Cement & Concrete Composites 26 (2004) 729–734

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Cement-bonded wood particleboard with a mixture of eucalypt and rubberwood

Esmeralda Y.A. Okino *, Mário R. de Souza, Marcos A.E. Santana, Marcus V. da S. Alves, Maria Eliete de Sousa, Divino E. Teixeira

Laboratorio de Produtos Florestais, IBAMA/LPF, SAIN Av. L4 Lote 04, Brasília, DF 70818-900, Brazil

Received 27 November 2002; accepted 31 January 2003

Abstract

Six eucalypts species *Eucalyptus camaldulensis* Dehnh., *E. citriodora* Hook, *E. cloeziana* F. Muell, *E. grandis* Hill ex. Maiden, *E. pilularis* Sm., and *E. urophylla* S. T. Blake) and two clones of rubberwood (*Hevea brasiliensis* (Willd ex Adr. de Juss) Muell. Arg.), planted in Brazil, were used to manufacture wood cement-bonded particleboard (CBWP). Boards measuring $450 \times 450 \times 13$ mm were manufactured in a wood/cement/water ratio of 1:4:1, by weight; nominal density of 1.4 g/cm^3 and 4% of additive ($CaCl_2 \cdot H_2O$) using a mixture of each eucalypts species (50%) and the two clones of rubberwood (25% of each). Three replications were fabricated for each treatment and the physical and mechanical properties of the boards evaluated according to ASTM D 1037-96a [Standard test methods for evaluating properties of wood-base fiber and particle panel materials. ASTM D 1037-96a, vol. 04.09. ASTM, 1998]. The results of modulus of elasticity ranged from 4090 to 4771 MPa. The results of modulus of rupture ranged from 5.8 to 6.4 MPa. Internal bond were similar to those found in the literature. Screw withdrawal values were up to 2020 N. The panels showed very good dimensional stability. The mixture of species and also the addition of calcium chloride have improved the physical and mechanical properties of the panels. Decay fungi tests were conducted according to the ASTM D 2017-81 [Standard test method for accelerated laboratory test of natural decay resistance of woods. ASTM D 2017-81, vol. 04.09. ASTM, 1994-e1. p. 324] for two representative wood-attacking fungi, a brown-rot fungus *Gloeophyllum trabeum* (Persoon ex Fries) Murrill and a white-rot fungus *Trametes versicolor* (Linnaeus ex Fries) Pilát. Twelve samples were tested and after 12 weeks of exposure the average weight loss was determined. The test indicated that CBWP was classified as ''highly resistant'' and the samples gained weight.

Keywords: Inorganic-bonded particleboard; *Hevea brasiliensis*; *Eucalyptus* spp.; Clone; Physical and mechanical properties; Biodegradation; *T. versicolor*; *G. trabeum*; White and brown-rotters

1. Introduction

Eucalypt is one of the most successful fast-growing plantation species in tropical and sub-tropical regions. Its worldwide importance is growing. Eucalypt wood is a valuable raw material for many uses, from sawnwood for construction and furniture to pulp and panels. According to estimates, eucalypts plantation covers probably between 8 and 12 million hectares, over 4 million in Brazil alone. The genus is extremely diversified with wood density ranging from about 450 to over 1000 kg/m^3, colors from light brown to dark red. From the many eucalypts species, some 20 have been planted extensively throughout the world, but well over 100 have been the subject of trials. The most widely planted are *Eucalyptus camaldulensis*, *E. globulus*, *E. viminalis* and *E. nitens* in temperate areas, *E. saligna*, *E. citriodora*, *E. tereticornis* and *E. grandis* in subtropical regions and *E. urophylla* and *E. deglupta* in tropical climates. *E. urophylla* has been especially successful in recent years, Kauman et al. [1].

Rubberwood tree generally performs best in climates of the tropical lowland and evergreen rainforest regions. It has a light straw to light brown coloured timber with the sapwood generally being indistinguishable from the heartwood. Wood density varies from 550 to 650 kg/m^3 and has the strength properties associated with other

* Corresponding author. Tel.: +55-61-316-1510; fax: +55-61-225-1182.

E-mail addresses: okino@lpf.ibama.gov.br (E.Y.A. Okino), msouza@lpf.ibama.gov.br (M.R. de Souza), marcos@lpf.ibama.gov.br (M.A.E. Santana), marcus@lpf.ibama.gov.br (M.V.S. Alves), eliete@lpf.ibama.gov.br (M.E. de Sousa), divinot@lpf.ibama.gov.br (D.E. Teixeira).

0958-9465/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0958-9465(03)00061-1

medium density hardwoods. The average diameter is normally 30–35 cm and the length of the trunk is 3–5 m [2].

Cement-bonded wood particleboard (CBWP) is made of strands, particles or fibers of wood mixed with portland cement and small amounts of additives manufactured into panels, bricks, tiles and other products used by the construction industry in applications such as wall, roof sheating and tiles, floor, fences, and sound barriers. Wood is the aggregate and the reinforcing agent, cement is the binder, water is the reactant, and the additives are the catalyst.

The special characteristics that make CBWP desirable are high fire and decay resistance, low water absorption, and good dimensional stability [3]. It performs well in interior or exterior uses without treatment.

The wood to cement compatibility is still a problem to CBWP development. It has been found that organic materials inhibit cement setting and reduce cement strength. As described by Hachmi and Moslemi [4], wood–cement compatibility generally decreases as the extractive content increases. These extractives are generally composed of terpenes, fatty acids, tannins, carbohydrates, and inorganic materials [5]. Weatherwax and Tarkow [5,6] described a method to quantify differences among species by using the term inhibitory index, which compares the extension of wood–cement inhibition based on the percentage increase in setting time. Research on wood–cement mixtures revealed that hardwoods are generally more inhibitory to cement setting than are softwoods and also that decayed wood, heartwood, and bark could contribute to the longer setting time or complete setting failure of cement. Following this study, Hofstrand et al. [7] incorporated maximum temperature and the maximum slope of the temperature curve of the wood–cement mixture and neat cement, respectively, into the inhibitory index calculations (I). The inhibitory index of any species can be computed from the values of maximum temperature of hydration, the maximum slope of the exothermic curve, and the hydration time needed to reach maximum temperature of the inhibited cement when compared respectively with the values of the uninhibited cement. The smaller the I-value the higher the compatibility between cement and wood. Various treatments and additives, especially hot-water extraction of wood and calcium chloride additive to the cement have been reported to shorten the setting time of wood–cement mixtures [8,9].

Zhengtian and Moslemi [10] studied the influence of 30 inorganic and organic accelerators on hydration temperature of a western larch–cement mixture, and the most usual were $FeCl_3$, $CaCl_2$, $Ca(OH)_2$, $MgCl_2$, $Fe_2(SO_4)$, Na_2SiO_3, K_2SiO_3, $SnCl_2$, $AlCl_2$ and $Fe(NO_3)_3$.

Goodell et al. [11] examined the decay resistance of three formulations of wood–cement composites produced from virgin and recycled southern yellow pine chips when exposed to *Trametes versicolor* and *Gloeophyllum trabeum*. Specimens attacked by *T. versicolor* had a greater weight gain than *G. trabeum* ranging from 2.5% to 11.2%.

Souza et al. [12] evaluated the durability of low and high density conventional and CO_2-injected aspen cement-bonded particleboards of *Populus* sp. to white-rot *T. versicolor* and brown-rot *Postia placenta*. No measurable wood degradation was observed. Instead of weigh loss, substantial weight gains ranging from 6.0% up to 18.0% was observed, and white-rot fungus was found to be associated with greater weight gain than the brown-rot fungus.

Sujan et al. [13] exposed oven-dried rubberwood pieces for 9 weeks against seven Basidiomycetes, a wood rotting fungus isolated from rubber wood. The mean value of weight losses were 25.9% for *Lenzites palisotii*, 21.0% for *Ganoderma applanatum,* 11.2% for *T. corrugata*, 9.7% for *Polyporus zonalis*, 7.7% for *Lentinus blepharodes*, 5.3% for *Schizophyllum commune*, and 3.3% for *Fomes senex.*

Hong [14] determined the weight losses of oven-dried rubberwood blocks, when exposed to seven Basidiomycetes such as *G. applanatum*, *Poria* sp., *S. commune* e *T. corrugata.* After 70 days of fungi exposure the samples presented a weight losses of 20.3% for *S. commune*, 24.3% for *G. applanatum* and 33.8% for *T. corrugata.*

Botelho et al. [15] evaluated the natural durability of six eucalypts species, and the heartwood of *E. pilulares* showed the higher resistance against both fungi tested, *T. versicolor* and *G. trabeum*, followed by the *E. camaldulensis*, *E. cloeziana*, *E. urophylla* and *E. citriodora*, which were classified as "highly resistant". *E. grandis* was the least durable showing a weight losses of 23% and 12% for *T. versicolor* and *G. trabeum*, respectively.

The main purpose of this research is to manufacture CBWP using a mixture of six eucalypts species and rubberwood particles, two extensively available wood species planted in Brazil, and evaluate the physical and mechanical properties according to ASTM D 1037-96a standard [16], and the natural durability of the cement-bonded blocks against white- and brown-rot by means of ASTM D 2017-81 [17]. An attempt has been made to evaluate the compatibility of wood mixture and cement curing.

2. Materials and method

2.1. Hydration test

The hydration test method used was the same as described by Hofstrand et al. [7] and Moslemi and Lim [18]. Particles were ground in a mill and screened in US standard sieves of $-20+42$ mesh. Type II commercial portland cement was used in 200 g batches. Distilled water (90.5 ml) was added to a mixture of cement (200 g) and wood (15 g ovendry basis) in a polyethylene bag for 3 min. The amount of water added was based on experiments reported by Weatherwax and Tarkow [5,6] that suggested the use of 2.7 ml of water per gram of groundwood (adjusted to ovendry basis) and additional 0.25 ml of water per gram of cement. The cement–wood–water mixture was placed in a wide-mouth insulated flask with a thermocouple wire and then covered with styrofoam. The flask was sealed with wrapping tape. The temperature of the mixture was measured and plotted against time. Exploratory work indicated that the hydration temperature start to change after 4 h of test. The time to attain maximum temperature was considered to be the required setting time of the mixture.

To calculate the inhibitory index (I) of the species it was used the following equation:

$$I = 100[((t_2 - t_2')/t_2') * ((T_2' - T_2)/T_2') * ((S_2' - S_2)/S_2')]$$

where t_2 = inhibited cement [1], t_2' = uninhibited cement [2], T_2 = inhibited cement, T_2' = uninhibited cement, S_2 = maximum slope of inhibited cement, and S_2' = maximum slope of uninhibited cement.

The effect of the inhibited cement setting was classified according to Table 1 [19].

Two replications were applied to each species of wood–cement–water mixtures and neat cement. All the experiments of this study were conducted at room temperature that ranged from 23 up to 29 °C. Chemical additive such as $CaCl_2$ at 4% based on inorganic weight was incorporated to the hydration test.

2.2. Wood species

Six 18 years-old eucalypt species namely, *E. camaldulensis* Dehnh., *E. citriodora* Hook, *E. cloeziana* F. Muell, *E. grandis* Hill ex. Maiden, *E. pilularis* Sm., and *E. urophylla* S. T. Blake were tested. Two 35 years-old rubberwood clones of *Hevea brasiliensis*, AVROS 1301 and IAN 717 were also tested. Five trees per species were collected.

2.3. Particles

Planks of all species were processed into blocks of 170 × 150 × 25 mm and converted into flakes of 40 × 25 × 0.5 mm using a drum knife flaking machine. The particles were reduced using a hammer mill with openings of 9.25 mm in diameter and then screened.

[1] Inhibited cement = wood–cement–water mixture.

[2] Uninhibited cement = cement–water mixture.

Table 1
Inhibitory index used to classifying wood–cement compatibility

Inhibitory index (%)	Grade
$I < 10$	Low inhibition
I = 10–50	Moderate inhibition
I = 50–100	High inhibition
$I > 100$	Extreme inhibition

2.4. Experimental design

Mixtures of each of six eucalypts species (50%) and two rubberwood clones, AVROS 1301 (25%) and IAN 717 (25%), of *H. brasiliensis* were prepared, totaling six mixtures of eucalypts and rubberwood. These mixtures were used for the hydration test and boards manufacturing. Three replications were made in each experimental condition, totaling 18 single-layer CBWP with a target density of 1.4 g/cm^3.

2.5. Manufacture of CBWP

In this study fresh type II portland cement, manufactured by Cimento Votorantin, was used as the binding agent. The wood/cement/water ratio was set at 1:4:1, by weight. Calcium chloride dihydrated at 4% based on cement weight was added to the mixture to assist the cement setting. The mixture of cement, wood particles and calcium chloride ($CaCl_2$) solution was blended in a rotatory blender and hand formed in a mat with moisture content of approximately 20%. The mat was cold pressed at 4.0 MPa for 12 h. The cured boards, measuring 450 × 450 × 13 mm, were conditioned at 65 ± 2% relative humidity and 20 ± 1 °C of temperature for one month. Tests were conducted according to ASTM D 1037-96a standard [16], and for each panel, three specimens for tensile strength, four specimens for water absorption and thickness swelling, five specimens for internal bond, three for density and moisture content and two specimens for screw withdrawal, were cut.

2.6. Statistical analysis

The results of each wood cement-bonded particleboard were submitted to analysis of variance ANOVA at 5%, using the statistical analysis system-SAS and means differences were tested using the HSD Tukey test [20].

2.7. Decay resistance of CBWP

Samples of CBWP were tested according to ASTM D 2017-81[17] for natural durability using two representative wood-attacking monocultures of fungi, brown-rot fungus *Gloeophyllum trabeum* (Persoon ex Fries.) Murrill, and a white-rot fungus *T. versicolor* (Linnaeus ex

Table 2
Decay resistance expressed as either weight loss or residual weight according to ASTM D 2017-81 [17]

Average weight loss (%)	Average residual weight (%)	Decay resistance class
0–10	90–100	Highly resistant
11–24	76–89	Resistant
25–44	56–75	Moderately resistant
45 or more	55 or less	Slightly resistant or nonresistant

Fries) Pilát. Two feeder block of $0.3 \times 2.9 \times 3.5$ cm in size, with the long axis in the grain direction was used the *Pinus* sp. for white-rot fungus and *Cecropia* sp. for white-rot fungus. The number of blocks replications per test condition was 12 specimens measuring 2.5×2.5 cm by thickness of the boards. The percentage weight losses were calculated in the individual test blocks from the conditioned weights before and after exposure to the decay fungi. This percentage provided a measure of the relative decay susceptibility or, inversely, of decay resistance of the sampled material. The blocks were rated after testing according to Table 2.

3. Results and discussion

3.1. Hydration test

The mean values of inhibitory index are presented in Table 3. The mixture of eucalypt and rubberwood without additive were classified as "moderate inhibition" and when 4% of $CaCl_2$ was added as chemical additive, it was graded as "low inhibition". *E. citriodora* with *H. brasiliensis* in all treatments have shown to be the most inhibitory mixture. *E. urophylla*, *E. cloeziana* and *E. camaldulensis* with *H. brasiliensis* were the most compatible mixtures.

Table 3
Effect of additives on the maximum hydration temperature and time of mixture of eucalypt and rubberwood

Mixture of species	Inhibitory index[a] (%)	
	No $CaCl_2$ added	Addition of $CaCl_2$[b]
E. citriodora:H. brasiliensis	41.64	0.87
E. pilularis:H. brasiliensis	17.97	−0.77
E. grandis:H. brasiliensis	27.10	−0.22
E. cloeziana:H. brasiliensis	20.76	−0.17
E. camaldulensis:H. brasiliensis	21.13	−0.31
E. urophylla:H. brasiliensis	20.72	−0.39

[a] Each value represents the mean value of two replications of wood/cement/water mixture.
[b] 4% of chemical additive $CaCl_2$.

3.2. Physical and mechanical properties of CBWP

The means and the statistical comparisons of mechanical properties of eucalypt and rubberwood CBWP are listed in Table 4. The values of modulus of elasticity (MOE), modulus of rupture (MOR), screw withdrawal (SW) and stress at proportional limit (SPL) were very homogeneous and showed no significant difference according to the ANOVA test. The MOE values were between 4090 and 4771 MPa. The values of MOE were well above the requirements set forth by BISON for building board type HZ [21]. The values of MOR ranged from 5.8 to 6.4 MPa. The values of SPL ranged from 3.2 to 3.7 MPa, which are about the half of MOR values. The values of internal bond (IB) ranged from 0.19 to 0.34 MPa. The wood cement-bonded particleboard produced with *E. grandis* and *H. brasiliensis* and *E. urophylla* and *H. brasiliensis* mixtures showed the highest and the lowest IB values, respectively. The different species tested showed significative difference only for the property of IB, with two homogeneous groups in the means difference test. The values of screw withdrawal perpendicular to the plane of the board-SW were between 1500 and 2020 N.

Table 4
Mechanical properties of eucalypt and rubberwood cement-bonded wood particleboard mixture[a]

Treatment[b]	MOE[c] (MPa)	MOR[c] (MPa)	SPL[c] (MPa)	IB[d] (MPa)	SW[e] (N)
E. cloeziana:H. brasiliensis	4651[A]	6.0[A]	3.4[A]	0.23[AB]	1687[A]
E. camaldulensis:H. brasiliensis	4636[A]	5.9[A]	3.5[A]	0.29[AB]	2020[A]
E. citriodora:H. brasiliensis	4616[A]	5.8[A]	3.2[A]	0.33[AB]	1657[A]
E. pilularis:H. brasiliensis	4771[A]	6.0[A]	3.2[A]	0.30[AB]	1500[A]
E. urophylla:H. brasiliensis	4489[A]	6.3[A]	3.2[A]	0.19[B]	1723[A]
E. grandis:H. brasiliensis	4090[A]	6.4[A]	3.7[A]	0.34[A]	1559[A]
BISON type HZ[f]	3000	9.0	–	0.40	–

[a] Mean within a column followed by the same capital letter are not significantly different at the 5% level using the Tukey's studentized range (HSD) test.
[b] Each treatment consisted of 50% of each eucalypt species plus 25% *H. brasiliensis* (IAN 717) and 25% *H. brasiliensis* (AVROS 1301).
[c] Mean of nine samples (three for each of three replicates).
[d] Mean of 15 samples (five for each of three replicates).
[e] Mean of six samples (two for each of three replicates).
[f] BISON cement-bonded building board type HZ [21].

Table 5
Mean values of physical properties of cement-bonded wood particleboard of mixture of eucalypts and rubberwood[a]

Treatment[b]	Density[c] (g/cm³)	Moisture content[c] (%)	Water absorption[d] (%)		Thickness Swelling[d] (%)	
			2 h	24 h	2 h	24 h
E. cloeziana:H. brasiliensis	1.240[A]	10.26	12.2[A]	14.4[A]	1.5[A]	1.6[A]
E. camaldulensis:H. brasiliensis	1.227[A]	10.78	12.5[A]	14.8[A]	0.9[A]	1.1[A]
E. citriodora:H. brasiliensis	1.223[A]	10.55	14.0[A]	16.5[A]	1.1[A]	1.2[A]
E. pilularis:H. brasiliensis	1.213[A]	10.81	12.7[A]	15.1[A]	1.3[A]	1.5[A]
E. urophylla:H. brasiliensis	1.197[A]	10.58	13.9[A]	16.7[A]	1.7[A]	1.8[A]
E. grandis:H. brasiliensis	1.220[A]	10.99	12.5[A]	15.2[A]	1.8[A]	1.8[A]
BISON type HZ[e]	1.200	9.00	–	–	–	1.2–1.8

[a] Mean within a column followed by the same capital letter are not significantly different at the 5% level using the Tukey studentized range (HSD) test.
[b] Each treatment consisted of 50% of each eucalypt species plus 25% rubberwood (IAN 717) and 25% rubberwood (AVROS 1301).
[c] Mean of nine samples, three for each of three replicates.
[d] Mean of 12 samples, four for each of three replicates.
[e] BISON cement-bonded building board [21].

The physical properties and the statistical comparison of cement-bonded particleboard of eucalypts and rubberwood mix are listed in Table 5. All the properties evaluated (density, water absorption (WA), and thickness swelling (TS)) showed no evidence of significant difference for the treatments evaluated.

The values of TS ranged from 0.9% to 1.8% after 2 h of water immersion and from 1.5% to 1.8% after 24 h. Thus, after 24 h these two limits increased to 93% and 88%, respectively. During the first 2 h the TS was 1.33% in average, and after the last 22 h it increased to 22.2%. The values of WA, after 2 h, ranged from 12.2% to 14.0%. After 24 h these limits increased to 14.4% and 16.7% for CBWP of *E. cloeziana* and *H. brasiliensis* and *E. urophylla* with *H. brasiliensis* mixtures, respectively. During the first 2 h the WA was 13.0% in average and after the last 22 h increased to 19.1%.

All physical and mechanical properties are very close to those wood cement-bonded particleboard described in the literature [22–25].

3.3. Decay resistance of CBWP

Mean weight percent gain for cement-bonded particleboard and weight percent losses for sound eucalypts and rubberwood were shown on Table 6. Instead of weight loss, all cement-bonded particleboard specimen had shown weight gain. This fact was expected with these panels as a consequence of the carbonation reaction, a typical chemical reaction that occurs with curing of cements. According to Table 1, the CBWP tested was classified as "highly resistant". In comparison, the clean wood samples show significant weight loss during the tests, mainly for rubberwood, according to decay tests performed by Okino et al. [26] and Yamamoto and Hong [27].

Table 6
Weight loss in a 12-week accelerated decay test of cement-bonded particleboard of eucalypts and rubberwood mix, exposed to *G. trabeum* (Pers. ex Fr.) Murrill and *T. versicolor* (Linnaeus ex Fries) Pilát

Treatment (1:1, w:w) *H. brasiliensis* with	Average weight loss[a] (%)	
	G. trabeum	*T. versicolor*
E. cloeziana	−4.03	−3.82
	1.73[b]	1.60
E. camaldulensis	−4.18	−3.67
	2.07	0.85
E. citriodora	−4.47	−3.95
	2.18	1.93
E. pilularis	−2.99	−3.67
	1.29	0.93
E. urophylla	−4.03	−3.92
	1.86	1.83
E. grandis	−3.58	−3.45
	1.60	1.12
	Average weight loss[c] (%)	
Species/sound wood		
E. cloeziana	3.19	4.52
	1.65[b]	1.51
E. camaldulensis	2.50	4.25
	1.28	1.28
E. citriodora	4.86	8.18
	0.90	3.02
E. pilularis	1.46	3.56
	0.78	2.00
E. urophylla	3.32	5.74
	1.42	1.29
E. grandis	12.35	22.96
	3.86	5.93
H. brasiliensis[d] (IAN 717)	38.49	36.72
	5.52	10.68
H. brasiliensis[d] (AVROS 1301)	36.81	37.49
	8.01	13.16

[a] Mean of nine samples, three specimens for each board.
[b] Standard deviation.
[c] Mean of 10 samples for each species. From [15].
[d] Mean of 12 samples, four specimens for each tree. From [26].

4. Conclusion

Eucalypts and rubberwood are suitable species to make wood cement-bonded particleboard. The hydration test has shown that all six mixtures of species were compatible with portland cement. The mixtures investigated were classified as being of "moderate inhibition", even without addition of chemical additive. Calcium Chloride enhanced the performance of the mixtures, which grades were classified as being of "low inhibition".

Even though the WCBP's presented results of MOR and IB lower than the BISON type HZ requirements, they can be used where no direct structural applications is required. Physical and mechanical properties were close to those reported in the literature.

A good application for this product could be as a material where dimensional stability and durability (wet walls) are required.

Acknowledgements

The authors wish to thank the technicians Mr. João E. Anacleto, Zenon L. de Souza, Getúlio F. de Almeida, and Luiz Domiciano Santana for his technical assistance, and those who were directly or indirectly involved in this study.

References

[1] Kauman WG, Gerard J, Jiqing H, Huaijun W. Processing of eucalypts. Commonw Forest Rev 1995;74(2):147–54.
[2] Lampila T. Opportunities for rubberwood: plywood. In: International Forum on Investment Opportunities in the Rubberwood Industry, 20–23 September, Kuala Lumpur. 1993. p. 1–22.
[3] Dinwoodie JM, Paxton BH. The long-term performance of cement-bonded wood particleboard. In: Inorganic Bonded Wood and Fiber Composite Materials—Second International Conference, Moscow. 1991. 45pp.
[4] Hachmi M'H, Moslemi AA. Correlation between wood–cement compatibility and wood extractives. Forest Prod J 1989;6:55–8.
[5] Weatherwax RC, Tarkow H. Effect of wood on setting of portland cement. Forest Prod J 1964;12:567–70.
[6] Weatherwax RC, Tarkow H. Effect of wood on the setting of portland cement: decayed wood as an inhibitor. Forest Prod J 1967;7:30–2.
[7] Hofstrand AD, Moslemi AA, Garcia JF. Curing characteristics of wood particles from nine northern Rocky Mountain species mixed with portland cement. Forest Prod J 1984;2:57–61.
[8] Biblis EJ, Lo CF. Sugars and other wood extractives effect on the setting of southern pine–cement mixtures. Forest Prod J 1968;8:28–34.
[9] Moslemi AA, Garcia JF, Hofstrand AD. Effect of various treatments and additives on wood–portland cement–water systems. Wood Fiber Sci 1983;2:164–76.
[10] Zhengtian L, Moslemi AA. Influence of chemical additives on the hydration characteristics of western larch wood–cement–water mixtures. Forest Prod J 1985;35(7):37–43.
[11] Goodel B, Daniel G, Liu L, Mott L, Frank R. Decay resistance and microscopic analysis of wood–cement composites. Forest Prod J 1997;47(11/12):75–80.
[12] Souza MR de, Geimer RL, Moslemi AA. Degradation of conventional and CO_2-injected cement-bonded particleboard by exposure to fungi and termites. J Trop Forest Prod 1997;3(1):63–9.
[13] Sujan A, Tan AG, Stevens M. Some studies on fungal deterioration of rubberwood (*Hevea brasiliensis*). International Research Group on Wood Preservation. Document No IRG/WP/2140. 6 pp.
[14] Hong LT. The decay of tropical hardwoods. II. Mass loss and degradation of cell-wall components of *Hevea brasiliensis* caused by *Ganoderma applanatum*, *Poria* sp., *Schizophyllum commune* and *Trametes corrugata*. The Malaysian Forester 1982;45(1):124–6.
[15] Botelho GML, Santana MAE, Alves MV da S. Caracterização química, durabilidade natural e tratabilidade da madeira de seis espécies de eucaliptos plantadas no Distrito Federal. Revista Árvore 2000;24(1):115–21.
[16] American Society for Testing and Materials—ASTM: Standard test methods for evaluating properties of wood-base fiber and particle panel materials. ASTM D 1037-96a, vol. 04.09. Philadelphia: ASTM, 1998 (Annual Book of ASTM Standards).
[17] American Society for Testing and Materials—ASTM: Standard test method for accelerated laboratory test of natural decay resistance of woods. ASTM D 2017-81, vol. 04.09. Philadelphia: ASTM, 1994-e1. p. 324–8 (Annual Book of ASTM Standards).
[18] Moslemi AA, Lim YT. Compatibility of southern hardwoods with portland cement. Forest Prod J 1984;34(7):22–6.
[19] Garcia, JF. An evaluation of the rate of heat evolution of portland cement, northern Rocky Mountain species. MS thesis. University of Idaho, Moscow, Idaho. 1981.
[20] SAS - Statistical Analysis System/STAT. User's Guide. Release 6.03. Cary, NC: SAS Institute Inc, 1988.
[21] BISON Wood–Cement Board 1978, Bison-Report. 10p.
[22] Teixeira DE, Guimarães TM. Tratamento de partículas de *Acácia mearnsii* De Wild. para produção de chapas de cimento-madeira. IBAMA/DIRPED/LPF, Série Técnica, n. 11, 1989. 9 pp.
[23] Del Menezzi CHS, Souza MR de. Influence of bark on properties of wood–cement particleboards made with eucalypt. In: 1st International Conference on Wood and Wood Fiber Composites, Stuttgart, 13–15 April 2000. p. 423–8.
[24] Almeida D. Caracterização de Chapas de cimento e partículas de madeira de eucalipto do cerrado. Dissertação de Graduação. Departamento de Engenharia Florestal, Universidade de Brasília, DF. 1997. 15pp.
[25] Sudin R, Chew LT, Ong CL. Storage effects of rubberwood on cement-bonded particleboard. J Trop Forest Sci 1989;1(4):365–70.
[26] Okino EYA, Alves MV da S, Santana MAE, Sousa ME de. Durabilidade natural de madeira sólida, de chapas aglomeradas e de chapas de cimento-madeira de *Hevea brasiliensis*. Brasil Florestal 2002;21(73):39–46.
[27] Yamamoto K, Hong LT. Location of extractives and decay resistance in some malaysian hardwood species. J Trop Forest Sci 1989;2(1):61–70.