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Original article

Use of lignocellulosic waste in the manufacture of wood-cement composites for non-structural construction purposes

Uso de residuos lignocelulósicos en la elaboración de compuestos madera-cemento para fines constructivos no estructurales

Utilização de resíduos lignocelulósicos no fabrico de compósitos de cimento-madeira para fins de construção não estruturais

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ABSTRACT

The aim of this study was to evaluate the main characteristics of the compounds produced with cement, sand and lignocellulosic waste for the production of wood-cement compounds. Residues of *Bambusa vulgaris* var. *vulgaris* (bamboo) and *Manilkara sp.* (maçaranduba) were used to determine compatibility with Portland cement CP IV-32. The physical-mechanical tests were carried out in the Forestry Technology laboratories, belonging to the Forestry Science Department, at the Federal Rural University of Pernambuco, and the Federal University of Espírito Santo, Brazil; based on the ABCP standard, 2002. The mixture used was 1: 0.05: 3: 0.4, respectively cement, lignocellulosic, sand and water. From the hydration temperatures obtained, it was possible to establish the possibility of using Portland cement CP IV-32 in the production of cement-wood-sand-water compounds. During the determination of the degree of compatibility of the cement with the bamboo and maçaranduba, the resistance to the compression presented the most evident results for the non-structural use of the obtained compounds. The non-destructive method of stress waves proved to be an excellent tool for determining the dynamic elastic modulus of cement-wood-sand-water compounds.

Keywords: wood; hydration; compatibility; strength; application.

RESUMEN

El presente trabajo tuvo como objetivo evaluar las principales características de los compuestos producidos con cemento, arena y residuos lignocelulosicos para la elaboración de compuestos madera-cemento. Se utilizaron residuos de *Bambusa vulgaris* var. *vulgaris* (bambú) y *Manilkara sp.* (maçaranduba) para determinar la compatibilidad con el cemento Portland CP IV-32. Los ensayos físico mecánicos se realizaron en los laboratorios de Tecnología Forestal, perteneciente al Departamento de Ciencia Forestal, en la Universidad Federal Rural de Pernambuco, y la Universidad Federal de Espíritu Santos, Brasil; a partir de la norma ABCP, 2002. La mezcla utilizada fue 1: 0,05: 3: 0,4, respectivamente cemento, lignocelulósico, arena y agua. A partir de las temperaturas de hidratación obtenidas se pudo establecer la posibilidad de la utilización del cemento Portland CP IV-32 en la producción de compuestos cemento-madera-arena agua. Durante la determinación del grado de compatibilidad del cemento con el bambú y la maçaranduba, la resistencia a la compresión presentó los resultados más evidentes para la utilización no estructural de los compuestos obtenidos. El método no destructivo de las ondas de tensión resultó una herramienta excelente para determinar el módulo elástico dinámico de los compuestos cemento-madera-arena-agua.

Palabras clave: madera; hidratación; compatibilidad; resistencia; aplicación.

RESUMO

O objectivo deste trabalho foi avaliar as principais características dos compostos produzidos com cimento, areia e resíduos lignocelulósicos para a produção de compostos de cimento-madeira. Resíduos de Bambusa vulgaris var. vulgaris (bambu) e Manilkara sp. (maçaranduba) foram utilizadas para determinar a compatibilidade com o cimento Portland CP IV-32. Os ensaios físico-mecânicos foram realizados nos laboratórios de Tecnologia Florestal do Departamento de Ciências Florestais da Universidade Federal Rural de Pernambuco e da Universidade Federal do Espírito Santo, Brasil, com base na norma ABCP, 2002. A mistura utilizada foi 1: 0,05: 3: 0,4, respectivamente cimento, lignocelulósico, areia e água. A partir das temperaturas de hidratação obtidas, foi possível estabelecer a possibilidade de utilizar o cimento CP IV-32 Portland na produção de compostos de cimento-madeira-arenito e água. Durante a determinação do grau de compatibilidade do cimento com bambu e maçaranduba, a resistência à compressão apresentou os resultados mais evidentes para a utilização não-estrutural dos compostos obtidos. O método não destrutivo das ondas de tensão provou ser uma excelente ferramenta para determinar o módulo elástico dinâmico dos compostos de cimento-madeira-madeira-água.

Palavras-chave: madeira; hidratação; compatibilidade; resistência; aplicação.

INTRODUCTION

Garces *et al*., (2017), coinciding with Barbosa *et al.* (2014) and Ronquin *et al*., (2014), establish that the primary and secondary wood processing industries generate large amounts of waste that can cause serious environmental problems; therefore, the development of products from these wastes is an option of interest in construction activity (Ardanuy *et al.,* 2015; Amoo *et al*., 2016 and Fernández *et al.,* 2017).

Wood-cement composites have many advantages over other conventional wood materials, such as better insulation and fire performance, better resistance to water immersion, bactericidal properties and rigidity; coinciding in this sense with the works developed by Bertolini *et al.,* (2014), Garces *et al.,* (2017) and Castro *et al*., (2019).

Compared to concrete, the compound reduces the cost, reuses wood waste and improves the thermal performance of conventional concrete panels, preserving their mechanical qualities.

Quiroga and Rintoul (2015) conclude that knowledge of the mechanical and structural behaviour of wood composites can contribute to projecting and improving their properties at a minimum cost. The strength and stiffness of these compounds depends on the properties of wood and cement, the mineralization treatment of wood, the density or degree of compaction of the material and the cement-wood ratio (Baracho Jr. 2016, Ortega and Gil, 2019).

Baracho Jr. (2016), specifies the advantages of wood-cement composites to take advantage of the high specific rigidity, impact resistance and strength-to-weight ratio of wood, a low-cost and easy-to-process renewable resource.

Therefore, the present work aims to evaluate the main characteristics of the compounds produced with cement, sand and lignocellulosic waste for the production of wood-cement compounds.

MATERIALS AND METHODS

Working conditions

For the materialization of the present investigation were used residues obtained during the processing of the species *Manilkara* sp. in the sawmill Manassu Ltda., located in the metropolitan region of the city of Recife.

The residues of *Bambusa vulgaris* var*. vulgaris* come from the plantations of the Company Celulose e Papel de Pernambuco - CEPASA, of the João Santos Industrial Group, located in Jaboatão dos Guararapes, also in the State of Pernambuco.

The different tests were developed at the Forest Technology Laboratory, belonging to the Forest Science Department, at the Federal Rural University of Pernambuco.

The granulometry of the residues and washed sand were determined in a Viatest Electromagnetic Stirrer, model 76733, at the Soil Management and Conservation Laboratory of the Department of Agronomy, belonging to the same university.

The 100 g of each air-dried material were randomly collected and tested in the agitator, according to the Brazilian standard NBR 7181: 1988.

The residues of both species were pre-treated after being immersed in water for 15 days and dried in the open air. They were then immersed again in an aqueous solution of sodium hydroxide at 2 % concentration for 24 hours, dried and packaged until their subsequent use, according to the methodology used by Baracho Jr. (2016).

Methodology used

Test of compatibility of lignocellulosic material with Portland cement

The determination of the compatibility of the waste was carried out by obtaining the maximum hydration temperature of standard samples (pure cement + water) and those of *Manilkara sp.* and *Bambusa vulgaris var. vulgaris* treated with 2 % NaOH in an adiabatic system.

The procedures used to determine compatibility are the same as those adopted by Velásquez *et al*., (2005):

- Treated sample: 200 g of Portland cement, 20 g of lignocellulosic residue and 100 ml of distilled water.
- Standard sample: 200 g of Portland cement and 100 ml of distilled water.

The maximum temperatures of the maçaranduba and bamboo samples are compared with the maximum temperature of the standard sample.

The aptitude or compatibility coefficient (A), is determined according to the equation adopted by Vilela and Du Pasquier (1968) and used by Viera *et al.,* (2004) and Baracho Jr. (2016) (Equation 1).

$$A = \frac{T_m - T_o}{T_M - T_o} * 100 \qquad (1)$$

Where:

Coefficient of compatibility (%)
T_m - Maximum sample temperature (ºC);
T_o - Ambient temperature (ºC);
T_M - Maximum standard sample temperature (ºC).

Vilela and Du Pasquier (1968), classify woods as Very Good when the compatibility is above 80 %, Good between 60 - 79 %, Regular between 50 - 59 % and Bad when the compatibility coefficient is below 50 %, classification also adopted by Baracho Jr. (2016).

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Determination of the physical and mechanical properties of compounds

For the preparation of the compounds formed from the use of cement+wood+sand+water, it was decided to adopt the ratio 1:0,05:3,0:0,4 respectively.

The mortar for the compounds was prepared manually in a polyethylene tray. Initially the cement is added to the sand until a homogeneous mixture is obtained. Then the lignocellulosic residue is added. Once the mixture is homogenized, the water is slowly placed until a consistent mass is formed.

The test bodies of the formed compounds are prepared in cylindrical steel moulds of 5 x 10 cm, to which low viscosity diesel oil is applied internally to facilitate dismantling after pre-cure. After 24 hours of preparation of the moulds, the dismantling of the test bodies is carried out.

The samples are conditioned for 28 days for complete hardening, in accordance with the specifications of the ABCP standard (2002). Ten test bodies are prepared from each residue of the species investigated (maçaranduba and bamboo), totaling a universe of 20 test bodies.

Density and compression determinations are performed at the Wood Science Laboratory of the Forestry and Wood Science Department of the Center for Agricultural Sciences of the Federal University of Espirito Santos (UFES).

The density is obtained from the relation between the weight and the volume of the sample, according to the procedures exposed in the NBR 7190:1997 standard.

Evaluation of cement + bamboo + sand + water compounds using non-destructive methods

The compounds are evaluated through the use of non-destructive testing, such as ultrasound, according to Beraldo and Martin (2007), Correa *et al.,* (2014), in order to determine compatibility using the Steinkamp BP-7 equipment, which has exponential transducers of 45 kHz resonance frequency coupled (Figure 1).

Figure 1. - Steinkamp BP-7 equipment for ultra-sound testing

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The ratio used for cement-bamboo-sand-water was 1:0,05:3,0:0,4. Calcium chloride is also applied at 11 % concentration. The speed of the ultrasonic pulse (Vpu) varies according to the life time of the test bodies (Beraldo and Martins, 2007), being a procedure to evaluate the alterations produced in the mixture as the cohesion and hardening reactions of the compound occur. The maximum amplitude of Vpu is considered an appropriate indicator of the degree of compatibility between wood and cement according to Beraldo and Balzamo (2009).

From the density data of the test bodies and the Vpu, the dynamic modulus of elasticity (Ed1) is determined from the implementation of the equation, (Equation 2).

$$E_{d1} = \rho\,(Vpu)^2 \qquad (2)$$

Where:

E_{d1}- dynamic modulus of elasticity by ultrasound (MPa);
p- density of the test body (g/cm^3);
Vpu - velocity of the ultrasonic pulse (m/s).

RESULTS AND DISCUSSION

Compatibility of cement with maçaranduba and bamboo waste

The Table 1 shows the hydration temperature of the samples analysed, defining that the maximum hydration temperature of the standard sample (pure cement + water) is 42,50°C, at 7 hours after starting the process.

Table 1. - Evaluation of the compatibility coefficients (A) of the cement-maçaranduba and cement-bamboo mixtures

Time, h	Temperature ° C		
	model	maçaranduba	bambú
1	26,80	28,20	29,00
2	27,20	28,60	30,20
3	30,80	29,20	31,50
4	32,80	30,20	32,20
5	39,50	32,40	33,00
6	40,60	32,70	34,40
7	42,50	33,10	35,80
8	41,40	34,70	37,30
9	40,80	35,40	36,00
10	39,60	35,80	35,20
11	37,80	35,10	33,20
12	35,40	34,80	32,10
13	3,80	33,20	31,50
14	32,10	31,40	30,10
15	32,00	30,00	29,90
16	30,50	29,40	29,50
17	29,10	28,70	28,90
18	28,60	28,40	28,70
AC		53,79	64,14

A greater heat release is observed in the cement sample + bamboo at 8 hours (37.30 °C) and in the cement sample + maçarandumba (35,80 °C) at 10 hours, which makes it possible to reduce the action of the paste's retardant substances, thus prolonging the hardening time.

The ambient temperature in the Forest Technology Laboratory is 28°C. The compatibility coefficients obtained for bamboo (64,14 %) and maçaranduba (53,79 %), positively classify the use of these wastes as raw materials for the production of bricks, cement-wood compounds or bamboo cement. In the case of bamboo, the compatibility index is considered good and that of maçaranduba is considered regular; having as references the methodologies proposed by Vilela and Du Pasquier (1968) and Baracho Jr. (2016).

Figure 2 shows the hydration curves for each sample, where the maximum temperatures of the compounds produced are obtained between 1 and 3 hours after the maximum temperature of the standard sample (cement + water), coinciding with the results obtained by Viera *et al.,* (2004).

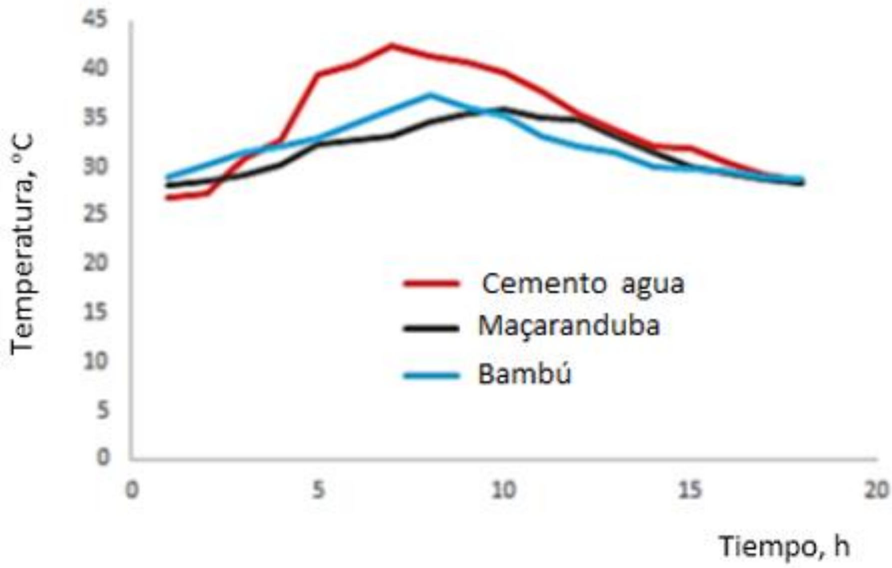

Figure 2. - Cement, maçaranduba and bamboo hydration curve

Physical and mechanical properties of processed compounds

After defining the proportions of the mixtures to produce the wood+cement+sand+water composites, the technological data are obtained from the density, compression and modulus of Elasticity tests using stress waves (Ed_2) (Table 2).

Table 2. - Average values of physical and mechanical properties of compounds

Compound	D(g/cm³)	f_c (MPa)	Ed_2 (MPa)
bambú	1,88	10,08	8920
	(2,41)	(14,74)	(10,15)
maçaranduba	1,85	9,76	8327
	(3,07)	(14,83)	(10,80)

D- density; fc - simple compressive strength, Ed2 - dynamic modulus of elasticity.
Data in brackets refer to coefficients of variation (%).

Using a means-average comparison analysis, using the t-test for independent samples for a significance level of 5 %, no significant differences for the physical and mechanical properties between cement+bamboo and cement+maçaranduba compounds can be seen

Macedo *et al*., (2012), obtained in compounds made from a mixture of the wastes of six Amazonian species, an axial compression resistance between 3,25 MPa for the wastes washed with hot water for 2 h and 8,06 MPa for those of the previous condition with the addition of 5 % calcium chloride.

Considering this minimum limit of resistance to compression, the compounds of cement-bamboo-sand-water (10,08 MPa), cement-maçaranduba-water (7,96), fully satisfy this requirement specified in the standards (Santos, 2009), so it is proposed to apply these elements in civil construction, but with non-structural functions.

The non-destructive method of stress waves is an excellent tool to determine the dynamic elastic modulus of cement-wood-sand-water compounds; coinciding with Oliveira *et al.* (2017).

Bamboo averages at 8 920 MPa and maçaranduba averages at 8 327 MPa showed no statistical difference at the level of 5 % by the T-means comparison test.

It is possible to use woody fragments of different dimensions and geometries, some of more than 5,0 cm, in association with the Portland cement CP IV - 32, as shown in this work.

The initiative to use wood particles under the conditions in which they are generated during processing in sawmills, construction companies or as industrial waste helps to reduce the production costs of cement-based compounds by eliminating unnecessary steps in the preparation of the compounds.

Portland cement CP IV-32 can be used in the production of cement-wood-sand-water compounds.

Considering the minimum limit of resistance to the compression, the compounds of cement-bamboo-sand-water (10,08 MPa) and cement-maçaranduba-water (7,96 MPa); they can be applied in the civil construction, without structural functions.

There are no significant differences in physical and mechanical properties between cement+bamboo and cement+maçaranduba compounds.

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Conflict of interests:

The authors declare not to have any interest conflicts.

Authors' contribution:

The authors have participated in the writing of the work and analysis of the documents.