



## Influence of accelerating admixtures in wood-cement panels: characteristics and properties

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**ABSTRACT.** Current research evaluated the use of *Pinus* sp. wood dust from lumber industries wastes on the composition of wood-cement panels. The experiment comprised the manufacture and characterization of wood-cement panels with granulometry-controlled wood dust, without any previous treatment, and four chemical accelerating admixtures (calcium chloride, magnesium chloride, aluminum sulfate and sodium silicate). Results showed that chloride admixtures had excellent behavior and the highest performance. The combination of wood dust and calcium chloride admixture had the best performance for the properties under analysis within the chloride admixtures.

**Keywords:** wood dust, cement, composites, panels, accelerating admixtures.

## Uso de aditivos aceleradores em painéis de cimento-madeira: características e propriedades

**RESUMO.** Esse trabalho tem como objetivo apresentar uma contribuição no estudo de painéis de cimento-madeira utilizando pó de madeira obtido de rejeitos de madeira de *Pinus* sp. Os estudos consistiram na execução e caracterização de painéis de cimento-madeira, utilizando pó de madeira com granulometria controlada sem tratamento prévio e quatro aditivos aceleradores de pega (cloreto de cálcio, cloreto de magnésio, sulfato de alumínio e silicato de sódio). Os resultados obtidos demonstraram que os aditivos à base de cloretos apresentaram excelente comportamento, obtendo os melhores desempenhos. Dentre os aditivos à base de cloretos, a combinação do pó de madeira e o aditivo à base de cloreto de cálcio foi aquela que apresentou os melhores desempenhos para as propriedades analisadas.

**Palavras-chave:** pó de madeira, cimento, compósitos, painéis, aditivos aceleradores.

### Introduction

The use of wood-cement composite panels allows faster construction, especially when applied in a modulated way on construction sites, through the elimination of a series of steps and other issues in the implementation of the finishing touches. Some of the many advantages in the use of panels as building elements comprise geometric accuracy, variety of sizes, shape finishing, incorporation of overlays at the factory and easy installation of frames.

Due to the fact that they are made of cement-based materials, another advantage in the use of these panels is their high resistance to termites and humidity when compared to wood. The fact that they are fire resistant and virtually non-combustible gives one a feeling of security. The thermal and acoustic isolation provided by the panels should also be considered (RAMIREZ-CORETTI et al., 1998).

Furthermore, the use of wood-cement composite panels require less raw material (wood) (such as shape, dimensions, natural defects) when

used in plywood and battens. Usually wood dust is obtained from industrial wastes coming from furniture manufacture or from pallets unusable by other companies.

Another aspect to consider is the replacement of fiber-cement panels derived from asbestos which is being gradually banned in many countries worldwide. The toxicity of cement-asbestos plates have been put to test in Brazil and in some states the use of asbestos is restricted and even prohibited. The differential characteristic of the wood-cement plate is its low cost and especially its high durability, justifying once again research on the wood-cement plate.

In general, wood-cement panels are composed of cement, wood in the form of fibers or particles, water and chemical admixtures. The cement has the basic function of acting as a binder with physical and mechanical characteristics of strength and durability. Wood increases the press-up resistance, decreases density and improves other qualities such as thermal and acoustic isolation, according to Krüger et al. (2009). Admixtures and eventually additions act as

facilitators in the affinity of cement with wood, since in their composition there are substances that favor the relation between cement and wood.

Accelerating admixtures are products added to the mixture to accelerate the setting time and the rate of strength development at early stages. Usually the most commonly used accelerators are based on calcium chloride, ferric chloride, magnesium chloride, aluminum sulfate and sodium silicate. Additions of calcium chloride also result in a decrease in the dormant or induction period in the hydration of tricalcium silicate ( $C_3S$ ).

The admixtures' main function is the acceleration of setting time and the increase in the rate of early strength development of the composite during hardening. They can be used when the composite material is molded at low temperatures (2 to 4 °C), or in the case of precast concrete (due to the necessity of fast unmolding) and urgent repair services.

Moslemi et al. (1983) was one of the researchers who employed calcium chloride as an admixture in wood-cement composites. By evaluating the use of this admixture they showed that there was a significant decrease in the time of setting time, although this fact depended on the species of wood used. According to these authors, decrease in the time of setting time is due to the emergence of strong links between wood and cement through the action of calcium chloride. Their remarks indicate that  $CaCl_2$  enhances crystal formations and the linking between the cement and the wood particles is thus increased.

According to Simatupang et al. (1995), the best admixtures to reduce the setting time of wood-cement composite are those based on potassium carbonate ( $K_2CO_3$ ), but such admixtures are very expensive. Further, the same authors observed that the use of hydrogen carbonate and potassium admixture ( $KHCO_3$ ) together with potassium carbonate reduces some of the costs.

On the other hand, aluminum sulfate ( $Al_2SO_4$ ), which works in much the same way as the chloride, increases the compound's initial strength. It is important to note that some authors like Fan et al. (1999) used sodium silicate with aluminum sulfate to study the dimensional behavior of these composites by varying humidity and temperature.

The above-mentioned research shows that few studies are extant which evaluate the influence of these admixtures in wood-cement composite, especially in different species of wood.

Current research evaluates the influence of accelerating admixtures in panels of wood-cement composite (*Pinus* spp.) and identifies the admixture with the best performance in the evaluated properties.

## Material and methods

Four accelerating admixtures were used to minimize the effect of delaying the time to handle the cement due to organic compounds found in the wood. Two admixtures were based on chloride: calcium chloride ( $CaCl_2$ ) and magnesium chloride ( $MgCl_2$ ). The other two admixtures were based on sodium silicate ( $Na_2SiO_3$ ) and basic aluminum sulfate ( $Al_2SO_4$ ).

### Preparation of panels

Panel production was undertaken with high early strength Portland cement (CP V ARI) since, according to Alberto et al. (2000), this type of cement not only provided good compatibility with *Pinus* spp. wood, but also high compressive strength at an early stage, reducing the composite's curing time.

In current research the material used was *Pinus* spp. wood, as mentioned earlier, in the form of wood dust, with controlled particle size obtained by the mechanical processing of waste on a commercial scale in the Brazilian lumber industry. This wood dust showed the fineness modulus of 1.57, according to Brazilian standard (ABNT, 1987). Figure 1 shows the grain size curve.

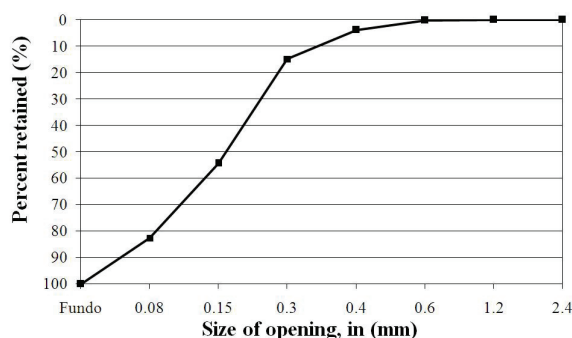


Figure 1. Grading curve for wood dust used.

After classification, the material was packed in sealed bags and kept at room temperature up to the production of test samples.

Before the molding of the panels, the wood dust samples were removed to determine the moisture rate present in the wood and adapt it to Brazilian standard (ABNT, 2009). Since it had a direct influence on the amount of water added to the mix, an adjustment was done, according to Equation (1), also used by Fan et al. (1999).

$$\text{Water corrected} = (a/c) * C + M * (0.30 - TU) \quad (1)$$

where:

a/c = water - cement ratio;  
 C = amount of cement (g);  
 M = quantity of wood (g);  
 TU = moisture content of wood (%).

The ratio wood: cement adopted was 1:4, that is 25% content of wood dust, with water/ cement ratio (a/c) of 0.40. After applying water to correct the humidity of wood (Equation 1), the water : cement ratio changed to 0.43.

The dosage used for each admixture was 4% over the cement mass and was maintained constant throughout the experiment.

After the correct proportioning of all materials, an intermittent mixer of inclined axis (cement mixer) was used in the following order: first, half of the wood dust was added; then, all the cement; finally, the remaining wood. After homogenizing the mixture, water, previously mixed with the admixture with a pressurized pistol, was added. The mixture was weighed and shaped to pressing.

For the molding of the panels, the projected density of  $2.0 \text{ kg dm}^{-3}$  and dimensions (385 x 505 x 15 mm) were adopted according to the press used in current work. Since the plate had approximately  $3000 \text{ cm}^3$ , the amount of each component of the composite was determined.

Three panels (385 x 505 x 15 mm) were molded simultaneously for each admixture. Two samples for each type of test were extracted from each panel (total of six samples), except the internal bonding strength from which four samples were extracted (total of twelve samples).

The panels were pressed at room temperature with 4 MPa pressure and immediately clipped and maintained for a period of 24 hours for hardening process. After this step, the panels were removed from the stapling device and stacked in a climatic chamber at  $20 \pm 1^\circ\text{C}$  and relative humidity  $65 \pm 5\%$  for a period of 28 days to complete the curing (hardening) process.

### Panel analysis

Molding and de-molding of the panels followed. Panels were placed in an incubator for 14 days at  $20 \pm 1^\circ\text{C}$  and relative humidity  $60 \pm 5\%$  and samples were extracted for the following tests:

1- Density of panels: American standard (ASTM, 1982) with six samples;

2- Total water absorption: six samples measuring 150 x 150 mm (width x length), American standard D 1037-34-22 and D 1037-100 (ASTM, 1982), during 2 and 24 hours of immersion;

3- Compressive strength and elasticity module: six samples measuring 25 x 100 mm (width x length) (ASTM, 1982);

4- Flexural strength and elasticity module: six samples measuring 50 x 250 mm (width x length) (EN, 1995);

5- Internal bonding strength: twelve samples measuring 50 x 50 mm (width x length), American standard D 1037 - 78B (ASTM, 1982);

## Results and discussion

### Densities of panels

Table 1 shows the average rates of panel thickness produced with four kinds of admixtures.

**Table 1.** Average density of the panels.

Admixture	Density <sup>+</sup>	C.O.V. (%)	Analysis of variance (95% confidence)*
CaCl <sub>2</sub>	1.51	3.58	A
MgCl <sub>2</sub>	1.48	4.03	A
Al <sub>2</sub> SO <sub>4</sub>	1.48	3.63	A
Na <sub>2</sub> SiO <sub>4</sub>	1.46	3.38	A

<sup>+</sup>Average of six specimens (or samples); \*The same letter in the column shows that averages are not significantly different by Tukey's test (HSD), at 5% significance level.

Rates in Table 1 demonstrated that variations in the obtained density rates were very small and there was no significant difference in the analysis of variance among the obtained averages with a 95% significance level (shown in Table 1 by the symbol 'a'). This fact may be explained by the homogeneous characteristic of the composite with small particle size (wood dust) and not influenced by the type of admixture used. Above rates are higher than those found by Mendes et al. (2011) and may be justified by the method of panel implementation.

### Total water absorption

The average rates of total water absorption obtained after 2 and 24 hours of immersion in water for different types of admixtures are shown in Table 2.

**Table 2.** Average rates of water absorption according to admixture.

Admixture	Total water absorption (%)					
	2 hours			24 hours		
	Average <sup>+</sup> (%)	C.O.V. (%)	Analysis of variance (95% confidence)*	Average <sup>+</sup> (%)	C.O.V. (%)	Analysis of variance (95% confidence)*
CaCl <sub>2</sub>	2.10	42.77	Ab	4.66 a	25.33	A
MgCl <sub>2</sub>	2.80	34.37	A	5.59 a	22.51	A
Al <sub>2</sub> SO <sub>4</sub>	1.52	68.53	B	3.97 a	38.96	A
Na <sub>2</sub> SiO <sub>4</sub>	4.93	43.74	C	8.02 b	34.32	B

<sup>+</sup>Average of six specimens; \*The same letter in the column shows that averages are not significantly different by Tukey's test (HSD) with 5% significance level.

Table 2 shows that the lowest rates of total water absorption occurred with aluminum sulfate-based admixture for 2 and for 24 hours. The highest rates were obtained for test samples of the panels produced by a sodium silicate-based admixture. This behavior may be justified by the fact that admixtures based on chloride and aluminum sulfate increased the amount of ions that reacted with tricalcium aluminate ( $C_3A$ ) found in cement and accelerated setting time, providing a more compact and, therefore, a more waterproof system.

The difference in admixture behavior may also be explained by the ionization mode in the mixture. So that the dissolution of calcium could be accelerated, acids ions must have sufficient mobility to penetrate the silicate molecules in the cement. Consequently, the particle size was highly important. It may be observed that calcium chloride has a very small size ion, 0.27 nm, which is smaller than silicate ions.

Chloride-based admixtures form small crystals in the shape of fibers, indicating a rapid crystallization. Calcium chloride accelerates the initial reaction between tricalcium aluminate ( $C_3A$ ) and gypsum also present in cement. The sulfates react first, followed by the reaction of tricalcium aluminate ( $C_3A$ ) with chloride to form ettringite, long crystals in the shape of needles. This crystallization forms an intricate mesh that makes the mold more compact and more waterproof, justifying thereby the test results.

Table 2 also reveals that there is no significant difference between the chloride-based admixtures both for the period of 2 hours as for 24 hours immersion in water. The same situation may be observed when comparing the calcium chloride-based admixture with aluminum sulfate-based admixture. The difference between the averages was established for the admixture based on sodium silicate and compared to other admixture types.

The high coefficient of variation observed in Table 2 could be explained by the adopted method which consisted in molding the panels in the laboratory. The adopted method consisted of pressing simultaneously the three panels. Therefore, the external panels would be different from the internal one.

### Compressive strength and elasticity modules

Table 3 shows the results of strength and elasticity module according to the type of admixture.

Table 3 shows that the highest rates of compressive strength were obtained for the panels produced with chloride-based admixtures (averages differ significantly from those produced with admixtures based on sulfate and silicate). The panels produced with the sodium silicate were statistically lower than those produced with chloride-based admixtures. The efficiency of chloride-based admixtures is due to increased ability to dissolve cement components due to increased ion mobility in small sized ions. It may be observed that the rates for calcium chloride are similar to those reported by Savastano Jr. et al. (1999), although the fiber used in their study was long wood fiber.

The compressive strength rates in this study were higher than the ones reported in other authors. The above may be attributed to the following factors:

- The material used in this experiment consists of a very fine grain (Figure 1) with a greater homogeneity of the composite; in other words, the wood particles are distributed more equally in the test samples, balancing the pressure distribution;
- the material used by Okino et al. (2004), for example, was wood dust too, but it was an uncontrolled source material, obtained from sawmill equipments;
- The ratio wood: cement for current research was 1:4, higher than that in the above-mentioned authors. Naturally this fact produced a higher compressive strength rate;
- The nominal density of current work was also higher, in contrast to other studies.

The average rates for the elasticity module showed that there was a different behavior when sodium silicate was employed when compared to the behavior of rates obtained for the compressive strength. This difference is due to the fact that the elasticity module is the relationship between pressure and deformation. In fact, it is demonstrated that the deformation produced in test samples was influenced by the type of admixture used.

**Table 3.** Average rates of compressive strength and elasticity modules (MPa).

Admixture	Effect of the admixture in compressive strength					
	Compressive Strength			Elasticity Module		
	Average + (MPa)	C.O.V. (%)	Analysis of variance (95% confidence)*	Average* (MPa)	C.O.V. (%)	Analysis of variance (95% Confidence)*
$CaCl_2$	18.13	13.39	A	3392.24	31.43	A
$MgCl_2$	17.99	17.54	A	2983.45	20.94	A
$Al_2SO_4$	14.86	18.75	B	2541.03	21.47	B
$Na_2SiO_4$	12.36	16.05	C	3243.35	30.88	a

\*Average of six specimens. \*The same letter in the column shows that averages are not significantly different by Tukey's test (HSD) at 5% significance level.

The lowest average rate of compressive strength for the panels was obtained with a sodium silicate-based admixture. These panels showed a smaller deformation and a high elasticity module. The admixture based on sodium silicate acts by involving the wood particles and isolating them from the cement's high alkalinity. The useful life of the composite is consequently increased. This protection modified the interaction between the crystals of cement and wood and resulted in a different behavior for the elasticity module.

#### Flexural strength and elasticity modules

The average flexural strength rates and elasticity modules which depend on the type of admixture are shown in Table 4.

Analyzing the rates in Table 4, it may be observed that higher rates of flexural strength were obtained for panels prepared with calcium chloride-based admixture while maintaining the behavior obtained for compressive strength. Panels with an admixture based on sodium silicate showed the lowest flexural strength and compression.

The panels produced with sodium silicate-based admixture showed statistically lower rates when compared to panels produced with other admixtures (Table 4).

The highest rates obtained in the elasticity module were for panels with chlorine-based admixtures when compared to others. They were statistically lower than those by sodium silicate-based panels. This fact is justified by the silicate's mode of action consisting in the isolation of wood particles which is not enough to ensure a better flexural strength and lower deformability.

Results obtained by other authors, such as Mendes et al. (2011) using particles with a thicker grain size, showed that chloride-based admixtures had the best performances for the parameters of compressive and flexural strength. In current research, the same result for a small grain size, or rather, the wood dust, was obtained. It seems that, regardless of particle size of wood dust, the interaction between the admixture, wood and

cement components is what determines the composite's final behavior. When the compressive strength rates are taken into account, it seems that rates in current work are higher than those reported by other authors for thicker grain size. This fact demonstrates that it is possible to obtain good results for any grain size, which only depends on the process.

Statistical analysis showed that there was a significant difference between the rates of flexural strength for the panels molded with the sodium silicate-based admixture and those of molded panels with other admixtures. Admixture based on sodium silicate seems to provide lower values for the flexural strength.

#### Internal bonding strength

Table 5 shows average rates for testing internal bonding strength according to the type of admixture.

Table 5 demonstrated that the highest rates obtained for the internal bonding strength in the panels were produced with chloride-based admixtures. Considering the minimum value of 0.4 MPa adopted by certain companies for this test, the chloride-based admixtures provided average rates higher than the above minimum. However, the panels prepared with other admixtures registered lower rates.

The high coefficient of variation observed in Table 5 could be explained again by the method adopted, or rather, the molding of panels in the laboratory. The method consisted of pressing simultaneously three panels. Since this study aimed to compare different types of admixtures and not to get a significant average, the coefficient of variation did not invalidate the results because other studies will be conducted with the admixture with the best performance.

Statistical analysis showed significant differences between rates for panels produced with aluminum sulfate-based admixture and panels produced with sodium silicate-based admixture when compared to panels produced with chloride-based admixtures.

**Table 4.** Average values of flexural strength and elasticity modules (MPa).

Admixture	Effect of the admixtures on the Flexural strength					
	Strength			Elasticity Modules		
	Average+ (MPa)	C.O.V. (%)	Analysis of variance (95% confidence)*	Average+ (MPa)	C.O.V. (%)	Analysis of variance (95% confidence)*
CaCl <sub>2</sub>	4.72	10.75	A	2725.53	22.68	A
MgCl <sub>2</sub>	4.55	19.31	A	3036.19	30.95	A
Al <sub>2</sub> SO <sub>4</sub>	4.32	11.01	A	2512.93	15.97	a
Na <sub>2</sub> SiO <sub>4</sub>	3.31	19.02	b	1863.96	28.62	b

\*Average of six specimens; \*The same letter in the column shows that averages are not significantly different by Tukey's test (HSD) at 5% significance level.

**Table 5.** Average rates of internal bonding strength (MPa).

Admixture	Internal Bond+	C.O.V. (%)	Analysis of variance (95% confidence)*
CaCl <sub>2</sub>	0.54	29.88	a
MgCl <sub>2</sub>	0.57	32.69	a
Al <sub>2</sub> SO <sub>4</sub>	0.34	31.54	b
Na <sub>2</sub> SiO <sub>4</sub>	0.26	41.82	b

\*Average of twelve specimens; \*The same letter in the column shows that averages are not significantly different by Tukey's test (HSD) with 5% significance level.

## Conclusion

The main feature of current work was the use of very fine grain size of wood dust with cement and admixture. Based on the study's results, it was verified that admixture with a chloride basis had an excellent behavior in several properties.

Average strength and elasticity module rates were higher for the panels produced with chloride-based admixtures and less for those based on aluminum sulfate or sodium silicate, both for compressive and flexural strength.

In the case of testing internal bonding strength, the panels made with chlorine-based admixtures provided the highest rates, even higher than that recommended by some manufacturers.

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