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-ply [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 $\Delta A_{ij}$ is the area under load–displacement curve between crack lengths $a_j$ and $a_i$, 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, $\Delta A_{12}$, between the loading and unloading curves.

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±25 m$^2$/g with different weight percentages

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(2, 4, 6, and 8). A mixture of epoxy resin with SiO$_2$ micro particles 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.](image)

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>
<thead>
<tr>
<th>SiO$_2$</th>
<th>Microcomposites</th>
<th>Nanocomposites</th>
</tr>
</thead>
<tbody>
<tr>
<td>no additives</td>
<td>548</td>
<td>548</td>
</tr>
<tr>
<td>2 wt%</td>
<td>1312</td>
<td>1907</td>
</tr>
<tr>
<td>4 wt%</td>
<td>1492</td>
<td>1704</td>
</tr>
<tr>
<td>6 wt%</td>
<td>2433</td>
<td>1167</td>
</tr>
<tr>
<td>8 wt%</td>
<td>1805</td>
<td>1516</td>
</tr>
</tbody>
</table>

![Fig. 3. Load–displacement curve in woven roving glass fiber/epoxy composites.](image)
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.

References