Composites in O&P

Volume 1

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When fabricating Prosthetic and Orthotic appliances, reinforced thermoset plastics are quite often the materials of choice. These materials can provide very high specific strength and stiffness as well as acceptable toughness for most O&P applications. Many factors can affect the ultimate properties of these materials so it is imperative for practitioners and technicians to understand these factors to enable them to create optimized products for their patents. One of the factors to be considered during the design of a reinforced plastic parts is fiber orientation. Fiber reinforced plastics (FRP's) have properties that vary greatly depending on the direction they are measured in relation to the direction of the fibers. This fact causes FRP's to be classified as anisotropic materials. This is in contrast to materials such as metals which are called isotropic. In an FRP the strength and stiffness is always going to be greatest when measured parallel to the fibers and least when measured perpendicular to the fibers. This is because the strength measured parallel to the fibers is "fiber dominated" and the strength perpendicular to the fibers is "matrix (resin) dominated" When talking about fiber orientation it is customary to speak of it in terms of angles so we can think of a 0 degree fiber to be parallel to the load and a 90 degree fiber to be perpendicular to the load. What many don't fully appreciate is how quickly strength and stiffness properties diminish as the load become off axis from the fibers. This is where intuition will often fail us. A 0 degree fiber will provide the greatest stiffness, and a 90 degree fiber will offer the least stiffness, This would lead many to surmise that a 45 degree fiber would offer half the stiffness of the 0 as it is half way between the 0 and 90. The truth of the matter is the 45 degree fiber only offers about a quarter of the stiffness of the 0 as seen in figure 1. The situation is even more significant when considering the strength of a laminate. Figure 2 shows that when the fiber angle gets even a bit off axis from the direction of the loads (X1 stress) the strength falls very rapidly. In a typical laminate the story gets far more complex as there are generally multiple plies, each with a unique fiber orientation. Here, each ply contributes to the ultimate properties of the laminate. In order to visualize this plots can be

Figure 1

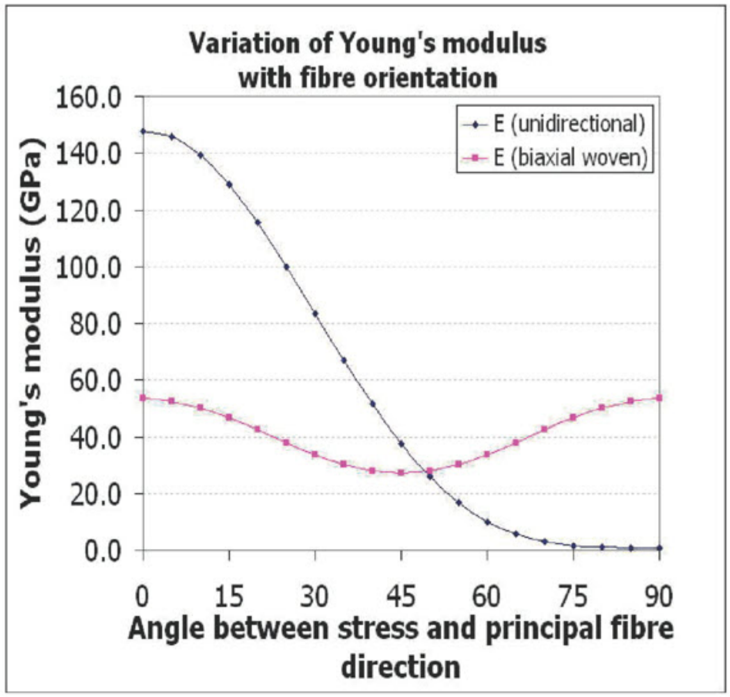
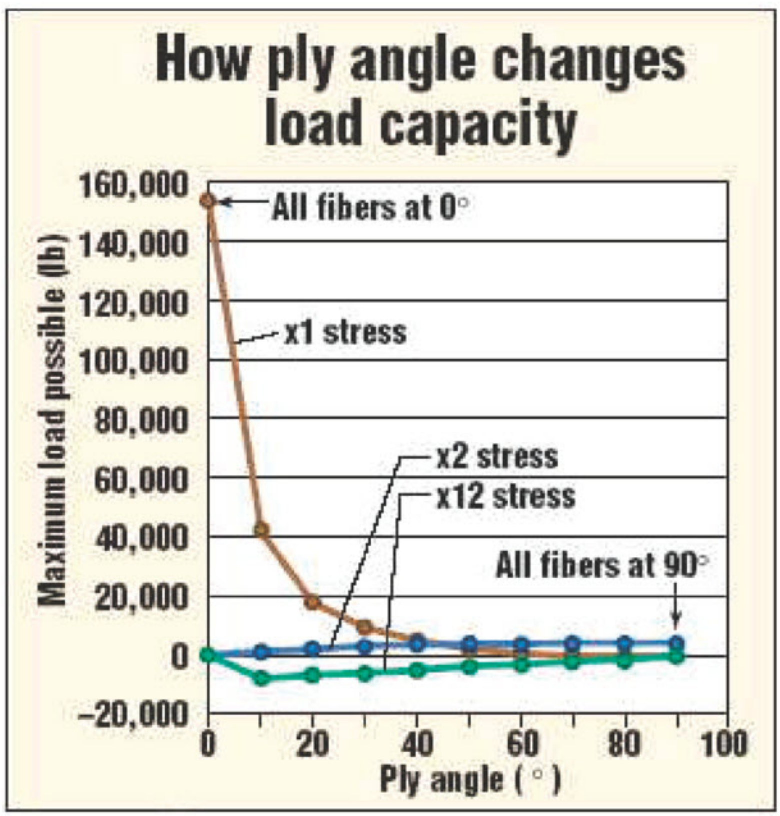


Figure 2



created. Figure 3 and 4 show carpet plots showing how strength and rigidity properties vary with different percentages of 0, 90 and 45 fibers within a laminate. To use these plots first go to the point on the x axis that shows the percentage of 45 degree fibers. Then, move along the y axis until you come to the value designating the percentage of 0 degree fibers which will also show the percentange of 90 degree fibers. This point will show you the strength or modulus (rigidity) of a laminate consisting of this combination of fiber orientations. By understanding how changing the orientation of the fibers within a laminate changes the mechanical properties it is possible to tailor these properties to match a particular design intent. For instance, if one desires to create a laminate that has identical stiffness properties in all in-plane directions or what is called a quasi-isotropic laminate it can be accomplished. A laminate with a fiber orientation of 0, +60, -60 is one such laminate. Understanding the effects of fiber orientation is of great importance in the design of FRP's. It is however only one of several factors that determine the properties of a laminate. So far the discussion has been on the tensile properties of a laminate. Under this form of loading all of the fibers within the laminate are subjected to the same load. The properties that we are often interested in are the flexural properties. For instance, if a given load is put on the the toe plate of an AFO or the medial brim of a transfemoral socket, how much is it going to deflect? In this example we need to consider not only the fiber orientation but also the stacking sequence or where within the laminate each orientation resides. The stacking sequence is a very important consideration when designing with FRP's and as such will be the topic of the next discussion.

Figure 3

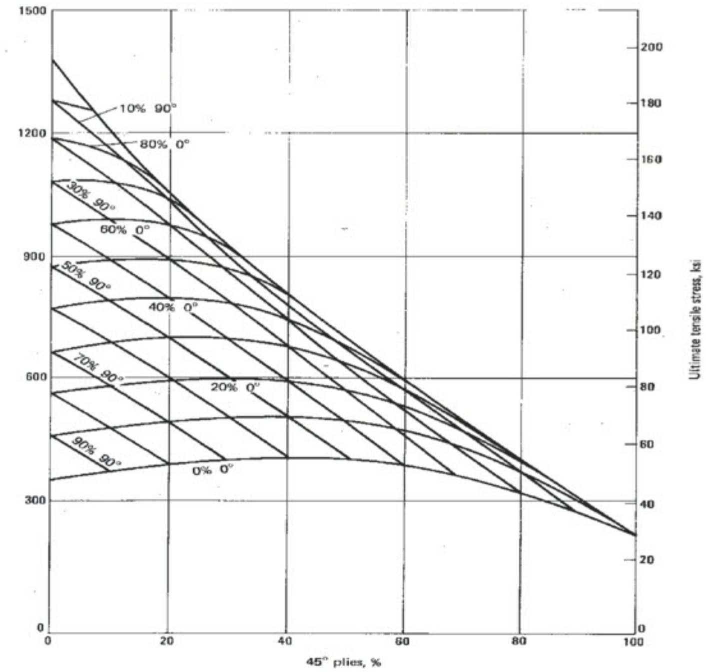


Figure 4