FRACTURE TOUGHNESS OF 3-D BRAIDED COMPOSITES AND Z-DIRECTIONAL MICROFIBER COMPOSITES

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Introduction

Delamination of layered fabric-reinforced organic polymer composite materials represents one of the most prevalent, structural, life-limiting failure modes. The growth of the delamination results in a loss of stiffness and could eventually result in catastrophic failure [1]. Hence it is of great importance that the interlaminar fracture toughness of laminated fabric/resin composites be high and have good fatigue durability.

Various techniques have been introduced to enhance the interlaminar strength of layered composite materials. An alternative approach is to manufacture special fabrics using advanced textile technologies such as multi-directional warp knitting, 3-D weaving or a through-the-fabric stitching process [2]. These methods are slow and result in 3-D orientation of fibers in the fabric structures. All these approaches work in their primary goal, but they degrade the composite's in-plane properties [3].

A method of fabricating composites with improved delamination resistance by interlaminar z-directional flock-fiber placement has been developed [4]. The effect of this interlaminar flock fiber reinforcement on the Mode I fracture toughness is compared with Mode I fracture toughness of 3-D braided fabric reinforced composites. This comparison will provide the cost effectiveness of z-directional microfiber reinforcement to enhance the delamination resistance.

Experimental

The four types (Table 1) of tubular 8-layer 3-D braided fabrics were prepared by tying E-glass yarns (Type G-37-1/0-0.7Z, supplied by AGY, Aiken, SC, USA) to 504 fixed hooks (7 rings x 72 hooks per ring) and 576 of sliding hooks (8 rings x 72 hooks per ring) on the 3-D braiding machine. The braiding operation is a 4-step 1x1 sequence, which was described elsewhere.

Table 1 Preform samples produced

	Braiding angle	Ends /hook
Sample 1	30°	2 ends
Sample 2	30°	4 ends
Sample 3	45°	2 ends
Sample 4	45°	4 ends

The plate shape rectangular preforms (open-width) were impregnated with two-part epoxy resin system (Type 2000 epoxy resin / Type 2060 amine currant supplied by FiberGlast Inc., Brooksville, OH, USA), then assembled in a standard sequence for vacuum bagging. The vacuum bag assembly was cured at 80 °C for 2 hours initially, and post cured at 80 °C for 2 hours. The completely cured composite plates were machined into the specified test specimen dimensions for mechanical testing.

Mechanical properties of fabricated samples were evaluated on Instron 4400 and 5600 systems: Mode I interlaminar fracture toughness (ASTM5528-94a), tensile (ASTM D 3039/ D 3039M-00), in-plane shear strength (ASTM D 3846-94). A minimum of 5 replicate specimens were prepared in warp and weft direction for each test.

Results and Discussion

The energy release rate, G_I, reflects the energy available for an increment of crack extension. G_I is also called crack extension force or crack driving force. The plot of G_I versus crack extension is called an R-curve. Figure 1 shows R-curves (Mode I fracture toughness) of 3-D braided fabric composites derived from the load-displacement and load – delamination length data.

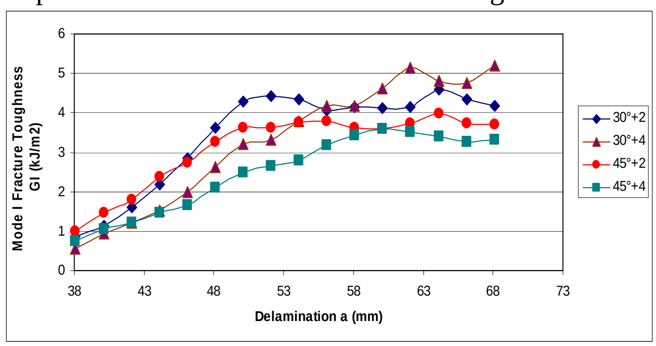

Fig. 1 R-curves for 3D braided fabric.

In Table 2, a summary of Mode I fracture toughness (G_{IC}) values for various 3-D braided composites are presented. A steady state propagation value G_{IC} (prop) of a particular sample is determined from the first local maximum G_I value of the R-curve in Fig. 1. It is observed that samples with 4 ends per hook show a lower G_{IC} values compare with those of the samples with 2-ends per hook at the same braiding angle. The effect of braiding angle on the delamination resistance is explainable from the fact that yarns of higher braiding angle contribute less to the crack closing force near to the tip of a moving crack (obliqueness effect).

Table 2.Mode I Fracture toughness of 3D braided fabrics

Sample	V_f (%)	GI (prop)	Improvement
S1 (30°+2)	50.93	4.44	12.7
S2 (30°+4)	49.70	4.17	11.9
S3 (45°+2)	42.12	3.79	10.8
S4 (45°+4)	52.76	3.58	10.2
Control	N/A	0.35	1.0

This observation can be attributed to the fact that for the 3-D braided composites, the system needs more strain energy to not only open the crack in the epoxy resin but also break/pullout the interlayer braided yarn segments in the crack tip region (Fig.2). So even after the crack begins to propagate, the force will decrease at a very slow rate as seen in prominently for Sample # 1(30°+2), 3(45°+2), 4(45°+4).

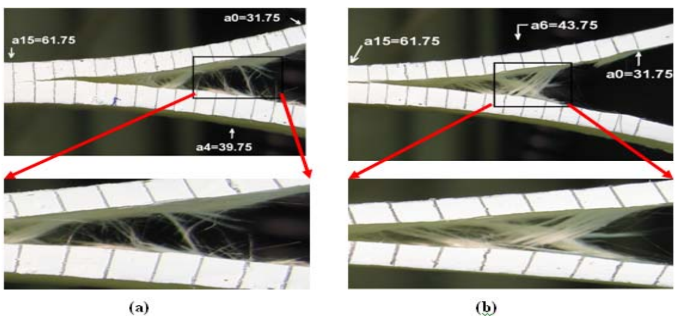

Fig. 2 Fiber bridging (a) and yarn bridging (b) in 3-D composites.

Hoskote et. al [4] introduced z-dirctional flock fibers into interlaminar matrix resin layers to increase the fracture toughness by the dissipation energy contribution of the fiber pulling/break in the fiber bridges along the delamination path. A typical fiber bridging along the delamination path during a DCB testing is shown in Fig. 3.

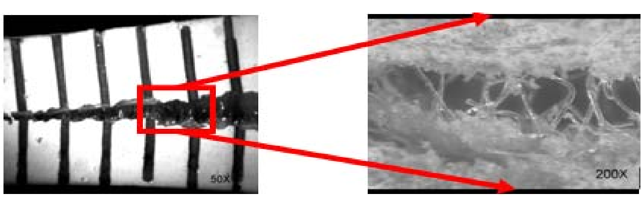

Fig. 3 Toughening mechanism of Z-fiber reinforced laminar composites.

Table 3 presents a summary of G_{IC} values for Z-microfiber reinforced laminar composites. Flocked laminar composites, either single side or double side, showed a dramatic improvement in fracture toughness over the control (unflocked) [7].

Fig. 4 shows the extent of improvement in fracture toughness of 3-D braided and Z-microfiber reinforced composites using data taken from Tables 2 and 3. Both 3-D braided preform reinforced composites and Z-directional micro-fiber reinforced composites show a dramatic improvement in the Mode I fracture toughness compared to the 2D-glass fabric/epoxy composites (control).

Table3. Fracture toughness of z-fiber reinforced laminar composites

Sample	**G_{IC} (kJ/m^2)**	**Improvement**
Unflocked control (C)	0.35	1.0
One side N20 (SN20)	2.65	7.6
One side N3 (SN3)	2.70	7.7
One side milled glass (SMG)	1.20	3.4
2- side N20 (DN20)	3.15	9.0
2- side N3 (DN3)	3.00	8.6
2-side milled glass (DMG)	1.10	3.1

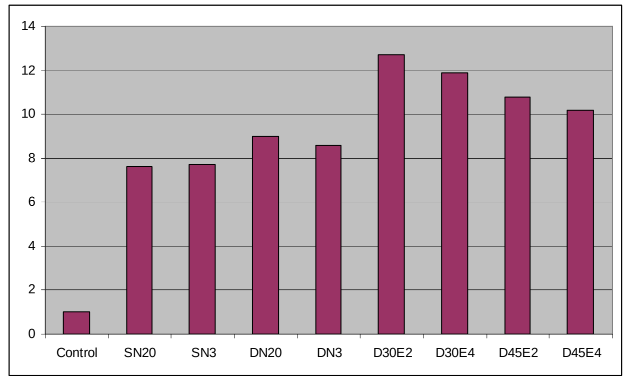

Fig. 4 Comparison of Mode I fracture toughness for 3-D braided and Z-microfiber reinforced composites.

Conclusions

The fracture toughness of 3D braided composites improved 10-12 folds over standard glass fabric/epoxy laminar composites, while the addition of though-thickness z-reinforcement in the form of flock fibers produced 8-9 folds improvements in mode I fracture toughness. It is obvious that although the G_{IC} value is higher for 3 D braided composite, it takes a much longer time to design and fabricate braided preforms than using flocking technology in the manufacturing of Z-directional microfiber reinforced composites. On another point, it is expected that fabrication of various sample geometries is much more easily achieved and at a lower cost using the z-reinforced laminar composite technology.

References

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