Families Of Hygrothermally Stable Asymmetric Laminated Composites

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Extended Abstract

Coupling between deformation modes of laminated composites can be used to tailor the elastic response of a structure advantageously. This coupling between applied forces and curvature deformations such as extension-twist or extension-bending coupling can only be obtained with asymmetric layups. However, asymmetric stacking sequences usually result in significant post-cure warping and hygrothermal instability.

Previous attempts to design laminates with elastic tailoring focused first on obtaining the desired coupling properties and then trying to meet the hygrothermal stability constraints. These stacking sequences have not been shown to be optimum in terms of the magnitude of extension-twist coupling nor the number of plies. To this end, an alternative approach is adopted in this work whereby a rigorous, systematic search for hygrothermally stable laminates is performed. In the present work, hygrothermal stability is considered to be the objective rather than a constraint.

Simple, material-independent, necessary and sufficient conditions for hygrothermal curvature stability of a laminated composite plate have been derived from the approximations of Classical Lamination Theory. It is then proven that no asymmetric solution to these equations exists for laminates with less than five plies. With the derived equations, a single independent solution is found for laminates of five plies. Multiple families of hygrothermally stable asymmetric stacking sequences are presented for six-, seven-, and eight-ply laminates. Further, it is shown that they imply hygrothermal twist stability in a geometrically non-linear model as well.

Verification using a finite element method was performed to demonstrate the validity of the derived solution. Similarly, an experimental verification was made by manufacturing two laminate plates: an antisymmetric stacking sequence conforming to the derived hygrothermal stability conditions and its corresponding symmetric stacking sequence; matching post-cure warping displacements between the two laminates indicate comparable hygrothermal stability. Finally, a numerical sensitivity analysis demonstrates the robustness of the solution with respect to small errors in ply orientation, reflecting manufacturing tolerances.

In conclusion, this work provides a comprehensive method for the design of hygrothermally curvature-stable composite laminates. When applied to asymmetric stacking sequences, the laminates will retain their elastic coupling properties. Rather than optimizing a laminate design for a given coupling with hygrothermal stability as a constraint, laminates with the desired coupling can be selected from within the derived hygrothermally stable families. The material independence of the stability conditions provides robustness against variability in material properties.