EFFECTS OF $CaCl_2$ AND NaCl ON STRENGTH AND SORPTION PROPERTIES OF CEMENT-BONDED RATTAN COMPOSITE PANELS

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Abstract:
The aim of this study was to compare the effects of calcium chloride ($CaCl_2$) and sodium chloride (NaCl) as accelerators on the strength and sorption properties of cement-bonded composites produced from hammer-milled rattan cane (Laccosperma secundiflorum) fibre particles. 150x150mm composite boards were manufactured at cement: rattan ratios of 4:1, 4.5:1 and 5:1 at a target density of 1000kg/m^3. Only bending strength, water absorption and thickness swelling properties were evaluated. Addition of $CaCl_2$ and NaCl improved board properties to varying degrees, depending on cement-rattan mixing ratio and salt concentration. Both accelerators enhanced the Modulus of rupture (MOR) of the composites particularly at 4% concentration. However, the MOR of the samples treated with 4% $CaCl_2$ were higher (4.4 – 6.91MPa) than those of the samples treated with 4% NaCl (2.54 - 3.65MPa). Water absorption by the untreated samples at 24 hours (36.7% - 46%) was reduced by both $CaCl_2$ (24.1 – 36.3%) and NaCl (30.6 – 38.7%). The thickness swelling (TS) of all composites at 24 hours, except for samples produced with cement-rattan ratio of 4.5 to 1 and 2% NaCl, fell within acceptable limit (<2%). It was concluded that NaCl at 4% concentration is a possible substitute for $CaCl_2$ in cement-bonded rattan composite manufacture.

***Key words**: rattan cane; cement composite; calcium chloride; sodium chloride.*

INTRODUCTION

Cement-bonded composites (CBC) are low density products manufactured from a mixture of hydraulic cement and particles generated from lignocellulosics such as wood and agricultural residues. These products tend to combine the good qualities of cement, i.e., relatively high resistance to water, fire, fungus, and termite infestation; and good sound insulation with those of wood, i.e., high strength to weight ratio, nailability, and workability (Okino *et al*. 2005). They are used in building construction as fire resistant and acoustic panels (Wolfe and Gjinolli 1999, Ajayi 2006).

In recent years, the attention of researchers, particularly in the developing countries, has been focussed on the production of CBCs from agricultural fibres and residues (Savastano *et al.* 2001, Ajayi 2006, Roma Jr. *et al.* 2008). This is because large volumes of natural fibres generated in many of these countries, including Nigeria are largely under-utilised. Yet, many of them face the challenge of affordable housing provision for their teaming populations. Estimates show that housing deficit now stands at over 16 million units in Nigeria. An average of 1 million housing units per year is required not only to replenish decaying housing stock, but also to meet rising demand (Olorunnisola 2012).

Rattans are spiny, climbing, monocotyledonous palms generally found near water courses. Their distribution is largely confined to tropical and subtropical forests of Asia, Africa and the Pacific where they are usually collected almost exclusively from wild populations and used predominantly for furniture manufacture. The different parts of the plant are also used for basketry, mat making, binding, sporting goods (Ogunwusi 2012). However, a large volume of soft and immature portions of rattan cane is usually discarded during harvesting. Again, large quantities of fungus- infested/stained canes are usually discarded during furniture production. Cane wastage has been estimated by Liese (2002) at well over 30% of rattan harvested. Some of these considerable losses could be resolved with its alternative use for cement-bonded composite production as discussed by Olorunnisola (2005).

Like many other lignocellulosics, rattan cane tends to inhibit cement hydration when mixed with Portland cement for CBC manufacture. Several chemicals are used as accelerators to increase in the rate of setting in such composites. However, calcium ($CaCl_2$) is most widely used due to its predictable performance characteristics and successful application in concrete works over several decades. Addition of $CaCl_2$ improves cement curing by reducing moisture loss through evaporation during early hydration period by releasing the normal heat of hydration earlier and by accelerating the hydrating action. Sodium chloride is an ionic compound made up of equal numbers of positively charged sodium and negatively charged chloride ions. Early studies by Henry and Griffin (1964) on sodium chloride in mixing water reported that it caused increase in the compressive strength of concrete at concentration of 25gm per 1kg of solution, with accompanying reduction in water vapour transmission. It was, however, also reported that NaCl had erratic effects in concrete, causing set acceleration in some cements and retarding effects in others (Mattus and Gilliam 1994). Shi *et al.* (2011) also reported that de-icers containing NaCl caused substantial compressive strength loss in concrete. However, no study has been reported so far on the effect of NaCl, a readily available and relatively cheap salt, on the bending strength and sorption properties of CBCs, though both salts are well known for their water retention capacity which tends to impact positively on cement curing.

OBJECTIVE

The main objective of this study, therefore, was to compare the effects of the addition of $CaCl_2$ and NaCl at different levels of concentration on the bending strength, water absorption and dimensional stability of rattan cement-bonded rattan composites.

METHOD, MATERIALS AND EQUIPMENT

Freshly harvested, rattan cane (*Laccosperma secundiflorum*) samples obtained from rattan processors were air-dried for three weeks to reduce their moisture and sugar contents, hammer-milled into fibre particles and and used in composite production 'as received'. The properties of the $CaCl_2$ and NaCl as provided by their manufacturers are presented in Table 1.

Table 1

The Chemical Compositions of the $CaCl_2$ and NaCl Salts

Salt	Property	Value
$CaCl_2$		
	Assay	90% min.
	Iron	0.002% max.
	Sulphate	0.05% max.
	Heavy mteals (e.g. lead)	0.002% max.
	$CaCl_2$ (molecular weight)	110.99
NaCl		
	Sodium	38.7g/100g
	Iodine	>15 ppm

The oven-dry moisture content of the "as received" rattan cane fibre particles was determined in accordance with BS 812-109 (1990), while sieve analysis was carried out with a set comprising 2.36mm, 1.7mm, 1.18mm, 0.85mm, 0.6mm and 0.045mm sieves in accordance with BS 812-103 (1990). To determine water absorption by the 'as received' rattan cane fibre particles, 20g of the fibres were completely immersed in 300ml of distilled water. The soaked fibre particles were filtered after 24h and washed with distilled water. The fibre particles were weighed after draining off the excess water and the water absorption value in percentage was then computed as in Aggarwal *et al*. (2008). Two replicates were used and the mean values of the results obtained are reported.

For composite manufacture using $CaCl_2$ and NaCl as chemical accelerators for the different sets of triplicate samples, each salt was dissolved in the water used for the mixing process in two proportions by mass of cement, i.e., 2 and 4%. For the control samples, no salt was added to the mixing water. The composite samples were then manufactured by manual dry-mixing of rattan particles and Type 1, general purpose Portland cement (class strength 42.5 grade) in a plastic container at three cement: wood ratios by mass, i.e., 4:1, 4.5:1 and 5:1 respectively. The potable mixing water was then added to the dry mixture based on the equation developed during preliminary studies on water requirements for rattan-cement composite mixtures:

$$Q= 0.36C \qquad (1)$$

where: Q = Quantity of water (Millilitres);
C = quantity of cement in the mixture (grams).

Each wet mixture was poured into single units of 150x150x25mm metallic moulds, placed in a hydraulic cold press set at a pressure of 6.6 N/mm^2 and pressed for 6 to 8 hours, but left in the mould for 24 hours. Once de-moulded, the composites were cured at ambient room temperature (20 ± 2^0C) under wet towels for the first seven days, and then in a chamber maintained at a constant temperature and relative humidity of 25 ± 2^0C and 65±5% respectively for 21 days. Three specimens from each mixture were tested at 28 days. The oven dry moisture content, density and bending Modulus of Rupture (MOR) of the samples were determined in accordance with Indian standard, IS 14862 (2000). The 3-point bending test was conducted on a 20kN capacity Universal Testing Machine (Shimadzu, Model AGS2000G) adopting a span of 100mm and mid-span deflection rate of 1.0mm/min.

To determine water absorption (WA) in, and thickness swelling (TS) of the rattan-cement composites, three 150x150mm specimens each were thoroughly sand-papered and dried in an electric oven set at 60± 5^0C until constant weight (≤0.1% weight change) was achieved. The specimens were then brought to room temperature (25±2^0C) at a relative humidity of 65±5%. This drying method was selected to minimize any modification to the capillary pore structure that may be caused by a higher temperature and more rapid drying (Guneyisi and Gesoglu 2008). The dry mass and thickness of each specimen were first measured and recorded. The specimens were then completely immersed horizontally in potable water maintained at a temperature of 20±2^0C. Water Absorption after 1 and 24 hours respectively were calculated from the increase in weight of the specimen during submersion, while the Thickness Swelling of each board was expressed as a percentage of the original thickness. All composite property test results were subjected to analysis of variance procedure for 2-factorial experiment at 5% level of significance.

RESULTS AND DISCUSSION

Physical Characteristics of the Wood Particles

Table 2 shows the 'as received rattan cane fibre particle distribution. Close to 80% of the fibre particles were retained on sieve sizes ranging from 0.6 and 0.045mm, an indication that the rattan fibres were relatively small. The mean water absorption at 24 hours was 365.8%. This value compares favourably with those reported by Agopyan (1988), Aggarwal *et al.* (2008), and Olorunnisola and Agrawal (2009) for different types of wood and vegetable fibres used in cement composites, i.e., *Eucalyptus Tereticornis* (286 - 433.0%), sisal fibre (239%), jute (214%), piassava fibre (34.4 – 108%), coir fibre (117-171%), banana (400%), aak (350%), castor (235%), bhabar (185%), bamboo sticks (145%), arhar flakes (170 -200%), and arhar powder (250-320%) It can be inferred, therefore, that the rattan cane fibre particles were highly hygroscopic.

Table 2

Sieve Analysis of the 'As Received' L. secundiflorum Fibre Particles

Sieve Aperture (mm)	Retained Particles (%)	Cumulative Particles retained (%)
2.36	0.72	0.72
1.70	5.42	6.14
1.18	0.84	6.98
0.85	13.32	20.30
0.60	24.17	44.47
0.045	53.72	98.19
Pan	1.82	100.0

Density of Cement-Bonded Rattan Composites

The densities and the oven dry moisture contents of the composite samples are shown in Fig. 1 and Fig. 2 respectively. The density values ranged between 1.06 and 1. 28g/cm^3, i.e., 1060-1280Kg/m^3 while the moisture content ranged between 4.0 and 11.6%. The density of all the composite samples exceeded the minimum value of 1000Kg/m^3 stipulated in ISO 8335 (1987) for cement-bonded composites. Expectedly, there was a general increase in density with increase in cement content. While the addition of $CaCl_2$ contribued to a slight increaase in the density of the composite samples, while the addition of NaCl did not. The moisture contents of the samples were below the 12% maximum value specified for cement-bonded composites in ISO 8335 (1987). Analysis of variance (ANOVA) presented in Table 3 also showed that the addition of both $CaCl_2$ and NaCl as chemical accelarators resulted in a signficant incease in the moisture content of the composite samples. This was expectedly due to the well-known water retention property of both salts. The positive implication of the water retention is that cement hydration would be enhanced.

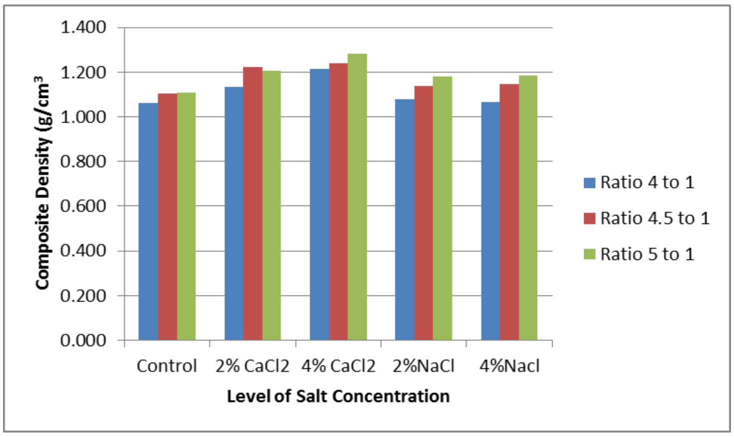

Fig. 1.
The densities of the composite samples.

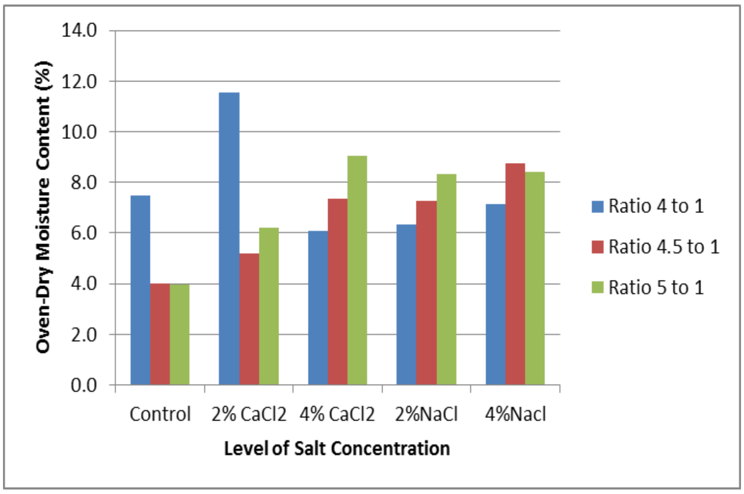

Fig. 2.
The oven dry moisture contents of the composite samples.

Table 3
ANOVA on Effects of Cement-Rattan Ratio and Accelerator on Composite Moisture Content

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cement : Rattan Ratio	10.864	2	5.432	8.102	0.001537	3.315
Accelerator	48.221	4	12.055	17.980	1.25E-07	2.689
Interaction	107.514	8	13.439	20.045	4.64E-10	2.266
Within	20.113	30	0.670			
Total	186.712	44				

Modulus of Rupture

As shown in Fig. 3, the MOR of the composites ranged between 0.86 and 6.91MPa. These values generally compare favourably with the range of values (1.7 to 5.5MPa) reported by the Forest Products Laboratory (1999) for several kinds of low density (500 to 1000kg/m^3) cement-bonded particleboards. The MOR values of the samples treated with 4% $CaCl_2$ were generally higher (4.4 – 6.91MPa) and compare favourably with the range of values (5.8 to 6.4MPa) reported by Okino *et al.* (2004) for cement-bonded particleboard produced from a mixture of eucalyptus and rubberwood. However, all the MOR values recorded fell below the minimum of 9.0MPa stipulated in ISO 8335 (1987) for cement-bonded composites. The cement-rattan mixing ratio had no significant effect on the MOR as shown in the ANOVA in Table 4.

Modulus of rupture is an index of the maximum load-carrying capacity in bending when cement-bonded composite products are used as panels in ceiling and roofing where they are subjected to flexural stresses. It's value depends primarily on the bonding strength between the aggregate material and cement. The relatively low values obtained in the present study suggest that the cement-bonded rattan composites could be used for ceiling and such allied applications.

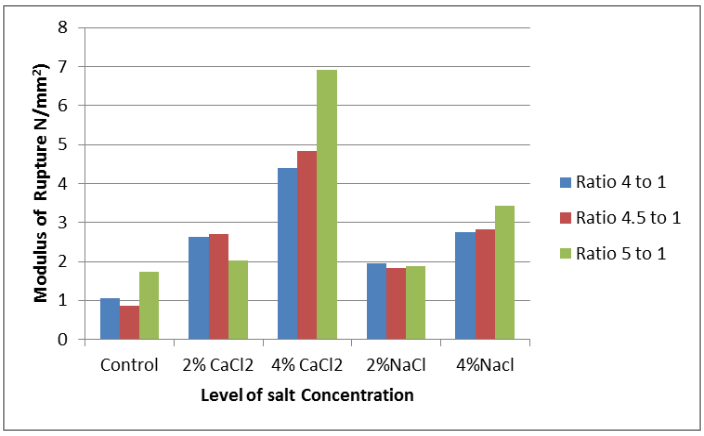

Fig. 3.
The Modulus of Rupture of the composite samples.

Table 4

ANOVA on Effects of Cement-Rattan Ratio and Accelerator on MOR

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Cement: Rattan Ratio	3.76572	2	1.88286	4.621171	0.017803	3.31583
Accelerator	91.40237	4	22.85059	56.08302	1.69E-13	2.689628
Interaction	10.02712	8	1.253391	3.076241	0.011818	2.266163
Within	12.22327	30	0.407442			
Total	117.4185	44				

Water Absorption

The test results for WA at 1 hour and 24 hours respectively are presented in Fig. 4 and Fig. 5. The WA values ranged between 15.0 and 38.8% and between 24.1 and 46.1% after 1h and 24h of immersion respectively. It is clear from the 1H test results that the cement-bonded rattan composite samples had a relatively high water absorption capacity, and may therefore not be installed outdoors. The control (untreated) samplesexhibited the highest WA, regardless of the rattan-cement ratio, perhaps due to their relatively low moisture content and the presence of more void spaces within the composite. The $Cacl_2$-treated samples generally absorbed less water than the and NaCl-treated samples, particularly at 4% level of concentration.

Thickness Swelling

The 1h and 24h TS values obtained for the composite samples ranged between 0.2 and 1.7%, and between 0.4 and 2.1% respectively (Fig. 6 and Fig. 7). Except for the samples produced using the cement-rattan mixing ratio of 4.5 to 1 and 2% NaCl as chemical accelerator, the TS values at 24h were quite low and satisfied the maximum TS values of 1.8% and 2.0% specified by BS 5669 (1989) and ISO 8335 (1987) standards respectively for cement-bonded composites. The addition of $CaCl_2$ at 4% level of concentration had the greatest effect on the the reduction of TS, while NaCl addition resulted in a genral increase in the TS. However, since the increses observed were still within acceptable limits, bith As shown in the ANOVA presented in Table 6, wood-cement ratio and the combined effects of wood-cement ratio and pre-treatments had significant effects on 24-TS.

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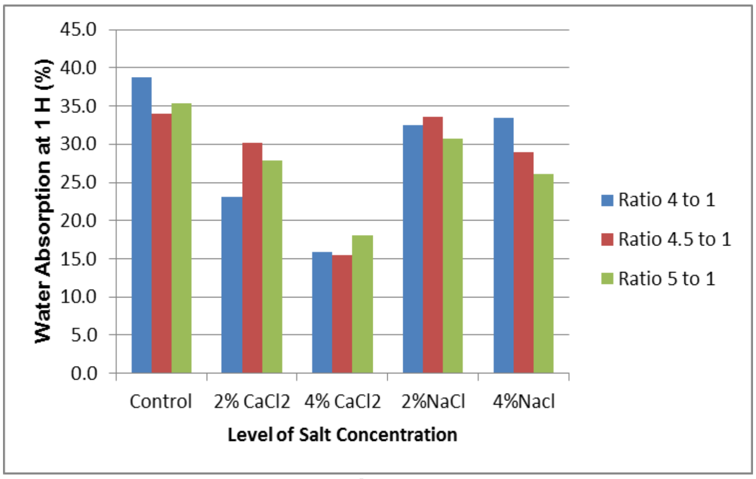

Fig. 4.
Water absorption by the composite samples at 1 Hour.

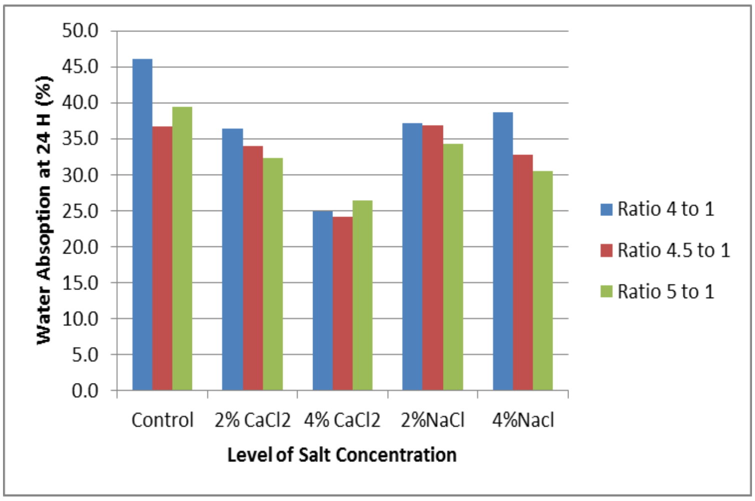

Fig. 5.
Water absorption by the composite samples at 24 Hour.

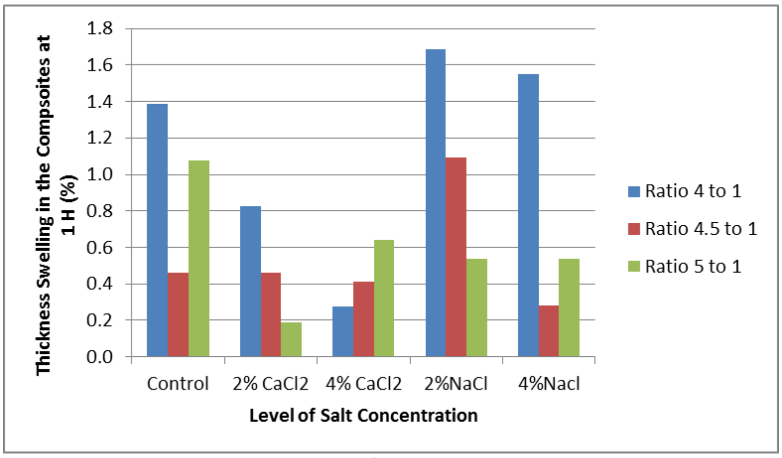

Fig. 6.
Thickness swelling of the composite samples at 1 Hour.

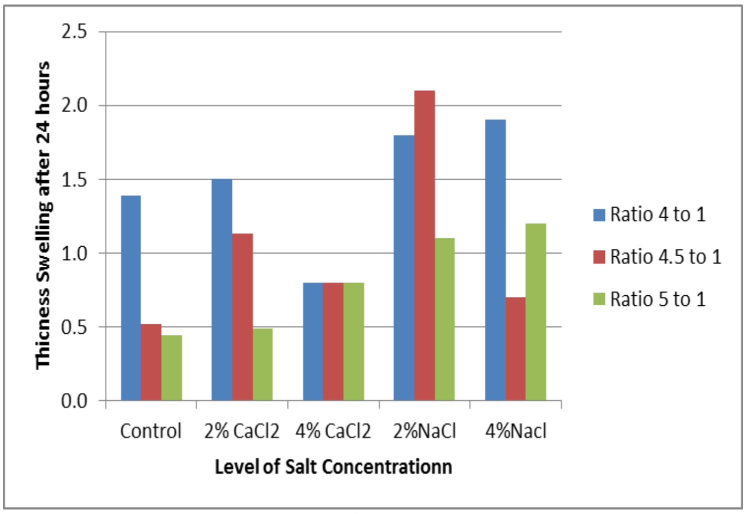

Fig. 7.
Thickness swelling of the composite samples at 24 Hour.

Table 6

ANOVA on Effects of Cement-Rattan Ratio and Accelerator on 24H WA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	155.9743	2	77.98714	6.339014	0.005055	3.31583
Columns	1152.719	4	288.1798	23.42406	7.3E-09	2.689628
Interaction	143.0197	8	17.87746	1.45313	0.215911	2.266163
Within	369.0817	30	12.30272			
Total	1820.795	44				

CONCLUSIONS

Wood-Cement composites were produced from rattan (*Laccosperma secundiflorum*) fibrous particles. The composites were tested for bending strength, water absorption and thickness swelling. Results obtained showed that calcium chloride had a more positve effect than sodium chloride on the flexural strength, water absorption and thickness swelling of cement-bonded rattan composites. However, given its acceptable performance, the use of sodium chloride is recommended as a substitute for composite manufacture if calcium chloride is not available.

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REFERENCES

Aggarwal LK, Agrawal SP, Thapliyal PC, Karade SR (2008) Cement-bonded composite boards with arhar stalks. Cement & Concrete Composites 30:44–51.

Agopyan V (1988) Vegetable fibre reinforced buildiing materials – developments in Brazil and other Latin American countries in Swamy, R.N. (ed.) Concrete Technology & Design Vol. 5: Natural fibre reinforced cement and concrete, Blackie and Son Ltd., Glasgow. Pp. 208-242.

Ajayi B (2006) Properties of maize stalk based cement bonded composites. Forest Products Journal 56(6):51-55.

British Standards Institute (1989) Particleboard Part 4. Specifications for cement bonded particleboard BS 5669.4. Published British Standards Institute, London.

British Standards Institute (1990) Testing Aggregates Part 103. Methods for determination of particle size distribution BS 812-103.1. Published British Standards Institute, London.

British Standards Institute (1990) Methods for Determination of moisture content, BS 812-109. Published British Standards Institute, London.

Guneyisi E, Gesoglu M (2008) A study on durability properties of high performance concretes incorporating high replacement levels of slag. Materials and Structures 41:479-493.

Henry RL, Griffin DF (1964) The effect of salt in concrete on compressive strength, water vapor transmission, and corrosion of reinforcing steel. Available from http://www.stormingmedia.us

Indian Standard (2000) Fibre cement flat sheets-specification. IS 14862, Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002, India. Pp. 14.

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

Liese W (2002) Challenges and constraints in rattan processing and utilization, in: Rattan current research issues and prospects for conservation and sustainable development, J. Dransfield, F. O. Tesoro and N. Manokaran (Eds), pp. 35–42. FAO, Rome.

Mattus CH, Gilliam TM (1994) A literature review of mixed waste components: sensitivities and effects upon solidifcation/stabilization in cement-based matrices. A publication of the U.S Department of Energy office of technological development. Washington D.C. 20585. Available from http://www.osti.gov/bridge/

Ogunwusi AA (2012) Challenge of Industrial Production and Processing of Rattans in Nigeria. JORIND 10(2):50-59.

Okino EYA, de Souza MR, Santana MAE, Alves MV, de Souza ME, Teixeira DE (2004) Cement-Bonded Wood Particleboard with a Mixture of Eucalypt and Rubberwood. Cement & Concrete Composites, 26:729-734.

Olorunnisola AO (2005) Dimensional stability of cement-bonded composite boards produced from rattan cane particles. Journal of Bamboo & Rattan 4(2):173–182.

Olorunnisola AO, Agrawal SP (2009) Strength and sorption properties of cement-bonded composites produced from eucalyptus (*Eucalyptus Tereticornis* Sm.) veneer waste. Journal of Applied Science, Engineering & Technology 9:10-23.

Olorunnisola AO (2012) Looking beyond the challenges of affordable housing development in nigeria: capitalizing on the engineering opportunities. The 18th Engr. Lawrence Oluwemimo Arokodare Memorial Lecture published by the Nigerian Society of Engineers, Ibadan Branch, Nigeria. Pp. 40.

Roma Jr.LC, Martello LS, Savastano Jr.H (2008) Evaluation of mechanical, physical and thermal performance of cement-based tiles reinforced with vegetable fibres, Construction and Building Materials, 22:668-674.

Shi X, Fay L, Peterson MM, Berry M, Mooney M (2011) A FESEM/EDX investigation into how continuous deicer exposure affects the chemistry of Portland cement concrete. Construction and Building Materials, 25(2):957-966.

Wolfe RW, Gjinolli A (1999) Durability and strength of cement bonded wood particle composites made from construction waste. Forest Prod. J. 49(2):24-31.