JOINING COMPOSITE MATERIALS —

MECHANICAL OR ADHESIVE?

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The Problem

The Achilles heels of composite structures are the joints. (Aren't heels joints?) Many designers will tell you that designing the composite laminate is fairly simple, but that far more time is devoted to the designing of the joints. The joints connect laminate sections together; provide mechanisms for the inclusion of secondary structures, such as fittings, ribs, bosses, and dividers; and connect the composites to surrounding structures — metals, wood, ceramics, plastics or other composites. While the primary purpose of joints is structural, they may have other functions such as electrical or thermal conductor or insulator, sealant, or vibration damper. The variety of applications of joints is, in part, the problem. A single joining method simply cannot be applied overall. Hence, in complex structures, many different joining methods could be used at the same time. However, each particular instance can usually be considered separately, thus reducing even the most complex composite structure to a series of individual joining situations.

Typically, there are two basic joining methods — mechanical and adhesive. These are generally used independently in each joint, but can be combined to achieve special benefits, as will be discussed later in this article. The choice between mechanical joining and adhesive joining is one of the major decisions which must be made. The characteristics of each of the systems are briefly summarized in Table 1. You should be cautious in depending too much on any brief summary of joint types or fabrication. These are important and difficult subjects and the problems are often hidden. As was once said, “The devil is in the details.”

Mechanical Joining

The basic method of mechanical joining is done by drilling holes in the two materials to be joined (such as two composite laminates) and then placing a mechanical fastener through the holes and fixing the fastener in place. The types of fasteners usually dictate the fixing method. For instance: bolts are fixed with nuts, screws are fixed through the interaction of the threads and the materials to be bonded, rivets are fixed by heading the rivet itself, and pins are fixed by simple interference with the holes.

Because these methods do not rely upon the nature of the surfaces of the materials being bonded, little or no surface preparation is required. The only dependence on the materials is the strength of the materials at the joint location. For instance, if the materials are crushed easily, bolts and nuts may exert too much compressive force and the materials could be deformed. Also, if the materials are not strong in shear, screws may not hold.

Drilling the holes can cause delamination of composites. This drilling should be done with proper backing and support and in consideration of the type of composite material being drilled (Kevlar®, fiberglass, and carbon fibers behave quite differently during drilling and require different drill configurations). Additional problems with mechanical fastening can arise because of the cutting of the fibers which must occur when the holes are drilled to accommodate the fasteners. These problems arise especially if the composite has been closely designed to the limits of performance. Good joint design will overbuild in the joint region, usually by increasing the number of fibers. This can be done by using more composite material (thicker joint areas), by adding additional or longer fibers (adding cloth or unidirectional fibers in the joint area), or by reinforcing with a non-composite material such as a strip of wood or metal.

Mechanical fasteners create point loads at the contact points. These localized forces may cause localized failure. Point load failures are usually prevented in the same way that failures from drilling holes in the laminate are prevented (thicker materials, added reinforcements). Therefore, a primary consideration in choosing mechanical joining is whether the materials are strong enough to withstand the forces exerted by the mechanical fasteners themselves or whether they can be easily improved in the critical region.

The long term effects of mechanical fasteners in joining composites have not been fully explored. Some of the long term considerations include fatigue because of the point loads in particular, corrosion between the fasteners and the composite (especially true in carbon fiber composites joined with aluminum), and admission of moisture through the joint itself.

Mechanical fasteners withstand peel forces well, but do not contribute significantly to tensile forces. These forces and the others important in joint design are illustrated in Figure 1. Mechanical joints have poor performance in tensile. The tensile loading situation can be simulated by a simple example. Imagine, for instance, two standard sheets of paper that have three staples joining them across the bottom of one sheet and the top of the other. If the sheets are then pulled in tension, they will deform, load at the staples disproportionately, and separate at the staples. Composite laminates behave similarly.

Mechanical fasteners are typically metallic and therefore increase the overall weight of the joint, especially because the mechanical fasteners are often closely spaced to reduce the problem of poor resistance to tensile forces. To reduce the weight, light metals such as aluminum or titanium can be used, but at a higher cost compared to the traditional steel fasteners. Some new work in fasteners made of composites has been reported, although they have not yet gained wide-spread usage.

Lest you think that mechanical joining of composites is all negative, some discussion of the advantages of this type of joining should be made. The mechanical joining system is simple, reliable, proven, and easy to inspect. These are, perhaps, the primary reasons that mechanical joining is still used so extensively. Moreover, mechanical fasteners rarely limit the use temperature of the composite which is, therefore, usually dictated by the composite itself.

Adhesive Joining

A wide variety of materials is available when adhesives are used to bond materials together. The choice of which adhesive is best is usually dictated by the type of composite to be bonded, the application of the bonded composite, the service environment, and cost. The general classes of adhesives are: structural, hot melt, pressure sensitive, water-based, and radiation cured. In general, the structural adhesives dominate when joining of composites is required. The most common polymers in the structural adhesives class are: epoxies, polyurethanes, acrylics, cyanoacrylates, anaerobics, silicones, and phenolics.

The first consideration in choosing an adhesive should be an assurance that the composite and the adhesive are chemically compatible. When compatibility is good, the bonds between the composite and the adhesive are optimized. Generally, the rule of thumb for compatibility is that the closer the chemical nature of the composite resin is to the adhesive, the better the performance.

The choice of adhesive should next be viewed in terms of the service environment. This could include factors such as temperature, solvent and moisture resistance, UV-light exposure, expected service life, and the loads expected during use. No simple rules exist for examining all these factors for each of the available adhesives. Good engineering experience, in consultation with the manufacturer of the adhesive, is often the best way to make the choice.

In some cases, the operational factors in making the bond will strongly dictate the choice. For instance, although all adhesives require excellent surface preparation of the materials to be joined, some adhesives require a stricter regimen than do others. Also, some adhesives are more forgiving in the fabrication of the joint. Some adhesives require little time to form an acceptable joint while others require clamping and exacting cure conditions.

The strength of the adhesive bond requires that the adhesive completely spreads over the surface of the substrates to be joined. This is called wetting the surface. Wetting is improved by chemical compatibility between the surfaces and the adhesive. Wetting is also improved when the bonding surfaces are clean. Bonding is also improved when some mechanical interlocking exists between the adhesive and small irregularities on the surfaces of the materials to be joined. Therefore, the first step in making an adhesive bond is often a roughening of the surfaces to be bonded. This is followed by a cleaning to remove all oils, greases, debris, and other surface contaminants. This cleaning can be very complex, for instance, when oxide layers must be removed from metals. That may require chemical etching, sand blasting, plasma treatment, or other sophisticated cleaning approaches. Following these, metals may need to have a primer applied to both protect the cleaned surface and improve chemical compatibility with the adhesive. Most adhesive manufacturers will recommend the primer and the surface preparation should these be needed. Once primed and prepared, the time elapsed to application of the adhesive should be kept short.

The adhesive can be applied in many ways. Some are liquids and are often metered onto the surface using a melt pump or other liquid regulating system. Liquid adhesives could, of course, be brushed on or wiped on in situations not requiring high precision of adhesion placement and quantity control. However, remember that the adhesive is generally not reinforced and is, therefore, lower in strength than the typical composite it is joining. Therefore, proper procedure is to use only enough adhesive to completely cover the bonded surfaces. To facilitate the proper application of adhesive quantity, many adhesives can be purchased as films or sheets which are simply laid in place. Adhesives might also be supplied as pastes or even solids (powdered). These require some special care in ensuring that they are placed correctly. Heat and pressure may be necessary.

After application of the adhesive, the parts to be bonded should be carefully aligned in the designed configuration. They are usually held in place with clamps or some equivalent mechanical restraining device. The parts should then remain in this fixed position until after the adhesive has solidified. Bonding tooling and jigs or fixtures are often utilized at this stage to ensure alignment and proper contact during this stage.

Some adhesives, especially structural ones, are solidified through heated curing. Others adhesives may cure with moisture, evaporation of a solvent, UV-light exposure, or some other sophisticated method. Of course, adhesives requiring only pressure and contact are also known (like Scotch® tape) but these are not often structural.

Obviously, considerable effort is required to insure good adhesive bonding. What are the advantages to be gained from this effort? In aerospace applications, the major advantage is often weight savings. Also, the distribution of the forces over a wide area contributes to the long term performance of the part. Further, moisture and solvent intrusion is often eliminated by the self-sealing nature of many adhesives. Many adhesives are quite flexible when compared to the composite materials they are joining, thus providing shock and vibration reduction.

An issue not often appreciated is the ability of adhesive materials to join together complex shapes. Related to that is the ability of adhesive to join thin sheets through their natural distribution of forces.

Some composite fabricators have been successful in reducing operation times by applying the adhesive to an incompletely cured composite laminate and then co-curing both the laminate and the adhesive. This not only reduces fabrication time, it also generally improves bond strength.

Combination of Mechanical and Adhesive Joining

Do you use both a belt and suspenders? Fears of failure for one or the other joining methods lead some fabricators into dual application of joining methods. There are, however, some occasions when application of both a mechanical joining device and an adhesive are required. For instance, if the interface is best joined mechanical but a sealed joint is required, then both must be used. Also, fast curing adhesives may be used as a method of rapid assembly before the permanent mechanical joints are installed.

In some applications, the use of an adhesive bonding agent can spread the peak loads inherent in mechanical joints and improve joint performance.

Summary

We have discussed, in general terms, the differences between mechanical and adhesive joining methods. Each has certain advantages over the other, but also has disadvantages. The choice is complex and should be made with careful consideration of the application purpose, the use environment, and the fabrication process. Cost is, of course, a critical consideration, but should be considered in more depth than just the cost of the joining materials.

We have not discussed joint design, failure modes, inspecting and testing. These are also very important issues which may factor into the overall selection process. Generally, these issues are best resolved with composite design experts.

Additional Reading and References

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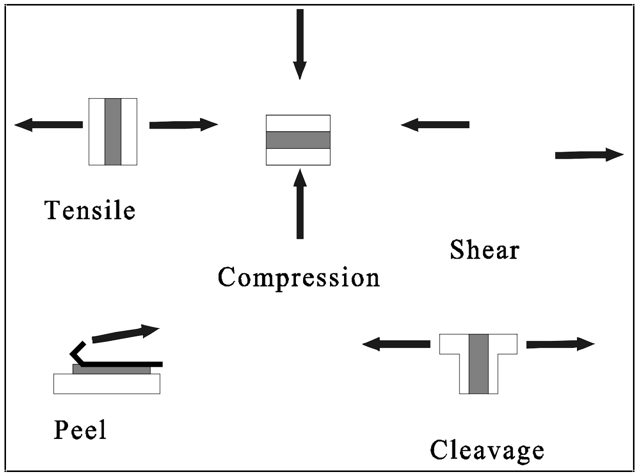
Property	Mechanical Joining	Adhesive Joining
Cost	Higher cost	Lower cost
Time to make the joint	Several steps, joint assembly rapid	Few steps, long cure
Surface preparation	Minimal	Extensive, critical
Thin sections	May not be possible	Can be done
Joint weight	Heavy	Light
External surface aspects	Protrusions	Can be smooth
Temperature limitations	Limited by the laminate	Adhesive may limit
Laminate fiber damage	Can be important	Not important
Ability to inspect	Easy	Difficult
Environmental issues	Can have galvanic corrosion	Solvent sensitivity
Moisture penetration	No resistance	Self-sealing
Stress concentrations	Significant	Can be very low
Long term loads	Relaxation and fatigue effects Creep	
Sensitivity to peel forces	Resistant	Susceptible
Sensitivity to tensile forces	Susceptible	Resistant
Vibration dampening	No damping	Inherent damping
Health and safety	Cutting, drilling, thermal dangers	Solvent, thermal dangers


Tensile
Compression
Shear
Peel
Cleavage