Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol 3, No 7, 2012

Optimization of Tensile Strengths Response of Plantain Fibres Reinforced Polyester Composites (PFRP) Applying Taguchi Robust Design

C. C. Ihueze[1], E. C. Okafor[1*], A. J. Ujam[2]

1. Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria
2. Department of mechanical/production engineering, Enugu State University of Science and Technology, Enugu, Nigeria

* E-mail of the corresponding author: cacochris33@yahoo.com

Abstract

This study focuses on the use of control factors(volume fraction of fibers (A), aspect ratio of fibers (B) and fibers orientation (C)) to determine the optimum tensile strength of plantain fibers reinforced polyester resin. Tensile tests was conducted on the replicated samples of plantain empty fruit bunch fiber reinforced polyester composite(PEFB) and plantain pseudo stem fiber reinforced polyester (PPS) respectively using Archimedes principles in each case to determine the volume fraction of fibers. To obtain the optimum properties a Monsanto tensometer were used conduct tensile tests to establish the control factor levels quality characteristics needed to optimize the mechanical properties being investigated. 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 employing Minitab 15 software. The optimum values of the control factors are established for empty fruit bunch composites and for pseudo stem fiber composite. The empty fruit bunch fiber reinforced polyester matrix composite has the optimum tensile strength of 40.28MPa , while the pseudo stem plantain fiber reinforced matrix composite has the tensile strength of 30.51MPa. The properties studied depend greatly on the reinforcement combinations of control factors and the composites of empty fruit bunch are stronger in tension than that of pseudo stem.

Key Words: composite matrix, plantain fibers, tensile strength, pseudo-stem, empty fruit bunch. Taguchi.

1. Introduction

Tensile strength of plantain fiber reinforced polyester composites is the maximum stress the material will bear when it is subjected to a stretching load. 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 (Abdalla et al., 2008). It provides a good combination in mechanical property, thermal and insulating protection. Binshan et al., (1995) 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 (Marriot and Lancaster, 1983; Robinson, 1996) and need processing before consumption. Plantain production in Africa is estimated at more than 50% of worldwide production (FAO, 1990; Swennen, 1990). Nigeria is one of the largest plantain producing countries in the world (FAO, 2006). Plantain fiber can be obtained easily from the plants which are rendered as waste after the fruits have ripened. So plantain fiber can be explored as a potential reinforcement.

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 the composites do not reach the same level of strength as the glass fiber composite (Oksman and Selin, 2003). It was then realized that the full economic and technical potential of any manufacturing process can be achieved only while the process is run with the optimum parameters. Taguchi technique is a powerful tool for the design of high quality systems (Taguchi and Konishi, 1987; Taguchi, 1993). The Taguchi approach enables a comprehensive understanding of the individual and combined from a minimum number of simulation trials. This technique is multi – step process which follow a certain sequence for the experiments to yield an improved understanding of product or process performance (Basavarajappa et al, 2007).

In the present work polyester was used as a matrix material and plantain fibers used as reinforcing material to produce a composite material to evaluate the various mechanical properties like Tensile strength (TS), at different reinforcement combination to achieve the optimum strength.

2. Literature/Background of Study

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 fiber composites (Bledzki, Sperber and Faruk, 2002; Mishra et al, 2004). Many studies had been carried out on natural fiber likes kenaf, bamboo, jute, hemp, coir, sugar palm and oil palm (Arib et al. 2006; Khairiah & Khairul 2006; Lee et al. 2005; Rozman et al. 2003; Sastra et al. 2005). 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 (Lee et al. 2005; Myrtha et al. 2008; Sastra et al. 2005). 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 (1981), 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: fiber length and D is the diameter of the fiber. 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 make different types of loading conditions and this study aims at exploiting this inclination to achieve an optimal design specification for materials subjected to dynamic working conditions.

3. Material and Methods

The methodology of this study employs traditional and experimental design methods of Taguchi method to optimize the tensile, strength of plantain fiber reinforced polyester composite.

3.1 Plantain fiber extraction and Chemical treatment

The plantain fiber was mechanically extracted from both stem and empty fruit bunch. The fibers were 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 solution of water and methanol (Saline treatment) in the ratio of 4:6 and then neutralized with dilute acetic acid in the ratio of 100:10 and finally washed with water. The resultant fibers were dried at 30^{o}C for 72 h before the examination of the tensile test.

(a) Plantain stem fiber

(b) Plantain empty Fruit Bunch Fiber

Figure 1: Depiction of plantain fibers types

3.2 Determination of fiber 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 (Jones 1998; Barbero 1998) and implementation of Archimedes principals.

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 manufacturing method adopted for the design 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, 1996) to consolidate the laminate and removing the trapped air. A mild steel mold of dimensions (300×300×5) mm 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 subjected to tensile tests using Hounsfield Monsanto Tensometer. The plantain stem and empty fruit bunch fiber reinforced composites were prepared for tensile test in according to ASTM D638. Tests were carried out in Hounsfield Tensometer model –H20 KW with magnification of 4:1 and 31.5kgf beam force. The cross head speed is 1 mm/min. Each specimen was loaded to failure. The force - extension curve was plotted automatically by the equipment. The ultimate tensile strength and elastic modulus of the samples were thereafter determined from the plot.

3.4 Design of experiments (DOE) and Degree of Freedom (DOF) rules

Taguchi Robust design technique was applied for greater the better option of signal to noise ratio (eq. 2) using the measured properties as quality characteristics and choosing three factor levels (Low, medium, high). The computed SN ratio for the quality characteristics were evaluated and optimum control factor levels established for the parameters. The signal to noise ratio condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. The S/N ratio for maximum tensile strength which comes under larger is better characteristic, was calculated as logarithmic transformation of the loss function as shown in (2) (Ross, 1993). The variance of quality characteristics is measured as mean squared deviation MSD as expressed in (1).

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

$$\frac{S}{N} = -10\ Log_{10}\ (MSD) \qquad (2)$$

According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of chosen quality characteristics, (DOF) can be calculated by the formula of (3) expressed as

$$(DOF)R\ = P * (L - 1) \qquad (3)$$

(DOF)R = degree's of freedom, P = number of factors, L = number of levels

(DOF)R = 3(3 – 1) = 6

Therefore, total DOF of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus L_9 orthogonal array was selected and applied; the selection of orthogonal array depends on three items in order of priority, viz, the number of factors and their interaction, number of levels for the factors and the desired experimental solution or cost limitation. A total of 9 experiments were performed based on the run order generated by the Taguchi model. The model response is tensile strength; in the orthogonal array, first column is assigned to Volume fraction (%), second column is assigned to Aspect Ratio (l_f/d_f), and third column is assigned to Fiber orientations (± degree). The objective of the model is to maximize the tensile strength of PFRP.

4. Discussion of Results

In this study the tensile strength of plantain fiber 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 fiber reinforced polyester composite were used to obtain the value of quality characteristics of tensile strength using different levels of control factors as in table1.

The response tables for means and SN ratios shows that the volume fraction has the highest contribution in influencing the composite tensile strength, followed with fiber orientation as depicted in table 5 and figure 2-5.

Table 1: Experimental outlay and variable sets for mechanical properties

S/N	**PROCESSING FACTORS**	**LEVEL**				
		1	**2**	**3**	**UNIT**	**OBSERVED VALUE**
1	A: Volume fraction	10	30	50	%	
2	B: Aspect Ratio (l_f/d_f)	10	25	40	mm/mm	Tensile Strength,
3	C: Fiber orientations	±30	±45	±90	Degree	

Table 2 and table 3 show Taguchi DOE orthogonal array and Design matrix implemented for the larger the better signal to noise ratio (SN ratio).

Table 2: Applicable Taguchi Standard Orthogonal array L_9

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

The tensile test signal -to-noise ratio for plantain empty fruit bunch fiber reinforced polyester composite is calculated with (2) using values of various experimental trials and presented as in table 3 so that for first experiment,

$$SNratio_{exp\,1} = -10 \times \log\left\{\frac{1}{3}\left[\frac{1}{(19.24679487)^2} + \frac{1}{(21.79487179)^2} + \frac{1}{(20.52083333^2)}\right]\right\} = 26.21033$$

Equation (1) is used in the computation of the mean standard deviation MSD as recorded in the following tables.

Table 3: Experimental design matrix for tensile test using composite made from plantain pseudo-stem fiber reinforced polyester composite (ASTM-D638)

Expt. No.	A: Volume fraction (%)	B: Aspect Ratio (l_f/d_f)(mm)	C: Fiber orientations (± degree)	Specimen replicates tensile response (MPa) Trial 1	Trial2	Trial 3	Mean ultimate tensile response (MPa)	MSD	SNratio
1	10	10	30	19.24679487	21.79487179	20.52083333	20.52083	0.002393	26.21033
2	10	25	45	18.92628205	18.84615385	18.88621795	18.88622	0.002804	25.52286
3	10	40	90	21.74679487	20.03205128	20.88942308	20.88942	0.002299	26.38388
4	30	10	45	23.79807692	25.30448718	24.55128205	24.55128	0.001662	27.7933
5	30	25	90	34.51923077	32.37179487	33.44551282	33.44551	0.000896	30.4778
6	30	40	30	25.000000	22.75641026	23.87820513	23.87821	0.001762	27.54083
7	50	10	90	31.33012821	34.93589744	33.13301282	33.13301	0.000916	30.37945
8	50	25	30	37.72435897	37.17948718	37.45192308	37.45192	0.000713	31.46902
9	50	40	45	28.23717949	28.86217949	28.54967949	28.54968	0.001227	29.11098

The tensile test signal-to-noise ratio for plantain empty fruit bunch fiber reinforced polyester composite is calculated with (2) using values of various experimental trials and presented as in table 4 so that for first experiment,

$$SNratio_{Exp\ 1} = -\log\left\{\frac{1}{3}\left[\frac{1}{(31.63461538)^2} + \frac{1}{(23.22115385)^2} + \frac{1}{(27.42788462^2)}\right]\right\} = 28.55628$$

Similarly, Equation (1) was utilized in the computation of the mean standard deviation MSD and recorded in table 4.

4: Experimental design matrix for tensile test using composite made from plantain empty fruit bunch fiber reinforced polyester composite (ASTM-D638)

Expt. No.	A: Volume fraction (%)	B: Aspect Ratio (l_f/d_f)(mm)	C: Fiber orientations (± degree)	Specimen replicates tensile response (MPa)			Mean ultimate tensile response (MPa)	MSD	SNratio
				Trial #1	Trial#2	Trial #3			
1	10	10	30	31.63461538	23.22115385	27.42788462	27.42788	0.001394	28.55628
2	10	25	45	17.74038462	17.78846154	17.76442308	17.76442	0.003169	24.99101
3	10	40	90	21.74679487	23.1250000	22.43589744	22.4359	0.00199	27.01067
4	30	10	45	29.47115385	31.00961538	30.24038462	30.24038	0.001095	29.60612
5	30	25	90	39.90384615	41.10576923	40.50480769	40.50481	0.00061	32.14822
6	30	40	30	26.6025641	28.66987179	27.63621795	27.63622	0.001313	28.81741
7	50	10	90	40.14423077	34.53525641	37.33974359	37.33974	0.000725	31.39424
8	50	25	30	37.48397436	37.08333333	37.28365385	37.28365	0.000719	31.43012
9	50	40	45	30.84935897	32.27564103	31.5625	31.5625	0.001005	29.97899

4.1 Evaluation of mean response

Table 5: Evaluated quality characteristics, signal to noise ratios and orthogonal array setting for evaluation of mean responses of PEFB

Experiment number	Factor A	Factor B	Factor C	Mean ultimate tensile response (MPa)	SNratio
1	1	1	1	27.42788	28.55628
2	1	2	2	17.76442	24.99101
3	1	3	3	22.4359	27.01067
4	2	1	2	30.24038	29.60612
5	2	2	3	40.50481	32.14822
6	2	3	1	27.63622	28.81741
7	3	1	3	37.33974	31.39424

8	3	2	1	37.28365	31.43012
9	3	3	2	31.5625	29.97899

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 determine which factors are significant. Since the L_9 experimental design is orthogonal it is possible to separate out the effect of each factor. This is done by looking at the control matrix, table 5 and calculating the average SN ratio ($SNav$) and mean (Mms) responses for each factor at each of the three test levels as follows:

For factor A average responses

A is at levels 1 in experiment 1, 2 and 3 so that the average responses are obtained as

$$SNav1 = \frac{28.556 + 24.991 + 27.011}{3} = 26.8527$$

$$Mms1 = \frac{27.42788 + 17.76442 + 22.4359}{3} = 22.5427$$

A is at levels 2 in experiment 4, 5 and 6 so that the average responses are obtained as

$$SNav2 = \frac{29.606 + 32.148 + 28.817}{3} = 30.1903$$

$$Mms2 = \frac{30.24038 + 40.50481 + 27.63622}{3} = 32.7938$$

A is at levels 3 in experiment 7, 8 and 9 so that the average responses are obtained as

$$SNav3 = \frac{31.394 + 31.430 + 29.979}{3} = 30.9343$$

$$Mms3 = \frac{37.33974 + 37.28365 + 31.5625}{3} = 35.39528$$

For factor B average responses

B is at levels 1 in experiment 1, 4 and 7 so that the average responses are obtained as

$$SNav1 = \frac{28.556 + 29.606 + 31.394}{3} = 29.8520$$

$$Mms1 = \frac{27.42788 + 30.24038 + 37.33974}{3} = 31.6693$$

B is at levels 2 in experiment 2, 5 and 8 so that the average response are obtained as

$$SNav2 = \frac{24.991 + 32.148 + 31.430}{3} = 29.5230$$

$$Mms2 = \frac{17.76442 + 40.50481 + 37.28365}{3} = 31.8509$$

B is at levels 3 in experiment 3, 6 and 9 so that the average responses are obtained as

$$SNav3 = \frac{27.011 + 28.817 + 29.979}{3} = 28.6023$$

$$Mms3 = \frac{22.4359 + 27.63622 + 31.5625}{3} = 27.2115$$

For factor C average responses

C is at levels 1 in experiment 1, 6 and 8 so that the average responses are obtained as

$$SNav1 = \frac{28.556 + 28.817 + 31.430}{3} = 29.601$$

$$Mms1 = \frac{27.42788 + 27.63622 + 37.28365}{3} = 30.7826$$

C is at levels 2 in experiment 2, 4 and 9 so that the average responses are obtained as

$$SNav2 = \frac{24.991 + 29.606 + 29.979}{3} = 28.192$$

$$Mms2 = \frac{17.76442 + 30.24038 + 31.5625}{3} = 26.5224$$

C is at levels 3 in experiment 3, 5 and 7 so that the average responses are obtained as

$$SNav3 = \frac{27.011 + 32.148 + 31.394}{3} = 30.1843$$

$$Mms3 = \frac{22.4359 + 40.50481 + 37.33974}{3} = 33.4268$$

This procedure is also followed in the computation of response for mean of PPS. The above computations were then implemented in Minitab 15 software and the results are presented in tables 6 and 7. Figures 2-5 are the excel graphics for SN ratio and mean tensile strength of plantain empty fruit bunch and pseudo stem fiber reinforced composites based on Larger is better quality characteristics.

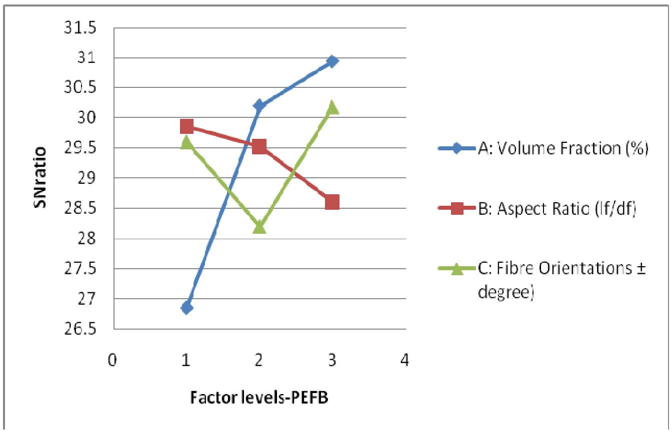
Table 6: Response Table for SN ratio and mean tensile strength of plantain empty fruit bunch fiber reinforced composites based on Larger is better quality characteristics

Response	Signal –to- Noise Ratios			Means of quality characteristic		
Level	A: Volume Fraction (%)	B:Aspect Ratio (lf/df)	C:Fiber Orientations (± degree)	A: Volume Fraction (%)	B:Aspect Ratio (lf/df)	C:Fiber Orientations (± degree)
1	26.85	29.85	29.60	22.54	31.67	30.78
2	30.19	29.52	28.19	32.79	31.85	26.52
3	30.93	28.60	30.18	35.40	27.21	33.43
Delta	4.08	1.25	1.99	12.85	4.64	6.90
Rank	1	3	2	1	3	2

Table 7: Response Table for SN ratio and mean tensile strength of plantain pseudo stem fiber reinforced composites based on Larger is better quality characteristics

Response	Signal -to -Noise Ratios			Means of quality characteristics		
Level	A: Volume Fraction (%)	B:Aspect Ratio (lf/df)	C:Fiber Orientations ± degree)	A: Volume Fraction (%)	B:Aspect Ratio (lf/df)	C:Fiber Orientations ± degree)
1	26.04	28.13	28.41	20.10	26.07	27.28
2	28.60	29.16	27.48	27.29	29.93	24.00
3	30.32	27.68	29.08	33.04	24.44	29.16
Delta	4.28	1.48	1.60	12.95	5.49	5.16
Rank	1	3	2	1	2	3

The average SN ratios and mean of means of the response tables are plotted against test levels for each of the three control parameters. In figure 2-5 it is found that factor A which is the volume fraction of fibers has a stronger effect on SN ratios and mean of means than the other two control factors and hence more significant than other two control factors.



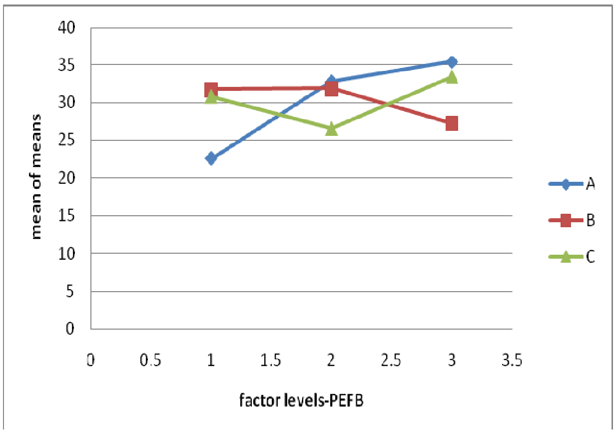
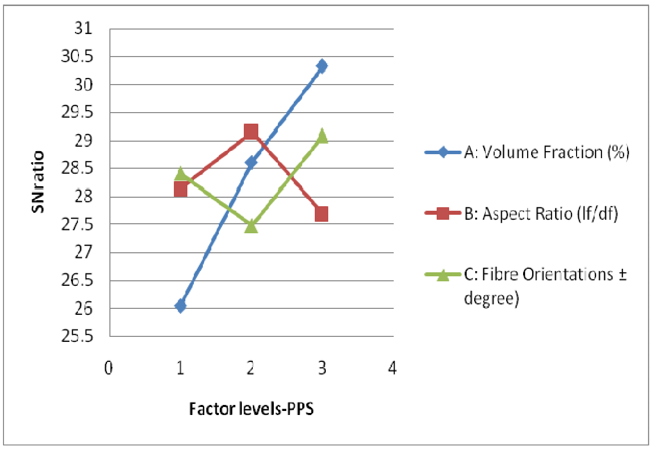


Figure 2: Main effect plots for signal-noise ratio-PEFB **Figure 3: Main effect plots for means ratio-PEFB**



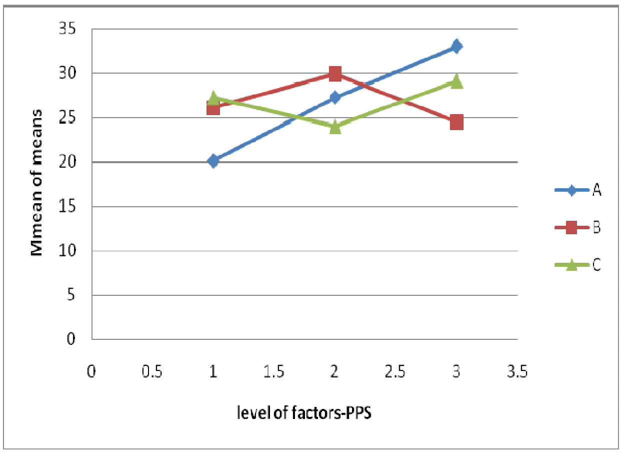


Figure 4: Main effect plots for signal-noise ratio-PPS **Figure 5: Main effect plots for means-PPS**

4.2 Estimation of expected tensile responses based on optimum settings

According to Radharamanan and Ansui (2001), 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 (4):

$$EV = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + \cdots + (n^{th}_{opt} - AVR) \qquad (4)$$

Where, EV= expected response, AVR = average response, A_{opt} = mean value of response at optimum setting of factor A, B_{opt} = mean value of response at optimum setting of factor B, C_{opt} = mean value of response at optimum setting of factor C, So that for the empty fruit bunch and from figures 2 and 3 and table 5:

$$EV_{EFB\ Tensile} = 30.2 + (35.4 - 30.2) + (31.85 - 30.02) + (33.43 - 30.2) = 40.28MPa$$

The expected responses is similarly computed for pseudo stem and presented in table 8. As a result of plots of figures 2-5 one can conclude that the optimal settings of control parameters are as presented in table 8

Table 8: Optimum setting of control factors and expected optimum strength of composites

Composite and property	Control factor	Optimum level	Optimum setting	Expected optimum strength
Empty fruit bunch /tensile	A	3	50	40.28MPa
	B	1	10	
	C	3	90	
Pseudo stem/tensile	A	3	50	38.51 MPa
	B	2	25	
	C	3	90	

4.3 Regression model for optimum tensile strength

TENSILE STRENGHT (Pseudo Stem) = 15.7 + 0.324A - 0.054B + 0.0505C (5)

Table 9: Regression analysis for plantain pseudo stem fiber reinforced composites

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	15.684	4.876	3.22	0.024
A: Volume fraction (%)	0.32365	0.08221	3.94	0.011
B: Aspect Ratio (l_f/d_f)	-0.0543	0.1096	-0.50	0.641
C: Fiber orientations (± degree)	0.05047	0.05265	0.96	0.382
S = 4.02732 R-Sq = 76.9% R-Sq(adj) = 63.1%				

TENSILE STRENGHT (EFB) = 20.5 + 0.321A - 0.149B + 0.0693C (6)

Table 10: Regression analysis for plantain empty fruit bunch fiber reinforced composites

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	20.507	6.237	3.29	0.022
A: Volume fraction (%)	0.3213	0.1051	3.06	0.028
B: Aspect Ratio (l_f/d_f)	-0.1486	0.1402	-1.06	0.338
C: Fiber orientations (± degree)	0.06931	0.06735	1.03	0.351
S = 5.15122 R-Sq = 69.7% R-Sq(adj) = 51.6%				

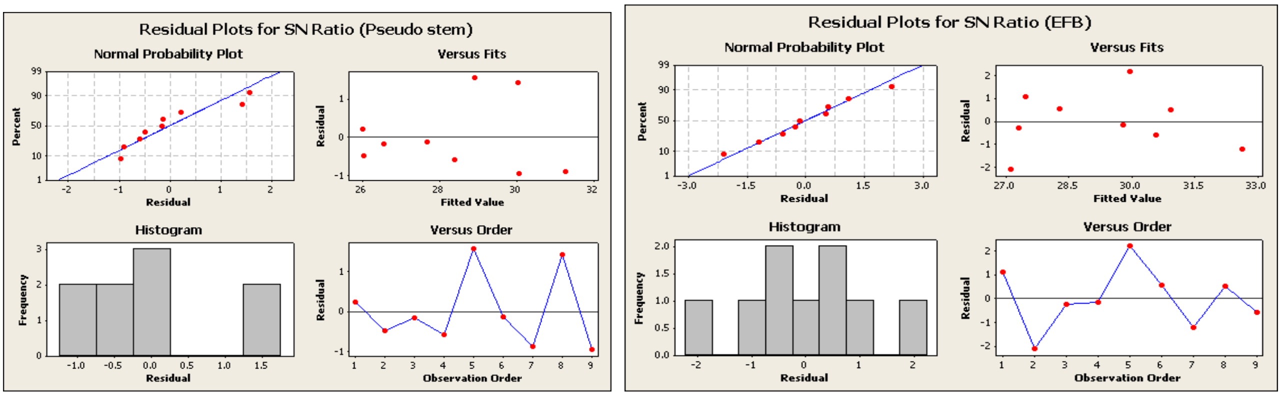


Figure 6: Residual plots of tensile strength SN Ratio for plantain Pseudo stem and plantain empty fruit bunch fiber reinforced composites

The coefficient of determination (R-Sq) is the proportion of variability in a data set that is accounted for by a statistical model of 5 and 6, it indicates that the predictors explain 76.9% and 69.7% of the variance in Tensile strength of plantain fiber reinforced composites when reinforcement is Pseudo stem and Empty fruit bunch respectively.

The plots of fig 6 include a run order plot, a lag plot, a histogram, and a normal probability plot. A residual plot is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; otherwise, a non-linear model is more appropriate. The residual plot shows a fairly random pattern, this random pattern indicates that a linear model provides a decent fit to the data. The data look fairly linear, although there might be a slight curve in the middle. Overall, linear regression is appropriate for these data at this level.

5. Conclusions

The mechanical properties of plantain fiber reinforced polyester matrix composite (PFRP) have been extensively studied with following deductions:

1. The empty fruit bunch fiber reinforced polyester matrix composite has the optimum tensile strength of 40.28MPa when the control factors (volume fraction of fibers, aspect ratio of fibers and fibers orientation) are set 50%, 10 and 90 degree respectively, while the pseudo stem plantain fiber reinforced matrix composite has the tensile strength of 38.51MPa when the control factors (volume fraction of fibers, aspect ratio of fibers and fiber orientation) are set 50%, 25 and 90 degree respectively.
2. The properties studied depend greatly on the reinforcement combinations of control factors.
3. The composites of empty fruit bunch are stronger in tension than that of pseudo stem.

6. References

Abdalla F. H., Megat M. H., Sapuan M. S. and B. B. Sahari (2008). determination of volume fraction values of filament wound glass and carbon fiber reinforced composites. ARPN Journal of Engineering and Applied Sciences. VOL. 3, NO. 4, pp. 7-11

Acott, Chris (1999). "The diving "Law-ers": A brief resume of their lives.". *South Pacific Underwater Medicine Society journal* 29 (1) pp 39-42.

ASTM D3171 "Fiber content of resin-matrix composites by matrix digestion".

Basavarajappa, S., G. Chandramohan, J.P. Dawim, (2007). Application of Taguchi techniques to study dry sliding wear behavior of metal matrix composites, Materials and design, 28: 1393-1398.

Binshan S. Y., Alrik L. Svenson and Lawrence C. Bank. (1995). Mass and Volume Fraction Properties of Pultruded Glass Fiber-Reinforced Composites. Research Report, Composites Volume 26 Number 10, Elsevier Science Limited, U.K.

Box GEP, Hunter WG, Hunter JS. (1978). Statistics for experimenters. New York: Jhon Wiley and Sons.; 291–334.

Box, G.E.P.; Hunter, J.S. (1957). Multi-factor experi-mental design for exploring response surfaces, Annals of Mathematical Statistics 28: 195-241. Cambridge University Press, Cambridge.

Clyne, T. W. and Hull, D. (1996). An Introduction to Composite Materials, 2nd ed.

Derek Hall, (1981) "An introduction to composite material", Cambridge University press

Food and Agriculture Organization. (1990). Production Yearbook 1990. FAO, Rome.

Food and Agriculture Organization. (2006). Production Yearbook 2004. FAO, Rome.

Jones R. M. (1998). Mechanics of composite materials. 2nd Ed. Edwards Brothers, Ann Arbor. Montgomery, D.C. (2009). Design and Analysis of Ex-periments; 7th edition. Hoboken, NJ: Wiley.

Mishra, S. K. and Singh, V. P.:(2004). Long-term hydrological simulation based on the Soil Conservation Service curve number, J. Hydrol. Process., 18, 1291–1313,

Oksman, K., M and J.F. Selin, (2003). Natural fibers as reinforcement in polylactic acid (PLA) composites. J. Comp. S. Skrivars ci. Technol., 63, pp 1317-1324.

Radharamanan, R and Ansuj, A.P (2001), "Quality Improvement of a Production Process using Taguchi Methods", Proceedings of Institute of Industrial Engineers Annual conference, Dallas, Texas, May 20-22, 2001, Paper Solutions.

Robinson J.C (1996). Bananas and Plantains. CAB International, UK. pp. 238

Swennen R (1990). Plantain cultivation under West African Conditions: A reference Manual. Int. Inst. Trop. Agric., Ibadan , Nigeria. pp. 24

Taguchi, G. (1993). Taguchi on Robust Technology Development: Bringing Quality Engineering Upstream. ASME. New York.

Taguchi, G. and Konishi, S., (1987). Orthogonal Arrays and Linear Graphs , American Supplier Institute Inc., Dearborn, MI.