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# Unidirectional vs. Standard vs. Quasi-Isotropic Plate

The mechanical properties of fiber-reinforced composite materials are dependent on the orientation of the fibers, since fibers only have meaningful strength in one direction. There are three main strategies for orienting these fibers in carbon fiber-reinforced plastics.

**Unidirectional:** If all of the fibers in a composite are oriented in the same direction, the material is called "unidirectional". It will have the maximum possible strength and stiffness along the direction of the fibers, but its strength will be greatly diminished if loaded in other directions. It is generally used in long, thin parts that need to be as strong and stiff as possible in a single direction.

**Standard:** The most common type of carbon fiber plate, "standard" refers to material with the fibers oriented in two perpendicular directions. This plate is stiffest and strongest in the direction of the fibers, but still has a fair amount of strength in other directions. Parts can often be designed such that the fibers are running in the directions that matter the most, saving substantial costs.

**Quasi-Isotropic:** When a part requires equal strength and stiffness in many different directions, "quasi-isotropic" material can be used. This material has fibers running in more than two directions. Using layers of fabric with fibers at -45°, 0°, 45°, and 90° gives an excellent balance between economics and performance. The resulting plate has properties that are uniform enough for virtually all applications, and it can be made by stacking two types of commercially available woven fabric. It is more expensive than standard plate, but its consistent properties can be absolutely necessary for certain parts and applications, such as flat parts that rotate at high speeds, parts with thin features in many different directions, or parts that need to resist both twisting and bending.

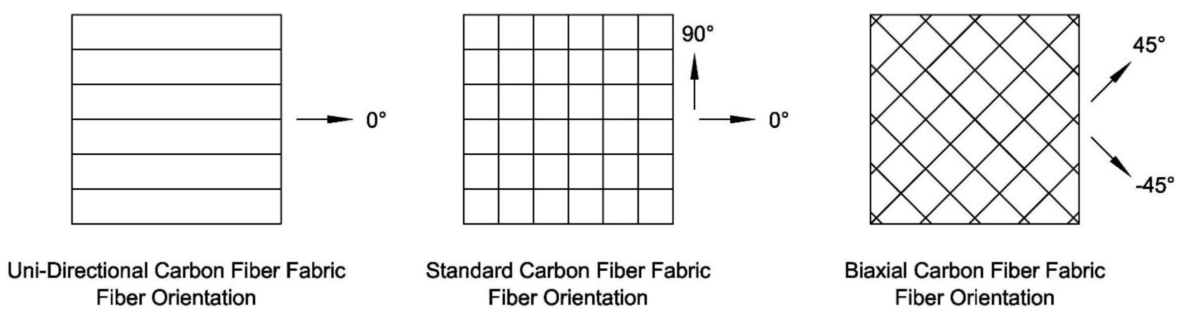


FIGURE 1. Fiber orientations in commonly available carbon fiber fabric

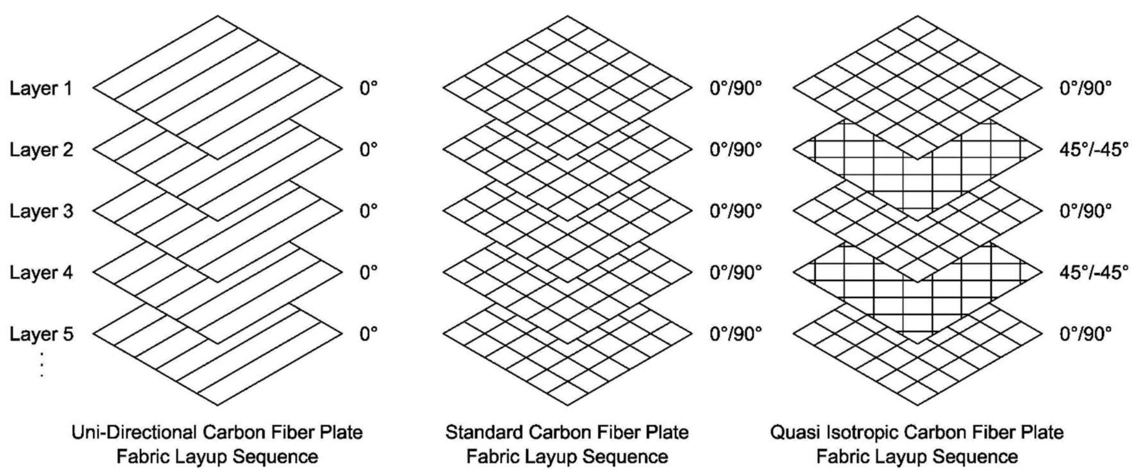


FIGURE 2. Common layup sequences used to make carbon fiber plate

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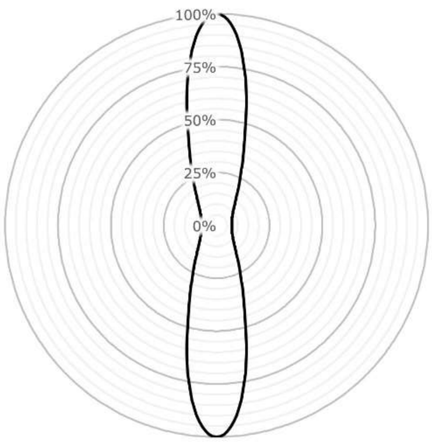
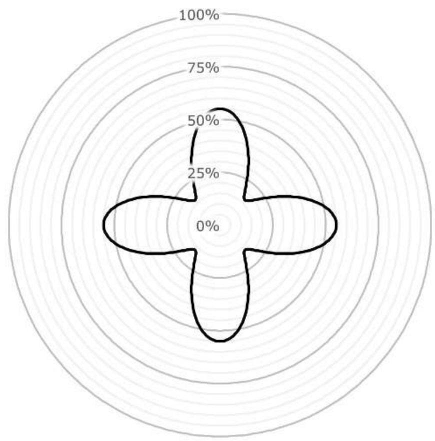
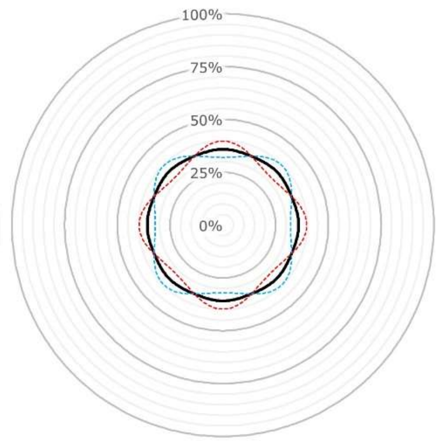
Figure 3 below gives a more quantitative view of the differences in stiffness between unidirectional, standard, and quasi-isotropic plate. These graphs show the bending stiffness typical of the different types of plate as they are loaded in all the possible directions from 0° to 360°.




Unidirectional
(Fibers along 0°)




Standard
(Fibers along 0°/90°)




Quasi-Isotropic
(Fibers along -45°/0°/45°/90°)

FIGURE 3. Polar plots of bending stiffness as a function of loading angle

Looking at the plot for unidirectional material, we see that it is very stiff in bending along the fibers at 0° (the vertical axis). However, the range of angles with high stiffness is quite small, and the stiffness falls off rapidly beyond about 20° on either side of the fibers. Unidirectional fabric is perfect for situations where loading will occur in one very specific direction, but should never be used where stiffness or strength are required along a significant range of directions. This is especially true at angles close to 90°, where the stiffness falls to 1/15$^{th}$ of its value at 0°!

The plot for standard material clearly shows the peaks in stiffness along the fibers at 0° and 90°. It can't compete with unidirectional material when loaded in one direction, but by dividing its stiffness along two perpendicular directions, it becomes much more useful for general purpose parts. Also, the difference between the stiffest and most flexible directions (0° and 45°) is much less severe than unidirectional plate – about a factor of 3 instead of a factor of 15.

The plot for quasi-isotropic plate shows its usefulness in situations when parts will be loaded in many different directions. The black line shows the bending stiffness of plate with exactly equal stiffness coming from fibers at -45°, 0°, 45°, and 90°. This plot is very nearly a circle – which means that it will have very similar bending stiffness along all directions. This is typical of quasi-isotropic material 1/8" thick or thicker.

The dotted lines show materials that are a bit stronger when bent in one direction than the other – this is generally the case for materials thinner than about 1/8". The bending stiffness of thin composite materials is generally quite expensive to balance, because the fine-tuning of the fiber positions requires many layers of very thin fabric (which is generally very expensive per pound). If thin material balanced in bending stiffness is required, contact us for a custom layup quote.

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The layup sequence of quasi-isotropic plate is critical to the performance of the material. The total number of fibers running in each direction should be similar, but the position of the fibers within the material is also important. Material closer to the outside surfaces of a plate contribute much more to the bending stiffness of the plate, and the layers should be arranged such that the contributions of all the fibers to the bending stiffness is roughly equal.

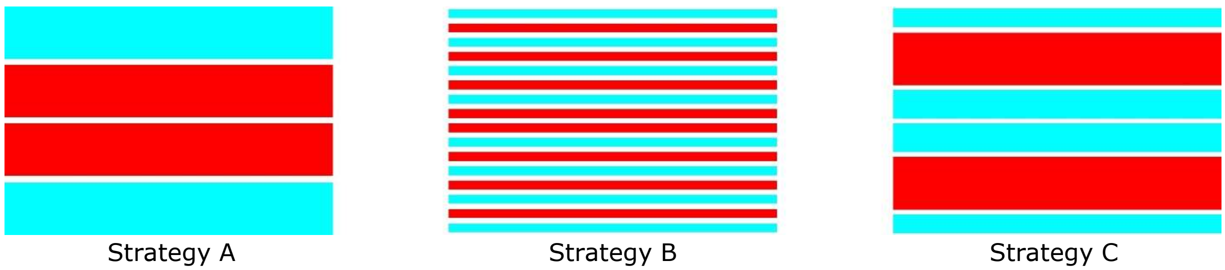


FIGURE 4. Three quasi-isotropic layup strategies (blue is -45°/45°, red is 0°/90°)

Figure 4 shows how different types of fabric can be arranged in a quasi-isotropic material. All three strategies use equal amounts of the two different types of fabric, which means they are balanced when loaded in tension. However, the material is distributed differently, which means they will have different properties when loaded in bending.

Strategy A is simple, using equal layers of the thickest possible fabric. Since the 45° fabric is closer to the outside, it will contribute much more to the bending stiffness of the material - in fact, with this layup, 87.5% of the bending stiffness comes from the 45° layers! This means that this plate will be much stiffer when bent along directions close to 45° then directions closer to 90°.

Strategy B works around this problem by alternating many layers of thin fabric. This works well, since on average, neither type of fabric is much closer to the surface than the other. However, this is only economical for thick plate. In order to use this strategy for thin plate, the layers must be very thin, and thin fabric is generally quite expensive.

Strategy C creates a layup which is balanced in bending, but does not require many layers of thin, expensive material. This reduces the cost of thinner quasi-isotropic panels without sacrificing performance.

Still have questions about composite materials and how they can be utilized for your project? Contact Hillside Composites at 1(800) 220-1880, or email us at sales@hillsidecomposites.com for further assistance.