ONLINE ISSN 2069-7430
ISSN-L 1841-4737
**PRO LIGNO**
www.proligno.ro
Vol. 11 N° 4 2015
pp. 192-198

# EFFECTS OF NaOH CONCENTRATION AND FIBRE CONTENT ON PHYSICO-MECHANICAL PROPERTIES OF CEMENT-BONDED RATTAN FIBRE COMPOSITES

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***Abstract***

*Fibre cement composites are generally used as non-conventional materials in building construction. The sources of fibre are, however, many and varied. There is also a current emphasis on the use fibres derived vegetable materials. This study investigated the effects of sodium hydroxide (NaOH) concentration and fibre-cement ratio on strength and sorption properties of cement-bonded composites produced from rattan cane (Laccosperma secundiflorum fibre). Fibre production was carried out using 10, 15 and 20% sodium hydroxide solutions (w/v) respectively. Composites were manufactured in a low pressure system incorporating rattan fibre at 5, 10 and 15% by weight of cement respectively. The mean Modulus of Rupture (3.5 to 6.4MPa), Water absorption at 1 h (18.5 - 24.2%) and 24 h (19.3 – 26.5%) and Thickness Swelling at 1 h (0.1 -1.4%) and 24h (0.6 – 7.3%) of the composites produced compared favourably with values reported in literature for fibre-reinforced cement composites. Also, fibre content, NaOH concentration and the interaction of both variables had significant effects (p<0.05) on the water absorption characteristics of the composites.*

***Key words****: rattan; fibre; chemical digestion; cement composite.*

## INTRODUCTION

In recent years, natural fibres derived from wood and vegetable sources including coconut husk, sisal, jute, flax, sugar cane bagasse, bamboo, hemp, straw, switch grass, kenaf etc., have been investigated for possible use in the manufacture of non-conventional composites as alternatives to asbestos-cement products (Savastano *et al.* 2003, O'Donnell *et al.* 2004, Sudin and Swamy 2006, Saxena *et al.* 2008). These relatively plentiful, short, strong, and cheap fibres are particularly suited for the reinforcement of flat and corrugated thin-sheet components (typically about 10mm thick) for roofing, exterior and interior wall paneling etc. The matrix is usually a cement paste or mortar and the fibre content can be as high as 10% or more by weight of cement (Mindess 1995, Morgan *et al.* 1995, Baski *et al.* 2003). Apart from low cost, other benefits of natural fibres over synthetic ones such as carbon, steel, polypropylene and glass fibres include low density, acceptable specific strength, easy extraction, $CO_2$ sequestration, and biodegradability (Saxena *et al.* 2008). Besides, fungal cellar tests on selected natural fibre-reinforced materials have shown little microbiological activity, attesting to their potential long-term durability (Soroushian *et al.*1995).

However, natural fibres sometimes suffer degradation in the alkaline environment of cement matrix. An efficient way of minimizing the degradation is chemical pulping which dissolves the middle lamella, the alkali-soluble hemicelluloses and the thermoplastic lignin that binds the fibres together, thereby isolating the individual fibres to become reinforcing units and enhancing their durability (Coutts 1988, Bentur and Szilard 1998). In the kraft process often used to produce chemical pulp for fibre-cement composite, the chips are typically treated with sodium sulphide or sodium hydroxide, under conditions of high temperature and pressure resulting in pulp yields of between 45 and 60%. The process operates under alkaline conditions which cause less harm to cellulose than the acidic condition of the alternative sulphite process (Coutts 1988).

Rattan canes are numbered among the important commercial non-timber forest products employed in furniture manufacture in many parts of the tropics. However, over 30% of rattan stems harvested at any particular time for furniture manufacture is wasted. Besides, only about 20% of the over 600 known rattan species produce the most sought-after fine quality canes of commercial value. The low quality canes are seldom utilised due to inflexibility, tendency to breakage, poor mechanical properties (Liese 2002). Previous studies have confirmed the suitability of a number of rattan cane particles of different species for cement-bonded composite production (Olorunnisola and Adefisan

2002, Adefisan and Olorunnisola 2007, Olorunnisola 2008). These studies were on the use of hammer-milled rattan particles for cement-bonded composite production.

**OBJECTIVE**

The objective of this study, therefore, was to investigate the effects of chemical digestion on the strength and sorption properties of fibre-cement composites from rattan cane (*Laccosperma secundiflorum)*.

**MATERIALS AND METHODS**

**Particle Digestion and Fibre Characterization**

Rattan canes harvested from Gambari forest reserve Ibadan, Oyo state, Nigeria were cut into billets, air-dried for two weeks and hammer-milled into particles for digestion (Fig. 1). The particles were digested using the kraft (soda) process. Sodium hydroxide (NaOH) solutions were prepared at three different concentrations, i.e., 10%, 15% and 20% (w/v) and used to digest the particles at a pressure of 1 atmosphere for 2h. The fibres obtained (Fig. 2) were then washed with cold water and oven-dried. Their moisture content and loose bulk densities were then determined in accordance with BS 3797 (1990).

***Fig. 1.***
***Hammer-milled Rattan Cane Particles***

***Fig. 2.***
***NaOH-Digested Rattan Cane Fibres***

**Fibre-Cement Composite Production**

Fibre-cement composites were manufactured by manual dry-mixing of ratan fibres and Type 1 Portland cement (general purpose, class strength 42.5) in a plastic container at different fibre contents (5%, 10% and 15% respectively) and a target density of 1,500kg/ $m^3$. From preliminary experiments, 50ml potable water was found adequate and was used for mixing. Each wet mixture was poured into single units of 150 x 150 x 25mm metallic moulds, placed in a hydraulic cold press set at a pressure of 355kg/$cm^2$ (6.6N/$mm^2$) 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$^0$C) under wet towels for the first seven days, and then in a chamber maintained at a constant temperature and relative humidity of 25 ±2$^0$C and 65 ± 5% respectively for 21 days. Three specimens from each mixture were tested at 28 days. The moisture contents and oven-dry densities of the specimens were also determined.

**Composite Property Tests**

Three 150 x 50mm specimens obtained from each NaOH concentration and fibre-cement ratio combinations were subjected to bending test to obtain the Modulus of Rigidity (MOR) and fracture toughness in accordance with Indian standard, IS 14862 (2000), on the 28$^{th}$ post-production day. Both properties were measured in 3-point loading perpendicular to the direction of casting adopting a span of 100mm and mid-span deflection rate of 1.0mm/min on a 20kN capacity Universal Testing Machine (UTM) (Shimadzu, Model AGS2000G). Toughness was defined as the energy absorbed during the flexural test and divided by the specimen cross-sectional area. The absorbed energy, often calculated by integration of the area below the load-deflection curve, was automatically generated by the UTM.

For the determination of water absorption and thickness swelling, three 150 x 150mm specimens each were thoroughly sand-papered and dried in an electric oven set at 60 ± 5$^0$C until constant weight (≤0.1% weight change) was achieved. The specimens were then brought to room temperature (25 ± 2$^0$C) 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 of each specimen was first measured and recorded. They were then completely immersed horizontally in potable water maintained at a temperature of 20 ±2$^0$C (Fig. 4). 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. Investigations on the relationship between density and water absorption by immersion were conducted to predict the 24h total water absorption of the composites based their density in line with the predictive equation proposed by Sarja (1988) for wood concretes, i.e.,

$$w = (800/ \rho)\ 50 \qquad (1)$$

where: w = total water absorption compared with the dry weight of concrete oven-dried at 105$^0$C (%)
ρ = Density of oven-dried concrete (Kg/m$^3$)

**Statistical Analysis**

All property test results were subjected to analysis of variance procedure for 2-factorial experiment at 5% level of significance.

## RESULTS AND DISCUSSION

### Physical Properties of the Rattan Cane Fibres

Table 1 shows the physical properties of the digested rattan cane fibres. The fibre yields obtained at 10 to 20% NaOH concentration ranged between 30 and 53.8%. The yield decreased with increasing NaOH concentration. The loose bulk density ranged between 124 and 140kg/m$^3$ at a moisture content range of 4.1 – 5.7%. The bulk density values are comparable to the 120.2kg/m$^3$ reported by Olorunnisola (2004) for un-digested rattan cane particles but are relatively low, compared to the loose bulk densities of some other fibres that have been reportedly used in literature for making fibre reinforced cement composite such as piassava (470- 861kg/m$^3$) and jute (301kg/m$^3$) (Aggarwal *et al*. 2008). There was a discernible relationship between NaOH concentration and bulk density of the fibre with the fibres produced at lower NaOH concentration (10%) exhibiting higher bulk density.

*Table 1*

*Physical Properties of NaOH-Digested Rattan Cane Fibres*

| NaOH concentration (%) | Fibre Yield (%) | Moisture Content of Rattan Cane Fibre (%) | Loose Bulk Density (Kg/m$^3$) |
|---|---|---|---|
| 10 | 44.8 | 5.7 | 140 |
| 15 | 53.8 | 4.5 | 126 |
| 20 | 30.0 | 4.1 | 124 |

*Table 2*

*Densities and Moisture Contents of the Rattan Fibre-Cement Composite mples*

| Specimen Designation[1] | Fibre Content (%) | NaOH Concentration[2] (%) | Mean Thickness[3] (mm) | Oven Dry Density[3] (Kg/m$^3$) | Oven Dry Moisture Content (%) |
|---|---|---|---|---|---|
| RFC2.510 | 2.5 | 10 | 6.3 | 1595 | 7.9 |
| RFC 2.515 | 2.5 | 15 | 6.7 | 1485 | 7.3 |
| RFC 2.520 | 2.5 | 20 | 6.5 | 1595 | 5.5 |
| RFC 5.010 | 5.0 | 10 | 10.2 | 1455 | 9.6 |
| RFC 5.015 | 5.0 | 15 | 6.3 | 1465 | 6.6 |
| RFC 5.020 | 5.0 | 20 | 10.5 | 1506 | 10.6 |
| RFC 7.510 | 7.5 | 10 | 11.6 | 1403 | 8.9 |
| RFC 7.515 | 7.5 | 15 | 7.8 | 1325 | 6.6 |
| RFC 7.520 | 7.5 | 20 | 11.4 | 1353 | 8.2 |

[1]**RFC**= Rattan Fibre Composite. The first figure in each designation represents fibre content, while the second figure represents NaOH concentration, e.g., RWF 2.510 means 2.5% fibre content and 10% NaOH concentration
[2]Concentration of NaOH was on the basis of mass per volume (w/v) of water
[3]Average of three values

**Density of Composites**

Fig. 3 shows the rattan cane fibre-reinforced composits produced. The oven-dry densities of the composites ranged between 1325 and 1595Kg/m$^3$ while the moisture content varied between 5.5 and 10.6% (Table 2). These values are much higher than those reported by Olorunnisola (2004, 2005) and Olorunnisola et al., (2005) for cement-bonded particleboards from the same rattan species. This is largely due to the fat that the cement contents of the composites reported in these previous studies were less than the 85% used in the current study. This assertion is further corroborated by the fact that, there was negative correlation between bulk densities of the rattan fibres produced at different NaOH concentrations (Table 1) and the densities of the composites. As would be expected, also, the density of the composites decreased with increase in wood fibre content. Composites produced with the lowest fibre content (2.5%) therefore exhibited the highest density.

***Fig. 3.***
***Samples of the Rattan-fibre cement Composites Produced***

**Modulus of Rupture (MOR)**

The MOR of the composites (Table 3) ranged between 3.5 and 6.4MPa. These values compare favourably with values reported in literature (3.84 - 6.18N/mm$^2$) for fibre reinforced cement composites produced sisal fibres by Agopyan (1988). Fibre content, NaOH concentration and the interaction of both variables had significant effects on the MOR of the composites. There was a general decrease in MOR with increase in fibre content, indicating a progressive decrease in bond strength. This observed decrease in MOR at high fibre volumes can be explained on the basis of inefficient compaction and lower density of the mix. As noted by Hannant (1978), strength properties of natural fibre- reinforced composites are functions of fibre content (volume or mass), fibre aspect ratio, fibre properties, properties of the constituent materials, and casting pressure. The observed decrease may also be attributed to section depth effect. As shown in Table 2, there was an increase in section depth (thickness of specimens) with increase in fibre content. Hannant (1978) had also noted that the MOR for deep sections would likely be less than for thin sections because the primary cracks tend to be wider for deep sections than for thin sections.

**Water Absorption**

Water Absorption (WA) at 1 and 24h are presented in Table 3 showing a range of 18.0 to 24.2% after 1h and between 19.3 and 26.0% after 24h of immersion respectively. Only the fibre content had significant effect on the WA of the composites. There was an increase in WA with increase in fibre content. This could be attributed to decrease in density and corresponding increase in porosity with increasing fibre content. Composites produced using fibres digested with 20% NaOH solution and incorporated at 5% exhibited the lowest WA, while composites produced at 20% fibre content exhibited the highest WA. The 24h WA values compare favourably with findings of Okino *et al.* (2004) on WA in eucalyptus-cement composites and that of Oyagade (2000), Olorunnisola and Adefisan (2002), Ajayi (2003, 2006), Olorunnisola (2005), and Aggarwal *et al.* (2008) on cement-bonded composites

ONLINE ISSN 2069-7430 ISSN-L 1841-4737 PRO LIGNO www.proligno.ro Vol. 11 N° 4 2015 pp. 192-198

*Table 3*

***Strength and Sorption Properties of the Rattan Fibre-Cement Composite Samples***

| Specimen Designation[1] | Fibre Content (%) | NaOH Concentration[2] (%) | MOR[3] ($N/mm^2$) | [3]WA (%) | | TS | |
|---|---|---|---|---|---|---|---|
| | | | | 1h | 24 h | 1h | 24h |
| RFC 2.510 | 2.5 | 10 | 4.5 | 18.2 | 20.1 | 0.1 | 0.6 |
| RFC 2.515 | 2.5 | 15 | 4.8 | 18.9 | 19.6 | 1.2 | 2.6 |
| RFC 2.520 | 2.5 | 20 | 6.4 | 17.5 | 19.3 | 0.3 | 0.9 |
| RFC 5.010 | 5.0 | 10 | 4.4 | 18.0 | 24.2 | 1.3 | 1.7 |
| RFC 5.015 | 5.0 | 15 | 3.7 | 21.7 | 22.6 | 0.7 | 1.5 |
| RFC 5.020 | 5.0 | 20 | 4.2 | 22.5 | 25.0 | 0.3 | 4.0 |
| RFC 7.510 | 7.5 | 10 | 4.1 | 23.2 | 26.5 | 0.7 | 3.5 |
| RFC 7.515 | 7.5 | 15 | 3.5 | 23.7 | 25.2 | 1.4 | 1.7 |
| RFC 7.520 | 7.5 | 20 | 5.0 | 24.2 | 26.0 | 0.4 | 1.5 |

**1RFC**= Rattan Fibre Composite. The first figure in each designation represents fibre content, while the second figure represents NaOH concentration, e.g., RWF 2.510 means 2.5% fibre content and 10% NaOH concentration
**2**Concentration of NaOH was on the basis of mass per volume (w/v) of water
**3**Average of three values

*Table 4*

***Comparison of Observed and Predicted 24h Water Absorption***

| Specimen Designation | [1] Oven-Dry Composite Density ($Kg/m^3$) | [1] Observed Water Absorption at 24h (%) | Predicted Water Absorption at 24h (%) | Percentage Difference (%) |
|---|---|---|---|---|
| RFC 2.510 | 1595 | 20.1 | 25.1 | +24.8 |
| RFC 2.515 | 1485 | 19.6 | 26.9 | +37.4 |
| RFC 2.520 | 1595 | 19.3 | 25.1 | +29.9 |
| RFC 5.010 | 1455 | 24.2 | 27.5 | +13.6 |
| RFC 5.015 | 1465 | 22.6 | 27.3 | +20.8 |
| RFC 5.020 | 1506 | 25.0 | 26.6 | +6.2 |
| RFC 7.510 | 1403 | 26.5 | 28.5 | +7.6 |
| RFC 7.515 | 1325 | 25.2 | 30.1 | +19.8 |
| RFC 7.520 | 1353 | 26.0 | 29.6 | +13.7 |

[1]Average of three values

manufactured using agricultural and forestry residues such as coconut husk, maize stalk, coffee husk, arhar stalks, and rattan furniture waste.

A comparison of the observed and the predicted WA values is presented in Table 4. The percentage differences between observed and predicted WA values are relatively small. This suggests that the prediction model could be used in determining the anticipated water absorption of the eucalyptus fibre-cement composites.

**Thickness Swelling**

The TS values of the composites at 1 and 24 hours are shown in Table 3. The values ranged between 0.1 and 1.4 at 1 hour, and 0.6 and 4.0 at 24 hours. These TS fall within the range of values reported by Olorunnisola (2004, 2005) in previous works on cement-bonded particleboards from the same rattan cane species. These values are relatively low suggesting that the composites from rattan cane are dimensionally stable and could be used for outdoor applications in roofing and ceiling, among others. Only the fibre content had significant effect on the TS of the composites at 1hr and 24hr.

**CONCLUSIONS**

Fibre-Cement composites were produced from rattan cane **(***Laccosperma secundiflorum***)**. The composites were tested for strength and water absorption properties. Results obtained showed that:
1. Digestion of the rattan cane particles in 10 to 20% NaOH solution (w/v) for two hours at a cooking pressure of 1 atmosphere is sufficient to produce fibres for acceptable fibre-cement composite manufacture.

2. Rattan cane fibre digested with 10% to 20% NaOH solution and used to produce fibre-reinforced cement composites that meet the minimum bending strength requirement of 4.0 N/mm$^2$ stipulated in Indian Standard IS 14862 (2000) for category 1, Type B fibre cement flat sheets intended for internal and external applications such as roofing, ceiling and wall tiles.

**ACKNOWLEDGEMENTS**

This study was conducted at the Organic Building Materials Division, Central Building Research Institute (CBRI), Roorkee, 247 667, India, with a post-doctoral fellowship grant award jointly sponsored by the Council for Scientific and Industrial Research (CSIR), India, and The Academy of Science for the Developing Countries (TWAS), Italy. The financial support by CSIR/TWAS and the technical/moral support by the CBRI are hereby acknowledged with thanks.

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