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PREFORM BINDER TECHNOLOGY

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PREFORM BINDER TECHNOLOGY

by

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ABSTRACT

This paper will discuss the critical properties and processing characteristics of directed fiber preforms as they relate to the different types of binder systems that can be used to produce the preforms. General presentation of the effects of the different binder systems in preforms will be made. A new integral string binder roving product will be introduced with some comparative data.

BACKGROUND

Directed fiber preforms have been used in the composite industry for the past sixty some years. They are a chopped fiber mat made as an intermediate product in the shape of the part they will be used to reinforce. Directed fiber preforms, or just "preforms" for our purposes, replace the use of roll goods and other types of chopped fiber reinforcements, such as those found in sheet molding compounds or used in spray up processes.

Preforms are made by chopping lines of fiberglass roving, which are strands of glass filaments collected into a tow or bundle, and depositing them onto a screen through a vacuum is being pulled. The screen is in the shape of the part desired and the vacuum holds the chopped in place. Applied with the chopped fibers is a binder that will hold the fibers together once the binder has been processed either with heat or light depending on the type of binder. See Figure 1 for a typical schematic of the preform process.

The sole purpose of the binder in a preform is to hold the chopped fibers together so the preform can be handled and molded into a part. How the binder does this determines many of the preform's properties, affecting its strength, stiffness, loft and permeability. Compatibility of the binder to molding resin may also impact a part's surface appearance and coupling of the resin to fibers.

For many years the "Holy Grail" of directed fiber preforming has been to discover a perfect binder with which to hold together the reinforcing fibers without adverse impact on the molding process or the finished part. When fabricating glass fiber preforms, the method of holding this mass of individual strand bundles together generally requires more than just a simple adhesive. The dynamic requirements for handling and molding of the preform can lead to some rather significant compromises in the choice of a binder versus the physical and aesthetic requirements needed for the part.

PREFORM CHARACTERISTICS

As a preform is a subcomponent of a molded part, the ultimate determinate of a good or acceptable preform is that it can make an acceptable molded part. That is, the molded part using the preform meets all of the specified requirements for strength and appearance. It is from these molded part requirements that the necessary preform properties are made known and developed.

To begin with, the need for a fiber reinforcement in a part is to add strength to the resin matrix, and often times a fiber content in some form is specified for a part. To achieve this with a given resin and part thickness, a mat weight or areal density can be determined for a preform. One advantage of preforms over mats or fabrics is that preforms can be made to any variety of weight, whereas mats are discrete weights often requiring several layers. Even when unspecified, practicality provides a range of acceptable fiber contents for a part, that is of preform mat weights, in that too much fiber can cause non-fills in molding, while too little can lead to resin richness and cracking. The other advantage of preforms over mats, fabrics, and cloths is that they are to the shape of a part. Parts having any significant geometry would bridge or wrinkle or stretch over radii leading to resin richness in corners, unacceptable surface appearances or areas of reduced fiber content. Obviously, the design and manufacture of preforms needs to meet these requirements of areal density and part geometry.

Other properties of a preform relate more to the molding process and the part producability. One important factor is the loft or thickness of a preform. Loft is a function of both the mat weight of a preform (It is easy to see that the more glass in a preform the thicker it is.), and the amount of open space in the vertical stack up of fibers due to their conformability. This latter is a result of many variables including the type of fiber, the type of binder used to hold the fibers together and how the preform was made: e.g., how much compaction was used when the binder was set. To mold acceptably, a preform needs to fill the cavity of the closed mold, otherwise resin rich areas would occur. Preforms that are too thick generally provide non-fills when molded. In either case an areal density problem may be occurring or, if the density is right, than the processing of the preform is in question.

Closely related to loft is the permeability of the preform; see Attachment 1. This is the ability of the resin to be pushed through the preform during molding. If the preform's mat weight is correct, loftier preforms are more permeable as there is more space for the resin to flow through. Impermeable preforms are just that: fiber dense that create dry spots upon molding.

Apart from loft and permeability but involving many of the same processing parameters, are the preform's strength and stiffness. Sometimes mistakenly thought of as the same in a preform, strength and stiffness are distinct properties. Preform strength, specifically mat tensile strength; see Attachment 2, is a measure of how strong the fibers of a preform are adhered to one another. A weak preform can experience wash when molding, the condition where the resin as it flows through the preform actually pushes the preform fibers out of place. This is visual in the molded part as directional fiber alignment, is usually unacceptable to the appearance requirements of the part, and indicates an area of weakness due to fiber orientation and content change. Generally, higher mat tensile strength is always better.

The perform tensile test determines the tensile load of a fiber glass perform or a glass mat. A test for preform mat tensile has been adapted from industry standards for determining integrity of chopped strand mat. The specimen is cut to a 12"x 12" test size and is then clamped into test position with pneumatic grips; again see Attachment 2. The test is run at a crosshead machine speed of 0.20 in/min. Once the specimen has reached maximum load the crosshead returns and the test is completed. The data recorded is Peak Load and Extension at Peak Load..

Stiffness, which is a property different than mat tensile strength, is the ability of a preform to hold its shape. A preform with no stiffness is not much better than a piece of mat. On the other hand, preforms that are too stiff may expose inconsistencies between the screens used to make the preforms and the mold; that is, too stiff a preform may not conform to mold and may cause problems in glass content or molding issues such as resin richness. Again, do not confuse stiffness with mat tensile strength. On one hand, imagine a very strong preform that cannot be torn apart but collapses like a wet rag under its own weight. On the other, there is a preform that holds its shape and does not want to bend, but can be readily pulled apart. Of course, the best and worst of both are also possible: a strong, stiff preform and essentially a pile of glass. A preform's strength and stiffness not only affect how a part may be molded but also play a large roll in the manufacturing process. How well and how much the preform can be handled without being damaged, how it can be stacked and stored, how well it carries resin, etc.

Straightforwardly, both strength and stiffness are functions of the preform's binder, its amount and processing. (Both also are functions of glass type and mat weight, but as these tend to be more givens when wanting to adjust a preform's strength and stiffness.) This leads to a discussion of preform binders.

PREFORM BINDER TYPES

There are three general types of binders: powder, liquid and string. The powders and liquids are generally sprayed onto the preform at some, often various points, in its production process. String binders are applied with the glass when making the preform, either as a separate line or as part of the glass roving. In fact, when applied as a separate line, string binder can be in processing somewhat more akin to the powders and liquids, as it is a separate spray of material.

A separate spray pattern of binder, requiring air in all cases for conveyance, has the adverse effect of disrupting the glass conveyance if they are applied at the same time. Hence, getting the proper areal density and uniformity of mat weight becomes problematic. If they are applied separately to avoid this problem, then a cycle time penalty is incurred. Needless to say, separately sprayed binders require their own spraying equipment and process set ups in addition to that used for the glass fibers.

Transfer efficiency of a separately sprayed binder is also a concern both from the loss of binder including where it ends up and what problems it may cause there, and from the fact that more binder is actually used to replace what failed to transfer into the preform in the first place.

Liquid emulsions have been the mainstay of directed fiber preforming and have provided excellent flexibility in the application and strength of the binder. The performance of these liquid emulsions can be tailored for a broad spectrum of adhesion characteristics depending on the choice of molecular weight and crosslink density of the polymers. The emulsions can be applied using atomizing sprayers at various concentrations during the forming process. Timing of the spray delivery and the concentration of the emulsion (solids) can all be easily adjusted to provide more or less adhesion to the glass.

Unfortunately, emulsion binders have several problems. To begin with they require preparation of the emulsion itself usually involving some mixing, the addition of a curative, and all the process control needed for an intermediate processing material. The liquid binders require a large amount of energy to remove the water and cure the remaining polymers. Off gassing and vapors from the exothermic polymer reactions can also lead to health and environmental concerns. The atomized over-spray from these binders, registered as a drop in transfer efficiency meaning more binder needs to be used, can create a great deal of contamination surrounding the process. The sticky residue gets on the screens, and inside the air-handling equipment. The combination of this buildup and processing heat creates additional maintenance and clean up and, in a worst-case scenario, could result in a fire.

Powder binders consisting of finely granulated thermoset or thermoplastic polymers do provide for a dry spray application in the preforming operation. These powders, once applied to the glass fibers, can be reacted thermally (melted or cured) or light activated with UV curatives. Their primary advantage in the preforming process is that they require significantly lower thermal energy than do emulsion binders.

Transfer efficiency and distribution of the powders can be difficult to control. The spray pattern and uniformity within the preform can also be problematic. Powders tend to migrate through the glass fibers toward the forming screen. This causes a binder-rich surface that can detract from the molding process and part appearance. High levels of waste and the possible need for material recycling can result in additional expense in the process.

Strings and binder fibers are not a recent phenomenon. There have been a number of different types of binder fibers that have been used with glass to provide adhesive functionality to directed fiber preforms. Synthetic (thermoset or thermoplastic) fibers chopped dry along with glass fibers can provide a more uniform distribution and better bridging in the preform than powder binders. When chopped together, there also isn't the need for synchronizing and maintaining a secondary application system for delivery of the binder.

However, the issues related to feeding and chopping of two radically different types of fibers at the same time could be challenging. There is added complexity in maintaining separate fiber inventories and in keeping the proper blending ratios of both products going into the chopper. The choice of a synthetic fiber with the right combination of tenacity for chopping and the thermal characteristics needed for binder adhesion can also be a challenge. Glass fibers that have been selectively coated with additional binder and blended into traditional rovings are available. These products are limited in their thermal range and are costly to produce.

Consequently, string binders have not been used to great degree. However, a new family of preform rovings containing a string binder is a solution to these long time problems. This roving has appropriately-sized and drawn glass fibers that have been co-mingled with special thermoplastic synthetic fibers; see photograph #1. It is the co-mingling and matching of the string binder to the glass roving that allows this new material to overcome several of the issues mentioned above. These ready-to-chop rovings provide both reinforcement and binder that can be individually tailored to specific preform applications and various molding processes.

Comparatively, the string applied as part of the roving package provides a tight control on the amount of binder applied. If the amount of binder in the roving is 7%; the amount of binder in the preform is 7%. The binder dispersion is the same as the glass. This has the limitation of making binder content changes not available with the glass being applied. On the other hand, it induces none of the variability that occurs with the individually sprayed systems. Sprayed binder systems generally create preforms with significant binder variations, so that one area of a preform is stiff and strong, while another area may be immediately adjacent is weak or limp. On robotically made preforms, there is a desire to always do more programming to get better dispersion of the binder. On manually made preforms, the tendency is to add too much binder, adding cost as binders are not cheap, to avoid weakness.

Related to the variation in preform binder as applied, is transfer efficiency of the binder. The co-mingled string binder generally is 100% transferred into the preform. Losses of the co-mingled binder due to the vacuum through the screen are generally small. As expected preform binder contents are very close to the percentage of binder in the roving. For the separately sprayed systems, there is tendency to get an amount of binder not on the preform; that is, excess binder is sprayed off the part edges. Additionally, for the liquid and powder sprays, which are significantly smaller in particle size than string, a substantial portion is sucked through the screen by the vacuum. Their transfer efficiency, the percentage of binder applied that actually ends up in the preform, is usually much less. String Binder Rovings can be processed using most standard chopper designs. These rovings have a continuous and uniform supply of binder that exhibits nearly 100% transfer efficiency to the preform screen. Once on the screen, the preform requires that sufficient heat be applied (between 300 to 450 F depending on string type, remember usually 300+ F temperatures are required for any heat cured thermoset binder) to briefly melt a portion of the thermoplastic fibers. The molten polymer then contacts the surrounding glass fibers becoming a hot-melt adhesive that solidifies after cooling. The resulting preform can be immediately removed from the screen with no residue or sticking and has excellent integrity and handling properties.

A list summarizing the quality aspects needed for a roving product of this type to be successful in the composite fabrication process is shown in Exhibit #1. Note that the performance expectations of the string binder roving are far-reaching with respect to all stages of the process leading up to the final part quality.

A general comparison of the characteristics of the different binder types is shown in tables 1 and 2.

The mechanical properties of two composites, one molded with a preform made from emulsion binder and the other with string binder were compared. Both preforms were made with the same fiberglass product consisting of the same size chemistry and strand geometry. The comparison in table #3 indicates that no significant differences in the composite properties were observed. The synthetic fiber used for the string binder does not interfere with the coupling between the glass and matrix polymer.

CONCLUSION

Directed fiber preforms made with co-mingled, thermoplastic String Binder Rovings offer a viable alternative to preforms made using other binder systems. In many instances, they are advantageous as in turns of transfer efficiency, ease of handling and maintenance of associated equipment.

APPLICATION

One project to use a co-mingled string binder for preforming was begun in June of 2005. Conversion of a single production cell was involved. In the first year following the conversion, the cell has produced over 50,000 string binder preforms that have been fabricated, molded and shipped to their respective customers. There has been no reports of any problems with the string binder parts.

Also, in this instance, the preform binder was being converted from a thermoset liquid binder that was cured by the use of gas-heated ovens. The conversion provided a significant energy savings by not using the oven to set or cure the binder system. Rather, a form of localized heating is being used in conjunction with the string binder, which was not possible with the previous liquid binder used. The energy savings is further fueling the push to implement the string binder system on other parts.

See photographs 2, 3 and 4 below of the production, string binder preform and molded part.

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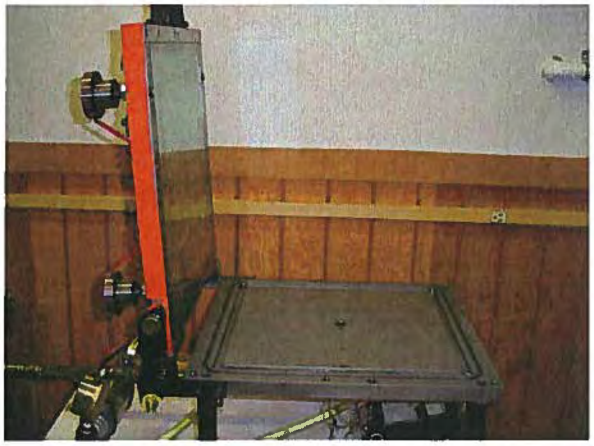
Mr. Sesco has over 25 years of experience in non-metallic Materials and Processes, including work on composites at MFG, Plascore, General Electric Electromaterials, Grumman Aerospace, and in fuel containment at Rockwell International, Uniroyal Plastics, and Amfuel. He holds a Bachelors in Chemical Engineering and a Masters in Philosophy, both from The Ohio State University, and also an MBA.

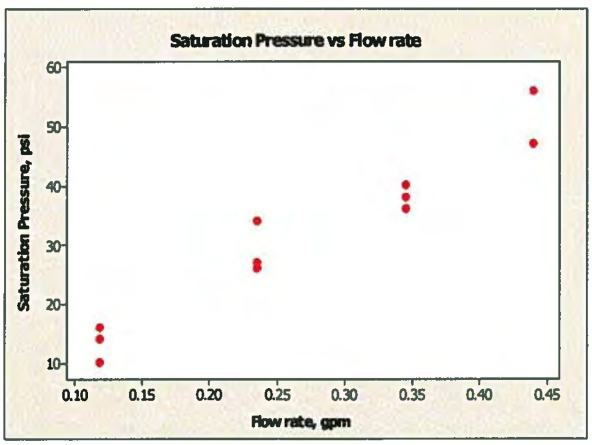
TABLE 3

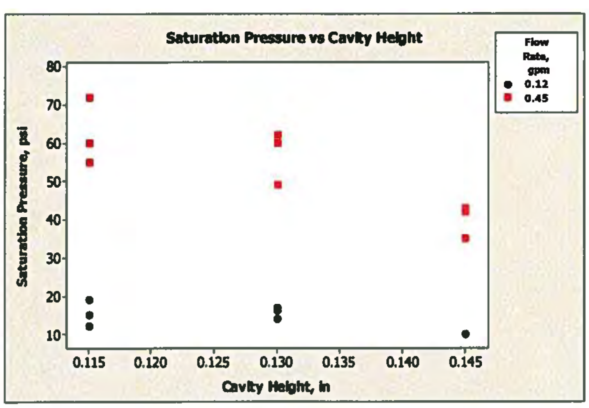
Results: ASTM		5509 Glass/liquid binder	5509 Glass/string binder	
TENSILE STRENGTH D-638				
Average		118	124	MPa
Standard deviation		19	18	
Number of samples		6	6	
FLEX STRENGTH D-790				
Average		204	203	MPa
Standard deviation		16	25	
Number of samples		6	6	
SECANT MODULUS D-790				
At 2.5 mm & 22C	Average	9830	9180	MPa
	Standard deviation	1200	1100	
	Number of samples	6	6	
At 2.5 mm & 70C	Average	7920	8720	MPa
	Standard deviation	1300	1300	
	Number of samples	6	6	
UN-NOTCHED IZOD D-4812				
Average		1690	1530	J/m
Standard deviation		210	130	
Number of samples		6	6	
Break Type		6P	6P	
GLASS CONTENTS D2584				
Average		51.07	47.82	% wt
Standard deviation		2.13	2.67	
Number of samples		6	6	
SPECIFIC GRAVITY @24C D-792				
Average		1.46	1.49	
Standard deviation		0.04	0.02	
Number of samples		6	6	
WATER ABSORPTION D-570				
Average		0.65	0.53	% wt
Standard deviation		0.076	0.029	
Number of samples		5	5	

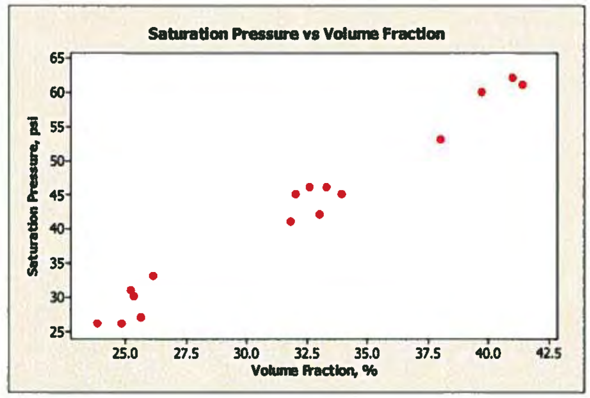
ATTACHMENT 1: PREFORM PERMEABILITY

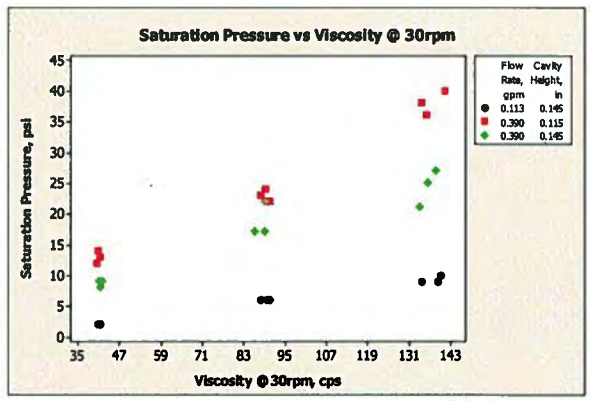


PREFORM PERMEABILITY TEST









PREFORM PERMEABILITY GRAPHS

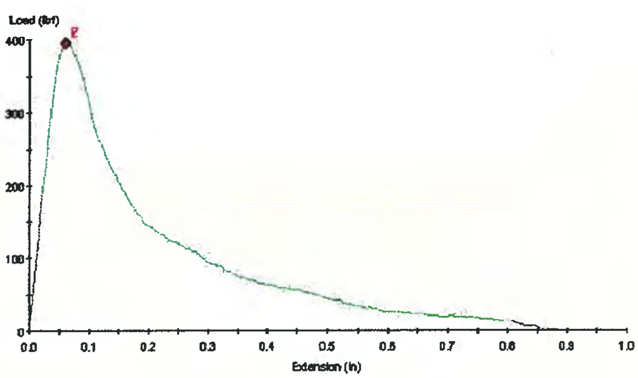
The permeability of a material is a measurement of how easily a known viscosity fluid will pass through the material. Knowing the permeability of a glass reinforcement to be used in a closed mold situation can help with selection, processing and troubleshooting.

MFG is a liquid composite molder (LCM) involved in compression molding, resin transfer molding (RTM & RTM-Light) and infusion molding. For the LCM industry, the level of difficulty in pushing a resin through a reinforcement can be predicted to an extent by the permeability of that reinforcement. However, permeability is only one of the factors that will influence reinforcement selection.

ATTACHMENT 2: PREFORM TENSILE

PREFORM TENSILE TEST

The perform tensile test determines the tensile load of a fiber glass perform or a glass mat. The specimen is cut to a 12"x 12" test size and is then clamped into test position with Pneumatic Grips using maximum air pressure. The test is run at a crosshead machine speed of 0.20 in/min. Once the specimen has reached maximum load the crosshead returns and the test is completed. The data recorded is Peak Load and Extension at Peak Load.



PREFORM TENSILE GRAPH

EXHIBIT 1

Customer Process

"Critical to Quality" for Product Performance

Preform Fabrication

Tangle-free package payout
Low fuzz buildup on contact points
Complete chopping of strands
Uniform lay-down on screen
Complete dispersion of string fibers
Glass strands conform to contours
Preform releases from screen
Preform maintains handling integrity

Molding Performance

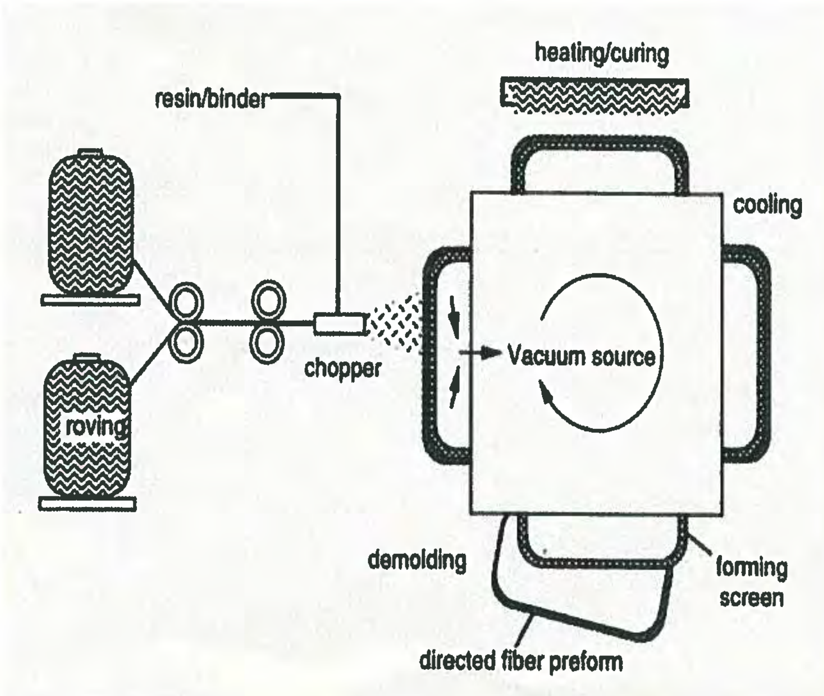
Preform fits well into mold cavity
Preform maintains loft/volume in mold
Resin flows easily to wet preform
Air is evacuated quickly
Resin does not allow fibers to move
Preform does not shift or lose uniformity
String doesn't remelt/plate to mold surface

Finished Part

Part releases easily from mold
Low surface distortion/waviness
No resin-rich or resin-starved areas
Glossy defect-free surface
Little or no fiber print-through
Excellent Mechanical Properties

String Binder

CO-MINGLED STRING BINDER ROVING
PHOTOGRAPH 1



BASIC PREFORM PROCESS
FIGURE 1

STRING BINDER PREFORM PROCESSING
PHOTOGRAPH 2

STRING BINDER PREFORM
PHOTOGRAPH 3

MOLDED PART
PHOTOGRAPH 4