Diyala Journal of Engineering Sciences Vol (14) No 4, 2021: 79-89

Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Improvement of the Mechanical Characteristics of Fiber Metal Laminate (FMLs) Used for Aircraft Wing Using Epoxy-Resole

Saad Theeyab Faris[1*], Ali Adwan Al-katawy[2], Ahmed Mohammad Kadhum[1]

[1]Department of Mechanical Engineering, University of Diyala, 32001 Diyala, Iraq
[2]Department of Material Engineering, University of Diyala, 32001 Diyala, Iraq

ARTICLE INFO

Article history:
Received 8 August 2021
Accepted 28 October 2021

Keywords:
Hybrid composite materials
Fiber metal laminates
Mechanical properties
FMLs

ABSTRACT

The Fiber Metal Laminates (FMLs) was studied and improved the mechanical properties were used for aircraft wing. The FMLs are consisting of metal sheets reinforced with fiber bonded by matrix phase. The FMLs consist of seven layers to produce the Hybrid composite materials that made from 2024-T3 Aluminuim sheets with carbon and glass fibers as reinforcement and bonded using adhesion materials that are locally manufactured from resole resin with adding using epoxy resin. By using the FMLs, the mechanical characteristics have been improved and the weight of the aircraft wing has been reduced. The mechanical characteristics have been improved comparing to other FMLs using commercial epoxy. The FMLs with carbon and glass fibers have high tensile strength and elastic modulus but low yield and elongation comparing with the FMLs of carbon fibers as a reinforcement. The flexural modulus and impact toughness is high for the FMLs with glass fiber comparing with jute fibers with adding using carbon fiber as areinforcement.The Aramid Reinforced Aluminum Laminates (ARALLs) have low fatigue strength than FMLs using carbon fiber as reinforcement. The FMLs are lower ratio of ultimate to yield strength and density than 2024-T3 Aluminum alloy that commonly used in aircraft wing.

1. Introduction

Hybrid composite materials are mixing two or more different fibers within layer by layer. The beneficial of different properties of fibers employed in hybride composite materials and designed based on it. Fiber Metal Laminates (FMLs) is the lightweight materials that can be fabricated by merge the formability of metals and advanced characteristics of composite materials (see Figure 1). They can be created by bonding of composite laminates plies with metal sheet. They have high strength and stiffness to weight ratio, high corrosion resistance and excellent fatigue characteristics [1]. The FMLs were recently used in aerospace industries since they have high fatigue resistance as well as low weight comparison with materials like metals. They combine the good characteristics of metals and fiber-reinforced composites. Metals have ductility, impact resistanceand damage tolerance, Fiber-reinforced composites have high specific stiffness, corrosion, and fatigue resistance [2]. The rapid development and progress of composites technology has been spawned by the high specific strength, stiffness, and toughness offered compared with other engineering materials. Hybrid materials made from a strong fiber and a well-suited matrix. The fiber-matrix interface is equally important in determining the mechanical performance of the Hybrid materials. The development of a hybrid materials is the quality of the interface [3]. Epoxy-phenolics are expensive materials and

---

[*] Corresponding author.
E-mail address: saaddiab_eng@uodiyala.edu.iq
DOI: 10.24237/djes.2021.14407

mixture of thermosetting phenolic and epoxy resins. These materials have excellent shear and tensile strength over a wide temperature range [4].

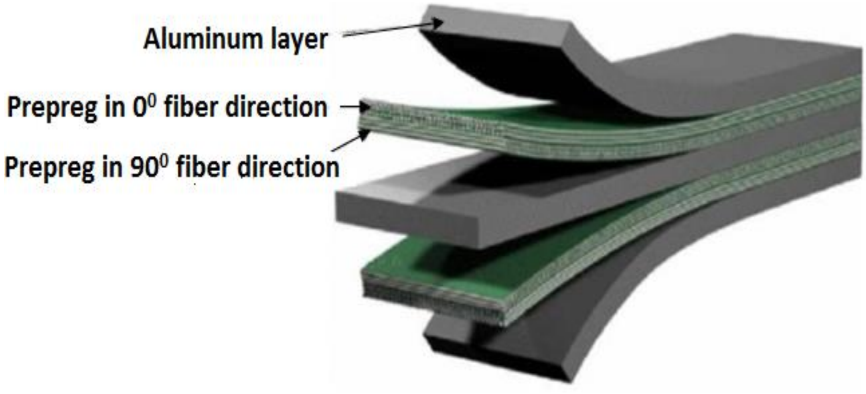


Figure 1. Schematic presentation of FMLs [5]

During year 1978, Aramid Reinforcement Aluminum Laminates (ARALLs) was the first FMLs developed by Aerospace department of Delft University of technology Netherlands and it was commercially available in 1982 [6]. In 1987, the new FMLs was patented where the glass fibers is used instead of aramid fibers because glass fiber (GLARE) has superior impact behavior. In 1990, the GLARE has applied on the floor structures of the Boeing 777. In 1997, the GLARE was used as skin material of Airbus A380-800. Now, the GLARE is the FMLs standard, which were used as the skin material for Airbus Aircraft [7]. Mohammed et al improved the tensile and flexural of The FMLs with flax fibers have high tensile strength and elastic modulus comparing to FMLs with kenaf fibers but have low flexural strength [8]. Chandrasekar et al studied the tensile and compressive strength and fatigue properties of FML. The tensile strength for FMLs (aluminum/carbon/flax) was superior and 23% higher than FMLs (aluminum/carbon/ sugar palm) while 5% higher than FMLs (aluminum/carbon/flax/sugar palm) configuration. FMLs (aluminum/carbon/flax) have excellent fatigue resistance [9]. Patil investigated the tensile, flexural and impact test of FMLs. The CARALL has higher mechanical properties as compared to ARALL and GLARE [10]. Hassan et al, 2015[11]: studied the tensile and flexural properties of GLARE. The numbers of layers in GLARE were increased that lead to give good strength but it was led to increase in thickness of laminates. The delamination of GLARE was weak with increasing the number of layers in GLARE. Ahmed, 2016[12]: showed the development for the fiber metal laminates sandwich material. It represented that pure metal mixed with sum other material through the process like stir and GPIT offered that increasing better mechanical properties than reducing the weight and cost. It gave good substitutive materials for improving the fuel efficiency. Yelamanchi et al 2020 [13], using a continuously 3D printed carbon fiber reinforced composite. The initial results show that the tensile strength of the investigated FMLs is considerably superior to the plain composite materials. The FMLs seem to surpass the impact performance of the plain composite.

2. Materials and methods

2.1. Materials used for fabrication of FMLs

The properties of materials were used to fabricate the FMLs can be shown in tables 1,2,3 and 4. The FMLs plate is consist of aluminum sheets. in this study, the reinforcement fibers in the FMLs consist of three of SikaWrap-301C carbon fiber and E-Glass fiber EWR450. The bond materials in the FMLs consist of blend of epoxy resin with resole resin.

Table: Mechanical and physical Properties of resins [14, 15]

Property	Viscosity (MPa.s)	Density ($g.cm^{-3}$)	Compressive strength (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	pH	Pot life min
Sikadur52 epoxy	430	1.1	53	50	25	7.7	10
Resole resin	4000-7000	1.2	-	-	-	6.5-7.5	> 20

Table 2: Mechanical and physical Properties of fibers [16, 17]

Property	Material	Color	Orientation	Density ($g.cm^{-3}$)	Thick (mm)	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation at break%
EWR 450	E-glass fiber	White	45° (Woven roving)	1.88	0.3	331	25.86	3.4
SIikawrap 301 C	Carbon fiber	Black	0° (Unidirectional)	1.8	0.17	4900	230	2.1

Table 3: Properties of Mechanical and physical of 2024-T3 alloy of aluminium [18]

Property	Thickness (mm)	Density ($g.cm^{-3}$)	Ultimate strength (MPa)	Yield strength (MPa)	Elongation (%)	Endurance limit (MPa)	Elastic modulus (GPa)
Value	0.5	2.78	435	290	10-15	138	73.1

Table 4: Aluminium 2024-T3 Chemical compositions used in this study [18]

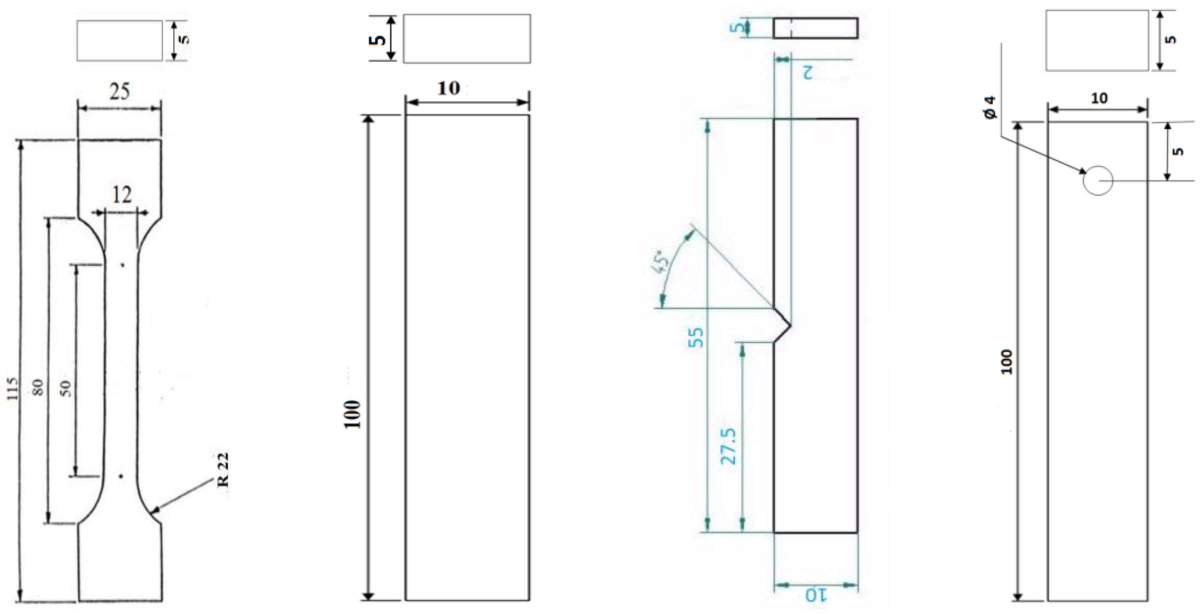
Component	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Other each	Another total	AL
Wt. %	0.1	3.8-4.9	0.5	1.2-1. 8	0.3-0.9	0.5	0.15	0.25	0.05	0.15	Reminder

2.2 Preparation of CAGRALLs

The Hand lay- up technique was used to made of FMLs. The 80% of epoxy with 20% of resole resin was mixing ratio that used. The weight fraction 0.2 wt for reinforcement was used in this study. Samples consist of seven layers (Al/Ca90/G45/Al/ G45/Ca90/Al) were used in this study. the cutting of these samples according to ASTM standard for each test was done by using CNC water jet machine. For each test using at least three specimens.

2.3. Mechanical tests

The Figure 2a shows the tensile test specimens were cut according to ASTM D-638. The three flexural points tests were commonly used in the hybrid composite materials. The Figure 2b represents the flexural test specimen according to ASTM D790 standard. The Charpy V-notched impact test with pendulum (300-Joule) according to the standard ISO 179 (see Figure 2c). The reversed bending fatigue test cantilever according to standard HSM 19 for carrying out fatigue test (see Figure 2d). At room temperature laboratory, All tests were done.



(a) (b) (c) (d)

Figure 2. Schematic of the tests specimen for this study: (a) tensile test (b) flexural test (c) impact test (d) fatigue test (Note: All dimensions in mm)

3. Results and discussion

The Figure 3 shows the tensile samples before and after testing. The tensile strength values for three specimens can be presented in Figure 4. It showed that the tensile strength was varied from 176 to 231 MPa. The different in fabrication methods of FMLs led to varied in results where the tensile load carrying capacity increases up to certain extend and after that, there is a sudden fall at load later. The tensile strength for the FMLs using Aluminium sheets with carbon fiber (225 MPa) is lower than the FMLs using aluminium sheets with carbon and glass fiber [5].

(a) (b)

Figure 3. Tensile test sample: (a) before the test (b) after the test

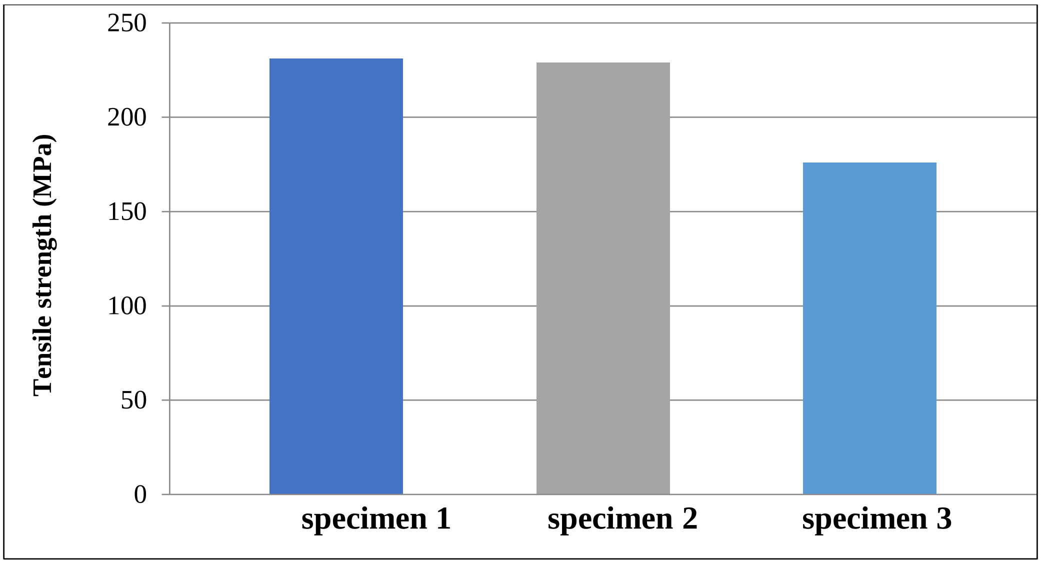


Figure 4. Values of Tensile strength for FMLs

The elastic modulus values of FMLs can be showed in Figure 5 for three specimens. The figure indicates that elastic modulus was varied from 2.5 to 2.78 GPa. The FMLs have high elastic modulus comparing to FMLs due to reduce the number of layers and use carbon and glass fibers instead of jute fibers. The elastic modulus for the FMLs using Aluminium sheets with carbon fiber (2 GPa) is lower than the FMLs using aluminium sheets with carbon and glass fiber [13].

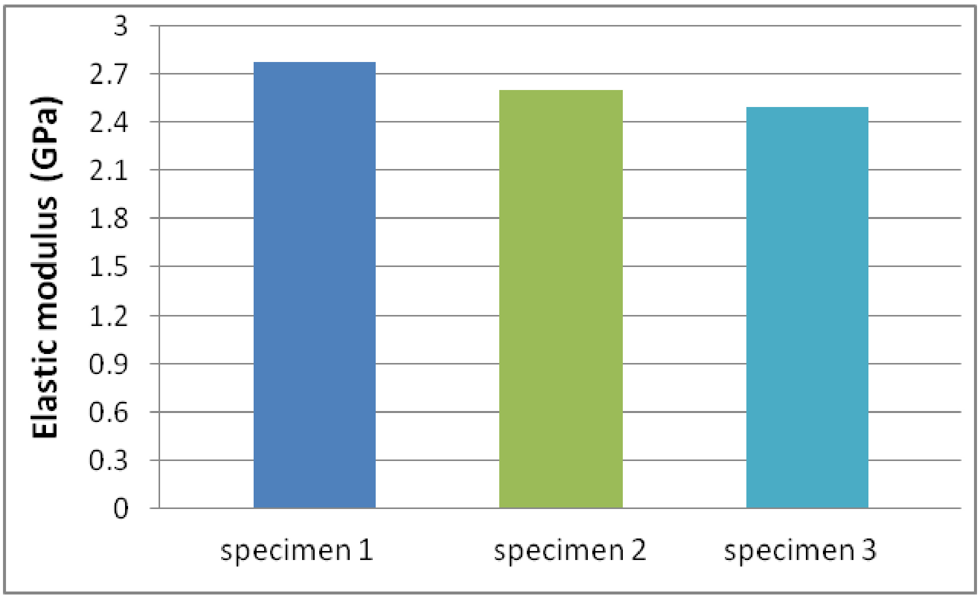


Figure 5. Values of Elastic modulus for samples

The values of yield strength can be showed in figure 6 for three specimens which indicates a variation from 169 to 179 MPa. The ratio of ultimate to yield strength of FMLs was obtained of about 0.97 to 1.3 in this study comparing with Aluminium base alloy 2024-T3 (1.5) and it is noted that the ratio was lower. The yield strength for the FMLs using Aluminum sheets with carbon fiber (200 MPa) is higher than the FMLs using aluminum sheets with carbon and glass fiber [13].

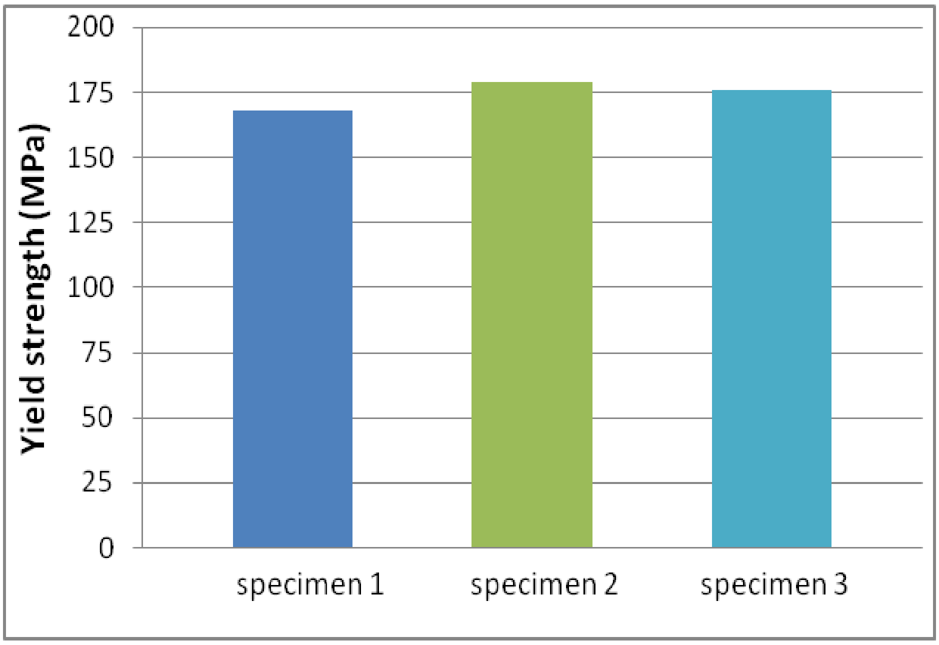


Figure 6. Yield strength values for FMLs for this study

Figure 7 shows the elongation at fracture values of FMLs for three specimens. The figure indicates that elongation at fracture was varied from 9 to 17 %. This variation was occurred due to the different in fabrication method. Rajkumar et al obtained of about 8.5% [11]. The FMLs have high elongation at fracture comparing to CACAGRALLs due to increase in layers and use blend of epoxy-resole instead of epoxy. The elongation at fracture for the FMLs using Aluminum sheets with carbon fiber (24.5 %) is higher than the FMLs using aluminum sheets with carbon and glass fiber [13].

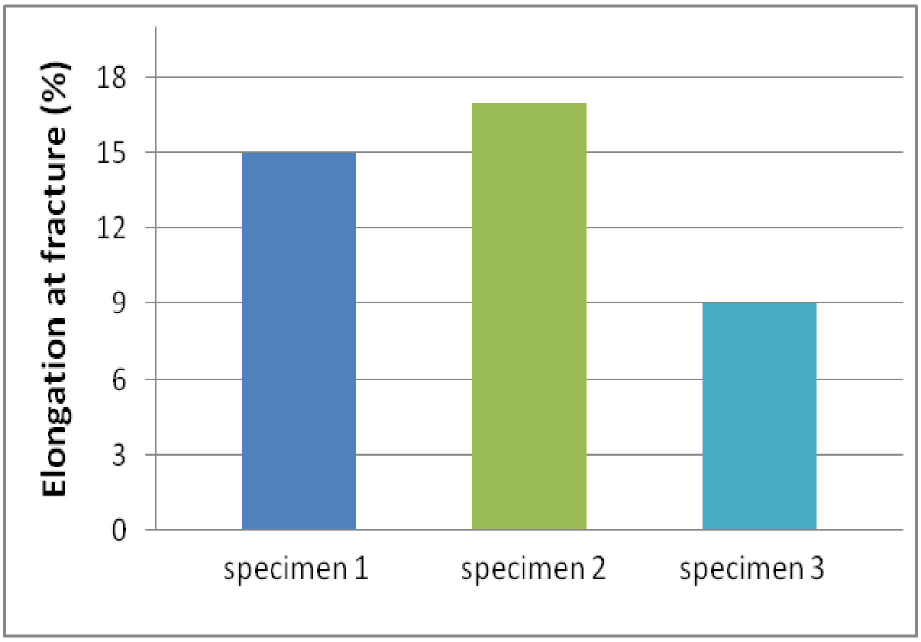


Figure 7. Elongation at fracture values for FMLs

The flexural samples before and after testing can be showed in Figure 8. Figure 9 can be showed the values of flexural strength for FMLs. The variation of the flexural strength was from 154 to 589.2 MPa with four specimens. The FMLs have high flexural strength comparing to FMLs when using average of flexural strength values for FMLs. The flexural strength for the FMLs using Aluminum sheets with carbon fiber (320 MPa) is lower than the FMLs using aluminum sheets with carbon and glass fiber [20].

(a) (b)

Figure 8. Flexural test sample: (a) before test (b) after test

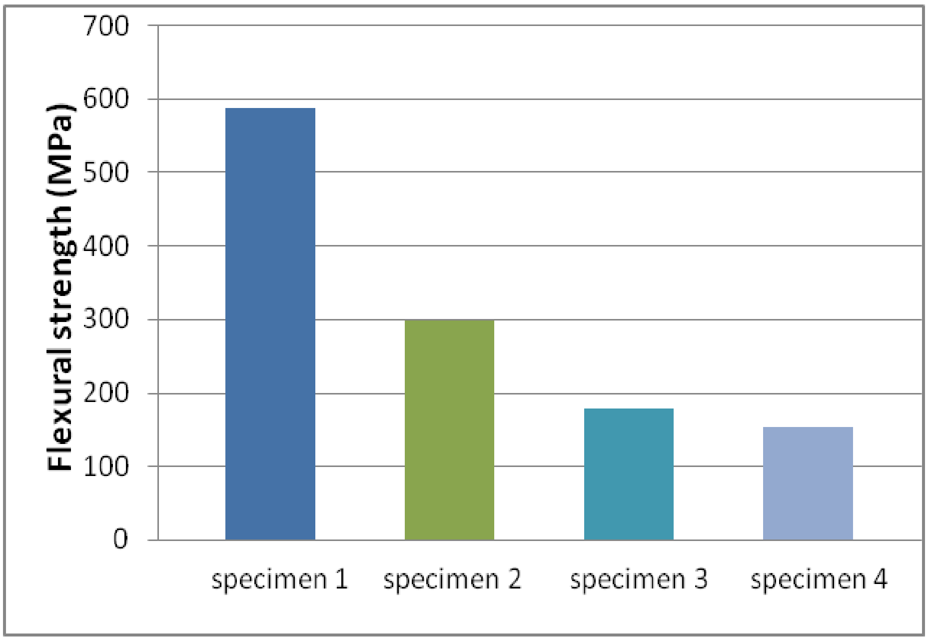


Figure 9. Flexural strength values for samples

The flexural modulus values for FMLs can be presented in Figure 10 which it indicates that flexural modulus was varied from 4.9 to 7.33 GPa. The flexural modulus for the FMLs using Aluminum sheets with carbon and jute fibers (1.73 GPa) is lower than the FMLs using aluminum sheets with carbon and glass fiber [19].

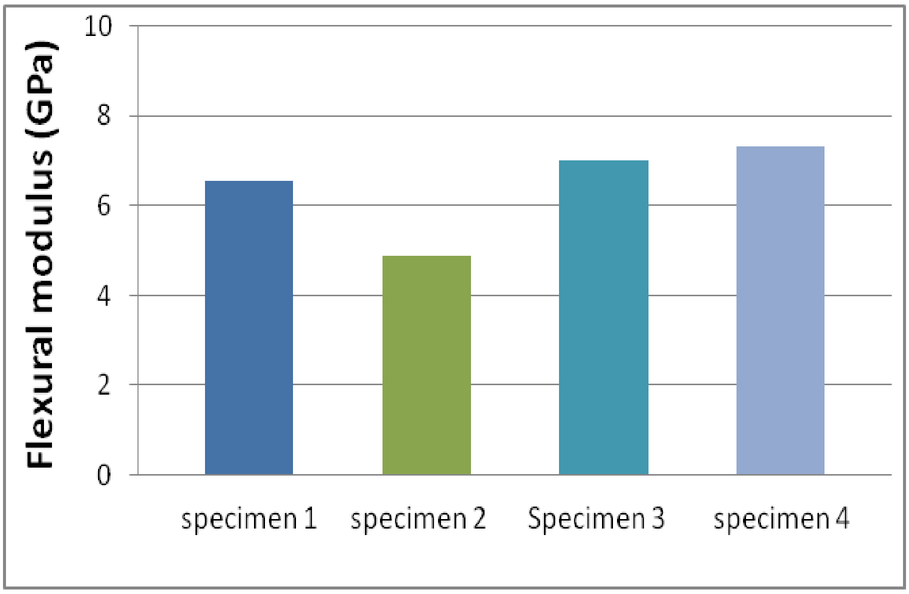


Figure 10. Values of Flexural modulus for FMLs

Figure 11 shows the values of shear strength for FMLs in which indicates that the variation of shear strength was from 8.67 to 31 MPa. Chandrasekar et al used commercial epoxy, aluminum sheets reinforced with carbon, flax and sugar palm fibers (CAFSRALLs) to produce FMLs and obtained that the shear strength was lower than 7 MPa [14]. The FMLs have high shear strength comparing to CAFSRALLs.

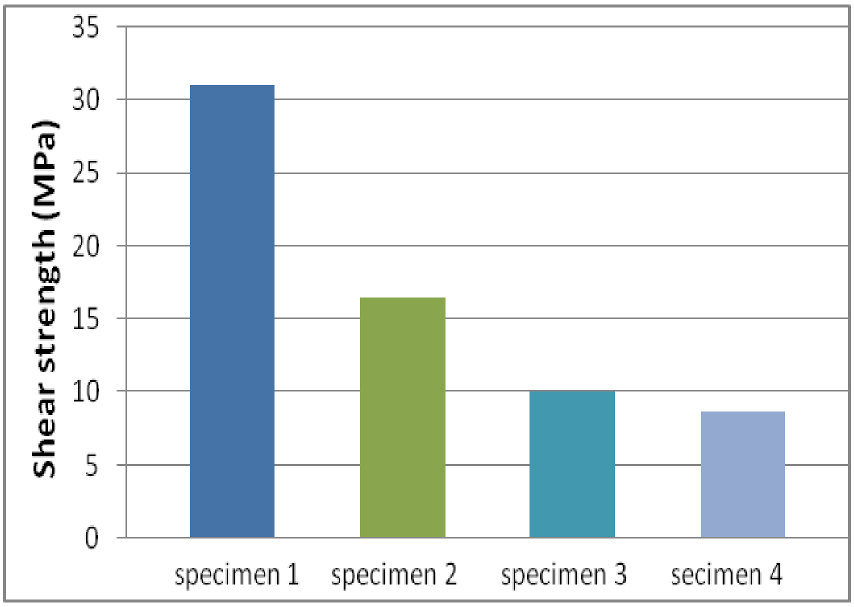


Figure 11. Shear strength values for FMLs

The impact samples before and after testing can be presented in Figure 12 which showed the impact toughness for three samples of FMLs. The variation of impact toughness is from 35 to 38.75 10-4 J/mm3. The impact toughness for the FMLs using Aluminum sheets with carbon and jute fibers (23.24 10-4 J/mm3) is lower than the FMLs using aluminum sheets with carbon and glass fiber [19].

(a) (b)

Figure 12. Impact test sample: (a) before; (b) after

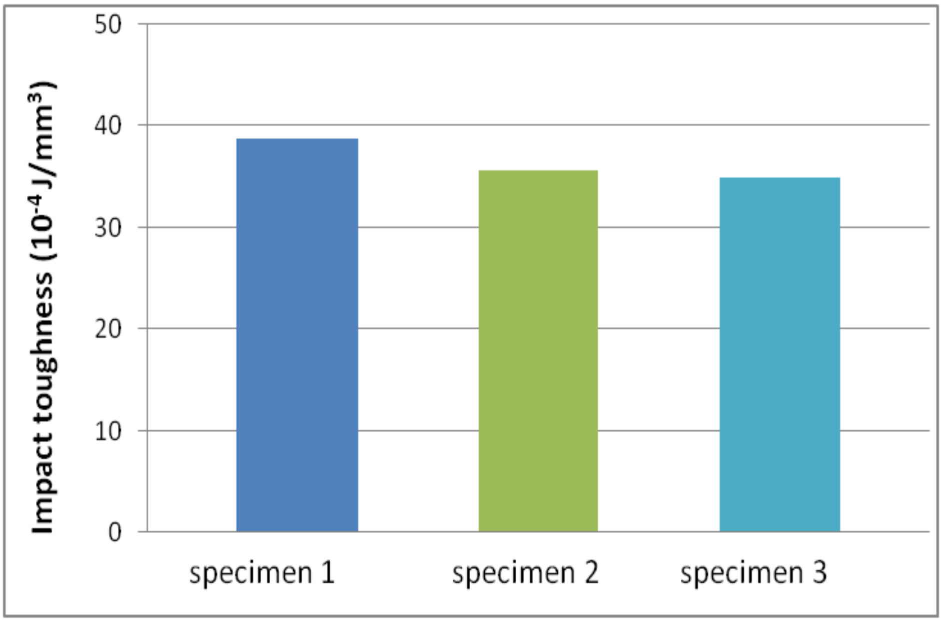


Figure 13. values of Impact toughness for samples

The fatigue samples before and after testing can be showed in figure 14. the number of life cycles for FMLs under the fluctuating loadings that lead to failure comparing with GLARE can be showed in Figure 15. The range of stresses was equal pluas and minus one. The number of life cycle was obtained of about 2.7253 x 104 cycles for FMLs at fluctuating stress (100 MPa). the number of life cycle was obtained about of 5.726 x 103 cycles for FMLs at fluctuating stress (200 MPa),. The FMLs have lower number of life cycles to failure comparing to ARALLs.

(a) (b)

Figure 14. Fatigue test sample: (a) before test (b) after test

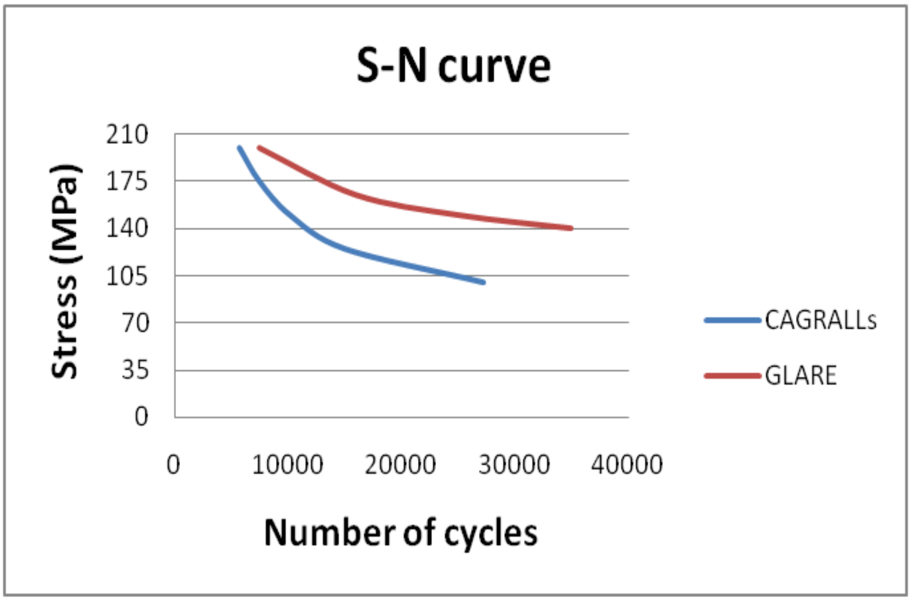


Figure 15. S-N curve for FMLs

The metal density value like aluminum and steel is 2.78 and 7.86 gram per cubic meter respectively [17]. However, it of fabricated FMLs was achieved of about 1.7704 g/cm^3 thus a reduction of 36.3% of aircraft wing weight. It indicated that the weight of aircraft wing is reduced using the FMLs comparing of metals like aluminum and steel.

4. Conclusion

The aim of using hybrid materials is to give good mechanical properties as well as lower weight. The mechanical characteristics of FMLs were experimentally investigated. The results showed that FMLs have high of tensile strength, elongation at fracture and flexural strength with carbon and glass fibers comparing to FMLs using carbon fibers. The FMLs with carbon and jute fibers have low elastic modulus, low flexural modulus and low impact toughness comparing to FMLs using carbon and glass fibers. The ratio of ultimate to yield strength of FMLs was lower comparing with Aluminum base alloy 2024-T3. The FMLs have high shear strength comparing to CAFSRALLs. The FMLs have high fatigue resistance comparing to ARALLs. A 36.3% weight reduction of aircraft wing using FMLs over aluminum alloy 2024-T3 was obtained.

Acknowledgments

The authors would like to thank co-operation of the Mechanical Engineering

Department University of Diyala for its help and support in doing this work.

References

[1] Matthews, F. L., Davies, G. A. O., Hitchings, D., and Soutis, C. Finite element modelling of composite materials and structures. Abington Cambridge CB1 6AH, England: Woodhead Publishing Limited, Abington Hall, 2000.

[2] Rajkumar, G. R., Krishna, M., Murthy, H. N., Sharma, S. C., and Mahesh, K. V. (2012). Experimental investigation of low-velocity repeated impacts on glass fiber metal composites. Journal of materials engineering and performance, 21(7), 1485-1490.

[3] Lin, Y., Ehlert, G., and Sodano, H. A. (2009). Increased interface strength in carbon fiber composites through a ZnO nanowire interphase. Advanced functional materials, 19(16), 2654-2660.

[4] Landrock, A. H., and Ebnesajjad, S. (2008). Adhesive’s technology handbook (second edition). William Andrew.

[5] Emberey, C. L., Milton, N. R., Berends, J. P. T. J., Van Tooren, M. J. L., Van der Elst, S. W. G., & Vermeulen, B., Application of knowledge engineering methodologies to support engineering design application development in aerospace. In 7th AIAA ATIO Conf, 2nd CEIAT Int'l Conf on Innov and Integr in Aero Sciences, 17th LTA Systems Tech Conf; followed by 2nd TEOS Forum (2007): p. 7708.

[6] Sathyaseelan P., Logesh K., Venkatasudhahar M., and Dilip Raja N. " Experimental and Finite Element Analysis of Fibre Metal Laminates (FML’S) Subjected to Tensile, Flexural and Impact Loadings with Different Stacking Sequence." International Journal of mechanical & mechatroncs Engineering, 15(3) (2015): 23-27.

[7] Hombergsmeier, E. "Development of advanced laminates for aircraft structures." In Proceedings of 25th International Congress of the Aeronautical Sciences. (2006): 3-8.

[8] Mohammed, I., Talib, A. R. A., Sultan, M. T. H., Jawaid, M., Ariffin, A. H., and Saadon, S., Mechanical properties of fiber-metal laminates made of natural/synthetic fibre composites. BioResources, 13(1) (2018): 2022-2034.

[9] Chandrasekar, M., Ishak, M. R., Salit, M. S., Leman, Z., Jawaid, M., and Naveen, J., Mechanical Properties of a Novel Fibre Metal Laminate Reinforced with the Carbon, Flax, and Sugar Palm Fibres. BioResources 13.3 (2018): 5725-5739.

[10] Patil, N. A., Mulik, S. S., Wangikar, K. S., and Kulkarni, A. P. Characterization of Glass Laminate Aluminium Reinforced Epoxy-A Review. 2nd International Conference on Materials Manufacturing and Design Engineering, Procedia Manufacturing, 20 (2018): 554-562.

[11] Hassan, M. K., Abdellah, M. Y., Azabi, S. K., and Marzouk, W. (2015). Investigation of the Mechanical Behavior of Novel Fiber Metal Laminates. International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 15(3), 112-118.

[12] Ahmed S.M. (2016), A Review on Fibre Metal Laminate Sandwitch Panel, International Journal of Engineering Trends and Technology,32, 3671-3685.

[13] Yelamanchi, Bharat, et al. "The Mechanical Properties of Fiber Metal Laminates Based on 3D Printed Composites." Materials 13.22 (2020): 5264.

[14] Khdir, Y. K., and Hassan, G. I., USE OF DIFFERENT GRADED BRASS DEBRIS IN EPOXY-RESIN COMPOSITES FOR IMPROVING MECHANICAL PROPERTIES, 4th International Engineering Conference on Developments in Civil & Computer Engineering Applications, (2018): 2409-6997.

[15] Ismail, I. N., Ishak, Z. A. M., Jaafar, M. F., Omar, S., Zainal Abidin, M. F., and Ahmad Marzuki, H. F., Thermomechanical properties of toughened phenolic resole resin. Solid state science and technology, 17(1) (2009): 155-165.

[16] Astrom, B., Manufacturing of Polymer Composites, Chapman & Hall, (1997): 1-175.

[17] Al-Mutairee, H. M., & Al-Hamdani, H. A., Flexure Behavior of Hybrid Continuous Deep Beam Strengthened by Carbon Fiber Reinforced Polymer. Journal of University of Babylon, 25(5) (2017): 1580-1592.

[18] American Society for Metals., Metals handbook. 2. Properties and selection: nonferrous alloys and special-purpose materials. American Society for Metals, 1990.

[19] Vasumathi, M., and Murali, V., Effect of alternate metals for use in natural fibre reinforced fibre metal laminates under bending, impact and axial loadings. International Conference on DESIGN AND MANUFACTURING. Procedia Engineering, 64 (2013): 562-570.

[20] Rajkumar, G. R., Krishna, M., Narasimhamurthy, H. N., Keshavamurthy, Y. C., and Nataraj, J. R. Investigation of tensile and bending behavior of aluminum based hybrid fiber metal laminates. International Conference on Advances in Manufacturing and Materials Engineering (AMME). Procedia Materials Science, 5 (2014): 60-68.