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EVALUATION OF HYGROTHERMAL EFFECTS ON THE MECHANICAL PROPERTIES OF FIBER-METAL LAMINATE

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ABSTRACT
The specimens of Fiber metal laminates (FML) were prepared with aluminium plates and glass fiber/epoxy resin prepreg. This study aims to evaluate the effect of different environmental conditions (hygrothermal) on the mechanical properties of FML, The FML is fabricated by hand layup method and then compressed using compression molding machine .The tensile strength, flexural strength and impact energy of the laminates for two different condition for each test was carried out as per the ASTM standards. The effect of hygrothermal with alternate layer of metal and glass fiber is investigated experimentally and the results were compared. The experimental results were found to be varying under different environmental conditioning.

Keywords: *Fiber-metal laminates, Hygrothermalconditioning, Tensile, Bending, Impact.*

INTRODUCTION
Composite materials gained its interest during the past few decades after the successful use of these materials in applications of Military aircrafts during the Second World War. Fiber Metal Laminates (FML) consists of alternately stacked layers of sheet metal and fiber reinforced polymers. When metals and fibers are used separately they had certain advantages and drawbacks. For example an alloy of Aluminium has low fatigue strength; similarly carbon fiber also has low impact strength. When the two materials were combined together the advantages of material is increased reducing their own drawbacks [1, 2].

The combination of fiber and metal is also used to overcome the characteristics like corrosion, bearing strength, impact resistance and the repair ability of the composite materials. Hence the material has the property and characteristics of both the metal and composite [2].

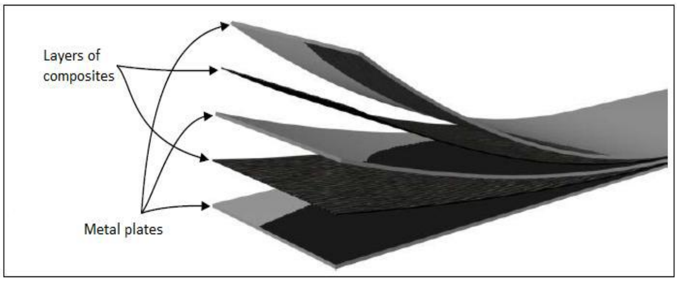

Fig. 1. Fiber-metal laminate (FML) [3]

During the last three decades, there has been a search for lightweight materials that can replace the traditional aluminium alloys in aerospace structures [3]. For an optimal structural design, a new material is needed which combines high strength, low density and high elasticity modulus with improved toughness, corrosion resistance and fatigue properties. Fiber reinforced composites materials almost cover all these demands, except for fracture toughness.

In 1978, researches were carried out to increase the fatigue performance of aluminium alloys at the National Aerospace Laboratory and at the Delft University of Technology in Netherland. An improvement of the fatigue behavior in laminate sheet materials is obtained by introducing a high strength aramid fiber into the adhesive layers. As a result of all these studies, they introduced ARALL, first fiber metal laminate at the Faculty of Aerospace Engineering at the Delft University of Technology in Netherland [4].

In 1990, another attempt to improve ARALL laminates, adopting High strength glass fiber instead of aramid fibres, called GLARE (Glass reinforced) was developed successfully. Glass reinforced aluminium (GLARE) is the successor of Aramid aluminium laminate (ARALL).

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Finally, a new concept for fiber metal laminates (ARALL & GLARE), the Spliced Laminates, is launched by the Structural Laminates Company (SLC) in 1992. Spliced laminates are defined as
FML in which the aluminium layers are interrupted such that the dimensions of the spliced sheets depend on the autoclave dimensions
only [5].

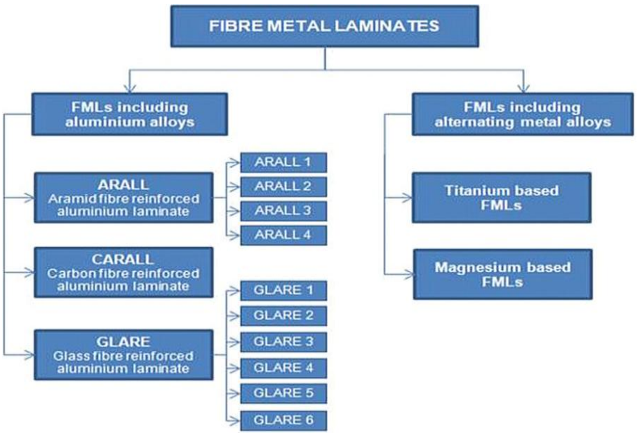

Fig.2. Classification of FMLs based on the metal plies [2]

Aircraft operate in a wide variety of environments, ranging from cold, dry, air conditions at cruise altitude to hot, humid air-conditions in tropical environments. It is therefore important that the materials from which aircrafts are built to maintain their properties during their entire lifetime, even in the most severe environments. The bond between the glass fiber and the epoxy matrix plays a very important role in stress transfer in composites. In general, the influence of moisture in composite materials is most notably present in polymer matrix and also affects the fiber/matrix interface. Polymers, such as epoxies, are prone to absorb moisture when exposed to humid environments. This takes place through a diffusion process, in which water molecules are transported from areas of high concentration to areas of low moisture concentration [6].

In Glare, basically only the outer aluminum layers are exposed as a result of its lay-up design. The prepreg layers are only exposed through free edges of the laminate and holes. Moisture and chemicals however can penetrate the composite lamina at free edges. Thermal degradation due to elevated temperature exposure is also important, since it can affect the integrity of the composite laminate [6, 7].

Experimental

Materials
Glass fiber/epoxy (GF/*E*) prepreg with GSM 400 specification is used for metal/fiber laminate preparation. The fiber reinforcement was plain woven roving. Aluminum alloys 6061-T4 sheets, Epoxy resin (LY 556), Organic modifier Araldite (HY 951) were supplied by Zenith Industries, Bangalore, India.

Hybrid composite processing
The aluminum sheets used for manufacturing this laminate has 0.70 mm thick and its composition is aluminium 6061-T4. In order to processing this FML material, the aluminium sheets have been subjected to cleaning treatment for removing any impurities on aluminium surface. These plates were stacked alternately with glass fiber/epoxy prepreg layers of approximately 0.70 mm thick, with the fibers oriented at 0/90° and a volume fraction of 40% glass fiber.

The laminates were manufactured by the hand layup process, where the aluminium plates were arranged to form three layers of metal stacked with two layers of glass fiber. FML was kept for curing for 24 hours at room temperature.

Hygrothermal Conditioning
The FMLs were subjected to hygrothermal conditioning in a climatic chamber in order to evaluate the influence of moisture combined temperature. This hygrothermal conditioning was based on ASTM D 5229 M-04 for composites undergoing mechanical tests in humid conditions.

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The samples were exposed to 176°F (80°C) and relative humidity of 90%. The average period of conditioning was of three weeks, long enough for the material reach the saturation with moisture. The temperature must remain below the resin glass transition temperature in order to avoid onset of irreversible damage (swelling and cracks), which permanently changes the absorption characteristics of the material.

Tensile test

Tensile testing of the specimens was carried out as per ASTM D3039 Standard by using the Kalpak Universal Testing Machine which has a maximum capacity of 50 kN. The Test specimen was positioned vertically in the grips of the upper and lower jaws of the UTM. The testing speed of the cross head is fixed as 0.50mm/min. A computer connected with the testing machine was utilized. The breaking load for each specimen is recorded by the computer system attached with the Universal testing machine.

Fig. 3. Tensile test- specimen before failure

Fig. 4. Tensile test- specimen after failure

Fig.3. Shows the tensile testing of the laminate and the elongation of the specimen was continued until rupture was observed and the failure of the specimen after tensile test is shown in the Fig. 4.

Flexural test

Flexural testing is carried out by three point bending method as per ASTM D 790 standard by using universal testing machine (UTM) that was used to perform the tensile tests on the specimens and corresponding Load v/s Displacement curve is obtained. The ultimate breaking load is obtained from the graph and by using the formula the flexural stress is calculated.

$$\text{Flexural stress, } \sigma = 3PL / 2bd^2$$

$$\text{Flexural Modulus} = L3m/4bd^3$$

Where P = applied load, b = width of the specimen, d = thickness of the specimen, L =span length, m= slope from the graph.

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Fig. 5. Flexural test setup in universal testing machine

Fig. 6. Flexural test -specimen after failure

Fig.5 shows the flexural test of the specimen by three point bending method, where the load is applied at the mid span the specimen and the corresponding values are recorded. The failure of the specimen after flexural test is shown in the Fig.6.

Impact test

Impact tests are designed to measure the resistance to failure of a material to a suddenly applied force such as collision, falling object or instantaneous blow. Material toughness is the ability of a material to absorb energy during plastic deformation. Izod impact testing is an ASTM D 7136 standard method of determining impact energy. The specimens are cut into required dimension as per standards and tested. The Izod test is most commonly used to evaluate the relative toughness or impact toughness of materials and as such is often used in quality control applications where it is a fast and inexpensive test. It is not a definite test it is just used as a comparison test. Izod test sample usually have a V-notch engrave into the specimen.

A pendulum with adjustable weight is released from a known height. A rounded point on the tip of the pendulum makes contact with the specimen. The impact strength of the specimen is obtained directly from the reading scale in the impact tester.

Fig. 7. Impact test -specimen loaded in the Impact Tester

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Table 1. Specimens subjected to different environmental conditioning

Specimen no	Test name	Conditions
1	Tensile	Not subjected to hygrothermal condition
2	Tensile	Subjected to Hygrothermal condition
3	Bending	Subjected to Hygrothermal condition
4	Bending	Not subjected to hygrothermal condition
5	Impact	Subjected to Hygrothermal condition
6	Impact	Not subjected to hygrothermal condition

Results and discussions

Hygrothermal Conditioning

The effects of moisture present in the atmosphere should always be considered in the design of structural laminates. Therefore, moisture can penetrate into the polymer matrix by means of the diffusion process. The moisture absorbed into polymer matrix composites can reduce the strength and stiffness of the laminate due to the plasticizing effect of the matrix, with the weakening of the fiber/matrix interface. These decreases on the mechanical properties are particularly significant at elevated temperatures. Thus, the presence of moisture into composite can generate significant changes in the physicochemical characteristics of the matrix. Figure 8 shows the results from moisture absorption in the aluminium FML until 21 days of exposure in a hygrothermal conditioning chamber.

By analyzing the curves of moisture absorption for this laminate can be seen that after approximately 21 days of conditioning, the material absorbs moisture average of 0.15% of weight. Also can be observed that after a certain period of exposure it is not absorbed a significant increase of moisture absorption, indicating that the equilibrium was reached. This stabilization occurred after about 480 hours or 20 days of exposure to hygrothermal conditioning. The moisture absorption in this laminate is lower than that one observed in neat epoxy resin or in glass fiber/epoxy laminates since the literature report values in these cases from 1.0 to 3.5wt% [5]. This evidence proves the performance of the outer layers of aluminium, acting as barriers to the diffusion of moisture in the laminate.

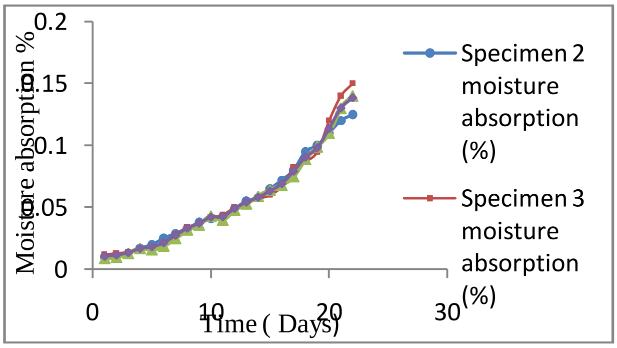

Fig. 8. Moisture absorption results.

Tensile test

The tensile tests are the main form of assessment of mechanical properties of structural composites in short-term trials and static requests. From the results obtained in the tensile tests recorded by means of stress-strain curves, variables such as tensile modulus, tensile stress, strain at yield point and ultimate stress are calculated. In this work it was analyzed the tensile properties of the FML without conditioning and after subjected to hygrothermal conditionings.

Table 2 show the tensile properties values of FML after subjected to environmental conditionings. It was observed that, both the tensile strength and the ultimate tensile strength changes. This small variation for ultimate tensile stress and modulus of elasticity may be in function of some defects generated during the environmental conditioning, degrading the interface and causing probably few fiber/matrix and composite/metal delamination.

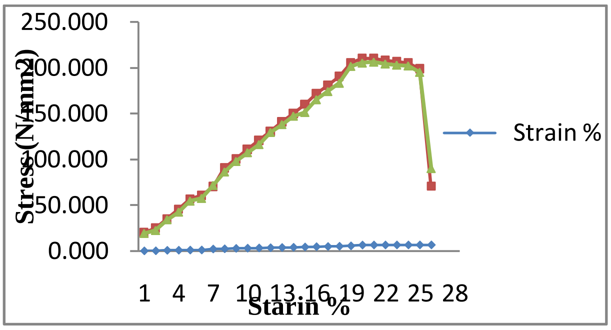

Fig. 8. Experimental Stress - Strain results.

Table. 2. Tensile results of aluminium FML.

Aluminium based FMLs	Tensile stress (MPa)	Ultimate tensile strength (MPa)	Tensile strain (%)
Unconditioned (Specimen 1)	126.28	210.474	3.494
Hygrothermal Conditioning (Specimen 2)	121.23	200.567	5.980

Flexural test

The flexural properties of the fiber metal laminates have been evaluated and the results are tabulated in the Table 3. The FML (Specimen 4) which is not conditioned to hgrothermal has higher flexural strength than FML (Specimen 3) which is conditioned to hygrothermal effect for three weeks. It is observed that the flexural strength for FML is 239.4 MPa for specimen 4 in experimental results whereas the flexural strength for FML is 145.81 MPa for Specimen 3. The difference in the value is due to the hygrothermal conditioning which reduce the flexural strength. The Stress-Strain curve for flexural test is shown in Fig.9.

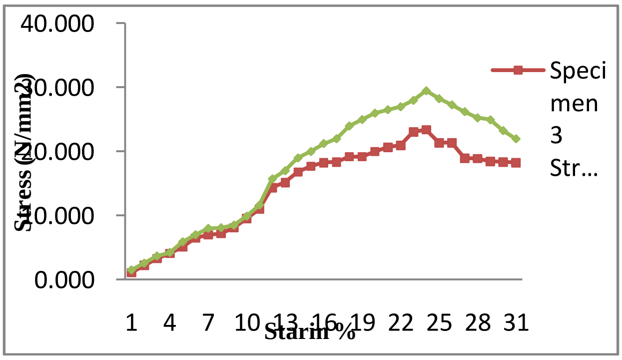

Fig. 9. Experimental Stress - Strain results.

Table. 3. Flexural results of aluminium FML.

Aluminium based FMLs	Flexural strength (MPa)
Unconditioned (Specimen 4)	239.4
Hygrothermal Conditioning (Specimen 3)	145.81

Impact test

Impact energy absorbed for FML specimens 5 which is conditioned at humidity and temperature is found to be 3.70 Joules whereas for specimen 6 which is not conditioned energy found to be 3.97 Joules by experimental results. This may be due to ingress of moisture into the laminate which reduces the energy absorption capacity. The experimental results are shown in Table 4.

Table. 4. Impact test results of aluminium FML.

Aluminium based FMLs	Impact Energy absorbed (Joules)
Unconditioned (Specimen 5)	3.70
Hygrothermal Conditioning (Specimen 6)	3.97

CONCLUSION

The influence of moisture in mechanical properties of Glare was investigated. It was observed that the FML absorbs moisture up to the saturation point (3 weeks). For aluminum, during the hygrothermal conditioning, the oxide protective layer, promoted by chromic acid anodize, reduces corrosion. As a result, in Glare composites the top and bottom aluminum layers prevents moisture absorption and only the free edges of the laminate are prone to moisture intake. These results into a significantly lower rate of moisture absorption compared to other reinforced composites.

For all specimens studied, the strength values decreases when exposed to hygrothermal conditioning. Wet conditioning induces strong matrix plasticization, moisture adsorption tends not to be uniform throughout the material. Hygrothermal conditioning also reduces the Tensile strength and bending strength of FML. A common phenomenon due to moisture uptake in composites is related to induce resin plasticization and, consequently, reduces the mechanical strength values of the laminates, as found in this work.

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