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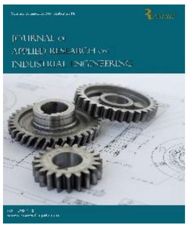

Optimization of Parameter Settings to Achieve Improved Tensile and Impact Strength of Bamboo Fibre Composites

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ABSTRACT

There is great interest in application of natural fibres, such as bamboo fibre, as reinforcement in composite production. Herein, to achieve high performance under optimum process conditions, experimental design and optimization techniques are used to investigate the best parameter settings for processing bamboo fibre polyester composites. Single response optimization of the properties of bamboo fibre polyester composites using Taguchi orthogonal array, analysis of variance and Post hoc test was carried out. The test samples comprised of untreated, mercerized, acetylated and mercerized-acetylated bamboo fibre composites at fibre contents of 10, 20, 30, 40, and 50 wt %. All composite samples were fabricated using conventional hand lay-up process on randomly oriented long bamboo fibres. It was found that optimum parameter setting for impact strength was achieved at mercerization treatment and 30wt% fibre content with impact strength of 158.23 J/cm. For flexural strength, optimum parameter setting was found to be mercerization treatment at 50 wt % level of fibre content which resulted to flexural strength of 62.7 MPa. The optimum parameter setting for tensile strength is observed at mercerized-acetylation treatment at 50 wt% fibre content with tensile strength of 72.96 MPa. However, no significant difference, ($P <.005$) was observed in flexural strength, tensile strength and impact strength of mercerized and mercerized-acetylated fibre composites. This study established a research approach to improve bamboo fibre composite properties for more extended applications and to obtain optimal operating conditions by using optimization techniques. It will also serve as a guide for composite manufacturers on parameter settings selection.

1. Introduction

Natural fibres such as bamboo fibre are of interest in composite production due to their renewable and ecological characteristics amongst other properties [1-5]. One natural fibre with a lot of potentials in composite production is Bamboo fibre. It is considered a promising renewable resource in composite production because of its high growth rate, ease of processing, multiple application potentials and high specific strength [6-9]. Though suitable as an engineering material, further research is necessary to

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improve bamboo properties for more extensive engineering applications [10, 11]. Besides, natural fibres differ in their chemical constituents and performance characteristics. Therefore, for each natural fibre and production process, there is need to obtain optimal parameter setting for improved composite properties. A possible research approach to improve bamboo fibre composite properties for more extended applications and to obtain optimal operating conditions is by using optimization techniques.

Thus, in this study Taguchi orthogonal array and analysis of variance were applied to determine the optimal parameter setting for improving tensile, flexural and impact strength of bamboo fibre/polyester composites. Applying design of experiment in production process can reduce production cost, time and result to products and processes with better function and high reliability [12-14]. It is anticipated that this study will provide a guide on factor setting for composite manufacturers.

2. Materials and Methods

2.1. Materials

Bamboo fibres were obtained from sound bamboo culms in a forest in Aba. Unsaturated polyester resin (average molecular weight of 2200, boiling point of 154°C, specific density of 1.194 g/cm^3 and viscosity 0.24 Pa.s at 25^{0}C) was purchased from Zhejiang Tianhe Resin Company Limited, China and used as matrix. Methyl Ethyl Ketone Peroxide (MEKP) and cobalt naphthenate were purchased from CAMIC chemicals, Aba and used as accelerator and catalyst, respectively.

2.2. Bamboo Fibre Extraction

Bamboo culms were split into strips of about 10 cm long and soaked in a solution containing 8% v/v sodium hypochlorite, 5% w/v sodium hydroxide and 0.5% w/v sodium chloride for 12 h at room temperature. Subsequently, to loosen the fibres, the bamboo strips were subjected to a pressure of 2 MPa in a hydraulic press. The fibres were extracted by manually scraping the pressed strips. Water was used to rinse the extracted fibres after which the fibres were dried in an oven at 60°C until a steady weight was obtained.

2.3. Experimental Design

Two operating parameters–treatment at four levels and treatment at five levels, were selected to assess the compressive and impact strength of the composites. The factors and their levels are given in *Table 1*.

Table 1. *Factors and level selection for composite formulation.*

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
Fibre content (PHR)	*10*	*20*	*30*	*40*	*50*
Surface modification	*Crude*	*Mercerized*	*Acetylated*	*Mercerized-Acetylated*	-

PHR = per hundred resins

Using Taguchi method, an L20-Othorgonal Array was selected for the study. *Table 2* contains the L20-OA design matrix generated by “Minitab” software.

Table 2. *L20-OA design matrix for composite formulation.*

Experiment Number	Treatment	Fibre Content
1	*1*	*1*
2	*1*	*2*
3	*1*	*3*
4	*1*	*4*
5	*1*	*5*
6	*2*	*1*
7	*2*	*2*
8	*2*	*3*
9	*2*	*4*
10	*2*	*5*
11	*3*	*1*
12	*3*	*2*
13	*3*	*3*
14	*3*	*4*
15	*3*	*5*
16	*4*	*1*
17	*4*	*2*
18	*4*	*3*
19	*4*	*4*
20	*4*	*5*

The sequence for Taguchi optimization in this study is as follows:

- Select factors.
- Select Taguchi orthogonal array.
- Conduct experiments.
- Measure the responses.
- Analyze results (Signal-to-noise ratio): The desirable parameter settings are determined through analysis of the "Signal-to-Noise" (SN) ratio where factor levels that maximize the appropriate SN ratio are optimal. There are three standard types of SN ratios depending on the desired performance response [15-17]. The following equations were used for the SN analysis.

$$\text{Smaller the better} = -10\log\frac{1}{n}\sum y_i^2. \tag{1}$$

$$\text{Nominal the best} = 10\log\frac{\bar{Y}^2}{S^2}. \tag{2}$$

$$\text{Larger the better} = -10\log\frac{1}{n}\sum\left(\frac{1}{{y_i}^2}\right). \tag{3}$$

These SN ratios are derived from the quadratic loss function and the unit is decibel (dB).

2.4. Composite Formulation

In composite production, polyester resins were used as matrix while bamboo fibres served as reinforcement. The bamboo fibre polyester composites were fabricated by conventional hand lay-up process followed by light compression moulding technique with five different fibre loading (10 wt, 20 wt, 30 wt, 40 wt and 50 wt Per Hundred Resins (PHR), which was coded as P1, P2, P3, P4, and P5 respectively). First, unsaturated polyester resin was mixed with 1wt% cobalt naphtenate accelerator and 1 wt% MEKP catalyst. Second, the fibres were placed in a mould and the resin mixture was poured evenly on the fibres and allowed to wet completely. Then, a load of 50 kg was applied over the mould for 12 h during the curing process of the composites. Third, the cast of composites were removed from the mould and post-curing was done at 80^0C for 4 hours. Silicon spray was used as a releasing agent for easy removal of cured composite panels from the mould. Lastly, the samples of proper dimensions, according to ASTM standards, were cut out as test specimens from the sheet.

2.5. Chemical Modification of Fibres

The fibres were subjected to mercerization, acetylation and mercerized-acetylation treatments and classified as mercized, acetylated and mercirized-acetylated, respectively. The untreated fibre samples were classified as crude.

2.5.1. Mercerization treatment of fibre

Alkali solution (8 wt% NaOH concentration) was prepared by diluting sodium hydroxide (NaOH) pellets in water. Bamboo fibres were immersed in the NaOH solutions for 60 min at 32^0C [18]. Thereafter, the fibres were washed under running tap water until all traces of excess alkali were completely removed. Then, the fibres were oven dried to a constant weight at 60^oC until a constant weight was achieved. The dried fibres were storedin plastic bags to avoid exposure to moisture.

2.5.2. Acetylation treatment of fibre

Non-catalyzed room temperature acetylation method was employed [19]. 10 g of fibres, from each run in the experimental design, was soaked in a beaker containing 200 ml of 15% acetic acid for 50 min. The fibres were then transferred to a beaker containing 200 ml of 5% acetic anhydride for 30 min. The fibres were removed from acetic anhydride and washed with running water until acid-free and dried to a constant weight in an oven set at 80^0C.

2.5.3 Mercerized-acetylation treatment of fibre

Bamboo fibres prepared using the mercerization method described in *Section 2.5.1* were subjected to acetylation treatment to produce mercerized-acetylated fibres.

2.6. Characterization of Bamboo Fibre Polyester Composites

2.6.1. Tensile test

Tensile strength testing of all specimens was conducted according to ASTME 8 on 15 mm × 200 mm × 3 mm composite samples. The gauge length between the two clamps was set at 100 mm. Three identical tests specimen for each section thickness per sample were tested at room temperature with a strain/loading rate of 5 mm/min using a computerized Instron Testing Machine (Model 3369). The test piece which is of gauge length 100 mm was fixed at the edges of the upper and lower grip of the Instron testing machine tensile force applied until failure.Load displacement plots were obtained on an X–Y recorder and the testing machine displayed the ultimate tensile strength and yield strength.

2.6.2. Flexural test

Flexural test were performed using 3-point bending method according to ASTM D790-03. During flexural test, rectangular specimens having dimensions of 100 mm x 20 mm x 3 mm was lied on support spans in Instron Testing Machine (Model 3369) and a load of 5 KN was applied to the centre of the specimen by the loading nose of the Instron machine producing a three point bending at a crosshead speed of 5 mm/min, at a room temperature. The test was stopped when a specimen broke. In each case, three samples were tested and the average value was reported.

2.6.3. Compressive test

The compressive test was carried out in accordance with ASTM D 695-96. The specimens were cut to 25mm x 25mm x plate thickness and then ground with carbide sand paperto obtain a smooth surface. The test was carried out in an Instron testing machine (Model 3369) equipped with a 50 kN load cell and a compression test fixture. Samples were placed on the machine and pressure was applied continuously at the rate of 2 mm/min until the samples failed. Three replicates were tested.

2.6.4. Impact strength test

Impact testing was done according to ASTM/A29M-15. The tests were carried out using Izod Impact Testing method on Hounsfield Impact Testing Machine (Tensometer Ltd., Croydon, England) on 75 mm x 15 mm x 3 mm samples. The specimen was notched at an angle of 45º from 28 mm end length of 75 mm. The specimen was subjected to impact blow and the amount of impact energy absorbed by the specimen was read off on a calibrated scale attached to the machine as a measure of impact strength in Joules.

3. Results and Discussion

3.1. Tensile Strength

The average tensile strength values measured from the experiment and their corresponding S/N ratios are listed in *Table 3*. The S/N ratios were calculated using *Eq. 3*. An L_{20} orthogonal array was used to collect the experimental data. Column 2 and Column 3 were used to represent the two control factors. The first factor, which is the treatments, contains 4 levels which were denoted by 1-4 while the second factor, which is the fibre content, contains 5 levels which were denoted by 1–5. *Table 4* contain the S/N ratio values of tensile strength by factor level. The level with the highest signal-to-noise ratio value is optimum level for the control factor. The results show that level 4 of treatment, which is mercerized-acetylation and level 5 of fibre content, which is P5 is the optimum factor combination for tensile strength of the composite. This corresponds to the main effect plot (See *Fig. 1*).

Table 3. *Factor level, mean tensile strength and their corresponding signal-to-noise level of bamboo fibre polyester composites.*

Exp. No.	Treatment	Fibre Content	Tensile Strength (Mpa)	S/N Ratio (dB)
1	*1*	*1*	*55.995*	*29.975*
2	*1*	*2*	*59.914*	*33.557*
3	*1*	*3*	*59.588*	*32.276*
4	*1*	*4*	*63.700*	*33.587*
5	*1*	*5*	*65.390*	*34.489*
6	*2*	*1*	*53.521*	*32.540*
7	*2*	*2*	*61.369*	*33.964*
8	*2*	*3*	*62.377*	*34.217*
9	*2*	*4*	*62.968*	*34.206*
10	*2*	*5*	*64.394*	*34.432*
11	*3*	*1*	*49.277*	*28.832*
12	*3*	*2*	*57.922*	*32.414*
13	*3*	*3*	*55.164*	*31.473*
14	*3*	*4*	*56.828*	*30.382*
15	*3*	*5*	*58.270*	*31.368*
16	*4*	*1*	*60.409*	*33.845*
17	*4*	*2*	*69.913*	*35.452*
18	*4*	*3*	*60.077*	*33.568*
19	*4*	*4*	*69.387*	*35.625*
20	*4*	*5*	*72.964*	*36.414*

Table 4. *Response for signal-to-noise ratios of tensile strength-larger is better.*

Level	Treatment	Fibre Content
1	*32.78*	*31.30*
2	*33.87*	*33.85*
3	*30.89*	*32.88*
4	*34.98*	*33.45*
5		*34.18*
Delta	*4.09*	*2.88*
Rank	*1*	*2*

3.1.1. Main and interaction effect of treatment and fibre content on tensile strength

Fig.1 shows the main effects of treatment and fibre contents on tensile strength. The main effect of mercerized-acetylated bamboo fibres on tensile strength (*Fig. 1a*) has the highest values, followed by that of mercerized fibre composites. Mercerized-acetylated fibre composite has the highest tensile strength with an average tensile strength of 66.5 MPa followed by mercerized fibre composites with average of 60.93 MPa for all levels of fibre content. Acetylated fibre composites show the lowest tensile strength among all treatments with an average of 55.49 MPa.

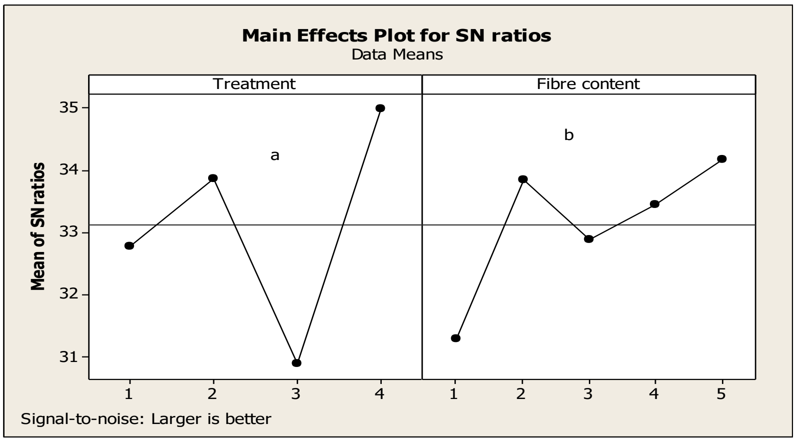

Fig. 1. *Main effect plot for signal-to-noise ratio of treatment and fibre content on tensile strength.*

Similar observation was made by [20] on rice husk-oil palm fibre hybrid composite where mercerization showed the highest tensile strength (the authors did not analyse tensile strength of mercerized-acetylated fibre composites). Mercerization produces better effect as it increases surface roughness and decreases the surface polarity. During mercerization, NaOH cleans the fibres surface by removing impurities, waxes and part of the lignin as lignin acts as a cementing substance that holds the fibre together [21]. Partial removal of lignin causes some debonding of the fibrils which leads to exposure or protruding of some of them. Such protrusion will produce mechanical bonding of the fibres and consequently, improve fibre-matrix interaction resulting to improved properties of the composite [22-25]. Similar observations were also made by [26] on bamboo fibre epoxy composites, [27] on 5% (w/V) NaOH treated coir fibre polyester composite and [28] on sisal polyester composite. Acetylated fibre composites exhibited the lowest tensile strength. Acetylation probably causes agglomeration of the filler, weakening the interfacial regions and making them less resistance to crack propagation. However, mercerizing before acetylation improves the tensile properties of acetylated fibre composites as this method blends the advantages of mercerization and acetylation to yield excellent tensile properties.

As shown in *Fig. 1b*, the tensile strength increases with increase in fibre content in the composite. For mercerized and mercerized-acetylated fibre composites, there is a marginal reduction in tensile strength at fibre content P3. Rashed et al. [29] made similar observation on jute fibre reinforced polypropylene composite. The authors observed an increase in tensile strength with increase in fibre content up to 10% fibre content. The increase in tensile strength was attributed to the reinforcing effect of natural fibres. However, they attributed the reduction in strength to poor dispersion of fibres in polymer due to strong inter fibre hydrogen bonding which holds the fibres together. Girisha et al. [30] also reported similar results.

A slight decrease in tensile strength is observed at P3 with subsequent increase up to the maximum fibre content of P5 for crude, acetylation and mercerization-acetylation (*Fig. 1b*). Similar observation, where tensile strength decreases after an initial increase, with further increase at very high fibre content, has been made by previous researchers [31-33]. However, Figure 1b shows that mercerized fibre composite showed a steady increase in tensile strength up to the maximum fibre content of P5.Tensile strength of

72.96 MPa was obtained at the optimal parameter setting. The tensile strength is comparable to the result of previous studies Prasanna et al. [34] reported maximum tensile strength of 19.8 MPa on sisal fibre polyester composite; Hussain et al. [35] reported maximum tensile strength of 15.06 MPa on bamboo fibre polyester composite. Neslihan et al. [36] observed a tensile strength of 35 MPa on bamboo fibre epoxy composite. Shito et al. [37] observed tensile strength of 35.1 MPa on single bamboo fibres MAPP composite. Chukwudi et al. [38] observed a maximum tensile strength of 23.50 MPa on Rafia palm polyester composites. Maximum tensile strength of 2 MPa was observed by [39] on sisal polyester composites while maximum tensile strengths of 52 MPa on banana fabric polyester composite and 39 MPa on cotton fibre polyester composites was observed by [40] and [41]. The interaction plots of treatment and fibre content on tensile strength are illustrated in *Fig. 2*. No appreciable interaction was observed.

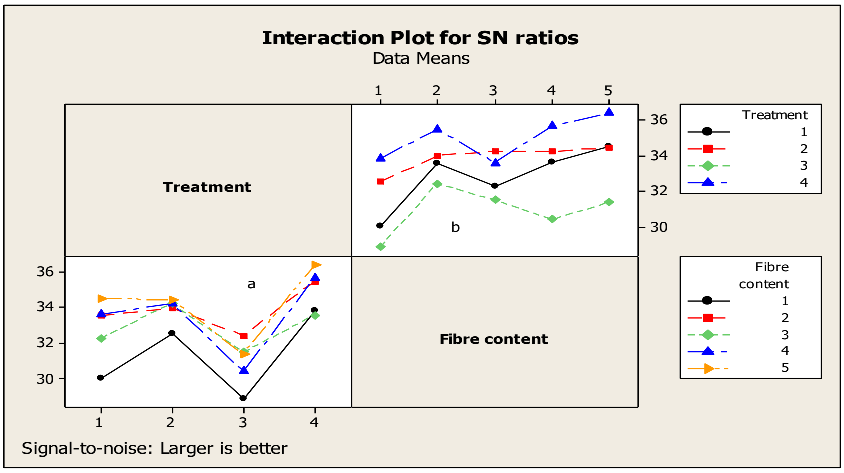

Fig. 2. *Interaction plot for signal-to-noise ratio of treatment and fibre content on tensile strength.*

3.1.2. Analysis of variance and post hoc test for tensile strength

The Analysis Of Variance (ANOVA), generated using Minitab 17 software, is shown in *Table 5*. ANOVA was conducted to determine if the differences in the main effect and interaction effects on tensile strength among the treatments and among the fibre contents are significant. *Table 5* shows a significant main effect of treatments on tensile strength, $F\ (3, 80) = 7.83$, $P < .001$ and also a significant main effect of fibre content on tensile strength, $F\ (4, 80) = 4.40$, $P = .003$. The interaction effect was not significant, $F\ (12, 80) = 0.28$, $P = .99$.

Test of equality of error variance was conducted to investigate if the error variance of the dependent variable is equal across the groups. The result of the test, shown in *Table 6*, indicates equal error variance. Thus, a post hoc test that assumes equal error variance was chosen for mean comparison, in this case, a Turkey HSD post hoc test. A post hoc test, shown in *Table 7* & *8* was carried out to determine the factor levels with significant mean difference in the group.

Table 5. *Tests of between-subjects effects: dependent variable -tensile strength.*

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected model	*2824.954*[a]	*19*	*148.682*	*2.341*	*.007*
Intercept	*41889.979*	*1*	*41889.979*	*659.496*	*.000*
Fibre content	*1116.943*	*4*	*279.236*	*4.396*	*.003*
Treatment	*1491.341*	*3*	*497.114*	*7.826*	*.000*
*Fibre content * Treatment*	*216.669*	*12*	*18.056*	*.284*	*.990*
Error	*3811.088*	*60*	*63.518*		
Total	*48526.020*	*80*			
Corrected total	*6636.041*	*79*			

R Squared = .626 (Adjusted R Squared = .644)

Table 6. *Levene's test of equality of error variances*[a]*: dependent variable-tensile strength.*

F	**df1**	**df2**	**Sig.**
1.119	*19*	*60*	*.357*

The fibre content P1 has significantly lower tensile strength than P2, P4, and P5 (*Table 7*). There is no significant difference in the tensile strengths among P2, P3, P4 and P5 fibre contents. This indicates that increasing the fibre content beyond P2 up to P5 has no significant impact on the tensile strength of bamboo fibre polyester composite. *Table 8* indicate that the tensile strength of mercerized-acetylated fibre composite is significantly higher than that of crude and acetylated composites. However, there is no significant mean difference in the tensile strength of mercerized-acetylated and mercerized composites.

Table 7. *Turkey HSD multiple comparison of tensile strength among various fibre contents.*

	P1	**P2**	**P3**	**P4**	**P5**
P1		*-8.2673**	*-5.2916*	*-8.7628**	*-10.7328**
P2	*8.2673**		*2.9756*	*-.4956*	*-2.4655*
P3	*5.2916*	*-2.9756*		*-3.4712*	*-5.4412*
P4	*8.7628**	*.4956*	*3.4712*		*-1.9700*
P5	*10.7328**	*2.4655*	*5.4412*	*1.9700*	

Table 8. *Turkey HSD multiple comparison of tensile strength among various treatments.*

	Crude	**Mercerized**	**Acetylated**	**Mercerized-Acetylated**
Crude		*-1.7228*	*5.2258*	*-6.8640**
Mercerized	*1.7228*		*6.9486**	*-5.1412*
Acetylated	*-5.2258*	*-6.9486**		*-12.0898**
Mercerized-Acetylated	*6.8640**	*5.1412*	*12.0898**	

Hence, the tensile strength results show that, (1) while the main effect of treatment and fibre content on tensile strength is significant, the interaction effects are not significant. The main effect of mercerized-acetylated bamboo fibres on tensile strength has the highest values for each fibre content level with the acetylated fibre composites showing the lowest tensile strength among all treatments and (2) the optimum parameter setting for tensile strength is observed at mercerized-acetylation treatment and P5 fibre content with tensile strength of 72.96 MPa. The posthoc test shows that the effect of mercerized-acetylation on tensile strength of the fibre composites is significantly higher than that of untreated and acetylation. However, no significant difference is observed between the effect of mercerization and mercerized-acetylation on tensile strength of the fibre composites. The effect of P5 level of fibre contents on tensile strength is found to be significantly higher than P1. However, P5 level of fibre content is not significantly higher than P2, P3, and P4 levels of fibre contents.

3.2. Flexural Strength

The average flexural strength values measured from the experiment and their corresponding S/N ratios are listed in *Table 9*. The S/N ratios were calculated using *Eq. 3*. *Table 10* gives the S/N ratio values of flexural strength by factor levels. The level with the highest signal-to-noise ratio value is optimum level for the control factor.

Table 10 shows that level 2 and level 4 of treatment, which are mercerized and mercerized-acetylated, have almost the same highest S/N ratio value. Level 5 of fibre content, which is P5, have the highest S/N ratio in fibre content.

Table 9. *Factor level, mean flexural strength and the corresponding signal-to-noise level of bamboo fibre polyester composites.*

Exp. No.	Treatment	Fibre Content	Mean Flexural Strength (Mpa)	S/N Ratio (dB)
1	*1*	*1*	*3.997*	*9.402*
2	*1*	*2*	*15.668*	*23.213*
3	*1*	*3*	*21.804*	*26.124*
4	*1*	*4*	*42.949*	*32.222*
5	*1*	*5*	*54.565*	*34.588*
6	*2*	*1*	*10.156*	*19.715*
7	*2*	*2*	*18.448*	*24.851*
8	*2*	*3*	*24.461*	*27.716*
9	*2*	*4*	*32.277*	*29.969*
10	*2*	*5*	*62.696*	*35.705*
11	*3*	*1*	*9.697*	*18.616*
12	*3*	*2*	*29.969*	*28.973*
13	*3*	*3*	*20.185*	*25.878*
14	*3*	*4*	*11.893*	*21.139*
15	*3*	*5*	*37.945*	*31.339*
16	*4*	*1*	*17.237*	*24.335*
17	*4*	*2*	*28.311*	*28.167*
18	*4*	*3*	*33.037*	*30.146*
19	*4*	*4*	*18.988*	*25.103*
20	*4*	*5*	*37.235*	*30.928*

Table 10. *Response for signal to noise ratios: flexural strength.*

Level	Treatment	Fibre Content
1	*25.11*	*18.02*
2	*27.59*	*26.30*
3	*25.19*	*27.47*
4	*27.54*	*27.11*
5		*33.14*
Delta	*2.63*	*15.12*
Rank	*2*	*1*

3.2.1. Main and interaction effect of treatment and fibre content on flexural strength

The main effect plot for S/N ratios of treatment and fibre contents on flexural strength is shown in *Fig. 3*. The main effect of mercerized and mercerized-acetylated bamboo fibres on flexural strength of the composite (*Fig. 3a*) have the highest values followed by that of crude fibre. Similar observation on alkaline treated fibre composite was made by [28]; the authors reported increase in flexural strength of alkaline treated sisal fibre/unsaturated polyester composite from 1 MPa in untreated fibre to 1.5 MPa in alkaline treated fibre. They attributed this to increase in fibre-matrix interaction due to removal of some portions of lignin, hemicelluloses and cellulose, resulting in increased surface area available for contact with the matrix. Shah et al. [39] also observed improvement in the flexural strength and modulus of alkaline treated (6% wt) woven banana fibre/unsaturated polyester composite over untreated fibre composite from 58 MPa to 64 MPa for flexural strength. They attributed the improvement to improved wetting of the treated fibre with the matrix. This results from removal of artificial and natural impurities and waxy substances from the fibre surface and imparting rougher surface to the fibre surface after mercerization which eventually results to better mechanical interlocking and improved interfacial adhesion. Other researchers also reported similar behaviour in; polyester resin reinforced with long and short hemp and kenaf fibre, wood flour–PP composite, coir-polyester composite; with about 22% increase in flexural strength from 38 – 49 MPa in untreated fibre to 49 to 56 MPa in alkaline treated fibre composites, kenaf epoxy composite [42-44].

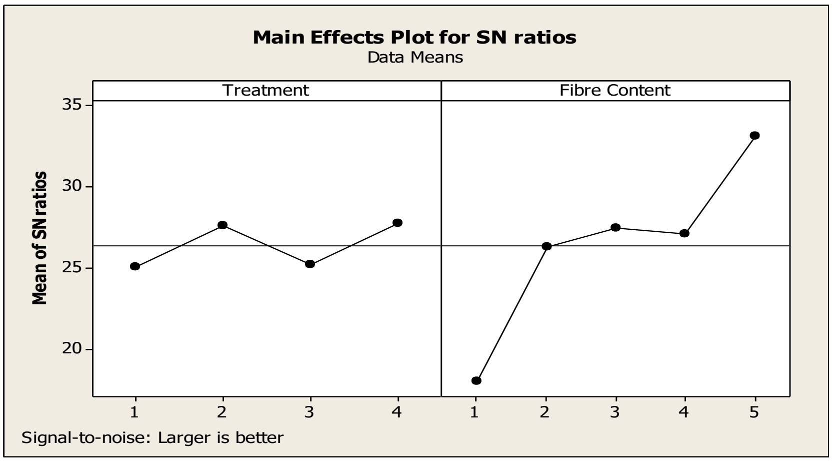

Fig. 3. *Main effect plot for signal- to- noise ratio of treatment and fiber content on flexural strength.*

Acetylated fibre composites have the lowest flexural strength. Acetylation probably causes agglomeration of the filler, weakening the interfacial regions. Similar observation was made by kallakas et al. [41], the authors reported a decrease in flexural strength of uncatalyzed acetylated wood flour – PP composite over unmodified wood flour composite from 36.2 MPa to 33.4 MPa. They attributed this to poor interfacial adhesion between the PP matrix and the acetylated wood flour. *Fig. 3b* shows that there is general increase in flexural strength with increase in fibre content. For all treatments, P1 has the lowest flexural strength while P5 has the highest. Krishnan et al. [44] reported similar finding of an increase in flexural strength with increase in fibre content of PP/Isora composite from 43.25 MPa in 5 wt% fibre content to 45.6 wt% in 15 wt% fibre composite. They attributed the increase to the nature of the natural fibre which acts as a rigid filler responsible for increasing the stiffness of the polymer matrix. Other researchers also found similar behaviour in; Grewia optival/PF composite, Habiscus Sabdarifa/UF Composite, Piassava fibre polystyrene composite, and cotton fibre reinforced isophthallic polyester composite [45-48].

The flexural strength at the optimum parameter setting is 62.7 MPa. The flexural strength is comparable to the results of previous studies where maximum flexural strength of 54.1 MPa and 56.78 MPa where obtained on Sisal fibre polyester composite and Sisal/bamboo hybrid polyester composites, respectively [34]. Maximum flexural strength of 38.98 MPa was reported for bamboo fibre polyester composites [35]. Maximum flexural strength of 70 MPa was reported on bamboo fibre epoxy composites [36]. Maximum flexural strength of 54.31 MPa was obtained by [27] on Coir polyester composite while [39] observed flexural strength of 64 MPa on woven Banana fabric polyester composites.

The interaction effect of treatment and fibre content on flexural strength is shown in *Fig. 4*. There is interaction among the various fibre treatments and levels of fibre content. At the low fibre content of P1, the crude fibre composite has the lowest flexural strength while mercerized-acetylated composite has the highest flexural strength but as the fibre content increases, the flexural strength of mercerized and crude fibre composite becomes higher.

It could be that acetylation reduces the protruding micro fibrils from the mercerized frayed fibres. However, increase in fibre content leads to increase in available micro fibrils and rough surface, in mercerized-acetylated fibre composites, to form an improved interlocking bond with the matrix.

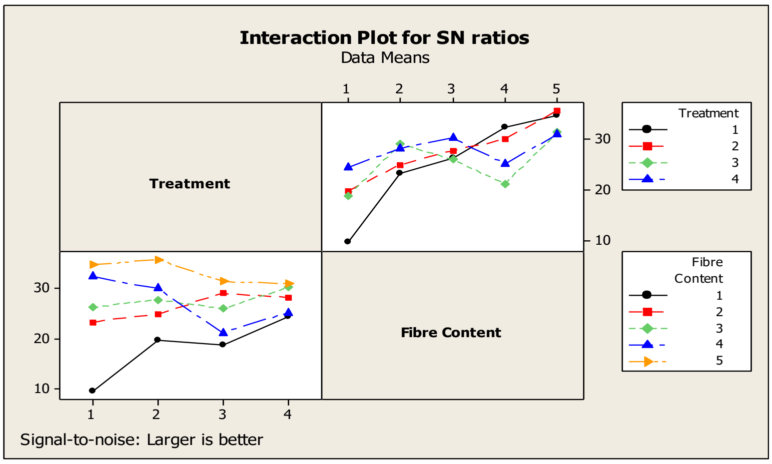

Fig. 4. *Interaction plot for signal-to-noise ratio of treatment and fibre content on flexural strength.*

3.2.2. Analysis of variance and post hoc test for flexural strength

ANOVA generated using Minitab 17 software, is shown in *Table 11*. ANOVA was conducted to determine if the differences in the main effect and interaction effects on flexural strength among the treatments and among the fibre contents are significant. *Table 11* shows a significant main effect of treatments on flexural strength, *F (3, 80) = 6.54, P =.001* and also a significant main effect of fibre content on flexural strength, *F (4, 80) = 90.38, P<.001*. The interaction effect was significant, *F (12, 80) = 12.40, P < .001*.

Table 11. *Analysis of variance and Post Hoc test for flexural strength*.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected model	*17462.478*[a]	*19*	*919.078*	*27.891*	*.000*
Intercept	*56502.027*	*1*	*56502.027*	*1.715E3*	*.000*
Fibre content	*11912.981*	*4*	*2978.245*	*90.381*	*.000*
Treatment	*646.851*	*3*	*215.617*	*6.543*	*.001*
*Fibre content * Treatment*	*4902.646*	*12*	*408.554*	*12.398*	*.000*
Error	*1977.134*	*60*	*32.952*		
Total	*75941.639*	*80*			
Corrected total	*19439.612*	*79*			

a. R Squared = .898 (Adjusted R Squared = .866)

Table 12. *Levene's test of equality of error variances: dependent variable - flexural strength.*

F	df1	df2	Sig
1.703	*19*	*60*	*0.061*

Test the null hypothesis that the error variance of the dependent variable is equal across groups

a.Design: intercept + Fibre content + Treatment + Fibre content*Treatment

Test of equality of error variance was conducted to investigate if the error variance of the dependent variable is equal across the groups. *Table 12* indicates equal error variance. Thus, Turkey HSD that assumes equal error variance was chosen for mean comparison to determine the factor levels with significant mean difference in the group and presented in *Table 13* & *Table 14*.

There is a significant mean difference between the flexural strength of acetylated composites and other treatments (*Table 13*). There is no significant difference among other treatments. The mean difference shows that acetylated composites has significantly lowest flexural strength among all the treatments while there is no significant difference among the flexural strength of crude, mercerization and mercerized-acetylated fibre composite. This shows that statistically, chemical modification does not significantly enhance the flexural strength of bamboo fibre composite. *Table 14* indicate significant mean differences in flexural strength among the levels of fibre content. There is no significant difference among the flexural strength of fibre contents P2, P3 and P4 while they are significantly different from P1 and P5. Thus, in order to achieve a significant increase in flexural strength, high fibre content is required.

Table 13. *Turkey HSD Post Hoc multiple comparison of flexural strength among various treatments.*

	Crude	**Mercerized**	**Acetylated**	**Mercerized-Acetylated**
Crude		*-1.811*	*5.858**	*.8351*
Mercerized	*1.811*		*7.669**	*2.646*
Acetylated	*-5.858**	*-7.669**		*-5.023**
Mercerized-Acetylated	*-.835*	*-2.646*	*5.023**	

Table 14. *Turkey HSD Post Hoc multiple comparison of flexural strength among various levels of fibre content.*

	P1	**P2**	**P3**	**P4**	**P5**
P1		*-12.827**	*-14.600**	*-16.255**	*-37.838**
P2	*12.827**		*-1.772*	*-3.427*	*-25.011**
P3	*14.600**	*1.772*		*-1.654*	*-23.238**
P4	*16.255**	*3.427*	*1.654*		*-21.583**
P5	*37.838**	*25.011**	*23.238**	*21.583**	

Hence, a significant main and interaction effect of treatment and fibre content on flexural strength was observed. Mercerization and mercerized-acetylation produced better main effect on the composites than other treatments while the least effect was observed in acetylation. A general increase in flexural strength with increase in fibre content, for all treatments, was observed. The optimum parameter setting for flexural strength was found to be mercerization treatment and P5 level of fibre content which resulted to flexural strength of 62.7 MPa. The post hoc test indicated that the flexural strength of mercerized and mercerized-acetylated fibre composites is statistically significantly higher than that of other composites. However, no significant different was observed in flexural strength of mercerized and mercerized-acetylated fibre composites. The effect of P5 level of fibre content on flexural strength was significantly higher than that of all other levels of fibre content.

3.3. Impact Strength

The average impact strength values measured from the experiment and their corresponding S/N ratios are listed in *Table 15*. The S/N ratios were calculated using *Eq. (3)*. *Table 16* contain the S/N ratio values of impact strength by factor level.

3.3.1. Main and interaction effect of treatment and fibre content on impact strength

The main effect of treatment and fibre contents on impact strength is shown in *Fig. 5*. In *Fig. 5a*, mercerization has the highest positive effect on the impact strength of the fibre composites. Unmodified fibre composites show the lowest impact strength.

Table 15. *Factor level, mean impact strength and the corresponding signal-to-noise level of bamboo fibre polyester composites.*

Exp. No.	Treatment	Fibre Content	Mean Impact Strength (J/cm)	S/N Ratio (dB)
1	*1*	*1*	*105.642*	*40.4535*
2	*1*	*2*	*155.599*	*43.82421*
3	*1*	*3*	*182.248*	*45.17447*
4	*1*	*4*	*132.943*	*42.47087*
5	*1*	*5*	*130.078*	*42.27101*
6	*2*	*1*	*121.658*	*41.68095*
7	*2*	*2*	*125.174*	*41.88239*
8	*2*	*3*	*158.247*	*43.79078*
9	*2*	*4*	*180.035*	*44.98056*
10	*2*	*5*	*194.488*	*45.6011*
11	*3*	*1*	*110.894*	*40.88479*
12	*3*	*2*	*171.224*	*44.57203*
13	*3*	*3*	*173.177*	*44.6705*
14	*3*	*4*	*135.981*	*42.63379*
15	*3*	*5*	*132.075*	*42.3006*
16	*4*	*1*	*126.345*	*41.89238*
17	*4*	*2*	*135.156*	*42.59417*
18	*4*	*3*	*145.660*	*43.23304*
19	*4*	*4*	*154.688*	*43.51206*
20	*4*	*5*	*192.014*	*45.61425*

Table 16. *Response table for signal to noise ratios of impact strength-larger is better.*

Level	Treatment	Fibre Content
1	*42.84*	*41.23*
2	***43.59***	*43.22*
3	*43.01*	***44.22***
4	*43.37*	*43.40*
5		*43.95*
Delta	*0.75*	*2.99*
Rank	*2*	*1*

Among the modified fibre composites, acetylated fibre composites have the lowest impact strength. Acetylation probably causes agglomeration of the filler, weakening the interfacial regions and making them less resistance to crack propagation. *Fig. 5b*, shows that generally, the impact strength increases with increase in fibre content up to level 3 of fibre content, P3 after which a decline in impact strength was observed. This could be as a result of voids and imperfection which increases with increase in fibre content which results to poor interfacial adhesion and low interfacial strength.

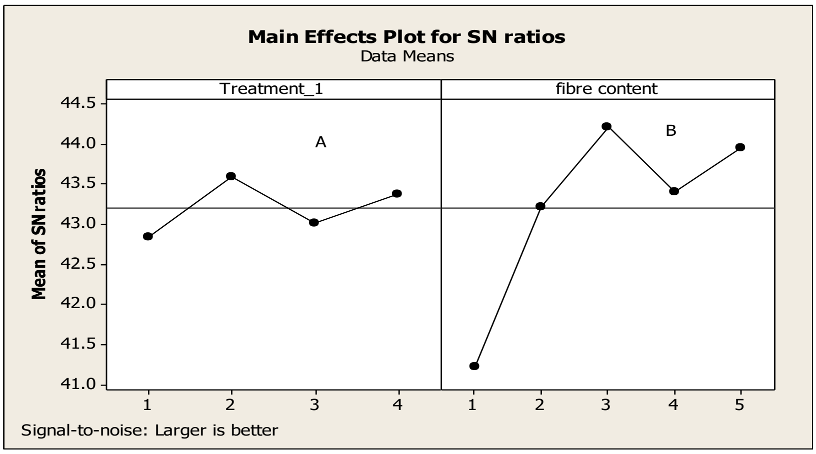

Fig. 5. *Main effect plots for signal-to-noise ratio of treatment and fibre content on impact strength.*

Interaction effect was observed for treatment and fibre content on impact strength (*Fig. 6*). At the low fibre contents of P2 and P3, high impact strength was observed for crude and acetylated fibre composites but as the fibre content increases, the impact strength drastically reduced and became much lower than that of mercerized and mercerized-acetylated composite. Similar behaviour on impact strength of unmodified and acetylated fibre composites was observed by [47], they reported that the impact strength of unmodified and acetylated Piassa fibre reinforced polyestyrene composite increased with increase in fibre contend up to 4 wt% and 2.5 wt% respectively after which a steady decline was observed. They attributed the decrease in impact strength to the inability of the matrix to wet the fibres as the fibre content increased. Similar behaviour has been reported by other researchers on–sisal fibre reinforced polylactide composites, and, sisal and bamboo fibre reinforced polyester hybrid composites [34, 49]. Wiphawee et al. [50], observed a steady decline on the impact strength of untreated bamboo fibre PLA composite with increase in fibre content. They attributed it to poor interfacial adhesion between fibre and matrix.

A steady increase in the impact strength of mercerized and mercerized-acetylated composites with increase in fibre content was observed up to the maximum fibre content of P5. The highest impact strength was observed at P5 fibre content for mercerized and mercerized-acetylated fibre composites. Mercerization prior to acetylation improved the impact strength of acetylated fibre composite. Wiphawee et al. [50], reported steady increase in impact strength of treated bamboo fibre PLA composite over the untreated composite. Prasanna et al. [34], made similar observation on sisal and bamboo fibre reinforced polyester hybrid composite. They reported that alkaline treatment improved the impact strength of the composite.

Surface roughness of mercerized fibre improved relative to that of crude fibre with increase in fibre content; this resulted to improved fibre-matrix adhesion leading to higher impact strength. It also seems that acetylation reduced the protruding micro fibrils from the mercerized frayed fibres. However, increase in fibre content lead to increase in available microfribrils and rough surface in mercerized-acetylated fibre composites, to form an improved interlocking bond with the matrix. Thus, mercerized and mercerized-acetylated composites showed the highest impact strength.

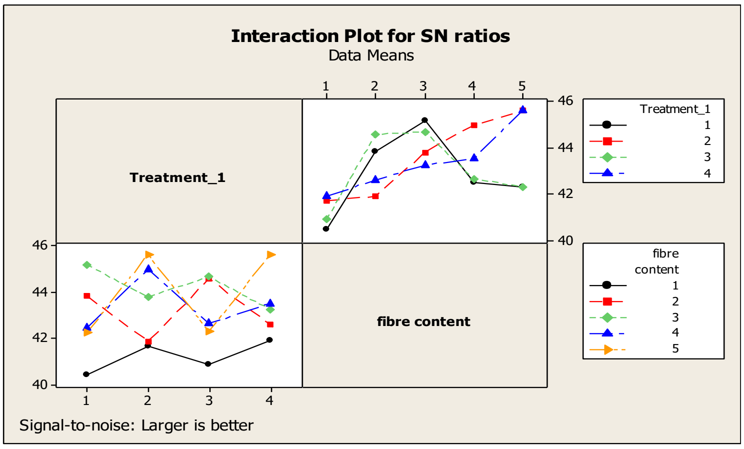

Fig. 6. *Interaction plot for signal-to-noise ratio of treatment and fibre content on impact strength.*

3.3.2. Analysis of variance and post hoc test for impact strength

ANOVA generated using Minitab 17 software, is reported in *Table 17*. A significant main effect of treatments on impact strength, *F (3, 119) = 6.97, P < .001* and a significant main effect of fibre content on impact strength, *F (4, 119) = 49.98, P <.001* was observed. The interaction effect was significant, *F (12, 119) = 19.27, P < .001*.

Test of equality of error variance was conducted to investigate if the error variance of the dependent variable is equal across the groups. The result of the test, shown in *Table 18*, indicates unequal error variance. Thus, a Games Howell post hoc test which assumes unequal error variance was chosen for mean comparison. The post hoc test results are reported in Tables' 19 and 20.

Table 17. *Analysis of variance: dependent variable-impact strength.*

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	*81893.782*^{a}	*19*	*4310.199*	*23.791*	*.000*
Intercept	*2634387.899*	*1*	*2634387.899*	*1.454E4*	*.000*
Fibre content	*36219.386*	*4*	*9054.847*	*49.980*	*.000*
Treatment	*3787.658*	*3*	*1262.553*	*6.969*	*.061*
*Fibre content * Treatment*	*41886.738*	*12*	*3490.561*	*19.267*	*.000*
Error	*18116.851*	*100*	*181.169*		
Total	*2734398.532*	*120*			
Corrected Total	*100010.633*	*119*			

a. R Squared = .819 (Adjusted R Squared = .784)

Table 18. *Levene's test of equality of error variances^a: dependent variable - impact strength.*

F	**df1**	**df2**	**Sig.**
4.082	*19*	*100*	*.000*

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + Fibre content + Treatment + Fibre content * Treatment

There is no significant difference on the mean impact strength among the various treatments of bamboo-polyester composites (*Table 19*). This is in agreement with the result of the analysis of variance (*Table 17*). *Table 20* indicates significant mean differences in impact strength among the levels of fibre content. Fibre content P1, has significantly lower impact strength than fibre contents, P2-P5. The fibre content, P2 has significantly lower impact strength than P3. There is no significant difference in the impact strength among fibre contents P3, P4 and P5. This shows that increase in fibre content improves the impact strength up to P3 fibre content after which no significant improvement was observed.

Table 19. *Games Howell's multiple comparison of impact strength among various treatments.*

	Crude	**Mercerized**	**Acetylated**	**Mercerized-Acetylated**
Crude		*-14.618*	*-3.368*	*-9.470*
Mercerized	*14.6*		*11.250*	*5.147*
Acetylated	*3.36*	*-11.250*		*-6.102*
Mercerized-Acetylated	*9.47*	*-5.147*	*6.102*	

Table 20. *Games Howell's multiple comparison of Impact strength among various levels of fibre contents.*

	P1	**P2**	**P3**	**P4**	**P5**
P1		*-30.653**	*-48.697**	*-34.776**	*-46.028**
P2	*30.653**		*-18.044**	*-4.123*	*-15.375*
P3	*48.697**	*18.0447**		*13.921*	*2.669*
P4	*34.776**	*4.1233*	*-13.921*		*-11.252*
P5	*46.028**	*15.3754*	*-2.669*	*11.252*	

The analysis of the main and interaction effect of treatment and fibre content on impact strength shows that, the level of fibre content and the interaction between treatment and fibre content has significant effect on impact strength. However, treatment has no significant influence on impact strength of bamboo fibre polyester composites. A steady increase in the impact strength of mercerized and mercerized-acetylated composites with increase in fibre content was observed up to the maximum fibre content of P5. The optimum parameter setting for impact strength was observed at mercerization treatment and P3 fibre content with impact strength of 158.23 J/cm. The post hoc test shows that there is no significant difference among the effect of various treatments on the impact strength. The P3 level of fibre content was found to be significantly higher than that of P1 level of fibre contents. However, no significant difference among the effects of P3, P4 and P5 fibre contents on impact strength was observed.

4. Conclusion

This research focused on optimization of parameter settings to obtain bamboo fibre/polyester composites of improved properties. An attempt was made to obtain optimal parameter setting for Tensile strength, Flexural strength and impact strength of bamboo fibre polyester composites using Taguchi orthogonal array with focus on effect of fibre content and surface modification. Post hoc test was used to determine the parameter settings that are significantly different from others. The optimization was carried out with the goal of obtaining high performance composite and to produce a guide for composite producers and manufacturers in parameter settings selection. This research should serve as a decision guide to composite manufacturers on the choice of parameter settings based on the desired properties and the particular application of their composite product.

Conflict of Interest

There is no conflict of interest in connection with this paper, and the material described here is not under publication or consideration for publication elsewhere.

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