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Optimization of Hardness Strengths Response of Plantain Fibers Reinforced Polyester Matrix Composites (PFRP) Applying Taguchi Robust Design

E. C. Okafor [a] *, C. C. Ihueze [a], S. C. Nwigbo [b]

[a] *Department of Industrial and Production Engineering, Nnamdi Azikiwe University Awka, Nigeria*
[b] *Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Nigeria*

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ABSTRACT

Volume fraction of fibers (A), aspect ratio of fibers (B) and fibers orientation (C) are considered as control factors in the determination of hardness strength of plantain fiber reinforced polyester composites (PFR P). These properties were determined for plantain empty fruit bunch (PEFB) and plantain pseudo stem (PPS). Hardness tests were conducted on the replicated samples of PEFB fiber reinforced polyester composite and PPS fiber reinforced polyester respectively using Archimedes principles in each case to determine the volume fraction of fibers. Taguchi robust design technique was applied for the greater the better to obtain the highest signal to noise ratio (SN ratio) for the quality characteristics being investigated. The empty fruit bunch fiber reinforced polyester matrix composite has the maximum hardness strength of 19.062N/mm^2 and a mean design strength of 17.978N/mm^2, while the pseudo stem plantain fiber reinforced matrix composite has the maximum hardness strength of 18.655 N/mm^2 and a mean design strength of 18.0385N/mm^2. The properties studied depend greatly on the reinforcement combinations of control factors.

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1. INTRODUCTION

Natural fibers obtained from cellulose-based plants are being used as reinforcement of polymer composites owing to both environmental and technical advantages, the facts that composites in general can be custom tailored to suit individual requirements have desirable properties in corrosive environment; provide higher strength at a lower weight and have lower life-cycle costs has aided in their evolution [1]. It provides a good combination of mechanical properties and thermal and insulating protection. Binshan et al. [2] observed that these qualities in addition to the ability to monitor the performance of the material in the field via embedded sensors give composites an edge over conventional materials. Plantains (Musa spp., AAB genome) are plants producing fruits that remain starchy at maturity [3] and need processing before consumption. Plantain production in Africa is estimated at more than 50% of worldwide production [4].

Nigeria is one of the largest plantain producing countries in the world [5]. Plantain fiber can be obtained easily from the plants which are rendered as waste after the fruits have ripened. So plantain fibers can be explored as a potential reinforcement. Manufacturing processes for components made from thermoset composites usually require the optimal achievement of important composite property factors like the fiber volume fraction which determines the strength of the composites [2]. Two standard approaches are usually adopted to examine fiber fraction in a composite, namely destructive and nondestructive evaluation [8]. Standard methods have been available by burning small composite samples at 550-600^{o}C, resulting in complete oxidation of the resin, to determine glass fiber fraction [6]. Acid digestion methods have also been used for the measurement of carbon fiber volume fraction [7, 8]. However, various nondestructive methods have been used according to [9], including ultrasonic pulse propagation, x-radiography and dielectric constant measurements [8]. This paper presents a comprehensive procedure based on the Archimedes principle applicable in determination of volume fraction values for natural fibers.

* Corresponding Author Email: cacochris33@yahoo.com (E. C. Okafor)

Many investigations have been made on the potential of the natural fibers as reinforcements for composites and in several cases the result have shown that the natural fiber composites own good stiffness, but do not reach the same level of strength as the glass fiber composite [10]. It was then realized that the full economic and technical potential of any manufacturing process can be achieved only when the process is run with the optimum parameters.

One of the most important optimization processes is Taguchi method [11]. Taguchi technique is a powerful tool for the design of high quality systems [12, 13]. The Taguchi approach enables a comprehensive understanding of the individual and combined parameters from a minimum number of simulation trials. This technique is a multi – step process which follows a certain sequence for the experiments to yield an improved understanding of product or process performance [14].

In the present work polyester and plantain fibers were used as a matrix reinforcing materials resepectively to produce a composite material. This composite was used to evaluate the Hardness strength (HS) at different reinforcement combination to achieve the optimum strength.

2. LITERATURE/BACKGROUND OF STUDY

Natural fibers are an alternative resource to synthetic fibers as reinforcement for polymeric materials for the manufacture of cheap, renewable and environmentally friendly composites [37]. Waste Natural fibers have the advantages of low density, low cost, and biodegradability [38]. With the growing global energy crisis and ecological risks, natural fibers reinforced polymer composites and their application in design of equipment subjected to impact loading have attracted more research interests due to their potential of serving as alternative for artificial fibers composites [15,16]. Many studies have been carried out on natural fibers, like kenaf, bamboo, jute, hemp, coir, sugar palm and oil palm [17,18, 19, 20; 21]. The reported advantages of these natural resources includes low weight, low cost, low density, high toughness, acceptable specific strength, enhanced energy recovery, recyclability and biodegradability [19; 22, 21]. This study seeks to design and manufacture a natural fiber based composite at optimal levels of material combination to achieve maximum strength while maintaining earlier established properties.

According to Derek [23], many factors must be considered when designing a fiber-reinforced composite such as: Fiber length and diameter: the strength of a composite improves when the aspect ratio (L/D) is large, where L and D are the length and diameter of the fiber, respectively. The amount of fiber: the strength and stiffness of the composites increase with increasing the volume fraction. Orientation of fibers: the orientation of fibers has a great role in the strength of the composites. One of the unique characteristics of fiber-reinforced composites is that their properties can be tailored to take different types of loading conditions [19], and this study aims at exploiting this inclination to achieve an optimal design specification for materials subjected to dynamic working conditions. For Design of Experiments (DOE), different methods are used. In cases where one observes many inputs and interactions, and there is also a time limitation, the Taguchi approach is used for DOE [34, 35, 36]. The method is especially suitable for industrial use, but it can also be used for scientific research.

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality [28]. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. Radharamanan and Ansuj [31] upheld that it can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence. Also, the Taguchi method allows for the analysis of many different parameters without a prohibitively high amount of experimentation [28]. In this way, it allows for the identification of key parameters that have the most effect on the performance characteristic value so that further experimentation on these parameters can be performed and the parameters that have little effect can be ignored.

3. METHODOLOGY

The methodology of this study employs traditional and experimental design methods of Taguchi technique to optimize the hardness strength of plantain fiber reinforced polyester composite

3. 1. Plantain Fibers Extraction and Chemical Treatment

The plantain fiber was mechanically extracted from both stem and empty fruit bunch [32]; Figure 1 depicts the extracted plantain empty fruit bunch fibers and plantain pseudo stem fibers. The fibers were then soaked in a 5% NaOH solution for 4 hours; alkali treatment is a chemical method which can change the constituents of fibers. The fibers were further treated with a 4:6 ratio solution of water and methanol (Saline treatment) and then neutralized with dilute 100:10 ratio of acetic acid, and finally washed with water. The resultant fibers were dried at 30^{o}C for 72 hrs before formulation of composites.


(a) Plantain stem fiber


(b) Plantain EFB Fiber

Figure 1. Depiction of fiber types

3. 2. Determination of Fibers Volume Fraction Through Archimedes Principle Calculations of volume fraction of plantain fiber is achieved following the derivations from rule of mixtures based on the procedures of [24, 25] and implementation of Archimedes principle [26] applying Equations (1) to (8) and experimental details of step 1 to 8.

$$M_c = M_f + M_m \tag{1}$$

$$V_f = \frac{M_f}{\rho_f} \tag{2}$$

$$V_m = \frac{M_m}{\rho_m} \tag{3}$$

$$V_c = V_f + V_m \tag{4}$$

$$V_{fr} = \frac{V_f}{V_c} \tag{5}$$

$$V_{fr} = \frac{V_f}{V_f + V_R} \tag{6}$$

$$V_R = \left(\frac{1 - V_{fr}}{V_{fr}}\right) V_f \tag{7}$$

$$v_m = \frac{V_m}{V_c} \tag{8}$$

Equation (7) means that once the volume of fibers is determined by the Archimedes principle and the volume fraction decision is taken, the volume of resin can be calculated, where

M_c = Mass of composite specimen, (g); M_f = Mass of plantain fiber, (g); M_m = Mass of matrix, (g); ρ_f = Density of plantain fiber, (g/m^3); ρ_m = Density of matrix, (g/m^3); V_c = Volume of composite specimen, (cm^3); V_m = Volume of matrix, (cm^3); V_m = Matrix volume fraction; V_R = volume of resin; V_{fr} = volume fraction of fibers; V_f = volume of plantain fibers (cm^3) determined using Archimedes principle that the volume of water displaced is equivalent to the volume of fiber. Because the calculation of the volume of an irregular object (such as plantain fibers) from its dimensions is a mirage by traditional method, such a volume can be accurately measured by placing the object into water based on steps below. It follows from the Archimedes principle that the volume of the displaced water is equal to the object volume [26].

Step 1: The mass of a sizable quantity of plantain fiber lump (m_f) sample is determined using digital METLER(R) balance (Precision: 0.0001g) and then a small container (C_s) of known or previously determined density and mass, is used to contain the fibers ensuring that the small container is completely filled with plantain fiber.

Step 2: A graduated glass cylinder was then filled with about 100 ml of water.

Step 3: Errors due to parallax was avoided by viewing the meniscus from a 0/180 degree angle, that is held up to eyes and then take the water volume measurement from the base of the curved water meniscus.

Step 4: The water volume from Step 3 is recorded and denoted as (V_0)

Step 5: The object (small container + fibers) is then placed into the cylinder. The water level will rise, noting that the object must be completely covered with water.

Step 6: Step 3 is repeated and recording the new water level as V_1.

Step 7: The volume V_0 (Step 4) is subtracted from V_1 (Step 6) to calculate the volume of the object, such that (small container + fiber) = V_1-V_0.

But the volume of water displaced (V_d) = [volume of fiber (V_f)] + [volume of small container (C_s)]. Therefore:

$$Vol.of\ fibers = \left(Vol.Displaced - \frac{C_s}{\rho_s}\right) \tag{9}$$

Step 8: Finally, the density of plantain fiber is determined by dividing the fiber mass (Step 1) by its volume (Step 7).

3. 3. Sample Formation and Determination of Mechanical Properties Flat unidirectional arrangements of the fibers were matted using polyvinyl acetate as the bonding agent. They were arranged to a thickness of 1.2mm and dried at room temperature for 72 hours. The composite fabrication method adopted for this study is based on open molding Hand lay-up processing technology in which the plantain fiber reinforcement mat is saturated with resin, using manual rollout techniques of Clyne and Hull [27] to consolidate the laminate and removing the trapped air. A mild steel mold of dimension 300mm×300mm×12mm was used for casting the composites in a matching group of 10, 30 and 50% volume fractions and 10, 25, 40 mm/mm aspect ratio based on design matrix of Table 2. At the time of curing, a compressive pressure of 0.05MPa was applied on the mould and the composite specimens were cured for 24 hours. Replicate samples of plantain fiber reinforced polyester matrix were then tested for hardness strength using Hounsfield Monsanto Tensometer. The plantain stem and empty fruit bunch fiber reinforced composites were prepared for Brinell hardness test. Tests were carried out in Hounsfield tensometer model –H20 KW with magnification of 4:1 and 31.5kgf beam forces. The cross head speed is 1 mm/min. The hardness tests were conducted in accordance with ASTM Standard E 10, with a ball indenter of 2 mm diameter, a test load of 122.32 kg is applied on the specimens for 30sec.

3. 4. Signal to Noise Ratio and Application of Taguchi Methodology Taguchi Robust design technique was applied for greater the better option of signal to noise ratio as expressed in (11) using the measured properties as quality characteristics and choosing three factor levels (Low, medium, high) for an L_9 (3^3) array design matrix. The computed S/N ratio for the quality characteristics were evaluated and optimum control factor levels established for the parameters.

The S/N ratio for maximum (hardness strength) which comes under larger is better characteristic, was calculated as logarithmic transformation of the loss function as shown in (11)[28, 29]. The signal to noise ratio measures the sensitivity of the quality investigated to those uncontrollable factors (error) in the experiment. The higher value of *S/N* ratio is always desirable, because greater *S/N* ratio will result in smaller product variance around the target value. In order to perform *S/N* ratio analysis, mean square deviation (*MSD*) for "the-bigger-the-better" quality characteristic and *S/N* ratio were calculated from the following equations:

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad (10)$$

$$\frac{S}{N} = -10\, Log_{10}\,(MSD) \quad (11)$$

where, y_i is the hardness strength under constant load for ith replicate experiment. The Brinell hardness number (H_b) is an important surface mechanical property and it's known as a resistance of the material to deformation [33]; it is calculated for the composites using Equation (12). The large size of indentation and possible damage to test-piece limits its usefulness [33].

$$H_b = \frac{L}{\left(\frac{\pi D}{2}\right)\left[D-(D^2- d^2)^{\frac{1}{2}}\right]} \quad (12)$$

where, L = load (kg), D = Diameter of the ball (mm); d = diameter of the indentation (mm).

4. RESULTS AND DISCUSSION

In this study the hardness strength of plantain fibers reinforced polyester were investigated for optimum reinforcement combinations to yield optimum response employing Taguchi methodology. The signal to noise ratio and mean responses associated with the dependent variables of this study are evaluated and presented. Traditional experimentation on replicated samples of empty fruit bunch and pseudo stem fiber reinforced polyester composite were used to obtain the value of quality characteristics of hardness strength using different levels of control factors levels as in Table1. The response table for means of S/N ratios shows that the volume fraction has the highest contribution in influencing the composite hardness strength (36.89421 %), followed with aspect ratio (33.60374 %) and then fiber orientation (17.39334 %) as depicted in Table 5 and 6. Tables 2 and 3 show Taguchi DOE orthogonal array and Design matrix implemented for the larger the better signal to nose ratio (S/N ratio) respectively. These led to results of Figure 1 and Table 4 for optimum control factor levels on which response surface method two levels factor design was based.

5. EVALUATION OF MEAN RESPONSE

A standard approach to analyzing these data would be to use the analysis of variance (ANOVA) to determine which factors are statistically significant. But Taguchi approach uses a simpler graphical technique to achieve this purpose. Since the L_9 experimental design is orthogonal it is possible to separate out the effect of each factor. This is done by examining the control matrix of Table 4 and calculating the average S/N ratio ($SNav$) and mean (Mms) responses for each factor at each of the three test levels as outlined in Table 5 based on the methods of Ihueze et al. [30]. The calculated responses for S/N ratio and mean as per each factor and level are tabulated in Tables 5, 6, 7 and summarized in Table 8; the range (Delta) is the difference between high and low response. The larger the (Delta) value for a parameter, the larger the effect the variable has on the hardness strength of the composites. This is because the same change in signal causes a larger effect on the output variable being measured [28].

TABLE 1. Experimental outlay and variable sets for mechanical properties

S/N	Processing Factors	Level			
		1	2	3	Unit
1	A: Volume fraction	10	30	50	%
2	B: Aspect Ratio (l_f/d_f)	10	25	40	mm/mm
3	C: Fiber orientations	±30	±45	±90	Degree

TABLE 2. Applicable taguchi standard orthogonal array L_9

Experiment Number	Parameter 1:A	Parameter 2:B	Parameter 3:C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

TABLE 3. Experimental Design Matrix for Hardness Test Using Composite Made from Plantain Pseudo Stem Fibers Reinforced Polyester Composite

Expt. No.	A: Volume fraction (%)	B: Aspect Ratio (l_f/d_f)	C: Fiber orientations (± degree)	Specimen replicates *Hardness* Response Nmm^{-2}			Mean *Hardness* response Nmm^{-2}	MSD	SNratio
				Trial #1	Trial#2	Trial #3			
1	10	10	30	18.1420273	18.0376327	18.0902788	18.0899	0.00305	25.1486
2	10	25	45	18.5375435	18.6088086	18.5735089	18.5732	0.00289	25.3777
3	10	40	90	18.1420273	18.0552808	18.0989661	18.0987	0.00305	25.1529
4	30	10	45	18.0552808	17.2742411	17.6837489	17.6710	0.00320	24.9410
5	30	25	90	18.2262635	18.9244696	18.6088086	18.5865	0.00289	25.3808
6	30	40	30	16.2519486	16.2211334	16.2365858	16.2365	0.00379	24.2098
7	50	10	90	18.2262635	18.1420273	18.1844610	18.1842	0.00302	25.1938
8	50	25	30	17.6837489	18.9244696	18.3870923	18.3317	0.00298	25.2540
9	50	40	45	18.0552808	18.2262635	18.1420273	18.1411	0.00303	25.1731

TABLE 4. Evaluated quality characteristics, signal to noise ratios and orthogonal array setting for evaluation of mean responses of PPS

Exp No	A	B	C	Mean hardness response (Nmm^{-2})	SNratio
1	1	1	1	18.08998	25.14869
2	1	2	2	18.57329	25.37774
3	1	3	3	18.09876	25.15293
4	2	1	2	17.67109	24.94101
5	2	2	3	18.58651	25.38088
6	2	3	1	16.23656	24.20987
7	3	1	3	18.18425	25.19386
8	3	2	1	18.33177	25.25401
9	3	3	2	18.14119	25.17312

TABLE 5. Average responses obtained for Volume fraction (A) at levels 1, 2, 3 within experiments 1 to 9

Quality characteristics Factor level	Average of response for different experiment	Response value
$\boldsymbol{SNav1}$	$(A_1 + A_2 + A_3)/3$	25.22645
$\boldsymbol{Mms1}$	$(A_1 + A_2 + A_3)/3$	18.25401
$\boldsymbol{SNav2}$	$(A_4 + A_5 + A_6)/3$	24.84392
$\boldsymbol{Mms2}$	$(A_4 + A_5 + A_6)/3$	17.49805
$\boldsymbol{SNav3}$	$(A_7 + A_8 + A_9)/3$	25.207
$\boldsymbol{Mms3}$	$(A_7 + A_8 + A_9)/3$	18.21907

TABLE 6. Average responses obtained for Aspect Ratio (B) at levels 1, 2, 3 within experiments 1-9

Quality characteristics Factor level	Average of response for different experiment	Response value
$SNav1$	$(B_1 + B_4 + B_7)/3$	25.09452
$Mms1$	$(B_1 + B_4 + B_7)/3$	17.98177
$SNav2$	$(B_2 + B_5 + B_8)/3$	25.33754
$Mms2$	$(B_2 + B_5 + B_8)/3$	18.49719
$SNav3$	$(B_3 + B_6 + B_9)/3$	24.84531
$Mms3$	$(B_3 + B_6 + B_9)/3$	17.49217

TABLE 7. Average responses obtained for fiber orientation (C) at levels 1, 2, 3 within experiments 1-9

Quality characteristics Factor level	Average of response for different experiment	Response value
$SNav1$	$(C_1 + C_6 + C_8)/3$	24.87086
$Mms1$	$(C_1 + C_6 + C_8)/3$	17.55277
$SNav2$	$(C_2 + C_4 + C_9)/3$	25.16396
$Mms2$	$(C_2 + C_4 + C_9)/3$	18.12852
$SNav3$	$(C_3 + C_5 + C_7)/3$	25.24256
$Mms3$	$(C_3 + C_5 + C_7)/3$	18.28984

TABLE 8. Summary of responses and ranking for hardness strength of plantain pseudo stem fiber reinforced composites based on Larger is better quality characteristics

Response	Signal to Noise Ratios		
Level	A: Volume fraction(%)	B:Aspect Ratio (lf/df)	C:Fiber Orientations (± degree)
1	25.23	25.09	24.87
2	24.84	25.34	25.16
3	25.21	24.85	25.24
Delta	0.38	0.49	0.37
Rank	2	1	3
Response	**Means**		
Level	**A: Volume fraction(%)**	**B:Aspect Ratio (lf/df)**	**C:Fiber Orientations (± degree)**
1	18.25	17.98	17.55
2	17.50	18.50	18.13
3	18.22	17.49	18.29
Delta	0.76	1.01	0.74
Rank	2	1	3

Table 8 shows the evaluated responses and their ranking for hardness strength of plantain pseudo stem fiber reinforced composites based on Larger is better quality characteristics for signal to noise ratio and mean values.

This procedure is also followed in the computation of response for mean of PEFB. The above computations were then implemented in Minitab 15 software and the results are presented in Tables 8 and 10. Figures 2-5 are the excel graphics for S/N ratio and mean tensile strength of plantain empty fruit bunch and pseudo stem fiber reinforced composites based on Larger is better quality characteristics. Table 10 is the Response table for hardness strength of plantain empty fruit bunch fiber reinforced composites based on Larger is better quality characteristics for signal to noise ratio and response mean values.

Close examination of Figures 2-5 indicates that the hardness strength of plantain empty fruit bunch fiber reinforced polyester composites increases with increase in fiber orientation. As the fiber orientation increases, the amount of strength in hardness becomes higher due to change in stress distribution

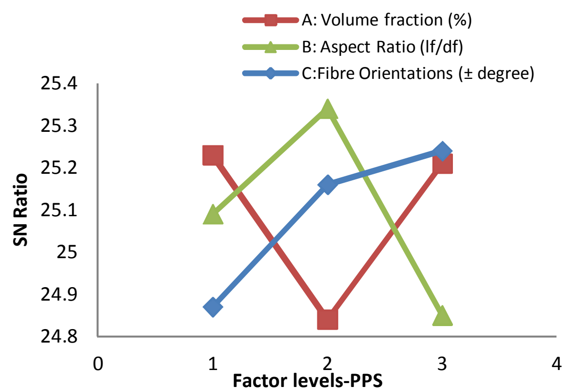

Figure 2. Main effect plots for signal-noise ratio-PPS

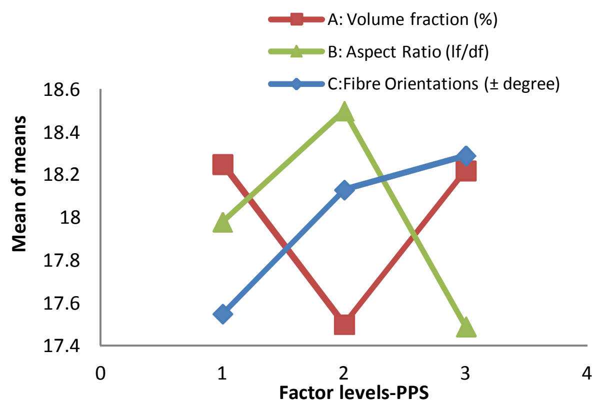

Figure 3. Main effect plots for means-PPS

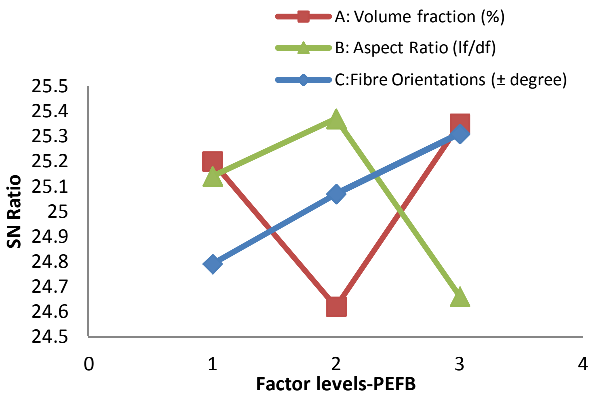

Figure 4. Main effect plots for signal-noise ratio-PEFB

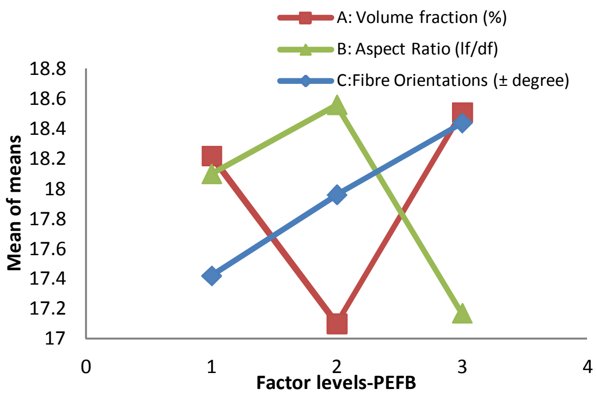

Figure 5. Main effect plots for means ratio-PEFB

Figure 4 shows graphically the effect of the three control factors on hardness strength of plantain empty fruit bunch fiber reinforced composites. Analysis of results gives the combination factors resulting in maximum hardness strength of the composites. From analysis of these results it is concluded that the factors combination $A_3B_2C_3$ yields maximum hardness strength of the composites.

Table 10 clearly spelt out the influence of various control factors for plantain empty fruit bunch fiber reinforced composites. The response of the S/N ratio shows that the volume fraction (A) factor has major impact on hardness strength of plantain fiber reinforced composites followed by Aspect ratio and fiber orientation.

Figure 5 depicts the variations of hardness strength of plantain empty fruit bunch fiber reinforced polyester composites with all the three working parameters. The hardness strength decreases for increasing values of volume fraction up to level II (30%) before increasing towards level III (50%). But in the case of aspect ratio, hardness strength increases up to the level II (25), and then its value decreases from level II to level III. Using Equations (11)-(13) for the nine experiments the signal to noise ratio, and mean square deviation (MSD) were calculated and the results are presented in Table 8.

TABLE 9. Experimental design matrix for hardness test using composite made from plantain empty fruit bunch fibers reinforced polyester composite

Expt. No.	A:Volume fraction (%)	B:Aspect Ratio (l_f/d_f)	C:Fiber orientations (± degree)	Specimen replicates *Hardness* Response Nmm^{-2} Trial #1	Trial#2	Trial #3	Mean *Hardness* response Nmm^{-2}	MSD	SNratio
1	10	10	30	18.22626355	18.22294265	18.22460361	18.2246	0.003011	25.21316
2	10	25	45	18.53754355	18.22626355	18.38709233	18.38363	0.002959	25.288
3	10	40	90	17.27424114	18.74328346	18.09896614	18.03883	0.003083	25.10958
4	30	10	45	18.22626355	16.47078851	17.43215143	17.3764	0.003329	24.77679
5	30	25	90	18.22626355	18.9244696	18.60880867	18.58651	0.002897	25.38088
6	30	40	30	15.37771453	15.29877697	15.33840646	15.3383	0.004251	23.71549
7	50	10	90	18.53754355	18.8668444	18.71067993	18.70502	0.002859	25.43849
8	50	25	30	18.53754355	18.8668444	18.71067993	18.70502	0.002859	25.43849
9	50	40	45	18.53754355	17.68374893	18.14202738	18.12111	0.003049	25.15885

TABLE 11. Signal to noise ratio response for hardness strength

Exp No	EFB hardness strength	MSD	SN ratio	Pseudo stem hardness strength	MSD	SN ratio
1	18.2246	0.003011	25.21316	18.08998	0.003056	25.14869
2	18.38363	0.002959	25.288	18.57329	0.002899	25.37774
3	18.03883	0.003083	25.10958	18.09876	0.003053	25.15293
4	17.3764	0.003329	24.77679	17.67109	0.003206	24.94101
5	18.58651	0.002897	25.38088	18.58651	0.002897	25.38088
6	15.3383	0.004251	23.71549	16.23656	0.003793	24.20987
7	18.70502	0.002859	25.43849	18.18425	0.003024	25.19386
8	18.70502	0.002859	25.43849	18.33177	0.002983	25.25401
9	18.12111	0.003049	25.15885	18.14119	0.003039	25.17312

TABLE 10. Summary of responses and ranking for hardness strength of plantain empty fruit bunch fibers reinforced composites

Response	Signal to Noise Ratios		
Level	A: Volume fraction(%)	B: Aspect Ratio (lf/df)	C: Fiber Orientations (± degree)
1	25.20	25.14	24.79
2	24.62	25.37	25.07
3	25.35	24.66	25.31
Delta	0.72	0.71	0.52
Rank	1	2	3
Response	**Means**		
Level	A: Volume fraction(%)	B: Aspect Ratio (lf/df)	C: Fiber Orientations (± degree)
1	18.22	18.10	17.42
2	17.10	18.56	17.96
3	18.51	17.17	18.44
Delta	1.41	1.39	1.02
Rank	1	2	3

6. ESTIMATION OF EXPECTED RESPONSES AND CONFIRMATION OF EXPERIMENTS

The confirmation of experiment is the final step in Taguchi design of experiment and analysis technique. The confirmation experiment is conducted to validate the inference drawn during the analysis phase. For conducting the confirmation experiments the optimum conditions are set for the significant parameters and selected numbers of experiments are carried out under specified conditions. The average of the confirmation experiments results is compared with the anticipated average based on the parameters and levels tested [28].

According to Radharamanan and Ansui [31], the expected response is estimated using the optimum control factor setting from the main effects plots; by employing the response table for signal to noise ratio and the response table for mean, the expected response model is as in Equation (13):

$$EV=AVR+(A_{opt}-AVR)+(B_{opt}-AVR)+(C_{opt}-AVR)+..+(n^{th}{}_{opt}-AVR) \quad (13)$$

Where

EV= expected response
AVR = average response
$A_{op\,t}$ = mean value of response at optimum setting of factor A
$B_{op\,t}$ = mean value of response at optimum setting of factor B
$C_{op\,t}$ = mean value of response at optimum setting of factor C

The expected responses are therefore computed with Equation (13) and presented in Table 12. The relationship between hardness strength and combination of control factors is obtained using linear regression technique and presented in Equations (14) and (15).

$$\text{HARDNESS STRENGHT (Pseudo stem)} = 17.9 - 0.0009A - 0.0163B + 0.0103C \quad (14)$$

$$\text{HARDNESS STRENGHT (EFB)} = 17.6 + 0.0074A- 0.0312B + 0.0156C \quad (15)$$

Based on the main effects plot of signal to noise ratio of Figures 2-5, the optimum setting of composites parameters for the hardness strength of plantain empty fruit bunch and pseudo stem fibers reinforced polyester composites are compiled and presented in Table 12.

TABLE 12. Optimum setting of control factors and expected optimum strength of composites

Composite and property	Control factor	Optimum setting	Expected optimum strength
Empty fruit bunch /hardness	A	50 %	19.63 N/mm^2
	B	25	
	C	90Degrees	
Pseudo stem/hardness	A	50 %	19.06 N/mm^2
	B	25	
	C	90Degrees	

7. CONCLUSIONS

An experimental study is carried out for plantain fibers reinforced polyester composites to optimize the hardness strength, and investigate the effects of volume fraction, aspect ratio and orientation of fibers. Taguchi's robust design method can be used to analyse the hardness properties of fibers reinforced composites as described in the paper, the following conclusions can be drawn from the work.

i. The hardness behaviour of plantain fibers reinforced composites can be analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for identifying significant control factors. The paper has therefore successfully established the design range of application for the material studied using Taguchi method.

ii. The empty fruit bunch fibers reinforced polyester matrix composite has the hardness strength of 19.062 when the control factors (volume fraction, aspect ratio and orientation of fibers) are set at 50%, 10 and 90 degree respectively, while the pseudo stem plantain fiber reinforced matrix composite has the hardness strength of 18.655 when the control factors (volume fraction, aspect ratio and orientation of fibers) are set at 10%, 10 and 90 degree respectively.

iii. Based on the signal to noise ratio, the design setting of composite parameters for the optimum hardness strength of plantain empty fruit bunch fiber reinforced polyester composites and plantain pseudo stem fiber reinforced polyester composites are as follows: volume fraction = 50%, fibers aspect ratio = 25 and fibers orientation = 90 degrees

iv. The results indicates that fibers volume fraction and fibers aspect ratio are the most significant factors affecting the hardness strength of the composites. Although the effect of fibers orientation is significantly less for both psudo stem and empty fruit bunch, it cannot be ignored as it is one of the major load bearing components in the composites.

v. The study can be extended using other methods like response surface methodology, Plackett-Burman designs, Box-Behnken designs etc. Above all, the properties studied depend greatly on the reinforcement combinations of control factors.

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Optimization of Hardness Strengths Response of Plantain Fibers Reinforced Polyester Matrix Composites (PFRP) Applying Taguchi Robust Design

E. C. Okafor [a], C. C. Ihueze [a], S. C. Nwigbo [b]

[a] *Department of Industrial and Production Engineering, Nnamdi Azikiwe University Awka, Nigeria*
[b] *Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Nigeria*

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چکیده

کسر حجمی از الیاف (A)، نسبتی از الیاف (B) و جهت گیری الیاف (C) به عنوان عوامل کنترل کننده در تعیین سختی فیبر درخت موز و مواد تقویت شده مرکب پلی استر (PFR P) در نظر گرفته شده است. این خواص برای یک شاخه خالی از میوه درخت موز (PEFB) و یک شبه ساقه موز (قسمتی از تنه درخت)(PPS) تعیین شده است. آزمون‌های سختی بر روی نمونه‌های فیبر PEFB تکرار شده است و کامپوزیت تقویت شده پلی استر و الیاف PPS تقویت شده پلی استر به ترتیب برای تعیین کسر حجمی از الیاف، از اصول ارشمیدس در هر نمونه مورد استفاده قرار گرفته است. برای به دست آوردن بهترین و بالاترین سیگنال به نسبت نویز (نسبت SN) و برای تعیین خصوصیات کیفی از روش طراحی تاگوچی استفاده شده است. شاخه خالی از میوه به همراه ماتریس کامپوزیت فیبر تقویت شده پلی استر، دارای حداکثر قدرت سختی ۱۹,۰۶۲ نیوتن بر میلی‌متر مربع می باشد و متوسط سختی طراحی شده برابر است با ۱۷,۹۷۸ نیوتن بر میلی متر مربع، در حالی که شبه ساقه موز تقویت شده با فیبر ماتریس کامپوزیت دارای حداکثر قدرت سختی ۱۸,٦۵۵ نیوتن بر میلی‌متر مربع بوده و متوسط سختی طراحی شده برابر است با ۱۸,۰۳۸۵ نیوتن بر میلی‌متر مربع. خواص مورد مطالعه تا حد زیادی در ترکیب عوامل کنترل کننده تقویت بستگی دارند.

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