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Analysis of Tensile Strength of Bamboo Reinforced Polyester Composite

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Nigerian grown species of bamboo called bambusa vulgaris which was examined to analyze its tensile strength. The fibre characteristics and tensile strength were investigated at three different fibre lengths and fibre loadings i.e 10, 30,50mm and 10, 30, 50 wt.% respectively. Fibre length was varied in each fibre loading from 10mm to 50mm, the tensile strength of the three different series of composites varies from 28.32Mpa to 38.10Mpa. The predicted optimum tensile strength is 44.51Mpa. Generated results have been validated by the confirmation of experiments at three replications, when the control factors were set at 30mm and 30% wt or (level 2, level 2), using Taguchi's design of experiments approach. It was observed from the analysis of variance of the samples that there is a variation in the increase of tensile strength of the bamboo that are dependent on the fibre length and fibre loading used. The percentage contributions of parameter according to the pooled ANOVA for signal-to- Noise ratio showed that the fibre length (36.61%) in controlling variation and mean strength is significantly smaller than the fibre loading (44.15%).

Keywords: *Bamboo, Bambusa vulgaris, Tensile strength, Taguchi's experimental design, fibre length, fibre loading*

1. Introduction.

Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. The different systems are combined judiciously to achieve a system with more useful structural or functional properties no attainable by any of the constituent alone [Shaw et al. 2010]. The strength of bamboo is greater than many timber products, but lesser than the tensile strength of steel. Bamboo is readily available and is emerging as low cost, light weight, and environmentally friendly. Tensile test is the most basic type of mechanical test. It is not difficult to perform and it is not expensive compared to other mechanical tests

2. Materials and Methods

General purpose grade unsaturated orthophathalic polyester resin (RGP 67G), was obtained from Center for Composite Research and Development, JuNeng Nigeria Limited, Nsukka. The bamboo fibres were extracted mechanically from the young stem of bamboo plant, shredded and air-dried for about a week until constant mass. The dried fibres were chopped into 10mm, 30mm and 50mm fibre lengths and 10%, 30% and 50% weight fraction used as reinforcement materials in the composite preparation, by hand lay-up method using a three-piece stainless steel mould having dimensions 200x 150x30mm. Methyl ethyl ketone peroxide (MEKP) and cobalt napthenate of commercial grade were used as the catalyst and accelerator respectively for resin curing.

2.1. Volume Fraction and Density of Fibre

The density and volume fraction of fibres used for the sample preparation was calculated by a method which enables the rule of mixtures analysis of measured composite properties. The picnometric procedure was adopted for measuring the density pc of the composite of mass Mc at a given mass fraction of resin Mr. Volume fraction Vr of resin was calculated using the following relationships:

$$V_r = \frac{M_r \rho_c}{M_c \rho_r} \quad (1)$$

Where ρ_r is the resin density then, the volume fraction V_f and density ρ_f of fibre where calculated using the following equations: [1]

$$V_f + V_r = 1 \quad (2)$$

$$\rho_r = \frac{M_f \rho_c}{M_c V_f} \quad (3)$$

The density of fibre was also measured using archimedes principle. Both results produced similar results and an average value of 960kg/m^3 was obtained as fibre density.

Table 1. Mass of Fibre and Volume of Resin used for Samples Preparation

Fibre Volume Fraction (%)	10.70	31.70	52.00
Fibre Weight Fraction (%)	10.00	30	50.00
Mass of Fibre (g)	86.40	259.00	432.00

Volume of the Resin (cm^3)	804.00	615.00	432.00
Mass of Resin (g)	843.00	656.00	468.00

Source: Field experiment

2.2. The Taguchi Approach to Robust Parameter Design

In the early 1980s, Genichi Taguchi, a Japanese engineer, introduced his approach to using experimental design for:

- designing products or processes so that they are robust to environmental conditions;
- designing/developing products so that they are robust to component variation; and minimizing variation around a target value.

In parameter design, there are two types of factors that affect a product's functional characteristic: control factors and noise factors, at this stage of design, the specific values for the system parameters are determined. Usually, the objective is to specify these nominal parameter values such that the variability transmitted from uncontrollable or noise variables is minimized.

3. Selection of an Orthogonal Array

In selecting an appropriate OA, the pre-requisites are: (a) selection of process parameters and interactions to be evaluated and (b) selection of number of levels for the selected parameters [2].

The process parameters were already decided and are given in Table 1. It was also decided to study each selected parameter at three levels. With two parameters each at three levels, the total degree of freedom (DOF) required is 4 [= 2(3- 1)]. As per Taguchi's DOE approach, the total DOF of t selected OA must be greater than or equal to the total DOF required for the experiment. So, an L_9 (2^3) orthogonal array was selected for the present work.

4.1 Experimental-Analysis snd Discussion

The tensile tests were performed according to ASTM D638 standard using Universal Testing Machine at a crosshead speed of 5 mm/min. Specimens for each sample were tested and the tensile strength and tensile modulus were expressed as:

$$\text{Tensile strength (MPa)} = P/bh \quad (4)$$

Where; P = Pulling force (N), b =Specimen width (m), and h = Specimen thickness (m)

Robust design is an "engineering methodology for improving productivity during research and development so that high-quality products can be produced quickly and at low cost" [3]. The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult or too expensive to control). Nine trial conditions with three repetitions are used in this work. The selected quality characteristic, tensile strength, is 'higher the better' (HB) type, the S/N (signal to noise) ratio, for 'higher the better' type of response was used as given in the following equation:

$$(S/N)_{HB} = -10 log \left[\frac{1}{n}\left(\frac{1}{y_1^2} + \frac{1}{y_2^2} + \cdots \frac{1}{y_n^2}\right)\right] \quad (5)$$

Where y_1, y_2 ......y_n are the responses of quality characteristic for a trial condition repeated n times.

The S/N ratios were computed using equation 5 for each of the 9 trials and mean response for each factor at the three levels is presented in Table 3. [4] Along with the raw data. The average value of the tensile strength for each parameter at levels 1, 2 and 3 are plotted in figure 2. The average values of S/N ratios of various parameters at levels 1, 2 and 3 are plotted in figure 1.

The summary of the responses and ranking for tensile strength of bamboo fibre reinforced Polyester composites on the bases of the larger the better quality, for Signal to Noise Ratio, and mean of means lead to the conclusion that factor combination of A_1 B_1 gives the minimum strength while A_2 B_2 gives the maximum strength as shown in Figure 1 and Figure 2. It is found that as far as the tensile strength is concerned; B and A have significant effect on the composite. The range (Delta) is the difference between higher and lower response. The larger the (Delta) value for a parameter, the larger the effect the variable has on the tensile strength of the composites. This is because the same change in signal causes a larger effect on the output variable being measured. It is clear from table 4 and 5 that the fibre weight fraction is ranked 1st and fibre length 2nd.In order to confirm Taguchi's design of experiment and to study the significance of the parameters in affecting the quality characteristic of the mechanical properties analysis of variance (ANOVA) was performed. The pooled ANOVA of the raw data (tensile strength) is given in Table 6. The S/N ANOVA (pooled version) is given in Table 7. It is clear from ANOVAs that the parameters A and B (fibre length and fibre weight) significantly affect both the mean value as well as the variation of the tensile strength because these are significant in both the ANOVAs. The percent contributions of parameters as quantified under column P of Table 6 and Table 7 reveal that the fibre weight (B) in controlling the mean and variation is significantly larger than the fibre length (A). [5] Software MINITAB 16 was used to analyze the Taguchi design of experiment, and the linear regression equations.

Table 2. Experimental Outlay and Variable Sets for Mechanical Properties

S/N	Processing Factors	Factor's designation	Level		
			1	2	3
1	Fibre Length (mm)	A	10	30	50
2	Fibre Weight Fraction (%)	B	10	30	50

Source: Field experiment

Table 3. Experimental Design Matrix for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites.

Expert. Run	Fibre Length (mm)	Fibre Weight. Fraction (%)	Measure Response (Mpa)			Mean Tensile Response	SN Ratio (dB)
			Trial 1	Trial 2	Trial 3		
1	10	10	28	27.83	29.13	28.32	29.03655249
2	10	30	41.40	39.50	39.70	40.20	30.07877224
3	10	50	37.80	37.51	35.69	37.00	31.34769209
4	30	10	38.80	38.40	38.30	38.50	31.70880621
5	30	30	45.20	44.92	44.88	45.00	33.06412024
6	30	50	41.60	40.32	41.08	41.00	32.25352731
7	50	10	35.80	35.00	34.20	35.00	30.87682137
8	50	30	38.33	37.00	36.63	37.32	31.43392063
9	50	50	39.20	38.20	36.90	38.10	31.61049495
Total			346.13	338.68	336.51		

$\bar{T}_{TS}$ = Overall mean of TS $= \frac{346.13+338.68+336.51}{3\times 9} = 37.83 Mpa$

TS= Tensile strength.

Table 4. Summary of the Responses and Ranking for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites on the Bases of the Larger the Better Quality. (Signal to Noise Ratio)

Responses	Signal to Noise Ratio	
Levels	A: Fibre Length (mm)	B: Weight Fraction (%)
1	30.83	30.54
2	32.34	32.20
3	31.31	31.75
Delta	1.51	1.65
Rank	2	1

Source: Field experiment

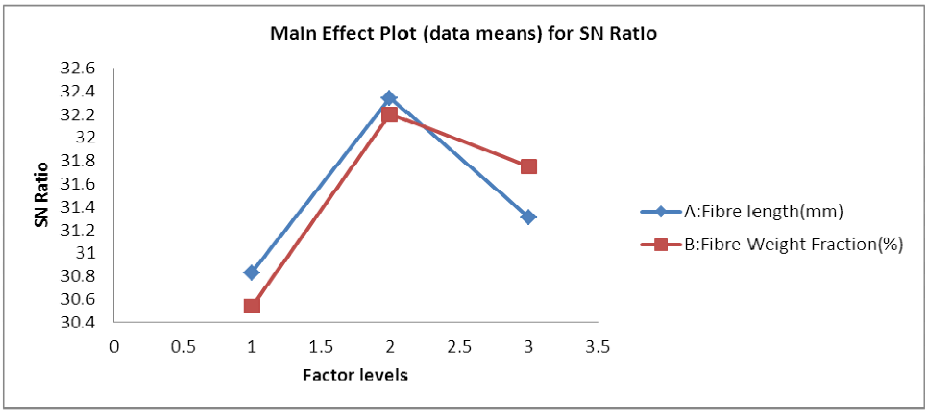

Figure 1. Graph of Signal-to-Noise Ratio against Factor Levels (1,2and3) for Tensile Strength

Table 5. Summary of the Responses and Ranking for Tensile Strength of Bamboo Fibre Reinforced Polyester Composites on the Bases of the Larger the Better Quality. (Mean of Means)

Responses	Means	
Levels	A:FibreLength (mm)	B: Weight Fraction (%)
1	35.17	33.94
2	41.50	40.84
3	36.81	38.70
Delta	6.33	6.90
Rank	2	1

Source: Field experiment

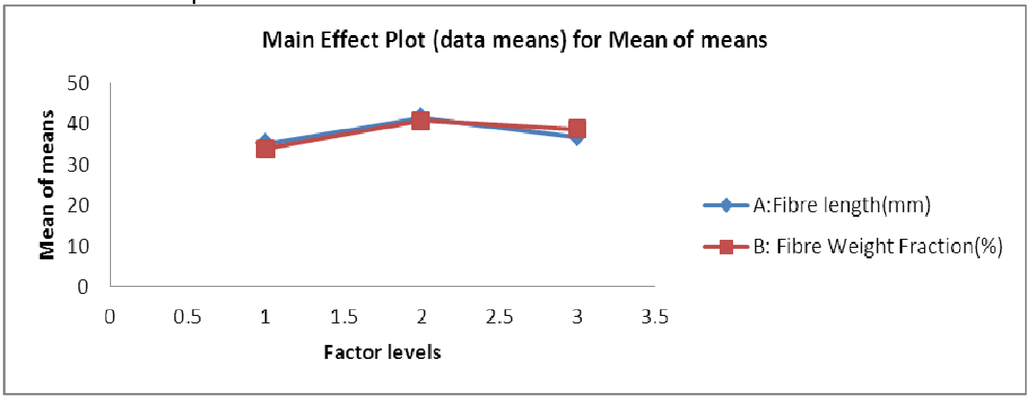

Figure 2. Graph of Mean of Means against Factor Levels (1, 2 and 3) for Tensile Strength

Regression Analysis: Tensile Strength versus A: Fibre Length, B: Fibre weight

The regression equation is
Tensile strength = 33.0 + 0.0408 A + 0.119 B

Predictor	Coef	SE Coef	T	P
Constant	33.032	4.303	7.68	0.000
A	0.04083	0.09465	0.43	0.681
B	0.11900	0.09465	1.26	0.255

S = 4.63692   R-Sq = 22.7%   R-Sq(adj) = 0.0%

4.2 Estimating Optimal Tensile Strength

The optimal tensile strength (μTS) is predicted at the selected optimal setting of process parameters. The significant parameters with optimal levels are already selected as: A2B2. The interaction effects are not being considered in estimating mean and confidence interval around the estimated mean due to poor additivity between parameters and interactions. The estimated mean of the response characteristic can be computed as [4]:

$$\mu TS = \bar{A}_2 + \bar{B}_2 - \bar{T}_{Ts} \quad (6)$$

Where:

$\bar{T}_{Ts}$ = overall mean of Tensile strength = 37.83Mpa From (Table 3)

$\bar{A}_2$ = mean value of Tensile strength with parameter at optimum

level : $\bar{A}_2$= 41.50 From (Table 5)

$\bar{B}_2$ = mean value of Tensile strength with parameter at optimum

level : $\bar{B}_2$= 40.84 From (Table 5)

Hence;

μTS= 41.50 + 40.84 – 37.83 = 44.51Mpa

A confidence interval for the predicted mean on a confirmation run can be calculated using the following equation [3]:

$$C.I = \sqrt{F_{\alpha}(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad (7)$$

Where; $F_{\alpha}(1, f_e) = F\ ratio\ required\ for\ \alpha$; α=risk; f_e= error DOF;

V_e= error variance

n_{eff} = effective number of replications.

$$n_{eff} = \frac{N}{1+[Total\ DOF\ associated\ in\ the\ estimate\ of\ mean]} \quad (8)$$

R = number of repetitions for confirmation experiment; N = Total number of experiments.

Using the values;

Ve = 6.855, and fe = 12 From (Table 6)

Total DOF associated with the mean (μTS) = 2x2= 4

Total trials = 9; N = 3x9 = 27

α = 0.05; $F_{0.05}$ (1, 12) = 4.75 (tabulated value, from F- tables)

$n_{eff} = \frac{27}{1+4}$ = 5.4

$$C.I = \sqrt{4.75 \times 6.855\left[\frac{1}{5.4} + \frac{1}{3}\right]} = \pm 4.109$$

The calculated C.I. is: C.I = ±4.109

The predicted optimal Tensile strength is: μTS = 44.51Mpa

The 95% confidence interval of the predicted optimal tensile strength is:

$(\mu TS - C.I) < \mu TS(Mpa) < (\mu TS + C.I)$.

40.401 < μTS (Mpa) < 48.619

4.3. Experimental Validation

The last stage of Taguchi's robust technique is the confirmation of the experiment. Three confirmation experiments were conducted at the optimal setting of the process parameters. The average value of tensile strength was found to be 44.54Mpa. This result was within the confidence interval (95 %) of the predicted optimal tensile strength.

Table 6. Pooled ANOVA (Raw Data: Tensile Strength) for mean

source	DOF	SS	V	F ratio	P(%)
A	2	64.72	32.36	1.90	38.75
B	2	74.86	37.43	2.44	44.83
Total	8	167	-	-	100
e(pooled)	4	27.42	**6.855**		16.42

DOF=Degree of freedom, SS=sum of squares, V=Variance, P= Percentage contribution, e = error, A- Fibre length, B- Fibre Weight fraction
Tabulated F-ratio at 95% confident level: $F_{0.05:1:12} = 4.75$, $F_{0.05:2:12} = 3.88$

Table 7. Pooled ANOVA (Raw Data: Tensile Strength) for (Signal to Noise ratio)

source	**DOF**	**SS**	**V**	**F ratio**	**P(%)**
A	2	3.620	1.810	1.73	36.61
B	2	4.366	2.183	2.37	44.15
Total	8	9.889	-	-	100.0
e(pooled)	4	1.903	0.476		19.24

Source: ANOVA generated output

4. Conclusion

The experimental investigations on the analysis of tensile strength of bamboo reinforced polyester composites were conducted. The experiments lead us to the following conclusions obtained from this study:

The successful fabrication of a new class of polyester based composites reinforced with short bamboo fiber is possible by simple hand lay-up technique; and

The bamboo reinforced composite has an optimum tensile strength of 44.51MPa when the control factors (Fibre length, Fibre loading) are set at (30mm and 30%wt) or (level 2, level 2);

The percent contribution of parameters in affecting variation in tensile strength:

parameter	Percent Contribution on Tensile strength
Fibre length (A)	36.61
Fibre Weight Fraction(B)	44.15

The predicted optimal range at 95% confidence interval of the Tensile strength is:

$40.401 < \mu TS \text{ (Mpa)} < 48.619$

References

[1] Ratna Prasad et al., *Banana empty fruit bunch fibre reinforced polyester composites*

[2] Roy R.K., *A prime on Taguchi method,* Van Nostrand Reinhold, New York, 1990.

[3] Phadke M.S., *Quality Engineering using robust design practice*, 1989.

[4] Ross P.J., *Taguchi techniques for quality Engineering*, McGraw-Hill Book Company, New York, 1996.
[5] Hari Singh, *Optimizing tool life of carbide inserts for turned parts using taguchi's design of experiments approach*, Proceedings of the international multiconference of engineers and computer scientists 2008 vol 11 IMECS 2008, 19-21 March, 2008, Hong Kong.

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