Scholars Journal of Engineering and Technology (SJET) **ISSN 2347-9523 (Print)**
Abbreviated Key Title: Sch. J. Eng. Tech. **ISSN 2321-435X (Online)**

A Unit of Scholars Academic and Scientific Society, India
www.saspublishers.com

Prediction of Tensile Stress-Strain Behavior of Natural Fibers Metal Laminates

Hicham Laribou[1*], Abdelali El-Bakari[2]
[1]Laboratoire de Microstructure et de Mécanique des Matériaux, Université de Lorraine, Nancy and Metz, Lorraine, France
[2]Laboratoire de Mécanique et génie civil, Université Abdelmalek Essaadi Tanger, Avenue Khenifra, Tétouan 93000, Morocco

Original Research Article

***Corresponding author**
Hicham Laribou

Article History
Received: 09.07.2018
Accepted: 15.07.2018
Published: 30.07.2018

DOI:
10.36347/sjet.2018.v06i07.003

Abstract: Fiber–metal laminates (FMLs) are high-performance hybrid structures based on alternating stacked arrangements of fiber-reinforced plastic (FRP) plies and metal alloy layers FMLs have benefits over both aluminum and fiber reinforced composites. In this work, a jute fibers and effect of fiberFE volume fraction on tensile behavior of this novel material is investigated. A numerical simulation method based on finite element modeling (FEM) ie used to predict the tensile proprerties of FMLs and compared with a result obtained by a modified classical laminate theory (CLT) given in literature. Good agreement is obtained between the models predictions and mathematical results. The obtained results show that the fiber volume fraction improves elastic and plastic moduli, yield stress and ultimate tensile stress considerably. Statistical analysis of data is done and an estimated tensile strength of each FMLs as a function of fiber volume fraction is obtained
Keywords: Fiber metal laminates, Finite element analysis, yield strength prediction.

INTRODUCTION

The Fiber Metal Laminates (FMLs) are a family of hybrid metallic–polymer matrix composite materials made from multi thin layered materials based on the stacked arrangement of Aluminum alloys sheets and fibers embedded in adhesive i.e rubber toughened epoxy. The variant with glass fibers is called Glare and his first commercial use was in 1987. The laminated layout creates a material with high strength, excellent rigidity, insulation proprieties and great lightness [1].

The prospect of a possible 20% weight reducing for aircraft structures was the prime driver behind the Glare development. Indeed, Krishnakumar *et al.*, [2] have deduced that the tensile strength of many FMLs is better than different aerospace alloys with an advantage of weight reduction. The conventional design principles and methods available for aluminum were taken as a starting point, and were adapted for the specific features of Glare such as anisotropy and elastic fibre layers. This ensured a better acceptance of these methods and principles by the aircraft industry. Many methods for Glare already existed, because they were part of the material development that was carried out in Delft by MSc- and PhD-students during the last fifteen years. It had to be proven that these structural analysis methods were accurate and reliable for industrial application as well [1].

Moreover, Luciano *et al.*, [3] presented analytical form relations for determining proprieties of composite lamina from the proprieties of constituent. Otherwise, Hagenbeek *et al.*, [4] presented also an analytical procedure for the calculation of uniaxial stress-strain behaviour of Glare. Wu *et al.*, [5] presented an analytical modelling and numerical simulation of the tensile proprieties of hybrid FMLs. Furthermore, Mourssavi-Torshizi *et al.*, [6] studied the tensile proprieties of novel FMLs experimentally, analytically and trough finite element method by the use of the modified Classical Laminate Theory (CLT) to obtain the stress-strain behaviour of developed FMLs analytically.

In this paper, we will proceed by the use of the finite element method to modelling a Fiber Metal Laminates, based on the aluminum alloy A5086 and epoxy reinforced with jute fiber in ANSYS. A good agreement will be obtained between the model predictions and experimental results. Then the validation of the modelling approach will be approved by an analytical model available in the literature [6]. Finally, we will study the effect of jute fiber volume fraction on the tensile properties of the FLMs obtained.

MATERIALS AND METHODS
Materials
The aluminum alloy AA5086 is the most common type metal used for setting up a FMLs for their low density and their high mechanical properties. In the present work the aluminum alloy AA5086 with bilinear elasto-plastic behaviour has been used as the metal part in the FMLs, and its chemical composition and some mechanical characteristics are given by Tables-1and 2.

Table-1: Chemical composition of the aluminum alloy AA5086

Al	Fe	Ti	Mg	Mn	Si	Zn	Cu	Cr
95,2%	0,36%	0,02%	3,83%	0,23%	0,17%	0,01%	0,01%	0,15%

Table-2: Some mechanical characteristic of the aluminum alloy AA5086 [6]

Elastic young's modulus Eel	Tangent modulu Epl	Yield strength Syt
46,5GPa	770 MPa	275 MPa

Recently environmental standards are becoming more and more severe. These regulations have led to the emergence of a promising alternative that consists in developing biocomposite materials developed with ecofriendly reinforcements from renewable natural resources. Vegetable fibers seem to be the best candidates, hence the choice in this study to use a jute fibers which offer a high strength with a low cost. Tables-3 and 4 give a chemical composition and mechanical properties for the jute fibers.

Table-3: Chemical composition of jute fibers [7]

Cellulose	Hemicellulose	Lignin	Ash	Wax	Moisture
61-71%	13,6-20,6%	12-13%	0,5-2%	0,5%	12,6%

Table-4: Mechanical properties of jute fibers [8]

Property	Tensile strength (MPa)	Modulus of Elasticity (GPa)	Elongation at break (%)	Density (g/cm3)
Value	410-780	26.5	1.9	1.48

As the matrix material we used an epoxy resins in the present study, which offers a high tensile strength, high rigidity, chemical resistance, fire resistance and low curing shrinkage. Its application fields are widespread and remain very useful [9] [10].

Calculation methods
Most commercial FEM codes provide 2D elements suitable for stress analysis of composite and sandwich structure. In our current case, three general pathways (micro, meso and macro-scale) of modelling FMLs have been outlined by [7], and the dimensions of finite element model were chosen to be 175mm x 25mm x 1mm based on the recommendations of [6].

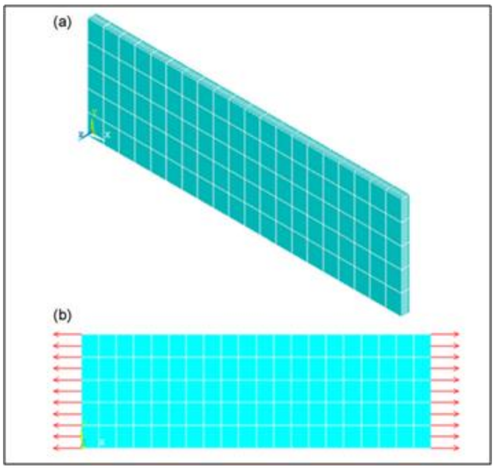

Fig-2: Finite element model: (a) meshing; (b) boundary conditions

In this study the FMLs were modeled by commercially available FEM software, ANSYS 11 with SHELL 91 element. SHELL 91 is a nonlinear layered structural shell element. The element is defined by eight nodes non- linear element used to discrete the domain of our ANSYS product. Tensile load is applied on the vertical sides of the finite element model in 20 substeps to capture the non-linear behaviour of the FMLs (Figure-2). The bilinear elasto-plastic behaviour of the AA 5086 layer is incorporated using the Von-Mises plasticity option in ANSYS. Also, a numerical simulation, based on finite element modelling is employed to predict the stress–strain response of FMLs. Micromechanics relates the elastic properties of the lamina with the individual properties of fiber and matrix and their volume fraction $C^* = (C_f, C_m, V_f)$ with, C^* is elasticity of matrix, C_f is elasticity of fiber, C_m is elasticity of metal and V_f is a fiber volume fraction. [Luciano and Barbero, 1994] presented an analytical closed form solution of for doing so without the need of experimentation by using periodic microstructure approach. As for the basic material properties, the metal volume fraction approach was proven to be valid for shear stiffness and blunt notch and yield strength.Section Headings

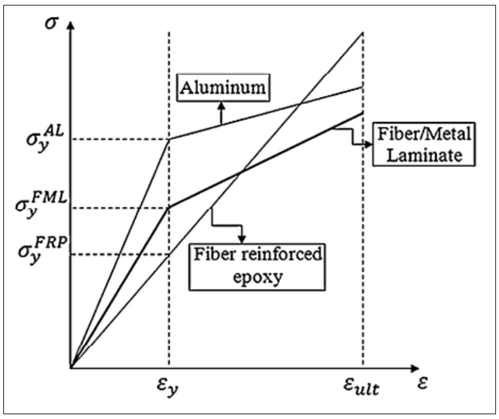

Fig-3: Schematic illustration of Stress-Strain curves

The mathematical model as provided by [6] has been used in the present investigation to validate the results of FEM. It can be observed from Figure-3 that, stress–strain curve of FML is separated into two parts. In the first part both aluminum and fiber reinforced plastic (FRP) layers like glass/epoxy and Kevlar/epoxy

The mathematical model is a modification of the Classical Laminate Theory (CLT) to consider the elasto-plastic behaviour of the FML. MATLAB codes were written to implement the mathematical model and obtain the results.

For a linear-elastic material behaviour [12]:

$$\sigma_{\mathrm{FML}} \leq (\sigma_{\mathrm{y}})_{\mathrm{FML}} \tag{1}$$

$$(\sigma_{\mathrm{y}})_{\mathrm{FML}} = \frac{E_{\mathrm{FML}}}{E_{\mathrm{AL}}}(\sigma_{\mathrm{y}})_{\mathrm{AL}} \tag{2}$$

When $\sigma_{FM\mathrm{L}}$ is total stress in laminate, (σ_y) is yield stress of laminate, $_{EFML}$ is the young's modulus of the laminate, E_{Al} is the young's modulus of aluminum layer and $(\sigma_y)_{AL}$ is yield stress of aluminum layer. The equation can be derived as:

$$\sigma_{\mathrm{FML}} = \left(\frac{E_{\mathrm{AL}}t_{\mathrm{AL}} + E_{\mathrm{FRP}}t_{\mathrm{FRP}}}{t_{\mathrm{FML}}}\right) \cdot \varepsilon_{\mathrm{FML}} \tag{3}$$

Where t_{Al} is the total thickness of aluminum layers, t_{FRP} is the total thickness of fibrous layers consist of one Kevlar/epoxy layer and two glass/epoxy layers. The thickness of each Glass/epoxy layer was about 0.35 mm and thickness of Kevlar/epoxy layer was about 0.3 mm. t_{FM}L is the total thickness of all layers, and $\varepsilon_{\mathrm{FML}}$ is total strain of laminate. E_{FRP} is the Young's modulus of the fibrous Layer which was calculated using classical laminate theory. In the second part aluminum becomes plastic. For elastic–plastic laminate:

$$\varepsilon_{\mathrm{FML}} \geq (\varepsilon_{\mathrm{el}})_{\mathrm{AL}} \tag{4}$$

Where $(\varepsilon_{el})_{AL}$ is elastic strain of aluminum layer. The modulus of elasticity in this part is calculated in the same way as the first part but with $(E_{pl})_{AL}$ instead of $(E_{el})_{AL}$.

$$\hat{E}_{FML} = \frac{(E_{pl})_{AL} t_{AL} + E_{FRP} t_{FRP}}{t_{FML}} \quad (5)$$

$$\sigma_{FML} = (\sigma_y)_{AL} \frac{t_{AL}}{t_{FML}} \left(1 - \frac{E_{pl}}{E_{el}}\right)_{AL} + \hat{E}\varepsilon_{FML} \quad (6)$$

Figures Where $(E_{pl})_{AL}$ is tangent modules of aluminum stress–strain curve in plastic region, and $\hat{E}_{FML}$ is tangent modules of FML stress–strain curve in plastic region. Now the overall stress-strain behaviour of the FML can be estimated from. (3) and (6). The designation of laminates with fiber volume fraction matrix and volume fraction designation is given by Table-5.

Table-5: Designation of FMLs

Fiber volume fraction	Matrix volume fraction	Designation
0.2	0.8	Al/JRE (0.2)/Al/JRE (0.2)/Al
0.4	0.6	Al/JRE (0.4)/Al/JRE (0.4)/Al
0.6	0.4	Al/JRE (0.6)/Al/JRE (0.6)/Al
0.8	0.2	Al/JRE (0.8)/Al/JRE (0.8)/Al

RESULTS

The exploitation of all the data previously obtained has allowed to getting the stress–strain curves for each FMLs given in Table-5 by using a Finite Element Analysis (FEA) and analytically computation. The set of stress strain behavior curves obtained are shown in Table-6.

Table-6: Variation of tensile strength in function fo fiber volume fraction

Fiber volume fraction Vf	Tensile strength (FEA) MPa	Tensile strength (Analytically) MPa
0.2	183.99	184.04
0.4	194.90	194.91
0.6	206.04	205.84
0.8	216.98	216.77

By analyzing these different obtained curves, we have managed to correlate a variation of tensile strength as a function of fiber volume fraction. As shown in Figue-5, both outputs of mathematical and the finite element model are plotted for the two calculation methods (FEA and analytically one) the FMLs tensile strength constantly increases as the fiber fraction volume grow.

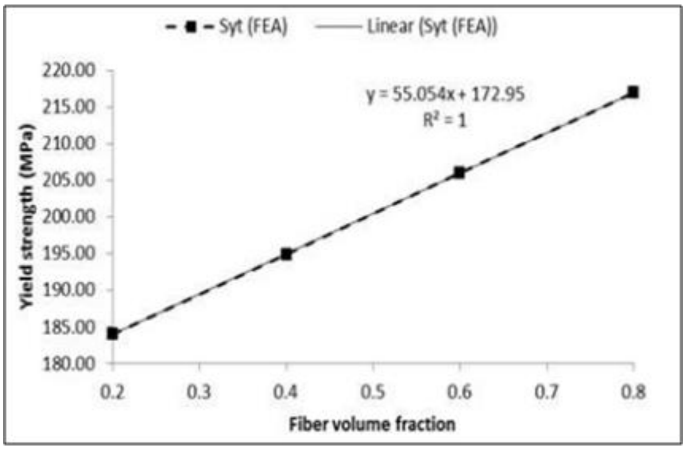

Fig-4: Variation of tensile strength with fiber fraction volume

The stress–strain curves that are obtained with analytical prediction curves and FEM prediction results; it is clear that analytical calculations and finite element modeling results are in good agreement; the final remarks remain the same. And a good correlation is obtained comparing with the last model.

Furthermore, Figure-6 shows also that the elastic and plastic moduli grow with fiber fraction volume with close value for FEA and analytically method.

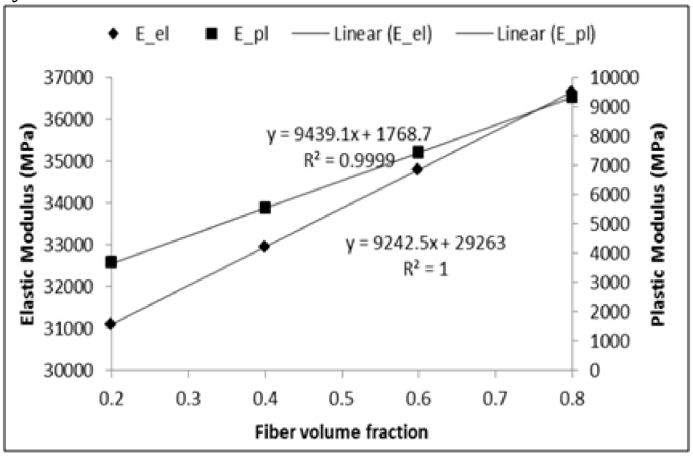

Fig-5: Variation of elastic and plastic moduli with fiber volume fraction

From the results it can be concluded that the fiber volume fraction orientation in laminate improve modulus of elasticity, yield stress and ultimate tensile stress considerably Hence, the final goal of this study consists of holding out the tensile strength behaviour. This reflects the ability of this model to provide a powerful tool as a tensile strength behaviour prediction. This new approach based on the statistical analysis of the results, following linear regression equations are proposed for predicting different parameters:

For elastic modulus of FML: E_{el} = 9242.5V_f + 29263
For plastic modulus of FML: E_{pl} = 9439.1V_f + 1768.7
For tensile yield strength of FML: S_{yt} = 55.04V_f + 172.9

CONCLUSION

The effects of fiber volume fraction on tensile properties of fiber/metal laminates are simulated. The performed numerical study in this paper is to predict the tensile properties such. elastic and plastic moduli and yield strength of new aluminum and Jute fibers based FMLs using Finite Element Method. In this approach, elastic–plastic behavior of the aluminum sheets was modeled by a bilinear relation and fiber reinforced plastic layers was assumed to be linear elastic up to fracture. The results of the Finite Element Method are validated using already published mathematical model.

REFERENCES

1. Gunnink JW, Vlot A, Alderliesten RC, van der Hoeven W, de Boer A, Sinke J, Ypma MS, de Vries TJ, Wittenberg T. Towards technology readiness of fibre metal laminates. InGLARE Technology development (GTO), ICAS 2000 CONGRESS 2000.
2. Krishnakumar S. Fiber metal laminates—the synthesis of metals and composites. Material And Manufacturing Process. 1994 Mar 1;9(2):295-354.
3. Luciano R, Barbero EJ. Formulas for the stiffness of composites with periodic microstructure. International Journal of Solids and Structures. 1994 Nov 1;31(21):2933-44.
4. Hagenbeek M, Van Hengel C, Bosker OJ, Vermeeren CA. Static properties of fibre metal laminates. Applied Composite Materials. 2003 Jul 1;10(4-5):207-22.
5. Wu G, Yang JM. Analytical modelling and numerical simulation of the nonlinear deformation of hybrid fibre–metal laminates. Modelling and Simulation in Materials Science and Engineering. 2005 Mar 24;13(3):413.
6. Moussavi-Torshizi SE, Dariushi S, Sadighi M, Safarpour P. A study on tensile properties of a novel fiber/metal laminates. Materials Science and Engineering: A. 2010 Jul 15;527(18-19):4920-5.
7. Soltani P, Keikhosravy M, Oskouei RH, Soutis C. Studying the tensile behaviour of GLARE laminates: a finite element modelling approach. Applied Composite Materials. 2011 Aug 1;18(4):271-82.
8. Khan JA, Khan MA. The use of jute fibers as reinforcements in composites. InBiofiber Reinforcements in Composite Materials 2015 (pp. 3-34).
9. Sanjay MR, Arpitha GR, Yogesha B. Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: A review. Materials today: proceedings. 2015 Jan 1;2(4-5):2959-67.

10. Mohan P. A critical review: the modification, properties, and applications of epoxy resins. Polymer-Plastics Technology and Engineering. 2013 Jan 15;52(2):107-25.
11. Paluvai NR, Mohanty S, Nayak SK. Synthesis and modifications of epoxy resins and their composites: a review. Polymer-Plastics Technology and Engineering. 2014 Nov 20;53(16):1723-58.
12. De Vries TJ, Vlot A, Hashagen F. Delamination behavior of spliced fiber metal laminates. Part 1. Experimental results. Composite structures. 1999 Oct 1;46(2):131-45.