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FIBRE BREAKS IN INTERLAYER HYBRID COMPOSITES DETECTED WITH IN-SITU SYNCHROTRON COMPUTED TOMOGRAPHY AND SIMULATED WITH A FIBRE BREAK MODEL

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ABSTRACT

Interlayer fibre-hybrid composites are made of two or more fibre types embedded in the same matrix and have a layered structure. Multiple failure modes occur even in a simple unidirectional (UD) hybrid composite loaded in longitudinal tension. The fracture of the low elongation (LE) fibre layer is one of the failure mechanisms, which is determined by the accumulation of fibre breaks.

The development of the fibre breaks in a UD bundle of fibres is the basis of several longitudinal strength models [1]. As fibre breaks occur in the composite, the broken fibres lose their load carrying capabilities locally and shed their load to nearby fibres, increasing their stress level [2]. The increased stress level in the vicinity of fibre breaks tends to form fibre break clusters. Fibre break clusters develop differently in hybrid composites than in non-hybrids. The presence of a second fibre type imposes constraints on the cluster development and therefore creates synergetic effects [3]. With the introduction of ultrafast synchrotron computed tomography (CT) these effects can now be investigated experimentally.

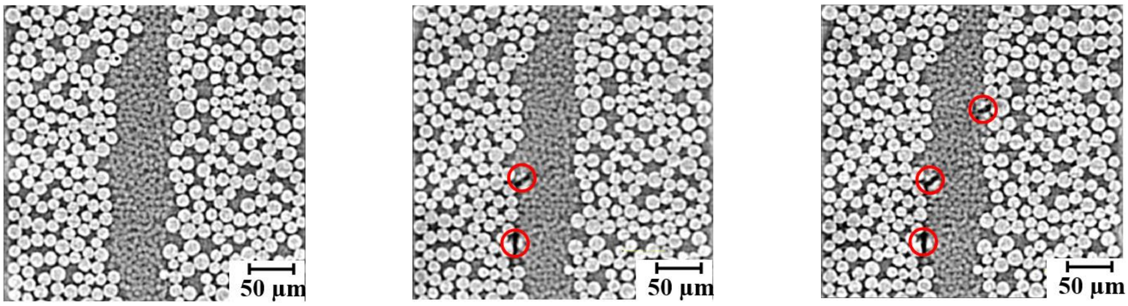
The short acquisition time allows *in-situ* detection of fibre breaks and correlation with the applied longitudinal strain. Detecting fibre breaks as a function of the applied stress and comparing the results with modelling predictions is a powerful tool to gain new insights into the fibre break development in hybrid composites.

In-situ tensile tests were performed on two carbon/glass interlayer hybrid composites and one non-hybrid carbon fibre composite. The cross-ply stacking sequences of the three composites tested are shown in Table 1, where C stands for carbon/epoxy layers and G for glass/epoxy layers. The subscript for each layer refers to the number of consecutive layers of carbon or glass and the superscript to the orientation of the layer. The CT scans were performed on the TOMCAT beamline at the Paul Scherrer institute using an in-house developed GigaFRoST camera [4] for the X-ray detection.

Table 1: Composite material stacking sequences.

Name	Stacking sequences	Thickness [mm]
CF	$C_4^{90}/C_{10}^{0}/C_4^{90}$	1.02
Hyb-1	$C_5^{90}/G_5^{0}/C_1^{0}/G_5^{0}/C_5^{90}$	0.82
Hyb-2	$C_5^{90}/G_4^{0}/C_1^{0}/G_1^{0}/C_1^{0}/G_1^{0}/C_1^{0}/G_4^{0}/C_5^{90}$	0.96

The in-situ synchrotron CT tensile test results were then analysed with an in-house developed automated algorithm to detect fibre breaks in the volume of the material for several applied stresses. Figure 1 shows the longitudinal cross-section of the Hyb-1 stacking sequence at 0% , 60% and 98% of the ultimate failure stress. The carbon fibre breaks are a distinctive feature in the images, as dark pixels appear in the fibre break locations. The fibre break locations are indicated in the figure and their number increases with the applied strain.



(a) (b) (c)

Figure 1: Fibre break objects in Hyb-1 composite for different applied strains: (a) 5%, (b) 63% and (c) 98% of the LE fibre layer failure strain. The red circles are highlight the carbon fibre breaks.

The experimental results were compared with an improved version of the model of Swolfs et al. [3]. Figure 2 shows the increase in the duplet density (clusters made of two fibre breaks) in the carbon fibre layer as a function of the applied stress predicted by the model and observed experimentally. Both the modelling and experimental results show a higher duplet density in the hybrid composites prior to the failure of the LE fibre layers compared to the CF. Hybrid composites are able to sustain higher levels of fibre break damage. This effect contributes to explain the synergetic effects commonly found for the initial failure strain in carbon/glass hybrids [3].

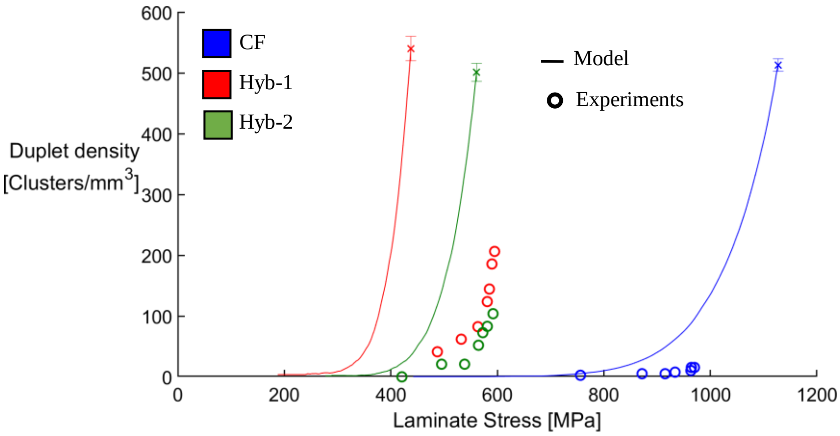


Figure 2: Increase in the number of duplets predicted by the strength model (lines) and observed experimentally (circles).

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