THE GUND COMPANY
MANUFACTURERS & FABRICATORS OF ENGINEERED MATERIAL SOLUTIONS

Flexural Strength in Composite Materials

Rigid and Thermoplastic

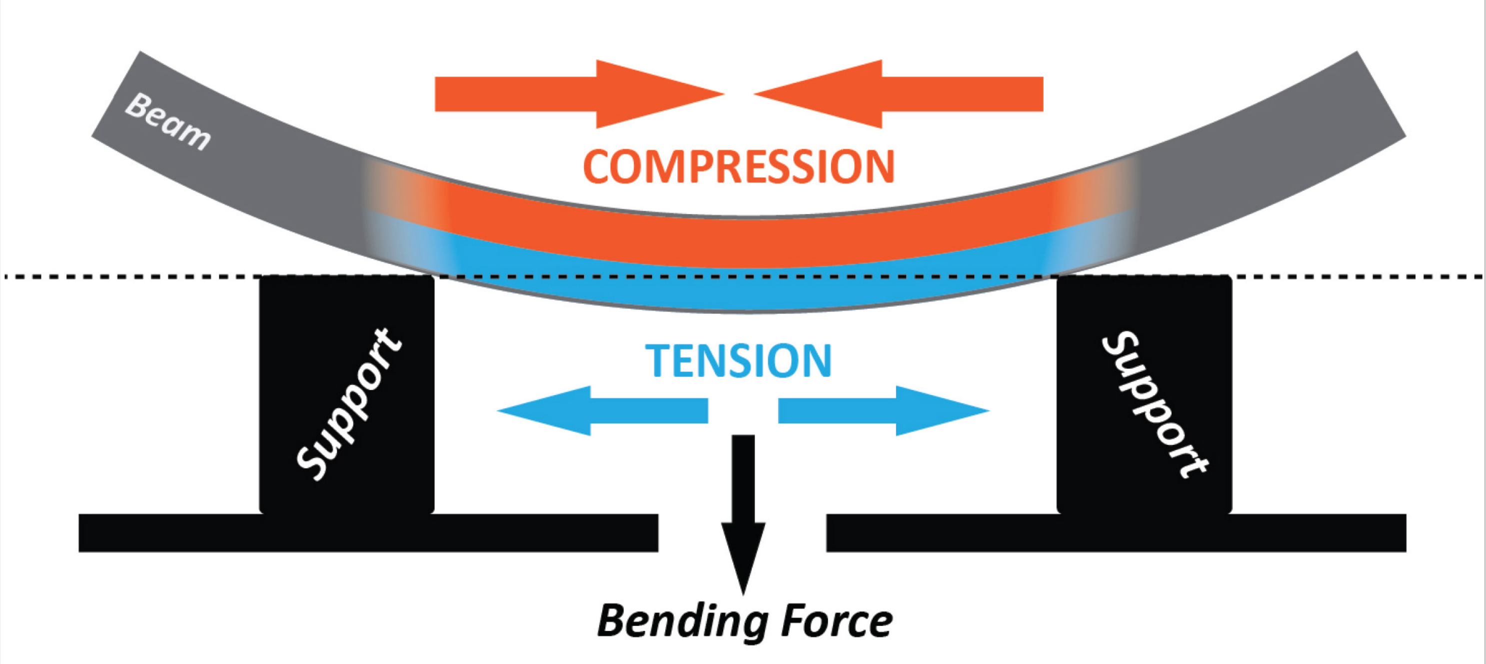
WHAT IS FLEXURAL STRENGTH?

Flexural strength (bending strength) is an important mechanical property for design engineers since many applications often deal with bending stresses. While beam theory is well established and taught in mechanics of materials classes worldwide, composite flexural strength theory is not commonly found in a typical undergraduate curriculum. This technical paper provides an overview of flexural strength relating to composite materials.

Briefly covering the definition of flexural strength is necessary to discuss flex strength in composite materials. Figure 1 - provides a simple diagram showing the stresses involved in a beam bending. Stress is concentrated on the top and bottom surfaces at the midpoint between the two supports.

This example will focus only on a simple supported beam with a center load (how materials are tested to determine flex strength). In Figure 1, the maximum stress on the material is at the point of the highest deflection and is a combined tensile and compressive stress. It is also essential to understand that the highest stress that the beam sees is on the top and bottom surfaces. At the center point of the cross-section, the tensile and compressive stress goes to zero. However, there is still shear stress in the mid-point.

FIGURE 1



A beam under bending stress has tension on one face and compression on the opposite face[1]

Flexural Strength in Composite Materials (cont.)

MAXIMUM STRESS

To further illustrate maximum stress in a beam, the following shear and moment diagram of a beam with a single center load supported at both ends will be used. The diagram shows the moment at its peak at the mid-point between the two supports (L/2).

Shear stress is constant across the beam. When L becomes smaller, it reduces the bending moment and overall bending stress. At some point, L becomes so small that the bending stress is no longer the critical stress as the shear stress takes over as the primary stress.

$\sigma_{max} = y_{max} M_{max} / I$

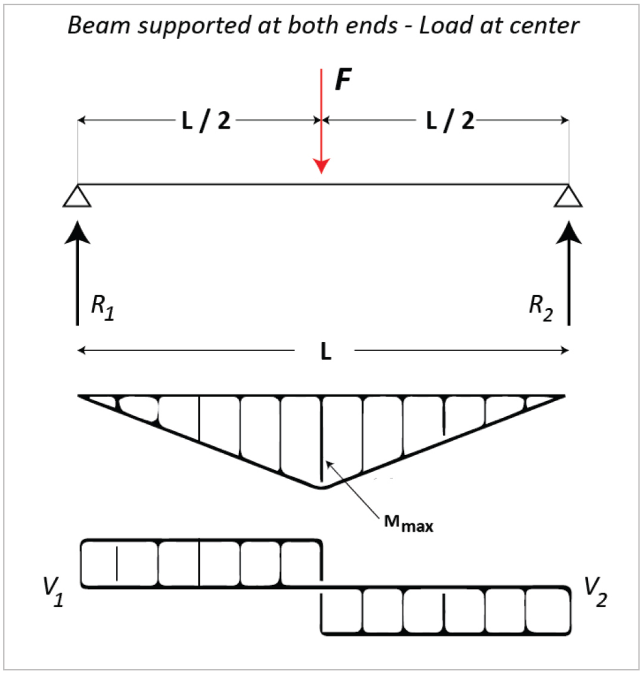
$V_{max} = -F$ where F = load (N, lb)

Y_{max} = max deflection (m or mm, inch)

M_{max} = Moment (N·m, inch·lb) for a simply supported beam = F L/4

I = Moment of Intertia (depends on beam shape)

FIGURE 2



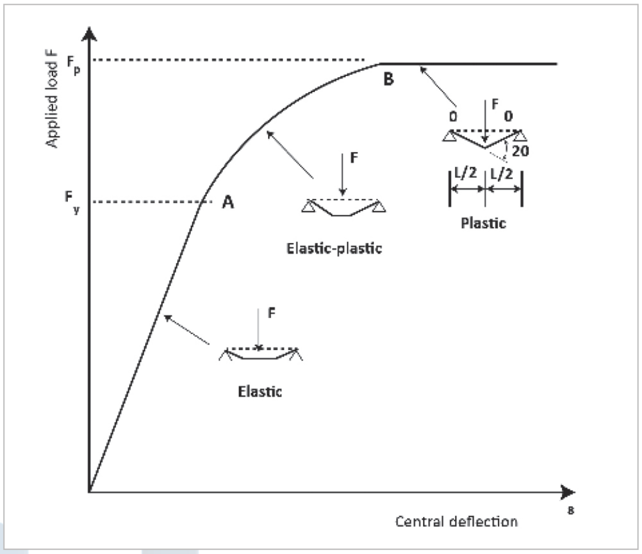
Moment and shear diagram for simple supported rectangular beam[2]

THE IMPORTANCE OF BEAM SHAPE

Since bending stress is inversely proportional to the moment of inertia, the larger the moment, the lower the bending stress if all else is held constant. The following list of shapes and their moment of inertia equations illustrate how shape can significantly impact bending stress.

Square	Ix = a4/12	a= side length
Rectangle	Iy = b3 h/12	b= base, h = height
Circle	Ix = π r4/4	r= radius
I-Beam	Ic = bh3/12 – (b-tw)h3w/12	tw =web thickness

FIGURE 3



Load vs. deflection of a simple beam showing elastic, elastic/plastic, and plastic regions[3]

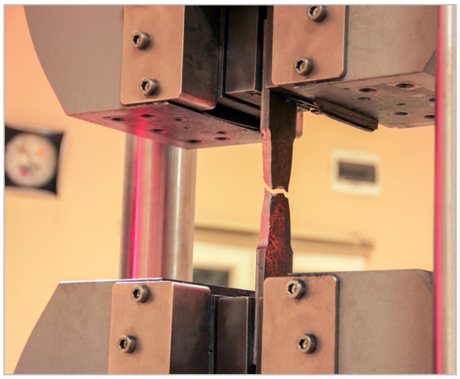
Flexural Strength in Composite Materials (cont.)

WHY IS FLEXURAL STRENGTH SIGNIFICANT?

In applications that put structures under bending stress - flexural strength could be the critical design parameter. Whether it is 2-foot-long support for a bus bar, the flooring in a metro rail car, or a 100-meter-long spar for a wind blade, all-composite component designs need to consider the flexural strength and modulus carefully. In many applications, the stiffness required to keep the system from deflecting is a safety consideration. That is why high-modulus fibers (such as carbon) are frequently deployed in composites. The stiffness-to-weight ratio becomes critical to the design - metal or traditional glass fiber composites - often cannot be used.

Flexural strength in composites is unique because it can be custom-engineered for a specific application. Applications where the primary stress is bending, such as support members, can be uniquely designed to increase the safety factor while at the same time lowering the overall size, weight, and cost. Applications in sporting goods, construction, transportation, aerospace, and military are so common today that high performance is expected. No one wants to have a heavy and flexible surfboard or walk across a footbridge that moves and feels like a rope swing. Composite designers must utilize all options available to provide a design optimized for safety, performance, and cost.

TENSILE STRENGTH TEST EXAMPLE



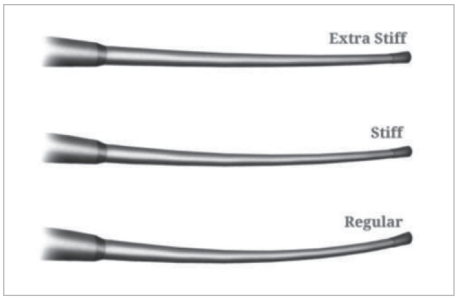
FLEXURAL STRENGTH IN COMPOSITES

Flexural strength in composites is unique because it can be custom-engineered for a specific application. Composites for applications where the primary stress is bending, such as support members, can be uniquely designed to increase the safety factor while at the same time lowering the overall size, weight, and cost. As previously illustrated in Figure 1, the top and bottom surfaces of a beam in flex will experience the highest stress concentrations. Composite materials, by definition, are not homogeneous and do not exhibit isotropic properties. Thus, composite designers can leverage the anisotropic characteristics of composites to their advantage when flexural strength is required in a specific application. The following sections will cover four ways composites can be optimized for flexural strength.

COMPOSITE SHAPE

Like metals, a shape can be critical to flexural strength and stiffness. The same overall principles apply to composites, as do metals. Many of the same structural shapes in metals are also available in composites, such as angle, channel, and rectangular tubing. However, with composites, there is a unique opportunity to customize the shape for an application as necessary. A completely customized shape allows control over the moment over inertia and placement of reinforcements on the outer skins where critical stresses are located.

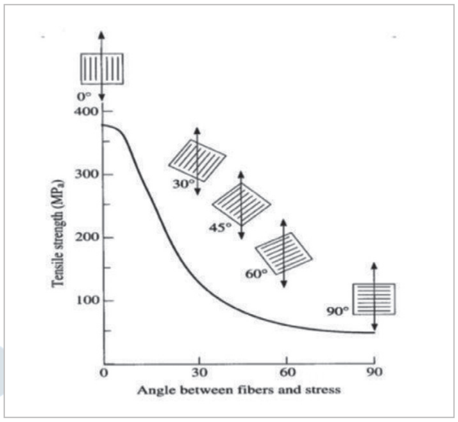
COMPOSITE SHAPE EXAMPLE



FIBER ORIENTATION

Fiber orientation is one of the primary drivers of composite tensile strength and modulus. The highest strength will be achieved when all fibers are oriented in the same direction as the applied load. Likewise, the lowest strength is achieved when the fibers are perpendicular to the applied load. Since flexural strength combines tensile stress on one side of the beam and compressive stress on the opposite side, this same phenomenon applies to flexural strength and stiffness. When the fiber is 100% oriented down the length of the beam, it will achieve the highest flexural strength (see Figure 4).

FIGURE 4



The general effect of fiber orientation on tensile strength[4]

Flexural Strength in Composite Materials (cont.)

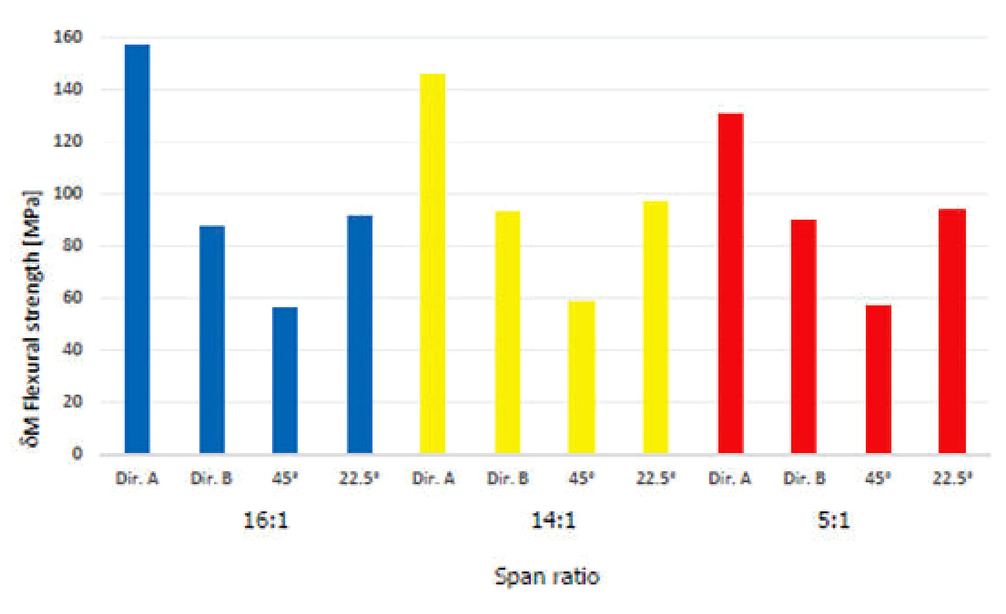
FIBER ORIENTATION (cont.)

Gund Company has many experimental examples demonstrating the effects of fiber orientation on flexural strength. One study showed the change in flexural strength of Ranprex wood laminate composite. In this study, flexural specimens were cut from a laminate board. Wood veneer is oriented in a 0/90-degree pattern in this composite. However, the data shows that clearly, more fiber is introduced in direction A (see Figure 5). The lowest flexural strength was measured in specimens cut at the 45-degree orientation. In this orientation, both the 0-degree and 90-degree layers have a 45-degree orientation relative to the direction of the stress.

If maximum stiffness and bending stress are desired, and the design will allow it, unidirectional fiber orientation down the length of the beam is optimal. Note that many times, there are other design factors to consider and unidirectional fiber orientation is not possible. Cross-plies or different orientations are required in many cases to provide a balance of properties for the composite.

FIGURE 5

FLEXURAL STRENGTH OF RANPREX ML20E - C2R



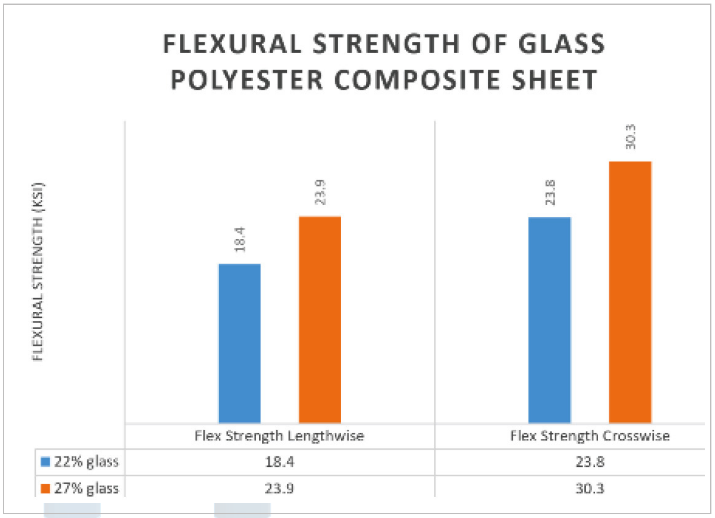
Flexural Strength of Ranprex C2R laminated wood composite at various orientations. (The Gund Company)[5]

FIBER CONTENT

Logically, if the fiber acts as the primary reinforcement in a composite, it makes sense that fiber content will significantly impact flex strength and stiffness. Depending on the composite, fiber content adjustment can be somewhat limited. There are lower and upper limits to the amount of fiber that can be inputted into the composite without causing other problems. For example, too low fiber content in a pultrusion can cause voids and frequent line breaks during production. If the fiber content is too high in a pultrusion and pull forces get too high, the fiber will not completely wet out with resin.

The Gund Company has performed many experiments, which demonstrate the relationship between fiber content and flexural strength. In one experiment, the customer requested higher flexural strength than the standard glass polyester composite sheet product offered. Figure 6 shows the results of the trials where the flexural strength was increased by increasing the glass loading (using the same type of glass reinforcement).

FIGURE 6



Flexural Strength of GPO sheet with changing glass content[6]

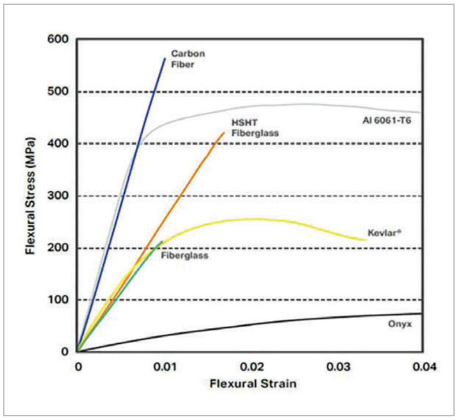
Flexural Strength in Composite Materials (cont.)

TYPE OF REINFORCEMENT

Reinforcements used in composites have a wide range of inherent tensile strength and modulus. For example, standard e-glass has a typical tensile strength of 3450 MPa and modulus of 72 GPa[5], while T700 carbon fiber has a tensile strength of 4900 MPa and modulus of 230 GPa[6]. Since the fiber tensile strength directly translates to the composite tensile strength, and flexural strength is a function of the composite tensile strength, the strength of the reinforcement directly correlates to the composite flexural strength. In other words, if fiber A and fiber B are loaded in equal volume fractions, but fiber A has significantly higher strength, one would expect the composite with fiber A to be higher in flexural strength. Note that equal loading should be considered in volume fraction or volume percentage and not weight percentage since reinforcement densities can vary.

The chart shown in Figure 7 demonstrates how just changing the reinforcement can dramatically affect the flexural strength, strain, and modulus.

FIGURE 7



Flexural Stress vs. Flexural Strain of composites with various reinforcements[7]

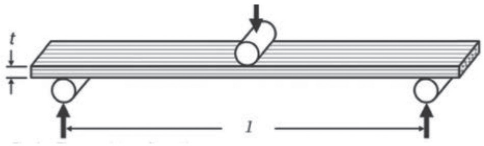
FLEX STRENGTH TEST METHODS

Flexural strength is a common quality control test performed on composites since it is a low-cost, straightforward test to check the mechanical properties. Flexural strength testing can also be a good screening test when comparing material mechanical differences.

While many different flexural strength test standards are available, two prevalent test methods used for composite materials are ASTM D790 and ISO 178. These standards describe the test method for measuring the flexural strength of reinforced plastics and composites using a three-point bending technique.

While specimen size differs slightly between these two methods, the basic premise is the same, and the results are similar. However, results from one test method should never be compared to those from another method, especially if all conditions are not well documented. Several test method conditions can change the outcome, such as:

SPAN-TO-THICKNESS RATIO | BEAM DIAMETER | CROSSHEAD SPEED



Since thinner materials often break at low forces, it is also essential to have the proper load cell to provide adequate accuracy. For example, a 100,000 lb/f load cell would not provide accurate results for specimens breaking around 100 lb/f. The Gund Company has test frames ranging from 0 to 1,000 lb/f (4,448 N) up to 120,000 lb/f (533,786 N). Flexural strength testing temperature range is subzero and up to 300°C.

SUMMARY

Flexural strength and modulus can be essential considerations when designing a composite component. When designers have flexural strength concerns, there are many options and levers to pull with composites. Whether it is the shape, reinforcement type, or fiber loading, it is possible to attain the safest and most efficient design. Flexural strength is crucial for applications like support beams, flooring, and wind blades. The paper describes how stress is distributed in a beam under load, with the highest stress at the midpoint. The shape of the beam affects its strength, with different shapes having different resistance to bending. Flexural strength can be optimized by customizing the shape, aligning fibers with the load direction, adjusting fiber content, and choosing the right type of reinforcement. Standard testing methods for flexural strength include ASTM D790 and ISO 178. The paper concludes that understanding and optimizing flexural strength is essential for safe and efficient composite designs, and The Gund Company offers expertise to help with these projects.

REFERENCES

(1) Bending schematic, https://www.bestfunquiz.com/q-trivia-quiz-on-bending-stress-in-strength-of-materials/1
(2) Moment and shear diagram, https://www.engineeringtoolbox.com/beam-stress-deflection-d_1312.html
(3) Restrained beam design, http://fgg-web.fgg.uni-lj.si/~/pmoze/ESDEP/master/wg07/l0820.htm
(4) Fiber Orientation, https://www.intechopen.com/chapters/39412
(5) Owens Corning E-glass datasheet
(6) Toray T700 datasheet
(7) Flexural Stress vs. Flexural Strain Curve of various reinforcements, https://hawkridgesys.com/blog/quick-tips-markforged-part-strength

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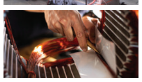
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The Gund Company provides a wide range of material solutions from rigid, glass epoxy composites to high-temperature, silicone sponges.

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