SSRG International Journal of Material Science and Engineering
ISSN: 2394 – 8884 /doi:10.14445/23948884/IJMSE-V7I2P103

Volume 7 Issue 2, 13-17, May-Aug 2021

Original Article

Fibre - Laygeometry and Its Influence on Mechanical Properties of Doum Palm (Hyphaene Thebaica) Fibre Reinforced Polymer Composite

Adamu Alhaji Umar[1], Adamu Baba Wada[2]

[1]*Department of Mechanical Engineering, Bayero University, Kano, Nigeria.*
[2]*Department of Welding and Fabrication Technology, Jigawa State Polytechnic, Dutse, Nigeria.*

Received Date: 05 July 2021
Revised Date: 11 August 2021
Accepted Date: 21 August 2021

***Abstract** - This study was conducted to determine the effect of fiber-laygeometry on mechanical properties of Doum palm fiber-reinforced composite with a view of finding the best lay geometry that will give the best mechanical properties. Composites of four different fiber-laygeometries were developed, their mechanical properties were evaluated. Ultimate tensile strength, Young's modulus, percentage elongation, flexural strength, Impact Strength, and hardness were determined. The result showed that fiber-laygeometry affects the mechanical properties of the composite. As the fiber-laygeometry increases from 0^0 to 90^0, the tensile strength, percentage elongation, and impact strength all decreased while flexural strength and tensile modulus increase. However, fiber-laygeometry has no significant effect with respect to hardness. The best fiber-laygeometry that gives the optimum mechanical properties is at 0^0 orientations*

Keywords - *Composite, Doum Palm, Epoxy Resin, Fibre, Laygeometry*

I. INTRODUCTION

The development of composite materials, as well as the related design and manufacturing technologies, is one of the most important advances in the history of materials. Composites exhibit great resistance to wear, corrosion, and high-temperature exposure, among others. These unique characteristics provide the mechanical engineer with design opportunities not possible with conventional monolithic (unreinforced) materials [1]. Composite materials are among the most advanced and adaptable engineering materials that consist of two or more constituents combined at a macroscopic level and are not soluble in each other [2]. This combination results in better properties than those of the individual components used alone. Unlike metallic alloys, each material retains its distinct physical, chemical, and mechanical properties. Composite materials typically have a fiber or particle phase that is stiffer and stronger than the continuous matrix phase and serve as the principal load-carrying members [3]. Composite materials are also ideal for structural applications that involve high strength and low weight. They are resistant to corrosion and have good fatigue characteristics. They provide some flexibility in design through the variation of the fiber orientation or stacking sequence of fiber and matrix materials [2].

Composite laminates are processed by stacking lamina with varying fiber orientations to achieve the desired structural behavior [4]. The mechanical behavior of such laminates is anisotropic in nature. As such, it depends on fiber lay geometry such as shape, size, distribution, and orientation of fibers, and thickness of lamina [5]. Consequently, the lamina is supposed to be designed in a way that will satisfy the specific requirements of each application to obtain the maximum advantages from the directional properties of materials [3].

Some of the research conducted earlier in the field of fiber-reinforced composites include; [8] Evaluated the effect of fiber orientation on mechanical properties of sisal fiber reinforced epoxy composites with $0^0/90^0$, $90^0$and $\pm45^0$, the results indicated that the orientation 90^0 shows better mechanical properties compare than $0^0/90^0$. The effect of varying fiber size and fiber weight fraction on the tensile and impact properties of the rice husk fiber reinforced polyester composites was also examined by [9] which discovered that both fiber size and fiber weight fraction have a significant effect on the tensile and impact characteristics, tensile and impact strength increased steadily with increase in fiber loading up to 15 %wt, then decreased at 20 %wt. [10] discovered that the composites with 30° fiber orientation show better micro-hardness, tensile strength, flexural strength, inter-laminar shear strength, and impact strength. [11] studied the mechanical properties of Dum palm, Luffa gourd, and Baobab plant fibers, and the result showed that Dum palm fiber has the highest strength and is expected to be more crystalline, followed by Luffa gourd fibers and finally Baobab fiber which is less crystalline in nature.

II. MATERIALS AND METHODS

A. Materials and Equipment.

In this work, the materials and equipment used were: Doum palm leaves, epoxy resin, and hardener, mold and releasing agent, knife, electric furnace Type CWF 11/23, mechanical sieve, Mettler weighing balance Type PM6100, beaker, stirrer, nose mask, and hand gloves, roller, brushes, ceramic plates, plastic bowls, spoon, hydraulic press M12000, electric furnace CWF 11/23 and hack saw

B. Methods

a) Preparation of the Doum Palm Fibre:

The Doum Palm leaves used in this study were sourced from Sawo village, Jigawa State, Nigeria. Leaves were cut from the tree, washed with water to remove dirt, and dried under the sun for two weeks. The leaves were taken to an electric muffle furnace and further dried for 24 hours at 100ºC to ensure the complete removal of moisture. Fibers were extracted from Doum palm leaves by serration process. Each fiber was sieved using mesh and separated according to the fiber size, and grouped accordingly [4] [9].

b) Preparation of Matrix Materials

The matrix material was prepared by measuring the required quantity of Epoxy Resin and the corresponding hardener using a weighing balance and then mixed in the ratio of 10:1 and stirred. After stirring, the quantity of matrix material to be used for each layer was measured [8][4].

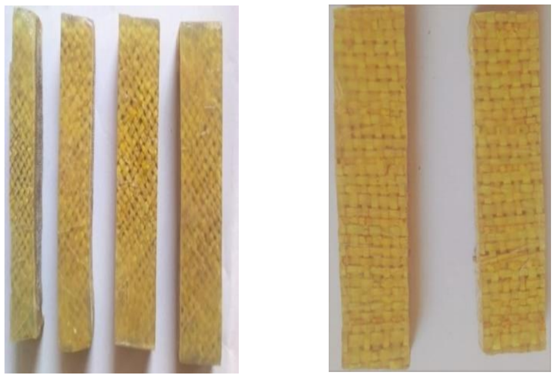
c) Production of Composites

The production of the composites was carried out by the conventional hand lay-up technique. Composites of the same composition (Polymer 60wt % and fiber 40wt %) with four layers and four different fiber-laygeometries were prepared for testing. Composites plates produced were rectangular in shape at room temperature [5]. Proper care was taken during the production of the laminates to ensure uniform thickness, minimum voids in the material, and homogeneity was maintained [6] [12].

The laminates were produced by placing the Doum palm fiber one over the other with a matrix in between the layers. Brush and Roller were used to distribute matrix materials uniformly and compacted to remove entrapped air.

The composite produced was placed under a load for about 24 hours for proper curing at room temperature. After curing, the specimens of suitable dimensions were cut to suit the ASTM dimension for mechanical tests.

Fig. 1 (a) and (b) are the samples of the produced composites.



(a) (b)

Fig. 1: Sample of Composite (a) ± 45^0, (b) 0/90^0

C. Mechanical Properties

a) Ultimate Tensile Strength (UTS), Young Modulus (E), and Percentage Elongation: Tensile test was conducted using the universal testing machine. The test specimen was prepared in the form of dumbbell shape with dimensions$(165 \times 19 \times 3)mm$, gauge length (100) mm. A crosshead speed of 5mm/min was chosen according to the ASTM D638 standard. The testing process involves placing the specimen in the testing machine and applying load to it until fracture [8]. The tensile force was recorded as a function of the increase in gauge length. Ultimate tensile strength (UTS), Young's modulus (E), and percentage elongation (EL) were computed using equations (1), (2), and (3), respectively.

The ultimate tensile strength of the specimen was calculated using equation 1.

$$\sigma = \frac{p}{b \times d} \quad (1)$$

where; σ is ultimate tensile strength, p is the load at the break, b is the initial width of the sample, and d is the initial thickness of the sample.

The young modulus of the composite was calculated using equation 2.

$$E = \frac{\sigma}{\varepsilon} \quad (2)$$

Where; E is the tensile modulus, σ is ultimate tensile strength, and ε is the strain of the sample.

The percentage elongation of the composite was calculated using equation 3

$$EL = \frac{e}{l} \times 100\% \quad (3)$$

where EL is the percentage elongation of the specimen, *e* is elongation at failure of the specimen, and *l* is the initial gauge length of the specimen.

b) Flexural Strength: the flexural strength was measured under a three-point bending approach. The test was performed in accordance with ASTM D790 [9]. Rectangular specimens of size $(125 \times 12.7 \times 3.2)mm$ were subjected to a load on the universal testing machine with a support span length of 100mm with a speed of 5mm/min. The modulus of rupture (MOR) was computed at this point using equation (4)

$$\sigma_{fm} = \frac{3pl}{2bd^2} \quad (4)$$

where; σ_{fm} Is flexural strength, *p* is the load at the break, *l* is the support span, *b* is the width of the sample, and *d* is the depth or thickness of the sample.

c) Impact Strength: The impact test was conducted according to ASTM D256 using the Charpy V-notch impact testing machine. The dimensions, gauge length, and V-notch were according to the standard [9]. The specimen size $(63.5 \times 12.7 \times 12.7)mm$ was placed between a special holder with the notch oriented vertically and towards the origin of impact. The specimen was struck by a "tup" attached to a swinging pendulum. The specimen breaks at its notched cross-section upon impact, and the upward swing of the pendulum was used to determine the amount of energy absorbed in the process. The impact strength was computed using equations (5).

$$\text{Impact strength} = \frac{E}{A}\ (J/m^2) \qquad (5)$$

where; E is the energy absorbed (J), and A is the area of the specimen.

d) Hardness: The hardness test was conducted according to ASTM D2240 using a Rockwell hardness testing machine. The specimen was cut into *(25×25×10) mm* square strips. The test was performed by gradual pressing of a presser foot of diamond-tipped indenter, which penetrates to a certain depth on the specimen [11]. The hardness value depends on the depth to which the indenter penetrated the specimen.

III. RESULTS AND DISCUSSION

A. Ultimate Tensile Strength (UTS), Young Modulus (E), and Percentage Elongation:

from Fig. 2, the results obtained showed that the tensile strength of the composites decreases with an increase in fiber-laygeometry from 0^0 to 90^0 orientation. Therefore, the tensile strength of the developed composite significantly decreases with an increase in fiber-laygeometry from 0^0 to 90^0; this is because of poor adhesion between fiber and matrix and the orientation of the fiber, same was observed by previous researchers [11] [18].

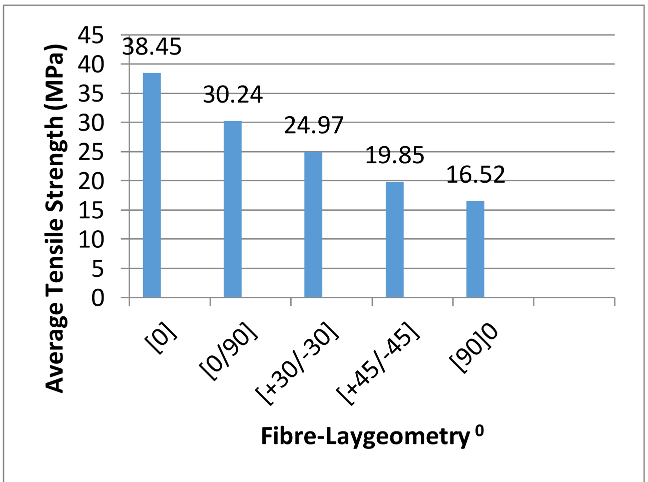


Fig. 2: Variation of tensile strength of composite with fibre-laygeometry

The Young's modulus, from Fig. 3, it was found to increase with increase in fibre lay-geometry from 0^0 to 90^0 orientations even though some fluctuations were observed in between. The maximum tensile modulus obtained was for composites with $[90/90/90/90]^0$ orientation. The possible reason for increase in tensile modulus may be due to proper adhesion between the fibre and matrix. This was also observed by previous researchers [20][11].

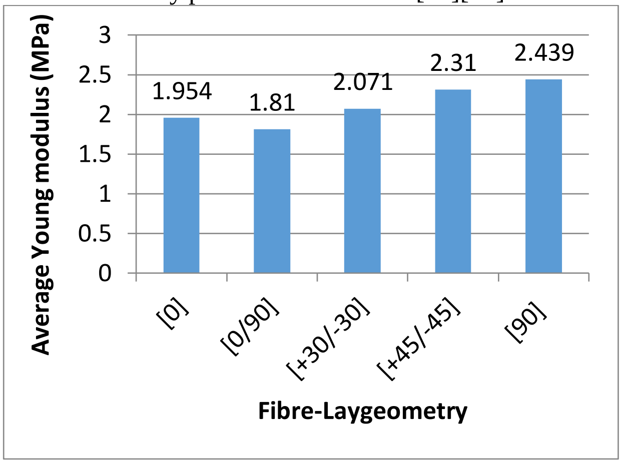


Fig. 3: Variation of Young's modulus of composite with fibre-laygeometry

The percentage elongation of the developed composite was optimum at $[0/0/0/0]^0$ orientation and significantly decreases with increase in angle of orientation as shown in Fig. 4.

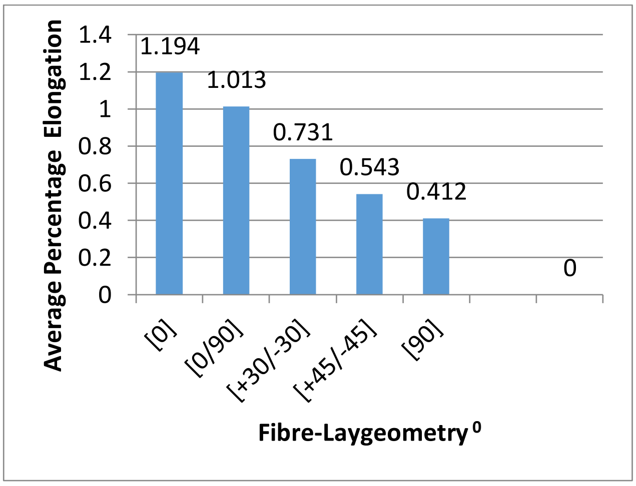


Fig. 4: Variation of percentage elongation of composite with fiber-laygeometry

B) Flexural Strength:

It is evident that fiber orientation is having a significant effect on the flexural strength of the composites. It is interesting to note that flexural strength increases with an increase in fiber orientation from 0^0 to 90^0 as shown in Fig. 5**,** The highest impact strength (12.97 kJ/m^2) was obtained at $[0/0/0/0]^0$ orientation because the direction of bend is parallel to the direction of the fiber. The fluctuation of the result is a result of the change in the direction of the fiber. This is at par with the work of other researchers [11, 19]

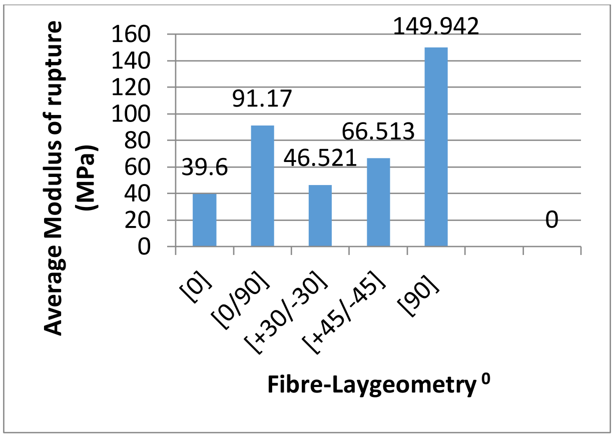


Fig. 5: Variation of flexural Strength of composite with fiber-laygeometry

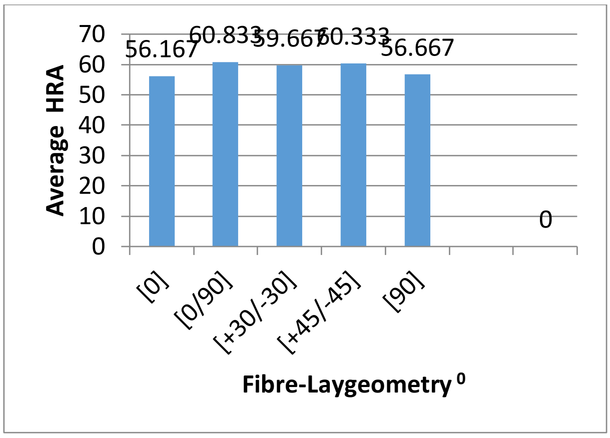


Fig. 7: Variation of the hardness of composite with fiber-laygeometry

C) Impact Strength:

The impact energy values of the composites developed with different lay geometry were recorded during the impact tests; the result showed that the resistance to impact decrease with an increase in fiber orientation, as shown in Fig. 6. The high strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite for such applications should therefore be determined not only by usual design parameters but by its impact or energy absorbing properties.

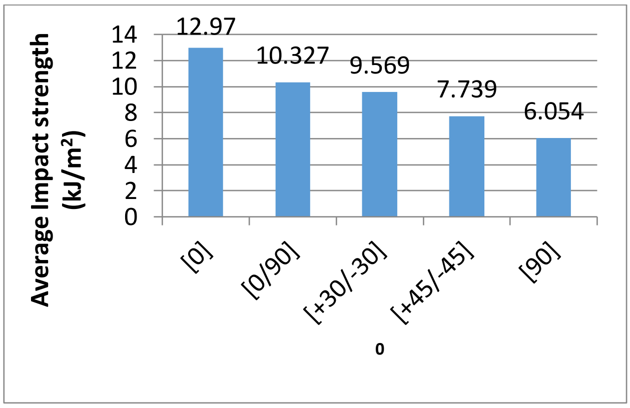


Fig. 6: Variation of impact strength of composite with fiber-laygeometry

D. Hardness:

The result of the effect of fiber-laygeometry on the hardness of the composite is presented in Fig. 7. There was not much variation in hardness of the composites with respect to fiber orientation, and it has been noticed that composites with cross-linked fiber-laygeometry of [0/90]°, [+45/-45]°, and [+30/-30]° exhibit higher hardness compared to composite with unilateral 0° and 90° orientations. This might be as a result of better dispersion of the fibers in the matrix with minimization of the void between the matrix and the fiber [12].

IV. CONCLUSION

The influence of Fibre-laygeometry on mechanical properties of the developed epoxy-based composites reinforced with Doum palm fiber which is composed of 60%wt polymer and 40%wt fiber, have been studied. The mechanical properties test results showed that as the fiber-laygeometry increases from 0° to 90°, there was a significant effect with respect to tensile strength, percentage elongation, and impact strength, all of which decreased, while flexural strength and tensile modulus increased and there was no significant effect with respect to hardness. The best laygeometry of the fiber that gives the optimum mechanical properties is at 0^0 orientations.

APPENDIX A

Summary of Result of Mechanical Properties Test

Fibre - Laygeometry	Tensile Strength (MPa)	Young modulus (MPa)	Percentage Elongation (%)	Modulus of rupture (MPa)	Impact strength (kJ/m²)	HRA
[0]°	38.45	1.954	1.194	39.60	12.970	56.17
[0/90]°	30.24	1.810	1.013	91.17	10.327	60.83
[+30/-30]°	24.97	2.071	0.731	46.52	9.569	59.67
[+45/-45]°	19.85	2.310	0.543	66.51	7.739	60.33
[90]°	16.52	2.439	0.412	149.94	6.054	56.67

REFERENCES

[1] P. Mallick, Fiber-Reinforced Composites- Materials, Manufacturing, and Design, Boca Raton: CRC Press. (2008).

[2] I. Abdullahi and A. A. Umar, Potentials of unsaturated polyester – groundnut shell composite as material in building industry, Bayero Journal of engineering and technology, 52(2) (2010) 78-84.

[3] S. Thirumalini and M. Rajesh, Reinforcement Effect on Mechanical Properties of Bio-Fiber Composite, International Journal of Civil Engineering and Technology, 8(7) (2017) 160-166.

[4] S. C. Han, A. T. Tabiei and W. Park, Geometrically nonlinear analysis of laminated composite thin shells using a modified first-order shear deformable element-based Lagrangian shell element, composite structure, 82(1) (2008) 465-474.

[5] J. O. Akindapo, A. M. Umar and O. Sanusi, Development of Roofing Sheet Material Using Groundnut Shell Particles and Epoxy Resin as Composite Material, American Journal of Engineering Research (AJER), 4(6) (2015) 165-173.
[6] F. Campbell, Structural Composite Materials, ASM International. (2010).
[7] R. Khandan, S. Norooz, P. Sewell, J. Vinney, R. and M. R. Ramazani, optimum design of fiber orientation angles in composite laminate plates for minimum thickness, British Colombia, Canada. (2010).
[8] M. Ramesh, Studies on Mechanical and Machining Characteristics of Hybrid Natural Fiber Composites, India, (2014).
[9] W. Aboshora, M. Abdalla and F. Niu, Compositional and structural analysis of epicarp, flesh and pitted sample of Doum fruit (HyphaenethebaicaL.), International Food Research Journal, 24(2) (2017) 650-656.
[10] K. Krishan, Agarwa and A. Gaurav, A Study of Mechanical Properties of Epoxy Resin in the presence of Different Hardeners. (2019).
[11] O. Ondiek, T. Ngetha, N. Keraita, and B. Byiringiro, Investigating the Effect of Fiber Concentration and Fiber Size on Mechanical Properties of Rice Husk Fiber Reinforced Polyester Composites, International Journal of Composite Materials, 8(5) (2018) 105-115.
[12] D. Janaki, Processing and Characterization of Jute/Glass Fibre Reinforced Epoxy Based Hybrid Composites, Department of Mechanical Engineering National Institute of Technology, Rurkela. (2013).
[13] B. Somen and S. Alok, Processing and Characterization of Epoxy Composites Reinforced with Short Palmyra Fiber, Bankok, Thailand. (2016).
[14] ASTM D638, Standard Test Method for Tensile Properties of Polymer Matrix Composite Material, West Conshohocken: ASTM International.: American Society for Testing and Materials. (2002).
[15] ASTM D790, Standard Test Method for Flexural Properties of Polymer Matrix Composite Material, West Conshohocken: PA.ASTM International, American Society for Testing and Materials. (2011).
[16] ASTM-D256, Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics, West Conshohocken: PA 19428-2959: American Society for Testing and Materials. (2004).
[17] ASTM D2240, Standard Test Method for Hardness Properties of Polymer Matrix Composite Material, West Conshohocken: ASTM International, American Society for Testing and Materials. (2011).
[18] S. Biswas, B. Deo, A. Satapathy and A. Patnaik, Effect of fiber loading and orientation on mechanical and erosion wear behavior of glass epoxy composites, Polymer Composite, 32(9) (2011) 665-674.
[19] S. Alam, F. Habib, M. Irfan, and W. Iqwal, Effect of Orientation of Glass Fibre on Mechanical Properties of GRP Composites, Journal of Chemical Society of Pakistan, 32 (2010) 265-269.
[20] P. Amuthakkannan, V. Manikandan, J. T. Winowlin, and M. Uthayakumar, Effect of Fiber Length and fiber content on Mechanical Properties of Short Basalt Fiber Reinforced Polymer Matrix Composites, Materials Physics and Mechanics. (2013) 107-117.
[21] M. Kumaresan, S. Sathish and N. Karthi, Effect of Fiber Orientation on Mechanical Properties of Sisal Fiber Reinforced Epoxy Composites, Journal of Applied Science and Engineering, 18 (2015) 289-294.
[22] H. Mishra, B. Dash, S. Tripathy and B. Padhi, Study on Mechanical Performance of Jute-Epoxy Composites, Journal of Polymer-Plastic Technology Engineering, 39(1) (2000) 187-198.
[23] O. Babatunde, A study of the development, characterization, and degradability of polyester/nano-locust bean pods ash composite, Department of metallurgical and materials engineering, Ahmadu Bello University, Zaria, (2015) 17-21.
[24] S. M. Aminu, O. Sunmonu and K. Bello, Effect of chemical modification on mechanical properties of Luffa Gourd, Dum Palm and Baobab fiber-reinforced composites, Standard Scientific Research and Essays, 2(10) (2014) 541-545.
[25] H. Obasi and G. Onuegbu, Biodegradability and Mechanical Properties of Low-Density Polyethylene/Waste Maize Cob Flour Blends, Journal of Applied Sciences and Engineering Research, (2013) 233-240.