EXPERIMENTAL STUDY OF THE INTERLAMINAR FRACTURE OF COMPOSITE MATERIALS IN MODE III

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Abstract

This paper focuses on the study of interlaminar fracture of composite materials in mode III using the Modified Split Cantilever Beam (MSCB) test. MSCB test is applied to investigate the dependency of the mode III energy release rate on specimen width and material type. For this purpose, three different specimen widths (12, 20, and 35mm) and three different materials (carbon fabrics, glass fabrics, and unidirectional glass) are tested. A delamination is introduced at the mid-plane of the tested specimens. All specimens have the same average thickness of 6mm. The length and the initial crack length of the specimens are 154mm and 90mm respectively. The corresponding load configuration is applied in order to get a pure mode III effect on the crack tip. Experimental results show that the energy release rate (G_{IIIc}) is accurately determined for the 12mm specimen's width. A similar behavior for the different materials is observed. The propagation of the crack is smooth and repetitive. A maximum load of 1100N and 710N is obtained for glass and carbon specimens respectively. Specimen with 20 and 35mm width show local or total damage of the specimen before any mode III crack propagation.

1. Introduction

Composite materials are used to design and fabricate structures with high mechanical performance and low weight (vehicles and in primary aircraft structural components). The use of composites has many advantages especially when it comes to improving strength to weight ratio. However, failure in composite may occur especially under impact due to fiber failure but mainly due to delamination and crack propagation.
Studies concerning the delamination of laminated composite materials have been covered by many authors such as Martin [2], and Lee [5] over the last thirty years. But even though standard tests for mode I, mode II and mixed mode I-II were well established and verified. Contrariwise, mode III interlaminar fracture is still ambiguous and there isn't so far a generally approved method to calculate the critical energy release rate G_{IIIc}.

Different researchers (e.g. Donaldson [10]) proposed the Split Cantilever Beam test (SCB) to study the behavior of composite materials in mode III delamination, while Lee [5] developed the Edge Crack Torsion test (ECT). The ECT test is considered to be a very important contribution to the mode III fracture developments. The effect of friction in the ECT test was proven to be insignificant but a dependence on the crack length, which means deviation of the load displacement curves from linearity and sometimes damage of the specimen before delamination. The type of specimen used in SCB test is very similar for testing modes I and II. Studies showed that the bending moment from the loading P

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generates a substantial Mode II strain energy release rate near the free edges, and thus the simple SCB test cannot be used to determine G_{IIIC} as proposed.

The aim of this study is to conduct experiments for mode III delamination based on the MSCB test developed by Martin et al [2]. The MSCB is a modification of the original Mode III SCB test. The bending moment at the delamination front is minimized by imposing two loads on each arm of the SCB specimen such the net moment at the delamination front is zero (Fig. 1). In the MSCB the maximum mode II strain energy was reduced by eliminating the bending moment leading to a higher mode III outcome. Szekrényes [3, 6, 7, 11] showed that the mode II effect faced in this case is in the margin of 2%.
In this study experiments are applied for 3 different materials and for 3 different specimens widths. The variation in the specimens' width will allow studying the influence of this dimensional property with the energy release rate, and identifying the proper width that gives the most accurate results.

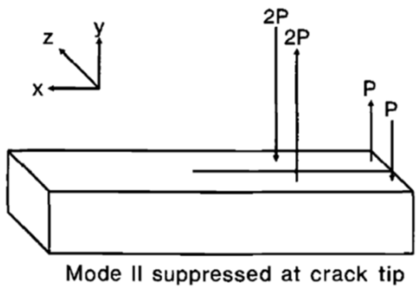

Figure 1. The Modified Split Cantilever Beam: Loading Configuration [3].

The mode III energy release rate is computed using the Irwis-Kies expression [6]. The equation used is developed by combining the effect of different theories: Euler-Bernoulli beam theory, Timoshenko beam theory, the free torsion effect and Saint Venant effect (Eq. 1). The definitions of all the coefficients and functions used in (Eq. 1) are well explained in [6].

$$G_{MSCB} = \frac{12P^2a^2}{b^4hE_{11}}\left[f_{EB2} + f_{TIM2} + f_{FT2} + f_{S-V2} \right] \tag{1}$$

2. Experimentation

Three different types of composite materials are tested: Unidirectional fiberglass (glass UD), glass fabrics and carbon fabrics. The material properties provided by the supplier are verified via experimental testing and identified using the ASTM standards D3039M-14 and D7264M-07. Material properties are presented in (Table 1):

Table 1. Properties of the three materials.

Specimen Type	E_{11} (GPa)	E_{22} (GPa)	G_{12} (GPa)	v_{12}
Glass UD	44.5	9	4.5	0.2
Glass Fabrics	43	9	5.5	0.27
Carbon Fabrics	140	10	7	0.3

The fiber orientation adapted for all the layers of the specimens is of 0 degree. In order to induce delamination in the specimens, an initial crack of 90mm is introduced in the structure during fabrication via a non-perforated release film. The same procedure is applied on all specimens. All the specimens are fabricated using prepreg in an Autoclave with vacuum bag and application of 5 bars

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pressure inside the autoclave.The only difference among the MSCB specimens lies in the number of plies. The thickness of the glass UD specimens is 5.98mm (26 layers x 0.23mm). The thickness of the glass fabric specimens is 6.24mm (24 layers x 0.26mm). And finally the thickness of the carbon fabric specimens is 6.3mm (18 layers x 0.35mm). The length of all the specimens is 154 mm.

In order to perform the MSCB test, the corresponding fixture is designed and fabricated to be coupled with the Universal Testing Machine (UTM). (Fig. 2) shows a typical test configuration with a specimen and the fixture mounted between the grips of the UTM.

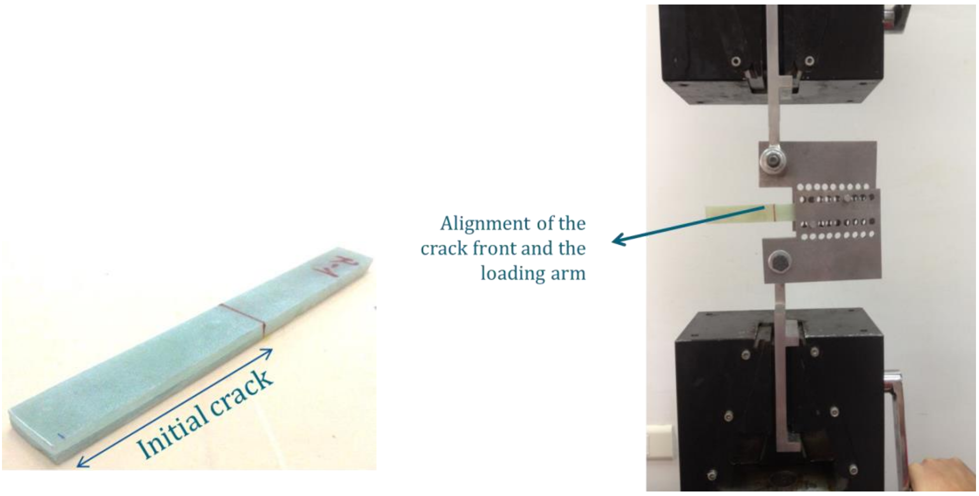

Figure 2. Specimen - MSCB Fixture.

As shown in (Fig. 2), specimens are placed between the two loading plates. A condition should be respected to maintain the equilibrium of moments created by the applied forces (Fig. 3) [6].

$$1.02 \leq \frac{a}{(s_1+s_2)} \leq 1.09 \quad (2)$$

Where, a = the crack length between the delamination front and the first pin at A
s_1 = the distances between the loading pins A/B
s_2 = the distances between the loading pins B/C

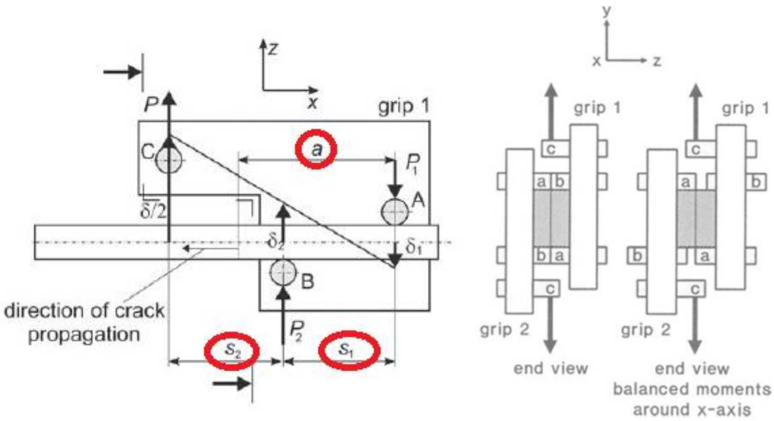

Figure 3. Illustration of the MSCB Specimen [6].

In the present study, the ratio in (Eq. 2) is 1.04 with the selected parametric values: a=80mm, s_1=39.1mm, and s_2=37.4mm.
Applying tensile load using the UTM causes the loading plates to act opposite to each other leading to the tearing of the specimens that are tightly fixed by the pins' surfaces and the plates. The shearing of

the two sides of the specimens that are separated by the release film layers is clearly seen and identified. The instant at which the crack further propagates is easily detected by a drop in the force-displacement graph (Fig. 4) and heard during experimentation due to the propagation of the delamination through the specimen itself. The final crack after propagation could be observed easily since the initial crack length is marked on the specimen. The experimental data provided with the maximum load are used to compute the critical energy release rate.

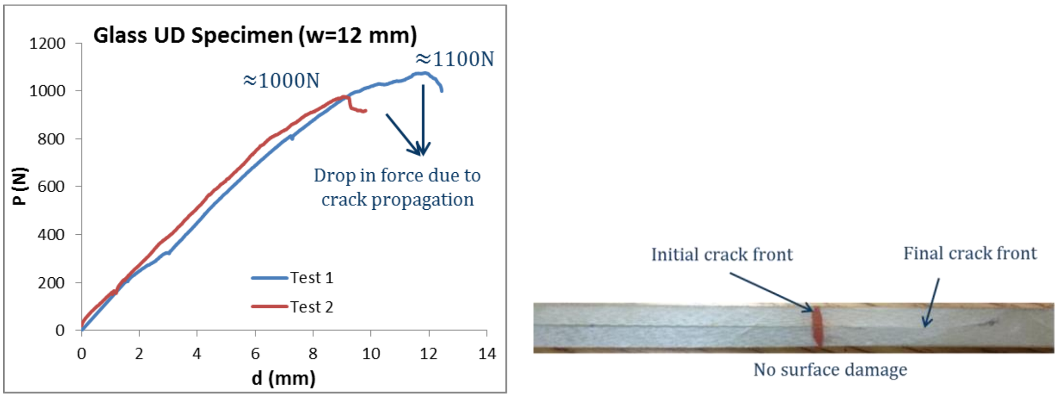

Figure 4. Load versus displacement (12mm width) for UD fiber glass-Crack propagation.

3. Results and discussion

(Fig. 5) shows a plotting of the loading versus the displacement for the three different materials with the same width of 12mm. A similar behavior could be noticed with almost the same slope, but with a lower P_{max} (maximum load) for the carbon fabrics. All the tests conducted with a 12mm width for the 3 different materials were repetitive leading to a of slope of 115N/mm. The maximum load for the glass UD and fabrics is 1075N and 1110N respectively. The maximum load for the carbon fabrics is 750N. Crack propagation occurred smoothly without damaging the surface of the specimen in contact with the loading pins.

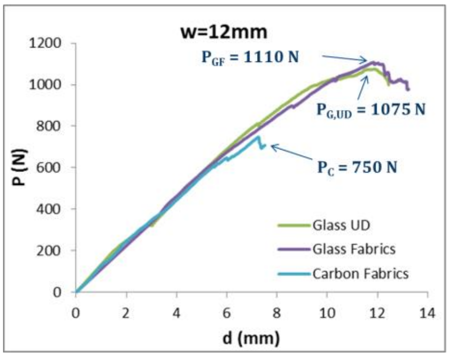

Figure 5. Load versus displacement (12mm width) for 3 different materials.

For the specimens with a width of 20mm, 2 different sets of results are obtained. Some specimens are subjected to local failure of the surface under the pins before any crack propagation could take place. In the case of an effective crack propagation a local surface damage is seen under the loading pins creating some discontinuities in the load displacement curve. A slope of 238N/mm and a maximum load of 1950N are obtained in the case of glass fabrics specimens (Fig. 6). Same behavior is obtained for all tested materials.

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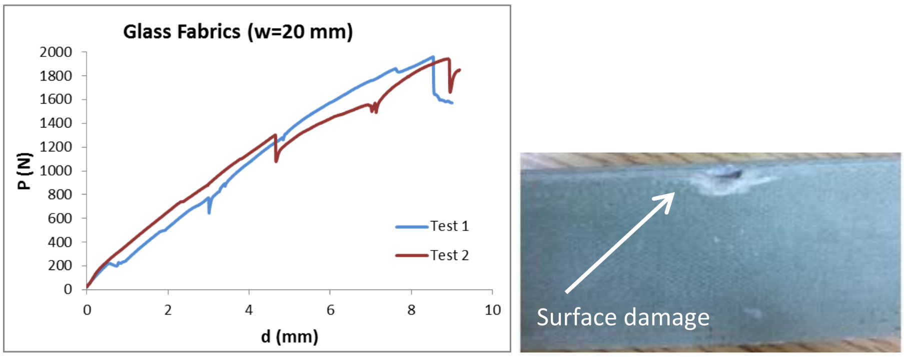

Figure 6. Load versus displacement (20mm width) for glass fabrics-surface damage.

In (Fig. 7) results of the carbon fabrics specimens are plotted for the width of 35mm. No crack propagation is obtained in this case for the 3 types of materials. An significant surface damage and penetration under the pins are observed. The load at the crack tip isn't enough to cause crack propagation before specimen failure. This behavior is observed for all tested materials.

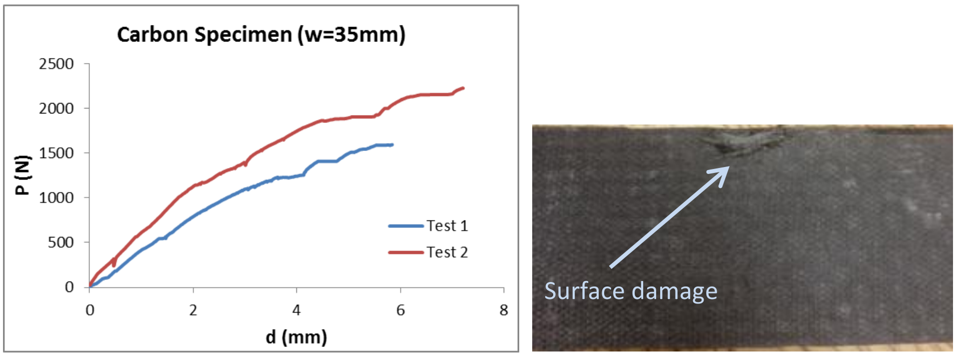

Figure 7. Load versus displacement (35mm width) for carbon fabrics-surface damage.

As mentioned in (Eq. 1) the critical energy release rate is calculated taking into consideration bending, shearing, Saint-Venant effect, and twisting of the specimen arms. Calculation of G_{IIIc} requires the knowledge of the material properties, the dimensions of the specimens and the maximum load before the crack propagation. (Fig. 8) shows the G_{IIIc} computed for the 3 materials with 2 widths (12 and 20mm). We notice a good correlation between 12 and 20mm width for the glass UD and fabrics and a significant variation for the carbon fabrics. The obtained results are in accordance with the values observed in the literature [5,6] and [8]. The difference obtained between the 12 and 20mm width are highly affected by the test parameters and conditions.

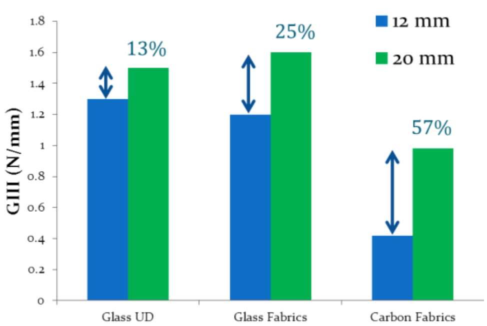

Figure 8. Mode III Critical Energy Release Rate (G_{IIIc}).

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3. Conclusions

It is clear that the energy release rate does not depend on the fibers type as much as it depends on the matrix. The maximum value is obtained for the glass fibers (UD and glass fabrics) comparing with carbon fabrics specimens. This could be explained by the higher content of resin in the glass specimens wich leads to a higher percentage in the matrix and comsequently to a higher resistance to crack propagation.
Accurate results are obtained for the 12mm width specimens for the 3 types of materials and for a thickness range between 5.98mm and 6.3mm. As the width increases, the surface damage of the specimens becomes significant and the forces needed for crack propagation become higher leading to an important twist which in turn increases the impurity of the mode of delamination.
Studies dealing with this kind of composites failure are still being conducted, they aim to reproduce a pure mode III case experimentally, and to obtain accurate energy release rate values aiming to adopt a standard test for mode III delamination. For this reason, other experiments are planned in the near future to extend the study, to enrich, and improve the obtained results. To reduce the effect of the twisting moment, the thickness of the specimen can be reduced to less than 6 mm. The tested specimens are made of only 0 degrees plies, some other stacking sequences can be realized in order to minimize the effect of the surface damage. Parametric studies (thicknesses, initial crack length, Interface orientation, etc..) can be also done in the aim of selecting the proper dimensions and conditions for the MSCB test.

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