Journal of Forestry Research and Management. Vol. 20(2).117-132; 2023, ISSN 0189-8418
www.jfrm.org.ng

Effects of Glass Powder Pozzolan on Dimensional Stability and Strength Performance of Wood Particle-reinforced Cement Composite

[*1]Falemara Babajide Charles, [2]Kundum Dunka, [3]Ajayi Babatunde,[4]Kehinde Sesan Aina and [3]Oyeleye Ibukun

[1]Rural Construction and Ambience (CONSTRAMBI)/USP Lab, Biosystems Engineering Department, Faculty of Animal Science and Food Engineering, University of Sao Paulo-USP, Pirassununga, Brazil
[2]Federal College of Forestry, Jos, Plateau State
[3] Federal University of Technology, Akure, Ondo State.
[4] Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State.
falemara.bc@frin.gov.ng

ABSTRACT

Cement manufacturing process is considered to be a major contributor to global CO_2 emission. This therefore necessitate the need to explore possible alternatives of reducing cement production and consumption while further ameliorating carbon footprint. The experiment was carried out to investigate the pozzolanic effects of waste glass powder as partial replacement of cement on the dimensional stability and strength performance of wood composite. This was done at 1200 kg/m^3 nominal board density and 3:1 binder/wood particles mixing ratio and 3% curing reagent concentration. The experimental set up was Completely Randomized Design (CRD) consisting of four treatments of 100:0, 75:25, 50:50 and 25:75 cement/glass powder blending proportions. The result of the study revealed that the water absorption (%WA) and thickness swelling (%TS) of the composite board after 24hours immersion ranged between 6.86 and 14.11%; and 0.12 to 0.37% respectively. Boards produced at cement replacement with 25% by weight of glass powder had a comparably and significantly lower water absorption and thickness swelling than the control (100:0), but higher than board produced at 50% and 75% glass powder cement replacement. The modulus of rupture (MOR) ranged between 8.84 N/mm^2 and 17.79 N/mm^2, while the modulus of elasticity (MOE) ranged between 3074.57 N/mm^2 and 6441.85 N/mm^2.Boards produced at 75:25 cement/glass powder blending proportion had the highest (72.38 Joules) impact strength. The highest compression strength (116.24 N/mm^2) was observed in board produced at 25% glass powder cement replacement level which is significantly higher than the compression strength (112.78 N/mm^2) of the control (100:0) without no glass powder. The optimum glass powder replacement at 25% cement supplement produced composite board with highest dimensional and strength properties. Therefore, it can be concluded that glass powder is suitable as cement supplement in wood composite manufacture.

Keywords: Cement Substitute, Composites, Pozzolans, Strength, Value addition

Introduction

The increasing demand for eco-friendly materials, increasing depletion rate, and soaring prices of petroleum-based plastics and pressing environmental regulations have all triggered a growing interest towards the field of composites (Abdul *et al.*, 2012). Wood-based composite (reconstituted composites) manufacturing has become a substantial industry nowadays. Many countries rely heavily on it for construction applications. The desire for more complete utilization of wood and wood wastes has continuously led to the development of wood composite industries. These industries reduce woody materials to small particles as well as make use of the enormous wastes from the sawmills and reconstruct it onto valuable products in large sheets of desired thickness. These reconstituted composites are in form of hardboard, fiberboards, particleboards, laminated beams, wood cement composites, wood plastic composites, among others

The use of cement for wood-based composites is encumbered with some limitations. Embrittlement of the lignocellulosic component is known to occur and is caused by the alkaline environment provided by the cement matrix. Moreover, the presence of extractives, and hydroxyl groups as well as hemicellulose, carbohydrates, and lignin components in reinforcement particles have influence on the cement composite final curing rate and final strength (Nazerian *et al*. 2011, Rana *et al*., 2020). Moreover, producing cement-based composites is not economical, considering the rising cost of Portland cement. Reducing the cost of CBCs production and overcoming the inhibitory interference of extraneous materials in lignocellulosic particles are of great interest (Nicole *et al*., 2010; Fabiyi, 2013).

In addition, cement industry is a major contributor to the overall global CO_2 emissions. According to Benhela *et al*. (2013) the cement industry accounts for between 5% and 7% of global carbon dioxide (CO_2) emissions with one ton of CO_2 released into the atmosphere during production of a ton of cement and this have made it necessary to find an eco-friendly alternative. To overcome these problems, various schemes have been developed by finding an alternative way of substituting Portland cement with natural pozzolans. Some common pozzolanic materials include volcanic ash, fly ash, rice husk ash, glass powder and condensed silica fume. All these materials can react with lime at normal temperatures to make natural water-resistant cement (Nicole *et al*., 2010). In view of this, decrease in the amount of CO_2 released into the atmosphere during Portland cement production can be achieved by supplementing with natural pozzolans to reduce cement consumption and carbon footprint. Based on this fact, using waste glass powder as partial replacement of cement would go a long way to reduce cement-based composite production cost, minimize environmental pollution, enhance municipal solid wastes management, and also contribute positively to the economic growth of the society.

Furthermore, the use of finely ground glass as a pozzolanic material has been encouraged as a result of continual accumulation of waste glass and its environmental issues. Millions of tonnes of controlled waste from household, commercial and industrial are disposed of in landfill sites in the most developing and developed countries causing a rise in landfill costs and environmental problems. Dumping and accumulation of waste glasses in landfill constitutes environmental nuisance and pollution as they are not biodegradable (Jiang *et al*., 2022). The recycling of waste glasses is a major issue in urban areas of developed countries (Shayan and Xu, 2004), which has resulted in significant interest in its utilization.

Glass is amorphous and has high silica content, which are the primary requirements for a pozzolanic material. A particle size of 75 µm or less is reported to be favourable for pozzolanic reaction (Shao *et al.,* 2000). The pozzolanic behaviour of glass powder is dependent on factors including chemical composition, particle size and reactive pore solution (Shayan and Xu, 2006; Schwarz *et al.,* 2008). Value addition of glass in wood composite is best achieved if it is used as a cement replacement material.

The production of hybrid cements from the mixture of cement and glass powder is not a new discovery. Various studies had reported its pozzolanic suitability and partial replacement for sand and concrete blocks production (Park *et al.,* 2004, Aly *et al*., 2011, Kinga *et al*., 2015, Aseel *et al*., 2015). However, information on the suitability of powdered glass as binders for wood-particle composites has not been adequately reported in published articles which thus necessitated this research study. The study therefore investigated the effects of pozzolanic glass powder as partial replacement of cement on the dimensional stability and strength performance of wood cement composite.

Materials and Method

Preparation of Materials

The sawdust particle, *Triplochiton scleroxylon* (Obeche)) was subjected to hot water pretreatment at 100°C for 30 minutes to remove inhibitory water soluble extractives, sieved (80µm wire mesh sieve) to obtain homogenous particles, air dried for 7 days so as to reduce the moisture content to approximately 12%, stored and sealed in polythene bags to prevent further moisture absorption. Waste glass used for this investigation was collected from glass sheets cutting shops, crushed in pieces in a cone crusher mill, ground in a ball mill and sieved into desired particle size using a 75 µm sieve (Aly *et al*., 2011). The Ordinary Portland cement was purchased from the market, while the additive ($CaCl_2$) was purchased from the scientific chemical laboratory, identified and confirmed in the Chemistry Laboratory of Federal College of Forestry, Jos, Plateau State Nigeria. The chemical composition of the glass powder and ordinary Portland cement are as stated in Table 1 according to Bajad *et al*. (2012).

Table 1: Chemical Composition of Glass Powder and Cement

Composition	Ordinary Portland Cement	Glass powder
Silica (SiO_2)	20.2	72.5
Alumina (Al_2O_3)	4.7	0.4
Iron oxide (Fe_2O_3)	3.0	0.2
Calcium oxide (CaO)	61.9	9.7
Magnesium oxide (MgO)	2.6	3.3
Sodium oxide (Na_2O)	0.19	13.7
Potassium oxide (K_2O)	0.82	0.1
Sulphur trioxide (SO_3)	3.9	-
Loss of ignition	1.9	0.36
Fineness % passing (sieve size)	97.4(45 µm)	80 (45 µm)

Source: Bajad et al., (2012)

Board Formation

The production parameters were based on board density of 1200 kg/m^3,3:1 binder/wood particles mixing ratio and 3% curing reagent (Calcium chloride - $CaCl_2$). The proportionate mixture and replacement of cement with glass powder (Cement/Glass Powder) was varied at 100:0, 75:25, 50:5 and 25:75. The formation process (Plates 1-4) was based on modified procedures of Jiang *et al*. (2014) and Falemara *et al*. (2014; 2016). The measured wood particles, glass powder and cement were homogenously mixed together before mixing with measured quantity of water as shown in Eq i (Ajayi and Olufemi, 2011). Deionized water was used to dissolve the curing reagent chemical additive ($CaCl_2$) prior to mixing with the homogenous slurry of cement, wood particles and glass powder. The additive enhanced removal of remnant extraneous materials in the wood as well as facilitates quick and proper setting of the cement with the particles.

$$\boldsymbol{Wt = W(0.30 - MC) + 0.35C} \ldots\ldots Eq\ i$$

Plate 1: Pretreating of the Sawdust in Hot Water

Plate 2: Homogenous mixing of the materials (Sawdust, Cement and Glass Powder)

Plate 3: Air drying of the sawdust particle after pretreatment

Plate 4: Formation Process of the Composite Board (spreading, moulding, cold pressing and 28 days curing/air-drying)

Where: Wt is weight of water (g), W is oven dry weight of the particles (g), MC is the moisture content (%) approximately 12 % and C is the weight of cement and glass powder (g)

The blended stock was then transferred and formed on the mould covered with cellophane sheet, while another cellophane was placed on top of the formed mat to prevent sticking with the cover. The formed mat was transferred to the cold press and pressed under pressure of 1.23 N/mm^{2}to the required thickness for 24 hours. Thereafter, the formed mat was demoulded and cured for 28 days. The board was then cut into specimen sizes for further investigation.

Variables Measured

True Density: The true density of the composite board was determined from its mass and measured volume in kg/m^3. This was calculated based on the formula as stated in Eq. *ii*

$$Density(kg/m^2) = \frac{Mass\ (Kg)}{Volume\ (m^3)} x\ 100 \ldots\ldots Eq\ ii$$

Dimensional Stability and Density - (Water absorption (WA) and Thickness Swelling (TS)): The water absorption and thickness swelling tests were carried out according to the procedure of Ajayi and Olufemi (2011). The test samples cut to 50mm x 50mm specimen and immersed in cold water for 24 hours. The initial thickness and weight of the samples were measured and recorded before and after immersion in cold water. The percentage water absorption and thickness swelling for each test samples were calculated as shown in Eqs. iii and iv respectively:

Water Absorption (WA)

$$WA(t) = \frac{W(t)-Wo}{Wo} x\ 100 \ldots\ldots\ldots Eq\ iii$$

where WA (t) is the water absorption at time t, W_0 is the oven dried weight and W (t) is the weight of specimen at a given immersion time t.

Thickness Swelling (TS)

$$TS(t) = \frac{T(t)-To}{To} x\ 100 \ldots\ldots\ldots\ldots Eq.\ iv$$

where TS (t) is the thickness swelling at time t, T_0 is the initial thickness of specimens and T (t) is the thickness at time t.

Bending Strength Tests -(Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)): The boards were cut into 194 mm (length) x 50mm (width) for bending strength properties assessment carried out on Universal Testing Machine in accordance with American Standard for Testing Materials (ASTM C150/C150M-20, 2020).). The test was carried out by placing the samples on the 3-point flexural testing machine. A perpendicular load (2.000 N) was applied directly on the sample at the center cutting across the entire width of the board at a constant speed. At the point of break of the specimen the MOE and MOR properties were obtained and calculated using Eqs v and vi:

$$MOE = \frac{P_{bp}L^3}{4bh^3Y_p} \ldots\ldots\ldots\ldots\ldots Eq.\ v$$

$$MOR = \frac{3P_bL}{2bh^2} \ldots\ldots\ldots\ldots\ldots\ldots Eq.\ vi$$

where P- Maximum load (N), Pbp- Load at the proportional limit (N), Yp- Deflection corresponding to Pbp (mm), B- Width of the specimen (mm), H- Thickness of the specimen (mm), andL- Span (mm)

Failure Mechanism Test – (Impact and Compressive Strengths): A fully instrumented Avery Denison test machine was used to conduct the impact test of the board composite sample. The compressive strength test was done in accordance with ASTM C109 (2016) in an INSTRON machine at a loading rate of 0.15 cm per minute. The samples were cut into specimen of size 50 x 50 mm. The specimens were tested with an increasing load until failure occurred to obtain the maximum compressive load.

Experimental Design and Statistical Analysis

The experimental set up was Completely Randomized Design (CRD) consisting of four treatments replicated 5 times. This resulted in 20 experimental units. These treatments include blending proportion of 100:0 (Cement/Glass Powder), 75:25 (Cement/GP), 50:50 (Cement/GP) and 25:75 (Cement/GP). The data collected were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine significant effects glass powder on dimensional stability and strength performance of wood composite. Follow up test was done using Duncan Multiple Range Test (DMRT) where significant differences exist.

Results

Effects of Blending Proportions on True Density of the Wood Composite

The density of the composite board ranged between 1108.24kg/m^3 and 1197.32kg/m^3. This revealed that the blending proportion of 100:0 (control) had the highest density (1197.32kg/m^3), followed by BP 75:25 (1145.88kg/m^3), BP (50:50) with board density of 1134.12kg/m^3, while the least board density was observed in 25:75 blending proportion of cement to glass. This implies that composite boards produced with only cement binder had the highest board density, while composite boards produced with the least quantity and proportion of cement had the lowest board density. In order words, the lowest the quantity of cement proportion of glass powder, the lower the density of the composite board. The blending proportion had no significant effects (p≥0.05) on the true density of the composite boards. However, composite boards produced at 100:0 BP had the highest board density (1197.32±56.07kg/m^3), while 25:75 BP had the lowest (1108.24±173.99kg/m^3) as revealed in Figure 1.

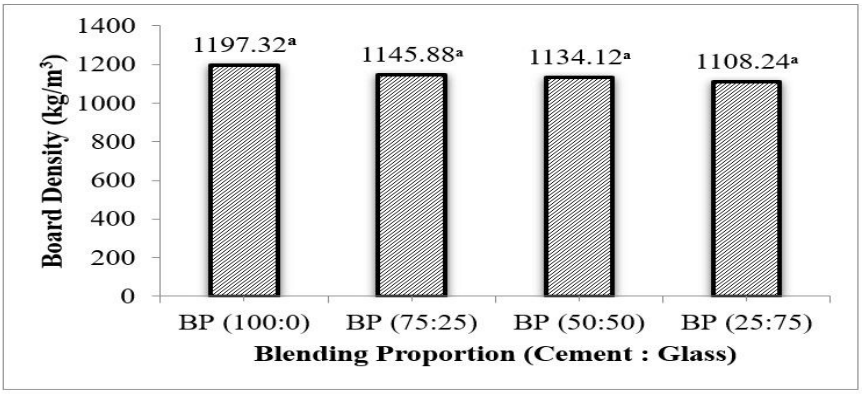

Figure 1: Effect of Blending Proportion on Board Density
Means on the same bar having the same letters are not significantly different (p≥0.05)

Effects of Blending Proportions on the Dimensional Stability (Water Absorption and Thickness Swelling) of the Wood Composite

Composite board produced at 100:0 blending proportion had the lowest water absorption and thickness swelling (Figure 2). This signifies that the lower the proportion or quantity of cement to glass, the higher the water absorption and thickness swelling of the boards. The most dimensionally stable board was produced at 75:25 considering boards produced with mixture of cement and glass powder. Significant differences exist between 100:0 BP and 50:50BP; 100:0 and 25:75; 50:50 BP and 25:75; and 75:25BP and 25:75. On the other hand, there were no significant differences between 100:0BP and 75:25BP and between 75:25BP and 50:50BP on the water absorption of the board. In similar trend, the effects of blending proportion on thickness swelling (%TS) showed that there were significant differences between composite boards produced at 100:0 BP and 50:50BP; 100:0 and 25:75; 50:50 BP and 25:75; and 75:25BP and 25:75. On the contrary, there were no significant differences between 100:0BP and 75:25BP and between 75:25BP and 50:50BP on the thickness swelling of the board. Since there were no significant differences between boards produced at 100:0BP and 75:25BP, thus boards produced at 75:25 BP is equally

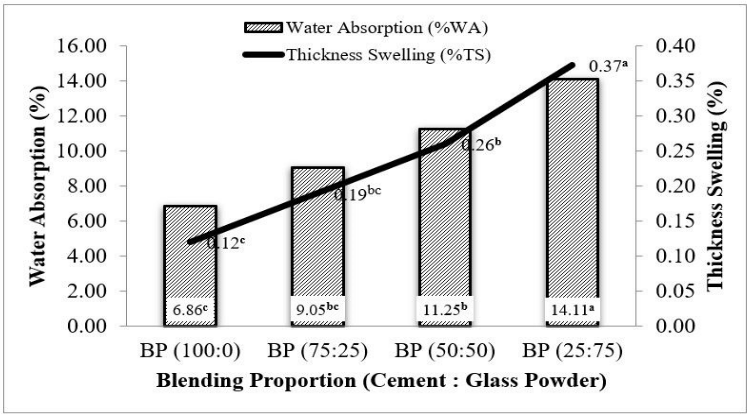

Figure 2: Effect of Blending Proportion on WA and TS (%) of the Board

Means on the same bar having the same letters are not significantly different (p≥0.05)

as dimensionally stable as board produced with only cement (100:0) used as binder. Consequently, cement can significantly be partially replaced by 25% of glass powder for the production of dimensionally stable composite board.

Effects of Blending Proportions on Bending Strength (Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)) of the Wood Composite

Wood composite produced at 100:0 cement/glass blending proportion had the highest modulus of rupture and modulus of elasticity, while wood composite board produced at 25:75 blending proportion had the lowest modulus of rupture and modulus of elasticity (Figure 3). This implies that as the ratio of glass powder to cement increases, the modulus of rupture and modulus of elasticity reduces. Board produced at 75:25 glass powder to cement blending proportion was the strongest and stiffest compared to the reference sample which had no glass powder supplement. Also, for Modulus of Elasticity (N/mm^2) of the composite, significant differences exist between wood composite produced at 100:0BP and 75:25BP, 100:0BP and 50:50BP, 100:0BP and 25:75BP, 75:25BP and 50:50BP, 75:25BP and 25:75BP, and 50:50BP and 25:75BP. Compared with the control which had no glass powder supplement, board produced at the lowest

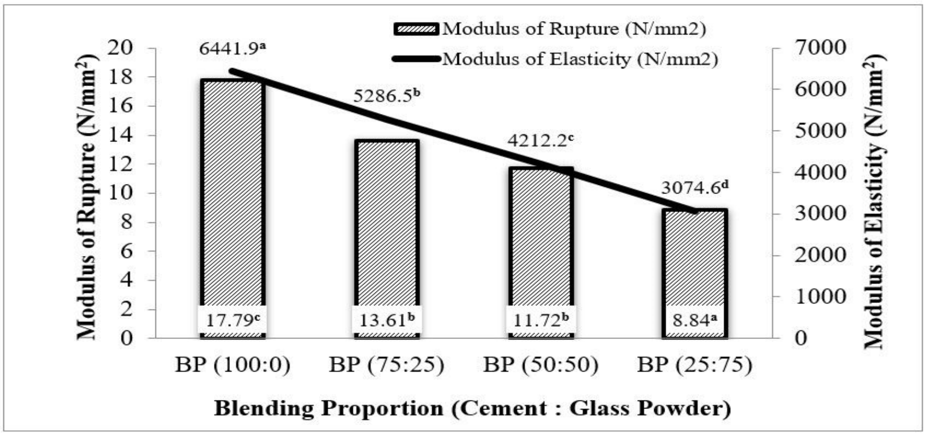

Figure 3: Effect of Blending Proportion on Modulus of Rupture (N/mm2) Modulus of Elasticity (N/mm2) of the Board

Means on the same bar having the same letters are not significantly different (p≥0.05) proportion of glass powder (25%) had the highest significant modulus of rupture of 13.61N/mm^{2}and modulus of elasticity 5286.51N/mm^2, while board produced that highest blending proportion (75%) had the highest significant impact strength. This is followed by 50:50 blending proportion, and 100:0 blending proportions with impact strength values of 71.13J and 70.25J respectively. The least significant impact

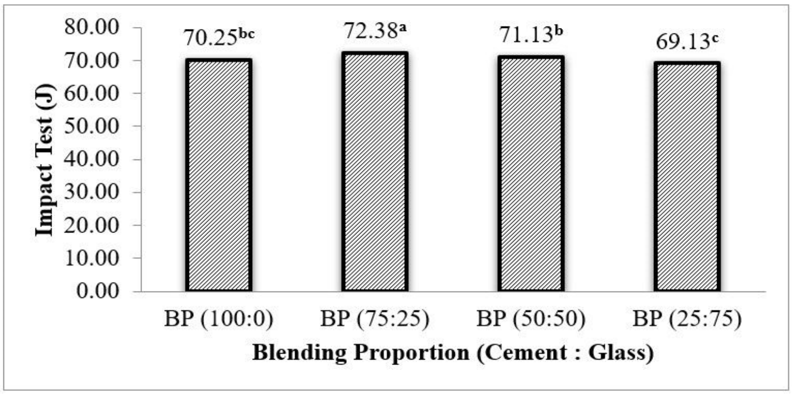

Figure 5: Effect of Blending Proportion on Impact Test (J) of the Board
Means on the same bar having the same letters are not significantly different (p≥0.05)

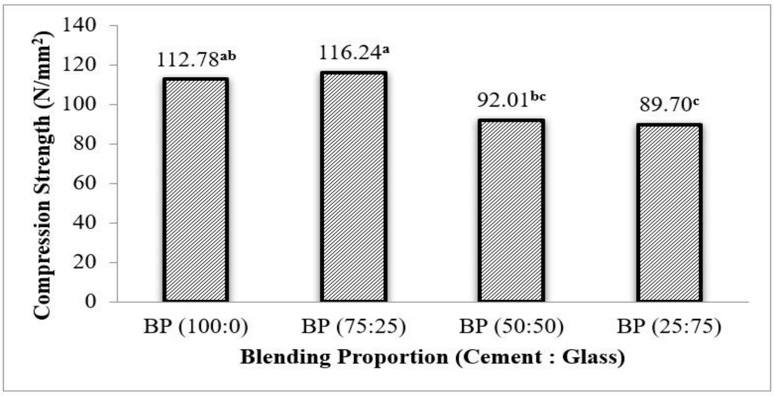

Figure 4: Effect of Blending Proportion on Compression Strength (N/mm2) of the Board
Means on the same bar having the same letters are not significantly different (p≥0.05)

lowest significant modulus of rupture of 8.84N/mm^{2}and modulus of elasticity 3074.57N/mm^2. This consequently implies that the optimum replacement level of cement with glass powder as supplement to produce the strongest and stiffest wood composite is at 25%.

Effects of Blending Proportions on Failure Mechanisms (Impact and Compressive Strengths) of the Wood Composite

Composite boards produced at 75% of cement and 25% of glass powder had the strength was observed in composite board produced 25:75 blending proportion with 69.13J (Figure 4). The compression strength of the boards ranged between 89.70N/mm^2 and 116.24N/mm^2 (Figure 5). Blending proportion of 75:25 (cement/GP) resulted in composite boards with highest significant compression strength of 116.24N/mm^2, followed by 100:0 BP (112.78N/mm^2), 50:50 BP (92.01N/mm^2) while 25:75 BP had the lowest significant compression strength of 89.70N/mm^2. The implication of the above stated result is that composite board produced at blending proportion of 75% of cement and 25% of glass powder had the highest compression strength compared to composite board produced at 25% cement and 75% glass powder which had the lowest compression test. Also, board produced with 25% by weight of glass powder partial replacement of cement indicated higher compression strength than boards produced with only cement used as binder.

Discussions

Effects of Blending Proportions on the True Density of the Wood Composite

The density of the composite board varied between 1108.24 kg/m^3 and 1197.32 kg/m^3 (Figure 1). These values are comparably similar to values obtained in related research studies. Erakhrumen *et al.* (2008) observed that cement bonded particle board from proportional mixtures of pine and coir particles had a density ranging between 1.13 and 1.79 g/cm^3. Sotannde *et al.* (2012) in their study on the evaluation of cement-bonded particle board produced from *Afzelia africana* wood residues reported board density which varied from 1.17 g/cm^3 to 1.22 g/cm^3 with an average of 1.20g/cm^3, while Gautam *et al.* (2014) in their critical study of effectiveness of glass powder in concrete reported a maximum density of 2471 kg/m^3. It was also observed that the density of the composite board decreased with decrease in proportion of cement with glass powder. However, composite board is reported to be influenced by density and quantity of the particles used (Zhou and Kamdem, 2002). The density of glass powder, cement and Obeche wood were 2579 kg/m^3, 3150 kg/m^3 (Bajad *et al*., 2012) and 407.5kg/m^3 (Falemara *et al*., 2012) respectively. Cement exhibited the highest density among the materials used in the production of the composite. This therefore justified the reason for increase in board density with increase in cement/glass powder blending proportion. Board with the higher quantity of cement had the higher density value. This validates the assertion, that density of cement composite board is dependent on the proportion of the cement in the matrix.

Effects of Blending Proportions on the Dimensional Stability (Water Absorption and Thickness Swelling) of the Wood Composite

Water absorption (%WA) and Thickness swelling (%TS) are physical properties associated to dimensional stability of the composite board. They give an indication of the behaviour of cement composite board when used under severe humidity conditions. As such they are significant properties for boards meant for external use in service. The result of the study revealed that the water absorption (%WA) and thickness swelling (%TS) of the composite board after 24hours immersion ranged between 6.86 and 14.11%; and 0.12 to 0.37% respectively (Figure 2). The pattern of water absorption and thickness swelling variations as observed in this study are in conformity with the assertions of many research findings (Nazerian *et al*., 2011; Sotannde *et al.,* 2012; Falemara *et al*., 2014; 2016). The observed trend in the water absorption and dimensional instability can be ascribed to lower amount of cement content in the composite resulting in weak fiber-matrix adhesion, increased porosity and lower density. Based on European standard, the thickness swelling of cement bonded board ranged between 1.2 to 1.8% (EN 310, EN 317, EN 319, 1993). The values for thickness swelling of composite board (0.12 to 0.37%) obtained in this study are far less than the maximum acceptable range of values of the European standard. Nazerian *et al*., (2011) in their study indicated minimum water absorption and thickness swelling of 14.2% and 1.56% respectively. This high value is due to the effect of wood extractives and curing reagent on the hydration kinetics of cement paste and wood particle reinforced cement composite.

Sotannde *et al.,* (2012) on the other hand reported maximum water absorption and thickness swelling of 44.07% and 4.66% respectively in their assessment of *Afzelia africana* wood residues reinforced cement composite. Similarly, Falemara *et al*., (2014) investigated the strength and dimensional stability performance of cement bonded board Produced from Groundnut Shell. They reported that water absorption and thickness swelling of the boards ranged between 3.71 to 17.84% and 0.11 to 0.73% respectively. In similar vein, Falemara *et al*., (2016) in their investigation on the physico-mechanical strength of bamboo reinforced cement composites reported a range of values from 15.84 to 24.28% and 1.38 to 3.21% for water absorption and thickness swelling respectively. Ashraf and Hamdoun (2013) in their study on the suitability of *Prosopis chilensis* Wood for Cement Bonded Aggregates posited that higher wood content (lower cement: wood ratio), would result in greater water absorption due the hydrophilic nature of wood bounded by lower cement content. Increase in the cement content will result in more coating of the wood particles and improved wood particles-cement matrix bonding, and thus lower water absorption. Increasing replacement proportion of glass powder significantly increases water absorption and thickness swelling which may affect the pozzolanic hydration process of the glass powder with the cement. This will consequently result in poor wood particle-cement adhesion, resulting in increased water absorption. Erakhrumen *et al*. (2008) reported that reducing the cement content in composite manufacturing might lead to a large surface area of exposed particles and free internal spaces, which are possible contributing factors to the trend in the instability of the board with lower cement proportion. As observed in the study, board produced at 75:25 blending proportion had a comparably lower water absorption (9.05%) and thickness swelling (0.19%) to that produced with only cement binder which had water absorption and thickness swelling of 6.86% and 0.12% respectively. This according to Taha and Nounu, (2008) can be attributed to the fact that glass by nature is an impermeable material, so it could be assumed that the inclusion of glass particles as cement supplement in the composite board can reduce its permeability.

Nwaubani and Poutos (2013) investigated the effect of glass powder particle size on performance of cement mortars and reported that water absorption increased with increased glass powder content. The reduction in water absorption and water accessible porosity as affirmed by Du and Tan, (2014) is also ascribed to the pozzolanic reaction of glass powder, which can refine the pore structures and decrease the connectivity. The refined pore structure, particularly the interfacial transition zone (ITZ) is the main reason for this reduced permeability. Du and Tan, (2014) further affirmed that pozzolanic reaction requires hydration products, CH, whose amount is governed by the cement content. Therefore, there is an optimum cement replacement level, beyond which no further pozzolanic reaction of GP can occur. The results in this study indicate that GP will exhibit apparent pozzolanic reaction provided that the replacement level is lower than 25%, while above 25%, GP can only play the role of inert filler without being activated. This occurrence was brought about by the reduction in dimensional stability with an increase of the waste glass replacement resulting in higher water absorption and thickness swelling.

Effects of Blending Proportions Bending Strength (Modulus of Rupture (MOR)

and Modulus of Elasticity (MOE)) of the composite board

The modulus of rupture (MOR) ranged between 8.84 N/mm^2 and 17.79 N/mm^2, while the modulus of elasticity (MOE) ranged between 3074.57 N/mm^2 and 6441.85 N/mm^2 (Figure 3). These values meet up with the minimum requirements as stipulated by international standards. Based on ANSI A208.1 (2009) and EN 312 (2003) standards for general-purpose particleboard, the minimum requirements for modulus of rupture (MOR) of particleboard panels for general uses are 11 MPa and 12.5 MPa, while that of modulus of elasticity (MOE) requirements are 1,700 and 1,800 MPa, respectively. Similarly, EN 310 and ISO 8335 requirements for MOR and MOE, specifies 9 MPa and 3000 MPa, respectively. The range of values as obtained in this study is higher than values reported by Sakar *et al*., (2012) in their study on mechanical properties and dimensional stability of cement bonded particleboard from rice husk and sawdust, they documented values ranging from 2.48 N/mm^{2}to 5.36 N/mm^2 for MOR and 1684.28 N/mm^2 to 3569.28 N/mm^2 for MOE. The maximum value of MOR (17.79 N/mm^2) as obtained in this study is higher than the maximum value of 13.70Mpa observed for cement-bonded particleboard as reported by Nazerian *et al*. (2011). Papadopoulos *et al.* (2006) produced a cement-bonded OSB using oriented strand-type particles. For boards produced with cement:wood ratio of 1:1 they found MOR values of about 3.1 MPa and MOE values of about 467 MPa, which are lower than those observed in this research study

In similar manner, Del Menezzi *et al*. (2007) in their studies, assessed the effects of oriented strands and silica fumes on medium density wood-cement boards. They observed that the inclusion of 10% of silica fume to the matrix, improved all mechanical properties of boards, but particularly MOR and MOE. This trend is similar to that observed by Lange *et al.* (1989) and Simatupang (1987), though using higher silica content of 25% to 45%.

It was observed in this study that the MOR and MOE strength properties begin to drop beyond partial cement replacement with 25% by weight of glass powder. At 50% and 75% the bending strength reduced. This trend is similar to the findings of Du and Tan (2014) who reported comparable occurrence when glass powder was used in partially replacing cement in concrete. They asserted that flexural strength also increases with increase in glass powder content up to 20% replacement, while there was strength reduction above 20% glass content. This is also in collaboration with the findings of Raju and Kumar (2014) who reported that as the percentage of replacement of cement with glass powder increases, strength increases up to 20% and beyond that, it decreases. The increase in strength up to 20% replacement of cement by glass powder may be due to the pozzolanic reaction of glass powder and its inherent high silica content. Also, it effectively fills the voids and gives a denser concrete microstructure. However, beyond 20%, the dilution effect takes over and the strength starts to drop.

Du and Tan (2014) reported that compared to the cement hydration process, glass powder, depending on its fineness, would usually react pozzolanically at a lower rate. This is such that, the replacement of cement by glass powder might contribute to lower strength at an early age, but would increase it at a later age. Compared to composite manufacture, previous studies underscored the fact that pozzolanic reaction of glass powder have influence on the strength properties of mortar/concrete at varying glass powder content (by dry weight) to the matrix binder ratio. Shao *et al*., (2000) noted that concrete produced with partial cement replacement of 30% glass powder and particle size less than 38 μm did not exhibit higher compressive strength until after 90 days of curing. Shi *et al*., (2005) also reported that higher compressive strength from 28 days be achieved by mortar with 20% glass powder, provided that the particle size of glass powders is close to or lesser than that of Portland cement as similarly acknowledged by Khmiri *et al*. (2013) and Shayan and Xu (2004).

Effects of Blending Proportions on Failure Mechanisms (Impact and Compressive Strengths) of the composite board

Impact strength (Energy at break) is an important property that gives an indication of overall material toughness. It gives an indication of the resistance of a material to vibration or shock loading. Impact strength of fiber-reinforced polymer is governed by the matrix–fiber interfacial bonding, and the properties of matrix and fiber (Aliotta *et al*., 2019). When composites undergo a sudden force, energy is dissipated by the combination of pullouts of fibers as well as and fiber-matrix fracture and deformation (Wambua *et al.,* 2003). The result of the impact strength as observed in this study ranged between 69.12 and 72.38 Joules. Boards produced at 75:25 blending proportion had the highest impact strength. The improvement in the impact strength of the composite boards could be attributed to the presence of particles well bond by the binder (Yamashita *et al*., 1999). Aly *et al*. (2011) asserted in their study that the replacement of Ordinary Portland Cement by 20 % waste glass improves the impact strength of cement composites at 28 days of hydration compared to the control specimen

The development of compressive strength of the composite board containing varying blending proportions of glass powder to cement as supplement ranged between 89.70N/mm^2 and 116.24N/mm^2. However, the value is much higher than value reported by Sotannde *et al*., (2012) with the compressive strength ranging between 8.34 and 24.7N/mm^2 for wood cement flake boards; and Nazerian *et al*., 2011 with compressive strength ranging between 46 and 53MPa.

The highest compression strength (116.24N/mm^2) was observed in board produced at 25% blending proportion which is higher than the compression strength (112.78 N/mm^2) of the control (100:0) with no glass powder supplement. This implies that the optimum glass powder replacement is at 25% glass powder supplement. Shilpa and Kumar, (2014) in their study on the effects using glass powder in concrete gave compression strength of 12.93 MPa and 33.86MPa at 40% to 20% cement replacement respectively. Nwaubani and Poutos (2013) significantly noted that that the lower compressive strength of the PC/Glass (pozzolanic) mixtures can be attributed to the coarser particle size of the glass powder used. This has obviously diminished the pozzolanic reactivity of the particles and therefore the associated benefits in terms of increased compressive strength and improved durability performance.

Conclusions

The pozzolanic effects of glass powder on dimensional stability and strength performance of wood composite was investigated. This was done using four blending proportions of 100:0, 75:25, 50:50, and 25:75. From the outcome of the study, the following conclusions can be summarized;

1. The study established the suitability of glass powder pozzolan as cement supplement in the production of wood composite board.
2. Board with the higher quantity of cement had the higher density value

which inferred that density of cement composite board is depended on the amount of cement in the matrix.

3. Glass powder exhibits apparent pozzolanic reaction provided that the replacement level is lower than 25%, while above 25% results in higher water absorption and thickness swelling.
4. The bending, compressive and impact strengths of cement composites after 28 days post curing was higher at an optimum level of 25% glass powder cement replacement, while a decrease in these properties were observe when the glass powder content was above 25%.
5. The optimum glass powder replacement at 25% cement supplement produced composite board with highest modulus of rupture, modulus of elasticity and compressive strength compared to the control with no glass powder content.
6. Finally, the composite board met the requirements of physical and strength properties for cement bonded composite board as stipulated by European standards and specifications for cement-based particleboards.

References

Abdul Khalil, H.P.S., Bhat, I.U.H., Jawaid, M., Zaidon, A. Hermawan, D. and Hadi, Y. S. (2012): Bamboo fiber reinforced biocomposites: a review. *Materials & Design*, 42: 353–368

Ajayi, B. and Olufemi, B. (2011): Properties of cement-bonded flake-boards from *Gmelina arborea* and *Leucaena leucocephala*. *Int. J. Biol. Chem. Sci.* 5(2): 586-594

Aliotta, L., Gigante, V., Coltelli, M.B., Cinelli, P., Lazzeri, A. (2019) Evaluation of Mechanical and Interfacial Properties of Bio-Composites Based on Poly (Lactic Acid) with Natural Cellulose Fibers. *Int J Mol Sci*. 20(4):960.

Aly, M., Hashmi, M.S.J., Olabi, A.G., Messeiry, M., Hussain, A.I. and E. F. Abadir, E.R (2011): Effect of Nano-clay and Waste Glass Powder on the Properties of Flax Fiber Reinforced Mortar. *ARPN Journal of Engineering and Applied Sciences*. 6(10): 19-28

American Society for Testing and Materials- ASTM C109 (2016): *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*. C01.27. Book of Standards Volume: 04.01

ANSI.A208.1 (2009): Particleboard. American National Standard, ANSI A208.1-2009, National Composite Association, Lesburg, VA.

Aseel, B., Abdul-Hussein, E., AL-Hassani, S. and Reem A.M. (2015): Effect of Nature Materials Powders on Mechanical and Physical Properties of Glass Fiber / Epoxy Composite. *Eng. &Tech. Journal*, 33(1): 175-197

Ashraf M.A.A. and Hamdoun A.A. (2013): Suitability of *Prosopis chilensis* (Mesquite) Wood for Cement Bonded Aggregates. *Journal of Forest Products & Industries*, 2(4): 16-21

ASTM C150/C150M-20. (2020). Standard Specification for Portland Cement. ASTM International: West Conshohocken, PA, USA, 2020.

Bajad, M.N., Modhera, C.D. and Desai, A.K. (2012): Resistance of Concrete Containing Waste Glass Powder Against M_gSO_4 Attack. Accessed on the 27th of June 2016 from http://www.nbmcw.com/articles/concrete/28979-resistance-of-concrete-containing-waste-glass-powder.html

Benhelal, E., Zahedi, G., Shamsaei, E. and Bahadori, A. (2013): Global strategies and potentials to curb CO_2 emissions in cement industry, *Journal of Cleaner Production*, 51: 142-161.

Del Menezzi, C.H.S., Vinicius Gomes de Castro, V. and Rabelo de Souza, M. (2007): Production and Properties of a Medium Density Wood-Cement Boards Produced with Oriented Strands and

Silica Fume. *Maderas. Ciencia Y Tecnología* 9(2): 105-115

Du, H. and Tan, K.H. (2014): Waste Glass Powder as Cement Replacement in Concrete. *Journal of Advanced Concrete Technology* 12: 468-477

Erakhrumen, A.A., Areghan, S.E., Ogunleye, M.B., Larinde, S.L. and Odeyale, O.O. (2008): Selected physico-mechanical properties of cement bonded particleboard made from pine (*Pinus caribaea* M.) sawdust-coir (*Cocos nucifera* L.) mixture. *Sci Res Essay* 3:197–203

European Committee for Standardization - EN 319 (1993): *Particleboards and Fiberboards, Determination of Tensile Strength*. European Standardization Committee, Brussels

European Committee for Standardization - EN 317 (1993): *Particleboards and Fiberboards, Determination of Swelling in Thickness after Immersion*. European Standardization Committee, Brussels

European Committee for Standardization- EN 310 Standard (1993): *Wood Based Panel. Department of Modulus of Elasticity in Bending and Bending Strength*, European Committee for Standardization, Brussels, Belgium.

European Committee for Standardization- EN 312 Standard (2003): *Particleboards Specifications*. European Committee for Standardization, Brussels, Belgium.

Fabiyi, J.S. (2013): Suitability of Portland Cement and Rice Husk Ash Pozzolan Systems for Cement Bonded Composites Production. *J. Mater. Environ. Sci.* 4 (6): 848-854

Falemara, B.C., Ajayi, B., Agbajie, J. and Binuyo, G. (2014): Strength and Dimensional Stability Properties of Cement Bonded Board Produced from *Arachis hypogaea* (Groundnut) Shell. Sudano-Sahelian Landscape and Renewable Natural Resources Development in Nigeria. *In the book of Proceedings*: 37th Annual Conference of the Forestry Association of Nigeria, Minna, Niger State. 496-506pp

Falemara, B.C., Ajayi, B., Owoyemi, J.M. and Folorunso, S. (2016): Physical and Mechanical Properties of Bamboo (*Bambusa vulgaris* Schrad. Ex Wenld) Based Cement-Bonded Composites as Influenced by Production Variables. Mangroves and Wetlands of Sub-Sahara Africa: Potential for Sustainable Livelihoods and Development. *In the book of Proceedings*: 38th Annual Conference of the Forestry Association of Nigeria, Portharcourt, Rivers State, March 7th – 11th 2016. 801-816

Falemara, B.C., Owoyemi, J.M., and Olufemi B (2012): Physical Properties of Ten Selected Indigenous Wood Species in Akure, Ondo State, Nigeria. Journal of Sustainable Environmental Management. *Scientific Journal of Association of Women in Forestry and Environment. (JSEM)* 4: 16-23

Gautam S., Ashish K.S., Akhil B. and Ajit S.A. (2014): A Critical Study of Effectiveness of Waste Glass Powder in Concrete. *International Archive of Applied Sciences and Technology Int. Arch. App. Sci. Technol*; 5(3): 31-35

International Organization for Standardization. (1987): Cement-bonded particleboards – Boards of Portland or equivalent cement reinforced with fibrous wood particles. ISO 8335, Stockholm, 9pp.

Jiang, X., Xiao, R., Bai, Y., Huang, B. and Ma, Y. (2022). Influence of waste glass powder as a supplementary cementitious material (SCM) on physical and mechanical properties of cement paste under high temperatures. *Journal of Cleaner Production*, 340: 130778.

Jiang, Y.F., Liu, H.W. and Jia, T.F. (2014): Water Absorption of Basalt Fiber and Mineral Glass Powder Reinforced Wood Composites. *Advanced Materials Research*, 1048: 475-478

Khmiri, A., Chaabouni, M. and Samet B. (2013): Chemical behavior of ground waste glass when used as partial cement replacement in mortars. *Construction and Building Materials*, 44: 74-80.

Kinga, K., Janusz, M. and Michał, L. (2015): Fly Ash Based Fiber-Reinforced Geopolymer Composites as the Environmentally Friendly Alternative to Cementitious Materials. *Proceedings of 2015* International Conference on Bio-Medical Engineering and Environmental Technology (BMEET 2015) London, March 21-22, pp. 164-171

Lange, H.; Simatupang, M. H and Neunauer, A. (1989): Influence of latent hydraulic binders on the properties of wood-cement composite. In: *Inorganic Bonded Wood and Fiber Composite Materials*. USA, 1: 48-52.

Nazerian, M., Gozali, E., & Ghalehno, M. D. (2011). The influence of wood extractives and additives on the hydration kinetics of cement paste and cement-bonded particleboard. *Journal of Applied sciences*, 11(12), 2186-2192.

Nicole, M.S, Zhiyong, C. and Charles, C. (2010): Wood-Based Composite Materials Panel Products, Glued-Laminated Timber, Structural Composite Lumber, and Wood–Non wood Composite Materials. Chapter 11. Forest Products Laboratory. Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 11:1 – 11:28

Nwaubani, S.O. and Poutos I.K. (2013): The Influence of Waste Glass Powder Fineness on the Properties of Cement Mortars. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*.2(2) 110-116

Papadopoulos, A.N., Ntalos, G.A. and Kakaras, I. (2006): Mechanical and physical properties of cement-bonded OSB. On line First *Holz als Roh- und Werkstoff*64 (6): 517-518.

Park, S.D.B., Lee, B.C. and Kim, J.H. (2004): Studies on mechanical properties of concrete containing waste glass aggregate. *Cement and Concrete Research*, 34(12): 2181–2189

Raju, S. and Kumar, P.R. (2014): Effect of Using Glass Powder in Concrete. *International Conference on Innovations & Advances in Science, Engineering and Technology*. 3(5): 421-427

Rana, M.N., Islam, M.N., Nath, S.K., Das, A.K., Ashaduzzaman, M. and Shams, M.I. (2020). Influence of chemical additive on the physical and mechanical properties of cement-bonded composite panels made from jute stick. *Journal of Building Engineering*, 31, 101358.

Sarkar, M., Asaduzzaman, M., Das, A.k., Hannan M.O. and Shams, M.I. (2012): Mechanical properties and dimensional stability of cement bonded particleboard from rice husk and sawdust. *Bangladesh J. Sci. Ind. Res.* 47(3), 273-278

Schwarz, N, Cam, H. and Neithalath, N. (2008): Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash, *Cement and Concrete Composites,*30(6): 486–496

Shao, Y., Lefort, T., Moras, S. and Rodriguez, D. (2000): Studies on concrete containing ground waste glass. *Cement and Concrete Research*, 30(1), 91-100.

Shayan, A. and Xu, A. (2006): Performance of glass powder as a pozzolanic material in concrete: a field trial on concrete slabs, *Cement and Concrete Research*, 36(3): 457–468

Shayan, A. and Xu, A., (2004): Value-added utilization of waste glass in concrete. *Cement and Concrete Research,* 34(1), 81-89.

Shi, C., Wu, Y., Riefler, C. and Wang, H., (2005): Characteristics and pozzolanic reactivity of glass powders. *Cement and Concrete Research*, 35(5): 987-993.

Shilpa R. and Kumar, P.R. (2014): Effect of Using Glass Powder in Concrete. *International Journal of Innovative Research in Science, Engineering and Technology*3(5): 421-427

Simatupang, M.H., Lange, H. and Neubauer, A. (1987): Einflu§ der Lagerung von Pappel, Birke, Eiche und Lärchesowie des Zusatzes von SiO2-Feinstaub auf die Biegefestig keitzementge bundener Spanplatten. *Holz alsRoh- und Werkstoff*45 (4): 131-136.

Sotannde, O.A., Abiodun O. Oluwadare, A.O., Ogedoh, O. and Adeogun, P.F. (2012): Evaluation of Cement-Bonded Particle Board Produced from *Afzelia Africana* Wood Residues. *Journal of Engineering Science and Technology*. 7(6): 732 - 743

Taha, B. and Nounu, G. (2008): Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. *Construction and Building Materials*, 22(5), 713-720.

Wambua, P., Ivens, J. and Verpoest, I. (2003): Natural fibres: Can they replace glass in fibre reinforced plastics? *Composites Science and Technology*,63(9):1259–1264.

Yamashita, Y., Watanabe, H. and Takeda, S. (1999): Rubber wood characteristics of its supply and development of its utilization. *For. Res*. 71: 65−70.

Zhou, Y. and Kamdem, D.P. (2002): Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood removed from service. *Forest Products Journal* 52 (2): 73-81.