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Analysis of Thermal and Physical Response of Bio-Composite Reinforced Ceiling Board

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ABSTRACT

Asbestos used in the production of ceiling board can cause asbestosis, which may lead to cancer. Moreover, environmental concerns have directed attention of researchers to waste recycling and recovering. Wastes are menace to the environment and unfortunately there are abundant wastes with poor disposal systems in third world countries like Nigeria. It is therefore imperative that alternative recovery measures are introduced to curb their adverse effects. Agricultural wastes utilized in this study includes rice and coconut husks as the basic raw materials. The thermal and physical response of bio-composite reinforced ceiling board was analyzed in this study. The aim of this research was to investigate the effectiveness of utilizing sustainable bio-composites as reinforcement materials in building construction. Cement and starch were used as binders and they also assisted in improving the ceiling board strength. A comprehensive set of experiments was conducted to evaluate the thermal and physical properties of the bio-composite reinforced ceiling board. Box Behnken method was employed in the design and development of the test samples. The produced samples were subjected to thermal conductivity, density measurement, thickness swelling and water absorption tests. The results showed density values ranging from 432 – 863 kg/m^3, thickness swelling values of 1.32 – 13.99%, thermal conductivity values of 0.024 – 0.036 W/mK and water absorption rate of 3.26 – 32.2%. The density of the produced bio-composite reinforced ceiling board is lower than that of asbestos with density range of 1500 – 1950 kg/m^3 though asbestos gave better water absorption rate of 0.5 – 3.0%. It was observed that run D1 with 50% biomass comprising 28 g of coconut husk and 28 g of rice husk gave the optimal response with a thermal conductivity of 0.0024 W/mK, density of 795 kg/m^3, thickness swelling of 5.96% and water absorption of 8.77%. The results showed that the bio-composite reinforcement improved the thermal and physical performance of the ceiling board. Additionally, the effects of different bio-composite reinforcement materials on the properties of the board were examined. The results demonstrated that the addition of bio-materials greatly improves the thermal insulation properties of the ceiling board, making it a promising alternative to traditional building materials. Moreover, the study discussed the potential applications of this bio-composite reinforced ceiling board in the construction industry. In conclusion, this study provides important insights into the potential use of bio-composites in building construction and their effect on the thermal and physical performance of building materials.

1. Introduction

The growing concerns on health implications of using asbestos based material and effects of ozone affinity compound on the environment has shifted the attention of researchers to bio-wastes materials. Kumar et al [1] foreseen that due to severe climate change, the use of environment-friendly materials that satisfy net-zero emissions is inevitable. Bio-wastes being by-products of nature satisfactorily maintain emission balance. Even the use of hydrocarbon base materials are not appropriate as Abonyi et al [2] reported that pollutants emanating from petroleum hydrocarbons are toxic in nature.

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Bio-waste particulates have many advantages such as low cost, low weight, high toughness, sufficient hardness, good thermal properties, lower pollution, and biodegradability over conventional reinforcing material [3 – 6]. Availability of a vast array of agro-waste byproducts such as sugarcane bagasse, rattan shavings, rice husk, coconut husk and tobacco stalks had prompted researchers to investigate the potentials of these agricultural residues as raw material for cement-bonded boards. Environment-friendly bio-waste has been reported as potential materials for buildings and constructions [1, 7]; ultimately leading to low cost housing provisions [8]. Moreover, the use of agro-wastes aids in reducing wastes burden in the environment thereby reducing environmental pollution resulting from these waste materials; thus, contributing to recycling and recovering these waste materials for economic benefits [5, 8-10].

Rice husk has been successful used as good substitute for wood, wood-based board products and asbestos in the production of environmental friendly particle boards and ceiling board [3, 8, 11, 12]. The use of rice husk and other agro-wastes in production of low cost construction material has reduce the demand for the production of industrial wood from the natural forests which is already in a decline. Rice husk is not only easily available but possesses low bulk density (90-150 kg/m^3), good toughness, abrasive in nature, and resistance to weathering [3, 8].

Coconut (Cocos nucifera L.) is a member of the palm family [13]. The coconut fruit consists of four layers: namely, exocarp, mesocarp, endocarp and endosperm [13]. The mesocarp known as husk, the endocarp is the shell and endosperm is the edible kernel. Exocarp is the outmost layer which is smooth and varies in colour depending on the age of the fruit. Coconut husk is abundant in nature, cost effective, non-toxic, renewable, low thermal conductivity, and low bulk density [14]; it is a light weight material with density of 1.1–1.5 g/cm^3 and tensile strength 105–593 MPa [15]. Omar et al [16] employed coconut husk in the development of ceiling board for thermal insulation to reduce heat flux by maintaining the temperature of the building thereby creating a comfortable environment within the house in hot and humid region. Gypsum plaster Type 1 has been replaced by coconut husk in production of gypsum board [17]. De Silva et al [18] reported the use of coconut husk in developing a cost-effective, thermally insulated ceiling sheet system that reduces the operational energy required for temperature control and ensures consistent temperatures within enclosed spaces. Generally, insulator keeps the home cooler in hot weather and warmer in cold weather thereby lessening the burden of heating and cooling appliances that is required to keep the house comfortable; thus, reducing the cost of energy [19].

A ceiling board is a horizontal slab covering the upper section of a room or internal space. In modern buildings, electric lights, smoke detector, security cameras are commonly installed in ceilings. In the past, ceiling boards were produced using asbestos a fiber existing naturally in rocks formation throughout the world. It was used because of its high tensile strength, poor heat conductivity and good fire resistance. However, asbestos causes asbestosis, which leads to cancer. It becomes imperative that environmentally friendly and low cost materials will be exploited as alternatives to asbestos. In this study, rice husk and coconut husk are used as reinforcement and cassava starch and cement as binders in the production of ceiling board. Recycled low-density polyethylene (rLDPE) and breadfruit seed coat have been used to produce ceiling board [20]. The study revealed that 16.205% filler-binder ratio, 200°C compaction temperature in 9.569 min compaction time and 10.956 MPa compaction pressure gave optimal responses of 0.584 W/mK thermal conductivity, 0.772% thickness swelling and 0.26% water absorption. Cane wood and palm kernel fibre (PKF) had been used as filler material in producing ceiling boards, with recycled low-density polyethylene (LDPE) as the binder [21]. The work showed that process parameters of 15% cane wood, 10% PKF, 75% LDPE, 6 min press time, 7 bar press pressure and 198°C press temperature gave optimal response factors of thermal resistivity, water absorption and thickness swell of 16.192 W/mK, 4.669% and 6.594% respectively.

This study explores rice husk and coconut husk as filler material in ceiling board production with starch and cement as binders. Rice husk is one of the agricultural wastes that have a good thermal insulating property, because they are difficult to burn and less likely to allow moisture to propagate mold or fungi. Coconut fiber (coir) is a natural fiber extracted from the husk of coconut and used in products such as floor mats, doormats, brushes, animal bedding and mattresses. These materials are chosen due to their very important physical and thermal properties which are similar to those of conventional ceiling boards. Since the component of the developed ceiling board are waste byproducts, they can easily be sourced and processed into useable ceiling boards at affordable cost.

2. Materials and Methods

The raw materials utilized in this research include rice husk, coconut husk, cement, cassava starch, and water.

2.1 Preparation of material

Rice husks and coconut husks were thoroughly washed with water in different vessels to remove impurities. The washed husks were oven dried at 65°C for 5 hours to reduce their moisture content. The husks were separately grinded using milling machine into particulate size and sieved to a particle size of 300 μm. After sieving, the fibers were measured so as to obtain the right proportion of all the constituents as presented in table 2. At the end of the measuring stage, cement was poured into a pan and the fiber were sprinkled into the container containing the cement while stirring to avoid bunching as water is being added. The percentage of biomass filler used in relation to biomass-cement mixture is presented in table 3. Care was taken to ensure good distribution of fiber in order to increase the strength of the material. Starch prepared using hot water was added to the mixture of cement and bio-mass to reduce porosity and enhance the binding of the bio-composite. Starch was added because it exhibits viscosity modifying characteristics [22]. The entire composition was stirred thoroughly resulting in a homogeneous mixture.

2.2 Molding of the system

The mold was first cleaned and greased with oil for easy removal of sample from mold. Metal foil was placed in the mold to wrap each sample before they are placed into the hydraulic pressing machine. The metal foil helps to prevent the samples from having direct contact with the mold and also assist in effective heat transfer from the press to the sample. Wax is applied on the surfaces of the mold and the metal foil to prevent the samples from sticking during the pressing period. The wax also assists in the easy removal of the metal foil from the mold and during unwarping. The homogenous mixture obtained was transferred into mold. The dimension of the mold is 163 X 142 X 5 mm. A metal spatula was used to tamp the composite in order to remove air voids, to level the surface and also to give a compacted surface. The mold cover was put in place and the mold was transported to hot hydraulic pressing machine for compression.

2.3 Compressing of the mixture

The mold along with the mixture in it was place into the hot hydraulic pressing machine. The compression of the mixture was done for 25 minutes to allow for effective compacting of the mixture. The compression pressures were 13, 15, 19, 23 and 29 MPa and the compression temperatures were 160, 170, 185, 200 and 210°C. This process assisted in the curing and setting of the sample. After compaction, the sample and mold were taken out and allowed to dry and cure in ambient environment. After curing, the dried sample was removed from the mold, and the sample was then kept in a vertical position for safety, and then the various tests were carried out and recorded.

2.4 Design of experiment

Box-Behnken design was used in formulating the required number of experimental run to be carried out. It is a type of response surface design that does not contain an embedded factorial or fractional factorial design. It allows efficient estimation of the first- and second-order coefficients because the design often have fewer design points. Box-Behnken designs also ensure that all factors are never set at their high levels simultaneously. Three factors (biomass ratio, press pressure and press temperature) were considered in this study as shown in table 1. The process parameters biomass ratio, press pressure and press temperature are designated with A, B and C respectively. Box-Behnken design generated twenty experimental runs as shown in table 2.

Table 1 - Levels of the factors for the three factors Box-Behnken design for the ceiling board production

Factor	**Names**	**Unit**	**αLow**	**Low**	**Mean**	**High**	**α High**
A	Biomass ratio	%	0	20	50	80	100
B	Press Pressure	MPa	13	15	19	23	29
C	Press Temperature	ºC	160	170	185	200	210

The predicted density for the ceiling board production is taken as 726kg/m^3 (0.726g/cm^3) and the volume of the mold is given as 115.73 cm^3 (16.3 X 14.2 X 0.5 cm); the calculated mass of the ceiling board became 84 g. Using 84 g as the overall total mass, the mass percentage of the constituent were determined. Having the mass of the additives as constant (i.e. cement and starch maintaining 14 g respectively) for the entire sample production, using the Box-Behnken design, the masses of rice husk and coconut were as outlined in table 2.

Table 2 - Box-Behnken design for the production of the ceiling boards

Runs	**Coconut husk (g)**	**Rice husk (g)**	**Press Pressure (MPa)**	**Press Temperature (ºC)**
A1	**11**	**45**	**15**	**170**
A2	**45**	**11**	**15**	**170**
A3	**11**	**45**	**23**	**170**
A4	**45**	**11**	**23**	**170**
B1	**11**	**45**	**15**	**200**
B2	**45**	**11**	**15**	**200**
B3	**11**	**45**	**23**	**200**
B4	**45**	**11**	**23**	**200**
C1	**0**	**56**	**19**	**185**
C2	**56**	**0**	**19**	**185**
C3	**28**	**28**	**15**	**185**
C4	**28**	**28**	**25**	**185**
D1	**28**	**28**	**19**	**160**
D2	**28**	**28**	**19**	**200**
D3	**28**	**28**	**19**	**185**
D4	**28**	**28**	**19**	**185**
E1	**28**	**28**	**19**	**185**
E2	**28**	**28**	**19**	**185**
E3	**28**	**28**	**19**	**185**
E4	**28**	**28**	**19**	**185**

2.5 Determination of physical properties

2.5.1 Water absorption test

Water absorption test was conducted by weighing the samples and then submerging the weighed samples in water for 24 hours. After soaking the sample for 24 hours, the sample was removed from water, cleaned, dried and re-weighed.

$$\% \, Water\ absorption = \frac{m_f - m_0}{m_0} \times 100 \qquad (1)$$

where
$m_f \ = \ weight\ after\ soaking$
$m_0 \ = \ weight\ before\ soaking$

2.5.2 Density test

The tests were carried out based on BS EN 323

$$Density = \frac{masss}{volume} \qquad (2)$$

2.5.3 Thickness swelling test

The initial thickness of the sample was measured using a micrometer screw gauge then after submerging in water for 24 hours, the new thickness was measured.

$$\% \, Thickness\ swelling = \frac{t_f - t_0}{t_0} \times 100 \qquad (3)$$

where
$t_0 \ = \ thickness\ of\ wet\ sample\ immersed\ in\ water$
$t_f \ = \ thickness\ of\ dry\ sample$

2.6 Thermal conductivity

The instrument used for this test was the 78HW -1 constant temperature magnetic stirrer, the sample is trimmed to 50 mm X 50 mm and was place on top the equipment, when it has been heated up (initial temperature), after one minute the temperatures is recorded. The thermal conductivity test is calculated using the formula below:

$$Thermal\ conductivity, K = \frac{Q}{A(T_1 - T_2)} \qquad (4)$$

where
$T \ = \ thermal\ conductivity\ (W/mK)$
$A \ = \ cross - sectional\ area\ of\ the\ heat\ flow\ in\ square\ meter$
$Q \ = \ thermal\ flux\ (W)$
$T_1 \ = \ high\ temperature\ on\ the\ surface\ in\ degree\ Kelvin$
$T_2 \ = \ low\ temperature\ on\ the\ surface\ in\ degree\ Kelvin$

3. Results and Discussion

This study considered the production of ceiling board using local agricultural waste and determining their responses which are water absorption, density, thickness swelling and thermal conductivity. Biomass ratio, press pressure and press temperature were the process parameters varied in this study. Response Surface Design (RSM) of Box Behnken Design (BBD) was used to optimize the ceiling board properties. The combination of the independent variables along with the experimental response is represented in the Table 3.

It could be observed that the least percentage water absorption of 2.36% is associated with 20% biomass ratio (11 g of coconut husk and 35 g of rice husk) at 23 MPa press pressure and 170°C press temperature. The highest percentage water absorption of 32.2% occurred at 100% biomass ratio (56 g of coconut husk and 0 g of rice husk) at 19 MPa press pressure and 185°C press temperature. The average percentage water absorption of the produced bio-composite reinforced ceiling board is 15.03%. The water absorption of the produced board is within the range reported in literature for bio-composite reinforced ceiling. Water absorption of 0.52 - 0.63%, 6.8 - 10.3%, 7.5 - 14.5%, 9.0 - 39.8%, 5.88 - 66.67%, 6.67%, 11.20% and 20.3% were reported by [9], [12], [8], [7], [10], [3], [16] and [23] respectively. ISO 16459 recommended that the percentage water absorption of ceiling boards produced from natural fibers should not exceed 12%. All the samples with rice husk of 45 g and above recorded water absorption below 12%. The biomass ratio of 28 g of coconut husk and 28 g of rice husk at 50% biomass and low press temperature of 160°C gave relatively good water absorption rate of 8.77%. Low water absorption improves durability and guarantees better resistance to mold growth.

The least density of 432 kg/m^3 is associated with 80% biomass ratio (15 g of coconut husk and 11 g of rice husk) at 15 MPa press pressure and 200°C press temperature. The highest density of 863 kg/m^3 occurred at 20% biomass ratio (45 g of coconut husk and 11 g of rice husk) at 23 MPa press pressure and 170°C press temperature. The average density of the produced bio-composite reinforced ceiling board is 622.4 kg/m^3. It is relatively denser than ceiling board produced from waste paper, sodium silicate and cement which has average density of 375 kg/m^3 [9] but less dense than board produced from rice husk and urea formaldehyde with an average density of 815 kg/m^3 [11] and that produced from rice husk, cassava starch, and epoxy resin with an average density of 1400 kg/m^3 [12]. Moreover, the density of the produced bio-composite reinforced ceiling board is lower than that of asbestos with density range of 1500 – 1950 kg/m^3 [8]. It implies that there is appreciable weight reduction in the developed ceiling board compared with asbestos ceiling board.

Table 3 - The response factors with the input parameters

	Factor 1	Factor 2	Factor 3	R1	R2	R3	R4
Std.	**A: Biomass Ratio**	**B: Press Pressure**	**C: Press Temperature**	**Water Absorption**	**Thermal Conductivity**	**Thickness swell**	**Density**
	%	**MPa**	**°C**	**%**	**W/mK**	**%**	**kg/m^3**
A1	**20**	**15**	**170**	**3.29**	**0.027**	**1.32**	**756**
A2	**80**	**15**	**170**	**25.14**	**0.028**	**7.35**	**469**
A3	**20**	**23**	**170**	**2.36**	**0.030**	**11.42**	**863**
A4	**80**	**23**	**170**	**23.27**	**0.028**	**13.99**	**650**
B1	**20**	**15**	**200**	**9.34**	**0.032**	**11.47**	**526**
B2	**80**	**15**	**200**	**25.70**	**0.036**	**12.54**	**432**
B3	**20**	**23**	**200**	**11.79**	**0.034**	**7.45**	**558**
B4	**80**	**23**	**200**	**26.47**	**0.036**	**4.55**	**594**
C1	**0**	**19**	**185**	**5.77**	**0.032**	**6.25**	**613**
C2	**100**	**19**	**185**	**32.20**	**0.035**	**9.35**	**450**
C3	**50**	**13**	**185**	**14.21**	**0.026**	**10.52**	**577**
C4	**50**	**25**	**185**	**12.62**	**0.029**	**12.90**	**804**
D1	**50**	**19**	**160**	**8.77**	**0.024**	**5.96**	**795**
D2	**50**	**19**	**200**	**17.27**	**0.036**	**6.92**	**467**
D3	**50**	**19**	**185**	**13.47**	**0.029**	**10.15**	**661**
D4	**50**	**19**	**185**	**13.96**	**0.030**	**10.74**	**658**
E1	**50**	**19**	**185**	**14.00**	**0.033**	**12.01**	**634**
E2	**50**	**19**	**185**	**14.67**	**0.034**	**11.67**	**657**
E3	**50**	**19**	**185**	**13.33**	**0.033**	**10.87**	**670**
E4	**50**	**19**	**185**	**13.00**	**0.029**	**9.89**	**614**

The swelling thickness of ceiling board refers to the increase in thickness due to exposure to moisture or water. The least percentage swelling thickness of 1.32% is associated with 20% biomass ratio (11 g of coconut husk and 45 g of rice husk) at 15 MPa press pressure and 170°C press temperature. The highest percentage swelling thickness of 13.99% occurred at 80% biomass ratio (45 g of coconut husk and 11 g of rice husk) at 23 MPa press pressure and 170°C press temperature. The average percentage swelling thickness of the produced bio-composite reinforced ceiling board is 9.37%. ISO 16459 recommended that the percentage water swelling of ceiling boards produced from natural fibers should not exceed 5%. Only sample A1 and B4 with 20% biomass ratio (11 g of coconut husk and 45 g of rice husk) at 15 MPa press pressure and 170°C press temperature; and 80% biomass ratio (15 g of coconut husk and 11 g of rice husk) at 23 MPa press pressure and 200°C press temperature respectively met the standard requirement for water swelling. Nevertheless since the produced bio-composite ceiling board is meant for indoor applications, the average 9.37% water swelling is not of great concern.

The least value of thermal conductivity of 0.024 W/mK is associated with 50% biomass ratio (28 g of coconut husk and 28 g of rice husk) at 19 MPa press pressure and 160°C press temperature. The highest value of thermal conductivity of 0.036 W/mK occurred at three experimental points B2, B4 and D2 at 200°C press temperature. The average thermal conductivity of produced bio-composite reinforced ceiling board is 0.031 W/mK. This is very close the previous thermal conductivity reported for bio-composite reinforced board [8, 9].

3.1 Analysis of variance for water absorption for the developed ceiling board

Table 4 presented the developed bio-composite ceiling board's analysis of variance for water absorption. The Model F-value of 125.18 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Moreover, P-value less than 0.05 indicate model terms are significant. For water absorption, A, C, AC, A^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant. The "Lack of Fit F-value" of 4.98 implies there is a 5.14% chance that a "Lack of Fit F-value" this large could occur due to noise. The "Pred R-Squared" of 0.9422 is in reasonable agreement with the Adj R-Squared" of 0.9833; having a difference is less than 0.2. Adeq Precision measures the signal to noise ratio.

Table 4 - Analysis of variance table for water absorption

Source	Sum of Squares	df	Mean Square	F Value	P-value Prob> F	Remark
Model	1188.79	9	132.09	125.18	< 0.0001	Significant
A-Biomass Ratio	1024.14	1	1024.14	970.62	< 0.0001	Significant
B-Press Pressure	0.37	1	0.37	0.35	0.5663	
C-Press Temp	82.31	1	82.31	78.01	< 0.0001	Significant
AB	0.86	1	0.86	0.82	0.3875	
AC	17.17	1	17.17	16.27	0.0024	Significant
BC	4.53	1	4.53	4.29	0.0651	
A^2	57.77	1	57.77	54.75	< 0.0001	Significant
B^2	0.015	1	0.015	0.014	0.9075	
C^2	0.16	1	0.16	0.15	0.7023	
Residual	10.55	10	1.06			
Lack of Fit	8.79	5	1.76	4.98	0.0514	not significant
Pure Error	1.76	5	0.35			
Cor Total	1199.34	19				
R-Squared = 0.9912	Adj R-Squared = 0.9833			Pred R-Squared =0.9422		Adeq Precision = 43.3

A ratio greater than 4 is desirable. The ratio of 43.323 indicates an adequate signal. This model can be used to navigate the design space. The model equation with all the input factors and their interactions for water absorption is given as:

$$Water\ Absorption^{1} = 24.17 + 0.74A - 2.61\,B + 0.24\,C - 3.09 \times 10^{3}\,AB - 3.32 \times 10^{3}\,AC + 0.02\,BC + 2.27 \times 10^{-3}\,A^2 + 2.52 \times 10^{-3}\,B^2 - 4.82 \times 10^{-4}\,C^2 \quad (5)$$

Based on the regression model of P-value less than 0.05 and eliminating the coefficients terms with P-value greater than 0.05 which indicates insignificant, the prediction model was developed. Equation (6) shows a developed model equation that can be used to predict the ceiling board water absorption from the constituent parameters.

$$Water\ Absorption = 24.17 + 0.74A + 0.24\,C - 3.32 \times 10^{3}AC + 2.27 \times 10^{-3}\,A^2 \quad (6)$$

Equation (5) can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space. Equation (6) is a quadratic model relating water absorption and constituent parameters. The model indicated that only biomass ratio and press temperature had effects on water absorption of the developed board. The model showed that increasing the biomass ratio content leads to increase in water absorption while press temperature favors slightly increase in water absorption.

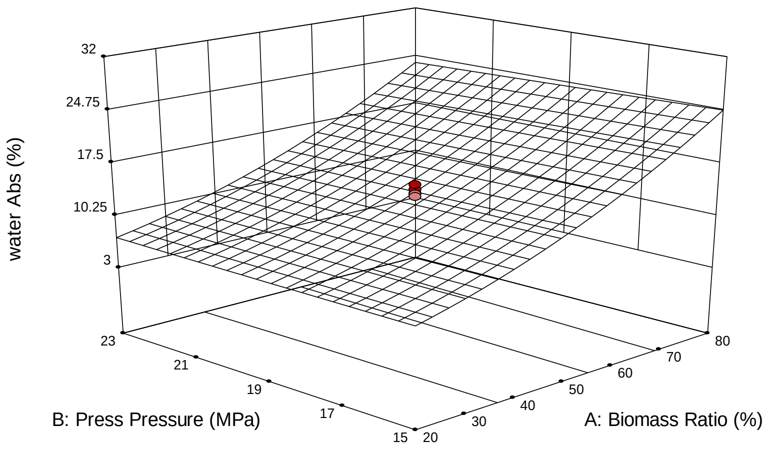

Fig. 1 - A plot of water absorption press against pressure and biomass ratio

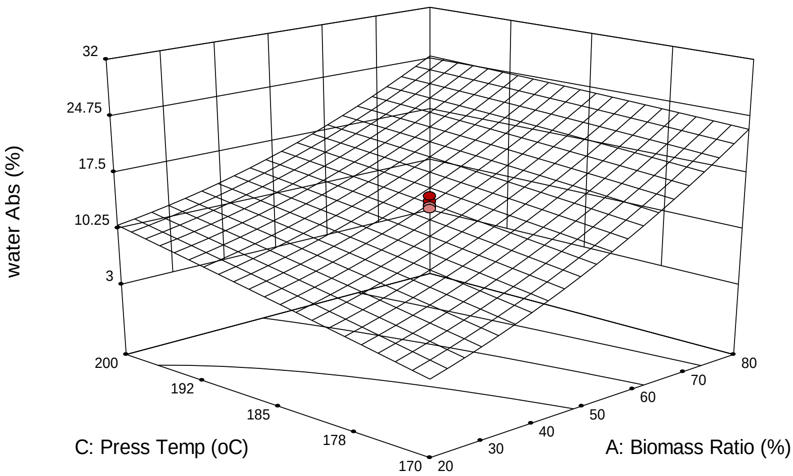

Fig. 2 - A plot of water absorption against press temperature and biomass

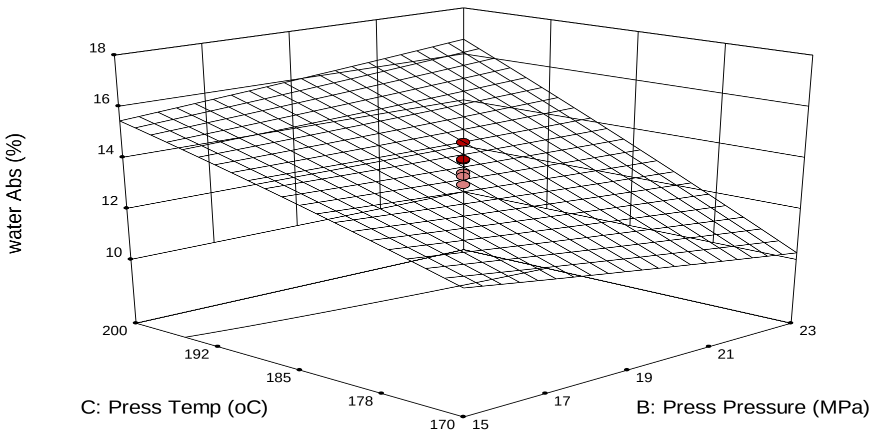

Fig. 3 - A plot of water absorption against press temperature and press pressure

Figures 1-3 show the plots of water absorption of the developed bio-composite ceiling board against the process parameters (biomass ratio, press temperature, and press pressure). Figure 1 indicated that decrease in both press pressure and biomass ratio will give a lower water absorption. A water absorption of 3% might be achieved at press pressure of 15 MPa and biomass ratio of 20%. Thus, increasing the biomass ratio content leads to increase in water absorption while pressure favors the decrease in water absorption due to adhesion. Biomasses are naturally hydrophilic in nature hence will absorb more water if increased. The treatment of the biomass will altered its hydrophilic nature. Figure 2 showed that low water absorption is associated with low press temperature and biomass ratio while figure 3 revealed that low water absorption is associated with low press temperature and high press pressure.

3.2 Analysis of variance for thermal conductivity for the developed ceiling board

Table 5 - Analysis of variance table for thermal conductivity

Source	Sum of Squares	df	Mean Square	F Value	P-value Prob> F	Remark
Model	2.089E-004	9	2.321E-005	9.41	0.0008	Significant
A-Biomass Ratio	8.935E-006	1	8.935E-006	3.62	0.0862	
B-Press Pressure	6.755E-006	1	6.755E-006	2.74	0.1290	
C-Press Temp	1.480E-004	1	1.480E-004	59.98	< 0.0001	Significant
AB	3.675E-006	1	3.675E-006	1.49	0.2503	
AC	6.688E-006	1	6.688E-006	2.71	0.1307	
BC	2.693E-007	1	2.693E-007	0.11	0.7479	
A^2	1.165E-005	1	1.165E-005	4.72	0.0549	
B^2	1.878E-005	1	1.878E-005	7.61	0.0202	Significant
C^2	1.041E-006	1	1.041E-006	0.42	0.5305	
Residual	2.467E-005	10	2.467E-006			
Lack of Fit	2.373E-006	5	4.746E-007	0.11	0.9860	not significant
Pure Error	2.230E-005	5	4.459E-006			
Cor Total	2.336E-004	19				
R-Squared = 0.8944		Adj R-Squared = 0.7993		Pred R-Squared = 0.7857		Adeq Precision = 9.969

Table 5 presented the developed bio-composite ceiling board's analysis of variance for thermal conductivity. Model F-value of 9.41 implies the model is significant with P-value less than 0.05. There is only a 0.08% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. In this case only C, B^2 are significant model terms and could be used in the prediction of thermal conductivity as indicated in equation (8). As stated earlier, values greater than 0.1 specify the model terms are not significant. It implies that the press pressure had no effect on the thermal conductivity of the produced bio-composite ceiling board but its quadratic value has significant effect on the thermal conductivity as shown in figure 5. The "Lack of Fit F-value" of 0.11 implies the Lack of Fit is not significant relative to the pure error. There is a 98.60% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good since it is desirable for the model to fit.

Equation (7) was developed in terms of actual factors and can only be used to make predictions about the response for given levels of each factor. The levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

$$Thermal\ conductivity^{1} = -0.09 - 3.36 \times 10^{-4}A + 4.57 \times 10^{-3}B + 6.34 \times 10^{-4}C - 6.39 \times 10^{-6}AB + 2.07 \times 10^{-6}AC - 3.46 \times 10^{-6}C + 1.02 \times 10^{-6}A^2 - 8.97 \times 10^{-5}B^2 - 1.22 \times 10^{-6}C^2 \quad (7)$$

Equation (8) shows a developed model equation that can be used to predict the thermal conductivity of the ceiling board from the constituents' parameters. Based on the regression model of P-value less than 0.05, significant parameters were chosen. In this case C and B^2 are significant model terms. Also, the relationship between thermal conductivity and the input parameters is a quadratic model.

$$Thermal\ conductivity = 6.34\ X\ 10^{-4}\ C - 8.97\ X\ 10^{-5}\ B^{2} \quad (8)$$

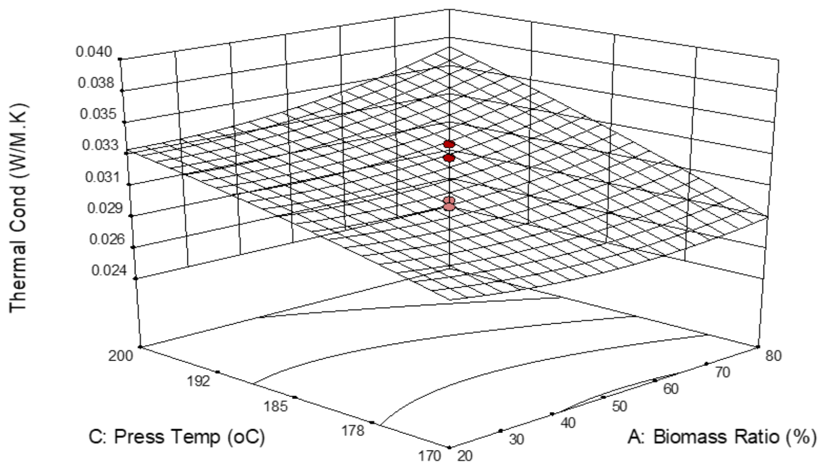

Fig. 4 - A plot of thermal conductivity against press temperature and biomass ratio

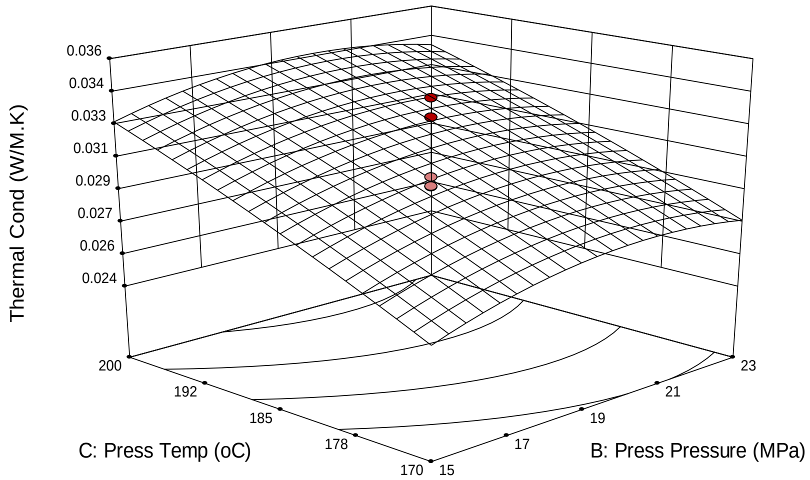

Fig. 5 - A plot of thermal conductivity against press temperature and press pressure

Figures 4 and 5 depicted the plots of thermal conductivity of the ceiling board against input parameters. From the plots, it is seen that an increase in the biomass ratio as well as press pressure will lead to an increase in the thermal conductivity of the produced bio-composite ceiling board while increase in press temperature will reduce the thermal conductivity. However, the optimal thermal conductivity of 0.024 W/mK was obtained at 19 MPa press pressure and 160°C press temperature with 28 g of coconut husk and 28 g of rice husk. The press pressure has a quadratic relationship with thermal conductivity.

3.3 Analysis of variance for swelling thickness for the developed ceiling board

Table 6 indicated the developed bio-composite ceiling board's analysis of variance for swelling thickness. The Model F-value of 56.87 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values of less than 0.05 indicate model terms are significant. In this case A, B, AB, AC, BC, A^2, C^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant; hence, press temperature does not have effect on the swelling thickness of the produced bio-composite ceiling board but its quadratic value does. The "lack of fit F-value" of 0.09 implies the lack of fit is not significant relative to the pure error. There is a 99.11% chance that a "lack of fit F-value" this large could occur due to noise. Non-significant lack of fit is required for the model to fit. Equation (9) was developed considering all the input parameters and their interactions. As stated earlier, equation (9) should not be used to determine the relative impact of each factor on thickness swelling because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Table 6 - Analysis of variance table for swelling thickness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	Remark
Model	190.52	9	21.17	56.87	< 0.0001	Significant
A-Biomass Ratio	10.52	1	10.52	28.26	0.0003	Significant
B-Press Pressure	5.58	1	5.58	14.98	0.0031	Significant
C-Press Temp	0.92	1	0.92	2.47	0.1473	
AB	6.90	1	6.90	18.52	0.0016	Significant
AC	13.59	1	13.59	36.51	0.0001	Significant
BC	103.34	1	103.34	277.63	< 0.0001	Significant
A^2	15.59	1	15.59	41.89	< 0.0001	Significant
B^2	1.69	1	1.69	4.54	0.0589	
C^2	33.34	1	33.34	89.56	< 0.0001	Significant
Residual	3.72	10	0.37			
Lack of Fit	0.30	5	0.059	0.086	0.9911	not significant
Pure Error	3.43	5	0.69			
Cor Total	194.25	19				
R-Squared = 0.9808	Adj R-Squared = 0.9636			Pred R-Squared = 0.9628		Adeq Precision = 29.736

$$Swelling\ Thickness^1 = -499.85 + 0.86A + 12.13B + 3.99C - 8.75 \times 10^{-3}AB - 2.95 \times 10^{-3}AC - 0.07BC - 1.18 \times 10^{-3}A^2 + 0.03B^2 - 6.88 \times 10^{-3}C^2 \quad (9)$$

Based on the significant model terms, equation (10) predicts the thickness swelling of the produced bio-composite reinforced ceiling board:

$$Swelling\ Thickness = 0.86A + 12.13B - 8.75 \times 10^{-3}AB - 2.95 \times 10^{-3}AC - 0.07BC - 1.18 \times 10^{-3}A^2 - 6.88 \times 10^{-3}C^2 \quad (10)$$

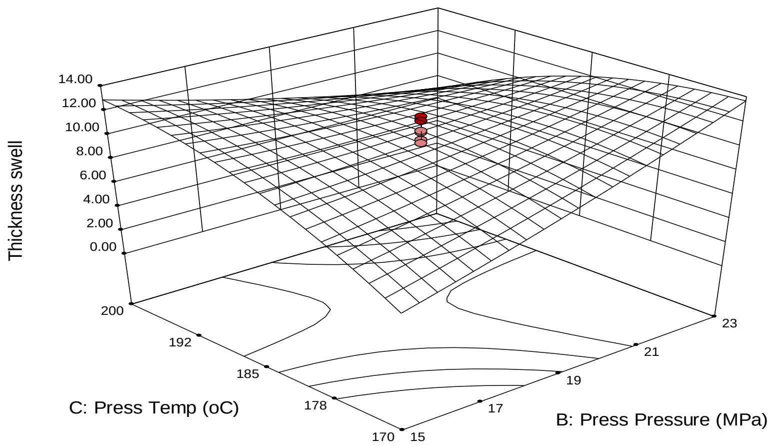

Fig. 6 - A plot of swelling thickness against press temperature and press pressure

Figure 6 depicted the plot of swelling thickness against press temperature and press pressure. It is seen that the plot is parabolic in nature due to the quadratic value of press temperature in equation (10). Thus high and low pressures will lead to reduction in swelling thickness while decrease in press temperature will lead to the decrease in the swelling thickness of the produced bio-composite ceiling board. The least percentage swelling thickness of 1.32% occurred at 15 MPa press pressure and 170°C press temperature with 20% biomass ratio (11 g of coconut husk and 45 g of rice husk).

3.4 Analysis of variance for density for the developed ceiling board

Table 7 depicted the developed bio-composite ceiling board's analysis of variance for density. The Model F-value of 52.16 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant. In this case A, B, C, AB, AC, A^2 are significant model terms. Values greater than 0.1 indicate the model terms are not significant. It means that all the process parameters contributed to low density of the produced samples. The "Lack of Fit F-value" of 1.64 implies the Lack of Fit is not significant relative to the pure error. There is a 30.13% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good for the model to fit. The "Pred R-Squared" of 0.8881 is in reasonable agreement with the "Adj R-Squared" of 0.9604; with a difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable.

Table 7: Analysis of variance table for density

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**P-value Prob> F**	**Remark**
Model	2.699E+005	9	29983.80	52.16	< 0.0001	significant
A-Biomass Ratio	50603.28	1	50603.28	88.03	< 0.0001	significant
B-Press Pressure	54651.54	1	54651.54	95.08	< 0.0001	significant
C-Press Temp	1.018E+005	1	1.018E+005	177.02	< 0.0001	significant
AB	5206.23	1	5206.23	9.06	0.0131	significant
AC	24585.92	1	24585.92	42.77	< 0.0001	significant
BC	1117.01	1	1117.01	1.94	0.1935	
A^2	27274.20	1	27274.20	47.45	< 0.0001	significant
B^2	2301.11	1	2301.11	4.00	0.0733	
C^2	1042.63	1	1042.63	1.81	0.2078	
Residual	5748.11	10	574.81			
Lack of Fit	3566.78	5	713.36	1.64	0.3013	not significant
Pure Error	2181.33	5	436.27			
Cor Total	2.756E+005	19				
Adj R-Squared = 0.9604	R-Squared = 0.9791		Pred R-Squared = 0.8881			Adeq Precision = 25.850

The value of 25.850 indicates an adequate signal. This model can be used to navigate the design space.

$$Density^1 = 1012.61 - 24.90A + 9.19B + 6.39C + 0.24AB + 0.13AC - 0.22BC - 0.05A^2 + 0.99B^2 - 0.04C^2 \quad (11)$$

Equation (11) was generated in terms of actual factors and can only make predictions about the response for given levels of each factor. Thus, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor on density of the produced bio-composite reinforced ceiling board because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space. Equation (12) predicts the effects of the input parameters and their interactions on the density of the produced bio-composite reinforced ceiling board. It is based on the significant model terms of table 7.

$$Density = -24.90A + 9.19B + 6.39C + 0.24AB + 0.13AC - 0.05A^2 \quad (12)$$

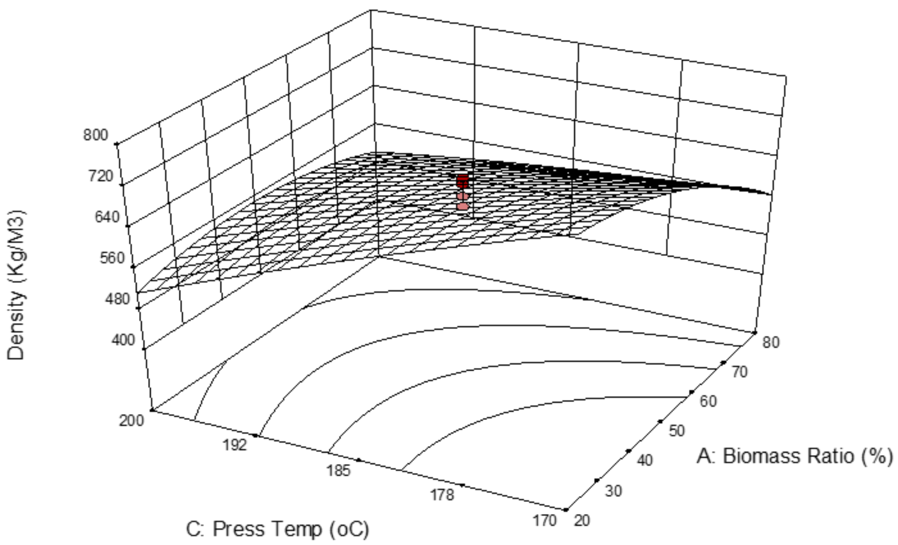

Fig. 7 - A plot of density against press temperature and biomass ratio

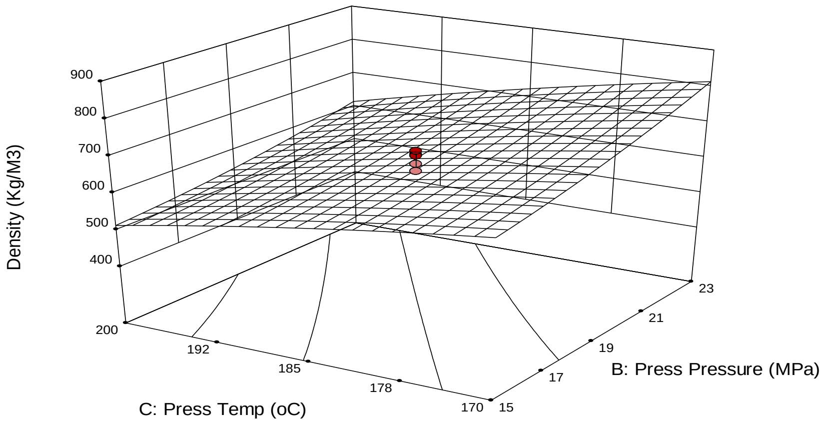

Fig. 8 - A plot of density against press temperature and press pressure

Figures 7 and 8 showed the plots of density of the produced bio-composite reinforced ceiling board against the process parameters. It is seen that an increase in temperature will lead to a decrease in density while an increase in the press pressure leads to slight increase in the density. Bio-mass ratio has a quadratic effect on the density. The optimal density of 432 kg/m^3 occurred when 80% biomass comprising 45 g coconut husk and 11 g rice husk was compressed by hydraulic pressure of 15 MPa at temperature of 200°C for 25 minutes. Coconut husk has been reported to have relatively low density ranging from 1200 to 1500 kg/m^3 [15, 24] also, rice husk possesses very low density of 90-150 kg/m^3 [3, 8]. The low density of the produced bio-composite reinforced board could be utilized not only in construction industry but in manufacturing of light weight vehicle parts such as dashboard components, door panels, headliners, floor panels, trim and molding. It could be used in various aerospace applications such as soundproofing, thermal insulation, partition panels, berths, storage compartments, galley components and radar-absorbing materials. The benefits of using the low density bio-composite reinforced board includes weight reduction which translates to fuel efficiency, cost savings, reduced environmental impact and increased design flexibility.

The potential applications of this bio-composite reinforced ceiling board in the construction industry are vast and varied. With its strong durability and lightweight nature, making them easier to handle and transport, this material has the potential to revolutionize the construction industry. Its use in various structural components such as walls, ceilings, and floors can provide a sustainable and cost-effective solution for builders. Additionally, its eco-friendly composition makes it a desirable choice for environmentally conscious construction projects. Moreover, the versatility of this material allows for its use in both residential and commercial buildings, making it a viable option for a wide range of construction projects. Besides, leveraging on bio-composites' thermal properties for energy-efficient buildings, it utilizes natural fibers' sound-absorbing properties for improved soundproofing. It offers a unique, eco-friendly aesthetic for ceiling adding up the entire beauty of the building. The application of the developed bio-composite ceiling boards will utilize bio-composites' durability and resistance to natural disasters thus providing a sustainable alternative to traditional ceiling materials.
Moreover, the potential applications of this bio-composite reinforced ceiling board extend beyond the construction industry, with potential uses in other fields such as transportation and aerospace. It could be integrated into modular building systems thereby contribute in achieving green building certifications. Bio-composites often emit fewer volatile organic compounds (VOCs) than traditional materials. Due to enhanced durability bio-composites, the developed ceiling board can be more resistant to moisture, mold, and pests. Overall, this material has the potential to greatly impact the construction industry and provide a sustainable and innovative solution for builders.

4. Conclusions

The ever increasing cost of building materials in Nigeria has made the search for substitute materials which are less expensive. The aim of this paper is to use agricultural wastes in the production of ceiling boards which are environment friendly, cost effective and possessing better mechanical and physical properties. The waste materials used include rice husk and coconut husk as fibers and both cement and starch as binders. The composite boards produced were subjected to various tests and using design expert software, it was observed that run D1 with 50% biomass comprising 28 g of coconut husk and 28 g of rice husk gave the optimal response with a thermal conductivity of 0.0024 W/mK, density of 795 kg/m^3, thickness swelling of 5.96% and water absorption of 8.77%. The results when compared to those of asbestos cement, cork and wood boards showed its potential use as a ceiling board. However, the average percentage water absorption for the produced bio-composite reinforced ceiling board of 15.03% is high compared with recommended upper limit of 12% for natural fibers reinforced ceiling boards. Further study on reducing the average percentage water absorption of the ceiling board will encourage its use in construction industries. The produced bio-composite reinforced ceiling board can be used in various structural components such as walls, ceilings, and floors can provide a sustainable and cost-effective solution for builders. Moreover, its eco-friendly composition makes it a desirable choice for environmentally conscious construction projects. It has potential applications not only in the construction industry, but other fields such as transportation and aerospace.

References

[1] Kumar B, Adil S, Pham DH, Kim J. Environment-friendly, high-performance cellulose nanofiber-vanillin epoxy nanocomposite with excellent mechanical, thermal insulation and UV shielding properties. Heliyon. 2024 Feb 15;10(3).
[2] Abonyi MN, Nwabanne JT, Ohale PE, Nwadike EC, Igbonekwu LI, Chukwu MM, Madiebo EM. Application of RSM and ANFIS in the optimal parameter evaluation for crude oil degradation in contaminated water amended with PES. Case Studies in Chemical and Environmental Engineering. 2023 Dec 1;8:100483.
[3] Asha A. Fabrication of particle boards from rice husk. Cellulose. 2017;28:38.
[4] Jose AS, Athijayamani A, Jani SP. A review on the mechanical properties of bio waste particulate reinforced polymer composites. Materials Today: Proceedings. 2021 Jan 1;37:1757-60.
[5] Dara JE, Omenyi SN, Nwigbo SC. Potentials of castor seed shell as a reinforcement in aluminum matrix composite development. UNIZIK Journal of Engineering and Applied Sciences. 2021 Dec 1;19(1):400-8.
[6] Patel RV, Yadav A, Winczek J. Physical, mechanical, and thermal properties of natural fiber-reinforced epoxy composites for construction and automotive applications. Applied Sciences. 2023 Apr 20;13(8):5126.
[7] Ohijeagbon IO, Bello-Ochende MU, Adeleke AA, Ikubanni PP, Samuel AA, Lasode OA, Atoyebi OD. Physico-mechanical properties of cement bonded ceiling board developed from teak and African locust bean tree wood residue. Materials Today: Proceedings. 2021 Jan 1;44:2865-73.
[8] Ataguba CO. Properties of ceiling boards produced from a composite of waste paper and rice husk. Int. J. Adv. Sci. Eng. Technol. 2016 Feb 2;2:117-21.
[9] Ekpunobi UE, Ohaekenyem EC, Ogbuagu AS, Orjiako EN. The mechanical properties of ceiling board produced from waste paper. British Journal of Applied Science & Technology. 2014 Oct 22;5(2):166-72.
[10] Okoli CC, Ezeagu CA, Okonkwo VO. Investigation on the Physical properties of Particleboard produced from Biodegradeable Waste and Plastics. Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE). 2023 Nov 13;1(4):24-40.
[11] Dhand D. Fabrication and Analysis of Thermal Insulation Boards from Rice Husk. Asian Journal of Engineering and Applied Technology. 2018 Oct 9;7(S2):26-9.
[12] Ameh EM, Nwogbu CC, Agbo AO. Production of Ceiling Board Using Local Raw Materials. Advance Journal of Science, Engineering and Technology. 2019 Jun 30;4(6):1-5.
[13] Nadzri SN, Sultan MT, Shah AU, Safri SN, Talib AR, Jawaid M, Basri AA. A comprehensive review of coconut shell powder composites: Preparation, processing, and characterization. Journal of Thermoplastic Composite Materials. 2022 Dec;35(12):2641-64.
[14] Onukwuli S, Okpala C, Nnaemeka F. Review of benefits and limitations of coir fiber filler material in composites. International journal of latest technology, management & applied science. 2022;11(5):13-20.
[15] Adeniyi AG, Onifade DV, Ighalo JO, Adeoye AS. A review of coir fiber reinforced polymer composites. Composites Part B: Engineering. 2019 Nov 1;176:107305.
[16] Omar MF, Abdullah MA, Rashid NA, Rani AA, Illias NA. The application of coconut fiber as insulation ceiling board in building construction. InIOP Conference Series: Materials Science and Engineering 2020 Jun 1 (Vol. 864, No. 1, p. 012196). IOP Publishing.
[17] Hankhuntod P, Phoo-ngernkham T, Krittacom B. Development of sustainable gypsum board made from coconut and water hyacinth fibers. InAIP Conference Proceedings 2022 Nov 17 (Vol. 2681, No. 1). AIP Publishing.
[18] De Silva AR, Jayasinghe R, Abeyrathna W, Jayasingha KR, Halwaturaa RU. Developing a low-cost thermally insulated ceiling sheet system using coir fibre. 2023 Jun; https://doi.org/10.32388/JP9GVT
[19] Dara JE, Ubani NO, Ofordum RC. Investigating the thermal properties of Hyparrhenia Rufa (giant thatch grass). UNIZIK Journal of Engineering and Applied Sciences. 2024 Jul 13;3(3):861-7.
[20] Ezenwa ON, Obika EN, Azaka OA, Nwadike EC. Effect of filler carbonization on agro-waste based ceiling board. Advances in Mechanical Engineering. 2021 Feb;13(2):1687814021994403.
[21] Jeremiah Lekwuwa C, Jude Ebieladoh S, Anthony Emeka E, Echezona Nnaemeka O, Onyemazuwa Andrew A, Kingsley Chidi N. Production and thermo-structural analysis of a hybridized natural fibre-based ceiling board for building applications. Advances in Mechanical Engineering. 2023 Dec;15(12):16878132231216677.
[22] Akindehinde AA, Schmidt W, Uzoegbo HC, Iyuke SE. The influence of starches on some properties of concrete. Advances in Cement and Concrete Technology in Africa. 2013 Jan; 637-646.
[23] Agaja S.A., Ayourim P. and Nwaezeapu A. O. (2021) Production and Test of Mechanical Properties of Ceiling Board Produced From Local Waste Materials, International Journal of Advances in Engineering and Management (IJAEM), 3 (11): 99-105.
[24] van Dam JE, van den Oever MJ, Keijsers ER, van der Putten JC, Anayron C, Josol F, Peralta A. Process for production of high density/high performance binderless boards from whole coconut husk: Part 2: Coconut husk morphology, composition and properties. Industrial Crops and Products. 2006 Sep 1;24(2):96-104.