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Damage Tolerance of Composites Containing Hybrid, Carbon-Innegra, Fibre Reinforcements

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Abstract : Carbon fibre (CF) - polymer laminate composites have very low densities (approximately 40% lower than aluminium), high strength and high stiffness but in terms of toughness properties they often require modifications. For example, adding rubbers or thermoplastics toughening agents are common ways of improving the interlaminar fracture toughness of initially brittle thermoset composite matrices. The main aim of this project was to toughen CF-epoxy resin laminate composites using hybrid CF-fabrics incorporating Innegra™ a commercial highly-oriented polypropylene (PP) fibre, in which more than 90% of its crystal orientation is parallel to the fibre axis. In this study, the damage tolerance of hybrid (carbon-Innegra, CI) composites was investigated. Laminate composites were produced by resin-infusion using: pure CF fabric; fabrics with different ratios of commingled CI, and two different types of pure Innegra fabrics (Innegra 1 and Innegra 2). Dynamic mechanical thermal analysis (DMTA) was used to measure the glass transition temperature (Tg) of the composite matrix and values of flexural storage modulus versus temperature. Mechanical testing included drop-weight impact, compression-after-impact (CAI), and interlaminar (short-beam) shear strength (ILSS). Ultrasonic C-Scan imaging was used to determine the impact damage area and scanning electron microscopy (SEM) to observe the fracture mechanisms that occur during failure of the composites. For all composites, 8 layers of fabrics were used with a quasi-isotropic sequence of [-45°, 0°, +45°, 90°]s. DMTA showed the Tg of all composites to be approximately same (123 ±3°C) and that flexural storage modulus (before the onset of Tg) was the highest for the pure CF composite while the lowest were for the Innegra 1 and 2 composites. Short-beam shear strength of the commingled composites was higher than other composites, while for Innegra 1 and 2 composites only inelastic deformation failure was observed during the short-beam test. During impact, the Innegra 1 composite withstood up to 40 J without any perforation while for the CF perforation occurred at 10 J. The rate of reduction in compression strength upon increasing the impact energy was lowest for the Innegra 1 and 2 composites, while CF showed the highest rate. On the other hand, the compressive strength of the CF composite was highest of all the composites at all impacted energy levels. The predominant failure modes for Innegra composites observed in cross-sections of fractured specimens were fibre pull-out, micro-buckling, and fibre plastic deformation; while fibre breakage and matrix delamination were a major failure observed in the commingled composites due to the more brittle behaviour of CF. Thus, Innegra fibres toughened the CF composites but only at the expense of reducing compressive strength.

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