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Experimental evaluation of interlaminar shear stress of CAJRAL type fibre metal laminates prepared with surface treated aluminium sheet by sobbing technique

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ABSTRACT

Purpose: Fiber metal laminates (FML) are a new composite, particularly the CAJRAL type laminate, consisting of aluminium and a carbon/jute/epoxy composite. The present work aims to develop low-density Fiber metal laminates (FML) with good mechanical properties for aerospace applications.

Design/methodology/approach: FML combines the good characteristics of metal, such as ductility and durability, with the benefits of fibre composite materials, such as high specific strength, high specific stiffness, good corrosion resistance and fatigue resistance. The present work introduces an FML consisting of aluminium and Carbon/Jute/epoxy layers. The FML was produced by the hand lay-up technique. The aluminium sheets were surface-treated with the sobbing method. Two combinations of laminate sequencing were selected: Ca 0°/Ca 45°/Al/Ju 45° and Ca 0°/Al/Ca 0°/Al/Ju 0°.

Findings: The structure characterisation after bending tests is shown and discussed. The three point-bending tests are conducted according to ASTM D 2344 standard specifications. Sample-1 (Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0°) is a better result.

Research limitations/implications: Preliminary studies have shown that the metal layers in the laminates and the composite carbon layer, particularly in the bend area of the laminate, significantly impact the nature of the damage. Laminate indicates the complexity of the degradation process of these materials.

Practical implications: The orientation of the reinforcing fibres influences the degree of the laminate structure and affects the ability to form laminates. An important factor influencing the properties of the laminate as a whole is to provide high adhesive properties of the composite-metal connections.

Originality/value: By replacing aluminium with jute. It is observed that the tensile and flexure stresses of the CAJRAL with Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0° are more compared with Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0°.

Keywords: Fiber metal laminates, Three-point bending test, Interlaminar shear stress, Laminate sequencing

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PROPERTIES

1. Introduction

The materials engineering domain constantly faces changes from pure aluminium to metal matrix composites, and metal matrix composites have now become the choice of material used in aerospace industries [1]. When aluminium is reinforced with ceramic particles [2], there is a subsequent improvement in its mechanical properties. Furthermore, [3-5] graphite-reinforced composites [6], CNT-reinforced composites [7] and FML composites[8] are found to be processing. A new way of processing is helpful [9,10] though there were some issues. [11,12] Mechanical properties of fibre meal laminates and the impact of thermal cycles are studied [13]. In addition to hydrothermal effects [14], Silane treatment improved shear strength [15], and preheat treatment has an impact on the life of the FML composites [15]. Tensile properties depend upon the choice of fibres [16,17].

A sandwich laminate structure achieves the main advantage of hybrid laminates: a positive balance of mechanical qualities [18]. Reinforcement with the metal and fibre is challenging as there is a greater possibility of de-lamination. Lawcock et al. concentrated on interlayer delamination and fracture development behaviour in the aluminium and composite layers and failure characteristics. Depending on the material and bending conditions, acquiring complicated loading conditions during bending in a given state of stress is preferable, leading to mixed-type damage. The bending experiments give us more knowledge of how composite materials fail in real-world applications. The strength of the adhesive bond between a polymer composite and a metal laminate can be significantly influenced by surface preparation; adhesion controls this.

There are many methods for surface preparation, including chemical, electrochemical, and mechanical methods. Additionally, the same characteristics of FMLs are determined by the interface bond between the composite ply and metal ply layer. In the literature, many evaluation methods, including interfacial fracture and interlaminar shear, have been suggested to evaluate the adhesive connection in composite laminates. The interlaminar shear stress [17,19, 20-23] of an FML laminate made of layers of aluminium, carbon fibre, jute, and epoxy with different orientations are examined in this article. Following trials with bending, the surface morphology is shown and analysed. Many adhesion and strength tests rely on comparatively simple mechanics [25,26]. Tensile, compressive, flexural, and interlaminar shear strengths are frequently used to assess samples [27-35].

The CAJRAL type laminate, composed of aluminium, carbon, jute, and epoxy, is an example of a fibre metal laminate (FML). FML combines the beneficial characteristics of metal, such as ductility and durability, with the positive attributes of fibre composite materials, such as high specific strength, specific stiffness, superior corrosion resistance, and fatigue resistance. The main objective of the research is to fabricate an FML using layers of carbon, jute, epoxy, and aluminium.

2. Materials and methods

FML laminates consisting of sheets of 2024 T3 aluminium alloy and a polymer with carbon fibre reinforcement were employed in this experiment. The aluminium alloy sheet gauge had a 0.2 mm thickness. Unidirectional carbon filaments encased in an epoxy resin matrix comprise the composite layers. The nominal carbon fibre diameter is about 0.6 mm. The sobbing technique is used for surface preparation to enhance the surface roughness. The roughness will result in better bonding between laminates and matrix material [24].

In the experiment, fibre metal laminates are fabricated using hand lamination. The FML is prepared using the hand lay-up method. The first step is placing a Teflon sheet on top of a glass plate. To act as a relieving agent, smear wax varnish over the Teflon sheet. The Teflon sheet is placed over the wooden stencil to fix it. Epoxy (LY556) and hardener (HY951), at a weight ratio of 10:1, make up the matrix ingredients that must be applied. The fibres should be arranged following the required ply angle, size, and layer count. The fibre-matrix layers' surface is rolled to remove air pockets and cavities. Using a hand brush, coat the jute fibre mat with the resin-based matrix material coating to hydrate it completely. The aluminium sheet should be positioned using normal measurements. Roll again to get rid of any voids and air pockets. Apply the resin-based matrix material coating on the metal sheet. After that, use a hand brush. The previous steps are repeated until the necessary number of fibre metal laminate layers have been created. Add a glass plate next, then another Teflon sheet. For around four hours, the fibre-metal laminates are cured in the environment. After that, the laminates are crushed for 10 minutes using compression moulding equipment at 70 kg/cm^2 and 700 degrees Celsius. The current research work produces two different sequences of FMLs with different stacking orders.

2.1. Laminates orientation

The CAJRAL specimens considered for the short beam bending test are oriented with stacking sequences of Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0° (Sample-1). The CAJRAL specimens to be subjected to the bending test are stacked in the orders of Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0° (Sample-2). The carbon fibre is placed in the top and bottom layers of the laminate. Figure 1 shows the sequence of arrangement for Sample-1.

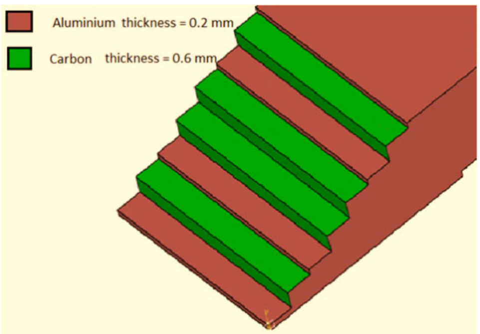


Fig. 1. Material orientation-CAD modeling

A three-point bending test is carried out by a UTM machine. The test was deemed complete when the sample deflected by 25 mm while being moved by the crosshead at a rate of 50 mm per minute. Till the sample cracks, the weight bearing on it increases gradually and consistently. A three-point bending test is carried out by a UTM machine. The test was deemed complete when the sample deflected by 25 mm while being moved by the crosshead at a rate of 50 mm per minute. Till the sample cracks, the weight bearing on it increases gradually and consistently. Figure 2 shows the compression moulding machine used for the fabrication process. Figure 3 shows the specimens prepared for carrying out the three-point bending tests. Figure 4 shows the microscopic image of the aluminium surface. We can see a formation of pits, valleys and peaks due to the sobbing action on the surface of the aluminium.

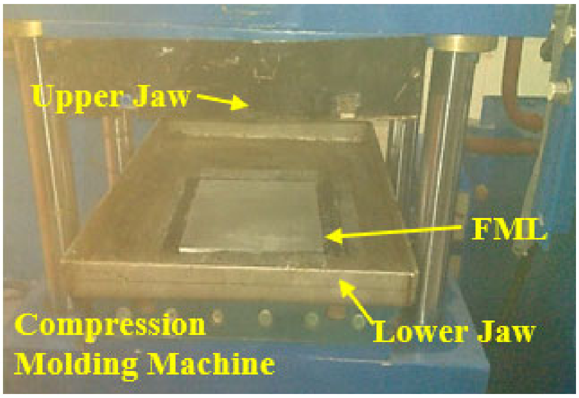


Fig. 2. Compression moulding machine

Compression moulding was used to create carbon-fibre epoxy composites with good mechanical properties. It can produce high-strength sheet moulding parts. Figure 2 shows a schematic representation of the compression moulding process machine setup.

2.2. Fabricated specimen

Compression moulding's experimental set-up is loaded with the arrangement of Figure 2. Hydraulics controls can be used to move the machine up and down. Electricity is used to heat the bottom face of the machine's surface at a pre-determined temperature. Figure 3. shows the incompression moulding method for producing composite samples.

2.3. Scanning Electron Microscopy (SEM)

SEM examines changes in the orientation of micro-structure materials with the help of a microscope. SEM also facilitates monitoring the failure approach at the micro level. Figure 4 shows the SEM image of the aluminium surface.

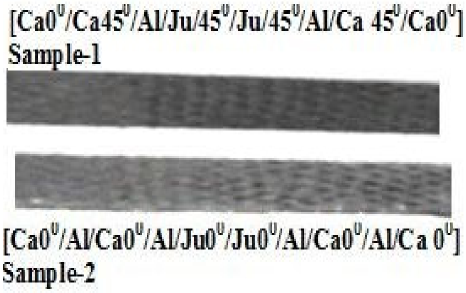


Fig. 3. ASTM D 2344 specimen for carrying out three-point bending test image

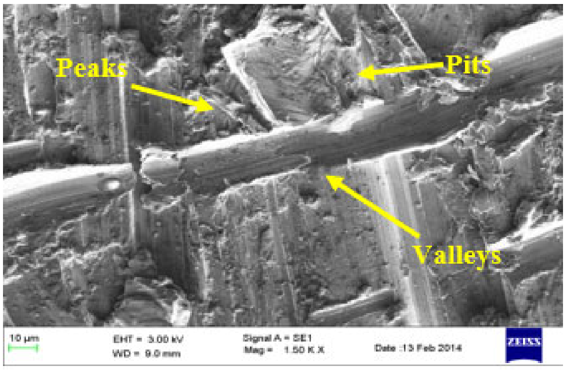


Fig. 4. SEM Image of sobbed aluminium surface

3. Results and discussion

3.1. Bending-short beam shear test

Short beam test (Fig. 5) geometry of CAJRAL specimen is conducted on the test specimens. They are prepared according to ASTM D 2344, and the dimensions of the specimens are 38.1 mm in length, 12.8 mm in width, and 4 mm in thickness.

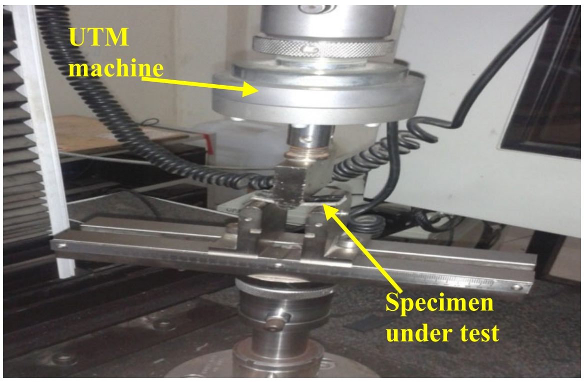
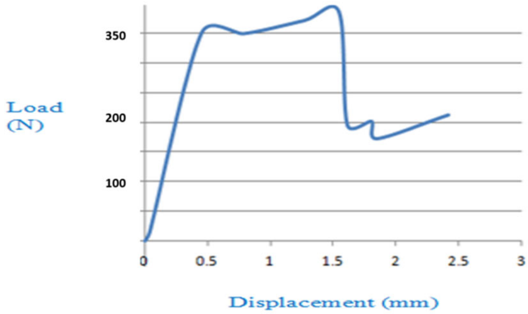


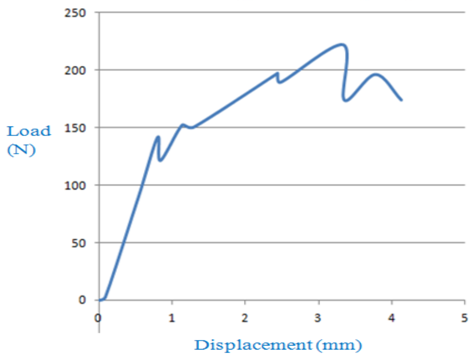
Fig. 5. Experimental setup for short beam shear test

3.2. Flexure loading

As described above, the CAJRALL specimens made for the flexure test are cut and tested under the ASTM D2344 standard. Figures 6a and 6b display the test finding load and displacement curve. From Figure 6a, we can see that there is a steady increase in load until it reaches the yield point. But beyond the yield point, we can identify a rise and fall in the load vs displacement curve. As the flexural load increases steadily, the sheet metals in the FMLs start to delaminate because of poor adhesion between the fibres, matrix and sheet metals. It leads to the rise and fall of stress vs strain values. In Figure 6a, we can see that the ultimate load reaches a point of 400 N. Beyond 400 N, the load suddenly falls, and finally, it reaches the point of failure at around 223 N. Similarly, in Figure 6b, there are more rise and fall points before it reaches the ultimate point around 225 N. We can see that, beyond the given point, the failure of the FMLs reaches around 174 N.



a)



b)

Fig. 6. Stress and strain graph with stacking sequence: a) sample 1 – Ca 0°/Ca 45°/Al/Ju/45°/Ju/45°/Al/Ca 45°/Ca 0°, b) sample 2 – Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0°

3.3. Interlaminar shear stress formula and calculation

Interlaminar shear stress (ILSS) is calculated using the formula:

Table 1.
Interlaminar shear stress (N/mm^2) calculation

Sl. No	Sequence	Sample	Load	Average load, N	ILSS, N/mm^2
1.	Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0°	1	376.018	376.018	7.17
		2	391.777		
		3	260.422		
2.	Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0°	1	249.665	224.914	3.74
		2	203.078		
		3	222.001		

$$\tau = \frac{3P}{4bh} \tag{1}$$

where:
P – maximum compressive force, N;
b – measured specimen width, mm;
h – measured specimen thickness, mm.

The experimental findings of axially loaded CAJRAL specimens are shown in Figures 6a and 6b. It is discovered that the bending stress for CAJRAL with layers 8 and 10 is 376.07 N and 224.91 N, respectively. It is evident by comparing the two graphs that, in both the samples initially, there is a steady increase in load until the yield point, and after the yield point has been attained, there is variation in loads as seen. Further, such ups and downs or rises and falls in loads are due to the delamination between the fibres and metal plates.

Table 1 shows the theoretical results, sample-1 (Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0°) and sample-2 (Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0°). From the Table 1, it can be seen that the Interlaminar shear stress values for sample-1 are higher than those for sample-2.

4. Conclusions

The paperwork focuses on developing carbon fibre reinforced with aluminium and jute laminate (CAJRAL). Since carbon fibre costs more than other fibres, Jute, a natural fibre, is substituted for it on a few layers to reduce pollution. The developed FMLs were subjected to mechanical tests. Additionally, an effort is being made to make low-weight CAJRAL by substituting jute for aluminium because of the low-weight feature of FMLs. It is observed that the tensile and flexure stresses of the CAJRAL with Ca 0°/Ca 45°/Al/Ju 45°/Ju 45°/Al/Ca 45°/Ca 0° (Sample-1) are more compared with Ca 0°/Al/Ca 0°/Al/Ju 0°/Ju 0°/Al/Ca 0°/Al/Ca 0° (Sample-2). The arrangement of fibre metal laminates has better Interlaminar shear stress. The experimental findings show that sample-1 has very good results, with a maximum variation of 91.5% compared to sample-2. So, in the paper, it has been found that the sobbing technique gives better output.

Additional information

The work presented in this paper was presented in “Two Days Virtual National Meet on Nano Interface Science (NIS-2021)”, Chettinad Academy of Research & Education, Chennai, India, 2021.

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