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FABRICATION, TESTING AND ANALYSIS OF ANISOTROPIC, CARBON/GLASS HYBRID COMPOSITES

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Abstract

Anisotropic carbon/glass hybrid composite laminates have been fabricated, tested, and analyzed. The laminates have been fabricated using vacuum-assisted resin transfer molding (VARTM). Five fiber complexes and a two-part epoxy resin system have been used in the study to fabricate panels of twenty different laminate constructions. These panels have been subjected to physical testing to measure density, fiber volume fraction, and void fraction. Coupons machined from these panels have also been subjected to mechanical testing to measure elastic properties and strength of the laminates using tensile, compressive, transverse tensile, and in-plane shear tests. Interlaminar shear strength has also been measured. Out-of-plane displacement, axial strain, transverse strain, and in-plane shear strain have also been measured using photogrammetry data obtained during edgewise compression tests.

The test data have been reduced to characterize the elastic properties and strength of the laminates. Constraints imposed by test fixtures might be expected to affect measurements of the moduli of anisotropic materials; classical lamination theory has been used to assess the magnitude of such effects and correct the experimental data for the same. The tensile moduli generally correlate well with experiment without correction and indicate that factors other than end constraints dominate. The results suggest that shear moduli of the anisotropic materials are affected by end constraints.

Classical lamination theory has also been used to characterize the level of extension-shear coupling in the anisotropic laminates. Three factors affecting the coupling have been examined: the volume fraction of unbalanced off-axis layers, the angle of the off-axis layers, and the composition of the fibers (i.e., carbon or glass) used as the axial reinforcement. The results indicate that extension/shear coupling is maximized with the least loss in axial tensile stiffness by using carbon fibers oriented 15° from the long axis for approximately two-thirds of the laminate volume (discounting skin layers), with reinforcing carbon fibers oriented axially comprising the remaining one-third of the volume.

Finite element analysis of each laminate has been performed to examine first ply failure. Three failure criteria - maximum stress, maximum strain, and Tsai-Wu - have been compared. Failure predicted by all three criteria proves generally conservative, with the stress-based criteria the most conservative. For laminates that respond nonlinearly to loading, large error is observed in the prediction of failure using maximum strain as the criterion.

This report documents the methods and results in two volumes. Volume 1 contains descriptions of the laminates, their fabrication and testing, the methods of analysis, the results, and the conclusions and recommendations. Volume 2 contains a comprehensive summary of the individual test results for all laminates.