Amanda Fernandes Pereira da Silva
(Organizadora)

ENGENHARIAS:

Pesquisa, desenvolvimento e inovação 2

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APRESENTAÇÃO

Os mais diversos ramos do conhecimento possuem grandes dos desafios a serem superados, é o do saber multidisciplinar, aliando conceitos de diversas áreas. A curiosidade científica é o pilar de motivação que estimula as investigações baseadas no conhecimento existente objetivando a geração de novos materiais, produtos e equipamentos.

Nesse sentido, esta coleção “Engenharias: Pesquisa, desenvolvimento e inovação 2” traz capítulos ligados à teoria e prática em um caráter multidisciplinar, tendo um viés humano e técnico. Apresenta temas relacionados as áreas de engenharias, dando um viés onde se faz necessária a melhoria contínua em processos, projetos e na gestão geral no setor fabril.

De abordagem objetiva, a obra se mostra de grande relevância para graduandos, alunos de pós-graduação, docentes e profissionais, apresentando temáticas e metodologias diversificadas, em situações reais.

Boa leitura!

Amanda Fernandes Pereira da Silva

SUMÁRIO

CAPÍTULO 5

EVALUATION OF PROPERTIES OF COMPOSITES MADE OF MINERAL BINDERS, WASTE WOOD PARTICLES AND KRAFT PULP FIBERS FROM *Eucalyptus* spp. AND *Pinus* spp.

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ABSTRACT: The use of wood particles obtained from construction and demolition waste (CDW) can increase the value of material that would otherwise be discarded. The objective of this study was to evaluate physical and mechanical properties, in the hardened state, of composites produced with two mineral binders (Portland cement and gypsum), two different compositions of wood particles from CDW with dimensions P1 and P2, kraft pulp fibers from Eucalyptus spp. and Pinus spp., and water. All composite properties evaluated varied in function of binder applied (Portland cement or gypsum) and particle size (P1, P2 or kraft fibers). In relation to particle size, P2 presented lower results for dry bulk density, flexural strength and compressive strength of composites. Flexural and compressive strength of composites with P1 had an increase in values of 115% and 44%, respectively, in comparison to P2 composites. Based on species applied in composite production (eucalyptus and pinus), the dry bulk density of composites was similar, but for flexural and compressive strength, the values of eucalyptus composites were 24% and 21% higher, respectively, than pinus composites. Construction wastes can be applied for composite production, with adequate results, but the composition must be evaluated previously to indicate the best final use.

KEYWORDS: Cellulose, waste wood, Portland cement, gypsum, composite.

AVALIAÇÃO DAS PROPRIEDADES DE COMPÓSITOS DE LIGANTES MINERAIS, PARTÍCULAS DE RESÍDUOS DE MADEIRA E FIBRAS DE POLPA KRAFT DE *Eucalyptus* spp. E *Pinus* spp.

RESUMO: A utilização de partículas de madeira obtidas a partir de resíduos de construção e demolição (RCD) pode aumentar o valor do material que seria descartado. O objetivo deste trabalho foi avaliar as propriedades físicas e mecânicas, no estado endurecido, de compósitos produzidos com dois aglomerantes minerais (cimento Portland e gesso), duas composições diferentes de partículas de madeira de RCD com dimensões P1 e P2, fibras de celulose *kraft* de *Eucalyptus* spp. e *Pinus* spp., e água. Todas as propriedades dos compósitos avaliados variaram em função do aglomerante utilizado (cimento Portland ou gesso) e granulometria (P1, P2 ou fibras *kraft*). Em relação ao tamanho de partícula, a partícula P2 apresentou resultados inferiores para densidade de massa seca, resistência à flexão e resistência à compressão dos compósitos. As resistências à flexão e compressão dos compósitos com partículas P1 tiveram um aumento nos valores de 115% e 44%, respectivamente, em comparação aos compósitos produzidos com partículas P2. Com base nas espécies aplicadas na produção de compósitos (eucalipto e pinus), a densidade de massa seca dos compósitos foi semelhante, mas para resistência à flexão e compressão, os valores dos compósitos de eucalipto foram 24% e 21% maiores, respectivamente, do que os compósitos de pinus. Os resíduos de construção podem ser aplicados para produção de compósitos, com resultados adequados, mas a composição deve ser avaliada previamente para indicar o melhor uso final.

PALAVRAS-CHAVE: Celulose, resíduos de madeira, cimento Portland, gesso, compósito.

1 I INTRODUCTION

Civil construction is the most important sector in the Brazilian economy, with revenues near 10% of GDP (DECONCIC, 2018) and consumption of nearly 50% of natural resources in the country (CBCS, 2014). However, this activity produces a large amount of residues, contributing to exhaustion of landfill capacity (Rodríguez-Orejón et al. 2014).

Studies have been conducted to minimize carbon dioxide emissions from civil construction, which is responsible for approximately 40% of them (Kilbert, 2016). In recent years, researchers have concentrated efforts to find alternatives to attenuate the environmental impact caused by economic growth, to develop so-called green technologies (Kisku et al. 2017). Buildings and other structures with wood components use constructive processes with low energy consumption, and consequently discharge a low percentage of carbon in the form of CO_2. This characteristic is important, since the rising concentration of carbon dioxide in atmosphere is contributing to global warming (Feng et al. 2020; Qiao et al. 2020). Incorporation of wood as construction material results in reduction of CO_2 emissions, and uses sustainable materials (Corinaldesi et al. 2016; Akkaoui et al. 2017).

Wood residues represent nearly 31% of all waste volume from the construction of residential structures (Miranda et al. 2009; Rodríguez-Orejón et al. 2014), and are considered a recyclable or reusable resources (Höglmeier et al. 2013). Thus, it is necessary develop and refine innovative and ecologically friendly technologies to transform wood residues into material with higher value (Hossain et al. 2018). The use of wood particles is interesting to produce composites in function of their low cost compared to synthetic fibers. Besides this, they are renewable, not abrasive, have high biodegradability, low density and high porosity, among other positive characteristics (Ashori et al. 2011; Tabarsa et al. 2011; Onuaguluchi et al. 2014). From an environmental perspective, wooden products have advantages compared to mineral products for the building sector, like lower global warming protection (GWP) over life cycle and additional temporary carbon storage. An approach that promotes timber buildings can therefore contribute to reaching climate protection targets (Hafner and Schäfer, 2018).

One solution is the development of wood composites with inorganic binders such as Portland cement, magnesium cement and gypsum (Herreral and Cloutier 2008; FPL 2010). Portland cement is one of the industrial products used most in the world, but since it is produced by burning limestone and clay at high temperature, its manufacture is responsible for 2% of primary energy consumption and 5% of all industrial energy consumption in the world (Hendriks et al. 1998). On the other hand, with increasing concern for environmental quality and sustainability, some properties of gypsum are attractive, such as lower energy use and lower emission of CO_2 due to the lower temperature (between 135ºC and 180ºC) applied in calcination, and lower thermal conductivity (Dai and Fan 2015; Lushnikova and Dvorkin 2016).

Wood composites are an alternative to incorporate residues to produce new materials (Jorge et al. 2004). They are made of mixture of binder and wood particles (FPL, 2010) where the first step is binding, to transmit strength between fibers, keeping them protected from external influence, allowing their proper orientation. Since they are produced by heterogeneous materials, their properties depend on the proportion and characteristics of the components, so their physical and mechanical properties must be studied to evaluate the performance of the material or final product. The development of composites for civil construction by applying fibers is an interesting alternative, able to minimize environmental harm (Khorami and Ganjian 2013; Ramis et al. 2014). Considering their sustainability, particleboard panels are made from residual, natural and biodegradable raw materials, they are environment friendly and can be properly seen as an alternative to synthetic-based commercial products, especially for thermo-acoustic applications in green (mainly based on renewable resources) constructions (Hazrati-Behnagh et al. 2016). The wood-cement composites manufactured with a new method vibro-dynamic compression processing, demonstrated the possibility to produce and introduce wood-cement elements molded in a desired geometrical shape, whilst guaranteeing a stable behavior during handling, storage, transport and their use in construction works for buildings (Parchen et al. 2016).

Research related to cement composites containing natural fibers has been increasing to develop sustainable products with low cost, low density, adequate performance and raw material availability (Onuaguluchi and Banthia, 2016). Cellulose fibers can be applied in cement composites, and generally are obtained by a mechanical or chemical process, such as the kraft process.

The use of short fibers from angiosperms instead of long fibers from gymnosperms to reinforce cement composites, as described by Tonoli et al. (2010), can improve the mechanical performance of composites. In cement composites, fiber granulometry can influence compatibility and production viability. For example, Na et al. (2014), studying cork particles, found that smaller particles, due to their higher specific surface area, enable obtaining higher amounts of free extractives in the blend. Also, each wood species has different types and numbers of extractives, resulting in diverse effects in cement hydration.

The objective of this study was to evaluate the physical and mechanical properties, in the hardened state, of wood composites produced with two mineral binders (Portland cement and gypsum), two different compositions of wood particles from construction and demolition waste (CDW), with dimensions P1 and P2, and kraft pulp fibers from *Eucalyptus* spp. e *Pinus* spp.

2 I MATERIAL AND METHODS

2.1 Materials

The composites were made with two binders (Portland cement and gypsum), an accelerator setting time admixture, two types of wood particles (eucalyptus and pinus), two types of kraft pulp fibers (eucalyptus and pinus), and water.

The Portland cement was the CP V ARI type, comparable with cement type III in accordance with ASTM C150 (ASTM, 2019). It has Blaine modulus of 4955 cm²/g and density of 2.98 g/cm³. Gypsum (slow hardening) has Blaine modulus of 1.02 cm²/g and density of 2.63 g/cm³. The materials were characterized also for granulometry (Figure 1) and chemical composition (Table 1).

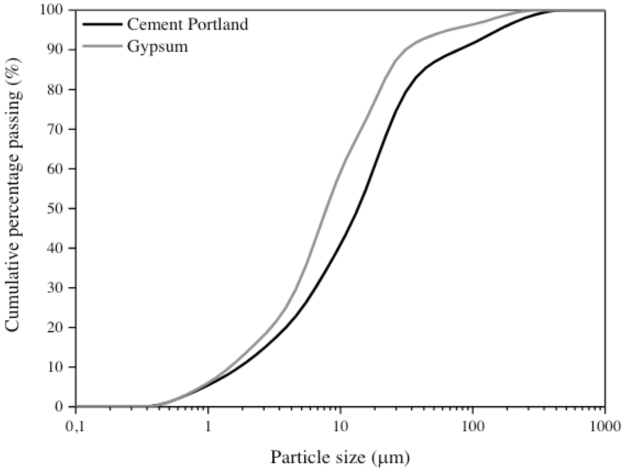

Fig 1 Particle size composition of Portland cement and gypsum

Source: The authors.

Parameters	**CaO (%)**	**MgO (%)**	**SO_3 (%)**	**SiO_2 (%)**	**Al_2O_3 (%)**	**SrO (%)**	**Fe_2O_3 (%)**	**K_2O (%)**	**CO_2 (%)**	**I. R. (%)**	**F. L. (%)**
Cement	-	5.5	3.1	-	-	-	-	-	-	11.8	3.5
Gypsum	42.7	0.1	51	0.3	0.1	0.1	< 0.1	< 0.1	-	-	5.63

Legend: I. R. – insoluble residue; F. L. – firing loss.

Tab 1 Chemical composition of mineral binders

Source: The authors.

The accelerator setting time admixture – used in wood-cement composites – is comparable to Type C in accordance with ASTM C494 (ASTM, 2019) (5% in relation to cement mass), with density of 1.27 g/cm³ and based on Na silicate.

The construction and demolition wastes (CDW) were from eucalyptus and pinus wood. The material was ground in a portable hammer mill with 5 HP operating at 1160 rpm. Particles that passed through the mill were classified as P1, and particles that passed through the mill and also through a 1.2 mm sieve were classified as P2. Particles were also classified in function of density ASTM D2395 (ASTM, 2017), unit weight ASTM C29 (ASTM, 2017), moisture content ASTM D4442 (ASTM, 2016), pH TAPPI 252 (TAPPI, 2002), solubility in cold water ASTM D1110 (ASTM, 1984), solubility in 1% NaOH ASTM D1109 (ASTM, 1984) and chemical composition ASTM C136 (ASTM, 2014) (Table 2; Figure 2).

Particle	Basic density (g/cm³)	Unit weight (g/cm³)		Voids index (%)		Moisture content (%)	pH	Solubility in cold water (%)	Solubility in 1% NaOH (%)
		P1	P2	P1	P2				
Eucalyptus	0.348	0.145	0.115	58.29%	66.92%	13.81	7.71	0.67%	17.30%
Pinus	0.315	0.138	0.113	56.18%	64.12%	12.3	7.69	0.96%	20.94%

Tab 2 Characterization of wood particles

Source: The authors.

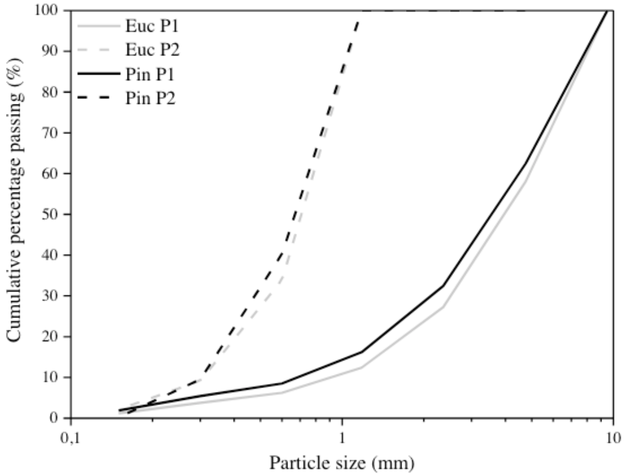

Fig 2 Particle size composition of the wood particle

Source: The authors.

Unbleached kraft cellulose from eucalyptus and pinus wood (Figure 3) were characterized in function of fiber dimension, based on mean of 30 fibers per species. Fiber length, fiber diameter and lumen diameter (Table 3) were measured with an Olympus microscope, and fiber cell wall thickness was calculated based on Equation 1.

$$e = [(LF - LL)/2)] \qquad \text{Eq. 1}$$

Where: e= cell wall thickness (μm); LF= fiber diameter (μm); LL= lumen diameter (μm).

Parameter		Fiber length (µm)	Fiber diameter (µm)	Lumen diameter (µm)	Cell wall thickness (µm)
Eucalyptus	Minimum	910.0	11.0	0.5	2.5
	Mean	1,256.0	18.0	5.0	6.7
	Maximum	1,850.0	25.0	10.0	11.5
	Standard deviation	213.2	3.6	2.0	1.9
Pinus	Minimum	2,120.0	35.0	5.0	2.5
	Mean	3,220.0	51.0	30.0	10.6
	Maximum	5,000.0	75.0	69.0	20.0
	Standard deviation	710.9	11.6	17.5	5.6

Tab 3 Eucalyptus and pinus kraft cellulose fiber dimensions

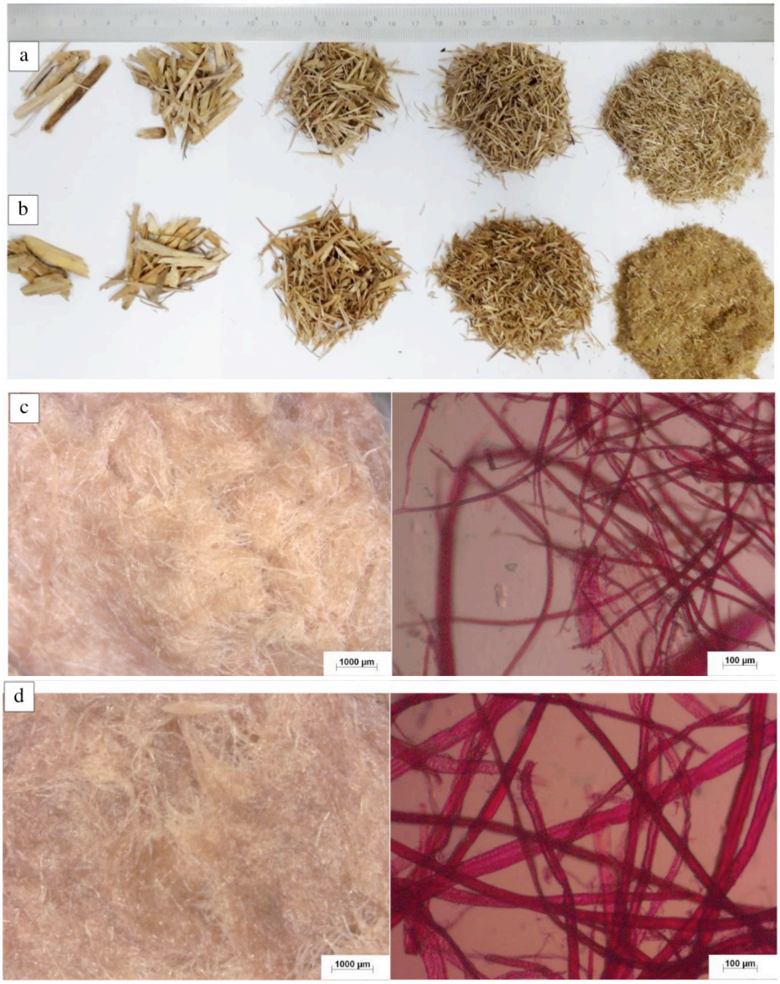

Fig 3 Eucalyptus (a) and Pinus (b) wood particles, fraction from sieve from left to right: 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm and 0.30 mm. Kraft pulp and individual fibers from eucalyptus (c) and pinus (d)

Source: The authors.

2.2 Methods

2.2.1 Pretreatment of wood particles

Wood particles were pretreated in cold water for 48 h in a proportion of 1:10 (wood:water). Then they were air-dried for 72 h, and kiln-dried for 24 h. As particles were dried, water compensation as proposed by Simatupang (1979) was applied (Equation 2).

$$Ca = R_{a/a} \times C + (FSP - U) \times M \qquad \text{Eq. 2}$$

Where: Ca = water consumed (g); R (a/a) = water/binder ratio; C = binder consumed (g); FSP = fiber saturation point (adopted as 30%); U = wood moisture content (%); M = wood mass (g).

2.2.2 Composite production

Composites were produced with a fixed water/cement ratio of 0.50 and water/gypsum of 0.70. The binder/particle ratio was 1:0.15 by mass. For production of composites with cement and gypsum, some adaptations were applied. In both, particles were added in the final 60 seconds of mixing. At the end, the mixture was homogenized manually for 30 s and prismatic samples (4 x 4 x 16 cm^3) were molded to perform the tests of dry bulk density, flexural strength ASTM C348 (ASTM, 2019) and compression strength ASTM C349 (ASTM, 2018) after 28 days.

Factorial analysis was applied in a 2 x 3 x 2 scheme, with 2 binders (Portland cement and gypsum), 3 particle types (P1, P2 and cellulose) and 2 wood species (eucalyptus and pinus). For comparison of means, ANOVA and the Tukey test at 99% probability were applied.

3 I RESULTS AND DISCUSSION

3.1 Characterization of materials applied for composite production

3.1.1 Binders

Based on granulometry (Figure 1), gypsum had more particles with small dimensions than Portland cement CPV ARI, so it was thinner. In relation to chemical composition (Table 1), cement CPV ARI had the stipulated limits for MgO, SO_3 and firing loss (F. L.), but exceed the limit of 1.50% for insoluble residue (I. R.), in accordance with ASTM C150 (ASTM, 2019). The excess of insoluble residue (I. R.) may be related to failures in the burning and cooling steps in the Portland cement manufacturing process used (Battagin, 2011). On the other hand, gypsum satisfied the values stipulated by ASTM C28 (ASTM, 2010).

3.1.2 Wood particles

Eucalyptus and pinus particles had similar basic density (Table 2). It is known (FPL, 2010) that wood is composed of pores and cavities, and variation in these apertures and cell wall thickness cause some species to have more substances by volume unit than others, and hence higher basic density.

For the unit weight, the particles presented different values according to the species (eucalyptus and pinus) and the particle type (P1 and P2) evaluated. Considering the particle species, the eucalyptus P1 particle had a unit weight of 5% higher than that of the pinus P1 particle. While the eucalyptus P2 particle had a unit weight of 2% higher than that of the pinus P2 particle. The similarity between the unit weight values for the different species may be related to the proximity between the basic density values of the CDW wood particle species. However, when considering the particle type, for the eucalyptus species, the P1 particle had a unit weight of 26% higher than the P2 particle. While, for the pinus species, the P1 unit weight particle had of 22% higher than the particle P2. This behavior may be related to the shape of the particles. Similarly, in sands used for the production of mortar, the variation in unit weight can sometimes be explained by the sphericity of the sand grains (Carasek et al. 2016). For the void index, it is possible to observe that the values for the P2 particle are higher than the values of the P1 particle.

Moisture content and pH for both species were similar. For water and NaOH solubility, pinus particles had values 48% and 21% higher than eucalyptus. Solubility in NaOH is considered a measure of wood deterioration, because greater wood degradation is associated with higher solubility in alkaline solutions (Kawase 1962; Pettersen 1984). So, in this study, pinus particles were more degraded than eucalyptus in function of their higher NaOH solubility.

Particle size composition of the wood particle (Figure 2) was similar, as expected in function of the classification.

3.1.3 Unbleached kraft fibers

Pinus and eucalyptus are from different botanical groups, so fiber dimensions are expected to be different. Pinus fibers were 156% longer, 183% larger in fiber diameter, 500% larger in lumen diameter and 58% greater in cell wall thickness. Also, pinus kraft fiber had more heterogeneity in relation to length. Mechanical behavior of composites produced from fibers is influenced by type, length, diameter, texture and fiber distribution (Karade 2010; Khorami and Ganijan 2011), so the dimensions of kraft cellulose will influence composite properties in different ways.

3.2 Physical and mechanical properties of composites

Table 4 shows the mean values of the evaluated properties indicated the variations between materials applied in composite production.

SOURCE	PROPERTIES					
	Dry bulk density (kg/m^3)		Flexural strenght (MPa)		Compressive strenght (MPa)	
A – Binder	**S**		**S**		**S**	
1 – Portland cement	1,388.80	a	3.36	a	8.76	a
	8.75%		30.53%		50.89%	
2 – Gypsum	1,137.59	b	2.58	b	7.08	b
	16.40%		51.99%		20.75%	
B - Type	S		S		S	
1 - Particle 1	1,424.43	a	3.81	a	9.34	a
	7.88%		12.27%		29.81%	
2 - Particle 2	1,212.51	b	1.77	b	6.47	c
	8.93%		78.71%		67.21%	
3 - Cellulose	1,152.64	b	3.33	a	7.95	b
	21.15%		12.20%		17.50%	
C - Specie	NS		S		S	
1 - Eucalyptus	1,263.83	a	3.29	a	8.67	a
	14.61%		31.93%		18.70%	
2 – Pinus	1,262.55	a	2.65	b	7.17	b
	17.52%		51.56%		61.99%	

S = Calculated F significant at probability of 99%; NS = Calculated F not significative at probability of 99%. Mean values with the same letter do not differ statistically. Red values indicate the coefficient of variation (%).

Tab 4 Mean values and coefficient of variation (%) obtained by factor analysis of properties in the hardened state for each factor and their interactions

Figure 4 shows the mean values of dry bulk density at 28 days indicate the variations between cement and gypsum.

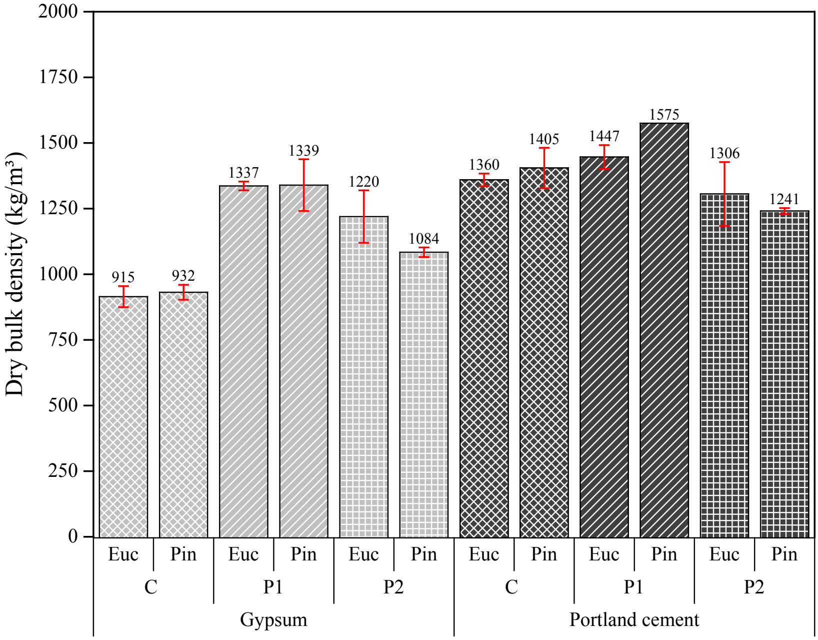

Fig 4 Dry bulk density of composites

In relation to kind of binder (Table 4), there were statistical differences. Composites were produced with the same binder/water ratio, so the variance was the result of density, which is higher in cement than gypsum, so the final dry bulk density composites with Portland cement (1,388.80 kg/m³) was higher than the composite produced with gypsum (1,137.59 kg/m³).

Comparison of the type of particle – P1 (1,424.43 kg/m³), P2 (1,212.51 kg/m³) and Kraft fiber (1,152.64 kg/m³) – there was only statistical equivalence between P2 particle and the Kraft fiber. The P2 particle comprises the particles passing through the 1.2 mm sieve, that is, particles with dimensions smaller than the P1 particle. The statistical difference observed between the composites produced with the P1 and P2 particles can be explained by the unit weight values obtained for these particles. For weight dosages, there is a decrease in the volume of wood present in the traces produced with the P1 particle when compared to the P2 particle. This is because, the unit weight of the P1 particles is higher than the P2 particles, regardless of the wood species. When dosing the materials in weight, the particles with the lowest unit weight start to present greater volume in the composition, which contributes to the decrease of density and increase of the voids index (Turgut 2007; Morales-Conde et al. 2016; Rocha et al. 2019a; Rocha et al. 2019b).

Considering species in the composition, *Eucalyptus* spp. (1,263.83 kg/m³) and *Pinus* spp. (1,262.55 kg/m³), both were similar statistically, which can be the effect of the proximity of basic density values of the two particle types. The statistical equivalence indicated that, independent of species, dry bulk density tended to be equal for the different composites.

Figure 5 shows the flexural strength of the composites after 28 days revealed the influence of the type of particle on the results.

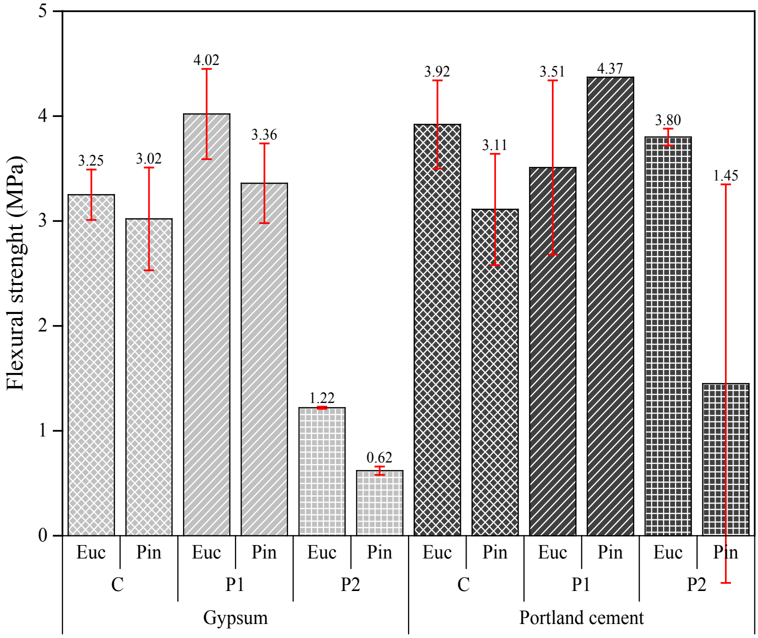

Fig 5 Flexural strength of the composites

Table 4 shows there was a significant statistical difference in the flexural strength of the composites between those produced with Portland cement (3.36 MPa) and gypsum (2.58 MPa). This can be attributed to the different physical and chemical characteristics of the binders, such as density and chemical composition. In addition to Portland cement, it has greater binding capacity.

Comparison of the type of particle – P1 (3.81 MPa), P2 (1.77 MPa) and kraft fiber (3.33 MPa) – there was only statistical equivalence between P1 and kraft fiber. The composite produced with P2 had lower values, a result that can be explained in function of binder applied.

Composites produced with Portland cement and the P2 particle, as shown in Table 02, the content of solubility in cold water to the pinus particles was 48% higher than that of eucalyptus particles. Therefore, the extracts of pinus particles may have had a greater influence on the decrease in performance of composites. Researchers observed that the smaller the particle, the larger the surface area and, consequently, the greater the amount of extracts released into the mixture (Na et al. 2014). In addition, each wood species has different types and amounts of extracts, causing different effects on cement hydration (Karade et al. 2006; Na et al. 2014). This result also indicates that the content of the accelerator setting time admixture used for the production of the composite, as recommended by Rocha et al. (2016), and the pre-treatment carried out on the particles, as indicated by Lima (2009), may not have shown efficiency or not be sufficient, since the samples containing the pinus particles, were influenced by the extracts of the wood particles during healing.

In composites produced with gypsum and P2 particle, it is believed that, as the extractives do not negatively influence the mechanical properties of the gypsum (Dai and Fan 2015; Rocha 2017), there is a physical effect influenced by the decrease in particle size. In this way, the increase in the surface area of the wood particles may have contributed to the increase in the absorption of the water used for the production of the composite. Knowing that the stoichiometric demand for gypsum hydration is 18.6%, the excess amount of water used for the production of the composite is necessary to provide workability (Khalil et al. 2014; Kirchheim et al. 2018). During the production of the specimens of this study, the composites produced with gypsum and the P2 particle showed high consistency, so that the molding was hampered due to the lack of workability. Therefore, it is believed that the amount of water absorbed by the P2 particle may have exceeded the fiber saturation point value estimated by 30%. This behavior may have contributed to the heterogeneity of the composites and, consequently, to the low results obtained.

On the other hand, the highest values were obtained for composites produced with the P1 particle and Kraft fiber. The behavior of composites produced with the P1 particle indicates that the larger size of the particles tends to contribute to the performance of the composite when subjected to the flexural strenght. It is worth noting that the flexural strength of composites produced with the P1 particle (3.81 MPa) increased by 115% compared to the flexural strength of the composites with the P2 particle (1.77 MPa). It is also important to highlight that when mass dosing materials, particles with lower unit weight (represented by the P2 particle) start to present a greater volume in the composition (Rocha et al. 2019a; Rocha et al. 2019b). Researchers explain that the amount of wood particles present in composites is able to influence their mechanical performance (Turgut 2007; Morales-Conde et al. 2016).

For composites produced with Kraft fiber, researchers (Ardanuy et al. 2011; Fernández-Carrasco et al. 2014) explain that the fibers tend to act as agents that contribute to the formation of crystals of hydrated compounds, in such a way so that, in regions close to the fibers, a higher concentration of hydrated particles is formed, in addition to a denser microstructure, that is, a porous network with increasingly smaller pores.

Other researchers (Carvalho et al. 2008) reported that, as in this study, composites produced with gypsum and Kraft fiber showed satisfactory mechanical results. This can be explained by the water retention made by the Kraft fiber that allows the formation of larger crystals around it, contributing to better adherence in the plaster matrix. In general, composites produced with the particle P1 or with cellulose tend to present better performance of flexural strength when compared with the particles evaluated in this study.

Comparison of the species - Eucalyptus spp. (3.29 MPa) and Pinus spp. (2.65 MPa) - there was a statistical difference between the two species used. This effect can be explained by the fact that eucalyptus fibers are short when compared to pinus fibers that are long. Researchers (Savastano Jr. et al. 2000; Chung 2005; Li et al. 2006; Tonoli et al. 2010; Xie et al. 2015) claim that the shorter particles - represented by the eucalyptus specie - tend to present better dispersion in composites, contributing to better flexural strength, that is, greater load capacity. It is important to highlight that the flexural strength of composites produced with eucalyptus increased by 24% when compared to the strength of composites produced with pinus. Thin, but also long particles have to be preferred when mechanical properties (Frybort et al. 2010).

Figure 6 shows the mean values of compressive strength at 28 days were variable in function of binder and particle species.

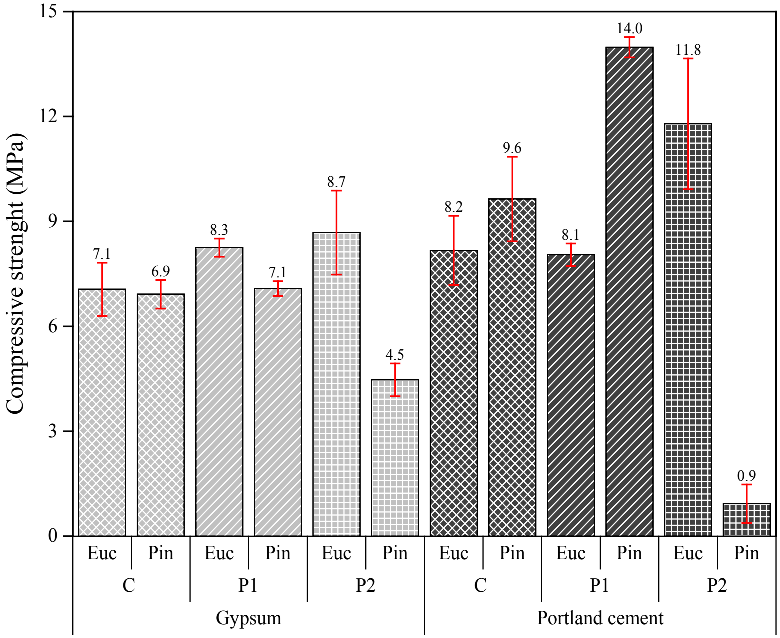

Fig 6 Results of compressive strength of the composites

Table 4 shows there was a significant statistical difference in the flexural strength of the composites between those produced with Portland cement (8.76 MPa) and gypsum (7.08 MPa). This effect, like for flexural strength, is influenced by physical and chemical characteristics of binders. Despite developing better mechanical behavior, composites produced with Portland cement tend to have a higher dry bulk density than composites produced with gypsum.

Statistical differences were observed when comparing of the type of particles, considering P1 (9.34 MPa), P2 (6.47 MPa) and kraft fiber (7.95 MPa). Lower values of compressive strength were verified for composites with P2 particle, as occurred in the flexural strength test. These particles, as described previously, released more extractives in function of their dimensions, for composites produced with Portland cement, and had higher absorption, and consequently lower percentage of available water for binder hydration, for composites with gypsum.

On the other hand, higher values were observed for composites with P1 and kraft fiber. The behavior of composites with P1 indicated that the larger particle dimension tends to increase compressive strength, as observed in flexural strength. The composites produced with P1 particles (9.34 MPa) higher compressive strength than those produced with P2 (6.47 MPa). The composites produced with the P1 particle indicates that the particles with the lowest dry bulk density – represented by the P2 particle – start to present a greater volume in the composition (Rocha et al. 2019a; Rocha et al. 2019b). Researchers explain that the amount of wood particles present in composites is able to influence their mechanical performance (Turgut 2007; Morales-Conde et al. 2016).

On the other hand, for composites with kraft fibers, the material contributed to the formation of crystals of hydrated composites, resulting in a denser microstructure (Ardanuy et al. 2011; Fernández-Carrasco et al. 2014).

In general, composites produced with the P1 particle tend to have better compressive strength performance when compared to the particles evaluated in this study.

Considering species in the composition, *Eucalyptus* spp. (8.67 MPa) and *Pinus* spp. (7.17 MPa), significant differences were verified. Like the results for flexural strength, this effect can be explained by better dispersion of eucalyptus fibers in the composite. Also, as reported in Table 2 and described in flexural strength results, the content of solubility in cold water to the pinus fibers was 48% higher than in eucalyptus. So, extractives from pinus fibers might have negatively influenced the hydration of Portland cement. The composites with eucalyptus fibers had 21% greater compressive strength than the composite with pinus fibers.

4 I CONCLUSION

Particles from civil construction and demolition waste had different percentages of extractives soluble in cold water and 1% NaOH, and also different fiber dimensions, which influenced the characteristics of the composites.

All composite properties evaluated varied in function of binder applied (Portland cement or gypsum) and particle size (P1, P2 or kraft cellulose fiber). In relation to particle size, P2 presented lower results in dry bulk density, flexural strength and compressive strength of composites.

Based on species applied in composite production (eucalyptus and pinus), dry bulk density of composites was similar, but for flexural and compressive strength, eucalyptus had better results than pinus.

Civil construction wastes can be applied for composite production, with adequate results, but the composition must be evaluated previously to indicate the better final uses of the material.

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