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EFFECTS OF SODIUM HYDROXIDE CONCENTRATION AND FIBRE CONTENT ON CEMENT-BONDED COMPOSITES FROM EUCALYPTUS VENEER WASTE

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Abstract:
This study investigated the effects of sodium hydroxide concentration and wood fibre-cement ratio on strength and sorption properties of cement-bonded composites produced from eucalyptus (Eucalyptus tereticornis Sm.) veneer waste. Wood digestion was carried out using 10, 15 and 20% (w/v) sodium hydroxide solutions respectively. Composites were manufactured in a low pressure system incorporating digested wood at 5, 10 and 15% inclusion by weight of cement respectively at a target density of 1200kg/m^3. The Modulus of Rupture (MOR) (2.3 and 4.4MPa) compared favourably with values reported in literature for fibre reinforced cement composites, while MOR/ultimate tensile strength ratio ranged between 2.8 and 7.1. Fibre digestion with 20%NaOH solution and incorporation at 5% content (by weight of cement) exhibited the lowest water absorption. The observed 24h thickness swelling satisfied international standards. Fibre content, NaOH concentration and the interaction of both variables had significant effects (p<0.05) on 1h and 24h WA respectively

Key words: *Eucalyptus; Veneer waste; Chemical digestion; Cement composite.*

INTRODUCTION

Up until the 1970s, asbestos-cement sheets remained the most favoured products employed for ceiling and roofing purposes due largely to its excellent performance characteristics. However, in the last three of decades, there has been a concerted global effort aimed at discouraging the continued use of asbestos-cement products. This is due to the detrimental work-related health hazards associated with handling of asbestos (Baski *et al.* 2003, Saxena *et al.* 2008). As alternatives, fibres derived from various sources including hardwoods and softwoods (cellulose fibre), coconut husk (coir fibre), sisal, jute, flax, sugar cane bagasse, bamboo, hemp, straw, switch grass, kenaf, etc are being used (Savastano *et al.* 2003, O'Donnell, *et al.* 2004, Sudin and Swamy 2006, Saxena *et al.* 2008). These relatively short, strong, cheap, and plentiful fibres, with relatively low energy demand, are particularly suited for the reinforcement of thin-sheet cement components such as flat and corrugated sheets and shingles which have a typical thickness of about 10mm. 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 (Baski *et al.* 2003).

However, wood fibres sometimes suffer degradation in the alkaline environment of cement matrix. The most efficient way of minimizing the degradation is the adoption of chemical pulping treatments to isolate the individual fibres to become reinforcing units and enhancing their durability (Bentur and Szilard 1998). The chips are typically treated with sodium sulphide and sodium hydroxide, under conditions of high temperature and pressure and gives 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 (since cellulose is more easily hydrolyzed by acids than by alkalis).

Previous studies have been conducted on the use of eucalyptus wood particles and fibres for cement-bonded composites (Semple *et al.* 2002, Savastano *et al.* 2003, Okino *et al.* 2004). There is a need to study the behavior of wood fibre - composites from Indian-grown species. The objective of this study, therefore, was to investigate the effects of sodium hydroxide concentration and wood fibre-cement mixing ratio on strength and sorption properties of fibre-cement composites from Indian-grown *E. tereticornis* Sm veneer waste.

MATERIALS AND METHODS

Peeler cores from *E. tereticornis* Sm. veneer manufacturing waste with an average length of 1.24m and average diameter of 44cm, were obtained from Yamuna Nagai, Himachal, India. These were cross-cut to billets of about 30cm each and hammer-milled into chips for digestion. Sodium hydroxide (NaOH) solutions were produced at three different concentrations, i.e., 10%, 15% and 20% (w/v) and used to digest the chips at a pressure of 1 atmosphere for 2h. The fibres were then washed with cold water. The loose bulk densities of the fibres were determined in accordance with BS 3797 (1990). For water absorption test, 20g of oven dried samples were completely immersed 300ml of distilled water and washed after 24h. Water absorption was computed as in Aggarwal *et al*. (2008).

Fibre-cement composites were manufactured by manual dry-mixing of eucalyptus wood fibres and Type 1 Portland cement (class strength 42.5) in a plastic container at different fibre contents (5%, 10% and 15% respectively) and a target density of 1,300kg/m^3. From preliminary experiments, 50ml potable water was found adequate for mixing. Each wet mixture was cold - pressed at a pressure of 355kg/cm^2 (6.6N/mm^2) for 6 to 8 hours. Once de-moulded after 24 hours, 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 to obtain the Modulus of Rigidity (MOR), water absorption and thickness swelling in accordance with Indian standard, IS 14862 (2000). The moisture contents and densities of the specimens were also determined. All 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 Eucalyptus Fibres

As shown in Table 1, the loose bulk density of the fibres ranged between 195 and 276kg/m^3 at a moisture content of 5.0 – 6.2%, while the water absorption ranged between 283.7% and 299.7%. The bulk density and water absorption values compare favourably with those reported in literature for different types of wood and vegetable fibres used in cement composites) (Aggarwal *et al.* 2008). There was no clearly discernible relationship between NaOH concentration used for digestion and bulk density/ water absorption of the pulps. Pulps produced at 15% NaOH concentration exhibited the highest bulk density and water absorption rate.

Density of Composites

The green densities of the composites ranged between 1300 and 1600Kg/m^3 while the moisture content varied between 7.6 and 12.0% (Table 2). The density values fall within the range of values stipulated for structural wood fibre concrete, i.e., 1200 – 2000Kg/m^3. Composites produced with 10% NaOH-digested fibres exhibited the highest density values. Also, as would be expected, the density decreased with increase in wood fibre content.

Modulus of Rupture (MOR)

The MOR of the composites (Fig. 1) ranged between 2.3 and 4.4MPa. These values are within the range of values (1.7 to 5.5MPa) reported in compilation of physical and mechanical properties of several kinds of low density cement-bonded particleboards (500 to 1000kg/m^3) by Forest Products Laboratory (1999). They are, however, lower than 5.8 to 6.4MPa reported by Okino *et al.* (2004) for cement-bonded wood particleboard produced with a mixture of eucalyptus and rubber wood and the minimum of 9.0MPa stipulated in ISO 8335 (1987). Only samples produced using fibres digested with 10% and 20% NaOH solution and incorporated at 5% fibre content met the minimum requirement of 4.0N/mm^2 stipulated in Indian Standard IS 14862 (2000) for category 1 Type B fibre cement flat sheets intended for internal and external applications. The relatively low MOR of the composites could be attributed to the relatively low pressure and the resulting low density of the composites. There was a general decrease in MOR with increase in fibre content, indicating a progressive decrease in bond strength. This can be explained on the basis of inefficient compaction and lower density of the mix. The observed decrease may also be attributed to section depth effect. As shown in Table 3, there was an increase in section depth.

Table 1

Physical Properties of NaOH-Digested Eucalyptus Wood Chips

NaOH concentration (%)	Moisture Content of Pulp Fibre (%)	Loose Bulk Density (Kg/m^3)	24h Water Absorption (%)
10	5.0	195	289.8
15	6.2	276	299.7
20	6.2	239	283.7

Table 2

Densities and Moisture Contents of the Composites

Specimen Designation[1]	Fibre Content (%)	NaOH Concentration[2] (%)	Mean Thickness[3] (mm)	Mean Density[3] (g/cm^3)	Moisture Content (%)
EFC510	5	10	10.6	1.60 ±0.02	11.3
EFC515	5	15	10.6	1.47 ± 0.08	10.1
EFC520	5	20	9.3	1.62 ± 0.01	10.6
EFC1010	10	10	11.8	1.46 ± 0.03	12.0
EFC1015	10	15	11.7	1.29 ± 0.01	8.5
EFC1020	10	20	11.9	1.39 ± 0.08	9.2
EFC1510	15	10	13.2	1.32 ± 0.03	9.9
EFC1515	15	15	12.8	1.33 ± 0.05	7.6
EFC1520	15	20	12.9	1.28 ± 0.06	10.0

[1]The first figure in each designation represents fibre content, while the second figure represents NaOH concentration, e.g., EFC 510 means 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

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Table 3

ANOVA on the Effects of Fibre-Cement Ratio and Sodium Hydroxide Concentration on Properties of Eucalyptus Fibre -Cement Composite

Source of Variation	Degree of Freedom	Mean Square Modulus of Rupture	Mean Square WA (1h)	Mean Square WA (24h)	Mean Square TS (1h)	Mean Square TS (24h)
Fibre Content (A)	2	4.77*	115.23*	93.10*	0.12	0.51
NaOH Concentration (B)	2	2.22	51.92*	34.25*	0.27	1.79
Interaction (AB)	4	1.00	49.47*	40.37*	0.31	0.98
Error	18	0.66	3.81	3.34	0.83	0.60
Total	26					

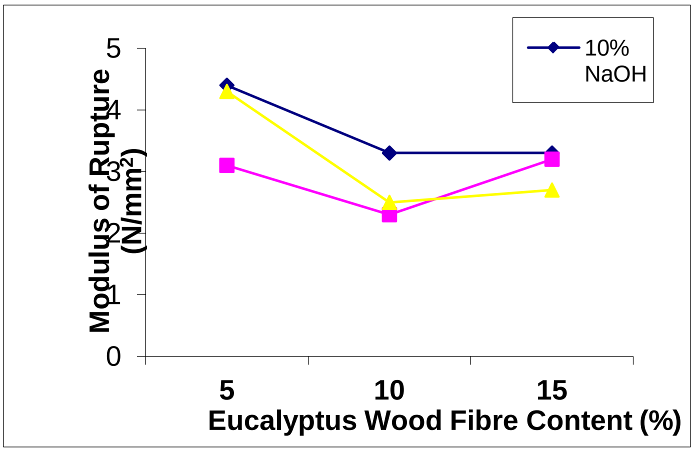

Fig. 1
Effects of NaOH Concentration and Fibre Content on Modulus of Rupture.

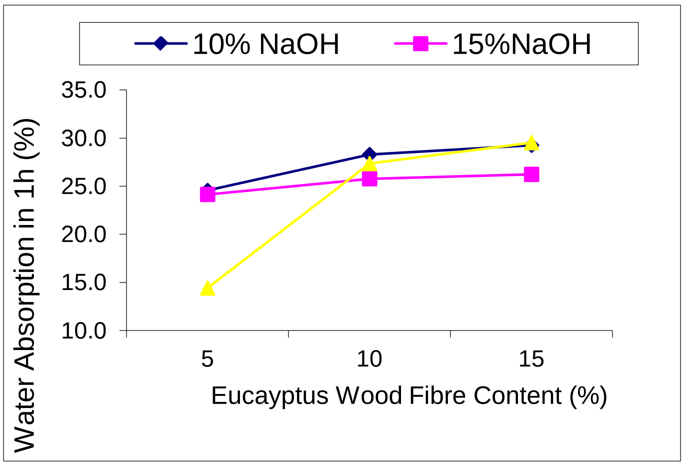

Fig. 2
Effects of NaOH Concentration and Fibre Content on 1h Water Absorption.

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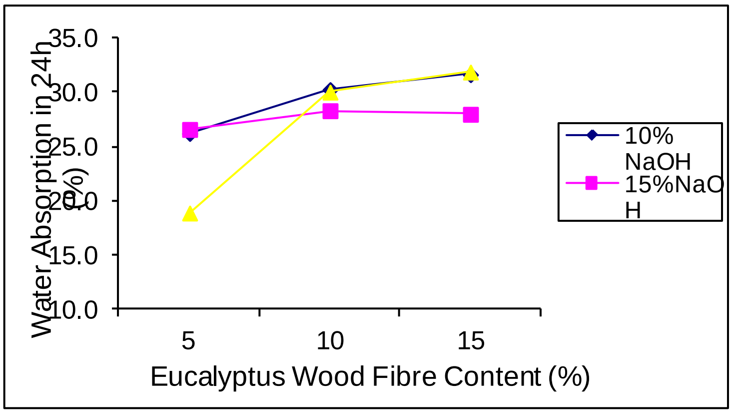

Fig. 3
Effects of NaOH Concentration and Fibre Content on 24h Water Absorption.

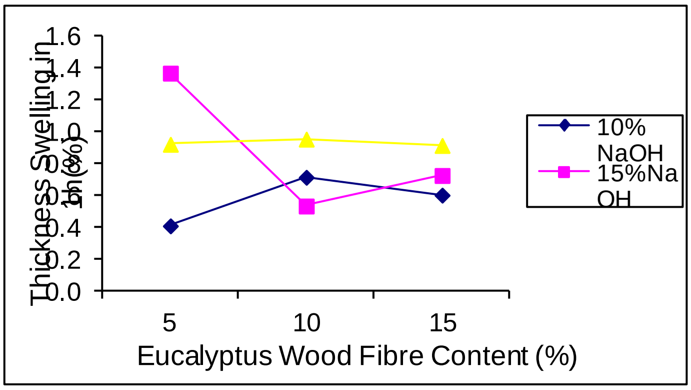

Fig. 4
Effects of NaOH Concentration and Fibre Content on 1h Thickness Swelling

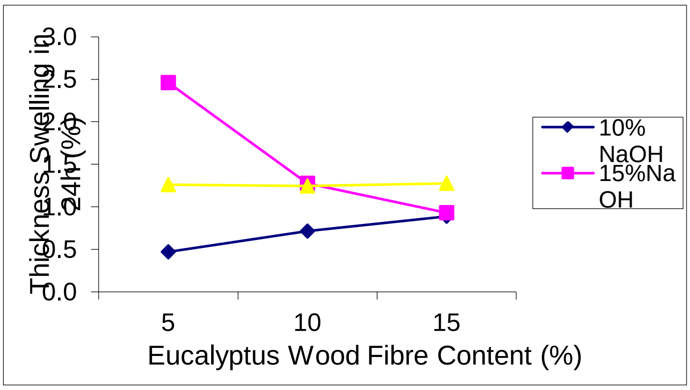

Fig. 5
Effects of NaOH Concentration and Fibre Content on 24h Thickness Swelling.

(thickness of specimens) with increase in fibre content. Hannant (1978) had 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. Only fibre content had significant effect (at 0.05 level) on the MOR of the composites (Table 3). Also, the MOR values of composites produced with fibres digested with 10 and 20% NaOH were virtually the same, suggesting that 10% NaOH would be sufficient for the digestion of the eucalyptus wood particles for fibre-cement composite production.

Water Absorption and Thickness Swelling

Water Absorption (WA) values ranged between 14.4 and 29.5% after 1h and between 18.9 and 31.9% after 24h of immersion respectively (Fig. 2 and 3). Composites produced using fibres digested with 20% NaOH solution and incorporated at 5% exhibited the lowest WA, while composites produced at 15% fibre content exhibited the highest WA. This could be attributed to decrease in density and corresponding increase in porosity with increasing fibre content. Fibre content, NaOH concentration and the interaction of both variables had significant effects ($p<0.05$) on 1h and 24h WA respectively (Table 3). In virtually all specimens, between 80 and 90% of the water was absorbed in the first 1 hour of soaking, perhaps a reflection on the great affinity for water. The TS (Fig. 4 and 5) ranged between 0.4 and 1.4% after 1h and between 0.5 and 2.5% after 24h of immersion respectively. The TS at 24h satisfies BS 5669 (1989) requirements. Composites produced with fibres digested with 10% NaOH gave the lowest TS values at 1 and 24h respectively.

CONCLUSIONS

Wood-Cement composites were produced from eucalyptus (*Eucalyptus tereticornis* Sm.) veneer waste. The composites were tested for strength and water absorption properties. Results obtained showed that digestion of the eucalyptus particles in 10% 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. Eucalyptus pulp fibre digested with 10% to 20% NaOH solution and incorporated at 5% fibre content can be used to produced 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.

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