

Characterisation of large diameter through-thickness metallic pins in composites

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Introduction: There is an increasing demand for the use of functional through-thickness reinforcement (TTR) in composites using elements whose geometry exceeds the limitations of existing TTR methods e.g., for the embedding of photonic sensors [1]. Existing TTR methods like tufting, stitching, and z-pinning, place strict limitations on the properties of the reinforcing elements [2]. Previous work on the static of insertion of large diameter TTR pins into heated prepreg stacks [3] has proven a feasible and robust reinforcement process capable of providing accurate TTR element placement with low insertion forces and tow damage compared with existing methods for similar element sizes (>1mm diameter) like post-cure drilling. However, the local mechanical performance and failure mechanics of these pinned laminates has not yet been reported. The work investigates the influence of varying pin diameters (1.2, 1.5, and 2.0 mm), inserted into preforms using the static insertion method, on in-plane (tension and compression) and out-of-plane (mode I interlaminar fracture toughness).

Materials and Methods: The prepreg system used in this work was 12k (650 gsm) BX180-220 carbon-benzoxazine prepreg manufactured by SHD Composite Materials Ltd [4]. The prepreg has a 2 × 2 twill weave with each cured ply of this material measuring 0.66 mm and a fibre volume fraction (v_f) of ~60%. Through-thickness reinforcing pins were manufactured from 304 stainless steel rods with diameters of 1.2, 1.5 and 2.0 mm machined to a length of 25 mm with a 45° conical point machined into the leading edge of the rods to allow for parting of the prepreg preform tows. Pin insertion was carried out using the static insertion method detailed in [3], whereby pins were inserted into heated prepreg preforms. Post-insertion, the pins were replaced with flat-ended versions of length matching the final composite thickness. The preforms were then cured at 160°C for 2 hours and then 180°C for 2 hours in an autoclave at 7 bar pressure. In-plane specimens had a 4-layer quasi-isotropic configuration $[0/90, \pm 45]_s$, whereas mode I specimens had a 6-layer $[0/90]_{3s}$ configuration. Mechanical test specimens were prepared and evaluated according to the following standards: tensile – ASTM

D3039 , compression - D695 , filled-hole tensile and compression – ASTM D6742 , and double cantilever beam (DCB) – ASTM D5528.

Conclusions: Figure 1 shows the results of in-plane mechanical characterisation of pinned and baseline samples for the range of pin diameters. Tensile strength is generally unaffected by the presence of pins up to 2 mm diameter. Tensile failure transitions from delamination failure in baseline specimens to complete tow rupture in pinned samples. The presence of the pins therefore acts to suppress the delamination failure in the material and encourage higher energy tow rupture which balances the potential local degradation caused by the stress concentration at the pin, resulting in an unaffected tensile strength. Tensile modulus is improved by the presence of the TTR pins, doubling in 1.2 mm pinned samples. There is a significant degradation in compressive strength, increasing in severity with pin diameter to a maximum of a 42% reduction in 2.0 mm diameter pinned samples.

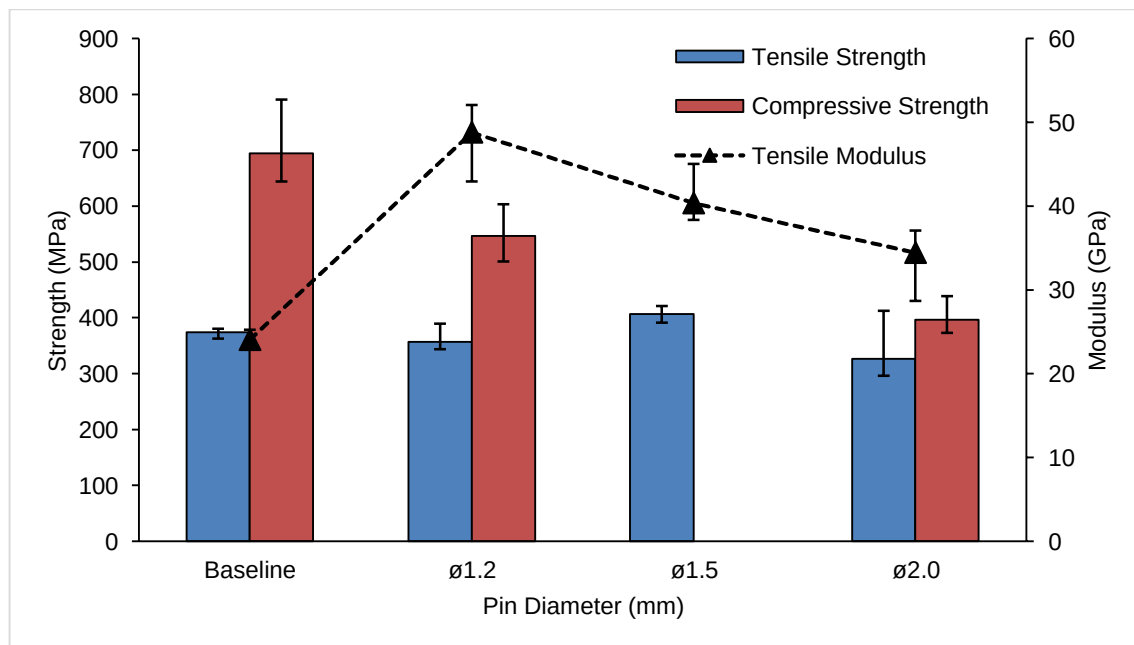


Figure 1. Comparison of in-plane mechanical characterisation results.

Figure 2 shows average mode I fracture response for baseline and pinned samples. Maximum fracture toughness is doubled by the presence of pins. This is the result of the bridging effect of the pins, which eventually de-bond from the composite and resulting in pin pull-out. This result supports suppression of delamination under in-plane tension. Although the pinned G_{IC} value seems unaffected by pin diameter, the initial rise of the curves and location of the peak differs, moving forward as the pin diameter increases. This is likely because of a greater area of influence of the pin on the tows as the pin diameter increases, which affects local tow deformation. This phenomenon requires further study.

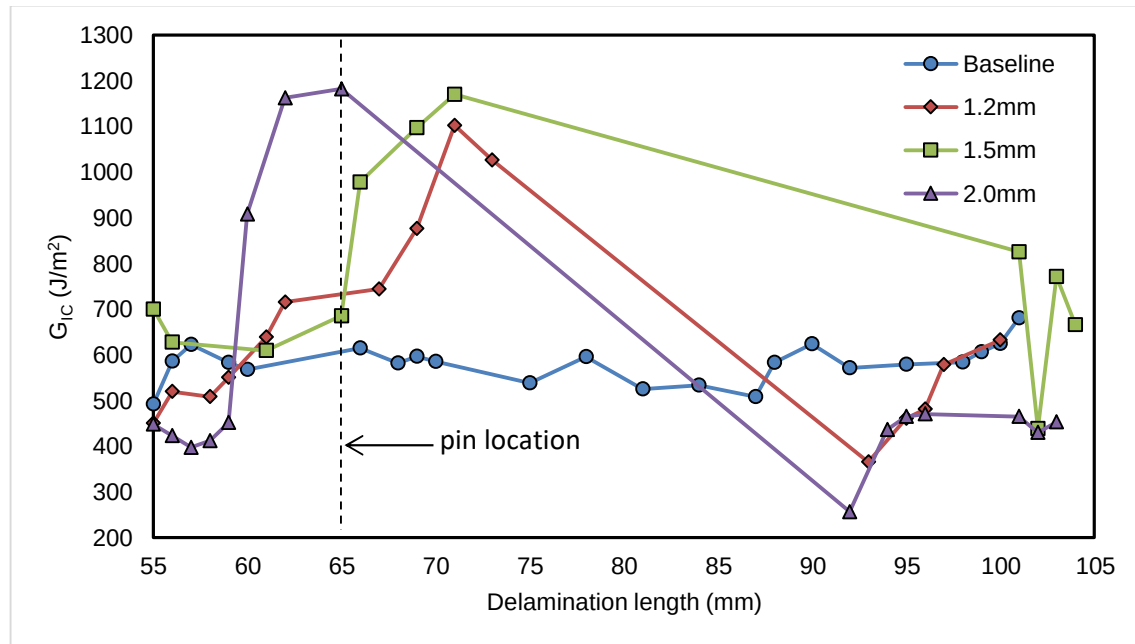


Figure 2. Mode I fracture toughness (DCB) results.

The lack of significant deterioration of in-plane tensile properties in pinned laminates produced using static insertion is counterintuitive. This result has validated the robustness of the static insertion process expands the range and forms of materials that can be inserted through-the-thickness compared with existing TTR methods. This has potential applications for integration of large diameter multifunctional elements, joining, and more efficient integration of moulded-in holes

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