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THE EFFECTS OF POLYVINYL ALCOHOL FIBRE ADDITION ON SELECTED PROPERTIES OF CEMENT – BONDED RATTAN FIBRE CEILING BOARDS

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Abstract

The effects of Polyvinyl Alcohol (PVA) fibre incorporation in rattan fibre–cement composite ceiling boards were investigated. Two rattan (1mm and 2mm) and PVA (4mm and 6mm) geometric fibre lengths were used for composite production. Rattan and PVA fibre contents were kept constant at 5% and 2% respectively. Triplicate samples of 250mm × 50mm × 6mm boards were tested for density, strength and dimensional stability, while 95mm diameter specimens were tested for thermal conductivity. Results showed that the Modulus of elasticity of the boards ranged between 1431 and 7855N/mm^2, while the Modulus of Rupture ranged between 4.3 and 8.4N/mm^2. PVA fibre incorporation had a significant effect on the bending strength of the boards containing 6mm PVA fibres. The 24h water absorption (5.6 -15.2%) was acceptable but the thickness swelling (2.4 - 4.7%) was higher than the recommended 2%. PVA incorporation increased the thickness swelling of the boards except those produced with 1mm rattan fibres. The thermal conductivity values (0.59–1.06W/m˚C) were outside the range of 0.15-0.50W/m˚C recommended for ceiling boards but close to that of dense concrete (1.0 - 1.8W/m˚C). It was concluded that 6mm PVA fibres improves flexural strength of rattan fibre-cement composites.

Key words: *fibre–cement; ceiling boards; rattan; PVA fibre; dimensional stability.*

INTRODUCTION

Chronic shortages of suitable housing exist in many parts of the world. Reasons for these shortages include rapid population growth, inefficient utilisation of natural resources, shortage in supply and the cost of building materials. It is evident that the solution to the global housing problem in the developing world lies largely in the development of low cost building materials. Such materials should, nevertheless, satisfy the many production, construction, economic, cultural, safety, and health requirements. Cement boards appear to have the potential to satisfy the requirements. There are four categories of cement boards, i.e., Fibre cement board (FCB), Cement bonded particle board (CBPB), Wood strand cement board (WSCB), and Wood wool cement board (WWCB). Each type of board has its own manufacturing process (Ahmed *et al.* 2017).

Fibre cement boards exhibit improved toughness, ductility, flexural capacity, and crack resistance as compared to non-fibre reinforced cement-based materials. Among the different types of fibres used in cement-based composites, natural fibres offer distinct advantages such as availability, renewability, and low cost, among others. Also, natural fibres used in cement-based matrices can be divided into two categories – unprocessed natural fibres and processed natural fibres. The unprocessed natural fibres are used in the manufacturing of low fibre content composites and occasionally have been used in manufacturing thin sheet high fibre content composites. Generally these fibres are used in low cost housing projects. On the other hand, processed natural fibres, such as kraft pulp fibres, using sophisticated manufacturing processes to extract the fibres, are used for manufacturing thin sheet fibre reinforced cement products (Sarja 1988).

Rattan is a close relative of the palm tree. It is a type of a vine that rapidly grows in the jungles of South Eastern region Asian, sub - tropical Africa, and the pacific. It grows in the shape of a pole, and its diameter varies between 25 and 75mm. Rattan is one of the strongest woods and possesses the ability to grow up high as 30m. The solid core of rattan along with vertical grains is harvested and cut into smaller sections as rattan canes which are very popular for their uses in furniture manufacture in many parts of Asia and tropical Africa. The canes, particularly the *Lacosperma secundiflorum* species, have also been reported as good sources of fibre for cement board manufacture (Olorunnisola *et al.* 2005, Olorunnisola 2008). Rattan can be considered as a potential natural fibre source for cement board manufacture given its short growth rotation period- it can be harvested in less than seven years after planting.

High-performance fibres made of polyvinyl alcohol (PVA) were developed some 20 years ago in Japan. When added to concrete or mortar, the fibres develop a molecular and chemical bond with the cement during hydration and curing. The result is concrete with high tensile strength and ductility. Horikoshi (2006) reported that PVA fibre could be used in fibre - cement roofing manufacture as asbestos replacement. No study has been reported so far on the effect of PVA incorporation in rattan fibre-cement composite ceiling board production. The Objectives of this study, therefore, is to determine the effects of PVA fibre incorporation in cement - bonded rattan fibre composite ceiling boards on their physical, mechanical and thermal properties.

MATERIALS COLLECTION AND PREPARATION

Mature, freshly harvested rattan canes were sourced from harvesters, duly identified in a herbarium as *Laccosperma secundiflorum species,* and cut into about 5cm long billets (Fig. 1). The billets were then hammer – milled and sieved (Fig. 2). Only 1mm and 2mm rattan fibres were used for composite manufacture. The 4 and 6mm long PVA fibres (Fig. 3) were procured from an international source. Ordinary Portland cement (general purpose, class strength 42.5) was procured from the local market. The distilled water used was stored at room temperature (20±2^{0}C).

Fig. 1.
The crushed rattan canes.

Fig. 2.
The Sieved rattan fibre.

Fig.3.
A packet of PVA fibres.

The rattan fibre cement boards were produced using cement and rattan fibre for the control, and cement, rattan fibre and PVA for the experimental samples. For each mixture, 150 g of cement and rattan fibre representing 5% by mass of cement were used. For the experimental samples the PVA fibre content was 2%. For each set of specimens, the 4 mm and 6 mm PVA fibres were first pre – mixed with the 1 mm and 2 mm long rattan fibres. Portland cement and water were then added and the composite was thoroughly hand mixed. Each consistent mixture was then compacted in mould to produce 250mm × 50mm × 6mm specimens which was vibrated at 50 cycles per minute for 60 seconds. After 24 hours of cold pressing, the boards were demoulded, covered with water-proof polyvinylchloride sheet and cured in a ventilated room at a relative humidity of 70±5% for 28 days.

The boards were then sand papered and trimmed. The density of each board was calculated as the ratio of the mass over density.

Fig. 4.
A mixture of rattan, PVA fibre and cement.

Fig. 5.
The fibre cement boards.

The Moduli of Elasticity (MOE) and Rupture (MOR) of the boards loaded perpendicular to the direction of casting were determined by three-point bending test on a 60kN capacity servo-hydraulic universal testing machine at room temperature. The MOE and MOR were calculated using Equations 1 and 2.

$$\mathrm{MOE} = \frac{PL^3}{4bh^3\Delta} \qquad (\mathrm{N/mm^2}) \qquad (1)$$

$$\mathrm{MOR} = \frac{3PL}{2bh^2} \qquad (\mathrm{N/mm^2}) \qquad (2)$$

where:

P = Load
L = span (mm)
b = width (mm)
h= thickness (mm)
Δ = deflection (mm)

Water absorption and thickness swelling test was carried out in accordance with ASTMD 1037-89 (2010). The samples were immersed in water at ambient temperature. The water absorption was calculated using Equation 3:

$$\mathrm{Wa} = \left(\frac{m_1 - m_0}{m_0}\right) \times 100\ (\%) \qquad (3)$$

where:

m_0 = is the initial mass (g) , m_1 = final mass after immersion in water for 24 h

The thickness swelling was calculated using Equation 4:

$$\mathrm{TS} = \left(\frac{TS_1 - TS_0}{TS_0}\right) \times 100\ (\%) \qquad (4)$$

where: TS_1 = Final thickness of the sample after immersion in water for 24 hours (mm).
TS_0 = Initial thickness the sample before immersion (mm).

The thermal conductivity test was carried out on triplicate samples of *95mm diameter specimens* using an apparatus consisting of five parts: the power module and voltage regulator which supply steady power, a cylindrical container which housed the specimen, a heating element which served as the primary source of heat to the specimen, a data logger which was used to record the heat transmitted from the specimen and served as the interface transforming the heat signal into digital signal, the computer which recorded and processed the signal. A sensor needle was encased in the reflective cylindrical casing and the specimen to be tested was placed directly above the probe and then the heating element (supplied by 0.1 amp, ~ 0.15 – 0.2V electric supply). The temperature and rate of heat transfer were digitally plotted into a graph using a software (EasyLogUSBV530) on the computer. The experiment was carried out at a temperature of 120±2^{0}C. The temperature gradient over a period of1 hour was read from the graph. The thermal conductivity was calculated using Equation 5:

$$K = \frac{QL}{A\Delta T} \qquad \left(\frac{W}{mK}\right) \qquad (5)$$

where:

K = Thermal conductivity
Q = Rate of heat transfer in $\frac{\text{Joules}}{s}$ or Watts
A = Area of the body (m^2)
ΔT = Temperature difference ℃ and L = Thickness of the material (m)

RESULTS AND DISCUSSION

Effects of PVA fibre incorporation on the Density of the Boards

The average densities of the composites are presented in Table 1. The values were 1685 and 1714Kg/m^2 for the control composite samples produced with 1mm and 2mm rattan fibres respectively. The addition of PVA fibre decreased the density of the boards suggesting that the PVA fibres tend to produce low density boards.

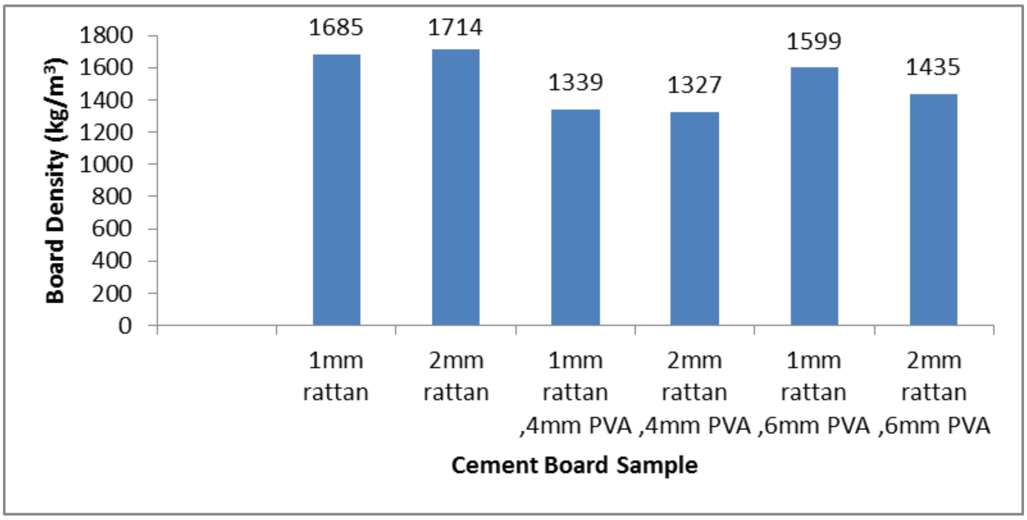

Fig. 6.
Effects of PVA on the Density of the Boards.

Effects of PVA fibre incorporation on the Modulus of Elasticity of the boards

The mean MOE values obtained are shown in Fig. 7. The mean MOE for the two control samples were 4969.9 and 7855.0N/mm^2 for the 1mm and 2mm rattan fibres respectively. The values ranged between 1431N/mm^2 and 2536.8N/mm^2 for the PVA experimental samples. The MOEs of the control samples were similar to values (4477.7 to 6803.0N/mm^2) reported by Olorunnisola et al. (2005), Olorunnisola (2007), Adefisan and Olorunnisola (2012) and Olorunnisola and Agrawal (2015) for rattan-cement boards. The MOE was significantly reduced with the incorporation of PVA fibres, and though the samples containing 6mm PVA fibres had higher MOE value than those of the boards containing 4mm fibres. A better performance of larger PVA fibres had been reported by Ahmed and Mihashi (2011). Also, the 2mm rattan boards had lower MOE compared to the 1mm boards. PVA addition lowered the MOE of the boards. This is in conformity with the findings of Hu *et al.* (2013) on a study of the mechanical properties of PVA fibre-reinforced concrete. The researchers reported that increasing the amount of PVA fibre in concrete resulted in a decrease in compressive strength and elastic modulus. However, while the PVA fibres had a negative effect on the MOE, it improved the fracture toughness and ductility. Test samples showed an outright breakage of the control samples during failure while the PVA samples had less cracking and were resistant to breakage even after failing under flexural load. This finding supports the general claims that PVA fibre addition tends to enhance the ductility of cement products particularly if the fibres are thoroughly mixed and homogenously dispersed throughout the mortar or concrete. As reported by Xu *et al.* (2011), the addition of PVA fibre in lightweight cementitious composite material resulted in an improvement in its ductility, fracture toughness and impact resistance.

Effects of PVA fibre incorporation on the Modulus of Rupture of the boards

The MOR of the cement boards ranged were 6.21 and 8.410N/mm^2 for the 1mm and 2mm control samples. The values ranged between 4.30 and 6.260N/mm^2 for the experimental boards containing PVA fibres (Fig. 8). These figures compare favourably with the 0.6 – 5.60N/mm^2 reported by Olorunnisola *et al.* (2005) and Adefisan and Olorunnisola (2012) for cement-bonded boards produced with *L. secundiflorum* rattan canes. However, incorporation of PVA fibres generally lowered the MOR of the boards significantly. A strong positive correlation (r^2 = 0.8691) was observed between MOE and MOR of the boards, which contradicts the findings of Olorunnisola (2007) who observed a weak positive correlation between MOE and MOR in rattan–cement composites.

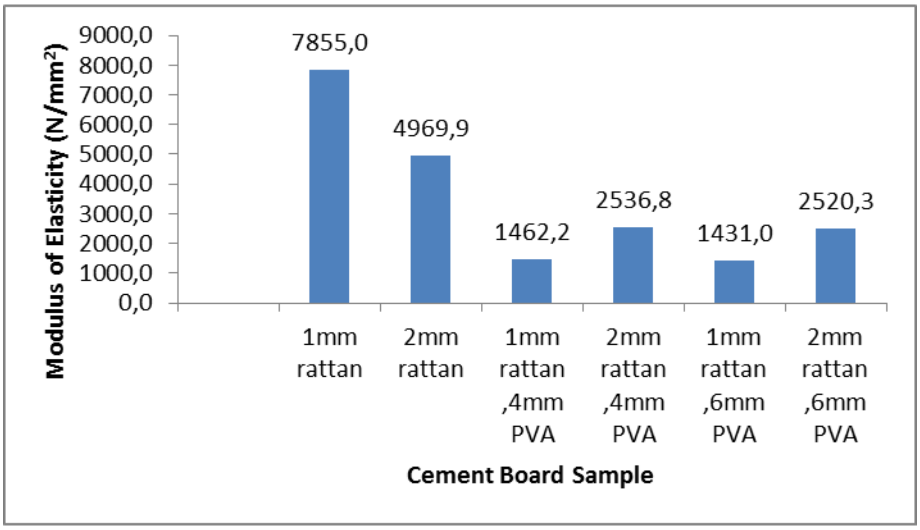

Fig. 7.
Effects of PVA on the MOE of the Boards.

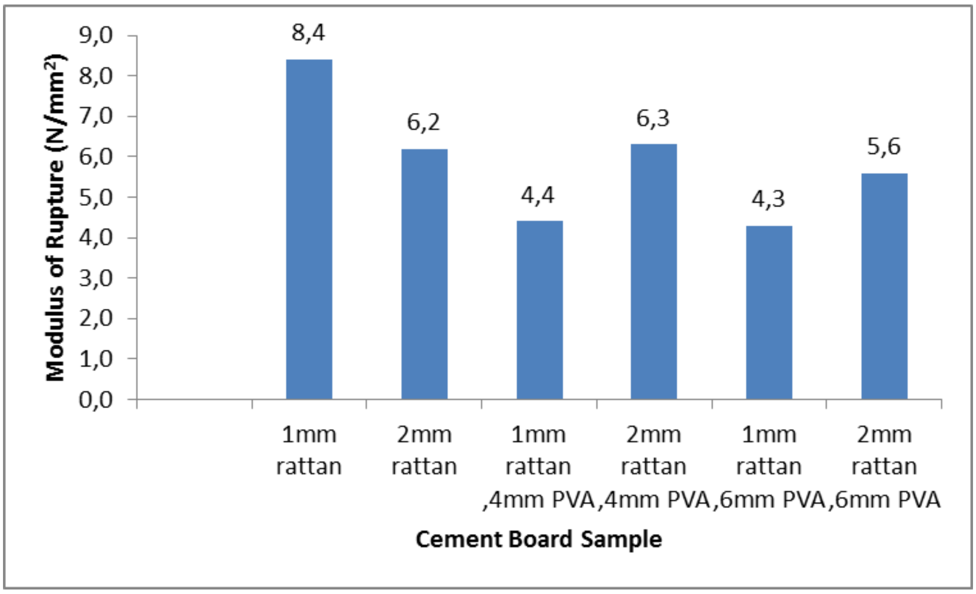

Fig. 8.
Effects of PVA on the MOR of the Boards.

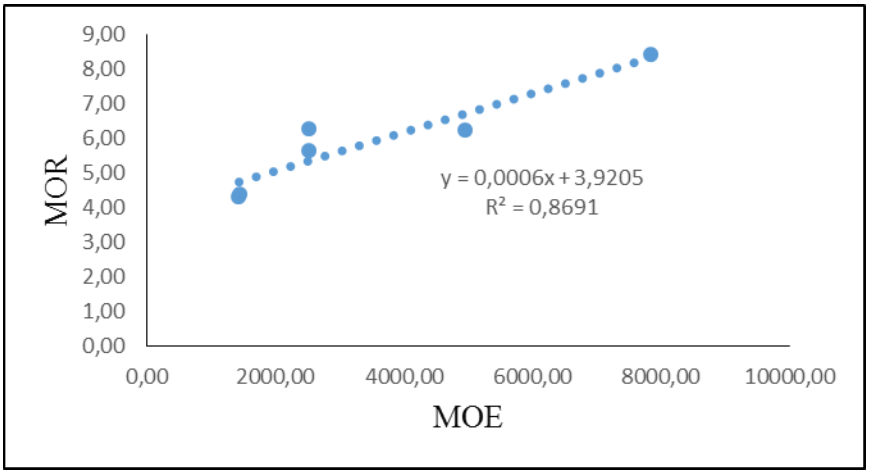

Fig. 9.
Correlation between MOE and MOR of the boards.

Effects of PVA fibre incorporation on the water absorption and thickness swelling of the boards

The Water Absorption (WA) and Thickness Swelling (TS) values obtained after 24 hours of water immersion are shown in Fig. 10. The mean WA value for the 1mm rattan fibre cement control samples (5.6%) was about twice that of the 2mm control samples (11.10%) indicating that the longer fibres absorbed more water. Also, the addition of PVA fibres significantly increased the WA of the 2mm rattan boards. The TS of all the board samples exceeded the maximum of 2% specified by the Bureau of Indian Standards. Also, there was a sharp increase in TS with the transition from 4mm to PVA fibre length suggesting that 4mm PVA fibre length was the limit if dimensional stability is to be maintained. It had been noted by Olorunnisola (2007) that the thickness swelling of cement - bonded composites is highly dependent on particle geometry.

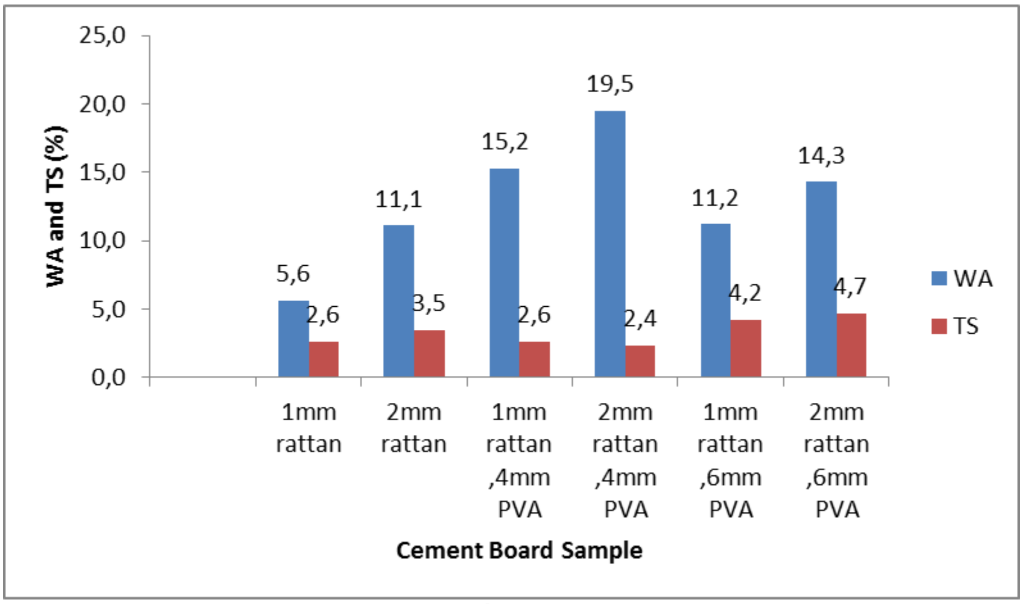

Fig. 10.
Effects of PVA on the WA and TS of the Boards.

Effects of PVA fibre incorporation on the thermal conductivity of the boards

Table 1 shows the computed thermal conductivities of the board samples. The thermal conductivity of the control samples fell between 0.38 and 0.74 while that of the PVA rattan fibre composites ranged between 0.59 and 1.07W/^{0}Cm. The 2mm rattan control sample had the lowest thermal conductivity value (0.38W/^{0}Cm). Addition of the 4mm PVA fibres lowered the thermal conductivity of the boards while the addition of the 6mm PVA fibres increased the thermal conductivity. The thermal conductivities of common asbestos boards ranges from 0.14 for Asbestos mill boards to 0.74 for Asbestos – cement boards (engineeringtoolbox.com). Hence all the boards except those produced with 2mm rattan and 6mm PVA fibres exhibited good potentials as ceiling board materials with desirable insulation properties.

Table 1

Thermal conductivity of the boards

Board Sample	**Density** (kg/m^3)	**Thermal Conductivity** (W/^{0}Cm)
1mm rattan	1685.08	0.74
2mm rattan	1714.23	0.38
1mm rattan + 4mm PVA	1338.57	0.67
2mm rattan + 4mm PVA	1327.37	0.61
1mm rattan + 6mm PVA	1598.88	0.59
2mm rattan + 6mm PVA	1435.44	1.07

CONCLUSIONS

The following are the conclusions drawn from the study:

i. The density and strength of rattan-cement boards containing longer (6mm) PVA fibres were higher than those containing shorter (4mm) PVA fibres.
ii. The rattan - PVA fibre reinforced cement boards displayed relatively low bending strength compared to ordinary rattan fibre cement - bonded composite.
iii. PVA fibre addition significantly increased the water absorption of the boards but the boards could still be used under moderate moisture exposure.
iv. The range of thermal conductivity values for the PVA - rattan composite boards (0.38 - 0.59W/^{0}Cm) is comparable to those of some existing ceiling boards used in present day building construction.

REFERENCES

Adefisan OO, Olorunnisola AO (2012) strength and sorption properties of cement bonded composites made from *Calamus deeratus* and *Laccosperma secundiflorum* canes. ASUU Journal of Science 1(1):51-66.

Ahmed BA, Tahir MP, Rahim S, H'ng PS, Zakiah A, Ahmed SH (2017) Physical-mechanical characteristics of cement-bonded kenaf bast fibres composite boards with different densities. Journal of Engineering Science and Technology, 12(8):2254-2267.

Ahmed SFU, Mihashi H (2011) Strain hardening behaviour of lightweight hybrid polyvinyl alcohol (PVA) fiber reinforced cement composites, Mater. Struct. 44(6):1179–1191

ASTM (2010) Standard test methods for evaluating properties of wood-base fiber and particle panel materials, D1037-06a. West Conshohocken, PA: ASTM International.

IS 14862 (2000) Bureau of Indian Standards, Fibre cement flat sheets-specification, 2000.

Horikoshi T, Ogawa Saito AT, Hoshiro H (2006) Properties of polyvinyl alcohol fiber as reinforcing materials for cementitious composites, Int. RILEM Work. High Perform. Fiber Reinf. Cem. Compos. Struct. Appl., RILEM SARL, pp. 145-153.

Hu W, Yang XG, Xing HG, Xiang J (2013) Experimental research on the mechanical properties of PVA fiber reinforced concrete, Res. J. Appl. Sci. Eng. Technology. 5(18):4563–4567.

Olorunnisola AO, Pitman A, Mansfield William H (2005) Strength properties and potential uses of Rattan-Cement composites. In: Journal of Bamboo & Rattan, 4(4):343-352.

Olorunnisola AO (2007) Effects of particle geometry and chemical accelerator on strength properties of rattan - cement composites. Afr. J. Sci. Technol. 8(1):22 - 27.

Olorunnisola AO (2008) Effects of Pre-Treatment of Rattan (Laccosperma secundiflorum) on Hydration of Portland Cement and the Development of a new Compatibility Index. Cement and Concrete Composites, 30(1):37-43.

Olorunnisola AO, Agrawal SP (2015) Effects of NaOH concentration and fibre content on physico-mechanical properties of cement-bonded rattan fibre composites. Pro Ligno, Int. J. of Wood Eng. 11(4):192-198.

Sarja A (1988) Wood Fiber reinforced concrete. In R.N Swamy (Ed), Natural fibre reinforced cement and concrete. Blakie and sons Ltd, Glasgow. pp. 63-91.

Xu B, Toutanji HA, Lavin T, Gilbert JA (2011) Characterization of Polyvinyl alcohol Fiber reinforced organic aggregate cementitious materials, Key Eng. Matter, 466:73–83.