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Compressive Behaviours of Oil Bean Shell and Wood Particulates/ Epoxy Composite Board

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Authors' contributions

This work was carried out in collaboration among all authors. Author EO designed the study, performed the statistical analysis, in addition, he managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The compressive behaviours (compressive strength, compressive energy, Young's modulus, failure time, and compressive strain) of epoxy composite board, reinforced with oil bean pod shell particulates (OBPS) and mahogany timber saw dust (SD) were investigated in this research. The samples were prepared with five different fillers (OBPS and SD) percentage (10, 15, 20, 25 and 30 vol.%) in the ratio of 1:1. Both filler materials where treated with 5(w/v)% Sodium hydroxide solution to enhance their mechanical properties. All the composite samples were tested according to ASTM standards, by using the Universal Testing Machine. Results obtained from the research showed that fillers loading had significant ($P \leq 0.05$) effect on all the compressive behaviours investigated. In addition, the results showed that the fillers significantly improved all the compressive parameters. The compressive strength of the composite increased from 14.54 to 48.19 MPa, as the fillers loading increased from 10 to 30 wt.%, while the Young's modulus increased by 49%. The compressive energy increased from 21.4 to 146 Nm. Data gotten from this research can be useful in the production of composite boards for engineering applications.

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1. INTRODUCTION

There is rising shortage of trees timbers for construction purposes due to none availability of trees and environmental concerns. Therefore, the use of alternative materials in replacement of trees timber is on the rise, and agricultural materials are now being considered. For instance, wood polymer composites are being utilized in engineering applications, such as in the automotive, construction, marine, electronic, and aerospace industries [1-2]. Mahogany tree (*Swietenia mahagnoni*) is a straight-grained, reddish-brown hardwood. Mahogany resists wood rot, making it attractive in boat construction and outdoor decking [3]. Mahogany is also used in musical instruments, mostly the wooden parts of acoustic and electric guitars. In addition, it is used in drum shells because of its ability to produce a very deep, warm tone, when compared to other woods, such as maple or birch [4-5].

Composite consists of two or more materials combined in a definite ratio that allows a new identifiable material to be formed. Epoxy resins are used widely in making composite materials, and are the most versatile of the commercially available matrix materials. In addition, they have a wide range of physical characteristics and mechanical properties [6]. In order to design a composite material to operate efficiently and safely under compressive loading, it is essential to be able to know its compressive strength, taking the various possible failure manners of the structure under different conditions into account [7]. Additionally, for optimal performance of the composite, it is important to know the knowledge of the mechanical properties of both the resin and the fibre. Resin tensile elongation to break should be at least as high as that of the reinforcement, although there are special cases in which the fibers provide stiffness only and will not see high ultimate stress levels [8]. It is well known that most advanced fibre composites are stronger in tension (in the fiber direction) than in compression. This is due to fact that the compressive strength of unidirectional composites is governed by microbuckling of fibres embedded in the matrix [9 -10].

Mechanical failure of composite materials had become active research area, due to increasing demand of composite materials in industrial applications. Many researches have highlighted the use of various agricultural materials in composites production, and their results have acceptable outcomes for many industrial and engineering applications. Kalaycioglu and Nemli [11] investigated on the parameters affecting the properties of kenaf fiber and from their study it was found that press temperature, time, density and shelling ratio affects the physical and mechanical properties of particleboards. The performance of composites made from wheat straw and waste veneer splinters were studied by [12]. They reported that with the exception of modulus of elasticity, all the others mechanical properties (modulus of rupture, internal bond and impact strength) and physical characteristics (thickness swelling and water absorption) studied decreased with increase in wheat straw content [12]. Additionally, researches by Budiansky and Fleck [13] and Kyriakides et al. [14] provided necessary information on plastic microbuckling, initiation and localization of deformation of composites into kink bands, respectively. Furthermore, the potential of carbonized bagasse (waste from sugar cane) as fillers in composites were studied by [15]. They reported that as the filler loading increased the tensile strength, abrasion resistance, and hardness properties improved.

From literature review, much work have been done on natural materials composites, but there is dearth of information on oil bean pod shell (OPBS) and mahogany sawdust (SD) Epoxy resin composites. Therefore, the objective of this study was to investigate and evaluate the compressive behaviours (compressive strength, compressive energy, Young's modulus, failure time, and compressive strain) of OBPS and SD reinforced epoxy composites, to establish its practicality in engineering applications.

2. MATERIALS AND METHODS

2.1 Samples collection and preparation

The oil bean pod shells and Mahogany timber used for this study were collected from Ozoro, Delta State, Nigeria. The oil bean pod shells were ground into particulates size with a burr mill, the particulates were treated with 5% NaOH for 1 hour to enhance their mechanical properties, and sieved with 150 µm sieve. To obtain the saw dust from the timber, the mahogany timber was sawed with fine teeth saw blade. The saw dust was later treated with 5% NaOH solution for 1 hour, air-dried, and sieved with a 300 µm stainless sieve. Fig. 1 showed the pictures of the oil bean tree and the oil bean pod shells.

2.2 Composite Preparation

The Epoxy composites board was prepared by reinforcing epoxy matrix with fillers (SD and OBPS particulates) using the hand-lay-up technique, which was followed static compressive loading. The composite matrix was prepared by mixing epoxy resin and hardener in a ratio of 7:3. The Epoxy composite samples were prepared with varying weight of the fillers, in the ratio of 1:1, as presented in table 1. after curing, the composite boards were cut in testing samples according to ASTM standard.

2.3 Compression Test

The compression test of the samples was done according to ASTM D3410 standard. Each sample was placed unidirectional under the compression loading cell of the Universal Testing Machine (Testometric model), ensuring that the sample was at alignment with the loading cell. The compression was done according to ASTM D3410 standard, at a cross head speed of 1.5 mm/min [16-17]. As the compression of each sample by the machine progressed, a stress-strain curve was plotted automatically by the Machine (Fig. 2.), in relation of the sample resistance to compression, up to the maximum compressive stress point.

Compressive strength is the maximum stress a material can sustain under crush loading. Compressive strength was calculated by dividing the maximum load by the original cross-sectional area of the sample during the compressive test [18]. Yield strength is the maximum stress that the sample can withstand without causing plastic deformation. It is the stress at which a material exhibits a specified permanent deformation and is a practical approximation of elastic limit [18]. The tests were conducted at ambient temperature (25±4˚C). Seven samples were tested and the average values were recorded.

Fig. 1a. An oil bean tree

Fig. 1b. Oil bean pod shells

Table 1. Compositions of the epoxy composite samples

Code	Composites
S1	Epoxy composite reinforced by 10 wt.% of fillers loading
S2	Epoxy composite reinforced by 15 wt.% of fillers loading
S3	Epoxy composite reinforced by 20 wt.% of fillers loading
S4	Epoxy composite reinforced by 25 wt.% of fillers loading
S5	Epoxy composite reinforced by 30 wt.% of fillers loading

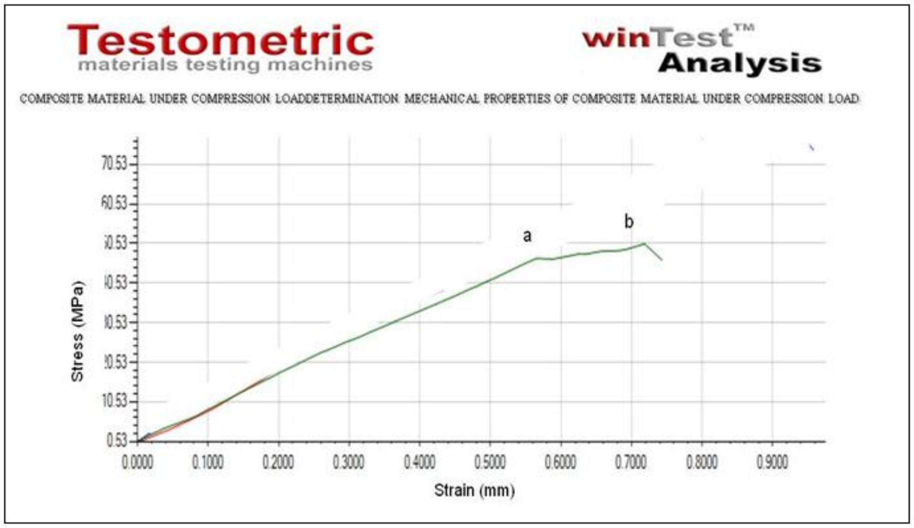

Fig. 2. A stress-strain deformation curve of Epoxy/OBPS/SD composite under compressive loading

a = Failure point, b = Maximum compressive point

2.4 Statistical Analysis

Data obtained from this research were subjected to Analysis of variance using SPSS software (version 20.0). Furthermore, the mean values were separated using Duncan's multiple range tests at 95% confidence level.

3. RESULTS AND DISCUSSION

Table 2 showed the Analysis of Variance (ANOVA) results of the effect of fillers loading on the compressive behaviours of epoxy composites. As shown in Table 2, OBPS and SD fillers had significant effect on all the compressive behaviours of the composites studied. In addition, Table 3 showed the regression equations, showing the relationships between the fillers loading and the compressive behaviours of the composite samples. From the results presented in Table 3, the high correlation values ($r \geq 0.90$) showed that strong relationship existed between the fillers loading and the various compressive behaviours.

Results of the compressive tests of the composite samples are presented in Figs. 3 to 7. As shown in the plots (Figs. 3 to 7), it can be clearly seen that the fillers were effective mechanism of matrix strengthening, as the results showed that the compressive behaviours of the samples were enhanced with the addition of the fillers. From the results obtained, the addition of the fillers improved the compressive strength 69%, while the Young's modulus increased from 446.56 MPa to 872.56 MPa, as the fillers loading increased from 10 to 30 wt.%. Similar result was reported by [16], when the addition of the rigid nanoparticles increases compressive yield strength of matric resins 89.1 MPa at 0 wt.% to 94.78 MPa at 20 wt.%. These results can provide essential information in composite board production for industrial applications, mostly in the construction industries.

Table 2. ANOVA for response of compressive behaviours of Epoxy/OBPS/SD composite to fillers loading

Source of variation	Dependent variable	df	Sig
	Compressive strength	4	8.02E-15*
	Young's modulus	4	1.05E-13*
L	Failure time	4	3.29E-12*
	Compressive energy	4	6.26E-14*
	Compressive strain	4	5.88E-15*

*L = Filler loading; * =Significant at (P ≤0.05); df = degree of freedom*

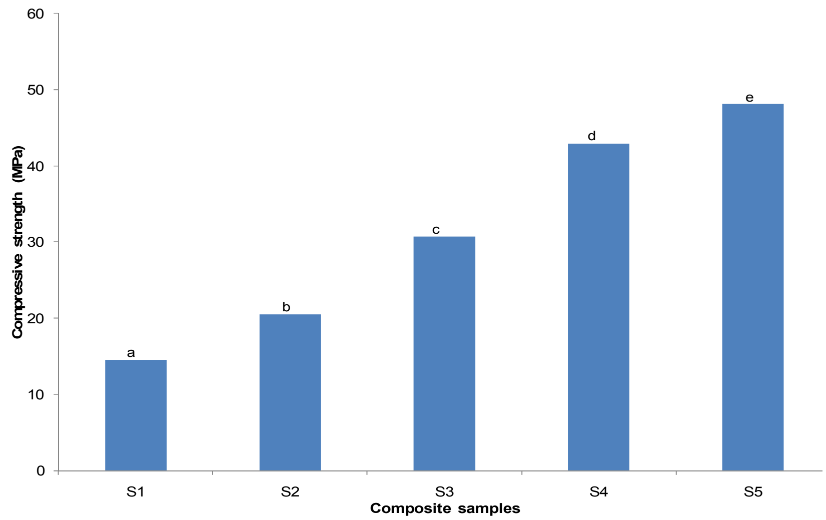

Fig. 3. Effect of fillers loading on the compressive strength of composite board
Bars with the same common letters means that they are not significant different at (P ≤0.05)

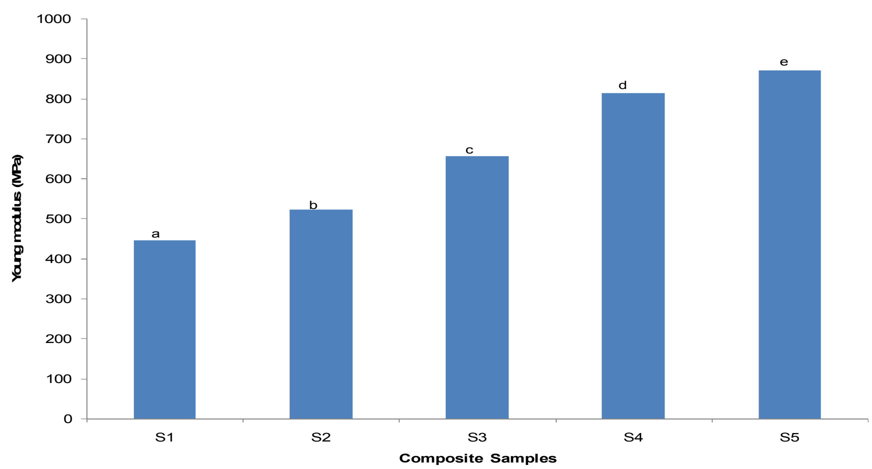

Fig. 4. Effect of fillers loading on the compressive Young's modulus of composite board
Bars with the same common letters means that they are not significant different at (P ≤0.05)

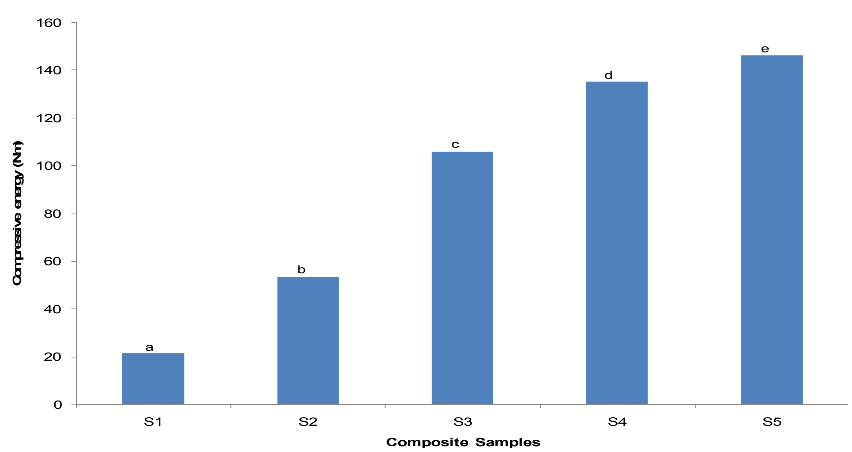

Fig. 5. Effect of fillers loading on the compressive energy of composite board
Bars with the same common letters means that they are not significant different at (P ≤0.05)

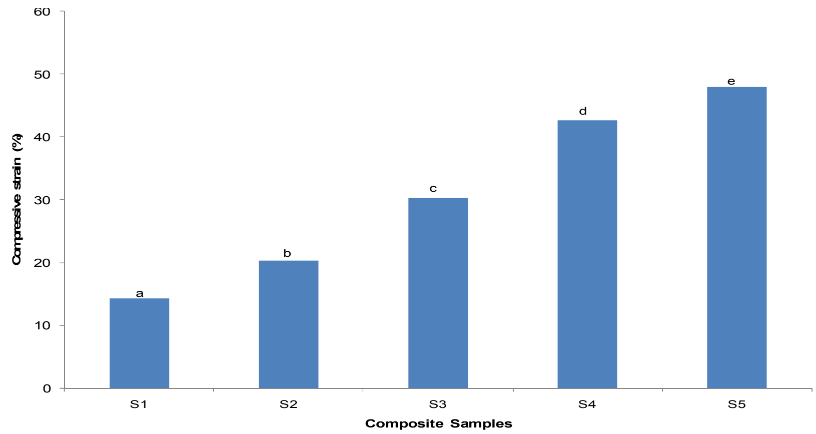

Fig. 6. Effect of fillers loading on the compressive strain of composite board
Bars with the same common letters means that they are not significant different at (P ≤0.05)

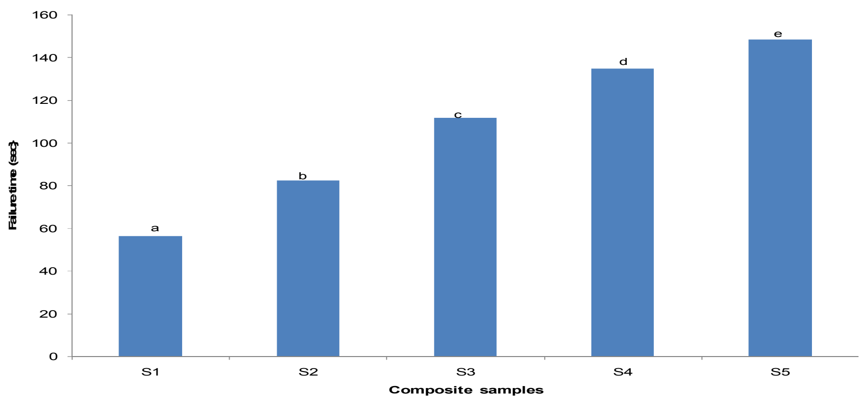

Fig. 7. Effect of fillers loading on the compressive failure time of composite board
Bars with the same common letters means that they are not significant different at (P ≤0.05)

Table 3. Regression equations of compressive behaviours of Epoxy/OBPS/SD composite as a function of its fillers loading

Parameter	Linear equation	R^2	r
Compressive strength	y = 8.973 x + 4.481	0.983	0.991
Young's modulus	y = 114.5 x + 319.3	0.979	0.989
compressive energy	y = 33.14 x - 6.965	0.958	0.978
Compressive strain	y = 8.968 x + 4.262	0.983	0.992
Failure time	y = 23.67 x + 35.88	0.984	0.992

Where x = filler loading rate; R^2 = coefficient of determination; r = correlation

Matrix and reinforcement (fillers) modification helps to provide an effective approach to improve compressive behaviours of the composites boards. When a composite, especially for unidirectional fiber reinforced composites, is subjected to a longitudinal compressive load, several main failure modes, which include microbuckling, kinking, fibre failure, and longitudinal cracking and shear failure, are involved [13,19]. Fibre microbuckling and kinking can be easily seen from the samples surface and the fracture surfaces of the compressive samples [16]. Cho et al. [20] reported 10% and 16% improvement in longitudinal compressive strength of carbon/epoxy composites with 55% fiber volume fraction by adding 3 wt.% and 5 wt.% graphite nanoparticles in epoxy matrices. Additionally, the compressive strength of nano-calcium carbonate/epoxy and its fiber composites were studied by He et al. [21]. Their resulted revealed a noticeable improvement of 13.5% and 14.1%, increases in compressive strength, for the cured bulk epoxy matrix and its fiber composites filled with 4 wt.% nano-$CaCO_3$.

4. CONCLUSIONS

The compressive response and behaviours of oil bean pod shell and hard wood saw dust reinforced composites were studied in this research. The fillers reinforcement was seen to improve the compressive behaviours of the composites samples. The results from the research showed that the compressive strength of the composite board increased by about 60% as the filler loading rate increased from 10% to 30%. Apart from the compressive strength, the other four parameters showed remarkably increment as the fillers loading rate increased from 10% to 30%. Results obtained from this work can be helpful in composite board modifications for industrial applications, mostly in the construction industries.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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