DCB Interlaminar Fracture Toughness of Glass Fiber/ Modified Epoxy Nano Composite Laminates

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Abstract---Delamination crack growth in laminated composites is investigated using experiments and modified beam theory. Tests were performed on cross-ply E-glass/nano modified epoxy specimens under the static conditions. The load–displacement response is monitored in the tested coupons along with crack length. Crack growth and strain measurements were compared with those from the modified beam theory. The matrix of the nanocomposites were obtained by adding 2%, 4%, 6%, 8%,10% of nanoclays in weight into epoxy matrix.

Keywords: Mode 1 interlaminar Fracture Toughness, MBT, Nano clay, woven fabric, Double Cantilever Beam.

I. INTRODUCTION

Glass fiber-reinforced composites (GFRPs) are a typical of advanced engineering materials that exhibit high strength-weight and modulus-weight ratios and are widely used in the aerospace, military, sporting goods and automobile industries. Epoxy resins are a very attractive class of polymer for their high strength and stiffness, high temperature resistance and thermal stability, low creep, good adhesion, and excellent process ability and chemical resistance.

Nanoclays have been considered a very attractive reinforcement in epoxy systems. Montmorillonite clay has a layered structure in which individual layers of typically 1 nm in thickness and 0.1–2 micrometer in length and width has interlayer spacing of 2–3 nm. These layers are bonded together by Van der Waal's forces. In its natural state this clay exists as stacks of many platelets [1–3]. It has been widely reported that the dispersion state of nanoplatelets play a vital role in determining the mechanical and physical properties of the composite as well as fracture behaviour and toughening mechanisms.

Previous many studies [4–7] suggested that intercalation is key to improved fracture toughness, whereas complete exfoliation promotes strength and stiffness of the nanocomposites. A balance between an intercalated and exfoliated structure may be beneficial to simultaneously improve both the modulus and toughness without sacrificing strength in epoxy resin matrices [8].

Carbon nanotubes (CNT) have shown a high potential to improve the mechanical properties of polymers as well as electrical properties [9,10]. Gojny et al. [11] reported that DWCNT (double walled CNT) could increase both tensile strength and fracture toughness.

Florian et al. [12] studied the influence of different carbon nanotubes on the tensile properties as well as fracture toughness and explained the contribution of nano mechanical mechanisms to enhancement of the fracture toughness. However, CNT has not been widely used to improve the mechanical properties because of its high material cost. Since the first discovery by Toyota researchers on the reinforcing effect of relatively cheap nanoclay on the polymeric material [13], many researchers have focused on it: Weiping et al. [14] reported that nanoclay could increase the fracture toughness of epoxy by 2.2 and 5.8 times.

Lei et al. [15] studied the dependences of Young's modulus and fracture toughness on clay concentration using the tensile and 3-point bending methods. Qi et al. [16] investigated the effect of several nanoclay additives, which were mixed with DGEBA epoxy resin using a mechanical stirrer, on tensile modulus, tensile strength and fracture toughness of the nanocomposite.

Ho et al. [17] increased the tensile strength and Vickers hardness value of the epoxy using nanoclay mixed by mechanical stirring method. As mentioned above, most of researchers have been interested in the mechanical properties of nanocomposites at the room temperature. A study on the nanocomposite is important since it can affect the structural characteristics of a composite structure when it is used as a matrix of the laminates or the reinforcement of a foam core. It was reported that the characteristics of a composite structure could be improved when the nanoclay reinforced epoxy was used as a matrix of laminates.

The fracture toughness was measured using the double cantilever beam (DCB) specimen with respect to the particle content at the room (25 ºC). The double cantilever beam is the most widely used test configuration for measuring the mode I interlaminar fracture toughness. Extensive research has been conducted on the influence of such factors as specimen dimensions, temperature, moisture, and loading rate on the mode I delamination behaviour using double cantilever beam specimens.

II. MATERIALS

A DGEBA-based epoxy resin (Araldite LY 556) was used as matrix material in this study. Due to a very low viscosity and long average pot life at 25 ºC, it is especially suited for resin infusion techniques. In addition, an epoxy hardener (Araldite HY 951) has been used. The fraction of this component has been suggested by the manufacturer for the neat epoxy (10:1). The nano-modification was achieved by commercial nanoclay, namely I30P. They are surface modified lamellae of montmorillonite, 1 nm thick and with lateral dimensions from 70 to 150 nm have been used as reinforcement for neat and nanomodified epoxy laminates. Fiber material used is E-Glass fiber of 200 gsm. Six different compositions have been carried out as 2,4,6,8 and 10% of nanoclay in the epoxy matrix material.

Initially epoxy was weight measured and taken into 1000 ml double neck flask and heated to 50ºC. After reaching the 50ºC, stirring operation was carried out using mechanical stirrer and maintains the temp 65ºC. In the mean time nanoclay was dissolved in acetone and stirred well by glass rod. This mixture was poured into epoxy resin and continues the stirring up to 1hr with temp 65ºC.

To reach finer results, the obtained system was then homogenised with sonication. The sonication process is shown in Fig.1 was always operated at the maximum power amplitude of 200 W. Conversely, various duty cycles (25%, 50%, and 75%) were chosen, in order to investigate the effect of this parameter on the fracture toughness. The process was continued for about 40 min. Then, before moulding, an extensive degassing process was carried out in order to reduce the amount of trapped air and, to avoid the voids in the matrix.

A low-vacuum pump has been used to induce a very low pressure in the resin's pot and to promote bubbles explosion. After 30 min most of air was released providing a brownish mixture. At the end of the degassing process, the modified resin was devoid of any bubble and translucent is shown in Fig.2.

Fig. 1: Sonicator

Laminates were fabricated by using compression moulding. Moulds were cleaned by acetone and wax was applied on the mould surface. Before starting the laminating process fibres were cut into 27cm X 27cm. Then resin was applied as thin layer on the mould with the help of brush. After this one layer of fiber was placed over the resin layer and then another layer resin was applied over the glass fibre fabric. After reaching 7th layer a Teflon film 50µm thick has been used to create a pre-crack on the DCB specimens for a distance of 50 mm. Then this was repeated till the 14 layers were over. All the fabric layers were placed with their warp direction parallel to the longitudinal direction of the mould. Finally resin was applied on the fiber then the mould was closed and placed inside the compression moulding machine. A 1500 psi pressure and 80 ºC temperature maintained for 2 hours. Then the mould was removed from machine and demoulded. The resulting laminate thickness was about 3 mm. Geometry and sizes of specimens were those suggested by ASTMD 5528-01.

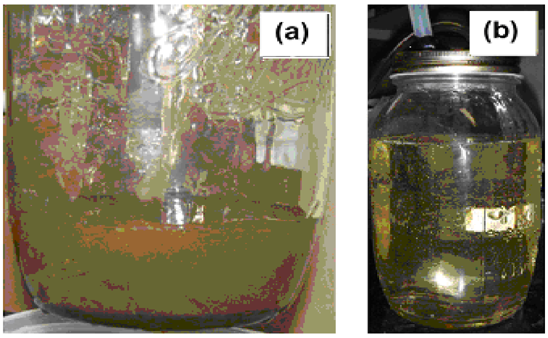

Fig. 2: .Nanomodified resin appearance; (a) after 30 min degassing; and (b) at the end of degassing process.

III. RESULT AND DISCUSSION

A. *Mode 1 Interlaminar Fracture Toughness Testing*

The preferred specimen type in most Mode I interlaminar fracture test is double cantilever beam (DCB), which consists of a rectangular uniform thickness unidirectional laminated composite specimen schematically shown in Fig3.

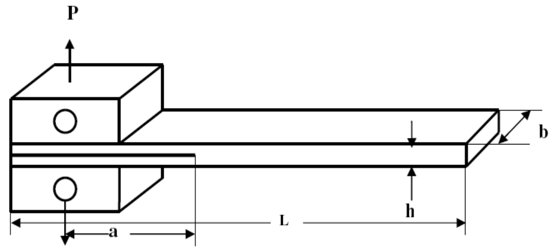

Fig. 3: Double cantilever beam specimen with load blocks used for Mode I testing

A non-adhesive teflon film was inserted in the mid-plane of the laminate during fabrication which acted as delamination initiator. The loading blocks were mounted on the top and bottom surfaces of the end of DCB specimen arms. The delaminated end of the DCB specimen was opened by quasi-static loading at a displacement control mode with a constant crosshead speed of 2 mm/min. Delamination lengths are determined visually during the test. For more accurate delamination length readings the use of a travelling microscope is recommended by ASTM.

B. *Interlaminar Fracture Toughness, G_{ic} Calculations*

The interlaminar fracture toughness calculation is based on beam theory (with corrections for load-blocks) as described by ASTM D5528 [18].There are various mathematical expressions used to calculate the strain energy release rate for delamination in fiber composites. These include simple beam theory, transverse shear deformation theory, modified beam theory with consideration of transverse shear deformation and crack tip singularity. All the expressions available it has been found that the modified beam theory gives more accurate results when compared with experimental results shown in the table 1.

$$G_{IC}=\frac{3P\delta}{2ba}$$

Where,
P – Load (N),
δ - Load point displacement (m),
b - Specimen width (m),
a - Delamination length (m)

Composite Laminates	Mode I G_{IC}(MBT) (J/m^2)
0%	750.35
2%	1219.51
4%	1150.10
6%	1100.00
8%	1080.00
10%	1020.00

Table 1: Result Summary

IV. CONCLUSION

The preliminary experimental results of this research aiming to assess the benefits deriving from the matrix nano modification of composite laminates made by compression moulding on mat glass fabrics have been presented. The experimental program was aimed at investigating the following properties: mode I fracture toughness and crack propagation resistance for neat and clay-modified epoxy. The 2% nano modified epoxy composite laminates shows significant improvements in the fracture toughness and crack propagation resistance.

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