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Interlaminar Fracture of Micro and Nano Composites

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The goal is to study the effect of the SiO_2 micro and nano – particles addition on the strength of epoxy composite based on glass fibers using (2, 4, 6 and 8) wt% of SiO_2, the interlaminar fracture toughness (G_{IC}) of 16-plies $[M]_{16}$ of woven roving glass fiber /epoxy composites prepared by hand lay – up technique were investigated, using DCB test (mode I). The results computed using area method shows that the Interlaminar fracture toughness was increase with the filler content, higher values of G_{IC} were observed for nano SiO_2 composites as compared to microcomposites, because nano SiO_2 behave as a barrier for crack propagation and the large surface density of these nanoparticles take a position in the polymeric chain restricting the movement for these chains leading to higher values of G_{IC} in comparison with micro SiO_2. The lower value of G_{IC} found in 6 and 8 wt% is lower because, of the agglomeration of nano particles. This reflects the behavior of laminated nanocomposites into the same as microcomposites.

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1. Introduction

In materials science, laminated composites are assemblies of layers of fibrous composite materials. They are being used in critical engineering structures due to their high specific stiffness and specific strength [1]. The interlaminar fracture or delamination is associated with the failure of the weakest components of the composite material, i.e. the matrix and the fiber matrix interface. It was found that the popular approach for characterizing this parameter is through the application of the linear elastic fracture mechanics (LEFM), which enables the critical strain energy release rate of fracture energy, G_{IC} to be determined, one of the most popular specimen geometries for interlaminar crack growth tests is in the mode – I, double cantilever beam (DCB) test [2]. Gong et al. [3] studied mode I interlaminar fracture toughness of composite materials using double cantilever beam, specimens composed by quasi-homogeneous and uncoupled multidirectional (MD) laminates using 16 or 26-ply. The results show that G_{IC} increases as the adjacent ply angles from 0° to 45°. Lauk and Fu [4] investigated the polymer composites filled with hard inorganic particles of nano to micro scaled sizes. The result shows a very complex variation of fracture toughness with increasing particle fraction. It was shown that their influencing extent depends on critical values of composite strain or stress, respectively.

2. Theoretical part

2.1. Area method

From the load–displacement curve and crack length measurements, the calculation of mode I interlaminar fracture toughness (G_{IC}) used in this study is based on the area method [5] (see Fig. 1), where ΔA_{ij} is the area under load–displacement curve between crack lengths aj and ai, and w is the specimen width. The DCB specimen is loaded linearly to P_1 where the crack begins to extend. During crack extension from a_1 to a_2, the load drops to P_2. If the specimen is then unloaded, the loss in strain energy due to crack extension is simply the area, ΔA_{12}, between the loading and unloading curves.

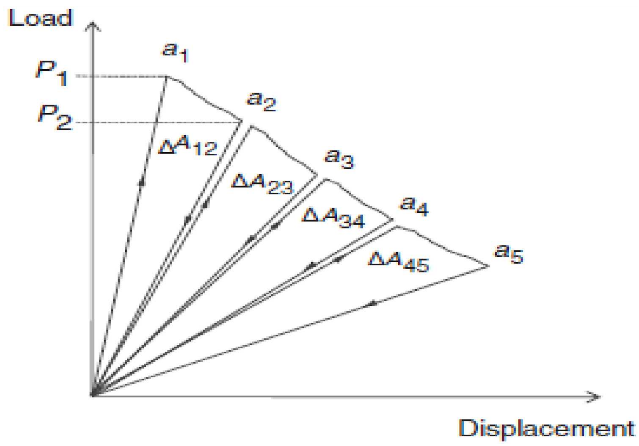

Fig. 1. Area method. $G_{IC} = \frac{\Delta A_{ij}}{w(a_j - a_i)}$ $\left[\frac{\mathrm{J}}{\mathrm{m}^2}\right]$.

3. Experimental part

Epoxy resin type Quick mast 105 was provided by DCP Company/Jordan with density 1.04 g/cm^2 used with its hardener in ratio (1:3), the epoxy mixed with hardener in a container then the mixture was used to prepare composites. E-glass type woven roving mat (WRM) with density 450 g/m^2 and length (12 mm diameter and 120 mm length)., micro SiO_2 particles have a density 2.1 g/cm^2, particle size 100 μm and nano SiO_2 particles have a density 0.05 g/cm^2, particle size 12 nm with surface area 200$\pm$25 m^2/g with different weight percentages

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(2, 4, 6, and 8). A mixture of epoxy resin with SiO_2 microparticles were mixed in a clean container using magnetic stirrer, hardener was added to the mixture of epoxy resin and micro silica particles to prepare microcomposites, a thin layer of mixture was spread on glass plate mold using a brush, one sheet of glass fiber was stuck on glass plate, then immersed in the mixture, a rolling brush was used to remove the entrapped air bubbles from specimen. The above stage was repeated until 16-plies were reached; the specimens were left in room temperature for 24 hours for curing, they were casted in an oven for 1 h at 50 °C. The same procedures were repeated for nanocomposites but by using ultrasonic method. To prepare nanocomposites, the mixing process involved. Mixing of nano SiO_2 particles with the epoxy resin by sonication method, using same weight ratios, hardener was added to the mixture. The above stages were repeated until 16-plies were reached for DCB.

3.1. Preparation of DCB specimens

Mode I energy release rate for double cantilever beam (DCB) is G_{IC}. An aluminum foil with thickness of 0.02 mm was inserted in the mid-plane denoted by (a) with an insert length of 50 mm, as in Fig. 2. During the lay-up process for creating the pre-crack. A pair of metallic hinges was glued to the loading end of the specimens in order to enable the load to be applied. Dimension of specimen according to ASTM (5528-01) was 250 mm long, 20 mm wide and 10 mm in thickness, the scale of crack length scale was 10 mm [6].

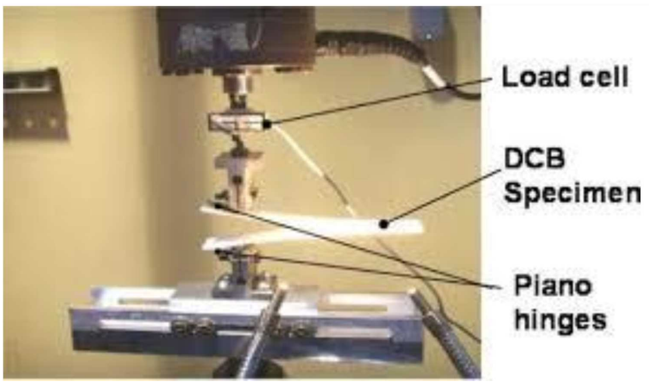

Fig. 2. Loading of DCB specimens.

4. Results and discussion

From load–displacement curves of epoxy composites (Fig. 3), data reduction methods such as area method was used to calculate the average values of interlaminar fracture toughness (G_{IC}). It was shown that the toughness of glass fiber/epoxy laminates were affected by the addition of micro SiO_2 particles with different weight percent ratio (2, 4, 6, and 8 wt%). A study were reported significant improvements in average G_{IC} 1312 J/m^2 higher than for woven roving composites 548 J/m^2 as shown in Table I. It was observed that average G_{IC} was increasing with the increasing of weight ratio, because the micro silica have interparticle distance in micro scale, so that it fill the space between the intersection points of warp and weft yarns, which behave as inhibitor to crack propagation, this acts as a crack-speed decreasing mechanism which can absorb significant amounts of fracture energy [7].

TABLE I

Average G_{IC} values [J/m^2] using area method.

SiO_2	Microcomposites	Nanocomposites
no additives	548	548
2 wt%	1312	1907
4 wt%	1492	1704
6 wt%	2433	1167
8 wt%	1805	1516

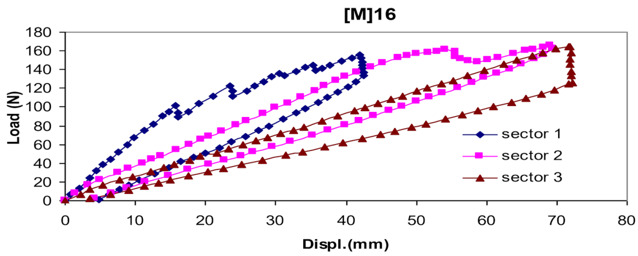

Fig. 3. Load–displacement curve in woven roving glass fiber/epoxy composites.

Higher average G_{IC} value was found for 6 wt%, because of the good interlocking between the particles, matrix and fibers and because the toughening of composites produced by incorporation of micro SiO_2 particles which become pinned and tend to bow out between the particles forming secondary cracks. For silica nanoparticles, it was shown that average G_{IC} value for nanocomposites was 1907 J/m^2 for 2 wt%, which was higher than for woven roving composites 548 J/m^2, and the G_{IC} values for nanocomposites were higher than microcomposites, because load was increasing with the increasing weight percent, this give good indication that these composites have resistance to crack propagation. In 6 wt% nanocomposites, the load was decreased, this was because of the agglomeration of nano SiO_2 which act as a weakness points in the composites. In 8 wt% nanocomposites, load was increased but the displacement was decreased, this means that when the filler ratio was increased the nanoparticle act as barrier for crack propagation and because nano silica particles take places in the polymeric chain restricting the movement of chain, this act on the crack propagation distance, Table I. The explanation of the higher average G_{IC} with the increasing in filler content was because of the toughening mechanism with filler particles act as crack blunting. [8].

5. Conclusions

The addition of micro and nanosilica particles to woven roving composites has an effect on the value of G_{IC}, the interlaminar fracture toughness G_{IC} for nanocomposites was higher than that for microcomposites.

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