NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Composite Produced from Continuous Bamboo Fibre with Carbonized Bone Particles in An Epoxy Matrix: Evaluation of Physical Properties

[1]Ikpoza, E; [2]Akpobi, J.A.

[1,2]Department of Production Engineering, University of Benin, Benin City, Nigeria.

Email: emmanuel.ikpoza@uniben.edu [1] john.akpobi@uniben.edu[2]

Article Info

Received 02 February 2021
Revised 21 February 2021
Accepted 25 February, 2021
Available online 01 March. 2021

Keywords:
composites, bamboo, fibre, ANOVA

https://doi.org/10.37933/nipes/3.1.2021.21

https://nipesjournals.org.ng

Abstract

This paper investigates the potential use of bamboo fibre and carbonized bone particles in an epoxy matrix for the production of a new composite material to be used in small scale horizontal axis wind turbine blade production. Water absorption and thickness swelling tests were carried out to assess the physical property of the composite. The optimum values for composites produced using continuous bamboo fibre – carbonized bone – epoxy composition of 40%, 10% and 50% respectively gave values for water absorption and thickness swelling as 6.55% and 0.09% respectively. The results of analyses of variance (ANOVA) carried out revealed 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 water absorption and thickness swelling of the composite for the wind turbine blades produced from the continuous bamboo fibres.

1. Introduction

It has been noted that an important component of the horizontal axis wind turbine is the rotor with the blades [1]. The blade is what extract the energy from the wind which it transmits through the shafts to drive the generator which produces the electricity. A lot of research has been ongoing with the aim to develop optimum materials for the production of wind turbine blades.
Since the 1970s, most blades for horizontal axis wind turbines have been made from composites. The most common composites consist of fiberglass in a polyester resin, but vinyl ester and wood–epoxy laminates have also been used. More recently, carbon fibres have become widely used in blade construction, not necessarily as a replacement for fiberglass, but to augment it. [1]

Evidently, 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) has been seen as 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 CO_2 emissions [3]

It has been posited by [4] that natural fibre reinforced polymers are a potential environmentally friendly alternative for Carbon Fibre Reinforced Polymers or Glass Fibre Reinforced Polymers and could replace them in some current applications. Bamboo on the other hand has been found 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 using natural materials. This in turn helps in the reduction of energy consumption and pollution creation when building woven composites.

A number of researches have been on going to investigate and ascertain the desirable effects of cow bone as reinforcement particles in composites. The use of by-products as reinforcement is a modern technology for producing relatively inexpensive materials of high strength from suitable homogeneous matrix bases [5]. There have been studies [6] on the effects of uncarbonized (fresh) and carbonized bone particles on the microstructure and properties of polypropylene composites. The results from their study revealed that the addition of carbonized bone particles reinforcement has superior properties than uncarbonized bone particles composite based materials with an increase in the compressive strength, hardness values, tensile strength and flexural strength.

Therefore, there is a need to develop a material that is both environmentally friendly and possessing the required mechanical properties for deployment in small scale horizontal axis wind turbine blade manufacture.

2.0 Methodology

2.1 *Material collection and pretreatment*

We obtained fresh bamboo from a local wood shop in Benin City. The culms were processed into segments by cutting the culms before each node, then into strips. The strips were sized to a width of range 1.5-2.5 cm to ensure the bamboo was semi flat and not curved. The lignin content of the bamboo strips were removed, by soaking it for approximately 72 hrs in 0.1 M sodium hydroxide solutions. This solution was chosen based on the research by some authors [7], who 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, dried in air and later heated at 110 ^{o}C for two hours in an oven until they were dry. Edwards Rolling Machine in the sheet metal lab in the Faculty of Engineering workshop in University of Benin was employed to press and splinter the bamboo. The fibres were obtained from these splintered bamboo manually. The diameter of the fibres ranged from 0.8 mm to 2.3 mm.

Cow bone which was carbonized in a crucible furnace at about 550 ^{o}C for 45 min, was obtained at an animal feed processing factory in Benin City. The carbonized cow bone was grounded using a vegetable grinding machine. A sieve analysis was done on the grounded carbonized bone using a sieve size of 212um to obtain a fine particle size distribution.

The 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 Nig. Ltd. They are located in Port-Harcourt, Rivers State Nigeria.

2.2 *Composite experimental sample formation and testing*

A mixture experimental design with three variables serving as mixture components was used in this study to plan the experiments for the production of the composite for the wind turbine blade. This design was chosen because it has been established by numerous researchers as the best experimental design for production formulation in the field of engineering [8], [9]. A three-variable simplex-lattice design was used. This design is typically used whenever the components form a simplex region (the factor ranges are equal) which 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, (Stat-ease, Inc. Minneapolis, USA). The Design Expert® software was also used 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. Equations 1 and 2 show the relationship between the components of the mixture which also represent factors of the design.

Table 1: Coded and actual levels of the factors for the composites for the wind turbine blade formulation

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 meaning that changes in the levels of one component affect those of the others [10]. The continuous bamboo fibre was measured out in weights using a digital electronic scale having accuracy of 0.01g into a pan in batches according to the experimental design matrix in. The carbonized bone particles were also respectively measured out using the digital scale. Lastly the epoxy resin with the corresponding mixing ratio of the hardener (catalyst) was also measured out by weight using the digital scale 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 removal of the cured specimens. A pressure of about 80kN was applied to compress the composite. It was allowed to cure at room temperature for 24 hours before extraction. They were then subjected to water absorption and thickness swelling tests.

2.3 *Selection of appropriate model*

The statistical models available in the Design Expert software library were assess for their suitability for modelling the responses (water absorption and thickness swelling). These models include linear, quadratic, special cubic and cubic models and their suitability was assessed on the basis of their respective coefficient of determination (R^2 value), p value, F value etc.

3.0 Results and Discussion

The results of the analysis show the summary of model fit and lack of fit test for all three responses for the composite specimens as shown in Table 2.

Table 2: Summary of model fit results (continuous bamboo fibre composites)

Water absorption						
Source	Standard deviation	R^2	Adjusted R^2	Predicted R^2	PRESS	Remark
Linear	1.0300	0.8254	0.7962	0.7385	19.0800	
Quadratic	0.5200	0.9664	0.9478	0.8685	9.6000	
Special Cubic	0.2900	0.9905	0.9834	0.9648	2.5700	Suggested
Cubic	0.3400	0.9907	0.9784	0.9602	2.9100	Aliased
Thickness swelling						
Source	Standard deviation	R^2	Adjusted R^2	Predicted R^2	PRESS	Remark
Linear	0.0290	0.4190	0.3222	0.0659	0.0160	
Quadratic	0.0210	0.7768	0.6529	0.1323	0.0150	
Special Cubic	3.384E-03	0.9947	0.9907	0.9792	3.559E-04	Suggested
Cubic	3.891E-03	0.9947	0.9876	0.9763	4.063E-04	Aliased

It was found that the data for the responses was best represented by the special cubic model. The choice of these models was made based on the fact that the selected models displayed the highest R^2 value, lowest standard deviation, and lowest PRESS as shown in Table 2. Even though the cubic model displayed a higher R^2 value compared to the special cubic model, it was however not chosen because it was designated as “aliased” and this could be an indication that the experimental runs might not be enough to independently estimate all the terms for the model. These results were corroborated by the results of the lack of fit test which are presented in Table 3. For a model to be chosen for further analysis, its lack of fit should not be significant ($p>0.05$). Thus, following from these observations, the special cubic model was adopted for predicting the water absorption and thickness swelling, for the composite for the wind turbine blade produced from the continuous bamboo fibre.

Table 3: Lack of fit test results (continuous bamboo fibre composites)

Water absorption						
Source	Sum of square	degree of freedom	Mean square	F-value	p-value	Remark
Linear	12.0700	7	1.7200	12.8200	0.0063	
Quadratic	1.7800	4	0.4400	3.3100	0.1110	
Special Cubic	0.0200	3	6.520E-03	0.0480	0.9843	Suggested
Cubic	3.357E-03	1	3.357E-03	0.0250	0.8806	Aliased
Pure Error	0.6700	5	0.1300			
Thickness swelling						
Source	Sum of square	degree of freedom	Mean square	F-value	p-value	Remark
Linear	9.870E-03	7	1.410E-03	78.2100	< 0.0001	
Quadratic	3.736E-03	4	9.340E-04	51.8000	0.0003	
Special Cubic	1.461E-06	3	4.870E-07	0.02700	0.9933	Suggested
Cubic	6.933E-07	1	6.933E-07	0.03800	0.8523	Aliased
Pure Error	9.014E-05	5	1.803E-05			

3.1 *Analysis of Statistical Models*

Statistical analysis of the special cubic model was fitted to the experimental data for water absorption and thickness swelling. The process of fitting 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 water absorption and thickness swelling 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.

$$\begin{aligned} \mathit{Water\ absorption} &= 89.65X_1 + 69.47X_2 + 447.55X_3 - 3.25X_1X_2 \\ &- 13.65X_1X_3 - 11.88X_2X_3 + 0.31X_1X_2X_3 \end{aligned} \tag{3}$$

$$\begin{aligned} \mathit{Thickness\ swelling} &= -3.86X_1 - 3.21X_2 - 23.64X_3 + 0.14X_1X_2 \\ &+ 0.64X_1X_3 + 0.58X_2X_3 - 0.014X_1X_2X_3 \end{aligned} \tag{4}$$

Equations 3 and 4 were used to predict water absorption and thickness swelling for the composite for the wind turbine blades and the results are shown in Tables 4 – 5. For the results obtained for the responses under investigation, it was observed that the model predicted results were very similar to the experimental results, indicating the validity of the statistical models developed to predict the responses.

Table 4: Experimental and RSM predicted results for water absorption

Run	Actual values of factors			Response (%)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.0000	45.0000	15.0000	9.6000	9.1000
2	45.0000	45.0000	10.0000	13.9000	13.7000
3	41.7000	46.7000	11.7000	11.7000	11.8000
4	40.8000	45.8000	13.3000	11.2000	11.1000
5	40.0000	50.0000	10.0000	6.6000	6.5000
6	43.3000	45.8000	10.8000	12.4000	12.4000
7	42.5000	47.5000	10.0000	8.9000	8.9000
8	42.5000	47.5000	10.0000	8.9000	8.9000
9	45.0000	45.0000	10.0000	13.6000	13.7000
10	42.5000	45.0000	12.5000	11.9000	11.9000
11	40.0000	47.5000	12.5000	9.8000	9.8000
12	40.0000	45.0000	15.0000	8.5000	9.1000
13	40.8000	48.3000	10.8000	9.2000	9.3000
14	42.5000	45.0000	12.5000	11.8000	11.9000
15	40.0000	50.0000	10.0000	6.6000	6.5000

Table 5: Experimental and RSM predicted results for thickness swelling of elasticity

Run	Actual values of factors			Response (%)	
	Bamboo (%)	Epoxy (%)	Bone powder (%)	Actual Experiment	RSM Predicted
1	40.0000	45.0000	15.0000	0.1500	0.1500
2	45.0000	45.0000	10.0000	0.1100	0.1100
3	41.7000	46.7000	11.7000	0.1300	0.1300
4	40.8000	45.8000	13.3000	0.1300	0.1300
5	40.0000	50.0000	10.0000	0.1100	0.1100
6	43.3000	45.8000	10.8000	0.0900	0.0900
7	42.5000	47.5000	10.0000	0.1300	0.1300
8	42.5000	47.5000	10.0000	0.0300	0.0300
9	45.0000	45.0000	10.0000	0.0900	0.0900
10	42.5000	45.0000	12.5000	0.0300	0.0300
11	40.0000	47.5000	12.5000	0.1200	0.1200
12	40.0000	45.0000	15.0000	0.0900	0.0900
13	40.8000	48.3000	10.8000	0.1200	0.1200
14	42.5000	45.0000	12.5000	0.0900	0.0900
15	40.0000	50.0000	10.0000	0.1300	0.1300

3.2 *Analysis of Variance of Models*

The statistical significance and fit of the models developed (Equations 3 to 4) was assessed by carrying out analysis of variance (ANOVA) and the results are shown in Tables 6 to 7. Tables 6 and 7 show the ANOVA results for water absorption and thickness swelling for the composite respectively. Model terms are considered to be significant if they have a p value less than 0.05. The models developed to predict the responses 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 ($p < 0.0001$).

Table 6: ANOVA results for model representing water absorption

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	72.2900	6	12.0500	139.2700	< 0.0001
Linear mixture	60.2400	2	30.1200	348.1300	< 0.0001
X_1X_2	2.0900	1	2.0900	24.1600	0.0012
X_1X_3	0.3200	1	0.3200	3.7000	0.0908
X_2X_3	3.4800	1	3.4800	40.1800	0.0002
$X_1X_2X_3$	1.7600	1	1.7600	20.3300	0.0020
Residual	0.6900	8	0.0870		
Lack of fit	0.0200	3	6.520E-	0.0480	0.9843
Pure error	0.6700	5	0.1300		
Cor total	72.9800	14			

Table 7: ANOVA results for model representing thickness swelling

Source	Sum of Squares	Degree of freedom	Mean square	F value	p value
Model	0.017	6	2.84E-03	248.2200	< 0.0001
Linear mixture	7.18E-03	2	3.59E-03	313.7200	< 0.0001
X_1X_2	5.66E-04	1	5.66E-04	49.4300	0.0001
X_1X_3	4.22E-03	1	4.22E-03	368.0800	< 0.0001
X_2X_3	6.82E-03	1	6.82E-03	595.5500	< 0.0001
$X_1X_2X_3$	3.73E-03	1	3.73E-03	326.1400	< 0.0001
Residual	9.16E-05	8	1.15E-05		
Lack of fit	1.46E-06	3	4.87E-07	0.02700	0.9933
Pure error	9.01E-05	5	1.80E-05		
Cor total	0.017	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 access the fit of the models for predicting the responses. The results are shown in Tables 8. The R^2 value was greater than 0.99 for the models considered. For a good fit, there should be an excellent agreement between the R^2 value and the adjusted R^2 value. The value of standard deviation was small compared to the mean of the observations and this shows 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 8: Goodness of fit statistics for response models

Parameter	Water absorption	Thickness swelling
R^2	0.9905	0.9947
Adjusted R^2	0.9834	0.9907
Mean	10.3100	0.1000
Standard deviation	0.2900	0.0034
CV	2.8500	3.2900
Adeq. Precision	35.8300	52.1600

3.3 *Model Diagnostics*

Diagnosis of the models developed to predict the responses for the composite for the wind turbine blades was also carried out to assess their accuracy and indeed adequacy for the intended purpose. The diagnostic tools used to achieve this included the normal probability plot, plot of residuals versus predicted response, Plot of residuals versus experimental run order and plot of cook's distance versus experimental run order.

Figures 1 and 2 shows the normal probability plots for the models representing water absorption and thickness swelling for the composite made from the continuous bamboo fibres. A look at the results obtained for the composite shows that the residuals of the models did follow a normal distribution as seen from the fact that the points clustered around the straight line.

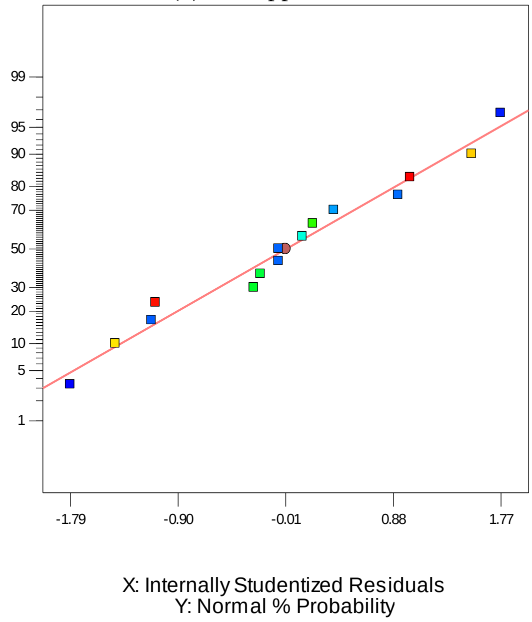

Figure 1: Normal probability plot for model representing water absorption

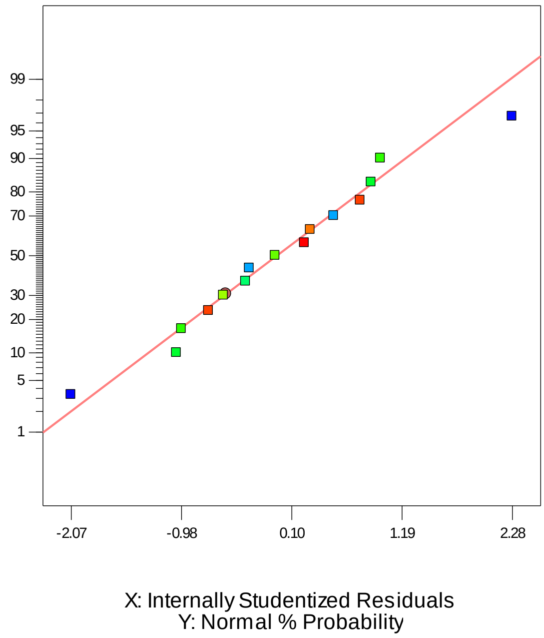

Figure 2: Normal probability plot for model representing modulus of elasticity

Figures 3 to 4 show the plots of the internally studentised residuals versus the predicted values for the models representing the water absorption and thickness swelling for the composite made from the continuous bamboo fibres. A look at the results obtained for the composite produced from the continuous shows that the responses exhibited a constant variance as seen from the random scatter of the points.

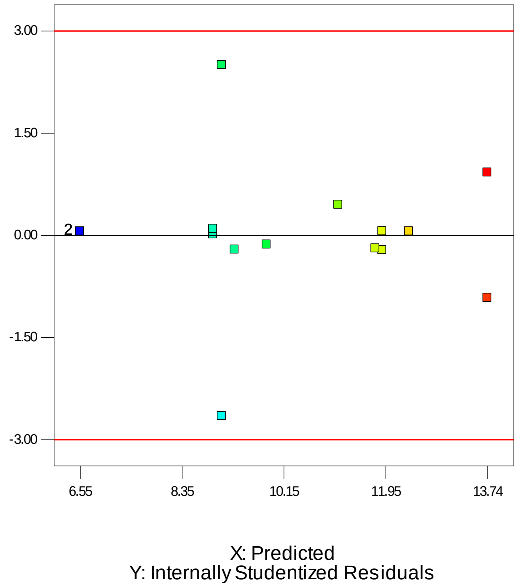

Figure 3: Plot of residuals versus predicted response for model representing water absorption (continuous bamboo fibre)

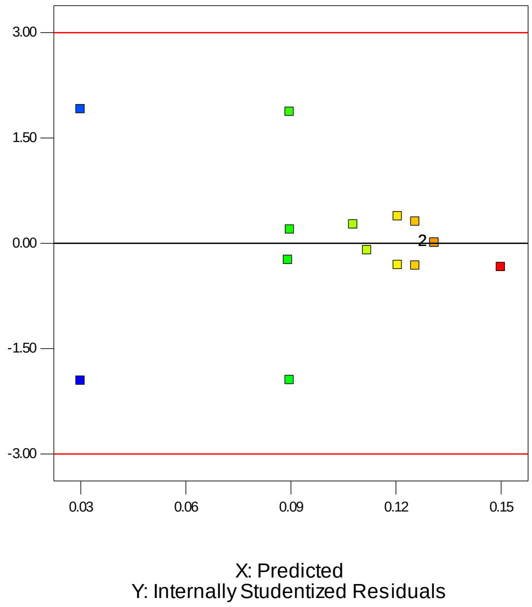

Figure 4: Plot of residuals versus predicted response for model representing thickness swelling (continuous bamboo fibre)

Figures 5 to 6 show the plots of the internally studentised residuals versus the experimental run order for the models representing the water absorption and thickness swelling for the composite made from the continuous bamboo fibres. A look at the results obtained shows that there were no hidden variables lurking in the background as seen from the random scatter of the points [11, [12].

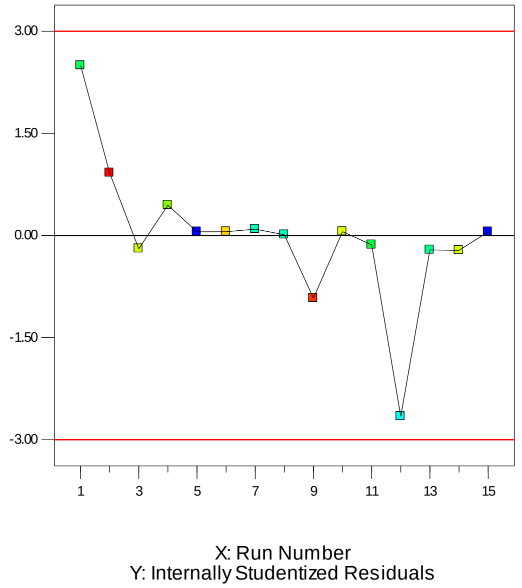

Figure 5: Plot of residuals versus experimental run order for model representing water absorption (continuous bamboo fibre)

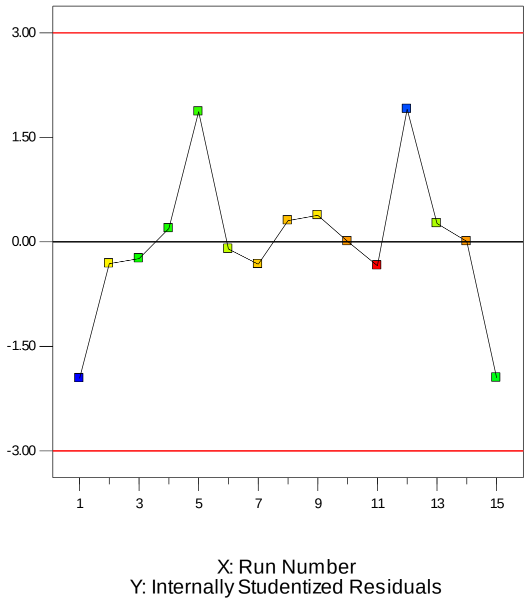

Figure 6: Plot of residuals versus experimental run order for model representing thickness swelling (continuous bamboo fibre)

Figures 7 to 8 show the plots of Cook's distance versus the experimental run order for the models representing the water absorption and thickness swelling for the composite made from the continuous bamboo fibres. A look at the results obtained for the composite produced from the continuous bamboo fibre show that all the values fell within the limits which is stipulated as 1. This indicates that the design did not contain possible outliers [13].

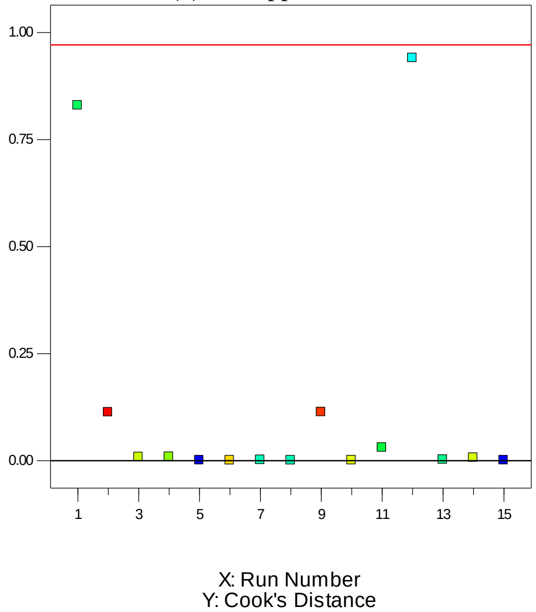

Figure 7: Plot of Cook's distance versus experimental run order for model representing water absorption (continuous bamboo fibre)

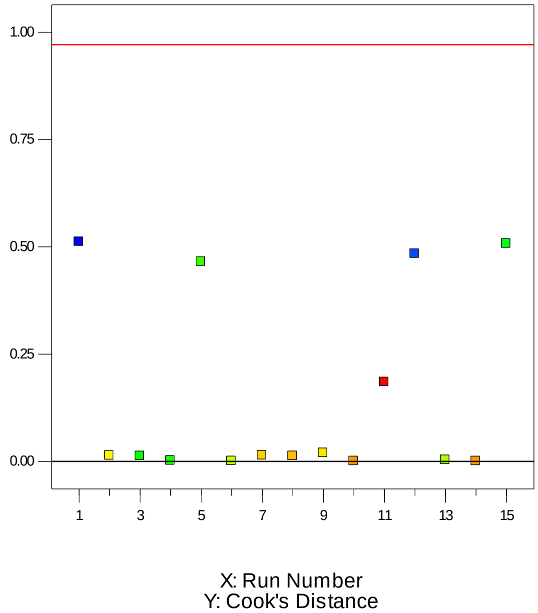

Figure 8: Plot of Cook's distance versus experimental run order for model representing thickness swelling (continuous bamboo fibre)

3.4 *Validation of RSM Model Results*

The model results were validated 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 9 to 10 show the parity plots for the models representing water absorption and thickness swelling for the composite. As shown in Figure 9 and 10, there was significant fit between the experimental results and the model predictions because all the points clustered around the 45^o diagonal line.

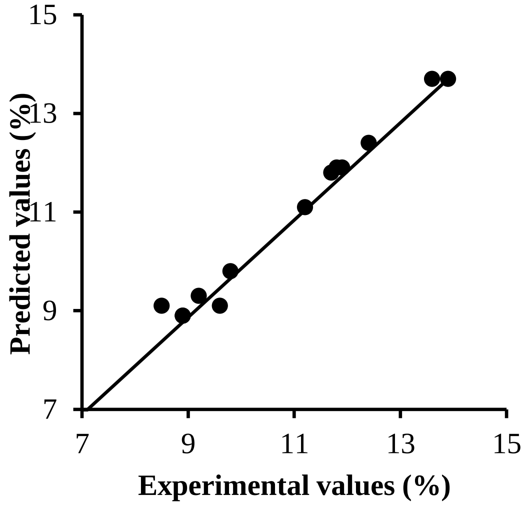

Figure 9: Parity plot for model representing water absorption (continuous bamboo fibre)

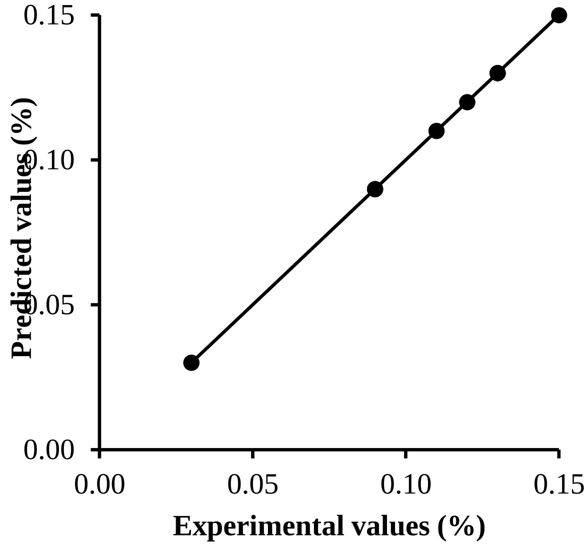

Figure 10: Parity plot for model representing thickness swelling (continuous bamboo fibre)

3.5 *Optimisation of Input Factors and Responses*

The responses and the corresponding input factors were optimised via numerical optimisation. In order to achieve this, the input factors were fixed in the range shown in the table of constraints (Table 9). For the responses, water absorption and thickness swelling were minimized. This is because they needed to be minimized 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 9: Table of constraints for numerical optimisation

Variables	Symbols	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
	Input variables/factors						
Bamboo (%)	X_1	is in range	40	45	1	1	3
Epoxy (%)	X_2	is in range	45	50	1	1	3
Bone powder (%)	X_3	is in range	10	15	1	1	3
	Output variables/responses						
Water absorption (%)	Y_4	minimize	6.56	13.94	1	1	3
Thickness swelling (%)	Y_3	minimize	0.025	0.15	1	1	3

The optimisation results are shown Table 10. This optimal point was chosen with the highest desirability of 0.968. The optimum values of water absorption and thickness swelling for the composite for the turbine blades produced from the continuous bamboo fibre were obtained as 6.55% and 0.09% respectively. The corresponding values of bamboo, epoxy and bone powder were 40%, 50% and 10% respectively.

Table 10: Optimisation results (continuous bamboo fibre composite)

Variable	Value
Bamboo	40%
Epoxy	50%
Bone powder	10%
Minimum water absorption	6.55%
Minimum thickness swelling	0.090%
Desirability	0.968

4.0 Conclusion

The potential use of bamboo fibre and carbonized bone particles for production of composite material for small scale horizontal axis wind turbine blades using epoxy as binder has been presented in this paper. Results obtained from this research suggests that small scale horizontal axis wind turbine blades can be produced from continuous bamboo fibre with carbonized cow bone using epoxy as a binder. The optimum values of water absorption and thickness swelling for the composite produced from the continuous bamboo fibre were obtained as 6.55% and 0.09% respectively with corresponding values of bamboo, epoxy and bone powder of 40%, 50% and 10% respectively. 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 physical properties of the wind turbine blades produced from the continuous bamboo fibres.

References

[1] Manwell JF, McGowan JG, Rogers AL. (2010); Wind Energy Explained: Theory, Design and Application, 2nd Edition; New York: John Wiley & Sons.
[2] Meng F, McKechnie J, Turner TA, Pickering SJ. (2017). Energy and environmental assessment and reuse of fluidised bed recycled carbon fibres. Composites, Part A.;100:206-14.
[3] CES EDU Pack 2014. Cambridge, United Kingdom: Granta Design Limited, 2014

[4] 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, vol. 2, no. 5, pp. 314-319
[5] Anagbo P.E. and Oguocha P.E.(2009): The Structure and Mechanical Properties of Palm Timber as a Fibre Composite. Journal of Engineering Materials and Technology. Vol. 111/21
[6] Asuke F, Aigbodion VS, Adulwahab M, Fayomi OSI, Popoola API, Nwoyi CI, Garba B. (2012); Effects of bone particle on the properties and microstructure of polypropylene/bone ash particulate composites; Elsivier, Results in Physics 2, pp135 – 141
[7] Deshpande A., Rao M. B. and Rao C. L., (2000). Extraction of bamboo fibers and their use as reinforcement in polymeric composites'. Journal of Applied Polymer Science, vol. 76, no. 1, pp. 83-92.
[8] Zen, M., Izzati, N., Abd Gani, S. S., Shamsudin, R. and Fard Masoumi, H. R. (2015). The use of D-optimal mixture design in optimizing development of okara tablet formulation as a dietary supplement. *The Scientific World Journal*, *2015*.
[9] Abutu, J., Lawal, S.A., Ndaiman, M.B., Lafia-Araga, R.A., Adedipe, O. and Choudhury, I.A. (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, pp. 787-797.
[10] Hirata, M., Takayama, K. and Nagai, T. (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), pp. 741-746.
[11] Box, G. E. P., Hunter, W. G. and Hunter, J. S. (1978). Statistics for experimenters. An introduction to design, data analysis, and model building. *Wiley Series in Probability and Mathematical Statistics (USA).*
[12] Box, G. E., Hunter, J. S. and Hunter, W. G. (2005). *Statistics for experimenters: design, innovation, and discovery* (Vol. 2). New York: Wiley-Interscience.
[13] Myers, R. H., Khuri, A. I., Carter Jr, W. H. (1989). Response surface methodology: 1966–1988. *Technometrics*, 31, pp. 137–57.