Effect of Micro-phase Separated Structures on the Cryogenic Mechanical Properties of Thermosetting Resins

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Liquid oxygen (LOX) storage tanks in space launch vehicles serve as critical structural components while containing oxidizers at cryogenic temperatures (~90 K). Although traditionally manufactured from aluminum, these tanks face limitations in weight reduction due to high density. Carbon fiber-reinforced polymer composites are promising alternatives; however, their application is hindered by the inherent brittleness of polymers at cryogenic temperatures. While rubber particles are commonly added to improve toughness, they often lead to a significant decline in the glass transition temperature (Tg) and elastic modulus, alongside an undesirable increase in the coefficient of thermal expansion (CTE) due to their relatively large particle size. To overcome these challenges, this study proposes a strategy to refine the micro-phase separated structure of thermosetting resins. A silicone-based oil is introduced as a soft additive, and a silicone-modified epoxy resin is employed as a bifunctional polymer to act as an interfacial stabilizer, effectively reducing interfacial energy and minimizing the domain size of the dispersed phase. This structural refinement aims to significantly enhance the fracture toughness of the resin while minimizing the reduction in elastic modulus and the increase in CTE. We systematically evaluate the mechanical properties at both ambient and cryogenic temperatures as a function of the soft additive content and the resulting phase-separated morphology. Furthermore, the impact of these micro-structures on the cryogenic CTE is investigated to ensure structural reliability for aerospace applications.