

CORE MATERIALS – PART I:

THE MEAT OF THE SANDWICH

By A. Brent Strong, Brigham Young University

Composites and Cores

Composite materials are all about choosing just the right material for the job and putting it in just the right place in the right way so that the properties of the entire structure will be better with the materials in combination than with the materials separate. (Whew! That’s a lot to expect.)

We usually describe composites in terms of resins and reinforcements—the familiar fiberglass surrounded by thermoset plastic. The fibers give enhanced strength, stiffness, and other desirable properties and the plastic gives shape and environmental protection. People newly acquainted with composites (such as the students I teach in my plastics and composites classes) probably think that these fiber-resin structures are all that there is to composites. But, those of us who have been in the industry realize that composite structures can be raised to a higher level of complexity. Those more complicated structures are the focus of this article.

Double Composite (Sandwich) Structures

You probably have never heard the term “double composite structure” before, but I think that it describes quite well the concept of a sandwich structure that has such an important position in the composites industry. The sandwich structure, as shown in Figure 1, consists of two traditional fiber and resin composites (the face sheets or skins or, extending the sandwich

analogy, the pieces of bread) which are bonded to the top and bottom of a core material (the meat of the sandwich). You can think of the bonding adhesive as the mayonnaise in the sandwich.)

The new sandwich structure that has been created is, therefore, a double composite because it is a composite structure overall but contains other composite structures (face sheets) within it.

Thinking of these sandwich structures as double composite structures emphasizes the concept that if the structure is to work properly, all the components must be tied together. We would also expect that the overall composite structure might have some of the same critical design and manufacturing issues as do the simpler composite structures. For instance, in designing and in making the fiber-resin composites and also in the sandwich structures we must consider the following:

- Trade-offs in the amount of each of the components in the composite for performance and cost,
- Careful selection of materials for optimum structural properties,
- Consideration of environmental conditions during use,
- Manufacturing of the sandwich structure, and
- Various other design and use issues, especially as related to the specific use.

These considerations, so critical in the design and manufacture of all fiber-resin composites, are critical as well to the performance of sandwich composites. We will, therefore, examine each of these design/manufacturing considerations so that the choices and compromises made in sandwich materials can be better appreciated and understood. Just as with resin-fiber composites, a particular component may be ideal in one area of consideration (such as

properties) but not be good in another (such as cost or manufacturing capability). Therefore, all the considerations must be weighed before the materials and manufacturing methods are chosen.

Trade-offs in the amount of component materials for performance and cost

The trade-offs between component materials in a sandwich composite goes right to the basic issue of why we would want to make a sandwich composite at all. The logical question is, why not just use resin-fiber composites without the core materials.

Understanding the value of sandwich composites requires that we first understand the nature of fiber-resin composites. The fiber-resin composites consist of relatively thin sheets of fibers (in various orientations) held in place by a resin matrix. The fibers lie in the plane of the sheet (usually called the x-y plane). In most resin-fiber composites, several layers of these thin sheets are stacked and bonded together to form a laminate structure. This combination of several sheets increases the tensile and flexural properties over those possible with a single, thin layer.

However, in the typical composite laminate, there are no fibers oriented perpendicular to the plane of the sheets. (The perpendicular direction is called the z-direction). These orientations are shown in Figure 2. Therefore, since fibers only have strength in their orientation direction, the strength in the z-direction is principally from the cured resin matrix.

If the composite is loaded in the z-direction, as is done in flexural or bending mode, the deflections can be unacceptably large because the reinforcing fibers have very little mechanical contribution in the direction of the flexural load. This flexural deformation is illustrated in Figure 3.

A quite different scenario is encountered when core materials are used to make a sandwich structure. The greater thickness of the core materials gives tremendous increases in

bending/flexural strength and, especially, stiffness. This effect is illustrated in Figure 4 where we can see that doubling the thickness (at the same weight as the resin-fiber composite) will give a 6-fold increase in strength and a 12-fold increase in stiffness. If the thickness is doubled again, still maintaining the same weight, the increase in strength doubles to 12-fold over the single skin and the stiffness increases to 48 times the stiffness of the non-sandwich composite.

Structural engineers have long known that increases in thickness will give these large increases in strength and stiffness. This is the principle on which I-beams work. As illustrated in Figure 5, the face plates of the I-beam are the upper and lower surfaces and these correspond to the resin-fiber laminates. The web of the I-beam corresponds to the core of the sandwich composite. Note that the web of the I-beam is relatively thin and, therefore, light weight. Likewise, the core materials are generally much lighter weight than the resin-fiber laminates. The increase in stiffness of the I-beam and of the sandwich composite are principally functions of the distance between the face plates and not of the nature of the web provided certain overall parameters are maintained.

There is an important difference between I-beams and sandwich structures. When the sandwich is subjected to a z-direction force, that force tends to be spread all across the surface of the core, thus diminishing the force in any single location. The I-beam is far less capable of spreading the force. Moreover, because the force is spread, the core material need not be as rigid or strong as required in an I-beam. In other words, the combination of the face sheet and the core material, if bonded properly together, will have much greater stiffness and much greater strength than would either material by itself. Truly this is a synergistic composite structure.

The design question becomes, therefore, how much resin-fiber composite to use for the face sheets and how much core to use. If we assume that a constant overall thickness is required, then clearly using more thickness of core material will reduce weight and increase thickness in the z-direction. In general, the use of more core material in place of face sheet will reduce costs since cores are usually less costly on a thickness basis than are face sheets. However, at constant overall thickness, increasing core thickness and reducing face sheet thickness will result in less strength and stiffness in the x- and y-directions. The optimization of these component thicknesses is clearly a compromise that must be decided for each application.

Some other types of structures that might give increased z-direction stiffness can be considered besides resin-fiber laminates and sandwich materials. For instance, a structure can be built up using struts between the laminate faces. This type of structure is usually shaped like an egg-crate. Such structures can be very stiff and strong, but are often difficult and expensive to build. Their most common use is for backing mold faces where access is easier because only one composite face is used.

Another construction uses plywood as the material between the composite laminate faces. This was an early construction and is still used in applications where weight is not a major consideration. Cost is also quite low for plywood. However, plywood is, itself, a laminate with its principle strength in the xy plane. Therefore, it has little z-direction contribution and is better thought of as a backing material than as a core material.

Material selection for optimum structural properties

We have, up to now, discussed sandwich structures in general, with little reference to specific core materials. Some core properties are critical to overall sandwich structure

performance. Other core properties are not as critical but might be a bonus in the choice of material for some specific applications. Table 1 lists the common core materials and some of the important characteristics commonly associated with each of the core materials.

The most common core materials can be divided into four general types: balsa wood, foams, honeycombs, and stitched/compressed materials. Within each category there are several specific types and these are also quite distinct in properties. Each has inherent advantages and disadvantages which should be considered for every application.

The nature of the core is important in determining the crush strength of the sandwich structure. Clearly the core material must be able to withstand the force applied in the z-direction. (Think of the deflections that would occur if the web or the core was made of rubber.) Hence, it is important that the core materials be strong and stiff in the z-direction. The common core materials are generally acceptable in stiffness and strength, but a reasonable designer would make up sandwich composites for testing and subject them to the anticipated maximum z-directional loading to be sure.

Another critical structural property is the ability of the core material to withstand x- and y-direction loads. Because the entire sandwich structure is bonded together, forces from the x- and y-directions will place the core into potential shear and buckling failure modes. These generally become worse as the core material is increased in thickness. Examples of some of the failure modes of core materials are shown in Figure 6.

A property of immense importance in some applications is impact damage resistance (or impact toughness). Here the high stiffness of a core material is often a disadvantage because high stiffness usually comes with high brittleness. As a result, when these highly brittle

materials are impacted, the core materials may shatter. The core materials that are best in resisting impact damage are those with slightly higher resilience. This property is generally associated with thermoplastic materials (such as polypropylene, non-crosslinked PVC or SAN).

Another property of interest is the resistance of the core material to crack propagation. Again, high stiffness and the resulting brittleness tend to result in high crack propagation. Still another property that is related to stiffness/brittleness is fatigue resistance. This property is sometimes discussed in terms of withstanding high dynamic loads.

Some comments are appropriate regarding the nature of composite testing. The structural properties of composites and other materials are usually determined using standard tests (such as ASTM), many of which were developed for metals. Many of those tests have been modified to give comparable results for traditional resin-fiber composite laminates, but few have been modified for sandwich materials. Therefore, sandwich materials are sometimes at a disadvantage when compared to other materials if only the test data are compared. If the property of interest corresponds directly to the test and is important in the performance of the structure, this disadvantage is justified. But, if the specifications are written around material properties that have may have little relationship to actual performance, then some alternate test might be devised that allows sandwich materials and metals or laminate composites to be compared fairly.

Some tests have been shown to be especially appropriate for sandwich materials and many of the most common applications. These include the Long Beam Flex test, the Roller Cart test, the Core Shear test, the Climbing Drum Peel test, Falling Dart Impact test, Flatwise Tensile

test, Vertical Flame Test, the NIST (NBS) Smoke Chamber test, and the Edgewise Compression test.

Environmental conditions during use

Clearly the core material must perform many functions well. It has structural requirements and a myriad of other properties required by the conditions of each particular use. Some have described the core material in sports terms. It is like the athlete who competes in the Decathlon—able to do many things well.

Some environmental conditions suggest special care in selecting the core material. These include the following:

- **Water absorption.** Some composite materials have a tendency to absorb water and might be avoided in marine environments. A related problem is entrapment of water, even when the core material itself does not absorb water. The water can adversely affect performance by adding weight and may diminish strength. Some of the composite materials could be subject to rot in moist environments.
- **Temperature:** The face plates of a sandwich material are usually quite good thermal insulators so the core is often protected from direct contact with high heat. Nevertheless, thermal degradation of the core over time is a possibility that should be considered whenever high thermal conditions exist. Thermal stability and toughness are often difficult to achieve at the same time. An advantage of most core materials is that their thermal insulative capabilities. Consequently, sandwich composites are widely used when thermal insulation is

required. A consideration in these applications should be given to the differences in coefficient of thermal expansion (CTE) between the composite and the face plates. If the CTE is too large, debonding can occur and most of the structural properties of the sandwich structure will be severely deteriorated.

- **Off-gassing.** Some applications are particularly sensitive to off-gasses that may be emitted by the core materials. Of course, the resin in the face might also be a problem with off-gassing. Some core materials, such as metals and a few of the polymeric types, have very low off-gassing and are therefore preferred when this problem is important, as might be the case in panels used in clean rooms.
- **Flammability.** Clearly some applications, such as panels for trains, planes, and ships have strict flammability requirements. These often also include requirements on smoke generation and toxicity. Some of the core materials are especially good in resisting burning and smoke generation.
- **Sound insulation.** Most core materials are excellent sound absorbers. However, when sound is a key part of the application, the best policy is to test the entire sandwich structure for sound suppression.
- **Vibration damping.** For shipping and other transportation applications, the ability of the material to absorb vibrations can be critical. The natural frequency of the core is a key component in absorbing these vibrations, but the entire structure has unique natural frequencies that must be determined by for the whole composite. Testing the entire structure is usually required.

Manufacturing of the sandwich structure

The most important part of manufacturing a sandwich structure is the bonding of the core material to the face plates. This is done with an adhesive film that is placed between the face plates and the core. That adhesive must be strong enough to transfer the load from side forces onto the face sheets and to resist debonding with the surface of the core. Experience has shown that tough adhesives work best because they can elongate slightly to accept small displacements without cracking.

The adhesive must be thick enough to give a good bond over the entire surface but not so thick that it becomes a point of failure. The adhesive is, after all, a non-reinforced resin layer that would have less strength than the resin-fiber laminate.

When the core material is balsa wood, some foams, some honeycomb materials, and some stitched-compressed materials, care must be taken to prevent excessive resin infusion into the core layer. If the resin were absorbed or flowed into the core material, that could starve the interface and greatly weaken the bond. Therefore, if the core absorbs resin, the amount of adhesive must be increased accordingly. With honeycomb, experience has shown that the correct amount of adhesive will wick slightly into the honeycomb cells to give a good bond to the walls of the cells but will not run down excessively. To achieve this moderate wicking, the viscosity of the adhesive material at the temperature used for curing of the adhesive must be carefully controlled. Some core materials have a scrim sheet (that is, a thin mat material) bonded to the top of the core to prevent excessive resin infusion.

In one circumstance the resin flow into the core is desired. That circumstance is when weight is not a problem and the core material might be subject to high vertical loads. In this case, sufficient adhesive is applied to allow for the resin to flow into the core and also have

sufficient to bond at the interface. The cells of the core material are designed to have resin within them so that they will be stronger in crush strength. (The resin inside the cells tends to keep the cells parallel, thus increasing the crush strength significantly.)

In almost all sandwich structure applications, after the core and the face plates are joined, the ends of the sandwich material usually need to be sealed. This sealing can be done by several different methods. One is to apply a thick resin, sometimes reinforced with milled fibers, along the edge. Another method is to shape the core so that it tapers to a smooth finish.

Summary

The ability to give z-direction strength and stiffness to a composite structure greatly expands the capabilities of composite materials. The composite structures can be made lighter weight and lower cost by using core materials. However, the complexity is also increased. There are more materials in a sandwich than in a traditional resin-fiber laminate and that means that there are more things that can go wrong. The bonding must be excellent between the core and the face panels, for example. Also, the amount and type of adhesive used to form this bond must be carefully chosen and the manufacturing process must be compatible with that choice. Finishing of the sandwich structure is more complicated than just the resin-fiber composite.

However, in spite of these difficulties, the use of core materials is increasing greatly. Cores are being used in an ever wider assortment of applications. The next article in this series will discuss those applications and why sandwich materials are so important in them.

Companies that have contributed to this article:

ATC Chemicals Inc., Maureen Bookbinder, 905/681-8112, maureen.bookbinder@atc-chem.com
www.atc-chem.com.

Baltek Corporation, Marc Anderson, 201/767-1400, manderson@baltek.com, www.baltek.com

Benecor Inc., Eric Pulley, 316/682-6144, benecor@benecor.org

DIAB Core Materials, Alex Gutierrez, 972/228-7649, alex.gutierrez@diabgroup.com,
www.diabgroup.com

Hexcel Corporation, 415/828-4200, www.hexcel.com

Impact Composites, Andy Dekeney, 713/463-7824

Lantor BV, Kees Swinkels, 31 (0) 318-537-272, kswinkels@lantor.nl

M.C. Gill Corporation, George Sorenson, 626/443-4022, georges@mcgillcorp.com,
www.mcgillcorp.com

Nida Core, Jack Lugas, 571/332-9903, jacklugus@cs.com

Plascore, Inc., Luke Young, 616/748-2229, luke.young@plascore.com

Rohacell, Blake Juhl, 801/495-9403, blake.juhl@degussa.com

Spheretex America, Inc., Juergen Boettcher, 904/273-0708, us-sales@spheretex.com

Tricel Corporation, Stephen Loudin, 800/352-3300, steve@tricelcorp.com

Ultracore, Wally Hansen, 925/454-3010, whansen@ultracorinc.com

Table 1 Common Core Materials and Their Properties

Core Materials	Characteristics and Benefits
Balsa wood (end grain)	Good shear strength, high fatigue endurance, low cost, high bondability, easily finished, good temperature range,
PVC foam (crosslinked)	High strength, high stiffness, low cost, easily bonded
PVC foam (linear)	Low cost, easily bonded, good impact resistance
PMI foam	High dimension stability under heat, excellent mechanical properties, solvent resistance, low thermal conductivity, high strength and stiffness
PEI foam	Low water absorption, high thermal stability, high strength, fire resistant, good dielectrics
SAN foam	No outgassing, high stiffness, high impact and fatigue strength, no environmental problems with resin or recycle
Ceramic foams	Unsurpassed thermal resistance, excellent thermal insulation, solvent resistance
Paper honeycomb	Low cost, high bondability, strong for weight
Polyimide-paper honeycomb	High strength to weight, corrosion resistant, good thermal insulation, fire resistant, easily shaped, excellent dielectric properties, high bondable
Polyolefin honeycomb	Rigid and elastic, high toughness, sound and vibration dampening, explosion containment vessels, scrim cloth available, high strength to weight, corrosion resistant, fungi resistant, thermoformable, recyclable
Engineering plastic honeycomb	Tough, relatively high temperature tolerant, excellent dielectric properties, good thermal insulator, fire resistant, fungi resistant, highly variable cell sizes and densities
High performance honeycomb	Carbon fiber reinforced, carbon-carbon, aramid, quartz, PBO, superior strength, superior thermal resistance
Metal honeycomb	Aluminum, titanium, stainless, nickel available, no outgassing, high temperature tolerant, fire resistant, fungi resistant, high thermal conductivity
Stitched-compressed	Excellent drape, needs to be fully wetted, high impact resistance, reduces cracks, absorbs resin for added strength