Design, Development and Testing of Fiber Metal Hybrid Composite Material for Aeroscpace Applications

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***Abstract*— During the last thirty years, air craft manufacturer searching for lightweight materials that can replace the traditional aluminium alloys in aerospace structures. For an optimal structural design, a new material is needed which combines better fatigue and impact resistance along with high strength to weight ratio like the fiber metal laminates FMLs. In the present research fiber metal laminates of carbon fiber and aluminum 2024- T3 were fabricated by using different adhesive and manufacturing techniques. Tensile test was performed to investigate the behavior of different types of laminates.**

***Keywords*—Fiber metal laminates; carbon fiber; aluminum 2024; tensile test**

I. Introduction

Fiber Metal Laminates FMLs are a new class of metallic composite materials. Their structure consist of thin metallic sheets bonded together with fiber reinforced adhesive matrices as shown in figure 1. The fiber metal composite technology combines the advantages of metallic materials and fiber reinforced matrix systems.

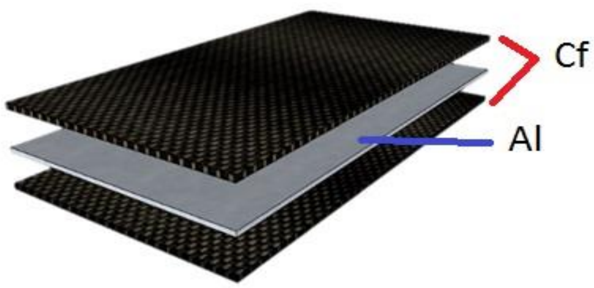

Figure 1: Alternative Layers of Fiber and Metal in FML

Metals are isotropic, have a high bearing toughness and impact resistance and are easy to repair, while fiber reinforced composites have excellent fatigue characteristics and high strength and stiffness. The fatigue problems in metals and the low impact resistance and toughness of composites can be overcome by the combination of both. Hybrid metal laminates are receiving considerable attention due to their good fatigue resistance high strength to weight ratio and their potential to offer superior durability to aerospace systems.

In the development of FMLs one of the main problem is of proper adhesion between metal and fiber reinforced composites. Different surface treatments are in use to overcome this limitation like mechanical, chemical, electrochemical, coupling agents and dry surface agents. Commercially available Glare used by Air bus A380 is fabricated through prepregs and autoclaves which is expensive technique and research is going on to produces FMLs with cost effective methods like VARTM. Limitation in VARTM is that it does not allow the proper wetting of fiber with epoxy due to presence of aluminum sheets between them.

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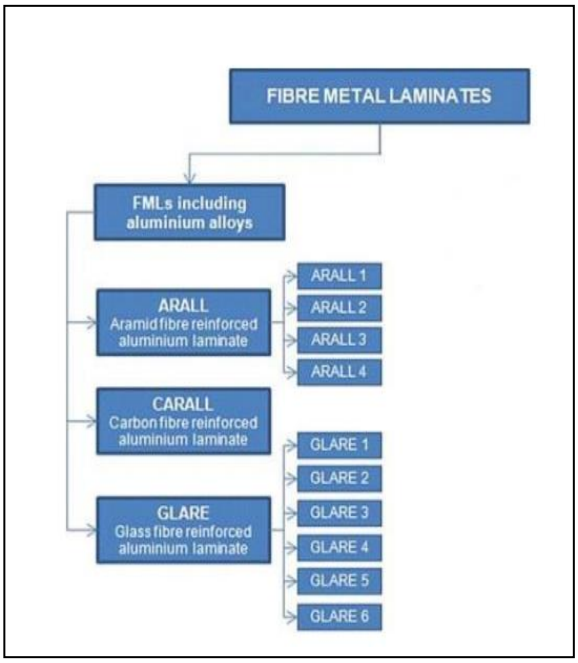
A. A. History

Technology was in search for light-weight materials that can replace the conventional aluminum alloys in growing aircraft industry. For a better structural design, a new material was need with better fatigue properties and high strength to weight ratio.

An improvement of the fatigue behavior in laminate sheet materials was observed by introducing a high strength aramid fiber into the adhesive layers. As a result of these researches,



they introduced ARALL, first fiber metal laminate, consisting of alternate layers of aramid fiber and aluminum sheets at the Faculty of Aerospace Engineering at the Delft University of Technology in Netherland [3].these initial researches opened the door for investigation of new trades of fiber metal laminates like CARRAL and Glare.

Figure 2: Tree Diagram of Aluminum based FMLs

B. Aim and objective

Main objective of the present research is to overcome the problem of cost for the manufacturing of FMLs by investigating new techniques for fabrication instead of expensive prepregs and autoclave methods, to get the proper adhesion of metal with adhesives and to investigate the effect of stacking sequence on the strength to weight ratio.

C. Benefits of use

FMLs are currently use by Airbus A380 in fuselage, lower wing skin panels of the Former Fokker 27 aircraft and the cargo door of the Boeing C-17. There are potential applications of FMLs in satellite development as electromagnetic shield material. FMLs could also be used in the nuclear reactor outer core where fatigue is problem so that safety issues in nuclear energy can be solve.

II. DESIGN

In the present research experiment were designed to overcome the limitation regarding to manufacturing and adhesion. Along with of liquid adhesive a new solid adhesive tape was also investigated. To overcome the poor adhesion between metal and fibers surface treatment was performed .Effect of stacking sequence on the strength also investigated to get the maximum strength to weight ratio.

A. Fabrication

Proper wetting of laminate with epoxy was impossible with the conventional VARTM manufacturing technique so the method was designed to modify. Application of epoxy was made directly with hand layup and after then laminates were placed under vacuum as shown in figure 2.

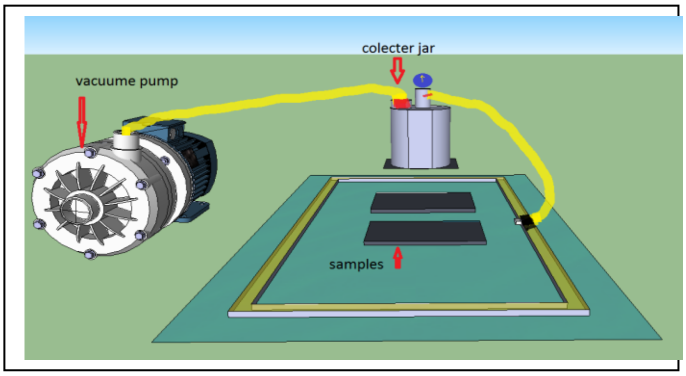


Figure 3: Schematic for Fabrication for “A” Type CARALL

Solid adhesive tape could also solve the problem of wetting. In these samples pressure is used to apply with the help of fixture as shown in the schematic figure 3.

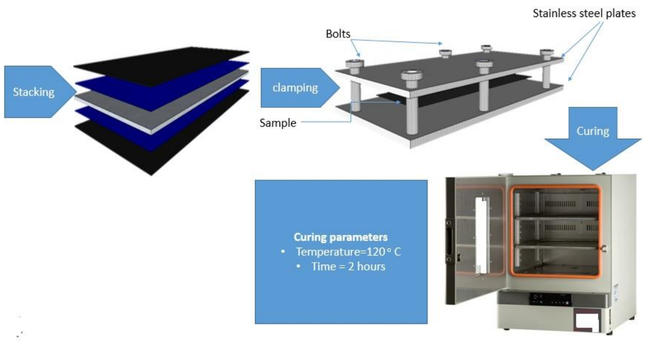


Figure 4: Schematic for Fabrication of “B” Type CARALL

B. Surface treatment :

To get the proper adhesion anodic oxidation was perform of the aluminum sheets in which aluminum was made anode and a cathode was made of stainless steel. Acidic solution is used as electrolyte. Redox reactions take place on the surface of anode and cathode as follows:

$$4Al + 3O_2 = 2Al_2O_3 \text{ (at anode)}$$

$$2H^+ + 2e^- = H_2 \text{ (at cathode)}$$

Al_2O_3 is porous in nature so that it change the morphology of aluminum surface. Porous structure provide good adhesion by providing the interlocking between the adhesive and metal surfaces.

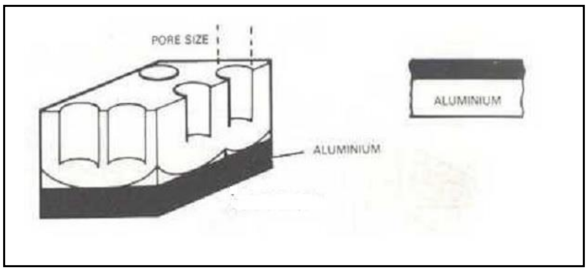
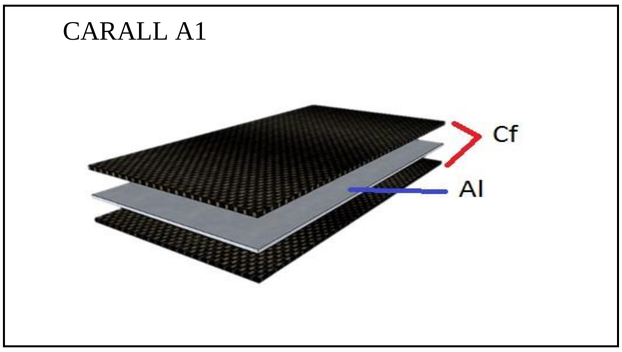
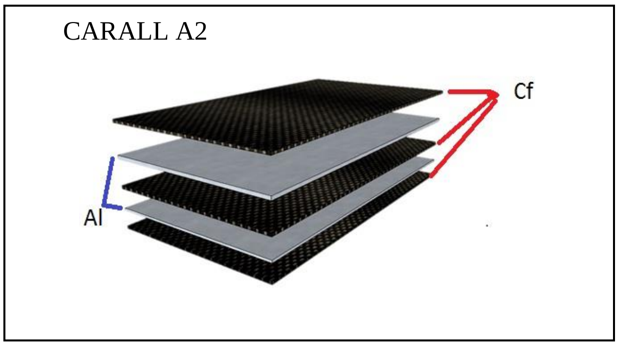


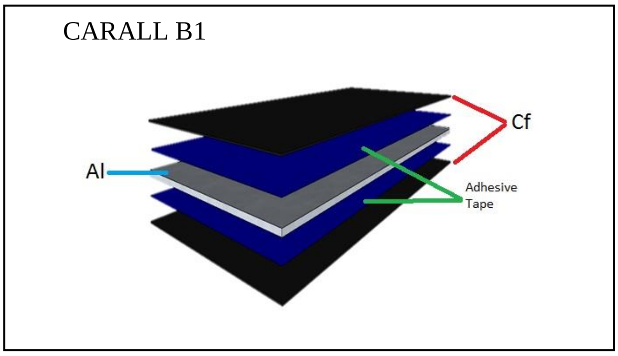
Figure 5: Schematic of Alumina Porous Layer

C. Stacking sequence

Two types of stacking sequence are investigated in both types of laminates. That are 2/1 (Cf/Al/Cf) and 3/2 (Cf/Al/Cf/Al/Cf). Here Cf is for carbon fiber and Al is for aluminum as shown in the schematics of figure 6.







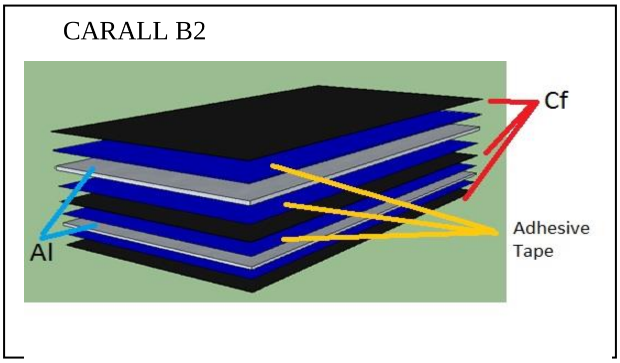


Figure 6: Schematics of Different Stacking Sequence of CARALL

III. MATERIALS AND EXPERIMENTATIONS

A. Materials

For fabrication of samples woven carbon fiber $0/90^0$ (Cf Woven)and epoxy 5052 is used for the type "A" samples and sheet of unidirectional $0/0^0$carbon fiber (Cf sheet) along with adhesive tape is used for the samples of type "B". Metal used for both types of samples is aluminum 2014-T3 of 0.5 mm thickness. A number of samples are made according to table 1:

Laminate	Constituent	Stacking sequence	Thickness
CARALL A1	Cf Woven / Epoxy 5052/ Al 2024-T3	2 Cf /1 Al	1.50 mm
CARALL A2	Cf Woven / Epoxy 5052/ Al 2024-T3	3 Cf/2 Al	2.75 mm
CARALL B1	Cf sheet/ Adhesive Tap/ Al 2024-T3	2Cf /1 Al	2.50 mm
CARALL B2	Cf sheet/ Adhesive Tap /Al 2024-T3	3Cf /2 Al	3.75 mm

Table 1

B. Anodizing

Before fabrication electrochemical surface treatment of anodizing is applied on the metal surface to change the morphology for the better adhesion of fiber with metals. Sulphuric acid anodizing of aluminum sheets were performed according to the following procedure in table 2.

Mechanical cleaning	To remove stains and corrosion residue grinding on 1200 C emery paper has been done.
Alkaline cleaning	After mechanical cleaning al plates are dipped in 11 wt % NaOH solution, in distilled water for 15 min. After degreasing Water break test is performed as mentioned in ASTM F22-13
De-oxidation	After degreasing de-oxidation or Acid etching is done in 30% Nitric acid at 80^{O} C in 70 % distilled water. (Used hot plate and magnetic stirrer). Plates are then Immediately rinse in water for water break test and parts were not allowed to dry during transferring from one tank to another
Anodizing	Plates were anodized in 15 % H_2SO_4 at room temperature. Pure aluminum used for cathode and Sample (ALUMINUM-2024) were the anode. 20 volts dc supply and current of 0.104 A were applied for 45 minutes

Table 2

Figure 5: Experimental setup for Anodizing of Aluminum

Effect of anodizing investigated though light microscope and the micrograph shows the effective porous structure for better adhesion on the surface of aluminum as shown in figure 6.

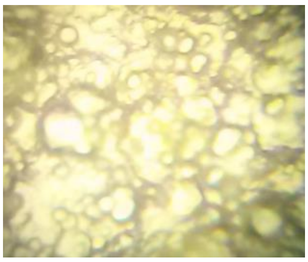


Figure 6: Micrograph of Anodized surface at 500x

C. Manufacturing

The Pressure moulding technique is used for the fabrication of samples. Before fabrication electrochemical surface treatment of anodizing is applied on the metal surface to change the morphology for the better adhesion of fiber with metals as the process described above. Two types of samples with different staking sequence were made.

For the "A" type CARALL hand lay-up is followed by vacuum bagging at the pressure of 70 torr.

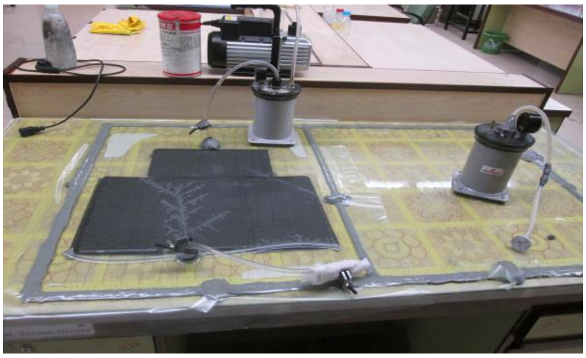


Figure 7: Experimental Setup for Fabrication of "A" Type CARALL

For the samples of "B" type CARALL pressure is applied through the fixture and sample are then cure in furnace at 120 ^{o}C for 2 hours.

Figure 8: Experimental Setup for Fabrication of "B" Type CARALL

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IV. TESTING AND RESULTS

After the fabrication samples are cut down in to 5 x 1 inch dimensions using metacutt machine. Tensile testing of theses samples performed by universal testing machine according to the ASTM D-3039 to measure the strength of fabricated laminates.

The morphology of anodized aluminum surface confirmed the presence of porous alumina structure on the surface of aluminum, which caused the interlocking of the epoxy/adhesive film on the surface of aluminum. Anodic oxidation on the surface of aluminum alloy 2024 increased the bond strength with epoxy resin and epoxy based adhesive film, which was confirmed by microscopic analysis

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Figure 9: Tensile Testing Machine

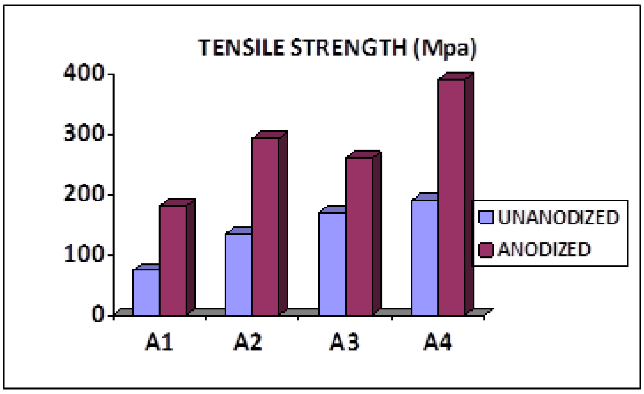

Figure 10: Results of Tensile Tests

Tensile strength of A4 samples is highest among all stacking sequences .A4 sample means Carall 4 which is adhesive film based and of 3-2 sequence as shown in fig 6.The strength is increased as result of anodizing on the surface of the metal where un anodized samples showed less tensile strength. It is concluded that anodizing increases tensile strength of laminates fabricated by adhesive film more than laminates which are unanodized and fabricated by epoxy. The reason is that adhesive film is more viscous when melted at 120 ^{0} C than epoxy and have better interlocking in pores of anodized surface.

V. CONCLUSION

Tensile tests results shows that anodizing of aluminum in FMLs give better strength and adhesive tape is more reliable in production of these laminates

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