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Optimal Design for Flexural Strength of Plantain Fibers Reinforced Polyester Matrix

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Abstract: This study considered the controlling factors, volume fraction of fibers (A), aspect ratio of fibers (B) and fibers orientation (C) in the determination of flexural strength of plantain fibers reinforced polyester composites (PFRP). These properties were determined for plantain empty fruit bunch fibers reinforced polyester matrix (PEFBFRP) and plantain pseudo stem fibers reinforced polyester (PPSFRP). Flexural tests were conducted on the replicated samples of PEFBFRP and PPSFRP respectively using Archimedes principles in each case to determine the volume fraction of fibers. To obtain the optimum properties being investigated for the results of the mechanical tests obtained using a Monsanto tensometer were used to establish the control factor levels needed to optimize the mechanical properties being investigated. The optimum values of the control factors were established for empty fruit bunch composites and for pseudo stem fiber composite. The empty fruit bunch fiber reinforced polyester matrix composite has the maximum flexural strength of 42.40MPa, while the pseudo stem plantain fiber reinforced matrix composite has the maximum flexural strength of 41.16MPa. The finite element analysis showed that the composite sample subjected to 48.228MPa will deflect 14.569mm within its elastic limit while the use of FTIR spectroscopy confirms that PEFPRFP is stronger than PPSFRP.

Key Words: composite matrix, plantain fiber, flexural strength, robust design, pseudo stem, empty fruit bunch

INTRODUCTION

Plantain production in Africa is estimated at more than 50% of worldwide production (FAO, 1990). Nigeria is one of the largest plantain producing countries in the world (FAO, 2006). Bio composites composed of biopolymers derived from renewable resources and cellulose fibers have been gathering much attention from the stand point of protection of the environment from plastic disposal problem and saving petroleum resources (LaMantia and Morreale, 2011). Extensive research was carried out by various researchers through the years, on improving the fiber matrix adhesion by various fiber surface treatments (Shibata, Cao and Fukumoto, 2008; Oksman, Skrifvars and Selin, 2003; Arbeliaz, Fernandez, Valea and Mondragon, 2006; Avella et al., 2007; Sreekumar, Joseph, Unnikrishnan and Thomas, 2011; Sawpan, Pickering and Fernyhough, 2011). However, Kiran, et al, (2011) noted that these techniques were not cost effective and improvement in mechanical properties was limited in most of the cases. In addition to fiber/matrix adhesion, processing method and processing conditions are also the key elements that have profound influence on mechanical properties of bio composites, as natural fibers are thermally unstable.

Jiang and Hinrichsen (1999) investigated composites based on biologically degradable polyester amide and plant fiber and found good mechanical properties, such as sufficient water resistance and biodegradability. Ochi (2008) studied the effect of processing temperature on tensile and flexural strengths of unidirectional kenaf/PLA composites and found the optimum processing temperature to be 1600C. Takagi et al (2008) studied the effect of processing pressure on the flexural strength and moduli of the bio composites. They found an increase in flexural strength and modulus with increasing molding pressure. Medina *et al*. (2009) showed the dependence of mechanical properties of natural fiber reinforced composites on the process pressure. Rassmann *et al*. (2010) observed an increase in tensile and flexural strength with processing pressure.

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. One of the most important optimization processes is Taguchi method. 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, Chandramohan, Ashwin, Prabu and Mukund, 2006).

Hence an attempt is made to analyze the influence of composite formulation process parameters (volume fraction of fibre (A), aspect ratio of fibre (B) and fibre orientation (C)) on flexural properties of plantain fiber reinforced polyester composites. For this purpose, an inexpensive and easy to operate experimental strategy based on Taguchi's parameter design has been adopted to study the effect of various process (Kiran et al., 2011).

Taguchi methodology has already been successfully applied for parametric appraisal in the wire electrical discharge machining process (Mahapatra and Patnaik, 2007), drilling of metal matrix composites (Basavarajappa, Chandramohan, Ashwin, Prabu and Mukund, 2006) and wear behavior of polymer matrix composites and erosion response of hybrid composites (ISO, 1172). The present study aims at studying the influence of volume fraction (%), aspect ratio and fiber orientation plantain fiber reinforced composites using the Taguchi method, finite element analysis and Fourier transform infrared spectroscopy (*FTIR*)

Two standard approaches are usually adopted to examine fiber fraction in a composite, namely destructive and non destructive evaluation. 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 fibre fraction (ISO, 1172). Acid digestion methods have also been used for the measurement of carbon fibre volume fraction (Bio, 1991). However, various non destructive methods have been used (Simon and Strunk, 1987) including ultrasonic pulse propagation, x-radiography and dielectric constant measurements. However, this paper therefore presents a comprehensive procedure based on the Archimedes principle applicable in determination of volume fraction values for natural fibers.

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 Flexural strength (FS) at different reinforcement combination to achieve the optimum strength.

METHODOLOGY

The methodology of this study employs traditional and experimental design methods of Taguchi method to optimize the flexural strength of plantain fibre reinforced polyester composite. The finite element model is generated using ANSYS 10.0 software to validate the safe stresses for the application of the material. A 3D solid 45 brick element with 8 nodes with 3 degree of freedom is used to mesh the geometry of the specimen. A refined mesh is obtained with 3000 elements and 3640 nodes. The popular SHIMADZU Fourier transform infrared spectrometer was used to establish the effects of fibers modification and distinction amongst the two composites of the plantain fibers.

Plantain fiber extraction and Chemical treatment

The plantain fibre was mechanically extracted from both stem and empty fruit bunch. The fibres 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 (silane 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 implementation of the flexural test

(a) Plantain stem fiber

(b) Plantain empty Fruit Bunch Fiber

Figure 1: Depiction of plantain fibres types

Determination of fiber Volume Fraction through Archimedes principle

Evaluation of volume fraction of plantain fibers is achieved following the derivations from rule of mixtures based on the procedures of (Jones, 1998; Barbero, 1998) and implementation of Archimedes procedures (Barbero, 1998). Archimedes principle states that when a body is totally or partially immersed in a fluid, the up thrust on it is equal to the weight of fluid displaced. The volume of fluid displaced is the same as the volume of body immersed and the density of a known mass immersed can be evaluated.

The volume of composites and moduli are evaluated following the rule of mixtures and classical empirical relations. By expressing

$$M_c = M_f + M_R \quad (1)$$

$$V_f = \frac{M_f}{\rho_f} \quad (2)$$

$$V_R = \frac{M_R}{\rho_R} \quad (3)$$

$$V_c = V_f + V_R \quad (4)$$

By writing volume fraction of fibres as

$$V_{fr} = \frac{V_f}{V_c} = \frac{V_f}{V_f + V_R} \quad (5)$$

$$V_R = \left(\frac{1 - V_{fr}}{V_{fr}}\right) V_f \quad (6)$$

Also by involving density ratios

$$\frac{M_{f2}}{V_{f2}} = \frac{M_f}{V_f} \quad (7)$$

where

V_{fr} = volume fraction of fibres, V_f = actual volume of fibres related to composition and volume fraction, V_c = volume of composite related to moulding and approximately equal to volume of mould for specific test, V_{f2} = volume of fibres of a measurable mass determined through application of Archimedes principle, V_R = volume of resin or matrix material, M_{f2} = mass of fibres determined through application of Archimedes principle.

From equation (5)

$$V_f = V_{fr} V_c \quad (8)$$

and from equation (7)

$$M_f = \frac{M_{f2}}{V_{f2}} V_f = \frac{M_{f2}}{V_{f2}} (V_{fr}\ V_c) \quad (9)$$

Next is to determine the mass of resin for specific composition of a certain volume fraction by the expression,

$$M_c = M_f + M_R \quad (10)$$

But mass of composite is not known so that equation (6) can be expressed as

$$\frac{M_c}{V_c} = \frac{M_f}{V_f} + \frac{M_R}{V_R} \quad (11)$$

Equation (11) expresses the density of composite as related to density of fibers and density of resin so that by knowing the density of resign as ρ_R, the mass of resin for making a composite of a particular volume fraction can be expressed as

$$\rho_R = \frac{M_R}{V_R}, \qquad M_R = V_R \rho_R \quad (12)$$

V_c is determined with expected number of replicate samples and the depth of the mould as specified by ASTM standard in mind. Remember also that for a particular volume fraction that computations of V_f , M_f and M_R are made.

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 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 flexural tests using Hounsfield Monsanto Tensometer. The plantain stem and empty fruit bunch fiber reinforced composites were prepared for flexural ASTM D790M. 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 elastic moduli of the samples were thereafter determined from the plot while the flexural strength was determined using the following equation

$$\sigma_f = \frac{3FL}{2bh^2} \quad (13)$$

Where σ_f = flexural stress (MPa), F = load (N), L = span (mm), h = thickness of the specimen (mm), b = width of the specimen (mm).

Taguchi Robust design technique was applied for greater the better option of signal to noise ratio 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 SN ratio for the quality characteristics were evaluated and optimum control factor levels established for the parameters.

According to Ross (1998), the Taguchi method can be used when the objective of the experiment is “larger-better”, “smaller-better”, or “on-target-better” The S/N ratio for maximum (flexural strength) which comes under larger is better characteristic, was calculated as logarithmic transformation of the loss function as shown in equation (15)

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \qquad (14)$$

$$\frac{S}{N} = -10\, Log_{10}\,(MSD) \qquad (15)$$

DISCUSSION OF RESULTS

In this study the flexural strength of plantain fibres 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 fibre reinforced polyester composite were used to obtain the value of quality characteristics of flexural strength using different levels of control factors as in table1. Table 2 and table 3 show Taguchi DOE orthorgonal array and Design matrix implemented for the larger the better signal to nose ratio (SN ratio) that led to results of figure 3 and 6.

Table 1: Experimental outlay and variable sets for mechanical properties

S/N	PROCESSING FACTORS	LEVEL			UNIT	OBSERVED VALUE
		1	2	3		
1	A: Volume fraction	10	30	50	%	
2	B: Aspect Ratio (l_f/d_f)	10	25	40	mm/mm	Flexural Strength,
3	C: Fibre 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	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 flexural test signal -to-noise ratio for plantain empty fruit bunch fiber reinforced polyester composite is calculated with (3) using values of various experimental trials and presented as in table 3 so that for first experiment,

$$\text{SNratio}_{\text{exp 1}} = -10 \times \log\left\{\frac{1}{3}\left[\frac{1}{(32.01172)^2} + \frac{1}{(31.64063)^2} + \frac{1}{(31.26953)^2}\right]\right\} = 30.00371$$

Equation (14) is used in the computation of the mean standard deviation MSD as recorded in the following tables.

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 looking at the control matrix of table 4 and calculating the average SN ratio ($SNav$) and mean (Mms) responses for each factor at each of the three test levels following the methods of Ihueze, Okafor and Ujam (2012).

Table 3: Experimental design matrix for flexural test using composite made from plantain empty fruit bunch fiber reinforced polyester composite (ASTM D-790M)

Expt. No.	**A: Volume fraction (%)**	**B: Aspect Ratio (l_f/d_f)(mm)**	**C:Fibre orientations (± degree)**	**Specimen replicates response (MPa) Trial #1**	**Trial#2**	***Flexural* Trial #3**	**Mean *Flexural* response (MPa)**	MSD	S/N ratio
1	10	10	30	32.01	31.6	31.26	31.64	0.001	30.00
2	10	25	45	20.41	22.65	21.53	21.53	0.002	26.63
3	10	40	90	15.35	15.35	15.35	15.35	0.004	23.72
4	30	10	45	38.86	35.93	37.40	37.40	0.000	31.44
5	30	25	90	24.02	24.60	24.32	24.31	0.001	27.71
6	30	40	30	21.5	25.00	23.25	23.25	0.001	27.27
7	50	10	90	30.76	30.76	30.76	30.76	0.001	29.76
8	50	25	30	34.96	35.35	35.15	35.15	0.000	30.91
9	50	40	45	36.32	36.91	36.62	36.62	0.001	31.27

- **Evaluation of mean response**

Table 4: 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	31.64063	30.00371
2	1	2	2	21.5332	26.6385
3	1	3	3	15.35156	23.72305
4	2	1	2	37.40234	31.44464
5	2	2	3	24.31641	27.71673
6	2	3	1	23.25195	27.27991
7	3	1	3	30.76172	29.76021
8	3	2	1	35.15625	30.91978
9	3	3	2	36.62109	31.27407

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
$SNav1$	$(A_1 + A_2 + A_3)/3$	26.78842
$Mms1$	$(A_1 + A_2 + A_3)/3$	22.8418
$SNav2$	$(A_4 + A_5 + A_6)/3$	28.81376
$Mms2$	$(A_4 + A_5 + A_6)/3$	28.32357
$SNav3$	$(A_7 + A_8 + A_9)/3$	30.65135
$Mms3$	$(A_7 + A_8 + A_9)/3$	34.17969

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
$SNav1$	$(B_1 + B_4 + B_7)/3$	30.40285
$Mms1$	$(B_1 + B_4 + B_7)/3$	33.26823
$SNav2$	$(B_2 + B_5 + B_8)/3$	28.425
$Mms2$	$(B_2 + B_5 + B_8)/3$	27.00195
$SNav3$	$(B_3 + B_6 + B_9)/3$	27.42568
$Mms3$	$(B_3 + B_6 + B_9)/3$	25.07487

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
$SNav1$	$(C_1 + C_6 + C_8)/3$	29.40113
$Mms1$	$(C_1 + C_6 + C_8)/3$	30.01628
$SNav2$	$(C_2 + C_4 + C_9)/3$	29.78574
$Mms2$	$(C_2 + C_4 + C_9)/3$	31.85221
$SNav3$	$(C_3 + C_5 + C_7)/3$	27.06666
$Mms3$	$(C_3 + C_5 + C_7)/3$	23.47656

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 8 and 10. 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.

The Figure 3 shows the effect of factors on the responses. Increasing the fiber content increases the flexural strength of plantain empty fruit bunch fiber reinforced composites. A maximum of 40.9 % contribution is attained in the flexural strength as a result of increasing fiber volume fraction. It then follows that fiber volume fraction is the prominent parameter followed by fiber orientation (24.7 % contribution) and then aspect ratio contributing 23 %.

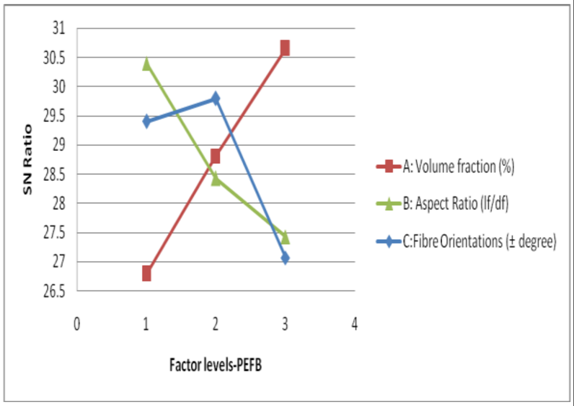

Figure 3: Main effect plots for signal-noise ratio-PEFBFRP

Based on the main effects plot of signal to noise ratio of figure 3, the optimum setting of composite parameters for the flexural strength of plantain empty fruit bunch fiber reinforced polyester composites and percentage contribution of each factor is compiles and presented in the graphics of figure 5

The flexural test signal-to-noise ratio for plantain pseudo-stem fiber reinforced polyester composite is calculated with (3) using values of various experimental trials and presented as in table 9 so that for first experiment,

$$SNratio_{Exp\ 1} = -\log\left\{\frac{1}{3}\left[\frac{1}{(32.01172)^2} + \frac{1}{(31.64063)^2} + \frac{1}{(31.26953)^2}\right]\right\} = 30.00371$$

Similarly, Equation (2) was utilized in the computation of the mean standard deviation MSD as recorded in table 9.

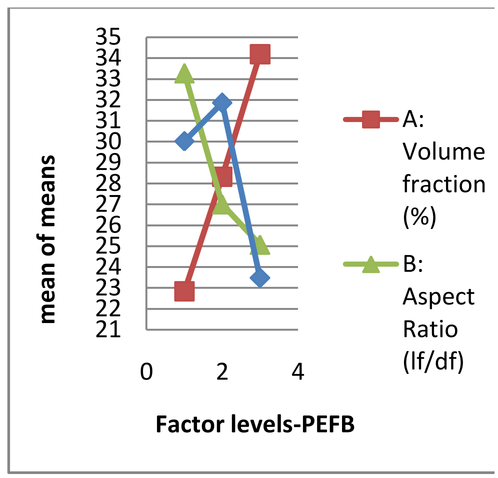

Figure 4: Main effect plots for Means-PEFBFRP

Table 8: Response Table for flexural strength of plantain empty fruit bunch fiber reinforced composites based on Larger is better quality characteristics

response	Signal to Noise Ratios			Means		
Level	**A: Volume fraction(%)**	**B: Aspect Ratio (lf/df)**	**C: Fibre Orientations ± degree)**	**A: Volume fraction(%)**	**B: Aspect Ratio (lf/df)**	**C: Fibre Orientations ± degree)**
1	26.79	30.40	29.40	22.84	33.27	30.02
2	28.81	28.43	29.79	28.32	27.00	31.85
3	30.65	27.43	27.07	34.18	25.07	23.48
Delta	3.86	2.98	2.72	11.34	8.19	8.38
Rank	1	2	3	1	3	2

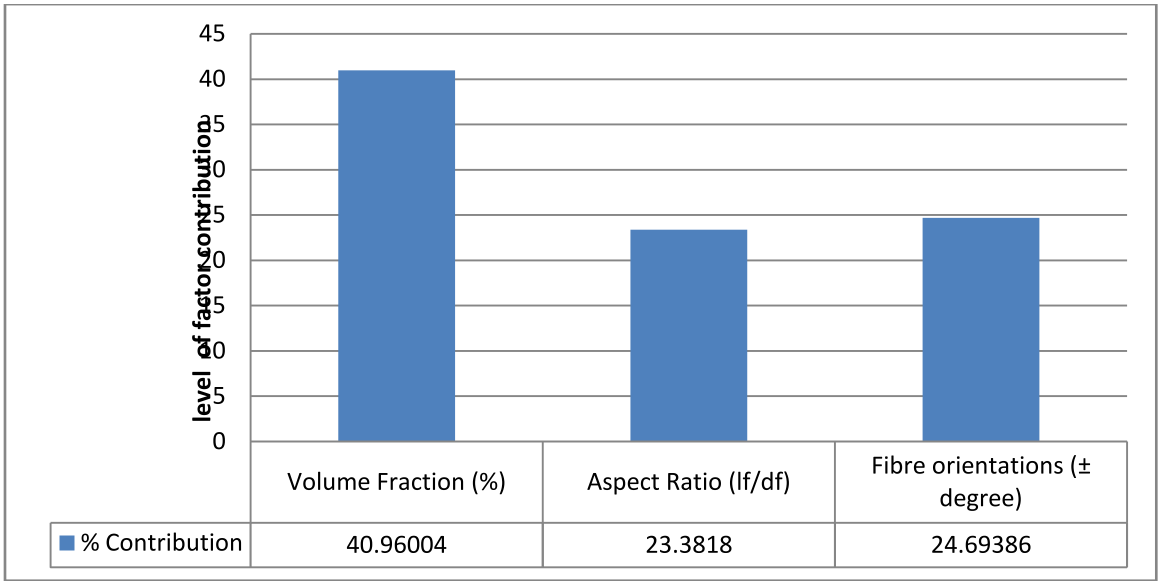

Fig 5: Percentage contribution of parameters on flexural strength

Table 9. Experimental design matrix for flexural test using composite made from pseudo-stem plantain fiber reinforced polyester composite (ASTM D-790M)

Expt. No.	**A: Volume fraction (%)**	**B: Aspect Ratio (l_f/d_f)(mm)**	**C: Fibre orientations (± degree)**	**Specimen replicates response (MPa) Trial #1**	**Trial#2**	***Flexural* Trial #3**	**Mean *Flexural* response (MPa)**	MSD	S/N ratio
1	10	10	30	32.01	31.64	31.26	31.64	0.001	30.00
2	10	25	45	15.23	15.42	15.33	15.33	0.004	23.71
3	10	40	90	12.30	12.50	12.40	12.40	0.006	21.86
4	30	10	45	36.91	33.80	35.36	35.36	0.001	30.95
5	30	25	90	22.26	23.63	22.95	22.94	0.002	27.20
6	30	40	30	15.35	18.75	17.05	17.05	0.004	24.54
7	50	10	90	30.76	36.91	33.84	33.84	0.001	30.51
8	50	25	30	30.76	30.76	30.76	30.76	0.001	29.76
9	50	40	45	31.05	29.29	30.17	30.17	0.001	29.58

Estimation of expected responses

The expected response is estimated using the optimum control factor setting from the main effects plots (Ross, 1988; Ihueze, Okafor and Ujam, 2012; Phadke, 1989). By employing the response table for signal to noise ratio and the response table for mean, the expected response model is as in equation (16):

$$\mathrm{EV} = \mathrm{AVR} + \left(\mathrm{A_{opt}} - \mathrm{AVR}\right) + \left(\mathrm{B_{opt}} - \mathrm{AVR}\right) + \left(\mathrm{C_{opt}} - \mathrm{AVR}\right) + \cdots + \left(\mathrm{n_{opt}^{th}} - \mathrm{AVR}\right) \qquad (16)$$

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 and presented in table 7

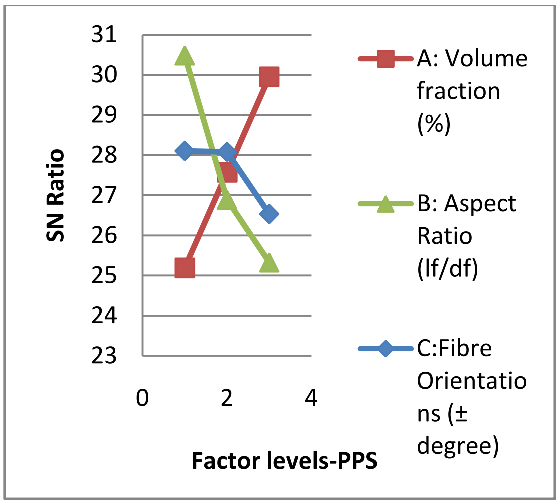

Figure 6: Main effect plots for signal-noise ratio-PPSFRP

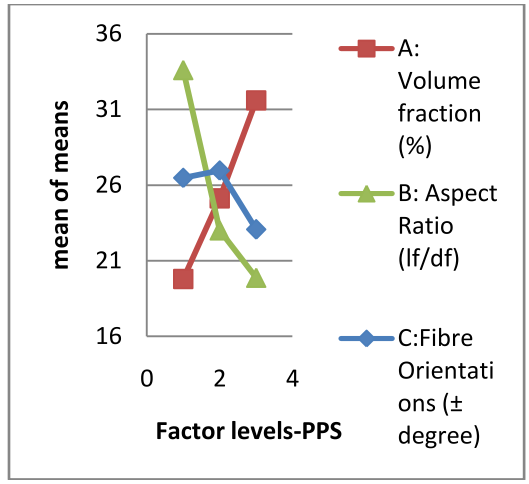

Figure 7: Main effect plots for means-PPSFRP

Table 10: Response Table for flexural strength of plantain pseudo stem fiber reinforced composites based on Larger is better quality characteristics

response	Signal to Noise Ratios			Means		
Level	A: Volume fraction(%)	B: Aspect Ratio (lf/df)	C: Fibre Orientations ± degree)	A: Volume fraction(%)	B: Aspect Ratio (lf/df)	C: Fibre Orientations ± degree)
1	25.19	30.49	28.10	19.79	33.61	26.48
2	27.57	26.89	28.08	25.12	23.01	26.96
3	29.95	25.33	26.53	31.59	19.88	23.06
Delta	4.76	5.16	1.57	11.80	13.74	3.89
Rank	2	1	3	2	1	3

Table 11: Optimum setting of control factors and expected optimum strength of composites

Composite and property	Control factor	Optimum setting	Expected optimum strength
Empty fruit bunch/flexural	A	50	42.4 MPa
	B	10	
	C	45	
Pseudo stem/flexural	A	50	41.16 MPa
	B	10	
	C	30	

VALIDATING RESULTS

This section tries to establish the difference between treated and untreated plantain fibers as well as the difference between the properties of plantain fibers composites using FTIR spectroscopy and finite element analysis to establish the safe stress of the composites.

- **ANSYS Finite Element Analysis**

The ANSYS results using ASTM790-10 standard of 2010, Total length = 300mm, Span =160mm = L, E = 9990.10and relevant equation of flexural stress and specimen geometry and Poisson's ratio of material of 0.38 gave the following results for PEFBFRP. The ANSYS finite element results are clearly depicted in figures 8-12 for minimum and maximum variables. Figure 8 shows the finite element model for composite analysis constructed with available data of sample while figure 9 depicts the maximum stress of 48.228MPa occurring at the extreme fibers in the x-direction and the minimum stress of -62.954MPa occurring ate inner fibers and at fixed end support. Figure 10 shows maximum deformation in x-direction as 14.569mm and figure 11 is a depiction of minimum stress of 14.569MPa occurring at mid span. Figure 12 is a vector plot depiction of maximum degree of freedom or maximum deformation or deflection occurring at the mid span of the composite sample. The finite element analysis then suggests that the composite sample subjected to 48.228MPa will deflect 14.569mm within its elastic limit.

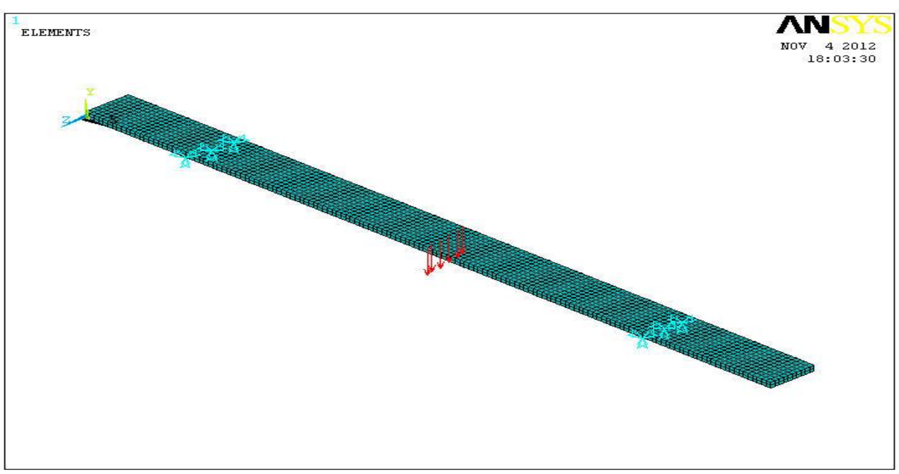

Figure 8: ANSYS Depiction of Finite element model of composite

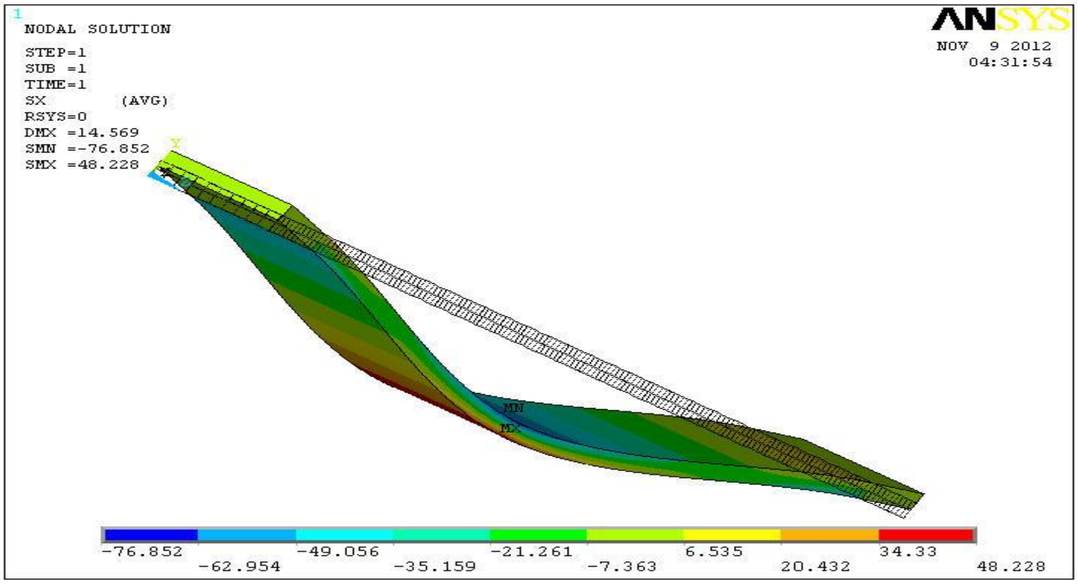

Figure 9: ANSYSIS depiction of bending, deflection and stresses

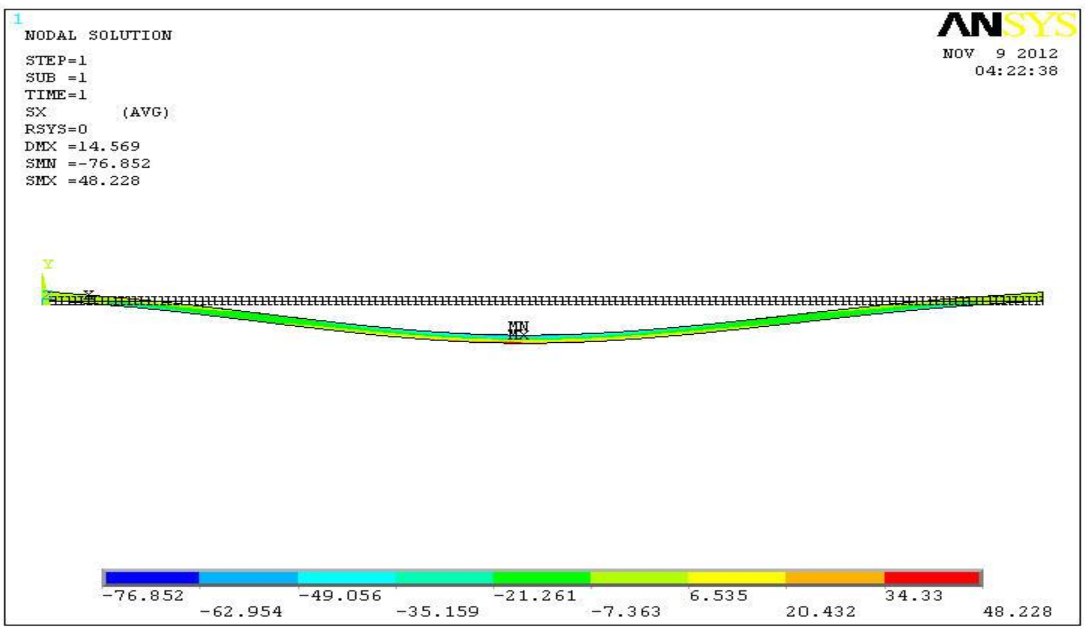

Figure 10: ANSYS depiction of composite variables with maximum deformation at x-direction

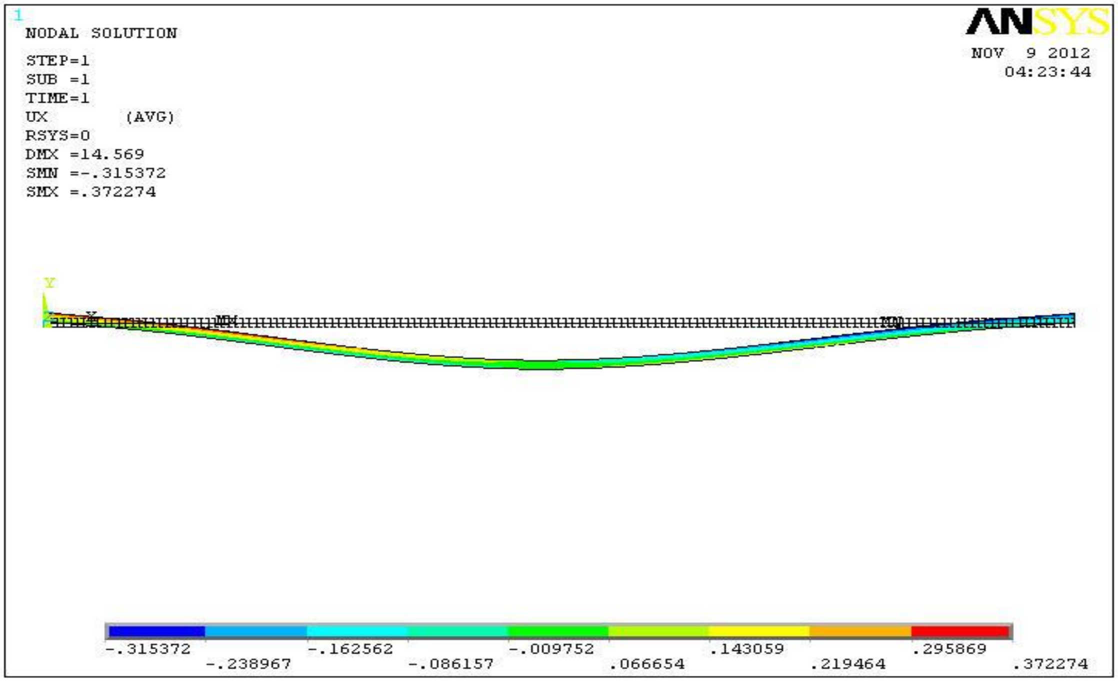

Figure 11: ANSYS depiction deformation for x-direction

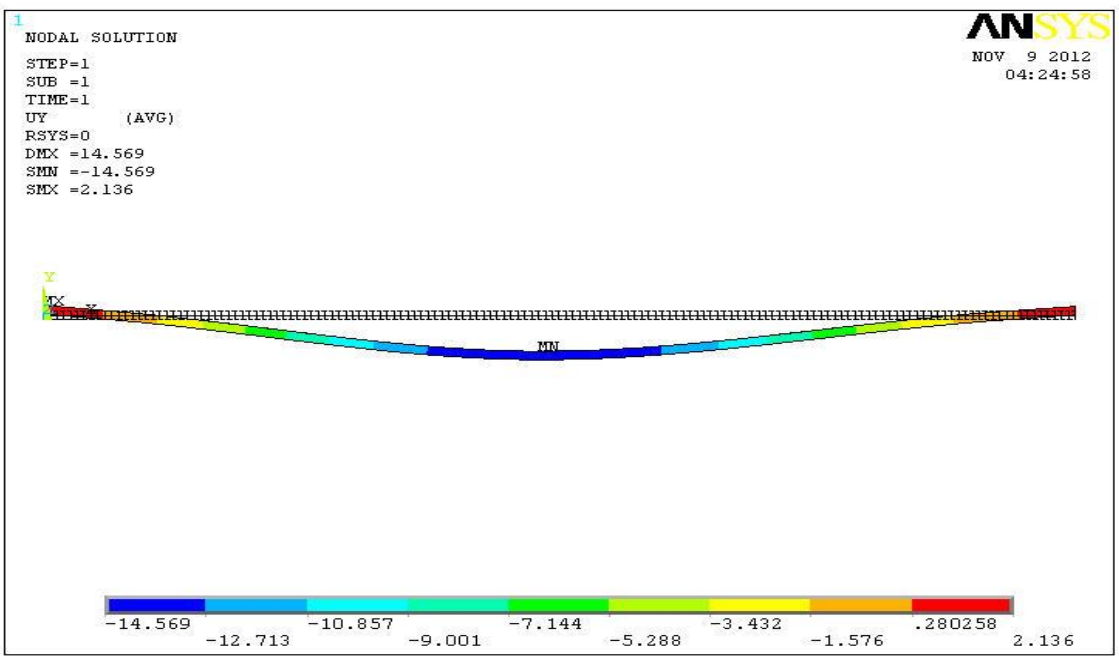

Figure 11: ANSYS depiction of minimum stress of -14.568MPa at mid span for y-direction

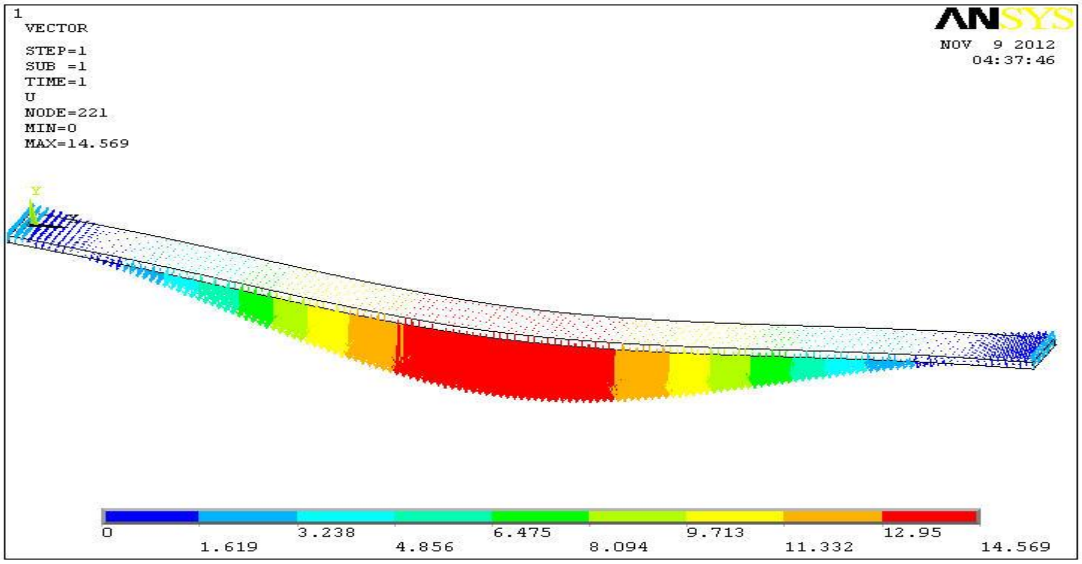

Figure 12: ANSYS depiction of vector plot and deformation

- **Fourier Transform Infrared Spectroscopy (FTIR)**

Nondestructive tests of Fourier transform infrared red spectroscopy (FTIR) was carried out on plantain fibers and composites of plantain to establish fibers modification with treatments that improved the strengths of fibers and composites. It must be recalled that low strength properties and water absorption which are addressed by fibers modification limit the application of natural fibers. FTIR spectroscopy measures molecular vibrations leading to bond stretching, bending and rotation. It measures the IR light absorbance of materials at wavelengths corresponding to wave numbers. The wave numbers of IR light absorptance of different functional groups are presented in Morisson and Boyd (2006), Kaplan (1993) and in Coates (2000).

Fibers modification is necessitated by the hydrophilicity and hygroscopicity of the inorganic fibers surfaces due mainly to the hydroxyl functional group, - OH of alcohols, acids and polysaccharides. The molecular structure of the in organic cellulose shows the presence of –OH functional group.

Figure 13 show clearly the presence of multifunctional vibration frequencies of molecular structures, and identifies clearly the presence of the hydroxyl functional group, -OH of interest at absorbance frequencies 3302.24cm^{-1}, 3348.61cm^{-1}, 3406.40cm^{-1} while figure 14 clearly show modification of the inorganic fibers by acetylating and silane treatment with the presence of absorbance frequencies of 1058.96cm^{-1} corresponding to ethers with C-O functional group and 3230.81 cm^{-1} and 3416.06cm^{-1} of amines (N-H), methacrylate.

Figure 15 is a clear depiction of absorbance frequency of 3435.34cm^{-1} with bond stretching for PEFBFRP with absorbance value of 48.12% while figure 16 shows bond stretching at 3441.12cm^{-1} with light absorbance of 45.692% for PPSFRP. The highest absorbance frequency of 3774.82cm^{-1} was recorded for PPSFRP with absorbance of 92.687%. This means that PPSFRP was mostly excited (vibrated) than PEFBFRP and accounts for the reason why PEFBFRP strength is better than that of PPSFRP and PEFBFRP is more stable than PPSFRP.

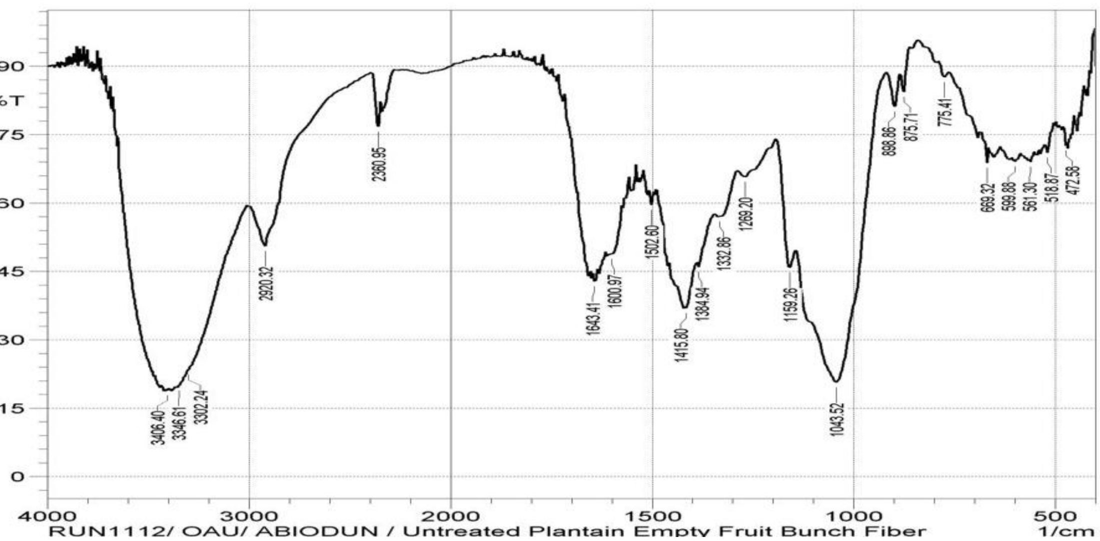

Figure 13: FTIR spectrum of untreated PEFBF

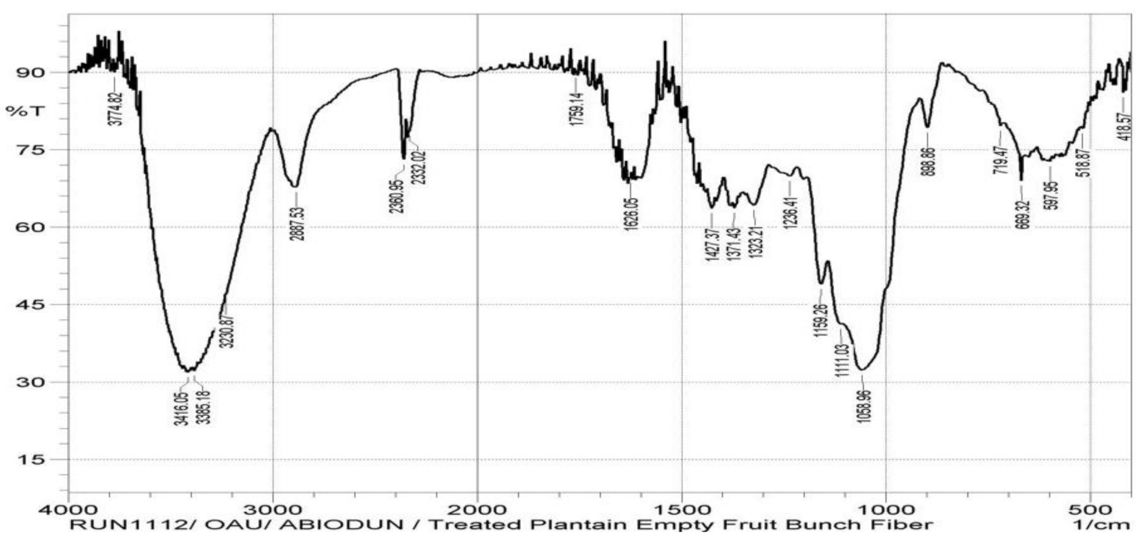

Figure 14: FTIR spectrum of Treated PEFBF

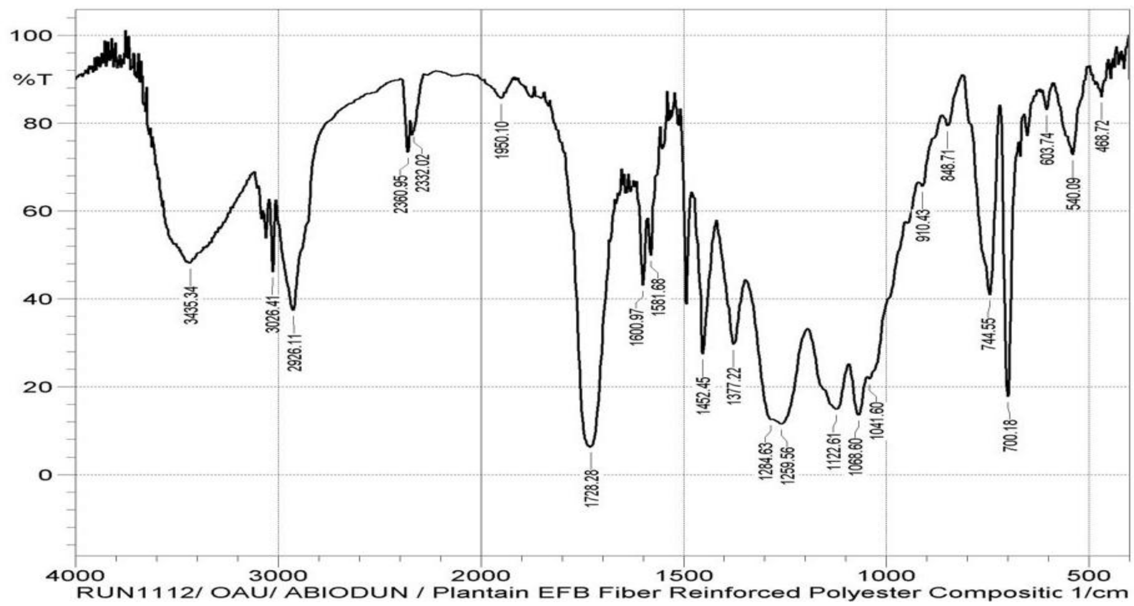

Figure 15: FTIR spectrum of PEFBFRP

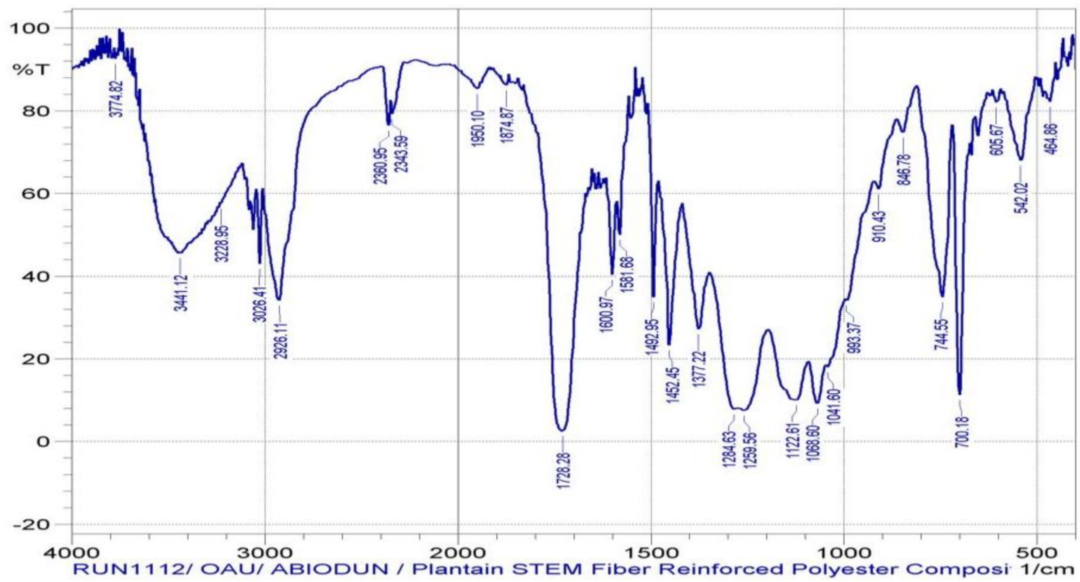

Figure 16: FTIR spectrum of PPSFRP

CONCLUSION

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

1. The empty fruit bunch fibre reinforced polyester matrix composite has the flexural strength of 42.4MPa when the control factors (volume fraction of fibres, aspect ratio of fibres and fibre orientation) are set 50%, 10 and 30degree respectively, while the pseudo stem

plantain fibre reinforced matrix composite has the flexural strength of 41.16MPa when the control factors (volume fraction of fibres, aspect ratio of fibres and fibre orientation) are set 50%, 10 and 30degree respectively.

2. The finite element analysis then suggests that the composite sample subjected to 48.228MPa will deflect 14.569mm within its elastic limit.
3. Light absorbance of materials can be used to characterize the strength of materials as light spectrum depends greatly on the type of materials.

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