EFFECTS OF ADDITIVE LEVELS ON DIMENSIONAL STABILITY AND STRENGTH OF CEMENT COMPOSITE BEFORE AND AFTER ACCELERATED AGING PROCEDURE

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ABSTRACT

Cement Bonded Composites were produced from the mixture of Bambusa vulgaris (Bamboo) particles and inorganic binder. The study investigated the influence of additive levels (1.5%, 2.5% and 3.5% w/w) on the dimensional and strength properties of bamboo cement composites. Properties assessed include Water Absorption (WA), Thickness Swelling (TS), Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Accelerated Aging (AA). The Water Absorption (WA) and Thickness Swelling (TS) properties decreased as the curing reagent concentration increased. The mean water absorption and thickness swelling before and after accelerated aging ranged from 7.1% to16.3% and 0.2% to 0.7% respectively. The mean modulus of rupture and modulus of elasticity before and after accelerated aging ranged from 3.9 N/mm2 to 5.6 N/mm2 and 1530 N/mm2 to 2687 N/mm2 respectively. The severity of the freezing and thawing aging resulted into breakdown of bonds, disintegration of particles subsequent increase in sorption properties and decrease in strength properties of the composite.

KEYWORDS:

Sorption properties, Strength properties, Additive level, Accelerated aging, Bamboo, Composite.

INTRODUCTION

The use of bamboo and other forms of lignocellulosic residues have been reported to be of value addition to the economy through sustainability, environmentally friendly, wealth and job creation potentials (Jorge et al., 2004; Onuorah, 2005). Bamboo, due to its fast growing and high yielding renewable potential offers exceptional prospective as replacement to wood, thus ensuring protection and sustainable management of our forests and forest resources.

Bamboo which is woody plant of biological and lignocellulosic origin is composed of inherent constituents (lignin, lignin, resins, tannins, waxes and inorganic, salts, ash and silica) and polysaccharides (soluble sugars, starches, celluloses, hemicelluloses), some of which tends to impair the reactions between the woody element and inorganic cement binder through a process called inhibitory effects (Wei et al., 2002) as well as affect cement curing and setting time (Wei et al., 1999). This consequently results into incompatibility between woody elements and inorganic cement (Jorge et al., 2004; Nazerian et al., 2011). Addition of an accelerator called additives into a mixture of cement-water slurry has been proven to accelerate hydration initiation process, thereby eliminating inhibitory substances from the lignocellulosic particles.

Cement curing reagents also called additives including calcium chloride - $CaCl_2$, sodium hydrogen carbonate - $NaHCO_3$ (Islam et al., 2013; Falemara et al., 2014), ferric chloride-$FeCl_3$ (Wang et al., 2016), ferric sulphate-$Fe_2(SO_4)_3$ (Amoo et al., 2016), calcium hydroxide-$Ca(OH)_2$, calcium carbonate-$CaCO_3$ (Azambuja et al., 2017), magnesium chloride-$MgCl_2$, sodium hydroxide-NaOH, aluminium chloride-$AlCl_3$ (Wang et al., 2016), sodium silicate-Na_2SiO_3, aluminum sulphate-$Al_2(SO_4)_3$ (Matoski et al., 2013; Nasser et al., 2016) have been reported to accelerate the setting of cement with different forms of lignocellulosic particles by reducing inhibitory effects and enhancing compatibility. The most used of these chemical additives is calcium chloride. This is due to the fact that it reduces cement setting time, increases maximum hydration temperature, speeds up the hydration of cement usually at the tri-calcium silicate reaction stage (Olorunnisola and Adefisan, 2002), improves the sorption and strength properties of cement composites by enhancing compatibility of cement and lignocellulosic particles (Olorunnisola, 2006). This therefore makes it imperative to investigate the effects of calcium chloride additive on the dimensional stability and strength properties of bamboo cement composite subjected to accelerated aging procedures.

Accelerated aging procedure was used to evaluate the inherent ability of bonds to withstand severe exposure conditions; this provided immediate and likely information on the behaviours of particle board in a critical long-term use and to give insight into degradation that could take place while in service. It explains the resistance of boards to weathering or degradation due to moisture, heat, spring back and shrinkage stresses (Ajayi and Olufemi, 2011).

MATERIALS AND METHOD

Materials Preparation

The bamboo culms (*Bambusa vulgaris* species) were harvested, de-limbed, cut into billets, nodes removed, further cut into strips and processed into particles in the hammer mill. The particles were then soaked in hot water at 100^0C and continuously stirred for 30 minutes to remove inhibitory substances that might inhibit compatibility with cement. The particles after pre-treatment were removed, drained of excess water and sun dried for 14 days to reduce the moisture content to about 12%. After drying the particles were sieved by passing through a 2.00 µm wire mesh.

The bamboo cement composite was produced at 1200 kg/m^3 nominal board density, 3.5:1 cement/bamboo mixing ratio (w/w) and three levels of calcium chloride ($CaCl_2$) additives (1.5%, 2.5% and 3.5%), measured quantity of water adapted from Fuwape (1995) and Raju et al. (2012), mould/board size of 350mm (Breadth) x 350mm (Width) x 6mm (Thickness) and pressing pressure at 1.23N/mm^2 and 10g of flax fibers used as reinforcement to improve strength of the board.

Board Formation

The board formation procedure was based on adapted methods of Badejo, *et al*., (2011) and Adefisan (2013). This involved measuring required quantity of cement, bamboo particle, calcium chloride and water based on the production variables of board density (1200 kg/m^3), mixing ratio (3.5:1) and additive levels (1.5%, 2.5% and 3.5%). The materials after measurement where homogenously and thoroughly mixed together in a bowl. Thereafter, the blended stock was poured in a wooden mould and reinforced with glass fibers to improve strength of the boards. The mould was initially under laid with formica sheet prior to formation of the board and then overlaid with polythene nylon after formation so as to prevent sticking of the stock materials to the plywood mould. The formed mat was pre-pressed and then transferred to the hydraulic cold pressed where it was compressed under pressure (1.23 N/mm^2) for a period of 3 days, after which the boards were removed from the cold press, demoulded and conditioned for 28 days in sealed polythene bags for 28 days for subsequent post curing. The board were finally removed, trimmed and cut into standard sizes for properties investigation (Plates 1a to 1j).

Variables Assessed

Dimensional stability assessment was done by immersing the samples in water for a period of 24hours to determine the water absorption (WA) and thickness swelling (TS) in accordance with ASTM, (2005). Strength properties for modulus of rupture (MOR) and modulus of elasticity (MOE) was determined on a M500-25KN Universal Testing Machine in accordance with ASTM C1225-08.

Accelerated Aging Procedure (Soak and Dry Cycles)

Accelerated aging test was determined to assess the resistance of the board to long term application or aging process. This was examined based on the simulated and formulated procedure of ASTM C1560-03. The test samples (152mm x 50mm x 6mm) were subjected to one complete cycle of accelerated aging involving immersion in water at 30ºC for 48hours, freezing for 24 hours, heating in dry air at 60ºC for 1 hour; and exposing to boiled water for 1hour (Plates 1a, 1b and 1c). After the completion of these abnormal and intensive treatments, samples were drained of excess water for 10mins. Thereafter, the weight and thickness of the samples were measured and determined. The percentage water absorption, thickness swelling, modulus of rupture and modulus of elasticity were evaluated.

Experimental Design and Statistical Analysis

The experiment was subjected to Completely Randomized Design (CRD) consisting of three additive levels as treatment replicated 5 times. Data collected from the dimensional stability and strength properties laboratory investigation were subjected to one way analysis of variance (ANOVA) which were further subjected to Duncan's Multiple Range Test (DMRT) follow up test for mean separation.

Plates 1 (a) Drying of the bamboo dust; (b) Dissolving of additive (Calcium chloride) for mixture with particle mix; (c) Homogenous mixing of the particle/cement binder/CaCl2 mix; (d) Flattening of the composite board; (e) Semi-finished cold pressed bamboo cement composite; (f) Cold pressing of the moulded bamboo cement composite at 1.23N/mm^2 pressure; (g) Demoulding of the bamboo cement composite; (h) Conditioning of the bamboo cement composite after demoulding for post curing; (i) Air drying of the bamboo cement composite; and (j) Cement Bonded Particle Boards Produced

RESULTS

Dimensional stability of the composite board before and after aging test

The effect of additive levels on the bamboo cement composite revealed a gradual decrease in water absorption and thickness swelling with increase in additive level (1.5 % to 3.5 %) before and after accelerated aging procedure (Figure 1). That is, the higher the additive level, the lower the absorption of water and decrease in the thickness of the bamboo cement composite. The decrease in water absorption and thickness swelling with increase in additive level ranged from 12% to 7.1% and 0.2% to 0.4% respectively before accelerated aging and 16.3% to 10.8% and 0.5% to 0.7% respectively after accelerated aging procedures (Figure 1). This indicates that increase in the additive level consequently led to decrease in the water absorption and thickness swelling of the bamboo cement composite, subsequently producing more dimensionally stable with less movement and stronger cement bonded composite, thickness wise and intake of moisture. Similarly, significant differences ($p \leq 0.05$) were observed between additive levels of 1.5 % and 2.5 %; 1.5 % and 3.5 %; and 2.5 % and 3.5 % on water absorption and thickness swelling of the bamboo cement composites before and after accelerated aging procedure (Figure 1).

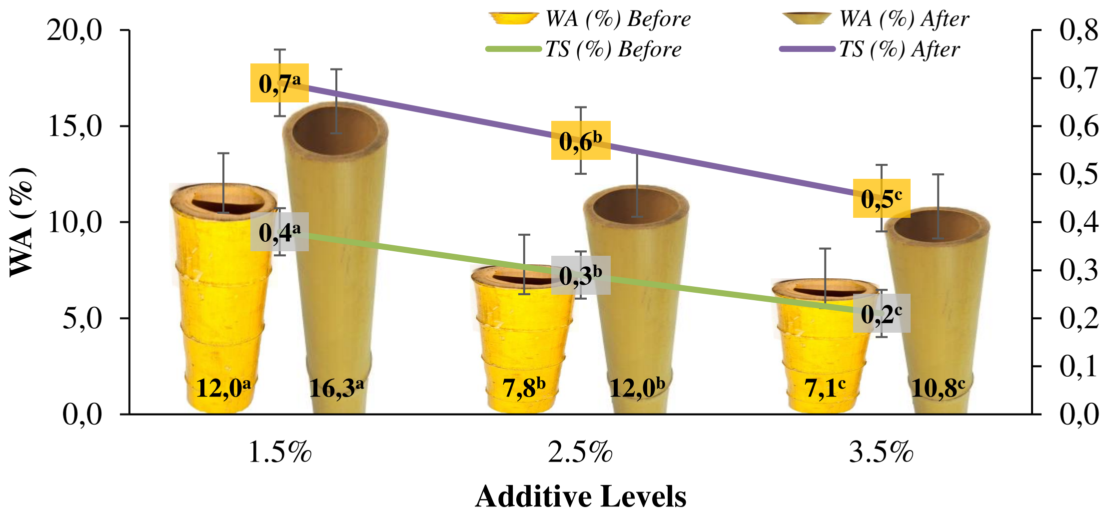
Strength properties of the composite board before and after aging test

The average values of the mechanical properties of the bamboo cement composite as determined on 3-point flexural loading point ranged from 4.1 N/mm^2 to 5.6 N/mm^2 and 3.9 N/mm^2 to 5.3 N/mm^2 for modulus of rupture before and after accelerated respectively, and 1530 N/mm^2 to 2567 N/mm^2 and 1763 N/mm^2 to 2687 N/mm^2 for modulus of elasticity before and after accelerated respectively (Figure 2). This implies that increase in additive level (1.5 % to 3.5 %) brought about increase in strength and stiffness of the boards, inferring that boards produced at highest level of CRC (3.5 %) were structurally stronger and had highest resistance to bending force than boards produced at lowest levels of CRC (1.5 %) as they contain more void spaces capable of facilitating initial break when load is applied. There were significant variations ($p \leq 0.05$) between the results of the modulus of elasticity and modulus of rupture of the bamboo cement composite as affected by the additive level before and after accelerated aging tests (Figure 2).

Percentage change in dimensional stability and strength properties after accelerated aging

A significant percentage increase ranging between 58.79% and 96.94% for water absorption and 41.64% and 65.85% for thickness swelling was observed after the accelerated aging test as the curing reagent increased from 1.5% to 3.5% (Figure 3). The highest significant percentage increment for water absorption (96.94%) was observed at 3.5% additive level, while the lowest percentage increment in water absorption and thickness swelling was observed at the lowest additive level (1.5%). This observed increment in water absorption and thickness swelling invariably implies that the dimensional stability of the bamboo composite board drastically reduced after the accelerated aging procedure.

Significant percentage decrease ranging between 6.63N/mm^2 and 13.71% for modulus of elasticity and 4.17% to 6.86% for modulus of rupture of the composite was observed after the accelerated aging procedure at various additive levels (Figure 4). The highest percentage reduction (13.71%) for modulus of elasticity of the bamboo cement composite was observed at additive level of 2.5%, while the lowest percentage reduction (6.63%) was observed at the highest additive level (3.5%). Similarly, the highest percentage decrease (6.86%) in modulus of rupture of the cement composite was observed at highest additive level (3.5%), while the lowest percentage reduction (4.17%) was observed at the lowest additive level (1.5%). This surmises that there were reduction in the strength properties of the bamboo composite board after the conditioned accelerated aging procedure.



Means in the same column having different superscripts are significantly different ($p \leq 0.05$)

Figure 1: Effect of Additive Levels (%) on WA and TS of Cement Bonded Composites before and after Accelerated Aging Test

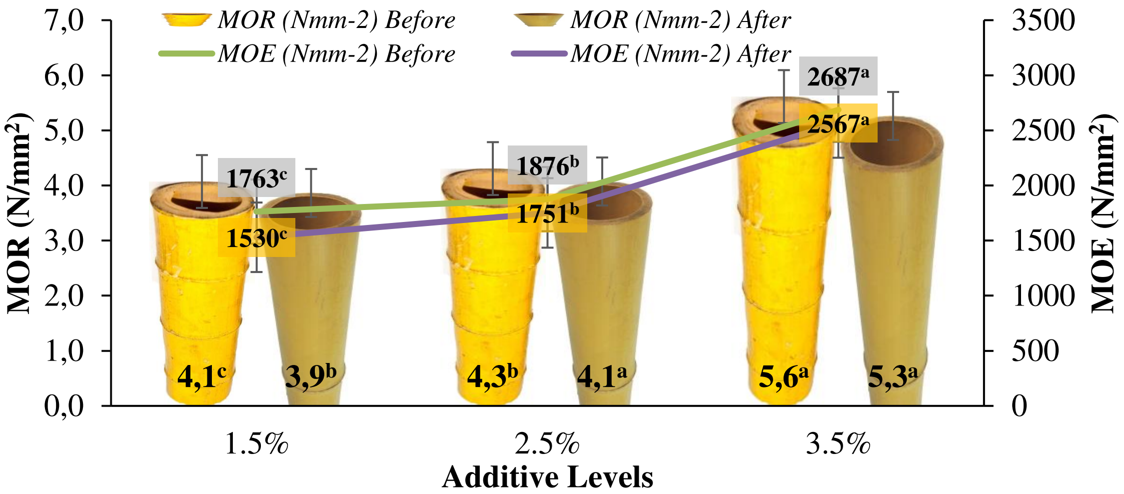


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Figure 2: Effect of Additive Levels (%) on MOR and MOE of the Cement Bonded Composites before and after Accelerated Aging Test

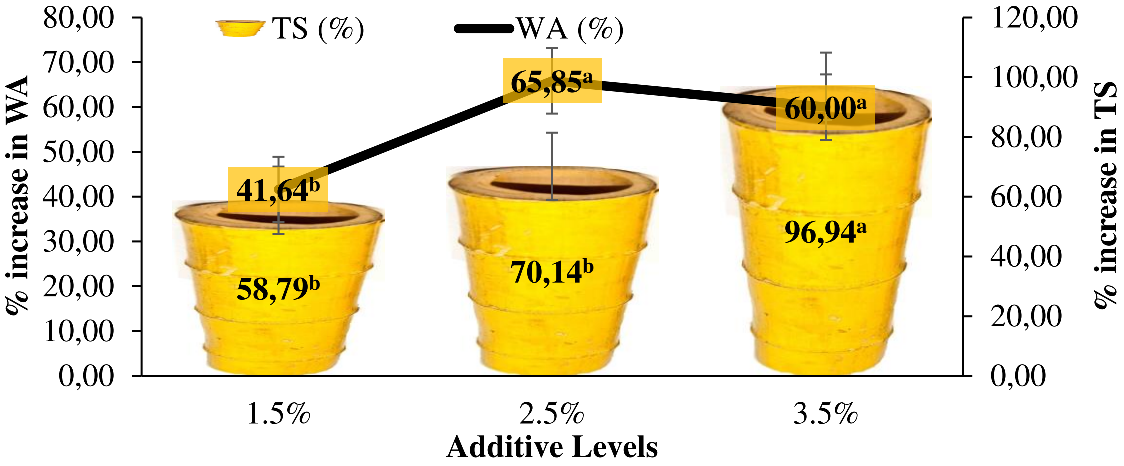

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Figure 3: Percentage change (%) in WA (%) and TS (%) of the Cement Bonded Composites as influenced by Additive Levels after Accelerated Aging Test

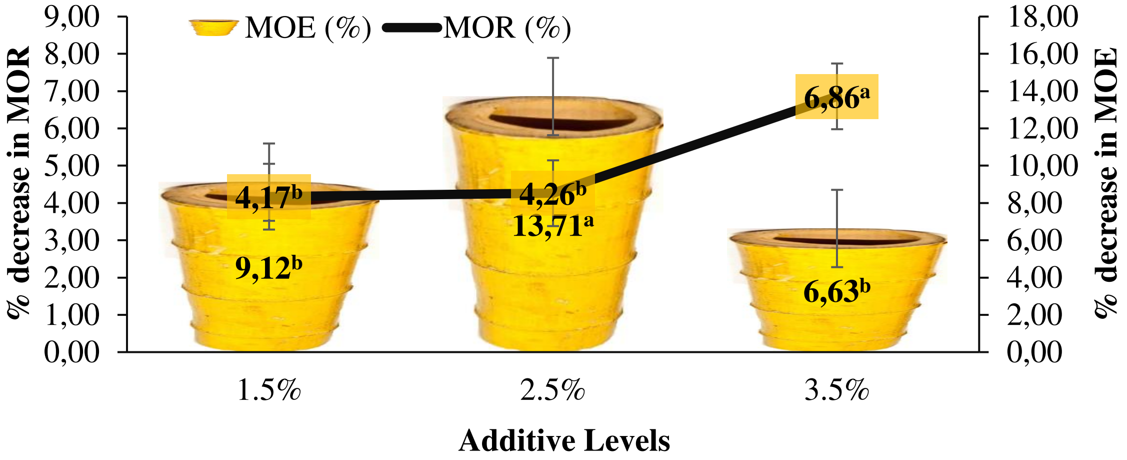

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Figure 4: Percentage change (%) in MOE (N/mm^2) and MOR (N/mm^2) of the Cement Bonded Composites as influenced by Additive Levels after Accelerated Aging Test

DISCUSSION

Dimensional properties of the composite board before and after aging test

The observed pattern of decrease in water absorption and thickness swelling of the bamboo cement composite with increased additive levels before and after accelerated aging (Figure 1) can be attributed to increased setting and curing time of cement with the particle as a result of higher additive content. This is in collaboration with the findings of Ajayi, (2003) who attributed the probable occurrence to enhanced fiber to fiber contact (Frybort *et al*., 2008) due to improved inter-and-intra particle bonding with cement, fewer void spaces (due to improved particles compatibility) and smoother board surfaces which perhaps have hindered absorption of water and increase the composite level of resistance to water penetration. Generally, the removal of the boards from the press, and the immersion in water caused spring-back, breakdown and deformation of bonds, brittleness and expansion of initial air voids (Ajayi, 2010). This phenomenon led to internal moisture movements and build-up in addition to structural transformations of water in the fiber cell wall (fiber swelling) and also in the fiber–adhesive interface, leading to dimensional changes of composite board, particularly in the thickness and linear expansion due to reversible and irreversible swelling of the boards (Abolghasem *et al*., 2015). In addition, the high concentration of calcium chloride caused retardation of inhibitory chemical substances (Frybort *et al*., 2008) and increased the exothermic reaction of cement binder to produce highly stable boards as observed in the increased dimensional stability of the bamboo cement composite with increased additive level.

Strength properties of the composite board before and after aging test

Higher additive levels resulted in improved strength of the bamboo cement composite in terms of increased modulus of rupture and modulus of elasticity before and after accelerated aging (Figure 2). This occurrence is not farfetched from higher compaction and improved particle-cement bonding interaction and fewer air voids caused by less inhibitory extraneous materials that would have hindered the setting of the cement binder with the particles. The result of this findings is consistent with the study of Wei and Tomita (2000), who reported that the mechanical properties and dimensional stability of composites can be improved with increased amounts of additives.

Percentage change in dimensional stability and strength properties after accelerated aging

The result of the percentage change in dimensional stability before and after accelerated aging is inconsistent with the study of Amoo *et al.* (2016) on the production of cement composite tiles using 2% $CaCl_2$ additive level. They reported a lower water absorption (5.5 to 6.6%) and higher thickness swelling (0.7 to 2.5%) values compared to the result of higher water absorption and lower thickness swelling reported in this study (Figure 1). In similar trend, Izekor and Erakhrumen (2015) in their study on the influence of calcium chloride ($CaCl_2$) and aluminium sulphate ($Al_2(SO_4)_3$) additives at 2% weight of cement obtained a relatively higher water absorption and thickness swelling values ranging from 8.78 to 25.89% and 0.16% to 3.39% respectively. The mean modulus of rupture (3.9 N/mm^2 to 5.6 N/mm^2) and mean modulus of elasticity (1530 N/mm^2 to 2687 N/mm^2) of the bamboo cement composite as obtained in this study are less than mean values of MOR (6.34 to 11.27 Nmm^2) and MOE (2835.80 to 4942.60 Nmm^2) for CBPBs treated with $CaCl_2$ reported by Izekor and Erakhrumen (2015) and higher than MOR and MOE ranging from 3.3 to 3.5 N/mm^2 and 1643.4 to 1702.6 N/mm^2 respectively for composite tiles reported by Amoo *et al.* (2016).

The accelerated aging significantly affected the water absorption and thickness swelling as well as strength properties (MOR and MOE) of the bamboo cement composite (Figure 3 and 4). 2.5% additive level produced bamboo cement composite board with the highest percentage increase in water absorption (60%), while the highest additive level (3.5%) had the highest percentage increase in thickness swelling (96.94%). The lowest additive level, in contrast, had the lowest percentage increase in water absorption (41.64%) and thickness swelling (58.79%). The effects of additive levels on the composite strength properties after accelerated aging on the other hand revealed that, 2.5% additive level recorded the highest percentage decrease in modulus of elasticity (13.71%), while the highest percentage decrease in modulus of rupture (6.86%) was observed at the highest additive level (3.5%). This is in agreement with the submission of Nazerian *et al.* (2011) that $CaCl_2$ generally reduced the flexural properties of the composites.

The high percentage increase in water absorption and thickness swelling of the bamboo cement composite after accelerated aging condition (Figure 3) can be attributed to higher additive content (Nazerian *et al*., 2011), de-icing salty nature of the chloride-based calcium chloride additive (Jang *et al*., 2018; Ghazy & Bassuoni, 2017; Shi *et al*., 2013) as well as hygroscopic nature of the additive (Izekor and Erakhrumen, 2015). Ferraz *et al.* (2012) further attributed this phenomenon to the diffusion of sugar to the composite surface, and solubilization and/or degradation of wood particle polymers caused by calcium hydroxide formed during cement hydration.

The efficient mechanism of calcium chloride in accelerating cement hydration with respect to setting and strength development (Natallia, 2016) particularly type II/V OPC (Oey *et al*., 2015) though has been studied at length, however previous studies have associated $CaCl_2$ salt with a damaging chemical reaction with cement matrix by formation of calcium oxychloride (COX) and complex salts (Jang *et al*., 2018; Peterson *et al*. 2013; Sutter *et al*. 2006; Jain *et al*., 2012). The inclusion of $CaCl_2$ deicing salts to cement composites produces chloride ions during cement hydration. High concentrations (above 3 mol) of the chloride (Cl^-) ions and cations (Ca^{2+}) in the de-icing salts can chemically react with cement-based materials forming complex salts and cause pH shifts (Ghazy & Bassuoni, 2017). This ions affects pore structure (capillaries, microcracks and air voids) of cement composites such that when the cement composites becomes dry, the salt solution evaporates resulting in salt crystallization and subsequently resulting into significant deterioration, mass loss, strength loss and internal ruptures as a result of crystal growth expansion in the cement matrix (Jang *et al*., 2018; Peterson *et al*., 2013; Juarez *et al.,* 2007; Neithalath *et al*., 2010) and further influencing its sorption characteristics. The pore cavities provide an avenue for the penetration and diffusion of some ions into the mixture. During the freezing and thawing process of aging, the CaO in the cement is dissolved, leading to instability of the cement matrix and increase in its porosity (Liu *et al*., 2014).

The increased water absorption and thickness swelling values and subsequent decreased modulus of rupture and modulus of elasticity values of the cement composite after accelerated aging (Figures 3 to 4) can be attributed to expansion and contraction during freezing and thawing process of the severe aging conditions and temperature gradient resulting in differential strain within the composite (Sumsion & Guthrie, 2013). The freezing and thawing simulated aging condition caused the evolution of air bubbles indicating that the newly created void spaces evolved were brought about by board's exfoliation, delamination and further enlargement under freezing condition. This invariably connotes that the severity of the aging procedure resulted into the delaminating, softening and plasticity of bamboo particle leading to failure in the wood/cement interface, breakdown of bonds and increase in TS and WA of boards (Ajayi and Olufemi, 2011).

CONCLUSION

The study investigated the influence of Calcium chloride additive levels on the sorption and strength properties of cement composite reinforced with bamboo fibers. Increase in additive level of calcium chloride brought about decrease in dimensional movement and increase in strength properties of the bamboo composite board. Similar trend was observed for WA, TS, MOE and MOR properties after accelerated aging. The strongest, stiffest and most dimensionally stable boards were produced at the highest additive level.

The efficiency of Calcium chloride in accelerating setting and enhancing compatibility though cased in the decreased dimensional stability (WA and TS) and subsequent increased strength (MOR and MOE) properties of the board. However, a diminishing effect was observed after subjection of the bamboo cement composite to severe accelerated aging in which high percentage increase in WA and TS alongside with percentage decrease in MOR and MOE were recorded. There is therefore the need to improve on the de-icing effect of calcium chloride on moisture stability and strength quality of composites for optimum production of a value added product that could withstand severe environmental conditions in service. The bamboo based cement composite could provide value-added panel product for alternative and affordable core and low cost houses in rural and urban environments. Thus, actualizing a revolution in utilization and management of fast growing bamboo, resource control and new technology design for structural application.

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