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ADVANCED EXPERIMENTAL TECHNIQUES FOR DETERMINATION OF THE TENSILE AND COMPRESSIVE FAILURE STRAIN OF CARBON/EPOXY COMPOSITES

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ABSTRACT

Carbon fibre reinforced composites are lightweight, stiff and have high strength, but usually fail catastrophically at relatively low strains. One of their most important design factors is therefore their failure strain which is difficult to determine using standard tests. The fibre failure strain in tension is strongly affected by the gauge length, because of the volume or Weibull effect. The longer the gauge length, the higher the probability of having defects which act as weak links and lead to early failure of the fibres. Unidirectional (UD) composites usually show lower tensile strain to failure than the fibre strain because of stress concentrations around the end tabs due to the gripping pressure. This effect leads to the usual tab-failure of UD composites which can be avoided by the use of special tapered specimens with ply drops [1], but it is too complicated for general material characterisation. Compression testing of UD composites is also complicated because it requires accurate specimen machining and special fixtures to avoid global buckling of the specimens and strain measurement is problematic as well. Simple but accurate determination of failure strains can therefore largely help modellers with valid input parameters for their analysis.
Two different approaches are presented, one for tensile and one for compressive failure strain determination. UD hybrid composites are studied nowadays for different reasons including enhanced damage tolerance, gradual failure and pseudo-ductility [2]. The tensile failure strain of the lower strain to failure component (i.e. carbon/epoxy) of a three layer inter-laminar hybrid composite (i.e. glass/carbon hybrid on figure 1a) can be determined accurately from the stress-strain graph of a lay-up configuration designed to delaminate unstably after the first fracture of the carbon layer. Figure 1b clearly shows the load drops corresponding to the fractures of the carbon/epoxy layers in the glass/carbon hybrid specimens. During the testing of the majority of specimens, carbon layer failure was observed in the gauge section. The reasons for this are: (i) The end tab stress-concentrations in the carbon layer were shielded by the higher strain glass/epoxy layers in the hybrid specimens. (ii) The use of thin specimens (h<1 mm) also reduced the stress concentrations at the end-tabs due to the lower failure load and modest grip pressure required to avoid the specimen slipping in the grips.

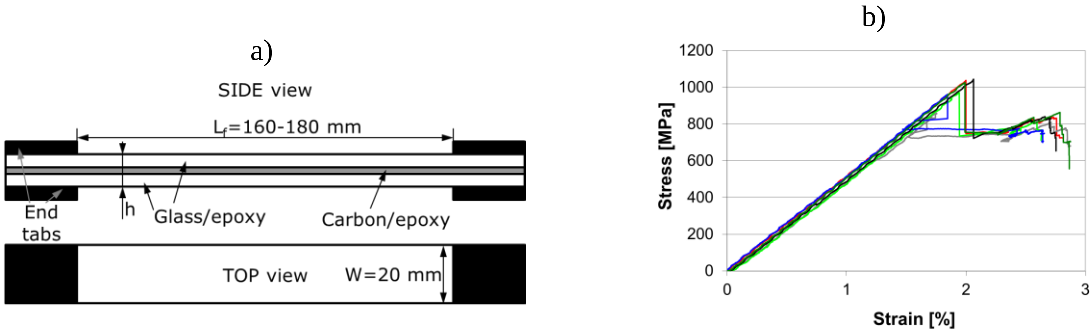

Figure 1: a) Schematic of an inter-laminar hybrid composite tensile test specimen, b) Stress-strain graphs of delaminating inter-laminar hybrid composite specimens

Another new approach is proposed for determination of the compressive failure strain of UD carbon/epoxy that fails by fibre fracture rather than shear instability, using a four point bending test setup. A carbon layer was put in the compressive side of the specimen backfilled with several glass/epoxy plies to offset the carbon plies from the neutral axis (centroid) of the cross section shown in the inset of Figure 2b. This way the carbon layer is put in compression between the inner loading noses without any grip effects and it is supported against buckling by the surrounding glass plies. The strain at the top surface of the carbon layer (highlighted with a red line in Figure 2b.) was calculated from the uniform curvature of the central section of the specimen under bending assuming a linear strain distribution. The position of the centroid, where the strain is zero, was calculated using the classical laminate theory. The constant radius and curvature of the central section was determined with an optical measurement system, which is capable of tracking dots on the edge of the bending specimens (see figure 2a.) and outputting the planar pixel coordinates of the points during the bending test. After scaling the pixel coordinates to mm, circular arcs were fitted on the deformed set of dots which allowed continuous monitoring of the curvature and therefore the strain in the carbon layer. The failure of the carbon layer can be detected as a decrease in the slope of the plot in figure 2b. Straight lines are fitted to the plot to show the difference between the initial and the final slopes and make the carbon failure strain determination more accurate. The new strain measurement technique was validated against conventional strain gauge measurements on symmetric and asymmetric hybrid specimens and showed good agreement. A significant benefit of the proposed new optical technique is that the measured strains are not limited by the possible de-bonding and fracture of the strain gauges, therefore the system can be operated reliably over a much wider strain range. The single transparent glass ply on top of the carbon layer allows damage analysis inside the specimen at the carbon/glass interface and revealed the multiple fractures (fragmentation) of the carbon layer which were reported earlier only in tension [2].

a) b)

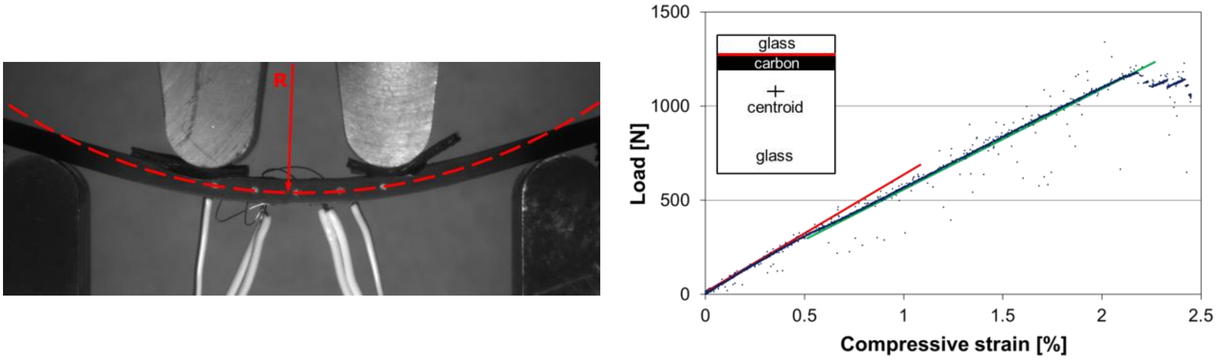

Figure 2: a) Deformation of a specimen in four point bending, b) Change in slope of the load-strain plot at compressive failure of the carbon layer

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