Influence of weave type and reinforcement in the fracture behavior of woven fabric reinforced thermoplastic composites

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Three composite materials have been selected with the same thermoplastic matrix (polyetherimide) and different types of fabric as reinforcement. Two of them are reinforced with glass fiber fabric (2/2 Twill and 8 Harness Satin) and the other with carbon fiber fabric (8 Harness Satin) [1]. The two types of fabric are represented in Fig. 1, while Table I shows the characteristics of the materials.

Characterization was carried out using Mode I and Mode II interlaminar fracture tests in order to determine the crack propagation resistance. In Mode I, five double cantilever beam (DCB) specimens were tested for each material (according to standard ASTM D5528). An Instron machine was used for testing at a constant loading rate of 0.5 mm/min and two metal piano hinges were adhered to the faces of the specimen with a special 3M adhesive [2, 3].

The determination of the delamination resistance under Mode I (opening) loading can be performed using the Corrected Beam Theory, Berry's Method or Direct Beam Theory [4, 5]. The Corrected Beam Theory was chosen, as the results obtained were more conservative. In this theory the value of the delamination energy was calculated using the value of the maximum load (P_{max}) in the following equation:

$$G_{Ic} = 3P_{max}\delta/(2B(a + |\Delta|)$$

where P_{max} the maximum load, δ the displacement, B the specimen width, a the crack length and Δ a correction factor which may be found experimentally by plotting the cube root of compliance $C^{1/3}$ as a function of crack length (Fig. 2). The results obtained for the three materials are presented in Table II.

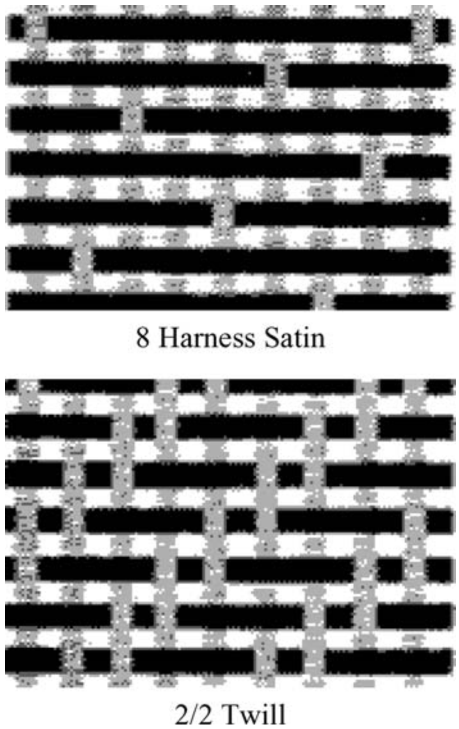

Figure 1 Types of fabric.

TABLE I Description of composite samples

Sample	Weight (g/cm^2)	Material type	Weave pattern	V_f (%)
A	300	*E*-Glass	8 Harness Satin	67
B	220	*E*-Glass	2/2 Twill	67
C	380	Carbon FT300	8 Harness Satin	58

In Mode II, five end notched flexure (ENF) specimens of each material were tested according to the Protocol for Interlaminar Fracture [5]. An Instron machine was used for testing at a constant loading rate of 0.5 mm/min [6, 7].

In this case, the determination of the critical strain energy release rate, G_{IIc}, for initiation of delamination under Mode II (in-plane shear) loading can be calculated using three methods: the Experimental Compliance Calibration, the Direct Beam Theory and the Corrected Beam Theory [4, 5]. Once again, the Corrected Beam Theory was chosen, as it is the most conservative.

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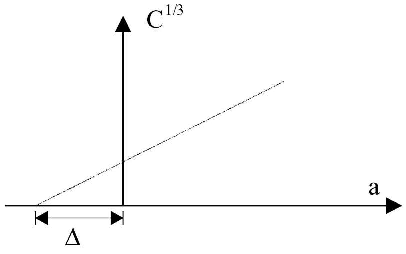

Figure 2 Plot of $C^{1/3}$- versus a.

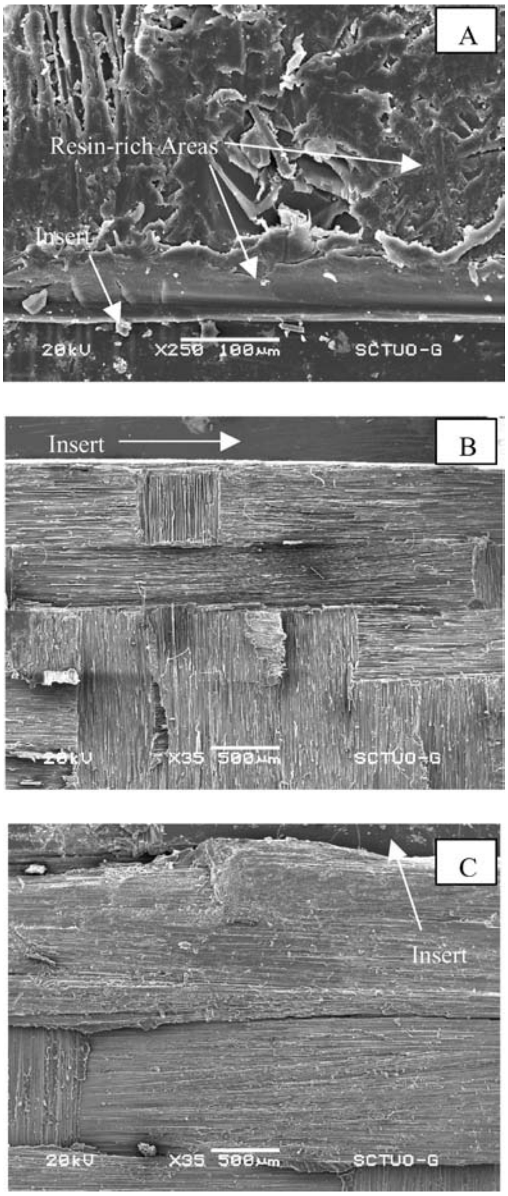

Figure 3 SEM photographs of Mode I fracture surfaces in zone next to insert.

In this theory, the values of G_{IIc} are calculated from:

$$G_{IIc} = 9P_{max}^2 a^2/16B^2Eh^2$$

where E is the value of the modulus measured during the compliance calibration for $a = 0$ and is calculated as:

$$E = L^3/4BCh^3$$

h being equal to half the specimen thickness and $1/C$ the initial slope of the load–displacement plot, ignoring any initial non-linearity due to play in the fixture.

The results obtained for the three materials are presented in Table II.

These results show that in Mode I the critical energy release (G_{Ic}) of the material reinforced with carbon fiber is larger, having a small difference ($\approx$10%) between the two materials reinforced with glass fiber. In Mode II, however, the two materials with 8 Harness Satin fabric reinforcement (glass and carbon) present very similar delamination energy values, while the material with 2/2 Twill reinforcement (glass) has a value larger.

TABLE II Results of fracture tests

Material	A	B	C
G_{Ic} (J/m^2)	2995.62 (503)	3223.56 (353)	4058.33 (776)
G_{IIc} (J/m^2)	2905.94 (357)	3593.38 (223)	2760 (405)

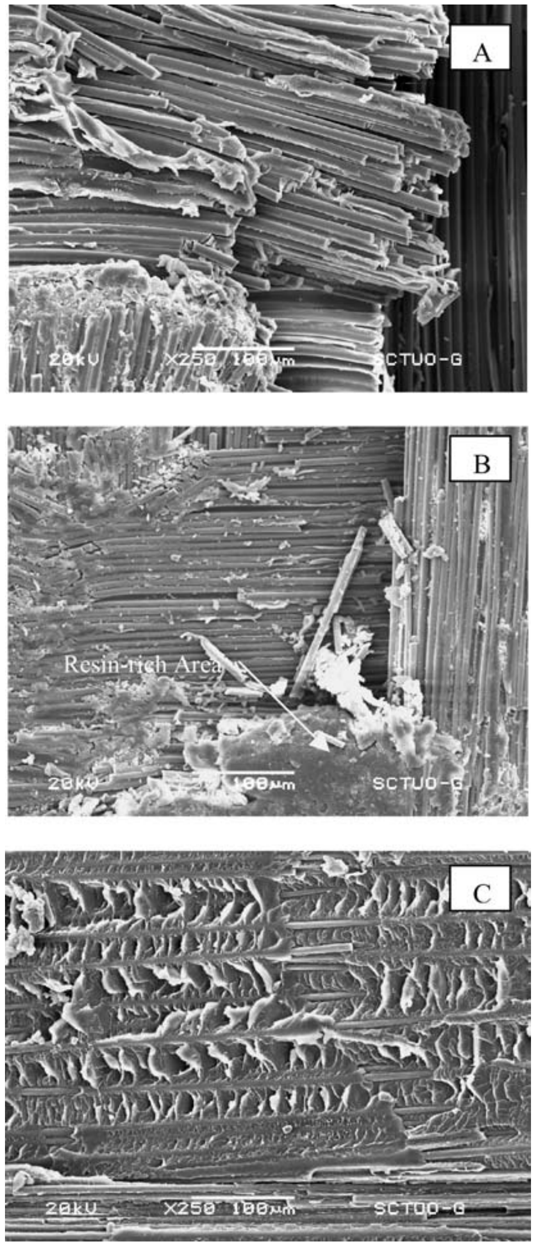

Figure 4 SEM photographs of Mode II fracture surfaces.

Fractographic analysis of the fracture surfaces was also carried out; the most interesting finding being the presence of large resin-rich areas in the zone next to insert in material *A* which is almost indiscernible (see Fig. 3).

The fracture surface presented by PEI matrix in Mode II for material *C* is interesting due to the important plastification that can be observed (see Fig. 4). This phenomenon cannot be found in materials *A* or *B*.

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