

MECHANICAL BEHAVIOUR OF CARBON AND JUTE FIBERS REINFORCED ALUMINIUM LAMINATES FABRICATED IN DIFFERENT STACKING SEQUENCES

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Abstract

In this research work, the mechanical properties of aluminium laminates having carbon fiber reinforcement and carbon-jute fibers reinforced aluminium laminates fabricated in different stacking sequences are studied. Here the fiber metal laminates are manufactured through the hand layup technique. A compression moulding machine was used to press the laminates during the production process. In this study, carbon and jute fibers along with thin aluminium sheets are used as reinforcement. Four different stacking sequences were selected. Each arrangement is symmetric and consists of ten layers of reinforcements. The fabricated laminates were subjected to tensile, compressive, flexural, hardness and impact tests. The test results show that the laminate L2 with outermost layers of carbon fibers revealed the highest tensile strength of 268 MPa, followed by L4 laminate with jute fibers outer layers having a tensile strength of 226 MPa. Whereas, the laminates L1 and L3 with outer layers of aluminium sheets show improved flexural and impact strength along with high hardness value. The flexural strengths are 246 MPa and 204 MPa respectively. Impact strength of 36 MPa, 32 MPa and hardness value of 64 HVN and 62 HVN respectively.

Keywords: Fiber metal laminate, CARALL, Mechanical, Epoxy, Tensile, Flexural, Impact

Introduction

The need for lightweight and high-performance materials in the aerospace industries allowed the development of a new class of materials known as Fiber Metal Laminates (FMLs). The metal and fibers are used as reinforcement in a common matrix material. The FMLs have the advantage of both metal and fiber. It has also enhanced damage tolerance and resistance to crack propagation. Glass fibers, carbon fibers, and Aramid fibers are the most commonly used Fibers in the FMLs, along with

Aluminium sheets. They are named based on the reinforcement as Glass Reinforced Aluminium Laminate (GLARE), Carbon Reinforced aluminium Laminate (CARALL) and Aramid-Reinforced aluminium Laminate (ARALL) (Sathyaseelan *et al.*, 2015; Kvam *et al.*, 2017; Zhang *et al.*, 2020; Khalid *et al.*, 2021). The different combinations of synthetic fibers and aluminium sheets showed elevated tensile strength and has effects on the strain rate sensitivity (Khalid *et al.*, 2021). In addition to

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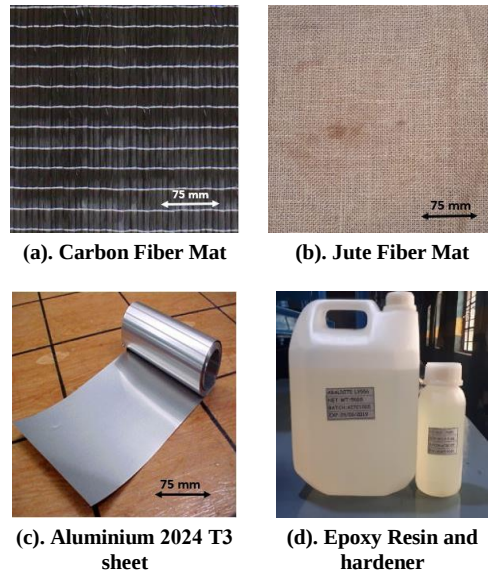


Figure 1 Reinforcement and Matrix material

that, it also has better resistance to fatigue and impact loads (Khalid *et al.*, 2021).

The research on natural fiber composites (NFC) is attracting researchers around the globe due to increased awareness about the environment (Gholampour *et al.*, 2019; Sathyaseelan *et al.*, 2020; Venkatasudhahar *et al.*, 2020; Sellamuthu *et al.*, 2021) besides with lightweight, eco-friendly and moderately better properties of natural fibers than synthetic fibers (Raja and Anand, 2020). Moreover, the production cost of natural fibers is equivalent lower than that of synthetic fibers (Rajesh and Pitchaimani, 2017). Hybridization is employed in NFCs, where more than one fiber is used as a reinforcement in the common matrix. Among the existing natural fibers, coir, banana, kenaf, areca, jute, sisal, and bagasse are the most repeatedly researched fibers (Vijay, 2018; Jafrey, 2020; Sagar *et al.*, 2020; Sathyaseelan *et al.*, 2020; Khan *et al.*, 2021; Khalid *et al.*, 2021). A combination of glass and jute fiber exhibited enhanced strength. (Khalid *et al.*, 2021).

Other than the reinforcement, chemical treatment, modification of the fiber surface (Khalid *et al.*, 2021), and the orientation, and stacking sequences arrangement of the reinforcement's fibers play a vital role in defining the developed composites' properties. Certain fibers are stronger along their longitudinal direction and can take a maximum tensile load, while other fibers can withstand more impact damage (Sathyaseelan *et al.*, 2019).

Several research has been carried out with various natural or synthetic fibers along different metal sheets to enhance the strength of the

Table 1. The details of the stacking sequences

S.No	Laminate Code	Stacking Sequence
1	L1	$[Al/Ca_0/Ca_{90}/Al/Ca_0]_s$
2	L2	$[Ca_0/Ca_{90}/Al/Ca_{90}/Ca_0]_s$
3	L3	$[Al/Ju_0/Ju_{90}/Al/Ca_0]_s$
4	L4	$[Ju_{90}/Ju_0/Al/Ca_0/Ca_{90}]_s$

composites. But, the literature addressing the usage of different fiber orientations is less. In this research, an effort has been made to study the effect of fiber orientation on the mechanical properties of the composite material made with carbon and jute fibers and aluminium sheet as the reinforcement. The polymer matrix of epoxy resin LY556 and hardener HY951 is employed. The fibers are orientated in the direction of 0 and 90 degrees. Four different stacking sequences were implemented for this study. Ten layers of reinforcement are used in each stacking sequence. The developed composites were then subjected to different mechanical characterization. Shown in Table 1.

Materials and Methods

Carbon fibers mat (240 GSM) and Jute fibers mat (190 GSM), and matrix materials Epoxy Resin LY556 and hardener HY951 were procured from M/s Sun Tech Fibers, Chennai. A 0.2 mm thick aluminium sheet AA2024-T3 was bought from M/s Jindal Steels, Chennai. Figure 1. (a - d) shows the Figures of reinforcement and matrix material.

Four different stacking sequences were chosen for the current study. Each sequence was designated as L1, L2, L3, and L4. Fibers are in orientations of 0 and 90 degrees. Laminates are symmetric, with ten layers of reinforcement maintained in all the stacking sequences.

Fabrication Method

A mould of 300 mm x 300 mm as shown in Figure 2 was used for fabricating the composite. Preliminary measures were taken before fabrication. The reinforcement was cut as per the dimension of the mould. A rough emery sheet is used to eliminate the smoothness of the aluminium sheet. The resin and hardener are prepared in a ratio of 10 :1 as per the weight of the reinforcement. The first stacking sequence (L1) is chosen; it has four layers of aluminium sheet, four layers of carbon fiber in a 0-degree orientation and two layers of carbon fibers in a 90-degree direction. At the beginning of the fabrication, the bottom plate of the mould is coated with a releasing agent like shoe wax. Then, an OHP sheet coated with shoe wax is laid over the mould surface. Later, the resin and hardener mixture is



Figure 2. A rectangular Mould



Figure 3. Laminate in compression moulding machine (Courtesy: CEG, Anna University)



Figure 4. Specimen as per ASTM standard

coated onto the OHP surface. Next, the first reinforcement in L1 (i.e.), the aluminium sheet, is gently laid on the resin surface. After that, a roller is rolled over the aluminium sheet to ensure the uniform spreading of resin over its surface.

Then the next coat of resin mixture is applied to it, then placed 0-degree carbon fiber on the resin surface and once again rolled. The same procedure is followed until all ten layers is made. Finally, an OHP sheet coated on both sides with shoe wax is laid on the tenth layer of the reinforcement upon which the top plate of the mould is placed. The whole setup is placed in atmospheric condition for 4 hours undisturbed. Later on, it is placed in a compression moulding machine shown in Figure 3 and compressed for ten minutes at 70 Kg/cm² pressure, where the compression chamber is maintained at 70°C. This compression process removes the trapped air bubbles and voids present in

the laminate. After compression, the laminate is removed from the mould. The outer OHP sheets are removed, and the laminate is cut as per the ASTM standards, as shown in Figure 4, to carry out the tests.

Mechanical Tests

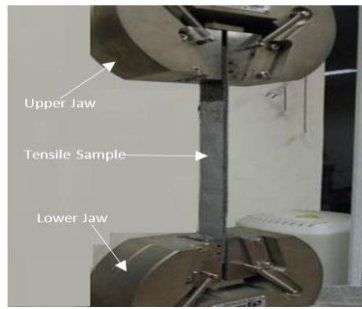
Once the specimens were prepared as per the ASTM standards. The mechanical characterization of the composite is being carried out. The tensile test is carried out on the sample to know the maximum axial load that the composite can withstand. The tensile test is performed in 50 kN capacity Instron UTM as per ASTM D3039. The specimen is fixed in the UTM, as shown in Figure 5 (a). The tensile load is applied with a uniform crosshead speed of 1 mm/min. The external load is applied until the failure of the specimen and the readings are recorded.

Similarly, the three-point bending method is adopted to test the flexural strength of the composite. The flexural test shows the bending capacity of the prepared composite laminate without failure. ASTM D 790 is followed in determining the flexural properties. The specimen is placed as shown in Figure 5 (b). The external load is applied at the middle of the sample, and the indicated values are noted. Later, the impact test on the laminate is executed as per ASTM D 7136 using the Izod impact method, as shown in Figure 5 (c). The impact test displays the maximum load that can be absorbed by the laminate when a sudden load is applied. The specimen is made with a V-notch in the middle to absorb impulse load.

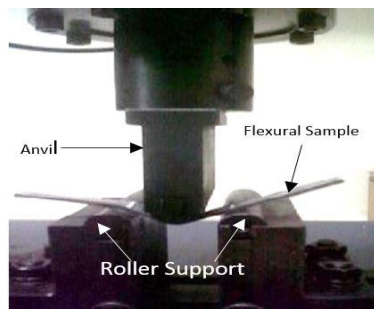
The average of five samples in each stacking sequence was calculated after the completion of mechanical testing. The fractured surfaces of the test specimen were observed in a Scanning Electron Microscope to recognize the mode of failure.

Results and Discussion

The tensile results in Figure 6 shows that the composite laminate L2 [Ca₀/Ca₉₀/Al/Ca₉₀/Ca₀]S with two alternate carbon fibers in 0° and 90° as the outer layers aluminium sheet as the intermediate layers exhibited a maximum tensile strength of 268 MPa. It shows that the carbon fibers can withstand maximum axial load. The carbon fibers had good bonding with the matrix material is good. Similar results were reported by different researchers, when the addition of carbon fiber increases the mechanical properties (Sathyaseelan *et al.*, 2015; Velu *et al.*, 2021)



(a). Tensile Test Set-up



(b). Flexural Test Set-up

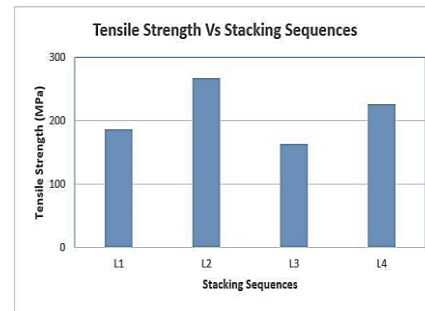
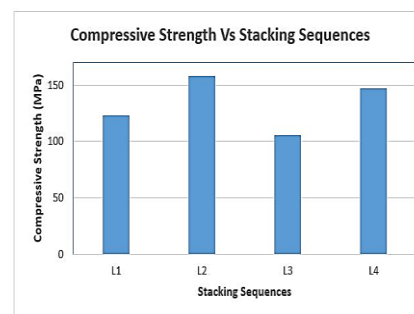


(c). Impact Test Set-up

Figure 5. Mechanical Testing of the Laminates

The second maximum tensile strength is observed in laminate L4 [Ju₉₀/Ju₀/Al /Ca₀/Ca₉₀]s with outer two layers of jute fibers at 90° and 0°. The results demonstrate that the fibers better bear the axial load than the aluminium sheets in the outer layers as in laminate L1 [Al/Ca₀/Ca₉₀/Al/Ca₀]s and L3 [Al/Ju₀/Ju₉₀/Al/Ca₀]s.

The compressive strength results in Figure 7. show that the composite laminate L2 [Ca₀/Ca₉₀/Al/Ca₉₀/Ca₀]S with two alternate carbon fibers in 0° and 90° as the outer layers aluminium sheet as the intermediate layers displayed a higher compressive strength of 158 MPa. It demonstrates that carbon fibers can withstand the highest

**Figure 6. Tensile Strength of Composite Laminates****Figure 7. Compressive Strength of Composite Laminates**

compressive load possible (Schlothauer *et al.*, 2020). The bonding between the carbon fibers and the matrix material is good. The second highest compressive strength is found in laminate L4 [Ju₉₀/Ju₀/Al /Ca₀/Ca₉₀]S. It has outer layers of two jute fibers at 90° and 0°. The findings show that fibers can bear compressive loads more than aluminium sheets in laminate outer layers as in L1 [Al/Ca₀/Ca₉₀/Al/Ca₀]s and L3 [Al/Ju₀/Ju₉₀/Al/Ca₀]s. similar results were stated by different researchers (Rajkumar *et al.*, 2014; Sathyaseelan *et al.*, 2015)

Where as in the case of flexural strength, the laminates L1 [Al/Ca₀/Ca₉₀/Al/Ca₀]s and L3 [Al/Ju₀/Ju₉₀/Al/Ca₀]s with outer skin layers of aluminium sheets reveal higher strength. The exterior aluminium layers act as a protective shield in taking up the bending load (Rajkumar *et al.*, 2014; Sathyaseelan *et al.*, 2015). In L1 laminate, the adjacent layers of carbon fibers, the next outer skin layer of aluminium sheets, and the intermediate layers of aluminium act as load-bearing structures. The carbon fiber and jute fiber layers of 0° and 90° next to the skin layers advance the laminate's bending strength. Thus, the results show that the composite laminates with skin layers of aluminium sheets exhibit better flexural strength (Harish and Rajesh, 2021) as shown in Figure 8.

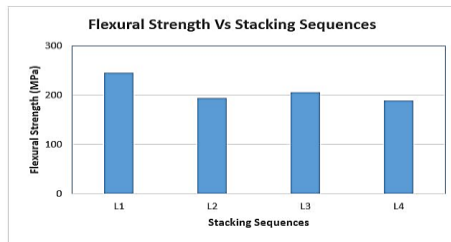


Figure 8. Flexural Strength of Composite Laminates

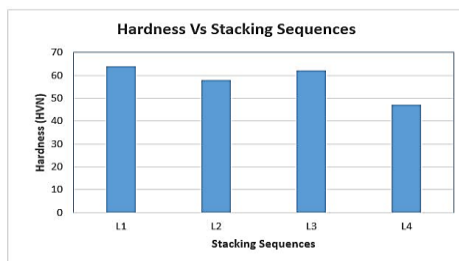


Figure 9. The hardness of Composite Laminates

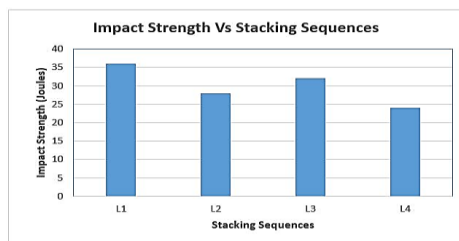


Figure 10. Impact Strength of Composite Laminates

Figure 9. depicts the hardness of the composite laminates. The composites with aluminium as skin layers are more rigid as the metal's hardness is a little higher than the fibers (Rajak *et al.*, 2019). The composite laminates L1 [Al/Ca₀/Ca₉₀/Al/Ca₀]s and L3 [Al/Ju₀/Ju₉₀/Al/Ca₀] has a hardness value of 64 and 62. The composites made with either carbon fibers or jute fibers as in L2 [Ca₀/Ca₉₀/Al/Ca₉₀/Ca₀]S and L4 [Ju₉₀/Ju₀/Al/Ca₀/Ca₉₀]S showed the hardness of 58 and 47, respectively.

Similar results were observed in the impact test as shown in Figure 10. where the composite laminates with outer aluminium layers observed maximum impact energy than composite laminates with fibers as outer layers.

The maximum impact strength of 36 joules is witnessed in the L1 laminate, followed by 32 joules in the L3 laminate. Composite laminates L2 and L4 displayed about 28 joules and 24 joules, respectively.

Conclusions

In this research work, the mechanical properties of aluminium laminates reinforced with carbon fiber (CARALL) and carbon-jute fibers reinforced aluminium laminates (CAJRALL) fabricated in varying stacking sequences were studied. The following conclusions were made :

The composite laminates L2 and L4 with outer layers of carbon and jute fibers showed enhanced tensile strength than other composite laminates. Hence these fibers can be used as a skin material for tensile load applications. The composite laminates with aluminium as the skin layer showed improved flexural, impact and hardness properties. This type of composite sequence can be used for applications where high flexural, impact and hardness is required. The bonding between the carbon fibers and the matrix material is good. The usage of carbon fibers in the FML's enhanced the mechanical strength in the earlier study conducted by different researchers too. Stacking sequences of the laminate plays a key role in determining the strength of the laminate along with fiber orientations. The CARALL composites can be used in lightweight applications with better strength. Furthermore, studies including shear tests and fatigue behavior of the developed composites can be carried out along with bearing strength. In addition to that different reinforcements can be used in the composite and their characterization can be studied.

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References

- Gholampour, A., and Ozbakkaloglu, T. (2019). A review of natural fiber composites: properties, modification and processing techniques, characterization, app J. Materials Science, Springer Science and Business Media LLC., 55(3):829-92.
- Harish, Kumar M., and N, Rajesh Mathivanan. (2021). Effect of face sheet on the flexural and tensile characteristics in GLARE laminates. Australian J. Mech. Eng., 7(2):21-18.
- Jafrey, Daniel James., D, S. Manoharan., G, Saikrishnan., and S, Arjun. (2020) Influence of Bagasse/Sisal Fibre Stacking Sequence on the Mechanical Characteristics of Hybrid-Epoxy Composites. J. Natural Fibers., 17(10):1,497-1,507.
- Khalid, M.Y., Al, Rashid A., Arif, Z.U., Sheikh, M.F., Arshad, H., and Nasir, M.A. (2021). Tensile strength evaluation of

- glass/jute fibers reinforced composites: An experimental and numerical approach. *Results in Eng.*, 10:10-32.
- Khalid, M.Y., Arif, Z. U., and Al, Rashid A. (2021). Investigation of Tensile and Flexural Behavior of Green Composites along with their Impact Response at Different Energies. *Int J. Precision Engineering and Manufacturing-Green Technol.*, 1(5):21-27.
- Khalid, M.Y., Arif, Z.U., Ahmed, W., and Arshad, H. (2021). Evaluation of tensile properties of fiber metal laminates under different strain rates. *Proceedings of the Institution of Mechanical Engineers. Part E: J. Process Mech. Eng.*, 7(2):11-18.
- Khalid, M. Y., Arif, Z. U., Al, Rashid A., Shahid, M.I., Ahmed, W., Tariq, A. F., and Abbas, Z. (2021). Interlaminar shear strength (ILSS) characterization of fiber metal laminates (FMLs) manufactured through VARTM process. *Forces in Mech.*, 4:10-38.
- Khalid, M.Y., Rashid, A.A., Abbas, Z., Akram, N., Arif, Z.U., and Márquez, F.P.G. (2021). Evaluation of Tensile Properties of Glass/Sisal and Glass/Jute Fibers Reinforced Hybrid Composites at Different Stacking Sequences. *Polymer Korea.*, 45(3):390-397.
- Khalid, M.Y., Al Rashid, A., and Sheikh, M.F. (2021). Correction to: Effect of Anodizing Process on Inter Laminar Shear Strength of GLARE Composite through T-Peel Test: Experimental and Numerical Approach. *Experimental Techniques.*, 5(3):15-23.
- Khalid, M.Y., Arif, Z.U., and Sheikh, M.F. (2021). Mechanical characterization of glass and jute fiber-based hybrid composites fabricated through compression molding technique. *Int J Mater Form.*, 14:1,085-1,095.
- Khalid, Muhammad Y., Ramsha Imran, Zia U., Arif, Naveed Akram, Hassan Arshad, Ans Al Rashid, and Fausto P. García Márquez. (2021). Developments in Chemical Treatments, Manufacturing Techniques and Potential. Applications of Natural-Fibers-Based Biodegradable Composites Coatings., 11(3):293.
- Khan, T., Sultan M.T.H., Shah A.U.M., A.H. Ariffin and M. Jawaid (2021) The Effects of Stacking Sequence on the Tensile and Flexural Properties of Kenaf/Jute Fibre Hybrid Composites. *J. Natural Fibers.*, 18(3):452-463.
- Kvam, David J., Yi, Yu Duan., Erica, Donnelly., and Alicia, Restrepo. (2017). "Finite Element Method and Analytical Studies on Fiber-Metal Laminates under Multiaxial Loadings." *Advanced Eng. Forum.*, 23:63-71.
- Raja, T., and P. Anand. (2020). Mechanical investigations on Neem/Banyan fibers reinforced with ceramic powder particulates hybrid polymer composite helmet. *IOP Conference Series: Materials Sci. and Eng.*, 988:12-19.
- Rajak, D. K., Pagar, D.D., Kumar, R., and Pruncu, C.I. (2019). Recent progress of reinforcement materials: a comprehensive overview of composite materials. *J. Materials Research and Technol.*, 8(6):6,354-6,374.
- Rajesh, M., and J. Pitchaimani. (2017). Mechanical characterization of natural fiber intra-ply fabric polymer composites: Influence of chemical modifications. *J. Reinforced Plastics and Composites.*, 36(22):1,651-1,664.
- Rajkumar, G.R., Krishna, M., Narasimhamurthy, H.N., Keshavamurthy, Y.C., and Nataraj, J.R. (2014). Investigation of Tensile and Bending Behavior of Aluminum based Hybrid Fiber Metal Laminates. *Procedia Materials Sci.*, 5:60-68.
- Sagar, Chokshi., Vijay, Parmar., Piyush, Gohil., and Vijaykumar, Chaudhary. (2020). Chemical Composition and Mechanical Properties of Natural Fibers. *J. Natural Fibers.*, 17(10):161-168.
- Sathyaseelan, P., Sellamuthu, P., and Palanimuthu, L. (2020). Dynamic mechanical analysis of areca/kenaf fiber reinforced epoxy hybrid composites fabricated in different stacking sequences. *Materials Today: Proceedings.*, 39(4):1,202-1,205.
- Sathyaseelan, P., and Sellamuthu, P. (2019). Influence of Stacking Sequences on Tensile Behaviour of Areca-Kenaf Hybrid Epoxy Composite. *Regular Issue.*, 8(6):3,040-3,044.
- Sathyaseelan, P., Sellamuthu, P., and L, Palanimuthu. (2020). Influence of stacking sequence on mechanical properties of areca-kenaf fiber- reinforced polymer hybrid composite, *J. Natural Fibers.*, 4:1-6.
- Sathyaseelan, P., Logesh, K., Venkatasudhahar, M., and Dilip, Raja N. (2015). Experimental and finite element analysis of fiber metal laminates (FML's) subjected to tensile, flexural and impact loadings with different stacking sequence, *Int. J. Mechanical and Mechatronics Eng.*, 15(3):23-27.
- Schlothauer, A., Pappas, G.A., and Ermanni, P. (2020). Material response and failure of highly deformable carbon fiber composite shells. *Composites Science and Technol.*, 199:108-115.
- Sellamuthu, P., Palani, S., and Palanimuthu, L. (2021). "Water absorption behavior of kenaf/areca reinforced hybrid composites". *Materials Today: Proceedings.*, 46(2):1,265-1,268.
- Velu, S., Joseph, J.K., Sivakumar, M., Bupesh, Raja V.K., Palanikumar, K., and Lenin, N. (2021). Experimental investigation on the mechanical properties of carbon-glass-jute fiber reinforced epoxy hybrid composites. *Materials Today: Proceedings.*, 46:3,566-3,571.
- Venkatasudhahar, M., P. Kishore, Kumar., and N. Dilip, Raja. (2020). "Influence of stacking sequence and fiber treatment on mechanical properties of carbon-jute-banana reinforced epoxy hybrid composites." *Int J. Polymer Analysis and Characterization.*, 25(4):238-251.
- Vijay, Chaudhary., Pramendra Kumar, Bajpai., and Sachin, Maheshwari. (2018). Studies on Mechanical and Morphological Characterization of Developed Jute/Hemp/Flax Reinforced Hybrid Composites for Structural Applications. *J. Natural Fibers.*, 15(1):80-97.
- Zhang, C., Zhu, Q., Wang, Y., and Ma, P. (2020). "Finite Element Simulation of Tensile Preload Effects on High-Velocity Impact Behavior of Fiber Metal Laminates". *Applied Composite Materials*. Springer Science and Business Media LLC., 27(3):251-68.