



EFFECTS OF ORIENTATION ON THE PROPERTIES OF FAN PALM FIBRE REINFORCED SHEET

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In this research, the effect of orientation of the strength of fan palm fibre reinforced sheets was investigated. The material used was fan palm fibre whose length varies from 0.8 to 1.7m with an average bulk density of 1.133g/cm³, specific gravity of 0.46 and Moisture Content (MC) of 7.40%. And the mould used was a wooden mould of 300×300×9 mm. The fibre was soaked in both water and cement slurry for 24 hours and 7 days. Soil sieve analysis was carried out using ASTM standard and curing was done for 28 days. The percentage of fibre in the sampled reinforce sheet was between 1-3% at various orientations (0, 30, 60° and 2D). The properties examined were Water Absorption (WA), Compressive Strength (CS) and Flexural Strength (FS). Data analysis was done using Response Surface Methodology (RSM). The results showed that the reinforced sheets with long fibre of 1, 2 and 3% have WA of 5.76, 3.72 and 5.05% respectively. While those with short fibre of 1, 2 and 3% have 6.87, 7.36 and 7.75% respectively. The CS of the reinforced sheets of 1, 2 and 3% fibre at 0, 30, and 600 orientations were 6.9568, 8.0779, 7.2330; 3.2870, 6.6764, 7.355; and 3.0592, 5.3215, 3.9090 N/mm² respectively and the FS results were also observed. The CS and FS of reinforced sheets at 00 and 300 fibre orientations seems to be the best.

1.0 Introduction

Over the years steel has been the dominating material used as reinforcement in concrete and mortar in the construction industries. Since then the cost of steel has continued to rise, this has led to increase in the cost of production of structural members. Asbestos cement sheet was introduced as an alternative to corrugated sheet because it does not suffer atmospheric corrosion and it is also cheaper. But asbestos was discredited in 1970s because of its extreme fineness; tiny asbestos fibres are easily suspended in the atmosphere and prolonged inhalation of these fibres results into a form of pneumoconiosis known as asbestosis which also increases the incidence of cancer of the lungs Encyclopedia Americana (1829). Two decades ago, asbestos was the major source of reinforcement in the fibre cement industries but as a result of the adverse effect, it was replaced with many other fibres, from glass, steel, synthetics and natural fibres. Fan palm is the tallest indigenous plant that is abundant and characterizes all types of savannah. The wood is moderately heavy and brown with black fibre (McHolam, 2001). It can tolerate high temperature and resists decay for at least 25 years. Its length varies over a wide range of 5-90 cm with cross sectional area of 4.368 mm² (Okeola, 1989). Fan palm has a surface area of 163.27 and 80.25 mm² for the fruits and seeds respectively (Yalcin and Ayse, 2016). African fan palm has a typical diameter of 40-50 cm as opined by Tropical Plants (2024). Osibodu (1986) observed that a single strand of fan palm fibre has a modulus of elasticity of 14.44 N and that ultimate tensile strength of 280.3 N/mm². Okeola (1989) researched on the pull-out strength of matrix or the anchorage bond between the fan palm fibres and the cement

paste and was calculated to be 1.92 N/mm^2 . More so, the flexural strength of fan palm fibre of 2.15 N/mm^2 was reported by Okeola (1989). The arrangement of fibres in a matrix has been proved (Bryan, 1986) that it affects the crack opening and propagation, and substantially improve the material toughness and when the fibres are not aligned in the direction of the principal tensile strain, fracture increases. Orientation is very important in design of composite materials because of anisotropy's effect. Based on this premises, this paper looked at the effect of orientation on the strength of fan palm fibre reinforced sheets.

2.0 Materials and Methods

2.1 Sample materials

Fan palm fibre was used to make the reinforce sheets. It has a length of 0.8-1.7 m it is as shown in Figure 1. Fan palm was bought from Sabo market Ilorin, Kwara state, Nigeria. And it was transported to the workshop where it was treated and the fibres were removed by beating and scraping.



Figure 1: Fan palm trees

2.2 Mechanical and physical properties of Fan palm

a. Bulk density

The average bulk density of fan palm was 1.133 g/cm^3 . The bulk density was determined using ASTM standard.

b. Specific gravity

The specific gravity was determined using Equation (1). And is the ratio of the fibre in the sun (air) to the weight of water occupying the equal volume of that fibre. An average specific gravity of 0.46 was observed.

$$\text{Specific grav.} = \frac{\text{density of sample}}{\text{density of equal volume of water}} \quad (1)$$

c. Moisture content

Moisture content of the sample material was determined using oven-drying method and as given by PAES 219, (2004) as given in Equation (2):

$$\text{MC}_{\text{wb}} = \frac{W_1 - W_2}{W_2} \times 100 \quad (2)$$

Where, MC_{wb} = Moisture content, %; W_1 = Initial mass of the sample, g; W_2 = Final mass of the sample, g.

Water absorption (W.A): Water absorption was determined using Equation 3.

$$\text{W.A} = \frac{W_s - W_o}{W_s} \times 100, \% \quad (3)$$

Where, Weight of saturated samples = W_s (g); Weight of oven dry samples = W_o (g)

2.3 Grain size analysis

The sample sand was dried in the oven-drying machine for 24 hours and sand was weighed and recorded along with the sizes of the sieves as the aperture decreases in size. The sample was shaken using sieve shaker for few minutes, and then each sieve was weighed and recorded with the retained sand. The percentage passing and retained was calculated based on the total weight of the sample. The result was showed in Tables 1 and 2 and the weight (W_t) of the sharp sand used was 1000 g.

Table 1: Grain size analysis

Sieve size, mm	Wt of empty sieve	Wt of sieve + retained sand (g)	Wt of retained sand (g)
4	554	557	3
3.35	454	468	14
2.36	480	490	10
1	522	583	61
0.5	498	737	234
0.4	491	593	102
0.25	470	846	376
0.063	302	462	160
Pan	275	310	35

Table 2: Grain size analysis

Sieve size, mm	% Passing	% Retained	Cumulated % Retained
4	94.4	0.3	0.3
3.35	98.3	1.4	1.7
2.36	97.3	1	2.7
1	91.2	6.1	8.8
0.5	67.3	23.9	32.7
0.4	57.1	10.2	42.9
0.25	19.5	37.6	80.5
0.063	3.5	16	96.5
Pan	0	3.5	100

2.4 Preparation of constituent materials and production of fan palm fibre reinforced composite

a. Defibering

The removal of fibres was done manually with the aid of knife, cutlass and club. The fibre were scraped and brushed thoroughly and carefully to remove all the deleterious lignin content which will affect the interfacial bond between the fibres and the matrix.

b. Mix proportion

The ratio of cement to sand is 1:2 and the water cement ratio is 0.5, the fibre content used ranges from 1 percent to 3 percent by weight of the cement.

c. Mixing and casting

The quantities of each material used were first weigh using weighing balances. The cement and the sand were mixed on a flat board using hand trowel, the mortar was thoroughly mixed as water was added proportionally to satisfaction. Wooden moulds of 300 x 300 x 9 mm (Figure 2) were used for the casting. The moulds were lubricated to enhance easy removal set composites from the moulds. About one third of the overall depth of the mould was compacted

with the mortar serving as the cover before the fibres were arranged at different angles. The fibres were covered and compacted again to prevent voids and honey combs. The cubs were made using mould 40 x 40 x 40 mm containing varied percentages of short fibres ranging from 1-3 % both the cubes and the flat sheets were removed from the mould after 24 hours.

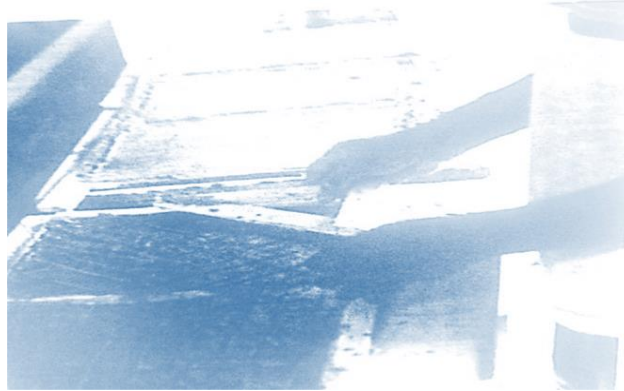


Figure 2: Moulds and arrangement of fibre
(The Figure was taking with black and white camera)

d. Orientation

Orientations of the fibres were 0° , 30° , 60° and 2D which is the discontinuous fibres or short fibres. The control experiment was without fibre and fibre orientation

e. Curing

Curing is the process of hydration in which a concrete composite gained strength. Curing was done by immersing the composites in water for 28 days after which they were kept to dry, getting them ready for testing. The flexural and compressive strengths were determined using Universal testing machine (Testometric) at University of Ilorin.

3.0 Results and Discussion

The mean compressive strength of 6.9568, 8.0778 and 7.2330 N/mm² at 1 % fibre content were obtained for the fan palm fibre reinforced sheets at fibre orientations of 0° , 30° and 60° respectively as showed in Table 3. While 3.2870, 6.6764 and 7.355 N/mm²; 3.0592, 5.3215 and 3.9090 N/mm² where obtained at 2 and 3% fibre content respectively (Table 3). More so, the mean flexural strength of 8.58, 7.84 and 7.23 N/mm² at 1% fibre content were obtained for the fan palm fibre reinforced sheets at fibre orientations of 0° , 30° and 60° respectively as showed in Table 4. While 3.29, 5.42 and 7.12 N/mm²; 1.67, 2.59 and 1.96 N/mm² where obtained at 2 and 3 % fibre content respectively (Table 4). Table 5 showed that fan palm fibre reinforced sheets with long fibre of 1, 2 and 3 % have water absorption of 5.76, 3.72 and 5.05 % respectively. While those with short fibre of 1, 2 and 3 % have 6.87, 7.36 and 7.75 % respectively.

3.1 The effect of orientation and fibre percentage on compressive strength of fan palm fibre reinforced sheet.

The mean compressive strength obtained varies from 6.9568 to 8.0778 N/mm² from different fibre orientations as showed in Table 3, which were higher than those values obtained by Anaidhuno et al. (2017) and this variation may be due to crops' properties because different fibres were used. The effects of fibre orientations and percentage of fibre were significant on compressive and flexural strength ($p < 0.05$) as shown in Table 6 because the compressive strength increases with increase in fibre orientation but decreases with increase in percentage of fibre in the fan palm fibre reinforcement sheets and this was depicted in the response surface plot of the relationship as shown in Figure 3. More so, the model that gave the best fit was a linear relationship as shown in Equation (4). However, the goodness of fit for the model was

expressed by the coefficient of determination (R^2) of 0.7177, which suggest that, the model could explain 71.77 % of the variability in the response and the model satisfies lack of fit test.

3.2 The effect of orientation and fibre percentage on Flexural strength of fan palm fibre reinforced sheet

Table 4 showed the average flexural strength of fan palm fibre reinforced sheets at different orientation degrees and the values were more than 2.15 N/mm² reported by Okeola (1989). And this difference may be due to fibre orientation considered during this research which was reported in Okeola (1989). However, the result shows that, flexural strength decreases with in decrease in fibre percentage but increases with increase in degree of orientation of fibre in the sheets as is shown in Figure 4, and the relationship was significant ($p < 0.05$) as it is shown in Table 7 and the model that gives the best fit is a linear model. The goodness of fit for the model was expressed by the coefficient of determination ($R^2 = 0.8720$). However, equation (5) presented the interaction between flexural strength, orientation of fibre and fibre percentage (amount).

3.3 The effect of orientation and fibre percentage on water absorption of fan palm fibre reinforced sheet.

The mean water absorption of the reinforced sheets ranges from 3.72 to 7.75%. This was higher than 66.50 and 63.2% reported for coir and palm kernel (Gram, 1983). The little variation could be due to adequate strength properties embedded in the fibre orientation, which could be related to the mechanical and physical properties of fan palm fibre. However, the water absorption decreases with increase in fibre percentage but increases with increase in degree of orientation of fibre in the fan palm fibre reinforced sheets. The mathematical expression in Equation (6) shows that a relationship occurs between the water absorption, fibre orientation and percentage of fibre. However, the effects of fibre orientation and percentage of fibre on water absorption is not significant ($p > 0.05$) (Table 8) and the model that gives the best fit is a linear relationship. The coefficient of determination R^2 was found to be 0.4445, indicating that the relationship between the three variables (predictors and response) is weak as is shown in Figure 5.

Table 3: The average compressive strength at different orientation of fibre arrangement

Fibre orientation	Mean Compressive strength @ 1% fibre	Mean Compressive strength @ 2% fibre	Mean Compressive strength @ 3% fibre
0 ⁰	6.9568	3.2870	3.0592
30 ⁰	8.0778	6.6764	5.3215
60 ⁰	7.2330	7.355	3.9090

Mathematical models

$$1. \text{ Compressive strength} = 0.029 * \text{Orientation} - 1.66 * \text{Fibre} + 8.22431 \quad (R^2 = 71.77\%) \quad (4)$$

$$2. \text{ Flexural} = 0.0153 * \text{Orientation} - 2.9050 * \text{Fibre} + 10.4261 \quad (R^2 = 87.20 \%) \quad (5)$$

$$3. \text{ Water Absorption} = 0.41011 * \text{Orientation} - 8.78375 * \text{Fibre} + 62.10558 \quad (6)$$

Table 4: The average flexural strength at different orientation of fibre arrangement

Fire orientation	Mean Flexural strength @ 1% fibre	Mean Flexural strength @ 2% fibre	Mean Flexural strength @ 3% fibre
0°	8.58	3.29	1.67
30°	7.84	5.42	2.59
60°	7.23	7.12	1.96

Table 5: The average water absorption at different orientation of fibre arrangement

Sample of Long fibre	% of Fibre	% of absorption
A	1	5.76
B	2	3.72
C	3	5.05
Sample of Short fibre	% of Fibre	% of absorption
A	1	6.87
B	2	7.36
C	3	7.75

Table 6: ANOVA on the effect of orientation and fibre percentage on compressive strength of fan palm fibre reinforced sheet

Source	SS	DF	MS	F-Value	P > F	Remark
Model	21.09	2	10.54	7.63	0.0225	*Sig
A	4.50	1	4.50	3.25	0.1214	
B	16.59	1	16.59	12.00	0.0134	
Resid.	8.30	6	1.38			
Cor T.	29.39	8				

*Significant @ P < 0.05

Table 7: ANOVA on the effect of orientation and fibre percentage on Flexural strength of fan palm fibre reinforced sheet.

Source	SS	DF	MS	F	P > F	Remark
Model	51.91	2	25.96	20.44	0.0021	*Sig
A	1.28	1	1.28	1.01	0.354	
B	50.63	1	50.63	39.86	0.0007	
Residual	7.62	6	1.27			
Cor T.	59.53	8				

*Significant @ P < 0.05

Table 8: ANOVA on the effect of orientation and fibre percentage on water absorption of fan palm fibre reinforced sheet

Source	SS	DF	MS	F	P > F	Remark
Model	1828.18	2	914.09	2.0	0.229	*Not sig.
A	1210.94	1	1210.9	2.6	0.164	
B	617.23	1	617.23	1.3	0.297	
Residual	2283.25	5	456.65			
Cor Total	4111.43	7				

Not significant @ P < 0.05

DESIGN-EXPERT Plot

Compressive
X = A: Orientation
Y = B: FIBRE

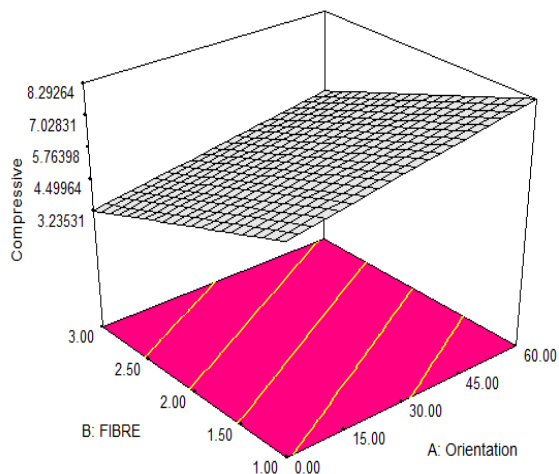


Figure. 3: Surface response plot of factors on compressive strength

DESIGN-EXPERT Plot

Flexural
X = A: Orientation
Y = B: FIBRE

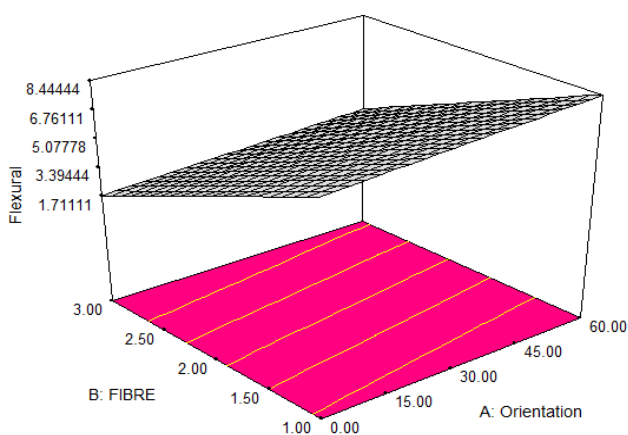


Figure 4: Trend of flexural strength due to fibre orientation and percentage in reinforced sheets

DESIGN-EXPERT Plot

Water Absorption
X = A: Orientation
Y = B: FIBRE

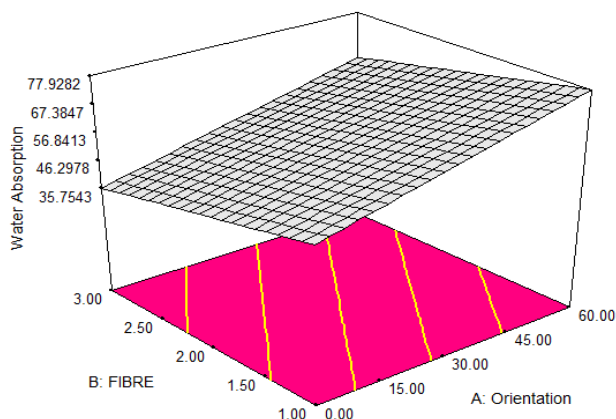


Figure 5: Trend of water absorption due to fibre orientation and percentage in reinforced sheets

4. Conclusion

From this study, three properties of the reinforced sheets (Water absorption, flexural strength and compressive strength) were examined. And the followings were concluded;

1. The effects of fibre orientation and percentage of fibre on water absorption is not significant at $p < 0.05$. And water absorption decreases with increase in fibre percentage but increases with increase in degrees of orientation of fibre in fan palm fibre reinforced sheets
2. Flexural strength decreases with in decrease in fibre percentage but increases with increase in degrees of orientation of fibre in the sheets and the relationship was significant at $p < 0.05$.
3. The effects of fibre orientations and percentage of fibre were significant on compressive at $p < 0.05$ and compressive strength increases with increase in fibre orientation but decreases with increase in percentage of fibre in the fan palm fibre reinforcement sheets.
4. More so, the compressive and flexural strength of the reinforced sheets at 0° and 30° fibre orientations seems to be the best. It is therefore, recommended that fibre reinforced sheets should be made using 0° and 30° fibre orientation.

5. Acknowledgement

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