INFLUENCES OF PARTICLE SIZE AND CEMENT CONTENT ON PROPERTIES OF CEMENT-BONDED COMPOSITES FROM EUCALYPTUS VENEER WASTE

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ABSTRACT

This study investigated the effects of particle size and wood-cement ratio on strength and sorption properties of cement-bonded composites from *Eucalyptus tereticornis* Sm. veneer waste. Composites were manufactured at a target density of 1000 kg/m^3 using sieved, hammer-milled eucalyptus particles at wood/cement ratios by weight of 10:90, 20:80 and 30:70 respectively. The loose bulk density of the eucalyptus particles ranged between 118 and 137 kg/m^3 at a moisture content of about 9.0 %, while water absorption at 24 hours ranged between 286.0% and 433.0%. Composites produced with particles retained on 0.045 mm sieve at 10% wood content exhibited superior strength properties and dimensional stability. The density of composites produced at 30% wood content was below 1000 kg/m^3, suggesting an upper limit of 20% for *E. tereticornis* Sm. particle addition in cement for composite production. The water absorption behavior of the composites indicates their unsuitability for outdoor applications.

KEYWORDS:

Eucalyptus; Cement composite; Water absorption.

INTRODUCTION

Cement-bonded composites (CBC), produced largely from a mixture of Portland cement and particles derived from compatible wood species and other lignocellulosics continue to find relevance in the global building industry in view of its admirable properties that have been enumerated by several researchers (Pereira *et* al 2006, Olorunnisola 2009). These include acceptable dimensional stability, resistance to biodegradation and fire, light weight, workability and non-emission of volatile organic substances. Some of the factors that influence the properties of CBC include geographic location and age of trees, cement content as well as particle geometry (size and aspect ratio).

Eucalyptus is a diverse genus of trees (and a few shrubs). It may be mature as a low shrub or as a very large tree There are more than seven hundred species of Eucalyptus, mostly native to Australia, with a very small number found in adjacent parts of New Guinea and Indonesia and one as far north as the Philippines islands. Eucalyptus trees are also cultivated throughout the tropics and subtropics including the Americas, England, Africa, the Mediterranean Basin, the Middle East, China and the Indian Subcontinent (Wikipedia 2009). The trees have many uses which have made them economically important. They provide many desirable characteristics for use as ornament, timber, firewood and pulpwood. Fast growth also makes eucalyptus suitable as windbreaks (Wikipedia 2009).

Eucalyptus was first planted in India around 1790 (Rao 1984). Since then, over 100 species have been introduced into the country, with *Eucalyptus tereticornis* Sm. acknowledged as one of the five most important species for pulping and veneer manufacturing (Purkayastha 1997). One of the wood residues generated during veneer manufacturing is peeler core waste for which economic means of utilization have to be found. Previous studies by Semple *et al.* (2002), Savastano, *et al.* (2003) and Okino *et al.* (2004) have shown that eucalyptus wood particles and fibres can be used for wood- and fibre-cement composite manufacture. Wood particles derived from five leaf-oil producing Western Australian mallee eucalypt species were found to be compatible with cement. The presence of bark in two out of the five species had some inhibitory effects on Portland cement (Semple *et al.* 2002).

The aim of this study was to investigate the effects of particle size and wood-cement mixing ratio on strength and sorption properties of wood-cement composites from eucalyptus veneer manufacturing waste.

MATERIALS AND METHODS

Particle Characterization

Peeler cores from *E. tereticornis* Sm. veneer manufacturing waste with an average length of 1.24 m and average diameter of 44 cm, were obtained from Yamuna Nagai, Himachal, India. These were air-dried in the laboratory at a temperature of 28± 2 ^{0}C and relative humidity of 40 ± 10% for about six months to reduce both the moisture and sugar contents. They were then cross-cut on a circular saw to billets of about 30 cm each and hammer-milled into particles. The oven-dry moisture content of the "as received" particles was determined, while sieve analysis was carried out with a set comprising 2.36 mm, 2.0mm, 1.7mm, 1.18mm, 0.85mm, 0.6mm and 0.045mm sieves in accordance with BS 812-103 (1990). Particles retained on 0.045mm, 0.6mm and 2.0 mm sieves were kept for experimental purposes. The loose bulk density of the sieved particles was determined in accordance with BS 3797 (1990).

For water absorption tests, 20g of oven dried particles retained on 2 mm, 0.6 mm and 0.045 mm sieves respectively were completely immersed in 300 ml of distilled water. The soaked particles were filtered after 24 h and washed with distilled water. The pH of the filtrate was determined using a graduated filter paper. The 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.

Composite Manufacture and Testing

Composites were manufactured with each of the three particle sizes at a target density of 1000 kg/m^3 as stipulated in ISO 8335 (1987). This was done by manually dry-mixing them with Portland cement in a plastic container at different cement: wood ratios by weight (90:10, 80:20 and 70:30) Potable water was then added to the dry mixture based on the equation proposed by Sandermann and Kolher (1964):

$$Q = 0.35C + (0.3 - M.C.) \qquad [1]$$

where Q = Quantity of water (Millilitres)

C = quantity of cement in the mixture (grams)

M.C. = Moisture content of the wood particles (%)

Each wet mixture was poured into single units of 150 x 150 x 25 mm metallic moulds, placed in a hydraulic cold press set at a pressure of 6.6 N/mm^2, pressed for between 6 and 8 hours, and 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 seven days, and then in a chamber for 21 days at a temperature of 25 ±2 ^{0}C and relative humidity of 65 ± 5 %. The moisture contents and densities of three specimens from each mixture were determined prior to property tests conducted on the 28th day.

Three 150 x 50 mm specimens from each composite were subjected to bending test to obtain the Modulus of Rupture (MOR) and toughness in accordance with ISO 8335 (1987). Both properties were determined from 3-point loading (perpendicular to the direction of casting) on a 20 kN capacity Universal Testing Machine (Shimadzu, Model AGS2000G). The span of each specimen was 100 mm while the cross-head speed was 1.0 mm/min. Toughness was defined as the energy absorbed during the flexural test divided by the specimen cross-sectional area. Tensile strength parallel to the plane of the specimens was also determined at the same cross-head speed on 150 x 50 mm.

For water absorption and thickness swelling tests, each specimen was 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 before complete immersion horizontally in potable water maintained at a temperature of 20 ±2 ^{0} C. Water Absorption 24 hours was 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 property test results were subjected to analysis of variance procedure for 2-factor factorial experiment at 5% level of significance.

RESULTS AND DISCUSSION

Physical Characteristics of the Eucalyptus Wood ParticlesTable 1 shows the distribution in the 'as received' eucalyptus particles while Table 2 shows the bulk densities and water absorption rates of the particles retained on different sieve sizes. Close to 50% of the particles were retained on sieve sizes ranging from 0.85 to 2.36 mm, while the loose bulk density ranged between 118 and 136 kg/m^3 at a

Table 1: Sieve Analysis of the 'As Received' *E. tereticornis* Sm. Wood Particles

Sieve Aperture (mm)	Retained Particles (%)	Passing Particles (%)	Cumulative Particles retained (%)
2.36	1.8	98.2	1.8
2.00	45.0	53.2	46.8
1.70	0.0	53.2	46.8
1.18	0.0	53.2	46.8
0.85	2.0	51.2	48.8
0.60	21.5	29.7	70.3
0.045	29.3	0.4	99.6
Pan	0.0	0.0	100.0

Table 2: Loose Bulk Densities and Water Absorption Rates of Eucalyptus Particles

Sieve Aperture (mm) on which particles were retained	Loose Bulk Density of Particles retained (Kg/m^3)	[1]24h Water Absorption (%)
0.045	124	433.0
0.60	118	405.3
2.00	137	286.0
'as received'	136	304.8

[1]Percentage of oven-dry mass

moisture content of 8.8 %. The values compare favourably with the loose bulk densities of other particles that have been reportedly used for making CBC such as cork (90-280 kg/m^3), coconut husk, rattan cane (78.0 -120.2 kg/m^3), sawdust and wood shavings from hard wood species (100 - 250 kg/m^3) (Karade 2003, Eriksson and Prior 2004, Olorunnisola *et al* 2005a,b, Olorunnisola 2006).

Water absorption at 24 hours ranged between 286.0% and 433.0%. Expectedly, there was a direct relationship between particle size and water absorption rate, with the smallest particles exhibiting the greatest absorption rate. The pH of the filtrates ranged between 6 and 6.5, indicating that the extractives derived from the particles were acidic.

Densities of Composites

Figure 1 shows samples of the eucalyptus-cement composites, while Table 3 shows their green densities. Composites produced with particles retained on the 0.045mm sieve consistently exhibited the highest density regardless of the cement content. Expectedly, the density decreased with increase in wood content and composite moisture content. The higher density of specimens having lesser amounts of particles reflects less void space and more continuous bonding of cement. The density of composites produced at 30% wood content was below 1000 Kg/m^3 stipulated in ISO 8335 (1987) as the minimum density for cement-bonded composites. This suggests that the upper limit of *E. tereticornis* Sm. particle addition in cement for composite production is around 20%.

Figure 2: Samples of Composites Manufactured

Table 3: Physical Properties of the Sieved Eucalyptus Particle-Cement Composites

Sieve Aperture on which particles were retained(mm)	Wood Content (%)	Mean Thickness of Board[1] (mm)	Mean Density[1] (kg/m^3)	Moisture Content[1] (%)
0.045	10	8.4	1250 ±0.01	1.7
0.6	10	8.8	1220 ± 0.01	3.6
2.0	10	9.0	1280 ± 0.04	4.1
0.045	20	10.3	1100 ± 0.06	2.6
0.6	20	10.7	1060 ± 0.02	3.3
2.0	20	10.6	1040 ± 0.01	4.4
0.045	30	11.8	990 ± 0.01	6.1
0.6	30	12.8	920 ± 0.03	5.5
2.0	30	13.2	890 ± 0.03	6.7

[1]Average of three values

Modulus of Rupture

The MOR of the composites produced with the different particle sizes and cement contents are shown in Figure 2. The values ranged between 0.5 and 1.8 N/mm^2 and compare favourably with the values reported by Semple *et al* (2002) for CBC produced from five Western Australian mallee eucalyptus species. Only composites produced with particles retained on 0.045 mm sieve exhibited MOR values that were within the range of values (1.7 to 5.5 N/mm^2) reported by the Forest Products Laboratory (1999) for low density cement-bonded particleboards. The MOR of all the composites however fell short of the minimum international standards of 9.0- 13 N/mm^2 (ISO8335 (1987).

The superior MOR of composites manufactured with particles retained on the 0.045 sieve is attributable to several reasons including density and section depth effects. These composites were generally denser and thinner in cross-section that others. It is a well established fact that denser composites tend to exhibit higher MOR values. Hannant (1978) had also noted that the MOR for composites having deep cross sections tend to be less than the MOR for thin sections because the primary cracks tend to be wider for deep sections than for thin sections.

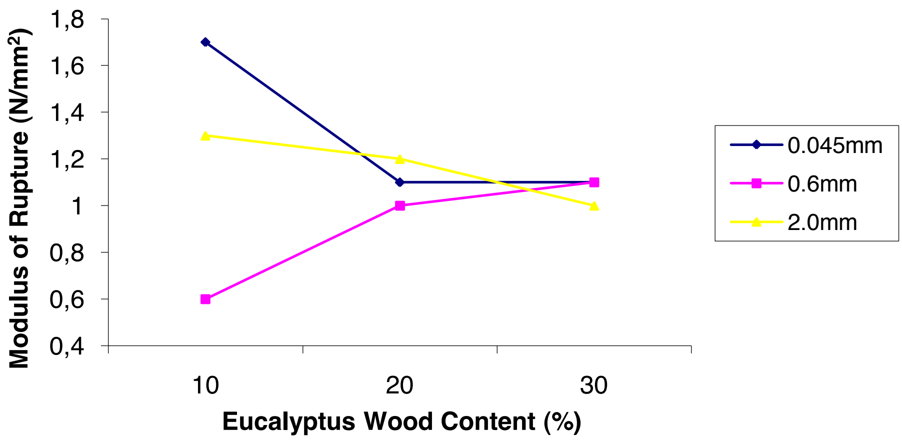

Figure 2: Effects of Particle Size and Wood Content on Modulus of Rupture of Composites

The MOR of the composites, except those produced with particles retained on 0.6 mm sieve, decreased with increase in wood content and particle size, indicating a progressive decrease in bond strength. As shown in Table 4, only particle size had significant effect on MOR. The observed decrease in MOR with increase in wood content may also be attributed to density and section depth effects. As shown previously in Table 3, there was an increase in section depth (thickness of specimens) and decrease in density with increase in wood content of the composites.

Water Absorption (WA)

The WA tests are presented in Figure 3. Composites produced with particles retained on 0.045mm sieve exhibited the lowest WA, while composites produced with particles retained on 0.6 mm sieve size and those produced at 30% wood particle content exhibited the highest WA. This could be attributed to their lower density and hence higher porosity. It is also an indication that the composites, particularly those incorporating more than 20% wood content, may not be suitable for external use. The WA values were higher than those reported by Semple *et* al (2002) for CBC produced from five Australian eucalyptus species. The values however compare favourably with published data on WA in cement-bonded composites manufactured using agricultural and forestry residues (Oyagade 2000, Ajayi, 2003, 2006, Olorunnisola and Adefisan 2002, Okino *et al.* 2004, Olorunnisola 2006, Aggarwal *et al.* 2008). Neither cement content nor particle size had significant effect on the WA.

Table 4: Analysis of Variance Test Results on the Effects of Wood-Cement Ratio and Particle Sizes on Properties of Eucalyptus-Cement Composite

Source of Variation	Degree of Freedom	Mean Square Modulus of Rupture	Mean Square WA	Mean Square TS
Cement Content (A)	2	0.05	1928.26	146.62*
Particle size (B)	2	0.41*	94.93	8.72
Interaction (AB)	4	0.22	15.98	5.39
Error	18	0.10	-15.13	7.17
Total	26			

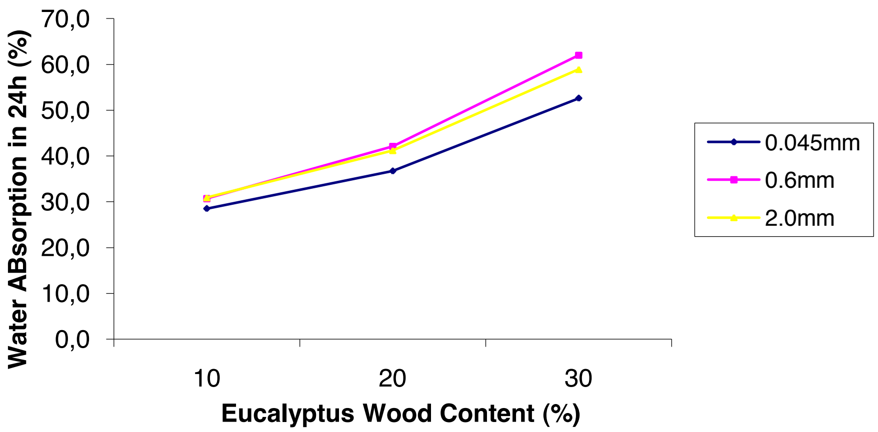

Figure 3: Effects of Particle Size and Wood Content on 24h Water Absorption

Thickness Swelling (TS)

The TS values are presented in Figure 4. They exceed the range of values reported by Semple *et* al (2002) for CBC from five Australian eucalyptus species, perhaps due to the higher WA mentioned in the preceding paragraph. Only composites produced with particles retained on 0.045mm sieve at 10 % cement content exhibited acceptable thickness swelling of about 2% that satisfied the ISO 8335 (1987), Part 4 1989, and BS 5669 (1989) requirements for cement bonded particleboards. The TS of composites produced with 20-30% cement content was quite high (3 -13%), again indicating that the *E. tereticornis* particles was quite hygroscopic and may therefore not be used at high contents for cement composite production, from the dimensional stability point of view. However, only the cement content had significant effect on TS.

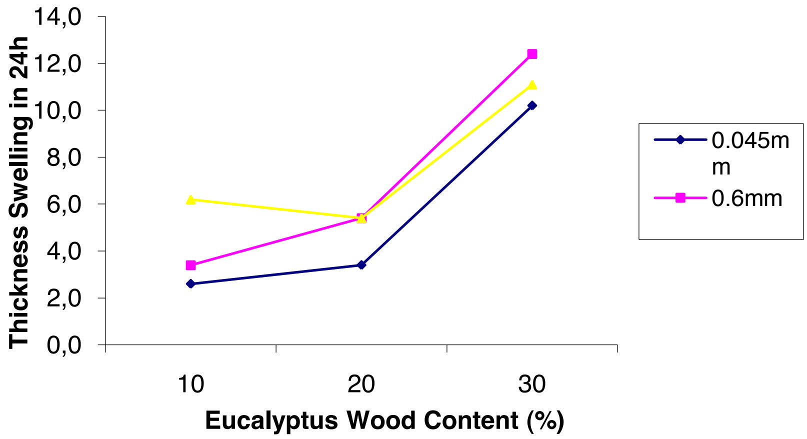

Figure 4: Effects of Particle Size and Wood Content on 24h Thickness Swelling

CONCLUSIONS

Wood-Cement composites were produced from eucalyptus (*Eucalyptus tereticornis* Sm.) veneer waste using different wood particle sizes and cement contents. Based on strength and water absorption property tests, the following conclusions were drawn:

1. Particles retained on 0.045mm sieve consistently out-performed other particles. They exhibited the least thickness, highest density, least moisture content and highest MOR and tensile strength, lowest water absorption and thickness swelling.

2. The bending strength of the cement-bonded eucalyptus wood composite fell short of the minimum international standards of 9.0- 13 N/mm^2. However, they could be used in ceiling applications where sound absorption is important.

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