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Evaluation and Optimization of *Lannea acida* Tree-Bark Particulate/Fibre Reinforced Epoxy Composites

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Abstract:- Evaluation of *Lannea acida* tree-bark particulate/fiber reinforced epoxy composites was carried out. By manually stripping the *Lannea acida* plant into strands and particles, fiber and particles were isolated. For the creation of the composites, the fiber and particle were then blended in the following ratios: 0:50, 5:45, 10:40, 15:35, 20:30, 25:25, 50:0. In all of the samples created, the epoxy-resin binder was kept at 50% and the hand lay-up method was used. Seven samples were produced from the particulate obtained with and without the fibers reinforcement. Physical properties, Mechanical properties, and Dynamic mechanical analysis (DMA) of the composites produced from *Lannea acida* tree bark particulate/fibre were evaluated. A predicted model was developed and optimized for the tensile strength using design expert 8.0.6. Density and water absorption measurements ranged from 1.472 to 1.836 g/cm^3 and 0.248 to 1.299%, respectively. Tensile and impact strengths (15.46–21.81 MPa and 5.52–6.61 J/mm^2 respectively) were found to increase as fiber content increased before sharply declining as fiber content increased. The damping factor was shown to rise with rising temperature, peaking in the transition zone and falling off in the rubbery zone. The optimization process gave the tensile strength of the produced composites to be 24.9196 MPa at the optimal condition values (26.33 % fiber loading and 1.48 kN load). The tests obtained from the *Lannea acida* tree-bark particulate/fiber falls within the range when compare with work of other researchers which show that it can be used as alternative material for the production of reinforce composite that can be used in construction and manufacturing of automobile interiors and body parts.

Keywords:- *Lannea acida Tree-Bark, Particulate/Fibre, Composite, Dynamic Mechanical Analysis, Mechanical Properties.*

I. INTRODUCTION

The high cost and health risk of conventional materials for construction is a key element influencing housing and industrial systems all over the world. Research into alternative materials that depend directly or indirectly on other sources of raw materials for their development has become necessary as a result of this. Nature creates plant structures that can endure natural forces, such as the bending employed in engineering, by using the idea of optimum reinforcing fiber orientation. To create similar, high-quality man-made composites, this idea serves as inspiration. According to Cordin et al. (2018), fiber-reinforced plastics generally exhibit improved features such low weight, corrosion resistance, high tensile strength, and modulus. In practically every aspect of our everyday lives, fiber reinforced polymer composites are used, and their use is growing astonishingly swiftly. Traditional composite structures, which are often made of synthetic fibers (Fiberglass), are manufactured, used, and removed; however, these processes are prohibited due to the rising levels of environmental contamination. This has led to the use of bio-fibers as reinforcing components for thermoplastics and thermosets (Nassar and Nassar, 2020, Kumaresan*et al.,* 2015).

According to Spoljaric*et al.* (2009), carbon, glass, and aramid fibers are extensively utilized as reinforcement in matrix polymers for technological purposes. However, these fibers have drawbacks such high production costs and challenges with recycling. Consequently, there has been a lot of interest in recent years in the use of cellulose fibers, both natural and recycled, to strengthen matrix polymers.

Vegetable fibers, often known as plant fibers, are becoming more and more prevalent in our daily lives. Plant fibers have long been an indispensable resource for humankind. For instance, construction has made extensive use of fibrous materials like bamboo and wood. The aerospace, automobile building (Dash *et al.,* 2000; Li *et al.,* 2000; O'Donnell *et al.,* 2004), and packaging industries (Averous*et al.,* 2001; Rowell *et al.,* 1996; Veluraja*et al.,*

1997) have all employed fibers from bananas, coir, jute, pineapple, and sisal.

Numerous research have been conducted recently that focus on utilizing tree-bark fibers/particulates in reinforced composites production; just to mention a few. Gupta (2009) looked into the creation of composite panels made from bark that are environmentally friendly, employing the barks of lodge pole pines that have been infected with the mountain pine beetle. The analysis of the components of the bark, creation of the bark board, evaluation of the mechanical properties, characterization, and improvement tests were completed. Several findings suggest that bark could be used to make bark boards. For further advancements and a production procedure that may be used in a commercial setting, the researcher proposed conducting additional research. Yemele et al. (2010) looked at how bark fiber content and size affected the mechanical properties of composites made of bark/HDPE. The effects of species, fiber quantity, and size on the flexural and tensile properties of the composite were found to be of special relevance. Black spruce bark composites were more brittle but also stronger than aspen bark composites. Barks from trees were used by Avci*et al.* (2018) to produced bio composites using polypropylene as binder; the results of physical and mechanical properties were satisfactory.

Hence, *Lannea acida* tree particulate/fiber reinforced epoxy composites were investigated and optimized in this study. According to Oumarou*et al.* (2017), *Lannea acida*, also known as "faruhi" in Fulani-Fulfulde (Nigeria), "fa'ar'u" in Hausa, "Mipadi" in Giziga, or "Timbiya" entering in Cameroun, is spreading throughout Sub-Saharan Africa. The Fulani cattle reavers typically utilize the tree's bark as a rope to transport livestock. The bark of this plant has not been used in the creation of composites, according to a review of the literature to date. Natural fiber composites can be used to improve production sustainability and fuel efficiency, two elements that are essential to the automotive industry. The use of *Lannea acida* tree-bark particulate/fiberas reinforcements using epoxy resin in the production of composites is anticipated to result in lower waste management costs, less environmental pollution, higher financial returns for farmers, as well as engineering components and structures that will meet specific desired properties.

II. MATERIALS AND METHODS

➢ *Material Collection and Preparation*

The *Lannea acida* tree bark was collected from Akwangain Nasarawa State and dried at room temperature and was grounded, sieved into size of 75µm as particulate. The fibersas presented in Plate 1were also extracted from the tree bark as reinforcement with the particulate using epoxy as matrix to produce the composites. Epoxy resin (LY556) and Hardener (HY951) were purchased from Galaxy Interiors and Chemicals Limited, No.17, Main Street, Suncity Estate, Galadimawa, FCT, Abuja.


Plate 1 Extracted Fibres of *Lanne aacida* Tree Bark

➢ *Preparation of the Composite Samples*

The hand lay-up method was used in the production of *the* reinforced epoxy composites using a wooden mold of dimension 300 x 100 x 5 mm.Seven samples with different compositions as presented in Table 1 were produced from the particulate obtained with and without the fibers reinforcement (Chandramohan and Marimuthu., 2011; Acharya, 2011; Das and Biswas, 2016). The *Lannea acida* particulate/fiber was laid in the mold, the resin spread uniformly over the particulate with and without the fiber by means of a brush until fibers were immersed in the resin. In order to improve the uniform thickness achieved during casting or curing, an external pressure plate was used. The mould was tapped severally at the edge to ensure uniform spread of the resin and remove air bubbles. To obtain a fine finished composite, the composites were forcefully removed from the mold after drying at room temperature for 24 hours.

Table 1 Compositions of Composites Samples

Code	Resin/Hardener (%)	Fibre (%)	Particles (%)
A	50	-	50
B	50	5	45
C	50	10	40
D	50	15	35
E	50	20	30
F	50	25	25
G	50	50	-

➢ *Determination of Physical Properties*

- *Moisture Absorption Test*

As per ASTM D570-98 standard, the impact of water absorption on the created composites was examined. Previously weighed samples were submerged in distilled water at room temperature for 72 hours. The samples were taken out of the water after 72 hours, and a digital electronic weighing scale was used to measure their weight. The weight was precisely measured in order to determine the moisture content. Equation (1) was used to determine the percentage of water absorption in the composites based on the weight difference between samples that were submerged in water and samples that were dry (BSI, 2003).

$$WA = \frac{WD_2 - WD_1}{WD_1} \times 100 \quad (1)$$

Where: WD_1= initial weight and WD_2 = final weight

- *Density Test*

The density of the produced composites was determined in accordance with ASTM D792-08. The density of the samples was determined based on Archimedes principle under standard temperature and pressure conditions. Each sample was immersed in a beaker containing a known level of water and the difference between the initial and final level of water in the beaker was calculated as the volume of the sample. The digital weighing balance was used to determine the mass of each sample. The density was calculated using equation (2), (BS 1881-Part114., 1983).

$$\rho = \frac{M}{V} \quad (2)$$

Where, M = mass (g)

V = volume (cm^3)

➢ *Determination of Mechanical Properties*

- *Hardness Test*

Hardness test was conducted in accordance with ASTM D 785 - 90 using the Universal Hardness Tester of Indentec, UK (model 8187.5 LKV). The dimension of the prepared test samples was 30 x 30x 30mm and surface smoothness maintained.

- *Impact Test*

The UN notched Charpy impact test was conducted to study the impact energy according to the ASTM D 256-06 a. The specimen dimensions were 60 x 12 x 5mm. The un-notched specimens are kept in cantilever position and the pendulum swings around to break the specimen. The impact energy (J) was Calculated from the dial gauge, which was fitted on the machine.

- *Flexural Test*

Flexural strength is the ability of the composites to withstand bending. This was carried out according to ASTM 790-07 using Universal (digital) testing machine. Sample dimensions of 100x10x5mmwas produced for the test. The test samples were placed between rollers and force (hydraulic handle) applied until the sample ruptured. This was estimated using equation (3).

$$MOR = \sigma_f = \frac{3pl}{2bt^2} \quad (3)$$

Where, MOR = Modulus of rupture, P = load (N), l = support span (mm), b = width (mm) and t = thickness (mm).

- *Tensile Strength*

The tensile strength of the composites was measured with Monsanto Tonometer Type ‘W’ with S/No. 9875 in accordance with the ASTMD638 procedure. The dimension of the sample was 100 × 10× 5 with gauge length of 40mm. The test was conducted by gripping each end of a reduced section specimen and slowing pulling it until catastrophic failure occurs and the load at which failure occurs was recorded and the load was divided by the area of the sample to obtain tensile strength.

➢ *Dynamic Mechanical Analysis of the Composites*

Dynamic Mechanical Analysis (DMA) was conducted in accordance with ASTM D7028 - 07. Specimens with dimensions 60 × 12 × 5 mm were tested using Netzch Dynamic Mechanical Analyser (DMA) Model no. 242E with data acquisition software. The furnace button was pressed to open the furnace and the sample placed manually on a holder using a clamp. The clamp is made up of two parts, the upper part and the lower part which is movable, the clamp was then closed by pressing the clamp button. Upon loading the specimen, the temperature rose to 30 °C and allowed to stabilize. The chamber was heated at a rate of 10 °C per minute until 180 °C. The analysis was performed in dual cantilever mode with oscillation amplitude of 60 µm, at frequencies of 2, 5 and 10 Hz. This system has software which analyses the experimental data for the storage modulus, loss modulus and damping factor (tan δ) and record them as functions of temperature.

➢ *Modeling and Optimization of Tensile Strength of Composites using Response Surface Methodology (RSM)*

The response surface methodology was employed to model and predict the optimum tensile strength of the produced composites using Design Expert 8.0.6 Software by employing the approach used by Hemachandran*et al.* (2016). The inputs variables considered were: the fiber loading (%) and applied load (kN) while the output was the tensile strength of the composites.

III. RESULT AND DISCUSSION

A. Physical Properties

➢ *Density*

Figure 1 presents the densities of the produced composites which varied from 1.472-1.836 g/cm^3. The density was observed to decrease with increasing *Lannea acida* tree-bark fibre contents. The decrease in densities could be related to the fact that the *Lannea acida* fibre are lighter in weight as compared with the particles but occupies substantial amount of space. Another reason for the decrease in density could be as a result of increase in pores in the sample due to poor inters facial bonding between the *Lannea acida* fibres and particles. The results reflect similar research results of other biowaste reinforced composites (Nitin and Singh 2013).

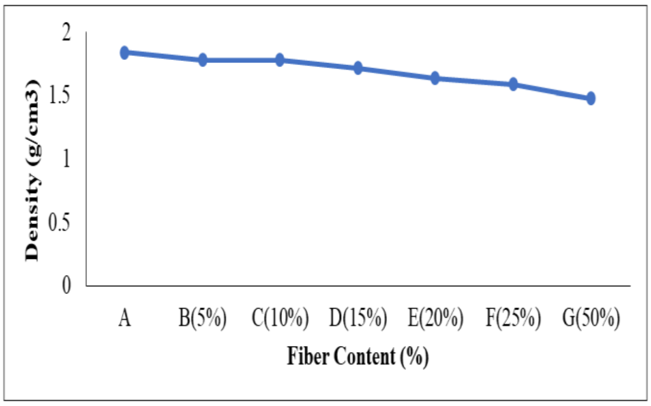

Fig 1 Effect of Fiber Content on Density of Composite Samples

- *Water Absorption*

Figure 2 shows the percentage water absorption of the produced composites, which is an important property used in selecting material for outdoor applications. It was observed that the percentage water absorption of the produced composites varied from 0.2482-1.299% after 72 hours of immersion for the respective produced composites samples. This is because natural fibres are highly hydrophilic due to hydroxyl (OH$^-$) group of polysaccharides found in cellulose that are capable of forming hydrogen bond between water molecules and the *Lannea acida* tree back. The increase in the number of voids (as a result of increment in fiber) which occurs between *Lannea acida* fibre and *Lannea acida* particles also permits more water to be absorbed. Similar observations are also made by several researchers (Raju *et al.*,2012) where they also established that as the filler content increases, water uptake also increases.

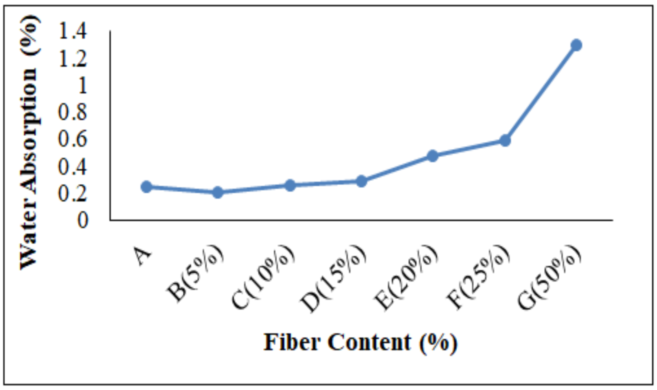

Fig 2 Effect of Fiber Content on Water Absorption of Composite Samples for 72 Hours

B. *Mechanical Properties*

- *Hardness*

Figure 3 shows the hardness value of the composites. It is observed that the hardness decreased with increase in weight fraction of *Lannea acida* tree-bark fiber contents. The decrease in hardness may be attributed to the porosity/void of the produced composites due to the increase in weight fraction of *Lannea acida tree-bark* fiber and decrease in weight fraction of *Lannea acida tree-bark* particulate.

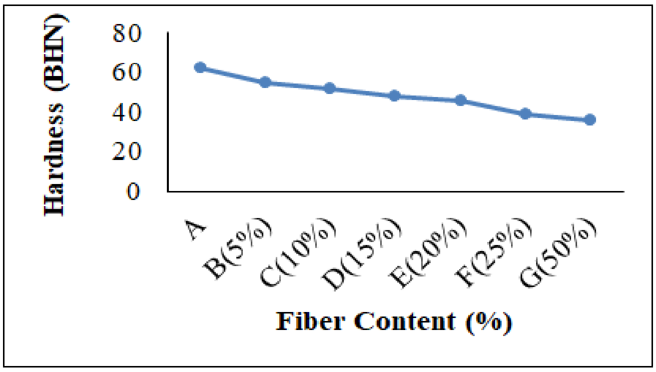

Fig 3 Effect of Fiber Content on Hardness of Composite Samples

- *Tensile Strength*

Figure 4 shows the tensile strength of the composites with increasing *Lannea acida tree-bark* fiber content which varied from 15.46 – 21.81 MPa. The tensile strength results of the produced composites were observed to increase with increasing *Lannea acida* tree-bark fibre content from 5 – 10 % and then decreases steeply between 15 – 50 %. This could be due to weakening of the interfacial attraction of the constituent composition as the fraction of the *Lannea acida* tree-bark particulate is reduced with increasing weight fraction of *Lannea acida* tree-bark fibre. Similar observations have been reported by Raju *et al.* (2012) who investigated the properties of groundnut shell particles reinforced polymer composite. In the study, the experimental results show that it is possible to produce composite panels using groundnut shell particles and vinyl ester as an adhesive. The addition of the particles improved the mechanical properties up to some weight % and further decreased with increased particle content in the samples.

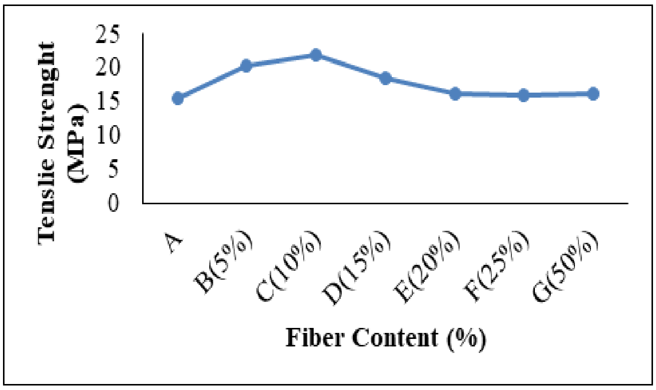

Fig 4 Effect of Fiber/particles Content on Tensile Strength of Composite Samples

- *Impact Strength*

Figure 5 show the impact strength of the produced composites which is the capability of the material to withstand a suddenly applied load normally expressed in terms of energy. The impact strength of the produced composites varies between 5.52 - 6.61 J/mm^2. Between 5 and 10% fibre loading, the impact strength was seen to rise with increasing fibre levels before dropping sharply.For larger fibre contents (over 10%), this may be due to the weak interfacial interaction between the fiber and matrix material and as the fraction of the *Lannea acida* tree-bark particulate reduces. Where as, the impact strength decreases steadily as the *Lannea acida* tree back fibre content further increases to the maximum. Mani et al. (2014) also noted the composite specimen exhibiting a similar behavior and thus, the authors attributed to the fact that the reinforcing particles been cellulose, absorbed more potential energy as its content increased in the matrix material.

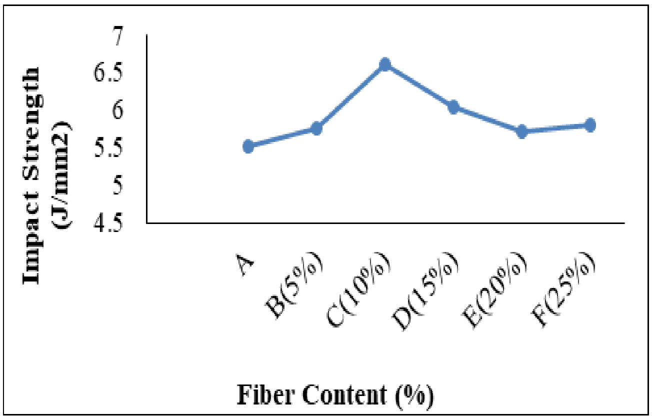

Fig 5 Effect of Fiber Content on Impact Strength of Composite Samples

C. *Dynamic Mechanical Properties*

- ➢ *Loss Modulus*

The amount of energy lost by materials as heat during one cycle of sinusoidal load is known as the loss modulus, which is the imaginary portion of the complex modulus (Gupta, 2017; Rana *et al.*, 2017). Figure 6 shows the variation of loss modulus of the composites with temperature at different frequencies. There was an evident enhancement in loss modulus with the addition of fibres in the matrix. Evidently, for all the samples analyzed, loss modulus was seen to decrease with rising temperature. Additionally, it was found that the values of loss modulus increased with frequency, supporting Ekhlas' (2016) contention that dynamic elastic characteristics are material-specific and that their magnitude is critically dependent on the frequency as well as the measuring circumstances and specimen history. With 20% (sample E) fiber content and a frequency of 10.0 Hz, the highest loss modulus value of 353.2169 MPa was obtained. The highest loss modulus value demonstrated by the 20% *Lannea acida* tree-bark particulate/fibre composite could be explained by the fact that larger degrees of reinforcement often show higher loss modulus and glass transition temperatures, as stated by Pickering *et al.* (2016).

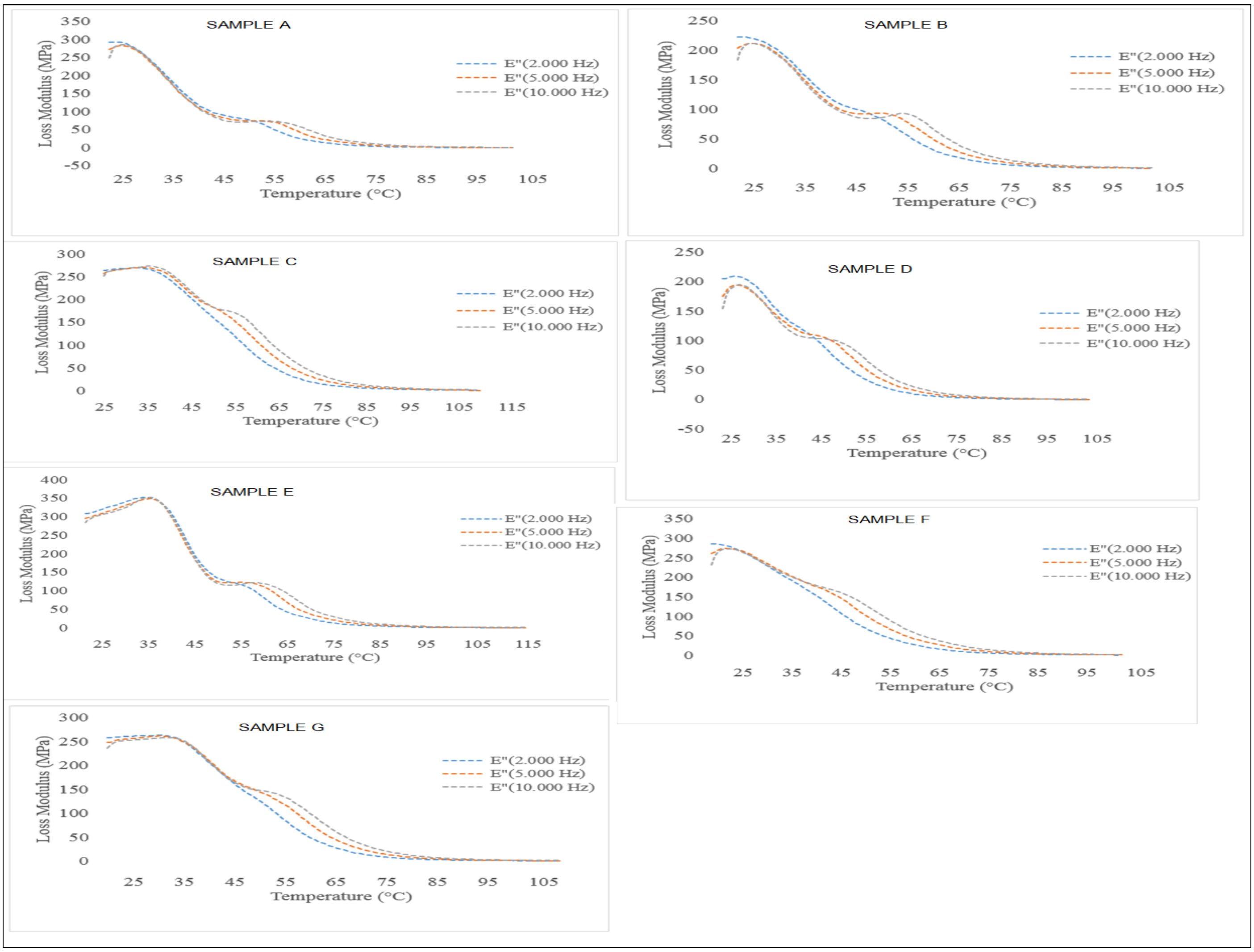

Fig 6 Effect of Temperature on Loss Modulus of the Respective Sample at Different Frequencies

- *Storage Modulus*

The storage modulus is the most crucial factor to consider when evaluating a composite material's ability to support loads. Storage modulus, which also provides information on the stiffness and load carrying capacity of composite materials, is the maximum energy that a material can hold throughout one cycle of oscillation. Figure 7 presents the variation of storage modulus of the composites produced from 0-50 % of the *Lannea acida* tree-bark fibrecontents in the matrix of *Lannea acida* tree-bark particulateat different frequencies (2.0, 5.0 and 10 Hz) as a function of temperature. Evidently, the storage modulus for the composites under investigation decreased with rising temperature. The reduction in fiber stiffness is what causes the drop in storage modulus values (Ekhlas 2013).According to Ekhlas (2013), who claimed that the dynamic elastic properties are material-specific, the values of storage modulus obtained were likewise seen to rise with rising frequencies. The author went on to say that their magnitude is significantly influenced by frequency, measuring conditions, and the specimen's past. Pothan et al. (2010) also noted that frequency, particularly at high temperatures and with increasing frequency, has a significant effect on the dynamic modulus.

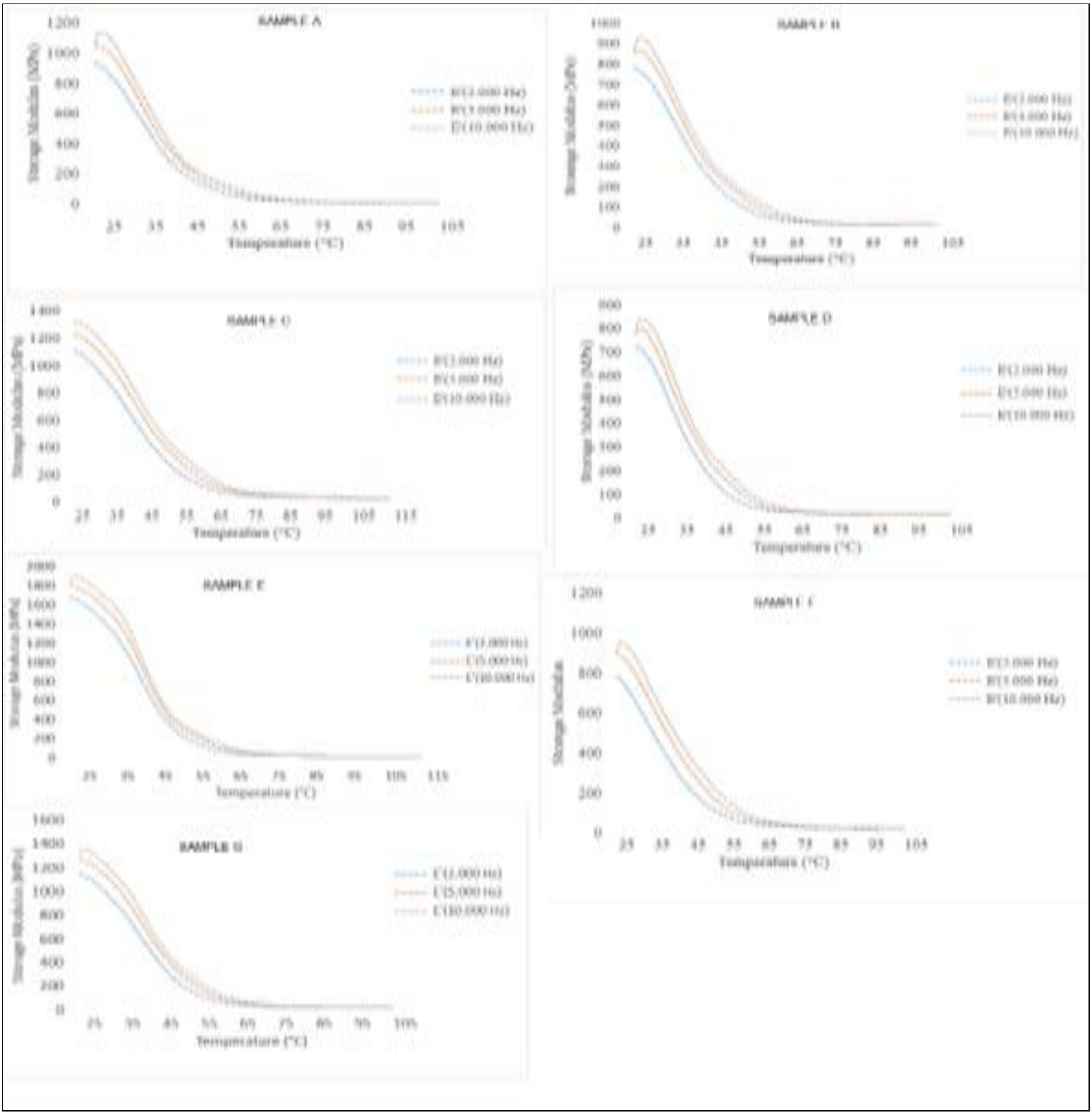

Fig 7 Effect of Temperature on Storage Modulus of the Respective Sample at Different Frequencies

- *Damping Factor (Tan δ)*

Damping(tan δ) is referred to as the ratio of loss modulus to storage modulus. The damping qualities of such a material are improved by a larger tan value (Gupta, 2018). Damping, which is typically expressed as the tangent of the phase angle, is a measurement of how well a material can dissipate energy when subjected to cyclic load. It displays the extent to which a material will absorb energy. Figure 8 shows the effect of damping parameters on produced composites as a function of temperatures at various frequencies. It was found that the damping factor rose with temperature, reaching its peak in the transition zone and falling in the rubbery zone. The temperatures corresponding to the peak (on the curve) represent glass transition temperatures of the composites produced. This suggests that once deformation is induced in the materials, the materials will not return to their previous shape, as indicated by the strong damping peaks in the composites (Pothan*et al.*, 2010). The damping values for the produced composites ranges from -0.0150 - 1.0268, 0.0426 - 0.8788, 0.0404 - 0.6781, -0.0128 -0.8769, 0.0120 - 0.8571, 0.0309 - 0.8262 and 0.0295 - 0.7694 for samples A, B, C, D, E, F and Grespectively. The produced samples' lower damping values indicate that they had good load capacity and robust fiber-to-matrix adhesion (Pothan et al., 2010).

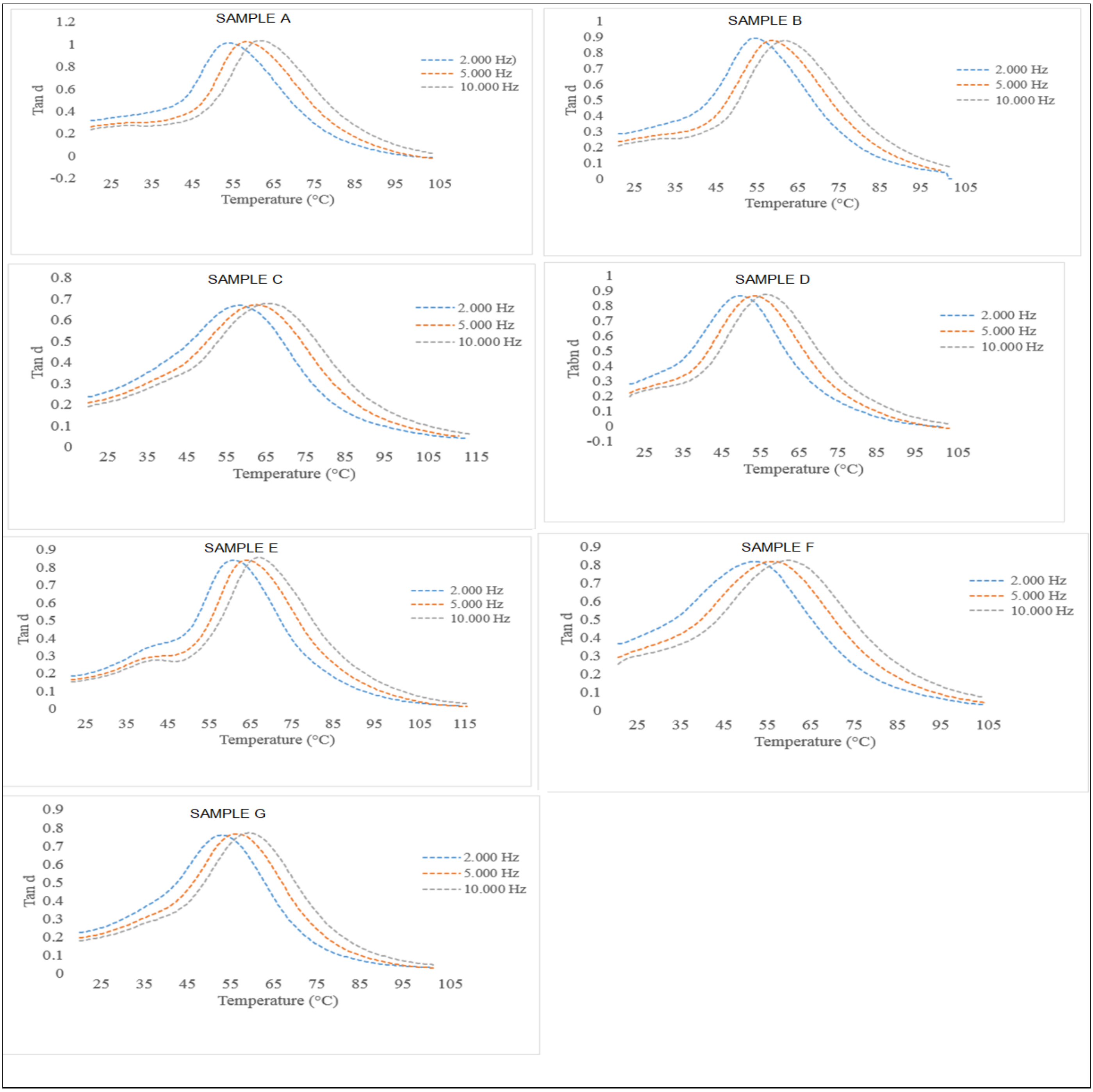

Fig 8 Effect of Temperature on Damping Factor of the Respective Sample at Different Frequencies

D. Predicted and Optimized Tensile Strength of the Produced Composites

The experimental data were analyzed to determine whether the experimental and predicted tensile strength values correlated and the result of the plot is shown in Figure 9. The distribution of the data points is reasonably close to the straight line, as indicated by the R^2 value of 0.9812. This shows a good correlation between the predicted and actual tensile strength, indicating that the model chosen is suitable for forecasting the tensile strength of the produced composites (Hemachandran*et al.,* 2016).

The result of optimization of tensile strength carried out using Design Expert 8.0.6 is presented in Figure 10. The optimization carried out was a maximization function at the combination of the fibre loading and load. The response surface plot (3-D plot) for tensile behavior of the composites is shown in Figure 11, and this displays the maximum value of tensile strength for various combinations of fibre loading (%) and the applied load. The result referring to the highest desirability of 1.00 (i.e 100 % probability that the optimisation result is achievable) and the optimum tensile strength was selected as shown in Figure 11. The optimization process gave a 24.9196 MPa tensile strength value at optimum 26.33 % fiber loading and 1.48 kN load. This is similar with the work carried out by Hemachandran*et al.* (2016) who carried out a study employing response surface technology to improve the tensile and impact characteristics of randomly oriented short sisal fiber reinforced epoxy composites. In their study, the sisal-epoxy composites were fabricated with varying fiber length of 10 to 75 mm and fiber loading of 10 % to 50 % by weight as per Response Surface Design.

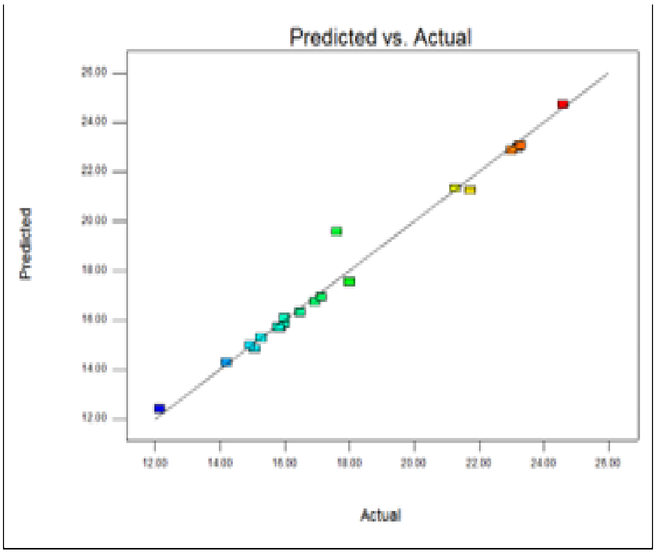

Fig 9 Plot of Predicted Versus Actual Tensile Strength of the Produced Composites

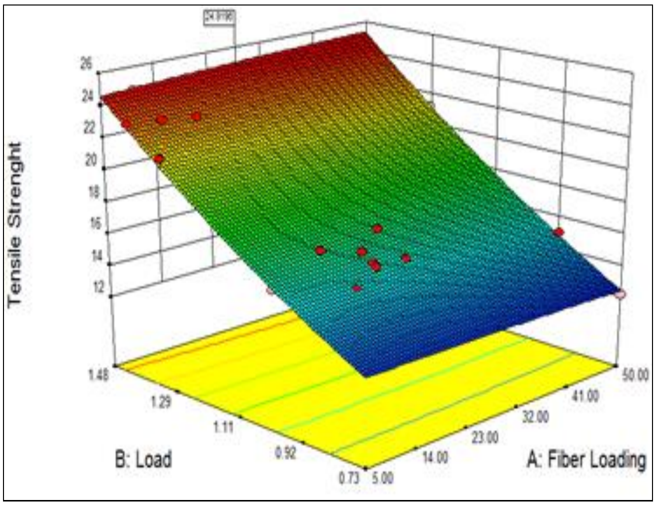

Fig 10 3-D Surface Plot for optimum Tensile Strength of the Produced Composite

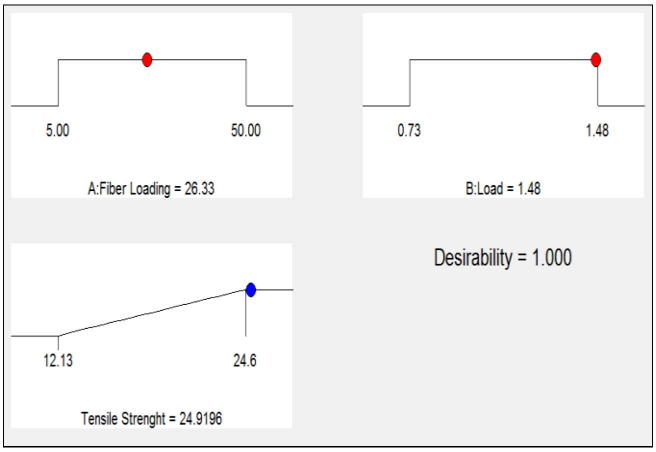

Fig 11 Optimization Result of Tensile Strength of the Produced Composites

IV. CONCLUSION

In this research, evaluation of the properties of epoxy reinforced composites produced from *Lannea acida* tree-bark particulate/fiber was carried out. The following conclusions were drawn;

- There was obvious changes in the physical properties of the produced composites; an increase in water absorption by the produced composites with increasing weight fraction of *Lannea acida* tree-bark fibre contents was observed.The density which was observed to decrease with increasing *Lannea acida* tree-bark fibre contents varies between 1.472-1.836 g/cm^3.
- There was an evident enhancement in loss modulus with the addition of fibres in the matrix. The loss modulus was observed to decrease with increasing temperature for all the samples investigated. The values of loss modulus increased with increasing frequencies The maximum loss modulus value 353.2169 MPa was obtained from 20% (sample E) fibre content at frequency of 10.0 Hz. The study revealed that the storage modulus decreased with increasing temperature for the composites investigated. The values of storage modulus were also observed to increase with increasing

frequencies; and this agreed with the submission of Ekhlas (2013).The damping values for the produced composites ranges between -0.0150 - 1.0268 for all the composite samples and they were low values indicate good load capacity and robust adherence between the matrix and the fibers.

- The optimization process gave the tensile strength value of the composites produced from *Lannea acida tree-bark particulate/fibre* to be 24.9196 MPa at the optimal condition values (26.33 % fiber loading and 1.48 kN load)when compared with work of other researchers which show that it can be used as alternative for the production of reinforce composite that can be used in construction and manufacturing of automobile interiors parts, body parts. This will also increase and encourage to some extent the production of *Lannea acida* tree-bark particulate/fiber.

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