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Estimating the Tensile Strength Properties of Plantain Fiber Ash Particulate and Silumin using Box-Behnken Design.

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ABSTRACT

This study utilizes response surface methodology (RSM) to estimate the engineering parameters of PFAP/silumin composites. The tensile strengths of the developed composites were evaluated using a Box-Behnken design (BBD), considering factors such as weight fraction, particle size, soaking time, plantain fiber ash particulate concentration, and silumin. The results indicate that the weight fraction of fibers has the greatest influence on tensile strength, with interaction effects being more significant than linear and quadratic effects. The predicted tensile strengths of the PFAP/silumin composites, obtained through RSM, closely matched the experimental values, validating the reliability of the software. The range of predicted tensile strengths was found to be 44.66 MPa to 64.05 MPa, while the obtained experimental values ranged from 40.31 MPa to 75.98 MPa. This study demonstrates the effectiveness of the BBD method in quickly obtaining optimum values of tensile strength for PFAP/silumin composites. Furthermore, this research highlights the promising potential of utilizing waste materials in the automotive industry, particularly in East Africa.

Keywords: Response surface methodology (RSM), Natural fibers, Hybrid composites, Tensile strength Agro-waste, Cellulose fiber, Box-Behnken design (BBD), Automotive industry.

INTRODUCTION

Fibers with extraordinary characteristics have been principally answerable for the innovative developments in composite materials advancement as unparalleled to orthodox materials. The usage of Fiber composites has increased over the years as a result of their elevated strength-to-weight ratio, which is key to countless engineering applications [1, 2, 3]. Over the years, attempts have been made to use natural Fibers in place of synthetic reinforcements of composite materials due to their desirable properties chief amongst them are biodegradability and good mechanical properties [4]; it is worthy of note that in using agro-waste, the cost is reduced to the barest minimum and the environment is sanitized.

Natural/agricultural Fibers are lavishly accessible and ecologically gentle, an advantageous contrast to conventional/synthetic Fibers. when Fiber and resin are Concatenated, a composite material that is better than the two original materials are formed and a hybrid is therefore achieved by combining two different items together so that the end result contains qualities relating to both of them. This work will hybridize the structures of cellulose Fiber materials and aluminium-silicon alloy which is within the Silumin compound the optimum ratio of the attendant composite mechanical properties, in this case, the tensile strength reached will cater for the needs of a motorbike lever application.

Hybrid composites have been proven to come with many related advantages, the possibility of combining the benefits of Fiber on aluminum metal matrix while simultaneously reducing their weaknesses is at the zenith of this work. The cost-cutting solution for customers involves combining silumin with environmentally friendly cellulose fiber. This innovative approach reduces the overall expense while ensuring that end users can still reap its benefits [5]. The concatenation of cellulose Fiber into a composite solution of silumin would undeniably enhance the robustness and create a more durable material, with a favourable angle to its lightweight, also applying multi-linear regression will provide an ideal option for applications while evaluating the effect of plantain Fiber and how essential consideration it is to the design of an automobile spare parts.

This development of plantain Fiber particulate composite will bring into bear both the mechanical needs of the product, in this case, the tensile strength and the economical limits with consideration on how pocket-friendly the end product will be to the end users.

The gain of unifying more materials from different resource classifications together to form a product means that we can enjoy the benefits of each material, but beyond that, this combination of different Fibers will improve as well as create a whole new set of qualities that cannot be achieved using just one type of Fiber or one specific material [6, 7]. This study is to evaluate the characteristic effect of plantain Fiber particulates on the tensile strength of Silumin in automotive applications.

RESEARCH QUESTION AND SHORT NOTE ON DATA.

What is the effect of plantain Fiber particulate and aluminum Silicon on tensile strength properties?

The research objectives were achieved and answers to the research questions were obtained using experimental data as obtained. After assessment of the data obtained it was ascertained that statistical analysis was feasible to estimate the influence of incorporated plantain Fiber particulate and aluminium Silicon on tensile strength properties.

Design of experiments Tensile strength was optimized using a standard response surface methodology design in the design of experiments called Box-Behnken design (BBD). BBD is a spherical and revolving design that consists of a central point and middle points of the edges [8]. BBD is more efficient compare to central composite design, Doehlert design, and 3-level factorial design because BBD is rotatable and does not contain combinations for which all factors are concurrently at their highest or lowest levels [9] Weight fraction, Particle size, soaking time, Silumin, and plantain Fiber ash particulate (PFAP) were employed as the five input factors in this study. The numeric factors were explained in ranges of 2.5–10 wt.%, 50–90 µm, 5–15 mins, 85-95wt.%, and 5-15wt.%, respectively, as shown in Table 1.Using the Design-Expert software (version 13, Stat-Ease Inc., MN, USA), runs were planned in a randomized order so as to minimize the effects of the uncontrolled factors. The runs were obtained with five numeric factors (k1) and five replicated central points (cp). This produced 45 experimental trials, five of which were replicated at the central points (0,0,0) as shown in Table 2. A key assumption made is that all numeric factors are continuous, measurable and controllable by experiments. The influence of the three numeric factors on the tensile strength of PFAP/Silumin composites can be modelled using a second-order polynomial shown in Eq1

$$Y = \beta_0 + \sum_{j=1}^{K} \beta_j X_i + \sum\sum \beta_{ij} X_i X_j \sum_{i=0}^{K} \beta_{jj} X_i^2 + e \quad (1).$$

where Y is the predicted response value (tensile strength), β_0 is the model constant, β_j is the linear coefficient β_{ij} is the interaction coefficient, $\beta_{jj}$is the quadratic coefficients, x is the independent factors in coded values, k is the number of factors studied and optimized in the experiment, and e is the experimental error.

DESCRIPTIVE STATISTICS (APPROPRIATE GRAPHS AND TABLES)

Table 1: Actual and coded factors for the Box-Behnken design

Factors	Type of factors	Code	Experimental Value		
			Lower (-1)	**Centre (0)**	**Higher (+1)**
Weight Fraction %	Numeric	A	2.50	6.25	10.00
Particle Size µm	Numeric	B	50.00	70.00	90.00
Time (Mins)	Numeric	C	5.00	10.00	15.00
Silumin wt.%	Numeric	D	85.00	90.00	95.00
PFAP wt.%	Numeric	E	5.00	10.00	15.00

Source: Barah, (2022).

Table 2 BBD and the experimental results

Run	Factors					Tensile Strength
	A: Weight Fraction %	B: Particle size um	C: Time Mins	D: Silumin %	E: PFAP %	
1	2.5	70	10	85	10	40.31
2	10	70	15	90	10	40.56
3	6.25	50	10	90	15	41.21
4	6.25	90	10	90	5	42.65
5	6.25	70	5	85	10	42
6	6.25	50	15	90	10	41
7	2.5	70	5	90	10	43.65
8	2.5	70	10	90	15	44.12
9	6.25	90	5	90	10	43.13
10	10	70	10	90	15	44.98
11	6.25	70	10	90	10	45.13
12	6.25	70	15	95	10	46.12
13	6.25	70	10	90	10	47
14	6.25	70	15	90	5	47.86
15	6.25	90	10	85	10	48.23
16	6.25	70	5	95	10	48.67
17	2.5	70	15	90	10	49
18	6.25	70	15	85	10	49.12
19	6.25	70	10	95	5	49.38
20	6.25	70	10	90	10	49.67
21	2.5	70	10	95	10	49.78
22	10	70	5	90	10	49.98
23	6.25	70	5	90	15	50.11
24	2.5	70	10	90	5	50.68
25	2.5	90	10	90	10	50.99
26	6.25	70	5	90	5	51.79
27	2.5	50	10	90	10	52.11
28	6.25	70	10	85	5	52.76

29	6.25	90	15	90	10	52.01
30	10	50	10	90	10	52.09
31	6.25	50	10	95	10	53.32
32	6.25	70	10	90	10	53.58
33	6.25	70	10	90	10	53.97
34	6.25	50	5	90	10	54.05
35	6.25	90	10	90	15	54.12
36	10	70	10	90	5	54.35
37	6.25	70	15	90	15	53.89
38	6.25	50	10	90	5	54.97
39	6.25	50	10	85	10	53.89
40	6.25	70	10	95	15	55.13
41	6.25	70	10	85	15	55.98
42	6.25	90	10	95	10	60
43	10	70	10	95	10	63.58
44	10	90	10	90	10	66.78
45	10	70	10	85	10	75.98

Source: Barah, (2022).

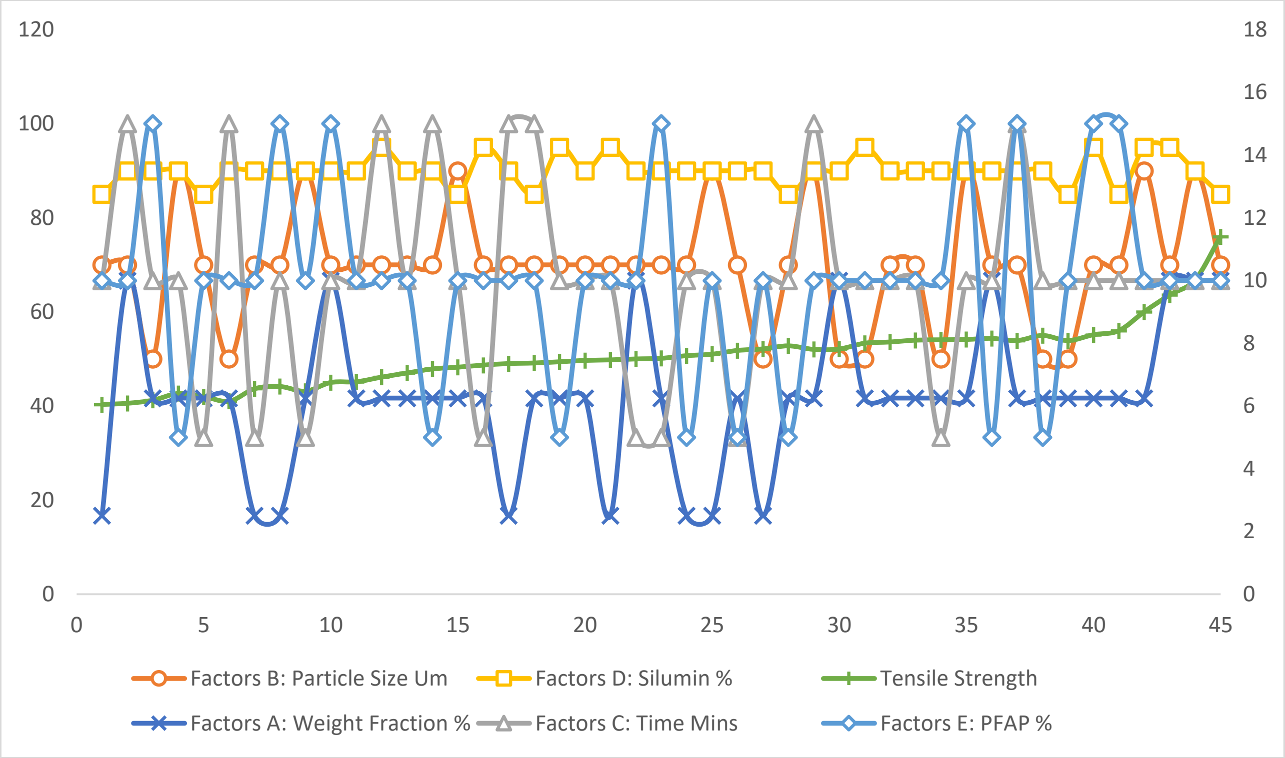

Fig 1. Graphical representation of experimental data

The graphical results showed good agreement between tensile strength and other parameters. The tensile strengths increased from 40.31 MPa lower range and 75.98 MPa higher with weight fraction showing its importance to navigating the design space for PFAP/silumin composites and shows a useful way to identify the relative impact of the factor by comparing other factors which were very close to the obtained experimental values range respectively.

RESULTS AND DISCUSSION

Model Fitting for Tensile Strength.

Box-Behnken design (BBD) was employed to create models between the numerical factors and the tensile strengths of the developed PFAP/Silumin composites based on their factors. Table 2 shows the experimental design, together with corresponding experimental values for the response (tensile strength) for PFAP/Silumin composites.

Runs 3, 5, 9, 11, 13, 15, 17, 19, 21, 23, 25 etc at the center point were employed to determine the experimental error and the reproducibility of the data. In order to obtain the best fit for each response set, the respective sequential model sum of squares values was considered. From each of these, the highest-order polynomial, where the additional terms are significant, and the model is not aliased, was chosen. By applying multiple regression analysis to the response, four quadratic models were found to be the best fit of the response in each set. Analysis of variance (ANOVA) was used to ascertain significant interaction between factors and tensile strengths based on their p values. P values less than 0.05 were considered significant while p values greater than 0.10 were non-significant and therefore removed and the final expressions of the best-fitting models were deduced. For the statistical significance of a model at a 95% confidence interval, the alpha value is 0.05 (5%). As such, for a given model to be satisfactory for use in estimating relationships between inputs and outputs, the probability value for a given factor must be very minimal (10%) are considered to be insignificant because above 0.1, the confidence interval is 90%, which cannot effectively justify model relationships [10].

Analysis of Variance for Model Statistical Significance

The tensile strength results for the developed PFAP/silumin composites were investigated using analysis of variance (ANOVA) in order to determine statistically significant factors in the fitted models (see Tables 3). Additionally, the models' lack-of-fits and the statistical significance of respective model coefficients were obtained.

The Model F-value of 5.80 implies the model is significant, corresponding to the reduced quadratic models for tensile strength of PFAP/silumin composites. There is only a 0.04% chance that an F-value this large could occur due to noise.

P-values < 0.0500 indicate model terms are significant. Values > 0.1000 indicate the model terms are not significant, as presented in Table 3 of ANOVA results for response surface-reduced quadratic model of tensile strength of PFAP/ silumin composites. The tensile strength models were statistically inspected using lack-of-ft values. Lack-of-fts of the models' p values corresponding to the reduced quadratic models for tensile strength of PFAP/silumin composites.

The Lack of Fit F-value of 2.15 implies the lack of fit is not significant relative to the pure error. There is a 23.86% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good as the model needs to fit.

Table 3. ANOVA results for response surface-reduced quadratic model of tensile strength of PFAP/ silumin composites.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	904.92	5	180.98	5.80	0.0004	significant
A-Weight Fraction	286.12	1	286.12	9.17	0.0043	
AD	119.57	1	119.57	3.83	0.0574	
BC	120.23	1	120.23	3.85	0.0568	
BE	159.14	1	159.14	5.10	0.0296	
C^2	219.86	1	219.86	7.05	0.0114	
Residual	1216.69	39	31.20			
Lack of Fit	1155.37	35	33.01	2.15	0.2386	not significant
Pure Error	61.32	4	15.33			
Cor Total	2121.61	44		**R^2**	0.1349	
Std. Dev.	6.53			**Adjusted R^2**	0.1147	
Mean	50.66			**Predicted R^2**	0.0159	
				Adeq Precision	6.1403	

Furthermore, the Predicted R^2 of 0.0159 is in reasonable agreement with the Adjusted R^2 of 0.1147; which shows a difference < 0.2.Adequate Precision measures the signal-to-noise ratio. A ratio > 4 is desirable. A ratio value of 6.140 recorded in models for tensile strength of PFAP/silumin composites indicates an adequate signal and preciseness of the estimate.

CONCLUSION

This study estimated the engineering parameters of PFAP/silumin composites through response surface methodology (RSM). The effect of weight fraction, particle size, soaking time, plantain Fiber ash particulate concentration, and silumin on tensile strengths of the developed composites was evaluated using Box-Behnken design (BBD). Fiber weight fraction was found to exhibit the greatest influence on the tensile strength of the developed PFAP/silumin composites. The interaction effect was found to more predominant than the linear and quadratic effects for tensile strength.

The results showed good agreement between tensile strength experimental and predicted values for R2, predicted R2, and adjusted R2. The predicted tensile strengths were within the range of 44.66 MPa to 64.05MPa for PFAP/silumin composites, which were very close to the obtained experimental values of 40.31 MPa lower range and 75.98 MPa higher range respectively.

The software's reliability was therefore validated since the errors in tensile strengths between the actual and predicted optimized composites were relatively low. The present work has shown that the BBD method is an economical way of gathering optimum values of tensile strength of PFAP/silumin composites in the shortest period of time. This type of study is extremely promising because it is the first step to building a synergy between waste materials and their utilization in automotive industry especially in east Africa.

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