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The Low-Energy Impact Resistance and Damage Tolerance of Thermoplastic-Based Fibre-Metal Laminates

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Fibre-metal laminates (FMLs), consisting of thin alternate layers of aluminium alloy and fibre-reinforced polymer-matrix composite, exhibit greater energy absorption under impact than monolithic aluminium or bulk composites. This has been attributed to membrane deformation of thin delaminated layers [1]. Current FMLs utilise thermoset-based composites, which offer higher strength, stiffness and temperature performance compared to other polymer composites, but are also brittle and have relatively long processing times. Thermoplastic-based composites, by comparison, have relatively short processing cycles, high fracture toughness, and the potential for post-impact repair. Consequently, interest in thermoplastic-based FMLs is growing and recent work has shown that a polypropylene-based FML exhibits excellent mechanical properties [2].

One of the major failure modes of composites and FMLs under low-energy impact loading is likely to be delamination, either within the composite or along the bi-material interface. The presence of delaminations will adversely affect structural integrity. Therefore, if further development of thermoplastic-based FMLs is to be justified, it is necessary to determine if the high fracture toughness of the matrix will improve resistance to impact-induced delamination. The study proposed here will investigate the low-energy impact response of FMLs based on two thermoplastics (polyamide and polypropylene) with glass-fibre fabric reinforcements. The FMLs will be manufactured in a simple heating and stamping procedure. The main aspects of the study will be optimisation of aluminium-composite interfacial fracture toughness, low-energy impact testing, evaluation of damage area through non-destructive inspection (NDI), damage tolerance, and potential for repair of impact damage.

Preliminary work has utilised a single cantilever beam specimen to evaluate the fracture toughness at the aluminium-composite interface. An ionomer resin interlayer was used for bonding the polyamide composite to the aluminium layer. A maleic anhydride modified polypropylene interlayer was used to bond the polypropylene system to a chromate treated aluminium layer. The interfacial Gc of the polyamide system is 1.2 kJ/m2 with the failure locus either through the ionomer resin or along the aluminium-ionomer interface. This is consistent with a unidirectional fibre-reinforced specimen [3]. In the polypropylene system, the interfacial Gc is 4.6 kJ/m2. Here, the failure locus is through the composite, leading to extensive fibre bridging and interlocking of the fibre tows at the intersections of the warp and weft yarns. It is notable that the glass fabric/polypropylene system yields a greater fracture toughness than the unidirectional counterpart which had a Gc in the region of 3 kJ/m2 [2]. This is attributed to the greater energy absorption by fibre bridging in the fabric structure. This suggests that the fabric reinforced composite will provide greater delamination resistance under impact. Currently, the interfacial Gc under impact loading (3 m/s) is being evaluated.

Once the interfacial fracture toughness has been evaluated and optimised, the low-energy impact response of plate structures will be investigated. An instrumented drop-weight impact tower and a laser Doppler velocimeter will be utilised to obtain force-time and velocity-time histories of low-energy (6-24J) impacts on the FMLs. The data will be reduced to obtain force-displacement plots and, hence, the total energy absorbed during each impact. The ultrasonic C-scan technique will then be used to assess the impact damage area. (The C-scan is a typical NDI technique for damage detection in bulk composite structures and its use in the current study will determine if it is suitable for NDI of FMLs.) Optical and scanning electron microscopy will also be used to elucidate the dominant failure modes. The post-impact damage tolerance will be assessed through comparison of the residual flexural strength of impacted specimens with the flexural strength of untested specimens. In addition, impacted specimens will be repaired through a repeat of the initial manufacturing cycle. The flexural strength of these specimens will then be evaluated to determine the potential for repair impact damage. The above low-energy impact testing regime will also be applied to bulk composite specimens and the results compared to those for the FMLs.

References

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