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# Physico-mechanical properties and decay resistance of *Cupressus* spp. cement-bonded particleboards

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**Abstract**

Control and hot water treated particles of cypress (*Cupressus* spp.) were used to manufacture cement-bonded particleboards (CBPB). Three replications were carried out for each treatment, totaling six single layered boards. Physical and mechanical properties of the boards were evaluated according to ASTM D 1037-96a [Annual Book of ASTM Standards, vols. 04–09. Philadelphia: American Society for Testing and Materials—ASTM, ASTM D 1037-96a, 1998] standard. The wood of cypress showed suitability as raw material for the manufacture of CBPB. All the properties of cypress CBPB were higher than the Bison HZ type building boards used as reference. The light color and easy wood processing of cypress wood are favorable parameters for panels manufacturing. The results corroborate those reported for CBPB using pine, rubberwood, acacia, babassu, and eucalyptus particles. The CBPB were also submitted to fungi decay resistance test according to ASTM D 2017-81 [Annual Book of ASTM Standards, vols. 04–09. Philadelphia: American Society for Testing and Materials—ASTM, 1994-e1. ASTM D 2017-81, p. 324–8] standard and exposed to the attack of *Gloeophyllum trabeum* (Persoon ex Fries) Murr. and *Trametes versicolor* (Linnaeus ex Fries) Pilát. Twelve specimens were tested for each treatment and the average weight loss was determined after 12 weeks of exposure. Laboratory tests showed that there was no measurable wood degradation (weight loss). Fungi mycelium did not even cover completely the surface of the specimens. CBPB when exposed to both brown- and white-rot fungi, rather than weight loss, showed weight gains ranging from 2% to 4%. Therefore, CBPB is technically suitable for exterior use where both moisture and favorable conditions for fungi development are present.


*Keywords:* Cypress; Cement-bonded particleboards; Physical and mechanical properties; Calcium chloride; Silica fume; Inhibitory index; Biodegradation; Fungi

## 1. Introduction

The gymnosperms, also known as evergreens, are characterized by marked features other than floral and seed peculiarities. Timber of cypress, mostly *Cupressus lusitanica*, occupies the leading position in the Kenyan timber market and is one of the few conifers widely planted outside of its natural habitat. It is used as a source of fuel and lumber in Guatemala. Colombia established a program to improve cypress timber quality of end products. Cypress is also used as a source of pulp in Venezuela and is one of the most commonly planted species in the Highlands of Costa Rica. In Brazil cypress plantations has shown good adaptation in the southern region, as a source of pulp and raw material for the panels industry.

According to studies of Haslett [3], the wood of *Cupressus macrocarpa*, *C. lusitanica*, *Chamaecyparis lawsoniana* and *Cupressocyparis leylandii* are similar. The timber is lightweight, stiff, and moderately strong with

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higher bending and compression properties than radiata pine (*Pinus radiata*). Due to their yellow-brown color, fine even texture, and luster, they are frequently compared to kauri (*Agathis australis*). Cypress wood has a characteristic odour, is graded as medium to low density and is highly suitable for use in exterior joinery, weatherboards, and boat building.

Cement-bonded particleboard (CBPB) has been manufactured using conventional technology, where the boards are kept under pressure for consolidation for several hours. A long pressing time is necessary because the hydration of ordinary Portland cement is a very slow process. Typically, hydration takes at least 8 h in the first stage (setting) where the reaction releases heat. The second stage (hardening) is considered completed in 28 days, although it may take years for the boards to reach maximum strength [4].

The characteristics that make CBPB desirable to construction applications are high fire and decay resistance, low water absorption, and good dimensional stability. It performs well in interior or exterior uses without any superficial treatment.

Lee [5] manufactured cement bonded cypress excelsior boards using excelsior of *Taxodium distichum* and concluded that cypress is a suitable species for cement-bonded boards. The values of mechanical properties were 924 MPa for modulus of elasticity (MOE) and 2.5 MPa for modulus of rupture (MOR), with board density of 0.512 g/cm$^3$, probably used for ceiling. The manufactured cement-bonded cypress excelsior boards showed the same bending properties as compared to commercial southern pine excelsior boards, according to a *t*-test.

Sandermann et al. [6] suggested a method to determine the initial hydration of cement by measuring the rate of temperature rise in a Dewar flask. Weatherwax and Tarkow [7,8] described a method to quantify differences among species by using the inhibitory index, which compares the extension of wood–cement inhibition based upon the percentage increase in the setting time. Hofstrand et al. [9] incorporated maximum temperature and the maximum slope of the temperature curve of the wood–cement mixture and neat cement, respectively, into the inhibitory index calculation ($I$).

Several studies in the past revealed that sugars available in wood have been identified as the most critical component in the production of CBPB [10,11]. For producing good quality boards, the amount of sugars in wood should not exceed 0.6% as stipulated by Weber [12] and Bever [13]. It makes some wood species not suitable to be mixed with cement and additional treatments of the wood particles are necessary.

Hardwoods and softwoods are commonly attacked by both brown- and white-rot fungi when in contact with ground. Investigation of CBPB degradation by fungi is not very common. Tests conducted in the UK Building Research Establishment (BRE) suggested that conventionally made CBPB are very resistant to the attack of the white-rot fungus *Pleurotus ostreatus* and to the brown-rot fungus *Coniophora puteana*. In fact, CBPB samples gained 5% in mass when tested against *C. puteana*, which is most likely due to a certain amount of carbonation of the cement matrix [14]. A similar statement was made by Pirie et al. [15] that cement-bonded particleboard composite during natural weathering undergoes changes such as continued hydration and carbonation. When conventional and $CO_2$ cement-bonded particleboard of *Populus* sp. were tested against the white-rot fungus, *Trametes versicolor*, and the brown-rot fungus, *Postia placenta*, there was no measurable wood degradation. On the contrary, substantial weight gain was also observed in this study [16].

The general purpose of this research was to manufacture wood CBPB using particles of cypress and to evaluate the physical and mechanical properties of the boards according to ASTM D 1037-96a standard [1]. An attempt has been made to evaluate whether hot water extraction of the particles would have any influence on the properties of the boards. An additional objective of this study was to evaluate the decay resistance of the conventional cypress CBPB under laboratory conditions when exposed to white- and brown-rot fungi according to ASTM D 2017-81 [2].

## 2. Material and method

### 2.1. Hydration test

The hydration test was conducted under the methodology describe by Moslemi and Lim [17]. The test equipment consisted of type J iron–constantan thermocouples with channels connected to a multipoint recorder precision microvolt potentiometer Model SD-100H, to simultaneously monitor the temperature changes inside the flasks.

Coarse wood material ranging from 1 to 3 mm was ground in a Wiley hammermill and screened in US standard sieves of $-20+42$ mesh. Type II commercial Portland cement (200 g) and screened wood (15 g ovendry basis) were dry mixed in a polyethylene bag, and received 90.5 ml of distilled water to be mixed for a period up to 3 min. As mentioned by Hofstrand et al. [9], the amount of water added was based upon experiments reported by Weatherwax and Tarkow [7,8], whose recommended 2.7 ml of water per gram of groundwood (adjusted to ovendry basis) and an additional 0.25 ml of water per gram of cement.

The wood–cement–water mixture was placed in a wide-mouth thermo flask. Iron–constantan thermocouple wires were inserted 1 cm into the mixture approximately in the center of the plastic bag and then covered

Table 1
Inhibitory index used to classify wood–cement compatibility

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

with styrofoam for insulation purposes. The flask was then sealed with wrapping tape. The temperature rise of the mixture was then plotted against the time. The time to attain maximum temperature of hydration was considered as the required setting time of the mixture.

Two replications were run for each treatment of wood–cement–water mixtures and neat cement paste. All the experiments of this study were conducted at room temperature, ranging from 23 to 29 °C. Chemical additives such as $CaCl_2.2H_2O$ at 4% and mineral additives such as silica fume at 10% level, based on the weight of inorganic materials, were incorporated solely to the mixtures containing wood.

The effect of the inhibited cement setting was classified according to Table 1 [18].

### 2.2. Particles preparation

Logs of *Cupressus* spp. were collected and processed into small blocks of 20×150×200 mm. These blocks were immersed in water for a period of time and converted into flakes of 40×20×0.6 mm through a rotative knive disc flaker. The flakes were processed in a hammer mill, classified in mechanical screens and only the particles collected in a 1×1 mm sieve were used for the experimental study. The particles were randomly assigned for two treatments to be used for CBPB manufacturing. The first part of particles was not treated at all and the second part was boiled in hot water for about 4 h. The purpose of the treatment of the particles was to decrease the amount of single sugars in order to enhance wood to cement compatibility.

### 2.3. CBPB manufacturing and testing

In this study fresh CP II-F 32 Portland cement was used. In board manufacturing, both wood/cement and water/cement ratios were set at 1:4, based on oven dry weight. Four percent of calcium chloride ($CaCl_2$)—based on cement weight—was added to the wood–cement mixtures as cement accelerator.

The cypress particles were coated with $CaCl_2$ dissolved in water prior to mixing with Portland cement in a drum blender.

In the forming station the mixture of cement and particles was formed into a mat in batches on separate caul plates. The mat measuring 450×450×13 mm was cold pressed at about 4.0 MPa for 12 h and consolidated into the target density of 1.4 g/cm$^3$.

The edge of the boards were trimmed to obtain the final panel size of 420×420 mm. The panels were conditioned in a controlled room at 20 ± 1 °C and 65 ± 2% of relative humidity to reach the equilibrium moisture content of 12%. The boards produced were processed into samples for physical and mechanical testing. From each panel, three specimens were tested for bending strength, four for water absorption (WA) and thickness swelling (TS), five for internal bond (IB), three for density (after conditioning) and moisture content, and two for screw withdrawal (SW). The boards were evaluated according to ASTM D 1037-96a [1] standard.

### 2.4. Statistical analysis

The experimental design consisted of two treatments—boiled and control particles—and three replications per treatment, totaling six single-layer CBPB.

The results of each property tested were submitted to one-way analysis of variance, using the statistical analysis system program—SAS [19] for checking significative effects of source type (particles) at 5% significance level.

### 2.5. Decay resistance test of CBPB

CBPB panels were tested according to ASTM D 2017-81 [2] against a brown-rot fungus *Gloeophyllum trabeum* (Persoon ex Fries.) Murrill, and a white-rot fungus *Trametes versicolor* (Linnaeus: Fries) Pilát. *Pinus* sp. and *Cecropia* sp. measuring 3×20×41 mm, were used as feeder blocks for the brown- and white-rot fungi, respectively. Twelve replications per test condition (fungus and treatments) and 10 control specimens measuring 25×25 mm were evaluated. The percentage weight loss was calculated for each test block from the conditioned weight before and after exposure to the decay fungi. The blocks were classified for decay resistance according to Table 2.

Table 2
Class of wood decay resistance expressed as either weight loss or residual weight according to ASTM D 2017-81 [2]

| Average weight loss (%) | Average residual weight (%) | Class resistance |
|---|---|---|
| 0–10 | 90–100 | Highly resistant |
| 11–24 | 76–89 | Resistant |
| 25–44 | 56–75 | Moderately resistant |
| 45 or above | 55 or less | Slightly resistant or non-resistant |

## 3. Results and discussion

### 3.1. Hydration test

The results obtained from the hydration test are shown in Table 3. When no additive was used in the cement hydration test, the mixture of cypress-cement was classified as "moderate inhibition" for either treatment of particles. When $CaCl_2$ was incorporated, the mixture was graded as "low inhibition". All values of inhibitory indexes are negative, probably due to the capacity of the $CaCl_2$ to buffer or minimize the adverse effect of the soluble sugars and extractives and also to accelerate the cement hardening and setting. The microsilica did not perform so efficiently as did the $CaCl_2$, nevertheless the mixture was graded also as "low inhibition". The boiling treatment applied to the particles has shown good results. Although the inhibition indexes of control and treated particles (hot water extraction) were graded the same, the treatment improved wood to cement compatibility for all levels of additives used.

### 3.2. Mechanical and physical properties of the CBPB

Results of the mechanical and physical properties of the CBPB are shown in Tables 4 and 5, respectively.

The results of the physical and mechanical properties of the CBPB showed no evidence of difference between the means of the two treatments (control and boiled particles) tested, according to the one-way analysis of variance at 5% significance level. All properties of the CBPB surpassed the minimum requirements set forth by the building type HZ code, mainly the MOE value that was more than two fold higher than that for the BISON CBPB [20].

Table 3
Effect of additives on the maximum hydration temperature and time of mixture of water–cement and wood–cement–water

| Treatment | Without additive | Calcium chloride[a] | Silica fume[b] |
|---|---|---|---|
| | $I_{max}$[b] (%) | $I_{max}$[b] (%) | $I_{max}$[b] (%) |
| *Cupressus* spp. (control particle) | 39.72[c] (4.76) | −0.77 (0.85) | 8.84 (2.51) |
| *Cupressus* spp. (boiled particle) | 18.11 (2.21) | −0.04 (0.21) | 3.61 (0.79) |

Numbers in parenthesis are standard deviation.
[a] 4% of chemical additive $CaCl_2$.
[b] 10% of mineral additive Silmix.
[c] Each value represents the mean of two replications for mixture of wood/cement/water.

Table 4
Mechanical properties of wood cement-bonded particleboards of *Cupressus* spp.

| Species | MOE[a] (MPa) | MOR[a] (MPa) | SPL[a] (MPa) | IB[b] (MPa) | SW[c] (N) |
|---|---|---|---|---|---|
| *Cupressus* spp. (control particles) | 6481[A] (870) | 11.1[A] (0.7) | 7.4[A] (0.3) | 0.45[A] (0.09) | 2274[A] (2.04) |
| *Cupressus* spp. (boiled particles) | 7121[A] (1261) | 12.4[A] (1.2) | 8.2[A] (0.9) | 0.40[A] (0.02) | 2368[A] (143) |
| BISON type HZ[d] | 3000 | 9.0 | – | 0.40 | – |

MOE = modulus of rupture, MOR = modulus of elasticity, SPL = stress at proportional limit, IB = internal bond, SW = screw withdrawal; Means within a column followed by the same capital letter are not significantly different at 5% level of significance using the one-way ANOVA test.
[a] Each value represents the mean of nine replications (three for each of three replicates).
[b] Each value represents the mean of 15 replications (five for each of three replicates).
[c] Each value represents the mean of six replications (two for each of three replicates).
[d] BISON [20] building board type HZ.

Table 5
Mean values of physical properties of cement-bonded particleboard of *Cupressus* spp.

| Treatment | Density[a] ($g/cm^3$) | Moisture content[a] (%) | Thickness swelling[b] (%) | | Water absorption[b] (%) | |
|---|---|---|---|---|---|---|
| | | | 2 h | 24 h | 2 h | 24 h |
| *Cupressus* spp. (control particles) | 1.29[A] (0.036) | 10.60[A] (0.36) | 1.1[A] (0.5) | 1.5[A] (0.6) | 9.2[A] (1.9) | 12.4[A] (2.2) |
| *Cupressus* spp. (boiled particles) | 1. 33[A] (0.017) | 10.53[A] (0.06) | 1.3[A] (0.1) | 1.8[A] (0.5) | 9.4[A] (0.5) | 12.6[A] (0.4) |
| BISON type HZ[c] | 1.200 | 9.00 | – | 1.2–1.8 | – | – |

Density after conditioning; Means within a column followed by the same capital letter are not significantly different at 5% level of significance using the one-way ANOVA test.
[a] Each value represents the mean of nine replications, (three for each of three replicates).
[b] Each value represents the mean of 12 samples, (four for each of three replicates).
[c] BISON [20] building board type HZ.

Table 6
Statistical analysis test of between-subjects effects of wood cement-bonded particleboards of *Cupressus* spp. obtained by the one-way analysis of variance

| Source[a] (Treatments) | MOR | MOE | SPL | IB | SW | DEN | WA | | TS | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 2 h | 24 h | 2 h | 24 h |
| *F* value | 2.701 | 0.524 | 1.973 | 0.904 | 0.432 | 3.0 | 0.020 | 0.024 | 0.246 | 0.571 |
| Significant (*p* value) | 0.176 | 0.509 | 0.233 | 0.396 | 0.547 | 0.158 | 0.894 | 0.885 | 0.646 | 0.492 |

No significant difference between means at 5% level of significance for $p_{\text{values}} \geqslant 0.05$.
MOE = modulus of rupture; MOR = modulus of elasticity; SPL = stress at proportional limit; IB = internal bond; SW = screw withdrawal; DEN = density (after conditioning); WA = water absorption; TS = thickness swelling.
[a] Treatments of the particles (control and boiled).

The treatment applied to the particles did not have any effect in further improving the mechanical and physical properties of the CBPB. According to the analysis of variance, no difference was detected between treatments and only one homogeneous group was observed.

Overall, the cypress CBPB from this study presented superior properties when compared with other cement-bonded composites studied using different lignocellulosic material such as epicarp of babassu fiber [21], particles of rubberwood [22] or acacia [24], flakes of pine [23], and excelsior of cypress [5].

The statistical analysis is presented in Table 6. The physical properties of the cypress inorganic-bonded particleboards presented in Table 5 showed that TS in water immersion, after 2 and 24 h, increased only up to 2%. WA after 2 and 24 h showed a higher increment, ranging from 9% to 13%. The obtained values of thickness swelling are in accordance with those described in the BISON [20] requirements, as well as with those in the literature [21–23].

### 3.3. Decay resistance of the CBPB

The results obtained after a 12-week accelerated decay test are presented in Table 7. Overall, both fungi failed to attack the CBPB specimens. Only a slight presence of mycelium was observed in the surface of the specimens of CBPB. It seems that the high alkalinity of the boards (pH of 11.3) was a major drawback for fungal development. The cypress CBPB rather than weight loss showed significant weight gain. Souza et al. [16] explained these weight gains as a consequence of the final curing process of the cement used in the CBPB's.

There was no statistical difference in weight gain neither between the two types of fungi nor between the treatments tested.

Table 7
Weight loss in a 12-week accelerated decay resistance test of cement-bonded particleboards of cypress exposed to *G. trabeum* (Persoon ex Fries) Murrill and *T. versicolor* (Linnaeus ex Fries) Pilát

| Treatment | Average weight loss (%) | |
|---|---|---|
| | *G.trabeum* | *T. versicolor* |
| *Cupressus* spp. (control particles) | −2.74 (1.55)[a] | −3.71 (1.39) |
| *Cupressus* spp. (boiled particles) | −2.52 (1.29) | −2.16 (0.63) |

Means of 12 samples, four specimens for each board.
[a] Numbers in parenthesis are standard deviation.

## 4. Conclusions

Treated and untreated particles of *Cupressus* spp. were used to produce wood cement-bonded particleboards. Based on this study the following conclusions can be drawn:

The potential of *Cupressus* spp. as a raw material for making CBPB was confirmed. Although it is an exotic species (not native) of wood in Brazil, cypress can be compared to rubberwood, pinus and acacia to make reconstituted panels due to its low density and easy workability. Its good adaptability in a region of Brazil can encourage programs to create economic plantations of this wood species.

The amount of extractive content and mainly the chemical composition of the extractive in the cypress wood, did not restrain the inorganic-bonded manufacturing process, cement hardening and setting. Incorporating chemical and or mineral additives during the manufacturing process enhances the curing of wood–cement–water mixture, and consequently, there is no need to treat the particles.

Mechanical and physical properties of the cypress boards were found to be equivalent or superior to those commercially available CBPB and other results described in the literature.

No measurable CBPB degradation (weight loss) occurred when samples were exposed to two types of wood-destroying Basidiomycetes in an accelerated laboratory standard test. Samples of CBPB tested with *G. trabeum* and *T. versicolor* showed weight gain instead of weight loss.

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