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TECHNICAL PAPER

Effect of groundnut (*Arachis hypogaea*) shell ash on the properties of periwinkle shell, sawdust and cement-bonded particle boards

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Abstract

In modern times, depleting resources have necessitated research on renewable and recyclable materials for particleboard production. This research is centered on using Groundnut Shell Ash (GSA) as a pozzolan for partially replacing cement in the production of Cement-Bonded Particle boards. A mix proportion of 40%, 33% and 27% for cement, periwinkle shell and sawdust respectively as recommended in the work of Odeyemi and others in 2020 was adopted in producing the boards. The cement was replaced with GSA at 0%, 4%, 8% and 12% respectively after which their physical and mechanical properties were determined. The densities of the boards ranged from 2330 to 2760 kg/m^3, water absorption ranged from 4.2 to 5.74% (in 2 h) and 5.8 to 9.08 (in 24 h) while the thickness swelling ranged from 3.21 to 5.12% (in 2 h) and 6.73 to 7.92% (in 24 h). The Modulus of rupture and Modulus of Elasticity ranged from 1368.45 to 5129 N/mm^2 and 1594.38 N/mm^2 to 2161.23 N/mm^2 respectively. These results fall within the acceptable limits of the American Standard Institute. Therefore, GSA is a suitable partial replacement for cement in producing cement-bonded particle boards.

Keywords Density · Groundnut shell · Modulus of elasticity · Modulus of rupture · Particle boards · Water absorption

Introduction

The need for a reduction in the volume of waste has led to global research on the application of waste for engineering purposes. Various methods of recycling wastes have become important in recent years, where alternative basic materials are utilized in making particle boards that are inexpensive and beneficial to the environment [7, 18, 28]. Waste has been defined as material that is unwanted after its primary use. The common type of waste is solidly produced by human activities [26]. Waste creates a dirty environment and makes it unhabitable [15, 29, 30].

Pozzolans are silica-based materials that combine with lime with cement to produce more calcium silicate hydrate, a material that holds concrete together [23]. They are often used as cement replacements. Pozzolans can be natural (agricultural wastes, volcanic ashes, etc.) or artificial (silica fumes, fly ash, blast furnace, etc.) pozzolans. Groundnut Shell Ash (GSA) is classified as agro-based (natural) pozzolans [16] and a good alternative for lightweight aggregate, which is used as a conglomerate in making concrete in some parts of Nigeria [19, 31, 33, 35]. The shells are hard, available in small sizes, possess great sticking properties

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along with binders and sand, and are economical compared to granite [3].

Groundnut belongs to the leguminous family [19, 35]. It is self-pollinated and has one to five kernels which grow in the soil and become pods. The groundnut shell contains 25–35% of the pod and seeds take up the remaining portion (65–75%) [25]. Nigeria is the third largest global producer of groundnut contributing 8.1% of the world's total groundnut production [31, 35]. Groundnut shells are usually found on farms as waste in large quantities, especially in the Northern parts of Nigeria such as Kebbi, Zaria, Sokoto and Yobe states. Using these shells will help in bringing down the costs of managing waste, and environmental pollution and increase farmers' income when there is demand for the waste [2]. Findings have shown that GSA is a suitable substitute for cement in concrete production. For example, Nwofor and Sule [27] recommended that 10% GSA can be included in concrete. Also, Suleiman et al. [34] reported that the major oxides in GSA are alumina (Al_2O_3), calcium oxides (CaO), iron Oxide (Fe_2O_3) and silica (SiO_2). These oxides are the main oxides required of a pozzolana. The oxide compositions of GSA are presented in Table 1.

Sawdust is a waste product from the timber industry causing environmental problems [6, 17]. They are usually disposed of in landfills thereby constituting an environmental nuisance. Predominately, particleboards are integrated with sawmills to properly utilize wood wastes [1, 3, 9].

Particleboard is a wood-based panel produced under pressure, occasionally at temperatures between 140 and 220 °C and with the use of adhesives [16]. Particleboards are used for doors, furniture, partition walls, and non-structural work (De Lima Felix et al. 2016). CBP boards are construction materials, predominantly of wood origin, which are very durable against insect attacks, and decay and are stable in varying humidity changes [8, 10, 24]. Technological innovation has brought about the utilization of industrial and agricultural wastes promoting total waste utilization, bringing down the cost of production of cement, giving a cleaner environment and increasing the earnings of farmers [5]. There are innovative products made from agricultural and industrial wastes, such as cement-bonded particle boards being produced from wood or vegetable biomass [12], Odeyemi et al., 2020a). CBP boards have been acceptable in developing countries, where they were utilized for roofing, ceiling boards, partitioning and shuttering [32].

Table 1 Oxide composition of GSA [34]

Oxides	Percentage
SiO_2	10.91
CaO	79.36
Fe_2O_3	2.16
Al_2O_3	4.23
K_2O	0.38
MgO	1.72
SO_3	0.01
TiO_2	0.60
CO_3	0.02
LOI	0.54

The focus of this study is to determine the properties (physical and mechanical) of periwinkle shells, sawdust, and CBP boards containing varying percentages of GSA as a partial substitute for cement. The research was limited to the utilization of 40%, 27% and 33% of cement, sawdust, and periwinkle shells respectively for producing the boards as recommended by Odeyemi et al. [28].

Methods

Materials

The materials utilized for this study are sawdust, periwinkle shells, Dangote cement brand of Limestone Portland Cement (Grade 42.5R), polythene bags, lubricant oil, boards, groundnut shells and calcium chloride (for accelerating the setting time of the cement). The treated samples of sawdust, ground periwinkle shells and groundnut shells used in the study are presented in Fig. 1.

Experimental procedure

The periwinkle shells and sawdust were washed using water to remove dirt before drying. Thereafter, the shells were pounded into particles with the help of a hammer mill. Both samples (periwinkle shell and sawdust) were pretreated by soaking the shells in hot water at 80 °C for 1 h whereas the sawdust particles were soaked in cold water for 24 h to allow for the total removal of starch and sugar which could hamper the setting time of cement as recommended by Atoyebi et al. [8] and Odeyemi et al. [28]. Afterwards, both samples were subjected to open-air drying to lower their moisture contents before usage. Groundnut shells were washed to remove residue before they were calcinated into ashes in a furnace at a temperature of 700 °C.

Four (4) percent calcium chloride by weight of cement was used as an accelerator. Equation 1 was used in determining the weight of water. The particle board in its fresh state was poured into a mould of 350 mm length, 350 mm width and 50 mm height. Batching of the materials was done by volume as presented in Table 2.

$$W_w = 0.6W_c + (0.3 - SMC)W_s \quad (1)$$

where W_w = Weight of water (g); W_c = Weight of cement (g); SMC = Sawdust Moisture content (%); W_s = Weight of sawdust.

Fig. 1 Materials used for the study, **a** Treated sawdust, **b** Ground periwinkle shell **c** Dried groundnut shells

Table 2 Composition of materials per m^3

Sample description	Cement	GSA	Periwinkle shell	Sawdust
Control sample	0.4	0	0.33	0.27
Sample 2	0.384	0.016	0.33	0.27
Sample 3	0.368	0.032	0.33	0.27
Sample 4	0.352	0.048	0.33	0.27

After laying out the mixture in the moulds, it was allowed to set for an hour. A polythene sheet was laid beneath the levelled mix material in the mould to prevent seepage and easy demolding. A steel plate covered with a polythene sheet was used as the pre-press mat to ease loading. A hydraulic pressure of 1.21 N/mm^2 was exerted on the boards for 24 h to compress the boards. Afterwards, the boards were removed from the moulds and kept in sealed polythene bags for 28 days to attain full curing.

The boards were subjected to mechanical (Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)) and physical (density, water absorption and thickness swelling) tests.

Physical tests

Density The boards were cut to 50 × 50 × 5 cm. For the test, three specimens were selected, weighed, and recorded to determine their volumes. Equation 2 was used for determining the density of the samples.

$$Density\left(kg/m^3\right) = \frac{W_d}{V_d} \tag{2}$$

Where W_d = Dried-weight of sample; V_d = Dried-volume of sample.

Water absorption In determining the water absorption, the initial weight (W_1) was determined using a weighing balance. The samples were soaked in water at room temperature for 24 h. Then, they were re-weighed and the new weight was recorded as W_2. Equation 3 was used in calculating the water absorption.

$$Water\ Absorption(\%) = \frac{W_2 - W_1}{W_1} \times 100 \tag{3}$$

where W_2 = Weight of board after soaking in water and W_1 = Weight of board before soaking in water.

Thickness swelling The boards were cut into 50 × 50 × 5 cm. The initial thickness of the specimens was measured using a calliper and noted as T_1. Afterwards, the samples were soaked in water for 2 and 24 h respectively. The thickness of the samples after staying in water for the designated periods was noted as T_2. Equation 4 [8] was used in calculating the percentage thickness swelling of the boards.

$$Thickness\ swelling = \frac{T_2 - T_1}{T_1} \times 100 \quad (4)$$

where T_2 = Thickness of the board after soaking in water and T_1 = Thickness of the board before soaking in water.

Mechanical tests

The flexural strength, that is, the Modulus of Rupture (MOR) of the boards was determined following the procedure spelt out in BS EN 12,390–5, (2019) while the tensile strength, that is, the Modulus of Elasticity (MOE) of the boards was also determined in accordance to the procedure stipulated in BS EN 12,390–13, (2013). A Universal Testing Machine (UTM) with model number FS50AT was used in carrying out the tests as shown in Fig. 2. The specimens were loaded until failure occurred. The failure parameters for each of the samples were obtained directly from the equipment.

Results and discussions

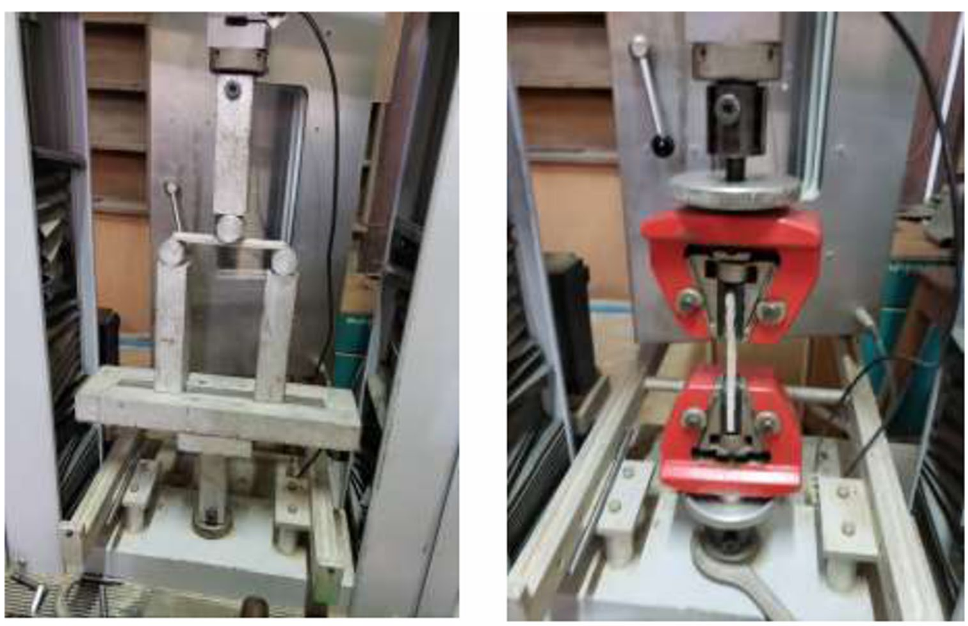
Physical test results

The physical test results obtained from the samples containing 0–12% GSA are presented in this section.

Density

The densities of the samples ranged from 1388 to 1645 kg/m^3. The International Organization for Standardization (1987) specified 1000 kg/m^3 as the minimum density for particle boards while the Indian standard of Cement bonded particle board specification (1995) specified 1250 kg/m^3. Likewise, the Japanese Industrial Standard (2003) recommended 800 kg/m^3 as the minimum density for particle boards. All the samples tested in the study met the requirements specified by the three (3) standards considered. However, only the sample without GSA had a density higher by 0.06% than the optimized density of 1644 kg/m^3 reported by Odeyemi et al. [28]. The samples with 4, 8 and 12% are lighter by 12.5, 12.66 and 15.77% respectively.

Figure 3 showed that as groundnut shell ash content increases, the density decreases, thus, making the ash a good cement replacement for density reduction in particle boards.



(a) (b)

Fig. 2 Mechanical Tests on samples, **a** Test on Modulus of rupture, **b** Test on modulus of elasticity

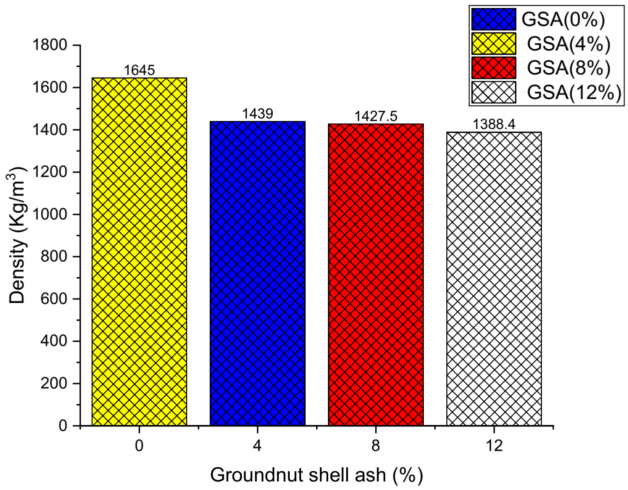


Fig. 3 Densities of particle boards

Water absorption

Figure 4 shows the water absorption capacity of the boards. The control sample without GSA recorded a water absorption capacity of 4.2% and 5.8% at 2 and 24 h respectively, while the sample with 12% GSA had peak values of 7.21% and 9.34% at 2 and 24 h respectively. All the samples did not exceed 13% at 2 h and 25% at 24 h, meeting the requirement of IS 14276 [20]. The samples without GSA and the one with 4% had lower water absorption capacity at 2 h by 8.3 and 6.1% respectively when compared with the optimized sample with 4.58 water absorption capacity reported by Odeyemi et al. [28]. The samples with 8 and 12% had higher water absorption capacity by 20 and 36% respectively.

Thickness swelling

The thickness swelling of the samples tested (presented in Fig. 5) at 2 h showed that the sample with 12% GSA showed the lowest swelling while the control sample (with no GSA) had the highest swelling. At 24 h, the control sample had the thickest swelling while the sample with 12% GSA had the least thickness swelling. All of the specimens did not exceed 8%, which met the requirements of the American National standards institute (1999). However, all the samples had higher thickness swelling at 2 h when compared with the optimized sample with a value of 1.5% thickness swelling reported by Odeyemi et al. [28].

The result showed that the incorporation of GSA in particle boards reduces the thickness swelling of the board.

Mechanical test results

The mechanical test results obtained from the samples containing 0–12% GSA are presented in this section.

Modulus of rupture (MOR)

From the result presented in Fig. 6, it was observed that sample 2 (containing 4% GSA) had the highest modulus of Rupture (MOR) at 5129 N/mm^2. This reveals more hydration reactions in the sample than in other samples. It also portends that silica was most dominant in the sample compared with others while calcite was present in a lesser proportion. However, sample 1 had the lowest Modulus of Rupture (MOR) at 1368.45 N/mm^2. These results follow the same trend as was reported by Ikumapayi et al. [19]. The American National Institute (1999) recommended a minimum flexural strength of 3 N/mm^2 for general-purpose particle boards. All the samples tested have strengths

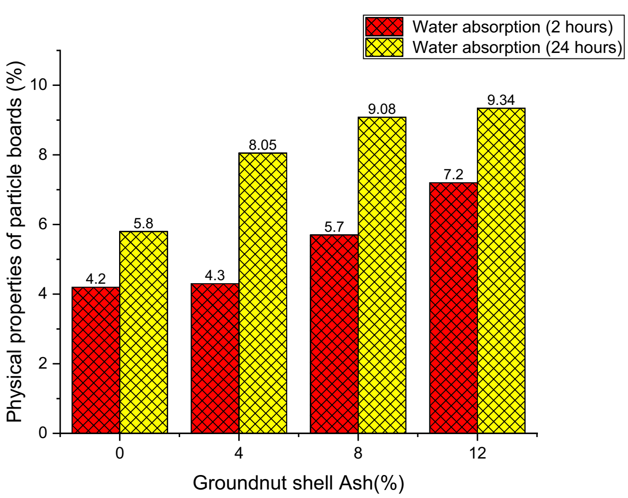


Fig. 4 Water absorption capacity of particle boards

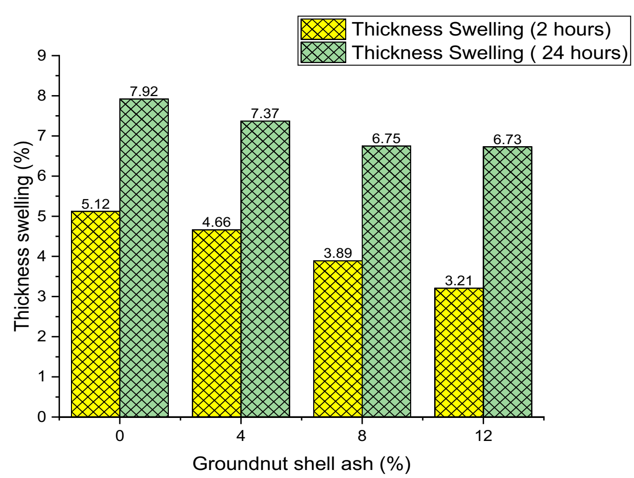


Fig. 5 Thickness swelling of particle boards

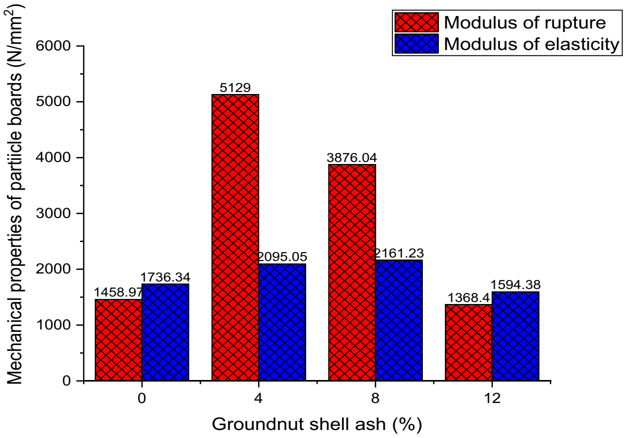


Fig. 6 MOR and MOE of particle boards

that are above this specification in the Standard. However, 4 and 8% incorporation of the ash improved the flexural strength of the board. Beyond this, the flexural strength declined. The 4 and 8% incorporation of the ash produced boards with strengths that are higher by 40 and 21% respectively when compared with the optimized MOR of 3060.38 N/mm^2 reported by Odeyemi et al. [28].

Modulus of elasticity (MOE)

The highest tensile strength was recorded by sample 3 with 8% GSA with a value of 2161.23 N/mm^2 while sample 4 with 12% GSA had the lowest strength with a value of 1594.38 N/mm^2. The results follow the same trend as that of the MOR and that of Ikumapayi et al. [19]. The American National Institute (1999) recommended a minimum tensile strength of 550 N/mm^2 for general-purpose particle boards. All the samples tested have strengths that are above this specification in the Standard. However, 4 and 8% incorporation of the ash improved the tensile strength of the board. Beyond this, the tensile strength declined. The 4 and 8% incorporation of the ash produced boards with strengths that are higher by 14 and 16% respectively when compared with the optimized MOE of 1805 N/mm^2 reported by Odeyemi et al. [28].

Conclusions

The properties of the periwinkle shell, sawdust and cement-bonded particle boards containing varying percentages of GSA were investigated in this study. The conclusions drawn from the study are:

(a) The inclusion of GSA in cement-bonded particle boards reduced the density for all the percentage inclusion. Thus, GSA inclusion made the boards to be lighter.
(b) The water absorption for the GSA blended cement-bonded particle boards is within acceptable limits by Standards.
(c) The thickness swelling for the GSA blended cement-bonded particle boards is within the limits specified by Standards.
(d) Using up to 8% GSA as a replacement for cement increased the MOR and MOE for all the samples tested. These values are the minimum value specified by the American Standard Institute.

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Declarations

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical Approval The Authors declare that they have not submitted the manuscript to any other journal for simultaneous consideration. The work is original and not published elsewhere.

Informed consent For this type of study formal consent is not required.

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