WEIGHT AND COST REDUCTION BY USING UNBALANCED AND UNSYMMETRIC LAMINATES

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1 Tarnished Golden Rules

There are two golden rules on composite laminate designers practice: balanced (with matching +/- off-axis plies) and mid-plane symmetric laminates. Unsymmetric laminates will warp on cool down but unbalanced ones will not. However these rules are not absolute. Not following them can lead to structural behavior that has no counter part with balanced, symmetric laminates. We can also expect simultaneously weight and cost reduction.

2 Why not Unbalanced?

A laminate being balanced or not is not a correct description. It is true only in a given coordinate system. It might give designer a false sense of confidence to live with orthotropic laminates only.

An unbalanced laminate has shear coupling; i.e., its stretching and distortion are coupled. It is an opportunity to select the material and ply orientations so the resulting stretching and distortion can work against or for each other for the benefit of laminate performance. Instead of avoiding such coupling we can reduce weight in using anisotropy that is unique with composite laminates.

3 How Many Angles

The use of 4 ply angles is another unchallenged rule of laminate design. The more ply angles there are the more isotropic the laminate will be leading ultimately to the black aluminum. We recommend to reduce the number of ply angles from 4 to 3 to 2. As the number of ply angles reduces, the number of ply failure modes reduces. Laminate optimization is simpler.

We also recommend to use ply angle as a continuous variable such as [0/±38] instead of $[0_m/\pm45_n]$ where ply numbers m and n are integers. They are not continuous variables; we cannot have fractional plies. If ply angles can change as continuous variables higher first-ply-failure (FPF) laminates can be obtained for having a better matched strengths between plies. These laminates will have no micro cracking before their ultimate strength is reached. FPF is more predictable because there is no need for an empirically determined matrix degradation.

As the number of ply angle is reduced, laminates can be more easily built by repeating sub-laminates using a repeat index $\boldsymbol{r}$. The traditional design practice does not take advantage of repeated index that can homogenize automatically the total laminate. A homogenized laminate is stronger and tougher. This simplifies laminate design process (fewer angles and higher repeats). For thin plies, ply drop by sub-laminate instead of individual ply would be possible. For highly homogenized laminates, ply drop can be on the outer surface, tool side surface, or in the interior of the laminate.

Based on anisotropic stiffness and strength of most ply materials available in the market, a good anisotropic sub-laminate is [0/25]. If each ply is made thinner, say, from usual 0.125 mm to 0.0625 mm, the degree of homogenization from this sub-laminate is increased; i.e., instead of having 16 repeated sub-laminates, we can have 32 repeats for the same laminate thickness.

With a highly homogenized laminate such as 16 repeats, another non-obvious method of assembly can be used. Instead of enforcing mid-plane symmetry of all laminates, a highly homogenized laminate can be unsymmetric. For unsymmetric laminate there is a bend-twist coupling matrix [B]. The components of this coupling can be reduced by the reciprocal of the number of repeats; i.e., if $\boldsymbol{r}$ is the number of repeats, B components are reduced by $1/\boldsymbol{r}$.

4 Non Crimp Fabric (NCF)

NCF is a unique process that can make bi-angle laminate such as [0/25] feasible. This fabric has a good balance among cost, handling, and performance. As the off-axis angle become shallow like 25 or less in degrees, it is more difficult to get such angle cut from unidirectional prepreg.

An even more important feature of bi-angle NCF is the one-axis layup. There is no longer a need for laying off-axis plies. They are imbedded in the bi-angle NCF. The labor savings, layup accuracy, and reduced scrap are all achievable with this process and product resulting in high quality and low cost.

Equally convenient is that a bi-angle laminate [0/25] can be made into a balanced laminate of [0/±25/0] by simply folding [0/25] NCF along the 0-degree axis. Balanced laminates are needed if applied shear or twisting is fully reversible. There are other design options such as having thick-thin ply combinations as well as hybridization. We can have thick [0] carbon with thin [25] glass. More on this unique thin ply NCF will be given by Philippe Sanial of Chomarat, the producer.

5 Conclusions

When the traditional rules for balanced and symmetric laminates are relaxed, many design options emerge. Anisotropic, unsymmetric laminates can make weight and cost benefits possible. Two key steps for success are: 1) to reduce the number of ply angles from 4 to 2 for increased FPF strength from better matched plies, and 2) the ply thickness also reduced by a factor of 2 so homogenization is more easily achieved leading to improved strength, toughness and ability to ignore mid-plane symmetry.

Optimum ply thickness is not absolute. It is recommended by having a small fraction (3 percent) of the total laminate thickness required. The exact number depends on the geometry and loading of the composite structure. Continuous variable for ply angles and continuous stacking for layup will allow us to escape the traditional constraining box of balanced and symmetric laminates. Design based on FPF would be more credible than LPF that requires more empirically determined degradation factor.

NCF plays a critical part in making high performance and low cost starting material. Its ability to have shallow ply angles, such as 25 degrees, is unique. One-axis layup for many structures becomes feasible. With these innovations, simultaneous weight and cost reduction is not only achievable but also by a significant magnitude. We expect major impact on many composite structures across many industries as we learn to master many no-obvious options in laminate design.

6 Applications

A number of applications will be discussed by other speakers including Sung Ha, Daniel Melo, and Sangwook Sihn. Suffice to say, significant weight and cost reduction can be achieved with the guidelines outlined in this presentation. It is hoped that these concepts can make composites more competitive by taking advantage of the intrinsically anisotropic composite materials.

References

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