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TAGUCHI OPTIMIZATION PREDICTION TO EVALUATE THE SYNERGETIC IMPACT OF COCONUT SHELL ASH PARTICLES ON THE TENSILE STRENGTH OF BANANA PSEUDO STEM FIBER COMPOSITES

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Abstract— Bananas are a significant fruit crop cultivated around the world, with a substantial amount of biomass being neglected as a waste. This research aimed to investigate the effect of Coconut Shell Ash particle (CSA) on the Tensile strength of Banana Pseudo Stem (BPS) fiber reinforced epoxy composites. The composite was prepared by hand lay-up method by mixing epoxy and hardener in a ratio 2 to 1. Three processing parameters were considered, namely: Particle

Polymer Composite, Coconut Shell Ash, Design of Experiment	Percentage (PP), Particle Size (PS) and Curing Time (CT). Each this factor is varied thrice, i.e., PP (3, 6, 9%), PS (20, 35, 45 μm) and CT (12, 24, 36 hrs). The results indicated that the PP was the most influential factor, followed by the PS, while CT had the least impact. The experimental findings were comparable to the predictions obtained through Taguchi optimization The former was 68.1 MPa while the latter was 68.6 MPa, respectively. However, both methods revealed $PP_9PS_{35}CT_{12}$ as the optimum combination. This shows that 9% (PP), 35 μm (CT) and 12 hrs (CT) are the optimal levels. Percentage error between the experiment and optimisation modelling was less than 3% while the normal probability plot shows that the residual is well aligned to the linear graph. Thus, the model developed can be reliably utilised to predict the strength of CSA filler composites.

I. Introduction

In recent years, there has been a notable increase in the use of synthetic products due to their cost effectiveness, overshadowing natural fibers. However, the environmental downsides of synthetic fibers, which do not decompose and contribute to pollution, are becoming more evident [1-5]. Key performance that determines the strength of natural fiber composites is the fiber/matrix adhesion strength. Degree of fiber modification and percentage fiber content in polymeric composites are the other influential parameters [6 - 8]. Although there are few contrary reports, increase in tensile properties because of increasing fiber content is widely reported in literatures [9-11]. This claim holds generally for most natural fiber composites up to the optimal level, including hybrid fiber composites. At the optimal level, load shared between fibers is sustained by the matrix, even after fiber fracture, leading to improved mechanical properties. However, beyond the optimal level, the matrix may be incapacitated to support additio nal fiber (load), resulting to composite failure, brittleness and low tensile strength [12-15]. Failure due to the above defects may stem from factors such as wrong processing techniques and poor fiber/matrix adhesion [8-10], studied the behavoir of stacking pattern on the tensile properties of woven banana (B)/jute (J)/carbon (C) hybrid composites. Epoxy, hand lay-up, and five layers, respectively, are the resin, processing method and number of laminates employed [16].

There are abundant literatures on the use of single reinforcement in polymer composite via experiment route. However, there is scarcity of literature regarding the use of CSA as filler in BPS fiber reinforced in epoxy composite, both through experimental methods and Taguchi optimization. To address this knowledge gap, this study combined experimentation and Taguchi optimization using three processing parameters, namely: percentage particles, particle size, and curing time. ANOVA analysis, mathematical model and a residual plot were developed to visualize the effectiveness of the optimizatio n process.

II. Materials and Methodology

A. Material

BPS normally considered as waste were sourced from National Institute for Horticulture Research, Ibadan, Nigeria (NIHORT). The CSA, on the other hand, was sourced locally and pulverized and sieved into three different sizes, i.e., 20, 35 and 45 μm as well as Epoxy Araldite LY564 resin and hardener Aradur HY951.

B. Composite Preparation

The composite samples were prepared as per the details contained in the work of [4-5, 9-10]. Epoxy resin was prepared by mixing resin (Aradite LY564) with the hardener (Aradur HY951) in 2:1. While the epoxy resin (81.2 wt.% and short BPS fiber (18.8 wt.%) were constant, the effect of CSA addition varied from 3, 6 to 9 wt.%. Wood Stirrer was used to thoroughly mix the CSA for 15 minutes to ensure uniform distribution before being impregnated into the BPS fibers using hand lay-up method to produce 9 composite samples according to Taguchi L_9 orthogonal array (see Table 1). The samples were allowed to be set with a varied time of 12, 24 and 36 hours.

C. Tensile Strength

Tensile tests are frequently used to determine both how far a material can stretch before breaking and how much force it can sustain before breaking. The stiffness of a material that represents the voltage module can be calculated using the voltage diagram. A dumbbell shape specimen was used for reinforced composite testing. Using Equation (1), the tensile test specimen was performed according to ASTM D 638 guidelines [4].

$$Tensile = Force\ (Load)/(Cross\ sectional\ area) \quad (1)$$

D. Taguchi Analysis

Three important factors affecting the Tensile strength of the composite are chosen in the study, namely: (1) the Particle Percentage (PP), (2) the Particle Size (PS) and (3) Curing Time (CT). The orthogonal array generated from Minitab data software is presented in Table 1. Unlike other methods, Taguchi optimization is essential in corresponding experimental values with theoretical modeling.

In this study, the larger the better option was selected because the higher fiber yield process is needed to optimal validation. Furthermore, Analys is of Variance (ANOVA) was carried out to determine the percentage contributed by each considered factor as well as the significant rate through p-value.

III. Results and Discussion

A. Tensile Strength

The results obtained for the Tensile strength analysis are presented in Table 1. The Tensile strength from each sample is determined after finding the average of three trials per sample.

Table 1: L9 orthogonal array, SN ratio, Tensile strength and designation

S/N	Particle Percentage (*PP*)	Particle Size (*PS*)	Curing Time (*CT*)	Tensile Strength	SN Ratio (dB)	Designation
1	3	20	12	60.1	35.57	$PP_3PS_{20}CT_{12}$
2	3	35	24	60.7	35.66	$PP_3PS_{35}CT_{24}$
3	3	45	36	60.3	35.60	$PP_3PS_{45}CT_{36}$
4	6	20	24	64.3	36.16	$PP_6PS_{20}CT_{24}$
5	6	35	36	66.2	36.41	$PP_6PS_{35}CT_{36}$
6	6	45	12	67.0	36.52	$PP_6PS_{45}CT_{12}$
7	9	20	36	67.7	36.61	$PP_9PS_{20}CT_{36}$
8	9	35	12	68.0	36.65	$PP_9PS_{35}CT_{12}$
9	9	45	24	67.7	36.61	$PP_9PS_{45}CT_{24}$

From the experimental results, sample #1 gave the lowest Tensile strength (60.1 MPa). With sample #1 ($PP_3PS_{20}CT_{12}$), PP_3 signifies 3% particle percentage, PS_{20} as particle size at 20 µm and CT_{12} as curing time at 12 hours. On the other hand, sample #8 ($PP_9PS_{35}CT_{12}$) gave the highest tensile strength of 68.0 MPa. $PP_9PS_{35}CT_{12}$ was obtained through 9 % particle percentage, 35 µm particle size and 12 hours curing time, respectively. This was because at higher reinforcement, the composite became harder due to the inclusion of lower diameter (PS of 35 µm) which aided uniform matrix/fiber dispersion.

Therefore, 35 µm PP also led to higher TS. The TS will continue to increase with reinforcement addition until the matrix can no longer bear the load transfer from the reinforcement [9, 11, 16]. Literature reports that uniform fiber/matrix dispersion is easily achieved with lower diameter PP, which ultimately leads to superior TS. The TS of this study (68 MPa) is higher than short pineapple polypropylene composite (21.5 MPa), snake grass fiber polyester composite (48 MPa) and coconut sheath polyester (45 MPa) [11] – highlighting the importance of CSA addition. Thus, $PP_3PS_{20}CT_{12}$ can be devel oped further for usage in dashboard of an automobile.

Processing method, fiber selection, geographical location, reinforcement makeup, and diameter of the reinforcement are among the factors that govern the behavior of a composite [1, 8, 17].

B. Signal to Noise Ratio

Figure 1 and Table 2 present the main effect for SN for Tensile strength and the Signal-to-Noise ratio (SN ratio) ranking of the optimization, respectively. Via the larger is better option in Minitab, the order of importance of the factors is determined. In addition, the optimal level in each of factors was obtained. In each factor, the difference between the highest and lowest, delta, is used to calculate the ranking order.

For instance, in Table 2, the delta of PP (1.01), PS (0.13) and CT (0.10) were first, second and third, respectively, because of their higher value. Thus, particle percentage is considered as the best factor in selecting the optimal Tensile strength, then the particle size and curing time (the least).

Table 2: SN ratio to determine the ranking of the optimal factors

Level	Particle percentage	Particle size	Curing time
1	35.62	36.12	36.25
2	36.37	36.24	36.15
3	36.62	36.25	36.21
Delta	1.01	0.13	0.10
Rank	1	2	3

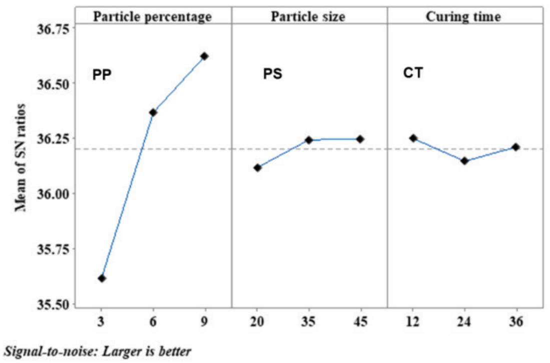

Figure 1: Main effect for SN for Tensile Strength

At the same time, the optimal level was determined in Figure 1 as PP9PS35CT12. With Figure 1, PP9 at level three (3), PS35 at level two (2) and CT12 at level one (1) gave the optimal levels. The result obtained in this section was in affirmation of the earlier experimental results in which sample #8 (PP9PS35CT12) is exactly like the optimisation result.

C. Analysis of Variance

The ANOVA of the optimization is presented in Table 3. The contributions of PP (95.60 %) the largest, then PS (1.94 %) and CT (1.05 %) was the least, while percentage error was merely 1.40 %. Correspondingly, the p-value PP (0.014) was considered significant since it was less than the threshold of 0.05 [9]. However, other factors including PS (0.420) and CT (0.571) which is greater than 0.05 were considered to be non-significant.

Table 3: Analysis of Variance for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Particle %	2	89.0067	89.0067	44.5033	68.12	0.014	95.60
Particle size	2	1.8067	1.8067	0.9033	1.38	0.420	1.94
Curing time	2	0.9800	0.9800	0.4900	0.75	0.571	1.05
Residual Error	2	1.3067	1.3067	0.6533			1.40
Total	8	93.1000					100

D. Mathematical Modeling and Regression Equation

Correlation between the experiment and optimization is presented in Table 4. The regression equation for the Tensile Strength is presented in Equation (2).

$$TS = 56.18 + 1.239PP + 0.0405PS - 0.0125CT \quad (2)$$

where:
PP = Particle Percentage,
PS = Particle Size, and
CT = Curing Time

The Equation (2) is used to obtain the FIT, i.e., the Taguchi optimisation prediction which is subsequently correlated with the experimental values. The difference between the optimisation and experimentation is called the RESIDUAL. According to literature [3, 4, 9], acceptable percentage error should be less than 10 %. From Table 4, errors in all the samples were less than 3.5 %. This shows that the model could be reliably used with minimal errors.

Table 4: Correlation between experiment and optimization

S/N	Tensile Strength (MPa)	FITS (MPa)	Residual (Difference)	% Error
1	60.1	60.5596	-0.45965	1.111
2	60.7	61.0175	-0.31754	1.559
3	60.3	61.2728	-0.97281	-2.725
4	64.3	64.1263	0.17368	-3.283
5	66.2	64.5842	1.61579	1.111
6	67.0	65.2895	1.71053	1.677
7	67.7	67.6930	0.00702	1.327
8	68.0	68.6009	-0.60088	-1.979
9	67.7	68.8561	-1.15614	0.731

E. Normal Probability Plot

The normal probability plot of the optimization is presented in Figure 2. The plot assists in visualizing the efficacy of the developed method. In this study, minimal deviation was observed along the linear plot. According to literature [9, 10], when the residuals are well aligned without much deviation, this implies the optimization is accurate for further usage. Contrarily, when outliners are conspicuously deviated from the linear plot, the model is discarded [4, 18–19].

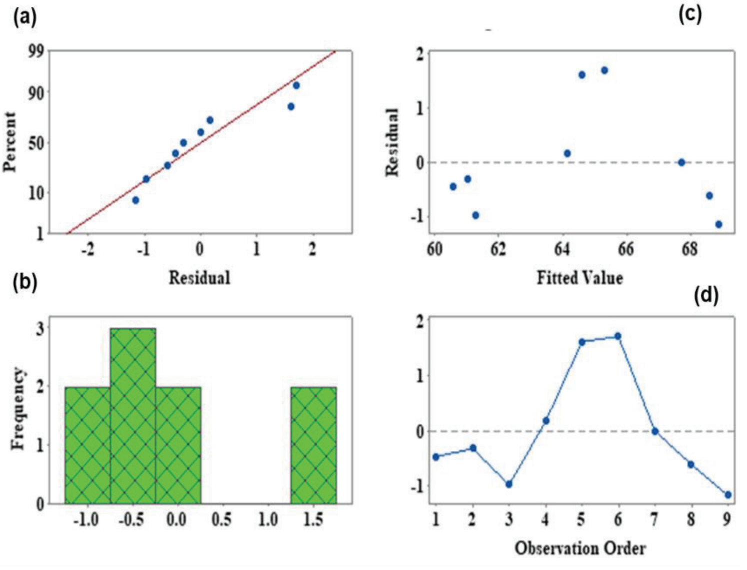

Figure 2: Residual Plot of (a) normal probability plot (b) histogram (c) versus fit (d) versus order

IV. Conclusion

With experimentation and optimization techniques, this study aims to evaluate the impact of CSA filler on the Tensile strength of BPS fiber composite. Three processing factors were considered, i.e., the particle percentage, particle size and curing time. From Signal to noise ratio and ANOVA analysis, particle percentage was most the significant factor to consider when tensile strength is needed. Next is the particle size while the curing time had the least influence. Experimental findings and Taguchi optimization prediction were similar ($PP_9PS_{35}CT_{12}$). 9% particle percentage, 35 μm particle size and 12 hour curing time yielded the optimum Tensile strength, according to the optimization.

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