EFFECTS OF THE LAYUP SEQUENCE ON THE TOUGHNESS AND LARGE DEFORMATION OF COMPOSITE TUBES IN BENDING

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Summary: Despite their high specific strength and stiffness, Carbon/Epoxy composites demonstrate brittleness, low toughness and small deformation. Toughened epoxies and thermoplastic resins have not changed these material properties considerably. This is the concern and experience at the material level. However, at the structure level, there are situations where composite structures can be made to exhibit large deformation, even similar to that of aluminum structures. This work presents the experimental and finite element analysis on three thick composite tubes with different layups. The effects of the layup sequence and fiber angle on the behavior of the tubes subject to bending are investigated. A generic design for composite tubes with large deformability and high fracture toughness is presented. Such tubes can support the same load and large deformation to match the mechanical behavior of high grade aluminum tubes. Rationale for the strategy of stacking sequence is presented.

1. Introduction
Carbon fiber composites due to the low fracture strain of the fibers, which is about 1.5%, demonstrate brittle behavior and small deformation before their abrupt fracture. Structures made of aluminum derive their large deformation from the ductility of the material. For example, aluminum alloy 7075-T6 may demonstrate more than 10% fracture strain in a tensile test. In contrast, a unidirectional Carbon/PEKK composite laminate shows less than 1.5% strain in the fiber direction (0º) and about 0.8% in the transverse direction (90º). The strain limit of the thermoplastic polymers such as PolyEtherEtherKetone (PEEK) or PolyEtherKetoneKetone (PEKK) is about 50%. However, it is clear that the large elongation of the resin does not help improving the ductility of the composite. Upon major fiber fracture, the rate of load transfer from broken fibers to the matrix would be too high for the resin to accommodate the sudden change, and abrupt fracture of composite would be unavoidable.

2. Research approach
This research is primarily focused on large deformation of composite structures. It was found that through a few mechanisms such as, fiber rotation, matrix extension and reducing the interaction of adjacent layers, fracture strain as large as 6% can be achieved for carbon fiber
thermoplastic composite tubes. Three composite tubes were designed, fabricated and tested in bending to explore the effects of the layup sequence on the behavior of composite tubes. It was learnt that including $0^\circ$ plies in the layup enhances the stiffness of the tube and increases the weight saving. Such tubes can perfectly substitute the aluminum tubes in the elastic limits. Nevertheless, wherever large deformation is a concern, low fracture strain of $0^\circ$ plies is the drawback and limits the performance of the tube. Tubes with angle plies can show large deformation and required strength and stiffness if they are located strategically at the positions that their required strain in bending is less than their fracture strains in the laminate form. To achieve this sub-laminate such as $\pm 45^\circ$ is set as the outer layer and sub-laminates such as $\pm 25^\circ$ with higher stiffness and lower strain are set as the inner layer for the tube. This is in contrast to classical design of the beams in bending, where one puts high strength high stiffness material as flange (furthest distance from Neutral Axis) and lower strength and stiffness materials as core.

By using the new novel approach, it was possible to develop a thermoplastic composite tube that exhibits similar stiffness, strength, and deformation as an aluminum tube, with significant reduction in weight. Figure 1 shows the load-strain curves of aluminum and composite tubes, designed and tested for an aircraft application [1-3].

![Figure 1: Force deflection curves for aluminum and composite tubes](image)

3. References