EXPERIMENTAL COMPARISON BETWEEN THE TRANSVERSE FRACTURE TOUGHNESS OF A UNIDIRECTIONAL LAMINATE CORRESPONDING TO EITHER LONGITUDINAL OR TRANSVERSE CRACK GROWTH.

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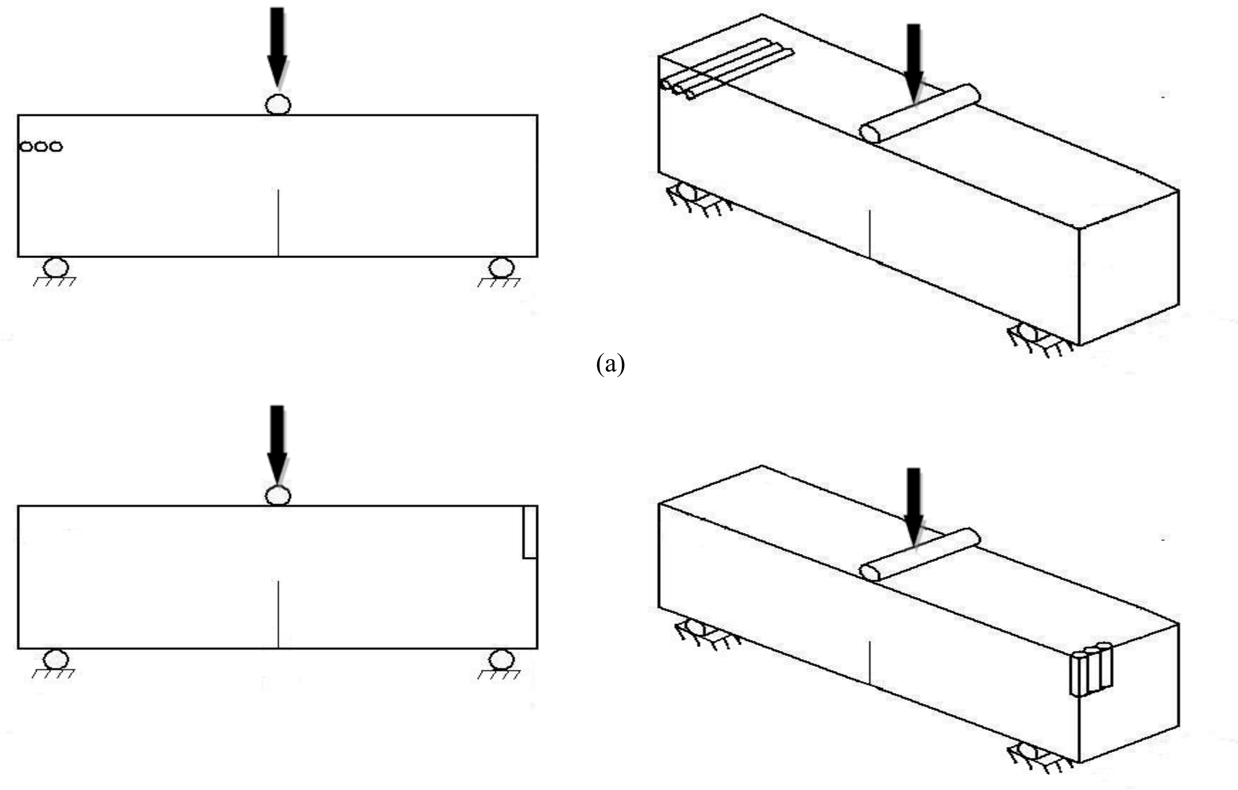
Abstract.
A test is developed to compare the transverse fracture toughness of a crack growing along the longitudinal and transverse directions of long-fiber-reinforced laminates. The test proposed is based on a three point bending (TPB) test. The starter crack will be generated inserting a non-adhesive nylon film prior to the curing process. Once the specimens are cured, this pre-crack will grow by a first static loading. Two different test specimens will be fabricated with the same dimensions and two different fibre orientations. In the first specimen configuration the fibres are orientated parallel the direction of crack growth whereas in the second one the fibres are perpendicular to the direction of crack growth. The comparison of the results for both specimens will enable to evaluate the influence of the direction of crack propagation on the transverse fracture toughness.

1. Introduction

The transverse fracture toughness of unidirectional laminates has received a considerable attention in the composite community given its influence on the failure mechanisms associated to off-axis loading. In general, the term transverse fracture toughness refers to the value measured for a crack propagating parallel to the fibre direction, denoted here as G_{1cl}. In fact, this is the only value which can be obtained employing the available standards, see e.g. ISO 15024 [1]. The absence of procedures to measure the value for a crack growing perpendicular to the fibre direction G_{1ct} is caused by the lack of experimental results in the literature. In practical applications, a large part of the engineering community assumes that both values of transverse fracture toughness, G_{1cl} and G_{1ct}, are identical in spite of the lack of experimental evidences justifying it.

The differences between the values of fracture toughness corresponding to different directions of crack growth could affect significantly the prediction of the overall performance of the structural components. Therefore, it is important to evaluate experimentally the adequacy of the hypothesis that assumes that these two values are identical. In order to carry out the pertinent comparison, two types of specimens, having the same dimensions, will be fabricated. The only difference between these two specimens will be the fibre orientation. These specimens will be based on the classic three point bending beam (TPB) specimens, see Figure 1. A pre-crack will be generated by the insertion of a demolding nylon film before the curing process.



(a)

(b)

Figure 1. Three point bending beam (TPB) specimens proposed to measure the transverse fracture toughness of a crack growing either (a) perpendicular or (b) parallel to the fibre direction, G_{1ct} and G_{1cl}, respectively.

The present work proposes an experimental study aimed at giving information about the similarity of G_{1ct} and G_{1cl}. Details regarding specimen fabrication and pre-insertion of the demolding nylon film will be described in the next section. Subsequently, the testing procedure is detailed in Section 3. Finally, Section 4 discusses the techniques which will be employed to obtain the values of the properties through the postprocessing of the experimental results.

2. Specimens fabrication

The test specimens are fabricated from AS4-8852 unidirectional fibre carbon/epoxy tape pre-preg, manufactured by Hexcel. Two laminates are fabricated, one of them with dimensions 150 mm x 150 mm, composed by 100 plies and the other one with dimensions 30 mm x 1200 mm with 53 plies. After the stacking process, the demolding film is inserted and subsequently the laminates are cured employing the autoclave curing cycle recommended by the manufacturer. Finally, the specimens are cut up from the laminates employing a diamond saw blade.

The TPB specimens is 100 mm long (the distance between supports will be 80 mm), with a thickness of 10 mm and height of 19 mm. The ratio between these dimensions is in accordance with the recommendations found in the literature, e.g. [2]. Considering these ratios as fixed, the size of the specimen is chosen by taking into account the limitations given by the stacking process and the requirements for a satisfactory curing process.

In the case of the laminate that is used to measure G_{1cl}, 53 layers are stacked. The future specimens with 100 mm length are situated next to each other in the laminate along the longitudinal direction in the laminate, and are cut up after the curing process. A cut of at least 8 mm depth is made in the middle of each future specimen before the curing process in order to insert the demolding film.

In the case of the laminate that is used to measure G_{1ct}, a single cut has to be made since the future specimens are situated next to each other along the thickness direction. The cut is at least 8 mm deep in the middle of one of the faces of the laminate.

In both cases, the demolding film is inserted, with its distance to the edge fixed by an adhesive film. Since no fibres are broken in the cutting process, a possible small excess in the depth of cut is not relevant since the resin fill possible discontinuities during the curing process.

Once both laminates are cured, the irregular edges are cut with a diamond saw blade. Employing the same tool, the laminates are cut up to get the dimensions described previously.

3. Testing procedure

Once the specimens has been cut up, the symmetric situation of the crack tip in both edges of the specimen is verified in order to assure the correct alignment of the demolding film. For this purpose, an optical microscope is employed. Subsequently, the edges are whitened in order to enable the measurement of the advance of the crack tip.

The tests are performed by employing a TPB fixture especially designed for this type of tests. The distance between supports is fixed to 80 mm. The crack is situated at the same distance of the two supports, and aligned in the direction of the applied load. This alignment is verified carefully since this is a key factor for the accuracy of measurements. The TPB fixture is attached to a universal testing machine.

An initial monotonic loading is applied in order to generate a sharp crack by growing the initial pre-crack produced by the insertion of the demolding film. The specimen is unloaded when the crack reaches a length of 9 mm. Subsequently, the symmetry of the crack is verified again by measuring the crack length at the two opposed edges.

A second monotonic loading is applied until reaching the total failure of the specimen. The load and displacements are recorded along with the crack length. These results are employed to estimate the values of the transverse fracture toughness.

4. Estimation of the transverse fracture toughness from the experimental results

The estimation of the transverse fracture toughness with longitudinal growth (G_{1cl}) and transverse growth (G_{1ct}) is based on two different methods: the first method is based on the variation of the compliance, whereas in the second one the area under the load-displacement curve is computed.

The first method is based on the change of the compliance (C) with the crack length. Under a displacement-controlled test, the value of the transverse fracture toughness can be obtained as,

$$G_{1c} = \frac{1}{2} \cdot \frac{U^2}{C^2} \cdot \frac{\partial C}{\partial A} \quad (1)$$

where U is the displacement corresponding to a certain crack length a, A is the crack area and $C(a)=U/F$ is the compliance, with F being the applied load. Typically, the compliance is considered as a function of the crack length a. The compliance values are obtained from the measured values of displacement U and load F. These compliance values are fitted by a quadratic function

$$C(a) = C_0 + C_1 \cdot \left(\frac{a}{w}\right) + C_2 \cdot \left(\frac{a}{w}\right)^2 \quad (2)$$

where w is a reference length of the specimen, e.g. the final length of the crack at the end of the test. C_0, C_1 and C_2 are coefficients to be fitted to the experimental results.

The second method is based on computing the area below the load-displacement curve between fictitious unloading processes from the points corresponding to certain values of the crack length. The area obtained can be identified with the energy dissipated during the increment of crack area between the two consecutive points. Thus, the transverse fracture toughness can be obtained by dividing this area on the load-displacement curve by the increment of crack area.

Finally, the results obtained for the two transverse fracture toughnesses, G_{1cl} and G_{1ct}, will be compared. In addition, these results will be contrasted with the results obtained for a test carried out on the same material according to the ISO 15024 standard [1].

5. Conclusions

A test is proposed to compare the transverse fracture toughness of a long-fibre-reinforced composite for the crack growing either longitudinally or transversely to the fibre direction. The main advantage of this test is the ability to measure these two properties by employing the same test specimen and procedure. This enables a comparison between the two types of propagation avoiding the possible influence of the test type on the comparison results. The specimen fabrication and testing along with the results postprocessing are briefly discussed.

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