PREPREG MATERIALS —

FIBERS AND RESINS EXACTLY RIGHT?

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The Promise

Many of the critical and nagging problems associated with traditional processing methods of FRP manufacturing can be solved by using prepreg materials instead of the more common wet methods such as layup and sprayup. For instance, would you like to have the following problems disappear?

- Resin-rich or fiber-rich areas (that is, poor distribution or uniformity).
- Labor of rolling the layup or sprayup to wet-out the fibers.
- Volatile vapor problems and regulation associated with volatiles (such as styrene).
- Messiness from wet resin.
- Improper or changing catalyst (initiator) system and poor cure time and gel time control.
- Need for greater strength or stiffness and problems with going to greater thicknesses to achieve the mechanical properties desired.

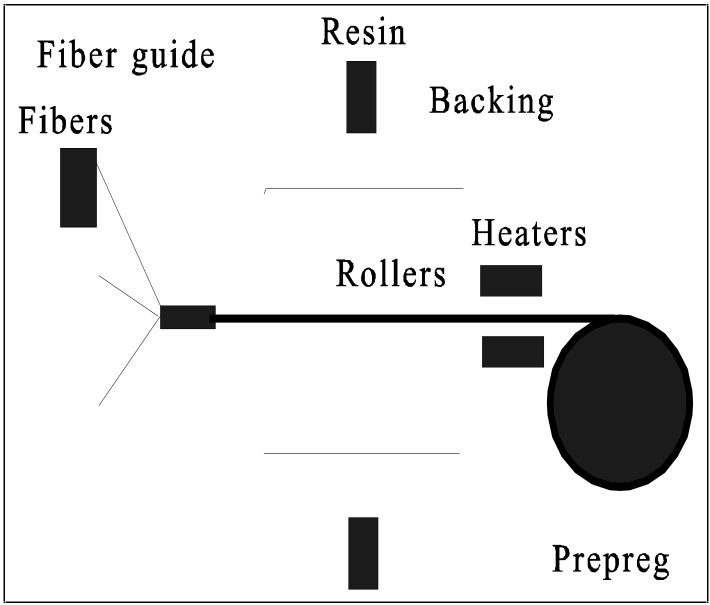
All these and many other problems can be solved by changing from the wet resin system that you are currently using to a system in which the resin and fibers are combined in a special product called a prepreg.

Does this sound too good to be true? What is the catch? There are, of course, some costs and other changes which have to be considered when prepregs are used, but the problems may not be as overwhelming as you think. Prepregs may now be acceptable for some of the parts you currently make with wet resin processes.

The Prepreg

What are prepregs? They are rolls of uncured composite materials in which the fibers have been preimpregnated (combined) with the resin. The name "prepreg" comes from "preimpregnation." This process of combining fibers with resin is done by prepreggers who specialize in supplying these materials. They use equipment designed to precisely introduce the proper amount of resin onto the fibers, work the resin into the fibers, and then package the material so that the user (you) can easily layup the prepreg into the desired shape and with the desired thickness. You then cure the layup (more details will be given) and the part is done.

The process for making prepregs is quite simple in concept and is depicted in Figure 1. The fibers are drawn from continuous fiber spools or reels and directed into a fiber guide that flattens and aligns the fibers onto a belt, thus forming a web or sheet of fibers. The fibers must be controlled at a precise thickness and each of the fiber bundles must be oriented so that each touches the neighboring bundle without overlap and without a gap between them. Alternately, instead of using fiber tows from reels to form the fiber sheet, the sheet could be formed by simply using woven fabric. The total width of the fiber array is typically 24 inches to 60 inches, although larger and smaller widths can also be obtained, usually by special request.



After being properly positioned, the fibers are mated with two backing sheets (top and bottom) which have been coated with resin to the proper thickness. The backing sheets are usually paper or polyethylene sheet and may have been previously coated with a release material to ensure that the prepreg will release cleanly and easily when it is used. Before being coated onto the backing material, the resin would have been mixed with the proper amount of catalyst (initiator), accelerator, and any other materials (such as filler or pigments) which would normally be mixed into the resin before cure.

The sandwich of backing materials, resin, and fibers is then compacted, usually with several sets of rollers. The sandwich is heated to a precise temperature and for a precise time to cause the resin to slightly cure and, therefore, slightly solidify through crosslinking. This is called b-staging. Care must be taken to insure that the sandwich is not heated too much, as this will cause the prepreg to be too stiff and seem “boardy.” However, if not heated enough, the precise distribution of resin and fiber could be altered because the resin could still flow as the prepreg is in storage. The sheet of material is then trimmed and wound up as prepreg material. Because the resin has already been initiated, the prepreg roll must be kept cool (refrigerated) to prevent premature curing.

The precise nature of the resin and fiber laydown ensures that the resin/fiber content will be constant and uniform across the entire sheet. Typical process variations are within ±5 grams/square yard for fiber content and ±2% on resin content. Thickness variations for the sheet of prepreg would be within ±.5 mil.

The process depicted in Figure 1 is for resins which are liquids at room temperature or which can be made liquid by some minor resin preheating in the resin mixing pot where all of the resin components are combined. The general term for this process is “hot melt application.” For resins that are solids at room temperature and cannot be easily melted, a slightly different process is used. In this process, called “solvent application,” the resin is dissolved in a solvent to make it a liquid and then the resin solution is coated onto the backing material or directly onto the fibers using a nip-roll system and then mated with the backing material. In the solvent application system, most of the solvent is removed during the heating stage so that the b-staged resin is relatively dry of solvent. For some applications, a minor amount of solvent can be left in the prepreg so that the prepreg material will be softer and tackier when it is layed up.

All of the common reinforcement fibers (fiberglass, carbon fibers, aramids, UHMWPE) are used in making prepregs. Carbon fibers and aramids are used principally in aerospace, sporting goods, and medical applications. Aramids and UHMWPE are used for armor applications. The largest application for fiberglass prepregs (about 40% of the total) is in electrical circuit boards, although other applications are growing rapidly and have great potential, as will be discussed later. Prepregs have even been made from textile fibers (like nylon) although these are for special purposes and are not common.

The reinforcements can also be in the form of fabrics, with plain, satin, and harness weaves being the most common. Mats are not used frequently because they are inherently less precise in fiber uniformity and the binders used to hold the mats together are often softened by the resin, solvents, or by the heat of the b-staging process, thus disturbing the resin/fiber mixture. When mat is used, it is made by a process similar to paper making, thus giving the uniformity that would be required for prepreg. Another important fabric type now being used is multiaxial stitch-bonded or knit reinforcement materials. These fabrics typically have several layers of unidirectional tapes layed down with different orientations and then sewn together by stitching. These multi-laminate materials therefore simplify the layup of the prepregs because some of the layup has been done already. Furthermore, the stitching gives strength in the third dimension (perpendicular to the plan of the fibers).

Most of the typical thermoset resins and some thermoplastic resins are commonly used in prepreg materials. The most common resin is epoxy, probably because the major markets for prepreg materials are in aerospace, sporting goods, and electrical circuit boards where the excellent mechanical, chemical, and physical properties of epoxies are needed. In Europe, however, epoxies are used for marine applications and America's Cup yachts.

Most prepreg companies have developed several of their own epoxy resins and also use resins from several resin manufacturers, as specified by the customer and to meet various needs. The epoxy resins can be grouped according to the cure temperatures with typical values being room temperature (chiefly commercial applications), 250°F cure (sporting goods and medical applications), and 350°F cure (aerospace applications).

Phenolics are used for applications such as aircraft interiors (flame retardance) and rocket nozzles (ablation). Polyimides (such as BMI and PMR-15) are used when very high temperature capabilities are needed.

Thermoplastics, which are not as common as thermosets, are used for their toughness, solvent resistance, or some other specialized purpose. Most of the thermoplastics used are very high performance resins, such as PEEK, PEI, and PPS which would compete with 350°F cure epoxies in aerospace applications. However, some new applications such as automotive body panels which depend up special properties, such as toughness, are using thermoplastics either alone or mixed with thermosets.

Polyesters and vinyl esters are also used to make prepregs. The principal applications are in tubular stock (such as fishing poles, ski poles, pole vaulting equipment, and similar products). When polyesters and vinyl esters are used, little to no styrene is used since large amounts of styrene would evaporate and change the resulting physical properties of the prepreg. To understand how styrene can be essentially eliminated in prepregs, remember that the two functions of styrene are as a crosslinker (that is a bridge between polymer chains), and as a viscosity modifier (solvent). In prepregs, heat is most often used to control the viscosity of the resin and to give the polymer chains sufficient movement that crosslinkers are not needed. If the crosslink density is not high enough, several non-volatile crosslinkers are available. Some prepreg formulations retain a small amount of styrene, chiefly to impart additional tackiness to the prepreg when it is used. Viscosity control of the resin is not required after the resin has been coated onto the fibers so if the resin is applied to the fibers using the solvent application system, the solvent (which could be styrene) is removed after the fibers are coated.

The Use

Prepregs are usually applied by hand, although some automated layup machines can be used if the area of the part and the number of parts to be made are large enough to justify the high cost of the machines. For instance, Boeing uses layup machines to make the tail sections of the new 777 airplane using epoxy/carbon fiber prepregs.

The process of layup, either by hand or by machine, is a simple one. The sheets of prepreg are placed onto the surface of the mold, which has typically been pre-coated with mold release. Layer after layer is applied until the proper thickness is reached. The fibers in the sheets have particular orientations. If the fibers were taken from spools, the orientation is in a single direction and the prepregs made from such fibers is called unidirectional tape. If fabric is used, the fibers have two perpendicular orientations and the prepreg is called cloth prepreg or two dimensional prepreg. In either case, great care is usually given to laying up each layer so that the fiber orientation is exactly as desired for maximum strength and efficiency. The ability to layup in specific orientations is an advantage of prepregs because it gives highly efficient structures and is why prepregs are used so widely in aerospace and sports applications. In other applications, such extreme care about orientation may not be necessary or worth the time involved.

For many tubular applications, the mold is really a metal rod (called a mandrel). The fibers are layed onto the metal rod by cutting the fibers to the proper length and width (where the width is the circumference of the mandrel). These strips of prepreg are then rolled onto the mandrel, often using a special machine.

After laying up the sheets of prepreg onto the mold or mandrel, the prepreg sheets must be consolidated, that is, squeezed together to make them a unitary structure and to remove the air that is unavoidably trapped between the layers. Several methods are available to accomplish this consolidation. Most of the methods do the consolidation during the curing step, if the cure is done with elevated temperatures, because the resin becomes thinner with the heat and will allow the trapped air to easily flow out. The thinning of the resin, if accompanied with some pressure, also binds the several layers together since resin will flow across the boundaries of the layers and result in a single, unitary structure.

The pressure can be applied by using a press, but is more commonly applied, especially in large parts, by covering the part with a air-tight sheet and applying a vacuum under the sheet. (This process is called “vacuum bagging.”) This vacuum pressure not only forces the layers together, but it also assists in the removal of the trapped air (and the removal of any residual solvent gasses, too). In the aerospace industries, the curing is often done inside an autoclave, thus obtaining not only the vacuum pressure but external pressure as well. When this is done, air is removed, consolidation is excellent, and small voids are essentially eliminated. All these result in improved mechanical properties. This improvement is often important in aerospace, but is rarely important in commercial products. Hence, curing of commercial parts is done in just an oven, with some provision for consolidation.

In the case of tubular parts which have been wound onto a mandrel, the consolidation is often accomplished by wrapping the outside of the layers with shrink wrap plastic (such as cellophane). With cure heating, the tape shrinks and squeezes the layers together. This method does not specifically remove the air, although that has not seemed to be a major problem.

The need to consolidate the layers of prepreg has been a major drawback in the use of prepreg materials for low-cost applications. However, both costs and difficulty of manufacture are considerations that should be examined in detail, and not just assumed to be major.

The Reality

Adoption of prepreg layup for applications which compete with wet layup and sprayup requires careful analysis of both real and current costs as well as hidden and future costs. Some of the most obvious cost elements are identified and compared in Table 1.

Cost Elements	Wet Techniques	Prepreg
Material	Resin and fibers only	Includes costs and profit of prepregging
Waste	Overshoot, dripping, short working time	Trim waste
Part properties	Short fibers limit some properties	Long fibers may reduce total weight
Wet out	Roll out required	No labor required
Consolidation	Done with roll out	Bagging or wrapping required
Storage	No special procedures	Refrigeration required
Rework	Often high because of non-uniformities and process variabilities	Little required
Part uniformity	Poor	High
Environmental	Vapor emissions with potential for regulation	None

The choice between the wet processes and prepreg probably depends upon the particular circumstances for each part and company. For instance, if the amount of material can be reduced because of the increased strength and stiffness that accompanies longer fibers, then the costs of prepregs may not be much more than the costs of resin and fibers separately. Or, if the amount of rework is extremely high, especially because of poor uniformity, then the cost of prepreg may be justified from labor savings. On the other hand, if the costs of consolidation are very high, then using prepregs could be too costly.

The Future

In general, prepreg manufacturers are anxious to expand their markets and seek new customers who are currently using wet techniques. This is especially true of those manufacturers who currently make fiberglass reinforced prepregs. They understand some of the problems that limit their penetration into the markets now dominated by wet techniques, and they are working on some of the problems. For instance, prepregs which have many months of shelf life without refrigeration are now beginning to be marketed. The number of prepregs that can be cured at room temperature or with only heat lamps is increasing. Prepregs with greater tack are being developed and these may not require bagging, but could be consolidated simply by rolling or by some other technique that does not require additional equipment. Very high volumes will cause the price of prepregs to drop significantly, and so pricing could be quite different in the future.

Several emerging markets seem to be well suited to the use of prepregs. For instance, prepregs could be valuable as overwraps for large structures such as bridge, freeway, and building columns. Other applications could the the overwrap of foam cores for use as telephone poles. European manufacturers have already shown the viability of the use of prepregs for marine applications.

In the final analysis, the decision about using prepregs may not be obvious and should be given some careful consideration, both now and, because the markets and materials are so dynamic, on a regular basis in the future.

Acknowledgements

The author wishes to thank Jon Poesch of Alliant Tech Systems, Ray Williams of Fiberite, Fred Isley of Hexcel, and William Werst of SACMA for their helpful advice and discussions.