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EVALUATION OF COMPRESSIVE AND ENERGY ADSORPTION CHARACTERISTICS OF NATURAL FIBER REINFORCED COMPOSITES (NFRC)

C. E Okafor

H. C. Godwin

Department of Industrial/Production Engineering, Nnamdi Azikiwe University Awka,

ABSTRACT: *The objective of this study targets a robust design and manufacture of natural fiber reinforced composites, the methodology has focused on the effective application of engineering strategies rather than advanced statistical techniques in optimization of plantain fiber reinforced polyester composites (PFRC) variables under compressive loading. Compressive Properties of PFRC were then evaluated based on ASTM D695-96; Crashworthiness of the new material was specified as an essential guide in vehicles and aircrafts design. At the optimal design level, the total Work Done per unit volume by PFRC was evaluated as 20.3* J/m^3*, while Specific Energy Absorption (SEA) is 0.019 J/kg. A simpler graphical technique of Taguchi methodology was utilized to determine which factors are significant and an orthogonal* L_8 (2^4) *experimental design applied to separate out the effect of each factor. Out of the five variables considered, the fiber material appeared to have a dominating influence on the compressive strength of PFRC followed by volume fraction of the fiber and then curing time of the composite. PFRC was found to have an optimal compressive strength of 109.062MPa. In general, the combination of Taguchi Design of Experiments (DOE) with studies on crushing energy and absorption characteristics has significantly improved the understanding of PFRC behavior under compression. The average value of specific work computed as 6.45E-03 J/kg represents the energy absorption limit and will be useful in selecting material during auto component design.*

KEYWORDS: Compression, Taguchi methods, Energy adsorption, Natural fiber, Total work

INTRODUCTION

Plantain production in Africa is estimated at more than 50% of worldwide production (FOA, 1990). Nigeria is one of the largest plantain producing countries in the world (FOA, 2006). Plantain fiber was then chosen in terms of its abundance availability as it is estimated that over 15.07 million tones of plantain is produced every year in Nigeria (Ahmed, 2004). Furthermore, plantain grows to its mature size in only 10months, where as wood takes a minimum of 10years (Xiaoya, Qipeng & Yongli, 1998). The fiber from the plantain empty fruit bunch and pseudo stem that are nowadays disposed as an unwanted waste, might be seen as a recyclable potential alternative to be used in polymeric matrix composite material (Satynarayana et al., 1987; Venkataswamy et al., 1987; Calado, Barreto and Dalmeida, 2000). The plantain plant (Musa Spp Acuminata) is a multivalent fiber producer; its fibers can be extracted from any part of the plant including the long leaf sheet and the pseudo-stem (Venkataswamy et al., 1987). Historically, plantain plant fiber has been used as a cordage crop to produce twine, rope and sackcloth. The current study on the compressive characteristics of plantain fiber reinforced composites was born out of the need to further utilize plantain fiber as a potential reinforcement for polyester composites. Plantain fibers can be obtained easily from the plants which are rendered as waste after the fruit have ripened; Ihueze, Okafor and Ujam (2012) has explored plantain fiber as a potential reinforcement for composites material, so the main aim of the current studies is to further investigate the use of plantain fibers with polyester matrix to improve the performance of engineering materials subjected to crash or compressive conditions and by so doing reduce the depletion in natural resources.

The output of this study will be considered to fit the criterion of sustainable design since, when compared with regular metals, it is expected to: (i) improve physical characteristics and structural performance thus requiring less material; (ii) reduce material and energy resources depletion; (iii) provide a material with better thermal property and therefore increase energy efficiency; and (iv) contribute to sustainable living through improving livelihood conditions of rural and farming communities by using agricultural or recycled waste products. The objective of this work therefore is to apply Taguchi methodology (Taguchi et al, 1990) in the study and optimization of compressive properties of plantain fiber reinforced polyester composite for application in auto body works.

Traditional approach to formulation of composite materials has not performed so well because a lot of factors contribute to the strength of a composite material (Ayşe and Kerim, 2012). The objective of the current research is composite-design improvement through the identifications of easily controllable factors and their settings, which minimize the variation in product response while keeping the mean response on target. By setting those factors at their optimal levels, the composites can be made robust to changes in operating and environmental conditions. Thus material performance variation can be reduced by exploiting the nonlinear effects of the material constituting parameters on the compressive strength of the composites. The primary goal of using Taguchi method is to keep the variance in the strength very low, even in the presence of noise inputs. Thus, the compressive strength is made robust against all variations (Roy, 2001). Two major tools used in the Taguchi method are the orthogonal array (OA) and the signal to noise ratio (SNR or S/N ratio). OA is a matrix of numbers arranged in rows and columns. In this array, the columns are mutually orthogonal. That is, for any pair of columns, all combinations of factor levels occur, doing so an equal number of times (Mavruz and Ogulata, 2010).

Many studies have been carried out on natural fiber reinforced composites (Anuar et al., 2006; Taşdemir et al., 2008; Kumar et al, 2009; Bushra et al., 2010), however a search of literature indicates little or no contribution on the robustification which is the process of finding and controlling inputs that contribute most to the random variability in the output of compressive characteristics of plantain fiber reinforced polyester composites. It becomes evident that since the operating environmental conditions are usually beyond the control of the product designers, this is the reason why traditional method that includes the use of mathematical calculations in formal engineering couldn't have performed any better, thus the application of Taguchi robust designs becomes essential. Sutharson, Rajendran, and Karapagaraj (2012) has experimentally investigated the compression strength of the natural fiber/glass reinforced polyester hybrid composites laminate and examined the influence of process parameters like stacking sequence, percentage of NaOH, treatment hours and oven curing time using Taguchi design method. Gaitonde et al. (2008) applied Taguchi's quality loss function approach for simultaneously minimizing the power and specific cutting force during turning of both PA6 and PA66 GF30 polyamides.

Taguchi's methods focus on the effective application of engineering strategies rather than advanced statistical techniques (Singh, Shan and Kumar, 2002; Mavruz and Ogulata, 2010). Taguchi views the design of a product or process as a three-phase program:

1. System design: This phase deals with the conceptual level, involving creativity and innovative research. Here, one looks for what each factor and its level should be rather than how to combine many factors to obtain the best result in the selected domain (Park and Ha, 2005).

2. Parameter design: At this level, once the concept is established, the nominal values of the various dimensions and design parameters need to be set. The purpose of parameter design is to investigate the overall variation caused by inner and outer noise when the levels of the control factors are allowed to vary widely. Quality improvement is achievable without incurring much additional cost. This strategy is obviously well suited to the production floor (Park and Ha, 2005; Taguchi, Chowdhury and Wu, 2005).

3. Tolerance design: This phase must be preceded by parameter design activities. With a successfully completed *parameter design*, and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions. This is used to determine the best tolerances for the parameters (Park and Ha, 2005; Zeydan, 2008). Taguchi methodology for optimization can be divided into four phases: planning, conducting, analysis and validation. Each phase has a separate objective and contributes towards the overall optimization process (Khosla, Kumar and Aggarwal, 2006; Roy, 2001).

REVIEW OF RELATED WORKS

Composites which is a combination of at least two different materials offer superior properties when compared to their essential components, the intended purpose is to produce a material which has superior properties that any of its components does not have (Ayşe and Kerim, 2012). The desired properties of matrix element therefore are work environment, strength, high stiffness, heat resistance and insulation (Milewski and Katz, 1998). In practice, the composite materials are generally planned to develop one or more of the following features: mechanical properties (modulus of elasticity, yield strength, tensile and compressive strength, hardness and impact resistance) (Anuar et al, 2006; Taşdemir et al., 2008; Kumar et al, 2009) corrosion resistance, fracture toughness, high temperature resistance, thermal conductivity or thermal resistance, electrical conductivity or electrical resistance, acoustic conductivity, sound conservatism.

Bushra et al (2010) reported that the development of strength in a composite depends on the existence of a strong interface, which can assure that the composite is able to bear load even after several fibers are broken because the load can be transferred to the intact portions of broken as well as unbroken fibers. According to Sutharson, Rajendran, and Karapagaraj (2012) the Taguchi method has produced a unique and powerful tool to improve composite materials quality. Since the product and process design has a great impact on the life cycle, the cost and performance of composite materials.

Herrera, Pillay and Vaidya (2003) made a study on the fiber-reinforced composites for automotive and transportation applications. They reported that improvements were seen in bending strength, bending modulus and fiber matrix interface of the banana / ecopolyester composites. Liu et al., (2004) reported that the compressive strength of unidirectional long fibre composites can predicted for plastic mi-crobuckling from a random two-dimensional distribution of fibre waviness, they further proposed an engineering model for predicting the compressive strength which is akin to weakest link theory for materials containing flaws. Large number of studies on natural fibers, especially, the natural fiber reinforced composite materials was conducted (Joshi et al., 2004; Netravali and Chabba, 2003) and results shows that the strength of composites depends greatly on the reinforcement combination.

In addition, many researchers have investigated the physical and mechanical properties of natural fiber reinforced composites (Wazzan, 2005; Kunanopparat et al., 2008; Kumar et al., 2009; Yuanjian, 2007; Anuar et al., 2006). However, since the strength of fiber reinforced composites depends of many variables (Ayşe and Kerim, 2012), finding an optimal combination of these constituting components remains a mirage using traditional method. Also the theoretical analysis of fiber reinforced composite plates by conventional/traditional methods poses some problems. Thus the vast applications of composites in automobile industries have emphasized the utilization of an efficient optimization technique for the formulation and analysis of composite materials. Therefore, to avoid these problems, an optimization technique developed by Taguchi (1986) has been applied to obtain an optimal setting for compressive strength of plantain fiber reinforced composites variables.

MATERIAL AND METHODS

Compressive Properties of plantain fiber reinforced polyester composites were evaluated based on ASTM D695-96, the block specimens has a nominal mass, volume and thickness of 0.006kg, $0.0000041m^3$, and 12.7mm respectively, the test was performed at 1.3 mm/s strain rate in a Haunsfield Tensometer. According to Mavruz and Ogulata (2010), Taguchi suggests that the response values at each inner array design point be summarized by a performance criterion called the signal to noise ratio. The S/N ratio is expressed in decibels (dB). Conceptually, the S/N ratio (η) is the ratio of signal to noise in terms of power. Another way to look at it is that it represents the ratio of sensitivity to variability (Taguchi, Chowdhury and Wu, 2005; Raymond, Andre and Geoffrey, 1992). The higher the SNR, the better the strength of the composites is.

Process Optimization Using Taguchi Method

Taguchi methodology is a powerful approach to optimizing the performance of the process using Taguchi's orthogonal arrays (OAs). The orthogonal array of $L_8(2^4)$ was chosen for the study based on the factors degree of freedom, it has 8 rows corresponding to the number of parameter combinations, with 4 columns at two levels as shown in Table 2. The idea is to maximize the SNR, thereby minimizing the effect of random noise factors, which have a significant impact on the composites strength (Zeydan, 2008; Palanikumar, 2006). Therefore, the method of calculating the S/N ratio depends on whether the quality characteristic is smaller-the-better, larger-the-better, or nominal-the-best (Taguchi, Chowdhury and Wu, 2005; Roy, 2001; Palanikumar, 2006; Ross, 1996).

Lower is better (flaws, trapped air etc.).

$$\frac{S}{N} = -10Log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

Higher is better (compressive strength).

$$\frac{S}{N} = -10\ Log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \tag{2}$$

Nominal is best (dimension, humidity etc.).

$$\frac{S}{N} = 10Log\left(\frac{\bar{y}^2}{s^2}\right) \tag{3}$$

Where n is the number of experiments in the orthogonal array and y_i the i^{th} value measured.

y^2 is the average of data observed and s^2 the variation. Detailed information about the Taguchi method can be found in many articles (Taguchi, Chowdhury and Wu, 2005; Roy, 2001; Ross, 1996). 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

$$(DOF)R = P * (L - 1) \tag{4}$$

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

(DOF)R = 5(2 – 1) = 5

Therefore, total DOF of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus L_8 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 8 experiments were performed based on the run order generated by the Taguchi model.

Crashworthiness defined as the resistance of a vehicle to protect its occupants from serious injury or death in accidents (Jacob et al., 2002). Therefore, it counts as an essential parameter for vehicles and aircrafts design and due to its importance, it has been a topic of researches for engineers and scientists over the years (Melo, Silva and Villena, 2008). In abroad range of automotive and aerospace applications collapsible impact energy absorbers as structure elements made of fibre reinforced composite materials are used (Thornton and Jeryan, 1988; Mamalis et al., 1997).

Total Work done in compression (W_T)

The area under the load-displacement curve represents the total energy absorbed and it can be calculated from the equation:

$$W_T = \int_{s_p}^{s} P_i ds \quad (5)$$

Where the P_i is the mean (average) crushing load, ds is the crushing distance. The SI unit for energy is the same as the unit of work – the joule (J). To explain the calculations of the work done, Hakim and Sultan (2010); Ihueze and Enetanya (2012) has proposed that the area under the stress-strain curve be divided into two regions. The first one is the pre-crushing and it is calculated by finding the area under the first section of the graph, the energy absorbed in the post-crushing stage is calculated as the area under the second region of the graph. Ihueze and Enetanya (2012) sees the energy absorbed during compression as that evaluated by first obtaining the graphics of stress-strain relationship and applying appropriate numerical method for the area under the graph.

Specific Energy Absorption (SEA)

The specific energy absorption (SEA) is the energy absorbed per the mass of the specimen and the SI units of the SEA is kJ/kg. Energy absorbed per unit mass (i.e. specific energy absorption) can be calculated from the equation:

$$SAE = \frac{W_T}{m} \quad (6)$$

Where

$$W_T = \int_{s_p}^{s} P_i ds \;=>\; P_m(D_f - D_i) \quad (7)$$

Energy absorbed per unit mass is given as

$$E_s = \frac{W_T}{M} \quad (8)$$

Design of Experiments

Experimental design is an important tool in composite materials research for improving the product realization process. The potential design factors (see table 1 and 2) were selected to investigate the best performance under given conditions.

Table 1- Main factors and Levels used in the experiment

Main Factors	Unit	Factor levels	
		Low (-)	High (+)
A. Volume fraction	(%)	20	50
B. Fiber Materials/reinforcement	-	Pseudo stem fiber (STEM)	Empty fruit bunch fiber (EFB)
C. Curing time	(hrs)	12	36
D. Post curing temperature	(^{o}C)	27	80
E. Fiber treatment	-	Untreated	Treated

Table 2. Standard $L_8(2^4)$ orthogonal array.

Exp	A	B	C	D	E
1	1	1	1	1	1
2	1	1	1	2	2
3	1	2	2	1	1
4	1	2	2	2	2
5	2	1	2	1	2
6	2	1	2	2	1
7	2	2	1	1	2
8	2	2	1	2	1

Evaluation of total work of compression

The amount of energy absorbed or work performed on the material per unit volume within the eight experimental plans proposed by Taguchi before and after crushing of manufactured composites material is presented in table 3.

Table 3. Computation of Total work done

EXP NO.	PRE-CRUSHING ENERGY(J/m^3) A_1	POST-CRUSHING ENERGY (J/m^3) A_2	TOTAL ENERGY $\sum \lvert A \rvert$ (J/m^3)
1	$\int_0^{0.029} (-3E+06x^3 + 78057x^2 + 2452.x + 3.610)\,dx = 1.2399$	$\int_{0.029}^{0.038} (-3E+06x^3 + 78057x^2 + 2452.x + 3.610)\,dx = 0.5315$	1.7714
2	$\int_0^{0.028} (52031x^3 - 13745x^2 + 7049x - 10.45)\,dx = 2.3780$	$\int_{0.028}^{0.043} (52031x^3 - 13745x^2 + 7049.x - 10.45)\,dx = 3.3696$	5.7476
3	$\int_0^{0.023} (6E+06x^3 - 53631x^2 + 13304x + 0.13)\,dx = 4.3707$	$\int_{0.023}^{0.041} (6E+06x^3 - 53631x^2 + 13304x + 0.13)\,dx = 10.4697$	14.8404
4	$\int_0^{0.019} (2E+06x^3 - 25545x^2 + 8830.x - 5.829)\,dx = 1.4898$	$\int_{0.019}^{0.04} (2E+06x^3 - 25545x^2 + 8830.x - 5.829)\,dx = 6.0761$	7.5659
5	$\int_0^{0.018} (-5E+06x^3 + 77647x^2 + 5536.x - 5.287)\,dx = 0.8214$	$\int_{0.018}^{0.036} (-5E+06x^3 + 77647x^2 + 5536.x - 5.287)\,dx = 1.6836$	2.505
6	$\int_0^{0.025} (4E+06x^3 - 38060x^2 + 10810x - 0.934)\,dx = 3.5472$	$\int_{0.025}^{0.043} (4E+06x^3 - 38060x^2 + 10810x - 0.934)\,dx = 8.8166$	12.3638
7	$\int_0^{0.023} (8E+06x^3 - 65126x^2 + 15792x + 4.801)\,dx = 4.5830$	$\int_{0.023}^{0.043} (8E+06x^3 - 65126x^2 + 15792x + 4.801)\,dx = 15.3348$	19.9178
8	$\int_0^{0.023} (-1E+06x^3 - 16258x^2 + 8741x - 0.422)\,dx = 2.1664$	$\int_{0.023}^{0.043} (-1E+06x^3 - 16258x^2 + 8741x - 0.422)\,dx = 4.6109$	6.7773

Following the methods of Ihueze and Enetanya (2012), the area under the stress-strain curve represents the total energy absorbed and it can be calculated by multiplying the area under the curve by the volume of the sample so that the work of the samples can be presented as in Table 8.

Evaluation of mean response

According to Ihueze, Okafor and Ujam (2012), Taguchi approach uses a simpler graphical technique to determine which factors are significant. Since the L_8 experimental design is orthogonal it is possible to separate out the effect of each factor. This is done by looking at the control matrix and calculating the average SN ratio ($SNav$) and mean (Mms) responses for each factor at each of the two test levels.

Estimation of expected responses and confirmation test

Once the optimal combination of process parameters and their levels was obtained, the final step in Taguchi methodology was to verify the estimated results against experimental value. The expected response is estimated using the optimum control factor setting from the main effects plots (Ross, 1988; Phadke, 1989; Radharamanan and Ansui, 2001; Ihueze et al., 2012); by employing the response table for for mean, the expected response model is as in equation (9):

$$\mathrm{C}_{opt} = m + (m_{\mathrm{Aopt}} - m) + (m_{\mathrm{Bopt}} - m) + (m_{\mathrm{Copt}} - m) + (m_{\mathrm{Dopt}} - m) + (m_{\mathrm{Eopt}} - m) \qquad (9)$$

Where

C_{opt} = expected Compressive response

m = average response

m_{Aopt} = mean compressive strength for parameter A at its optimal level

m_{Bopt} = mean compressive strength for parameter B at its optimal level

m_{Copt} = mean compressive strength for parameter C at its optimal level

m_{Dopt} = mean compressive strength for parameter D at its optimal level

m_{Eopt} = mean compressive strength for parameter E at its optimal level

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RESULTS AND DISCUSSIONS

Table 4. Experimental Design Matrix for compression test on Plantain Fiber Reinforced Polyester Composite

Exp no	A	B	C	D	E	Compressive strength (MPa)			Mean Compressive strength (MPa)	SN Ratio
						Trial # 1	Trial # 2	Trial # 3		
1	20	stem	12	27	untreated	83.36	83.65	83.08	83.363	38.4194
2	20	stem	12	80	treated	92.09	92.34	91.86	92.097	39.2848
3	20	EFB	36	27	untreated	104.16	107.24	108.81	106.74	40.5620
4	20	EFB	36	80	treated	110.64	110.21	111.07	110.64	40.8781
5	50	stem	36	27	treated	102.41	103.14	101.70	102.42	40.2070
6	50	stem	36	80	untreated	98.50	123.41	117.30	113.07	40.9437
7	50	EFB	12	27	treated	120.19	128.18	112.19	120.19	41.5586
8	50	EFB	12	80	untreated	111.33	110.32	112.34	111.33	40.9315

Figure 1. Main effect plot for mean

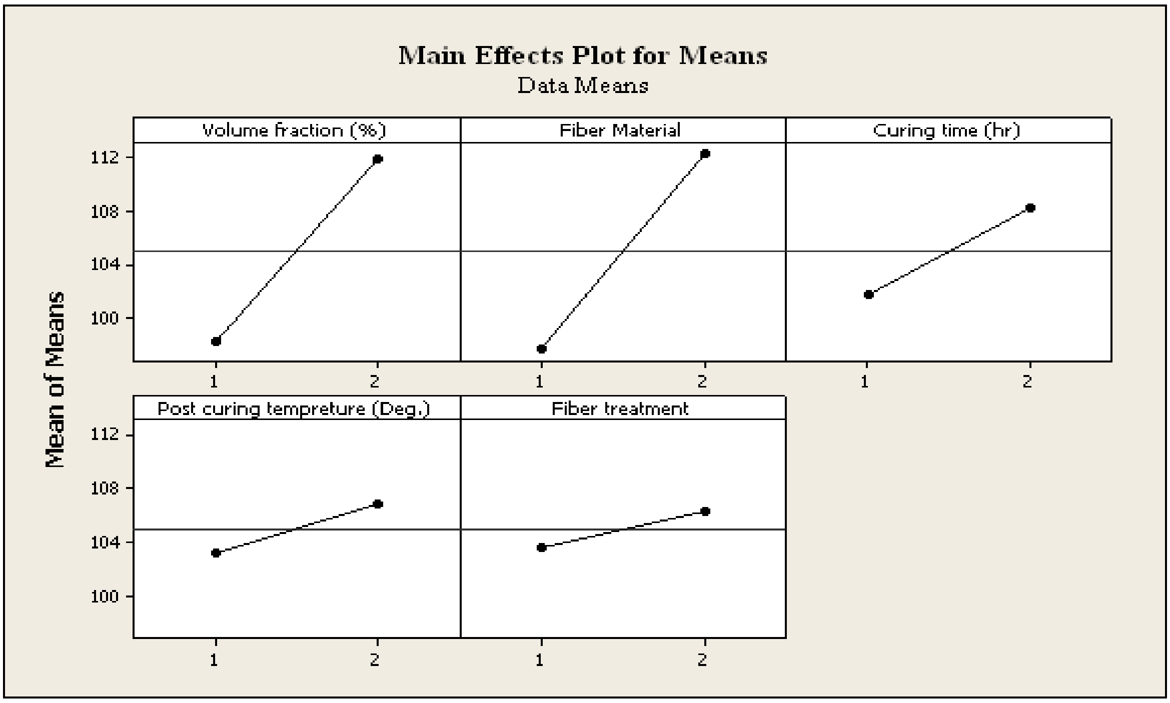
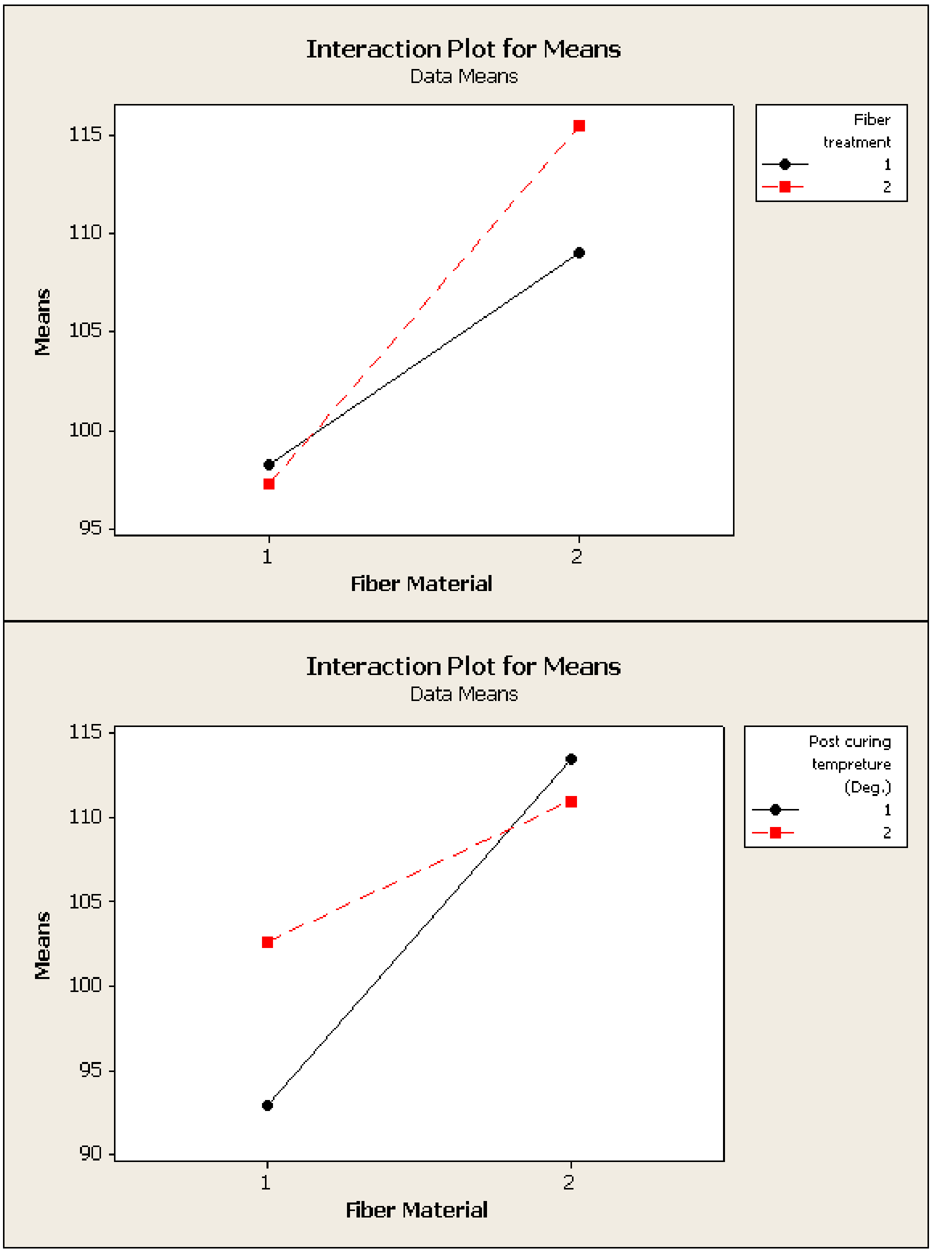


Figure 2. Interaction plots of fiber material with fiber treatment and post curing temperature for mean response



The interaction graphs are shown in Figure 2 and it is observed that the interaction of fiber material and fiber treatment shows significant effect on the compressive strength. Similarly the combination of factors $A_2B_2C_2D_2E_2$ gives maximum compressive strength shown in the Main effect plot of figure 1.

Table 5. Response Table for Means

Level	Volume fraction (%)	Fiber Material	Curing time (hr)	Post curing temperature (Deg.)	Fiber treatment
1	98.21	97.74	101.74	103.18	103.63
2	111.75	112.22	108.22	106.78	106.34
Delta	13.54	14.49	6.47	3.61	2.71
Rank	2	1	3	4	5

From table 5 the average mean response of contribution to compressive strength by the five factors is (111.75+112.22+108.22+106.78+106.34)/5 = 109.062

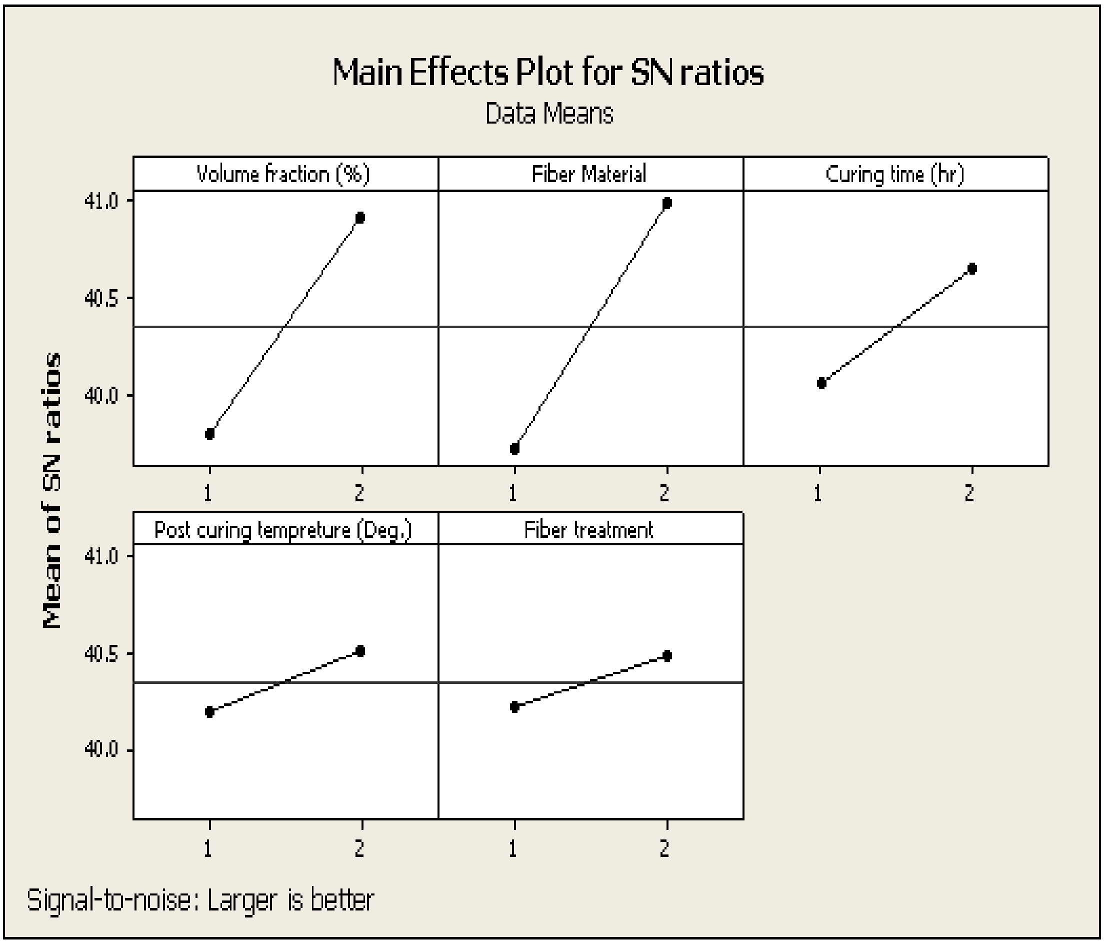


Figure 3. Main effect plots for SNratio

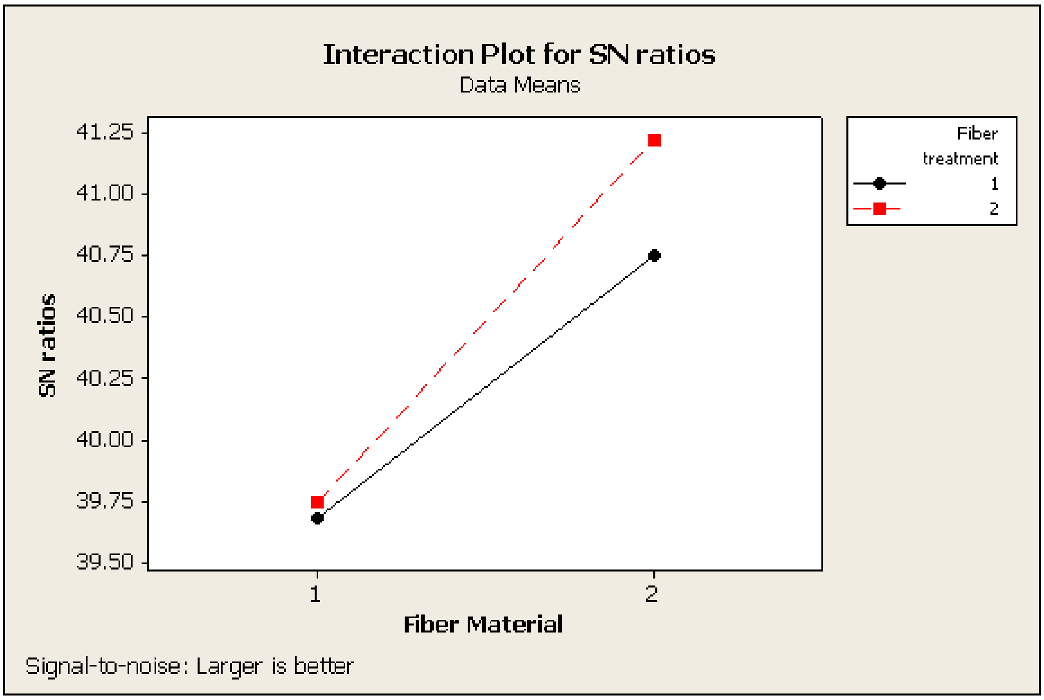


Figure 4. Interaction graph of fiber treatment and post curing temperature with fiber material for signal to noise ratio

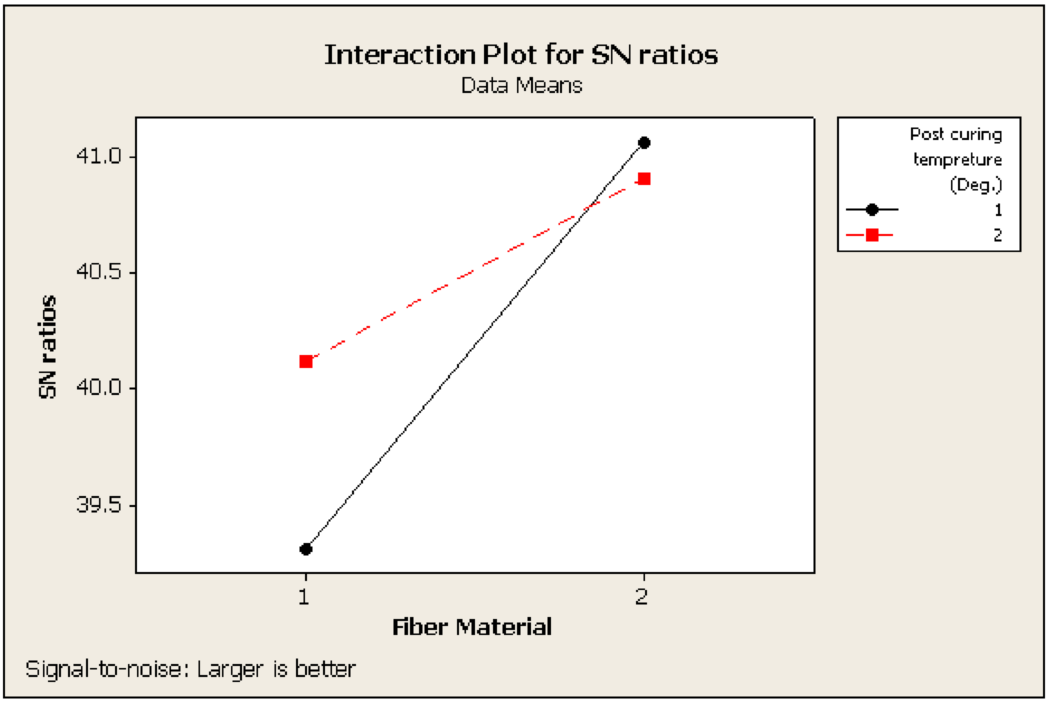


Table 6. Response Table for Signal to Noise Ratios (Larger is better)

Level	Volume fraction (%)	Fiber Material	Curing time (hr)	Post curing temperature (Deg.)	Fiber treatment
1	39.79	39.71	40.05	40.19	40.21
2	40.91	40.98	40.65	40.51	40.48
Delta	1.12	1.27	0.60	0.32	0.27
Rank	2	1	3	4	5

Based on the signal to noise ratio analysis, the optimum setting for compressive strength of plantain fiber reinforced composites will be A_2, B_2, C_2, D_2, E_2. The analysis indicated that fiber material has a dominating influence on the compressive strength of plantain fiber reinforced composites, followed by volume fraction of the fiber and then curing time of the composite.

Table 7. Optimum factor setting

Control factor	Optimum Level	Value
Volume fraction (%)	2 (High)	50
Fiber Material	2 (High)	EFB
Curing time (hr)	2 (High)	36
Post curing temperature (Deg.)	2 (High)	80
Fiber treatment	2 (High)	Treated

Expected responses and confirmation test

Optimal compressive strength (C_{opt}) is calculated based on equation (9) such that C_{opt} = 109.062 + (111.75 - 109.062)+ (112.22 - 109.062)+(108.22 - 109.062)+(106.78 - 109.062)+(106.34 - 109.062) = 109.062MPa.

A confirmation test was required in the present case study because the optimum combination of parameters and their levels ie A_2, B_2, C_2, D_2, E_2. Did not correspond to any experiment of the orthogonal array. A confirmation test was therefore conducted using the optimal combination and following the same methodology as adopted in this study; the value of mean compressive strength obtained from the experiment was then compared with the estimated value. It can be seen that the difference [(EST/EXP-1)*100] between experimental results and estimated result is only 0.11%, this indicates that the experimental value of compressive strength is very close to the estimated value.

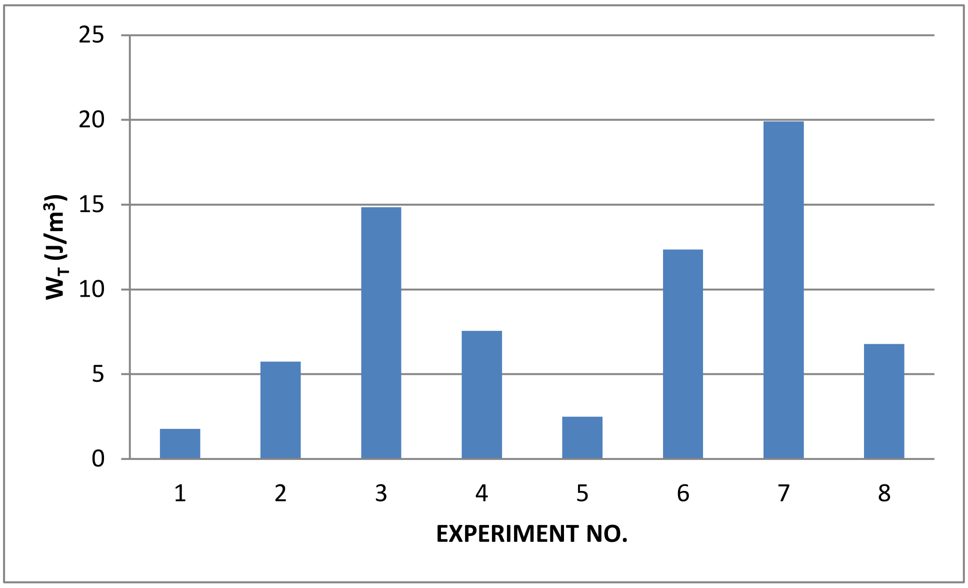
The optimum compressive strength of 109.17MPa for plantain fiber reinforced polyester composites indicates that reinforcing with plantain empty fruit bunch gives an improved strength, this is because when compared with the results of Bushra et al (2010) who studied the Mechanical Properties For Unsaturated Polyester (UP) Reinforced by Natural Fibers and found the compression values for the virgin (UP) and pseudo- stem banana woven fabric reinforced (UP) composite, which are 95.5 MPa and 107 MPa respectively.

Table 8. Work absorption (W_T) and specific energy absorption (SEA) data in relation to mean compressive strength (MPa)

Exp No	Mean Compressive strength (MPa)	SN Ratio	TOTAL ENERGY $\sum \|A\|$ (J/m^3)	W (J)	SEA (kJ/kg)
1	83.363	38.4194	1.7714	2.35652E-05	0.003928
2	92.097	39.2848	5.7476	6.08456E-05	0.010141
3	106.74	40.5620	14.8404	3.10202E-05	0.00517
4	110.64	40.8781	7.5659	1.02705E-05	0.001712
5	102.42	40.2070	2.505	5.06916E-05	0.008449
6	113.07	40.9437	12.3638	8.1663E-05	0.01361
7	120.19	41.5586	19.9178	2.77869E-05	0.004631
8	111.33	40.9315	6.7773	2.35652E-05	0.003928

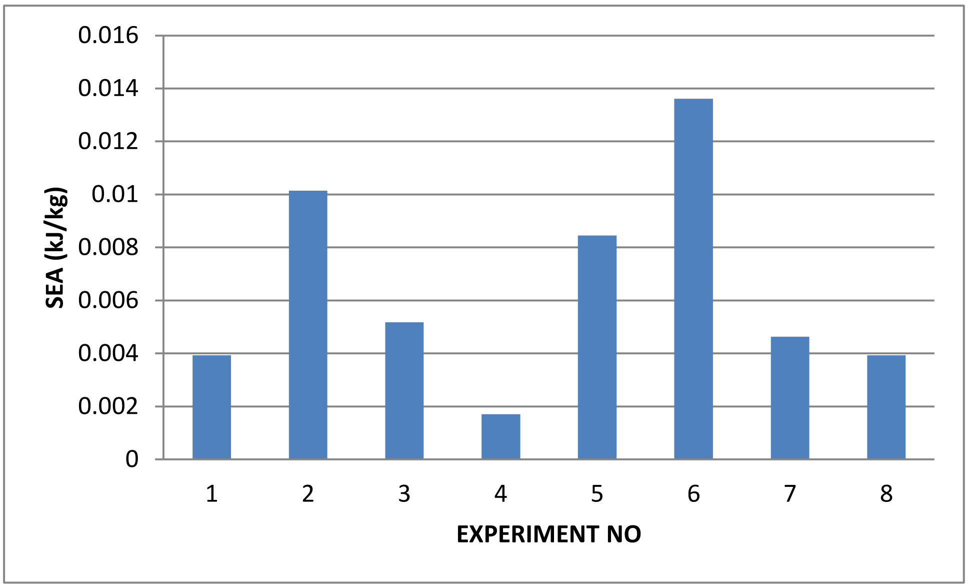
The total energy absorbed as a function of the specimen volume is shown in table 8. This energy was obtained by numerical integration of stress-strain curve. From the eight experiments performed based on Taguchi design, it is found that material combination of experiment seven subjected to axial compressive load has the maximum total energy absorption per unit volume of 19.9178 J/m^3 as shown in Figure 5. While the material combination of experiment one exhibits the minimum value of total energy absorption of 1.7714 J/m^3. Since tested specimens are different from each other with respect to their material combination, specific energy absorption (SEA) was found to be the suitable parameter to compare between the eight structural materials.

Figure 5. Total Energy Absorption (TEA) of the specimens.



The specific energy (SEA) that is dependent on the structure material combination was used for comparing the energy absorption of specimens resulting from the eight experiment plan as shown in Figure 6. The material combination of experiment six exhibits maximum specific energy absorption of 0.01361 kJ/kg, followed by experiment two (0.010141 kJ/kg) and Experiment five produced (0.008449 kJ/kg); the material combination of experiment four which came in last position has SEA of 0.001712 kJ/kg.

Figure 6. Specific Energy Absorption (SEA) within the eight experimental plan.



The average specific work SEA_{ave} is therefore calculated from table 8 as 6.45E-03 J/kg. The correlations between the factors and the compressive strength of plantain fiber reinforced composites were obtained by multiple linear regression. The regression models for optimum

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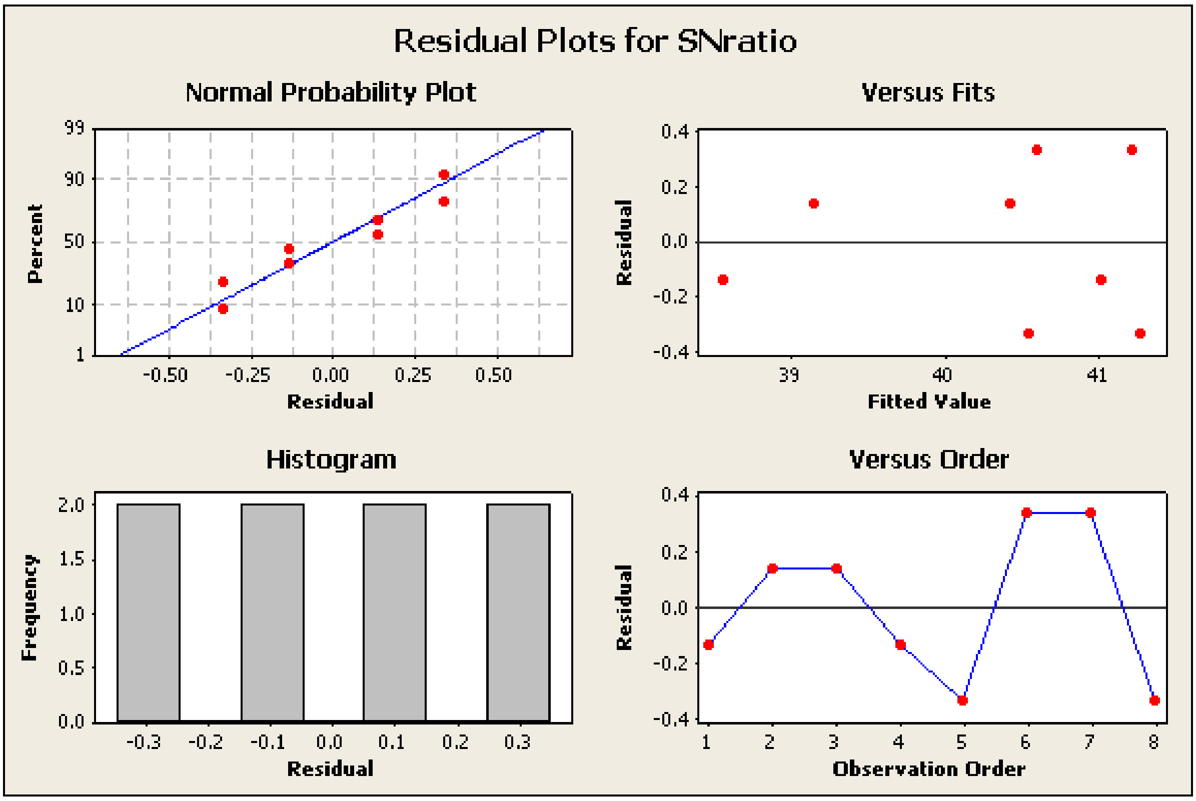
compressive strength of plantain fiber reinforced polyester matrix is as presented in equation 10.

Compressive strength = 43.8 + 13.5 A + 14.5 B + 6.47 C + 3.61 D + 2.71 E (10)

The coefficient of determination (R-Sq) is the proportion of variability in a data set that is accounted for by a statistical model of 10, it indicates that the predictors explain 90% of the variance in compressive strength of plantain fiber reinforced composites.

Figure 6. Residual plots of SN Ratios as independent variable



The plots of fig 6 include a run order plot, a lag plot, a histogram, and a normal probability plot. The plot 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. However, 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.

CONCLUSIONS

Composite materials have become common engineering materials and manufactured for different applications including aerospace parts, and automotive components. In this study, Taguchi Method has been successfully used and designed to optimize compressive strength of our experimental composite materials. The experiment conducted with the Taguchi method has also demonstrated that factor A_2, B_2, C_2, D_2, and E_2 are strongly recommended to the optimal condition. In the first series of trials, the combination of Taguchi Design of Experiments (DOE) with studies on crushing energy and absorption characteristics has significantly improved the understanding of plantain fiber reinforced composites materials learning. Taguchi's design of experiment method can be used to analyze the compressive strength of plantain fiber reinforced polyester composites as presented in this work. The following conclusion can be drawn from this work.

- Fabrication of fiber reinforced composites consisting of plantain fiber reinforcement in polyester matrix is possible.
- Taguchi Design of experiments method enabled successfully to analyze the compressive behavior of the composites with Volume fraction (%), Fiber Material, Curing time (hr), Post curing temperature (Deg.) and Fiber treatment as test variables.
- The predictive equations based on Taguchi approach is successfully used for the prediction of effect of various factors and predicted results are consistent with experimental observations. Therefore predicted results are satisfactory.
- Factorial design of the experiment can be successfully employed to describe the compressive characteristics of the composite samples and to develop the linear equations for predicting compressive strength with selected experimental conditions.
- From table 8, the type of fiber material is seen to contribute the most to the compressive strength of the composites.
- Confirmatory experiments were conducted to compare the predicted compressive properties with the experimental values of and good agreement between the predicted and experimental results were observed accounting for only 0.11 % difference..

FUTURE WORK

Future work may focus on other variables that were not considered in this study. Factors like rate of accetelation of fiber, fiber treatment at different levels of NaOH solution, fiber stacking sequence, Length of fibers etc.

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