Abstract

Objectives: The core objective of this characterization study is to clarify the effect of reniforement and the geometry of the reinforcement on the mechanical behavior of the vinyl-ester polymer composites. Methods: In this study, Polymer Matrix Composites (PMC) reinforced with both solid glass fiber (E glass) and hollow glass fiber (H glass) is prepared using traditional hand layup technique. Mechanical characterizations are carried out to find the effect of reinforcement on the tensile, compressive, flexural strength and impact resistance of the composites using Universal Testing Machine (UTM) and Charpy Impact. Findings: The characterization study on the mechanical behavior revealed that the hollowness of the fibre reinforcement significantly increased the strength and impact energy absorption capacity of the Hollow glass (H glass) fiber reinforced vinyl ester composites when compared to solid glass (E glass) fiber reinforced vinylester composites. Applications: Be a light weight and high strength materials, Hollow glass reinforced vinyl ester polymer composite can be used in various engineering applications particularly aircraft industry.

Keyword: Composites, Hollow Glass Fiber, Mechanical Characterization, Solid Glass Fiber, Vinylester

1. Introduction

Composite material is an advance engineering material composed of two or more different materials or phases (matrix phase and reinforcing phase) combined which are insoluble in each other. Today, usage of the composite materials particularly, the polymer composite is being continuously increasing in various advanced engineering applications ranges from Aerospace, Marine, Automobile, Civil structure, etc. The advantages of composites are high strength to weight ratio, good dimensional stability, and high stiffness strength and corrosion resistance. Vinylester Composites have received an increasing attention as engineering materials in the recent decades.

Hollow glass fibers, has their unique properties of combined of high specific strength and low weight. H-glass is a fiber, which has lower density when compared to a solid E-glass, and thus reduces the overall weight by up to 40% of cured laminates. Hollow glass fibers are more elastic in nature and have higher specific strength, compression strength characteristics when compared to E-glass fibers. The hollow structure itself is responsible for the H-glass fibers significant improvement in their mechanical and thermal properties in comparison to E-glass fibers. H-glass fiber based composites act as a very efficient shock and energy absorbers.

A comparative study on the tensile and flexural strength of solid (E glass) and hollow fiber reinforced polymer matrix composite revealed that the hollow fiber reinforced composites showed improved in various strength such as tensile and flexural when compared to the solid glass fiber reinforced composites. In a study, H-glass fiber and identical solid fiber reinforced composite samples are characterised using a bespoke method to evaluate the compression strength of the composites and it is observed that H glass fiber with hollow fractions of about 20–25% showed significant improvement in specific compressive strength when compared to solid fiber.

In another study, epoxy composite is fabricated using solid and hollow glass fiber as a reinforcement and the characterized for impact behaviour using drop weight setup. The mechanical investigations showed that the
presence of hollow glass fiber significantly reduced the overall weight of the composites and also improved impact resistance when compared to the solid glass fiber reinforced composites. In another work, the comparative characterization revealed that the hollow fiber reinforced composite showed lesser damage area when compared to the identical solid fiber reinforced composite. Also found that reduction of damaged area under rapid loading is mainly due to the transverse crushing of hollow glass fiber locally at the impacted area. Thus hollow fiber considerably increases the energy absorption capability when compared to the solid brittle glass fibres.

In another study, the comparative characterization study is carried to quantify the effect of reinforcement such as Hollow glass fiber, traditional solid glass fiber and C-shaped, solid glass fiber on the mechanical properties of the fibre. When compared to the traditional solid and hollow glass fibers, the C-shaped solid glass fiber showed about 40% increment in the mechanical properties of the composite and also C-shaped fiber reinforced composite showed improved damping when compared to the other two solid and hollow fiber reinforcements. The possible increment in the strength is mainly due to the high surface to volume ratio between the matrix materials and reinforcing glass fibers. In another work, the ultimate strength of the composites is found to be increased with increase of raping thickness. In a study, hollow glass fiber reinforced hybrid composite is evaluated for its mechanical behavior. It is found that hybrid composites with hollow fiber showed high specific strength when compared to the identical solid fibers and hence suggested these high specific strength and light weight composite as advanced attractive materials for various engineering applications.

In this study, Vinylester/Hollow glass fiber composites and Vinylester/E-glass fiber composites are prepared using a traditional hand lay-up manufacturing method. The mechanical behavior of the hollow fiber reinforced vinyl ester composite is evaluated, to find out the effect of the hollowness of fiber on the various mechanical strength of the composites.

## 2. Materials and Specimen Preparation

In this study, Vinylester resin is selected as matrix materials and both E glass fiber and H glass fiber as reinforcement. The physical properties of both solid and hollow glass fibers are tabulated in the Table 1.

The Vinyl ester polymer composites are fabricated by conventional hand-lay-up method using E glass and H glass fiber as reinforcement. Throughout the study, weight fraction (W_f) of the fiber and matrix are almost kept constant to clarify the hollowness effect of the fibre on the mechanical behavior of Vinyl ester composites. First, the vinyl-ester resin is mixed with desired amount of Accelerator (cobalt octoate), Promoter (dim ethyl aniline) and Catalyst (methyl ethyl ketone peroxide) to initiate the polymeration reaction. Then these pre-mixed vinyl ester resin is used to fabricate the composite specimens using solid and hollow glass fibers as reinforcement. Total of about 15 layers of bi-directional woven fiber is used in the entire study. Then the laminated composite is cured at room temperature for about 10 hours. Finally, at 80°C temperature the fabricated vinyl ester composite laminates are kept in hot air woven for post curing for two hours. The American Society for Testing and Materials (ASTM) standard based samples are cut from the fabricated specimens for various mechanical characterizations.

## 3. Characterization and Testing

The various mechanical characterizations such as tensile, compression, flexural and impact are conducted in order to quantify hollowness effect on the mechanical behavior of the glass/vinyl ester composite. Tensile strength and compression strength are characterized at ambient condition using the UTM machine, according to ASTM procedures D3039 and D3401 respectively. Flexural strength of the vinylester composites is measured; according to ASTM D790-15 by using three point bending method at room temperature. The notched Charpy impact test is performed at ambient condition, according to ASTM D256 standard. The charpy impact tests are carried out on the flat rectangular specimens (10 × 10 mm²) with notch at the middle of the specimens using the Charpy Impact tester with an impactor of 2 J. The experimental result of tensile

<table>
<thead>
<tr>
<th>Materials</th>
<th>Solid (E) Glass Fiber</th>
<th>Hollow (H) glass Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>2.55</td>
<td>1.91</td>
</tr>
<tr>
<td>GMS</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Diameter (µm)</td>
<td>10-13</td>
<td>10-12</td>
</tr>
</tbody>
</table>

Table 1. Physical properties of glass fibres
strength, compression strength, flexural strength, energy absorbed and hardness are tabulated in the Table 2.

### 4. Result and Discussion

The experimental characterization on E glass and H glass fiber reinforced vinyl ester composites are carried to clarify the hollowness effect on the tensile strength, compression strength, flexural strength and energy absorption of the vinyl ester composites. From the graphical representation of tensile strength, Figure 1, the solid glass fiber reinforced vinyl ester composite showed a maximum tensile strength of about 83.31 N/mm², whereas Hollow glass fiber reinforced vinyl ester composite showed a maximum tensile strength of about 96.14 N/mm², which is 16% more, when compared to solid glass fiber reinforcement. It can be observed from the experimental result that the tensile strength of the composites has great influence with the hollowness of the fiber. The increment in the tensile behavior of hollow glass fiber/vinyl ester composite is mainly due to the hollowness of the fiber. Previously it is found that the fiber diameter and the hollowness effect of the glass fiber have significantly increased the strength of the glass reinforced composites\(^3\),\(^8\). For same identical fiber, hollow structure of the H-glass increases the tensile behaviour of composites when compared to the solid fiber.

Like tensile behaviour, compressive strength of the vinyl ester composite also varied with the fiber type. Hollow glass fiber reinforced vinyl ester composite showed a compressive strength of about 70.99 N/mm², which 34 % more when compared to the compressive strength of solid fiber reinforced composites as shown in Figure 2. From the graphical representation of compression test result, it can be observed that the hollowness of fiber has a positive effect on the load bearing ability of the vinyl ester composite. Further it is previously found that the reduction of fiber wall thickness in the hollow fibre considerably increase the load bearing capacity of the hollow fibre reinforced composite, which will directly increase the hollowness of the fiber. The reduction of wall thickness significantly reduces the possibility for critical flaws in the glass fiber, which will considerably act as a failure initiators\(^12\). Also during the composite curing process, the thermal load on the fiber leads to possible toughening effect, which is again more predominant with increase of the hollowness in the hollow glass fibre\(^4\).

From the experimental characterisation of vinyl ester composite revealed that the composite reinforced with hollow glass fiber showed better flexural strength, when compared to the solid glass fiber reinforced vinyl ester composites. The solid glass fiber reinforced vinyl ester composite showed flexural strength 141.14 N/mm², however the hollow glass fiber reinforced vinyl ester composites showed flexural strength of 159.66 N/mm², which is 13% more, when compared to the solid glass fiber reinforced vinyl ester composites. The graphical interpretation

\[ \text{Table 2. Mechanical properties of E glass and H glass composites} \]

<table>
<thead>
<tr>
<th>Composite Specimens</th>
<th>Tensile Strength (N/mm²)</th>
<th>Compression Strength (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
<th>Energy absorbed (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fibre composite</td>
<td>83.31</td>
<td>52.90</td>
<td>141.41</td>
<td>5.5</td>
</tr>
<tr>
<td>Hollow Fibre composites</td>
<td>96.14</td>
<td>70.99</td>
<td>159.66</td>
<td>8</td>
</tr>
</tbody>
</table>

**Figure 1.** Tensile strength of vinyl ester composites.

**Figure 2.** Compressive strength of vinyl ester composites.
Characterisation of Hollow Glass Fibre Reinforced Vinyl-Ester Composites

of flexural strength of both E glass and H glass fibre reinforced composites is shown in Figure 3.

The reason for increment in flexural strength of hollow glass fiber reinforced vinyl ester composites is mainly due the hollow nature of the reinforcement. The hollow nature of the glass fiber makes it as little ductility when compared to solid glass fiber. Generally, hollow fiber is more elastic when compared to identical solid fiber. Further, the wall thickness to diameter ratio of the hollow fiber plays a critical role in the elastic behavior of the fiber. Thus, the combined effect of both improved ductile and compression strength of hollow fiber makes the hollow glass fiber reinforced vinyl ester composite to show better flexural strength when compared to the solid glass fiber reinforced vinyl ester composites.

Like other mechanical properties, H glass fiber reinforced vinyl ester composite absorbed impact energy of about 8.0 J during rapid loading, whereas solid glass fiber absorbed only of about 5.5 J, which is 40% lower than former one as shown in Figure 4. The increment in energy absorption capacity of the H fiber is due to the hollowness, which make the fiber more ductile and elastic during impact loading. It is previously concluded that impact induced damage is reduced in hollow fiber reinforced composites, when compared to solid fiber, due to transverse crushing of the hollow fibers during impact.8

5. Conclusion

In this work, the mechanical characterization is carried to clarify the hollowness effect on the mechanical behavior of the H glass fiber reinforced vinyl ester composites. Low density of H glass fiber in comparison with solid E glass fiber, reduce the overall weight of cured vinyl ester composites. The H glass fiber composite exhibit average values for the tensile strength, compression strength, flexural strength and absorbed impact energy of 96.14 N/mm², 70.99 N/mm², 159.66 N/mm² and 8.0 J respectively, which are significantly lower than those characterized identical solid glass fiber reinforced vinyl ester composites. The hollowness nature of H-glass fiber is mainly responsible for significant improvement in the mechanical properties of the vinyl ester composites. Thus, from the mechanical characterization, it is concluded that the hollow glass fiber reinforced vinyl ester composite showed potential advantages over the conventional solid glass fiber reinforced composite for various engineering applications.

6. References


