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Original Article

Mechanical Properties of Natural Bamboo Fiber Reinforced Fiber Metal Laminates with Different Layout Configurations

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Abstract *- The hybrid composite materials FMLs are known as Fiber Metal Laminates. FMLs are developed by laminating alternate aluminium alloy or metal and composite layers to improve the mechanical properties and material fracture characteristics. Recently, due to the globalization of business, new requirements like lightweight, high strength, high fracture toughness, and safety, the development of new materials that have superior properties to fulfil the current demands of aerospace industries and automation industries have reached a peak. Also, there is a peak demand for natural fiber in the manufacturing of FMLs. This presented work of research considered the development of FMLs with natural bamboo fiber, Al-2024-T3 aluminium alloy, epoxy as a resin, and the testing of FMLs for mechanical properties of FMLS. Also, development and testing FMLs with different fiber orientations to study the effect of fiber orientation on mechanical properties. Natural bamboo fiber metal laminates are developed by hand layout of an alternate layer of Al-2024-T3 aluminium alloy and a composite layer of epoxy-bamboo fiber followed by compression in the compression moulding machine with maintain 80°C for 10 min. The Pressure of 4KN is kept for 24 hours in a compression moulding machine to press the aluminum and bamboo-epoxy composite layers. The tensile properties of bamboo FMLs are extracted using the Universal Testing Machine (UTM) per the standard ASTM D 3039 for 0° and 90° fiber orientation. The tensile strength of natural bamboo fiber metal laminates is the optimum strength between Aluminum alloy and composite material. This research paper presents an experimental investigation by tensile test to extract mechanical properties of FMLs with 0° and 90° orientation of fiber and study the fiber orientation effect on mechanical properties. The tensile strength of FMLs with 0° fiber orientation is observed as 59.52% higher than that of the FMLs with 90° orientation of fiber. The modulus of elasticity in FMLs with 0° orientation of fiber is recorded more than two times that of the 90° fiber orientation FMLs.*

Keywords *- Fiber Metal Laminates, Mechanical Tensile Properties, Manufacturing Method, ASTM D 3039.*

1. Introduction - Fiber Metal Laminates

Fiber metal laminates were recently developed with dissimilar materials and fibers to enhance mechanical properties like high strength, high fatigue resistance, and better fracture characteristics to fulfil the demand of automation and aerospace industries like light structure and superior mechanical and fracture properties [1]. To meet the current needs of automation and aerospace industries, the hybrid structure fiber metal laminates were developed by alternate metal and composite layers [1, 2, 6]. Metal-Material like aluminium alloy like Al-2024-T3 [6, 10, 19], Al-7475-T6 [6-10], other metal-material like titanium [2, 4, 7, 10-13], magnesium [3, 5], and reinforced fiber like glass, aramid, carbon [3, 4, 6-9] used to develop the FMLs. Recently to develop eco-friendly FMLs, natural fiber metal laminates are on a peak by replacing natural fiber [5, 14] instead of glass or carbon fiber [15]. Epoxy was used with a hardener by a ratio of 10:1 [2, 3, 32, 34] to develop composite layers and for adhesive bonding [6, 16, 33] between metal alloys and composite layers. The hybrid structure of FMLs is developed by adhesive bonding of metal alloy sheets and layers of composite, so the surface treatment of aluminium sheets plays a significant role in enhancing the FMLs' strength. Many methods were used to prepare the surface of metal sheets or surface treatment. Generally, the mechanical abrasion method is used for the surface treatment of aluminum alloy because of its ease of use. Other surface treatment processes like alkaline, anodizing, and etching are used for surface treatment of metal alloy sheets to enhance the properties of FMLs [5, 6, 33]. Autoclave [21] and resin transfer moulding [16, 26] also manufacture fiber metal laminates instead of the hand layout process. Mechanical properties of FMLs depend on the aluminium sheet thickness, composite layer thickness, resin-to-fiber ratio, and overall thickness of FMLs. Global constitution properties can be predicated by two methods: metal volume fractions known as MVF [4, 13, 20] and classical laminate theory known as CLT [9, 11]. These theories are used to predict global constitute properties of FMLs and give accurate predictions of properties. MVF is an easy method to use to predict mechanical properties, tensile strength, modulus of elasticity, etc., compared to CLT.

Standard FMLs are developed by 0.2 to 0.5 mm thin metal alloy sheets and 0.2 to 0.3 mm thin composite layers with different fiber configurations or orientations [6-9]. The disadvantage of FMLs in their development is that they require a long time for the resin curing process. As FMLs are manufactured by a hybrid structure of metal alloy and composite material sheets, the possibility of delamination of layers can be observed during the cutting of FMLs. Generally, water jet cutting, wire cutting, and laser machining processes are used to cut or prepare specimens for testing. The water jet cutting process is better to use for cutting the FMLs when FMLs contain non-conducting material layers because wire cut and laser machining processes do not cut the material due to non-conducting material layers. In water jet machining, we need to optimize parameters like the flow of the water jet, distance of the nozzle, etc., to reduce the delamination of layers. Compared to the wire cut and laser machining process, more delamination occurs during the cutting of FMLs in the water jet machining process.

2. Literature Review

The development of FMLs for aerospace applications is advanced for better strength and fracture toughness compared to monolithic materials. FML’s development with monolithic aluminum Al-2024-T3 has better fracture toughness and fracture characteristics than pure monolithic aluminum Al-2024-T3. The crack growth of monolithic aluminum Al-2024-T3 rapidly increases, while GLARE and ARALL FML’s crack growth are slower and almost constant slow crack growth [1]. Mechanical properties of Zn-Al-based FML were tested using a CMT5205 electronic UTM machine, considering the extensometer’s span length of 25mm to measure deformation. Zn-Al-based FML’s strength is 103% compared with the original magnesium alloy [3]. The effect of using alternative metal material, magnesium instead of aluminum, is studied, and it observed that magnesium is 1.55 times less heavy than aluminum with minor differences in tensile strength, bending strength and impact toughness. So, magnesium is better than aluminium for FML's development in the application where less weight is required by compromising slight strength [10].

Tensile-strength prediction of titanium-based FMLs with different fiber orientations between 0 degree to 90 degree with a 15 degree difference in fiber orientation is carried out by tensile testing. It is predicted that as the fiber orientation angle increases, tensile strength decreases. FMLs with 0-degree fiber orientation give higher tensile strength, while FMLs with 90 degree fibber orientation give lower tensile strength of FMLs [11].

FMLs with continuous film stacking have better properties than monolithic steel plates with 0.8 mm thickness. FMLs with 2 mm thickness archive 29% weight reduction compared with the steel plate of 0.8 mm [20]. It is better to use FMLs for lightweight structures. However, the scaling also affects the strength of FMLs. The size of FMLs varies in 1D, 2D and 3D and compared the normalized stress of all specimens. The normalized stress increases in 2D with increases in the size factor, while in 1D and 3D, normalized stress decreases with increases in the size factor [24].

3. Material and Manufacturing of Fiber Metal Laminates

The hybrid composite FMLs are the composite material of thin metal alloy sheets and layers of reinforced composite. In this study, for metal alloy 0.4 mm thin sheet of aluminium metal alloy Al-2024-T3 (Special Metals-Mumbai) and composite layers, bamboo (yarn) fiber (The Yarn Guru India-Bhilwara) as reinforcement and LY556 epoxy resin with HY951 hardener (Heranba Industries Ltd. – Chennai) as a matrix was used to manufacture of natural bamboo fiber metal laminates FMLs.

Fig. 1 LY556 epoxy and HY951 hardener

Epoxy resin LY556 with hardener HY951 was employed as a matrix to reinforce natural bamboo fibers for natural bamboo-epoxy composite layers. Figure 1 shows resin LY556 epoxy and HY951 hardener. The hardener (HY951) was added by a ratio of 1:10 hardener to epoxy resin (LY556).

In the present research work to manufacture FMLs, a hand abrasion process by fine-grade sandpaper of 100-size grit involved to pre-prepare the surface of Al-2024-T3 to increase the adhesive strength at the intermediate between the layers of thin aluminium Al-2024-T3 sheet and thin layers of epoxy-bamboo reinforced composite. The prepared surface of Al-2024-T3 is then cleaned using lab-grade acetone to remove dust and oil particles from the surface of the aluminum Al-2024-T3 sheet. The stacking sequence of FML's Al-Epoxy-bamboo composite-Al-Epoxy-bamboo composite-Al to maintain the 1.8 mm FML's thickness. Total five layers of stacking with 3 layers of Al-2024-T3 with 0.4 mm thickness and 2 layers of Epoxy-bamboo composite with 0.3 mm thickness. A hand layup process followed by compression [12, 16-18, 34] in a compression moulding machine at room temperature for 24 hours was used to manufacture FMLs. Initially, an 80°C temperature was maintained for an interval of 10 min in a compression moulding machine to properly cure the epoxy resin.

The stacking sequence of FMLs in this study is considered as Al -2024 -T3 / Bamboo - epoxy Composite / Al -2024 -T3 / Bamboo - epoxy Composite / Al -2024 -T3. The first inner surface of Al-2024-T3 for the Top and Bottom sheets and both surfaces of Al -2024 -T3 for the Middle sheet were prepared by hand abrasion followed by cleaning with acetone. The bamboo yarn was wound on the middle aluminium sheet, followed by a layup of epoxy resin on both sides of the wounded aluminium sheet. It maintained a 40:60 ratio of fiber to resin and 0.3 mm thickness. Figure 2 shows bamboo yarn corn used for winding.

Fig. 2 Epoxy resin LY556 with hardener HY951

Also, a hand layup of epoxy resin was done on the inner surface of the top and bottom aluminium sheet and placed on the top and bottom side of the middle sheet to maintain the required stacking sequence. All stacking layers are compressed with a 4 KN load in the Compression moulding machine (CIPET - Ahmedabad) such that it maintains a 1.8 mm total thickness of FMLs. Figure 3 shows the manufacturing setup for developing natural Fiber Metal Laminates (FMLs).

Fig. 3 Manufacturing setup

4. Specimens Preparation and Experimental Tensile Testing

The test specimens of FMLs were prepared according to ASTM D-3039 standard [31] from the manufactured FMLs Sheet. Cutting FMLs test specimens from FMLs sheets was done using a water jet machining process. As shown in the figure rectangle, specimens of size 250 mm (L) x 15 mm (B) x 1.8 mm (t) were cut from FMLs sheet for 0° fiber direction (Figure 4) and 175 mm (L) x 25 mm (B) x 1.8 mm (t) were cut from FMLs sheet for 90° fiber direction (Figure 5) by water jet machining [31].

Based on Standard ASTM D-3039 [22-29], the mechanical properties of natural-bamboo fiber metal laminates were tested using UTM. Figure 6 shows the experimental setup for tensile testing. Rectangle FML specimens were placed with emery cloth to grip the specimen in Instron UTM. Gripping lengths of 56 mm and 25 mm were considered for 0° specimens and 90° specimens, respectively.

Quasi-static tensile tests were directed with a constant 1 mm/min [6, 23, 30, 31] of crosshead displacement to test the specimens with gauge lengths of 138 mm (0° specimen) and 125 mm (90° specimen) as per guidelines and recommendations in ASTM D3039 [31] for mechanical properties.

Two specimens were prepared and tested for better accuracy. The load-deflection and stress-strain illustrations were recorded for all specimens till the specimens failed. Mechanical properties like tensile strength and modulus of elasticity of specimens are noted from the tensile test results.

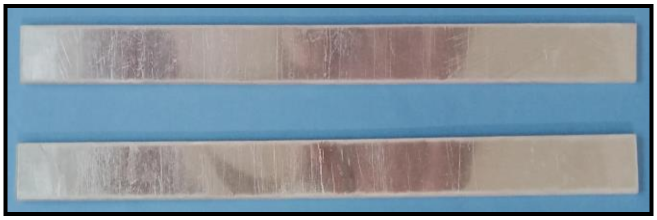

Fig. 4 0° fiber orientation specimens of size 250 mm (L) x 15 mm (B) x 1.8 mm (t) were cut from FMLs sheet

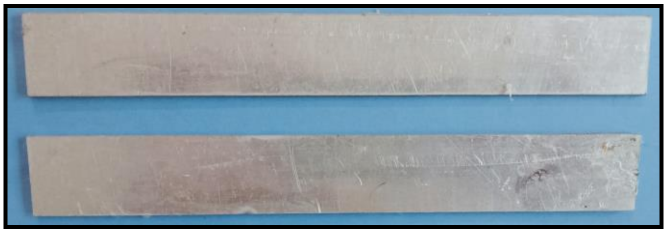

Fig. 5 90° fiber orientation specimens of size 175 mm (L) x 25 mm (B) x 1.8 mm (t) were cut from FMLs sheet

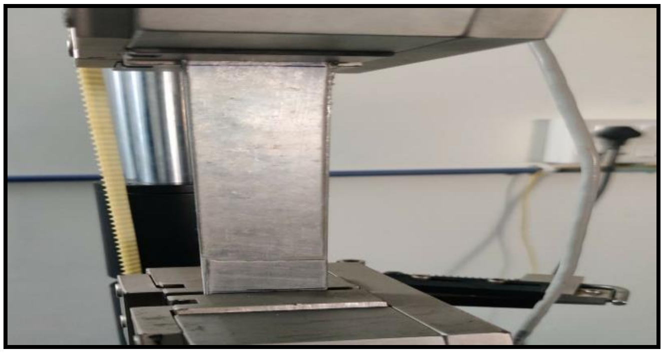

Fig. 6 90° fiber orientation specimens of size 175 mm (L) x 25 mm (B) x 1.8 mm (t) were cut from FMLs sheet

5. Results and Discussion

The load-deflection illustration (Figure 7) and stress-strain illustration (Figure 8) are recorded for a 0° fiber orientation specimen from the tensile test results. The Nominal strength of 268 MPa, Yield Stress of 189 MPa, and Modulus of Elasticity of 14708 MPa was recorded for the 0° fiber orientation specimen.

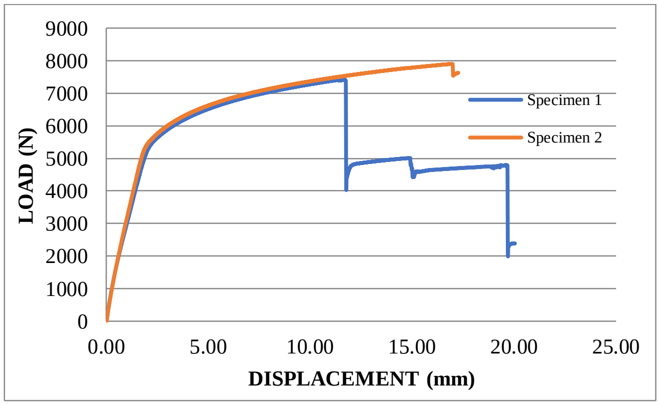

Fig. 7 load-displacement diagram (0° specimen)

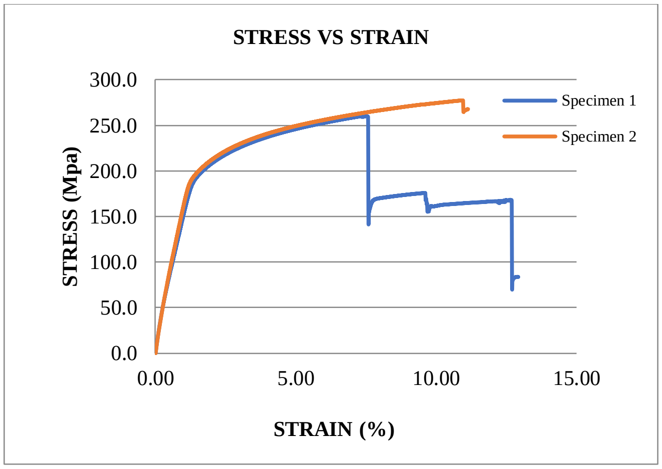

Fig. 8 load-displacement diagram (0° specimen)

Table 1. Tensile strength (0° specimen)

Specimen Type	Yield Stress	Max Load	Modulus of Elasticity (E)	Ultimate Stress
0 degree (Specimen 1)	187.98 MPa	7413.10 N	14.241 G Pa	260.00 M Pa
0 degree (Specimen 2)	190.22 MPa	7903.08 N	15.174 G Pa	277.30 M Pa
0 degree (Avg.)	189.10 MPa	7658.09 N	14.707 G Pa	268.65 M Pa

The load-deflection illustration (Figure 9) and stress-strain illustration (Figure 10) are recorded for a 90° fiber orientation specimen from the tensile test results.

The nominal strength of 168 MPa, Yield Stress 148 MPa, and Modulus of Elasticity 6635 MPa were recorded for 90° fiber orientation.

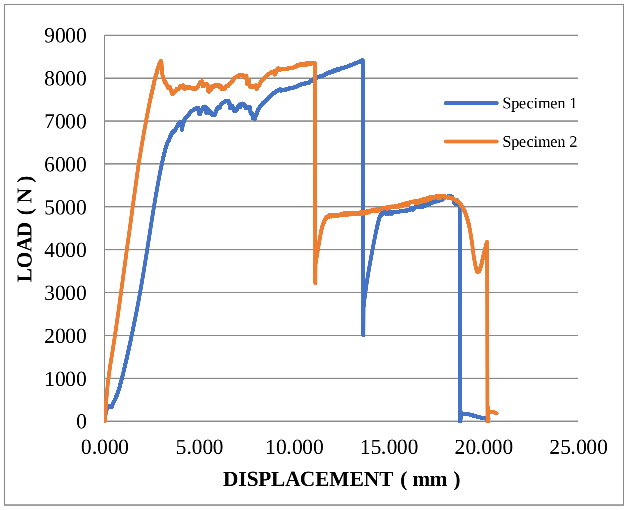

Fig. 9 Load-displacement diagram (90° specimen)

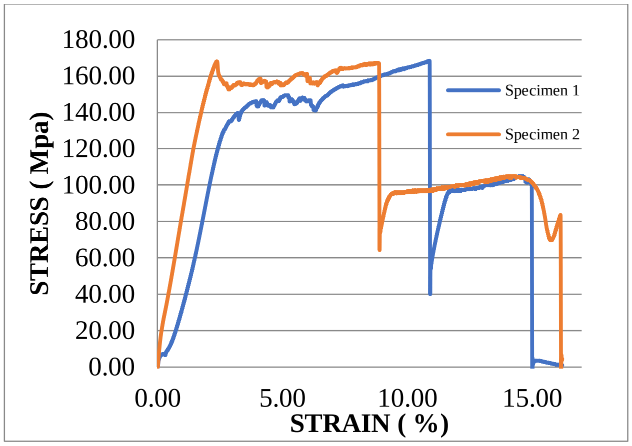

Fig. 10 Stress-Strain diagram (90° specimen)

Table 2. Tensile strength (90° specimen)

Specimen Type	Yield Stress	Max Load	Modulus of Elasticity (E)	Ultimate Stress
90 Degrees (Specimen 1)	131.522 MPa	8419.69 N	4973.97 MPa	168.39 MPa
90 Degrees (Specimen 2)	165.999 MPa	8399.95 N	8297.29 MPa	167.99 MPa
90 Degrees (Avg.)	148.76 MPa	8409.82 N	6635.63 MPa	168.19 MPa

The load-deflection illustration (Figure 9) and stress-strain illustration (Figure 10) are recorded for a 90° fiber orientation specimen from the tensile test results. The nominal strength of 168 MPa, Yield Stress 148 MPa, and Modulus of Elasticity 6635 MPa were recorded for 90° fiber orientation.

6. Conclusion

In this study, the tensile behaviors of two 0° fiber orientation specimens and two 90° fiber orientation specimens were carried out to extract the mechanical properties of FMLs and the fiber orientation effect on tensile strength and modulus of elasticity. The tensile strength of FMLs with 0° orientation of fiber is observed as 59.52 % higher than the FMLs with 90° orientation of fiber, and the Yield strength of FMLs with 0° fiber orientation is observed as 27.70 % higher than the FMLs with 90° fiber orientation. The Modulus of Elasticity in FMLs with a 0° orientation of fiber is recorded more than two times that of FMLs with a 90° orientation of fiber. The material tensile strength of natural fiber metal laminates is the optimum strength amongst the strength of aluminium Al -2024-T3 and composite material. It is observed that the tensile strength and modulus of elasticity reduce with the increases in the angle of fiber orientation. Using a 0° orientation of fiber is preferred for better strength. Conversely, the fiber orientation parallel to the load direction gives higher tensile strength compared to fiber orientation perpendicular to the load direction. The longitudinal elasticity is more than two times the transverse elasticity for natural bamboo fiber metal laminates.

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