Tensile behavior of glass fiber reinforced plastics subjected to different environmental conditions

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Received 7 May 2010; accepted 3 September 2010

Glass fiber reinforced plastic (GFRP) composites are being used in a large number of diverse applications ranging from aerospace to sports equipment. The mechanical and environmental characterization of these materials is necessary to further enhance their application spectrum. GFRP composites are subjected to different working environments when put into service. The mechanical behavior of polymeric matrix composites in particular is affected by the environmental conditions. There is an imminent need to investigate the mechanical behavior of these materials when subjected to various types of environments for different exposure times. The objective of the present research endeavor is to characterize the tensile behavior of the GFRP composites when exposed to brine, acid and base solution, Ganga water, freezing conditions and kerosene oil for four different exposure times. The experimental results show that the tensile strength of GFRP plates is affected at different levels when subjected to selected environmental conditions for various exposure times.

Keywords: GFRP, Environmental conditions, Tensile strength

Polymer matrix composites (PMCs) are increasingly being used in a wide range of applications where long-term service in different environmental conditions is required. In recent years, GFRP/polyester resin have received considerable attention as alternatives to steel and aluminum as structural materials in the construction, gas and liquid tanks, pipes, offshore platforms, marine, aircraft applications, automotive, recreational equipments and aerospace industries due to their high strength-to-weight ratio, competent mechanical properties and ease of handling1-5. The polymer matrix composites used in building construction, automotive application as well as in sports equipment may be exposed to a variety of environmental conditions such as continuous sun light, high moisture content and exposure to water. Similarly liquid storage tanks and pipes may be subjected to acidic attack if they are used for storing harmful chemicals. It is important to note that composites which are used in aerospace and marine applications may be subjected to freezing conditions. These materials have found application in drilling of offshore platforms of gas exploitation and civil infrastructure for the repair of bridges, where as long term exposure in water and humidity environment is present. Among these properties, the physical durability of the PMCs against physical and chemical composition changes is critical to their long-term survival6. The competitive quality and good mechanical properties of glass fiber has led them to widespread use in fiber reinforced plastic (FRP) composites7-10.

The prediction of the long-term performance of composite materials, particularly in harsh environments, has been an active research area. The glass fibers are commonly used in industrial applications, because of low cost and good mechanical properties. The lack of resistance of composite structures to degradation agents often becomes apparent within certain period of exposure11,12.

The effect of sea water on the bearing strength behavior of the woven glass fiber composite has been investigated. It was concluded that the bearing strength decreases as immersion period increases13. For long term stability of FRP composites in corrosive environments (CS2), it was found that glass fibers are highly resistant to corrosion14. The concentrated HCl and storage aging has led to strength reduction of the matrix/glass inter-facial bonds, causing decrease in the mechanical properties of the GFRP composites15,16. The moisture present in matrix can cause matrix swelling, inter-phase debonding, physical damage of the inter-phase and

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hydrolysis of the material; these are the main reasons of the deteriorated tensile strength\textsuperscript{17}. In the present investigation, the effects of the environmental conditions (NaOH, Ganga water, freezing condition, brine solution, kerosene oil and H\textsubscript{2}SO\textsubscript{4}) on the GFRP laminates with respect to time (64 h, 128 h, 256 h and 512 h) has been studied. It is found that as the exposure time of PMCs increase, the tensile strength of PMCs gradually reduces.

**Experimental Procedure**

**GFRP specimen preparation**

The polyester resin (elastic modulus = 3.25 GPa, and density = 1.35 g/cm\textsuperscript{3}) is manufactured by Ciba Geigy Ltd., and supplied by Northern Polymers Ltd., New Delhi, India. The short glass fiber (elastic modulus = 72.5 GPa, density = 2.59 g/cm\textsuperscript{3}, and length = 16 mm) were manufactured by Saint Gobian Ltd., India. The specimens used for experimentation were manufactured using the hand-layup technique. The E-glass randomly oriented fiber was used as the reinforcement in polyester matrix. A gel coat was applied on the mould prior to the lay-up process to facilitate easy removal of the GFRP plate. The polyester resin and the short glass fibers were mixed to form a void free mixture by constantly stirring the resin in the flask. The mixture was applied to the mold. The top plate of the mold was placed on the base plate and the bolts were tightened to apply pressure. The mold was left for room temperature (28°C) curing for about 24 h. Thus, GFRP specimens of 4 mm thickness were prepared. After the polyester composites were cured, they were cut into specimen size 200×15×4 mm\textsuperscript{3} according to the ASTM D3039 standards. Machine used for tensile testing of specimen is shown in Fig. 1.

**Fiber volume fraction**

In the FRP, the fibers are distributed throughout the matrix in a random manner. The cross-sectional area of the fiber relative to the total cross-sectional area of the unit cell is a measure of the volume of fiber relative to the total volume of the composite. This fraction is an important parameter in composite materials\textsuperscript{18}, and it is a number between 0 to 1. Since fiber and resin content affect the materials mechanical response and properties, it should be measured for material being tested and accounted for in predicting mechanical response. The fiber volume fraction can be determined experimentally by weighing GFRP plate, then burning the matrix and weighing the remaining fibers. According to ASTM D2584, specimens were prepared to find the volume fraction for glass fibers. The specimen was put in a crucible and was placed in a furnace; the matrix degraded leaving only the fibers. This method is known as the burn-off method. The burn-off method is simple and effective way to determine the volume fraction of fibers in composite materials. To check the reproducibility of the results three samples were taken into consideration. The range of fiber volume fraction for GFRP was found to be 0.25%. Table 1 shows the fiber volume fraction of glass fibers in GFRP plates.

**Environmental Characterization**

**Effect of NaOH**

The tensile strength of GFRP plates subjected to NaOH (0.1%) decreased with the exposure time. The tensile strength decreases after every time interval considered starting from 22% in the initial exposure of the specimen to the base solution. The reduction in tensile strength is up to 35% of the virgin specimen after 512 h. The reduction in strength is due to the attack of NaOH on polyester resin. The eroding effect of base can be clearly seen in the Fig. 2a, where the

<table>
<thead>
<tr>
<th>S.No.</th>
<th>GFRP plate weight, g</th>
<th>Fiber weight after burn-out, g</th>
<th>Density, g/mm\textsuperscript{3}</th>
<th>Fiber volume fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.283</td>
<td>0.795</td>
<td>1.284</td>
<td>0.2421</td>
</tr>
<tr>
<td>2</td>
<td>3.383</td>
<td>0.821</td>
<td>1.361</td>
<td>0.2427</td>
</tr>
<tr>
<td>3</td>
<td>3.604</td>
<td>0.930</td>
<td>1.384</td>
<td>0.2580</td>
</tr>
</tbody>
</table>

Fig. 16 Material testing system
fibers are visible on the surface. The percentage reduction in tensile strength of GFRP is almost linear. The base reacts with the resin and erodes it. Overall it can be concluded that base deteriorates the surface of the composite material made from polyester resin.

**Effect of Ganga water**

The tensile strength of GFRP laminates in case of exposure to Ganga water decreases initially up to 23% of the original sample and then it increases on further exposure to Ganga water. Finally, after continuous exposure to the Ganga water it tends to become constant. The reason can be accounted that in the water environment, water molecules enter rapidly into the inter-phase of the composites between the fiber and matrix, because of the capillary action. The fiber/matrix inter-phase can be degraded by a hydrolysis reaction of unsaturated groups within the resin. Debonding may occur at fiber/matrix inter-phase, due to this initial reduction in the tensile strength take place. After certain period of time, a saturation stage is reached where upon no more water seeps into the composite. All the voids and cracks of the laminates would be filled with water, which acts as a plasticizer to favor the strength.

**Effect of freezing conditions**

The GFRP composite are used in bridge and offshore platform retrofits, where they are subjected to freezing conditions\(^9\). The GFRP laminates were put in the freezing box maintained at the temperature of -10°C. It can be observed that the tensile strength in case of freezing conditions decreases on being initially exposed upto 7 %, which is not an appreciable change. On further exposure to deep freezing conditions the tensile strength reduces but as it is evident from graph that at the end of 512 h the reduction observed is only 13%. In this case, the reduction in tensile strength is low as compared to Ganga water. This may be attributed to the low moisture uptake in the freezing conditions. The curve reaches a saturation state after 216 h. Thus, the low degradation in tensile strength in freezing conditions justifies their use in low temperature applications.

**Effect of brine solution**

The decrease in tensile strength is about 15% which may be due to diffusion of water from the solution after a time period of 64 h. After that the reduction in tensile strength becomes nearly constant. It is clear from the graph that the reduction reaches a saturation state with the passage of time.

**Table 2δ** Percent reduction in tensile strength with exposure time

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Time</th>
<th>64 h</th>
<th>128 h</th>
<th>256 h</th>
<th>512 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NaOH</td>
<td>22.11</td>
<td>24.15</td>
<td>25.68</td>
<td>34.97</td>
</tr>
<tr>
<td>2</td>
<td>Ganga water</td>
<td>21.74</td>
<td>22.03</td>
<td>21.08</td>
<td>23.05</td>
</tr>
<tr>
<td>3</td>
<td>Freezing</td>
<td>7.05</td>
<td>8.5</td>
<td>12.64</td>
<td>13.40</td>
</tr>
<tr>
<td>4</td>
<td>Brine (3.5% NaCl)</td>
<td>11.5</td>
<td>13.42</td>
<td>13.81</td>
<td>16.07</td>
</tr>
<tr>
<td>5</td>
<td>Kerosene oil</td>
<td>11.61</td>
<td>18.11</td>
<td>15.59</td>
<td>16.07</td>
</tr>
</tbody>
</table>

Fig. 2δ Failed specimen under tensile loading (a) NaOH, (b) Ganga water, (c) freezing conditions, (d) brine solution and (e) kerosene oil

**Effect of kerosene oil**

Kerosene oil is an organic solvent. The decrease in tensile strength is noted to be 18%, when the GFRP is initially exposed to kerosene oil. It is because of the solution goes into the voids and weakens the fiber matrix interface. After that equilibrium is attained and the reduction tends to become constant with time. Figure 2 shows the failed specimen under tensile loading of GFRP under different environmental conditions (NaOH, Ganga water, freezing conditions, brine solution and kerosene oil) with exposure time of 512 h. Table 2 shows the percentage reduction in tensile strength with time period (64 h, 128 h, 256 h, and 512 h). Figure 3 indicates the comparison of % reduction in tensile strength in GFRP plates subjected to different environmental conditions (NaOH, Ganga water, freezing conditions, brine solution and kerosene oil). As it is clearly evident from the graph, the percentage reduction in tensile strength is more in case of NaOH as compared
to Ganga water, freezing conditions, brine solution and kerosene oil. Hence, it can be concluded that composite material is poorly resistant against the action of base, is actively resistant against the action of organic solvents. Thus, it can be used to make containers that can store organic solvents like kerosene oil.

**Effect of H$_2$SO$_4$**

The effect of varying concentration of H$_2$SO$_4$ was investigated on the tensile behavior of GFRP laminates. Figure 5 shows the percent reduction in tensile strength found for various concentrations of H$_2$SO$_4$. It is found that the GFRP plate shows remarkable change in tensile strength in case of 0.1% solution of H$_2$SO$_4$ and 60% solution of H$_2$SO$_4$. This may be due to the fact that at lower concentration diffusion is faster while at higher concentration acid attack is predominant. Figure 4 shows the failed specimen under tensile loading with different % of H$_2$SO$_4$ concentration. Table 3 shows the percentage reduction in tensile strength with exposure time. The percent reduction in tensile strength was more in case of 0.1% H$_2$SO$_4$, and there by decreased till 30% and finally increased for 60% H$_2$SO$_4$ as shown in Fig 5. Therefore, a trend cannot be generalized that with an increase in the concentration of H$_2$SO$_4$ there is going to be decreased in the percent reduction of strength. The important fact to note is that exposure of GFRP plates to H$_2$SO$_4$ is going to result in reduction in tensile strength.

It may be noted from Figs 3 and 5, that the percent reduction in tensile strength is more during the initial exposure of GFRP laminates to various environmental conditions. After the initial reduction in the tensile strength, further exposure to environmental conditions under investigation does not lead to appreciable change in the tensile strength of plates. Therefore it is important for the designers to note that there is going

<table>
<thead>
<tr>
<th>Time, h</th>
<th>64 h</th>
<th>128 h</th>
<th>256 h</th>
<th>512 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1% H$_2$SO$_4$</td>
<td>19.86</td>
<td>24.39</td>
<td>28.17</td>
<td>25.61</td>
</tr>
<tr>
<td>10% H$_2$SO$_4$</td>
<td>10.5</td>
<td>17.59</td>
<td>16.84</td>
<td>17.78</td>
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<tr>
<td>30% H$_2$SO$_4$</td>
<td>9.27</td>
<td>22.79</td>
<td>20.26</td>
<td>21.48</td>
</tr>
<tr>
<td>60% H$_2$SO$_4$</td>
<td>10.78</td>
<td>21.58</td>
<td>24.62</td>
<td>28.17</td>
</tr>
</tbody>
</table>

![Fig. 3δ Percent reduction in tensile strength with different environmental conditions](image3)

![Fig. 4δ Failed specimen under tensile loading (a) 0.1% H$_2$SO$_4$, (b) 10% H$_2$SO$_4$ (c) 30% H$_2$SO$_4$ and (d) 60% H$_2$SO$_4)](image4)

![Fig. 5δ Percent reduction in tensile strength with different concentrations of H$_2$SO$_4$](image5)
to be reduction in tensile strength of plates when exposed to different environmental conditions and the design of GFRP products should be done incorporating the adequate factor of safety.

**Reduction in weight**

The percent reduction in tensile strength of GFRP plates is maximum in case of exposure to NaOH solution and minimum in case of freezing conditions. Due to this reason, these two environmental conditions were selected for the investigation of change in weight with exposure time. There may be possibility of a correlation between the reductions in tensile strength of GFRP plates with change in weight. Table 4 shows the percentage change in weight with passage of time under NaOH and freezing conditions. It was observed from the calculated values that there was a decrease in weight for exposure to NaOH solution and increase in weight for exposure to freezing condition with an increase in exposure time. There is a need to investigate this phenomenon in much more detail as the percent reduction in tensile strength may be related to change in weight of GFRP plates subjected to different environmental conditions. The percentage change in weight with time of GFRP plates under different concentration of H_{2}SO_{4} is shown in Table 5. Figure 6 shows the percentage change in weight with exposure time for different percentages of H_{2}SO_{4} concentration. It was found that the weight of GFRP plates increased with the increase in concentration of H_{2}SO_{4} solution and decreased on exposure of GFRP plates to higher concentration of H_{2}SO_{4} solution (60%).

**Conclusions**

The effects of various environmental conditions on the tensile behavior of GFRP plate were investigated. The following conclusion can be drawn on the basis of the present experimental investigation:

All the environmental conditions considered, influence the tensile behavior of GFRP plate.

The GFRP plate subjected to NaOH solution showed the maximum percent reduction in tensile strength where as minimum percent reduction was found for exposure to freezing conditions.

The effect of varying concentration of H_{2}SO_{4} showed that the percent reduction in tensile strength is maximum at 0.1% H_{2}SO_{4} and 60% H_{2}SO_{4}.

It was also observed that there was no increase in weight with an increase in concentration of H_{2}SO_{4}. At
very high concentration (60%), there was a decrease in weight and an increase in the percent reduction in tensile strength, and this phenomenon needs to be further investigated.

The experimental study highlights an important aspect that environmental characterization of materials such as composites is essential for their widespread applications in newer and novel fields of science and engineering. The technique of adding various additives to make polymeric matrix composites resistant to various damaging environmental conditions is also an important research area seeking attention from researchers and engineers belonging to the composites fraternity.

References