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# EVALUATION OF MECHANICAL PROPERTIES OF COMPOSITE MATERIAL PRODUCED FROM SHORT BAMBOO FIBRE WITH CARBONIZED BONE PARTICLES IN AN EPOXY MATRIX

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***Abstract***

***In this study the potential use of short bamboo fibre and carbonized bone with epoxy as a binder for the production of a new composite material to be used in producing a light weight engineering material was investigated. The Modulus of rupture, modulus of elasticity and tensile stress tests to assess the mechanical properties of the composite were carried out. The optimum results from the composites produced using short bamboo fibre had a composition of bamboo – carbonized bone – epoxy composition of 40%, 10% and 50% respectively. The optimum values of modulus of rupture, modulus of elasticity, and tensile stress for the composite were obtained as 17.35 MPa, 7003.04 MPa, and 770.72 MPa respectively. The analyses of variance results show that all the model terms were significant indicating that changes in the levels of bamboo, epoxy and bone powder will have a significant influence on the modulus of rupture, modulus of elasticity and tensile stress of the composite material.***

***Keywords***: Composite, Bamboo, Carbonized bone, Epoxy, RSM, ANOVA

## 1. INTRODUCTION

Meng et al. [1], deduced that there had been a steady increase in the use of carbon fibre reinforced polymers (CFRP) across a wide range of aerospace (e.g., Boeing 787 airplane wing structures), automotive (e.g., BMW i3 body panels), energy (e.g., wind turbine blades), and sporting applications (e.g., fishing rods, bicycles). This is because CFRP contributes to significant weight reduction of the product while providing excellent performance. In the past 10 years, the annual global demand for carbon fibre (CF) has increased from approximately 16,000 to 72,000 tonnes and is forecast to rise to 140,000 tonnes by 2020 [2]. Production of carbon fibre requires the burning of high energy fossil fuels that also create considerable amounts of pollution. The primary energy of production of carbon fibres is 380-420 MJ/kg and this production results in 23.9-26.4 kg/kg of CO2 emissions [2].

Gutu, [3], noted that natural fibre reinforced polymers are a potential environmentally friendly alternative for carbon fibre reinforced polymers or glass fibre reinforced polymers and that they could be a suitable replacement for these types of composites in some current applications. Moreover, bamboo has been observed to possess tensile and compressive strengths stronger than several types of wood and close to the strength of steel. Using this material keeps the high mechanical strength while serving as natural resource. This in turn helps in the reduction of energy consumption and pollution creation when building woven composites.

A study to evaluate the mechanical properties of composite material produced from continuous bamboo fibre with carbonized bone particles in an epoxy matrix for deployment in small scale horizontal axis wind turbine blades was carried out by [4]. The optimum values of modulus of rupture, modulus of elasticity, and tensile stress for the composite were obtained as 110.50 MPa, 13130.70 MPa, and 8448.41 MPa respectively.

A research was also carried out by [5] to determine the water absorption and thickness swelling properties of the composite material produced from continuous bamboo fibre with carbonized bone particles in an epoxy matrix for deployment in small scale horizontal axis wind turbine blades. The optimum values for water absorption and thickness swelling as 6.55% and 0.09% respectively

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Some researchers have investigated and ascertained the desirable effects of cow bone as reinforcement particles in composites [6][7].

This study therefore evaluates the mechanical properties of a composite material produced from short bamboo fibre with carbonized bone particles in an epoxy matrix for use as a light weight engineering material.

## 2. MATERIALS AND METHODS

### 2.1. Material Collection and Pretreatment

Fresh bamboo (bambusa vulgaris) was obtained from a wood shop in Benin City, Nigeria. The bamboo culms were then sliced into segments by cutting them before each node, and then into strips. The strips were sized to a desired width of range 15mm to 25mm in order to ensure the bamboo strips were semi flat and not curved. The lignin in the bamboo strips was removed by soaking it for approximately 72 hours in 0.1 M sodium hydroxide solutions, [8]. Deshpande et al., [8] had determined that a very strong NaOH solution and a long soaking time will lead to greater lignin dissolution. The bamboo was thereafter rinsed with distilled water to neutrality. They were air dried and later heated at 110°C in an oven for two hours until they were dry. They were thereafter pressed using an Edwards Rolling Machine in the sheet metal lab in the Faculty of Engineering workshop in University of Benin by passing the strips through a smaller gap height which was further reduced for a re-pass. This was repeated until the gap height was small enough to cause the strips to separate into splintered bamboo pieces. The diameter of the fibres ranged from 0.8 mm to 2.3 mm. The next step involved the cutting of the bamboo fibre to obtain short bamboo fibre (see Plate 1). The length of the short fibres ranged from 2.00 mm to 5.00 mm. Table 1 shows the average fibre diameter from a sample size of 20 fibres, along with their standard deviation.

Table 1: Dimensions of short bamboo fibres.

| | |
|---|---|
| Minimum length | 2.00 millimetres |
| Maximum length | 5.00 millimetres |
| Average length | 3.72 millimetres |
| Standard Deviation | 1.0451 millimetres |

**Plate 1: A sample of the Short fibres**

Cow bone which was carbonized in a crucible furnace at about 550 °C for 45 min, was obtained at an animal feed processing factory in Benin City. The carbonized cow bone was crushed and grounded to powder. It was thereafter sieved to obtain a fine particle size distribution using a sieve size of 212 µm. Epoxy resin and catalyst which served as the matrix binder was obtained under the brand name of Epochem 105 Resin and Epochem 205 epoxy curing agent, from Epoxy Oilserv Nigeria Ltd, located in Port-Harcourt, Rivers State, Nigeria.

### 2.2. Composite Experimental Sample Formation and Testing

A three-variable simplex-lattice mixture experimental design with three variables serving as mixture components was used in planning the experiments for the production of the composite. This choice of the design was based on the fact that it has been established by numerous researchers as the best experimental design for production formulation in the field of engineering [9][10]. It is typically used whenever the components form a simplex region as was the case in this study. Since the number of points may be equal to just the number needed to estimate the model, the simplex-lattice design was augmented to allow for detection of lack of fit. For this purpose, the overall centroid was added to the check blends (50-50 combinations of the center point and each vertex). Five replications of the design points was done in order to appropriately estimate the lack of fit from the pure error. This took the total number of experimental runs to 15 which was implemented in the Design Expert® software version 7.0.0, from Stat-ease, Inc. Minneapolis, USA. The Design Expert® software was also employed to develop the statistical models to relate the input factors to the chosen responses. The factors investigated in this study as well as their respective ranges are shown in Table 1. The relationship between the components of the mixture which also represent factors of the design is shown in Equations (1) and (2).

Table 2: 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 |

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

where, $i$ = 1, 2, 3

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

Equations (1) and (2) show that the components of the mixture formulation are not independent implying that changes in the levels of one component affect those of the others [11].

Experimental samples of the prepared short bamboo fibre, the carbonized bone particles, and the epoxy resin with the corresponding mixing ratio of the hardener (catalyst) were measured out respectively in weights using a digital electronic scale with an accuracy of 0.01g into a pan in batches according to the experimental design matrix. The epoxy and hardener were prepared according to the manufacturer's specification. Each configuration was homogeneously mixed and put into the preformed wooden mould with dimensions based on ASTM D638 which had been previously rubbed with a petroleum jelly for the purpose of ease of extraction of the cured specimens. A pressure of about 80 kN was applied to the composite. It was allowed to cure at room temperature for 24 hours before extraction. Mechanical tests (modulus of rupture, modulus of elasticity and tensile stress) were thereafter performed on the specimens in the University of Benin, Strength of Materials Laboratory.

## 3. RESULTS AND DISCUSSION

### 3.1. Analysis of Statistical Models

Statistical analysis of the chosen models was done by fitting the models to the experimental data as obtained from the mixture experimental design. The special cubic model was fitted to the experimental data for all the responses (modulus of rupture, modulus of elasticity and tensile stress). The fitting of the appropriate models to the respective experimental data was achieved through multiple regression analysis which culminated in the estimation of the unknown model parameters. Substitution of the estimated model parameters into the respective models resulted in the final models for predicting modulus of rupture, modulus of elasticity, and tensile stress for the composite. The final model equations representing these responses in terms of the input factors, bamboo fibre level ($X_1$), epoxy level ($X_2$) and bone powder level ($X_3$) are presented thus.

$$\textit{Modulus of rupture} = 251.81X_1 + 208.29X_2 + 1467.13X_3 - 9.35X_1X_2 - 40.11X_1X_3 - 35.93X_2X_3 + 0.87X_1X_2X_3 \quad (3)$$

$$\textit{Modulus of elasticity} = 77200.56X_1 + 59755.84X_2 + 3.92\times10^5 X_3 - 2780.42X_1X_2 - 11152.95X_1X_3 - 9571.99X_2X_3 + 240.71X_1X_2X_3 \quad (4)$$

$$\textit{Tensile stress} = -7109.92X_1 - 5462.84X_2 - 37982.19X_3 + 256.05X_1X_2 + 1077.483X_1X_3 + 924.24X_2X_3 - 23.35X_1X_2X_3 \quad (5)$$

Equations (3) to (5) were used to predict modulus of rupture, modulus of elasticity, and tensile stress for the composite for the wind turbine blades 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 | 40.0000 | 45.0000 | 15.0000 | 19.1000 | 19.0000 |
| 2 | 45.0000 | 45.0000 | 10.0000 | 11.7000 | 11.7000 |
| 3 | 41.7000 | 46.7000 | 11.7000 | 14.7000 | 14.7000 |
| 4 | 40.8000 | 45.8000 | 13.3000 | 15.4000 | 15.3000 |
| 5 | 40.0000 | 50.0000 | 10.0000 | 17.3000 | 17.4000 |
| 6 | 43.3000 | 45.8000 | 10.8000 | 12.2000 | 12.2000 |
| 7 | 42.5000 | 47.5000 | 10.0000 | 11.1000 | 11.0000 |
| 8 | 42.5000 | 47.5000 | 10.0000 | 10.9000 | 11.0000 |
| 9 | 45.0000 | 45.0000 | 10.0000 | 11.7000 | 11.7000 |
| 10 | 42.5000 | 45.0000 | 12.5000 | 11.8000 | 11.7000 |
| 11 | 40.0000 | 47.5000 | 12.5000 | 13.2000 | 13.2000 |
| 12 | 40.0000 | 45.0000 | 15.0000 | 19.0000 | 19.0000 |
| 13 | 40.8000 | 48.3000 | 10.8000 | 14.5000 | 14.5000 |
| 14 | 42.5000 | 45.0000 | 12.5000 | 11.6000 | 11.7000 |
| 15 | 40.0000 | 50.0000 | 10.0000 | 17.5000 | 17.4000 |

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 | 40.0000 | 45.0000 | 15.0000 | 6086 | 6087 |
| 2 | 45.0000 | 45.0000 | 10.0000 | 5845 | 5846 |
| 3 | 41.7000 | 46.7000 | 11.7000 | 5654 | 5654 |
| 4 | 40.8000 | 45.8000 | 13.3000 | 5762 | 5763 |
| 5 | 40.0000 | 50.0000 | 10.0000 | 7001 | 7003 |
| 6 | 43.3000 | 45.8000 | 10.8000 | 4747 | 4747 |
| 7 | 42.5000 | 47.5000 | 10.0000 | 4091 | 4091 |
| 8 | 42.5000 | 47.5000 | 10.0000 | 4092 | 4091 |
| 9 | 45.0000 | 45.0000 | 10.0000 | 5847 | 5846 |
| 10 | 42.5000 | 45.0000 | 12.5000 | 3959 | 3960 |
| 11 | 40.0000 | 47.5000 | 12.5000 | 6898 | 6898 |
| 12 | 40.0000 | 45.0000 | 15.0000 | 6088 | 6087 |
| 13 | 40.8000 | 48.3000 | 10.8000 | 6112 | 6111 |
| 14 | 42.5000 | 45.0000 | 12.5000 | 3961 | 3960 |
| 15 | 40.0000 | 50.0000 | 10.0000 | 7005 | 7003 |

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 | 40.0000 | 45.0000 | 15.0000 | 726 | 727 |
| 2 | 45.0000 | 45.0000 | 10.0000 | 760 | 760 |
| 3 | 41.7000 | 46.7000 | 11.7000 | 753 | 753 |
| 4 | 40.8000 | 45.8000 | 13.3000 | 747 | 747 |
| 5 | 40.0000 | 50.0000 | 10.0000 | 771 | 771 |
| 6 | 43.3000 | 45.8000 | 10.8000 | 831 | 832 |
| 7 | 42.5000 | 47.5000 | 10.0000 | 906 | 906 |
| 8 | 42.5000 | 47.5000 | 10.0000 | 906 | 906 |
| 9 | 45.0000 | 45.0000 | 10.0000 | 760 | 760 |
| 10 | 42.5000 | 45.0000 | 12.5000 | 909 | 909 |
| 11 | 40.0000 | 47.5000 | 12.5000 | 687 | 687 |
| 12 | 40.0000 | 45.0000 | 15.0000 | 728 | 727 |
| 13 | 40.8000 | 48.3000 | 10.8000 | 761 | 761 |
| 14 | 42.5000 | 45.0000 | 12.5000 | 910 | 909 |
| 15 | 40.0000 | 50.0000 | 10.0000 | 770 | 771 |

**3.2. Analysis of Variance of Models**

Analysis of variance (ANOVA) was used to assess the statistical significance and fit of the models developed (Equations 3 to 5). The results are shown in Tables 6 to 8. The ANOVA results for modulus of rupture, modulus of elasticity, and tensile stress for the composite respectively shown in Tables 6, 7 and 8. Model terms are considered to be significant if they have a p value less than 0.05. This is usually interpreted to mean that changes in the values of the factor represented by that model term will have a significant effect on the response under consideration [12]. Conversely, model terms with p values greater than 0.05 are not considered significant and this means that that factor does not significantly influence the response under consideration. The results revealed that the models developed to predict modulus of rupture, modulus of elasticity, and tensile stress were all significant. This can be seen from the fact that the model p value in all cases was very much less than 0.05 ($p < 0.0001$). This implies that the models were adequate for predicting their corresponding responses. The lack of fit of the models developed to predict modulus of rupture, modulus of elasticity, and tensile stress was not significant. The level of fit indicates the degree of agreement between the experimental observations and the model predictions [13]

Table 6: ANOVA results for model representing modulus of rupture.

| Source | Sum of Squares | Degree of freedom | Mean square | F value | p value |
|---|---|---|---|---|---|
| Model | 118.8400 | 6 | 19.8100 | 2624.7300 | $< 0.0001$ |
| Linear mixture | 75.8800 | 2 | 37.9400 | 5027.6700 | $< 0.0001$ |
| $X_1X_2$ | 16.7300 | 1 | 16.7300 | 2216.8400 | $< 0.0001$ |
| $X_1X_3$ | 18.0700 | 1 | 18.0700 | 2394.4800 | $< 0.0001$ |
| $X_2X_3$ | 20.5600 | 1 | 20.5600 | 2724.2600 | $< 0.0001$ |
| $X_1X_2X_3$ | 14.5800 | 1 | 14.5800 | 1932.2500 | $< 0.0001$ |
| Residual | 0.0600 | 8 | 7.54E-003 | | |
| Lack of fit | 1.81E-03 | 3 | 6.04E-04 | 0.0520 | 0.9828 |
| Pure error | 0.0590 | 5 | 0.0120 | | |
| Cor total | 118.9000 | 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 | 1.71E07 | 6 | 2.85E06 | 2.17E06 | < 0.0001 |
| Linear mixture | 5.38E06 | 2 | 2.69E06 | 2.05E06 | < 0.0001 |
| $X_1X_2$ | 7.31E06 | 1 | 7.31E06 | 5.57E06 | < 0.0001 |
| $X_1X_3$ | 5.41E06 | 1 | 5.41E06 | 4.12E06 | < 0.0001 |
| $X_2X_3$ | 1.03E05 | 1 | 1.03E05 | 78711.98 | < 0.0001 |
| $X_1X_2X_3$ | 1.10E06 | 1 | 1.10E06 | 8.34E05 | < 0.0001 |
| Residual | 10.5000 | 8 | 1.31 | | |
| Lack of fit | 0.1500 | 3 | 0.049 | 0.024 | 0.9944 |
| Pure error | 10.3500 | 5 | 2.07 | | |
| Cor total | 1.71E07 | 14 | | | |

Table 8: ANOVA results for model representing tensile stress.

| Source | Sum of Squares | Degree of freedom | Mean square | F value | p value |
|---|---|---|---|---|---|
| Model | 82044.1900 | 6 | 13674.0300 | 22083.9800 | < 0.0001 |
| Linear mixture | 15051.1500 | 2 | 7525.5800 | 12154.0400 | < 0.0001 |
| $X_1X_2$ | 26578.4000 | 1 | 26578.4000 | 42924.9300 | < 0.0001 |
| $X_1X_3$ | 37005.2000 | 1 | 37005.2000 | 59764.5300 | < 0.0001 |
| $X_2X_3$ | 3190.5700 | 1 | 3190.5700 | 5152.8700 | < 0.0001 |
| $X_1X_2X_3$ | 10306.8000 | 1 | 10306.8000 | 16645.7900 | < 0.0001 |
| Residual | 4.9500 | 8 | 0.6200 | | |
| Lack of fit | 0.4000 | 3 | 0.1300 | 0.1500 | 0.9273 |
| Pure error | 4.5500 | 5 | 0.9100 | | |
| Cor total | 82049.1500 | 14 | | | |

Goodness of fit parameters such as coefficient of determination ($R^2$), adjusted coefficient of determination (adjusted $R^2$), predicted coefficient of determination (predicted $R^2$), coefficient of variation, standard deviation, adequate precision were used to further assess the fit of the models for predicting all the responses and the results are shown in Tables 8. The $R^2$ value was greater than 0.99 for all the models considered. The $R^2$ value is used to assess the level of fit between a model and experimental results. As can be seen from the results presented in Table 9, the models were characterised by high $R^2$ values indicating very good fit between the experimental observations and model predictions. The adjusted $R^2$ value was another important parameter used to assess the fit of the models. There should be an excellent agreement between the $R^2$ value and the adjusted $R^2$ value for a good fit. The value of standard deviation was small compared to the mean of the observations an indication that there was very little deviation between the individual experimental results compared to the mean value. This is a further confirmation of the very good fit of the model to the experimental results. The coefficient of variation (CV) was small for all the models considered.

Table 9: Goodness of fit statistics for response models.

| Parameter | Modulus of rupture | Modulus of elasticity | Tensile stress |
|---|---|---|---|
| $R^2$ | 0.9995 | 1.0000 | 0.9999 |
| Adjusted $R^2$ | 0.9991 | 1.0000 | 0.9999 |
| Mean | 14.1100 | 5543.1300 | 795.0300 |
| Standard deviation | 0.0870 | 1.1500 | 0.7900 |
| CV | 0.6200 | 0.0210 | 0.0990 |
| Adeq. Precision | 135.5800 | 388.7900 | 414.1500 |

**3.3. Model Diagnostics**

In other to assess the accuracy and indeed the adequacy for the intended purpose, diagnosis of the models developed to predict the responses for the composite also carried out. Figures 1 to 3 show the normal probability plots for the models representing the modulus of rupture, modulus of elasticity, and tensile stress for the composite. From the results obtained, the residuals of the models did follow a normal distribution as seen from the fact that the points clustered around the straight line.

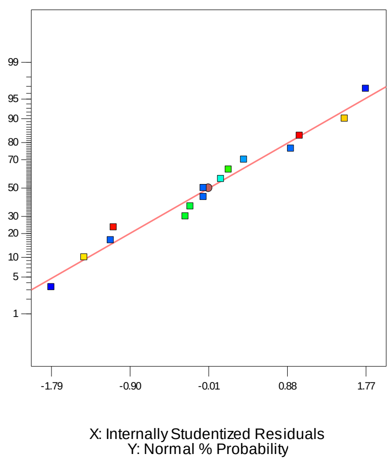


Figure 1: Normal probability plot for model representing modulus of rupture.

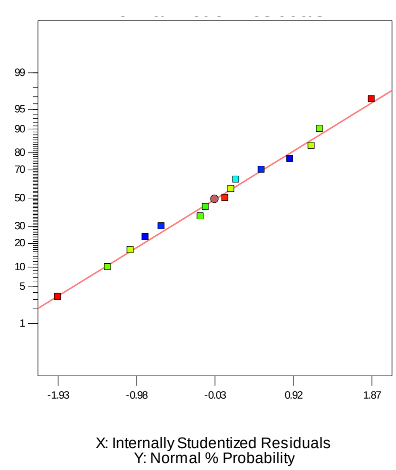


Figure 2: Normal probability plot for model representing modulus of elasticity.

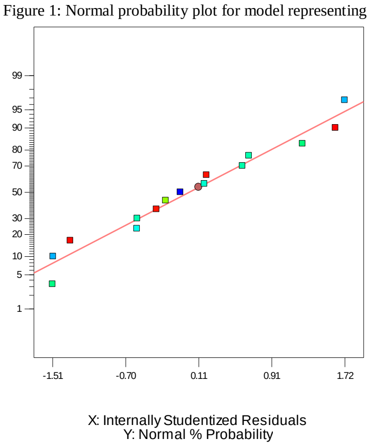


Figure 3: Normal probability plot for model representing tensile stress.

**3.4. Validation of RSM Model Results**

Validation of the model results was done by comparing their values with those obtained from the actual experiments. This was done in the form of parity plots which shows the comparison. Figures 4 to 6 show the parity plots for the models representing the three responses (modulus of rupture, modulus of elasticity, and tensile stress) for the composite. As can be seen in Figures 4 to 6, there was significant fit between the experimental results and the model predictions because all the points clustered around the 45º diagonal line.

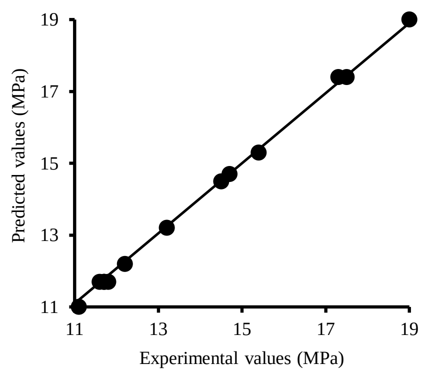


Figure 4: Parity plot for model representing modulus of rupture.

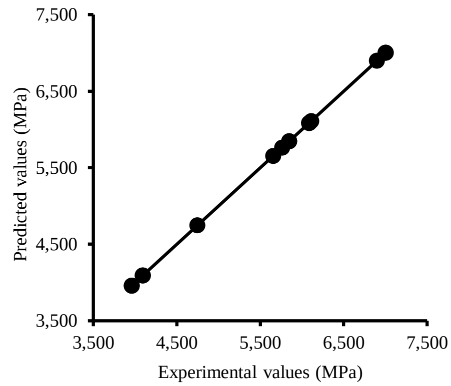


Figure 5: Parity plot for model representing modulus of elasticity.

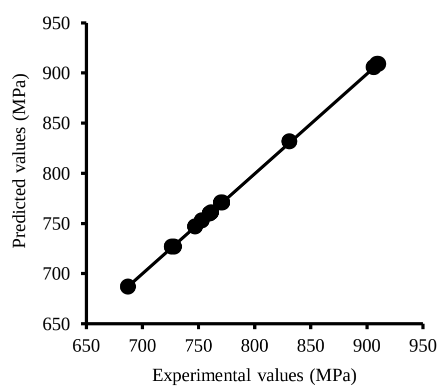


Figure 6: Parity plot for model representing tensile stress.

**3.5. Optimisation of Input Factors and Responses**

Numerical optimisation was used to optimise the responses and the corresponding input factors. The modulus of rupture, modulus of elasticity, and tensile stress were all maximised. This is because they needed to be maximised for better productivity. After evaluating the model graphs and the solutions suggested by the numerical optimisation package, the optimum conditions were chosen as the one with the highest desirability value. Table 10 shows the optimisation results. This optimal point was chosen with the highest desirability of 0.968. The optimum values of modulus of rupture, modulus of elasticity, and tensile stress for the composite for the wind turbine blades produced from the short bamboo fibre were obtained as 17.35 MPa, 7003.04 MPa, and 770.72 MPa respectively. The corresponding values of bamboo, epoxy and bone powder were 40%, 50% and 10% respectively.

Table 10: Optimisation results.

| Variable | Value |
|---|---|
| Bamboo | 40% |
| Epoxy | 50% |
| Bone powder | 10% |
| Maximum modulus of rupture | 17.35 MPa |
| Maximum modulus of elasticity | 7003.04 MPa |
| Maximum Tensile stress | 770.72 MPa |
| Desirability | 0.968 |

**4. CONCLUSION**

In this study, the mechanical properties of a composite produced from short bamboo fibre and carbonized bone particles in an epoxy matrix for a potential use as a light weight engineering material, was investigated. The following conclusions were drawn:

i. A new hybrid composite material produced from short bamboo fibre with carbonized cow bone using epoxy as a binder recommended for the production of a light weight engineering material has been formulated.
ii. The optimum values of modulus of rupture, modulus of elasticity, and tensile stress for the composite produced from the short bamboo fibre were obtained as 17.35 MPa, 7003.04 MPa, and 770.72 MPa respectively with corresponding values of bamboo, epoxy and bone powder of 40%, 50% and 10% respectively.
iii. ANOVA results shows that the model terms were significant indicating that changes in the levels of bamboo, epoxy and bone powder will have a significant influence on the mechanical properties of the light weight engineering material produced from the short bamboo fibres.

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