DEVELOPMENT AND ANALYSIS OF FRP BASED COMPOSITE FIBRE

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ABSTRACT

The current research describes the synthesis and testing of FRP under tensile loading and high temperature conditions. The FRP is produced using Vacuum Infusion technique and cut into different fibre sizes. The SEM (Scanning Electron Microscope) analysis is performed to determine the effect of matrix maturity, temperature, fibre inclination, and loading rate on fibre matrix. The findings have shown a relationship of fibre volume on thermal and mechanical characteristics of FRP.

Keywords: FRP, Tensile test, SEM


1. INTRODUCTION

The rapid growth in manufacturing has resulted in improved strength, toughness, density and lower material costs with improved durability. Composites have emerged as one of those materials that show such an improvement in properties that reveal their potential in a variety of applications. Composites are a fusion of two or more components, one of which is in the
matrix phase and the other in the form of particles or fibers. The use of natural or synthetic fibers in the manufacture of composite materials has given rise to important applications in various fields such as construction, mechanics, automotive, aerospace, bio-medicine and maritime transport.

2. LITERATURE REVIEW
Fiberglass is probably one of the best known reinforcing composites that was introduced in 1940 and consists of fiberglass reinforcements made from an unsaturated polyester matrix [1-3]. This fiber had many problems which led to the search for an alternative replacement as reinforcement. The fiber as reinforcement of the composite material had excellent physical, chemical, thermal and mechanical performance, durability and a biodegradable nature, which highlighted and favored its field of application. The use of natural fibers as a reinforcement in composite materials was a difficult task.

Ferreria et al. [4] improved fatigue resistance by using hybrid fiber composites with a polypropylene hemp layer next to the bonding interface, which was expected to produce a more uniform stress in the temporary areas. A main disadvantage of natural fibers (vegetable fibers) compared to synthetic fibers is their non-uniformity, their variety of dimensions and their mechanical properties (also between individual natural fibers (vegetable fibers) in the same crop) [5]. Polymer composites reinforced with natural fibers are widely recognized for their high specific strength and their modulus. With this in mind, this article focuses on the microwave treatment of partially and fully biodegradable composites. The advantage of microwave treatment is that it leads to much shorter cure times compared to heat treatment.

Natural fibers such as coconut fibers, rattan and bamboo are tested as reinforcements [6, 7]. Richardson and Zhang [8] used flow visualization experiments using resin transfer molds to develop a better understanding of the mold filling process for hemp carpet reinforced phenolic composites. Eucalyptus urograndis paste, which is used as a reinforcement for thermoplastic starch, has shown a 100% increase in tensile strength and a more than 50% modulus compared to unreinforced thermoplastic starch [9].

3. OBJECTIVES
FRPs are used in the aerospace industry, where they are exposed to different temperature conditions. Therefore, it is important to analyze its properties under different temperature conditions. Current research is examining the influence of volumetric fraction and temperature on the mechanical properties of FRP.
4. RESEARCH METHODOLOGY

The manufacturing of FRP panel was accomplished using Vacuum infusion technique. The details of steps followed in the manufacturing are described below.

1. The flat shape of aluminium or alloy is cleaned so as not to create even small dust particles. This is important for creating a leak-free vacuum bag.
2. The release agent applied to prevent the epoxy from sticking to the mould. (Fig. 2 (a)).
3. The reinforcement fabric and a shell layer are placed on the module during the normal preparation process. In this project, an additional layer of detachable film was placed between the mould and the reinforcements (Fig. 2 (b), 2 (c)). Sometimes an additional liquid is placed on top if the thickness of the reinforcements is small. The flow medium facilitates the flow of the resin (Fig. 2 (d)).
4. The inlet and outlet pipes are laid on both edges as shown in Figure 2 (d). The whole system is covered by an empty bag that acts as a counter form. A spiral wrap allows reinforcements to enter and exit evenly.
5. The vacuum bag is sealed with adhesive tape. The outlet is connected to the recovery vessel, which in turn is connected to a vacuum pump (Fig. 2 (e)).
6. A vacuum test is performed to check for leaks. This is done by pinching the inlet tube. The vacuum pump is turned on to create a vacuum in the bag. As soon as the vacuum is created, the vacuum pump stops and the pressure fluctuation in the vacuum is measured for approximately 10 minutes (Fig. 2 (e)).
7. Once the vacuum is installed in the system, the degassed resin and the hardener are mixed in the resin vessel and introduced through the inlet. The resin is sucked under pressure and infiltrates into the reinforcing fabric (Fig. 2 (f), 2 (g)).
8. Once the resin has saturated the reinforcing fabric, the inlet duct is pinched. The outlet is always connected to the collection container, the installation is always under vacuum.
9. The facility remains intact for 24 hours, after which it is separated from the resin container and collection container. It is aged in the oven for 4 hours at 650 °C and for another 2 hours at 850 °C.
10. After hardening, the detachable folds are carefully removed on both sides so as not to damage the FRP plate.
The next step involved cutting FRP panels to make FRP fibre. Two types of plates have been made with the infusion technique. The first used a fabric with fibers in both directions. The cutting force of the plate is moderate in both directions. The second type of plate was made using a unidirectional fabric. With these plates, the effort of cutting along the grain is less, but the effort of cutting perpendicular to the grain is high. Both woven panels and unidirectional panels have been fused using two types of materials, glass and carbon. The effort to cut the carbon fiber reinforced polymer plate (CFRP plate) was greater than that of the glass fiber reinforced polymer plate (GFK plate). Several tools have been tried to cut the panels. Sharp blades were also difficult with tight cuts. In addition, it is not possible to cut in a straight line without a precise guide mechanism. A mechanical saw was used to cut the FRP plate. Although the cuts were very clean, the effort to make a single fiber was high. It is practically not a viable option. Good scissors were also tried while it was possible to cut, which is impossible. A stacked cutter, as shown in Figure 3 (a), worked well for most panels. Tin cuts, also known as cuts, were used to cut unidirectional plates into 50mm wide strips in the direction perpendicular to the fibers. These strips were cut into fibers using the letter opener.

**Figure 2** Steps involved in Vacuum infusion process

**Figure 3** Cutting the FRP panels to fibre size
Two types of plates have been made with the infusion technique. The first used a fabric with fibers in both directions. The unidirectional fabric. With these plates, the effort of cutting along the grain is less, but the effort of cutting perpendicular to the grain is high. Both woven panels and unidirectional panels have been fused using two types of materials, glass and carbon. The effort to cut the carbon fiber reinforced polymer plate (CFRP plate) was greater than that of the glass fiber reinforced polymer plate (GFK plate). Several tools have been tried to cut the panels. Sharp blades were also difficult with tight cuts. In addition, it is not possible to cut in a straight line without a precise guide mechanism. A mechanical saw was used to cut the FRP plate. Although the cuts were very clean, the effort to make a single fiber was high. It is practically not a viable option. Good scissors were also tried while it was possible to cut, which is impossible. A stacked cutter, as shown in Figure 4 (a), worked well for most panels. Tin cuts, also known as cuts, were used to cut unidirectional plates into 50mm wide strips in the direction perpendicular to the fibers. These strips cutting force of the plate is moderate in both directions. The second type of plate was made using a were cut into fibers using the letter opener.

![Image](image_url)

**Figure 4** Cutting the FRP panels to fibre size

The yield of the compound or FRP was measured using a tensile test. Tensile stress and some shear stress are the two predominant types of stress that can be expected from concrete fiber. The thickness of each plate varies from 0.3 mm to 0.7 mm, making it difficult to hold the sample between the jaws of normal friction handles. It is also possible that the fiberglass plate is damaged on the handles. Therefore, commercially available aluminum or fiberglass sheets are often used as tab material, which are then secured in place by the friction handles. Fiberglass tabs are preferred over aluminum because the rough surface of fiberglass can be easily glued with epoxy glue to fiberglass panels manufactured in the laboratory. 1/16 inch (~1.6 mm) electrical grade fibers were used for tabulation.

1. The fiberglass sheet, approximately 1.6 mm thick (tongue material), is cut with a saw or scissors into 1-inch or 2.5-cm strips.
2. These strips are glued to the edge of the fiberglass film so that the strips are perpendicular to the direction of the fibers or to the direction of loading (see Figure 5 (a)). A clear measurement length of 10 cm is maintained between the two tabs.
3. The circular table saw is used to cut the fiberglass sheet with fiberglass tabs into narrow strips about 1 cm wide, as shown in Figure 5 (b).
The tensile tests were performed on a vertically mounted Instron universal tension-controlled test machine in accordance with ASTM D3039-14. The hydraulic powered Instron machine was equipped with a 250 kN load cell. The tests were performed at a constant travel speed of 0.035 mm / sec (2 mm / minute). Displacement was measured by measuring the transverse displacement. A DASY lab program was used to acquire the data and store it in ASCA format. The data is further analysed to obtain strength, deformation and other elastic properties. Inevitably, due to the nature of the test, there is a certain eccentricity due to misalignment in the machine during the positioning of the sample in the handles. Misalignment and eccentricity can cause large data variations and even cause premature failure of the FRP sample. Care must be taken to minimize misalignment by visually aligning the long axis of the specimen with the axis of the machine. At least 10-12 samples were analysed to obtain the average tensile response of the FRP sample. Figure 6 below shows the grips used for the test.

**Figure 5** Preparation of specimen for tensile testing. (All dimensions are in mm)

**Figure 6** (a) Friction grips for tensile tests of (b) GFRP and (c) CFRP strips

**5. RESULTS AND DISCUSSION**

Adequate consistency was observed in most FRP panels. The volume fractions for the 4 types of GRP panels produced are described in Table 1 below.
Table 1 Summary of the volume fractions of the GRP panels produced.

<table>
<thead>
<tr>
<th></th>
<th>GFRP Bi-</th>
<th>GFRPUni-</th>
<th>CFRP Bi-</th>
<th>CFRPUni-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>0.28 &amp; 0.7</td>
<td>0.35-0.5</td>
<td>0.45</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Volume</td>
<td>31%</td>
<td>22-30%</td>
<td>25%</td>
<td>18-25%</td>
</tr>
<tr>
<td>Effective</td>
<td>16%</td>
<td>22-30%</td>
<td>13%</td>
<td>18-25%</td>
</tr>
<tr>
<td>Specific</td>
<td>1.67</td>
<td></td>
<td></td>
<td>1.33</td>
</tr>
</tbody>
</table>

Unidirectional fabrics, in particular unidirectional fiberglass S, had a variable thickness and even empty spaces. In such cases, a greater variation in thickness and volume proportions can be expected. The difference in volume ratios changes in the elastic properties of FRP. The unique surface texture shown in Figures 7 and 8 is the result of production technology. The unprocessed pattern comes from the coating layer used in the manufacturing process.

During the infusion, the skin layers are completely moistened with the resin. When the release layer is removed from the FRP plate, it leaves an impression on the plate, creating the pattern on the FRP plate. Figure 9 shows the edge of the unidirectional CFRP fiber. As we can see, the fiber at the edges of the cutting process is only slightly damaged.

Figure 7 Microscopic images of the surface of (a) CFRP and (b) GFRP fibres

Figure 8 Microscopic image of the Longitudinal profile of CFRP fibre
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Figure 9 Microscopic image of the cut section of the CFRP fibre, focusing on the edge

Figure 10 SEM Images of GFRP fibres at (a) 200x, (b) 500x & (c) 2000x magnifications

SEM images were acquired on unidirectional GFRP and CFRP fibers with magnifications of 200x, 500x and 2000x.

The images are shown in figure 10 above. SEM images are enlarged and more detailed than OM images. The surface pattern observed on OM images can be seen more clearly on SEM images as shown in figure 11 below. Due to natural light, shadow and reflection in OM images, we get a better perception of depth in OM images than in SEM images.

Figure 11 SEM Images of CFRP fibres at (a) 200x, (b) 500x & (c) 2000x magnifications

As we can see, there is no clear difference between the GFK and CFK fibers on the surface. There is no clear difference since the production technique is identical. GRP fibers with lower magnification and different illumination are illustrated below to emphasize depth perception and show a 3D effect as shown in figure 12 below.
For the CFRP fiber in Figure 12 (left) above, we see the crater-like depressions that correspond to the OP image of the fiber profile shown in Figure 4-10. We can also see some exposed fibers along the edges. Figure 12 (right) shows the SEM image of a previously damaged fiberglass fiber. Observe the separation of the fibers along the length of the break. Average tensile response of CFRP and GFRP specimen have been summarized in the Table 2 below.

**Table 2** Summary of the volume fractions of the GRP panels produced.

<table>
<thead>
<tr>
<th></th>
<th>Gla</th>
<th>Gla</th>
<th>Carb</th>
<th>Carb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Vf in direction of</td>
<td>16%</td>
<td>22%</td>
<td>13%</td>
<td>22%</td>
</tr>
<tr>
<td>Strength (MPa)</td>
<td>194</td>
<td>578</td>
<td>398</td>
<td>953</td>
</tr>
<tr>
<td>Modulus (GPa)</td>
<td>4.0</td>
<td>9.9</td>
<td>6.6</td>
<td>19.9</td>
</tr>
</tbody>
</table>

We can see that the CFRP panel is about two times stronger and about two times stiffer than the GRP panel in unidirectional and bidirectional FRP panels. In addition, unidirectional FRP belts are about twice the number of reinforcing fibers in the load direction compared to woven FRP belts. Consequently, the unidirectional GRP bands are twice as strong for GRP and CFRP and have a modulus of elasticity twice that of the interwoven GRP bands. The summary of fibre pull out test is shown in table 3 below.

**Table 3** Summary of different fibres behaviour in single fibre pull-out tests

<table>
<thead>
<tr>
<th></th>
<th>Instances of Fibre</th>
<th>Pull-out energy</th>
<th>Peak bond stress</th>
<th>Equivalent bond</th>
</tr>
</thead>
<tbody>
<tr>
<td>St-Straight</td>
<td>0%</td>
<td>726</td>
<td>0.78</td>
<td>0.61</td>
</tr>
<tr>
<td>GFRP</td>
<td>30%</td>
<td>1040</td>
<td>3.32</td>
<td>0.94</td>
</tr>
<tr>
<td>PP-Crimped</td>
<td>0%</td>
<td>1051</td>
<td>2.16</td>
<td>1.22</td>
</tr>
<tr>
<td>CFRP</td>
<td>0%</td>
<td>2022</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>St-Hooked</td>
<td>0%</td>
<td>1459</td>
<td>3.38</td>
<td>2.1</td>
</tr>
</tbody>
</table>

We can see that the performance of GRP fibers is much better than that of straight steel fibers and on the same level as deformed polypropylene fibers. Although steel hook fibers may appear to have higher energy absorption, the maximum performance of fiberglass fibers and energy absorption at low crack openings correspond to steel hook fibers. It is obvious that by optimizing the composition and geometry of GRP fibers, much can be achieved, steel
fibers can be overcome both mechanically and in terms of durability. To study the influence of temperature on the bonding behavior of the fiber matrix, normal dog bone samples were printed and hardened for 7 days. After curing for 7 days, the sample was transferred to the oven (or freezer) for 7 days. If the sample is stored in the oven (or freezer) for 7 days, there is enough time for the temperature to have a significant impact on the matrix, fiber and fiber-matrix interface. Each sample was removed from the oven immediately before the test, which was carried out at room temperature. Each dog bone extraction test takes approximately 1,215 minutes. It is believed that the temperature variation in the fiber-matrix interface is negligible during the test period. The temperatures used in this study are -20°C, 20°C (room temperature), 50°C, 80°C, 100°C and 130°Celsius. In addition, the fiber samples were stored in the oven at 80 °C and 130 °C and observed under an optical and SEM microscope to examine any changes in the epoxy on the fiber surface.

Table 4 Summary of different fibres behaviour in single fibre pull-out tests

<table>
<thead>
<tr>
<th>Temper</th>
<th>Instance</th>
<th>Pull-out Energy</th>
<th>Peak Bond Stress</th>
<th>Equivalent Bond Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20°C</td>
<td>60%</td>
<td>1723.5</td>
<td>5.94</td>
<td>1.53</td>
</tr>
<tr>
<td>20°C</td>
<td>30%</td>
<td>1049.4</td>
<td>3.32</td>
<td>0.93</td>
</tr>
<tr>
<td>50°C</td>
<td>30%</td>
<td>886.5</td>
<td>2.62</td>
<td>0.79</td>
</tr>
<tr>
<td>80°C</td>
<td>25%</td>
<td>1472.7</td>
<td>3.89</td>
<td>1.31</td>
</tr>
<tr>
<td>100°C</td>
<td>0%</td>
<td>990</td>
<td>2.49</td>
<td>0.88</td>
</tr>
<tr>
<td>130°C</td>
<td>0%</td>
<td>486</td>
<td>1.92</td>
<td>0.43</td>
</tr>
<tr>
<td>-20°C</td>
<td>0%</td>
<td>4220</td>
<td>5.09</td>
<td>3.46</td>
</tr>
<tr>
<td>20°C</td>
<td>0%</td>
<td>2106</td>
<td>3.07</td>
<td>1.73</td>
</tr>
<tr>
<td>50°C</td>
<td>0%</td>
<td>1727</td>
<td>2.29</td>
<td>1.42</td>
</tr>
<tr>
<td>80°C</td>
<td>0%</td>
<td>2547</td>
<td>4.11</td>
<td>2.09</td>
</tr>
<tr>
<td>100°C</td>
<td>0%</td>
<td>1323</td>
<td>2.57</td>
<td>1.09</td>
</tr>
<tr>
<td>130°C</td>
<td>0%</td>
<td>943</td>
<td>3.37</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Figure 13 Comparison of peak and equivalent bond strength of GFRP and CFRP fibres at different temperatures

The glass transition temperature of the epoxy used to make FRP fibers is 900 °C. From the figures and tables above, we can see that there is practically no difference in binding responses at 500 °C and at room temperature, which is approximately 200 °C. Increase the temperature further to 800 °C, very close to the glass transition temperature of the epoxy resin. We see an improvement in adhesion performance for GRP and CFRP fibers. This may be due to the thermal expansion of the fiber, which allows better adhesion to the matrix. Another reason could simply be the accelerated hydration reaction at elevated temperature.
The positive effect decreases if we increase the temperature further. At 1,300 °C, the yield on the bonds declined dramatically.

5. CONCLUSION

Single fiber extraction tests were performed to examine the performance of the FRP-Fibrematrix interfacial bond. The effects of matrix maturity, temperature, fiber pitch, strain rate and oil coating on fiber-matrix interface bond performance were also examined. The loading capacity of the fiber reinforced composite material after the crack was examined using fiber relaxation tests. In order to assess the durability of FRP fibers, the change in tensile strength and adhesion after accelerated deterioration was finally examined. The results of the project have been successful and encouraging.

a) A composite GRP can be efficiently manufactured using simple and readily available components. While an effective fiber fraction of up to 30% has been obtained in the laboratory, leading to tensile strength compared to steel, the fibers can be mass produced with superior uniform quality.

b) The single fiber extraction performance of GRP fibers was superior to that of commercially available straight fibers and corresponds to the widely used deformed fibers. The unique texture contributes to a micro-layer effect in the pre-tear phase. The same texture helps to improve the resistance to friction when the fibers break.

c) The extraction of a single upper fiber has been successfully translated in response to bending. If fiber extraction has not started in the torn section, the fiber will break and a weak bending response will occur. To confirm the response of the fibers to a load other than the orientation of the fibers, a more detailed study of the inclined fiber extraction tests was carried out. We observed a break in the brittle fiber in most of the samples, which explains the weak bending reaction after the crack. Fiber breakage can be attributed to a combination of low cut resistance, low flexibility and ductility, as well as high damping friction due to the rough texture.

d) Premature breakage of the fiber before extraction can be corrected by modifying the interface between the fiber and the cement matrix. An oil coating has been used to successfully change the mechanism of a fragile fiber break to an energy-absorbing fiber extraction. The total energy absorption of oil-coated samples is always better than that of uncoated samples exposed to tilt, despite the loss of much of the chemical bond between the fiber and the matrix.

e) The extraction of FRP fibers is not affected by changes in temperature. The low temperature performance of -20 °C is superior to that of ambient temperature, however, GRP fibers have shown brittle fiber breakage in many samples. At the other end of the spectrum, the fibers performed well up to 100 °C, after which the binding performance decreased. SEM and OM images also showed slight deterioration near the edge on the fiber surface after 7 days of exposure at 130 °C.

f) Interestingly, at dynamic loading speeds, the tear strength increases not only up to twice, but also the tensile strength of the fiber itself. The performance of fiber and its cement-containing compounds under dynamic loading per static load is expected to be better.

REFERENCES


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