Asian Journal of Computer Science and Technology (AJCST)
Vol1.No.1 2013 pp 5-13.
available at: www.goniv.com
Paper Received :19-02-2013
Paper Published:20-03-2013
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

COMPARATIVE STUDY OF TENSILE AND FLEXURAL BEHAVIOUR FOR GLASS-FIBER-REINFORCED ALUMINIUM (GLARE) LAMINATES AND ALUMINUM

Asha Melba.V, Senthil Kumar.A, Vino.A
[#] Department of CAD /CAM Engineering
Sethu Institute of Technology, pulloor-626 115.
[1]ashamelba@yahoo.co.in [3]vinomechsss@gmail.com [2]asenthil123@yahoo.com

ABSTRACT

The objective of this research article was investigated to evaluate tensile and flexural properties of Glass-fiber-Reinforced Aluminium (Glare) laminates as well as Aluminium sheets of same thickness. In addition to that the tensile and flexural strength of Glare laminates were compared with values of aluminium sheets. In this article, the aluminium based FMLs were fabricated using hand layup technique and cut as per ASTM standards. Three types of layers such as 2/1 Glare, 3/2 Glare and 5/4 Glare laminates were prepared. Computer controlled UTM machine used to determine the tensile, flexural properties and failure mode of the Glare laminates and Plain aluminium sheets with same thickness. From the test results the graphs were plotted for load vs displacement, tensile and flexural strength vs layers thickness. It shows that tensile and flexural strength of Glass-fiber-Reinforced Aluminium (Glare) laminates purely depend on the volume percentage of fibre and it exhibits improvement over the properties of aluminium sheets.

Keywords: Glass-fiber-Reinforced Aluminium laminates (Glare), aluminium sheet, hand lay-up technique, tensile property and flexural property.

1. INTRODUCTION

A new class of lightweight Fiber Metal Laminate (FML) has been developed for structural applications. They consist of thin aluminium alloy sheets bonded alternately with fibre-reinforced epoxy layers. These laminates are increasingly being employed in the aeronautical industry for structural applications. The mechanical property of FML shows better performance over the properties of both aluminum alloys and composite materials individually [1, 2]. Fiber metal laminates having growth in use of structural applications like automotive, marine, space structures and military use in the aircraft industry because of their significant weight reduction in structural design, high tensile and compressive strengths, good fatigue and corrosion resistance properties [3 - 5]. Polymer composites are susceptible to mechanical damages when they are subjected to efforts of tension, flexural, compression which can lead to material failure. Therefore it is necessary to use materials with higher damage tolerance & carryout an adequate mechanical evaluation. Damage tolerance of epoxy polymeric composites can be enhanced by improving the interlaminar properties by matrix reinforcement with fiber [6, 7]. Prashanth Banakar et al had conduct the experimental work to find out the tensile and flexural properties of Glare laminates. From this work, they were found that tensile and flexural strength of fiber metal laminates purely depends on the thickness of the layers [8].

Krishnakumar [9] showed that the tensile strength of many fiber-metal laminates is superior to that of traditional aerospace-grade aluminum alloys. Wu et.al [10] predicted the mechanical properties of Glare laminates using the metal volume fraction approach based on a rule of mixtures. Alderliesten

Asian Journal of Computer Science and Technology (AJCST)
Vol1.No.1 2013 pp 5-13.
available at: www.goniv.com
Paper Received :19-02-2013
Paper Published:20-03-2013
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

[11] had conducted the series of fatigue tests on Glare and plain aluminium alloy specimens and found that crack growth rates in fibre–metal laminates between one and two orders of magnitude lower than in aluminium alloy samples. Rajesh Mathivanan et al [12] fabricated GFRP and graphite-based GFRP laminates by hand lay-up technique. They conducted the ENF test to find out delamination resistance. Pourkamali Anaraki et al [13] investigated on the effect of repairing the center-cracked aluminum plates using the FML patches. The repairing processes were conducted to characterize the response of the repaired structures to tensile tests. Esfandiar et al [14] analyzed nonlinear behavior of GLARE 4-3/2 and GLARE 5-2/1 under in–plane tensile loading. Orthotropic plasticity and modified laminated plate theories were used to predict the elastic-plastic behaviour of GLARE laminates

2. EXPERIMENTAL WORK

Three types of layers such as Glare2/1 Glare3/2 and Glare5/4 were fabricated. Glare 5/4laminates consisting of five 0.3 mm thick aluminum sheets supplied by JSK Industries and four 300 gms/m^2 E-glass chopped strand mat supplied by Goa Glass fibre Ltd. and Epoxy resin.These plies were fabricated using a hand-layup technique [15]. Hand-layup technique was chosen as it was ideally suited to manufacture low volume with minimum tooling cost [12]. The nominal weight fraction of fibers in GFRP was kept constant at 60%. The plies were laminated in such a way that the warp and weft directions were parallel to the edges of the laminates. The plates were then post-cured in an oven at 100°C for 4 hours after they had been cured under 15 kPa pressure for one day at room temperature [15]. These laminates were then cut up to 250x25 mm for tensile specimens and 127x12.7mm for flexural specimens as per standard ASTM D3039 and D790 [16,17] respectively.

The processing of glare laminate was i) hand abrasion by 200 grit Aluminium oxide papers, to create a roughness, ii) Etching in acetone, iii) Washing by dilute alkaline solution upto 5mins at 60˚c to 70˚c, iv) rinsing in hot water and Etching aluminium sheets in sulfochromic solution (FPL-Etch) based on ASTM D2674 [18] and D2651 [19] standards.

Figure 1 Acetone Cleaning

Figure 2 Epoxy resin coating

A. *Tensile test*

Tensile specimens are 250 mm long, 25 mm width and Glare 2/1 with 1.10mm thickness, Glare 3/2 with 1.50mm thickness and Glare 5/4 with 3.40 mm thickness. The tensile specimens of gauge length 100 mm were prepared [16].Tensile tests were performed on a Autograph-AGIS-Shimadzu-50KN capacity universal testing machine at a crosshead rate of 5 mm/min which corresponds to a strain rate of 0.2% per second. Tensile properties were determined from these specimens [8]. Fig. 3 and Fig. 4 show the specimen before and after tensile testing. Fig. 5 shows the specimen during tensile testing.

Specimens are mounted on the grips of a universal testing machine and gradually loaded in tension while recording load. The ultimate strength of the material can be determined from the maximum load carried before failure and also various failure modes were analysed. After that, the stroke was monitored with displacement transducers then the stress-strain response of the material can be determined, from which the tensile strain, modulus of elasticity were derived [16].

Figure. 3 specimen before tensile testing

Figure. 4 shows the specimen after tensile testing

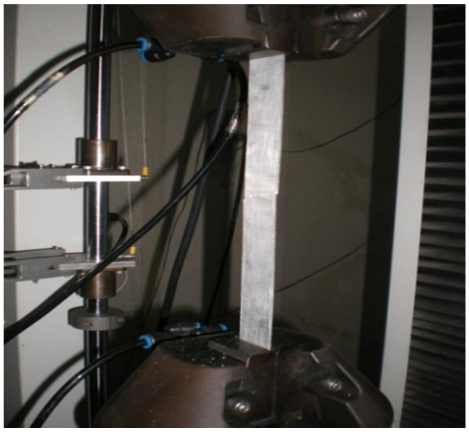


Figure. 5 specimen during tensile testing

B. Flexural test

Flexural specimens are 127 mm long, 12.7 mm width and Glare 2/1 with 1.10mm thickness, Glare 3/2 with 1.50mm thickness and Glare 5/4 with 3.40 mm thickness were prepared. Specimen rests on two supports and is loaded by means of a loading nose midway between the supports. A support span-to-depth ratio of 16:1 was used. Flexural tests were performed on an Autograph-AGIS-Shimadzu-50KN capacity universal testing machine at a crosshead rate of 5 mm/min. The specimen was deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain of 5.0 % was reached, whichever occurs first [17].

Figure. 6 specimen before Flexural testing

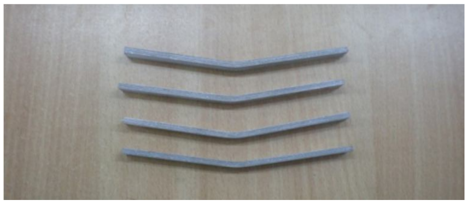


Figure. 7 specimen after Flexural testing

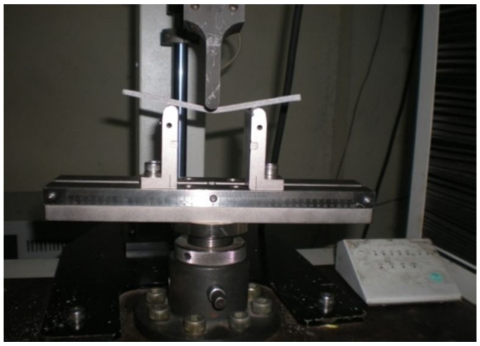


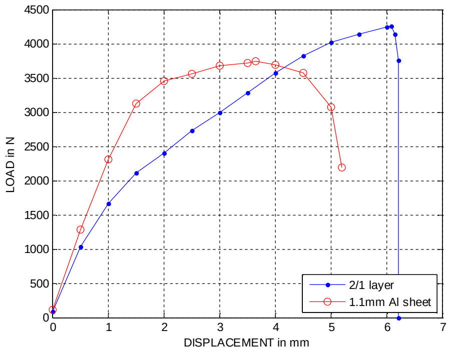
Figure. 8 specimen during Flexural testing

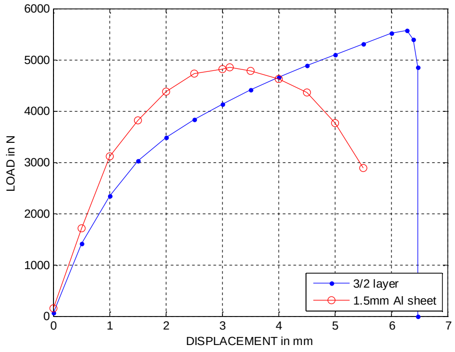
Figure. 9 Computer Controlled UTM Machine (SHIMADZU-50KN)

3. RESULTS AND DISCUSSION

From the test results (Table II to V) tensile and flexural behaviours were presented and also Load vs. Displacement, Tensile and flexural strength vs. layer thickness were discussed.

A typical Load vs. Displacement graph of Glare2/1, 3/2 and 5/4 laminates and also Aluminium sheets with same layer thickness was recorded during tensile test as per ASTM D3039 standard. Graph was drawn from these recorded values are shown in Fig.10 (a), Fig.10 (b) andFig.10(c).





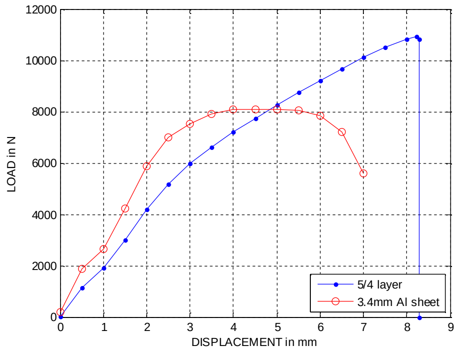


Figure.10 (a,b,c) Load vs. Displacement of glare and aluminium sheets for Tensile test

Fig 10(a) shows the load increases to reach the peak value at 4250.96N in case of glare laminate, but the load increases to reach the peak value at 3737.5 N for aluminium sheet. Glare laminate takes higher load to fracture the specimens due to nature of fibre strength with that of aluminium sheets. In addition, Glare laminates experienced maximum displacement at peak load around the value of 6.083mm, after the fracture of specimen load suddenly gets downward in glare laminate due to ductility and brittle behaviour. But aluminium sheet experienced maximum displacements at peak load around the value of 3.65mm after the fracture of specimen. The load takes minimum displacement to get down due to nature of ductility. Similarly, Glare3/2 and Glare 5/4 laminates reach peak load at 5189.62N and 10928N respectively. Incase of aluminium sheets with same thickness reach peak load at 4849N and 8087.5N respectively. Displacements of glare laminate were around the value of 6.028mm and 8.223mm respectively. Similarly, displacements of aluminium sheets were around the value of 3.13mm and 8mm respectively. The results have revealed that Glare laminates takes higher load to fracture the specimens than aluminium sheets.

Asian Journal of Computer Science and Technology (AJCST)
Vol1.No.1 2013 pp 5-13.
available at: www.goniv.com
Paper Received :19-02-2013
Paper Published:20-03-2013
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

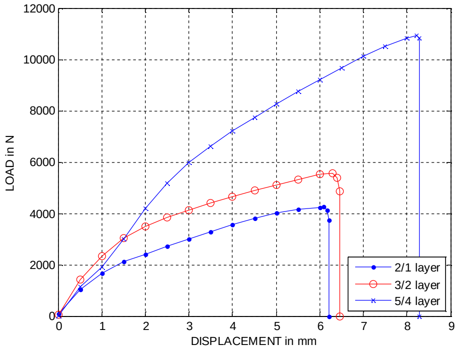


Figure.11 (a) Load vs. Displacement of Glare

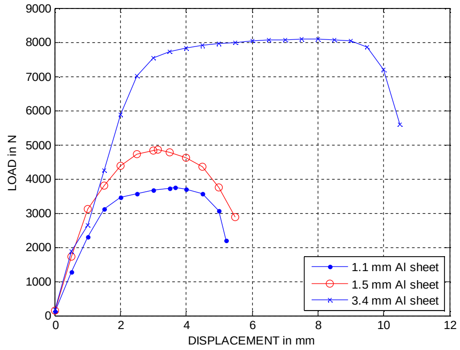


Figure.11 (b) Load vs. Displacement of Aluminium sheets

Fig 11 (a) shows the load vs. displacement curves of Glare 2/1, 3/2 and 5/4 laminates. Fig 11 (b) shows load vs. displacement curves of aluminium Sheets with same layer thickness. In Fig 11 (a) revealed that Glare 5/4 laminates required more load to fracture the specimens compared to that of Glare 3/2 and 2/1 laminates. Because Glare 5/4 includes 44% of fibre and 66% of aluminum. Incase of Glare 3/2 and Glare2/1 includes 40% and 33.33% of fibre respectively. It concluded that Volume percentage of fibre increases and so it tends to withstand more load. Load required to fracture the specimens completely depends on the thickness [8].In this article also, Load required to fracture the specimens completely depends on the thickness of specimen. i.e. volume percentage of fibre. If volume percentage of fibre increases, it is increasing the thickness of specimens. If 0.5 mm thickness increases nearly 25 to 30%, then more load required to fracture the specimens.

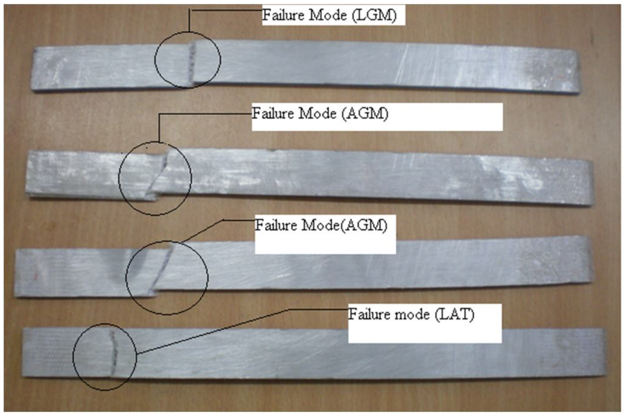
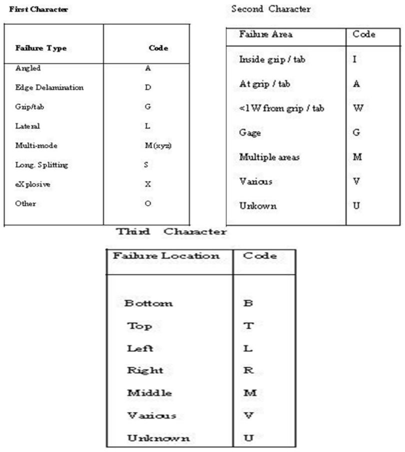


Figure 12 (a). Details of failure mode types

Table 1. (a, B, C)



First Character

Failure Type	Code
Angled	A
Edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
Long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip / tab	I
At grip / tab	A
<1W from grip / tab	W
Gage	G
Multiple areas	M
Various	V
Unkown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

FAILURE MODE TYPES

Typical specimens tested in tensile, which presented valid failure mode, classified in accordance with ASTM D3039 [16] and depicted in Tables 1A, 1B and 1C. After the tensile tests all specimens were evaluated and it was verified occurrence of failure by shear and/or debonding in the interface between laminate. Some of the specimens presented fractures in the middle of the specimens and some specimens presented fracture near to the tabs as classified in the ASTM and cited in Tables 1A, 1B and 1C. Therefore, occurred failure modes are considered valid and used to calculate the tensile strength and modulus of the tested specimens [16].

Asian Journal of Computer Science and Technology (AJCST)
Vol1.No.1 2013 pp 5-13.
available at: www.goniv.com
Paper Received :19-02-2013
Paper Published:20-03-2013
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

Figures 12(a) shows the failure modes and location of the tensile specimens. According to the ASTM standard, in this test LGM, AGM and LAT type failure mode occurs. L-Lateral, G-Failure area, M-Failure location. Similarly, In AGM, A-Angled; G- Gage; M-Middle; In LAT, L-Lateral; A- At Grip / Tab; T- Top. Angle gage middle failure mode occurs due to shear fracture, as a result of extensive slip on the active slip plane. Fracture surfaces frequently consist of a mixture of fibrous and granular fracture.

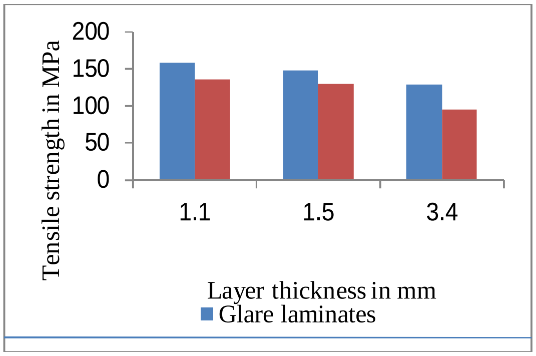


Figure.12 Tensile strength vs. Layer thickness

From Fig.12 shows tensile strength vs layer thickness of glare laminates and aluminium sheets. Tensile strength of 1.1mm layer thickness of glare laminate and Aluminium sheet is higher than that of 1.5mm layer thickness of glare laminate and Aluminium sheet. Similarly, tensile strength of 1.5mm layer thickness of glare laminate and Aluminium sheet is higher than that of 3.4mm layer thickness glare laminates and Aluminium sheets. Whenever layer thickness increases it tends to decrease tensile strength [8]. Obviously tensile strength of glare laminates is higher than aluminium sheets and it was proved by experimental work.1.1mm layer thickness glare laminate had 14.29% of higher tensile strength than aluminium sheets with the same thickness. Similarly, 1.5mm layer thickness, 3.4mm layer thicknesses had 12.86%, 25.99% more tensile strength than aluminium sheets respectively. Finally it concluded tensile strength of Glass-fiber-Reinforced Aluminium (Glare) laminates purely depend on the volume percentage of fibre and it exhibits advance over the properties of aluminium sheets.

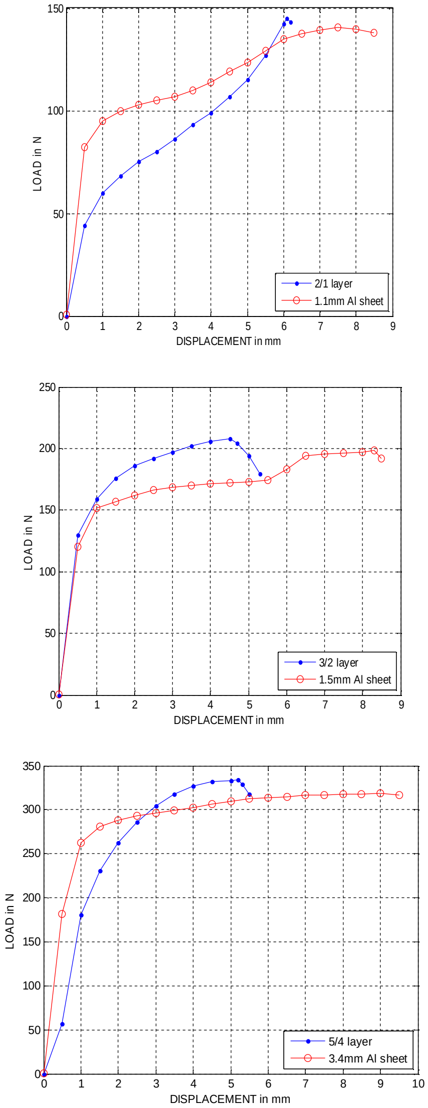


Figure.13 (a,b,c) Load vs. Displacement of glare and aluminium sheets for Flexural test

A typical Load vs. Displacement graph of Glare2/1, 3/2 and 5/4 laminates and also Aluminium sheets with same layer thickness was recorded during flexural test as per ASTM D790 standard are shown in Fig.13(a), Fig.13(b) and Fig.13(c) respectively. Fig 13(a) shows the load increases to reach the peak value at 153N for glare laminate and it experienced sudden force drop due to combined properties of metal and fibre. The load increases to reach the peak

Asian Journal of Computer Science and Technology (AJCST)
Vol1.No.1 2013 pp 5-13.
available at: www.goniv.com
Paper Received :19-02-2013
Paper Published:20-03-2013
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

at 140.5 N for aluminium sheet and it experienced gradual force drop due to nature of ductility. The results revealed that Glare laminate takes higher load to bend the specimens due to combined property of metal and glass fibre compared with that of aluminium sheets. In flexural test aluminium sheets experienced maximum displacement at peak load around the value of 7.5mm, but glare laminates experienced maximum displacement at peak load around the value of 6.081mm. During the flexural test, aluminium sheets experienced maximum displacement after the fracture of specimen compared to that of glare laminates, because of their excellent strength. Similarly, Glare 3/2 and 5/4 laminates reach peak load at around the value of 217.7N and 351.1N respectively. Incase of aluminium sheets, it reaches peak load at around the value of 198N and 318N respectively. Displacements of aluminium sheets were around the value of 8.3mm and 9mm respectively. But displacements of glare laminate were around the value of 4.5mm and 5.2mm respectively. These also pointed out glare laminates takes higher load to bend the specimens.

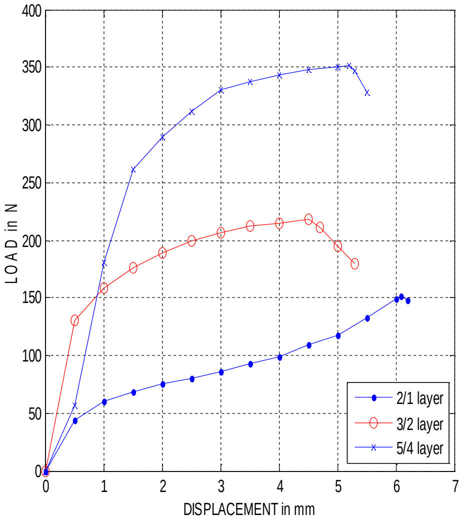


Figure.14 (a) Load vs Displacement of glare laminates

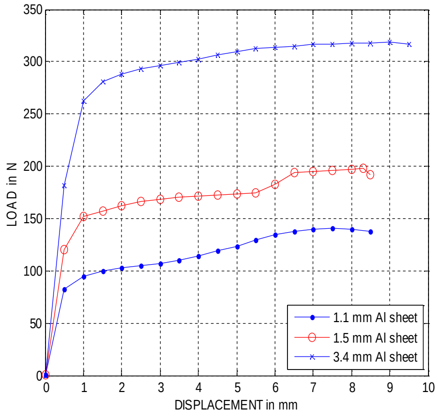


Figure.14 (b) Load vs Displacement of aluminium sheets

Fig 14 (a) shows the load vs. displacement curves of Glare 2/1, 3/2 and 5/4 laminates for flexural specimens. Fig 14 (b) shows load vs. displacement curves of aluminium Sheets with same layer thickness for flexural specimens. Comparison of Fig. 14 (a) and Fig. 14 (b), Glare laminate was required more load to bend the specimens than that of Aluminium sheets at all layers. From this, it revealed that load required to fracture the specimens completely depends on the volume percentage of fibre. If 0.5 mm thickness increases nearly 30%, then more load required to bend the specimens.

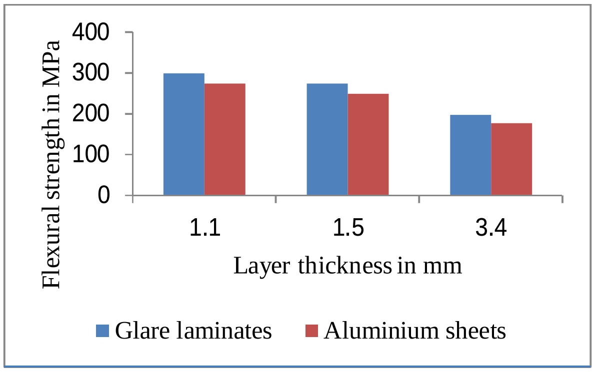


Figure.15 Flexural strength vs. Layer thickness

From Fig.15 shows flexural strength vs. layer thickness of glare laminates, aluminium sheets. Flexural strength of 1.1mm layer thickness Glare laminate and Aluminium sheet is higher than that of 1.5mm layer thickness of Glare laminate and Aluminium sheet. Similarly, flexural strength of

1.5mm layer thickness Glare laminate and Aluminium sheet was higher than that of 3.4mm layer thickness Glare laminates and Aluminium sheets. Whenever increase volume percentage of fibre, it tends to decrease flexural strength. Evidently flexural strength of glare laminates is higher than aluminium sheets and is proved by experimental work.1.1mm layer thickness Glare laminate had 8.14% higher flexural strength than aluminium sheets with same thickness. Similarly 1.5mm, 3.4mm layer thicknesses had 9.12%, 9.80% more flexural strength than aluminium sheets respectively. It concluded that Increase in volume of fibre percentage in Glare laminate tends to decrease Flexural strength.

TABLE II

TENSILE PROPERTIES OF GLARE LAMINATES

Layer	**Max. Breaking load in N**	**Max. Tensile strength in Mpa**	**Displacement at Peak load in mm**	**Specimen thickness in mm**
2/1	4250.96	158.58	6.083	1.1
3/2	5564.62	148.39	6.289	1.5
5/4	10928.0	128.56	8.223	3.4

TABLE I

TENSILE PROPERTIES OF ALUMINIUM SHEETS

Specimen thickness in mm	**Max. Breaking load in N**	**Max. Tensile strength in Mpa**	**Displacement at Peak load in mm**
1.1	3737.5	135.91	3.65
1.5	4849.0	129.33	3.13
3.4	8087.5	95.14	8.0

TABLE IV

FLEXURAL PROPERTIES OF GLARE LAMINATES

Layer	**Max. Breaking load in N**	**Max. Flexural strength in Mpa**	**Displacement at Peak load in mm**	**Specimen thickness in mm**
2/1	153.0	298.6	6.081	1.1
3/2	217.7	274.0	4.5	1.5
5/4	351.1	195.14	5.2	3.4

TABLE V

FLEXURAL PROPERTIES OF ALUMINIUM SHEETS

Specimen thickness in mm	**Max. Breaking load in N**	**Max. Tensile strength in Mpa**	**Displacement at Peak load in mm**
1.1	140.5	274	7.5
1.5	198.0	249	8.3
3.4	318.0	176	9.0

3. CONCLUSION

This article presents experimental investigation of tensile and flexural properties of Glass-fiber-Reinforced Aluminium (Glare) laminates and Aluminium sheets have been studied.

REFERENCES

[1] Vogelesang, L.B.; Vlot, A. *Journal of Materials Processing Technology*, v. 103, p. 1-5, 2000.

[2] E.M. Castrodezaa, J.M. Rodrigues Touçaa, J.E. Perez Ipiñab, F.L. Bastiana, "Determination of *CTOD*$_C$ in Fibre Metal Laminates by ASTM and Schwalbe Methods," *Material Research* vol 5, No. 2, 119 – 124, 2002.

[3] Abrate S. "Impact on laminated composite materials," *Appl Mech Rev* 1991;44(4):155–89.

[4] Botelho EC, Silva RA, Pardini LC, Rezende MC. "A review on the development and properties of continuous fiber/epoxy/aluminum hybrid composites for aircraft structures,"*Mater Res 2006*; 9(3):247–56.

[5] Tamer Sinmazçelik, Egemen Avcu, Mustafa Özgür Bora, Onur Çoban, "A review: Fibre metal laminates, background, bonding types and applied test methods," *Materials and Design* 32 (2011) 3671–3685

[6] B.M.Liaw, Y.X.liu and E.A.Vilars "Impact damage mechanism in Fiber metal laminates," *Proceedings of the SEM annual conference on Experimental and applied mechanics*, June 4-6, 2001, Portland, Oregon 536-539

[7] Y.X.Liu and B.M.Liaw, "Drop weight impact on Fiber metal laminates using various indenters," *Proceedings of SEM X International congress and Exposition on Experimental and Applied mechanics*, Costa Meas, CA, June 7-10, 2004, Paper no 386.

[8] Prashanth Banakar, "Influence of Fiber Orientation and Thickness on Tensile Properties of Laminated Polymer Composites," *International Journal Pure Applied science Technology*, 9(1)(2012), pp. 61-68

[9] Krishnakumar, S., "Fiber Metal laminates-the Synthesis of Metals and Composites," *Material and Manufacturing Processes*, Vol. 9, 1994, pp. 295-354.

[10] Wu, H. F., Wu, L. L., "Use of Rule of Mixtures and Metal Volume Fraction for Mechanical Property Predictions of Fiber-Reinforced Aluminum Laminates," *Journal of Materials Science*, Vol. 29, No. 17, 1994, pp. 4583- 4591.

[11] Alderliesten RC. Fatigure. In: Vlot A, Gunnick JW, "Fibre– metal laminates: an introduction," *Dordrecht: Kluwer Academic Publishers*; 2001 [chapter 11].

[12] Rajesh Mathivanan and Jerald.J, "Experimental investigation of low-velocity impact characteristics of woven glass epoxy composite laminates of EP3 grade," *Journal of Minerals & Materials charcterisation & Engg*, 2012;11(3)pp. 321-333.

[13] A. Pourkamali Anaraki, G. H. Payganeh, F. Ashena ghasemi, A. Fallah, "An Experimental Study on the Tensile Behavior of the Cracked Aluminum Plates Repaired with FML Composite Patches," *World Academy of Science, Engineering and Technology*," 2012 pp.61

[14] H. Esfandiar, S.Daneshmand, M.Mondali, "Analysis of Elastic-Plastic Behavior of Fiber Metal Laminates Subjected to In-Plane Tensile Loading," *International Journal of Advanced Design and Manufacturing Technology*, Vol. 5/ No. 1/ December- 2011

[15] Mohammad Alemi Ardakani, "An Experimental Study on the Impact Resistance of Glass-Fiber-Reinforced Aluminum (Glare) Laminates," (2008).

[16] ASTM, Standard test method for tensile properties of polymer matrix composite materials, ASTM D3039, Annual Book of ASTM Standards, *American Society for Testing and Materials*, PA, 15(03) (2006).

[17] ASTM, Standard test method for Flexural properties of Unreinforced and Reinforced Plastic and Electrical Insulating materials, ASTM D790, Annual Book of ASTM Standards, *American Society for Testing and Materials*, PA, 15(03) (2003).

[18] ASTM D2674 - 72(2012) Standard Methods of Analysis of Sulfochromate Etch Solution Used in Surface Preparation of Aluminum, *American Society for Testing and Materials.*

[19] ASTM D2651 - 01(2008) Standard Guide for Preparation of Metal Surfaces for Adhesive Bonding, , *American Society for Testing and Materials.*

[20] Jane Maria Faulstich, Paiva, and Mayerc and Mirabel Cerqueira Rezendea,' "Comparison of Tensile Strength of Different Carbon Fabric Reinforced Epoxy," *Materials Research*, Vol. 9, No. 1, 83-89, 2006.