A NOVEL TECHNIQUE TO ACCURATELY MEASURE THE FIBRE FAILURE STRAIN IN COMPOSITE LAMINATES UNDER A COMBINED IN-PLANE TENSION AND SHEAR STRESS STATE

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ABSTRACT

A simple and accurate test method is presented to investigate the influence of shear stresses on tensile failure of unidirectional carbon fibre/epoxy. Glass/carbon hybrid laminates are used to eliminate stress concentrations and avoid premature failure at the end-tabs. Free-edge delamination is suppressed using thin-plies. Angle-ply carbon/epoxy laminates have been designed to achieve combinations of tensile and shear stresses. It is shown that in-plane shear does not significantly affect the fibre failure strains.

1 INTRODUCTION

Failure prediction of composite materials under multi-axial loads has been always a difficult and challenging problem and many different failure criteria have been proposed. Lack of accurate experimental results for multi-axial cases is another problem which makes it difficult to judge between the criteria. Achieving accurate experimental measurements on basic mechanical properties of composite materials is a difficult task due to the problems of excluding premature failure mechanisms that are not always well appreciated [1]. Such a task is much more complicated for multi-directional and combined loading conditions. The disagreement on different failure criteria and also the outcomes of the World Wide Failure Exercises show that the behaviour of composites is still not fully understood under combined load cases[2]. Achieving accurate experimental results is one the most important parts of such a mission and due to the heterogeneous nature of composite materials, it is quite challenging.

The configuration of the test sample can affect and promote one or more failure modes. For instance, the specimens recommended by the ISO 527-5 and ASTM D5083–10 standards require prismatic end-tabs and ASTM D3039/D3039M–08 requires special tapered end-tabs to protect the specimen surface from the serrated grip faces. The end tabs can produce stress concentrations that can cause premature failure of the tensile samples. As a result, the strength of composite materials can easily be underestimated using end-tabbed tensile samples [3].

To mitigate this issue, a new testing method based on glass/carbon hybrid composites was introduced [4]. In this method, the UD carbon/epoxy layer is embedded between two UD glass/epoxy layers. The stress/strain concentration due to load introduction from the end-tabs is only experienced by the glass/epoxy layer and the strain in the carbon layer at the edge of end-tab is actually less than the strain in the middle of the specimen. Therefore, the failure should take place inside the gauge length and not be affected by the end-tabs. Figure 1 indicates the distribution of load-direction strain in the end-tab, glass and carbon layers obtained by Finite Element analysis: The area affected by the strain concentration is restricted to the glass layer and does not extend to the carbon layer. In this paper, this technique will be used to avoid any premature failure of the carbon/epoxy laminate due to end-tabs.

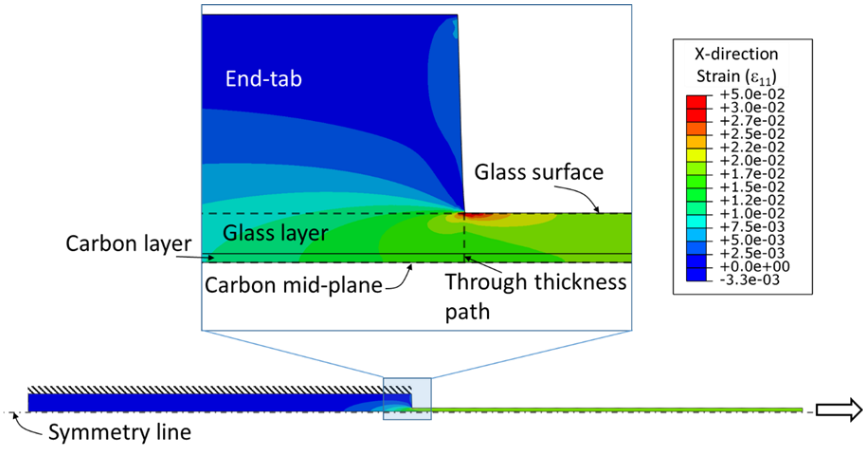

Figure 1- The distribution of x-direction strain (ε11) over the tabbed glass/carbon hybrid specimen [4]

The failure process of composite materials may involve several failure modes such as fibre failure, matrix cracking, delamination and to achieve accurate measurement, it is important to suppress any failure mode which is not desired. The aim of this paper is to study the effect of in-plane shear on tensile fibre failure. Therefore, it is important to avoid other failure modes, i.e. matrix cracking and delamination. Several works on thin-plies have proved that thin-plies can completely suppress free-edge delamination [5,6] and matrix cracking [7].

2 TESTING METHOD

In this paper, a novel method is presented to achieve combined stress combinations in composite materials. Carbon/epoxy thin-ply angle-ply laminates, $[\pm\theta]_S$ (θ=0°, 5°, 10°, 15°, 20°, 25°), are embedded in Uni-Directional (UD) glass/epoxy laminates and are designed to induce different combinations of in-plane shear and tensile stresses in the carbon plies. The final layup is $[0_G/\pm\theta_C]_S$ where G and C stands for the Glass and Carbon layers respectively. Using thin-ply laminates and UD glass layers on the outer surface of the carbon/epoxy laminates, suppression of any damage before fibre failure is achieved. In such a configuration, UD glass layers act as continuous end-tabs and the load is gradually and smoothly transferred to the specimen. Embedding thin-ply angle-ply carbon/epoxy laminates in UD glass layers will supress all unfavourable failure modes (matrix cracking, free-edge delamination and stress concentration at the end-tabs) so fibre failure in the carbon/epoxy laminates is expected to be the first failure mode. Longitudinal and transverse strains were measured using an Imetrum Video Gauge system and the shear strain in the fibre direction of each individual ply was worked out using these two normal strain components. Figure 2 indicates the schematic of such a test specimen.

Table 1- Materials used in this study

Material	E-glass/epoxy	SkyFlex USN020 Carbon/epoxy
Manufacturer	Hexcel	SK Chemicals
E11 (GPa)	43.9	101.7
Cured nominal thickness (mm)	0.127	0.03
Fibre per unit area (g/m2)	192	20

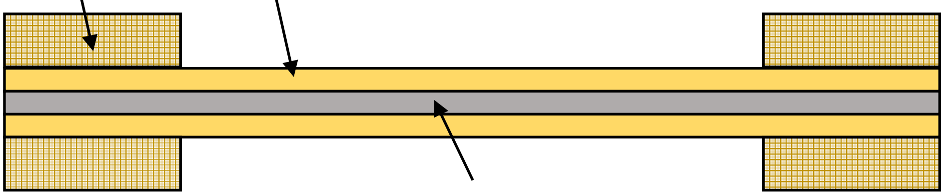

Figure 2 – Schematic of the angle-ply thin-ply laminate specimen embedded in continuous glass layers

3 RESULTS

Figure 3 indicates the stress-strain curves of $[0_{2G}/15_C/-15_C]_S$ laminates where G stands for the glass and C for the carbon layers. Specimens failed catastrophically by fibre failure in the gauge section followed by delamination. The stress-strain curves of other layups $[\pm\theta]_S$ (θ=0°, 5°, 10°, 15°, 20°, 25°) are similar and these curves are just shown as examples here. The normal strains along the fibre direction and also the shear strains at the fibre failure of the carbon/epoxy laminates are given in Table 2. All laminates have failed at very high fibre direction strains, with values similar to the failure strain of the UD carbon/epoxy layers with no shear, 1.83%. The shear strains introduced in the carbon epoxy layers at the failure strain are also measured directly and increase with the off-axis angle, θ. The small difference in the fibre failure strains of the UD and angle-ply laminates indicates that the presence of this level of shear strain does not affect the carbon fibre failure strain.

Table 2- Fibre direction and shear strains at the fibre failure of the carbon/epoxy laminate

Off-axis angle of the carbon/epoxy laminate (θ)	Fibre direction strain (%)	Shear strain (%)
0	1.83	0
5	1.85	0.44
10	1.80	0.88
15	1.82	1.40
20	1.77	1.95
25	1.65	2.53

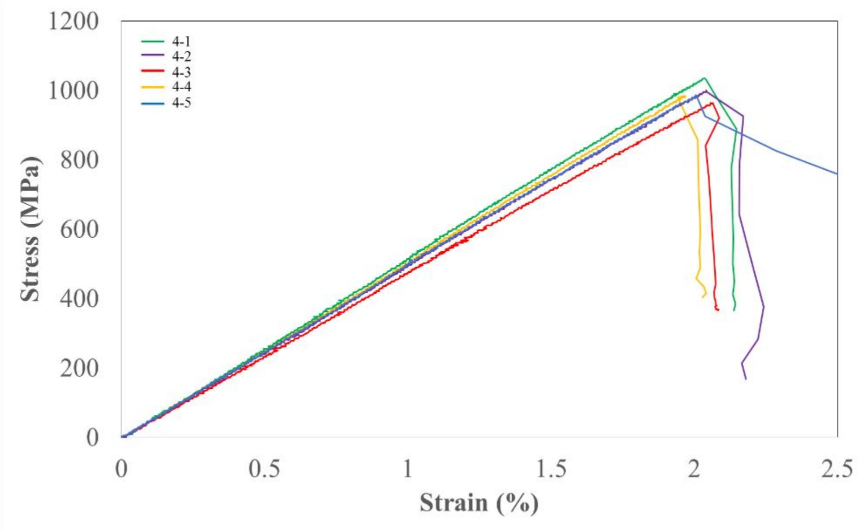

Figure 3 – Tensile stress-strain curves of different $[0_{2G}/15_C/-15_C]_S$ specimens

Fibre direction failure strains of the angle-ply laminates $[\pm\theta]_S$ (θ=0°, 5°, 10°, 15°, 20°, 25°) are shown against the induced shear strain values in Figure 4. The obtained results show that the fibre failure strain is not greatly dependent on the fibre orientation and therefore is not changed significantly by in-plane shear strains, even when they reach values as high as 2.47% shear strain.

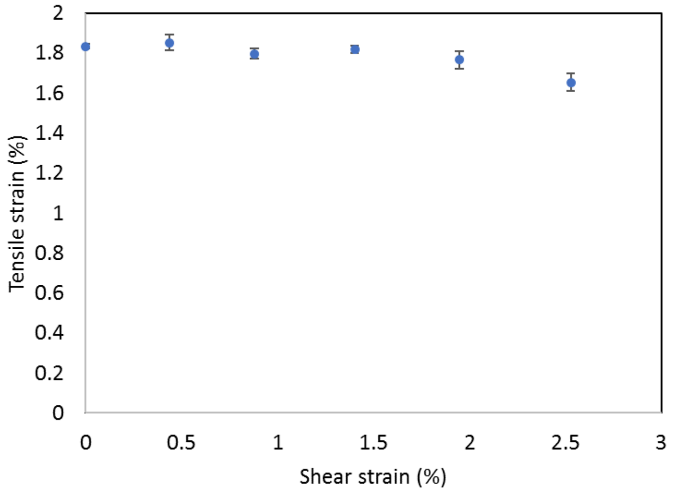

Figure 4- fibre failure strain of $[\pm\theta]_S$ (θ=0°, 5°, 10°, 15°, 20°, 25°) laminates embedded in UD glass layers versus different induced in-plane shear strain values

9 CONCLUSIONS

In this paper, a new, accurate and simple test method for measuring fibre failure strain under combined shear-tensile stresses was demonstrated. Using glass layers as the outer layer and thin-ply angle-ply carbon laminates assures suppression of premature failure modes before the desirable gauge section fibre failure. With the applied novel layup of $[0_G/\pm\theta_C]_S$ (θ=0°, 5°, 10°, 15°, 20°, 25°), it is possible to induce different values of in-plane shear stresses in the carbon-epoxy laminates and measure the fibre failure strains. The obtained results showed that the influence of shear stresses on the carbon tensile failure strains are not significant.

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