Materials Today: Proceedings 44 (2021) 2865–2873

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Physico-mechanical properties of cement bonded ceiling board developed from teak and African locust bean tree wood residue

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ARTICLE INFO

Article history:
Received 19 October 2020
Received in revised form 19 October 2020
Accepted 29 December 2020
Available online 16 February 2021

Keywords:
Composite ceiling boards
Cement
Teak wood dust
Wood residue
African locust tree

ABSTRACT

Over the years, the pursuit for locally sourced economical and environmentally safe materials has been on the increase in the development of composite boards. These locally sourced materials are organic materials from plants and livestock such as wood residue, feathers, rice husk, maize husk and bamboo fiber. Therefore, this study utilizes species of wood residue in the development composite ceiling boards. Ceiling boards were developed from teak and African locust bean tree wood residue using cement as a binder. The ceiling boards were made by varying the composite mass of the mix and mixing ratio of wood dust to cement. A constant load of 5 kN was used for the compaction process using a hydraulic pressing machine. Physico-mechanical properties of the ceiling boards such as moisture content, density, water absorption, drying shrinkage, tensile strength, and compressive strength were evaluated. The percentage of moisture content were 9.50 and 14.50% for teak and African locust bean tree wood dust, respectively. The values of density varied from 0.56 – 0.68 g/cm^3. The water absorption ranged from 9.0 to 39.8% after 24 h immersion and drying shrinkage ranged from 8.60 to 35%. The maximum impact energy obtained is 98 J. The highest tensile, compressive and flexural strengths for the ceiling boards were 1.09, 0.82, and 0.56 MPa, respectively. The composite samples showed that ceiling boards made from teak wood dust is most suitable for interior use. Cement was found to be suitable as a binder for the development of ceiling boards.

1. Introduction

Wood work activities in Nigeria has resulted in uncontrolled toxic waste. This uncontrolled waste is associated with the atmospheric air and consists of pollutants such as dusts and particles [1]. Nigeria has her major part of sawmill industries located in the wood producing rain forest regions, with a larger concentration in Osun, Ondo, Oyo, Ogun, Ekiti, Imo, and Lagos States. These states account for up to 89.5% of the wood processing activities in the country [2]. A report has shown that daily generation of wood residue in Nigeria is estimated at 104,000 m^3 and 294,000 tons per year [3]. Several years later, Owoyemi *et al.* [4] stated that as at 2010, an estimated value of 5.2 million tons of wood residue was produced each year in Nigeria. Hence, there is an increased pollution and environmental waste rate. Consequently, managing the residue produced from these activities can be done in different ways such as incinerating, landfilling and recycling. Some of these ways are not very effective [5]. For instance, landfilling can result in excess production of methane, which is toxic to the environment. More so, incinerating produces some harmful gases that can pollute the society. To end this menace, the most suitable method of utilizing these wood residues is by recycling to produce useful materials such as ceiling boards, particle boards, flake boards and so on [6]. Therefore, recycling of wood dust for the production of ceiling board would reduce environmental pollution. Globally, the use of wood dust as a raw material for the manufacture of ceiling board has several environmental, socioeconomic, and industrial benefits. This is because the wood residue generated from wood production processes can be converted into wealth [7] rather than direct harvesting of trees for the same purpose. The uti-

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https://doi.org/10.1016/j.matpr.2020.12.1170
2214-7853/

lization of locally sourced environmentally safe materials including livestock and plant residue in ceiling boards development is a proficient way of waste control. The usage of these wood wastes is to supplement the wood utilization in the production of composite boards for various applications [8]. Ceiling boards are commonly made from agro-industrial wastes particles including planar shavings, wood chips, and sawdust, which are obtained from wood waste. They can as well be made from other organic materials, which are corn cobs, rice husks, rice straw, feathers, sugarcane bagasse, and so on [9]. Ceiling boards are engineered plane piece of wood product used to shield an upper part of an enclosed space, adding beauty and aesthetics to the space. It helps to protect a space from the transmission of extreme temperature and regular incursion of reptiles and rodents [10]. The significance of ceiling boards cannot be exaggerated as evident in its use in constructions. Previous researches revealed that wood species such as beach pine, scots pine and norway spruce have been in use in the development of ceiling boards [11]. Ataguba [12] developed a standard composite ceiling board from waste paper and rice husk for low cost construction work which exhibited a good water absorption, density, and flexural strength properties. Ekpunobi *et al.* [9] worked on the development of ceiling boards from waste paper, fire retardant, and cement. The results revealed that the compressive strength was highest at 100% fiber waste paper content with a value of 0.66 MPa, which is the standard value required for the compressive strength of commercial ceiling board. An investigation by Yakubu *et al.* [13] on the production of agro-waste composite ceiling board produced from saw dust, rice husk, and maize husk revealed there was increment in the tensile strength with a decrease in density as the wood dust content increased.

Melo et al. [14] investigated the physico-mechanical properties of particleboards produced from wood, bamboo, and rice husk. The results revealed that the utilization of rice husk produced a poor quality of particleboard while the wood and bamboo gave better particle boards with a performance that met the European standard requirement. Other materials used for the development of ceiling boards are waste tea leaves [15], Kenaf [16], eggplant [17], waste grass [18], and so on. The prospect of using poplar chopped strands in the development of wood composite that was cement-bonded for building utilization was investigated by Ashori et al. [19]. $CaCl_2$ was added as cement setting accelerator. The properties of the board developed improved with an increase in the cement setting accelerator. More so, the physico-mechanical properties of the composite boards were equivalent or superior to the commercially available cement-bonded wood composites. Kochova et al. [20] produced cement-bonded composite boards using coir fibres of coconut husk. The study was to find solution to the potential problem in the cement-coir composites process. The results showed improvement in the physico-mechanical properties of the coir after pre-treatment while the thermal and the mechanical properties of the cement-coir composites were very close to the conventional wood-wool cement board. Akinyemi et al. [21] examined the effect of microwave irradiation pre-treatment in combination with an alkali substance (NaOH) and some other pre-treatment methods on the composite characteristics of bamboo-fibre cement. The fibre roughness, ductility, and toughness in the composites were improved using the microwave pretreatment methods when compared to the other methods. Teak wood has been used in the production of biofuel and also mixed with coal for the development fuels briquettes in previous studies [22–27]. Teak wood saw dust has also been mixed with pulverized polypropylene plastic in the production of wood-polypropylene plastic-cement composite boards [28]. However, this present work aims at using the wood residues of teak and African locust bean trees for the development of cement bonded ceiling boards. The usage of these residues will help in the waste disposal management problems by converting the residues into wealth.

2. Methodology

2.1. Materials

In this study, the wood dusts used were that of *Parkia biglobosa* (African locust bean tree) and *Tectona grandis* (teak). The wood dusts and ordinary Portland cement were obtained from Ilorin metropolis (8° 30′ 0.00″ N, 4° 33′ 0.00″ E), Nigeria. A quantity of 20 kg each of teak wood dust (TWD) and African locust bean tree wood dust (ALB) were sorted to remove dirt and pebbles. The wood dust was sun-dried for 2 days (6 h/ day) to reduce moisture content and then screened to two different particle sizes of 1.0 and 1.7 mm. The binder used was ordinary Portland cement of 5 kg combined at different ratios.

2.2. Sieve analysis

The wood dust particle size analysis was done in line with ASTM D1037 (1999) standard [29] for the dusts of the two species. A 40 g weight for each of the wood dust specie was measured, and positioned in a set of six sieves arranged in descending order of fineness, and then placed on a mechanical shaker (Model No.8664). The shaking process was carried out for 15 min as recommended by Harshavardhan & Muruganandam [30]. Seven different sieve sizes of 4750, 2360, 1700, 1000, 500, 250, and 150 µm were used. The weight of wood dust retained and total weight of sample was given as W_r and W_t, respectively. The percentage of wood dust retained on sieve was evaluated for each specimen based on Equation (1). The cumulative percentage of wood dust passing through sieve is expressed in Equation (2) as the difference between the percentage weight of total sample ($\%W_{ts}$) and the percentage weight of retained sample($\%W_{rs}$). The fineness modulus was determined using Equation (3). (See Fig. 1)

$$\text{Percentageofwooddustretainedonsieve} = \frac{W_r}{W_t} \times 100 \tag{1}$$

$$\text{Wooddustpassingthroughsieve}(\%) = \%W_{ts} - \%W_{rs} \tag{2}$$

where $W_{ts} = \%$ total weight of sample, $W_{rs} = \%$ weight of retained sample in the sieve, $W_r =$ weight of wood dust and W_t = total weight of sample

$$\text{Finenessmodulus} = \frac{\%\text{oftotalcumulativeweightretainedbetween80mmand0.15mm}}{100} \tag{3}$$

2.3. Mould preparation

The material used for the mould was mild steel with cross section $200 \times 20 \times 20 mm^3$. This was because mild steel is cost effective, easy to machine and readily available. It can withstand high pressure in the process of compression.

2.4. Formulation and sample production

The ceiling boards were developed through variation of base materials (Teak and African locust beans tree dusts) and the binder (cement), as shown in Table 1. Wood dust of 1000μ m sieve size was adopted due to the sieve analysis result. The procedure for the production of the ceiling boards can be seen in Fig. 2. Wood dust was blended with cement using the formulation in Table 1

Fig. 1. Sample dusts (a) teak wood (b) cement (c) African locust bean tree.

Table 1
Sample formulation of the ceiling boards.

Category	Sample ID	Wood dust (%)	Cement (%)
A	TA_1	70	30
	TA_2	70	30
	TA_3	70	30
	TA_4	70	30
	TA_5	70	30
B	TA_6	70	30
	TA_7	70	30
	TA_8	70	30
	TA_9	70	30
	TA_{10}	70	30
C	TA_{11}	50	50
	TA_{12}	50	50
	TA_{13}	50	50
	TA_{14}	50	50
	TA_{15}	50	50
D	ALA_1	70	30
	ALA_2	70	30
	ALA_3	70	30
	ALA_4	70	30
	ALA_5	70	30
E	ALA_6	70	30
	ALA_7	70	30
	ALA_8	70	30
	ALA_9	70	30
	ALA_{10}	70	30

and then mixed manually using a stirrer. The mixture was gradually poured into a mould lubricated with hydraulic oil and compaction was done using 5 kN load of a hydraulic press at room temperature. The curing of ceiling board was 7 days and it was then allowed to dry for another 14 days.

where category A = 1.0 mm particle size teak wood dust, category B = 1.7 mm particle size teak wood dust, samples TA_1 – TA_5 and TB_6 –TB_{10} = varied composite masses of 10, 12,14, 16, and 18 g. Category C = teak wood dust with particle size 1.7 mm, samples TA_{11}- TA_{15} = varied composite masses of 10,12,14,16, and 18 g. Category D = African locust bean tree wood dust of particle size 1.0 mm, category E African locust bean tree wood dust of particle size 1.7 mm, ALB_1–ALB_5 and ALB_6–ALB_{10} = varied composite masses of 10,12,14,16, and 18 g.

2.5. Particleboards characterization

2.5.1. Moisture content analysis

This parameter of wood dust was determined according to ASTM D1037 (1999) standard [29]. PMC moisture analyzer (Model No. PMC50/1) was used to determine the moisture content (mc) at the Central Research Laboratory, University of Ilorin, Nigeria. An empty can was weighed and the mass recorded as m_x. The damp wood dust sample was placed in the container weight and the mass recorded asm_s. The wood dust sample was sun dried. The

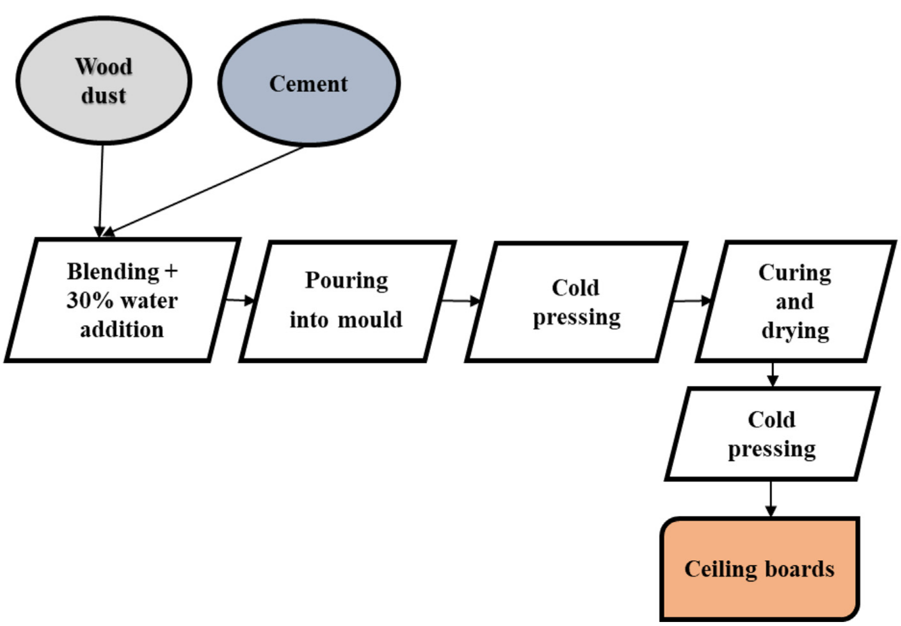

Fig. 2. Schematic representation of the production process of composite ceiling boards.

dried wood dust sample in the container was weighed and its mass recorded asm_y. The moisture content was evaluated using Equation (4).

$$\text{Moisturecontent(Mc)} = \frac{m_s - m_y}{m_y - m_x} \times 100$$

2.5.2. Density evaluation

Density was evaluated according to ASTM D1037 (2012) standard [31]. The ceiling board produced was sun-dried for 3 days (3 h/day) to a constant mass and the dry mass of ceiling board (M_D), was measured using a weighing balance. The volume of the ceiling board was calculated $V = l \times b \times t$ .The densityρ, was calculated using Equation (5).

$$\rho = \frac{M_D}{V} \tag{5}$$

where M_D = dried mass of ceiling board, ρ = Density (kg/m^3), where l = length, b = breadth and t = thickness.

2.5.3. Water absorption test

The water absorption (WA) capacity of the ceiling boards was done based on ASTM D1037 (1999) standard [29]. The experimental samples were immersed in water for 2 and 24 h at room temperature to investigate the short- and long-term percentage water resistance properties, respectively. The experiment was carried out 3 times and the average value for percentage water absorption was recorded for both phases of 2 and 24 h. The mass of dried ceiling board was recorded as $M_D$and the mass of ceiling board after immersing in water for 24 h was recorded as M_S[10]. Equation (6) was utilized to evaluate the percentage water absorption of the ceiling boards.

$$\text{WA}(\%) = \frac{MS - MD}{MD} \times 100 \tag{6}$$

where M_S = mass of the saturated ceiling board, M_D = mass of the dried ceiling board.

2.5.4. Drying shrinkage test

Experimental ceiling boards was immersed in water for 24 h according to ASTM D1037 (1999) standard [29], and their masses determined as$M_{st.}$ The ceiling boards was oven dried at a temperature of 40 °C. The mass of ceiling board was measured after cooling at room temperature as M_c the drying shrinkage D_s is evaluated using Equation (7).

$$D_s(\%) = \frac{M_{St} - M_c}{M_c} \tag{7}$$

2.5.5. Compressive strength test

The compressive strength of each ceiling board specimen is the ratio of optimum load at failure to the cross-sectional area of the ceiling board. Compressive test was done as highlighted by ASTM D1037 (2012) standard [31] using universal testing machine (UTM Testometric FS5080, 50 kN capacity). The load was gradually applied on the board specimen until failure and the load measurement (P_c) was documented. The experiment was carried out three time and the average compressive strength (σ) was evaluated using Equation (8).

$$\sigma = \frac{P_c}{A_c} \tag{8}$$

where P_C = optimum load applied until failure (N), A_C = specimen cross-sectional area (mm^2) and σ = compressive strength of the test specimen (MPa).

Fig. 3. Tensile test set up for the samples.

2.5.6. Tensile test

ASTM D1037 (1999) standard [29] was adopted in the preparation of the sample. The dumbbell-shaped sample was placed on the Universal Testing Machine (Testometric FS5080) as shown in Fig. 3 and tensioned until failure [31]. An expression of the formula is seen in Equation (9).

$$\sigma_t = \frac{W_t}{bt} \tag{9}$$

where $\sigma_t$is the tensile strength (N/mm^2), W_t is the failure tensile load (N), b and t are the 'breadth and thickness of the specimen, respectively (mm).

2.5.7. Flexural test

Flexural strength (FS) was determined by evaluating the axial bending strength of the board in accordance with ASTM D1037 (1999) standard [29] using Universal Testing Machine as shown in Fig. 4. A concentrated bending load was applied at the center

Fig. 4. Flexural test set up for the specimen.

of a beam using three-point loading on a length of $200 \times 20 \times 10mm$. Flexural strength was calculated by load deflection. The ultimate load was recorded and estimated using the formula in Equation (10).

$$FS = \frac{3PL}{2BD^2} \tag{10}$$

where FS = Flexural strength (N/mm^2), L= length between center of support (mm), B = width of test specimen (mm), H = thickness of test specimen (mm), D = thickness of the specimen

3. Results and discussion

3.1. Raw materials characterization and sieve analyses

Table 2 displays the moisture content, density, sieve analysis as well as fineness modulus (FM) of the wood dusts that was used for the ceiling board development. The TWD moisture content was 9.50% is lesser than that of ALB (14.60%). This implied that the African locust bean tree wood dust contributed exceedingly to the moisture content while producing the ceiling board. The IS3087 standard for ceiling boards useful for interior decoration indicated that the moisture content should be within the range of 5–15%, which shows that both samples are within the expected range of moisture content required. The bulk densities of TWD and ALB were 0.229 (approx. 0.23) and 0.235 (approx. 0.24) g/cm^3, respectively. More so, teak wood dust contributed lightly to the density of the ceiling boards as it has the least density of 0.23 g/cm^3. Cement has the highest density (2.16 g/cm^3), which improved the density of the ceiling board based on its proportion. Fig. 5 shows the results of the sieve analysis of TWD and ALB. It was observed that, the sieve size 500 μm of TWD had the highest percentage of weight retained of 30.15%. The other sieve sizes of 1000, 1700 and 250 μm, had percentage weight retained of 25.13, 21.60 and 15.1%, respectively. It was also observed that 500 μm of ALB had the highest percentage of weight retained of 26.26% and having other sieve sizes of 1000, 1700 and 250 μm, with percentage weight retained of 22.22, 19.20 and 20.20%, respectively. It can be deduced that to produce a larger quantity of ceiling boards using TWD and ALB, sieve sizes of 1000 and 1700 μm was selected for its production, this is because smaller particle sizes tend to absorb water more than larger particle sizes hence the choice of 1000 and 1700 μm which are of average particle size. Comparing the results obtained from the fineness modulus of both species of wood dusts, it was observed that African locust bean tree wood dust had fineness modulus value of 3.12 and teak tree wood dust had a fineness modulus of 3.35. Fine wood dust is known to have fineness modulus within the range of 2–4, which makes African locust bean tree wood dust less fine than teak tree wood dust. The particle size distribution was as a result of the intensity of the grinding and the required material densification.

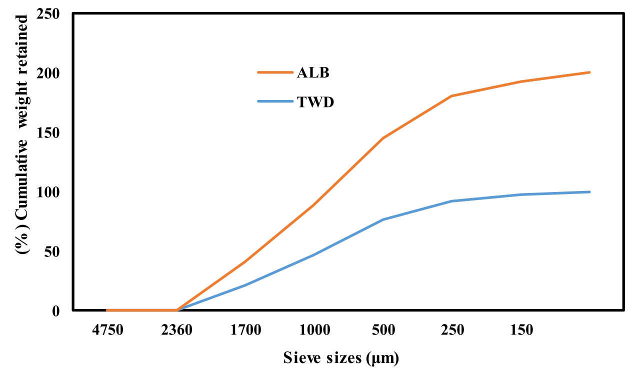

Fig. 5. Cumulative particle size distribution of teak wood and African locust bean tree wood dust.

3.2. Physical properties of the produced particleboards

3.2.1. Density

Fig. 6 shows the influence of composite mass, wood species, mixing ratios and particle sizes on density. The result showed an increase in density as the composite mass increased. The densities of the ceiling boards produced were between 0.51 and 0.68 g/cm^3 for samples $EALB_6$ and CTA_{15}. CTA_{15} had the highest value of density 0.68 g/cm^3 for a mass composition of 18 g at a compaction pressure of 5 kN and 30% water addition of the total mass and $EALB_6$ and BTA_6 had the least density of 0.51 g/cm^3. The trend of result showed that increasing mass of composite sample and cement content resulted in high density. This is because cement is denser than wood dust. Denser materials may give a better strength for composite boards which is a good characteristic of a ceiling board [32].

3.2.2. Water absorption

Fig. 7 represents the water absorption of the ceiling boards after 2 and 24 h. There was a great increase in the rate of water absorption from 2 h duration compared to that of 24 h duration with a value of 35%. It was deduced that the higher the composite mass of samples, the higher the percentage of water absorption. Water absorption also decreased with an increase in particle size. Samples of TA_5 with 1.0 mm sieve size has the highest percentage of water absorption (20%) while. TA_6 with 1.7 mm sieve size has the least percentage of water absorption (9%). Fig. 6 shows that a decrease in wood dust content and increase in cement content reduced the rate of water absorption for samples with ratio (WD: C, 50:50). This could be attributed to the hydrophilic nature of wood dust [33] and hydrophobic nature of cement. The water absorption values confirmed the claim that lignocelluloses generally tend to rise the hydrophilic nature of cement-bonded wood composites (CBWCs) due to large number of porous structures, which accelerates water penetration through capillarity [19].

3.3. Mechanical properties of ceiling board

3.3.1. Compressive strength

The compressive strength of the ceiling board presented in Fig. 8 shows that increasing the mass of the composite had negative effect on the produced ceiling boards as the compressive strength decreases with increasing composite mass. Sample ATA_1 and BTA_{10} had the highest and the least compressive strength of 0.819 and 0.063 MPa, respectively. This observation was in similar

Table 2
Properties of the raw materials.

Sample	R_D	M_C (%)	Bulk density (g/cm^3)	MMR (%)	FM
T_{WD}	17.5	9.5	0.229	30.15	3.35
ALB_{WD}	22.85	14.6	0.235	26.26	3.12
Cement	–	–	2.16		

*R_D – Relative density, M_C – Moisture content, MMR – Maximum mass retained, FM – Fineness modulus.

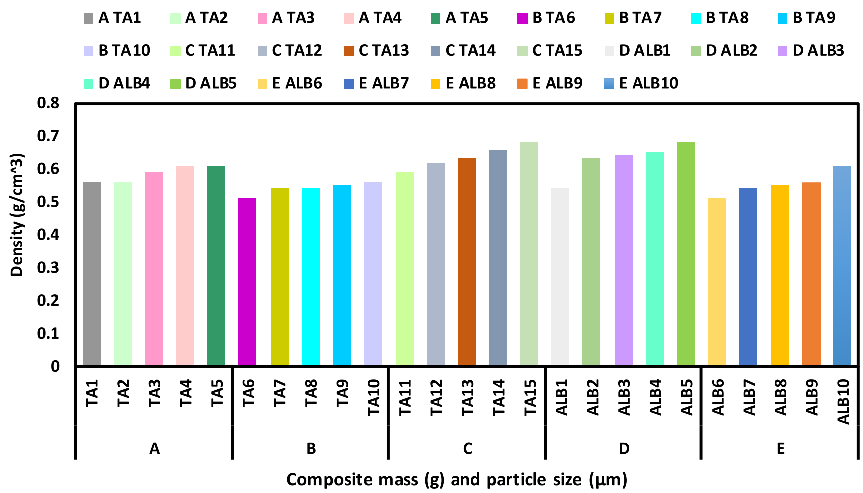

Fig. 6. The density of the ceiling boards.

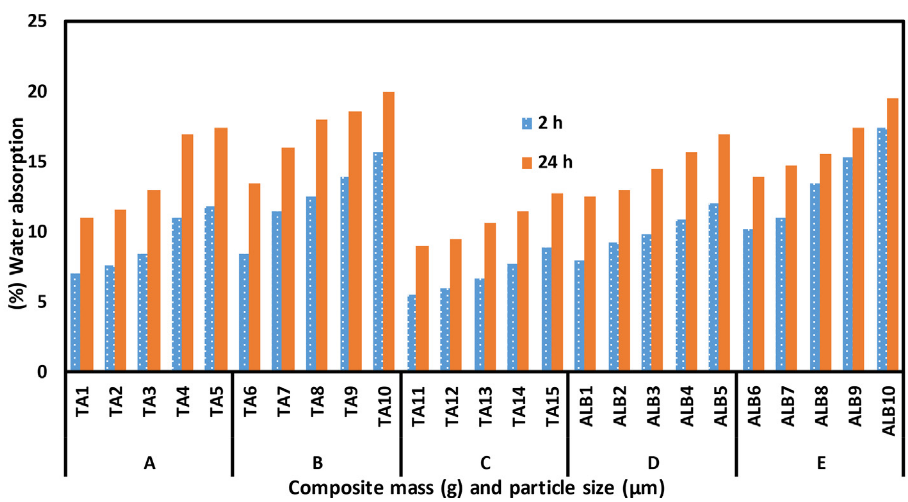

Fig. 7. The percentage water absorption of the ceiling boards.

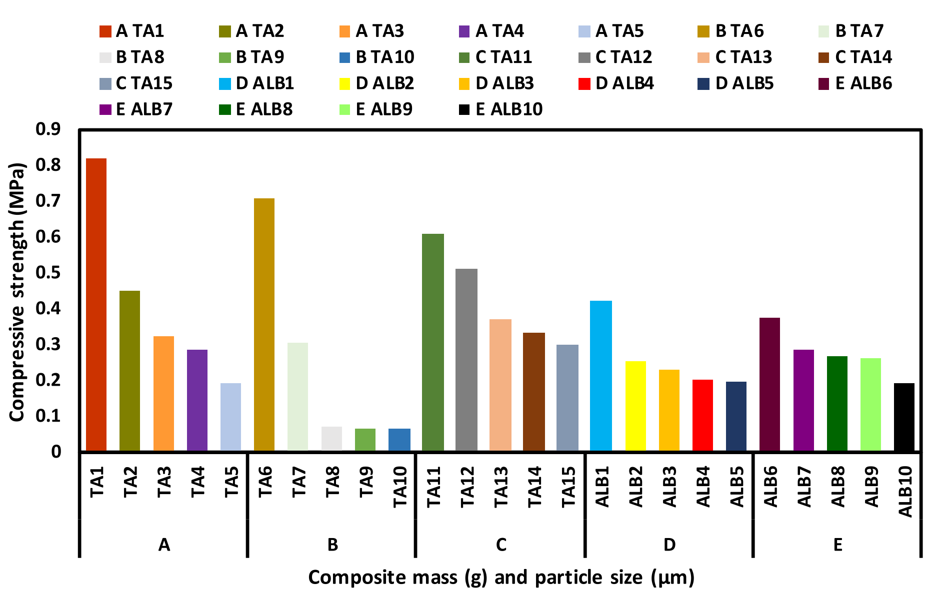

Fig. 8. Compressive strength of the ceiling board samples.

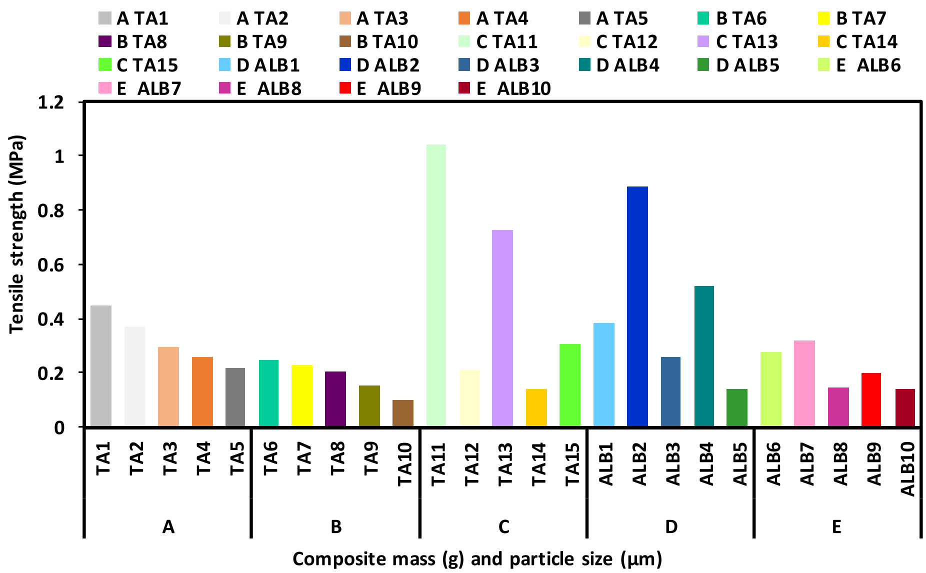

Fig. 9. Tensile strength of the samples.

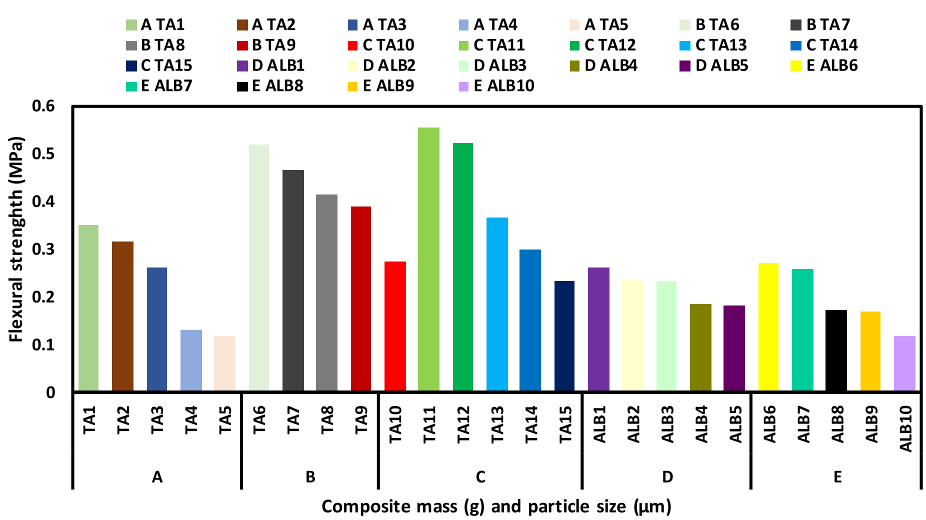

Fig. 10. Flexural strength of the samples.

trend with what was reported by Daniel & Hsiao [34], who studied thickness effect on compressive strength of unnotched composite. From the study, it was reported that the major type of fault that activates longitudinal compressive failure and fiber misalignment, has a declining influence on strength with increased fiber misalignment. The other factor responsible for declination of strength when thickness increases is that thickness increment makes compression testing difficult, hence, the tendency for early failure rises [34]. In this present study, it was observed that board made from samples in the category A, B, C had better compressive strength compared to samples made from samples in the category D and E.

3.3.2. Tensile strength

The tensile strength results in Fig. 9 revealed a decrease in tensile strength with an increase in composite mass that led to an increase in thickness. The result revealed that smaller particle sizes had better tensile strength. The values of the tensile strength obtained were in the range of 0.100 and 1.039 MPa for samples BTA_{10} and CTA_{11}. The result obtained is in close range with that of Nazerian *et al.* [35] with values within 0.69 to 2.69 MPa, which agrees with the standard BISON type HZ EN 634–2:2007 standard. It was also observed that as the thickness of the sample increases the tensile strength decreases hence the possibility of defect such as uneven planes and voids.

3.3.3. Flexural strength

Fig. 10 shows the flexural strength of the ceiling boards. There was an increase in flexural strength with increase in particle size, and decrease in flexural strength with increasing composite mass due to material thickness, which also means an increase in cross section area of the composite board. The decrease in strength was because the increase in cross section was greater than the applied force. The results revealed an optimum flexural strength value of 0.555 and 0.522 MPa for samples CTA_{11} and ATA_1, respectively. Consequently, the increase in thickness makes the sample density increase, hence, a decrease in the flexural strength which was due to increase in board segment hence poor compaction and decrease in composite strength [36]. Wood dust content

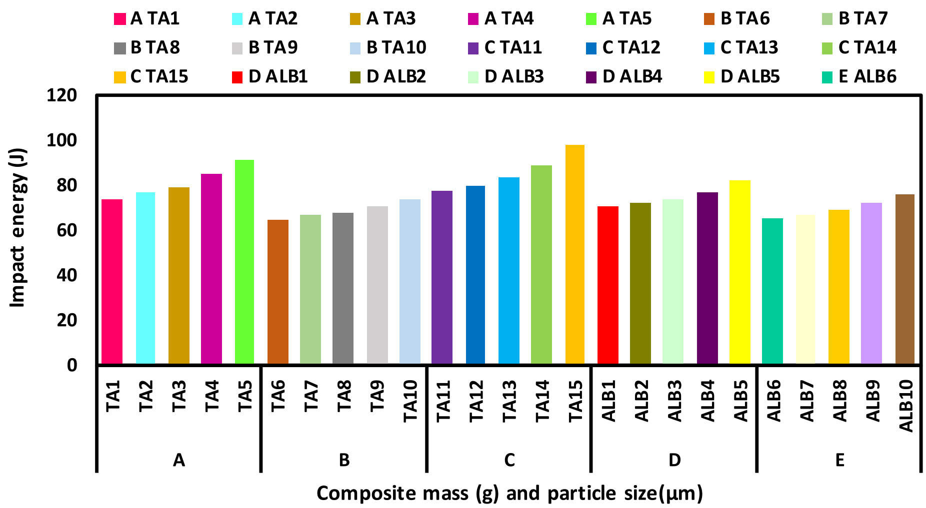

Fig. 11. Impact energy of the produced ceiling board.

reduction and cement content increment revealed increment in the flexural strength (modulus of rupture or bend strength) of the particle board.

3.3.4. Impact energy

The impact energy results in Fig. 11 showed that as the composite mass increases, there was a corresponding increase in the impact strength of the board. The highest impact energy of 98 J was recorded in boards produced from samples CTA_{15}. The impact and sorption strength also increased which was as a result of increased cement content in the mixture as affirmed by Ashori et al. [19]. It was reported that boards made with 50–60% wood content had better impact strength. This is because of better shrinkage and water absorption resistance properties exhibited by the samples. This was because as the particle size decreases the board accommodates more fiber/particle, hence, fewer voids and pore spaces between the particles when compared to corresponding particle of higher sizes [38].

4. Conclusion

The physico-mechanical properties of cement-bonded ceiling board developed from teak and African locust bean tree wood residue has been determined. The moisture content was in the range of 5–15% recommended. The density of the ceiling boards was between 0.56 and 0.68 g/cm^3. All the samples had water resistant capacity that are less than 40% based on available standards. The mechanical properties of the ceiling boards produced from teak wood dust was of an improved quality than that of samples produced from African locust bean tree wood dust. In conclusion, ceiling boards with better physico-mechanical properties can be produced technologically from teak tree wood dust using cement as a binder. Hence, industrial production of the board is achievable which will boost waste management sector through making wealth from waste.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors appreciate the technical staff of the Central Research Laboratory, University of Ilorin, Nigeria for their assistance during the sample preparation and testing.

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