codes may have additional requirements.

This standard has a number of tests within it. All will not be covered in detail (see the actual standard). Basically, the tests which must be run by an independent lab are:

1) Workmanship and Finish—This test spells out how many defects and blemishes are allowed after visual inspections, inking and sanding.
2) Structural Integrity—This series states what types of loading and impact the drain fittings, sidewalls and floor must withstand.
3) Water Resistance—This is the 100-hour boil test (212°F). *NOTE: Type Four bathtub units (thermoplastics) are tested at 180°F; not in boiling water.* The 100-hour boil test requires a certain size panel to be exposed to boiling water, normally for 100 hours. The panel is then visually inspected for color change, blisters, change in surface profile, cracks and loss of visible gloss. Each item is rated on a scale of zero to five, with zero being no change and five being extreme change approaching maximum possible, with one to four being the degree of change in between these extremes. The ratings are somewhat subjective and a certain degree of change in each category (e.g., color, change, blisters, cracks, etc.) is allowed. Failure occurs when any one area is rated above four or when the total of all five areas is above nine. *NOTE: The applicability of this test is to compare product to product. Field suitability has not been estab-*

lished. It has been used to rank materials under one set of conditions, but passing or failure does not automatically imply that material is or is not suitable for other types of applications. Suitability is determined by the user.

4) Color Fastness—This is a 200 hour weatherometer test.
5) Stain Resistance—The stain resistance to a number of chemicals is tested.
6) Wear and Cleanability.
7) Ignition Test.
8) Cigarette Test—This test checks if the unit can be ignited or irreversibly damaged by a cigarette burn.

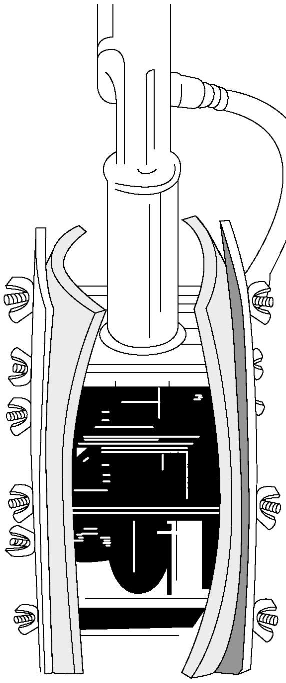


Figure 10/I.A3—Boil tester.

NOTE: Type Four units (thermoplastic faced) have a series of other test requirements; see the standard for details.

D. Color—Polyester resins possess a color that ranges from water-clear to dark amber. This color varies with resin type and formulation. Resin color is normally only important when the resin is used to make water clear castings and translucent sheeting.

NOTE: Additives like cobalt will affect the color. There are two color tests.

1) Gardner Color ASTM D 1544-74—This is the normal test; a test tube of resin is compared to known standards and is ranged from one (lightest) to 18 (darkest).
2) APHA Color (Hazen)—This test is used to rank resin when the Gardner color is registered at one or less. Again, a tube of resin is compared to known standards.
3) Spectrophotometer Measurements—A color standard must be established in order to run a color test. Normally, a color standard should be a gel coated panel. The standard may be developed by matching some other item such as vinyl, paint, etc. Once the match is selected, three matched panels should be made up. Each panel should be permanently marked on the back as 'Standard, Part Number ___, Color ___, Date ____.' Each panel should be at least three inches by five inches in size and placed in envelopes. One should go to the supplier, and one is a working standard that is used day-to-day. The third panel is retained as a master, stored in a cool, dark place, and only used when the working standard is in question. This is the final reference for color.

   If accurate color consistency is required, the master standard and working standard must be kept in the freezer when not in use. Color standards will change upon aging. That change can be minimized by storing between 0°F and 32°F. In this case, a freezer is necessary.

   NOTE: This freezer should not be used to store peroxides or food.

The equipment for running color is:

1) Fiberglass or glass mold.
2) Spray gun, one quart pressure pot, stem cut off so a small bottle (eight ounce jar) can be inserted. (one and two are used to prepare cured sprayouts for batch color comparisons.)
3) Light source—one of the following, in order of effectiveness:
   a) North light
   b) Fluorescent light (cool daylight bulbs)
   c) A light booth
   d) Color instrument.
4) A consistent observer with no color blindness for visual color comparison.

See the chapter on Color for further details.

E. Dielectric Strength, ASTM D 149—

1) Specimen—
   a) Specimens are thin sheets or plates having parallel plane surfaces and of a size sufficient to prevent flashing over. Dielectric strength varies with thickness and, therefore, specimen thickness must be reported.
   b) Since temperature and humidity affect results, it is necessary to condition each type of material as directed in the specification for that material. The test for dielectric strength must be run in the conditioning chamber or immediately after removal of the specimen from the chamber.
2) Procedure—The specimen is placed between heavy cylindrical brass electrodes which increase in voltage during the test. There are two ways of running this test for dielectric strength:
   a) Short-Time Test: The voltage is increased from zero to breakdown at a uniform rate of 0.5 to 1.0 kv.sec. The precise rate of voltage rise is specified in governing material specifications.

b) Step-by-Step Test: The initial voltage applied is 50 percent of breakdown voltage shown by the short-time test. It is increased at rates specified for each type of material and the breakdown level noted.

The term 'breakdown' used with these tests means passage of sudden current flow through the specimen and can be verified by instruments and visible damage to the specimen.

3) Significance—This test is an indication of the electrical strength of a material as an insulator. The dielectric strength of an insulating material is the voltage gradient at which electric failure or breakdown occurs as a continuous arc (the electrical property analogous to tensile strength in mechanical properties). The dielectric strength of materials varies greatly with several conditions, such as humidity and geometry, and it is not possible to directly apply the standard test values to field use unless all conditions, including specimen dimensions, are the same. Because of this, the dielectric strength test results are of relative rather than absolute value as a specification guide.

F. Fire Tests—The use, applicability and statements regarding fire test results must be handled with great care, as this whole area is in a great state of flux due to federal regulations. Different regulatory bodies have different requirements for a material's fire resistance. The major question to answer is: Does the fire resistance test predict what happens in an actual fire? The documented tests at this time are full scale tests which absolutely predict what will happen under actual fire conditions. Other currently available tests tell only how materials burn under a single set of conditions.

Listed on this and the following pages are common tests which have been used to rate the burning properties of polyesters, but may or may not be CCP recommendations. These tests are:

1) ASTM D 635—This test was designed to compare the flammability characteristics of different materials, in controlling manufacturing processes, or as a measure of deterioration or change in flammability rating prior to or during use. In the test, at least ten specimens five inches in length by 0.5 inches in width and thickness of the sample normally supplied (usually 1/8 inch) are marked one inch from each end. The specimens are held in position with the longitudinal axis horizontal and the transverse axis at 45 degrees to the horizontal. The specimens are ignited for 30 seconds with a Bunsen burner with the flame adjusted to a prescribed height. The rate of burning is calculated (inch per minute). This is not a very severe test and does not distinguish relative flammability characteristics between specimens which have good flame retardant properties. At best, it can only be utilized for rough screening work.

2) HTL-15 Intermittent Flame Test—The apparatus needed for conducting this test is quite simple. The test is much more severe than the test previously described because the specimen is suspended in a vertical position and heat from the burner will be carried upward by convection along the length of the specimen. In addition, the specimen is ignited five times using increasingly longer ignition periods. The sequence of ignition times and flame with withdrawals follows:

Applications	Ignition Time (Seconds)	Burner Withdrawn (Seconds)
1	5	10
2	7	14
3	10	20
4	15	30
5	25	50

In rating a sample, five specimens eight by 1/2 by 1/8 inches are burned. If the flame is extinguished within the period that the burner flame is withdrawn, the specimen has passed the ignition test. Each of the five test ignitions successfully passed is worth 20 toward the rating for that specimen. For example, if a specimen successfully passes the five ignitions and flame-off periods, it is rated at 100, four ignitions rate at 80, and so on. An average is taken of the ratings for the five specimens.

3) ASTM D 757—A Globar element is heated to 950°C and a specimen five by 1/2 by 1/8 inches is brought in contact with the bar for three minutes. After this period, the flame (if any) is extinguished. The distance burned is measured and the rate calculated in inches per minute. In cases where the compositions are highly flame resistant, the specimens will usually not ignite, but will char or (if ignition occurs) will extinguish themselves in a very short period.

4) ASTM E 162—In this method, a radiant heat energy source is used to supply heat to the surface of a specimen being tested. It is believed that in using a radiant energy source rather than supplying heat by a propagating flame, more accurate observations of the progress of the flame-front can be made. The heat source consists of a vertical 12 by 18 inch panel in front of which is placed an inclined six by 18 inch specimen. The specimen is oriented in such a

manner that ignition occurs at the upper edge and the flame-front moves downward. A factor derived from the rate of progress of the flame-front and another relating to the rate of heat liberation by the material under test are combined to provide a flame spread index. The amount of smoke evolved during the test can also be measured. It is pointed out in the ASTM Method that the method, although suitable for research and development for measuring surface flammability of materials, is not intended for rating materials for building code purposes.

5) ASTM E 84—This is a large scale test which requires a considerable amount of material and is quite expensive to set up and run. Only a few test 'tunnels' used for this test are in actual use in the United States. The purpose is to determine the comparative burning characteristics of the material being tested by evaluating the flame spread over its surface, fuel contributed by its combustion, and the density of smoke developed when exposed to a test furnace. Briefly, the specimen for combustion (after prior conditioning) is fastened to the roof of the tunnel and ignited by means of a gas flame impinging on the surface of the specimen. The gas flow is carefully regulated. During the test, air is drawn through the tunnel at a constant rate. Smoke density is measured by means of a light source and a photoelectric cell in the furnace vent; fuel contributed is measured by means of thermocouples placed near the vent end of the furnace. The furnace is calibrated using red oak flooring and asbestos board as standards. Conditions are adjusted so red oak spreads a flame the length of the furnace in five and 1/2 minutes ± 15 seconds (19.5 feet from the end of the gas flame to the end of the tunnel). This is considered (arbitrarily) as a classification of 100 while the flame spread of asbestos is zero. In testing a material, classification is made relative to these two ratings. Also, fuel contributed and smoke density is classified in respect to values obtained for red oak and asbestos.

6) ASTM D 2863—Flammability of Plastics Using the Oxygen Index Method

   a) Scope—This method describes a procedure for determining the relative flammability of plastics by measuring the minimum concentration of oxygen in a slowly rising mixture of oxygen and nitrogen that will just support combustion. This method is presently limited to the use of physically self-supporting plastic test specimens.

   b) Significance—This method provides a means for comparing the relative flammability of physically self-supporting plastics.

   c) Principle of Method—The minimum concentration of oxygen in a slowly rising mixture of oxygen and nitrogen that will just support combustion is measured under equilibrium conditions of candle-like burning. The balance between the heat from the combustion of the specimen and the heat lost to the surroundings establishes the equilibrium. This point is approached from both sides of the critical oxygen concentration in order to establish the oxygen index.

   d) Calculations—Calculate the oxygen index, n, of the material as follows:

      n, percent = (100 x O2)/(O2 + N2) where O2 is the volumetric flow of oxygen, CM1/S. at the limiting concentration determined and N2 is the corresponding volumetric flow rate of nitrogen, CM1/S.

There are a number of other tests which are, at times, used in the fiberglass industry. Only the most common generally accepted tests have been described here. Other tests can be found in text books and/or industry literature. All manufacturers of any product should have an inhouse testing program, but tests should not be run just to be running tests. Rather, tests should be run to determine how material will perform in the manufacturing process, to determine its quality, and to determine how the final product will perform for its intended end use.

G. Gel Time at Room Temperature—

1) Equipment Required:

   a) Timer—An inexpensive stopwatch may be picked up at a discount store; an example of a high end alternative would be a Sunshine gel meter. An alternate gel meter is the Shyodu. The mechanics between the two differ somewhat. A Sunshine meter should be used if close comparisons to CCP results are required.

   b) A thermometer is required. A glass thermometer, a good pocket thermometer, or an electronic thermometer can be used.

   c) Eight-ounce paper cups, wide mouth glass jars, or high-density plastic beakers are required.

   d) Some type of scale is required to measure both gel coat and catalyst, which must be measured consistently from test to test.

There are a number of choices available, depending on the degree of accuracy desired. Some options include:

- Graduated paper or plastic cups marked in cc's or ml's
- A syringe or 10 ml graduated cylinder; these can be picked up at any store that handles medical supplies, (e.g., food, drug, or discount stores)
- Small school balance or . . .
- Balance scale.

e) Spatula and stirring stick.

f) Water bath; options include:

- Fish tank, plus heater (only heated models are available, so other means of cooling would be necessary)
- Blue M Bath.

CCP has found the following can occur:

- Variation between gel meters (of the same type) can be up to 1/2 minute.
- Variation in mass size (container and volume) can be up to 12 minutes.
- Variation of temperature at 76°F versus 78°F can be more than a minute.
- Variation in repeatability (same meter, same mass, same temperature) can be up to 1/2 minute.

2) Measurement of Gel Time—Measured as the amount of time from when the catalyst is mixed in until it is no longer liquid. This test is normally run at 77°F. Temperature greatly affects this test.

a) Procedure:

a1) Adjust sample to 77°F (± 1°F).
a2) Check gel meter for proper operation.
a3) Set gel meter timer to zero.
a4) Accurately weigh in the required amount of catalyst (normally 1.2 percent methyl ethyl ketone peroxide) to 100 grams of sample unless otherwise specified.
a5) Simultaneously start the power and stir catalyst into sample. Stir in catalyst for one minute. Scrape the side of the jar while stirring.
a6) Place cup beneath Gel Meter. Attach glass rod to magnetic contact assembly. Center the rod in sample. Adjust the meter and rod for vertical alignment.
a7) Turn on test switch.
a8) When buzzer sounds, timer will stop. Turn power and test switch off. Record results.
a9) Clean all equipment and set timer back to zero.
a10) When measuring cure time, the gel timer can be used to determine the time until peak exotherm. See below for details.

b) Report—

b1) Record gel time to nearest 0.1 minute.
b2) Report any deviations from standard temperature and conditions.

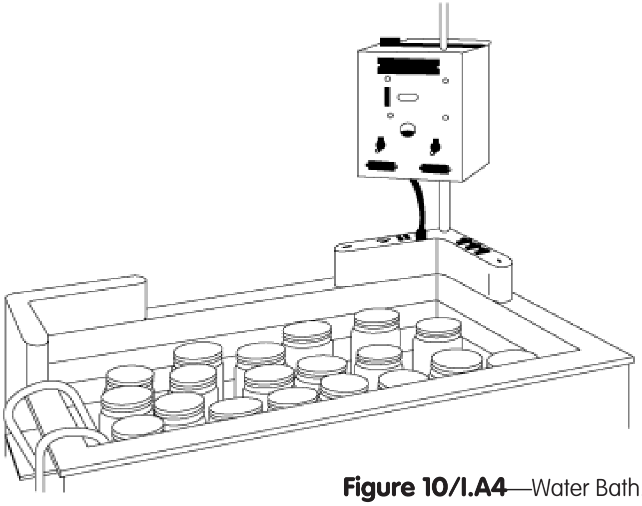


Figure 10/I.A4—Water Bath.

3) Measurement of Cure Time—Measured as the amount of time from when the catalyst is mixed in until the exothermic reaction has reached the maximum temperature for the 100 gram sample.

The gel-to-peak time is the time difference between the cure time and gel time.

Additional equipment is required to measure the peak exotherm. A strip chart recorder illustrated in the figure below or a thermocouple with 1°F graduations can be used.

The thermocouple is positioned into the sample while liquid or as a soft gel. The point of peak exotherm is centered both vertically and horizontally.

The sample should be insulated from the bench top and protected from other conditions affecting temperature.

Record the peak temperature and the time elapsed using a stop watch or gel meter timer.

Remove the thermocouple and clean the equipment.

4) Elevated Temperature (SPI)—This test is used when a resin will be processed by catalyst plus heat rather than a promoter. It provides a procedure for determining the relative reactivity between different batches.

- a) SPI Procedure for Running Exotherm Curves—
  - a1) Allow sample of uncatalyzed polyester resin to reach room temperature, preferably 75°F to 79°F.
  - a2) Weigh one hundred grams of resin into an eight ounce jar.
  - a3) Weigh two grams of catalyst (50 percent BPO paste) into resin in eight ounce jar.
  - a4) Stir catalyst into resin; stir well for one minute, being careful to avoid air entrapment.
  - a5) Pour catalyzed resin into a 19 by 150 mm test tube to a depth of eight 8 cm (approximately 20 grams of resin).
  - a6) Allow resin mixture to set at room temperature approximately fifteen minutes (plus or minus five minutes) away from strong light.
  - a7) Submerge test tube into constant temperature 180°F water bath.
  - a8) Insert thermocouple (iron-constantan) into center of resin mixture.
  - a9) Record time required for resin mixture to go from 150°F to 190°F as the gel time; the time from 150°F to peak exotherm as cure time; and the peak exotherm.

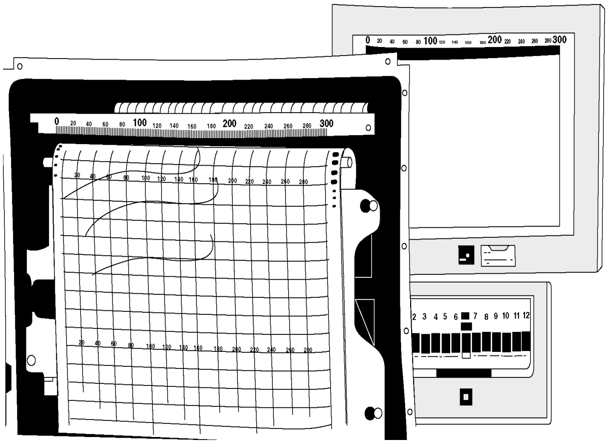


Figure 10/I.A5—SPI gel time recorder.

H. Grind—This test may or may not be run on gel coats. It normally is run on the pigment concentrates used to make the gel coat.

1) A small amount of material is placed on a grind gauge and leveled with a special draw-down knife.
2) The material is visually inspected to see at what thickness particles appear on the scale.
3) A grind gauge (Hegman normally used) is a stainless steel slab in which a variable depth trough is milled. The scale runs from zero (4 mils deep) to eight (0 mils deep).

I. Hide—This test determines at what thickness a gel coat will prevent a standard colored pattern from being visible. The thickness at which a gel coat will hide is normally set below its minimum application thickness.

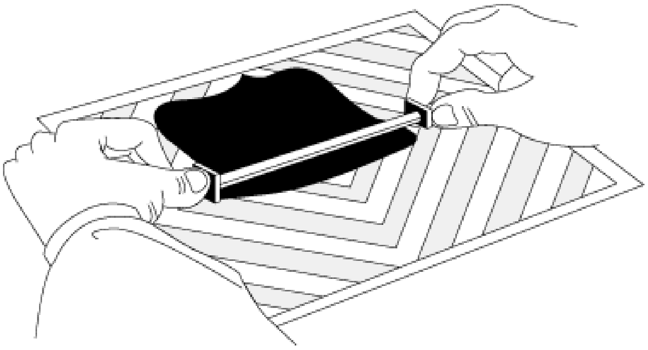


Figure 10/I.A6—Hide check.

1) A standard hiding paper is secured flat and a small quantity of gel coat is placed on it.
2) A draw-down bar is then used to spread the gel coat out evenly.
3) The thickness is then measured with a mil gauge. *NOTE: The gap on a draw-down bar will not deposit the same thickness of gel coat due to friction and fluid dynamics, (e.g., 10 mil gap may give only six to eight mils film thickness).*
4) The paper is then observed to see at what thickness of gel coat the pattern is no longer visible.

J. Nonvolatile (NV or Resin Solids or Vehicle Solids—This test is run only on the resin and monomer or solvent portion of any system. All pigments or fillers, if present, are separated out before the tests. This test is used to determine the ratio of base polyester resin to monomer (usually styrene). This is done by boiling off monomers or solvents which boil above 105°C. This ratio of base resin to styrene can affect the cured physical properties of the resin. It will vary according to type of material and application method. It can be as low as 40 percent resin and range to as high as 80 percent resin. (Refer to the data sheet of material for its proper range.)

Two methods are used in the industry. These are:

1) Foil Solids (based on ASTM D 1259)—
   - a) A folded rectangle of smooth six inch by 12 inch heavy duty aluminum foil is weighed to the nearest 0.0001 gram.
   - b) An eyedropper full of resin (approximately one gram) is placed inside the center of

the folded foil and quickly weighed to the nearest 0.0001 gram.

- c) The foil, with the resin inside, is placed between two glass plates and pressed to produce a three to four inch circle of resin.
- d) The foil is opened and placed in a clean 105°C oven for ten minutes.
- e) After foil is removed and cooled, it is reweighed to the nearest 0.0001 gram.
- f) The percent NVM is calculated:

  Percent NVM =
  100 x (weight e - weight a)
  (weight b - weight a)
- g) Percent monomer is 100 minus percent NVM.

This test is always done in duplicate; the results should be within 0.4 percent of each other.

2) Determination of Nonvolatile in Polyester Resins—

- a) Weigh a 60 mm aluminum dish (containing a bent paper clip to use as a stirrer) to four decimal point accuracy on an analytical balance.
- b) Fill a plastic eyedropper with the resin and wipe off the resin from the outside of the eyedropper.
- c) Weigh the eyedropper to four point decimal accuracy. Transfer about 0.5 gram of resin to the aluminum weighing dish; reweigh the eyedropper to determine the exact weight of resin transferred to the dish.
- d) Add two ml of toluene or toluene/acetone mix to the dish and mix into the resin using the bent paperclip.
- e) Dry the sample for 30 minutes in a 200°F oven and reweigh to four point decimal accuracy. The percent nonvolatile of the resin is:

  100 x (weight e - weight a)
  weight c
- f) Run three samples and average the results to get a final value for percent nonvolatile.

3) Pigment Solids—this test, in which a weighed gel coat is centrifuged, is not normally run except as a double-check for a particular reasons. The separated pigment is mixed with solvent and centrifuged, with the process repeated several times until the pigment is free of resin. The washed pigment is dried and weighed. Pigment solids are determined by:

100 x weight of dried pigment
weight of gel coat

NOTE: Be sure to subtract the weight of the container.

4. PHYSICAL TESTING—Note that in all physical tests, the test sample is preconditioned to assure full cure. If the part is not properly cured, the full physical properties cannot be obtained and failure or low readings may result, which may not be due to the material. Also, it is essential that the test samples for comparisons be constructed in an identical manner, as variances in thickness, type of substrate, and amounts of resin and reinforcement can change the results.

A. Tensile Strength, ASTM D 638—

1) Specimen—Specimens can be molded or machined from castings, laminates, or compression molded plaques. They are given standard conditioning. Typically 1/8 inch thick, their size can vary; their shape is like a dog bone, (e.g., 1/8 inch thick, eight and 1/2 inches long, 3/4 inch wide at the ends and 1/2 inch wide in the middle).

2) Procedure—Both ends of the specimen are firmly clamped in the jaws of a testing machine. The jaws may move apart at the rate of 0.2, 0.5, 2.0 or 20 inches per minute, pulling the samples from both ends. The stress is automatically plotted against strain.

3) Significance—Tensile properties are usually the most important single indication of strength in a material. The force necessary to pull the specimen apart is determined; also, how much the material stretches before breaking can be determined.

B. Flexural Properties, ASTM D 790—

1) Flexural Strength—

- a) Specimen is usually 1/8 inches by one by four inches. Sheet or plaques as thin as 1/16 inch may be used. The span and width depend upon thickness. Specimens are conditioned.
- b) Procedure—The specimen is placed on two supports spaced two inches apart. A load is applied in the center at a specified rate and the loading at failure is used to calculate the flexural strength (psi).
- c) Significance—In bending, a beam is subject to both tensile and compressive stresses.

2) Flexural Modulus—Calculated from the data generated during the flexural strength tests, flexural modulus is the material's ability to hold its shape under flexural loading, or its stiffness.

C. IZOD Impact ASTM D256—

1) Specimen is usually 1/8 by 1/2 by two and 1/2 inches. Specimens of other thicknesses can be

used (up to 1/2 inch) but 1/8 inch is frequently used for molding materials because of its representative average part thickness.

2) Procedure—A sample is clamped in the base of a pendulum testing machine so that it is cantilevered upward. The pendulum is released, and the force consumed in breaking the samples is calculated from the height the pendulum reaches on the follow-through.

3) Significance—The IZOD value is useful in comparing various types or grades of plastics and constructions. In comparing one plastic with another, however, the IZOD impact test should not be considered a reliable indicator of overall toughness or impact strength. Some materials are notch-sensitive and derive greater concentrations of stress from the notching operation. The IZOD impact test may indicate the need for avoiding sharp corners in parts made of such materials.

D. Compressive Strength, ASTM D 695—

1) Specimen— Prisms 1/2 by 1/2 by one inch or cylinders 1/2 inch diameter by 1 inch.

2) Procedure—

   a) The specimen is mounted in a compression tool between testing machine heads which exert constant rate of movement. Indicator registers loading.

   b) Specimens are usually conditioned.

   c) The compressive strength of a material is calculated as the psi required to rupture the specimen or deform the specimen a given percentage of its height. It can be expressed as psi either at rupture or at a given percentage of deformation.

3) Significance—The compressive strength of plastics is of limited design value, since plastic products (except foams) seldom fail from compressive loading alone. The compressive strength figures, however, may be useful in specifications for distinguishing between different grades of a material, and also for assessing, along with other property data, the overall strength of different kinds of materials.

E. Heat Distortion Temperature, ASTM D 648—

1) Specimen—Specimens measure five by 1/2 inch by any thickness from to 1/2 inch, conditioned (oven post-cured).

2) Procedure—The specimen is placed on supports four inches apart; a load of 66 or 264 psi is placed on its center. The temperature in the chamber is raised at the rate of 2°C + 0.2°C per minute. The temperature at which the bar has deflected 0.010 inch is reported as 'deflection temperature at 66 (or 264) psi fiber stress.'

3) Significance—This test shows the temperature at which an arbitrary amount of deflection occurs under established loads. It is not intended to be a direct guide to high temperature limits for specific applications. It may be useful in comparing the relative behavior of various materials in these test conditions, but it is primarily useful for control and development purposes.

F. Glass Content—

1) Procedure for Laminates With No Fillers—A small piece is accurately weighed and placed in a tared crucible. The sample is then burned in a furnace to remove all the resin. Sample residue is then weighed and percent glass is calculated.

2) Procedure for Laminates With Fillers—Many fillers break down under heating (e.g., calcium carbonate and hydrated alumina) and leave a partial residue. To determine the percent glass in a filled laminate, digestion and separation methods must be used; it is not easy to do.

G. Water Absorption, ASTM D 570—

1) Specimen—

   a) For molding materials, specimens are discs two inches in diameter and 1/8 inch thick. For sheet materials, specimens are bars three inches by one inch by thickness of the material.

   b) Specimens are dried 24 hours in an oven at 122°F, cooled in a dessicator and immediately weighed.

2) Procedure—Water absorption data may be obtained by immersion for 24 hours in water. Upon removal, the specimens are dried with a cloth and immediately weighed. The increase in weight is the water absorbed. It is reported as a percent of the original weight.

3) Significance—

   a) Various plastics absorb varying amounts of water and the presence of absorbed water may affect plastics in different ways.

   b) Electrical properties change most noticeably with water absorption.

   c) Materials which absorb relatively larger amounts of water tend to change dimension in the process. When dimensional stability is required in products made of such materials, grades with less tendency to absorb water are chosen.

H. Viscosity/Thixotropic Index (TI)/Sag—Viscosity is a material's resistance to flow. Tests include:

1) Gardner-Holdt ASTM D 154 and D1545—The rate of rise of an air bubble in a sample centered in an inverted corked glass tube is matched against known lettered standards at the same (77°F) temperature. The method has an accuracy of ± 5 percent.

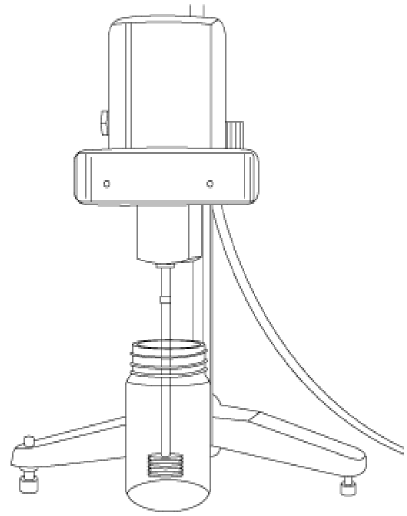


Figure 10/I.A7—Brookfield Viscometer.

2) Brookfield Viscosity—Equipment for this test includes Brookfield Model LV and RV viscometers and spindles (see Figure 10/I.A7). The procedure is as follows:
   a) Fill eight ounce wide mouth jar to within one inch of the jar neck.
   b) Adjust the temperature to 77°F (± 0.5°F), being careful to avoid inclusion of foreign material. Adjust the temperature by placing a lid on the jar and placing it in a 77°F constant temperature water bath until 77°F temperature is reached.
3) Thixotropic materials require a different method of measuring viscosity than that used with non-thixotropic materials:
   a) Laminating resins are thixotropic, (i.e., have a false viscosity). This makes it essential that the model of Brookfield, spindle, speed, and time of reading are noted. These must be in the same order to compare viscosities with other tests or resins. Normally, the LVF model, number two spindle at six RPM, is used and run the same way as an unaccelerated resin, except the sample is shaken for 20 seconds before testing, and readings are taken after two minutes.
   b) The thixotropic index (TI) is the ratio of the viscosities at low shear (6 RPM) divided by higher shear (60 RPM).
   c) Gel coat is a thixotropic material. The sample should be shaken prior to testing to determine the rate of recovery. A common procedure would measure the viscosity with the RVF model, number four spindle at two, four, and 20 RPM.
   d) The Thixotropic Index is the ratio of the viscosities of low shear (two or 2.5 RPM) divided by higher shear (20 RPM).
   e) Non-thixotropic materials can be measured at a single speed. A common procedure would measure the viscosity with the LVF model, number three spindle at 30 RPM.
4) Choose the spindle to be used. Remove lid from container and place spindle into sample, being careful to avoid entrapment of air bubbles beneath the spindle.
   a) Attach spindle to viscometer and lower spindle to level mark indicated on spindle.
   b) Start viscometer and set to specified speed for testing. Allow viscometer to run for two minutes. Stop and take reading.
   c) Determine viscosity from Brookfield conversion table.
5) Gel Coat Sag—This is normally checked in one of two ways:
   a) Spraying the gel coat 18 to 20 mils thick onto a glass panel. A sag gauge is then drawn across, leaving gaps. The panel is placed at a 90 degree angle and checked later to see if the gel coat has sagged and filled the gaps.
   b) A piece of one-inch tape is placed on a glass panel and 18 to 20 mils of gel coat are sprayed over the whole panel. The tape is pulled immediately after spraying and the panel is placed at a 90 degree angle. Later, the amount of sag into the one-inch area is noted.
6) Weight per Gallon—Tests are run after gel coat or resin samples have been in a constant temperature bath at 77°F for at least one-half hour.

How to Check Weight per Gallon			
Weigh gallon cup and lid.	Fill cup with resin.	Place lid on cup so that resin comes out small hole in top. Wipe off excess.	Weigh cup and resin. Subtract empty weight from filled weight.

The weight per gallon (see Figure 10/I.A8) equals the weight of the sample in grams divided by 10. For example:

Weight in grams	83.4 grams
Weight per gallon	8.34 pounds per gallon

5. SOURCES OF EQUIPMENT—Normally, lab supplies and equipment are purchased from a company that specializes in laboratory equipment. Such companies are good sources, but if a lab is being set up on a conditional basis, there are other sources of supply that are good to know. For example, many items can be purchased at a local drug store or discount store. Milliliters of catalyst can be measured in syringes that are calibrated in milliliters and which can be purchased in many states. A source that sells medical supplies for infant children can be a source to purchase cylinders or eyedroppers that are graduated in milliliters.

For many supplies, the best reference source is the Yellow Pages. Look under laboratory supplies—or, if seeking specific items, such as paper cups, look under paper cups first.

If a full laboratory is to be installed, obtain the catalogs of the laboratory supply companies.

For local supply sources, check the business telephone directory under Laboratory Supplies.

Major Laboratory Supply Companies

Fisher Scientific
9999 Veterans Memorial Drive
Houston, TX 77038
800-766-7000
281-820-9898
www.fisherscientific.com

Thomas Scientific
99 High Hill Road at I-295
PO Box 99
Swedesboro, NJ 08085-6099
800-345-2103
856-467-2000
www.thomassci.com

VWR Scientific Products
911 Commerce Court
Buffalo Grove, IL 60089
800-932-5000
847-229-0180
www.vwrsp.com

Specialized Equipment

(Not normally found in scientific laboratory houses)

Paul N. Gardner
316 N. E. First St.
Pompano Beach, FL 33060
800-762-2478

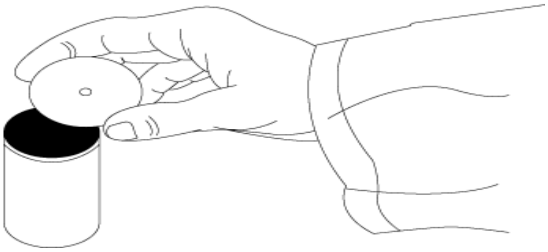


Figure 10/I.A8—Weight per galllon cup.

(This company offers a wide selection of hard-to-find items that are used by the plastics and paint industries, including Barcol impressors.)

Manufacturers of Specialized Equipment

Brookfield Engineering Labs (Viscometers)
240 Cushing St.
Stoughton, MA 02072
800-628-8139

Delval Glass (Boil Test Apparatus; Corrosion Tester)
1135 E. 7th Street
Wilmington, DE 19801
800-628-3641

Instron Corporation (Physical Testing Equipment)
100 Royall St.
Canton, MA 02021
800-564-8378

Davis Inotek (Sunshine Gel Meters)
1810 Grant Ave.
Philadelphia, PA 19115
803-343-1199

National and International Standards

American National Standards Institute (ANSI) Headquarters
1819 L Street NW
Washington, DC 20036
202-293-8020
www.ansi.com

American Society for Quality Control (ASQC)
600 N. Plankinton Avenue
Milwaukee, WI 53203
800-248-1946

Test Procedures

American Society of Testing and Materials (ASTM)
1828 L Street NW
Washington, DC 20036
202-223-8505

APPENDIX B: Polyester Resin Bulk Storage

Part Ten, Chapter II

In This Chapter

1. INTRODUCTION—This section covers general information for those who are considering the installation of storage tanks for unsaturated polyester resins. More detailed information should be acquired from equipment suppliers and tank fabricators.

Polyester resins can be safely and economically stored and handled in bulk with properly designed equipment.

Resin temperature control is especially important because polyesters are temperature sensitive and exposure to elevated temperature conditions drastically shortens their life. Polyester resins stored at low temperatures become very thick. This makes them very difficult or impractical to handle, as well as slowing down gel and cure times.

Ideally, the storage temperature is 72 to 78°F, and should not exceed 85°F. The expected storage life at ideal temperatures is about three months but will vary depending upon the resin. The usage life is cut in half for every 20°F over 73°F.

Storage tanks should be inspected frequently, particularly in warm summer weather, because styrene can polymerize on the tops and sides of the tanks, forming stalactites that sometimes break off and contaminate the resin. The vent line should be inspected before every bulk delivery to insure it is clear. A cleaning of the tank once per year is considered normal.

Agitation, or a recirculation system, is necessary for bulk storage of polyesters, particularly thixotropic polyesters, due to the settling or flotation of certain components.

2. TOTE TANKS—In a review of packaging alternatives, shipping/handling, and recycling and waste disposal, there are options that exhibit both advantages and disadvantages. While tote tanks, both stainless steel and disposable (cage exterior with polyethylene bladder), offer certain conveniences in material handling and in addressing concerns regarding container disposal, they do not allow practical agitation.

In the case of the plastic bladder disposable tote, the head opening does not accommodate the normal drum agitator assembly. Also, the use of plastic totes is not permitted by NFPA, whose standards are incorporated by reference by OSHA.

Modified mixers such as butterfly blades or chains are inadequate to agitate the entire content of the tote. Regular drum agitators are also inadequate to mix the entire content of the tote tank. In order to perform any useful mixing, the agitator must be operated at an adequate speed and the blade must extend sufficiently across the container.

As a polyester ages, some stratification may develop. This separation must be reincorporated to enable proper performance of the material and to prevent application difficulties.

Following the recommended procedure of five to 10 minutes mixing before each shift will accomplish reincorporation of any stratified components.

It is important to keep in mind potential mixing difficulties with tote tanks, and, as much as possible, to guard against problems generated by containers not favorable to content mixing.

It is also important to thoroughly inspect tote tank contents prior to use in order to avoid problems associated with such containers and with stratification.

Under normal aging, storage, and transporting conditions—except long, vibration-intense hauls—stratification will not occur before two weeks of age. This is not an endorsement of the use of product that is less than two weeks old without agitation; rather, it is intended to encourage the use of product before age creates the condition.

3. STORAGE TANKS—The storage tank may be either vertical or horizontal. If vertical, less surface area of the resin will be exposed to the atmosphere; therefore, there is less opportunity for evaporation and styrene buildup. In addition, less floor area is required and agitation cost is minimized. The bottom of vertical tanks should be dished or coned. Horizontal tanks should be sloped to allow complete drainage of the vessel. A vertical tank requires a higher enclosure if installed inside a heated structure. A clean-out port should be provided in the top as well as near the bottom of either type of tank.

Storage tanks may be located outside any building enclosure. If located outside, heating and/or cooling coils and insulation will be required for the tank. Transfer lines should be maintained at a constant temperature (72 to 74°F) by means of jacketed or self-limiting heat-traced pipe.

Underground storage of polyester resins is not recommended because the resin must be maintained at 70°F minimum temperature, which is higher than year-round ground temperature. Resin viscosity increases rapidly with a decrease in temperature.

APPENDIX B: Polyester Resin Bulk Storage

In addition, underground tank inspection and cleaning is more difficult, and monitoring the tank for leakage is also more difficult.

4. CONSTRUCTION—As a general rule, 304 grade stainless steel and phenolic-lined or epoxy-lined carbon steel tanks are recommended for promoted resins. Some coatings used for tank lining contain TBC inhibitor to prevent formation of polystyrene gel particles. For information concerning coatings and techniques used for lining of tanks, refer to the coatings manufacturer.

Some users report that DCPD-based resins have poorer quality life in stainless steel than in lined carbon steel. Stainless steel or lined carbon steel is suitable for orthophthalic- and isophthalic-based polyesters. In a tank's service life, cleaning will be required. Usually, when hot, caustic cleaning solutions or intense mechanical abrasion must be used; all lining must be replaced as well.

Do not use copper or brass fittings because these metals or alloys react with polyester resin and create compounds that may affect the cure, color or shelf life characteristics of a polyester. Cast iron or stainless steel fittings are satisfactory if designed to withstand normal pumping pressure.

It is desirable to have the tank vent attached to an air dryer or desiccator to remove all moisture from the air that goes into the tank. Excessive moisture may affect the resin and cause rusting in the system. A flame arrestor must be used on all vents. Check local codes for installation approval. Caution should be taken that the flame arrestor does not become blocked with polystyrene buildup. (The flame arrestor should be inspected before each bulk delivery to insure it is free of buildup.)

A thermometer should be installed so that the temperature of the resin can be observed at all times. The resin should not be allowed to rise above 85°F for an extended period of time. Experience has shown that in most locations— except in some areas of the southern United States—the temperature of a storage tank of resin which is enclosed in a well-ventilated shelter will not rise above 85°F. It is important that the shelter be provided with good ventilation 24 hours a day during the hot summer months, and that the roof, in particular, be well-insulated, or that suitable air conditioning is provided. Cooling jackets or coils could be needed for exterior tanks.

In some cases, it may be advisable to install a water sprinkler over the storage tank, especially if the tank is exposed to direct sunlight or where necessary to meet insurance or building code regulations.

5. SIZE—The storage tank should be approximately one and 1/2 times the maximum size of the shipment to be stored. A normal tank wagon shipment weighs from 40,000 to 45,000 pounds. Depending on the weight per gallon, a minimum tank size would be approximately 6,000 gallons.

6. INERT GAS ATMOSPHERE—If an inert gas atmosphere is used, make sure the inert gas does not bubble through the resin since this will reduce the stability of the resin.

7. LEVEL INDICATORS—Arrangements should be made for monitoring the level of liquid in the tank. Usually a daily visual check or stick measurement is adequate. Other methods such as radar gauges or differential pressure (DP) cells may be used, but must be considered in the tank construction.

8. STORAGE TANK CLEANING—To clean a polyester resin storage tank, a detergent wash, followed by a water rinse, followed by a solvent wash, is recommended. A cleaning compound supplier should be contacted for recommendations and suggestions for a cleaning compound and a cleaning spray head. *NOTE: Always use appropriate respirators while servicing the tanks; specific OSHA requirements should be adhered to when entering a confined space. All material, including cleaning liquids, must be disposed of in accordance with local and federal regulations.*

9. PUMP AND AGITATION—An air diaphragm pump is recommended if resin is to be recirculated. It can be installed in such a way that it operates only when the pressure in the system is relieved. If a gear pump is used in a recirculating system, it may heat the resin, causing changes in cure and viscosity. Gear or diaphragm pumps can be used as auxiliary equipment for unloading the resin, for intermittent delivery to a factory work area, or for periodic recirculation of the resin.

A gear or sliding valve pump operated at 350 to 450 RPM with an external relief device may be used. The size of the pump will depend upon the specific gravity and viscosity of the resin involved, the quantity required, and the length of transfer line involved. Pumps should be all iron, or suitable polymer construction. No copper bearing alloys should be used.

The tank must be equipped with some means of agitation if it is to be used for storing thixotropic resins which contain additives, such as a silica or an organic thickening agent. Silica tends to settle to the bottom because of its high specific gravity and the organic materials tend to migrate to the top.

A fully enclosed, explosion-proof, electrically-driven agitator mounted at the top of the storage tank is an ideal arrangement.

10. VALVES, PIPES, AND FITTINGS—When an epoxy- or phenolic-lined carbon steel storage tank is required, all pipe fittings and valves should be stainless steel. When a carbon steel tank is acceptable, iron valves and carbon steel pipe and fittings are satisfactory. Transfer lines to and from the storage tank should be sloped for drainage, and vented to prevent siphoning. Drain valves should be installed whereever drain problems may be encountered. Stems of valves should point up, wherever possible, to prevent locking up due to possible resin gelation.

Outlets and pipes should measure at least two inches in diameter (preferably three inches). Certain resins that are low in viscosity (200 to 500 cps), such as those used in the boat manufacturing industry, can be circulated or pumped through smaller diameter pipe. However, CCP recommends that no less than one and 1/2 inches in diameter be used. Temperature must be considered if using ceiling mount pipe.

The hookup from a plant work area to the storage tank will vary with the material being used, and the product being manufactured. When a spray gun is used, a recirculating system may be desirable. Do not use a configuration that creates a dead end, where resin remains static and cannot be returned to the storage tank. Resin that is not recirculated or used may eventually gel and plug the lines.

11. LOCATION—The location of storage tanks with respect to a work area depends on several factors. The most important factor will be local fire hazard codes and insurance recommendations. In general, it is recommended that tanks be located outside or enclosed within a suitable fire wall. In some cases, tanks can be installed in a separate building, if the building is located an acceptable distance from the manufacturing area.

12. LOSS PREVENTION GUIDELINES—Some loss prevention items that should be considered when planning bulk storage facilities are:

A. Compliance with all Federal, State, and Local codes (contact local Fire Marshall and insurance company for specific information).

B. The tank should be equipped with a pressure and vacuum relief valve to allow for normal tank breathing while the tank is being filled and emptied.

C. A flame arrestor must be installed with the tank pressure-vacuum relief valve.

D. Copper bearing alloys should not come into contact with resin. Exposure to these materials will inhibit resin cure.

E. All motors and electrical equipment, including instrumentation and lighting, should be suitable for flammable liquid storage installation. Most polyester resins have a flash point of about 88°F.

F. Sufficient grounding should be provided for the tank wagon or tank car, storage tank, pump, motor, etc., to prevent static electricity buildup and a potential explosion hazard.

G. No smoking or open flame should be permitted in the area of the resin storage facility.

H. The storage tank should be contained as required by regulations.

I. Storage tanks should be equipped with overflow alarms.

13. REFERENCE MATERIAL—Excellent information on storage may be obtained from the National Fire Protection Association (NFPA).

Specific references include:

- NFPA #30—Standards of the NFPA for Storage, Handling, and Use of Flammable Liquids, as recommended by the National Fire Protection Association.
- NFPA #70—National Electrical Code
- NFPA #77—Static Electricity as adapted by the National Fire Protection Association.

APPENDIX C: Definitions of Terms

— A —

ACCELERATOR—Additive that reduces gel and cure time of thermosetting plastics such as polyester gel coat and resin. Also called promoter or activator.

ACETONE—In the context of FRP, primarily useful as a cleaning solvent for removal of uncured resin from applicator equipment and clothing. VERY FLAMMABLE LIQUID.

ACI—Air Catalyst Integrator (ACI) valve, which is mounted on Binks spray guns. Functions as a point where catalyst and air are introduced, internally mixed, and atomized in preparation for external mixing with the resin or gel coat in a spray pattern.

ADHEREND—Any object or substance that is bonded to another with adhesive material.

ADHESIVE—Material that unites two surfaces.

ADHESIVE FAILURE—Failure in an adhesive joint that occurs between the adhesive material and the adherend; contrast with Cohesive Failure.

ADDITIVE—Substance added to resin mix to impart special performance qualities, such as ultraviolet absorbers, and flame retarding materials (waxes, accelerators, etc.).

AIR DRY—To cure at room temperature with addition of catalyst but without assistance of heat and pressure.

AIR-INHIBITED RESIN—Resin which cures with a tacky surface (air inhibits its surface cure).

ALLIGATORING—Wrinkling of gel coat film resembling alligator hide; caused by poor cure at time of contact with styrene from a subsequent or preceding coat.

ANTIMONY TRIOXIDE—Additive used to provide special flammability characteristics to a polyester.

ARCING—Spray method which should normally be avoided as it consists of directing spray passes by gun rotation at the wrist (arcing), as opposed to conventional stroke from shoulder, keeping fan pattern perpendicular to mold.

AREAL WEIGHT—Weight of a fiber reinforcement per unit area (width times length) of tape or fabric.

ATOMS—Smallest possible unit of an element; may combine with another atom or atoms to form a compound.

AUTOCLAVE MOLDING—Molding technique in which an entire composite assembly is placed in an autoclave (or closed vessel with pressure/heat capability) at 50 to 100 psi pressure to consolidate the laminate by removing entrapped air and volatiles.

AUTO-IGNITION TEMPERATURE—Lowest temperature required to initiate or cause self sustained combustion in absence of a spark or a flame.

AUTOMATIC MOLD—Mold (for injection or compression molding) that cycles repeatedly through injection phase without human assistance.

— B —

BAG MOLDING—Technique in which composite material is placed in rigid mold and covered with flexible bag. Pressure is applied by vacuum, autoclave, press, or by inflating the bag.

BALANCED—Laminate design term used with aligned-fiber composites to indicate that each ply oriented at plus theta degrees is matched by a ply at minus theta degrees. When plus theta is zero degrees, minus theta is 90 degrees. See related Symmetric. Laminate can be balanced and not be symmetric.

BARCOL HARDNESS—Degree of material's hardness obtained by measuring resistance to penetration by a sharp, steel point. This hardness corresponds roughly to the degree of cure in a gel coat or laminate.

BARCOL IMPRESSOR—Instrument invented by Walter Colman during World War II to measure hardness of soft metals; manufactured by Barber-Colman Company. Two types are commonly used in the FRP industry. Model 934 is used to check ultimate cure; Model 935 is used for initial readings prior to ultimate cure.

BATCH (OR LOT)—Identity for all material produced during one operation possessing identical characteristics throughout.

BENZOYL PEROXIDE (BPO)—Catalyst used in conjunction with aniline accelerators or where heat is used as an accelerator.

BI-DIRECTIONAL—Arrangement of reinforcing fiber strands in which half the strands are laid at right angles to the other half; a directional pattern that provides maximum product strength to those two directions.

BINDER—Bonding resin applied to glass fibers to hold them in position in a broadgoods textile structure. During lamination, this resin is dissolved by the styrene in polyester resin, and, if unsaturated, can become part of the final polymer network.

BINDERLESS CHOPPED STRAND MAT—Textile material consisting of short glass fibers held together with polymer fiber cross-stitch; resembles chopped strand mat without the binder. Also called Stitched Chopped Strand Mat.

BLEEDER CLOTH—Layer of woven or nonwoven material (not part of composite) that allows excess gas and resin to escape during molding process.

BLEEDING—Result of softening of backside of gel coat (typically by laminating resin, or post applied gel coat) which causes pigments (color) to reflow.

BLEED OUT—Excess liquid resin appearing at the surface, primarily occurring during filament winding or from an RTM mold tube.

BOND STRENGTH—Stress required (as measured by load/ bond area) to separate a layer of material from another material to which it is bonded. Also, amount of adhesion between bonded surfaces.

BRACE—Integral structural element used to stiffen or strengthen mold skin.

BREAKOUT—Separation or breakage of fibers when edges of a composite part are drilled or cut.

BRIDGING—Condition that occurs when textile or sheet material does not conform to inside edge or radius on mold or laminate surface.

BUCKLING—Failure mode usually characterized by fiber deflection rather than breaking.

BULK MOLDING COMPOUND (BMC)—Premixed blend of thermosetting resin, reinforcements, catalysts and fillers for use in closed molding process. Similar to sheet molding compound (SMC), but mechanical qualities are not as good and it is less expensive.

— C —

CARBON (OR GRAPHITE) FIBER—Reinforcing fiber known for its light weight, high strength, and high stiffness.

CARBOXYL—Chemical group characteristic of organic acids, which are incorporated into the polyester reaction process.

CAST POLYMER—Non-reinforced composite (resin used without reinforcing fibers). Combines polymers, fillers and additives as composites to meet specific applications requirements.

CATALYST—In scientific sense, substance that promotes or controls curing of compound without being consumed in the reaction (initiator). Within the composites industry, free radical initiators such as MEKP are often referred to as 'catalysts.' Such usage is scientifically inaccurate since initiator is consumed during usage.

CATALYST INJECTION—Used with spray equipment to catalyze polyester at spray gun, therefore eliminating need to clean system within gel time of polyester. Internal mix guns require a solvent flush for cleaning gun head.

CATALYST (PEROXIDE)—In FRP terms, substance added to resin or gel coat in controlled quantities to make it gel and cure. Catalyst is reduced by accelerator, creating free radicals, which in turn initiate polymerization.

CAVITY—Space between matched molds (pressure molds) in which laminate is formed. Also a term for a female mold.

CENTIPOISE (CPS)—Unit of measure used to designate a fluid's viscosity. At 70°F, water is one cps; peanut butter is 250,000 cps.

CHALKING—Dry, powder-like appearance or deposit on exposed gel coat surface.

CHARGE PATTERN—Ply schedule used in parts made from sheet molding (SMC); pre-weighed number of SMC plies cut from SMC sheet and oriented to fill mold cavity when placed in mold and compressed.

CHOPPED STRAND—Uniform lengths of fibers formed by cutting continuous strand yarn or roving, usually from 1/32 to two inches long. Lengths up to 1/8 inch are called milled fibers.

CHOPPED STRAND MAT (CSM)—Uniform lengths of fibers held together by binder and added to increase composite part glass skin thickness. Relatively inexpensive, generally used with other glass mats.

CLOSED MOLDING—Fabrication process in which composite part is produced in a mold cavity formed by joining of two or more tool pieces.

CLOTH—Fine weave of woven fiberglass.

COBALT—Used as accelerator for methyl ethyl ketone peroxide catalyzed polyesters.

COEFFICIENT OF THERMAL EXPANSION (CTE)—Material's fractional change in dimension for given unit change of temperature.

COHESION—Tendency of single substance to adhere to itself. Also, force holding single substance together.

COHESIVE FAILURE—Failure of adhesive joint that occurs either within adhesive material or within one or both adherends.

COMPOSITE—Material that combines fiber and binding matrix to maximize specific performance properties. Neither element merges completely with the other.

COMPRESSION MOLD—Mold that is open when material is introduced and that shapes material by heat and by the pressure of closing.

COMPRESSION MOLDING—See 'Closed Molding.'

COMPRESSIVE STRENGTH—Resistance to crushing or buckling force; maximum compressive load specimen sustains divided by its original cross-sectional area.

CONDENSATION POLYMERIZATION—Polymerization reaction in which simple by-products (e.g., water) are formed.

CONSOLIDATION—Processing step that compresses fiber and matrix to remove excess resin, reduce voids and achieve particular density.

CONTACT MOLDING—Open-mold process that includes spraying gel coat, followed by hand layup or sprayup with glass and resin. Also called open molding.

CONTAMINANT—Impurity or foreign substance that affects one or more properties of composite material.

APPENDIX C: Definitions of Terms

CONTINUOUS FILAMENT MAT (CFM)—Textile material comprising continuous fibers, typically glass, that are swirled randomly in a construction with more loft than chopped strand mat for the same areal weight.

CONTINUOUS FILAMENT STRAND—Individual fiber with small diameter, flexibility and indefinite length.

CONTINUOUS LAMINATING—Process for forming panels and sheeting in which fabric or mat is passed through resin dip, brought together between cellophane covering sheets, and passed through heating zone for cure. Squeeze rollers control thickness and resin content as various plies are brought together.

CONTINUOUS ROVING—Parallel filaments coated with sizing, gathered together into single or multiple strands and wound into cylindrical package. May be used to provide continuous reinforcement in woven roving, filament winding, pultrusion, prepregs, or high-strength molding compounds. (Also see 'Chopped Strand.')

COPOLYMER—Large chemical chain composed of two or more dissimilar groups.

CORD, REINFORCING—Loosely twisted cord made up from rovings and designed for incorporation in moldings where edge reinforcement and high strength ribs are necessary.

CORE—(1) Central component of a sandwich construction to which inner and outer skins are attached; common core materials include foam, honeycomb, paper and wood. (2) Channel in mold for circulation of heat-transfer media. (3) Part of complex mold tool that molds undercut parts, also called core pin.

CORE CRUSH—Compression damage to core.

CORE ORIENTATION—On honeycomb core, used to line up ribbon direction, thickness of cell depth, cell size, and transverse direction.

CORNER—Geometric feature characterized as point where three edges come together, as in a box corner. Can be either inside corner or outside corner.

COSMETIC STABILITY—Capability of substance or part to maintain appearance with respect to surface smoothness, color, gloss or other visual appearance characteristics.

CRAZING—Cracking of the resin due to internal stress.

CREEL—Device used to hold required number of roving spools or other supply packages of reinforcement in desired position for unwinding.

CREEP—Over time, dimensional change in material under physical load (beyond initial elastic deformation).

CROSS-LAMINATED—Laminated so some layers are oriented at right angles to remaining layers with respect to grain or strongest direction in tension.

CROSS-LINKING—Process of bridging two polymer chains, which converts liquid to thermoset solid.

CRYSTALLINITY—Quality of molecular structure in which atoms are arranged in orderly, three-dimensional pattern.

CURE—Polymerization or irreversible transformation from liquid to solid state with maximum physical properties, including hardness.

CURE TEMPERATURE—Temperature at which material attains final cure.

CURE TIME—Time required for liquid resin to reach majority of polymerized state after catalyst has been added.

CURING AGENT—Catalytic or reactive agent that initiates polymerization when added to resin; also called 'hardener.'

— D —

DAMAGE TOLERANCE—Measure of ability of structures to retain load-carrying ability after experiencing damage (e.g., ballistic impact).

DELAMINATE—Separation of layers due to failure of adhesion or cohesion of one component to others. Also includes separation of layers of fabric from core structure. May be associated with bridging, drilling, and trimming.

DELAMINATION—Laminate defect that occurs due to mechanical or thermal stress and is characterized by separation between laminae.

DEMOLD—To remove a part from a tool, or a tool from an intermediate model.

DENSITY—Weight per unit of volume, usually expressed as pounds per cubic foot.

DESIGN ALLOWABLE—Limiting value for material property that can be used to design structural or mechanical system to specified level of success with 95 percent statistical confidence.

DIALLYL PHTHALATE (DAP)—In reinforced plastics, high-boiling monomer which will polymerize with heat and catalyst into clear, hard polymer.

DIBUTYL PHTHALATE—Lubricant for spray equipment.

DIELECTRIC—Nonconductor of electricity; ability of material to resist flow of an electrical current.

DIELECTRIC STRENGTH—Voltage required to cause electrical arc to penetrate insulating material.

DIETHYLANILINE (DEA)—Accelerator used in conjunction with BPO catalyst, or as co-promoter for cobalt/MEKP systems.

DILUENT—Diluting (reducing or thinning) agent.

DIMENSIONAL STABILITY—Capability of substance or part to maintain its shape when subjected to varying forces, moments, degrees of temperature and moisture, or other stress.

DIMETHYLANILINE (DMA)—Accelerator used in conjunction with BPO catalyst; more effective than DEA.

DIMPLES—Small sunken dots in gel coat surface, generally caused by foreign particle, air void, or catalyst droplets in gel coat or laminate.

DISPERSION—Homogeneous mixture of suspended solid particles in liquid medium.

DISTORTION—Wavy gel coat surface reflection often found in conjunction with print-through. Commonly caused by problem in laminating system.

DOUBLER—Extra layers of reinforcement for added stiffness or strength where fasteners or other abrupt load transfers occur.

DRAFT ANGLE—Mold or mandrel's taper or angle for ease of part removal (minimum of 3 degrees is recommended).

DRAPE—Ability of fabric (or prepreg) to conform to shape of contoured surface

DRAIN OUT—Leaking, sagging and puddling of laminating resin from reinforcement.

DRY SPOT—Laminate defect that occurs during molding process and is characterized by dry, unwet fibers that have never been encapsulated by matrix material.

DUPLICATION MOLD—A mold made by casting over or duplicating another article.

— E —

EDGE—Geometric feature characterized as line formed where two panels on different planes come together. When angle between two panels is between zero and 180 degrees, edge is inside. When angle is between 180 and 360 degrees, edge is outside.

E-GLASS—Electrical glass; refers to borosilicate glass fibers most often used in conventional polymer matrix composites.

ELASTICITY—Capacity of materials to recover original size and shape after deformation.

ELASTIC LIMIT—Greatest stress material is capable of sustaining without permanent strain remaining after complete release of stress.

ELASTOMER—Material that substantially recovers original shape and size at room temperature after removal of deforming force.

ELONGATION—Increase in length of section under tension when expressed as percentage difference between original length and length at moment of rupture.

ENAMEL—Gel coat or surface coat which cures tack free.

ENCAPSULATING—Enclosing article in closed envelope of plastics) by immersion. Milled fibers or short chopped strands are often poured with catalyzed resin into open molds for casting electrical components.

END—Strand of roving consisting of given number of filaments is considered an end before twisting.

END COUNT—Exact number of strands contained in roving.

EXOTHERMIC HEAT—Internally developed heat accompanying chemical reaction, (e.g., curing).

EXTENDERS—Low-cost materials used to dilute or extend higher-cost resins without excessive reduction in properties.

— F —

FABRIC, NONWOVEN—Material formed from fibers or yarns without interlacing, (e.g., stitched nonwoven broad goods).

FABRIC, WOVEN—Material constructed of interlaced yarns, fibers, or filaments .

FABRICATION—Process of making composite part or tool.

FATIGUE—Failure of material's mechanical properties caused by repeated stress over time.

FATIGUE STRENGTH—Maximum cyclical stress withstood for given number of cycles before material fails.

FADING—Loss of color in gel coat.

FEEDEYE—Mechanism on filament winding machine through which roving is dispensed onto mandrel.

FELT—Fibrous material made up of interlocking fibers by mechanical or chemical action, pressure or heat. Felts may be made of cotton, glass or other fibers.

FEMALE—Archaic term formerly used to describe concave surface or inside edge or feature.

FIBER—Individual rod of sufficiently small diameter to be flexible, having known or approximate limit of length.

FIBER ARCHITECTURE—Arrangement of fibers and fiber bundles in textile construction.

FIBER BLOOMING—Fiber and resin are eroded by weathering or sandpaper at different rates. Resins erode before fiber. As a result, fiber rich surface, when sanded, often has fibers protruding; called fiber blooming.

FIBER CONTENT—Amount of fiber in composite expressed as ratio to the matrix by weight.

FIBER ORIENTATION—Direction of fiber alignment in nonwoven or mat laminate; most fibers are placed in same direction to afford higher strength in that direction.

FIBER PRINT—Cosmetic defect, visible on exterior gel coat surface that resembles fiber bundle and reflects architecture of glass reinforcement bundle at or near part surface.

FIBER REINFORCED PLASTICS (FRP)—General term for composite material or part that consists of plastic matrix containing reinforcing fibers such as glass or carbon having greater strength or stiffness than plastic. FRP is most often used to denote glass fiber-reinforced plastics. 'Advanced composite' usually indicates high-performance aramid or carbon fiber-reinforced plastics.

FIBERGLASS—Fibers similar to wool or cotton fibers, but made from glass; sometimes call fibrous glass. Glass fiber forms include cloth, yarn, mat, milled fibers, chopped strands, roving, woven roving.

FILAMENT—Single, thread-like fiber or number of these fibers drawn together. Variety of fiber characterized by extreme length, which permits its use in yarn with little or no twist and usually without spinning operation required for fibers.

FILAMENT WINDING—Process for production of high-strength, light-weight products in which tape, roving or single strands are fed from creel through bath of resin (or fed dry using pre-impregnated roving) and wound on suitably designed mandrel. Wound mandrel can be cured at room temperature or in oven.

FILLERS—Relatively inert organic or inorganic materials which are added to resins or gel coats for special flow characteristics, to extend volume, and to lower cost of article being produced.

FINISH—Surface treatment applied to fibers or filaments after they are fabricated into strands, yarn or woven fabrics to allow resins to flow freely around and adhere to them.

FIRE POINT—Lowest temperature at which liquid in open container will give off enough vapors to continue to burn once ignited. Fire point generally is only slightly higher than flash point.

FISH EYES—Circular separation in gel coat film generally caused by contamination such as silicone, oil, dust, water, freshly waxed mold, or low gel coat viscosity.

FLASH POINT—Lowest temperature at which substance emits enough vapors to form flammable or ignitable mixture with air near the surface of the substance being tested.

FLEXURAL MODULUS—Ratio, within elastic limit, of applied stress in test sample in flexure to corresponding strain in outermost fibers of sample.

FLEXURAL STRENGTH—Strength of material (in bending) expressed as stress of bent test sample at instant of failure; usually expressed in force per unit area.

FLOODING—High delivery rate from spray gun; in pigmented systems, difference in color between surface and bulk of film.

FLOW METER—Instrument designed to measure flow of liquid.

FRACTURE—Rupture of surface of laminate due to external or internal forces; may or may not result in complete separation.

FRAMING—Structure that supports mold skin and its bracing.

FREE RADICALS—Highly reactive molecular fragments capable of initiating chemical reactions, such as polymerization of polyester resins.

FRIABLE—Term used to describe material that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure.

FRP—Fiber Reinforced Polymers; with evolution of new fibrous materials, GRP (or GRFP) becomes Glass Reinforced Polymers term.

FUMED SILICA (Aerosil, Cabosil)—Thickening agent used in polyesters to increase flow or sag resistance qualities.

— G —

GEL—Partial cure stage in plastics resins of a viscous, jelly-like state where liquid material starts to transform into solid.

GEL COAT—Surface coat, either colored or clear, providing cosmetic enhancement and protection for the laminate.

GEL TIME—Length of time that catalyzed polyester remains workable after hardener is added.

GELATION—Transition of liquid to soft solid.

GENERATION—Term used to describe single step in progression from concept to master mold to production mold when molding composite parts with multiple molds from same pattern.

GLASS TRANSITION—Reversible change in amorphous polymer between viscous or rubbery condition and hard, relatively brittle one.

GLASS TRANSITION TEMPERATURE (Tg)—Approximate temperature above which increased molecular mobility causes a material to become rubbery rather than brittle. The measure value of Tg can vary, depending on the test method. (A widely accepted method is Differential Scanning Calorimeter—DSC.)

— H —

HAND LAYUP—Laminating by 'hand' as opposed to using spray equipment. Usually requires mat and fabric reinforcements in sheet form.

HAP—Acronym for Hazardous Air Pollutants. Over 180 chemicals identified by Congress in 1990 Clean Air Act, Section 112. In this law, Congress mandated EPA to control emissions of these chemicals. EPA has endeavored to do this through series of MACT standards (see 'MACT').

HARDENER—Substance that reacts with resin to promote or control curing action.

HEAT—Term used colloquially to indicate any temperature above ambient (room) temperature, to which part or material is or will be subjected.

HEAT-CONVERTIBLE RESIN—Thermosetting resin convertible by heat to an infusible and insoluble mass.

HEAT-DISTORTION TEMPERATURE (HDT)—Temperature at which test bar deflects certain amount under specified load (e.g., temperature at which material softens).

HEAT-PRESSURE LAMINATES—Laminates molded and cured at pressures not lower than 1000 psi.

HELICAL—Ply laid onto mandrel at an angle, often 45 degree angle.

HERMETIC—Completely sealed, air-tight.

HONEYCOMB—Manufactured product of sheet metal or resin-impregnated sheet (paper, fibrous glass, etc.) that has been formed into hexagonal shaped cells. Used as core material for sandwich construction.

HOOP—Ply laid onto mandrel at 90 degree angle.

HOOP STRESS—Circumferential stress in cylindrically shaped part as result of internal or external pressure.

HOT POT—Catalyst is mixed with gel coat or resin in material container prior to spraying, as opposed to internal or external gun mixing.

HYBRID COMPOSITE—Composite with two or more types of reinforcing fibers. Also refers to composite prepared from a polymer which uses more than one type of chemistry, such as XYCON® polyester/polyurethane hybrid material.

HYBRID RESIN—Resin with two or more types of chemistries combined.

HYDROPHOBIC—Moisture resistant capability, moisture repelling.

HYGROSCOPIC—Moisture absorbing capability.

— I —

IMPREGNATE—Saturation of reinforcement with a resin.

IMPREGNATED FABRIC—See 'Prepreg.'

INCLUSION—Physical and mechanical discontinuity occurring within material or part.

INHIBITOR—A substance designed to slow down or prevent chemical reaction; chemical additive that slows or delays cure cycle.

INJECTION MOLDING—Method of forming plastic to desired shape by forcibly injecting polymer into a mold.

INTEGRAL HEATING—System in which heating elements are built into a tool, forming part of the tool and usually eliminating need for oven or autoclave as heat source.

INTERFACE—Surface between two materials in glass fibers, (e.g., area at which glass and sizing meet). In laminate, area at which reinforcement and laminating resin meet.

INTERLAMINAR—Existing or occurring between two or more adjacent laminae.

INTERLAMINAR SHEAR—Shearing force that produces displacement between two laminae along plane of their interface.

IN SITU—In original position. In filament winding, used to indicate mandrel that remains in place after winding, as opposed to mandrel that is removed after winding.

ISOTROPIC—Arrangement of reinforcing materials in random manner, resulting in equal strength in all directions.

— J —

JACKSTRAWING—Prominence of fiberglass pattern having turned white in the laminate because glass has separated from resin due to excessive exothermic heat; usually associated with thick, resin rich laminates. Cosmetic problem only.

— K —

KEVLAR™—Strong, lightweight aramid fiber trademarked by Dupont; used as reinforcement fiber.

— L —

LAMINA—One layer of laminate; can be chopped fiber reinforced plastic layer, textile reinforced plastic layer, or core material, etc. Plural is laminae.

LAMINATE (noun)—Panel that consists of multiple laminae that are permanently bonded together.

LAMINATE (verb)—Action of manufacturing laminate (noun) by arranging one or more laminae. In FRP, each lamina usually consists of a fibrous reinforcement and a resinous matrix material.

LAMINATED PLASTICS—Material consisting of superimposed layers of synthetic materials that have been bonded together, usually by means of heat and pressure, to form single piece.

LAMINATION—Laying on of layers of reinforcing materials and resin, much like buildup of plywood. Several layers of material bonded together.

LAYUP—Placing reinforcing material onto mold and applying resin to it; can be done by hand or by using sprayup equipment. Layup is sometimes used as a term for the work piece itself.

LOW-PRESSURE LAMINATES—Laminates molded and cured in range of pressures from 400 psi down to and including pressure obtained by mere contact of plies.

LOW PROFILE—Resin compounds formulated for low, zero, or negative shrinkage during molding.

— M —

MACROSCOPIC—Large enough to be visible at magnification of 60x or less.

MACT—Acronym for Maximum Achievable Control Technology. Standards established by the EPA in response to the 1990 Clean Air Act, Section 112. These standards set forth regulations for reduced emissions of Hazardous Air Pollutants (see 'HAP').

APPENDIX C: Definitions of Terms

MALE—Archaic term formerly used to describe convex surface or outside edge or feature.

MANDREL—Elongated mold around which resin-impregnated fiber, tape or filaments are wound to form structural shapes or tubes.

MASS—Quantity of matter contained in a specific body. In reference to polyesters, mass is measured in terms of weight and/or volume.

MASTER MODEL—General term for full-scale representation of part design. Incorporates all geometry for one of the part surfaces. (See also 'Pattern' and 'Plug.')

MASTER MOLD—General term for durable, robust full-scale representation of part design. Used to produce multiple copies of production mold.

MAT—Fibrous reinforcing material composed of chopped filaments (for chopped-strand mat) or swirled filaments (for continuous-strand mat) with binder applied to maintain form; available in blankets of various widths, weights, thicknesses and lengths.

MATCHED-METAL MOLDING/MATCHED-DIE MOLDING—Method of closed molding in which reinforced plastics are molded between two close-fitting metal molds mounted in hydraulic press. Generally considered most economical mass production method for manufacturing FRP parts in large volumes.

MATRIX—Material in which fiber reinforcements of composite system is imbedded. Thermoplastic and thermoset resin systems can be used, as well as metal and ceramic.

MEK PEROXIDE (MEKP)—Abbreviation for methyl ethyl ketone peroxide; free radical source commonly used as initiator for polyesters in FRP industry.

MEK (SOLVENT)—Abbreviation for methyl ethyl ketone; colorless flammable liquid commonly used in spray gun clean up procedures.

MICRO CRACKING—Cracks formed in composites when thermal stresses locally exceed strength of matrix.

MICROSCOPIC—Small enough to require magnification much greater than 10x to be visible.

MIL—Unit used in measuring film thickness and diameter of fiber strands, glass, wire, etc., (one mil = .001 inch).

MILLED FIBERS—Carbon or glass used for making fiber-filled putty or BMC strands hammer-milled into short fiber lengths of 1/32 inch, 1/16 inch, 1/8 inch and 1/4 inch.

MODULUS OF ELASTICITY—Material property that describes relationship between tension, compression or shear forces, and deflection experienced by material. Known as Young's Modulus for isotropic materials in tension. Modulus is independent of specimen geometry; therefore, it is a material property.

MOISTURE ABSORPTION—Pick-up of water vapor from air by a material. Relates only to vapor withdrawn from air by a material ; must be distinguished from water absorption, which is gain in weight due to take-up of water by immersion.

MOLD—(1) To shape plastics parts by heat and pressure. (2) Cavity or matrix into/onto which plastics composition is placed and from which it takes its form. Female: Made into. Male: Made onto. (3) Assembly of all parts that function collectively in molding process.

MOLD CLAMPING METHOD—RTM process feature that describes how mold pieces are held together.

MOLD COAT—Coat of resin over bare mold. Used to seal mold and make smooth surface on which to mold parts. Essentially the same as a gel coat.

MOLD OPEN-CLOSE METHOD—RTM process feature for separating mold pieces to allow insertion of dry glass and removal of finished part.

MOLD RELEASE—A substance used on the mold or in the compound to prevent sticking and for ease of part release.

MOLD SKIN—Element of cure tool with hard surface that is polished to high gloss. This surface forms one external face of production part during molding process.

MOLDING—Forming of part by various means, such as contact, pressure, matched die and continuous laminating, into given shape.

MOLECULES—Chemical units composed of one or more atoms.

MONOFILAMENT—Single filament of indefinite length; generally produced by extrusion.

MONOMER—A relatively simple compound capable of polymerization with itself or with a compatible resin. It may also is be used to dissolve or dilute polyester.

— N —

NANOMETER—Abbreviated (nm) and equal to one millimicron or one billionth of meter, used to measure wavelengths of light.

NET SHAPE—Part fabrication resulting in final dimensions that do not require machining or cutting.

NON-DESTRUCTIVE INSPECTION (NDI)—Determining material or part characteristics without permanently altering test subject. Nondestructive testing (NDT) and nondestructive evaluation (NDE) widely considered synonymous with NDI.

NPG®—Registered trademark (of Eastman Chemical Company) for neopentyl glycol.

NON-AIR INHIBITED RESIN—Resin, cure of which will not be inhibited or stopped by presence of air, possibly due to surfacing agent added to exclude air from resin surface.

NON-VOLATILE MATERIAL—Material remaining after heating to condition short of decomposition.

— O —

ONE-OFF—Fabrication process in which single part is fabricated.

ORANGE PEEL—Backside of gel coated surface that takes on rough wavy texture of orange peel.

ORIFICE—Opening, generally referred to regarding spray tip size.

ORIGINAL EQUIPMENT MANUFACTURER (OEM)—Companies that design and build products bearing their name.

OUT-GASSING—Release of solvents, volatiles, gasses and moisture from composite parts under vacuum.

— P —

PAN (POLYACRYLONITRILE)—Base material in manufacture of some carbon fibers.

PARALLEL-LAMINATED—Laminated so all layers of material are oriented approximately parallel with respect to the grain or strongest direction in tension. Also called unidirectional. This pattern allows highest loading of reinforcement, but gives maximum strength in only one direction.

PART CONSOLIDATION—Process of composites fabrication in which multiple discrete parts are designed and fabricated together into single part, thus reducing number of fabricated parts and need to join those parts together.

PARTING AGENT—See 'Mold Release.'

PATTERN—General term for master model that is usually constructed from single material or material type. Pattern is generally not durable and suitable for producing only one (or small number) of molds. Sometimes used interchangeably with Plug.

PEEL PLY—Layer of material applied to a layup surface that is removed from the cured laminate prior to bonding operations, in order to leave clean, resin-rich surface ready for bonding.

PEEL STRENGTH—Strength of adhesive bond obtained by stress that is applied 'in a peeling mode.'

PEROXIDES—Category of compounds containing unstable O-O (or O-OH) Group: Oxygen to Oxygen atoms; used as initiators.

PHENOLIC RESIN—Thermosetting resin produced by condensation of aromatic alcohol with aldehyde, particularly phenol with formaldehyde.

PIGMENT—Ingredient used to impart color, as in gel coats.

PIGMENT SEPARATION—Mottled (varied color) appearance of gel coat surface.

PINHOLES—Small air bubbles in gel coat film, few enough to count. Generally larger in size than porosity.

PLASTICS—High molecular weight thermoplastics or thermosetting polymers that can be molded, cast, extruded or laminated into objects; major advantage of plastics is they can deform significantly without rupturing.

PLUG—General term for master model that is usually handcrafted from variety of materials. Plug is generally not durable; suitable for producing only one (or small number) of molds. Sometimes used interchangeably with 'Pattern.'

PLY—Fabric/resin or fiber resin/layer bonded to adjacent layers in composite.

PLY SCHEDULE—Layup of individual plies or layers to build laminate (FRP). Plies may be arranged (scheduled) in alternating fiber orientation to produce multi-directional strength part (see 'Fiber Architecture').

POLYESTER (Unsaturated)—Resin formed by reaction between dibasic acids and dihydroxy alcohols, one of which must be unsaturated (typically maleic anhydride) to permit cross-linking.

POLYMER—Large chemical chain composed of many repeating groups such as polystyrene.

POLYMERIZATION—Chemical reaction of linking molecules or chains of molecules.

POLYVINYL ALCOHOL (PVA)—Water soluble release agent.

POROSITY—Small air bubbles in composite or gel coat film; too numerous to count. Generally smaller in size than pinholes.

POSTCURE—Exposure of cured resin to higher temperatures than during molding; necessary in certain resins to attain complete cure and ultimate mechanical properties.

POT LIFE—See 'Gel Time.'

POTTING—Similar to encapsulating, except steps are taken to insure complete penetration of all voids in object before resin polymerizes.

PREFORM—Preshaped fibrous reinforcement formed by distribution of chopped fibers by air, water flotation, or vacuum over surface of perforated screen to approximate contour and thickness desired in finished part. Also, compact pill of compressed premixed materials.

PREFORM MAT—Fiber reinforced mat shaped like mold in which it will be used. Eliminates need for overlapping corners in molding.

PREHEATING—Heating of compound prior to molding or casting in order to facilitate operation, reduce molding cycle, or remove volatiles.

PREMIX—Mixture of resin, pigment, filler and catalyst for molding.

PREPREG—Resin-impregnated cloth, mat or filaments in flat form that can be stored for later use. Resin often partially cured to tack-free state called 'B-staging.' Additives can be added to obtain specific end-use properties and improve processing, storage and handling characteristics.

PRE-RELEASE—Premature release of the gel coat or laminate from the mold.

PRESSURE BAG—Tailored bag (usually rubber sheeting) placed against the in an open mold, hand layup process. Air or steam pressure (up to 50 psi) is applied between the bag and pressure plate located over mold.

PRIMARY LAMINATE—'Bulk' or 'second' laminate; laminate applied after skin coat has cured. Generally thicker than skin coat.

PRINT-THROUGH—Transfer through gel coat film of image of glass strands.

PRODUCTION MOLD—Durable, robust mold used to produce hundreds or thousands of part copies. Laminated production molds are best manufactured from laminated master molds.

PROFILE—Surface contour of part viewed from edge or cross section. When describing cosmetic features, profile is the roughness of surface on scale large enough to affect visual appearance but small enough to be insignificant with respect to dimensional functionality. Low profile corresponds to very smooth surface; high profile corresponds to surface with greater roughness.

PROMOTER—See 'Accelerator.'

PROTOTYPE—Process of creating test part not intended for commercial release that establishes design, material and fabrication parameters for new product. May require multiple iterations (repetitions) to arrive at final/commercial part design.

PULTRUSION—Automated continuous process for manufacturing composite rods, tubes and structural shapes having constant cross section. Roving and other reinforcements saturated with resin and continuously pulled through a heated die, where part is formed and cured. Cured part then automatically cut to length.

— R —

RAMPING—Gradual programmed increase/decrease in temperature or pressure to control cure or cooling of composite parts.

REINFORCED MOLDING COMPOUND—Reinforced compound in form of ready-to-use materials, as distinguished from premix, as 'BMC' or 'Gunk.'

REINFORCEMENT—Strong, relatively inert material molded into plastics to improve strength, stiffness and impact resistance. Usually fibers of glass, carbon, boron mineral, synthetic polymer, ceramic, textile, sisal, cotton, etc., in woven or nonwoven form.

RELEASE AGENT—See 'Mold Release.'

RELEASE FILM—Impermeable film layer that does not bond to composite during cure.

RESIN—Any of class of natural or synthetic polymers, solubilized or semi-solid, generally of high molecular weight having no definite melting point. Used in reinforced products to surround and hold fibers. Most resins are polymers.

RESIN INFUSION—To draw or force resin into dry reinforcement already in mold cavity.

RESIN PRESSURE HEAD—RTM process feature; state of pressure across a part from injection point to vent point; driving force that causes resin to flow through and saturate fiber pack.

RESIN RICH—Localized area filled with excess resin as compared to consistent resin/fiber ratio.

RESIN STARVED—Localized area lacking sufficient resin for fiber wetout.

RESIN TEARING—Separation of vehicle from pigments/ fillers in gel coat film, usually seen as black wavy lines.

RESIN TRANSFER MOLDING (RTM)—Molding process in which catalyzed resin is pumped into two-sided, matched mold where fibrous reinforcement has been placed. Mold and/or resin may or may not be heated.

RESIN TRANSFER SCHEME—RTM process feature that describes pathway used to transfer resins into fiber pack.

RIBBON DIRECTION—On honeycomb core, direction in which honeycomb can be separated; direction of one continuous ribbon.

ROVING—Collection of bundles of continuous filaments either as untwisted strands or as twisted yarns. For filament winding, generally wound as bands or tapes with as little twist as possible.

RUBBER PLUNGER MOLDING—Variation of matched-die molding process which uses heated metal female mold (or outer half) and rubber plunger male mold. Applicable for relatively small molds with modest undercuts where low pressures are involved.

— S —

S-GLASS—Magnesia/alumina/silicate glass reinforcement designed to provide very high tensile strength. Commonly used in high-performance parts.

SAGS/RUNS—Sag: Slumping of gel coat or resin film. Run: Running of gel coat film or laminating resin.

SANDWICH LAYUP—Laminate composed of two outside layers of reinforced material such as glass mat and inside layer or layers of honeycomb, glass cloth, or other lightweight core material.

SCRIMP—Seemann Composite Resin Infusion Molding Process. (See 'Resin Infusion.') Pulls vacuum before resin entry.

SEALANT—Applied to joint in paste or liquid from that hardens in place to form seal.

SECONDARY BONDING—Joining together by adhesive bonding of two or more previously cured parts, or subsequent lamination onto earlier cured laminate surface.

SET—To convert resin into fixed or hardened state by chemical or physical action, such as condensation, polymerization, vulcanization or gelation.

SHEAR—Stress resulting from applied forces. Caused by two contiguous parts of body sliding, relative to each other, in direction parallel to their plane of contact. In cross shear, plane of contact is composed of resin and glass fibers. In interlaminar shear (ILS), plane of contact is composed of resin only. In liquids, force and movement of components or layers against each other.

SHEET MOLDING COMPOUND (SMC)—Ready-to-mold, glass-fiber-reinforced, thickened polyester material primarily used in closed molding. Similar to bulk molding compound (BMC), but with improved mechanical properties.

SHELF LIFE—Length of time uncatalyzed polyester remains workable while stored in tightly sealed container; also referenced as 'storage life.'

SHOT—One complete cycle on injection molding machine. Shot weight is measured compound delivered to completely fill mold in injection or transfer molding.

SISAL—White fiber produced from leaves of agave plant. Used as reinforcing filler, in short chopped lengths, to impart moderate impact resistance.

SIZING—Water-soluble solution of chemical additives use to coat filaments; additives protect filaments from water absorption and abrasion. They also lubricate filaments and reduce static electricity (see chapter on 'Open Molding').

SKIN LAMINATE—Thin, glass laminate applied directly against gel coat to provide durability by eliminating entrapped air, and good cosmetic quality by isolating gel coat from subsequent laminate shrinkage due to exotherm heat.

SLAVE PUMP—Small, specifically sized pump driven by master gel coat or resin pump to deliver catalyst in ratio of one to three percent.

SOLVENT—Liquid used to dissolve and clean materials.

SPEC—Specification of properties, characteristics or requirements particular material or part must have to be acceptable to potential user of material or part.

SPECIFIC GRAVITY—Ratio of weight of any volume of substance to weight of equal volume of some substance taken as standard unit; usually water for solids and liquids, and air or hydrogen for gasses.

SPRAYUP—Process in which glass fibers, resin and catalyst are simultaneously deposited in mold. Roving is fed through chopper and ejected into resin stream directed at mold. Catalyst and accelerated resin may be sprayed from one or two guns. Glass resin mix is then rolled by hand before curing.

STABILIZER—Additive for polymers which aids maintenance of certain properties.

STIFFNESS—Structural property that describes relationship between forces and moments applied to, and stretching and bending deflections experienced by any item.

STRAIN—Deformation resulting from stress.

STRANDS—Primary bundle of continuous filaments combined into single compact unit without twist.

STRESS—Internal resistance to change in size or shape, expressed in force per unit area.

STRESS CORROSION—Preferential attack of areas under stress in corrosive environment, where such an environment alone would not have caused corrosion.

STRESS CRACK—External or internal cracks in composite caused by tensile stresses; cracking may be present internally, externally or in combination.

STYRENE MONOMER—Unsaturated aromatic hydrocarbon, used in plastics. In polyester, a reactive diluent.

SUBSTRATE—Material on which adhesive-containing substance is spread for any purpose, (e.g., bonding or coating).

SURFACE PROFILE—Cosmetic quality of surface (see 'Profile').

SURFACING AGENT—Material (commonly paraffin wax) that allows surface of polyesters to cure; limits adhesion of another coat of resin if first is thoroughly cured. May be removed by sanding or rubbing with steel wool.

SURFACING VEIL—Used with other reinforcing mats and fabrics to enhance quality of surface finish. Designed to block out fiber patterns of underlying reinforcements; also called 'surfacing mat.'

SYMMETRIC—Laminate design term used with composites to indicate that laminate is symmetric about the plane, midway through its thickness.

— T —

TACK—Stickiness.

TBPB—Abbreviation for tertiary-butyl perbenzoate used as catalyst (initiator) in high temperature molding of polyester resin systems.

TBPO—Abbreviation for tertiary-butyl peroctoate used as catalyst in high speed, heated cures of polyester resin systems.

TENSILE STRENGTH—Maximum stress sustained by composite specimen before it fails in tension test.

TEXTILE—Any type of sheet material made from fibers that are woven, knitted, knotted, stitched or bonded together.

THERMAL CONDUCTIVITY—Ability to transfer heat.

APPENDIX C: Definitions of Terms

THERMAL SHOCK—Temperature changes rapidly, causing large thermal stresses.

THERMAL STRESS—Occurs when change in temperature causes materials to expand and contract at different rates. Can form within and between layers of laminate as well as between laminate and steel frame.

THERMAL STRESS CRACKING—Crazing or cracking of some thermoset or thermoplastic resins from overexposure to elevated temperatures or cyclic temperature variations.

THERMOCOUPLE—Assembly used to sense and record temperature.

THERMOPLASTICS—Polymers that can be repeatedly softened when heated, hardened when cooled. Thermoplastics such as polymers and copolymers of acrylics, PET, polycarbonates, nylons, fluorocarbons and styrene are fast becoming important engineering materials.

THERMOSETS—Materials that will undergo or have undergone chemical reaction, leading to relatively infusible state. Typical materials are aminos (melamine and urea), unsaturated polyesters, alkyds, epoxies and phenolics; not reformable.

THIXOTROPIC—Condition in which material possesses resistance to flow until it is agitated (mixed, pumped, or sprayed).

THIXOTROPIC INDEX (TI)—Indication of sag resistance determined by dividing low shear viscosity by high shear viscosity.

TOOL—Mold, either one- or two-sided, and either open or closed, in or upon which composite material is placed to make part, also 'mold.'

TOOLING GEL COAT RESIN—Special polyesters designed for moldmaking.

TOUGHNESS—Measure of ability of material to absorb energy.

— U —

UNDERCUT—Negative or reverse draft on the mold. Split molds necessary to shape pieces that are undercut.

UNIDIRECTIONAL—Refers to fibers oriented in the same direction, such as unidirectional fabric, tape or laminate; often called UD.

UPPER MOLD TYPE—RTM process feature that describes materials and construction used for mating mold.

— V —

VACUUM BAG MOLDING—Molding process for minimizing emissions voids and maximizing reinforcement content, forcing out entrapped air and excess resin from layups, by drawing vacuum into flexible film draped over part. Also considered 'Resin Infusion.' Vacuum may be drawn after resin entry.

VACUUM-ASSISTED RESIN TRANSFER MOLDING (VARTM)—Infusion process where vacuum draws resin into one-sided mold; cover, either rigid or flexible, is placed over top to form vacuum-tight seal.

VAPOR BARRIER—Material through which water vapor will not pass readily or at all.

VEIL—Tissue of fibers which drapes and wets easily; of particular value to provide resin-rich barrier to corrosion or glass print, as in surfacing veil.

VISCOSITY—Fluid's resistance to flow.

VOIDS—Laminate defect that occurs during molding process; characterized by lack of resin material (entrapped air, un-wetted fibers).

VOLATILE MATERIAL—Material vaporizing under specific conditions short of decomposition; nonvolatile material remains.

VOLATILE ORGANIC COMPOUNDS (VOC)—Carbon-containing chemical compounds (e.g., solvents or liquids) that evaporate readily at ambient or process temperatures. Environmental, safety and health regulations often limit exposure to these compounds, so low VOC content is preferable.

— W —

WARP—Yarns running lengthwise and perpendicular to the narrow edge of woven fabric.

WARPAGE—Dimensional distortion in composite part.

WATER JET—High-pressure water stream used for cutting polymer composite parts.

WAX—Mold release agent or surfacing agent.

WEAVE—Pattern by which fabric is formed from interlacing yarns. In plain weave, warp and fill fibers alternate to make both fabric faces identical. In satin weave, pattern produces satin appearance with warp roving crossing over several fill rovings and under next one (e.g., eight-harness satin would have warp roving over seven fill rovings and under eighth).

WEAVE PRINT—Extreme form of fiber print resembling architecture of woven or stitched glass ply just below or near gel coat surface.

WEFT—Yarns running perpendicular to warp in woven fabric.

WET LAYUP—Application of liquid resin to dry reinforcement in the mold.

WET WINDING—Filament winding wherein fiber strands are impregnated with resin immediately before they contact mandrel.

WETOUT—Process in which reinforcing material can be completely saturated with resin. Rate usually determined visually and measured in elapsed time.

WETTING AGENT—Surface-active agent that promotes wetting by decreasing cohesion within liquid.

APPENDIX C: Definitions of Terms

WHISKER—Short single crystal fiber or filament used as reinforcement in matrix.

WIND ANGLE—Measure in degrees between direction parallel to filaments and established reference.

WINDING PATTERN—Regularly recurring pattern of filament path in filament winding after certain number of mandrel revolutions.

WIRE MESH—Fine wire screen used to increase electrical conductivity. Typically used to dissipate electrical charge from lightning or electromagnetic interference.

WITNESS MARK—Defect in gel coat surface profile that corresponds to some feature, either in underlying laminate or on/in molding surface; sometimes called mark-off.

WOVEN ROVING FABRIC—Heavy fabrics woven from continuous filaments in roving form. They drape well, are quickly impregnated are intermediate in price between mats and yarn cloths, and contribute to higher glass content.

WOVEN TAPE—Tape of various thicknesses woven from continuous filament yarns.

WRINKLE—Imperfection in surface of laminate that appears to be crease in one of outer layers; occurs in vacuum-bag molding when bag improperly placed.

— X —

X-AXIS—Axis in plane of laminate used as zero reference.

— Y —

Y-AXIS—Axis in plane of the laminate perpendicular to the x-axis.

YARN—Twisted strand of roving.

YOUNG'S MODULUS—Ratio of normal stress to corresponding strain for tensile or compressive stresses less than proportional limit of material.

— Z —

Z-AXIS—Reference axis normal to laminate plane in composite laminates.

ZERO MOLD—General term for intermediate piece of tooling that resembles production model but belongs to earlier generation. Molded from part-image master model (pattern or plug); subsequently used to produce master model.

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APPENDIX D: Painting Polyester Gel Coats

In This Chapter

1. DESCRIPTION—If painting of a gel coat part is desired, the most durable paint system to employ is a catalyzed urethane.

In general, two-component acrylic urethane or polyester urethane enamels maintain very good gloss and color retention when subjected to prolonged and severe atmospheric conditions. They will normally cure at ambient temperatures to a very tough, abrasion-resistant film with exceptionally high gloss.

Reputable sources for quality coatings include:

- Dupont
  www.dupontrefinish.com
- Sherwin-Williams Co.
  www.sherwin-automotive.com
- U.S. Paint Corporation (AWL Grip)
  www.uspaint.com

2. SURFACE PREPARATION—When re-coating (painting) a polyester gel coat, it is very important that the surface be clean and free from mold release agents, oil, grease, and other surface contaminants.

Follow the coatings manufacturer's directions for surface preparation, mixing, reducing, sweat-in, pot life, application coverage, film thickness, drying time, cleanup, physical data, precaution and safety, and other aspects.

If using for water immersion service (boats, tubs, showers, pools, spas, etc.), be sure that the paint is recommended for such use.

A. In the absence of surface preparation—instructions, a minimum surface preparation would include washing thoroughly PRIOR TO and AFTER sanding with CLEAN rags and V. M. & P. Naphtha (or coatings manufacturer's recommendations) to remove all contaminants.

B. Sand all gel coat surfaces with a medium grit sandpaper such as numbers 120, 220, or 320 to roughen the surface. Follow with an overall fine sanding to a smooth surface using number 400 grit sandpaper.

3. BAKING—Customer experience has demonstrated that gel coated laminates can be post-baked at temperatures up to 285°F for as long as two hours.

NOTE: If the fiberglass part is not completely cured before baking, distortion can occur during the bake cycle. It is better to prebake the part for one hour at the baking temperature before sanding. Then sand and bake.

4. OTHER SYSTEMS—Other paint systems can be used but may not have the exterior durability of catalyzed urethane. Match desired durability with paint quality. See paint manufacturer's recommendations.

APPENDIX E: Additional Information

Part Ten, Chapter V

In This Chapter

1. USEFUL CONVERSION FACTORS—

PEROXIDE/COBALT/POLYESTER RESIN	
1 fluid oz. MEK peroxide*	= 33.1 gms MEK peroxide
1 gm wt. MEK peroxide	= 0.0302 fluid oz. MEK peroxide
1 cc MEK peroxide	= 1.12 gms MEK peroxide
1 gm wt. MEK peroxide	= 0.89 cc MEK peroxide
1 fluid oz. cobalt**	= 30.15 gm. wt. cobalt
1 gm wt. cobalt	= 0.033 fluid oz. cobalt
1 cc cobalt	= 1.02 gms cobalt
1 gm wt. cobalt	= 0.99 cc cobalt
1 gal. polyester resin, unpigmented	= 9.2 lbs.
1 lb. polyester resin unpigmented	= 13.89 fluid oz.
1 lb. polyester resin unpigmented	= 411 cc
**9% active oxygen*	*** 6% solution*

WEIGHT		VOLUME	
1 gm (gram)	= 0.0022 lbs. = 0.0353 oz. = 0.001 Kg	1 cc (cubic centimeter)	= 1 ml (milliliter) = 0.000264 gallons = 0.0338 fluid oz.
1 lb. (pound)	= 16 oz. = 453.6 gms = 0.454 Kg	1 U.S. gallon	= 3785 cc = 128 fluid oz. = 231 cubic inches
1 oz. (ounce) (avoirdupois)	= 0.0625 lbs. = 28.35 gms = 0.0284 Kg	1 fluid oz.	= 29.57 cc (or ml) = 0.00781 gallons
1 Kg (Kilogram)	= 1000 gms = 2.205 lbs. (av.) = 35.27 oz. (av.)		

WEIGHT/VOLUMETRIC ADDITIVE CHART									
	% by Weight .01			% by Weight .10			% by Weight 1.0		
Approx. Volume^2	gm	cc^1	oz.^{1}	gm	cc^1	oz.^{1}	gm	cc^1	oz.^{1}
1 quart	.11	.11	.004	1.11	1.11	.037	11.12	11.12	.375
1 gallon	.44	.44	.015	4.45	4.45	.150	44.50	44.50	1.500
5 gallons	2.22	2.22	.075	22.25	22.25	.750	222.50	222.50	7.500
1 drum	23.58	23.58	.795	235.80	235.80	7.950	2358.50	2358.50	79.5000
	% by Weight 1.2			% by Weight 1.8			% by Weight 2.0		
Approx. Volume^2	gm	cc^1	oz.^{1}	gm	cc^1	oz.^{1}	gm	cc^1	oz.^{1}
1 quart	13.35	13.35	.450	20	20	.675	22.25	22.25	.750
1 gallon	53.40	53.40	1.800	80	80	2.700	89.00	89.00	3.000
5 gallons	267.00	267.00	9.000	400	400	13.500	445.00	445.00	15.000
1 drum	2830.20	2830.20	95.000	4240	4240	143.100	4717.00	4717.00	159.00

APPENDIX E: Additional Information

SPECIFIC GRAVITY FACTOR/ADDITIVES

1. Based on the weight/gallon of 8.33 pounds for approximate measurements; for more accurate additions, divide the number of cc's or oz. shown in the table on the preceding page by the proper factor supplied below:

970-C-981 Ethylene Glycol	1.11
970-C-903 Cobalt	1.02
970-C-960 Styrene	0.91
970-C-951 Inhibitor Solution	0.98
970-C-940 Wax Solution	0.91
970-C-943 Fisheye Solution	0.97

Specific gravity (factor) is the 'ratio of the weight of any substance to that of an equal volume of water.' The weight gallon of water is 8.33 pounds; therefore divide the weight/gallon of a given substance by 8.33 (see preceding examples). When using water as the standard, 1 cc or ml (volume) is equal to 1 gram (weight).

The specific gravity is a very useful conversion factor for converting volume to weight or weight to volume.

Example A:

If percent by weight is desired and the addition is to be by volume, divide weight desired by the specific gravity.

30 grams of catalyst desired
cc graduate going to be used
30/1.12 = 27 cc's to equal 30 grams

DENSITY COMPENSATION FACTOR/PRODUCTS

2. Based on an average weight/gallon of 9.8 pounds. For more accurate additions, divide the number of cc's or oz. shown in the table on the preceding page by the proper factor supplied below:

944-W-016	1.10
Other gel coats	0.97
040-4812	0.91

3. Cured weight/gallon:

Polyester resins (9.0 lbs. liquid)	9.90
Fiberglass (roving)	21.15

Example B:

If volume is known and gram weight is desired, multiply volume by specific gravity.

2000 cc's of white gel coat
Weight ÷ gallon of white gel coat is 10.9
10.9 ÷ 8.33 = 1.31 specific gravity
2000 x 1.31 = 2620 grams of white gel coat

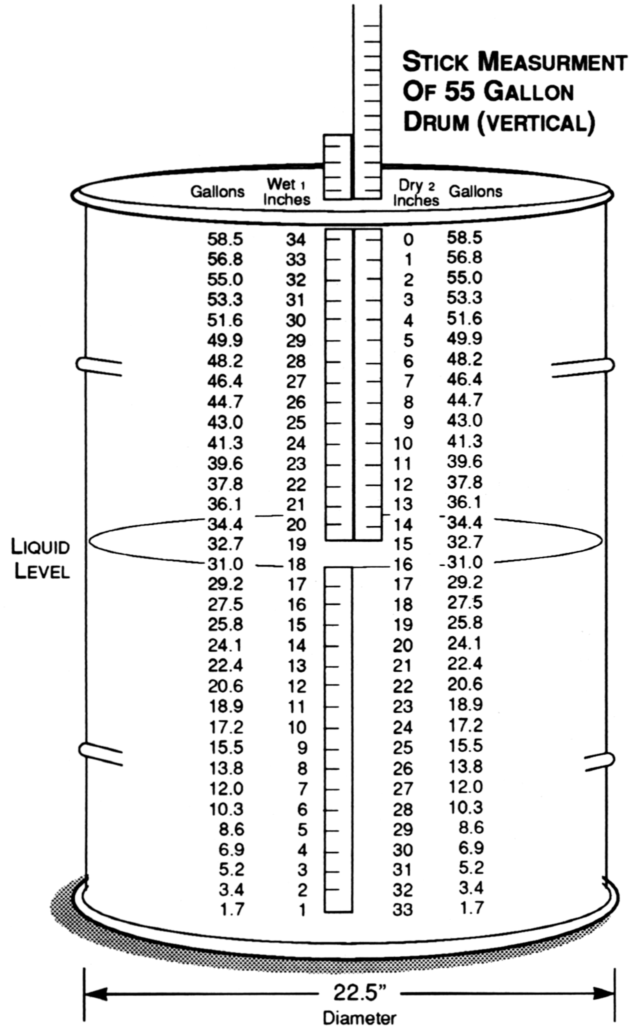
Remember:

Grams to cc's, divide by specific gravity
Cc's to grams, multiply by specific gravity

See Drum Measurement Chart in this section to determine how much material is in a drum.

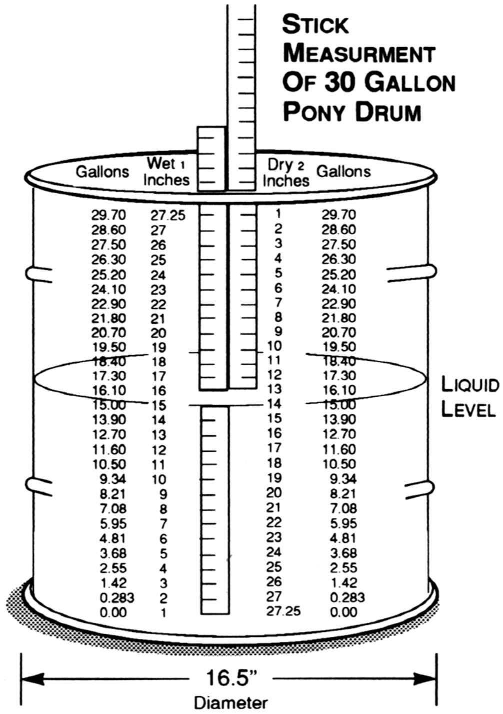
2. DRUMS (STICK MEASUREMENT)—

Note: Illustration applies to new steel drums only



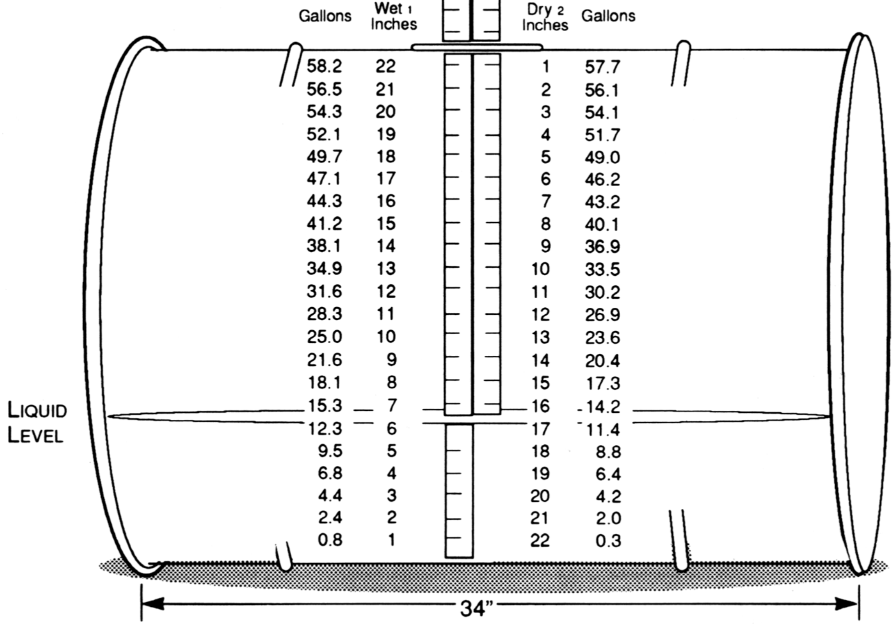
STICK MEASURMENT OF 55 GALLON DRUM (VERTICAL)

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
58.5	34	0	58.5
56.8	33	1	56.8
55.0	32	2	55.0
53.3	31	3	53.3
51.6	30	4	51.6
49.9	29	5	49.9
48.2	28	6	48.2
46.4	27	7	46.4
44.7	26	8	44.7
43.0	25	9	43.0
41.3	24	10	41.3
39.6	23	11	39.6
37.8	22	12	37.8
36.1	21	13	36.1
34.4	20	14	34.4
32.7	19	15	32.7
31.0	18	16	31.0
29.2	17	17	29.2
27.5	16	18	27.5
25.8	15	19	25.8
24.1	14	20	24.1
22.4	13	21	22.4
20.6	12	22	20.6
18.9	11	23	18.9
17.2	10	24	17.2
15.5	9	25	15.5
13.8	8	26	13.8
12.0	7	27	12.0
10.3	6	28	10.3
8.6	5	29	8.6
6.9	4	30	6.9
5.2	3	31	5.2
3.4	2	32	3.4
1.7	1	33	1.7



STICK MEASURMENT OF 30 GALLON PONY DRUM

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
29.70	27.25	1	29.70
28.60	27	2	28.60
27.50	26	3	27.50
26.30	25	4	26.30
25.20	24	5	25.20
24.10	23	6	24.10
22.90	22	7	22.90
21.80	21	8	21.80
20.70	20	9	20.70
19.50	19	10	19.50
18.40	18	11	18.40
17.30	17	12	17.30
16.10	16	13	16.10
15.00	15	14	15.00
13.90	14	15	13.90
12.70	13	16	12.70
11.60	12	17	11.60
10.50	11	18	10.50
9.34	10	19	9.34
8.21	9	20	8.21
7.08	8	21	7.08
5.95	7	22	5.95
4.81	6	23	4.81
3.68	5	24	3.68
2.55	4	25	2.55
1.42	3	26	1.42
0.283	2	27	0.283
0.00	1	27.25	0.00



STICK MEASURMENT OF 55 GALLON DRUM (HORIZONTAL)

Gallons	Wet[1] Inches	Dry[2] Inches	Gallons
58.2	22	1	57.7
56.5	21	2	56.1
54.3	20	3	54.1
52.1	19	4	51.7
49.7	18	5	49.0
47.1	17	6	46.2
44.3	16	7	43.2
41.2	15	8	40.1
38.1	14	9	36.9
34.9	13	10	33.5
31.6	12	11	30.2
28.3	11	12	26.9
25.0	10	13	23.6
21.6	9	14	20.4
18.1	8	15	17.3
15.3	7	16	14.2
12.3	6	17	11.4
9.5	5	18	8.8
6.8	4	19	6.4
4.4	3	20	4.2
2.4	2	21	2.0
0.8	1	22	0.3

1. **WET:** Measurement from drum bottom to top of material
2. **DRY:** Measurement from top of material to drum top

APPENDIX E: Additional Information

3. CONVERSION TABLE/MATERIALS COVERAGE CHART—

Conversion Table Millimeter/Inch

MM	INCHES
0.25400	0.01000
0.30480	0.01200
0.35560	0.01400
0.40640	0.01600
0.45720	0.01800
0.50800	0.02000
0.60960	0.02400
0.71120	0.02800
0.81280	0.03200
0.91440	0.03600
1	0.03937
2	0.07874
3	0.11811
4	0.15748
5	0.19685
6	0.23622
7	0.27559
8	0.31496
9	0.35433
10	0.39370
11	0.43307
12	0.47244
13	0.51181
14	0.55118
15	0.59055
16	0.62992
17	0.66929
18	0.70866
19	0.74803
20	0.78740

Gel Coat Wet to Cured Correlation

APPROX. MILS WET	MILS CURED
10	7
12	8
14	10
16	11
18	13
20	14
24	16
28	19
32	24
36	29

Resin to use to achieve 'x' percent of glass when glass weight is known. Determine what percentage of glass is desired; multiply glass weight by resin factor.

Desired % of Glass	Factor for Resin
30	2.33
31	2.22
32	2.12
33	2.03
33.33	2.00
34	1.94
35	1.86
36	1.78
37	1.70
38	1.63
39	1.56
40	1.50

MISCELLANEOUS

10 cc (ml) per catalyst cap
1 jigger = 1.5 fl. ounces
100 gms. = approx. 3 fl. ounces gel coat
or 1 ½" x 2 ½" (in 8 oz. jar)
1 fluid ounce = 2 tablespoons (T.)
= 6 teaspoons (t.)
= 29.6 cubic centimeters (cc)
1 cup = 8 fl. oz. = 16 T. = 48 t.
128 fl. ounces = 1 gallon
approx. 36 eye drops/gram of 970-C-951 (inhibitor solution)
approx. 30 eye drops/gram of 970-C-981 (viscosity thickener)
approx. 36 eye drops/gram of catalyst
Density glass = approx. 1.6 gms./cc
or 162.5 lbs./ft.^{3}
or 21.6 lbs./gallon

Materials Coverage Theoretical—Assuming No Loss

WET FILM THICKNESS	Sq. Ft./Gal.	Gal./1000 Sq. Ft.
0.001" (1 mil)	1600.0	0.63
0.003" (3 mils)	534.0	1.90
0.005" (5 mils)	320.0	3.10
0.010" (10 mils)	160.0	6.30
0.015" (15 mils)	107.0	9.40
0.018" (18 mils)	89.0	11.20
0.020" (20 mils)	80.0	12.50
0.025" (25 mils)	64.0	15.60
0.030" (30 mils)	53.0	19.00
0.031" (31 mils)	51.0	19.50
0.060" (60 mils)	27.0	38.00
0.062" (62 mils)	26.0	38.00

CATALYZATION

The importance of proper catalyzation when using polyesters cannot be emphasized enough. Over catalyzation, as well as under catalyzation, can cause a variety of problems. Using the 9.0% active oxygen catalyst, recommended catalyzation levels are:

	Recommended @ 77%	Minimum	Maximum
Gel Coats	1.8%	1.2%	3.0%
Laminating Resins	1.2%	.9%	2.4%
Marble Resins	1.2%	.5%	2.4%

Ideal catalyst level for gel coat is 1.8%; 1.2% for laminating and marble resins at 77°F. Add .07 catalyst to the ideal % for each °F below 77°F to no lower than 60°F and a maximum total of 3.0% gel coat and 2.4% for laminating and marble resins.

Example: When testing gel coat, ambient plant temperatures are found to be 70°F (or 7°F below 77°F):

7°F x .07 = 0.49

1.8% + 0.49 = 2.3% for that plant temperature

NOTE: Check liquid temperature of catalyst, resin and gel coat to be tested.

Units of Area

Unit	Square Inches	Square Feet	Square Yards	Square Centimeter	Square Meters
Sq. inch	1	0.006944	0.000772	6.45162	0.000645
Sq. foot	144	1	0.11111	929.034	0.092903
Sq. yard	1296	9	1	8361.31	0.836131
Sq. cm.	0.155	0.001076	0.00012	1	0.0001
Sq. meter	1550	10.7639	1.19598	10000	1

Units of Length

Unit	Inches	Feet	Yards	Centimeter	Meters
Inch	1	0.08333	0.02777	2.54	0.0254
Foot	12	1	0.3333	30.48	0.3048
Yard	36	3	1	91.44	0.9144
Mile	63360	5280	1760	160934	1609.34
Cm.	0.3937	0.03281	0.01094	1	0.01
Meter	39.37	3.3808	1.09361	100	1

Units of Volume

Unit	Cubic Inches	Cubic Feet	Cubic Yards	Cubic Centimeters
Cubic inch	1	---	---	16.3872
Cubic foot	1728	1	0.03704	28317
Cubic yard	46656	27	1	764.559
Cubic cm.	0.06102	---	---	1
Cubic meter	61203	35.314	1.3079	1000000

4. COMPARISON OF SIZES—

FROM 0 to 1 INCH
(ACCEPTED DEPTH-OF-FINENESS GAUGE READINGS, INCHES, MILLIMETERS, MICRONS, U.S. AND TYLER SIEVES)

FINENESS GAUGE READINGS						SIEVES	
Prod. Club	**Mils**	**Hegman**	**Inches**	**Millimeters**	**Microns**	**U.S. Std. Eq. No.**	**Tyler Mesh**
10	0.00	8	0.00000	0.0000	0		
	0.25	7½	0.00025	0.0064	6.4		
9	0.40		0.00040	0.0102	10.2		
	0.50	7	0.00050	0.0127	12.7		
	0.75	6 ½	0.00075	0.0191	19.1		
8	0.80		0.00080	0.0203	20.3		
	1.00	6	0.00100	0.0254	25.4		
7	1.20		0.00120	0.0305	30.5		
	1.25	5½	0.00125	0.0318	31.8		
	1.50	5	0 00150	0.0381	38.1	400	400
6	1.60		0.00160	0.0406	40.6		
	1.75	4½	0.00175	0.0445	44.5	325	325
5	2.00	4	0.00200	0.0508	50.8		
	2.10		0.00210	0.0533	53.3	270	270
	2.25	3½	0.00225	0.0572	57.2		
4	2.40		0.00240	0.0610	61.0	230	250
	2.50	3	0.00250	0.0635	63.5		
	2.75	2½	0.00275	0.0699	69.9		
3	2.80		0.00280	0.0711	71.1		
	2.90		0.00290	0.0737	73.7	200	200
	3.00	2	0.00300	0.0762	76.2		
2	3.20		0.00320	0.0813	81.3		
	3.25	1½	0.00325	0.0826	82.6		
	3.50	1	0.00350	0.0889	88.9	170	170
1	3.60		0.00360	0.0914	91.4		
	3.75	½	0.00375	0.0953	95.3		
0	4.00	0	0.00400	0.1016	101.6		
			0.00410	0.1041	104.1	140	150
			0.00490	0.1250	125.0	120	115
			0.00590	0.1490	149.0	100	100
			0.00700	0.1770	177.0	80	80
			0.00830	0.2100	210.0	70	65
			0.00980	0.2500	250.0	60	60
			0.01170	0.2970	297.0	50	48
			0.01380	0.3500	350.0	45	42
			0.01650	0.4200	420.0	40	35
			0.01970	0.5000	500.0	35	32
			0.02320	0.5900	590.0	30	28
			0.02800	0.7100	710.0	25	24
			0.03310	0.8400	840.0	20	20
			0.03940	1.0000	1000.0	18	16
			0.04690	1.1900	1190.0	16	14
			0.05550	1.4100	1410.0	14	12
			0.06250 (1/16″)	1.5875	1588.0		
			0.06610	1.6800	1680.0	12	10
			0.07870	2.0000	2000.0	10	9
			0.09370	2.3800	2380.0	8	8
			0.11100	2.8300	2830.0	7	7
			0.12500 (1/8″)	3.1750	3175.0		
			0.13200	3.3600	3360.0	6	6
			0.15700	4.0000	4000.0	5	5
			0.18750 (3/16″)	4.7600	4760.0	4	4
			0.22300	5.6600	5660.0	3½	3½
			0.25000 (1/4″)	6.3500	6350.0		
			0.31250 (5/16″)	7.9300	7930.0		
			0.37500 (3/8″)	9.5200	9520.0		
			0.43750 (7/16″)	11.1000	11100.0		
			0.50000 (1/2″)	12.7000	12700.0		
			0.62500 (5/8″)	15.9000	15900.0		
			0.75000 (3/4″)	19.1000	19100.0		
			0.87500 (7/8″)	22.2000	22200.0		
			1.00000 (1″)	25.4000	25400.0		

APPENDIX E: Additional Information

5. TEMPERATURE CONVERSION TABLE—

-100 to 0

C		F
73.3	-100	-148.0
-72.8	-99	-146.2
-72.2	-98	-144.4
-71.7	-97	-142.6
-71.1	-96	-140.8
-70.6	-95	-139.0
-70.0	-94	-137.2
-69.4	-93	-135.4
-68.9	-92	-133.6
-68.3	-91	-131.8
-67.8	-90	-130.0
-67.2	-89	-128.2
-66.7	-88	-126.4
-66.1	-87	-124.6
-65.6	-86	-122.8
-65.0	-85	-121.0
-64.4	-84	-119.2
-63.9	-83	-117.4
-63.3	-82	-115.6
-62.8	-81	-113.8
-62.2	-80	-112.0
-61.7	-79	-110.2
-61.1	-78	-108.4
-60.6	-77	-106.6
-60.0	-76	-104.8
-59.4	-75	-103.0
-58.9	-74	-101.2
-58.3	-73	-99.4
-57.8	-72	-97.6
-57.2	-71	-95.8
-56.7	-70	-94.0
-56.1	-69	-92.2
-55.6	-68	-90.4
-55.0	-67	-88.6
-54.4	-66	-86.8
-53.9	-65	-85.0
-53.3	-64	-83.2
-52.8	-63	-81.4
-52.2	-62	-79.6
-51.7	-61	-77.8
-51.1	-60	-76.0
-50.6	-59	-74.2
-50.0	-58	-72.4
-49.4	-57	-70.6
-48.9	-56	-68.8
-48.3	-55	-67.0
-47.8	-54	-65.2
-47.2	-53	-63.4
-46.7	-52	-61.6
-46.1	-51	-59.8
-45.6	-50	-58.0
-45.0	-49	-56.2
-44.4	-48	-54.4
-43.9	-47	-52.6
-43.3	-46	-50.8
-42.8	-45	-49.0
-42.2	-44	-47.2
-41.7	-43	-45.4
-41.1	-42	-43.6
-40.6	-41	-41.8
-40.0	-40	-40.0
-39.4	-39	-38.2
-38.9	-38	-36.4
-38.3	-37	-34.6
-37.8	-36	-32.8
-37.2	-35	-31.0
-36.7	-34	-29.2
-36.1	-33	-27.4
-35.6	-32	-25.6
-35.0	-31	-23.8
-34.4	-30	-22.0
-33.9	-29	-20.2
-33.3	-28	-18.4
-32.8	-27	-16.6
-32.2	-26	-14.8
-31.7	-25	-13.0
-31.1	-24	-11.2
-30.6	-23	-9.4
-30.0	-22	-7.6
-29.4	-21	-5.8
-28.9	-20	-4.0
-28.8	-19	-2.2
-27.8	-18	-0.4
-27.2	-17	1.4
-26.7	-16	3.2
-26.1	-15	5.0
-25.6	-14	6.8
-25.0	-13	8.6
-24.4	-12	10.4
-23.9	-11	12.2
-23.3	-10	14.0
-22.8	-9	15.8
-22.2	-8	17.6
-21.7	-7	19.4
-21.1	-6	21.2
-20.6	-5	23.0
-20.0	-4	24.8
-19.4	-3	26.6
-18.7	-2	28.4
-18.3	-1	30.2
-17.8	0	32.0

0 to 100

C		F
-17.8	0	32.0
-17.2	1	33.8
-16.7	2	35.6
-16.1	3	37.4
-15.6	4	39.2
-15.0	5	41.0
-14.4	6	42.8
-13.9	7	44.6
-13.3	8	46.4
-12.8	9	48.2
-12.2	10	50.0
-11.7	11	51.8
-11.1	12	53.6
-10.6	13	55.4
-10.0	14	57.2
- 9.44	15	59.0
- 8.89	16	60.8
- 8.33	17	62.6
- 7.78	18	64.4
- 7.22	19	66.2
- 6.67	20	68.0
-6.11	21	69.8
-5.56	22	71.6
-5.00	23	73.4
-4.44	24	75.2
-3.89	25	77.0
-3.33	26	78.8
-2.78	27	80.6
-2.22	28	82.4
-1.67	29	84.2
-1.11	30	86.0
-0.56	31	87.8
0	32	89.6
0.56	33	91.4
1.11	34	93.2
1.67	35	95.0
2.22	36	96.8
2.78	37	98.6
3.33	38	100.4
3.89	39	102.2
4.44	40	104.0
5.00	41	105.8
5.56	42	107.6
6.11	43	109.4
6.67	44	111.2
7.22	45	113.0
7.78	46	114.8
8.33	47	116.6
8.89	48	118.4
9.44	49	120.2
10.0	50	122.0
10.6	51	123.8
11.1	52	125.6
11.7	53	127.4
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4
37.2	99	210.2
37.8	100	212.0

100 to 1000

C		F
38	100	212
43	110	230
49	120	248
54	130	266
60	140	284
66	150	302
71	160	320
77	170	338
82	180	356
88	190	374
93	200	392
99	210	410
100	212	413
104	220	428
110	230	446
116	240	464
121	250	482
127	260	500
132	270	518
138	280	536
143	290	554
149	300	572
154	310	590
160	320	608
166	330	626
171	340	644
177	350	662
182	360	680
188	370	698
193	380	716
199	390	734
204	400	752
210	410	770
216	420	788
221	430	806
227	440	824
232	450	842
238	460	860
243	470	878
249	480	896
254	490	914
260	500	932
266	510	950
271	520	968
277	530	986
282	540	1004
288	550	1022
293	560	1040
299	570	1058
304	580	1076
310	590	1094
316	600	1112
321	610	1130
327	620	1148
332	630	1166
338	640	1184
343	650	1202
349	660	1220
354	670	1238
360	680	1256
366	690	1274
371	700	1292
377	710	1310
382	720	1328
388	730	1346
393	740	1364
399	750	1382
404	760	1400
410	770	1418
416	780	1436
421	790	1454
427	800	1472
432	810	1490
438	820	1508
443	830	1526
449	840	1544
454	850	1562
460	860	1580
466	870	1598
471	880	1616
477	890	1634
482	900	1652
488	910	1670
493	920	1688
499	930	1706
504	940	1724
510	950	1742
516	960	1760
521	970	1778
527	980	1796
532	990	1814
538	1000	1832

1000 to 3000

C		F
538	1000	1832
593	1100	2012
649	1200	2192
704	1300	2372
760	1400	2552
816	1500	2732
871	1600	2912
927	1700	3092
982	1800	3272
1038	1900	3452
1093	2000	3632
1149	2100	3812
1204	2200	3992
1260	2300	4172
1316	2400	4352
1371	2500	4532
1427	2600	4712
1482	2700	4892
1538	2800	5072
1593	2900	5252
1649	3000	5432

INSTRUCTIONS

To convert from Celsius to Fahrenheit:

1. Find Celsius degrees in center column.
2. Read equivalent Fahrenheit degree in right-hand column.

To convert from Fahrenheit to Celsius:

1. Find Fahrenheit degree in center column.
2. Read equivalent Celsius degree in left hand column.

INTERPOLATION FACTORS

0.56	1	1.8	3.33	6	10.8
1.11	2	3.6	3.89	7	12.6
1.67	3	5.4	4.44	8	14.4
2.22	4	7.2	5.00	9	16.2
2.78	5	9.0	5.56	10	18.0

C to F = C (1.8) + 32
F to C = (F-32) ÷1.8

6. RECORD OF CURRENT PRODUCTS—

This page is provided as a suggested format for recording CCP products currently used.

	PRODUCT CODE	GEL TIME	CATALYST	VISCOSITY
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				
20.				
21.				
22.				
23.				
24.				
25.				

APPENDIX E: Additional Information

7. GEL COAT SPRAY TEST SHEET

Purpose:
1. To determine proper amount of delivery.
2. To determine proper amount of catalyst.
3. To determine proper spray application.

For: ____
Date: ____
Number: ____

GENERAL	**COMMENTS/RECOMMENDATIONS**	
1. Spray area location		1.
2. Spray person		2.
3. Type parts		3.
4. Molds (condition, type wax, etc.)		4.
5. Method of spraying (molds tilted, scaffolding, etc.)		5.
6. Staging conditions		6.
7. Mixing procedures		7.
8. Moisture/oil		8.
9. Other		9.
CALIBRATION		
10. **Material**	Batch # Batch Date	10.
11. Temperature		11.
12. Gun		12.
13. Fluid orifice		13.
14. Needle		14.
15. Air cap		15.
16. Atomizing pressure		16.
17. Hose (atomizing)		17.
18. Supply (model /size/ratio)		18.
19. Pump air pressure		19.
20. Hose (fluid)		20.
21. GPM/PPM (454 g's is 1 pound)		21.
22. Other		22.
23. **Catalyst** (brand/type/lot)		23.
24. Supply		24.
25. Orifice size		25.
26. Dilution ratio		26.
27. Percent catalyst desired		27.
28. Gram s/cc's desired (line 21 x 27)		28.
29. Catalyst pressure		29.
30. Hose		30.
31. Catalyst atomizing pressure		31.
32. Hose		32.
33. Ball(s) setting		33.
34. Catalyst delivery		34.
35. Percent catalyst (line 34÷21)		35.
36. Control gel time		36.
37. Gun gel time		37.
38. Film gel time		38.
39. Layup time		39.
40. Other		40.
APPLICATION		
41. Identification (mold #/part #)		41.
42. Start/finish/total time		42.
43. Spray distance		43.
44. Number of passes		44.
45. Mils per pass		45.
46. Total mils		46.
47. Other		47.

MIXING

DO NOT OVER-MIX.

**OVER-MIXING CAN
REDUCE VISCOSITY.**

**GEL COAT SHOULD
BE MIXED FOR
10 MINUTES
PRIOR TO
SHIFT STARTUP.**

**THE GEL COAT
SHOULD BE
MIXED TO THE SIDES
OF THE CONTAINER.**

**USE THE LEAST AMOUNT
OF TURBULENCE
POSSIBLE.**

9. CATALYST LEVELS—

CATALYST LEVEL

IDEAL CATALYST LEVEL FOR GEL COAT IS 1.8% AT 77°F.

The following catalysts are recommended for use with CCP Gel Coats:

Luperox® DDM-9
Luperox® DHD-9
Chemtura Hi-Point 90
Norox® MEKP-925
Norox® MEKP-9

MINIMUM APPLICATION TEMPERATURE IS 60°F.

MAXIMUM CATALYST LEVEL IS 3.0%

MINIMUM CATALYST LEVEL IS 1.2%

ADJUST CATALYST LEVEL 0.07 FOR EACH DEGREE FROM 77°F.

IF COOLER THAN 77°F, ADD 0.07 UP TO A CATALYST LEVEL OF 3.0%.
EXAMPLE#1: TEMPERATURE OF GEL COAT IS 70°F.
7 X 0.07 = 0.49 + 1.8% = 2.3%

IF WARMER THAN 77°F, SUBTRACT 0.07 DOWN TO A MINIMUM CATALYST LEVEL OF 1.2%.
EXAMPLE #2: TEMPERATURE OF GEL COAT IS 85°F.
8 X (-0.07) = (-0.56) + 1.8% = 1.24%

APPLICATION HELPFUL HINTS

1. MIX GEL COAT PER RECOMMENDATIONS.

2. CHECK CALIBRATION ON A REGULAR BASIS.

3. THE FIRST PASS SHOULD BE A THIN, WET, CONTINUOUS FILM.

4. MAINTAIN A WET LINE.

5. SPRAY 3 PASSES FOR A TOTAL OF 18 MILS (± 2 MILS) WET.

GEL COAT WET-TO-CURED THICKNESS CORRELATION

Low VOC (HAP) Gel Coat
versus
Standard Gel Coat

MILS WET	MILS CURED Standard Gel Coat	MILS CURED with Low VOC (HAP) Gel Coat*
10	7	5 to 7% Improvement
12	8	
14	10	
16	11	
18	13	
20	14	
24	16	
28	19	
32	24	
36	29	

* Dependent on the actual VOC (HAP) of the gel coat, and on application and environmental conditions.

12. SERVICE KIT ITEMS—

SERVICE KIT ITEMS

Listed in this section are tools and equipment necessary for checking out field problems with polyester. The list can also be used as a basic reference for items a customer should have in order to run trouble-shooting and calibration tests.

Item		Source
Scales—Ohaus	0-250 gms 0-2000 gms	1 1
Single pan balance	0-2610 gms	2 1
Applicator sticks		1
Tongue depressors		2
Graduated cylinders	10 mil 100 mil 1000 mil	2 2 2
Paper tubs		2
Graduated measuring cups	3 oz/85 Ml	2
Measurematic Catalyst Dispenser		2
Small plastic bottles and eye droppers		7
Disposable gloves		2
Disposable particle mask		2
Disposable coveralls	Size M Size L	2
Disposable shoe covers	One size	2
Paint strainer		2
Magnifier flashlight	10X	3
Respirator		1

Item		Source
Pocket magnifier (for dry film thickness)		1
Mil gauges		3
Atomizing air gauge and regulator	#73-125	8
Drum mixer	5-21-0065	8
Putty knife		5
Can opener		5
Pocket thermometer	-30°F to +120°F	1
Adjustable wrench		5
Pliers		5
Screwdrivers		5
Masking tape		1
Barcol impressor	#934	6
Safety glasses		1
Tes Tape glucose enzymatic test strip (catalyst detector)		7
Draw-down bars and paper		3
Weight/gallon cup		3

SOURCES

1. Chemical/Scientific supplier (check Yellow Pages under 'lab supplies').

2. United Industrial Sales Co.
4410 Glenbrook Road
Willoughby, OH 44094
or other fiberglass supplier

3. Paul N. Gardner Company
316 NE First Street
Pompano Beach, FL 33060
Ph: 800-762-2478

4. BYK-Gardner
Rivers Park II
9104 Guilford Road
Columbia, MD 21046
Ph: 800-343-7721

5. Hardware store or similar establishment

6. Barber Colman
1354 Clifford Ave
Love's Park, IL 61132-2940
Ph: 815-637-3222

7. Drug store

8. ITW Poly-Craft
4100 McEwen, Suite 125
Dallas, TX 75244
Ph: 972-233-2500
Customer Service: 800-423-3694
Fax: 972-702-9502

APPENDIX E: Additional Information

13. EQUIPMENT MAINTENANCE AND CLEANUP PROCEDURES—

EQUIPMENT MAINTENANCE

Spray guns and support equipment represent a considerable investment. A planned program of maintenance should be put in place to protect that investment. Also, refer to equipment manuals for specific instruction.

A maintenance program should include the following review and checklist:

A. Maintain spare parts for all spray guns, pumps, hoses, catalyst injectors or catalyst slave pumps:
  - ☐ 1) Air cap, nozzle and needle.
  - ☐ 2) Packings and gaskets.
  - ☐ 3) Extra hoses and fittings.
  - ☐ 4) Extra gauges.

B. Continuously monitor the following:
  - ☐ 1) Catalyst flow.
  - ☐ 2) Condition of all hoses (no kinks or frayed hoses).
  - ☐ 3) Spray pattern and technique.
  - ☐ 4) Contamination—if present, remove.
  - ☐ 5) Use of proper protective equipment.

C. Daily checklist:
  - ☐ 1) Drain water traps every three hours—more often if needed.
  - ☐ 2) Mix gel coat adequately but not excessively.

    Do not overmix gel coats. Overmixing can break down a gel coat's viscosity, thereby increasing sag tendencies. Overmixing also causes styrene loss, which could contribute to porosity. Gel coats should be mixed once a day, for 10 minutes. The gel coat should be mixed to the sides of the container with the least amount of turbulence possible. Air bubbling should not be used for mixing. It is not effective and only serves as a potential for water or oil contamination.
  - ☐ 3) Inventory catalyst for day's use. Check catalyst level. If using a slave arm pump, check for air bubbles.
  - ☐ 4) Start pumps with regulator backed all the way out. Open valve and charge air slowly, checking for leaks. Do not let the pump cycle (both strokes) more than 1 per second.
  - ☐ 5) To shut down:
    - a) Turn off all air pressures and back regulator out.
    - b) Bleed lines.
    - c) Store pump shaft down to keep wet.
    - d) Check for material and catalyst leaks.
  - ☐ 6) Remove spray tips and clean thoroughly. Lightly grease all threads. Protect tips from damage.
  - ☐ 7) Secure the area. Remove all solvents and check for hot spots. Remove and properly dispose of any collections of catalyzed material, catalyst/material combinations, trimming, and FRP dust.

D. Weekly (or more often, if needed) checklist:
  - ☐ 1) Calibrate each spray gun for material flow.
  - ☐ 2) Calibrate each catalyzer or catalyst slave pump for catalyst flow.
  - ☐ 3) Check gel time of gel coat through the gun versus gel time of known control.
  - ☐ 4) Clean filter screens.

SPRAY EQUIPMENT CLEANUP PROCEDURES

These instructions are not all-inclusive. For specific instructions, consult equipment manuals.

- ☐ A. Relieve all pressure from pump and lines.
- ☐ B. Place pump in container of solvent.
- ☐ C. Wipe down outside of pump.
- ☐ D. Remove and clean spray tips.
- ☐ E. Turn up pressure slowly until pump barely pumps with trigger pulled.
- ☐ F. Run two to three gallons of solvent through pump and lines, spray into bucket for proper disposal, then relieve pressure. Do not let the pump cycle (both strokes) more than one per second.
- ☐ G. Carefully open bypass at filter.
- ☐ H. Remove and clean filter—replace if necessary.
- ☐ I. Immerse pump in clean solvent.
- ☐ J. Repeat Steps F through G.
- ☐ K. Wipe hoses and gun own.
- ☐ L. Grease or lubricate appropriate parts as necessary.
- ☐ M. Inspect for worn parts and order replacements.
- ☐ N. Make sure pump is stopped in the down position to prolong packing life.
- ☐ 0. Relieve all pressure and back regulators off to ZERO setting.

14. CATALYST PRECAUTIONS—

CATALYST PRECAUTIONS

STORAGE

Methyl ethyl ketone peroxide (MEKP) formulations should be stored as follows:

STORE IN ORIGINAL CONTAINER IN A COOL PLACE. For maximum shelf life storage temperature should be below 85°F (29°C), If peroxide freezes, thaw at room temperature. Do not apply heat. Large quantities (>500 lbs.) should be stored in a separate free-standing structure in accordance with all laws, regulations, and insurance carriers.

STORE SEPARATELY. Prevent contact with foreign materials, contaminants, PROMOTERS, RED OR WHITE LABEL ITEMS, IRON, BRASS, COPPER and other OXIDIZABLES or other flammable items. MEKP must be stored away from the manufacturing area and separated from other combustibles or materials that could induce decomposition. Failure to observe these precautions could result in fire or explosion.

NEVER STORE IN A REFRIGERATOR THAT CONTAINS FOOD OR THAT IS USED FOR FOOD STORAGE!

POST SIGNS AROUND STORAGE AREA READING:

DANGER!—NO SMOKING!—KEEP AWAY!
FLAMMABLE STORAGE!
AUTHORIZED PERSONNEL ONLY!

SAFETY AND HANDLING

MEKP catalyst formulations are oxidizing materials and should be handled with care. MEKP catalyst can be hazardous to personnel and equipment if not handled in a safe manner.

FIRST AID—AVOID CONTACT AND INHALATION!

EYES—Immediately wash eyes with large volumes of water for 15 minutes and get medical aid.

SKIN—Immediately remove contaminated clothing and rewash before wearing. Wash well with soap and water.

SWALLOWING—Administer milk or water and call a physician immediately. DO NOT induce vomiting. Have physician contact the appropriate state Poison Control Center which will be listed under Emergency Numbers on the first page of the local phone directory.

INHALATION—Remove to fresh air and get immediate medical aid. Prolonged inhalation should be avoided.

Personnel should wear proper PROTECTIVE CLOTHING when handling MEKP catalyst, such as SAFETY GLASSES, GLOVES, APRONS, AIR MASKS, BARRIER CREAMS, etc.

Drain containers thoroughly and flush empty containers with water-detergent mixture before discarding. Work area should be well ventilated. All work surfaces, containers, etc. in contact with MEKP should be scrupulously cleaned and all contamination avoided. Work area should be equipped with sprinklers.

Never bring into manufacturing area more MEKP catalyst than can be used immediately. Rotate stocks systematically according to date received or lot number, in order that the oldest materials are used first.

DO NOT MIX OR STORE WITH ACCELERATORS such as dimethyl or diethylaniline or cobalt naphthenate, thiols, or other promoters, accelerators or reducing agents. Special care must be taken to avoid contamination with combustible materials, strong oxidizing or reducing agents or accelerators for polymerization reactions, etc.

Equipment and containers for handling MEKP catalyst should be made of 304 or 316 stainless steel (vented), glass (vented), Teflon®, polypropylene, polyethylene, Tygon, silicone rubber, or high purity aluminum.

Dilution is not recommended. If the user elects to dilute material, use only pure suitable diluents. NEVER USE ACETONE!

IF SPILLAGE OCCURS, use a non-combustible material like vermiculite or perlite absorbent to soak up spilled material. Using a non-sparking shovel and/or dust pan, collect the saturated absorbent and deposit in double polyethylene bags and wet thoroughly with water. Remove the polyethylene bags of absorbent to a remote protected outside area that is safe from the spread of fire should the material self-ignite. Do not place bags in direct sunlight. For proper disposal contact a hazardous waste disposal company, local authorities, or state EPA. Any usage, paper towels, etc.,should be disposed of in this same manner. Be sure to remove any isolated or hidden pockets of MEKP.

FIRE

MEKP catalyst does not ignite easily but will burn very vigorously after ignition. This peroxide must be kept away from all sources of heat and ignition such as radiators, steam pipes, direct rays of the sun, open flames, and sparks.

SMALL FIRES—Use Class B Fire Extinguishers (dry chemicals, foam or carbon dioxide) or water fog. Halon is also recommended.

LARGE FIRES—NOTIFY FIRE DEPARTMENT IMMEDIATELY! Evacuate all non-essential personnel. Fight fire from a safe upwind distance with water, preferably a fog spray or foam. **AVOID INHALATION OF FUMES**—use air masks if available.

KEEP ENDANGERED CONTAINERS COOL WITH WATER SPRAY TO PREVENT OVERHEATING. FLUSH DAMAGED AREA WELL WITH WATER—AVOID WASHING MEKP DOWN SEWERS. FIRE MAY RESULT! DO NOT ATTEMPT CLEAN-UP UNTIL DAMAGED AREA IS AT ROOM TEMPERATURE AND ALL SIGNS OF DANGER ARE GONE.

All information in this bulletin is based on testing, observation, and other reliable sources of data. It is presented in good faith and believed to be accurate. The buyer and/or user assumes all risks and liabilities arising from the use or in connection with the use of these products. CCP neither assumes nor authorizes any person or company to assume for it any liability in connection with the sales and/or use of its products, CCP

HEADQUARTERS
P.O. Box 419389, Kansas City, MO 64141-6389
800.821.3590 • Tel: 816.391.6000 • Fax: 816.381.6337

RESEARCH FACILITIES
820 E. 14th Avenue, North Kansas City, MO 64116
Tel: 816.391.6000 • Gel Coat Fax: 816.391.6026 • UPR Fax: 816.391.6254

COMPOSITES PRODUCTION FACILITIES
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800.548.9500, ext. 6213

FAX NUMBERS:
Customer Service: 800.538.7329
Sales Department: 816.391.6215

INTERNATIONAL ORDERS
816.391.6255

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(Rev. 12/02, supersedes 06/01)

Seller warrants to Buyer that, at the time of shipment, the products sold hereunder shall meet Seller's then-applicable specifications for such product. Seller's specifications may be changed at any time without notice to Buyer. To assert a warranty claim, Buyer must give Seller notice in writing of the alleged failure of the product to conform to the applicable specifications (together with all identifying details, including the product code(s), description and date of purchase) within thirty (30) days of the date of shipment of the product to Buyer and, upon Seller's request, shall return the alleged nonconforming product. The failure of Buyer to assert a claim within such period shall be an admission by Buyer and conclusive proof that such product is in every respect as warranted and shall release Seller from all claims for damage or loss in respect of such product. THE WARRANTY DESCRIBED HEREIN SHALL BE IN LIEU OF ANY OTHER WARRANTY, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. THERE ARE NO WARRANTIES THAT EXTEND BEYOND THE DESCRIPTION ON THE FACE HEREOF. Without limiting the generality of the foregoing, the warranty provided above does not extend to damage, loss, or injuries caused by or in any way related to misuse, misapplication, abuse, improper handling or storage of the product; normal weathering (including but not limited to cracking and blistering); or any cause beyond the control of Seller. Seller further disclaims any and all liability for Buyer's decision to modify, amend or reject any recommendation set forth herein. Seller does not warranty or guarantee that implementation of any of the recommendations set forth herein constitute compliance with any federal, state or local laws or regulations. Final determination of the suitability of the product for the use contemplated, the manner of use, and whether the use infringes any patents is the sole responsibility of Buyer.

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