PSEUDO-DUCTILE FAILURE MECHANISM INTRODUCED INTO FINGER JOINTED THERMOPLASTIC PES INTERLEAVED CFRC

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Abstract

Pre-cut unidirectional carbon fibre prepreg composites, with an overlapped finger-joint architecture, were modified through the addition of polyethersulfone (PES) interleaves. The properties arising from these finger-jointed configurations were strongly dependent on the interply overlap region. When the tough thermoplastic interleaves spanned only the central portion of the overlap, a crack arresting failure mechanism was observed in tension. A pronounced plateau region or pseudo-ductile response was shown in conjunction with a strain hardening response after crack arrest. The local strain-to-failure of PES interleaved samples was ~3.2%, an increase of 85% compared to the pre-cut baseline (strain-to-failure 1.6%, pre-cut specimens without interleaves).

1. Introduction

The failure mode(s) of traditional carbon fibre reinforced composites (CFRCs) can be altered through the inclusion of interleaves. The addition of thermoplastics interleaves has been shown to easily enable repair,[1] as well as controlled alteration of the stiffness upon heating.[2] Insertion of a tough thermoplastic interleaved region in a CFRC is expected to improve shear properties in tension in matrix dominated failures/configurations.[3] This investigation follows a previous methodology for unidirectional discontinuous carbon fibre/epoxy prepreg composites for introducing pseudo-ductility.[4]

2. Motivation

The aim of the work is to introduce ductility into composites whilst retaining high performance as part of the High Performance Ductile Composite Technologies (HiPerDuCT) Project. The objective of the interleaved finger jointed overlap is to introduce a (pseudo)ductile failure mechanism which increases strain, through a crack arrest mechanism. A typical brittle composite stress-strain profile against an idealised (pseudo)ductile stress-strain profile is shown in Figure 1.

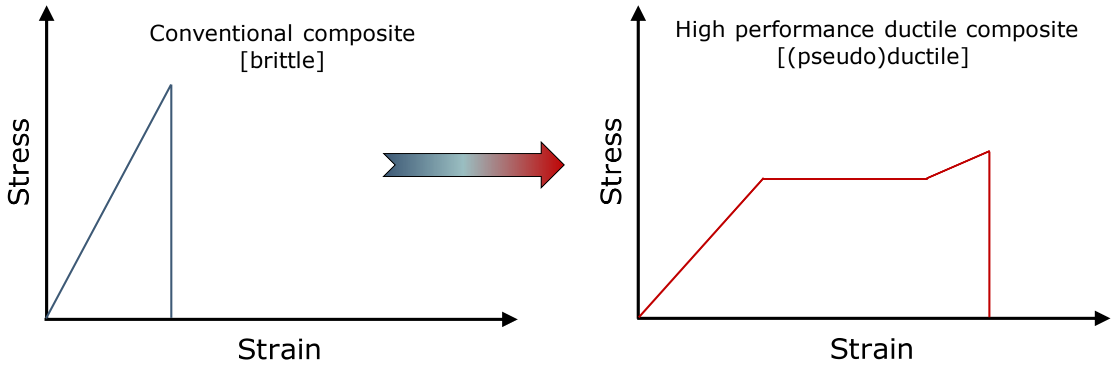

Figure 1. (Left) Typical stress-strain curve for a brittle composite, (Right) an idealized stress-strain curve for a (pseudo)ductile composite.

3. Modelling

“Simple” and “hybrid” architectures within the discontinuous finger jointed overlap region, Figure 2, were investigated in a finite element model using Abaqus FEA v6.14.

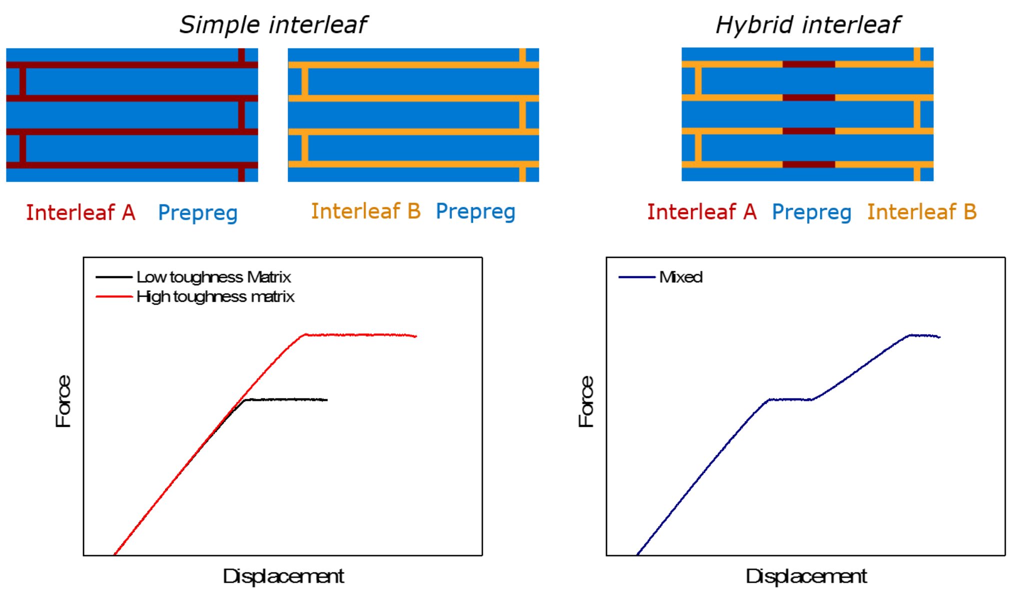

Figure 2. (Top) Schematic illustrating the arrangement of interleaves within the prepreg (blue) and discontinuous finger jointed architecture. Interleaf A (red) is a high toughness matrix and Interleaf B (yellow) is a low toughness matrix. (Bottom) The corresponding force-displacement model outputs.

In the simple interleaved discontinuous finger jointed architecture, where only one type of material is contained in the interleaf, a single failure ensues between the overlapped regions for both a low and a high toughness interleaves, albeit with a plateau region predicted when the crack is propagating in the interleaf bulk. One problem with the predicted force-displacement response for the simple interleaved specimens is that in a real specimen, with many overlaps arranged in series, failure will occur at the weakest overlap and many overlaps may never reach the plateau stage of the load-displacement response. Therefore, the overall ductility observed in such architectures will be very limited. Yet, in the hybrid interleaved configuration the predicted failure had a significant step-like mechanism and exhibits pseudo-ductility. The first plateau is dependent on the low toughness matrix failure onset. While the overall displacement of the plateau is determined by the total overlapped region length, and the variation in length of the two interleaved materials between the finger joints. The model predicts a final plateau failure for the hybrid case from the high toughness interleaf contribution, however, from previous studies this is unlikely unless a significant strain hardening response is observed in the material. Nevertheless, the advantage of the hybrid interleaved architecture is that the increase in load after the first plateau could ensure that all the overlaps in a series arrangement undergo the initial plateau stage before first failure. If this occurs, then the overall load-displacement response will exhibit ductile characteristics. The strain-hardening properties of polymers are strongly dependent on loading rate, which in this embodiment is strongly linked to the failure processes. In addition, literature is limited and predicting (accurately) the fracture dynamics and subsequent strain-hardening behaviour of specimens is notoriously difficult.

The desired failure mechanism in the hybrid case is reliant on the ability of the tough central region (Interleaf A) to arrest the crack growth after the initial fracture(s) in the low toughness material (Interleaf B). The fractures will most likely be generated at the cut sites between the prepreg under tension, at the highly stressed region of the overlap, which propagate along/within Interleaf B (low toughness region). For crack arrest to occur, Interleaf B must be less tough than Interleaf A. If the initial crack is arrested in the Interleaf A region, loading will continue to increase until the crack(s) develop, or additional crack(s) propagate from the other side of the finger joint, which then leads to specimen failure. A schematic of the crack arresting propagation within the finger jointed region is shown in Figure 3. The interface between Interleaf A and the prepreg is critical and must be sufficiently strong and tough to enable the crack to propagate into the bulk phase of the Interleaf A. If the progression of the crack is permitted at the prepreg and Interleaf A interface, then the system will fail in a catastrophic and brittle manner.

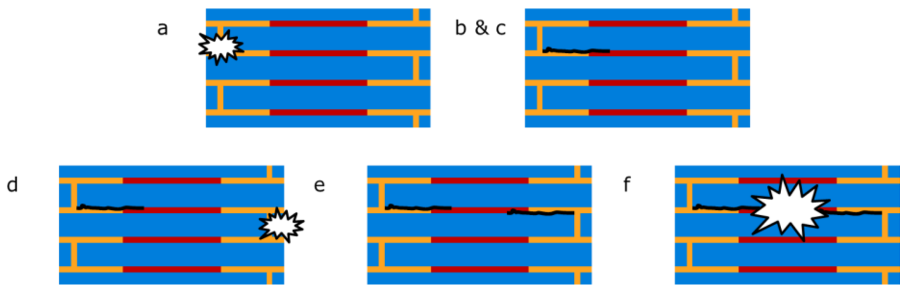

Figure 3. Schematic of the hybrid interleaved finger jointed sample failure mechanism. (a) Initial failure of the composite at the high stress state around at the edge of the cut sites of the prepreg (blue) for the finger joints. (b) The crack (black) propagates along the interface/bulk of the less tough interleaf (yellow) and (c) the crack growth is arrested by the tougher interleaf (red). The composite carries load until, (d) a crack is initiated on the opposite side and the crack progresses into the central toughened region (e). If the length and toughness of Interleaf A are chosen appropriately, the crack can be arrested once more. (f) When the crack can propagate though the toughened region the composite will fail. If the secondary crack is not arrested the toughened region fully the specimen will failure prematurely. For clarity additional cracks have not been added to the schematic at all interfaces, in practice cracks will form along all finger jointed sites when there is a failure in the corresponding side.

4. Experimental

4.1. Materials

- Unidirectional carbon fibre prepreg, M21/194/34%/T800S, Hexcel (GB) [Prepreg]
- Thermoplastic polyethersulfone (PES), 50 µm and 20 µm films, LITE S, LITE (Lipp-Terler) GmbH (AT) [Interleaf A]
- Epoxy film, M21 resin, 35 gsm, item recipe# B910330, batch# F367695B03, 2000-04-15, Hexcel (GB) [Interleaf B]

5. Results

Composites with a hybrid interleaved and finger jointed architectures, described previously,[5] were fabricated, tested in tension, and showed significant plateau regions and a crack arrest mechanism, Figure 5. The stress-strain curves for these specimens resemble closely the desired pseudo-ductile failure mechanism and show good correlation to the modelled outcomes.

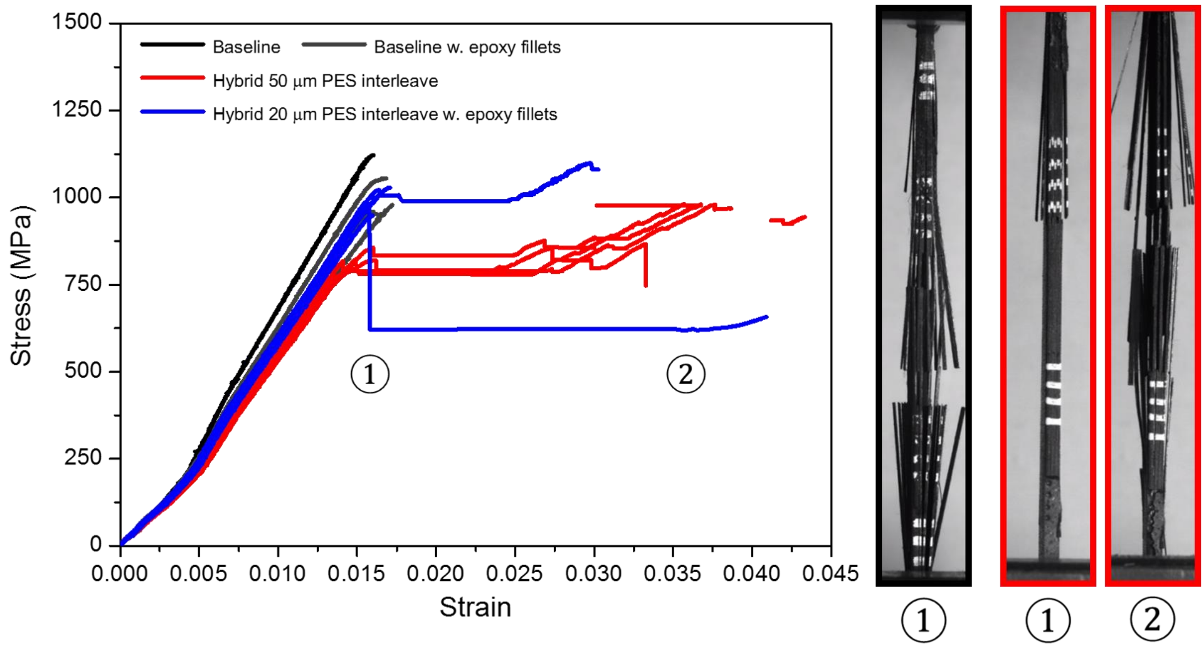

Figure 4. Tensile tests for finger jointed samples with baseline (black), baseline with epoxy fillets (grey), hybrid 50 µm PES interleaved (red), and hybrid 20 µm PES interleaved (blue).[5] ① and ② indicate the points on the stress-strain curves shown in the adjacent photographs for baseline and hybrid 50 µm PES interleaved specimens. N.b. Strains were recorded using an optical strain gauge.

6. Conclusions

A finite element model predicted the failure mode observed in a hybrid interleaved finger jointed architectures, and the desired pseudo-ductile failure crack arrest mechanism. The hybrid interleaved finger joined specimens final plateau was not observed in testing, indicating that the second crack growing from the other end of the finger joint was not sufficiently arrested in the high toughness region (Interleaf A, PES). The absolute difference in the toughness between regions, Interleaf A (high toughness) and Interleaf B (low toughness) in this instance PES and M21 resin, respectively, appeared to be closer than originally modelled which may account for the premature failures. Future studies are on-going to investigate the effect of different interleaf thicknesses and materials.

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