Results in Engineering 6 (2020) 100126

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.editorialmanager.com/rineng/Default.aspx

Physical and mechanical properties of cement-bonded particle board produced from African balsam tree (*Populous Balsamifera*) and periwinkle shell residues

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ARTICLE INFO

Keywords:
Particle board
Sawdust
Periwinkle shell
Mechanical properties
Physical properties

ABSTRACT

Reducing the amount of wastes deposited into the environment has become important. A fresh approach in doing this is by recycling them. This paper investigated the physical and mechanical properties of cement bonded particle boards from agricultural wastes. The particle boards were tested for their physical (density, water absorption and thickness swelling) and mechanical (modulus of elasticity and modulus of rupture) properties. Scanning Electron Microscopy (SEM) analysis was carried out to determine the internal microstructure of the boards. The results revealed that periwinkle shell and cement have a great influence on the density of the board, cement and sawdust have a great influence on water absorption and thickness swelling, cement has a great influence on Modulus of Rupture & Modulus of Elasticity for all the combinations tested. The SEM photograph of the cut surface of the boards showed good fibre matrix adhesion at mix ratio of 1:1.5 (cement/waste). At lower fraction of cement matrix to waste ratio, the cement bonded particle board lost its adhesive force. It was concluded that sawdust and periwinkle shells are suitable materials in the production of particle boards.

1. Introduction

The increasing demand for timber utilization is regarded as a key purpose for the high rate of deforestation which has a grave influence on the environment thus resulting in global warming [1,2]. This has also brought about unregulated felling of trees and over exploitation in plantation and natural forests resulting in fresh interest in lesser known timber species. Unfortunately, the need for wood products still surpasses timber supply, leading to continuous felling of trees without replacement [3]. The increasing demand for wood-based particleboards have resulted in challenges on the continued availability and supply of raw materials to these sectors in future. Yet, the necessity to minimize the reliance on timber and forest resources has resulted in renewed interest for alternate resources to replace timber raw materials in the manufacturing of particleboards [4–7].

Cultivated residues and non-wood plant fibres are alternate materials that could be used as the balance between demand and supply in the production of composite particleboards [8]. Several researches have been done on an extensive varieties of agricultural wastes from many parts of the globe such as rice husks, wheat straws, palm kernel fibre, egg shell and bagasse, since the need to lessen the over reliance on timber and wood resources has stimulated attention on the use of agricultural wastes in particleboard production [1,9–13].

Advancement in technology has further renewed the interest in the use of agricultural and industrial wastes. This will boost waste utilization, promote a cleaner environment and minimize production cost. It reduces the burning of agricultural wastes to the minimum, thus mitigating climate changes [14–16]. Many value-added products have been produced from agricultural and industrial wastes. These have removed many of the negative consequences caused by indecent dumping and burning of wood residues as nuisance.

Particleboards are composites made of pieces of wood bonded together. They are commonly used in producing cabinets, tabletops, speakers, sliding doors, kitchen worktops, and furniture. Sundry factors affect the features of the particleboards, foremost among them are fibre structure of the wood, species of wood, size and type of particles,

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https://doi.org/10.1016/j.rineng.2020.100126
Received 29 January 2020; Received in revised form 27 March 2020; Accepted 28 March 2020

(a) Sawdust (b) Ground periwinkle shells

Fig. 1. Agro-wastes used in the production of particle boards.

Table 1
Material composition of the particle board.

S/N	Sample	% Volume of Cement	% Volume of Sawdust	% Volume of Periwinkle Shell
1	A	40	40	20
2	B	40	30	30
3	C	40	20	40
4	D	30	35	35
5	E	30	25	45
6	F	30	45	25
7	G	25	25	50
8	H	25	50	25
9	I	25	37	38

hardness, density, compressibility and method of drying the particles. Cement-bonded particleboards are being studied with the aim of using various types of wood biomass, as the chemical compounds from wood have a tendency to inhibit cement hydration [8]. Generally, for broader ranges of applications, the regularly observed low-quality bonding between some wood species and cement due to the incompatibilities between the different materials is a challenge to be resolved. This gives information on the physical (thickness swelling, water absorption, density) and mechanical (MOR and MOE) properties of particleboards.

Sawdust, an agro-waste material, is a by-product of wood, produced from sawing of wood. Sawdust are tiny particles of wood that are obtained from wood processing. They are usually considered as wastes that cannot be utilized [17]. Sawdust finds little industrial applications and are often discarded, thus, causing environmental problems. Large amounts of sawdust are produced in Nigeria, in sawmills and wood-based industries. They constitute visual blight and pollute the immediate environment. In solving this menace, saw millers' often opt to burning them [18]. Burning them produces smoke and carbon dioxide which are harmful to human health and contribute to the depletion of the ozone layer. However, sawdust can be beneficial in the manufacture of fuel briquettes and particleboards [17].

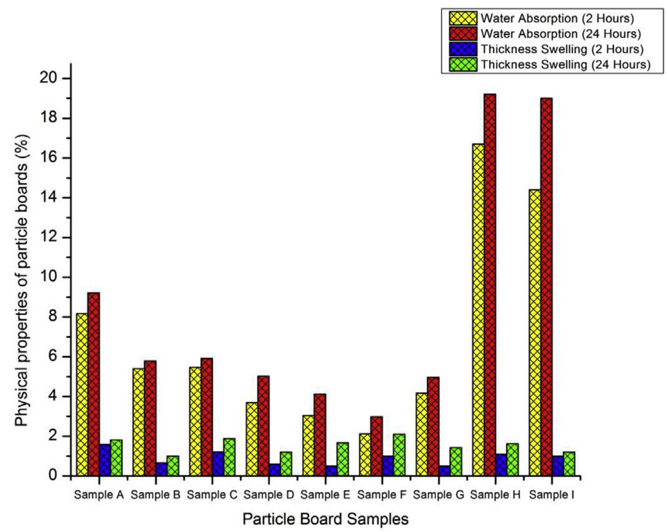


Fig. 3. Water absorption and thickness swelling of particle boards.

Periwinkles are marine snails which are abundant in the riverine

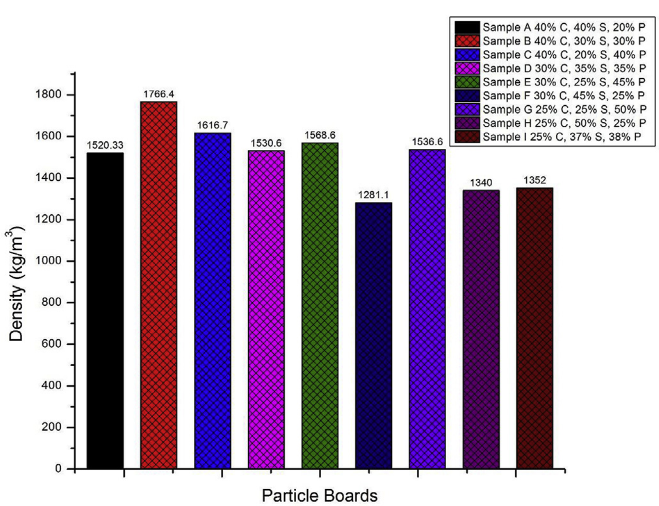


Fig. 2. Density of particle boards.

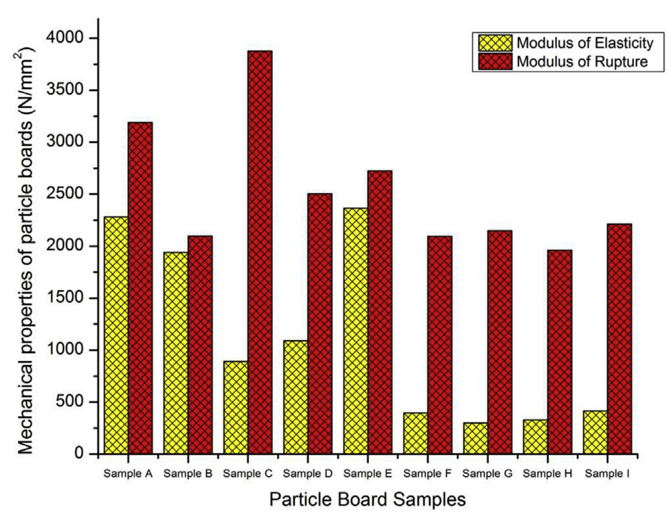


Fig. 4. Modulus of elasticity and modulus of rupture of particle boards.

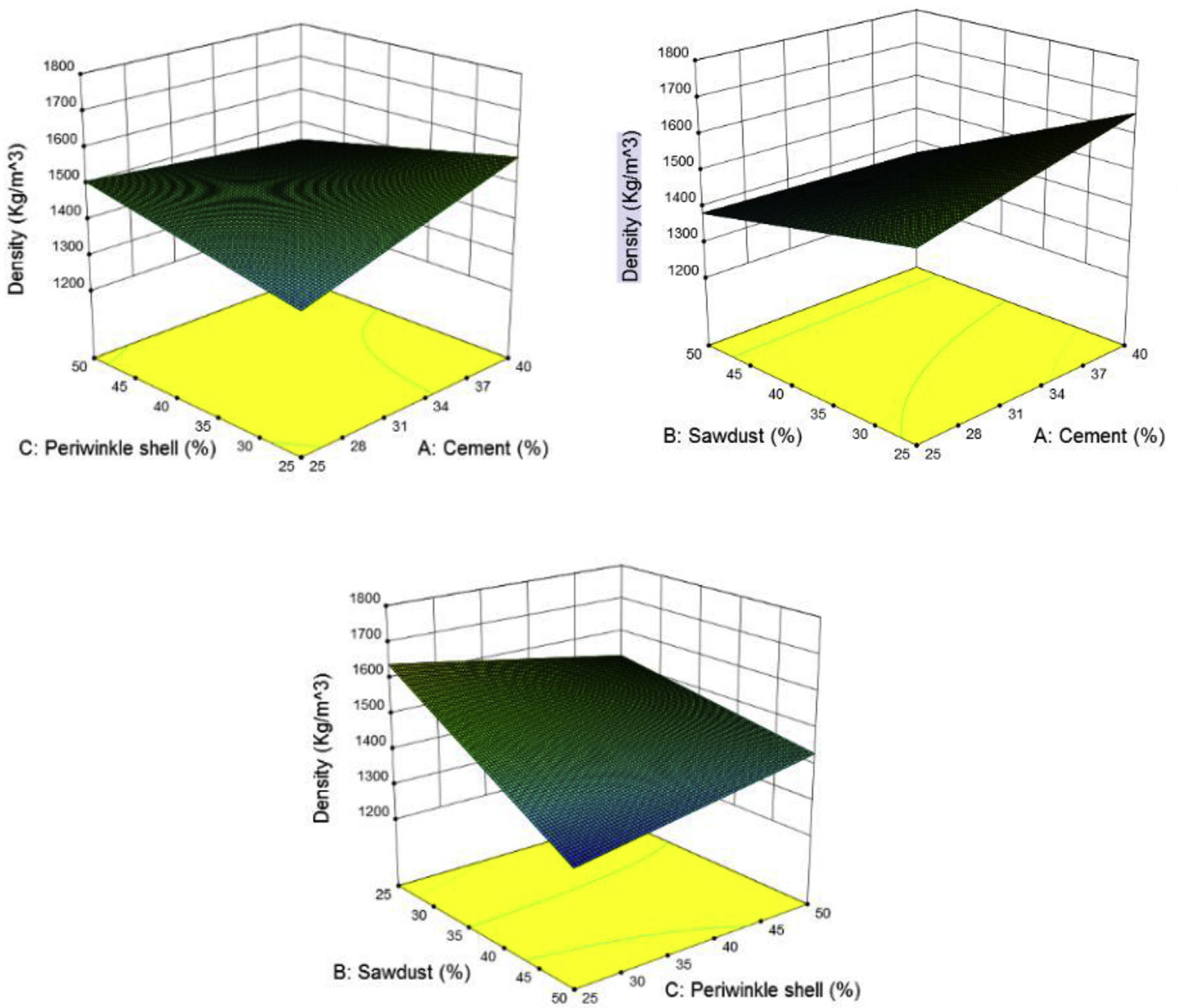


Fig. 5. Effect of material combination on density of particle board.

areas of Nigeria. The shells of periwinkles have been investigated for use in concrete as fine and coarse aggregates [19–22]. However, not much has been done to check its usefulness in particle boards.

Design–Expert 10.0 is a statistical software package from Stat-Ease Inc. designed to aid the design and explanation of multi-factor experiments. The software analyzes the influence of the factors and their relationship with other factors by varying their values in parallel. A Response Surface Model (RSM) can be adopted to map out a design space by means of a few numbers of experiments. This offers an estimation for the value of responses for every conceivable combinations of the factors by varying the values of all factors in parallel. The optimization feature makes it possible to deduce the optimum operating parameters for a process [23].

The aim of this research is to evaluate the properties of cement bonded particle board produced from African balsam tree (Populous Balsamiferous) and periwinkle shell residues and to determine the optimum combination of these materials that would give the highest strength using Design Expert 10.0.

2. Material and methods

2.1. Materials

The constituents of the particle boards produced in this research work were ordinary Portland cement (OPC, Grade 42.5R, Fineness 2.5%, Specific gravity 3.13, Consistency 28%, Initial and Final setting time of 75 and 150 min respectively), sawdust, periwinkle shell, water, lubricating oil, polyethylene bag and calcium chloride ($CaCl_2$). The calcium chloride ($CaCl_2$) was used as an additive to accelerate the setting time of the cement. Samples of the sawdust and ground periwinkle shell are shown in Fig. 1.

2.2. Experimental procedure

The periwinkle shell utilized for this study was cleaned by removing the impurities present in it and then sun dried for four (4) days. Afterwards, it was broken into tiny particle sizes with the use of a hammer milling machine. The pretreatment of both the periwinkle shell and sawdust particles was done by soaking them in hot water at 80 °C and thereafter, in cold water for 24 hours respectively for the full extraction of some unwanted water soluble chemical substances like starch, compounds of phenol and extracts of oil which may prevent the setting of cement utilized as the binder in the formation of the boards. The treated sawdust and periwinkle shell particles were sun dried again to a moisture content (M.C.) of 9% before usage.

The weights of all the materials were varied to produce nine different board samples as determined by the board mix ratio. The quantity of chemical additive used was measured as a percentage weight of the chemical to the weight of cement. The weight of water used was determined using Equation (1) [1] and weighed in a cylinder. Each of the materials (cement, periwinkle shell and sawdust) measured were inserted in polythene bags.

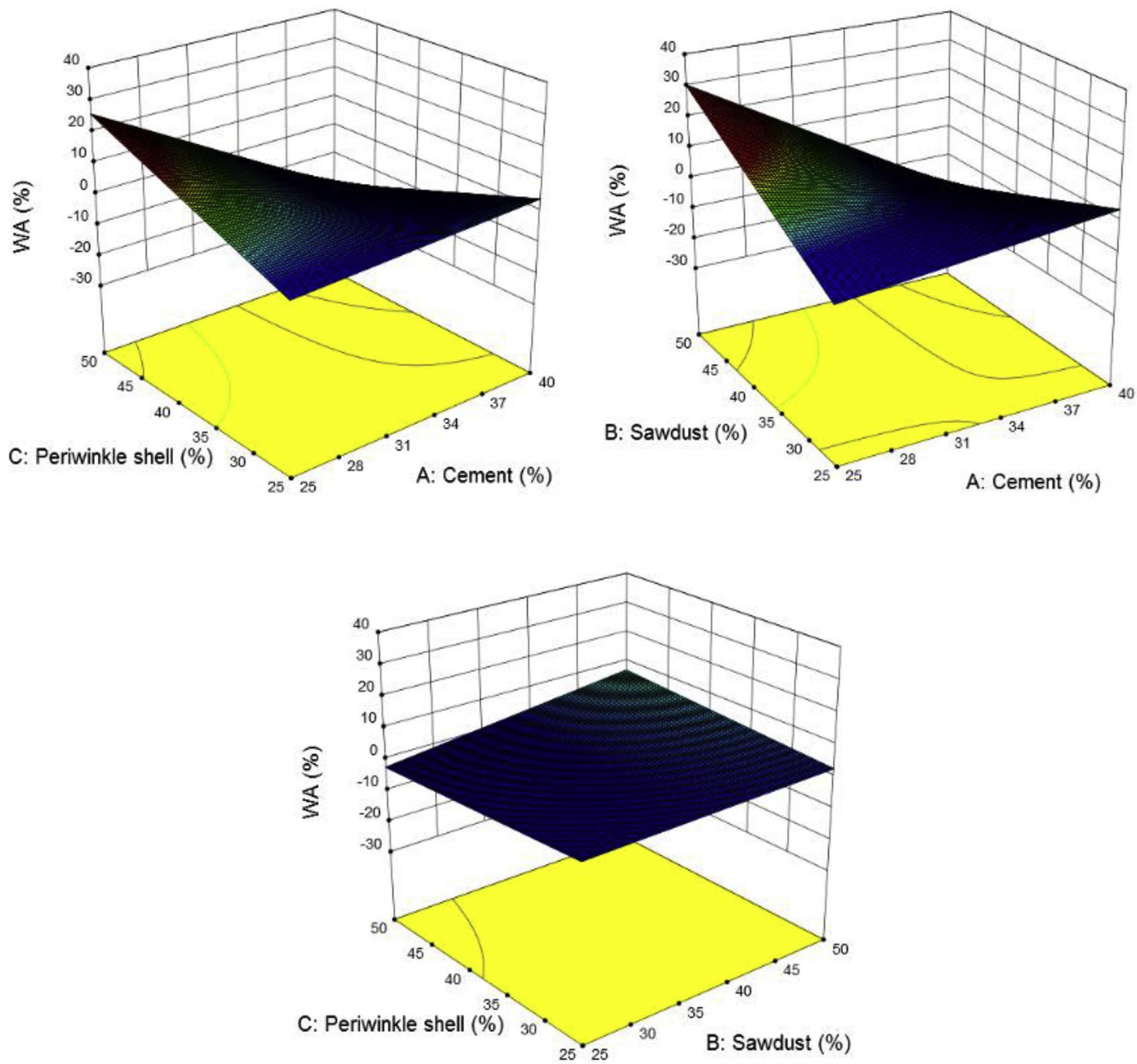


Fig. 6. Effect of material combination on WA of particle board for 2 h.

$$W_t = 0.60C_t + (0.3 - MC)W \quad (1)$$

where,

W_t = Weight of water(g); C_t = Weight of cement(g);

MC = Sawdust Moisture Content(Oven –Dry basis)%; W = Weight sawdust

The material composition adopted in producing the cement bonded particle boards is shown in Table 1. Some other factors that were kept constant for all samples are: Additive concentration ($CaCl_2$) = 4% of cement weight; Board thickness = 5 mm; Moisture content = 9%; Board size = 350 mm × 350 mm × 12 mm; Pressing pressure = 1.21 N/mm^2.

The quantities of cement (C), periwinkle shell (P) and sawdust (S) were measured out into a bowl. The required volume of additive was dissolved in the volume of water required and the mixture was thoroughly mixed. The water in which the chemical additive i.e. calcium chloride ($CaCl_2$) was dissolved was then added to the bowl containing cement, periwinkle shell and sawdust and evenly mixed to result into a lump free mix.

2.2.1. *Board formation*

The wooden moulds had a uniform size of dimension 350 mm × 350 mm x 12 mm and a cover of 20 mm. The cover was fabricated to fit properly into the moulds to ensure a final thickness of 5 mm for the boards produced. Boards produced were wrapped with polythene to ensure easy removal from the moulds. The pre-press mat was a caul plate made of iron. It was covered with polythene sheets to ease loading and reduce the thickness before loading to the cold press. Polythene was also utilized in covering the top of the moulds with the samples before the metal plate was put in place. The set-up was taken to the hydraulic press for cold pressing. Hydraulic pressure of 1:21 N/mm^2 was exerted for 24 h. Afterwards, the demoulded boards were cured for 28 days in sealed polythene bags to avoid loss of moisture. Circular saws were used to trim the edges of the samples to guarantee a smooth board testing. The boards were then cut into different specimen sizes and subjected to tests in accordance with [24]. The Water Absorption (WA), Thickness Swelling (TS), board density Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of the boards were then determined.

2.2.2. *Curing process*

After pressing, the compressed mat was released, the boards were demoulded and covered with polythene for 28 days in the laboratory to

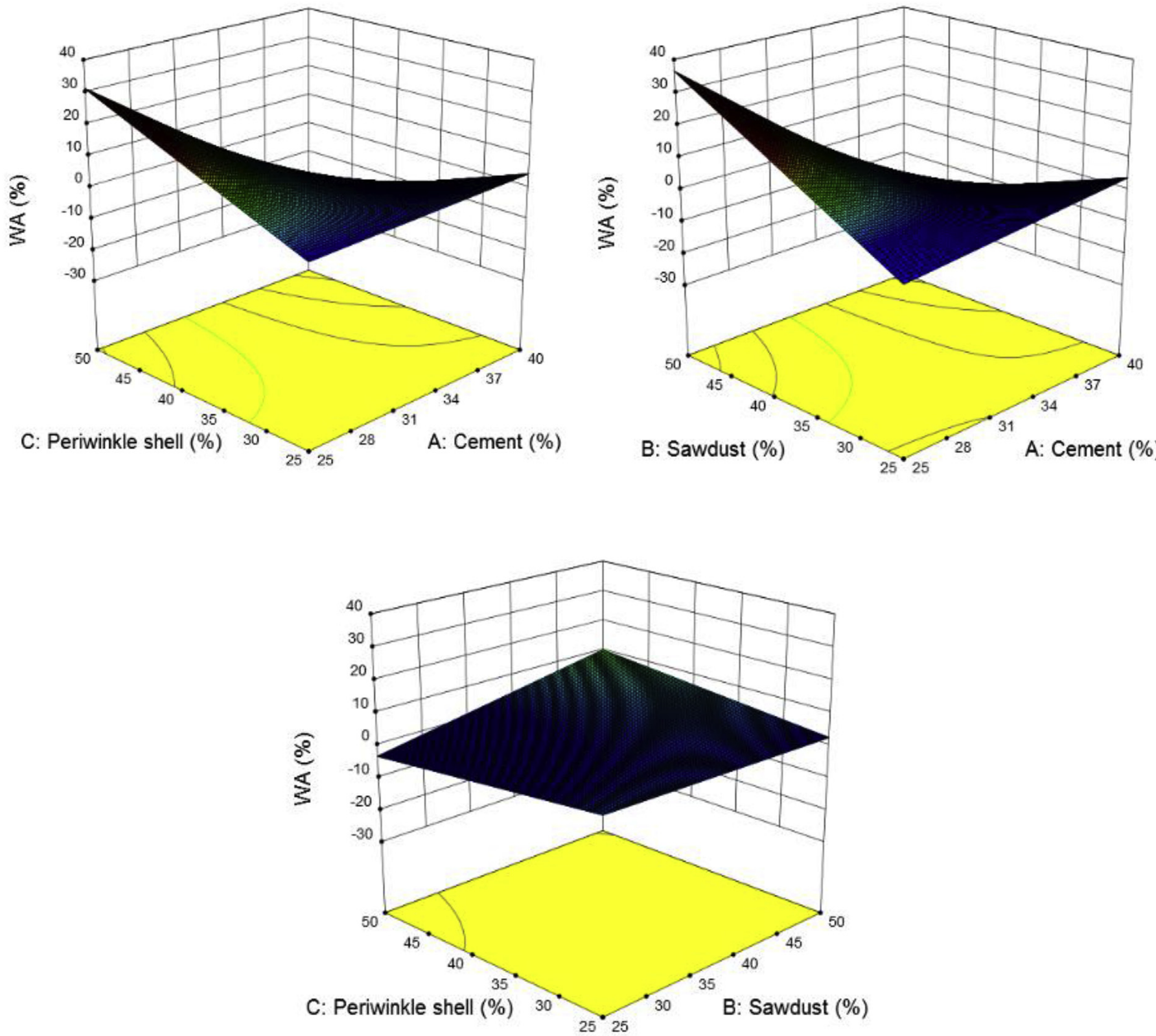


Fig. 7. Effect of material combination on WA of particle board for 24 h.

prevent possible loss of water and maintain constant ambient condition.

2.2.3. Testing of the board properties

The tests to which the boards were subjected are physical (density, water absorption and thickness swelling) and mechanical (MOR and MOE) tests. The boards were cut into 50 mm × 50 mm × 5 mm for physical test and 140 mm × 20 mm × 5 mm for mechanical test.

2.2.3.1. Physical test.

a. Density:

The density of the samples was determined as specified by BS EN 12390–7:2019 [25]. Three sample specimens were cut out and their weights were recorded with respect to their volume. Equation (2) [26] was adopted for calculating the bulk densities of the samples.

$$Density\ (g/cm^3) = W_a / V_a \tag{2}$$

where;

$W_a = Air\ Dried\ Weight;\ V_a = Air\ Dried\ Volume$

b. Water Absorption (WA)

The Water Absorption of the samples was determined as specified by BS 1881–122:2011 [27]. Three (3) specimen samples were cut out from the board and their weights were recorded as initial weight (W_i) using a weighing balance. Then, samples were weighed after been immersed in water using a time frame of 2 h and 24 h (at room temperature) and the weight of each specimen were recorded as final weight (W_f). To get the percentage water absorbed by each sample, Equation (3) [28] was adopted.

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

where;

$W_f = Final\ Weight\ of\ the\ Board;\ W_i = Initial\ Weight\ of\ the\ Board$

c. Thickness Swelling (TS)

The Thickness Swelling of the samples was determined as specified by ASTM standards D1037-03 [29]. The samples produced were cut and trimmed to 50 mm by 50 mm by 5 mm from the board. The initial thickness of the samples, taken with a Vernier caliper, was recorded as

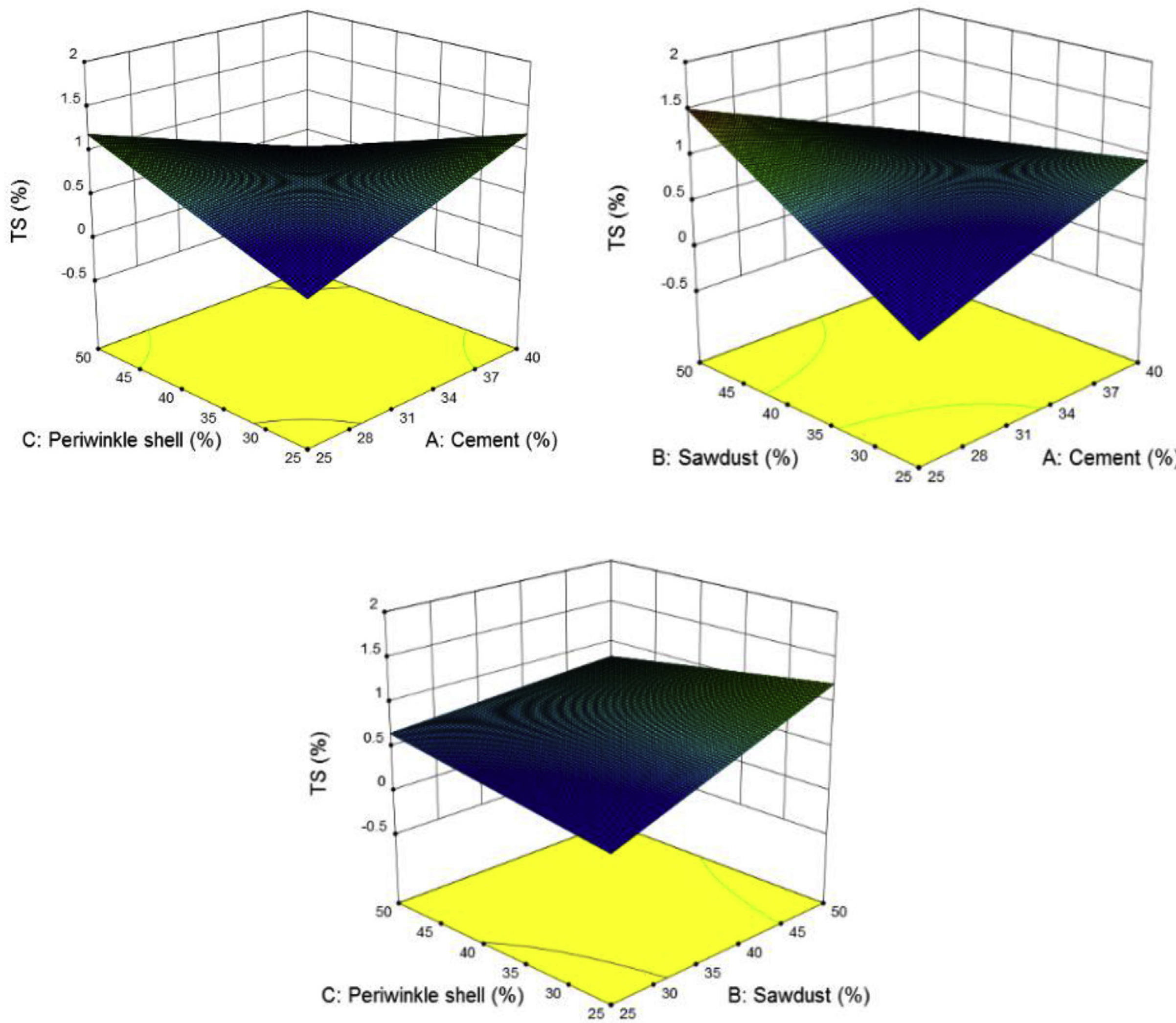


Fig. 8. Effect of material combination on TS after 2 h.

(T_i). The samples were then immersed in water for a period of 2 h and 24 h respectively and the thickness of each sample were recorded as final thickness (T_f). To get the percentage absorbed by each sample, Equation (4) [12] was adopted for calculating water absorption of each sample.

$$\textit{Thickness Swelling}(\%) = \frac{T_f - T_i}{T_i} \times 100 \quad (4)$$

where;

$T_f = \textit{Final Thickness of the Board}; T_i = \textit{Initial Thickness of the Board}$

2.2.3.2. Mechanical test. The samples were tested for Modulus of Rupture (MOR) as specified by BS EN 12390–5:2000 [30] and Modulus of Elasticity (MOE) as specified by BS EN 12390–13:2013 [31] using a Testometric Tensile testing Machine (FS50AT) at the Mechanical Engineering Laboratory, University of Ilorin. The samples were steadily loaded until the failure point. The failure loads for each specimen was recorded. Equations (5) and (6) [12] were used to determine the MOE and MOR of the specimen respectively.

$$\textit{Modulus of Elasticity } (MOE) = \left(3 \times P_{bp} \times L\right) / \left(12 \times Y_p \times bh\right) \quad (5)$$

where,

P_{bp} = load at the proportionality limit; L = Span length in mm; b = Width of the specimen in mm; h = Thickness of the specimen in mm; Y_p = *deflection corresponding to* P_{bp}

$$\textit{Modulus of Rupture } (MOR) = (3 \times P_b \times L) / (4 \times bh) \quad (6)$$

where

P_b = Maximum load; L = Span length in(mm); b = Width of the specimen in mm; h = Thickness of the specimen in mm

2.3. Optimization

The experimental setup was designed using Design Expert (Version 10), where an RSM in an Historical Data Design (HDD) was used to optimize the Cement, Sawdust and Periwinkle shell. The HDD allows for flexibility in importing data unlike other RSM design methods where the combinations would have to be designed before proceeding to the laboratory. Two independent variables (Cement, Sawdust and Periwinkle shell) with 9 experimental runs for density, water absorption, thickness swelling, MOE and MOR were considered.

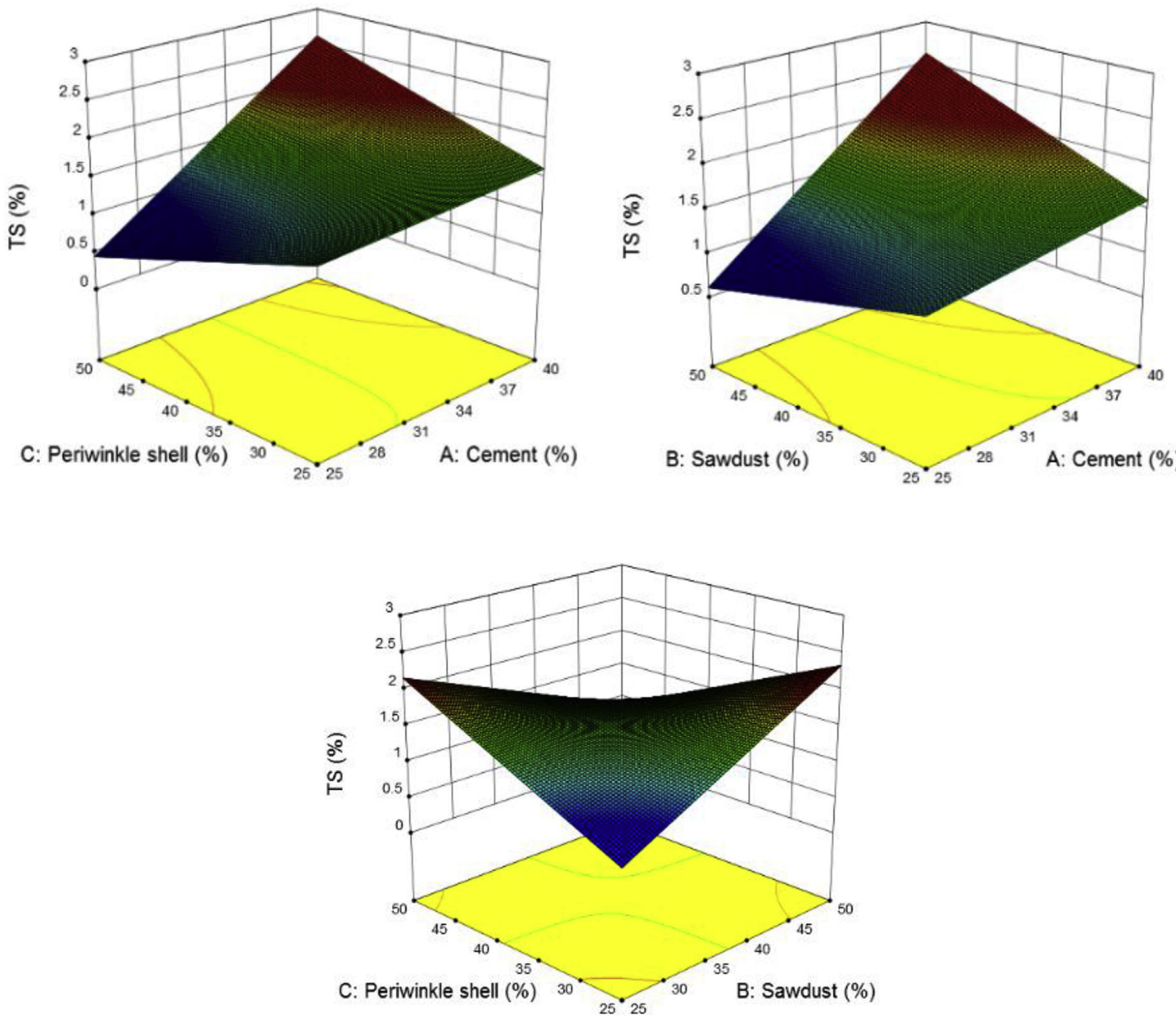


Fig. 9. Effect of material combination on TS after 24 h.

3. Results and discussion

The results for the Density WA and TS after two (2) hours and four (4) hours of testing are shown in Figs. 2 and 3 respectively. The MOE and MOR results are presented in Fig. 4.

The values obtained from the laboratory tests were analyzed with Design Expert 10.0.

3.1. *Effect of composite materials on density, water absorption, thickness swelling, MOE and MOR*

3.1.1. *Density*

Sample B had the peak density value of 1766.40 kg/m^3 and Board F had the least density of 1281.10 kg/m^3. The minimum density requirement by ISO 8335 [32] is 1000 kg/m^3. The IS 14276 [33] recommends a minimum density of 1250 kg/m^3 while JIS.A.5908 [34] endorsed a minimum density value of 800 kg/m^3. All particle boards produced met these recommended minimum standards. Fig. 5 shows the 3D relationship between the Density (kg/m^3), sawdust (%), cement (%) and periwinkle shell (%). The Figure reveals that as the percentage volume of sawdust and periwinkle shell increases, the density of the board reduces. However, the more the percentage volume of cement, the higher the board density.

3.1.2. *Water absorption*

Water absorption and thickness swelling reveals the dimensional stability of the particle boards. Board F had the least water absorption capacity with values of 2.12% and 2.98% at 2 hours and 24 hours respectively while Board H has the peak value of 16.70% and 19.20% at 2 and 24 h respectively. The maximum recommended water absorption by IS 14276 [33] is 13% for 2 hours and 25% for 24 hours. Water absorption for all the particle boards produced are within these recommended values. Fig. 6 and Fig. 7 show the 3D relationship between the water absorption (WA), sawdust, cement and periwinkle shell for two (2) and twenty-four (24) hours. The Figures show that with the increase in sawdust (%) and cement (%) there was an increase in Water Absorption but an increase in the quantity of periwinkle shell brought about a reduction in the water absorption.

3.1.3. *Thickness swelling*

From the observation for thickness swelling at 2 hours, it was discovered that boards E and G had the lowest thickness swelling while board C has the highest. At 24 hours, board F has the maximum thickness swelling and board B had the smallest thickness swelling. The American National Standards Institute [35] stipulated that the maximum thickness swelling is 8%. Thus, all the specimen tested fulfilled the thickness swelling requirement. Fig. 8 and Fig. 9 show the 3D relationship between the Thickness Swelling, sawdust, cement and periwinkle shell, for two (2) and twenty-four (24) hours. It was observed that as the quantity of

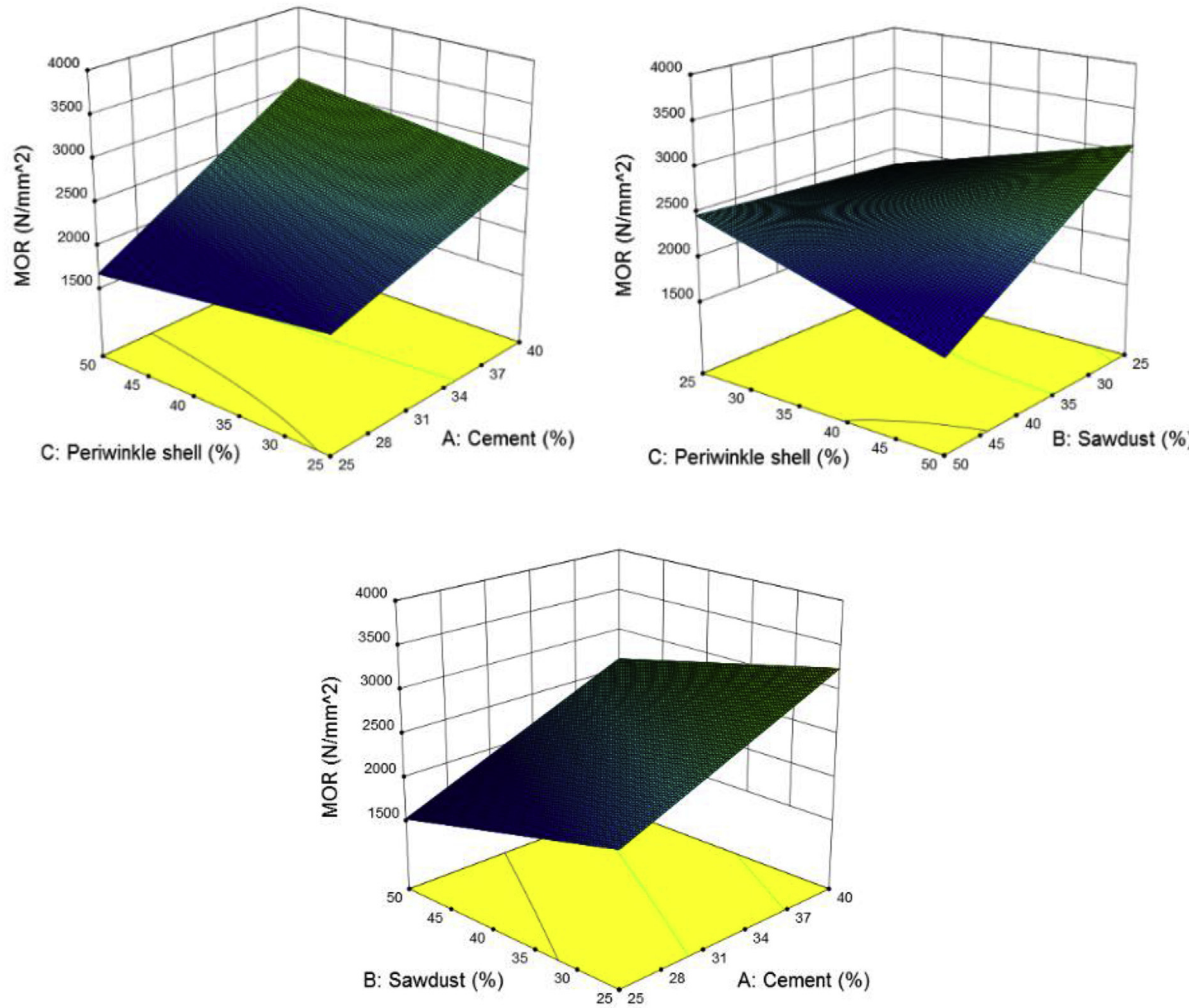


Fig. 10. Effect of materials combination on MOR.

sawdust and cement increases, the Thickness swelling also increases. However, the increase in the quantity of the Periwinkle shell reduces Thickness Swelling at two (2) and twenty-four (24) hours.

3.1.4. Modulus of rupture (MOR)

Particle Board C had the peak MOR value of 3876.554 N/mm^2 and Board H had the least MOE of 1961.726 N/mm^2. These values are above the minimum standard of 3 N/mm^2 specified by American National Standards Institute [35] for general purpose particle boards. They are also higher than the values reported by Atoyebi *et al.*, Zhou *et al.*, Ajayi and Badejo, and Aladejana and Oluyege [1,36–38] for particle boards produced from some other composite materials. Fig. 10 shows the 3D relationship between the MOR, sawdust, cement and periwinkle shell. It was noticed that increase in the quantity of sawdust and periwinkle shell resulted in the lowering of the MOR while the upsurge in the quantity of cement produced an increase of MOR.

3.1.5. Modulus of elasticity (MOE)

The Particle board E had the maximum MOE value of 2364.928 N/mm^2 while board G had the least MOE of 299.812 N/mm^2 [5,12,35]. reported that the minimum allowable MOE for particle boards is 550 N/mm^2. Particle boards F, G, H, and I fall below this standard. Fig. 11 shows the 3D relationship between the Modulus of Elasticity and the composite materials used. It was observed that with the increase in the percentage of sawdust and periwinkle shell there was a reduction in Modulus of Elasticity (N/mm^2). However, increase in the quantity of cement produced an increase in MOE.

3.2. Optimization

In optimizing the material combination, the design was to maximize the density, MOE and MOR while minimizing the water absorption & thickness swelling. The material quantities were kept in range of 25%–40% for cement, 25%–50% for sawdust and 25%–50% for periwinkle shell. The optimal result shows that at 40% Cement, 27% Sawdust and 33% Periwinkle shell, the Density = 1644.87 kg/m^3, Water absorption = 4.58, Thickness swelling = 1.5, MOR = 3060.38 N/mm^2 and MOE = 1805 N/mm^2. These values are within the recommended values by ISO 8335, IS 14276, JIS.A.5908 and American National Standards Institute [32–35]. This result has a combined desirability value of 0.68 as shown in Fig. 12.

3.3. Result validation

The relationship between the experimental and predicted values of the density, water absorption and thickness swelling are shown in Fig. 13, Fig. 14 and Fig. 15. The adequate precision values higher than 4.0 in the experiments signify a reasonable signal to noise level, denoting that their models can be relied upon to navigate the design space. This validates the results obtained.

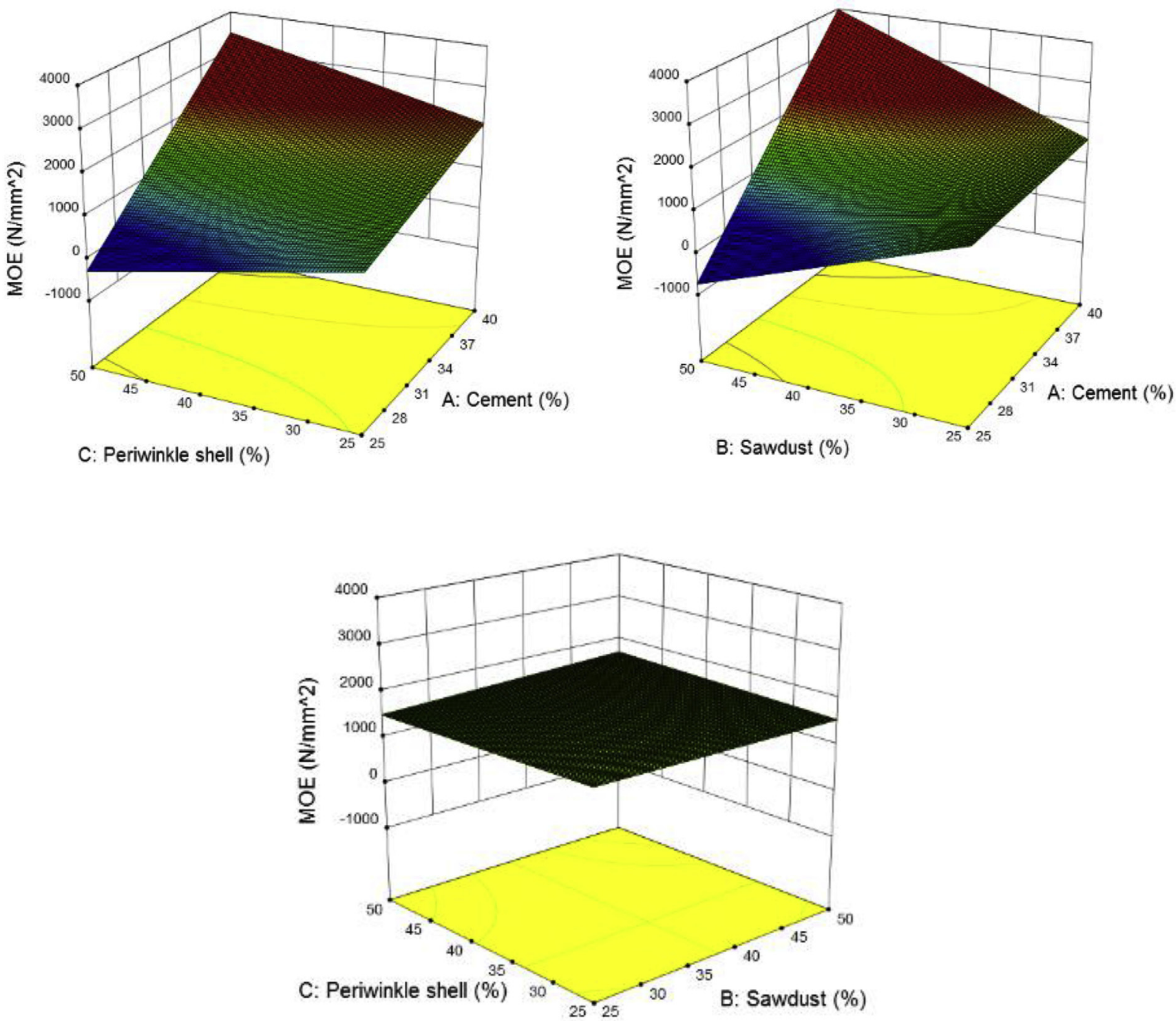


Fig. 11. Effect of material combination on MOE.

3.4. Scanning Electron Microscopy (SEM) analysis

The samples were subjected to SEM analysis to determine the internal microstructure of the boards and the results of the analysis are presented in Fig. 16. In the Figure, Cement is designated as 'C', Sawdust as 'S', while Periwinkle shell is designated as 'P'.

Samples A, B and C show good bonding amongst the particleboard constituent materials, an indication of very high adhesive force in the composite materials. If the boards are subjected to loads, such loads will be distributed to the materials evenly and will be able to repel the loads. The concentration of cement matrix at some regions in Sample B is as a result of inhomogeneous mixing of the composite materials which reduces the intermediate properties of the sample in those regions. Also, the appearance of dot-like spots in Sample C is a result of unsmooth finishes which could promote the formation of cracks in the sample.

Sample D shows that the increase in the sawdust residues resulted in the increase in toughness of the sample, but the crack in the sample set in as a result of insufficient of cement matrix to bind all the composite materials together. Sample E shows a lot of void within the composite materials which serve as point of failure being the result of reduction in the binding agent to promote the intermediate properties of the composite. Sample F reveal that the adhesive force between the particles of the composite is low as a result of increase in fraction of sawdust residues to cement matrix which will make the sample to fail under heavy load.

Sample G, H and I indicate poor structural properties, freely existing sawdust residues which serve as point of discontinuity and promote the formation of void in the samples promoting its inability to bear loads as the composite materials were not well bonded together.

Thus, it was observed that the boards with the higher percentage of cement were more compact than those with less percentage of cement. There is a good fibre matrix adhesion at mix ratio of 1:1.5 (cement/wastes). At lower fraction of cement matrix to waste ratio, the cement bonded particle board lost its adhesive force. This validates the outcome of the physical tests carried out on the samples.

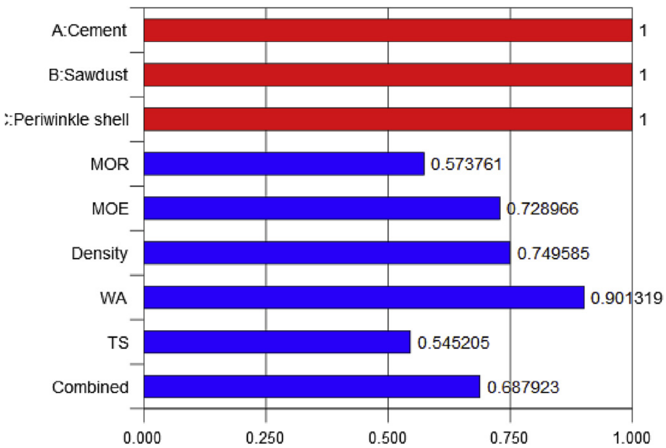


Fig. 12. Desirability value for optimum combination of cement, sawdust and periwinkle shell in particle board.

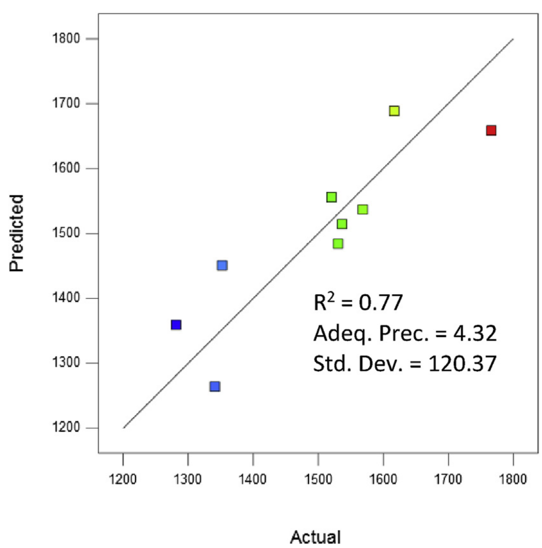


Fig. 13. Predicted density versus experimental density.

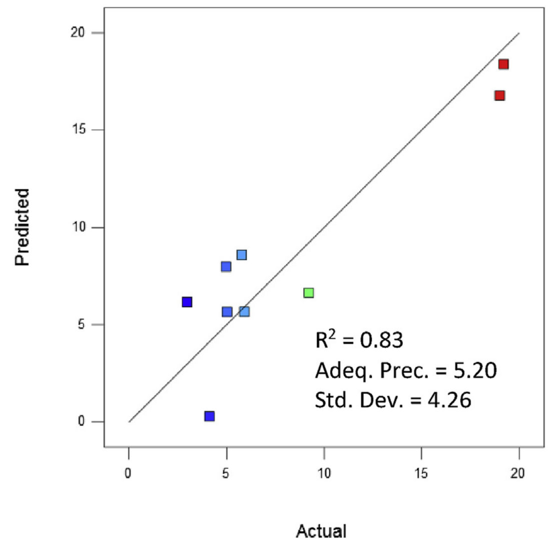


Fig. 14. Predicted WA versus experimental WA.

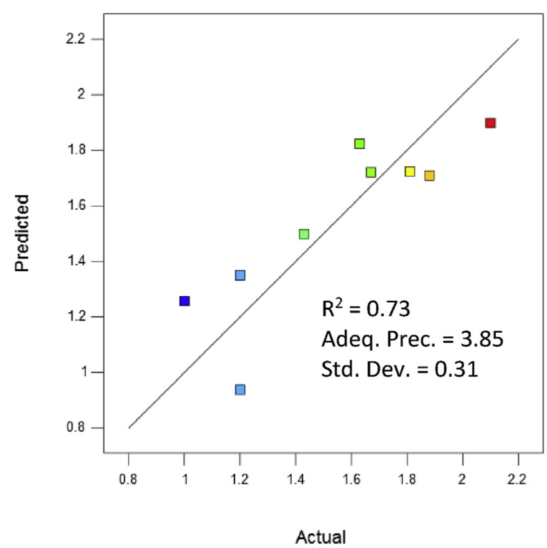


Fig. 15. Predicted TS versus experimental TS.

4. Conclusions

The properties of cement bonded particle boards produced for African balsam tree (*populous balsamiferous*) sawdust and periwinkle shell residue was determined using Design Expert 10.0 by varying the composition of cement, sawdust, and periwinkle shell. The following conclusions were drawn at the end of the research:

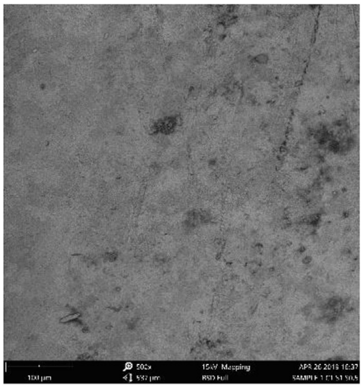
1. Sample B, with 40% Cement, 30% Sawdust and 30% Periwinkle shell, had the peak density value of 1766.40 kg/m^3 and Sample F with 30% Cement, 45% Sawdust, 25% Periwinkle shell, had the least density of 1281.10 kg/m^3. Thus, an increase in the quantity of Periwinkle shell and cement increases the density while the quantity of sawdust has no influence on the density of cement bonded particle boards.
2. Sample F with 30% Cement, 45% Sawdust, 25% Periwinkle shell, had the least water absorption capacity with values of 2.12% and 2.98% at 2 and 24 hours respectively while Sample H, with 25% Cement, 50% Sawdust and 25% Periwinkle shell, has the peak value of 16.70% and 19.20% at 2 and 24 hours respectively. Hence, a reduction in the quantity of cement and increase in the quantity of sawdust both increases the Water Absorption & Thickness Swelling of the samples while the quantity of Periwinkle shell has no effect on the WA and TS of cement bonded particle board.
3. An increase in the quantity of cement resulted to an increase in the MOE and MOR of the samples while the quantity of the Periwinkle shell and sawdust has no effect on these properties for cement bonded particle board.
4. The optimum combination of the materials is 40% Cement, 27% Sawdust and 33% Periwinkle shell. This combination gave a particle board with a Density of 1644.87 kg/m^3, Water absorption of 4.58, Thickness swelling of 1.5, MOR of 3060.38 N/mm^2 and MOE of 1805 N/mm^2.

Declaration of competing interest

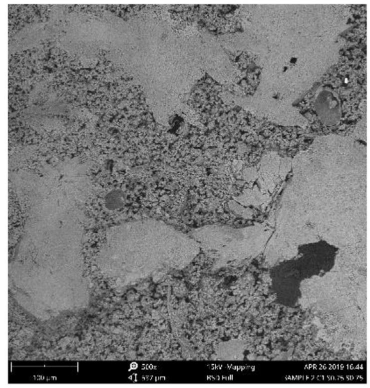
This research has not been funded by any organization. Thus, there is no conflict of interest.

CRediT authorship contribution statement

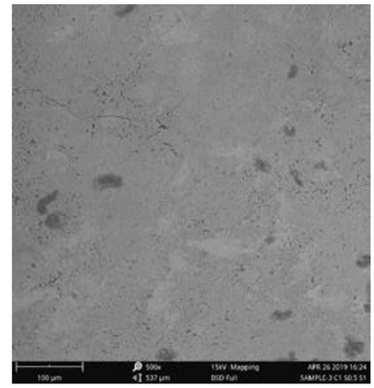
S.O. Odeyemi: Conceptualization, Investigation, Methodology, Supervision, Funding acquisition, Writing - review & editing. **R. Abdulwahab:** Investigation, Methodology, Funding acquisition, Writing -



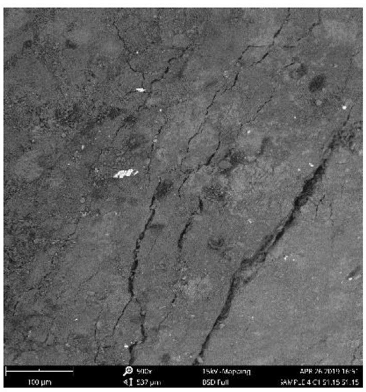
Sample A (40% C, 40% S, 20% P)



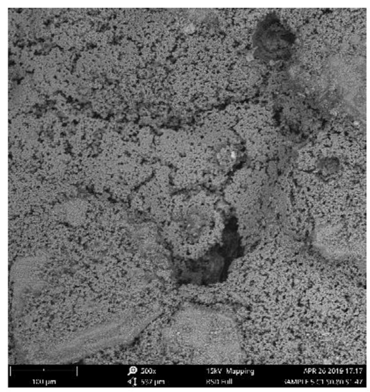
Sample B (40% C, 30% S, 30% P)



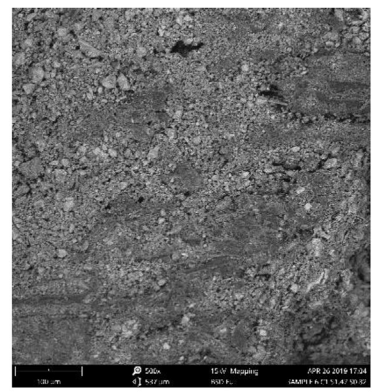
Sample C (40% C, 20% S, 40% P)



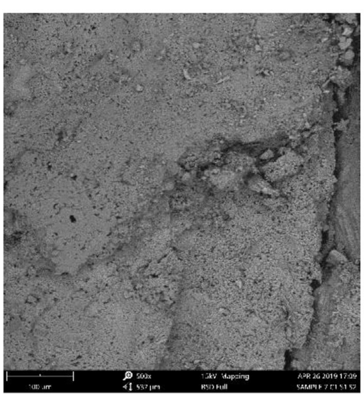
Sample D (30% C, 35% S, 35% P)



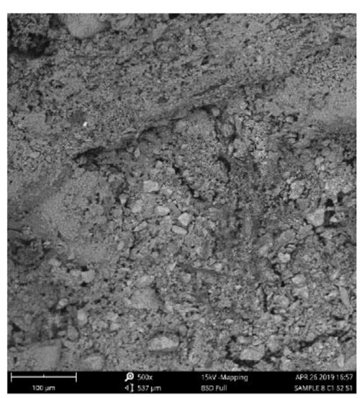
Sample E (30% C, 25% S, 45% P)



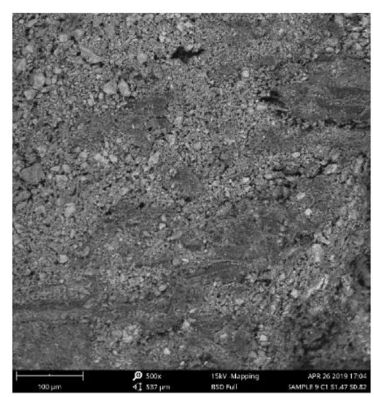
Sample F (30% C, 45% S, 25% P)



Sample G (25% C, 25% S, 50% P)



Sample H (25% C, 50% S, 25% P)



Sample I (25% C, 37% S, 38% P)

Fig. 16. Internal microstructure of particle boards.

review & editing. **A.G. Adeniyi:** Investigation, Methodology, Funding acquisition, Writing - review & editing. **O.D. Atoyebi:** Investigation, Methodology, Funding acquisition, Writing - review & editing.

Acknowledgement

We wish to acknowledge the academic staff of the Department of Civil and Environmental Engineering, Kwara State University, Malete, Kwara State, Nigeria, for appraising the work and making appropriate input.

References

[1] O.D. Atoyebi, T.F. Awolusi, E.E. Davies Iyinoluwa, Artificial neural network evaluation of cement-bonded particle board produced from red iron wood (Lophira alata) sawdust and palm kernel shell residues, Case Stud. Constr. Mater. (2018) 1–11.

[2] O.A. Sotannde, A. Oluyege, P.F. Adeogun, S.B. Maina, Variation in wood density, grain orientation and anisotropic shrinkage of plantation grown Azadirachta indica, J. Appl. Sci. Res. 6 (2010) 1855–1861.

[3] P. Elias, D. Boucher, Planting for the Future How Demand for Wood Products Could Be Friendly to Tropical Forests, Union of Concerned Scientists, 2014.

[4] A. Olorunnisola, O. Adejisan, Trial production and testing of cement-bonded particleboard from rattan furniture waste, Wood Fibre Sci 34 (2002) 116–124.

[5] F.A. Aisien, A.N. Amenaghawon, K.C. Bienose, Particle boards produced from cassava stalks: evaluation of physical and mechanical properties, South Afr. J. Sci. 5 (2015) 1–4.

[6] S.O. Odeyemi, M.A. Akinpelu, O.D. Atoyebi, R.T. Yahaya, Determination of load carrying capacity of clay bricks reinforced with straw, Int. J. Sustain. Constr. Eng. Technol. 8 (2017) 2180–3242. http://penerbit.uthm.edu.my/ojs/index.php/IJSCET.
[7] M.A. Anifowose, A.O. Adeyemi, S.O. Odeyemi, R. Abdulwahab, R.B. Mudashiru, Comparative study of ikirun and osogbo slag on concrete grade 20, Niger, J. Technol. 38 (2019) 283–288, https://doi.org/10.4314/njt.v38i2.2.
[8] H. Pirayesh, P. Moradpour, S. Sepahvand, Particleboard from wood particles and sycamore leaves: physico-mechanical properties, Eng. Agric. 8 (2014) 1–6, https://doi.org/10.1016/j.eaef.2014.07.003.
[9] R. Abdulwahab, S.O. Odeyemi, M.A. Anifowose, J.K. Ibrahim, Palm kernel shell as partial replacement for normal weight Aggregate in concrete, Ann. Fac. Eng. Hunedoara – Int. J. Eng. 17 (2019) 201–204.
[10] E. Guntekin, B. Karakus, Feasibility of using eggplant (Solanum melongena) stalks in the production of experimental particleboard, Ind. Crop. Prod. 27 (2008) 354–358.
[11] M. Gürü, S. Tekeli, İ. Bilici, Manufacturing of urea–formaldehyde-based composite particleboard from almond shell, Mater. Des. 27 (2006) 1148–1151.
[12] O.D. Atoyebi, S.O. Odeyemi, L.O. Azeez, A.E. Modupe, Physical and mechanical properties evaluation of corncob and sawdust cement bonded ceiling boards, Int. J. Eng. Res. Afr. 42 (2019) 65–75, https://doi.org/10.4028/www.scientific. .net/jera.42.65.
[13] E.Y. Salawu, O.O. Ajayi, A. Inegbenebor, S. Akinlabi, E. Akinlabi, Influence of pulverized palm kernel and egg shell additives on the hardness, coefficient of friction and microstructure of grey cast iron material for advance applications, Results Eng 3 (2019) 100025, https://doi.org/10.1016/j.rineng.2019.100025.
[14] S.H. Ghaffar, M. Burman, N. Braimah, Pathways to circular construction: an integrated management of construction and demolition waste for resource recovery, J. Clean. Prod. 244 (2020) 118710, https://doi.org/10.1016/j.jclepro.2019.118710.
[15] S.H. Ghaffar, J. Corker, M. Fan, Additive manufacturing technology and its implementation in construction as an eco-innovative solution, Autom. ConStruct. 93 (2018) 1–11, https://doi.org/10.1016/j.autcon.2018.05.005.
[16] S.H. Ghaffar, M. Al-Kheetan, P. Ewens, T. Wang, J. Zhuang, Investigation of the interfacial bonding between flax/wool twine and various cementitious matrices in mortar composites, Construct. Build. Mater. 239 (2020) 117833, https://doi.org/10.1016/j.conbuildmat.2019.117833.
[17] S.A. Abdulkareem, S.A. Raji, A.G. Adeniyi, Development of particleboard from waste styrofoam and sawdust, Niger, J. Technol. Dev. 14 (2017) 18, https://doi.org/10.4314/njtd.v14i1.3.
[18] U.D. Idris, V.S. Aigbodion, R.M. Gadzama, T.Y. Ahmed, Suitability of maize cob particles and recycled low density polyethylene for particleboard manufacturing, Materials Science, MSAIJ 8 (2012) 34–37.
[19] T. Soneye, A.N. Ede, G.O. Bamigboye, D.O. Olukanni, The study of periwinkle shells as fine and coarse aggregate in concrete works, in: 3rd Int. Conf. African Dev. Issues (CU-ICADI 2016), 2016, pp. 361–364.
[20] F. Falade, An investigation of periwinkle shells as coarse aggregate in concrete, J. Build. Environ. 30 (1995) 573–577.
[21] B.I.O. Dahunsi, Properties of periwinkle granite concrete, J. Civ. Eng. JKUAT. 8 (2002) 27–36.
[22] O.I. Agbede, J. Manasseh, Suitability of periwinkle shell as partial replacement for river gravel in concrete, leonardo Electron, J. Pract. Technol. 15 (2009) 59–66.
[23] M.J. Anderson, Design of Experiments, DOE) Made Easy and More Powerful via Design-Expert® Software, 2007.
[24] ASTM (American Society for Testing Materials), Standard Test Methods for Evaluating Properties of Wood-Based Fiber and Particle Panel Materials Static Tests of Timbers, D, Philadelphia, PA, 1999, 1037- 93, ASTM.
[25] B.S. EN 12390-7, Testing Hardened Concrete, Density of hardened concrete, 2019, 2009.
[26] S.O. Odeyemi, M.A. Anifowose, M.O. Oyeleke, A.O. Adeyemi, S.B. Bakare, Effect of calcium chloride on the compressive strength of concrete produced from three brands of Nigerian cement, Am. J. Civ. Eng. 3 (2015) 1–5, https://doi.org/10.11648/j.ajce.s.2015030203.11.
[27] BS 1881-122, Testing Concrete, Method for determination of water absorption, 2011, 2011.
[28] S.O. Odeyemi, R. Abdulwahab, M.A. Anifowose, R.J. Ibrahim, Impact of different fine aggregates on the compressive strength of hollow sandcrete blocks, Arid Zo. J. Eng. Technol. Environ. 15 (2019) 611–618. www.azojete.com.ng.
[29] ASTM D1037 - 12, Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials, 2012.
[30] B.S. EN 12390-5, Testing Hardened Concrete, Flexural strength of test specimens, 2000, 2000.
[31] BS EN 12390-13, Testing hardened concrete. Determination of secant modulus of elasticity in compression, 2013, 2013.
[32] ISO 8335, Cement Bonded Particle Board: Board of Portland or Equivalent Cement Reinforced with Fibrous Wood Particles, International Organization for Standardization, Stockhom, 1987.
[33] IS 14276, Indian standard, Cement Bonded Particle Boards Specification, Bureau of Indian Standards (BIS) Division, New Delhi, 1995.
[34] A. JIS, Japanese Industrial Standard, Particleboards, Japanese Standard Association, Japan, 2003, 5908.
[35] American National Standards Institute (ANSI), Particle Board Standard ANSI. A208.1-1999, Composite Panel Assoc., Gaithersburg, MD, 1999.
[36] Y. Zhou, D. Kamdem, Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood removed from service, For. Prod. J. 52 (2002) 77–81.
[37] B. Ajayi, S.O. Badejo, Effects of board density on bending strength and internal bond of cement-bonded flakeboards, J. Trop. For. Sci. 17 (2005).
[38] J. Aladejana, A. Oluyege, Assessment of selected physical and mechanical properties of cement Bonded Board Produced from Gliricidia sepium (Agunmaniye), PRO LIGNO 12 (2016) 39–50.