EFFECT OF REINFORCEMENTS COMBINATION ON THE MECHANICAL STRENGTH OF GLASS REINFORCED PLASTIC (GRP) HANDLAY-UP LAMINATES UNDER INCREASED TEMPERATURE CONDITIONS

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ABSTRACT
A number of hand lay-up GRP laminates of E-glass are produced in various reinforcements combinations. Careful record of their strength tested under room temperature is tabulated against each corresponding laminate. A close study of these results show that their laminate strength varied considerably from initial values, Strength of some combinations increased with increasing temperatures whereas those of some others dropped under the same increased temperature conditions. Investigations into finding suitable explanations for these strange behaviours by the afore-stated laminates remain in progress.

INTRODUCTION
The increasing use of GRP composites under elevated temperature conditions (wet and dry situations inclusive) has necessitated the improvement of the strength of such composites, which are made to serve within elevated temperature conditions with the primary aim of achieving a higher margin of safety and durability in operation[1,2]. Driers, boilers, pressure pipes, pressure vessels and speedboats are a few of such items that are required to operate within elevated temperature conditions. And, for obvious reasons, these equipment, at present are preferred in GRP rather than steel, aluminum, or any other materials employed previously in their manufacture [3]. One of the reasons being resistance to rusting when compared with mild steel; then cost, weight, flexibility of shape, heat conservation and indentation strength when compared with other metals such as aluminum, copper, lead, etc.

As early as the estimates of Voigt and Reuss, the strength of composites have always been shown to be directly proportional to their fibre volume fraction [4]. The only other factor considered to be of reasonable influence with regards to the strength of composites being their fibre - direction or orientation [5]. However, further works do reveal that the directional chance agreement of fibres sometimes exact an influence on the composite strength over and above the traditional fibre volume fraction dependence of composite strength [6]. The decision to undertake strength tests in tension, bending and indentation (hardness test) here goes a step further to rule out any influence in strength that may be credited to the orientation of fibres in any given direction.

The objective of this work is to find out what is the resultant effect strengthwise of combining fibre reinforcements during handlay-up laminations in varying proportions and within arrangement at random - particularly, when these laminates are employed in areas where elevated temperature conditions are operational.

EXPERIMENTAL PROCEDURES Materials
Six laminate specimens B, C, D, E, F and G having various reinforcements combination all of the E-glass family (selected at random) are employed for this purpose and produced in hand lay-up under similar laboratory conditions. The length, width and thickness of each specimen being made to conform to same size for all test samples (see tables5, 6,7,8,9, and 10). The tests are carried out under three subheadings: Tensile, Hardness and Bending and the test conditions also are three: first, tests on the untreated specimen for each subheading for each specimen sample: second; tests on specimen samples heated at 60°C (dry) for twenty four hours for each subheading for each specimen sample and third: tests on specimen sample heated at 80°C (inside water) for twenty - four hours for each subheading for each specimen sample. Note that the temperature ranges employed here fall within the values to which such items as: driers, pressure pipes, speed boat, etcetera all of which are made from fibre reinforced
laminates, operate.

Table 1 presents the various compositions of the laminates used in the experiment.

Table 1: Laminate compositions

<table>
<thead>
<tr>
<th>Specimen involved</th>
<th>Ply composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>5 plies of woven roving</td>
</tr>
<tr>
<td>C</td>
<td>2 plies of (42.7g) hardmat, 1 ply of woven roving, 2 plies of (42.7g) hardmat</td>
</tr>
<tr>
<td>D</td>
<td>1 ply of softmat, 2 plies of (42.7g) hardmat, 1 ply of woven roving, 2 plies of (42.7g) hardmat</td>
</tr>
<tr>
<td>E</td>
<td>8 plies of (42.7g) hardmat</td>
</tr>
<tr>
<td>F</td>
<td>2 plies of softmat, 4 plies of (42.7g) hardmat, 2 plies of softmat</td>
</tr>
<tr>
<td>G</td>
<td>12 plies of softmat</td>
</tr>
</tbody>
</table>

Test method
The tests are carried out in the laboratory using a multipurpose bending, hardness and tensile test machine. In tensile test, the specimens are gripped at both ends by the machine and continuous loading is achieved by turning the wheels of the machine until ultimate failure of break-up of the specimen is achieved. On the graphical paper inserted in the machine’s wheel drum, a graphical plot of the behaviour or movement of the machine is obtained as the specimen is loaded up to failure or break up point. Similarly, for bending test, a horizontal displacement at mid-point of the specimen (gripped at both ends by the machine) is achieved by hand rotation of the wheels as described above. By ratio, the reading of the horizontal displacement is also transferred to the graphical paper by the intermittent push-plotter on the paper-carrying drum. At break-up, the maximum or ultimate bend strength is reached and the silver liquid indicator on the drum reading rushes back to its reservoir. The hardness test is also achieved in the same way. The only difference being that Brinnel balls are used to achieve indentations on the specimen thickness. The indentation reaches a maximum at crack point of the specimen which is recorded by the push-plotter silver liquid indicator. This is the ultimate strength. The Brinnel hardness, \( H_b \) is calculated using the Brinnel equation:

\[
H_b = \frac{P}{\pi D^2 [D - \sqrt{(D^2 - d^2)}]}
\]

Where:
RESULTS AND DISCUSSION
The results of the study are presented in tables 2-4. All values below correspond to ultimate strength or strength of specimen at "break-up" point or at point at which crack initiates at the indentation hole. For a closer study here please see: (i) Tables 5 and 6; and figures 8 and 14 - showing laboratory test results and plots of specimen 'C' from where also the results in tables (2-4) were taken. (ii) Tables 7 and 8; and figures 8 and 14 - showing laboratory test results and plots of specimen 'D' whose summary appear in tables (2-4). (iv) Figures 4, 10 and 16 - showing plots of the test results of specimen F whose summary is contained in tables (2-4) and, finally (vi) figures 6, 12 and 18 - showing detailed plots of the test results of specimen G which is found contained in brief in tables (2-4) as well.

Table 3: test result: hardness test.

<table>
<thead>
<tr>
<th>specimen</th>
<th>Fibre reinforcement composition</th>
<th>Strength of laminate untreated (MPa)</th>
<th>Strength of laminate heated to 60°C (dry) for 24 hours (MPa)</th>
<th>Strength of laminate heated to 80°C inside water for 24 hours (MPa)</th>
<th>Behavior of laminate with increasing temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>5 plies of woven roving</td>
<td>1000.5</td>
<td>926.7</td>
<td>875.8</td>
<td>Strength decreases</td>
</tr>
<tr>
<td>C</td>
<td>2 plies of (42.7g) harmat ply of woven roving plies of (softmat)</td>
<td>407.4</td>
<td>513</td>
<td>548.9</td>
<td>Strength increases</td>
</tr>
<tr>
<td>D</td>
<td>1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat</td>
<td>651.8</td>
<td>560.4</td>
<td>667.0</td>
<td>Strength decreases</td>
</tr>
<tr>
<td>E</td>
<td>8 plies of (42.7g) hardmat</td>
<td>595.7</td>
<td>529.5</td>
<td>484.8</td>
<td>Strength decrease</td>
</tr>
<tr>
<td>F</td>
<td>2 plies of softmat 4 plies of (42.7g) hardmat 2 plies of softmat</td>
<td>590.7</td>
<td>644.1</td>
<td>642.6</td>
<td>Strength increases</td>
</tr>
<tr>
<td>G</td>
<td>12 plies of softmat</td>
<td>751.0</td>
<td>869.7</td>
<td>682.3</td>
<td>Strength increases</td>
</tr>
</tbody>
</table>

Table 4: Test Results: Bending Test

<table>
<thead>
<tr>
<th>specimen</th>
<th>Fibre reinforcement composition</th>
<th>Strength of laminate untreated (MPa)</th>
<th>Strength of laminate heated to 60°C(dry) for 24 hours (MPa)</th>
<th>Strength of laminate heated to 80°C inside water for 24 hours (MPa)</th>
<th>Behavior of laminate with increasing temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>5 plies of woven roving</td>
<td>10.2</td>
<td>8.1</td>
<td>4.4</td>
<td>Strength decreases</td>
</tr>
<tr>
<td>C</td>
<td>2 plies of (42.7g) harmat ply of woven roving plies of (softmat)</td>
<td>2.7</td>
<td>4.1</td>
<td>4.2</td>
<td>Strength increases</td>
</tr>
<tr>
<td>D</td>
<td>1 ply of softmat 2 plies of (42.7g) hardmat 1 ply of woven roving 2 plies of (42.7g) hardmat 1 ply of softmat</td>
<td>2.9</td>
<td>2.61</td>
<td>4.3</td>
<td>Strength increases</td>
</tr>
<tr>
<td>E</td>
<td>8 plies of (42.7g) hardmat</td>
<td>4.4</td>
<td>4.0</td>
<td>2.2</td>
<td>Strength decrease</td>
</tr>
<tr>
<td>F</td>
<td>2 plies of softmat 4 plies of (42.7g) hardmat 2 plies of softmat</td>
<td>4.0</td>
<td>5.2</td>
<td>5.1</td>
<td>Strength increases</td>
</tr>
<tr>
<td>G</td>
<td>12 plies of softmat</td>
<td>5.9</td>
<td>4.6</td>
<td>4.5</td>
<td>Strength decreases</td>
</tr>
</tbody>
</table>
A careful study of the above tables 2 to 4 clearly reveal the spectacular behaviour of specimens C, D and and their habit of increasing in strength with exposure to higher than room temperatures. This spectacular behaviour can be seen spanning the entire three different tests: tensile, hardness and bending. Similarly, specimens B, E and G belong to their own group. As these specimens become subjected to higher temperatures, their strengths begin to fail. Taking specimen B as a particular example, even though it has the highest fibre volume fraction, \( V_r \), the strength decreases as the temperature increases. The entire three different tests also confirm this behaviour. Hence, the behaviour of the specimens as discovered above cannot be said to have occurred by accident. neither can it be classified as experimental error. Also with the three different tests occurring in three different orientations: bending, tension and indentation, it cannot, however, be said to be influenced by the fibre directions in the laminates. Note also the way dry, wet and room temperature condition have been employed in the experiments. Consequently, in the design and lamination of pressure vessels, pressure pipes, speed boats, driers, etcetera preference must be made for such group of laminates such as specimens B, D and F rather than B. E and G. However, there is nothing yet to prove that such properties involving increasing strengths with increasing temperatures will still be in progress at much higher than temperature ranges already shown.

CONCLUSIONS
From the experimental results so far, we can now safely conclude that:

1. Certain reinforcements combination in handlay-up of E-glass exhibit the properties of increasing strength with increasing temperature.
2. As a result of this property, such laminates can be used in much wider range of temperature conditions than ever before and so higher margin of safety and durability in operation achieved.
3. This is indicative of the fact that improvement in the strength of laminates employed for use under elevated temperature conditions such as in speedboats, pressure pipes and pressure vessels can be achieved by careful combination of glass reinforcements during lamination.

ACKNOWLEDGEMENT
The assistance of Mr. Eme of the Civil Engineering Laboratory University of Nigeria, Nsukka, in carrying out the tests is thankfully acknowledged.

REFERENCES

EXPERIMENTAL TEST RESULTS, TABLES A D PLOTS REFERRED TO IN THE TEXT.
Material Specimen B Dimension: Width Thickness Length22.82mm 5.53mm 300mm
Composition: 5 plies of woven roving
Lamination Method: Handlay-up of E-glass in polyester resin
Treatment: Nil
Test: Tensile Test
Fibre Volume Fraction: \( V_1 \) == 0.71Cross
Table 5: Experimental Results of Specimen 'B' (Tensile Test: Untreated Specimen)

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Extension (mm)</th>
<th>Stress (Mpa)</th>
<th>Strain</th>
<th>Ultimate Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>1.0</td>
<td>7.9</td>
<td>3.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>1.7</td>
<td>15.8</td>
<td>5.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,400</td>
<td>2.4</td>
<td>26.9</td>
<td>8.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>4,500</td>
<td>2.9</td>
<td>35.3</td>
<td>9.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>6,000</td>
<td>3.5</td>
<td>47.6</td>
<td>11.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>7,400</td>
<td>4.1</td>
<td>58.6</td>
<td>13.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>8,900</td>
<td>4.6</td>
<td>70.5</td>
<td>15.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>10,400</td>
<td>5.1</td>
<td>82.4</td>
<td>17.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>11,250</td>
<td>5.4</td>
<td>89.1</td>
<td>18.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>13,400</td>
<td>6.0</td>
<td>108.2</td>
<td>20.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>14,800</td>
<td>6.6</td>
<td>117.3</td>
<td>22.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>16,800</td>
<td>7.3</td>
<td>133.1</td>
<td>24.3 x 10^{-3}</td>
<td>133.1</td>
</tr>
</tbody>
</table>

Material Specimen B Dimension Width Thickness Length 25.3mm - 5.53m - 3.00mm
Composition: -5 plies of woven roving
Lamination Method: -Handlay-up -or E-glass -In Polyester resin
Treatment: Healed, inside Water at 80°C for 24 hours
Test: -Tensile Test
Fibre Volume Fraction: \( V_f = 0.71 \)
Cross sectional Area = 139.9 x 10^{-6} m²

Table 6: --Experimental Results of Specimen 'B' (Tensile Test: Heated inside water at 80°C for 24 hours)

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Extension (mm)</th>
<th>Stress (Mpa)</th>
<th>Strain</th>
<th>Ultimate Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.7</td>
<td>3.6</td>
<td>2.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>1,450</td>
<td>1.9</td>
<td>10.6</td>
<td>6.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>2,350</td>
<td>2.8</td>
<td>16.8</td>
<td>9.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,800</td>
<td>3.6</td>
<td>27.1</td>
<td>12.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>5,300</td>
<td>4.4</td>
<td>37.9</td>
<td>14.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>7,000</td>
<td>5.2</td>
<td>50.00</td>
<td>17.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>8,500</td>
<td>5.8</td>
<td>60.7</td>
<td>19.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>6.4</td>
<td>71.4</td>
<td>21.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>11,900</td>
<td>7.1</td>
<td>85.0</td>
<td>23.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>13,800</td>
<td>7.8</td>
<td>98.6</td>
<td>26.0 x 10^{-3}</td>
<td></td>
</tr>
</tbody>
</table>

Material Specimen C Dimension Width Thickness Length 20mm 4.5mm 300mm
Composition: Two poles of (42.7g) hardmat One ply of woven roving Two plies again of (42.7g) hardmat
Lamination Method: Handlay-up of E-glass in polyester resin
Treatment: Nil
Test: Tensile Test
Fibre Volume Fraction: \( V_f = 0.51 \)
Cross sectional area = 90 x 10^{-6} m²

Table 7: experimental result of specimen 'C' (tensile test: untreated specimen)

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Extension (mm)</th>
<th>Stress (Mpa)</th>
<th>Strain</th>
<th>Ultimate Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,200</td>
<td>8.2</td>
<td>108.6</td>
<td>27.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>16,800</td>
<td>8.8</td>
<td>120.0</td>
<td>29.3 x 10^{-3}</td>
<td>120.0</td>
</tr>
</tbody>
</table>

Fig. 1. Graphic presentation or specimen ‘B’ (Tensile Test) plotted from the same origin
---------Heated specimen
----------Heated inside water at 80°C for 24hrs
* crushing strength
⊗ analysis graph

Edelugo
Material Specimen C Dimension:
Width Thickness Length 20mm 4.5mm 300mm
Composition: 2 plies of (427g) hardmat 1 ply of woven roving 2 plies again of (42.7g) hardmat
Lamination Method: Handlay-up of E-glass in polyester resin
Treatment: Heated, inside water at 80°C for 24 hours
Test: Tensile Test
Fibre Volume Fraction: \( V_f = 0.51 \)

Table 8: Experimental results of specimen ‘C’ (tensile test: heated inside water at 80°C for 24 hours)

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Extension (mm)</th>
<th>Stress (Mpa)</th>
<th>Strain</th>
<th>Ultimate Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>0.5</td>
<td>4.4</td>
<td>1.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>1.25</td>
<td>8.3</td>
<td>4.2 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>1,250</td>
<td>2.2</td>
<td>13.9</td>
<td>7.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>1,850</td>
<td>3</td>
<td>20.1</td>
<td>10.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>2,320</td>
<td>3.5</td>
<td>25.8</td>
<td>11.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,250</td>
<td>4.5</td>
<td>36.1</td>
<td>15.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,800</td>
<td>5</td>
<td>42.2</td>
<td>16.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>4,230</td>
<td>5.3</td>
<td>47.0</td>
<td>17.7 x 10^{-3}</td>
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</tr>
<tr>
<td>5,270</td>
<td>6.28</td>
<td>58.5</td>
<td>20.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>6,200</td>
<td>6.85</td>
<td>68.9</td>
<td>22.8 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>7,100</td>
<td>7.48</td>
<td>78.9</td>
<td>24.9 x 10^{-3}</td>
<td>78.9</td>
</tr>
</tbody>
</table>

Material Specimen D Dimension: Width Thickness Length 20mm 6mm 300mm
Composition: One ply of softmat Two plies of (42.7g) hardmat One ply of woven roving Two plies again of (42.7g) hardmat One ply again of softmat
Lamination Method: Handlay, up of E-glass in polyester resin
Treatment: Nil
Test: Tensile Test
Fibre Volume Fraction: \( V_f = 0.43 \)

Table 9: experimental results of specimen ‘D’ (Tensile Test: Untreated Specimen)

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Extension (mm)</th>
<th>Stress (Mpa)</th>
<th>Strain</th>
<th>Ultimate Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>0.5</td>
<td>0.5</td>
<td>1.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>1.18</td>
<td>8.3</td>
<td>3.9 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>1,460</td>
<td>1.6</td>
<td>2.2</td>
<td>5.3 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>2</td>
<td>16.7</td>
<td>6.7 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>2,450</td>
<td>2.25</td>
<td>20.4</td>
<td>7.5 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,450</td>
<td>3.75</td>
<td>28.8</td>
<td>9.2 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>3,900</td>
<td>3.0</td>
<td>32.5</td>
<td>10.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>4,450</td>
<td>3.3</td>
<td>37.1</td>
<td>11.0 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>5,450</td>
<td>3.75</td>
<td>45.4</td>
<td>12.5 x 10^{-3}</td>
<td></td>
</tr>
<tr>
<td>6,600</td>
<td>4.2</td>
<td>55.0</td>
<td>14.0 x 10^{-3}</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Fig. 2. Graphic presentation of specimen ‘C’ (Tensile test) plotted from the same origin

*crushing strength
® analysis graph

Material Specimen D Dimension Width Thickness Length 20mm 6mm 300mm
Composition: One ply of softmat Two plies of (42.7g) hardmat One ply of woven roving Two plies again of (42.7g) hardmat One ply again of softmat
Lamination Method: handlay, up of E-glass in polyester resin
Treatment: Heated, inside water at 80°C for 24 hours
Test: Tensile Test
Fibre Volume Fraction: \( V_f = 0.43 \)

Table 10 Experimental Results of Specimen D (Tensile Test: Heated inside water at 80°C for 24 hours)
<table>
<thead>
<tr>
<th>Mpa</th>
<th>600</th>
<th>1,550</th>
<th>2,450</th>
<th>2,940</th>
<th>4,000</th>
<th>4,450</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
<td>2</td>
<td>2.25</td>
<td>2.81</td>
<td>3</td>
</tr>
<tr>
<td>1.7</td>
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<td>6.7</td>
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</table>

![Graphical Presentation of Specimen “D” (Tensile Test)](image)

![Graphical Presentation of Specimen “C” (Tensile Test)](image)

![Graphical Presentation of Specimen “E” (Tensile Test) Plotted from the same origin](image)

![Graphical Presentation of Specimen “F” (Tensile Test)](image)

![Graphical Presentation of Specimen “B” (Hardness Test)](image)