Investigations on Aluminium wire mesh, Banana Fiber and Glass Fiber Reinforced Hybrid Composites

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Abstract

Objectives: In the fiber metal laminates aluminium has been preferred choice when it comes to the selection of the type of metal to be used as reinforcement in FML, due to its easy of availability, favourable mix of mechanical characteristics and low cost. Among fibers, glass has been found out to be most reliable as it is cheaper than its counterparts, and at the same time does not compromise on its mechanical properties.

Methods: The hand-layup process is employed to fabricate two types of composites: a normal GFRP and a GFRP hybrid. The hybrid, named GABGRP (glass-aluminium-banana-glass-reinforced plastic) comprises of layers of both aluminium and banana fibers as reinforcements in a glass fiber-base. The aluminium in this study has been employed in two different forms: foil and wire mesh. The GABGRP has been fabricated, and subjected to material testing to find out aluminium in which form, aluminium is more suitable as a reinforcement. The fabricated materials are cut in accordance to ASTM standards and are subjected to various mechanical tests, namely tensile, flexural, impact and hardness tests.

Findings: The investigation conducted on Glass-Aluminium Foil/Wire Mesh-Banana Fibre-Glass Hybrid Composites, it has been inferred that the GABGRP (with Al wire mesh) hybrid composite has the highest flexural strength among its counterparts. Also, the GABGRP (with Al wire mesh) hybrid composite has the highest tensile load capacity when compared with the other two composite types. GABGRP hybrid also has a higher toughness value than the standard GFRP. GABGRP (with Al wire mesh) also exhibits a lower hardness value, which shows that it is less brittle. Thus, it is inferred that the inclusion of banana fibers and aluminium wire mesh as reinforcements in GFRP hybrid composites influences its mechanical properties.

Improvement/Applications: The inclusion of aluminium as wire mesh and banana fibers in GFRP that influences its mechanical properties, contributing towards a higher flexibility, ductility, impact and tensile properties.

1. Introduction

Fiber Metal Laminates (FMLs) are hybrid composite consisting of alternative thin layer of meal plies and fibre reinforced epoxy. The fiber/metal composite technology combines the advantages of metallic materials and fibre reinforced matrix systems. The most widely used metal in fiber metal laminates is aluminium. Aluminium foils and meshes have extremely light in weight, have low density, high strength, excellent corrosion resistance and also cheap. Fiber metal laminates take advantages of metal and fiber-reinforced composites, providing superior mechanical properties to the conventional one. A relatively newer range of composites even employ natural fibers as reinforcements. The interest in natural fiber-reinforced polymer composite materials is rapidly growing both in

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terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable, and biodegradable. Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative as man-made fibers used for the manufacturing of composites.

From the previous investigation studies it is revealed that Glass Fiber Reinforced Plastics and Fiber Metal Laminates are the best alternatives in terms of lower cost and superior mechanical properties. According to \(^1\), GLARE (Glass Laminate Aluminium Reinforced Epoxy composites) are the most successful and popularly used type of fiber metal laminates. Wang\(^4\) experimented natural coconut fibres composites to find the tensile strength, fineness, weight distribution. Comparing to coconut coir fiber, the human hair reinforced glass fibre has comparatively higher ultimate stress. Moreover, other properties are also found enhanced comparing to coconut coir reinforced glass fibre. Ion Dinca, Adriana Stefan and Ana Stani\(^3\) mention about the higher behavior of carbon fibre aluminum laminates compared to aluminum-fibre glass laminates. According to \(^4\), natural fibers are renewable, cheap, completely or partially recyclable, and biodegradable. Plants, such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, etc., as well as wood, used from time immemorial as a source of lignocelluloses fibers, are more and more often applied as the reinforcement of composites. In\(^2\) carried out experiments using tensile and flexural (three-point bending) tests of natural fibers reinforced with composite materials (Musaceae/epoxy). The fracture toughness and fracture mode of Banana Fiber and GFRP were individually studied by\(^5\). Samples of several Jute-Bagasse-Epoxy \\& Jute-Lantana camera-Epoxy hybrids were manufactured and their properties studied by\(^6\). In\(^8\) studied the properties of bio-composites reinforced with natural fibers. In\(^8\) highlighted the influence of eco-friendly coconut coir and human hair inclusion on the mechanical properties of hybrid glass fiber reinforced composites.

In\(^12\) have experimented and have found that fatigue behavior in composites presented a decrease in fatigue life when greater tension was applied. In\(^14\) studied the mechanical behavior of Polypropylene and Human Hair Fibres and Polypropylene Reinforced polymeric composites and found that composite with 3 to 5 wt% of bio fibre shows higher flexural strength, flexural modulus and Izod impact strength than non-reinforced polymer. They also find that the tensile and flexural properties decrease when the fibre loading percentage increases. It has been noticed by\(^12\) that by adding of a small wt. percentage of Banana Fiber in GFREC enhances its properties to a great extent. The Hybridization of Banana Fiber and Glass Fiber not only improves the mechanical properties of FRP composite but also reduces its cost and makes it an eco-friendly composite. To put further emphasis on the influence of banana fibers as reinforcements, In\(^14\) have stated in their research work that polymer banana reinforced natural composites are the best natural composites among the various combinations of other natural fibers in polymer matrix composites. In\(^14\) have experiment and found that the hardness is decreasing with the increase in fibre length up to 20 mm. In\(^15\) studied the impact behavior of FML with aluminium as reinforcement. Usage of natural fibers as reinforcements also improve the mechanical properties of glass fiber reinforced composites. In\(^14\) there was slight increase in the thickness of the reinforcement materials. There was non-uniform distribution of reinforcement in material, Microstructure revealed fibre cracks which were oriented in line to the crack growth on the skin material. No other defects were observed. In\(^17\) Speed, feed rate and tool angle have significant influence on the entrance and exit damages but tool diameter does not have any influence. Similarly, the squares of all input factors have a dominant influence on the damages. Optimization has been done by setting the objective as minimizing the output responses.

However, no research has been done so far on the inclusion of both aluminium and banana fibers as reinforcements into GFRP hybrid composites. The present paper thus reports the influence of aluminium and banana fibers as reinforcements in hybrid glass fiber reinforced plastic composites. Aluminium is employed as reinforcement in GFRP both as foils and wire meshes, along with banana fiber-strands. The two types of composites: GFRP and GABGRP (Glass-Aluminium-Banana-Glass hybrid composite) are fabricated through hand-layup process and are subjected to a variety of mechanical tests in order to determine their mechanical properties and compare them.

### 2. Specimen Preparations

The specimens are prepared by a method called hand-layup process as seen in Figures 1, 2. In total, there are three types of specimen: the standard GFRP (Glass Fiber
Reinforced Plastic), and two variations of GABGRP (one with aluminium foils and the other with aluminium wire mesh as reinforcements). All the specimens have a thickness of 4 mm. The glass fibers are used in the form of woven roving, the banana fibers in the form of strands and aluminium as both foils and wire mesh. The foils and wire mesh have a thickness of 0.5 mm.

The GABGRP hybrid composite has a total of 9 layers, comprising of 5 Glass woven roving layers, 2 Aluminium foil layers and 2 Banana-fiber layers. The aluminium foils/wire mesh and banana fibers are used alternatively. The pure GFRP specimen, on the other hand, has 7 layers of just glass woven roving. The binding agent was used as a combination of epoxy resin-type LY556 and hardener-type HY951 in the ratio 10:1. While preparing GABGRP with aluminium foil, circular notches are punched in the foil to enhance bonding between the immediately adjacent layers as seen in Figure 3.

After fabrication, the specimens are cut according to ASTM standards for further mechanical testing as follows.

3. Mechanical Testing

After the specimens are cut in accordance to ASTM standards, (Table 1) they are subjected to mechanical tests.

Table 1. ASTM standards for specimen cutting

| Sl. No | TEST                     | SPECIMEN DIMENSIONS (1 x b) in mm |
|--------|--------------------------|-----------------------------------|
| 1      | Tensile                  | 175 x 25 (ASTM D3039)             |
| 2      | Flexural                 | 125 x 25 (ASTM D790)             |
| 3      | Impact (Drop Test)       | 60 x 60 (ASTM D3029)             |
| 4      | Hardness                 | 55 x 25                           |

3.1 Flexural Test

A total of 6 Specimens are prepared for the test. These specimens have been separated into three different groups, each consisting two specimens (Figure 4). The first two specimens are normal GFRP, the second group is GABGRP (Al Foil) and the third one is GABBRP (Al Wire Mesh). The 3-point bending test fixtures were then fitted in the UTM machine. The specimens were then loaded turn by turn, so that a span length of 100 mm was maintained for each specimen. The feed rate was set as 1 mm/sec. For each specimen, the bending test was done while the data was interpolated simultaneously in the ‘Horizon’ software.

‘Force’ and ‘Position’ were the two primary data variables collected as output, using which, Load vs. Deflection curves were plotted. The data was collected, the values of flexural stress and strain were estimated and the graphs were plotted (Figure 8).

3.2 Tensile Test

A total of 8 Specimens are prepared for the test. These specimens have been separated into four different groups, each consisting two specimens as follows (Figure 5). The first two specimens are normal GPRP, the second group
is GABGRP with notched aluminium foil reinforcement, the third one is GABBRP with notch-less aluminium foil reinforcement and the last group is GABGRP with aluminium wire mesh reinforcement.

The tensile test fixtures were then fitted in the UTM machine. The specimens were then loaded turn by turn, such that a span length of 100 mm was maintained for each specimen. The feed rate was set as 2 mm/sec. For each specimen, the tensile test was done while the data was interpolated simultaneously in the ‘Horizon’ software. ‘Force’ and ‘Position’ were the two primary data variables collected as output, using which, Load vs. Deflection curves were plotted (Figure 6).

Figure 5. Tensile testing of the specimen.

Figure 6. Impact testing of the specimen.

3.3 Impact Test

A total of 6 Specimens are prepared for the test. These specimens have been separated into three different groups, each consisting two specimens as follows (Figure 7). The first two specimens are normal GPRP, the second group is GABGRP (Al Foil) and the third one is GABBRP (Al Wire Mesh). Factories Plus - Drop Impact Tester was used for this purpose. The specimen size was fixed as 60 x 60 mm, and the drop speed was set as 3 m/s for all the specimen.

‘Peak force’, ‘Impact Energy’, ‘Total Deformation’ were some of the variables collected as output, using which graphs were plotted (Figure 8).

Figure 7. Hardness testing of the specimen.

Figure 8. Load vs. displacement graphs for flexural test.

3.4 Hardness Test

The hardness of both the specimens – GFRP and the hybrid were estimated using Brinell hardness tester (Figure 9) with a ball-indenter diameter of 10 mm. A load of 2000 kg was applied to the specimen to be tested. Each specimen was indented twice, the diameters measured, hardness values (BHN number) estimated for each, and a mean value arrived at.

Thus, a total of four mechanical tests were performed according to ASTM standards and the respective mechanical properties determined.

4. Results and Discussion

The mechanical properties were determined from the values of the various variables obtained as a result of the tests that were conducted. The data was interpolated to plot graphs and perform comparative studies.

4.1 Flexural Test

The ‘Load ‘ vs. ‘Displacement’ graph was plotted from the ‘Force’ and ‘Position’ values obtained as outputs of the flexural test (Figure 8).
The three types of graphs were plotted together as follows: The values obtained were tabulated to do a comparative flexural study (Table 2).

Table 2. Comparative flexural study

| Sl.No | SAMPLE ID                                      | ULTIMATE LOAD (KN) |
|-------|------------------------------------------------|--------------------|
| 1     | GFRP                                           | 108.75              |
| 2     | GABGRP (Aluminium foil and banana fibres reinforcement) | 270.88              |
| 3     | GABGRP (Aluminum wire mesh and banana fibres reinforcement) | 835.41              |

It has been observed from the graphs of the GABGRP hybrid that there is a resistance to load even after the breakage of the first layer of glass fibred. The reinforcements, especially aluminium, being ductile in nature, thus resist the fracture to some extent. Also the usage of wire mesh as reinforcement exponentially increases the capacity of the hybrid composite to withstand a larger load. It was also observed that the replacement of Al foils by Al wire mesh negated the de-lamination effect observed otherwise. It was observed that de-lamination in the case of GABGRP with Al foil reinforcement occurs due to improper bonding between the smooth surface of the foil and its adjacent glass fiber layer Figure 10.

4.2 Tensile Test

The ‘Load ’ vs. ‘Displacement’ graph was plotted from the ‘Force’ and ‘Position’ values obtained as outputs of the flexural test (figure 8). The three types of graphs were plotted together and a comparative tensile study is done (Table 3).

It is inferred that due to the presence of notches in the aluminium foil, the load-withstanding capacity of the foil reinforced GABGRP hybrid increases (Figure 11). This is due to greater bonding between the adjacent layers of the notched foil. And by replacing the foils with wire meshes, the load-withstanding capacity of the hybrid increases drastically. Here too, it is observed that the wire mesh inclusion in the GABGRP hybrid composite prevents de-lamination of the specimen unlike the case of GAGRP-Al foil hybrid, where a considerable amount of de-lamination is observed.

Table 3. Comparative tensile study

| Sl.No | SAMPLE ID                                          | ULTIMATE LOAD (KN) |
|-------|----------------------------------------------------|--------------------|
| 1     | GFRP                                               | 12200              |
| 2     | GABGRP (Aluminium Notchless Foil and Banana Fibres reinforcement) | 13900              |
| 3     | GABGRP (Aluminium Notched Foil and Banana Fibres reinforcement) | 14800              |
| 4     | GABGRP (Aluminum Wire Mesh and Banana Fibres reinforcement) | 19430              |

4.3 Impact Test

The impact energies (in Joules) of the hybrids and the standard GFRP were plotted (Figure 12). It is inferred...
that presence of Al wire mesh and banana fibers in the hybrid composite increases its impact energy and hence its toughness Table 4.

![Figure 12. Impact energy chart.](image)

**Table 4. Comparative impact energy chart**

| Sl.No | SAMPLE ID                          | IMPACT ENERGY (J) |
|-------|------------------------------------|-------------------|
| 1     | Standard GFRP                      | 3.641             |
| 2     | GABGRP (Al foil and banana fibres reinforcement) | 5.027             |
| 3     | GABGRP (Al wire mesh and banana fibres reinforcement) | 6.264             |

### 4.4 Hardness Test

Using the values of the diameter of indentation in each specimen after hardness testing, the respective BHN numbers were found out (Figure 13). Thus, it is inferred that the inclusion of Aluminium and Banana fibers makes the composite less hard. Being less hard, the hybrid composites are less brittle and more ductile (Table 5).

![Figure 13. Comparative BHN value chart.](image)

**Table 5. Comparative hardness study**

| Diameter in mm | GFRP | GABGRP (Al foil) | GABGRP (Al wire mesh) |
|----------------|------|------------------|-----------------------|
| Average (Diameter in mm) | 6.9  | 7.4              | 8                     |
| BHN (Diameter in mm)       | 44.54| 37.60            | 31.83                 |

### 5. Conclusion

From the investigation conducted on Glass-Aluminium Foil/Wire Mesh-Banana Fibre-Glass Hybrid Composites, it has been inferred that: The GABGRP (with Al wire mesh) hybrid composite has the highest flexural strength among its counterparts. Also, the GABGRP (with Al wire mesh) hybrid composite has the highest tensile load capacity when compared with the other two composite types. GABGRP hybrid also has a higher toughness value than the standard GFRP. GABGRP (with Al wire mesh) also exhibits a lower hardness value, which shows that it is less brittle. Thus, it is inferred that the inclusion of banana fibers and aluminium wire mesh as reinforcements in GFRP hybrid composites influences its mechanical properties, contributing towards a higher flexibility, ductility, impact and tensile properties.

### 6. References

1. Kaleeswaran P, Babu KMK, Kumar BSM. Fabrication of Fibre Metal Laminate (FML) and evaluation of its mechanical properties. International Journal of Applied Engineering Research. 2014; 9(26):8872–4.
2. Wei W, Gu H. Characterisation and utilization of natural coconut fibres composites. Materials and Design; 2009. p. 2741–4.
3. Chandramohan D, Marimuthu K. A review on natural fibers. International Journal of Recent Research and Applied Studies. 2011 Aug; 8(2):194–205.
4. Sapuan SM, Leenie A, Harimi M, Beng YK. Mechanical properties of woven banana fiber reinforced epoxy composites. Materials and Design. 2006; 27(8):689–93.
5. Santhanam V, Chandrasekaran M, Elayaperumal VA. Mode I fracture toughness of banana fiber and glass fiber reinforced composites. Advanced Materials Research. 2012 Dec; 622–623:1320–4.
6. Study of mechanical properties of hybrid natural fiber composite [Internet]. 2011. Available from: http://ethesis.nitrkl.
ac.in/2155/1/study_of_mechanical_properties_of_hybrid_natural_fiber_composite.pdf.

7. Silva LJD, Panzera TH, Christoforo AL, Durão LMP, Lahr FAR. Numerical and experimental analysis of biocomposites reinforced with natural fibres. International Journal of Materials Engineering. 2012; 2(4):43–9.

8. Senthilnathan D, Babu AG, Bhaskar GB, Gopinath KGS. Characterization of glass fiber–coconut coir–human hair hybrid composites. International Journal of Engineering and Technology. 2014 Feb–Mar; 6(1):1–8.

9. Mulinari DR, Baptista CARP, Souza JVC, Voorwald HJC. Mechanical properties of coconut fibers reinforced polyester composites. Procedia Engineering. 2011; 10:2074–9.

10. Choudhry S, Pandey B. Mechanical behavior of polypropylene and human hair fibres and polypropylene reinforced polymeric composites. International Journal of Mechanical and Industrial Engineering. 2012; 2(1):1–4.

11. Kumar A, Choudhary D. Development of glass/banana fibers reinforced epoxy composite. International Journal of Engineering Research and Applications. 2013 Nov–Dec; 3(6):1230–5.

12. Sakthivel M, Ramesh S. Mechanical properties of natural fiber (banana, coir, sisal) polymer composites. Science Park. 2013 Jul; 1(1):1–6.

13. Biswas S, Kindo S, Patnaik A. Effect of fibre length on mechanical behavior of coir fiber reinforced epoxy composites. Fibres and Polymers. 2011 Feb;12(1):73–8.

14. Ardakani MA, Khatibib AA, Asadollah S. A study on the manufacturing of glass-fiber-reinforced aluminum laminates and the effect of interfacial adhesive bonding on the impact behavior. Proceedings of the XIth International Congress and Exposition Orlando, Florida USA; 2008 Jun. p.1–9.

15. Dinca I, Stefan A, Stan A. Aluminum/glass fiber and aluminum/carbon fiber hybrid laminates. Incas Bulletin. 2010; 2(1):33–9.

16. Logesh K, Raja VKB, Velu R. Experimental investigation for characterization of formability of epoxy based fiber metal laminates using Erichsen cupping test method. Indian Journal of Science and Technology. 2015 Dec; 8(33):1–6.

17. Vinayagamoorthy R, Subramanyam KG, Kumar TN, Reddy YH. Modeling and analysis of drilling induced damages on hybrid composites. Indian Journal of Science and Technology. 2016 Apr; 9(16):1–10.