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Simulation and Experimental Investigation of Glass Reinforced Metal Using ANSYS

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Abstract – The ductile resistance of the fiber-metal laminates (FML) has been analyzed experimentally and simulated on three various different FML laminates that is made up of aluminium sheets of three different thicknesses namely 0.2mm, 0.3mm & 0.4mm. Tensile, compression and flexural tests on the specimens were carried out to analyze the ductile behaviour of the FML laminates. Load vs. displacement curve for flexural, compression and tensile test. The respective parameters like ultimate stress, young's modulus, longitudinal strength, flexural failure, flexural modulus, etc., are calculated from the plots. The results were compared with each other to evaluate what is the impact of metal layer thickness in the FML plates. There is good variation between metal layer thicknesses obtained by experimental and simulation results. Finally the best fiber to metal ratio is found out and the results are justified.

Index Terms – Fiber-metal laminates (FML), metal layer thickness, GLARE (Glass Laminate Aluminium Reinforced Epoxy),ANSYS.

1. INTRODUCTION

The aircraft industry is very conservative in the adoption of new designs and technologies. Significant safety issues and low profit margins provide little incentive to change. Even when new aircraft are introduced, they tend to build heavily upon past designs, introducing only incremental updates in technology. Large changes can occur, but the process is very slow.

GLARE – Glass Laminate Aluminium Reinforced Epoxy

It is a type of FML that is composed of several layers of aluminium sheets placed over one another along with the glass fiber laminates or defined as a fiber metal laminate that is a novel hybrid composite, consisting of thin aluminum and glass/epoxy layers.

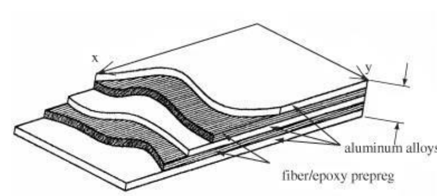


Fig 1.1- GLARE LAMINATE

Although GLARE is a composite material it looks like a bulk of aluminium metals sheets kept together. GLARE is invented in 1980"s and it is the most successful FML up to now among the various FML in composite field. It has the benefits of metals and composites simultaneously. GLARE is widely used in aircraft skins. GLARE got some serious attentions in recent days due to its large amount usage in the skin of AIRBUS A-380.

FIBRE - METAL LAMINATE:

Light weight composite materials are currently finding extensive use in a wide range of load bearing engineering applications. Fiber metal laminates (FMLs) are a family of highly fatigue and impact resistant laminated composite materials. They offer the structural designer a damage tolerant, light-weight and cost-effective replacement for conventional aluminum alloy sheets or composites in advanced transport structural applications. GLARE is the well-known member of the FMLs, consists of alternating thin layers of aluminum sheets and unidirectional glass/epoxy composite plies , and has been selected for the upper fuselage skin structures of airbus A380. The impact performance of the structures is one of the important safety issues. It has been known that GLARE enhances energy absorption and increases the ballistic limit than metal or composite from which it is made.

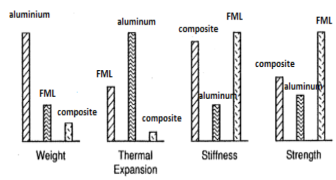


Fig1.2 -Comparison of physical properties

The main reason for switching to glass fibers is that aramid fibers failed at some loading conditions. But, fiber failure is unacceptable for the excellent fatigue resistance of FML. The glass fiber ply in GLARE does not have the disadvantage of failing fibers, and therefore GLARE became the most important variant for FML. Recently, GLARE laminate was selected for the upper fuselage skin structures of Airbus A380. It investigated the in-plane mechanical properties of GLARE with 2/1, 3/2 and 5/4 lay-up. The mechanical properties of GLARE were also predicted using the metal volume fraction approach based on a rule of mixtures. To achieve such a model, glass/epoxy composite should be modeled as an orthotropic linearly elastic solid and aluminum is assumed as an elasto-plastic solid. In the present research, the nonlinear tensile response of GLARE laminate is investigated under static tensile loading condition. Two approaches as orthotropic plasticity and modified laminated plate theories are used to predict the stress-strain response and deformation behavior of GLARE laminate. In the orthotropic plasticity model, a three parameter plastic potential function is used. In the second theory, the composite layers and aluminum sheets are assumed to be linearly elastic and orthotropic elastic–plastic solids respectively.

2. LITERATURE REVIEW

[1]Experimental and Numerical Investigation of Metal Type and Thickness Effects on the Impact Resistance of Fiber Metal Laminates-The impact response of fiber metal laminates (FMLs), has been investigated with experiments and numerical simulations, which is reported in this article. Low-velocity impacts were carried out to study the effects of metal type and thickness within FMLs.Glare5-3/2 laminates with two aluminum layer thicknesses and a similar FML containing magnesium sheets were impacted by drop weight tests. Also, a major part of this study was to accomplish a dynamic non-linear transient analysis to study the impact response of FMLs using the commercial finite element (FE) analysis code ABAQUS. By reviewing different approaches of modeling constituents of an FML, it is shown that the appropriate selection of elements has more significant role than failure criterion to predict acceptable results for this type of laminate and loading. The good agreement obtained between experimental and numerical results verifies the possibility of relatively simpler simulation by FE-analysis to predict overall response of FMLs under impact loading.

[2]Thickness influence on ballistic impact behaviors of GLARE 5 fiber- metal laminated beams: Experimental and numerical studies-This paper presents experimental and numerical investigations on ballistic impact behaviors of GLARE 5fiber-metal laminated (FML) beams of various thicknesses. A high-speed camera was used to measure impact and residual/rebound velocities and also to assess damage evolution in the FMLs. The incident projectile impact velocity versus the residual velocity (VI–VR) was plotted and numerically fitted according to the classical Lambert–Jonas equation for the determination of ballistic limit velocity, V50. The results showed that the V50 varied in a parabolic trend with respect to the metal volume fraction (MVF) and specimen thickness. The interfacial deboning as well as bending and stretching in aluminum layers played the significant roles in dissipating the impact energy in the GLARE 5 FML beams. The 3Dfinite element (FE) code, LS-DYNA, was used to model and validate the experimentally obtained results. Good agreement between experimental and numerical results was achieved. It was found that for a given specimen configuration, by increasing the projectile incident velocity up to its V50, the maximum contact force increased. By further increasing the projectile velocity above its V50, the maximum contact force was relatively invariant with respect to an increase in the projectile incident velocity.

[3]Experimental and Numerical Investigation on the High Velocity Impact Response of GLARE with Different Thickness Ratio-GLARE is a fiber metal laminate that is a novel hybrid composite, consisting of thin aluminum and glass/epoxy layers. The main advantage of GLARE is its high fatigue and impact loading resistance. Also its areal density is lower than metals or composites when they are used alone. In fact, it has benefits of metals and composites simultaneously. In this paper some 2/1 GLARE laminates are manufactured and impacted by 8.7 mm diameter blunt cylinder projectiles at energies up to that required to achieve complete perforation of the target using a helium gas gun. Aluminum and composite layers in these laminates have different thicknesses so the effect of changing thickness of aluminum or composite layers on the ballistic performance of GLARE, ie. Ballistic limit velocity and specific perforation energy can be investigated. The efficient thickness ratio to maximize the specific perforation energy is obtained, too. The same tests are analyzed numerically by LS-DYNA and the results show good agreement with experimental data. The results are discussed and commented upon.

[4]Analysis of Elastic-Plastic Behavior of Fiber Metal Laminates Subjected to In-Plane Tensile Loading-Fiber metal laminates are hybrid laminates consisting of thin alternating bonded layers of aluminum and fiber/epoxy. ARALL (Aramid aluminum laminate) and GALARE (glass fiber reinforced aluminum laminate) are specific kinds of fiber metal laminates that consist of thin aluminum sheets along with Kevlar/Epoxy and Glass/Epoxy composite layers, respectively. In this study, nonlinear tensile behavior of GLARE fiber metal laminates under in-plane loading conditions has been investigated. Due to the elastic-plastic behavior of aluminum layers, elastic analyses are not enough to accurately predict the tensile response. Thus, it is necessary to consider and explain the inelastic deformation behavior of GLARE laminates after yielding of aluminum alloy layers. Two appropriate analytical approaches, the orthotropic plasticity and modified classical laminated plate theories, have been used to predict the stress-strain response and deformation behavior of GLARE laminates. An acceptable agreement was observed between the two models. Results show that the GLARE behavior is almost bilinear under tensile loading condition and the tensile strength of unidirectional GLARE laminates are substantially stronger than aluminum alloys in the longitudinal direction.

3. FABRICATION OF GLARE

Introduction

The GLARE laminates consists of thin high-strength aluminum alloy sheets bonded together with glass/epoxy adhesive layers. The aluminum layers are of 2024-T3 type that using for the airplane fuselage. Glass fiber reinforced polymer layers are made by E-glass fiber layers and epoxy resin. The mechanical properties of materials are obtained according to ASTM A370 listed in table. Specimens were fabricated by hand lay-up method and pressed under 100 bar pressure for 18 hours (curing time of resin). For better adhesion between aluminum and resin, surface preparation for aluminum layers was performed by initial removing oil, abrading and cleaning by high-pressure water. The aluminum and glass/epoxy thicknesses are 0.2, 0.3&0.4 mm and 0.20 mm respectively.

For reducing the effect of unknown factors only one change is perform between orientations in the mid plane of the panel. The base of orientation is the rolling direction of aluminum layers. The difference of specimens is of the ratio of the thickness of aluminum layers to glass/epoxy layers.

Fabrication of laminated composites includes selecting a material system or a group of material systems and determining the stacking sequence for the laminate based on applied loads and constraints on optimizing and constraining factors such as cost, weight as related to aerospace and availability. Based on all the factors, glass/epoxy laminated composite plates were fabricated.

Laminate configuration

Fig 3.1-Glare1-1&2-1 configuration

Fig 3.2-Glare 1-2&2-2 configuration

Fig 3.3-Glare 1-3&2-3 configuration

4. FABRICATION OF GLARE LAMINATES

Preparation of glass fiber mat:

1. Glass Fibers of dimensions 330x330mm are cut from the big roll.

2.7, 6&5 glass fiber layers are required for preparing a GLARE Laminate.

3. The weight of all the glass fiber is measured using an electronic weighing machine.

Preparation of epoxy resin:

1. Epoxy Resin equal in weight to that of the fiber is weighed and taken separately.

2. Then hardener is added to the resin in the ratio of 1:10.

3. The epoxy resin mixture is then mixed thoroughly.

Preparation of the aluminium:

Both the upper and lower aluminium surface should be cleaned using acetone initially to remove the dirt present if any. Using sand paper to roughen the aluminium sheets.

Preparation of aluminum tabs:

1. Aluminum Tabs of dimensions 35x35x0.2 mm has to be fabricated.

2. Two such aluminum tabs are required for each specimen.

3. Initially the surfaces of aluminum tabs and specimen are made rough by using Emery sheet for good bonding.

4. Araldite is then used to bond both the tab and specimen.

Procedure for preparation of GLARE cross-ply laminate:

1. Place the polythene on the table. Apply wax on the surface of the lower polythene. Next place the first layer of glass fiber and apply the matrix by using dustless brush. Then use rollers to squeeze the excess resin.

2. Place the aluminium sheet over the glass fiber matrix and apply the matrix over the surface of the sheet. And again use the rollers to squeeze the excess resin. Repeat the procedure with alternating layers of Resin, Glass fiber and aluminium until the laminate are finished.

3. Finally place the glass fiber mat and apply the matrix. And applying the wax on the polythene paper. Then place the polythene on the top of the laminate.

4. Next the laminate is placed in the compression moulding machine under a pressure of about 100bar.

5. Then the laminate is allowed to cure under this condition for 24 hours. After 24 hours the laminate is removed from the compression molding machine. Then remove the polythene cover carefully after that the laminate is placed in the sunlight for more than half hour.

Surface preparation and curing

Considering bonded joints the surface preparation takes an important role in perfect bonding, we used hand abrasion technique to introduce roughness in the surface. The entire mould with glass fabric lay-ups has been kept in 24 hours for curing. The curing has been done at a room temperature. If the specimen is not cured properly the strength of the bond drastically reduces. The major defects found in bonding of two materials are disbanding, porosity, voids is mostly due to improper curing. There is also a possibility of voids generation due to vaporizing of water molecule present in the adhesive. To prevent dislocation of specimen in bond region proper load should be applied.

5. SPECIMEN PREPARATION

Tensile, compressive and bending test specimen has been prepared according to ASTM (American Society for Testing and Material) Standard from the fabricated laminated using a diamond cutter. The dimension of tensile, compression and bending specimen according to ASTM A370.

Specimen dimension

Table 3.1- Specimen dimension

S. no	Dimension	TEST		
		Bending	**Compression**	**Tensile**
1	Length	220	220	220
2	Width	60	60	60
3	Thickness	4	4	4

Calculation of fiber-metal fraction

WEIGHT of single sheet of bi-directional glass fiber = 0.047 kg

WEIGHT of single sheet of 0.2mm aluminum = 0.0583 kg

WEIGHT of single sheet of 0.3mm aluminum = 0.077 kg

WEIGHT of single sheet of 0.4mm aluminum = 0.0975 kg

Cutting specimens from the laminate for tension test:

1. Specimens having dimensions 300x60x3mm has to be cut from the laminate.

2.For this process we used Water jet cutting machine, which uses abrasive sand mixed with water as the cutting tool.3specimens are cut from the each GLARE laminate.

Cutting specimens from the laminate for bending test:

1. Specimens having dimensions 300x60x3mm has to be cut from the laminate.

2. For this process we used Water jet cutting machine, which uses abrasive sand mixed with water as the cutting tool.3 specimens are cut from the each GLARE laminate.

Cutting specimens from the laminate for compression test:

1. Specimens having dimensions 300x60x3mm has to be cut from the laminate.

2. For this process we used Water jet cutting machine, which uses abrasive sand mixed with water as the cutting tool.3 specimens are cut from the each GLARE laminate.

Testing specimen after cutting:

Fig 3.4-Testing specimen

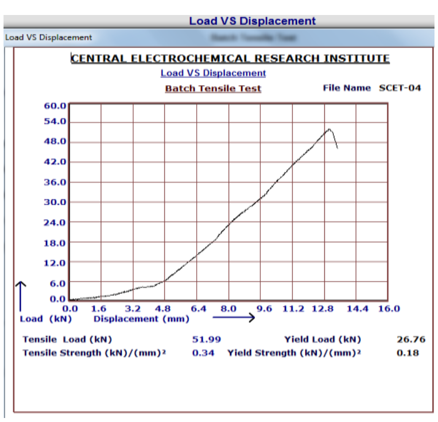
6. ASTM STANDARD FOR TENSILE TEST

As mentioned previously, tensile specimens are machined in the desired orientation and according to the standards.

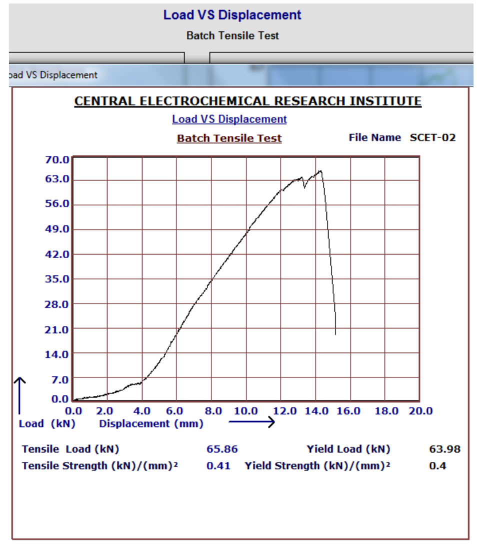
The central portion (gauge portion) of the length is usually of smaller cross section than the end portions. This ensures the failure to occur at a section where the stresses are not affected by the gripping device. The gage length is marked and elongation is measured between these markings during the test.

Fig 3.5-Tensile testing

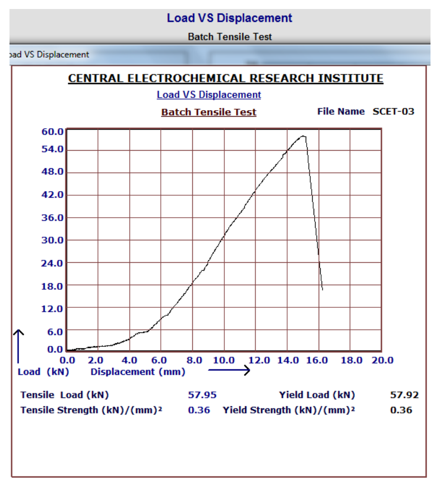
TENSILE TEST RESULTS:



Glare1-3&2-3



Glare1-2&2-2



Glare1-1&2-1

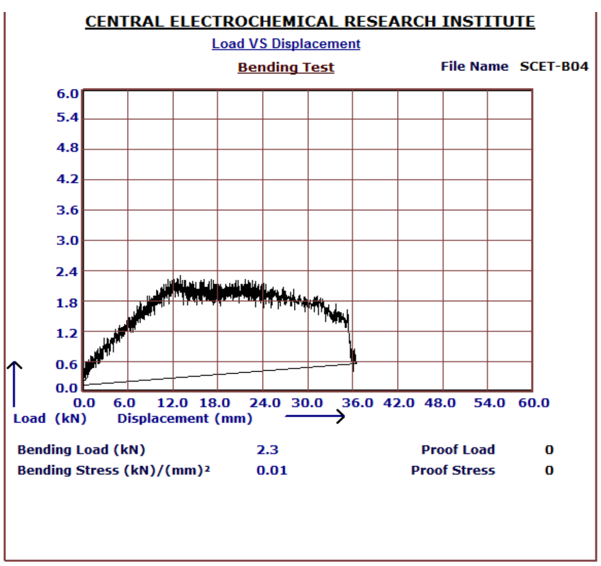
Table 3.2 Load vs. displacement tabulation for tensile test:

S.NO	MATERIAL	DISPLACEMENT (mm)	LOAD (kN)
1	**Glare1-1&2-1**	13.29	60.8
2		14.4	64.6
3		15.17	65.86
4	**Glare1-2&2-2**	14.16	54.65
5		14.98	57.72
6		15.09	57.95
7	**Glare1-3&2-3**	11.98	45.41
8		12.2	46.59
9		13.08	51.99

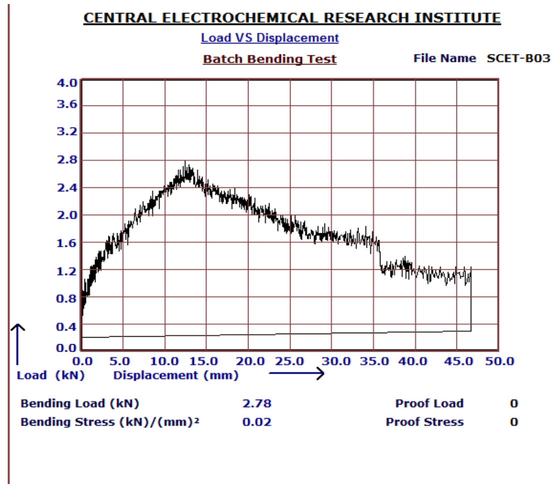
7. BENDING TEST

ASTM A370 outlines testing of flexural properties of polymer matrix composites using a bar of rectangular cross section supported on a beam and deflected at a constant rate. The test method summarizes two procedures. Procedure A outlines a three point loading system for center loading. Procedure B outlines a four point loading system for two equal loading points. Fabric-reinforced textile composite materials are also referenced within the ASTM A370 method. Flexural properties of many materials can vary depending on temperature, rate of strain and specimen thickness, it may be appropriate to test materials at varied parameters.

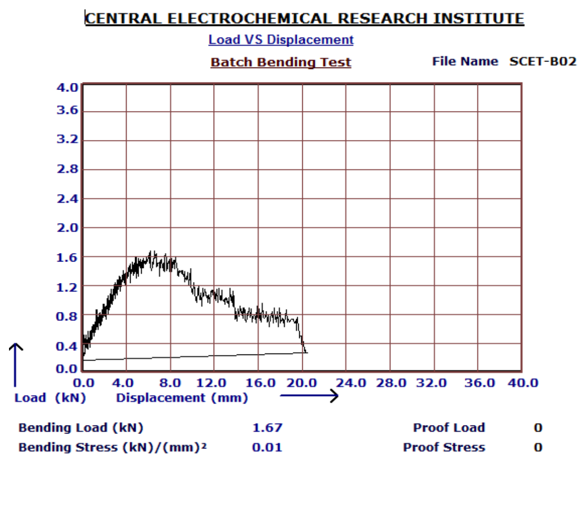
Fig 3.6 – Bending/Flexural testing



GLARE 1-3&2-3



GLARE 1-2&2-2



GLARE 1-1&2-1

Table 3.3-Load vs. displacement tabulation for bending test

S.NO	MTERIAL	DISPLACEMENT (mm)	LOAD (kN)
1	GLARE 1-1&2-1	4.88	1.52
		5.66	1.52
		6.64	1.67
2	GLARE 1-2&2-2	12.75	2.61
		12.8	2.52
		12.95	2.78
3	GLARE 1-3&2-3	16.98	1.89
		17.18	1.85
		17.29	2.3

8. COMPRESSION TEST

- To understand the concept of mechanical properties of glare metal
- To construct the load-displacement diagram based on Universal Testing Machine data
- To understand the material behavior under compression mode
- To understand how to determine:

a) Young's Modulus

b) Ultimate stress

c) Poisson's ratio (if equipment available)

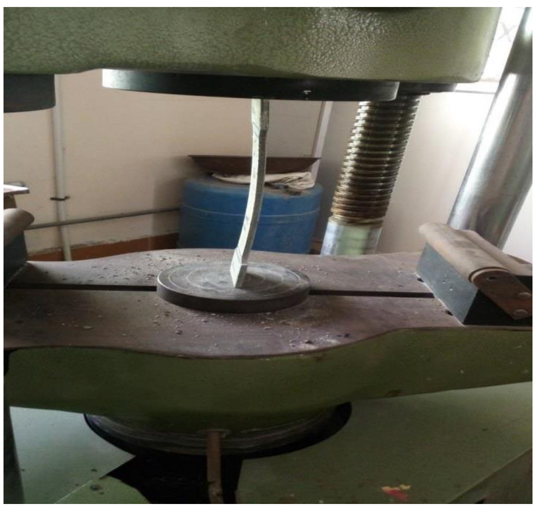
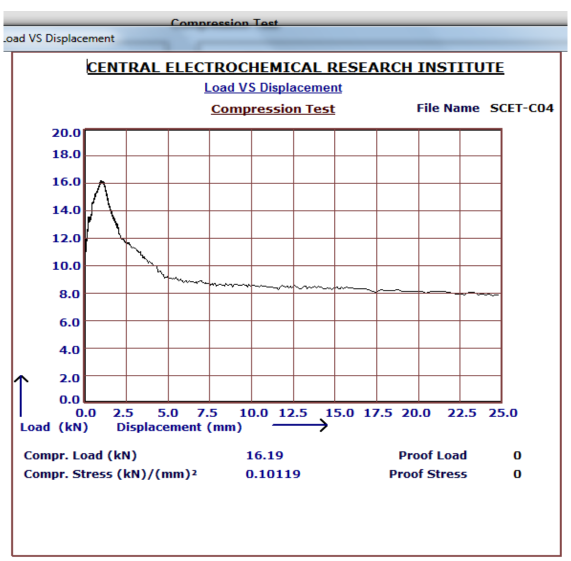
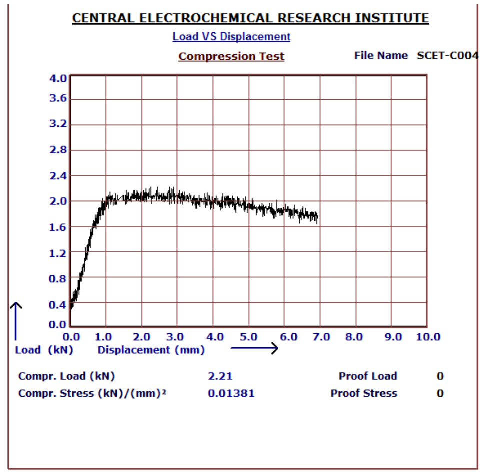


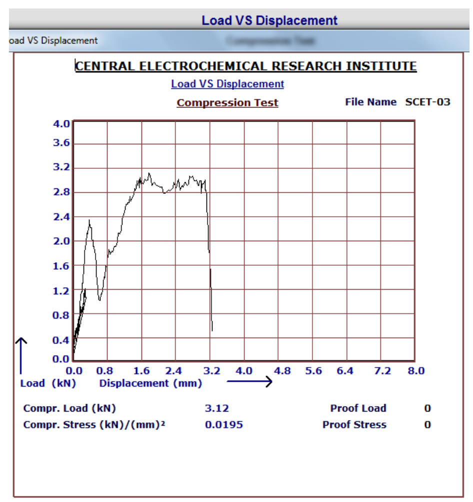
Fig 3.7- Compression test



Glare 1-1&2-1



Glare 1-2&2-2



Glare 1-3&2-3

Table 3.4-Load vs. displacement tabulation for compression test

S.NO	MATERIAL	DISPLACEMENT (mm)	LOAD (kN)
1	**Glare 1-1&2-3**	0.68	15.13
		0.71	15.26
		1.06	16.19
2	**Glare 1-2&2-2**	1.42	2.76
		1.59	2.94
		1.78	3.21
3	**Glare 1-3&2-3**	1.93	2.01
		2	2.07
		2.27	2.21

9. SIMULATION RESULT

Glare 1-3&2-3:

TENSILE TEST ANALYSIS

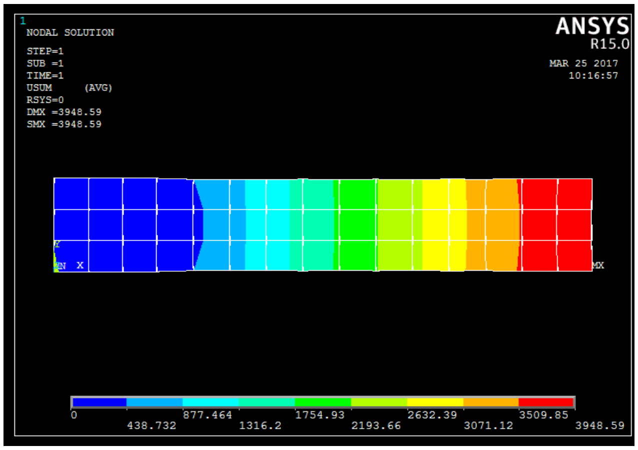


Fig 3.8 Displacement vector

COMPRESSION TEST ANALYSIS

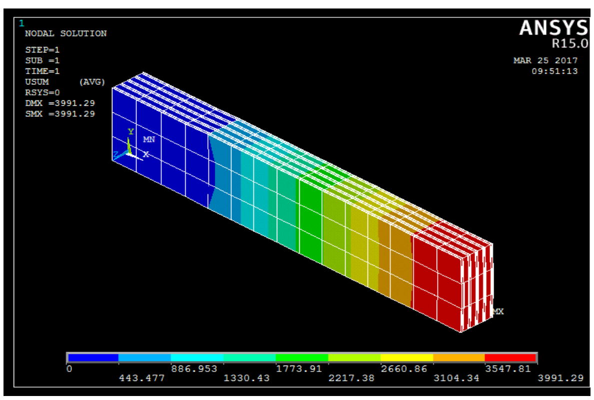


Fig 3.9 Displacement vector

BENDING TEST ANALYSIS

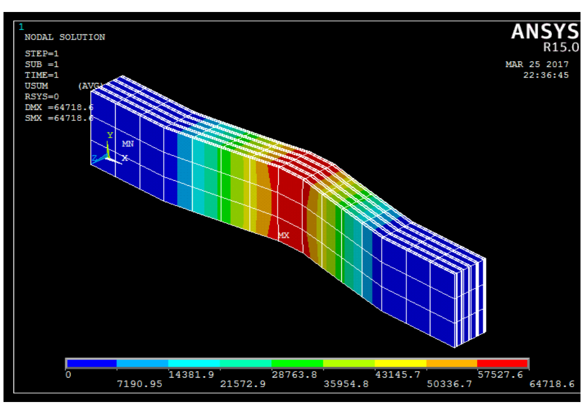


Fig 3.10 Displacement vector

Glare 1-2&2-2:

TENSION TEST ANALYSIS

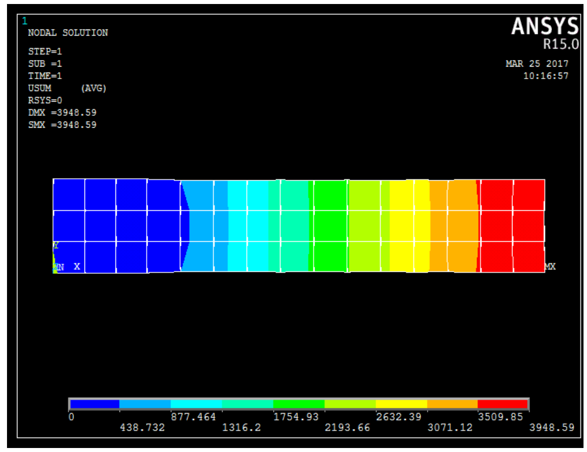


Fig 3.11 Displacement vector

BENDING TEST ANALYSIS

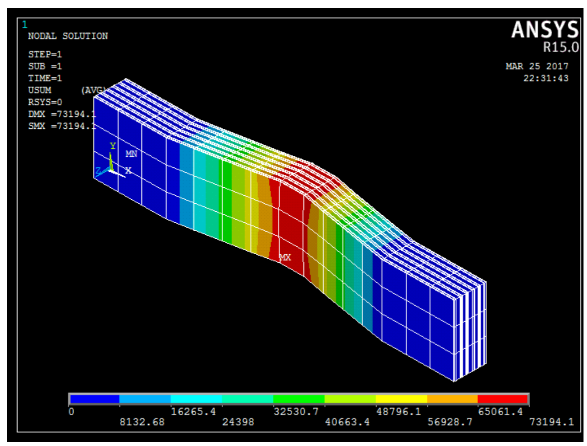


Fig 3.12 Displacement vector

COMPRESSION TEST ANALYSIS

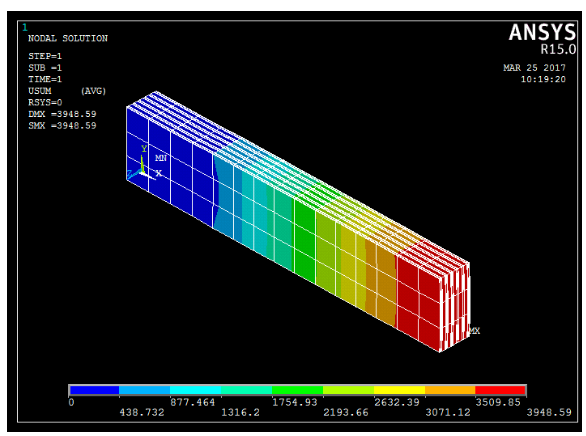


Fig 3.13 Displacement vector

Glare 1-1&2-1:

TENSILE TEST ANALYSIS

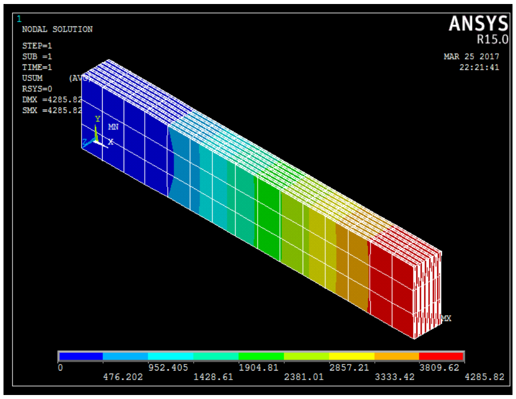


Fig 3.14 Displacement vector

COMPRESSION TEST ANALYSIS

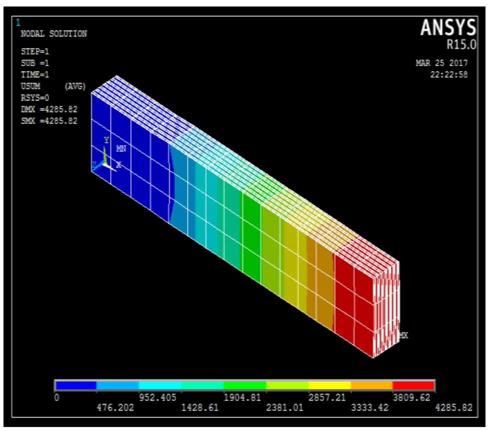


Fig 3.15 Displacement vector

BENDING TEST ANALYSIS

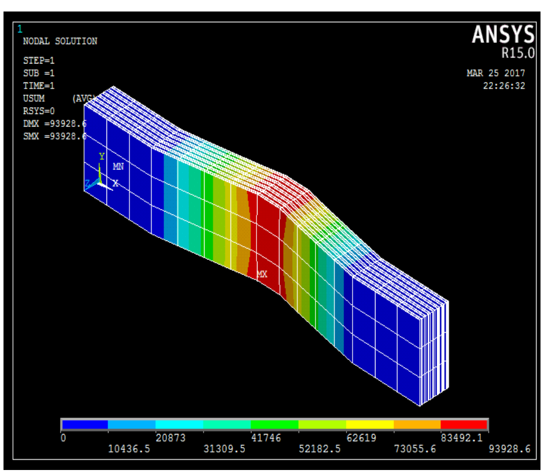


Fig 3.16 Displacement vector

ANALYSIS RESULT

From our simulation analysis it is found that even though the metal layer thickness in the GLARE 1-1&2-1 is minimal compared to the rest of the laminates but it tends to bear high load capacity and also have higher value for various parameters which estimates the strength of the laminate.

10. RESULT ANALYSIS

Companied tensile test result

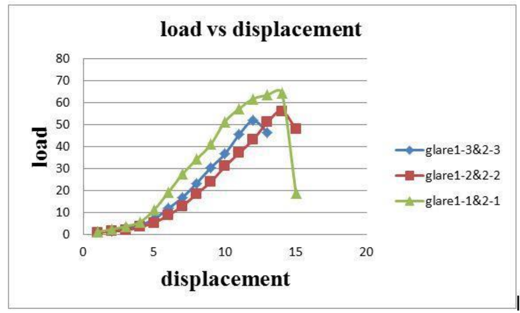


Fig 3.17 Companied tensile test result

Combined compression test result

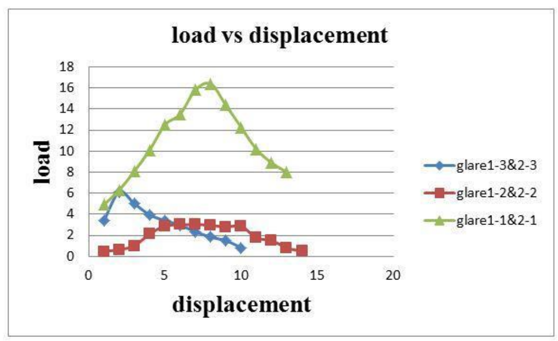


Fig 3.18 Combined compression test result

Companied bending test result

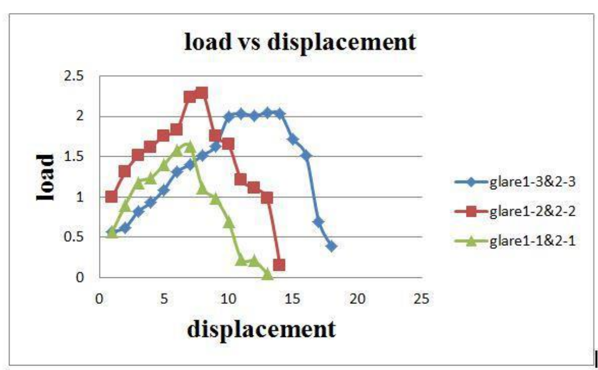


Fig 3.19 Companied bending test result

Table 3.5 -Ultimate stress tabulation

LAMINATE	ULTIMATE STRESS (kN/mm^2)
GLARE 1-1	1.22
GLARE 1-2	0.252
GLARE 1-3	0.168

Table 3.6-Combines results for tensile load testing

laminate	Combined load test result		
	Tensile test (kN)	Compression test (kN)	Bending test (kN)
Glare1-1&2-1	65.86	16.19	1.67
Glare1-2&2-2	57.95	3.21	2.78
Glare1-3&2-3	51.99	2.07	2.3

From the combined plots and tabulation it is very clear that the GLARE1-1 &2-1 has the better loading capabilities than the rest. Also the other mechanical properties such as yield stress, young"s modulus, flexural rigidity values are higher for the GLARE1-1&2-1 laminate which contains the 0.2mm aluminium in it. Hence, this result converges some interesting results and that is justified in conclusion.

11. CONCLUSION

Since the invention of composites the fiber metal laminates have gained much more attention for researchers who are witnessing excellent replacement for metals as well as pure composites. The metal layer in the fiber metal laminates dominates the change in entire strength of the whole laminate. From our experimental and simulation analysis it is found that even though the metal layer thickness in the GLARE 1-1&2-1 is minimal compared to the rest of the laminates but it tends to bear high load capacity and also have higher value for various parameters which estimates the strength of the laminate.

This clearly states that the physical strength of the FML is not increasing when the metal thickness is increased, rather it purely depends upon the no of layers of interaction between the metal and glass fiber also the bonding strength.

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