The Mechanism of Crack Propagation in mid Plane Layer of Laminated Composites

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Abstract

The mechanism of cracks propagation were studied for laminated composites. Double-cantilever beam (DCB) specimens was used to analyze the mechanism and behavior of cracks propagation in the mid plane layer for 16 plies of woven roving mat glass fiber (M) /epoxy composites $[M]_{14}$ in which the mid layer was (M/M) and the mid layer in which was (R/R) and chopped strand mat or random glass fiber (R) / epoxy composites $[R]_{14}$ in which the mid plane layer was (M/M) and the mid layer in which was (R/R) .The effect of the arrangement of the reinforcing fibres and ply stacking sequence for [M7//R1/R1//M7] and [R7//M1/M1//R7] was investigated . The results shows that in random composites, fiber bridging and pull-out was seen as a result of high deformation , the same phenomenon was observed for [M7//R1/R1//M7] this was due to the random glass fiber layers which reflect the same behavior of $[R]_{16}$,these phenomenon does not happened in woven roving composites and [R7//M1/M1//R7] .

Keywords: crack propagation, mid plane layer, laminated

1-Introduction

In materials science, laminated composites are assemblies of layers of fibrous composite materials . They are being increasingly used in critical engineering structures due to their high specific stiffness and specific strength [1]. Studies were carried out and reported for DCB tests, Compston and Jar [2] investigates the effect of fiber lay-up and matrix toughness on mode I and mode II interlaminar fracture toughness (G_{Ic} and G_{IIc}) of marine composites. Unidirectional and woven roving fibers were used as reinforcements. Two vinyl ester resins with different toughness were used as matrices. Results from both modes showed toughness variation that is consistent with matrix toughness. The paper concludes that composites with woven roving fibers show similar mode- I delamination characteristics to the unidirectional composites; but their mode II delamination characteristics, after crack initiation, are quite different. Pereira et al. [3] study mode I interlaminar fracture of woven glass /Epoxy multidirectional laminates using DCB test, it shows that the limited amount of valid result obtained (θ=15 and 30 ^{o}) and most specimens suffer interplay damage and crack branching.

De Moura et al. [4] study the interlaminar and intralaminar of laminated composites under mode I loading , it shows that bridging phenomenon important in intralaminar test and interlaminar fracture take place in resin rich region at interfaces between laminates while in intralaminar it occur in matrix fiber interface. Gong [5] study mode I interlaminar fracture toughness of composite materials on double cantilever beam (DCB) specimens composed by quasi-homogeneous and uncoupled multidirectional (MD) laminates using 16 or 26-ply .The results shows that G_{IC} increases as the adjacent ply angles from 0 ^{o} to 45 ^{o} .

Keršienė [6] study the effect of ply orientation on mode I interlaminar fracture toughness of woven carbon and glass composites . The results shows that G_{Ic} values for mode I and mode II were obtained for glass/epoxy specimen types: G_{Ic} = 0.577 kJ/m^2 [0//0] and G_{Ic} = 0.591 kJ/m^2 [0//90].

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2-Experimental Part

2-1 Materials

E- glass type Chopped strand mat (CSM) supplied from (Moulding L.t.d. /UK) with surface density 300 g/m^2 and length between (1-5cm) and E-glass type woven roving mat (WRM) with density 450 g/m^2 and length (12 mm diameter and 120 mm length).

2-2 Epoxy resin preparation

Epoxy resin type (Quick mast 105) was provided by DCP Company / Jordan with density 1.04 g/cm^2 was used with its hardener in ratio (1:3), the epoxy mixed with hardener in a container then the mixture was used to prepare composites .

2-3 Preparation of DCB specimens

The most widely accepted specimen geometry for determining the mode -I strain energy release rate is the double cantilever beam (DCB).

A 16-plies of glass fiber /epoxy resin were used to prepare the DCB specimens with loading system of end block which was very simple and easy to attach to the beams of the specimen. An Aluminum foil with thickness of 0.02mm was inserted in the mid-plane denoted by (a) with an insert length of 50 mm during the lay-up process for creating the primary crack. A pair of metallic hinges were glued to the loading end of the specimens in order to enable the load to be applied .The dimension of specimen according to ASTM (5528-01) [7] . The ply stacking sequence $[M]_{16}$,$[R]_{16}$,$[R_7//M_1/M_1//R_7]$ and $[M_7//R_1/R_1//M_7]$.

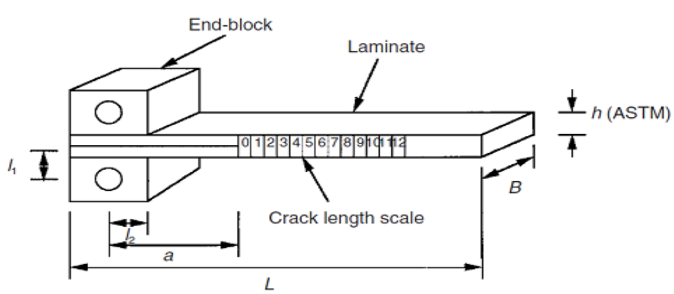

Figure (1) Specification of unloaded DCB specimen

During testing, the set up for DCB test was shown in figure (1), traveling microscope was used to observe the crack propagation.

The test was perform with Instron testing machine type (1122) ,with cross head speed of 0.5 mm/min.

3-Results and Discussion

3-1 Mechanism of crack propagation for Woven Roving mat Glass Fiber/ Epoxy Composites $[M]_{16}$

In this section, load -displacement curve for woven roving composites $[M]_{16}$ was investigated as shown in Figure (2). In each specimen three sectors were investigated. In any sector, the specimen was loaded and unloaded. When the specimen was loaded the crack extended for 10 mm and unloaded, in some cases, the crack propagate more than 10 mm in one sector, because of the fast crack propagation which was discussed later.

In sector 1 , the curve shows three regions ,the 1st region was linear region which occur before crack propagation , At linear region, the load was proportional to the small displacement, it mean that , All the load which applied on the arms would be converted to accumulated energy at the end of primary crack, so that when a available energy for crack growth is sufficient to overcome the resistance of material ,which include plastic work and surface energy . In the second region, the unstable crack propagation can be characterized by saw tooth shaped load profile, as seen in sector 1. Crack propagation generally proceeds in a discontinuous, or “stick-slip” manner .

The arm of the cantilever move up (the direction of load) , there are no bending occur along the arms as shown in Figure(3) ,the linear region followed by non linear region due to the failure mechanism supported by crack propagation and delamination , unstable crack propagation was observed in this section.

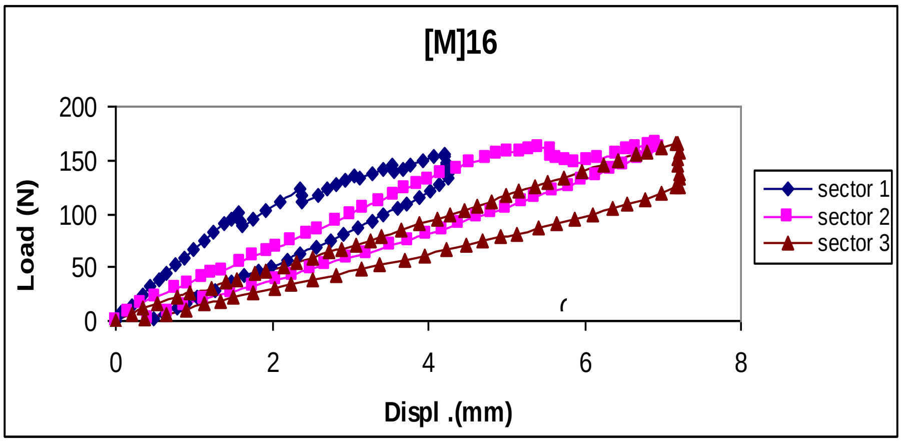

Figure (2) Load – Displacement curve in woven roving glass fiber /Epoxy composites

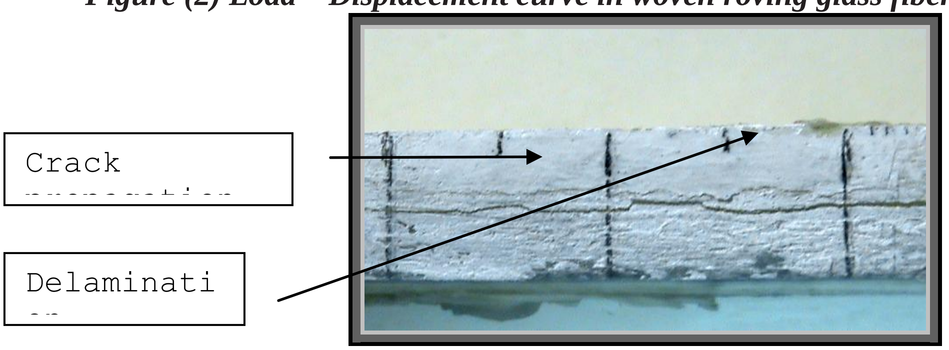

Figure (3) DCB test for woven roving glass fiber /Epoxy composites

In the 3rd region , during the unloading , linear behavior was observed until the load become zero ,this curve does not reach the starting point ,(i.e. original point for loading curve) , this means that there was a little deformation in the arm of specimens ,leading to little residual displacement .

In sector 2, slow crack propagation was observed, so that the crack propagate in the up and down layers, while fast crack propagation was observed in sector 3, in this case the crack propagated in mid – plane layer.

3-2 Mechanism of crack propagation in Random Glass Fiber / Epoxy Composites $[R]_{16}$

In Figure (4), the load- displacement behavior for random composites specimen under mode- I loading were represented by three sectors. The crack propagation and failure mechanism of the specimen were discussed based on the observation of fracture surface and side section using traveling microscope.

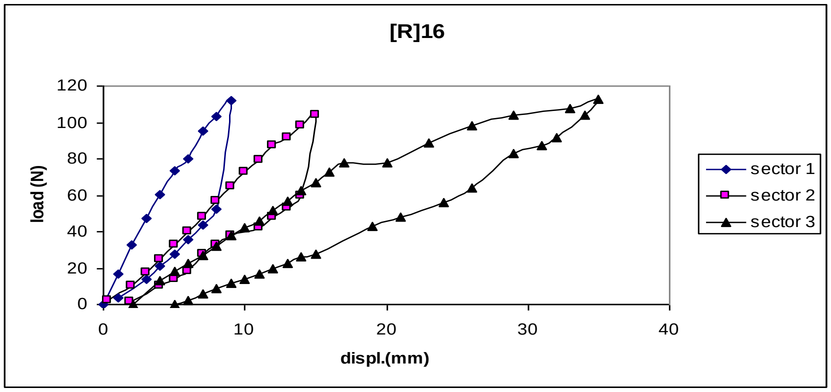

Figure (4) Load – Displacement curve in random glass fiber /Epoxy composites

In sector 1 , three regions were observed ,the first region was the linear region , in this region the load would increased with displacement , the slope for this region was represented by compliance ($C=\delta / P$) .

In the second region, the load was suddenly dropped, that mean that fast crack propagation was occurred due to the energy release during the test.

The third region represent the unloaded region, in this case the unloaded curve was not reach the starting point because of the high deformation in the arm of specimen, the interlocking between layers were very strong , so that the energy would accumulated and suddenly released ,the same behavior was observed for sector 2.

In sector 3, after linear region slow crack propagation was observed and move very slowly, this was lead to high deformation which occurred at the arm of the cantilever as a result of fiber bridging which was the main failure mode , it refer to the phenomena of unbroken fibers inkling and interconnecting the opposite fracture surface behind crack tip , which arises from the misalignment of the fibers across the crack plane and / or growth of crack in more than one plane ,as the load was increased, part of the energy was dissipated into the bridging zone.

The phenomena of fiber bridging occurs as the delamination progress along the length of the beam , and will increase the stiffness of specimen , the fiber bridging with delamination limited the crack propagation region as shown in Figure (5). Another failure mechanism was debonding which occur when the load was increased followed by pull -out behind the crack-tip, as shown in Figure (6) ,this phenomenon could be explained due to the random nature of this type of glass fiber which have spacing between their fibers (before hand lay –up process). During this process, the resin which cover the face of laminate would penetrated between the up and down layer and all the fibers were interlocked between these layers, this was because of the high adhesion and interlocking between the layers, so that the crack will be restricted forward and all the energy will convert to plastic deformation occur at the bending point of the arm leading to high deformation .

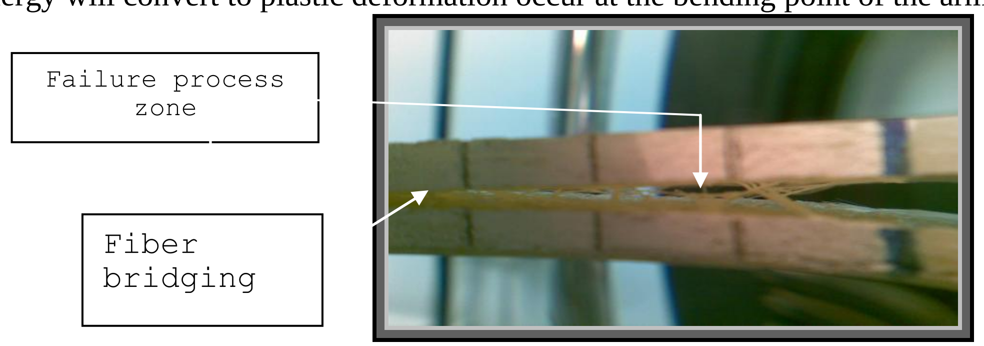

Figure (5) fiber bridging for random glass fiber /epoxy composites.

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Figure (6) broken fibers pulled out from the resin as an evidence of fiber bridging.

3-3 Mechanism of crack propagation in [M7//R1/R1//M7]

The stacking sequence refers to the orientation of the fibers in each ply which stack with another ply forming a laminates.

The sequence of the layers were designed as seven layers of mat (M) up and down of mid layer which were random (R) glass fiber types, in Figure (7) fast crack propagation was occur in sector 1, the same behavior was observed in sector 2, but the difference was in initiation value of load which was higher in sector 2 than in sector 1, this was because in sector 2 higher energy release rate was required for the crack to propagate.

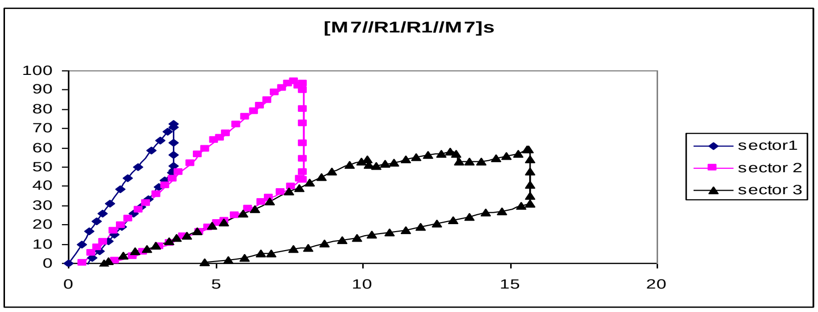

***Figure (7) Load –Displacement Curve* for [M7//R1/R1//M7]**

In sector 3, slow crack propagation would occur and the initiation value was less than in sector 1and 2, because most of the energy released in interlayer regions and as a residual displacement which was higher in sector 3 .The behavior of crack propagation in this specimen was similar to $[R]_{16,}$ this was because the mid layer which was (R1/R1) play an important role in crack propagation. The initiation value (the point at which non linear behavior will start i.e. the crack propagation region) of load for $[R]_{16}$ was higher than [M7//R1/R1//M7] because most of the released energy will transfer into plastic deformation and fiber bridging leading to high deformation in the arm of specimen during sector 3 test .

3-4 Mechanism of crack propagation in [R7//M1/M1//R7]

In Figure (8), the sequences of layers were design as seven layers of random glass fiber for the above and below layers of mid plane layers which were two layers of mat.

In this specimen slow crack propagation were observed in sector 1, 2 and three, this behavior was similar to the behavior of $[M]_{16}$, but the initiation value of load for this specimen was higher than $[M]_{16}$, this was because the random glass fiber layers required higher value of load .

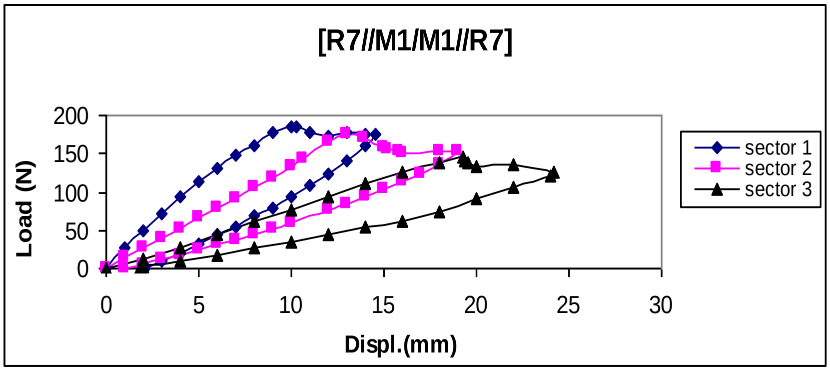

Figure (8) Load –Displacement Curve for [R7//M1/M1//R7]

4-Conclusions

It was found that fiber bridging was one of the failure mechanism associated with specimen in whom the mid layer was consist of random glass fiber plies.

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