Evaluation of Mechanical Properties of Composite Produced from Powdered Bamboo Fiber with Carbonized Bone Particles in an Epoxy Matrix

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ABSTRACT

This study examined the mechanical characteristics of a novel composite engineering material made from powdered bamboo fiber and carbonized cow bone with epoxy acting as a binder. The mechanical strength of the composite was evaluated using the modulus of rupture, modulus of elasticity, and tensile tests. The optimal composition of 40%, 10%, and 50% bamboo fiber, carbonized bone, and epoxy, respectively, were obtained. The composite's optimal modulus of rupture, modulus of elasticity and tensile stress were determined to be 13.60MPa, 4314.35MPa, and 556.16MPa, respectively. Analyses of variance showed that all of the model terms were significant, suggesting that variations in the amounts of bone powder, epoxy, and bamboo will significantly affect the composite material's tensile stress, modulus of elasticity, and modulus of rupture. Composite will find application in composite board production.

(Keywords: composite, powdered bamboo, carbonized cow bone, epoxy, ANOVA)

INTRODUCTION

Bamboo has been found to have tensile and compressive strengths that are stronger than several types of wood and comparable to the strength of steel. Using this material maintains high mechanical strength while serving as a natural resource, which in turn helps to reduce energy consumption and pollution creation when building woven composites.

Gutu (2013) noted that natural fiber reinforced polymers are considered a potential environmentally friendly alternative to carbon fiber reinforced polymers or glass fiber reinforced polymers and could replace these types of composites in some current applications.

The combination of two or more materials that results in greater quality than the individual components used alone is known as a composite material. Each material maintains its unique mechanical, chemical, and physical characteristics, unlike metallic alloys. Reinforcement and a matrix are the two components. When compared to traditional materials, the primary benefits of composite materials are their low density and great strength and stiffness. Because it examines the volume proportions of the constituents for the required lamina stiffness and strength, the micromechanical technique is seen to be more appropriate for the analysis of composite materials (Khayal, 2017).

According to Khalil, *et al.* (2012), scientists applauded the decision to impose restrictions for a safer and better environment, which also gave researchers a fresh focus on developing innovative eco-composite technology. Composites that offer superior ecological and environmental benefits over synthetic or traditional composites are known as eco-composite materials. Natural fibers or a range of natural polymers and polymer matrices can be used to create eco-composites. Though much has not yet been accomplished, this field has sufficiently garnered prominence in recent years and continues to grow daily. According to Khalil, *et al.* (2012), bamboo material has a greater strength-to-weight ratio and higher cellulose content.

Approximately 1,000 species of bamboo may be found worldwide, which reflects the diversity of the plant. Bamboo grows incredibly quickly; perhaps it would be more accurate to describe it as very quickly growing grass. Since ancient times, bamboo has been used for millennia in South America and many Asian nations. In many respects, bamboo can be seen as an environmentally sound alternative to wood. Unlike wood, which takes nearly 20 years to reach maturity, bamboo reaches maturity in 3 years. Bamboo's tensile strength is on par with mild steel once it reaches maturity. (Lobovikov, *et al.,* 2007).

Ikpoza and Akpobi (2021) evaluated the mechanical properties of composite material produced from continuous bamboo fibre with carbonized bone particles in an epoxy matrix. The study looked into the possibility of creating a new composite material for small-scale horizontal axis wind turbine blade production using carbonized bone and continuous bamboo fiber with epoxy as a binder. Tests for modulus of elasticity and modulus of rupture were performed to evaluate the composite's mechanical strength. The optimal composition was obtained from composites made with a continuous bamboo fiber, carbonized bone, and epoxy content of 40%, 10%, and 50%, respectively. The composite's ideal tensile stress, modulus of elasticity, and modulus of rupture were determined to be 110.50 MPa, 13130.70 MPa, and 8448.41 MPa, respectively.

In the same vein, Ikpoza and Edokpia (2022), evaluated mechanical properties of composite material produced from continuous bamboo fiber with carbonized bone particles in an epoxy matrix. This study examined the possibility of creating a new composite material that might be utilized to create a lightweight engineering material by combining carbonized bone and short bamboo fiber with epoxy as a binder. The mechanical properties of the composite were evaluated using the modulus of rupture, modulus of elasticity, and tensile stress tests. The composites made with short bamboo fiber yielded the best results when the bamboo, carbonized bone, and epoxy compositions were 40%, 10%, and 50%, respectively. The composite's ideal tensile stress, modulus of elasticity, and modulus of rupture were found to be 17.35 MPa, 7003.04 MPa, and 770.72 MPa, respectively.

Tensile testing of epoxy composite reinforced with bamboo fiber was studied by Wani and Shitole (2017). They made use of 0.4 mm thick bamboo strips. The composite was made of three layers of bamboo strips. It was discovered that the volume proportion of bamboo fibers was 0.2. Bamboo fiber strips have a tensile strength of 230 MPa in the fiber direction. Bamboo fibers have an elasticity modulus of 2480.26 MPa. It was discovered that the bamboo reinforced epoxy composite has a tensile strength of 26.417 MPa.

The beneficial effects of cow bone as reinforcing particles in composites have been the subject of numerous studies. A contemporary technique for creating reasonably priced, highly durable materials from appropriate homogenous matrix bases is the use of by-products as reinforcement. (Anagbo and Oguocha, 1989).

To improve the mechanical properties of polyester matrix composites and provide an alternative use for cow bone, which poses a challenge to the environment, particularly in developing nations, Adewole and Oladele (2015) investigated the impact of the particle size distribution of cow bone ash on the mechanical properties of cow bone ash-reinforced polyester matrix composites. The results demonstrate that the mechanical properties of the polyester matrix were improved by the addition of cow bone ash particles measuring 75, 106, and 300 μm.

The aim of this study is to examine the mechanical characteristics of a novel composite engineering material made from powdered bamboo fiber and carbonized cow bone with epoxy acting as a binder.

MATERIALS AND METHODS

Material Collection and Pretreatment

We purchased fresh bamboo (*Bambusa vulgaris*) from a woodshop in Benin City, Nigeria. The bamboo culms were cut into segments, and after that, they were chopped into strips. The bamboo strips were measured to a desirable width of 15 to 25 mm to guarantee that they were semi-flat and not bent. After soaking the bamboo strips in 0.1 M sodium hydroxide solutions for around 72 hours, the lignin was eliminated (Deshpande, *et al.,* 2000). According to Deshpande, *et al.* (2000), lignin dissolution will increase with a strong NaOH solution and a lengthy soaking period. After that, distilled water was used to neutralize the bamboo. After being allowed to air dry, they were then baked for two hours at 110 Celsius to finish drying. Next, the bamboo was grounded to obtain a powdered form of the bamboo fibre (Figure 1). A sieve analysis was done on the grounded bamboo to ascertain the particle gradation. The result of the sieve analysis is as shown in Figure 2

Figure 1: A Sample of the Grounded Bamboo Fibers.

Cow bone was obtained from an animal feed processing factory in Benin City and carbonized for 45 minutes at approximately 550 degrees Celsius in a crucible furnace. It was then crushed and processed into a powder. A sieve size of 212 µm was then used to obtain a fine particle size distribution. The catalyst and epoxy resin used as the matrix binder were purchased from Epoxy Oilserv Nigeria Ltd., based in Port-Harcourt, Rivers State, Nigeria, under the brand names Epochem 105 Resin and Epochem 205 epoxy curing agent.

Composite Experimental Sample Formation and Testing

The trials for the creation of the composite were planned using a three-variable simplex-lattice mixture experimental design, in which three variables functioned as mixture components. The design was chosen because it has been proven by several researchers to be the most effective experimental design for production formulation in the engineering area (Zen, *et al.,* 2015; Abutu, *et al.,* 2018).

As in this study, it is commonly employed when the constituents form a simplex region. The simplex-lattice design was modified to enable the identification of lack of fit because the number of points can be exactly the same as the number required to estimate the model. To do this, the check blends (50-50 combinations of the center point and each vertex) were supplemented with the overall centroid. To properly quantify the lack of fit from the pure error, five replications of the design points were carried out. This resulted in 15 experimental runs overall, which were integrated in Stat-ease, Inc.'s Design Expert® software version 7.0.0, located in Minneapolis, USA. Additionally, the statistical models that relate the input factors to the selected answers were developed using the Design Expert® software.

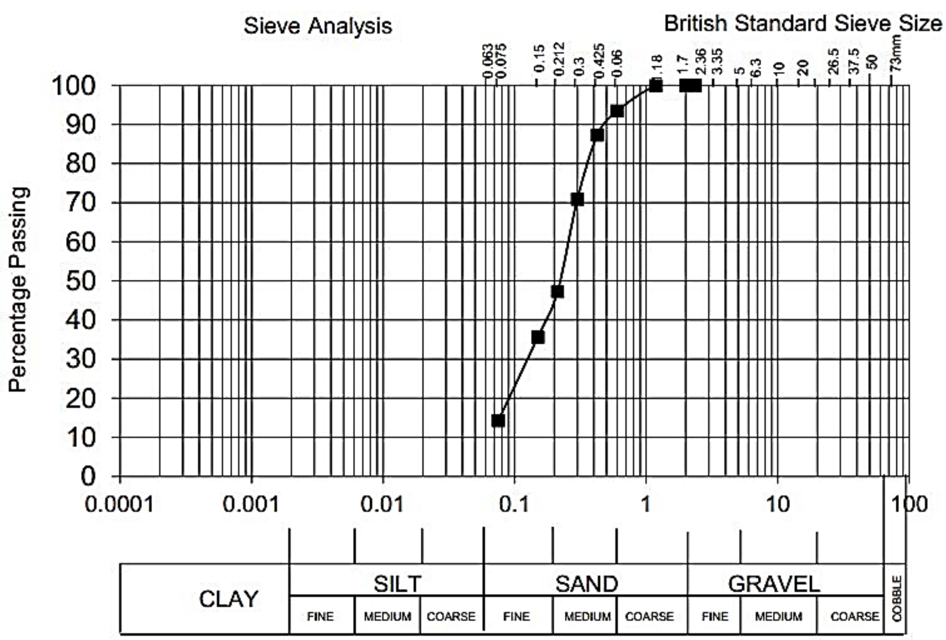


Figure 2: Particle Size Distribution of Grounded Bamboo Fiber.

Table 1 lists the factors examined in this study along with their corresponding ranges.

Table 1: Coded and Actual Levels of the Factors for the Composites.

Factors	Unit	Symbols	Variable levels	
			Low level	High level
Bamboo fibre	%	X_1	40	45
Epoxy	%	X_2	45	50
Bone powder	%	X_3	10	15

Equations (1) and (2) illustrate the relationship between the mixture's constituent parts, which also serve as design elements.

$$0 \le X_i \le 100 \quad (1)$$

where, i = 1, 2, 3

$$X_1 + X_2 + X_3 = 100 \quad (2)$$

The components of the mixture formulation are not independent, as demonstrated by equations (1) and (2), suggesting that variations in one component's level have an impact on the others (Hirata, 1992).

Using a digital electronic scale with an accuracy of 0.01g, experimental samples of the prepared powdered bamboo fiber, the carbonized bone particles, and the epoxy resin with the corresponding mixing ratio of the hardener (catalyst) were weighed out in batches into a pan in accordance with the experimental design matrix. The hardener and epoxy were made in compliance with the manufacturer's instructions. To facilitate the extraction of the cured specimens, each configuration was thoroughly mixed and placed into a prefabricated wooden mold that had been previously rubbed with petroleum jelly and had dimensions based on ASTM D638. The composite was subjected to an approximate pressure of 80kN.

Before being extracted, it was left to cure for a full day at room temperature. Figure 3 is a sample of the composite specimen for the powdered bamboo fiber to be used for tensile test. The specimens were then subjected to mechanical tests (tensile stress, modulus of rupture, and modulus of elasticity) at the University of Benin's Strength of Materials Laboratory.

Figure 3: Samples of the Composite Specimen for the Powdered Bamboo Fiber to be used for tensile test.

RESULTS AND DISCUSSION

Analysis of Statistical Models

By fitting the selected models to the experimental data derived from the mixture experimental design, statistical analysis of the models was carried out. For each response (tensile stress, modulus of elasticity, and rupture modulus), the experimental data was fitted to the unique cubic model. In order to estimate the unknown model parameters, multiple regression analysis was used to fit the suitable models to the corresponding experimental data. The final models for forecasting the composite's modulus of rupture, modulus of elasticity, and tensile stress were produced by substituting the estimated model parameters into the corresponding models. The following are the final model equations that reflect these reactions in terms of the input factors: the level of bone powder (X3), epoxy (X2), and bamboo fiber (X1).

$$\begin{aligned} Modulus\ of\ rupture = {} & +360.47X_1 + 298.06X_2 + 2187.25X_3 - 13.44X_1X_2 \\ & - 60.37X_1X_3 - 54.17X_2X_3 + 1.34X_1X_2X_3 \end{aligned} \quad (3)$$

$$\begin{aligned} Modulus\ of\ elasticity = {} & 87582.82X_1 + 74420.61X_2 + 5.01\times10^5 X_3 - 3315.55X_1X_2 \\ & - 13952.11X_1X_3 - 12692.03X_2X_3 + 316.16X_1X_2X_3 \end{aligned} \quad (4)$$

$$Thickness\ swelling = 95.21X_1 - 83.00X_2 - 605.39X_3 + 3.66X_1X_2 + 16.65X_1X_3 + 15.31X_2X_3 - 0.38X_1X_2X_3 \quad (5)$$

Equations (3) to (5) were used to predict modulus of rupture, modulus of elasticity, and tensile stress for the composite and the results are shown in Tables 3 – 5. For all the results obtained for all the responses under investigation, it was observed that the model predicted results were very similar to the experimental results. This is an indication of the validity of the statistical models developed to predict the responses.

Table 3: Experimental and RSM Predicted Results for Modulus of Rupture.

Run	Actual values of factors			Response (MPa)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.00	45.00	15.00	11.20	11.10
2	45.00	45.00	10.00	12.50	12.40
3	41.70	46.70	11.70	17.00	17.10
4	40.80	45.80	13.30	13.90	13.90
5	40.00	50.00	10.00	9.700	9.90
6	43.30	45.80	10.80	15.30	15.30
7	42.50	47.50	10.00	11.50	11.30
8	42.50	47.50	10.00	11.00	11.30
9	45.00	45.00	10.00	12.20	12.40
10	42.50	45.00	12.50	12.90	13.00
11	40.00	47.50	12.50	8.50	8.40
12	40.00	45.00	15.00	11.00	11.10
13	40.80	48.30	10.80	12.90	12.90
14	42.50	45.00	12.50	13.00	13.00
15	40.00	50.00	10.00	10.00	9.90

Analysis of Variance of Models

The models created (Equations 3 to 5) were evaluated for fit and statistical significance using analysis of variance (ANOVA). Tables 6 to 8 present the findings. Tables 6, 7, and 8 display the ANOVA results for the composite's modulus of rupture, modulus of elasticity, and tensile stress, respectively. If a model term's p value is less than 0.05, it is deemed significant. This is typically taken to indicate that the response being considered will be significantly impacted by changes in the values of the factor that that model term represents. (Beg, *et al.,* 2002).

Table 4: Experimental and RSM Predicted Results for Modulus of Elasticity.

Run	Actual values of factors			Response (MPa)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.00	45.00	15.00	3622	3619
2	45.00	45.00	10.00	2820	2821
3	41.70	46.70	11.70	5107	5107
4	40.80	45.80	13.30	4789	4788
5	40.00	50.00	10.00	3867	3864
6	43.30	45.80	10.80	4161	4164
7	42.50	47.50	10.00	2373	2380
8	42.50	47.50	10.00	2388	2380
9	45.00	45.00	10.00	2823	2821
10	42.50	45.00	12.50	4935	4938
11	40.00	47.50	12.50	3454	3455
12	40.00	45.00	15.00	3615	3619
13	40.80	48.30	10.80	4017	4017
14	42.50	45.00	12.50	4941	4938
15	40.00	50.00	10.00	3860	3864

Table 5: Experimental and RSM Predicted Results for Tensile Stress.

Run	Actual values of factors			Response (MPa)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.00	45.00	15.00	4.70	4.70
2	45.00	45.00	10.00	5.90	5.90
3	41.70	46.70	11.70	1.40	1.40
4	40.80	45.80	13.30	2.60	2.60
5	40.00	50.00	10.00	3.60	3.60
6	43.30	45.80	10.80	2.70	2.70
7	42.50	47.50	10.00	3.80	3.80
8	42.50	47.50	10.00	3.80	3.80
9	45.00	45.00	10.00	5.90	5.90
10	42.50	45.00	12.50	2.30	2.30
11	40.00	47.50	12.50	4.60	4.60
12	40.00	45.00	15.00	4.70	4.70
13	40.80	48.30	10.80	2.80	2.80
14	42.50	45.00	12.50	2.30	2.30
15	40.00	50.00	10.00	3.60	3.60

On the other hand, model terms that have p values higher than 0.05 are not regarded as significant, indicating that they have no discernible effect on the response in question.

The findings showed that the models created to forecast tensile stress, modulus of elasticity, and modulus of rupture were all significant. This is evident from the fact that the model p value was consistently significantly below 0.05 ($p < 0.0001$). This suggests that the models were capable of accurately forecasting the responses that matched them. The models created to forecast tensile stress, modulus of elasticity, and modulus of rupture did not significantly fail to fit. The degree of agreement between the model predictions and the experimental observations is indicated by the level of fit (Montgomery, 2005).

Table 6: ANOVA Results for Model Representing Modulus of Rupture.

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	67.0000	6	11.1700	389.7800	< 0.0001
Linear mixture	14.9900	2	7.4900	261.5600	< 0.0001
X1X2	0.03600	1	0.0360	1.2500	0.2953
X1X3	2.1600	1	2.1600	75.5300	< 0.0001
X2X3	3.4100	1	3.4100	118.9600	< 0.0001
X1X2X3	34.2500	1	34.2500	1195.3800	< 0.0001
Residual	0.2300	8	0.0290		
Lack of fit	6.75E-03	3	2.25E-03	0.0510	0.9833
Pure error	0.2200	5	0.0440		
Cor total	67.2300	14			

Table 7: ANOVA Results for Model Representing Modulus of Elasticity.

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	1.159E07	6	1.93E06	84932.9400	< 0.0001
Linear mixture	2.051E06	2	1.03E06	45080.1100	< 0.0001
X1X2	1.244E06	1	1.24E06	54698.4300	< 0.0001
X1X3	3.964E06	1	3.96E06	1.74E05	< 0.0001
X2X3	68175.3300	1	68175.33	2997.1900	< 0.0001
X1X2X3	1.889E06	1	1.89E06	83041.1200	< 0.0001
Residual	181.9700	8	22.7500		
Lack of fit	8.5500	3	2.8500	0.0820	0.9669
Pure error	173.4200	5	34.6800		
Cor total	1.159E07	14			

Table 8: ANOVA Results for Model Representing Tensile Stress.

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	84297.8500	6	14049.6400	2807.5700	< 0.0001
Linear mixture	50952.2300	2	25476.1200	5090.9500	< 0.0001
X1X2	2991.5800	1	2991.5800	597.8100	< 0.0001
X1X3	20416.7800	1	20416.7800	4079.9300	< 0.0001
X2X3	2454.5600	1	2454.5600	490.5000	< 0.0001
X1X2X3	23081.3800	1	23081.3800	4612.4000	< 0.0001
Residual	40.0300	8	5.0000		
Lack of fit	1.7900	3	0.6000	0.07800	0.9691
Pure error	38.2400	5	7.6500		
Cor total	84337.8800	14			

The models' ability to predict all of the responses was further evaluated using goodness of fit parameters like coefficient of determination (R^2), adjusted coefficient of determination (adjusted R^2), predicted coefficient of determination (predicted R^2), coefficient of variation, standard deviation, and adequate precision. The results are displayed in Tables 8 and 9. The R^2 value, which measures the degree of fit between a model and experimental results, was greater than 0.99 for all of the models studied. As can be seen from the results in Table 9, the models were characterized by high R^2 values, indicating very good fit between the experimental observations and model predictions. Another crucial metric for evaluating the models' fit was the adjusted R^2 value. For a good fit, the R^2 value and the adjusted R^2 value should have great agreement. The fact that the standard deviation was low in relation to the observations' mean suggests that there was not much variation between the individual experimental findings and the mean. This provides more evidence that the model fits the experimental data quite well. For every model taken into consideration, the coefficient of variation (CV) was low.

Table 9: Goodness of Fit Statistics for Response Models.

Parameter	Modulus of rupture	Modulus of elasticity	Tensile stress
R^2	0.9966	1.0000	0.9995
Adjusted R^2	0.9940	1.0000	0.9992
Mean	12.1800	3784.8300	556.7400
Standard deviation	0.1700	4.7700	2.2400
CV	1.3900	0.1300	0.4000
Adeq. Precision	74.6200	836.9300	132.7200

Model Diagnostics

The models created to predict the responses for the composite were also diagnosed in order to evaluate their accuracy and suitability for the intended use. The normal probability charts for the models that depict the composite's modulus of rupture, modulus of elasticity and tensile stress are displayed in Figures 4 through 6. The fact that the dots congregated around the straight line indicates that the residuals of the models did, in fact, follow a normal distribution.

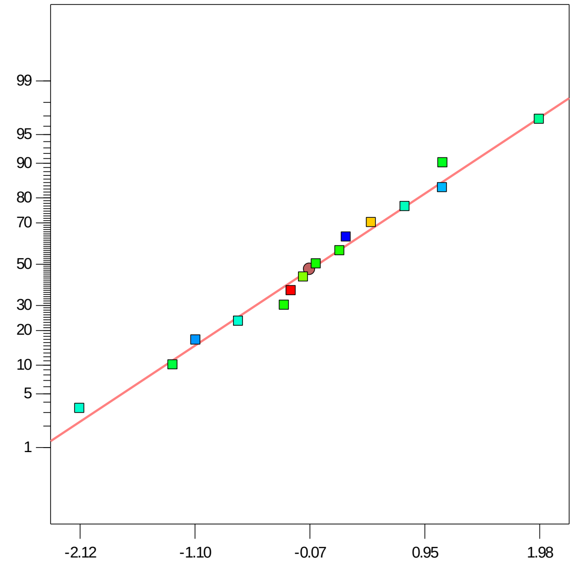


Figure 4: Normal Probability Plot for Model Representing Modulus of Rupture.

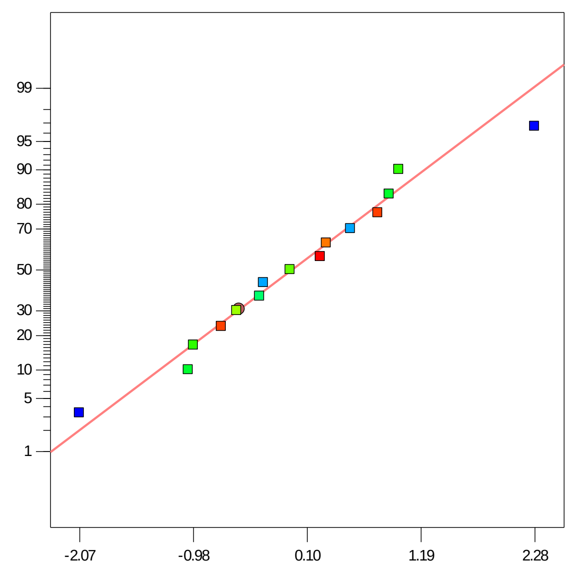
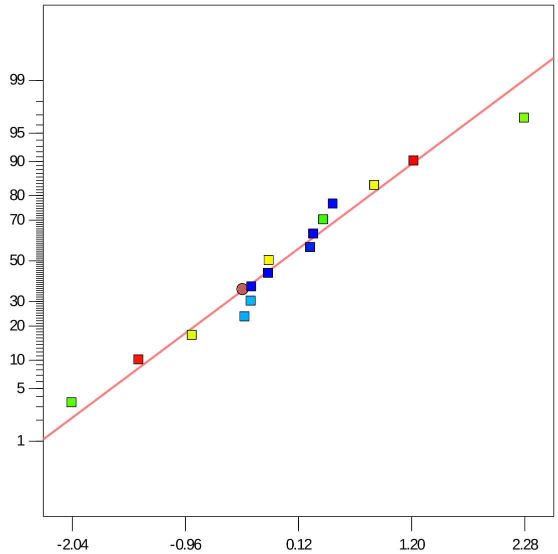


Figure 5: Normal Probability Plot for Model Representing Modulus of Elasticity.



X: Internally Studentized Residuals
Y: Normal % Probability

Figure 6: Normal Probability Plot for Model Representing Tensile Stress.

Validation of RSM Model Results

The model's output was validated by contrasting its values with those derived from the real experiments. Parity charts, which display the comparison, were used for this. The parity plots for the models that depict the three responses (modulus of rupture, modulus of elasticity and tensile stress) for the composite are displayed in Figures 7 through 9. All of the points clustered around the 45º diagonal line, indicating a significant fit between the experimental results and the model predictions.

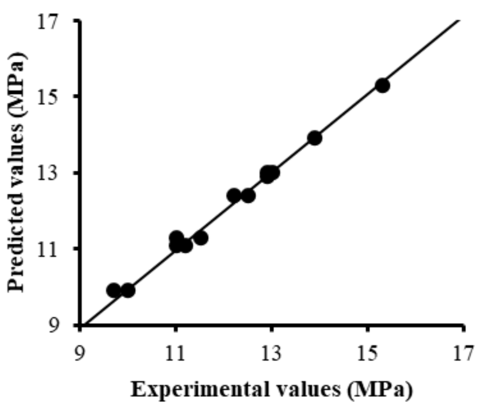


Figure 7: Parity Plot for Model Representing Modulus of Rupture.

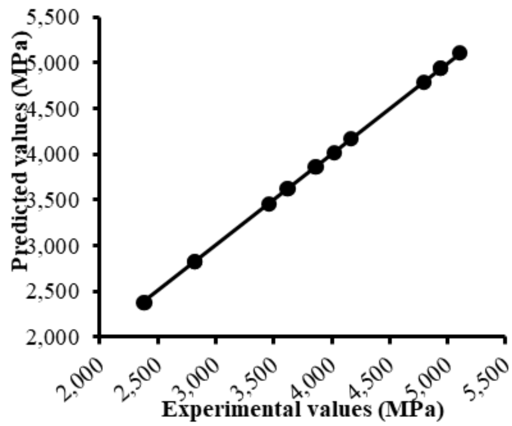


Figure 8: Parity Plot for Model Representing Modulus of Elasticity.

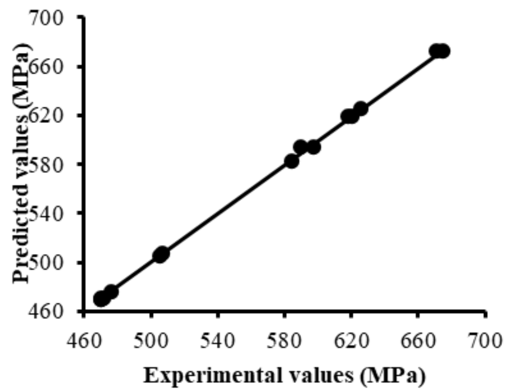


Figure 9: Parity Plot for Model Representing Tensile Stress.

3D Response Surface Plot showing Effect of Input Factors on Responses

To assess the impact of the input factors (level of bamboo fiber, epoxy, and bone powder) on the corresponding responses (modulus of rupture, modulus of elasticity, and tensile stress) for the newly created composite, three-dimensional (3D) response surface plots were created using statistical models. Two variables were varied within the experimental range while the other one remained constant at its center point value to create the response surface plots. The accompanying contour plots are two-dimensional charts that illustrate how two influences might simultaneously affect a selected response. Figures 10 through 15 shows the 3D Response Surface plots and the corresponding contour plots.

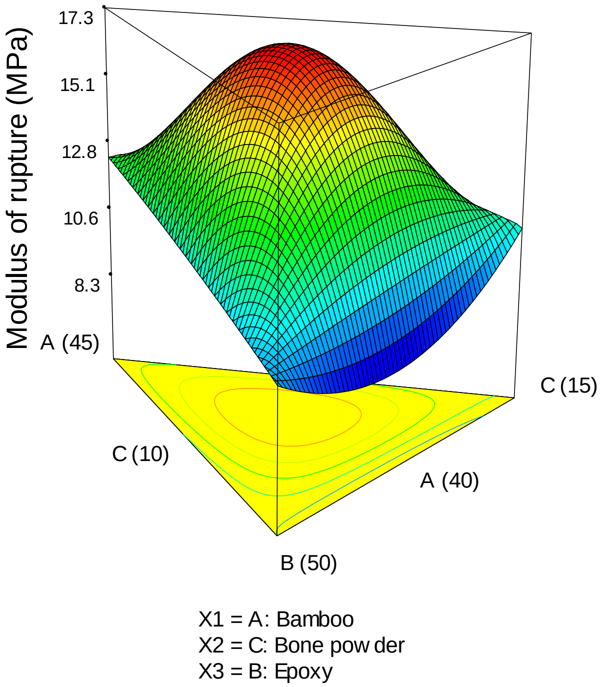


Figure 10: Response Surface Plot Showing the effect Bamboo, Bone Powder and Epoxy on the Modulus of Rupture of the Composite.

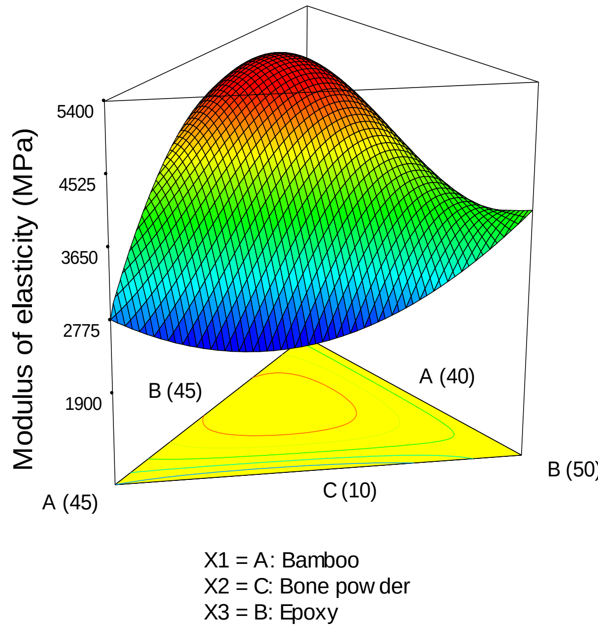


Figure 12: Response Surface Plot Showing the effect Bamboo, Bone Powder and Epoxy on the Modulus of Elasticity of the Composite.

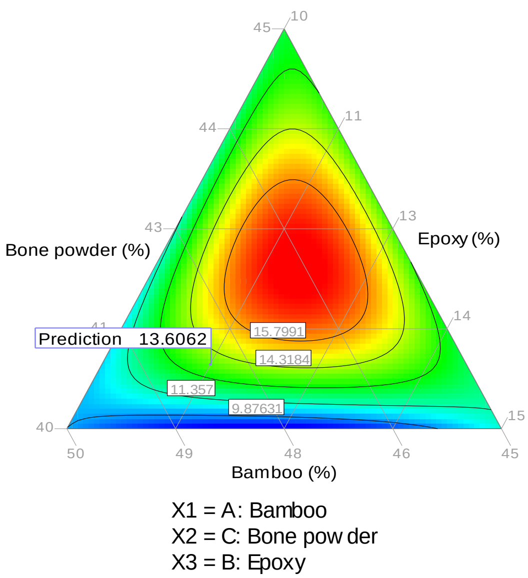


Figure 11: Contour Plot Showing the effect Bamboo, Bone Powder and Epoxy on the Modulus of Rupture of the Composite.

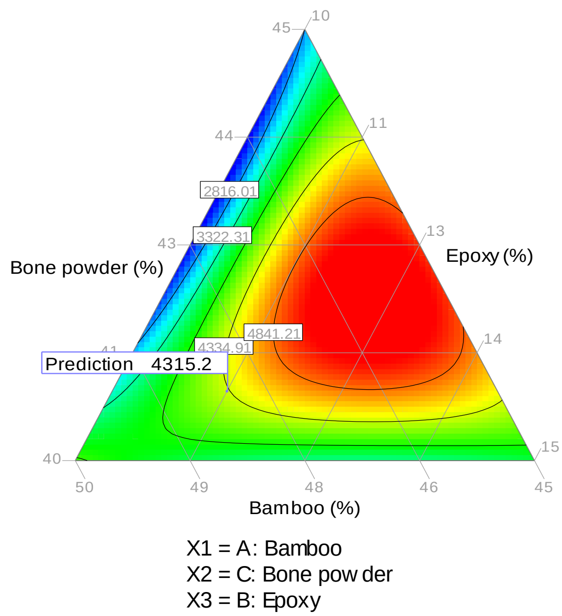
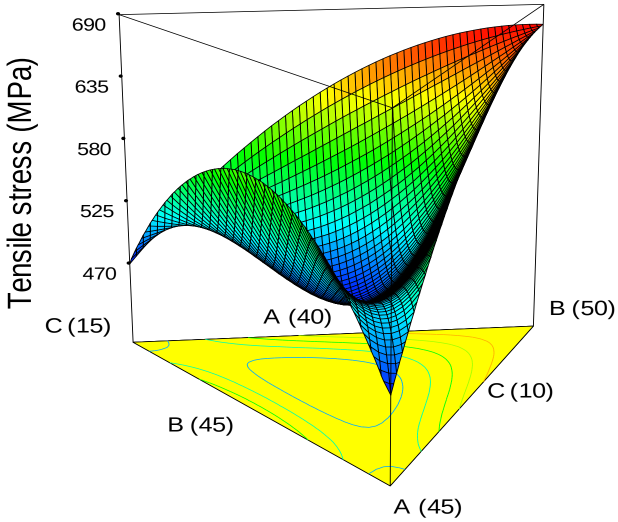
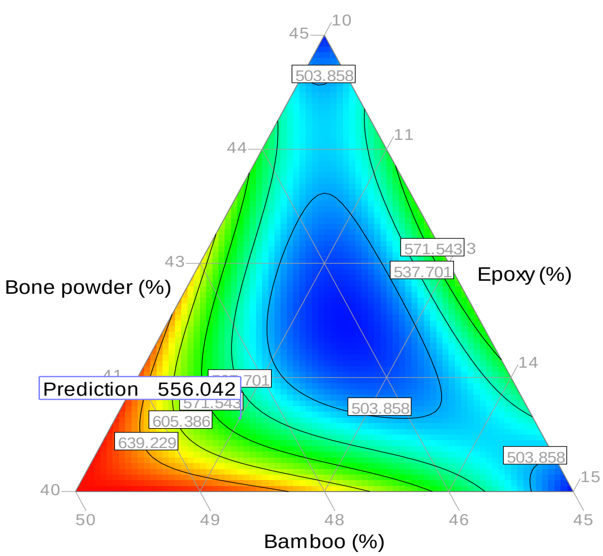


Figure 13: Contour Plot Showing the effect Bamboo, Bone Powder and Epoxy on the Modulus of Elasticity of the Composite.



X1 = A: Bamboo
X2 = C: Bone pow der
X3 = B: Epoxy

Figure 14: Response Surface Plot Showing the Effect Bamboo, Bone Powder and Epoxy on the Tensile Stress of the Composite.



X1 = A: Bamboo
X2 = C: Bone pow der
X3 = B: Epoxy

Figure 15: Contour Plot Showing the effect Bamboo, Bone Powder and Epoxy on the Tensile Stress of the Composite.

Figures 10 and 11 show that increasing the level of bone powder in the composite resulted in an increase in the modulus of rupture. This observation could be attributed mechanical strength which the cow bone impacts on the produced composite material (Ademoh and Olabisi, 2015). It can be inferred from the result trend that the addition of the cow bone into the composite formulation enhanced its modulus of rupture

Figures 12 and 13 follow the same trend as Figures 10 and 11. However, the bone powder and epoxy positively affected the modulus of elasticity while the reverse was the case for the bamboo fibre. The trend observed with respect to bone powder could be attributed to the strength of the cow bone which was consequently imparted on the formulated composite. It could also be as a result of good distribution and dispersion of the binder resulting in strong cow bone-binder interaction. This good particle dispersion improved the cow bone-binder interaction and consequently increased the ability of the composite to restrain gross deformation (Idris, *et al.*, 2015).

The results obtained for the tensile stress were similar to those of modulus of rupture and modulus of elasticity. This is because they are all mechanical properties. Generally, the tensile stress was positively influenced by the level of epoxy and bone powder while the reverse was the case for the bamboo fibre

Optimization of Input Factors and Responses

The responses and related input parameters were optimized by numerical optimization. Modulus of rupture, modulus of elasticity and Tensile stress were all maximized. The reason for this is that in order to increase productivity, they have to be optimized. The optimum conditions with the highest desire value were selected following an evaluation of the model graphs and the solutions recommended by the numerical optimization tool. The outcomes of optimization are displayed in Table 10. The ideal position with the maximum desirability of 0.968 was selected. For the new composite material made from powdered bamboo fiber, the composite's ideal modulus of rupture, modulus of elasticity, and tensile stress were 13.60 MPa, 4314.35 MPa, and 556.16 MPa, respectively.

Table 10: Optimisation Results.

Variable	Value
Bamboo	40.8%
Epoxy	47.9%
Bone powder	11.3%
Maximum modulus of rupture	13.60 MPa
Maximum modulus of elasticity	4314.35 MPa
Maximum Tensile stress	556.16 MPa
Desirability	0.968

CONCLUSION

This study examined the mechanical characteristics of a composite made from carbonized bone particles and powdered bamboo fiber in an epoxy matrix for possible application as a lightweight engineering material. The following deductions were made:

i. A new hybrid composite material has been created using carbonized cow bone and powdered bamboo fiber, with epoxy serving as the binder. This material is suggested for the creation of a lightweight engineering material.

ii. The composite made from powdered bamboo fiber had optimal values for modulus of rupture, modulus of elasticity, and tensile stress of 13.60 MPa, 4314.35 MPa, and 556.16 MPa, respectively. The corresponding values for bamboo, epoxy, and bone powder were 40.8%, 47.9%, and 11.3%, respectively.

iii. The model terms were significant, according to the ANOVA findings, suggesting that variations in the amounts of bone powder, epoxy, and bamboo will significantly affect the mechanical characteristics of the lightweight engineering material made from powdered bamboo fibers.

The results from this work were compared with Chin, *et al.* (2019) and Khan. *et al*., (2017). Whereas, the fiber configurations were different, they were similarly pretreated with NaOH solutions as was with this work and both had epoxy as the matrix binder although the at different composition levels with this work. The difference in values could be explained by the inclusion of carbonized bone particles in the matrix of this work whereas this was absent in the works of Chin, *et al.* (2019) and Khan. *et al*. (2017). This research material will find application as a composite board used in furniture works with load bearing capacity within the threshold of the values of the investigated mechanical properties.

REFERENCES

1. Abutu, J., S.A. Lawal, M.B. Ndaiman, R.A. Lafia-Araga, O. Adedipe, and I.A. Choudhury. 2018. “Study on Mechanical Properties of Fly Ash Impregnated Glass Fiber Reinforced Polymer Composites using Mixture Design Analysis”. *Engineering Science and Technology, an International Journal*. 21: 787-797.

2. Ademoh, N.A. and A.I. Olabisi. 2015. “Development and Evaluation of Maize Husks (Asbestos-free) based Brake Pad”. *Development*. 5(2): 67-80.

3. Adewole, T. and I. Oladele. 2015. “Effect of Cow Bone Ash Particle Size Distribution on the Mechanical Properties of Cow Bone Ash-Reinforced Polyester Composites”. *Chemistry and Materials Research*. 7(3): 40 – 46.

4. Anagbo, P.E. and P.E. Oguocha. 1989. “The Structure and Mechanical Properties of Palm Timber as a Fibre Composite”. *Journal of Engineering Materials and Technology*. 111(1): 21-25.

5. Beg, Q.K., R.K. Saxena, and R. Gupta. 2002. “Kinetic Constants Determination for an Alkaline Protease from *Bacillus mojavensis* using Response Surface Methodology”. *Biotechnology and Bioengineering*. 78: 289–295.

6. Chin S.C., K. Tee, F. Tong, H.R. Ong and J. Gimbun. 2019. “Thermal and Mechanical Properties of Bamboo Fiber Reinforced Composites”. *Materials Today Communication (Science Direct)*. 23: 100876.

7. Deshpande, A., M. Bhaskar Rao, and C. Lakshmana Rao. 2000. “Extraction of Bamboo Fibers and their use as Reinforcement in

Polymeric Composites". *Journal of Applied Polymer Science*. 76(1): 83-92.

8. Gutu, T. 2013. "A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization". *International Journal of Innovative Technology and Exploring Engineering*. 2(5): 314-319.

9. Hirata, M., K. Takayama, and T. Nagai. 1992. "Formulation Optimization of Sustained-Release Tablet of Chlorpheniramine Maleate by means of Extreme Vertices Design and Simultaneous Optimization Technique". *Chemical and Pharmaceutical Bulletin*. 40(3): 741-746.

10. Idris, U.D., V.S. Aigbodion, I.J. Abubakar, and C.I. Nwoye. 2015. "Eco-friendly Asbestos Free Brake-Pad: Using Banana Peels". *Journal of King Saud University – Engineering Sciences*. 27: 185-192.

11. Ikpoza, E. and J.A. Akpobi. 2021. "Evaluation of Mechanical Properties of Composite Material Produced from Continuous Bamboo Fibre with Carbonized Bone Particles in an Epoxy Matrix". *Nigerian Research Journal of Engineering and Environmental Sciences*. 6 (1): 22-31.

12. Ikpoza, E. and R.O. Edokpia. 2022. "Evaluation of Mechanical Properties of Composite Material Produced from Short Bamboo Fibre with Carbonized Bone Particles in an Epoxy Matrix". *Journal of the Nigerian Association of Mathematical Physics*. 64 (April - September): 171-180.

13. Khalil, H.P.S.A., I.U.H. Bhat, M. Jawaid, A. Zaidon, D. Hermawan, and Y.S. Hadi. 2012. "Bamboo Fibre Reinforced Biocomposites: A Review". *Materials and Design*. 42: 353–368.

14. Khan, Z., B.F. Yousif and M. Islam. 2017. "Fracture behaviour of Bamboo Fiber Reinforced Epoxy Composites". *Composites Part B: Engineering*. 116: 186-199.

15. Khayal, O.M.E.S. 2017. "Literature Review on Imperfection of Composite Laminated Plates". *Journal of Microscopy and Ultrastructure*. 5: 119–122.

16. Lobovikov, M., P. Shyam, M. Piazza, H. Ren, and J. Wu. 2007. "Non-Wood Forest Products: 18 World Bamboo Resources". A Thematic Study Prepared in the Framework of the Global Forest Resources Assessment. Rome, Italy: Food and Agriculture Organization of the United Nations.

17. Montgomery, D.C. 2005. *Design and Analysis of Experiments, 6th ed.* John Wiley & Sons, Inc.: New York, NY.

18. Wani, R.S. and R.R. Shitole. 2017. "Tensile Testing of Bamboo Fiber Reinforced Epoxy Composite". *IOSR, Journal of Mechanical and Civil Engineering (IOSR-JMCE)* e-ISSN: 2278-1684, p ISSN: 2320-334X, 07-11.

19. Zen, M., N. Izzati, S.S. Abd Gani, R. Shamsudin, and H.R. Fard Masoumi. 2015. "The use of D-Optimal Mixture Design in Optimizing development of Okara Tablet Formulation as a Dietary Supplement. *The Scientific World Journal*. 1-7.

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