EXPLORING MECHANICAL PROPERTY BALANCE IN TUFTED CARBON FABRIC/EPOXY COMPOSITES

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ABSTRACT

Background

"Tufting" is essentially one-sided stitching (Fig. 1) which avoids the addition of crimp onto the fibre architecture induced by standard stitching. The tufting stitch is never 'locked' and only remains in position because of frictional forces acting on it, leading to an almost tension-free structure. As such, tufting represents a very novel approach to localized through-the-thickness reinforcement in composite structures for the dry preform/liquid resin injection manufacturing route. A single needle takes a yarn through the fabric layers and returns back along the same trajectory, leaving a loop of the yarn on the back side of the plies (Fig. 2).

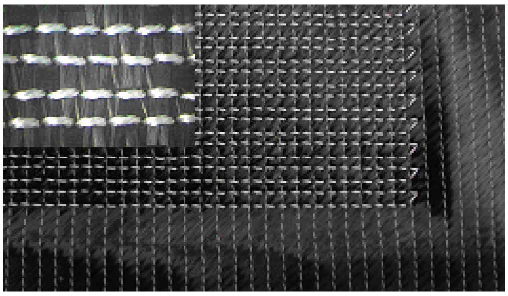

Figure 1: Top side of a tufted preform, with an enlargement in the top LH corner.

The concept of tufting for dry fabrics is analogous to Z-pinning for prepregs: they both intend to reduce the problem of delamination by introducing along the Z axis of the laminate a medium capable of bridging the propagating interlaminar crack. Similarly to Z-pinned structures, the increased delamination resistance of the cured tufted composite can be expected to be accompanied by a reduction in the in-plane properties [1]. Although the dry fabric fibres are relatively free to move apart during the tufting, the penetrating action of the 2mm diameter metal hollow needle inevitably damages some filaments in the fabric yarns. In addition, the presence of the thread itself introduces into the preform layers a certain degree of in-plane waviness which is expected to have an effect on the in-plane mechanical behaviour [2].

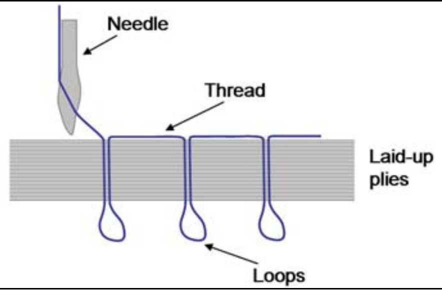

Figure 2: Schematic of the yarn arrangement in a tufted preform.

This work intends to draw some general baselines on the in-plane/out-of-plane properties balance in a Non-crimped Carbon Fabric/epoxy and in a 5 harness satin carbon fibre/epoxy composite reinforced by tufting in square 4mmx4mm and 3mmx3mm arrangement respectively with a Vetrotex Saint Gobain glass thread (EC9 68X3 S260 T8G H5). The crack bridging laws required for the analysis and modelling of the out-of-plane properties are defined by building and validating an analytical model of the mechanical behaviour of a single tuft within this composite.

Experimental

The dry preforms were tufted using a commercially available tufting head interfaced to a 6 axis computer controlled robot arm (Fig. 3). The reinforced woven fabric preform was resin injected by Resin Transfer Moulding technique using 1 bar pressure and cured at 180°C for 185 minutes whereas the tufted NCF preform was vacuum infused, cured at 80°C for 8 hours and post cured at 120°C for 5 hours.

Compression After Impact specimens were manufactured following the Boeing standard (BS 7260) and locally reinforced over a 50mmx50mm central area. After being impacted with energy of 15J, the ultimate compression strength was evaluated. The reinforcement resulted in a significant increase in the CAI value (Fig. 4).

In addition to the standard coupons for the determination of the quasi-static mechanical properties, some cured single-tuft miniature specimens were also prepared (Fig. 5). These are tested in both uniaxial pull-out and in a mode II (Z-shear) configuration (Fig. 6) in order to measure the bridging actions of the

Figure 3: *Kawasaki FS 20N* robot arm with a *KSL KL150* tufting head.

tufts and to determine the micromechanical failure mechanisms.

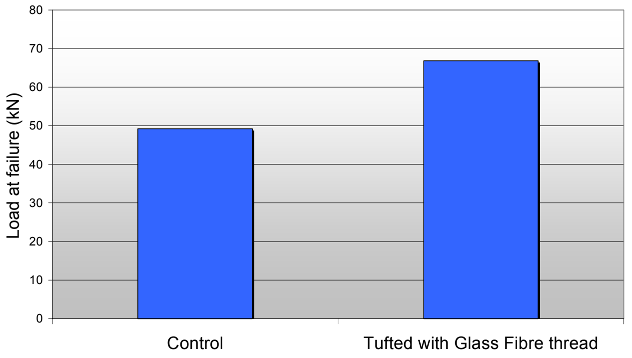

Figure 4: Comparison of CAI values for control and tufted specimens of the cured 5HS carbon fabric/epoxy material.

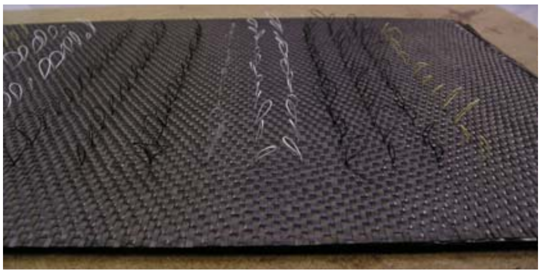

Figure 5: Dry 5HS preform bed showing individual well separated tufts in carbon, aramid and glass threads.

Modelling approach

There exists a strong analogy between the modelling approaches which can be employed to predict the mechanical response of Z-pins and tufts bridging delaminations; both these through-the-thickness reinforcements can be considered as embedded in Winkler's type foundations which exert distributed loads. Nevertheless the tuft behaviour differs from that of the Z-pin, because it can carry load only in tension and its shear/bending stiffness is usually negligible. A constitutive model for the mechanical response of Z-pins has been developed [3] for predicting the characteristic bridging actions in pure mode I and mode II loading conditions; according to this approach the Z-pin is described as an Euler-Bernoulli's beam. This model can be extended to the analysis of tufts by neglecting the shear and bending actions involved in the local equilibrium, thus assuming very large compliance to transversal loads. The constitutive equations for a tuft bridging under pure mode I and pure mode II loadings will be summarised and discussed together with a comparison of the model predictions with the experimental tests on the single tuft specimens.

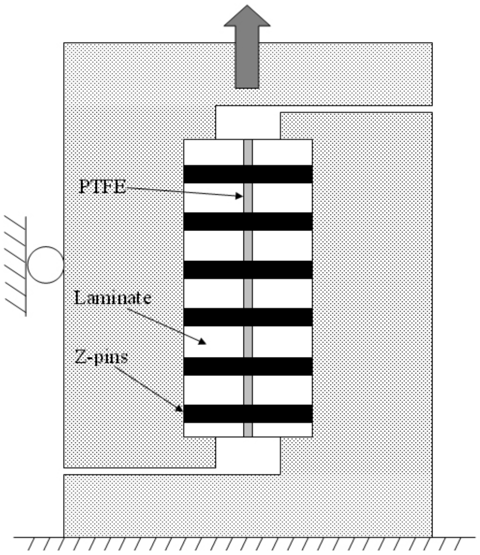

Figure 6: Schematic of 'Z-shear' test rig designed to test the shear resistance of through-the-thickness reinforcement elements, such as Z-pins or tufts [4].

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