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INTERLAMINAR FRACTURE TOUGHNESS BEHAVIOR FOR CFRP UNIDIRECTIONAL LAMINATES USING DCB TEST

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Abstract: *Laminated fibre-reinforced composites made of high strength fibres in a relatively weak matrix material are susceptible to delamination. The aim of this paper is to determine the critical energy G_c consumed by the material as the delamination front advancees. Mode I interlaminar fracture toughness was evaluated by a standard double cantilever beam (DCB). The determination of G_c was made on an Instron testing machine using a laminated composite carbon fiber oriented unidirectional.*
Key words: *DCB tests, carbon fiber, fracture toughness, interlaminar, delamination*

1. INTRODUCTION

Over the past few decades, fiber reinforced plastics (FRP) have been developed as the foremost material for products in fields such as mechanical, electrical, architectural, and structural engineering. Carbon fiber reinforced plastic (CFRP) has especially attained a prominent position in use as structural materials for aeronautical and space engineering (Arai, 2008).
The composites industry uses many of the laminates made by consecutive stacking with several layers of composite, in such materials, interlaminar fracture, or delamination corresponding to the break between two adjacent plies of the laminate is an important mode of rupture (Perrin, 2000).

In order to characterize the toughness of a material, meaning their resistances at the beginning of crack, two approaches are possible: one based on the constraints at the crack and one based on the concept of strain energy.

Several studies have already been presented on DCB testing of multidirectional specimens with θ/θ, θ/-θ and 0^0/ θ interfaces. During the tests, however, intraply cracking and crack jumping between neighbour interfaces are often observed (Morais, 2002, Rhee, 2000).

Fracture mechanics approach is frequently applied by means of an energetic analysis. In fact, Kinloch refers that the energetic criterion is advantageous relatively to the stress intensity factors approach. First, the strain energy release rate has an important physical significance related to the energy absorption (Davies, Blackman, and Brunner, 2000),

The interlaminar cracks tend to propagate through the weakest parts of composite laminates, including the fibre matrix interface and the resin-rich region between plies.

2. EXPERIMENTAL WORK

Several attempts to measure interlaminar fracture toughness Gc were made. Until now the only standardized test is the DCB (Double Cantilever Beam) mode I know as Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix composites (ASTM D-5528, 1994).

The present experiment was conducted at the doctoral stage in Universita degli di Palermo, Facolta di Ingegneria Dipartamento di Meccanica, Palermo, Italy.

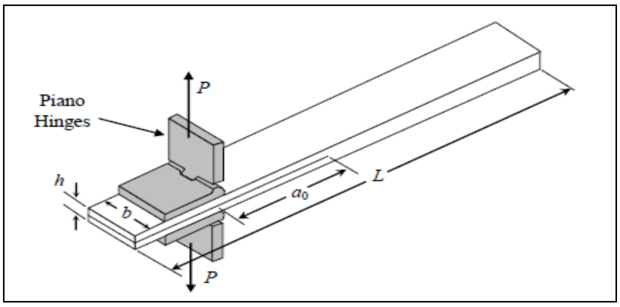

Fig. 1.Undeformed DCB specimen

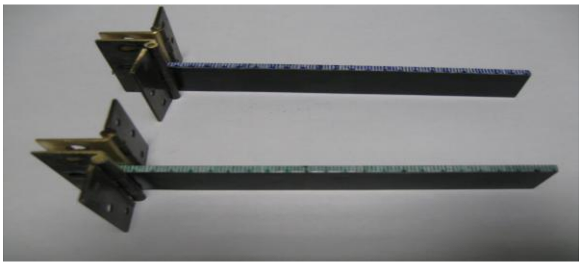
Fig. 2. Specimen used in the test

A test machine Instron 3367 with electric drive was used to test the specimens. The machine used Instron BlueHill software and has the following characteristics: maximum load: 30kN, maximum speed: 500mm/min, maximum stroke: 1194mm.

The problem analysed was a double cantilever beam (DCB) test used to determine mode I toughness. The DCB test specimen was made of a unidirectional fiber-reinforced laminate containing a thin insert at the mid-plane near the loaded end. Specimens were about 4 mm thick, 20 mm wide and about 154 mm long.

All tests are performed in laboratory conditions at room temperature.

To achieve the DCB test, has conducted a series of operations before the experiment. Initially, the specimens were cleaned on a side and painted a scale in order to determine the length of the crack. Then a pair of hinges was bonded with adhesive at the end where there is the initial delamination (see Fig. 2). In the case of unidirectional composites, the DCB sample is prepared such that crack propagation takes place in the fiber direction, which is the condition most vulnerable and therefore most conservative for the test. Under these conditions, the test is a good way to evaluate and optimize the properties of the fiber-matrix interface that is the composite.

Such a system allows full delamination growth monitoring capability on a side of the specimen, without eye strain.

3. RESULTS

The R-curves were obtained from the experimental P–δ curves given by the Instron's software. For the interlaminar

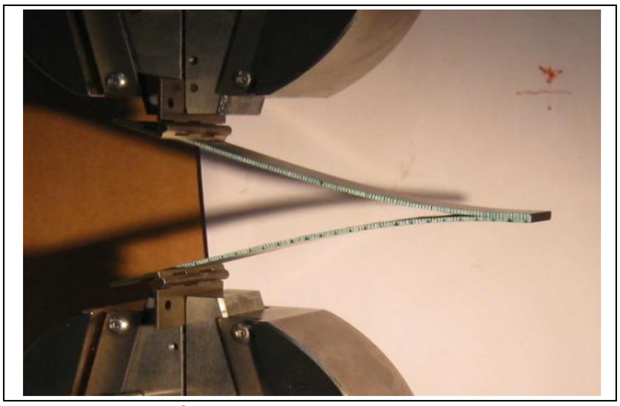

Fig. 3. Position of the specimen in the machine during the test

fracture characterization five tests were performed. The fracture energy can be calculated using the Irwin–Kies relation:

$$G = \frac{P^2}{2 \cdot B} \frac{dC}{da} = \frac{P^2 \cdot a^2}{B \cdot E \cdot I} \qquad (1)$$

Where:
G= critical energy release rate [J/m^2]
B= width of beam tested, [mm],
E = modulus of elasticity in bending, [MPa]
I= moment of inertia [mm^4]
a= crack growth [mm]

A visually observed initiation value for G_{Ic} can be calculated corresponding to the load and displacement at which the delamination is seen to grow from the insert on either edge of the specimen.

Data obtained during the test are: initial crack lenth a_0, (this can be confirmed after testing by separating the two components of the specimen by hand), displacement δ depending on load, P. This, together with specimen size, allows determining the interlaminar fracture tensile toughness of the material in mode I and making correction where necessary.

There are several ways in which the initiation and propagation G_{IC} corresponding values can be determined from the data obtained, and these values can be used to generate a resistance curve or R curve, by plotting the crack growth versus G calculated.

The experimental P–d curves of the DCB specimens are presented in Fig. 4. The critical fracture energy in mode I was evaluated using the method presented, shows the experimental R-curves obtained. A curve is drawn depends on the length of crack (a), this length was determined using a method, in witch the value of crack length was determined by processing images captured with the JVC camera using software Irfan View. A JVC camera is coupled to a monitor that take pictures to the DCB test every 2 seconds. In this way it can easily see the crack growth at any value of load.

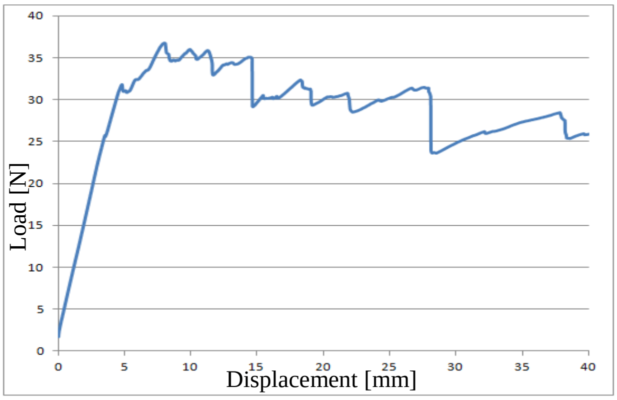

Fig. 4. Experimental P–d curves of the DCB specimens

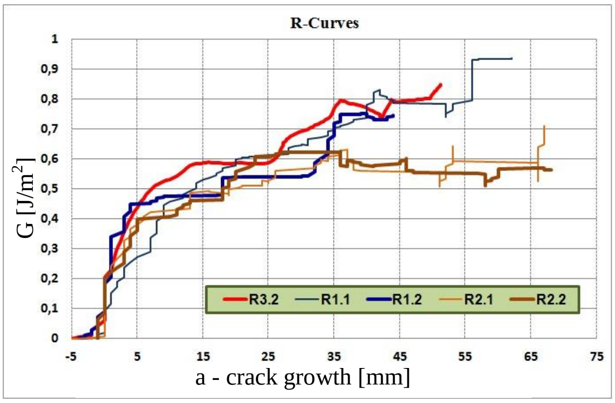

Fig. 5. Experimental R-curves obtained by interlaminar fracture tensile toughness

4. CONCLUSION

The mode I DCB test has been the most commonly used to characterise the delamination resistance of laminates.

This study was performed using the appropriate method of testing composite materials with unidirectional carbon fiber according to mode I of loading. The purpose was to determine the energy necessary to propagate the crack in function of the length of crack.

The measured interlaminar toughness characteristics of a material system will not only enable it to be ranked against competing material systems, but will also allow prediction of delamination growth in real structures, which will have a major role in both initial design and in assessing the significance of any delamination damage occurring during service.

5. ACKNOWLEDGEMENTS

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