RESIN TRANSFER MOLDING OF COMPOSITE STRUCTURES

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ABSTRACT

Resin Transfer Molding is a manufacturing process that is growing in acceptance and usage. RTM has the potential to become the lowest cost production method for many new high quality, high performance composite applications. Some of the more significant elements of the process are reviewed. Achieving the all important volume fraction is discussed. An application is examined and areas requiring further research are identified.

KEYWORDS: Resin Transfer Molding; Manufacturing.

ELEMENTS OF THE PROCESS

Resin Transfer Molding is a relatively straight forward process. A dry preform of reinforcing fiber materials is placed in a cavity in the mold half. The two halves of the mold are joined together and catalyzed resin is injected at low pressure into the mold, wetting out the preform. The part is allowed to cure in the mold. It is then de-molded and finished. Post cure may be required, depending on the type of resin and the cure cycle used in the mold. The finished part has mold-controlled surfaces on all sides. Inserts, ribs, bosses and cores can be molded in place. Both primary and secondary structures can be molded due to the high fiber loadings that can be achieved.

RTM can produce complex structures and large net shapes. The process offers potential for lower costs because of relatively fast cycle times, parts consolidation, potential for automation and control of the amount of material used. Chemical exposure to shop personnel is greatly reduced due to the nature of the RTM process; the chemicals are handled inside process equipment.

The mold must be designed to maintain its mechanical integrity under the temperature, chemical and pressure conditions required to make the part. It must also maintain its dimensional stability so that parts will be produced within specified tolerances and volume fractions. The number, size and location of resin inlet port and outlet, or vent positions, are critical to the success of the mold design. The geometric center of the part, gravity, resin flow front and path length, as well as the necessity to eliminate air in the part all influence these locations. Both the inlet port and the vents are to be furnished with shut-off mechanisms and may require provisions for pressurizing the resin during the cure cycle.[1]

Both pressure[2] and vacuum[3] have been suggested to improve the quality of RTM moldings. Many other factors affect the process, including type and thickness of reinforcement, volume fraction, resin characteristics, mold geometry, thermal charactertistics, temperature and ambient conditions. Such details as storage conditions and moisture content of the reinforcement and resin systems must be addressed. For example, if the reinforcement contains excess moisture when it is placed into the mold, it may react with the resin system to produce a small amount of gas which will increase the void content of the finished part. The fiber/matrix interface also must be considered. Knowledge of the chemistry, morphology, electrostatic nature and molecular conformation of the carbon fiber surface and the matrix resin system is essential for good adhesion in the composite.

Fiber sizing is intended to improve the handling of the fiber bundles as well as to provide a bond between the reinforcement and the matrix, thereby enhancing physical properties. The use of sizing and the type of sizing become important to the overall performance of the composite part. The effect of sizing on handling the reinforcement is significant when a thick preform must be handled in the dry condition without disturbing the orientation of the fibers and placed into the mold without pinching the fibers between the mold halves.

The parameters influencing the choice of the proper Epoxy resin system for RTM are viscosity, potlife, tensile modulus, glass transition temperature, tensile elongation and moisture absorbance. Lower viscosities permit good fiber wet-out and faster mold filling rates with reduced resistance or disturbance of material placement in the mold. Pot life must be matched to the size and complexity of the part. Sufficient time must be available to complete the injection. The tensile modulus of the resin system must be over 400 KSI or the composite compression strength will be less than the optimum value.

A high tensile modulus is required to adequately support the fiber reinforcement and prevent premature buckling. The glass transition temperature should be 50 to 100^{o} F. higher than the use temperature. This is because of the effect of absorbed moisture, which plasticizes the resin matrix and lowers the strength of the composite. The amount of moisture absorbed by the resin matrix should be small, ideally less than 2%. This will limit the amount of mechanical performance loss at elevated temperatures. The tensile elongation is a measure of the amount of brittleness in a resin system. Ideally, the elongation should be 3 to 5 percent if sufficient damage tolerance is to be expected in a resin system. A typical hot/wet in-service temperature for Epoxy is approximately 250^{o} F.

RTM is beginning to be used with Bismaleimide resins. BMI resins are commonly used in composites that will see hot/wet in-service temperatures up to 430^{o} F., or higher. A typical BMI resin is a one component solid that must be melted to form a liquid. At 250^{o} F., a common, commercially available resin system will reach a viscosity of 300 cps. The resin can be injected as a single component, or toughening modifiers can be mixed in during the injection process. Many flexibilizers such as allyl compounds and arylene ethers have been used as tougheners for BMI resins. The addition of a second ingredient would make the BMI injection process very similar to that for a two component Epoxy resin system. The BMI equipment would have to operate at a higher temperature.

RTM is used to produce parts of varying thicknesses but offers a practical method to easily produce thick composites. The use of a low viscosity resin injection system is a logical method to produce thick composites. After the process variables have been studied and modeled, they can be adjusted to produce thorough wet-out of all of the fibers, and to control the cure cycle to maximize the mechanical properties of the resin and the composite. Void free laminates should be able to be produced quickly when the effects of all of the process variables have been modeled and the production process has been optimized.

High fiber to resin ratios or volume fractions of 65 to 70 percent are achievable with RTM. Tolerances of the preform, mold tolerances and allowances to insert the preform into the mold without pinching at the part line all significantly affect the volume fraction. Research in preform make-up, mold design and manufacturing experience will be required to achieve high volume fractions.

Lowering costs on high production rate product runs is possible by using RTM. By the use of automated equipment such as filament winding, preform buildup can be completely mechanized, which can reduce labor costs and increase production speeds. The use of closed molds results in net shape parts that require a minimum of finishing. Heating the resin system throughout the process can also dramatically speed up the cure time, even with Epoxy and BMI systems. These processes can produce parts in hours or less versus days in an autoclave, with substantially lower initial capital costs.

ACHIEVING THE VOLUME FRACTION

The critical factor in Resin Transfer Molding is achieving the high volume fraction in the 65% plus range necessary for high performance components. This is not a serious problem for a flat or open part with edges that will be trimmed. The proper thickness of reinforcement is placed in a precision cavity. The edges may have a lower volume fraction, but it is not important because they will be trimmed later.

The real challenge is with a hollow part, or a part where the edges will not be trimmed. It is now necessary for all surfaces of the part to have the specified volume fraction in the mold. For a hollow part that has at least one opening, control of the volume fraction can be obtained by using a bladder with a mandrel inside of it. The preform is laid up in dry condition on this assembly. The mandrel is made as close to the finished inside dimensions as possible without making it so big that the reinforcement will be pinched at the edges when the mold is closed. At some time during the injection process, the bladder is pressurized, forcing excess resin out of the vents and achieving the specified volume fraction in the part. Depending on the geometry of the part, the mandrel will be rigid, flexible or washout type.

For parts that do not have an internal cavity, it may be possible to use a compressible elastomer, such as silicone, in the mold to provide a pressurizing mechanism. A bladder could also be used inside the mold, but external to the part, with or without a mandrel, which may be required due to undercuts. Expanding foam can be incorporated into the part to help drive off excess resin and could be considered in place of the mandrel and bladder for hollow parts.

APPLICATIONS

Carbon, fiberglass, Kevlar, Spectra, and other fibers and hybrids can be used in almost any imaginable form to make Resin Transfer Molded composites. Some typical high performance parts currently being made using RTM include wings, fins, tubular structures, bearings, fuel tanks, ship propellers, pressure vessels, missile launch tubes, automotive and truck components and body parts, etc. This list continues to grow. POLYCYCLE currently manufactures bicycle handlebars, as show in Figure 1, using RTM.[4]

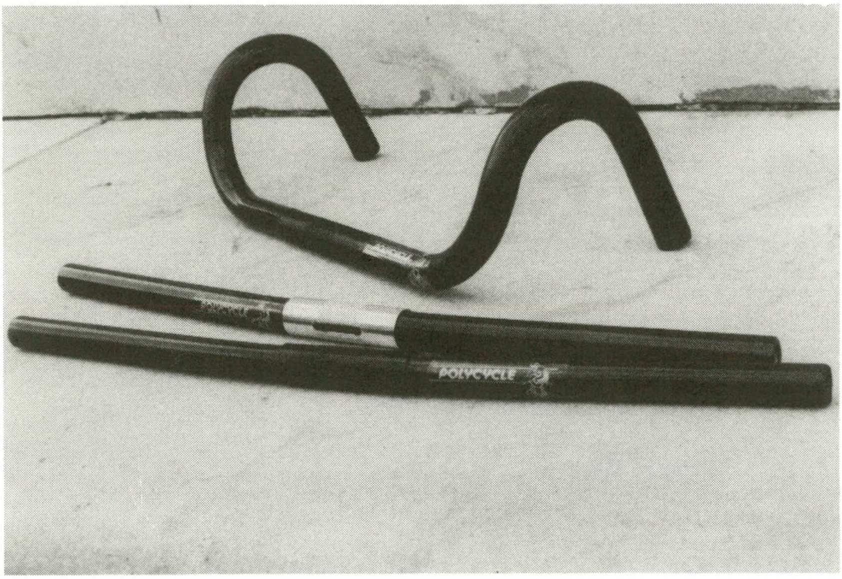

Figure 1. Mountain Bicycle (or "straight") bars and road bike (or "dropped") bars, manufactured by POLYCYCLE.

There are four basic components of the handlebars. The inside starts with a very light, knitted tube of Kevlar which is used basically to hold the mandrel and bladder assembly to a small diameter to facilitate further assembly work. Next, unidirectional material is rolled up over the Kevlar. A carbon fiber braided tube is assembled over the unidirectional fabric. Lastly, a ferrule made of 6061-T6 aluminum is assembled onto the carbon fiber tube and located at the center. This ferrule is usually black anodized, although it is also offered as buffed aluminum. A slot in the center of the ferrule is an innovation that serves two purposes. It allows the resin to flow evenly throughout the assembly during the injection process, and after curing, the hardened resin in the slot provides a mechanical lock to prevent the assembly from rotating in the ferrule when it is clamped in the bicycle stem. This is shown clearly in Figures 2 and 3.

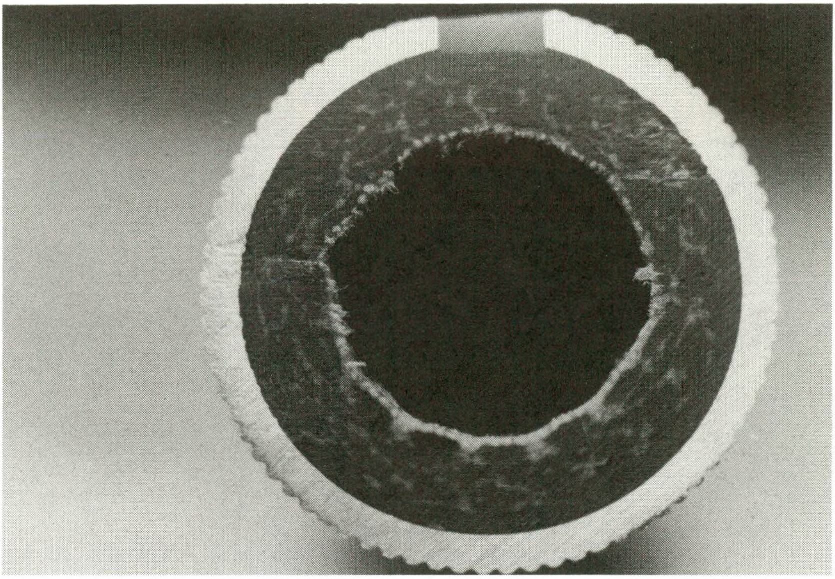

Figure 2. Cross section through a composite handlebar.

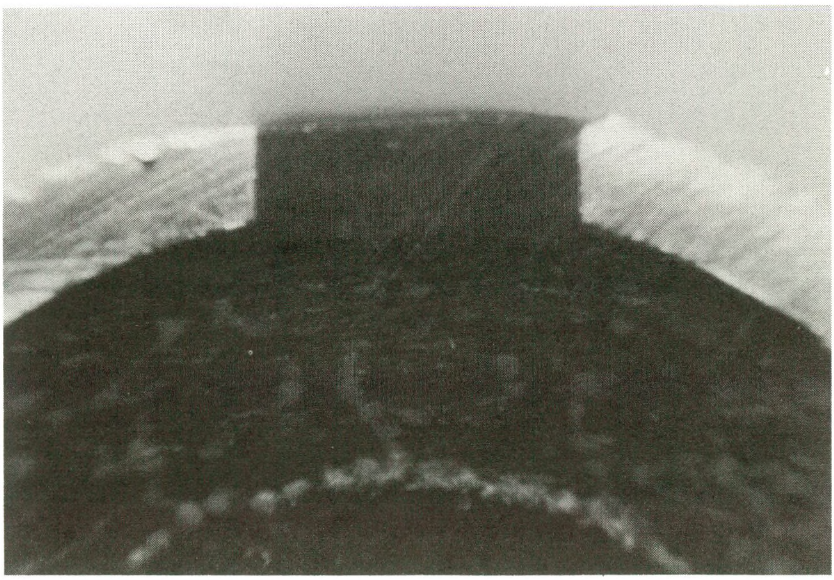

Figure 3. Enlarged view of the slot in the ferrule.

A great deal of analysis, development and experimentation went into these products and the tooling necessary to produce them. Due to an extensive shop testing program, they have performed flawlessly in the field, but they are expensive to produce. The U.S. bicycle market has no protection from international manufacturers, therefore competition is tough and sales of these products have not been very good. However, we continue to work to reduce costs and develop other products that will generate sales in the bicycle industry and other markets.

FUTURE RESEARCH

Some general areas that require future research to aid in the RTM manufacturing process include the following:

* Compatability and Wetability of reinforcments and sizing with resin systems. Guidelines are required in this area and such variables as moisture content, storage conditions, storage life, etc., should be standardized.

* Characterization and Certification of RTM products. As the process becomes more wide spread, this will be accomplished.

* Reducing the costs associated with the process. Automated layup, such as filament winding, is one way to accomplish this goal. Speeding up the injection process is desirable, but consideration must be given to pressure and quality, most notably eliminating air inclusions.

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BIOGRAPHY

Thomas F. Butryn has a B.E. in M.E. from Youngstown State University, an MBA from Kent State University, and is a registered P.E. in the State of Ohio.

He has 25 years of experience in design, process and construction engineering, operations, sales and management in the steel and composites industries. He is the founder, owner and operator of POLYCYCLE.

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