How does the fibre dominated strength of a laminate relate to the UD strength?

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Our previous workshops have considered the definition of strength and the measurement of strength of unidirectional fibre-reinforced composites in tension, compression, shear and transverse loading [1]. We now turn to the question of the relationship between laminate strength and that of the unidirectional material.

In principle, if the other plies do not affect the behaviour of the 0° plies that carry most of the load, the fibre dominated failure strain in laminates would be expected to be the same as the failure strain of the unidirectional material. The failure stress will obviously differ depending on the layup and laminate modulus. However, in a laminate there are also other potential mechanisms that may result in premature failure, especially due to delamination. The special state of stress at the free edge combined with the interaction with transverse cracks can cause delamination before 0° fibre failure. This can give rise to large differences in strength of laminates with the same proportions of different ply orientations depending on the stacking sequence and ply block thickness. This has been shown for quasi-isotropic IM7/8552, with different thicknesses achieved by either repeating sublaminates (dispersed plies) or increasing the thickness of material of the same orientation (blocked plies). All results were lower than expected based on the unidirectional strength (see Figure 1) [2]. Different strengths have also been found for the same quasi-isotropic laminates loaded along a primary fibre direction or at angle due to the different susceptibility to edge delamination [3]. Alternatively the presence of other plies may inhibit failure: (1) in compression, where adjacent plies with different orientations may constrain microbuckling, (2) in tension, the plies surrounding the 0° ply or absence thereof may affect the development of critical clusters of fibre breaks [4], and (3) in bending, surface plies may delay failure of the outermost 0° plies.

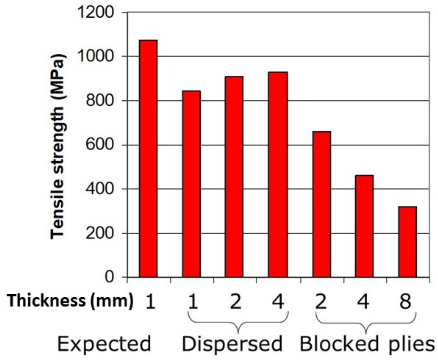

Figure 1: Strength of different IM7/8552 quasi-isotropic laminates

Transverse cracks, as well as contributing to premature delamination, may also affect 0° ply failure. This has been demonstrated in tension, where slightly earlier fibre direction failure occurred in cross-ply laminates with transverse cracks compared with similar laminates with very thin 90° plies where cracks were suppressed [5]. Modelling has suggested that the longitudinal tensile strength is reduced by 5% if the 0° and 90° ply blocks have the same thickness [4]. This knockdown increased to 17% when the 90° ply was four times thicker than the 0° ply. However, other models have suggested this effect to be barely present [6]. Experimental observations also found more fibre breaks in the 0° ply near the transverse crack than elsewhere in the 0° ply (see Figure 2) [7]. An earlier fibre direction failure has also been demonstrated in compression, where transverse cracks initiated by torsional loading reduced the failure stress under subsequent compression [8].

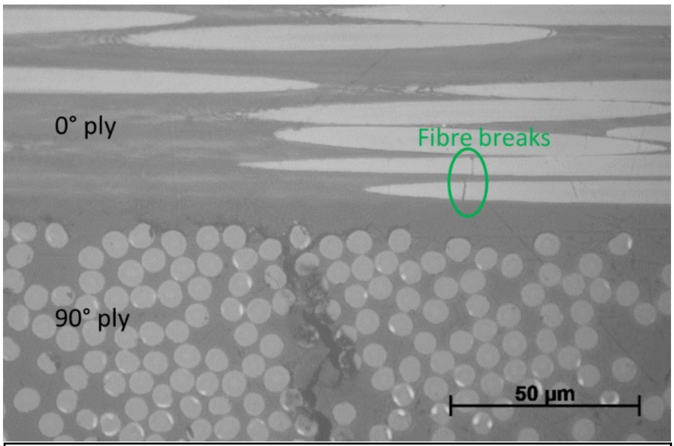

Figure 2: Increased probability of fibre breaks near the tip of a transverse crack.

In a laminate, the 0° plies may have other stress components present which could influence failure. However, tests on laminates with thin-plies to suppress premature failure due to transverse cracks and delamination have shown little effect of transverse compressive or shear stresses on the tensile failure strain of 0° plies [9, 10]. But in compression, the presence of other stress components may have a large effect, especially shear, which interacts strongly with compressive failure [11].

Residual thermal stresses induced during cure may be present at ply-level in laminates, but not in unidirectional material, and can influence failure. Also the volume of stressed material has an effect on strength, especially in tension [12]. However, it has been shown that if premature failure is avoided by using a layup not susceptible to delamination, careful attention is paid to how the load is introduced and the volume of stressed material is taken into account, tensile failure strain of quasi-isotropic carbon fibre laminates can be reconciled as being the same as that of unidirectional material [13].

These factors and available experimental evidence on the relation between laminate and unidirectional strength will be reviewed and discussed at the workshop.

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