ARTICLE OF THE MONTH

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COMPOSITE BASICS

SINKING YOUR TEETH INTO SANDWICH STRUCTURES IN LAYMAN'S LANGUAGE

BY ANDY MARSHALL

THE ADVANCED composites are the most recent of the new wave of materials that have appeared on the aerospace scene in the past 30 years, though they really aren't all that new. Some of the composites called, "advanced," are based on plain old glass drawn into fibers, and this was being done in the 1940s.

"Composite" is a general term which means an assembly of dissimilar materials intended to do a job that none of the individual materials can do by themselves. Under this definition, even reinforced concrete is a composite. "Advanced composites" refers to that group of materials usually associated with the aerospace business. They are carefully engineered and developed, and are uniquely suited to carrying substantial loads in fairly small structural members.

These materials consist of a resin matrix, usually an epoxy polyester, or vinylester, and a fiber reinforcement. The fiber reinforcement can be glass, Kevlar™, carbon fiber, Nextel™, quartz, boron or any of a number of other fibers, all of which are very small and very strong. They also impart a high degree of added strength to the resin matrix.

This added strength is so large that the composite performance as a structure is simply on another order of magnitude when compared to the strength of the resins themselves.

GLASS FIBERS

E glass, S glass and S2 glass are the fiber materials that might show up in the average airplane. In addition to these glass types there are several others that we don't usually talk about in an advanced composite summary because they are used in different fields. These are: C glass, which is used for its chemical resistance in the manufacture of ducting, blower hoods, fan housings and other structures for air movement where corrosive gases are involved; and

The new "advanced" materials in aircraft construction

M glass, which is a formulation of glass intended to have the highest possible elastic modulous. There is also L glass, which stands for Lead glass and is sometimes used in glass fiber form for radioactive shielding.

In addition to the different formulations which make up glass, the fibers themselves are quite different. For instance, a simple glass fiber that you think of as being the primary ingredient in fiberglass fabric can be any one of about 24 different yarns. All of these different yarns are made from about seven filaments ranging in size from a diameter of .000175 inches up to a diameter of about .000525 inches.

Each strand of yarn contains a great many of these filaments, and some of the heavier ones carry as many as 2000 or more filaments in a single strand of yarn. These yarns, of course, then may be twisted and plied so that the strand used to finally weave the cloth may have two, three, six or even more individual strands of fiber bundles in what appears to be a single yarn you see in a section of fabric.

It's not hard to see that simply specifying that you want something made out of glass cloth isn't really specifying anything at all. The variations are mind boggling.

Basically glass fibers are made out of sand, gravel, clay, limestone and such minerals, which are melted down and adjusted to get a very specific chemical content depending on the type of glass fiber desired. This molten glass is then drawn through tiny holes in platinum bushings into strands of glass fiber.

It's customary for the bushings to have a great many different holes in them so when you draw the fibers you draw a large number at the same time. All of the fibers in a single strand of glass are conventionally drawn as one group of fibers from the same pot of molten glass.

There are several companies that provide glass fibers on a commercial basis. The granddaddy of them all is the Owens Corning Fiberglass Co., but they now have spirited competition from PPG, Johns Manville, Certainteed and several others. The end result is that we have a steady supply of excellent-quality glass fibers to the many companies that use them to weave fabrics and make other products.

As you might assume from the lowly origins of these fibers, the cost for the basic glass fiber is really not very much. For many years it was only about 40 cents a pound, but with the cost of energy having gone up, it's now 70 to 80 cents a pound. This is not really much when you consider how much fiber you get out of a pound of glass.

CARBON FIBER

One of the most commonly mentioned fibers among the new materials is carbon fiber. This is another material of rather lowly origins. Typically carbon fibers are made by oxydizing, carbonizing and graphitizing in three separate operations, a strand of polyacrylnitrile fiber (pan), which is provided in a form very much the same as that used by the weavers of synthetic fabrics. This particular fiber, however, is very closely controlled because the quality and nature of the original pan fiber largely determines what structural properties the resulting carbon fiber will have after it is manufactured.

In addition to being manufactured from rayon or pan fibers, it can also be made from pitch fibers which are taken directly from oil or coal. These, theoretically provide a much lower cost method of making the material. All of the carbon and graphite materials are quite new, the early commercial fibers having been produced in the early 1970s.

The business of producing these fibers has been so attractive to so many companies that there are currently a large number of manufacturers of such fibers all competing vigorously with each other. There are nearly 15 worldwide, and these include such firms as Union Carbide, Hercules, Celanese, Courtalds, Toray, Hitco, Great Lakes and many others. At present, the plant capacity of these manufacturers is only being utilized at about a 15 or 20 percent rate, which bodes well for future applications and continuing lower prices.

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The price is another interesting subject. When they were first introduced into the commercial market in golf shafts, it was quite common for a single golf club with a carbon fiber shaft to retail for about $200 to $500. Now the carbon fiber that goes into these products can be purchased on the open market for about $15 a pound, down from about $50 per pound only two or three years ago, and the cost of the shaft is something less than $15.

The users of carbon fiber golf shafts have thus seen a tremendous benefit, but unfortunately their popularity has dropped, which is the opposite of what one would expect with such a sharp decrease in price. However, the lower price levels that we now see for carbon fibers has caused their rapid growth into many other areas, not the least of which is the entire aerospace industry. In the 1970s when these fibers were first commercially available, they were regarded as candidates only for very specialized applications.

Now many manufacturers are looking at carbon fibers to reinforce all sorts of rather ordinary structures. The material is currently even finding its way into the field of automotive engines and bodies where it occasionally can perform a spectacular job at a fairly modest cost premium. An example of this is in the main spring for a truck at General Motors in which they have realized a weight reduction in excess of 80 percent.

It was mentioned earlier that carbon fibers are made by three successive oven operations. These operations are all conducted simultaneously by pulling a bundle of fibers through all three oven steps under tension, thus allowing the continuous and reasonably economical production of the final fibers. A fiber line such as this has to be duplicated many times over in order to get a commercial production rate of reasonable size. A manufacturer will have hundreds of parallel lines in his plants in order to produce the numbers of millions of pounds per year quoted as plant capacity.

Another peculiar thing about the carbon fiber suppliers is that they can't seem to agree on a great many of the details of just what it is that they produce. For example, some refer to their fibers as, "carbon fibers," while others who produce what appear to be the same products will refer to them as "graphite fibers." The accuracy of these names is subject to rather intense debate at rather high levels of technology, and neither side takes kindly to admitting error.

Each of the manufacturers of carbon fiber has his own product line which may or may not duplicate the product line of one of the other manufacturers. In the case of the glass manufacturers, they are all manufacturing closely equivalent products, so it's pretty easy to switch from one manufacturer to another and be sure that you have a comparable structural material. With the graphite producers, however, each of their products represents a separate invention as far as they are concerned internally.

When you use a graphite material you must be careful to be sure and specify which producer made the yarn and which of his types of yarns actually went into this material. Since there are so many manufacturers and each of them has at least two or three different types of fiber in production, the result can be a lot of confusion among the users.

KEVLAR FIBERS

Another of the new types of fibers that we hear a lot about is Kevlar™. This Dupont material has many of the same attributes of carbon fiber in that it's very high strength and modulus, but it has very unique property possessed by neither carbon fibers nor glass fibers — it is an *extremely* tough material.

One form of the material, Kevlar 29, is used in bullet-proof vests by most of the police officers in the U.S. It is also used for ballistic armor for ships and various other vehicles in our armed forces. The product which does this is also extremely light, about half the weight of aluminum.

The Kevlar which usually finds its way into aircraft structures, however, is not Kevlar 29, but Kevlar 49, which has a much higher modulus and about the same strength. These materials are both quite unlike carbon fibers in that they neither conduct electricity nor are they electrically opaque to radio waves, two of the problems with carbon fiber.

Kevlar acts much more like glass fiber, but it is even better for electrical transmission structures such as radomes and antenna windows. The fiber diameters and general way of handling them to produce a composite are very much like both carbon fibers and glass fibers, but the form in which the material is available is somewhat different.

Kevlar is produced in only one fiber size, and these fibers are offered in bundle sizes, or "denier" grades. This ranges from 195 denier yarn, a bundle which contains 134 filaments, on up to a large roving bundle of 7100 denier, which contains proportionately more individual filaments. Dupont is constantly revising the array of products they offer, and deniers of up to 20,000 can be provided where very heavy materials are to be woven.

Now this is a little confusing because in the composite structures business nobody but Dupont uses the denier system. If you buy yarns or rovings of graphite you will be offered a 1K, 6K, or 12K strand. In this case, the "K" stands for thousands. A 12K bundle simply means that it has 12,000 filaments in a single strand of yarn that's wound on the bobbin. In the case of Kevlar, they offer you an 880 denier yarn but neglect to say that it contains 267 filaments, which would make it a little less than one-third the size of a 1K yarn in carbon fiber.

Kevlar, as mentioned above, has some rather remarkable mechanical properties, however, it suffers from one serious problem — it's very difficult to manufacture. It is made out of a chemical solution and is produced under rather secret conditions which Dupont will not divulge, and since they at present do not have a competitor, it's not possible to tell whether their pricing is reasonable or unreasonable.

Comparing it to products which go into similar structures, one can see that Kevlar is actually a pretty good buy in spite of the anguish and distress Dupont goes through in manufacturing it. The yarn has been offered to nearly all the weavers and is currently available from at least 10 manufacturers who also manufacture fabrics of fiberglass, and in some cases, of carbon fiber. These weavers compete vigorously with each other, and as a result the woven fabrics are quite generally available.

The vast number of variations of the glass fibers available is "mind boggling."

THE FIBER/RESIN INTERFACE

We've covered three different families of fiber materials which dominate the advanced composite field. Now let's talk about how we get these fibers into a structure. In other words, how do you locate them, arrange them, mix them, and how do you structurally attach them to each other and attach the whole mass to something else in order to carry a useful load?

Basically the resin matrix is the key to this whole operation. It was mentioned earlier that the resin matrix is the mass in which the fibers exist, but basically the resin does much more than just contain the fibers. The primary thing it does is to carry the load from one fiber to the next fiber and from the bundles of fibers or the group of reinforcements into another structure entirely, which may be embedded in the composite or adhesively bonded to it at a later stage. These resin materials actually distribute the loads within the structure from one member to another.

Another important subject is how to get this fiber to give a good, reliable bond to the resin so the load can get out of this fiber and into the next fiber. Because it is so important, this fiber resin interface has been the subject of a great deal of work within the composite industry over the last 40 years, much of it relating to E glass fibers.

The primary problem is that most resins which appear to give a good bond to the fiber will allow that bond to deteriorate over time, sometimes in only a few weeks. In the case of glass fibers and polyester resin (the same resins used to make small boats and pleasure craft of all sorts), that bond will appear to be quite satisfactory the day it is made, but about two or three weeks later it will show a drop in strength, perhaps five or 10 percent lower. Three or four months later that drop in strength might be 30 percent, and a year later as much as 60 or 70 percent. The problem is that the interface between the resin and the fiber is deteriorating.

In the case of glass, this deterioration usually involves the addition of a water molecule to the surface of the glass to make a new substance which is just not a very good structural material. To prevent his deterioration, as well as to improve the "wetting" of the resin into the glass fibers, it's common practice to treat the surface of the glass before using it to make a composite structure.

This treated fiberglass surface then makes a permanent and lasting bond to the resin system that will be applied. This treatment is usually called a "finish," and all of the weavers and prepreggers will apply a finish to the cloth, the exact details depending upon what sort of use is to be made of this fabric later on.

For example, one of the most commonly used finishes for E glass is called "Volan A." This material is actually a methacrylic chromic chloride complex and is applied directly to the clean glass fibers. The Volan finish is quite a good one, in that it will give a good bond to both epoxy and polyester resin systems, and also to the newer vinylesters. As a result, it's quite commonly used for fabrics which are sold in boat shops or which go to homebuilders of aircraft.

If all E glass fabrics had a Volan A finish, homebuilders wouldn't have much of a problem. However, there is a serious problem because a lot of fabrics have other finishes which are very unsuitable.

Another factor is that some fabrics have a starch and oil "binder" on them. This is really a lubricant which gets the fragile E glass yarns through the weaving operation without tearing them all up and destroying the structural integrity of the fabric. Fabrics which have this material still in place after weaving are called "griege goods" or "loom-state."

These materials cause serious problems if they are put into a reinforced plastic or a composite structure. Water goes right down the interface between the resin and the yarn because of the hydrophylic (water-loving) nature of both the surface of the glass and the binder. It is therefore common practice to burn off this binder after the fabric is woven, giving what is called a "heat cleaned" surface. This heat cleaned cloth then has the surface finish applied to it which is intended for the final use.

The problem doesn't end here, however, because many other surface finishes are put on for other totally different uses, such as release fabric, which is the very same glass cloth with a finish intended to *prevent* adhesion to resins. Some finishes are applied for the purpose of preventing the glass from chafing upon itself when it's used for fuel filtration in a bag house, and there is a lot of this sort of fabric circulating around.

There are some 25 or 30 different commonly used fiberglass finishes which may appear on woven glass cloth. All but five or six of these will do just the wrong thing to a composite structure. It's very important, therefore, that the homebuilder:

1) make sure just where his fiberglass cloth came from,

2) be sure that it has been properly treated with a finish which is going to give him the structural result that he is looking for, and

3) still has the finish in place and uncontaminated by water, smoke, coffee spills, grease, oil and such.

The standard caution is, don't buy surplus glass fabric for use in composite structures, because you never know where it came from. Also, since most finishes on glass fabric tend to deteriorate somewhat with age, it is a good idea to buy your glass fabric in reasonably small quantities, not more than you'll use up within a year or two.

Although Volan A is the only surface finish that was mentioned above, there are at least 10 or 20 more very good ones which are used by many of the weavers and prepreggers. The important thing is to be sure that one of the appropriate finishes was actually applied to the fabric you intend to use.

All of the above discussion about glass fiber surface treatment is intended to apply only to E glass. If we talk about S or S2 glass, the higher strength glass fibers, then the surface treatments are really very much like they are for carbon fibers. This is because neither S glass fibers nor carbon fibers can be heat cleaned to get rid of the starch and oil binder which would normally be used for weaving.

The reason for the inadvisability of heat cleaning S glass lies in its chemistry. At the 700-800 degree F temperatures involved to degrade the mechanical properties of the fibers, all the advantages are lost. In order to provide protection to the fibers for weaving, the same procedure is employed as is done with carbon fibers: a small amount of epoxy resin is coated on the fibers and carried on the fiber surface through all subsequent operations.

Consequently, both S glass and carbon fiber suffer from a problem in that both the housekeeping in the weavers plant and the quality of the weaving have a direct bearing on the strength of the composite. In other words, if the weaver gets the cloth dirty, greasy and oxidized during his weaving and storing operations, then whatever surface results from this mishandling is present in the composite structure. It is thus important that a suitable level of quality be conformed to in the weaver's mill.

Again, a warning to the homebuilder not to buy surplus carbon fiber fabrics or S glass fabrics. There may be a very serious problem involved which is entirely invisible to the unaided eye, a problem which cannot be detected in any way other than to make test laminates and test them structurally after a hot wet exposure.

In the case of Kevlar, we have a little different situation. The material cannot be heat cleaned since it is an organic and can't stand the 700 - 800 degree temperatures which are used to burn off the sizing and binder from ordinary E glass.

As a result, the sizing and binders are washed off Kevlar fabrics in a washing machine. This process is called "scouring," and if you are to use Kevlar fabrics as a part of a composite structure you want to be certain that they have been properly scoured before you start applying them to your structure.

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There's also a difference with different formulations of resins. If you're going to make a Kevlar and resin composite it's a good idea to test out the system that you propose to use as well as do some testing of the mechanical properties of the finished composite before you commit a large scale construction project to the materials you have in mind. In some cases, the resin manufacturer may have already run these tests and can furnish data on the combination you propose.

Carbon fiber materials also are not capable of being heat cleaned, and therefore they simply cannot be given the same lubrication treatment that E-glass fibers are given for weaving. They are also so fragile that it's not a very good idea to run them through a scouring machine, since this tends to tear up the yarn and make the fabric rather weak compared to what it is in the undamaged condition.

It's reasonably easy to tell if they have been because if the scouring has not been properly accomplished, the cloth will be very difficult to wet out and simply won't look right when the part has been finished. Although one might think that there would be some chemical surface materials to treat Kevlar yarn to improve the bond to the resin, so far there has none been developed.

Dupont Corp. is working on this problem. It is expected that within the next few years Kevlar will be more readily bondable to a larger array of resin systems. At present you really should use only epoxys or vinylesters. The polyesters simply don't bond to Kevlar very well.

As a result, the lubrication of the yarns for weaving and handling is accomplished just as with S glass, by simply putting a little bit of epoxy resin on the surface of the carbon fibers just after they are drawn from the oven when they are manufactured. This bit of resin is then joined with the epoxy resin that goes into the final product. You must be careful of the resin system that you choose when using carbon fiber or S glass materials in order to assure compatibility between the fiber finish material and the resin matrix system.

For example, if you use a polyester resin system with a lubricant on the fibers which is an epoxy resin, it's quite possible that you'll get very bad structural results. •

The second part of this article will cover the weaving of fabrics for composites as well as hybrid fabrics and unusual fibers. HOMEBUILT AIRCRAFT has not previously published technical articles such as this one, and we would like to hear your feedback regarding your interest in such articles. Please send your comments to: HOMEBUILT AIRCRAFT, Editorial Dept. 16200 Ventura Blvd., Suite 201, Encino, CA 91436.