

Mechanical Characterization and Analysis of Perforated Fibre Metal Laminates

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Abstract— Composite materials have been a subject of interest with various special types of advanced materials during the last decades. However increasing demand in aircraft industry for high-performance, lightweight structures have stimulated a strong trend towards the development of refined models for hybrid composites material known as Fibre Metal Laminates. Fibre Metal Laminates are hybrid composites built up from interlacing layers of thin metals and fibre reinforced adhesives. Metallic layers and fibre reinforced laminate can be bonded by mechanical technique and adhesive technique. Based on these approach adhesive technique with plain and perforated aluminium sheet is used to determine its effect as a Fibre Metal Laminate. Tests are conducted to determine the mechanical properties of the Fibre Metal Laminate and the results are tabulated. The test results are validated using ANSYS 12. The weight optimization of Fibre Metal Laminates with perforation is about 25% than that of without perforations.

Keywords— ARALL (Aramid Reinforced Aluminium Laminate), Composite Materials, Fibre Metal Laminate (FML), GLARE (Glass Reinforced Aluminium Laminate), Hybrid Composites, Spliced laminates.

I. INTRODUCTION

Over the last thirty years Composite Materials, Plastics and Ceramics have been the dominant emerging materials. The volume and number of applications of Composite Materials have grown steadily, penetrating and conquering new markets relentlessly. A Composite Material can be defined as the material that is obtained by judicial combining of two or more dissimilar materials, having different physical and electrical properties, in such a way that the resultant material properties are superior to any of the parental one. Composites are usually made of two phases-one is reinforcement phase and other is matrix phase [1]. Properties of composites arise as a function of its constituent materials, their distribution, and the interaction among them and as a result an unusual combination of material properties can be obtained. Hybrid composites are more advanced composites as compared to conventional Fibre Reinforced Polymer composites. Hybrids can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. They have better flexibility as compared to other fibre reinforced composites. Normally it contains a high modulus fibre with low modulus fibre [2]. The high modulus fibre provides the stiffness and load bearing qualities, whereas the low-modulus fibre makes the composite more damage tolerant and keeps the material cost low. The mechanical properties of a hybrid

composite can be varied by changing volume ratio and stacking sequence of different plies and also in different planes.

Fibre Reinforced Metal Laminates (FML) are hybrid composites consisting of alternating thin layers of Metal Sheets and Fibre-reinforced Epoxy prepreg. The most commonly used metal for Fibre Metal Laminates is Aluminium and the Fibres can be aramid or glass. These laminates possess some of the most desirable properties of both metal and fibrous composite materials. These hybrids exhibit a number of major advantages over conventional aluminium alloy structural materials and also fibre composites [2]. Most importantly, this family of Fibre Metal Laminates results in an ability to impede and arrest crack growth caused by cyclic loading that is significantly better than all materials currently on the market and even surpasses high-fatigue Li-Al alloys that are currently in development. Milling, Drilling, Sawing, Joining, etc. are similar to conventional practices for metals. Conventional lay-up methods for single-sided molds are also directly applicable to Fibre Metal Laminates lay-ups. Furthermore, this material can be produced as sheet material and it also can be cured in an autoclave as a complete structure, e.g. a large curved panel with co-cured doublers and stiffening elements. As a result, the fibre metal laminates are attractive hybrid materials for light-weight, fatigue critical large-scale structural applications [3].

The presented work reports experimental results that were gained in tensile tests and flexural tests. With the experimental data the mechanical characteristic of the Fibre Metal Laminates such as the Young's modulus, the Yield strength and the Ultimate tensile strength are found out. Additionally, the tensile and flexural data of the fibre metal laminates is compared to the experimental data of the individual laminates of the respective material. Validation of the experimental data is also done to verify the results.

II. LITERATURE REVIEW

The development of Fibre Metal Laminates, or Hybrid Composite Laminates, started back in 1967 when Kaufman [4] showed that a laminate of multiple adhesively bonded aluminium plies has about twice the fracture toughness of a single aluminium specimen of the same overall dimensions. In 1978, Johnson et al. [5] showed that the crack growth resistance and fatigue life in aluminium laminate is greatly enhanced compared to monolithic aluminium. In 1983, Johnson [6] showed that the improvement of damage tolerance was also true for laminated titanium versus

monolithic titanium. Vogelesang et al. at the Technische Universiteit Delft together with ALCOA developed the first fibre metal composite consisting of aluminium sheets and aramid fibre reinforced plies in the 1980s [6]. This first hybrid metal laminate is known as ARALL (Aramid Reinforced Aluminium Laminate). The NASA Langley Research Center subsequently developed a material similar in design to GLARE (Glass-Reinforced Aluminium Laminate), which is manufactured using dry fibres and vacuum assisted resin transfer molding. FMLs are known to be lightweight, have good fatigue properties and impact resistance, high specific static properties; they are flame and corrosion resistant and have good blunt notch strength [7], [8]. Spliced laminates are defined as FMLs in which the aluminium layers are interrupted such that the dimensions of the spliced sheets depend on the autoclave dimensions are known to have better mechanical properties [7]. These properties make FMLs, a very attractive material for aerospace applications.

III. EXPERIMENTAL DETAILS

A. Materials

In the present investigation Al8011 alloy is used as the basic aluminium sheet required for the fabrication of FML's. Both plain and perforated aluminium sheets are used to determine its effect on FML's as shown in Fig 1 & Fig 2. E-Glass fibres are used as reinforcing material and Epoxy resin is used as the matrix material. The thickness of the sheet is 0.7 mm. The chemical composition of the Al8011 alloy is given in Table I.

TABLE I
CHEMICAL COMPOSITION OF THE AL8011

Element	Al	Fe	Si	Mn	Mg	Cu	Ti	Cr
Weight(%)	97	0.7	0.5	0.4	0.2	0.1	0.02	0.01



Fig 1. Plain Al8011 alloy sheet

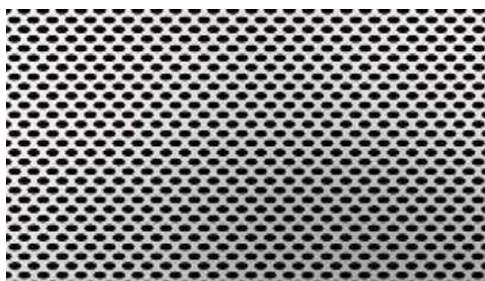


Fig 2. Perforated Al8011 alloy sheet

B. Fabrication of Fibre Metal Laminate

The overall generic scenario for production of Fibre Metal Laminate involves major activities. A brief illustration of the activities is given below.

1) *Raw Material Preparation:* During this the aluminium layer surfaces are pre-treated by chromic acid or phosphoric acid, in order to improve the adhesive bonding between metallic layer and fibre reinforced laminate [9]. Prior to bonding lay-up, the metal layer whose thickness is 0.7 mm is pre-treated to improve the adhesion to the prepreg as shown in Fig 2(a). The adhesive system in which the fibres are embedded contributes significantly to the performance of the laminates. The reinforced composite sheet is prepared according to the required dimensions. Etching and anodizing of the aluminium sheets takes place in tanks that measuring 14' long, 3' wide, and 7' deep for better bonding of FRP [10].

2) *Material deposition:* This includes cure preparation, including the tool cleaning and the part transferring in some cases, and the vacuum bag preparation in all cases [11]. This also includes the cutting, lay-up and debunking of the aluminium sheet and polymer composite sheet as shown in Fig 2(b). The adhesive system that is used in this laminate is Araldite LY556 resin & Hardener HY 951 hardener mixed in the ratio of 10:1 by weight as shown in fig 2(c) [12]. Manufacturing of laminate panels of aluminium sheet alternating with the glass fibre reinforced polymer prepreg sheet is a highly manual process. It is required meticulously to lay the prepreg onto the aluminium layers one layer at a time as shown in Fig 2(d).

3) *Curing of the laminate:* This includes the flow-consolidation process, the chemical curing reactions, as well as the solidification of the bond between fibre and metal layers as shown in Fig 2(e). Fibre Metal Laminate is cured in autoclave at 100 °C at a rate of 1.7-2.8 °C per minute for 4 hrs. 5 atm of vacuum pressure is then applied to the vacuum bagged setup. As a post curing process it is placed for 1 hr at 120 °C in autoclave.



Fig 2(a) Preparation of materials



Fig 2(b) Material Deposition



Fig 2(c) Applying Adhesive



Fig 2(d) Hand Lay -up



Fig 2(e) Curing of the Laminate.

TABLE III
SPECIMEN DETAILS

Case	Laminate definition	Thickness of the laminate (mm)	Prepreg orientation
A	3/2-0.70	4.00	0/0
B	3/2-0.70	4.00	0/0
C	3/0-0.70	2.10	----
D	3/0-0.70	2.10	----
E	0/2-0.00	1.90	0/0

Case A and Case C deal with plain aluminium sheet laminate composite. Case B and Case D deal with perforated aluminium sheet laminate composite. Case E deal with FRP's.



Fig 4 Case A



Fig 5 Case B



Fig 6 Case C



Fig 7 Case D



Fig 8 Case E

C. Specimens Details

A laminate coding system is used to comprehensively define laminates [13]. Laminate 3---3/2-0.7 is defined as 3 layers of aluminium with 2 fibre layers and each aluminium layer is 0.7 mm thick as shown in Fig 3.



Fig 3 Laminate Representation

D. Experimental Work

1) *Tensile Test:* Tensile test is probably the most fundamental type of mechanical test we can perform on a material. The tensile test were carried out according to ASTM standards D-3039 on a servo controlled COMPUTERIZED UNIVERSAL TESTING MACHINE. All the specimens were loaded till fracture and the readings like ultimate tensile strength and ultimate yield strength were noted.

2) *Flexural Test:* A flexural test produces tensile stress in the convex side of the specimen and compression stress in the concave side. The flexural test were carried out according to ASTM standard D-790 on a servo controlled COMPUTERIZED UNIVERSAL TESTING MACHINE. All the specimens were loaded on 3 point bend test bed till fracture occurred and the readings were noted.

2) *Comparison of Experimental test result with analytical result.*

The numerical comparison of the results is shown in TABLE IV. Snapshots of the FEA results is also shown below for UTS from Fig 10 to Fig 14.. This validates the findings for the Tensile Test Result.

IV. RESULTS AND DISCUSSIONS

A. *Tensile Test:*

The tensile properties of various combinations of the fibre metal laminates have been evaluated and the results are tabulated in the Table III. The plain aluminium sheet FML (Case A) has higher tensile properties than perforated aluminium FML (Case B) as perforated sheet contains holes which act as crack initiators.

TABLE III
Tabulated Experimental result of Tensile Test

Case	UTS (MPa)	UYS (MPa)	% Elongation at Break
A	206.09	104.13	6.53
B	143.22	67.31	5.35
C	174.84	139.38	8.69
D	58.85	22.98	5.35
E	90.45	25.35	2.22

TABLE IV
Comparison of Experimental Result with Analytical Result

Case	Experimental Result		FEA Result	
	UTS (MPa)	UYS (MPa)	UTS (MPa)	UYS (MPa)
A	206.09	104.13	205.30	102.65
B	143.22	67.31	146.60	65.86
C	174.84	139.38	179.91	146.60
D	58.85	22.98	58.06	22.34
E	90.45	25.35	95.59	28.29

3) *Finite Element Analysis Results:*

1) *Graphical Comparison of Experimental test result with Analytical result.*

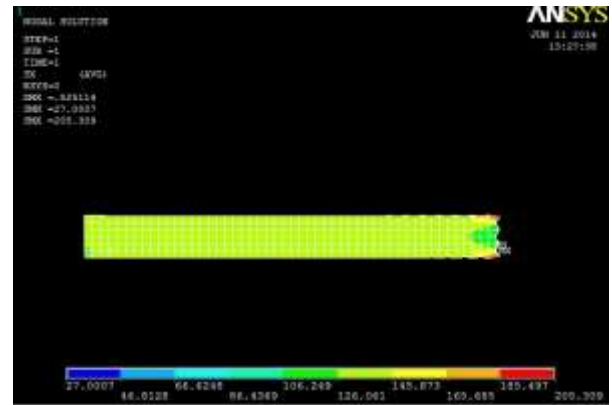


Fig 10 FEA for Case A

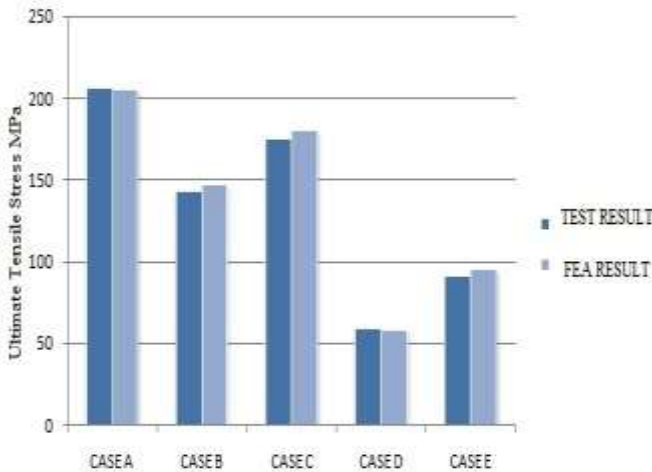


Fig 9 Graphical Comparison of Experimental test result with Analytical result

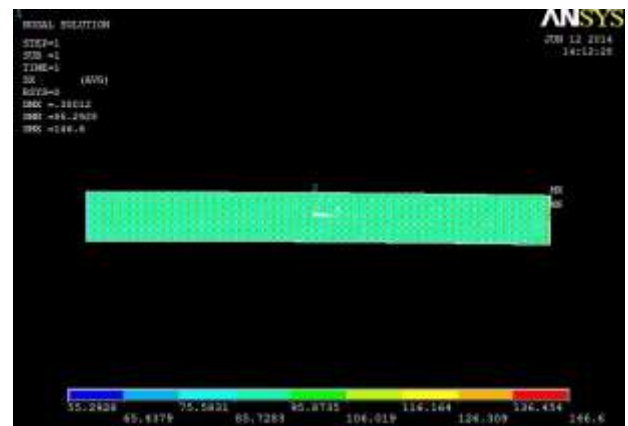


Fig 11 FEA for Case B

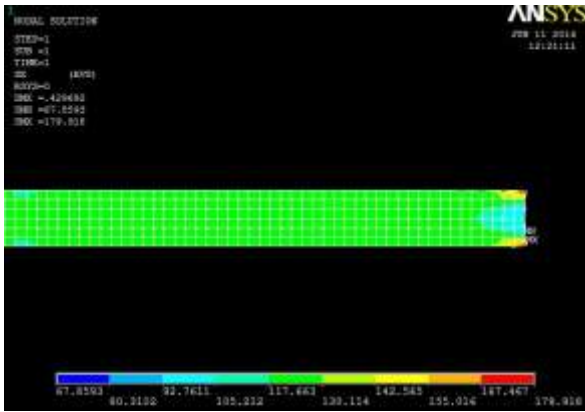


Fig 12 FEA for Case C

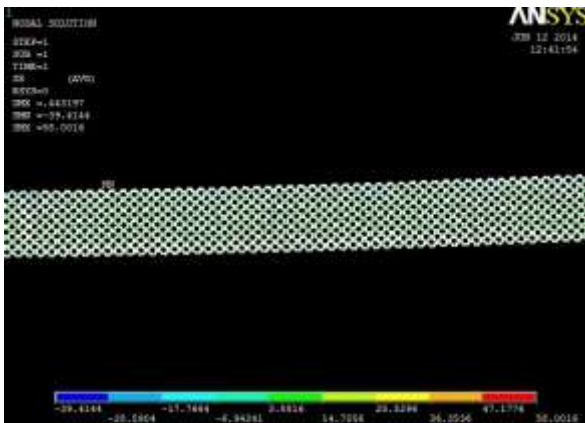


Fig 13 FEA for Case D

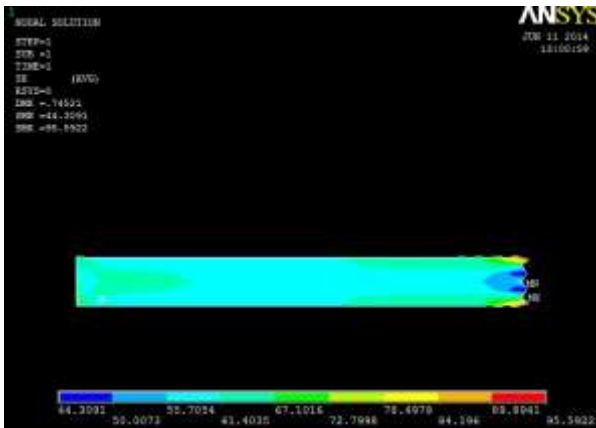


Fig 14 FEA for Case E

B. Flexural Test:

The flexural properties of various combinations of the fibre metal laminates have been evaluated and the results are tabulated in the Table V. The plain aluminium sheet FML (Case A) has higher flexural strength than perforated aluminium FML (Case B) as perforated sheet. It is observed that the flexural strength for hybrid composite is 288.95 Mpa for Case A in experimental result where as the flexural strength for hybrid composite is 159.00 Mpa for Case B. The

difference in the value is due to the presence of perforations which reduce the flexural strength as seen in Case B.

TABLE V
Tabulated Experimental result of Flexural Test

SI No	Case	Flexural Strength (MPa)
1	A	288.95
2	B	159.00
3	C	217.29
4	D	85.32
5	E	154.64

1) Graphical Comparison of Experimental test result with Analytical result.

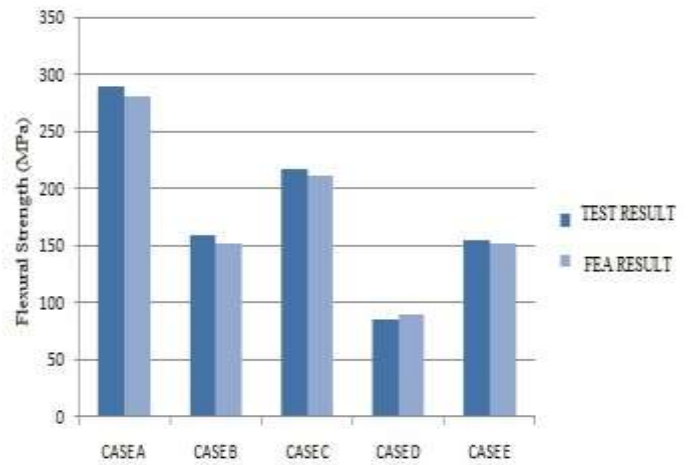


Fig 15 Graphical Comparison of Experimental test result with Analytical result

2) Comparison of Experimental test result with analytical result.

The numerical comparison of the results is shown in TABLE VI. Snapshots of the FEA results is also shown below for Flexural strength from Fig 16 to Fig 20.. This validates the findings for the Flexural Test Result.

TABLE VI
Comparison of Experimental Result with Analytical Result

Case	Experimental Result Flexural Strength (MPa)	FEA Result Flexural Strength (MPa)
A	288.95	280.03
B	159.00	151.37
C	217.29	211.08
D	85.32	89.14
E	154.64	151.37

3) Finite Element Analysis Results:

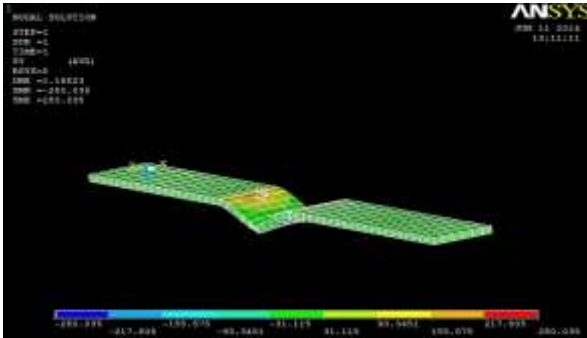


Fig 16 FEA for Case A

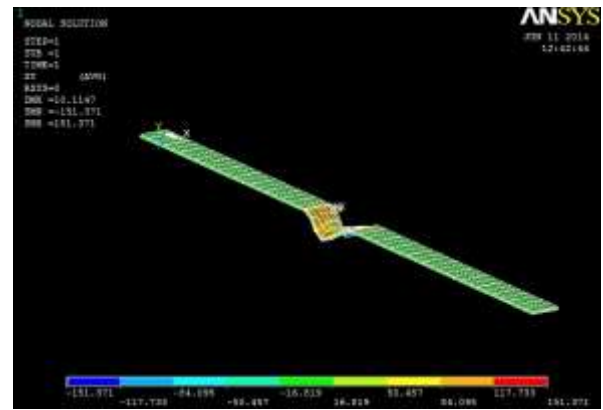


Fig 20 FEA for Case E

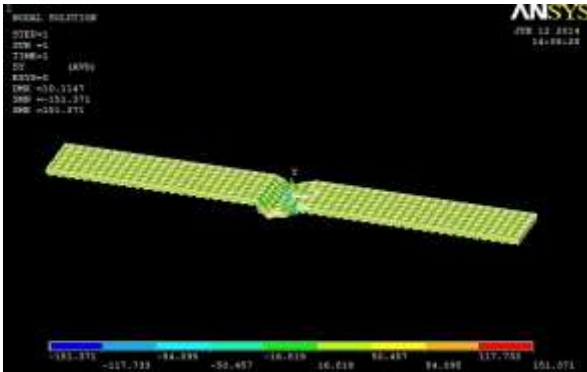


Fig 17 FEA for Case B

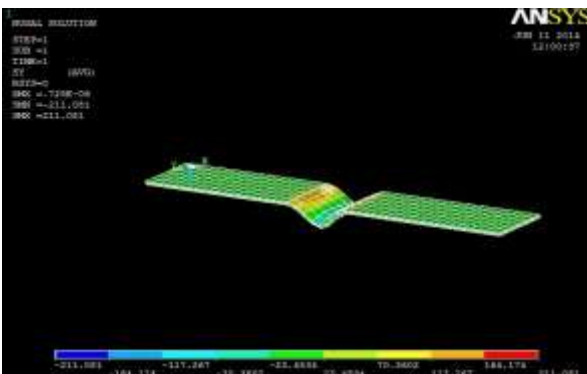


Fig 18 FEA for Case C

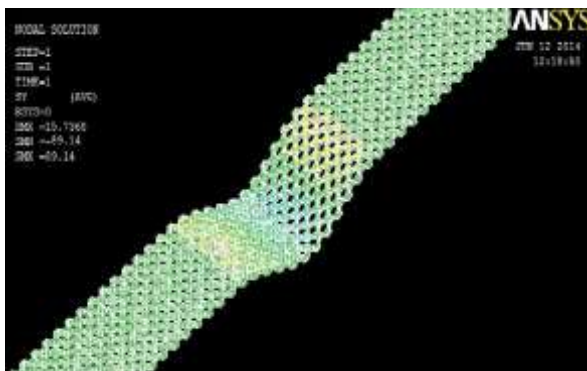


Fig 19 FEA for Case D

V. CONCLUSIONS

- The Tensile, Flexural strength is more in plain aluminium sheet FML (Case A), when compared to other combinations.
- Elongation is more for plain aluminium sheet fibre metal laminate (Case A) when compared to other combinations of FML's.
- The tensile strength of plain aluminium sheet fibre metal laminate (Case A) was found that is 206.09 MPa and flexural strength is 288.95 MPa.
- The tensile strength of perforated aluminium sheet fibre metal laminate (Case B) was found that is 143.22 MPa and flexural strength is 159.00 MPa.
- There is a reduction of 25% of weight in perforated aluminium sheet fibre metal laminate (Case B) when compared to plain aluminium sheet fibre metal laminate (Case A).
- Individual laminates (Case C, Case D & Case E) have inferior tensile and flexural strengths when compared to other FML's (Case A & Case B).
- The Finite Element Analysis result is agreeable with Experimental result.

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