PIONEERING TO PIECES OF GFRP KEESTER ORDINARY FOR ALUMINUM & SOFT-HEARTED GROOM DAY-SCHOOL UNWORTHY OF FLEXURAL LOAD

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Abstract- In our day-to-day living, we come across parts which are joined together. When parts take up the load, often the joint becomes the weakest link. This means that the strength of the joint is less than that of the parent components. Due to which, glass fiber reinforced plastics (GFRP) play a vital role in many engineering applications as an alternative to various heavy exotic materials. In this study, a series of GFRP butt joint were formed between two different adherent pipes of outside diameter 25.4 mm, inside diameter 22 mm and 175 mm long. The type of information to be derived is appropriate to study the flexural behavior of Aluminum and Mild Steel pipes reinforced with GFRP butt joint in terms of serviceability limit states requirements. The proposed bond model was established by calibrating the parameters of grade UA473 glass fiber sheets (preselected fiber angle +10° and -10° alternatively) by varying number of joint layers using the experimental results of four point bending tests carried out by the authors, taking into account the experimental bending moment versus extension. The study investigated that that aluminum pipe when adhered along with GFRP composite, the bending moment to bear exceeds as compared to aluminum pipe alone.

Keywords- GFRP composites, Four Point Bending test, Ply Drop, Bending Moment.

I. INTRODUCTION

Different types of joining methods are available to join two or more similar or dissimilar materials. Each of these techniques has its own advantages and limitations. If we consider fasteners, they require less skilled labor; the overall dimensions of fasteners are small. But the holes are made in the parent components, so that they can be fastened. This increases the stress concentration near the fasteners and weakens the parent components. Welded joints have several disadvantages such as welded joints may induce residual stresses, due to high temperatures involved and the cooling, various kinds of cracks develop in the weldment as well as in heat affected zones. An adhesive joint is another technique to join two parts. However, the adhesive joints are poor in tension and therefore joints should be designed carefully so that the interface is subjected primarily to shear stresses.

A new method is recently developed, in which, composites are used to join two parts together with a FRP material. Fiber Reinforced Polymers (FRP) is now being accepted as an important class of ‘Engineered Materials’, because it offers several outstanding properties.

People are exploring the application of polymer composites in various different directions. Composite made of fibers (Glass/ Carbon/ Kevlar) wetted with thermoset resin (epoxy/ polyester/ phenolic/ polyamide) and wound on the joint and the resin is allowed to get cured.

A FRP joint offers numerous advantages-
- The joining can be easily done at room temperature, as it is a cold working process.
- This method can be used to join similar or dissimilar materials. This overcomes the limitations of welding in which similar or certain pairs of materials can only be joined.
- This provides non-corrosive joint.
- The FRP joint offers high strength to weight ratio.

Due to these several advantages offered by FRP, now-a-days, FRP is being used in several industrial applications like Aircrafts, Auto Body, Bridge Reinforcements, Shafts and rods, etc.

II. EXPERIMENTAL TECHNIQUE

The basic raw materials for the preparation of the specimen were the adherents (Aluminum & Mild steel pipes), the reinforcing material (glass fiber) and the matrix material (epoxy resin).

Fig. 1 Detailed Geometry of Aluminum & Mild Steel adherent
As shown in Fig.1 the dimensions of the aluminium adherents were as follows:
Inner diameter of aluminium pipe $\approx 22.00$ mm.
Outer diameter of aluminium pipe $\approx 25.4$ mm.
Length of each aluminium pipe = 175 mm.

Aluminum: The modulus of elasticity was 69GPa. The average yield stress of aluminum was found to be 152MPa and ultimate tensile stress 175MPa.

Mild Steel: The modulus of elasticity was 210Gpa. The average yield stress of mild steel was found to be 330MPa and ultimate tensile stress 340MPa.

In this study, the reinforcing material was glass fiber sheets and the resin was epoxy. Glass fibers are very thin fiber (diameter $\approx 17$ µm) of grade UA473 made of pure glass material with 3 patches per layer configuration. The properties of epoxy resin, as supplied by the manufacturer, are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Specifications of Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Resin (100 parts by weight)</td>
</tr>
<tr>
<td>Hardener (9 parts by weight)</td>
</tr>
<tr>
<td>Supplier</td>
</tr>
<tr>
<td>Mixing</td>
</tr>
<tr>
<td>Processing time (pot life), minutes</td>
</tr>
<tr>
<td>Viscosity, mPa.s</td>
</tr>
</tbody>
</table>

III. PREPARATION OF SPECIMEN

Aluminum and Steel pipes were clenched onto the spindle oppositely with truncated cone and washer assembly as shown in Fig. 2. Glass fibers were cohered to the pipes (3 layers per patch with 2 mm circumferential distance) with prefixed proportion of solution made of Epoxy, Hardener and Amino Saline. In order to draw out superfluous solution, the sample is subjected to vacuum bagging at about -600 psi for 45 min. After the epoxy is cured at room temperature for about 24hrs, the specimen was post cured to have better polymerization. This is called as Post Curing. Specimen is subjected to higher temperature, about $80^\circ$C for 5-6 hours. The inside of oven is made of double walled enclosed area. Temperature is shown by temperature indicator and temperature control by relay switch for maintaining the required temperature. As the temperature increases so does the molecular activity and polymerization becomes complete with ester molecules, cross linking and then forming strong matrix.

The flexural strength of a joint is one of the primary requirements of a structure made of slender members. Usually bend tests are performed through a 3-point bend fixture, but in this study, the 3 point test set-up was not used because the center load then acts on the joint plane and the local stresses thus generated would probably affect the joint performance. In this study, flexure test was carried out on a four point bend specimen as shown in Figure 3. It is worth noting that a constant bending moment results between two inner load locations.

B.M. at A = 0
B.M. at D = 0
As the loading is symmetric about vertical,
Reaction at A, RA = P/2
Reaction at D, RD= P/2
Hence the bending moments are
Bending Moment at C= Reaction x distance= R/2 x 120
= P x 120/2
= P x 60

Also Bending Moment at B= P x 60 (Due to symmetry)
Hence the BM at any point between the downward loading points is 60 times the Load.

Lower limit Bending moment for aluminum adherent.
Finding by using first fiber yielding criterion (Lower Limit)
\[ I = \pi \times \frac{(D^4-d^4)}{64} \]
= \pi x \frac{6^4}{(25.5^4-22.1^4)}
= 9.05 \times 10^3 \text{ mm}^4
\[ \sigma = \frac{M}{I}\times i= 152\text{MPa} \]
\[ M = \frac{152 \times 0.05 \times 10^3}{12.75} \]
= 108N-m
Upper limit Bending moment for aluminum adherent.
Finding by using complete yield of aluminum criterion (Upper Limit)
\[ BM = 2\times \int_0^\pi \int_0^\pi r^2 \sin \theta \times \sigma \times r \sin \theta \times d\theta \times d\phi \]
\[ = 2\times \sigma \times \int_0^\pi \int_0^\pi \sin \theta \sin \phi d\theta \int_0^\pi r^2 \sin \phi d\phi \]
\[ = 2\times \sigma \times \int_0^\pi \sin \theta d\theta \int_0^\pi \sin \phi d\phi \]
\[ = 2\times \left( \frac{1}{2}\right) \times \sigma \times [-\cos \theta]_0^\pi \]
\[ = \frac{2}{3} \left( 3^1-1 \right) \sigma \times \sigma \times [-1 - 1] \]
\[ = \frac{2}{3} \times \sigma \times \sigma \times [3^1-1] \]

For characterizing the material, flexure tests were performed on a 10 ton capacity Universal Testing Machine. The distance between the two central loads was chosen to be small (only 60mm) as shown in Fig. 4. This was done (i) to increase the bending moment at the joint plane and (ii) the load points of the center loads acted on the FRP sleeve which is quite strong and as a result it did not cause any local plastic deformation. In the preliminary tests, the distance between the two center loads was substantially longer, applying loads on the surface of aluminum and mild steel adherents. As a result, the aluminum metal was found to fail at the contact point through a large local depression. Thus the specimen was failing due to local depression and not due to failure of joint. The device consists of a base fixture having rollers of 25 mm diameter. The specimen was placed on these rollers with a preselected fixed support span distance of 300 mm. A load was applied on the specimen with the help of upper fixture which also has two rollers of 25 mm diameter. The upper fixture was mounted on the test frame and properly aligned. All the four rollers are made of hardened alloy steel. The tests were performed in displacement control mode with the rate of displacement 0.2mm/min. A load was applied on the specimen with the help of upper fixture.

V. RESULTS AND DISCUSSIONS
The results of the flexural tests are classified into six parts:

1. Failure of Specimen made with single layer.
2. Failure of Specimen made by patch on gap with two layers and outward ply drop.
3. Failure of Specimen made by patch on gap with two layers and inward ply drop.
4. Failure of Specimen made by overlapped patches with two layers and outward ply drop.
5. Failure of Specimen made by patch on gap with three layers and outward ply drop.
6. Failure of Specimen made by patch on gap with three layers and inward ply drop.
1. Failure of Specimen made with single layer.

<table>
<thead>
<tr>
<th>No. of Layer</th>
<th>Specimen</th>
<th>FRP Outside diameter [mm]</th>
<th>Total load [N]</th>
<th>Bending Moment [N-m]</th>
<th>Mean Value ± S.D For BM</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-1</td>
<td>26.80</td>
<td>1306</td>
<td>78.36</td>
<td>80.66 ± 7.44</td>
<td>Fiber Broken C</td>
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<tr>
<td></td>
<td>1-2</td>
<td>26.86</td>
<td>1483</td>
<td>98.9</td>
<td>Fiber Broken T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-3</td>
<td>26.76</td>
<td>1244</td>
<td>74.64</td>
<td>Fiber Broken T</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:** C-Compression Side, T-Tension Side Failure

**Total load is considered by summation of peak load and initial load given manually.

2. Failure of Specimen made by patch on gap with two layers and outward ply drop.

<table>
<thead>
<tr>
<th>No. of Layer</th>
<th>Specimen</th>
<th>FRP Outside diameter [mm]</th>
<th>Total load [N]</th>
<th>Bending Moment [N-m]</th>
<th>Mean Value ± S.D For BM</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>B-1</td>
<td>27.5</td>
<td>4381</td>
<td>263</td>
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<td></td>
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<tr>
<td></td>
<td>B-2</td>
<td>27.8</td>
<td>3130</td>
<td>188</td>
<td>Fiber Broken C</td>
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<tr>
<td></td>
<td>B-3</td>
<td>27.77</td>
<td>3002</td>
<td>180</td>
<td>Fiber Broken T</td>
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<tr>
<td></td>
<td>B-4</td>
<td>27.58</td>
<td>2740</td>
<td>164</td>
<td>Fiber Broken C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-5</td>
<td>27.88</td>
<td>2855</td>
<td>171</td>
<td>Fiber Broken C</td>
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<tr>
<td></td>
<td>B-6</td>
<td>27.92</td>
<td>2881</td>
<td>173</td>
<td>Fiber Broken C</td>
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<tr>
<td></td>
<td>B-8</td>
<td>27.62</td>
<td>1846</td>
<td>111</td>
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<tr>
<td></td>
<td>B-10</td>
<td>27.58</td>
<td>3745</td>
<td>225</td>
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<tr>
<td></td>
<td>B-11</td>
<td>28.14</td>
<td>2916</td>
<td>175</td>
<td>Fiber Spread-Steel side</td>
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<tr>
<td></td>
<td>B-14</td>
<td>27.78</td>
<td>2426</td>
<td>146</td>
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<td></td>
<td>B-15</td>
<td>28.14</td>
<td>1498</td>
<td>90</td>
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<td></td>
<td>B-16</td>
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<td>2614</td>
<td>157</td>
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<td>B-24</td>
<td>27.56</td>
<td>1739</td>
<td>104.34</td>
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<tr>
<td></td>
<td>B-25</td>
<td>27.74</td>
<td>2955</td>
<td>177.3</td>
<td>Fiber Broken T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-26</td>
<td>27.66</td>
<td>1586</td>
<td>95.16</td>
<td>Fiber Broken T</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:** C-Compression Side, T-Tension Side Failure

**Total load is considered by summation of peak load and initial load given manually.

While conducting the flexural test on these specimens, it was found that the fiber comes apart at interface of tension side and aluminum pipe as shown in Fig. 5.

The Fig. 6 shows Extension versus Bending Moment of the specimen B-1 having 2 layers. The curve is linear initially and the load taken by the specimen increases linearly. As the load increases further, beyond 4381 N the specimen failed due to breakage of FRP on compression side at the joint plane and as a result the graph drops down.

**Fiber Broken –Compression Side (At Joint Plane)**

The Fig. 8 shows Bending Moment versus Extension: Combined graph for considerable specimens failed due to fibers broken on tension side at the joint plane.
Pioneering To Pieces Of GFRP Keester Ordinary For Aluminum & Soft-Hearted Groom Day-School Unworthy Of Flexural Load

Fig. 9 Graphs showing 2 Layer Outward Ply Drop specimens within limits of average bending moments

3. Failure of Specimen made by patch on gap with two layers and inward ply drop.

Table 4 Result computations for 2 Layer Inward Ply drop

<table>
<thead>
<tr>
<th>No. of Layer</th>
<th>Specimen</th>
<th>FRP Outside diameter [mm]</th>
<th>Total load [N]</th>
<th>Bending Moment [N-mm]</th>
<th>Mean Value ± S.D. for BM</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>B-19</td>
<td>27.56</td>
<td>2261</td>
<td>136</td>
<td>157.6 ± 69.63</td>
<td>Fiber Broken-T</td>
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<tr>
<td></td>
<td>B-20</td>
<td>27.74</td>
<td>1189</td>
<td>71</td>
<td>Fiber Broken-T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-21</td>
<td>27.66</td>
<td>2079</td>
<td>125</td>
<td>Fiber Broken-C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-22</td>
<td>27.78</td>
<td>3550</td>
<td>213</td>
<td>Fiber Broken-C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-23</td>
<td>27.64</td>
<td>4050</td>
<td>243</td>
<td>Al Yield</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 Result computations for 2 Layer Overlapped Inward Ply drop.

In this type, specimens were made by overlapping patches with outer ply drop. The overlap distance between two patches is maintained constant as 2 mm on each side of patch for every layer. In flexure test the breakage of these types of specimen took place with fiber broken in first layer as those layers didn’t have enough space for their expansion to relieve their stresses as result of which specimens were failed at earlier load as compared to previous types.

5-6. Failure of Specimen made by patch on gap with three layers and outward ply drop and inward ply drop.

Table 6 Result computations for 3 Layer Outward and Inward Ply drop.

Fig. 10 Bending Moment vs. Extension for 2 Layer Inward Ply Drop

Fig. 11 Hinge Formed in 2 Layer Inward Ply Drop during testing

Overall Comparison

Fig. 12 Comparison of 3 layer Outward & Inward Ply Drop
CONCLUSION

Omitting the specimens which were abruptly failed on account of unconventional error on making, specimens tested on single layer type showed an average bending moment $80.66 \pm 7.44$ N-m. Specimens of 2 layers outward ply drop demonstrated multifariousness failure kind but failure on tensile side was remarkable with average bending moment $161.32 \pm 47.53$ N-m. Whereas, for 2 layers inward ply drop recorded an average bending moment of $157.6 \pm 69.63$ N-m showing failure of specimen by formation of plastic hinge (Aluminum Yield). Results computed for specimens tested with overlapped 2 layers outward ply drop sort were second-rate of $126.5 \pm 18.5$ N-m as average bending moment. Similarly, 3 layers outward ply drop testing showed $161$ N-m and 3 layers in ward ply drop showed $108$ N-m average bending moment. Failure was seen as breaking of fiber on tensile side. This experimentation study evidently proved that specimens made on 2 layers outward ply drop sort showed results way above the upper limit that was computed theoretically earlier. Specimens with 2 layers inward and 3 layers Outward Ply Drop sort too demonstrated results higher than upper limit computed theoretically. Fibers Overlapped specimen failed abjectly.

SCOPE FOR FUTURE WORK

The study predicts that the bending stresses are very high At the innermost fibers of the FRP sleeve. This type of joining can also be used for T-joints, cross-joints, L-joints too. Same joints specimen can also be tested under torsional, bending and tensile loading conditions to check its strength under the same. These joints can also be used in congested areas of application.

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