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THE M.C.GILL DOORWAY

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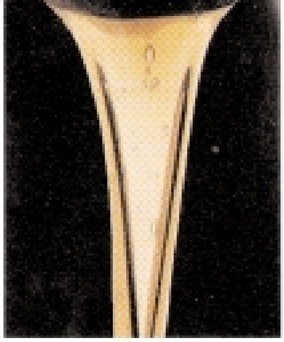
GILL COOKS COMPOSITE RESINS FOR THE '90s

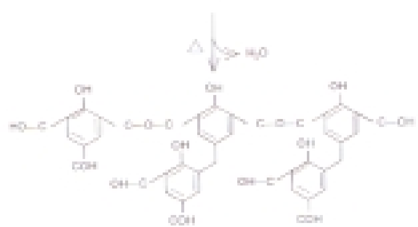


A RESIN IS A MATRIX IS A RESIN

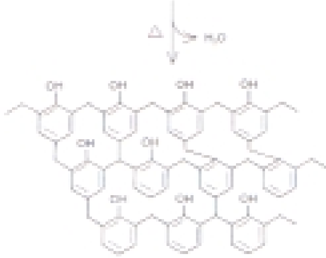
Phil Gill, Vice President-Operations, confers with a Gill chemist about a new resin formulation.

CURING STAGES OF PHENOLIC RESINS

"A" STAGE Low Molecular Weight Linear Polymer



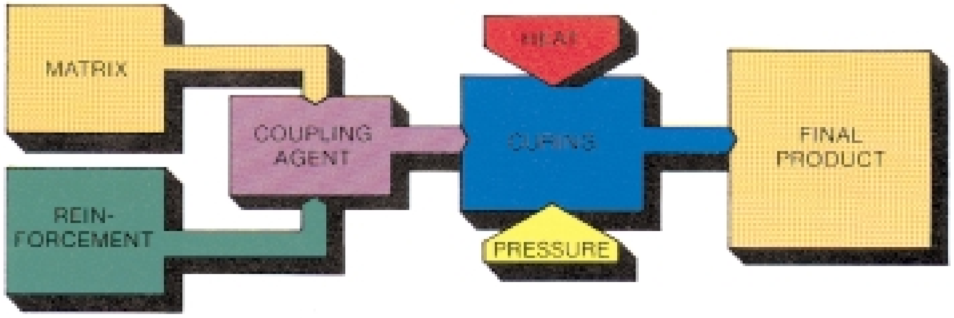
"B" STAGE Higher Molecular Weight, Partly Cross-Linked



"C" STAGE Fully Cross-Linked, Cured

Every industry has its jargon or buzzwords, and the field of advanced composites is no exception. In fact, even the term "advanced composites" is not sacred—in the 1960's and 1970's, it was "reinforced plastics." Nowadays, an advanced composite consists of approximately 50 percent reinforcement and 50 percent matrix. In the "old days" the ratio was the same, but we used resins, not matrices. And so, with apologies to Gertrude Stein, "a resin is a matrix is a resin."

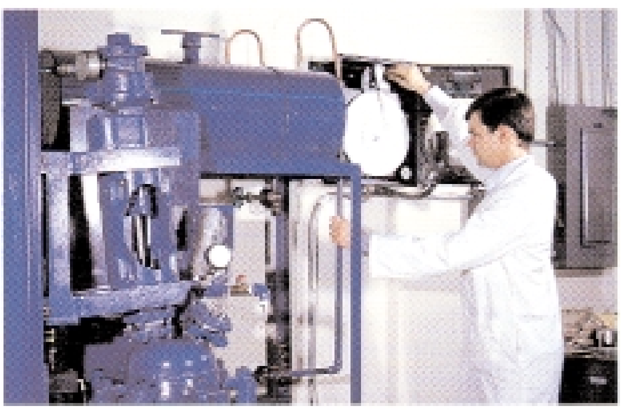
The principle purpose of a resin in a composite is to permanently integrate the reinforcements (hold them together, if you will) to achieve as many desired properties as possible. Generally, there are two groups of resins, *thermoplastic and thermoset.* The former is characterized by low processing costs lending themselves to mass produced products. Most thermoplastics can be processed at lower temperatures than thermosets; can be remelted and reprocessed; and they generally have poor fatigue, temperature, flame and solvent resistance. Low melting point resins such as ABS and polycarbonate can be reinforced, but they are generally considered nonstructural materials. A relatively new group of "engineering" thermoplastics, such as PEEK and PPS, has been developed with service temperatures of 225° to 400°F. There is high degree of interest in these resins because of their toughness and thermoplastic processing.



THE PROCESS OF MAKING A COMPOSITE

New resins and adhesives are carefully researched and developed to produce better composites.

M. C. Gill employee checking the roll of cloth after it has been pre-impregnated with resin. The "pre-preg" is used only for internal consumption.



The resins created in the chemical reactor make more desirable properties in laminates possible.

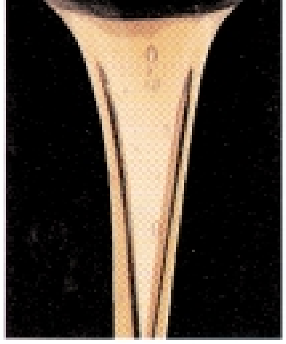
Complex new resin formulations are made possible by this laboratory chemical reactor.

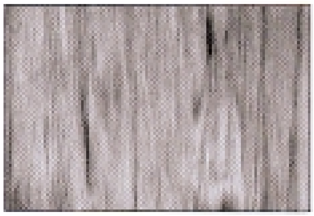
Thermoset resins undergo chemical changes during processing and become permanently insoluble and infusible. They generally have good dimensional stability and good fatigue strength; will not easily deform under loading; and have high solvent resistance. Common thermoset resins used by the M.C. Gill Corporation include: polyesters, epoxies, phenolics, acrylics, urethanes; as well as the more specialized polyimides, bismaleimides and silicones. Common materials used as reinforcements include: E Glass, S-2 Glass,® ceramic, aramid, nylon, and carbon (graphite). This wide range of resin and reinforcement choices enables us to select the optimum combination of materials for any given application.

Once the choice has been made, the reinforcement material is impregnated with resin and then cured to a finished product when subjected to heat and pressure. This yields composite materials for various structural designs — from contoured parts to multi-ply laminates to sandwich panel constructions. The common element in all these varied designs is the resin that is formulated as a low viscosity liquid and polymerized to a solid. (Polymerization is a chemical reaction in which more than two small molecules combine to form much larger molecules.)

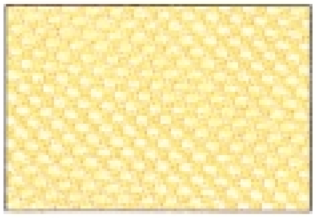
Curing a resin can be considered a three-stage

Shown on the cover is one of four reactors used to cook and modify thermoset resins at the M. C. Gill Corporation. The technician is reading the resin's viscosity which indicates the degree of polymerization, an important physical property.

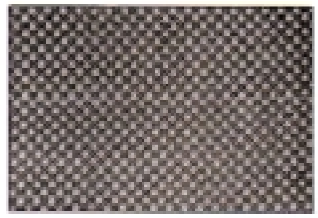




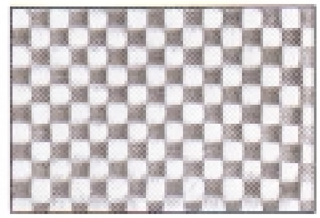
UNIDIRECTIONAL GRAPHITE



KEVLAR® PLAIN WEAVE

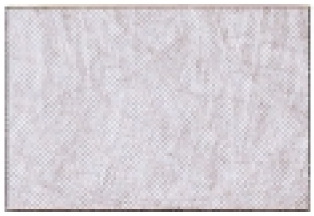


PLAIN WEAVE GRAPHITE

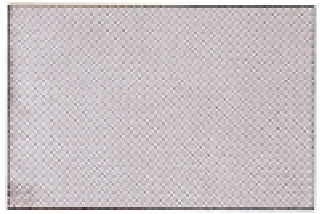


S-2 GLASS® WOVEN ROVINGS

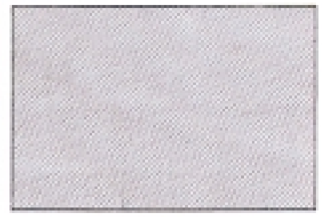
PLAIN WEAVE E-GLASS



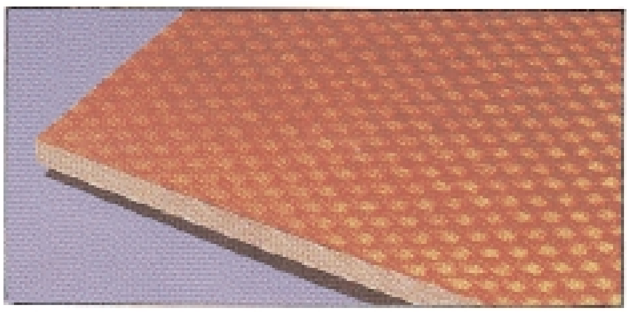
CHOPPED MAT



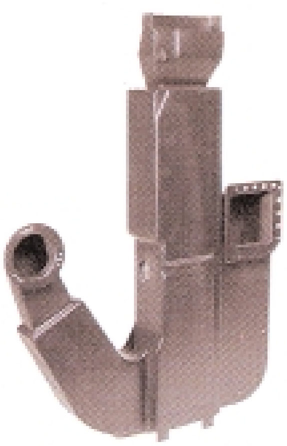
PLAIN WEAVE NYLON



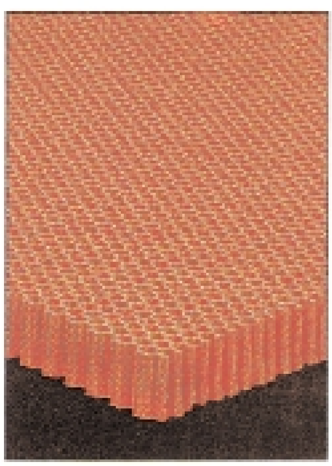
SATIN WEAVE E-GLASS



Polyester resin reinforced Kevlar® — used for personnel protecting armor.



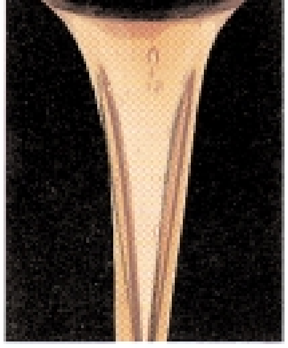
Epoxy resin reinforced fiberglass — used as a heating and ventilating "sound attenuator," fabricated for the Blackhawk helicopter.



Specially formulated phenolic resin impregnated in aramid paper honeycomb core — used as the core material in a variety of aircraft flooring and other sandwich panels.

chemical process. In Stage A, the resin is an unpolymerized, low viscosity liquid. While the resin is in this stage it is catalyzed and then impregnated into the specified reinforcements. By applying heat and pressure to the resin, bonds between the resin molecules begin to form. With many resins polymerization can be stopped so in Stage B the resin is semi-hard and can be laid up into shapes. The fully cured Stage C is the last phase wherein the resin becomes hard, insoluble and cannot be remelted. Depending on the type of resin, Stage C can happen at room temperature with no additional pressure (as with polyesters or epoxies) or it can require high temperature curing and added pressure (as with phenolics and polyimides).

Generally speaking, most of the "trade secrets" are concerned with resin formulation and processing expertise, because reinforcements are fairly standard and available to everyone. Even utilizing the same reinforcement, each resin group has distinct methods of processing and specific properties that will greatly affect performance of the finished part. Given the desired characteristics of the end product, the selection of a proper resin is a crucial design consideration. With the M.C. Gill Corporation's forty-five years of experience, one of the most modern laboratory and production facilities available…and the expertise and backgrounds of our research and manufacturing personnel…we believe we are as capable as any, and better than most, at selecting the proper combination of resins and reinforcements that will result in products with the properties required by our customers' most demanding specifications.



TYPES OF RESINS

Because thermoset resins are so widely used by the aircraft and aerospace industries, among other high-technology fields, and because they are a specialty of the M. C. Gill Corporation, the following paragraphs discuss the most widely used such resins.

POLYESTERS (ALSO VINYL ESTERS)

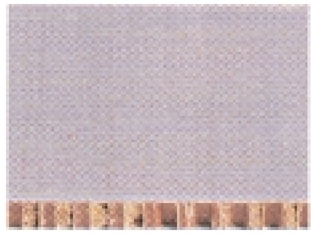
Polyesters were discovered in the 1930's and were the first resins used in development of reinforced fiberglass plastics. For a thermoset resin, polyesters are relatively low in cost and easy to process (vinyl esters are simply high performance polyester resins, that are more costly but offer better chemical resistance and improved mechanical properties). Polyesters are liquids with fast cure times and have minimal outgassing during cure cycle(s). They are readily extended with low-cost fillers, making them ideal for high-volume applications such as automotive, construction, marine, electrical and corrosion resistance applications. They have fairly high mechanical strength and perform well in high-impact applications such as cargo liners. M. C. Gill products using polyester resins include almost all of our cargo liners as well as the facings on some of our sandwich panels, e.g., Gillfloor 5007A, 5007B, and 5007C.

ADVANTAGES:

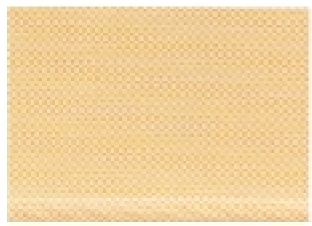
1. Low initial cost.
2. Easily modified to meet most fire retardant specifications.
3. Corrosion resistant grades available.
4. Can be formulated for satisfactory service in sunlight and wet environments.
5. Easily pigmented to any color, or made translucent.
6. Can be laid-up on very large, low-expense molds and cured at room temperature without pressure.
7. Non-toxic in food environment — not moisture sensitive in processing.
8. Will take high-filler loading in low-cost applications.

DISADVANTAGES:

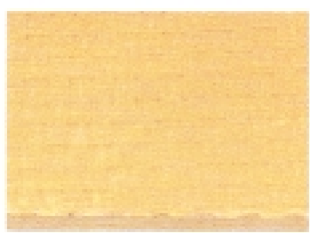
1. High smoke and toxic emissions in a fire.
2. Not suitable as an adhesive.
3. Service temperatures generally below 180°F.
4. High shrinkage during cure (4% to 8%) which can result in internal stresses and poor surfaces.
5. Medium mechanical strength, with a tendency to be brittle.
6. Non-polar molecules cause low interlaminar adhesion.



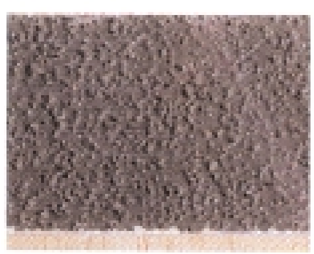
EPOXY
Gillfloor 4017, Type II — Unidirectional fiberglass reinforced epoxy resin laminate with Nomex® honeycomb core using epoxy adhesive. Used as lightweight aircraft flooring.



ACRYLIC
Gillfab 1009 — Thermoset acrylic resin reinforced nylon cloth. Bonded to acrylic windshields and canopies as reinforcement when bolting to airframe.



VINYL ESTER
Gillfab 1160 — Light weight ballistic laminate most effective at stopping shrapnel. Made of vinyl ester resin and Kevlar® reinforcement.



POLYESTER
Gillfab 5407 — Made from Gillfloor 5007B fiberglass reinforced polyester resin laminate facings and balsa wood core with an additional .030 non-skid coating.

EPOXIES

For some time epoxies have been the resin of choice for advanced composites and the one by which all others are referenced. They are more costly than polyesters and require more demanding processing including slower cures, which increases manufacturing expense. However, they are highly polar, which provides good adhesion to polar surfaces and metals. Due to their higher cost, they have found their commercial success mostly in high performance applications, such as high-strength composites, high-endurance coatings and electronic circuit boards. We believe they make the best adhesives and produce strong composites, but are not well suited for applications requiring high puncture resistance. Moreover, their usage in commercial aircraft interiors is rapidly declining because of their high smoke evolution in a fire.

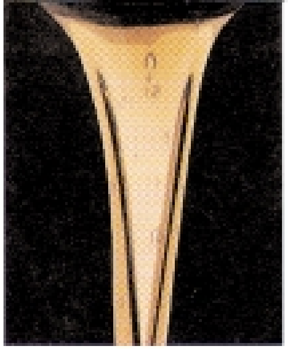
Much more than other resins, epoxies lend themselves to easy molecular modifications. The selection of the hardner and the activator greatly influences the resin's properties. Many M. C. Gill sandwich panels utilize epoxy in the construction of their facings, among them Gillfloor 4017, 4105, and 5166.

ADVANTAGES:

1. Can be formulated to have many (not all in one resin, however) of the following desired properties: high peel and flexibility, good dielectrics, 350°F service temperature, high mechanical strength, and resistance to chemicals, fire, and abrasion.
2. Excellent adhesion to metals, glass, and other polar surfaces. (Very difficult to delaminate.)
3. Can cure at room temperature or at elevated temperatures, with or without pressure.
4. 100 percent reactive so no gassing on cure or contaminating by-products.
5. Makes very good cloth prepregs for electronic circuit boards.

DISADVANTAGES:

1. Higher initial cost than polyesters.
2. High smoke evolution in a fire.
3. Poor service in exterior applications unless protected against ultraviolet light with paint or equivalent.
4. In aerospace applications, considered to have poor hot-wet strength characteristics at high temperatures (350°F and above).
5. Somewhat difficult to process (slow curing and moisture sensitive).



PHENOLICS

Phenolic resins are lower in cost than epoxies. They have been overlooked for advanced composite construction because they give off volatiles during cure, thus creating voids in the composite. A one percent void will reduce strength by about six percent. However, they are inherently non-burning and emit very low smoke evolution in a fire compared to almost any organic polymer and, as a result, they are highly desirable for use in aircraft interiors. They can be modified for toughness and adhesion but during the process, some of their desirable low smoke characteristics can be lost.

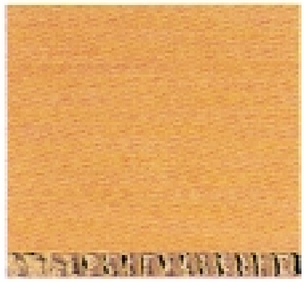
Nevertheless, in low smoke applications we believe phenolics are the most cost effective choice available. We have and are continuing to invest heavily, both in man-hours and dollars, in efforts to modify them and still retain their low smoke properties. Gilliner 1167 and 1367 are two of our cargo liners utilizing phenolic resins in their construction and are original equipment in McDonnell Douglas and Boeing aircraft respectively. It is also a component in Gillfloor 4004 and 4109 sandwich panels among others.

ADVANTAGES:

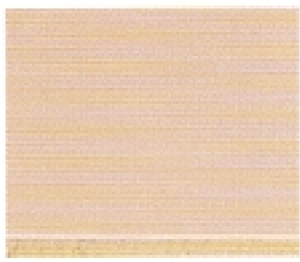
1. Low cost.
2. Non-burning and low smoke by most test methods.
3. Good strength retention at elevated temperatures if post cured.
4. Good mechanical strength and fair puncture resistance when modified.
5. Capable of withstanding prolonged high temperature (300° to 400°F).

DISADVANTAGES:

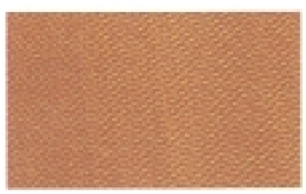
1. Light colors difficult to achieve.
2. Lower strength than epoxy — more similar to polyester.
3. Slow, high temperature curing and moderate pressures.
4. Emit 4 to 8 percent volatiles during cure, producing parts that may have porous surfaces with micro-voids.
5. Difficult to modify.
6. Must be prepregged, which increases cost.



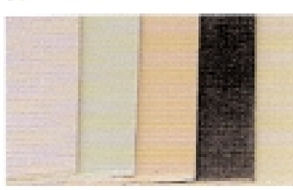
PHENOLIC
Gillfab 4122—Made from fiberglass cloth reinforced phenolic facings bonded to Nomex honeycomb core. Has minimal smoke emission.



EPOXY/URETHANE FOAM
Gillfab 5019—Fiberglass cloth reinforced epoxy resin laminate facings with polyurethane foam core. Used for sidewalls on liquor carts.



PHENOLIC
Gillfab 1167—Modified phenolic resin reinforced woven fiberglass cloth (without the 1 mil Tedlar® overlay). Used for low-smoke emission cargo liners in commercial aircraft.



POLYESTER
Gillfab 990C—Polyester resin reinforced chopped strand fiberglass mat. Used for laboratory counter and table tops. Excellent chemical resistance.

ACRYLICS

Acrylics are extremely translucent and have ultraviolet (sunlight) resistance. They are the best resin systems available to withstand weathering in an exterior environment (outdoors). Unfortunately, they burn, are structurally weak, and very difficult to process with reinforcements. The M.C. Gill Corp. is one of the few companies that can accomplish that process. Acrylics are highly polar and can be formulated into very strong but somewhat brittle adhesives. Typical products using acrylics are Gillfab 1000, 1009 and 1122, as aircraft windshield reinforcements.

ADVANTAGES:

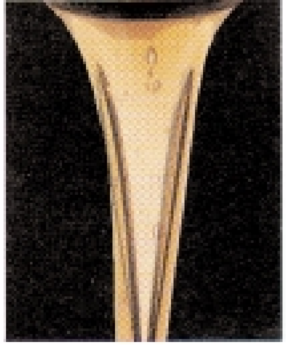
1. Excellent weathering.
2. Good impact strength.
3. Translucent or transparent.
4. Excellent adhesion.
5. Can be thermoformed.

DISADVANTAGES:

1. Burns easily in most flame tests.
2. Poor temperature resistance.
3. Difficult to process with reinforcements.
4. Relatively poor mechanical strength (similar to thermoplastic).
5. Poor scratch resistance.

SILICONES

Silicone is an inorganic resin having no carbon in its molecular structure, meaning there is almost no smoke emitted when burned. Normally used as a lubricant, it can be formulated to form a polymer that is weak, brittle, hard to modify, and difficult to process. Not surprisingly, it has experienced little commercial success, finding acceptance only where high temperature retention of mechanical and electrical properties is critical. The M.C. Gill Corp. is one of a very few companies that processes reinforced silicone resins for structural applications. Gillfab 1017, a high temperature resistant sheet, is a good example of a silicone product.



URETHANES

Urethanes can be formulated to achieve almost any property from flexible foams to roller-skate wheels to bowling balls. However, they are more costly than polyesters and have some toxicity problems when burned, so they have not found wide usage in low cost applications. Moreover, they have high smoke evolution in a fire. Urethanes are considered to have excellent abrasion resistance, adhesion, and toughness.

POLYIMIDES AND BISMALEIMIDES

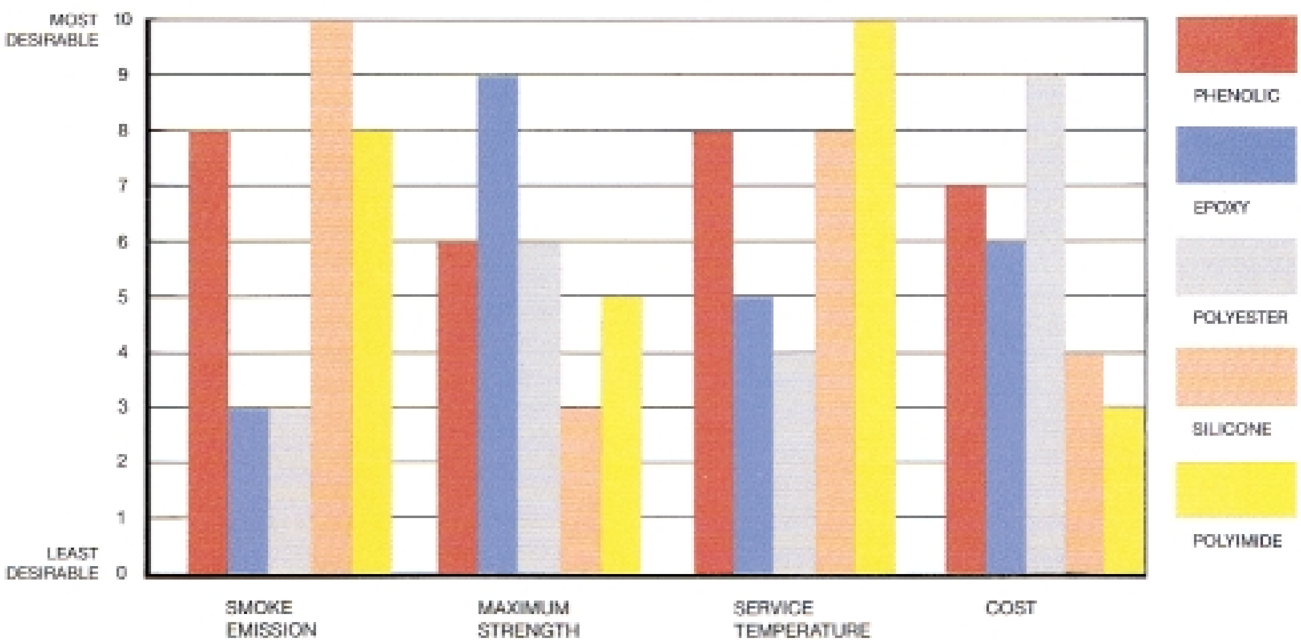
Polyimides are condensation-curing resins (they give off volatiles when curing). Service temperatures range up to 600°F, but are also processed at 600°F, making them difficult and expensive to produce. They perform essentially as high-temperature versions of phenolics, but costing much more and being much more difficult to process. Like phenolics, they are normally brittle, non burning and have low smoke evolution in a fire.

Bismaleimides cost even more than polyimides, process almost as easily as epoxies, and exhibit strength retention at elevated temperatures a little lower than polyimides — 400°F to 500°F. Most available literature fails to mention that they burn in FAA fire tests.

At room temperature, both of these resins are relatively weak and because of their cost, they are considered only for high-temperature applications.

WHICH RESIN IS THE BEST TO USE?

There are no hard and fast answers. Properties desired in the end use application is generally the deciding factor but even that answer has its limitations. For example, epoxies provide good mechanical strength, which is important. But, cost is also important and that factor would dictate polyester. If, as we expect, the FAA sets smoke emission criteria as the overriding characteristic, then phenolics are the best available. As the graphic below shows (10 being the most desirable), there is no cut and dried choice. The one constant in this seemingly confusing array of options is that the M.C. Gill Corporation will be continually improving and upgrading all the resin formulations we employ to ensure that no matter which resin our customers select, it will incorporate the latest technologies available and its performance will be second to none!



Errata — In our last issue, on page 9, third paragraph, the last sentence should read, "Likewise, Gilliner 1367 and Gilliner 1367A are qualified to Boeing Specification BMS 8-223, Class 2, Grade B, Ty 13 through Ty 70."

New Lightest Weight, Non-Burning Gillfloor Panels Selected For The MD-11

On February 8, 1990, the M.C. Gill Corporation was awarded the contract to supply passenger compartment flooring for McDonnell Douglas' new wide cabin MD-11 tri-jet. The award was made by General Dynamics, Convair Division, subcontractor to Douglas Aircraft Company.

The eight-figure award is one of the largest in the company's history and it signals the continuation of our long associations with both General Dynamics and McDonnell Douglas. The M.C. Gill Corp. will supply the raw stock panels and General Dynamics will prepare them for final installation in the MD-11.

GRAPHITE AND GILLCORE

Gillfab 4109 was selected as the material of choice for the passenger compartment and the cockpit flooring. It is constructed from unidirectional carbon reinforced phenolic facings bonded to an aramid honeycomb core. The unidirectional carbon, or graphite, was selected for the facing material because of its very light weight (approximately 20 percent lighter than other conventional floorings) and stiffness — characteristics shared by the aramid honeycomb core.

LOW SMOKE RESIN

Phenolic was the resin system of choice because it is inherently non-burning and exhibits very low smoke evolution in a fire. These two qualities are becoming increasingly important in today's aircraft safety requirements. Most important, it qualifies to McDonnell Douglas' rigid requirements — in this case DWG 7954400 Rev. D, Ty 1 & 2.

The M.C. Gill Corporation has long been in the forefront in the manufacture of low smoke and burn-through resistant composites not only for sandwich panels, but cargo liners as well.

McDonnell Douglas was one of M.C. Gill's first commercial customers and their selection of the company as a supplier for the 4109 flooring panels is another in a series that dates back almost forty years to 1951. We look forward to and fully expect to continue the relationship for at least another forty!