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Effect of wood particle treatment on the properties of gypsum plaster pastes and composites

Leandro Shiroma [1], Gladis Camarini [2], Antonio Ludovico Beraldo [1]

[1] FEAGRI, UNICAMP, Av. Cândido Rondon, 501 - Cidade Universitária Zeferino Vaz, Campinas - SP, CEP 13083-875
e-mail: leandro.shiroma@feagri.unicamp.br
[2] FEC, UNICAMP, Rua Saturnino de Brito, 224, Cidade Universitária Zeferino Vaz, Campinas, SP, CEP 13083-889
e-mail: gcamarini@gmail.com

ABSTRACT

In this work the performance of gypsum plaster and wood particle in pastes and composites was investigated. Wood particles of fineness 0.42 mm and 1.20 mm were employed. Natural wood particles and the treated ones in cold or hot water (80 °C) were performed. The effects of the extractives solutions from the treatments applied to the wood particles on wood-gypsum compatibility were studied. For pastes and composites, water-to-gypsum ratio was 0.65. Wood particles-to-gypsum plaster ratios were 5%, 10% and 15%, in mass. Kinetics of temperature, mechanical performance and dynamic elasticity modulus by ultrasound measurements were applied to evaluate the gypsum plaster pastes and its composites behaviors. Results show that the extractive solutions changed the time of gypsum plaster hydration, being more sensitive to hot water treatment. The composites compressive strength increase with the wood particles pretreatment. The best result was to room temperature treatment. The same performance was found to the modulus of elasticity. Treatments have improved significantly the flexural strength. The best wood particle content was 10%. These results show the possibility of using this wood waste with an easy and simple treatment to make eco-efficient building materials.

Keywords: Gypsum plaster, wood particle, composite, ultrasound, kinetics of temperature.

1. INTRODUCTION

Gypsum plaster is a calcium sulfate dehydrate ($CaSO_4 \cdot 2H_2O$) which is explored in different countries and its applications were widespread all over the world. Gypsum can be used in both natural and burnt forms. Natural gypsum is used in agriculture and for Portland cement production. Calcined gypsum is used to produce hemihydrates, extensively employed in buildings, ceramics and medical industries [1]. In the world there is a large amount of gypsum ore and Brazil has significant reserves located in the North, Northeast and Center-West of the country, being the largest gypsum producer in South America with 3,7 Mt, representing 2.5% of the world production, and placed at 10^{th} global producer [2].

The gypsum plaster supply chain has low energy consumption and CO_2 emission compared to those related to lime and Portland cement. Gypsum plaster products are fire resistant, cheaper, having thermal properties and it is easy to assemble [3]. However, gypsum plaster based composites are brittle matrixes and fibers can be used to improve this property. Another difficulty in using gypsum plaster is the quantity of waste produced due to the short period of setting times [4, 5].

In Brazil, the wood industry uses reforestation wood (*Pinus caribea* or *Eucalyptus*) to produce furniture, pencil, plates for building construction, pallets and other applications. The pallet industry produces around 2,000 tons per month of wood waste, mainly from *P. caribaea*, harvest from reforestation. The waste generated is composed of homogeneous particles due to the standardization of the tree cutting to produce the pallets. As reported, wood particle size is very important regarding to their chemical compatibility with the inorganic binders [6]. Unfortunately, these wastes are burnt or landfilled, which causes environmental problems such as air pollution, emission of greenhouse gases and occupation of useful land.

The disposal of wood particles has received increasing attention in recent years and new applications have been tried to give value to this waste. These applications can be the gypsum plaster composites production which has been studied since the 1980s [7, 8]. In the beginning, due to the light weight, good sound and

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thermal insulation properties, the products were used in interior wall and ceiling panels [7]. As an eco-friendly binder, gypsum plaster has been recognized to make new composites with wastes, and particularly, wood wastes.

Due to the amount of waste and its conditions, mainly the homogeneity of its composition, this wood particles are properly for using to make gypsum plaster composites for building applications, as components and also as plasterboards for ceiling and wall partitions.

However, inorganic binders and wood particles composite show several drawbacks. As a natural material the wood particle has a cellular structure with different proportions of inhibitory substances, e.g. cellulose, hemicelluloses, lignin and several extractives, and most of them dissolves in water and disturbs the gypsum plaster crystallization. The hydration of gypsum plaster in contact with natural wood particles can be improved by treating the wood particles or by using some additives. In the most of the cases, wood particles pretreatment is mandatory, allowing to obtain wood more suitable for composites production with inorganic binders [9].

Wood particles can be obtained from several sources, showing different chemical composition, and it is expected that their reaction with gypsum plaster can significantly differ [10, 11]. And also, the high water absorption capacity when employing wood particles changes the properties of the binder in the fresh state.

Despite that, Costa et al. [12] studied reinforced gypsum plaster composites with sugar cane bagasse fibers. They concluded that the best results were obtained at 1% and 2% (in weight) of fiber levels.

The behavior of the sisal fibers-gypsum plaster composite was studied by OLIVARES *et al*. [13], employing a non-destructive test by ultrasound. It was concluded that this technique was efficient for evaluating the material performance.

In the present paper, we investigated the performance of a commercial gypsum plaster (β-hemihydrate - HH) mixed with the extractive solutions from wood particles (WP) treatments and the evaluation of WP-gypsum plaster (WP-HH) composites to be employed as components, or as plates for buildings.

2. MATERIALS AND METHODS

At first, WP was treated with water at room temperature (RT) and at 80 °C (HW). The extractive solutions from the treatments applied to the WP were used in gypsum plaster pastes production. In a second step, composite from gypsum plaster and treated WP were produced. Figure 1 shows the proposed approach of this experimental work.

2.1 Materials

2.1.1 Commercial gypsum plaster (HH)

Commercial gypsum plaster was employed as a binder (Table 1). It was a β-hemihydrate (HH) used in the plaster industry for producing components and in buildings as renderings.

2.1.2 Wood Particles (WP)

WP was supplied by a factory of wooden pallets obtained from *Pine* trees. WP was separated by sieving in two sizes: 0.42 mm and 1.20 mm. These dimensions were chosen according to previous studies performed with thermoplastic composites [14, 15]. These fractions were used to prepare the extractive solutions and for making the composites for testing. The physical properties results of WP and HH are given in Table 1 [16, 17,18].

WP was employed (i) *in natura* (Nat) (without treatment), (ii) treated with water at room temperature (RT) and (iii) treated with water at 80 °C (HW). Aqueous treatments were employed to obtain the extractive solutions, aiming to verify their influence on HH pastes and on WP-HH composites.

WP was soaked in water for 2 hours, for each treatment. The particle content in the water was 5%, 10% and 15%, by mass. After 2 hours the extractive solution (S) was poured into a filter to separate of the WP. These extractive solutions from both WP sizes were used as mixing water to produce the HH pastes aiming to study their influence on setting times, by surveying the kinetics of temperature evaluation (variation of the hydration temperature across the time).

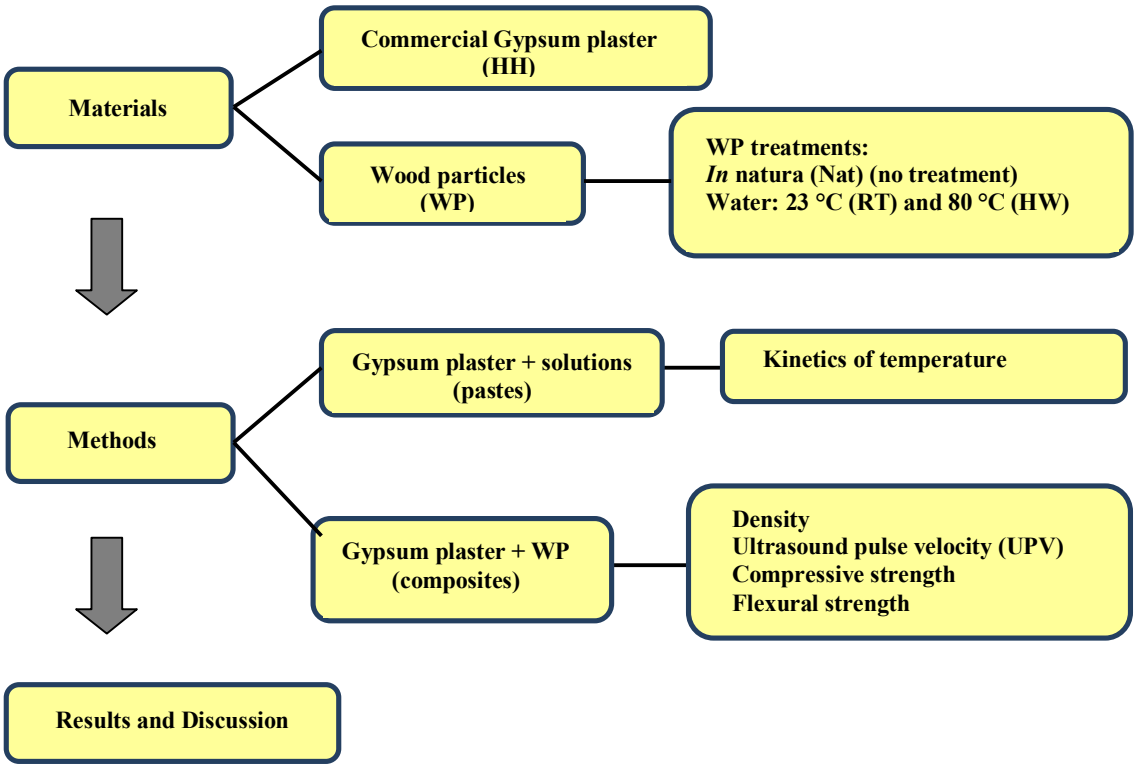


Figure 1: Experimental approach

Table 1: Physical properties of wood particles (WP) and gypsum plaster (HH).

Material	Particle size (mm)	Bulk density (kg/m^3)	Specific gravity (kg/m^3)	Fineness modulus
WP	0.42	220	1,200	-
	1.20	140	1,110	-
HH	-	610	2,550	1.02

2.2 Mix design and curing

2.2.1 Gypsum plaster pastes

Gypsum plaster pastes were manually prepared with water and the extractive solutions (S) from the WP treatments. The water-to-gypsum plaster ratio (w/gp) and the solution-to-gypsum plaster ratio (S/gp) were 0.65 (Table 2).

These gypsum plaster pastes were used to determine the kinetics of temperature and the influence of the extractive solutions on their setting times.

Table 2: Gypsum plaster pastes

Material	WP particle treatment	Pastes	WPW (%)	Particle dimension (mm)	w/g	S/gp
Gypsum Plaster Pastes	-	Plaster	0	-	0.65	-
	Water at room temperature (RT)	RT5-1	5	0.42	-	0.65
		RT10-1	10		-	
		RT-15-1	15		-	
	Hot water - 80 °C (HW)	HW5-1	5	0.42	-	0.65
		HW10-1	10		-	
		HW15-1	15		-	
	Room temperature (RT)	RT5-2	5	1.20	-	0.65
		RT10-2	10		-	
		RT-15-2	15		-	
	Hot water - 80 °C (HW)	HW5-2	5	1.20	-	0.65
		HW10-2	10		-	
		HW15-2	15		-	

2.2.2 WP-gypsum plaster (WP-HH) composites

The WP-HH composite mixtures are detailed in Table 3. The mixtures were manually prepared. After demolding (24 hours), the specimens were placed in an oven to dry at 60 °C, until constant mass. After drying, WP-HH composites were tested. Density, flexural strength, compressive strength, and dynamic modulus of elasticity by ultrasonic pulse velocity (UPV) were evaluated.

Table 3: WP-HH mixtures

Material	WP treatments	Composites	WP (%)	WP dimension (mm)	w/gp
Gypsum Plaster	-	Plaster	0	-	0.65
WP	Natural	Cnat5	5	1.20	0.65
		Cnat10	10		
		Cnat15	15		
	Water at room temperature (RT)	CRT5	5	1.20	0.65
		CRT10	10		
		CRT-15	15		
	Hot water - 80 °C (HW)	CHW5	5	1.20	0.65
		CHW10	10		
		CHW15	15		

2.3 Testing methods

2.3.1 Kinetics of temperature

In the fresh state the hydration of the pastes was determined by means of temperature development due to the exothermic hydration reactions. The temperature variations in the mixture, through the release of heat, indicate the beginning and the end of setting [19].

The equipment was a pseudo adiabatic system in which the studied mixtures are placed in order to isolate them from the external environment (Fig. 2). The temperature was measured by thermocouples (Pt 100) placed inside the mixtures. Temperature variations are recorded by a datalogger Field Logger Novus with four reading channels [20].

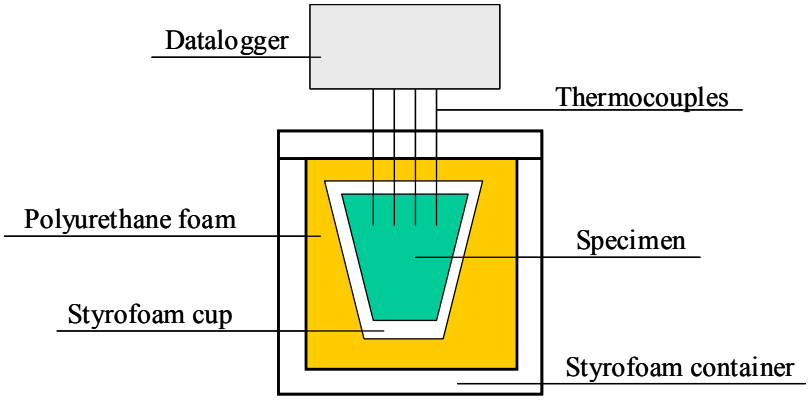


Figure 2: Scheme of the pseudo adiabatic calorimeter.

From these curves, it was possible to measure the maximum temperature reached during gypsum plaster hydration and the setting times (initial and final). RIDGE [19] found that from these curves it is possible to determine the initial setting times when the rate of temperature increase is 0.1 °C/min; final setting times is detected when the rate of temperature increasing is less than 0.1 °C/min.

2.4 Density

The density of the composites was determined by the mass per unit of volume of the material. To calculate this physical property the weight and dimensions were determined on prismatic specimens (40 mm x 40 mm x 160 mm).

2.5 Flexural and compressive strengths

Prismatic specimens (40 mm x 40 mm x 160 mm) were molded for flexural and compressive strength tests (Figure 3a and 3b). Compressive strength was performed in the halves from the flexural strength test [21]. Three prismatic specimens were molded for the flexural strength. Compressive strength was determined on six halves from the flexural strength test specimens. A universal testing machine Versa Tester with 150 kN capacity was used. The maximum loads were recorded and flexural and compressive strengths were calculated.

2.6 Dynamic modulus of elasticity

The dynamic modulus of elasticity was determined by the ultrasonic pulse velocity (UPV) in cylindrical specimens (50 mm diameter and 100 mm high). After molding, the specimens tops were withdrawn to allow the UPV measurements (Figure 3c). The equipment was a BP7 – Steinkamp, with contact transducers with exponential section, and 45 kHz of resonant frequency.

UPV was obtained by the wave propagation across the time (minutes) by positioning the transducers at the ends of the specimens until the time value remained constant (Figure 3c). To guarantee the results to all the mixture, the signal was taken until 130 min after mixing.

With the UPV results and the composites densities, the dynamic modulus of elasticity (E_d) was determined (Equation 1).

$$E_d = \rho * UPV^2 * 10^{-9} \quad (1)$$

Where: E_d = dynamic modulus of elasticity (GPa), ρ = density (kg/m^3), and UPV = ultrasonic pulse velocity (m/s).

2.7 Statistical analysis

The results were statistically analyzed by using the software Statgraphics Centurion XIV. The analysis of variance (ANOVA) was applied in order to evaluate the effects of the particle treatments (Nat, RT and HW) and the effect of the particle content (5%, 10% and 15%) on the properties of the gypsum plaster paste and the WP-HH composites. Averages were compared with Tukey test at the 99% level of statistical probability.

Figure 3: Tests performed: (a) flexural strength, (b) compressive strength, and (c) UPV

3. RESULTS AND DISCUSSION

The results allow detecting: (i) the influence of the extractive solutions on gypsum plaster pastes and (ii) the WP influence on gypsum plaster composites properties.

3.1 Gypsum plaster pastes

3.1.1 Kinetics of temperature

In the first step, it was evaluated the changes produced by the WP extractives on the gypsum plaster kinetics of temperature.

3.1.1.1 Room temperature (RT) solutions

Figures 4 and 5 show the kinetics of temperature of gypsum plaster pastes produced with WP extractive solutions at room temperature (RT) from the sizes 0.42 mm and 1.20 mm, respectively.

Results show a delay on the HH hydration with WP extractive solutions obtained by 0.42 mm WP size. The setting times were long as the WP content increases, denoting that this delay depends on the extractives content [22].

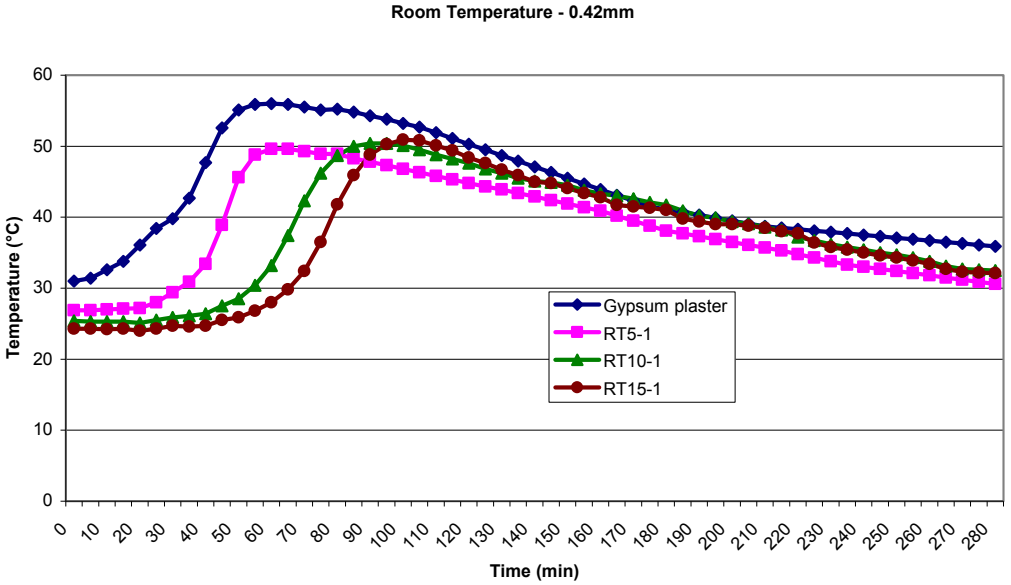


Figure 4: Kinetics of temperature results of HH paste with RT solutions from WP of 0.42 mm

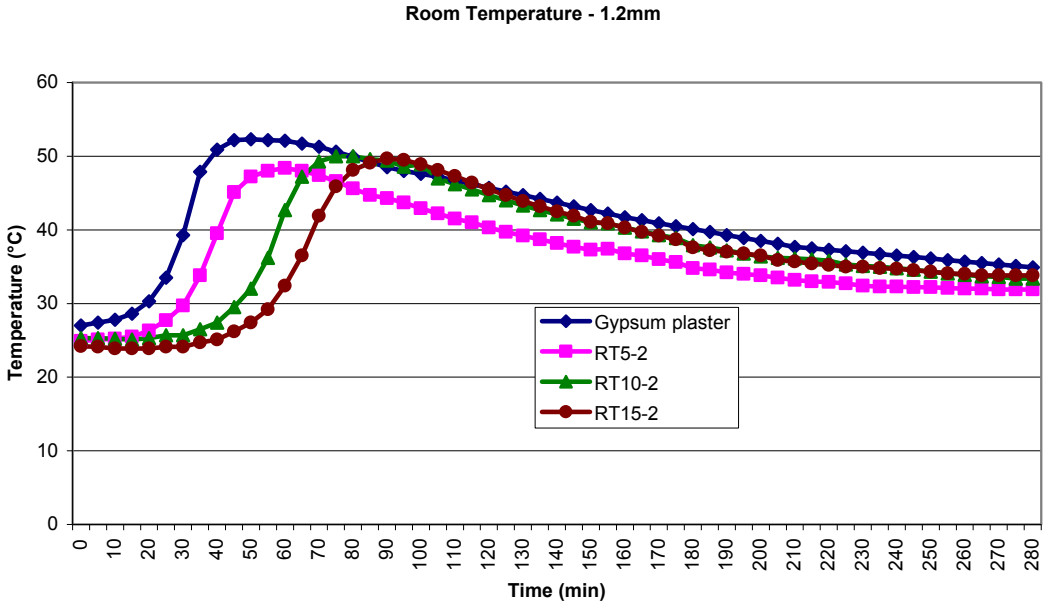


Figure 5: Kinetics of temperature results of HH paste with RT solutions from WP of 1.20 mm

The maximum temperature reached by the mixtures was similar (near of 50 °C) (Figure 4), but they were lower than the reference (gypsum plaster).

The solution from the coarser WP (1.20 mm) had the same behavior (Figure 5).

3.1.1.2 Hot water (HW) solutions

WP treatment with hot water (HW) changed significantly the HH kinetics of temperature showing the influence of the treated WP extractives on the HH hydration (Figures 6 and 7).

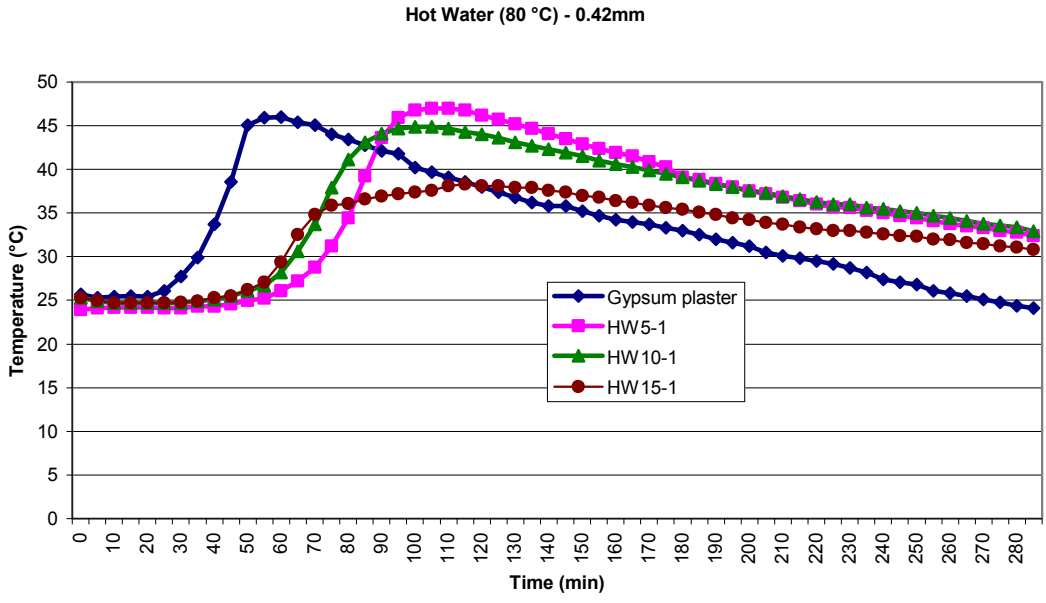


Figure 6: Kinetics of temperature results of HH paste with HW solutions from WP of 0.42 mm

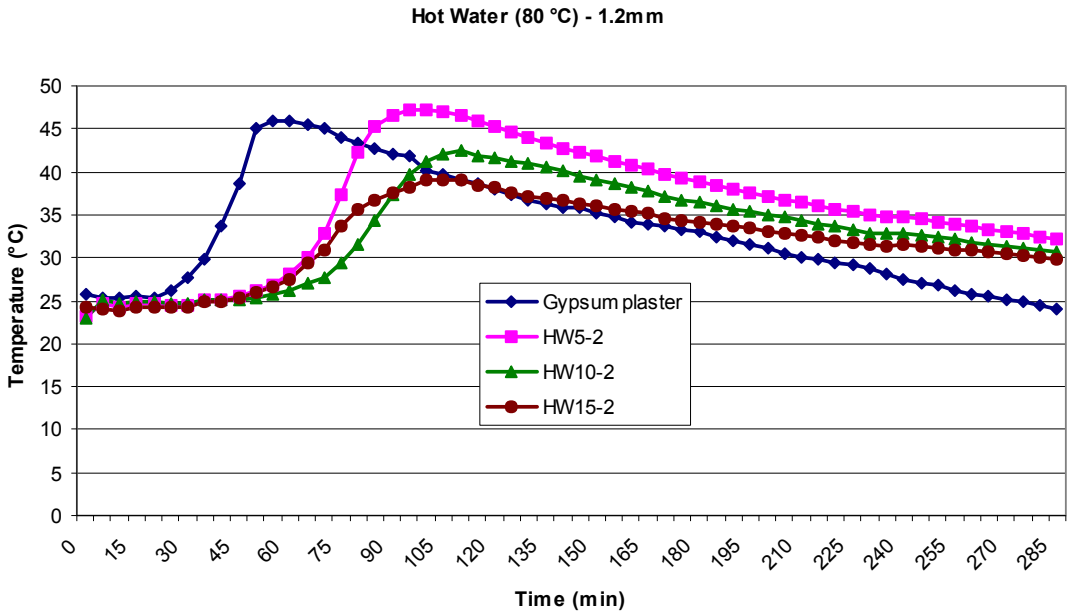


Figure 7: Kinetics of temperature results of HH paste with HW solutions from WP of 1.20 mm

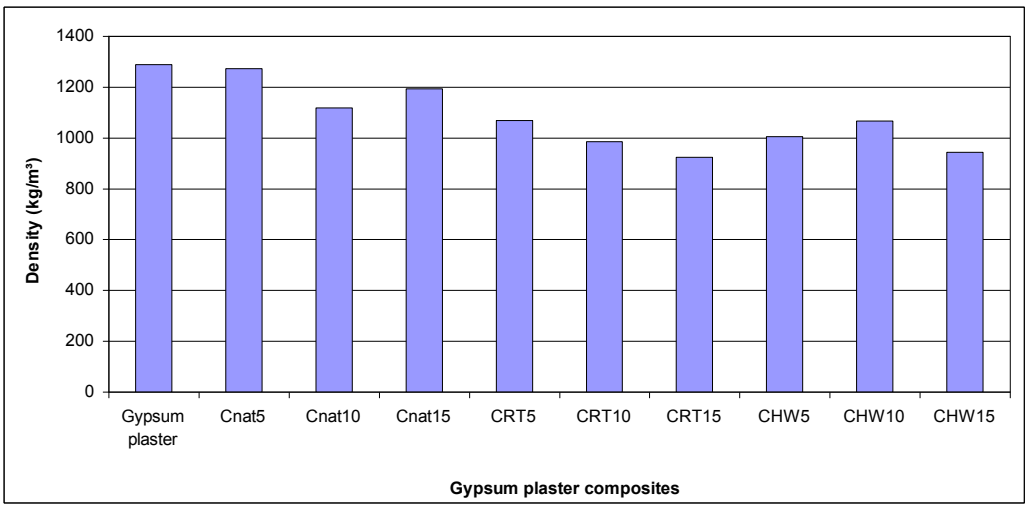
The initial setting time increased for all of the mixtures. The higher the WP content the smaller the temperature reached. Longer gypsum plaster setting times were observed for higher extractive solution concentration.

The kinetics of temperature of the mixtures with higher WP extractive concentration (15%) were significantly modified with respect to the other ones, denoting that HW treatment was more effective than environmental treatment (RT) for extracting wood chemical compounds.

3.2 WP-HH composites

3.2.1 Density

Except for the composite of gypsum and wood *in natura* particles at 5% (Cnat5), all of them showed density smaller than those ones of the reference (gypsum plaster) (Figure 8). The same results were obtained by Chinta et al. [23] on the properties of natural fibers on gypsum plaster composites.



Nat = *in natura*; RT = treated at room temperature; HW = treated at 80 °C.

Figure 8: Density results of the WP-HH composites

The higher wood particle ratio the lower the composite density. Treatments applied to the WP decrease the composites density, probably because WP porosity increases, enhancing the water consumption at the moment of the mixture with the gypsum plaster [7].

3.2.1 Ultrasonic pulse velocity (UPV)

Figures 9, 10 and 11 show the UPV across the time of the WP-HH composites named: *in natura* (Nat), WP treated with water at room temperature (RT) and treated with hot water (HW), respectively.

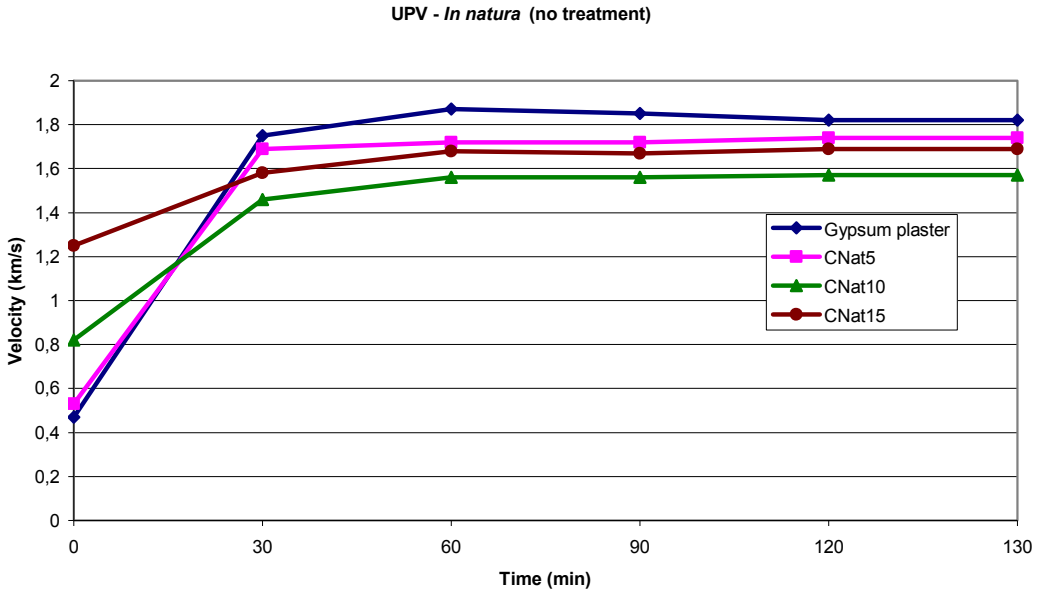


Figure 9: UPV across the time for WP-HH composites from particles *in natura* (CNat)

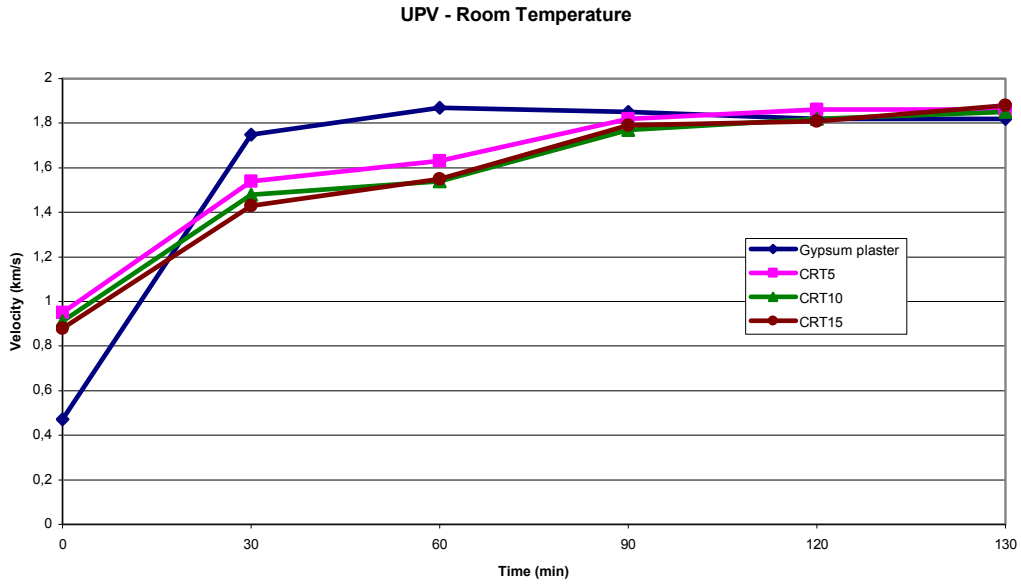


Figure 10: UPV across the time for WP-HH composites from WP treated at room temperature (RT)

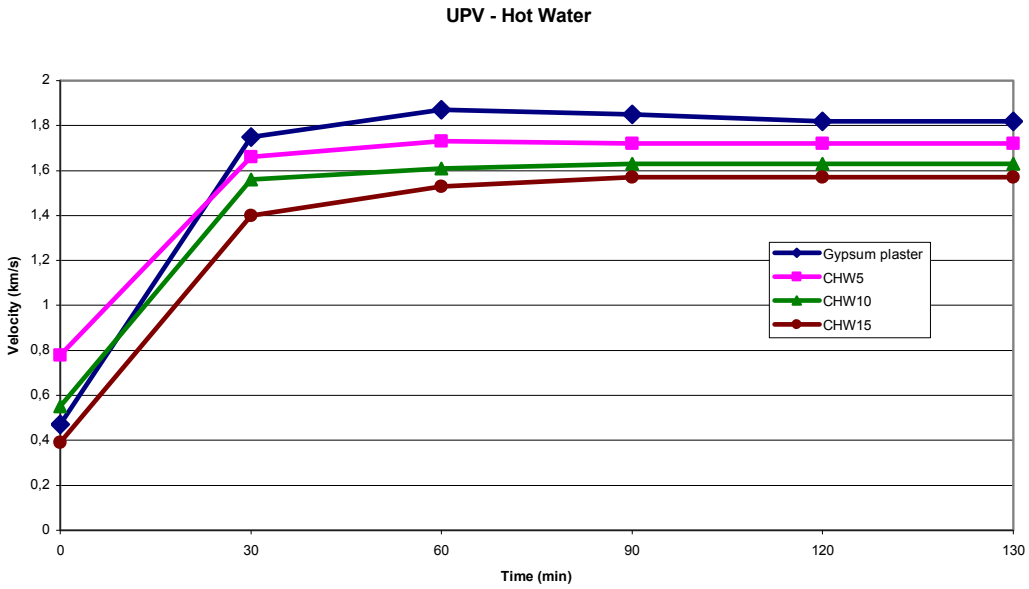


Figure 11: UPV across the time for WP-gypsum composites from WP treated at 80 °C (HW)

For CNat curves (Figure 9) the results in the first minutes are similar for gypsum plaster and CNat5, followed by CNat10 and CNat 15. After 30 min, the UPV stabilizes at the steady state and the UPV across the time for the gypsum plaster was 1.80 km/s, followed by CNat5, CNat15 and CNat10. There was no significant difference between CNat5 and CNat15, both showing UPV of 1.70 km/s.

For the CRT composite curves (Figure 10) there is no significant statistical difference on UPV for all of the WP content. The UPV results were similar and after 120 minutes the UPV stabilizes at 1.80 km/s - the same maximum UPV value reached by the gypsum plaster reference.

For the CHW composite curves (Figure 11) there is a clear tendency that as higher the WP contents the smaller UPV. HW treatment seems to be not efficient enough to properly remove the wood extractives, as reported by others authors [24, 25].

3.2.2 Dynamic modulus of elasticity (E_d)

The dynamic modulus of elasticity (E_d) was calculated by using the results of density of WP-gypsum plaster composites and the UPV, evaluated after the steady state (120 min), by using equation 1 (Figure 12). Except for the CNat5, E_d decreases with the WP treatments. As the WP content increase, the E_d decreases according to the ranking: Gypsum plaster > CNat > CRT > CHW. This reduction on E_d show the decrease on stiffness with the fiber addition.

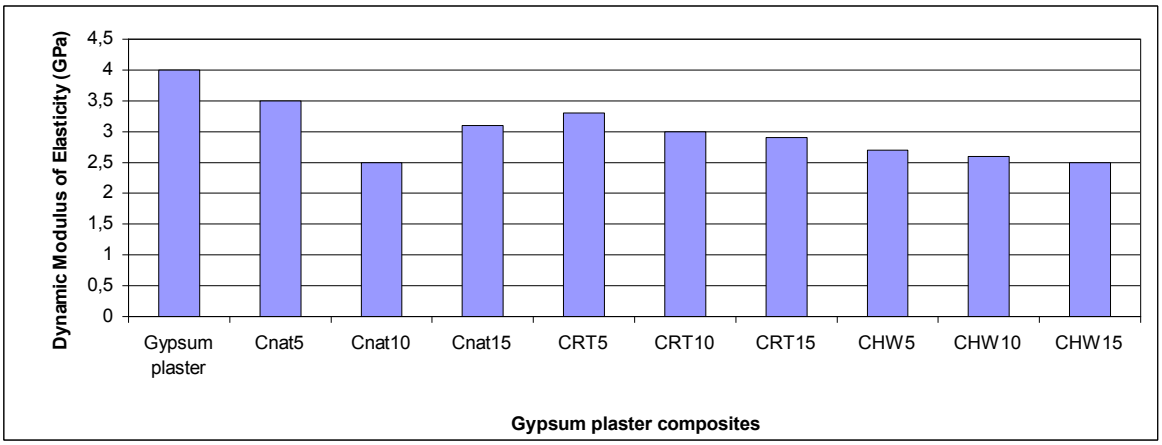
3.2.2 Compressive and flexural strengths

Figure 13 shows the composites compressive and flexural strengths of all WP-HH composites. For the composites with WP *in natura* (Cnat) there were no significant statistical differences of compressive strength according to its content. However, compressive strength was 40% lower than those of the gypsum plaster (7.1 MPa). The composite compressive strength with WP treated at room temperature (RT) and with 10% and 15% addition was closer to the reference ones (Plaster).

Flexural strength was also lower than those of the gypsum plaster (3.2 MPa), especially for 15% of natural WP addition (1.4 MPa). However, for the treated WP at 10% and 15% contents the flexural strength was closer to the reference ones. DAI e FAN [7] found similar results on gypsum-plaster sawdust composites.

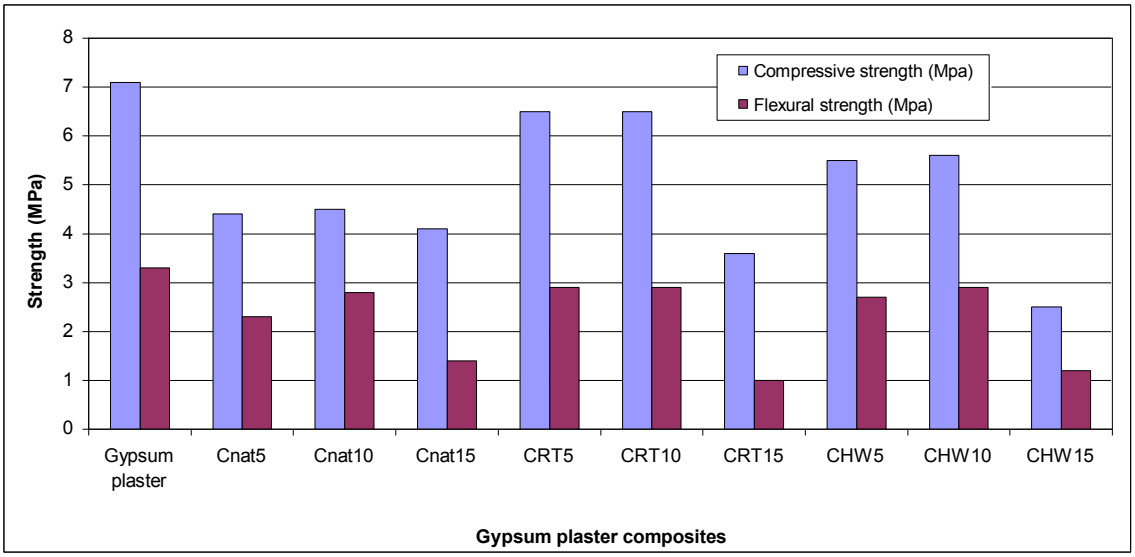
The mechanical performance of WP-HH composite can be affected by the poor interface between WP and gypsum plaster, and by the high water content in the WP due to its high water absorption [7, 26].

COQUARD *et al*. [27] reported that water could infiltrate between the crystals and weaken the gypsum plaster structure. This may be the reason of the lowest mechanical performance with HW pretreatment.



Nat = *in natura*; RT = treated at room temperature; HW = treated at 80 °C.

Figure 12: Dynamic modulus of elasticity of the WP-gypsum plaster composites



Nat = *in natura*; RT = treated at room temperature; HW = treated at 80 °C.

Figure 13: Compressive and flexural strengths of WP-gypsum plaster composites

The requirements of compressive strength for burnt clay bricks according to Brazilian Standard [28] should be higher than 1,5 MPa. The results obtained in this research show that all of the wood particles-gypsum plaster composites exceed the minimum value required by that Standard. This show a good possibility to use this waste to make gypsum plaster composites for buildings, giving a better destination to the wood particles.

4. CONCLUSIONS

The aim of this experimental study was to analyze the performance of gypsum plaster pastes and of their composites with WP, the effect of the extractive solutions from WP treatment (evaluated in pastes) and the composites made with the treated WP.

Based on the results of this work the following conclusions can be drawn.

- The kind of treatment applied on WP and the resulting extractives changed the gypsum plaster kinetics of temperature.

- Wood extractives increased plaster setting times and they were longer for higher WP content.

- WP treatments changed the composites UPV and their mechanical behavior. The best result was obtained for the composite produced with WP treated with water at room temperature (RT).

- The stiffness of the WP-HH composites diminished with WP content, showing a less brittle material.

- Composites compressive strength were higher than the minimum required by the Brazilian Standard for burnt clay bricks. This is indicative that this material can be used to make building components.

The use of gypsum plaster and its composite with WP keep the principles of sustainability and eco-efficiency, because gypsum plaster production needs a low energy and it is a binder with low CO_2 emission. By using WP is also an important strategy of CO_2 storage.

5. ACKNOWLEDGEMENTS

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