

Bridging the Gap: FRP and Advanced Composites

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Have you ever considered the following questions (stay with us, there is a reason we ask):

- How is country music related to composites?
- What's the relationship between popular music and composites?
- How are country and popular music related to each?

Music Categories

When you walk into a music store to buy a CD, you immediately note that the CDs are grouped according to the type of music played. There are sections for popular, country, rock, classical, jazz, and probably others. Then, within each section the CDs are arranged alphabetically by name of the artist or, in the classical section, by name of the composer. This system has its advantages, especially when you want to browse among various artists of a particular type, as, for instance, when you want a country CD but you are not quite sure which artist you are interested in or, alternately, you want a particular song and there are several artists who have recorded it.

However, a problem quickly arises if you are not sure the category of the artist. Even more troubling is the artist who intentionally crosses over from one category to another. Are some albums by that artist in one place and other albums in another? What if some songs on one album are of one category, like country, and other songs are another category? The recent movie, *Ray*, illustrates this difficulty. Ray Charles intentionally moved from gospel to rhythm and blues to popular to country and then back again. Some people even became angry with him because they felt that he was "defiling or degrading" the gospel music when he sang it in the rhythm and blues style. Where would you find Ray Charles in the music store?

Ray Charles and others, like Sting, Amy Grant, Glen Campbell, Selena, Shania Twain, Tim McGraw, and Nelly have successfully crossed over between musical types. In doing this they often show tremendous creativity. They are able to think more broadly than just a single genre. When successful, they have found elements in both musical types that can be blended into a style that is pleasing to a broader audience. In the case of Ray Charles, his biggest hit ever, *Georgia On My Mind*, was made when he changed record companies and thereby got an infusion of new ideas and resources—lush arrangements, orchestral backups, enhanced production facilities, wider distribution, and new musical concepts—all of which helped him think more broadly and create a new type of product. He became rich!

Composite Categories

We believe that crossover in composites is healthy and will lead to increased profits for those who can accomplish it successfully. We will discuss some ways in which this crossover has occurred and then some suggestions for future directions for new

crossovers. We will also discuss some companies that are actively doing crossover in their products and reveal some of the principles that they use to help them be successful in this work.

Traditionally composites are divided into two broad categories—FRP and Advanced. The generally-accepted characteristics of these two categories can be examined in three different categories—materials, processing/fabrication, and markets/philosophies which are presented in Tables 1, 2, and 3, respectively. We understand that, but presenting the two composite types in these tables, we have fallen into the same pattern as the music stores, that is, we have divided things into categories. We have done this for reference and for clarity. However, in our discussions of each of the aspects of composites—materials, processing/fabrication, and markets/philosophies—we will discuss how the categories can be bridged so that crossover can occur.

Materials Crossover

The major material differences, summarized in Table 1 (Comparison of Materials), are reflected in the names of the two types of composites and are the most obvious. FRP composites are generally made using fiberglass as the reinforcement or, especially in third world countries, natural fibers. Advanced composites use, generally, high performance fibers such as carbon/graphite fibers but, for special applications, another high performance fiber such as aramid, boron, quartz, polyethylene, PBO, PBI, ceramics, or, most recently, basalt could be used. In general, the FRP fibers cost about \$1/pound. The Advanced fibers very often cost up to \$20/pound but might be as low as \$1.50/pound for some types of forms. However, more exotic high performance fibers can easily range up to several hundred dollars per pound. FRP fibers are usually sold dry, that is, without resin and often in a bulk form such as roving or continuous tow.

The resins for FRP are generally polyesters or vinyl esters. These can be cured with peroxide initiators and, therefore, room temperature cures are feasible although heated cures are not uncommon. Advanced composite resins are usually epoxies because of generally good environmental resistance (thermal, solvent, toughness). For even better resistance, polyimides and high performance thermoplastics can be used. Cures of Advanced resins are almost always heated. The high performance resins cost roughly twice as much as the FRP resins (and maybe much more for specialized resins).

Many manufacturers of Advanced products have become fixed on the use of prepreg materials. They cite better resin/fiber control, lack of the need for resin mixing equipment, and ease of use in some processes as the key factors which lead them to use prepreps. However, prepreps are much more expensive than fibers and resin. Moreover, the costs of keeping prepreps (cold rooms, certifications, etc.) can also add significantly to the cost.

Cores are used to stiffen the vertical dimension. FRP cores are usually wood or inexpensive foams. Advanced core materials are lighter weight materials with exceptionally high stiffness.

Crossover concepts for materials:

- Advanced composite users should remember that the most distinctive property of carbon/graphite fibers is stiffness (modulus) and so, if that property is not key to the function of your part, you may not need to use a high performance fiber.
- Mixtures of fibers are commonly used in some Advanced composite applications, especially when strength is important but sufficient stiffness can be gained with small amounts of carbon on the outside of the part.
- Resin prices are usually strongly dependent on volume. Here we are not just talking about the savings one can get by buying in railcar quantities versus drums but, rather, the drop in basic resin price that comes when resin manufacturers add total capacity in a resin and focus significant research effort to product and process improvements. The thermoplastics market has seen this occur time and time again. Therefore, if the demand for a resin (such as a mid-range epoxy) was high enough to create significant additional investment by the resin companies, the price would undoubtedly drop. That may require some special pricing by the resin manufacturers to stimulate the market and some aggressive product development by the FRP industry to find products that are better is the resin is improved. Some FRP products, such as high temperature pipe, have already shown the value of epoxy in the marketplace.
- Advanced manufacturers might consider ways to eliminate prepregs, although this may mean some creative thinking in how the fibers and resin are combined using conventional production equipment (such as filament winding machines).

Processing/Fabrication Crossover

FRP processing and fabrication are generally oriented toward very high volumes whereas Advanced processing and fabrication will often make total production runs of under 100 parts and sometimes less than a dozen (see Table 2, Comparison of Processing and Fabrication Methodologies). Not surprisingly, the FRP processes are generally simpler and have wider tolerances than those used in Advanced composites.

Perhaps the biggest difference in FRP and Advanced processing is the control over the amount and direction of the fibers. Advanced composite manufacturers are interested in minimizing weight and that requires, among other things, precise directional control over the fibers. Small angular deviations significantly reduce the physical properties of the parts.

Vacuum bagging and autoclave manufacturing are important methods within the Advanced composite processing world. These are generally required on parts made with prepregs and where very high consolidation is demanded. However, some new advancements in bagging methods indicate that the high costs of bagging materials and the high failure rates of some parts might be eliminated by the use of new bagging systems. Furthermore, FRP manufacturers rarely use these high pressure techniques and make well-consolidated parts, often using presses and/or liquid resin techniques.

Crossover concepts for processing/fabrication:

- Controlling fiber direction is not unique to the composites marketplace. Textile manufacturers have been developing these technologies since the beginning of the industrial revolution in the eighteenth century. However, with only a few

exceptions, these textile manufacturers have not been highly involved in the composites business. We suggest that both FRP and Advanced composite manufacturers should explore joint projects with the textile manufacturers so that technologies of both textiles and composites can be combined to mutual benefit.

- Some manufacturing methods seem to be a nice compromise between fiber directional control and resin addition. Resin infusion methods like RTM, VARTM, and SCRIMP™ allow textile-fiber techniques to be used for controlling the orientation of the fibers and then closed mold techniques for adding the resin.
- Advanced composite manufacturers might consider using new molding techniques and materials that allow resin infusion to be done in molds of modest stiffness, perhaps backed dynamically by pressure-sustaining techniques.
- Investigate novel methods of curing such as IR, microwave, and heated tooling.
- Advanced might consider full compression molding of parts that have reasonably high volumes. (Large presses are no more expensive than autoclaves and the cycle times are less.)
- FRP might consider some pressurization method to eliminate hand working (wetout) of parts.
- Consider inventing manufacturing methods that are low cost and yet might use higher valued raw materials. Years ago the roll wrapping method was conceived and the result has been a significant reduction in manufacturing costs for products such as golf club shafts. Bladder molding of tennis rackets is also an improvement over the more expensive autoclave molding.

Market/Philosophy Crossover

Except for obvious highly critical parts where, for instance, safety issues are involved, the stringent requirements for performance and testing are probably excessive in Advanced composites (see Table 3, Market Applications and Philosophical Differences). On the other hand, quality standards for FRP are prone to be minimal or, at best, operative only after the part has been made. In both cases, some intermediate quality system might be appropriate. For instance, the operators could be empowered to check their parts using in-line, real-time quality measurement devices.

Equipment redesigns beg for reconsideration. An alternate to conventional sprayup manufacturing might be to distribute the resin simultaneously over the entire surface of the part by spraying from a series of nozzles and then quantify the addition by time or weight added.

Certification agencies need to consider the real needs of the users and not stay with standards that are unnecessarily stringent. Sometimes a category will have had tests established years ago when manufacturing methods and materials were not as reliable as they are today. This also invites designers and specifiers to reconsider safety factors.

Case Studies—Materials and Products for many markets

A few brief case studies might indicate how some companies have been able to bridge the gap.

Christensen Arms is a division of a company that has been making composite parts for many years. The parent company makes aerospace components, medical devices, and similar Advanced or crossover parts. However, the invention of composite rifles had really accelerated this company's thinking into areas where composites are not traditionally found. To the company's delight, the advantages of composites in the rifle market are reflected in better performance of the rifle (more accuracy) and lighter weight. These combine to give a higher value in the marketplace.

Norplex-Micarta is a manufacturer of thermoset products using, often, their own proprietary materials. They find new products by asking "What is the ultimate value to the customer?" This company also asks customers "What is your biggest problem?" Often, the answer to these questions will allow them to substitute their composite materials for a less expensive but also poorer performing material. Sometimes that requires a clever design such as mixing fiberglass and carbon fibers, precisely manufacturing the carbon fibers only on the outside of the part to give the stiffness required, but not more. Another product line molds composites directly to metals, thus mixing two materials that are normally not manufactured together. Sometimes the performance of a current product is just not as good. An example is the finger board of guitars, which is often made of ebony that wears relatively quickly and, when it does, distorts the sound. Composite finger boards wear longer and, therefore, give the guitar a more consistent sound. In this last application, we return to the subject of music and crossover.

This company is proud of their crossover products and actively markets their ability to solve problems with combinations of materials and manufacturing technologies. They have found that many of their customers seek them out because of this "can-do" attitude. By the way, they have developed a rating system that lets the company evaluate the potential return on products for time and effort expended. They are aggressive in helping potential customers, but also give each job a reality check.

Entec Composite Machines/Zoltek Materials has long been a manufacturer of composites filament winding equipment that is used in both the aerospace (Advanced composites) and commercial pipe manufacturing (FRP composites). However, the move toward producing commercial carbon fibers for the commercial market resulted in the development of "large tow" fiber products with 48,000-130,000 carbon filaments. However, while "large tow" has not been enthusiastically accepted in aerospace Advanced composites, Entec focused on developing specialized equipment for producing wind energy blades in the 40-60 meter length using a more "FRP manufacturing approach." They developed commercial fiber placement machines using aerospace technology and large tow carbon fiber prepreg materials for producing wind energy blades at fiber lay-down rates approaching 2000-2500 lbs/hr. Traditional aerospace Advanced materials fiber placement rates typically are in the 5-30 lbs/hr rate and not practical for producing commercial FRP products.

The big picture for FRP and Advanced Composites

Crossover products require creativity. Numerous studies have shown that creativity is enhanced through the combination of both right and left brain thinking. That concept can also be expressed as being able to think both linearly (logically) and laterally (intuitively). When these are both done, unique ideas are turned into useful products. But, to do this best requires that breadth of knowledge that comes from understanding technologies outside your own narrow field. Therefore, talk to each other!

In general, FRP companies need to become more technically proficient. Some are already highly technical, but most are not. Engineers who understand Advanced materials and techniques might be especially valuable if those engineers are capable of thinking out of the aerospace and government boxes. The obvious need of Advanced composite manufacturers is to break out of the aerospace and government mentality and begin to be entrepreneurial. To this end, some cooperation between FRP and Advanced companies might be appropriate.

Buying materials that are certified for government work is very costly and, in many cases, unnecessary. The specifiers of these materials should honestly look at why they require the mountains of testing and paperwork that currently accompany most aerospace materials. Often these requirements have come about because engineers are unwilling to take a stand that “enough is enough” as far as testing and certification are concerned. We are pleased that some movement has been made to simplify the certification process and believe that more should be done.

FRP manufacturers should become braver. They might find that an advantage of an FRP manufacturing moving into some Advanced materials or processes is that their FRP competitors are not likely to do it, thus giving the adventuresome FRP manufacturer the advantage of new and early-entry markets.

Both FRP and Advanced need to look for niche markets that lie between the two extremes. These markets tend to have high development costs but also high initial returns and also give the extra profits of being the first in the market. Look especially where the current products are inadequate and either advanced materials would improve them or the costs are too high and lower manufacturing costs would give penetration in the market.

Research developing new processes which utilize the best of FRP and Advanced should be actively pursued by companies in both segments of the composites market. This research should be done both within the companies and at universities or other research facilities where thinking that is vastly different from the norm is more common than the generally focused thinking within a single organization. This research need not be “blue skies” but can be quite applied either for a particular company or a particular product. Material suppliers should also participate in these market-development research project. They should remember that if the whole market grows, so too will their individual market. “A rising tide lifts all ships.”

Explore big markets where composites are underutilized. Example: oil fields and civil engineering. Penetration into these types of markets probably requires extensive education of the current engineers. The approaches of FRP and of Advanced are both important and might be best done in concert.

Reprise

Whether music or composites, breaking out of a category system imposed by someone else is generally beneficial. It requires creativity in thinking and execution. The thinking comes from a broad understanding of markets and techniques. The execution comes from a deep understanding of your own capabilities.

When Ray Charles wanted to really break out of the old mold, he went to a new record company. As we have already discussed, the new company contributed new ideas and new resources. We previously identified those resources in musical terms but they seem to work just as well in composite terms. Here they are again (with the composite equivalent in parentheses: lush arrangements (new designs), orchestral backups (better and more people focused on the products), enhanced production facilities (better manufacturing), wider distribution (more marketing power), and new musical concepts (new products)—all of which helped him (and you) think more broadly and create a new type of product. He (you) became rich!

Table 1. Comparison of Materials

Property	FRP Composites	Advanced Composites
Reinforcement Fiber	<ul style="list-style-type: none"> • Predominantly E-glass products • C-glass for corrosion • Limited “natural” fiber usage • Often referred to as: <ul style="list-style-type: none"> ○ FRP = fiber reinforced plastics ○ GRP = glass reinforced plastics ○ GFRP = glass fiber reinforced plastics 	<ul style="list-style-type: none"> • High strength S-glass (R- and T-glass versions) • Carbon and graphite • Aramid (like Kevlar™) • Boron • Quartz (fused silica) • Polyethylene (like Spectra™) • PBO and PBI fibers • Ceramic fibers • Basalt fibers
Typical Fiber Form(s)	<ul style="list-style-type: none"> • Continuous fiber roving and chopped fibers dominate • Woven roving products • Tight weave glass fabrics (numerous) • Glass veil materials • Commercial mat and stitched/bonded materials 	<ul style="list-style-type: none"> • Continuous fiber roving and tow materials dominate • Prepreg materials (unidirectional tapes and fabrics) • Higher fiber volumes (55-65%) • Complex structural textile products
Resin Matrix	<ul style="list-style-type: none"> • Polyester and vinyl ester leading candidates • Wide variety of polyester formulations • Phenolics for fire applications • Limited epoxy use in certain areas • Generally thermosets • Some thermoplastics (short fibers) 	<ul style="list-style-type: none"> • Epoxies generally baseline • Bismaleimides (BMI) and cyanate esters for higher temperatures • Polyimides • Numerous thermoplastics (PEEK, PPS, PEI, etc.) • Toughened resin system interest and use for damage tolerance
Application Temperature and Conditions	<ul style="list-style-type: none"> • Ambient temperature range (25-140°F typical) • Exposure to UV and weather conditions • Exposure to fuels, waste materials, water, sea water, and processing chemicals 	<ul style="list-style-type: none"> • Broader temperature exposure range <ul style="list-style-type: none"> ○ Space environments ○ Aerospace service conditions ○ Exotic fuels, solvents, fluids ○ Extreme conditions • 180-700°F environmental conditions much more possible • Cryogenic conditions
Core Material Usage	<ul style="list-style-type: none"> • Balsa and foam core materials • Core materials consistent with near-ambient use conditions • Core use technology built upon marine and boat market 	<ul style="list-style-type: none"> • Extensive use of honeycomb core materials <ul style="list-style-type: none"> ○ Aluminum ○ Nomex™ (aramid) ○ Carbon fiber • Extensive design and manufacturing technology base

Table 2. Comparison of Processing and Fabrication Methodologies

Property	FRP Composites	Advanced Composites
Production Quantities	<ul style="list-style-type: none"> • Production quantities often quite large: <ul style="list-style-type: none"> ○ 100's to 1000's or more ○ Pipe – usually miles/kilometers ○ Tank systems – usually on the order of several hundred 	<ul style="list-style-type: none"> • Production quantities often much smaller: <ul style="list-style-type: none"> ○ Typically less than few hundred ○ Complex parts may often be less than dozen or so
Manufacturing Processes	<ul style="list-style-type: none"> • Generally simple and requires only moderate labor skills • Filament winding, pultrusion, contact molding, “chop and spray”, resin infusion (RTM, VARTM, SCRIMP™) 	<ul style="list-style-type: none"> • Processes more complex and tightly controlled with process paperwork • Filament winding, fiber placement, hand lay-up and vacuum bagging, tape lay-up, resin infusion (RTM, VARTM, RFI, some SCRIMP™), thermoforming • Considerably more “quality control” and in-process inspections • Autoclave processing of many parts
Tooling Materials and Methods	<ul style="list-style-type: none"> • Steel and aluminum molds and tooling • Fiberglass tooling common • Tool surfaces often “gel” coated • Simple tooling fabricated for prototyping as well as some production • Overall tool cost significantly lower 	<ul style="list-style-type: none"> • Invar, steel and aluminum tooling • Very tight dimensional controls • Extensive tooling design efforts • Highly polished tool surfaces • Composite tooling using carbon fiber laminates • Higher temperature tooling requirements
Cure Methods	<ul style="list-style-type: none"> • Often ambient cure • Oven cure on some parts • Steam, heated platens, heated oil, electric heaters used in some tooling applications 	<ul style="list-style-type: none"> • Controlled oven or autoclave curing typically • Precise temperature-time-pressure-vacuum cycles for many parts • Heated tooling during most process steps

Table 3. Market Applications and Philosophical Differences

Property	FRP Composites	Advanced Composites
Application Temperature	<ul style="list-style-type: none"> • Generally ambient (25-140°F) conditions • Some extremes as a result of fluids and chemicals being processed 	<ul style="list-style-type: none"> • Typically built for high performance over broad temperature ranges • -65 to 165°F for many defense-related products • Cryogenic applications and space applications incur much lower temperatures • High temperature operating conditions in 300-700°F range incurred with aerospace parts
Economic Considerations	<ul style="list-style-type: none"> • Low cost – materials tend to be less expensive • FRP products are lower cost items 	<ul style="list-style-type: none"> • More performance driven than cost driven • Materials considerably higher in cost
Safety Factors	<ul style="list-style-type: none"> • Typically use SF = 2.0-5.0 • Built to endure more robust handling • Safety factors dependent upon certification standards 	<ul style="list-style-type: none"> • Typically use SF = 1.25-3.0 • Built to operate at extremes of performance capability • Safety factors dependent upon more rigid customer or industry standards
Design Factors	<ul style="list-style-type: none"> • Generally use vendor data or data derived from limited testing • S-basis or B-basis design approach using nominal properties • Designers often talk in terms of “fiber and resin <u>weight</u>” percent when preparing manufacturing specs 	<ul style="list-style-type: none"> • Generally develops extensive data base from numerous tests • A-basis often used although B-basis used (with backup testing to verify performance) • Designers often talk in terms of “fiber <u>volume</u>” and “resin <u>weight</u>” percent when preparing manufacturing specs • Designs usually incorporate number of environmental factors (temperature, aging, damage, pressure, moisture, etc.)
Testing and Certification	<ul style="list-style-type: none"> • Materials testing often limited to “quality control” upon material receipt • Testing often deferred to using material supplier data and past experience • Certification to industry standards: ASTM, API, UL, SAE, ANSI, ASME, BS • In-use testing predominates 	<ul style="list-style-type: none"> • Materials <u>and</u> structural component testing often extensive • Significant testing conducted at various environmental or load limit conditions • Not as much reliance upon vendor-supplied data • Certification more rigid, following requirements of customer and governing agency: DOD, NASA, FAA, DOT, NIST