ENGLISH VERSION

Potential use of curaua fiber (Ananas erectifolius) for cementitious production composite

Uso potencial de la fibra de curauá (Ananas acutifolius) para la fabricación de compuestos cementicios

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Fecha de Recepción: 03/08/2017
Fecha de Aceptación: 10/03/2018
PAG 155-160

Abstract

This study aimed to characterize and evaluate the performance of the Amazonian plant fiber curaua (Ananas erectifolius) as reinforcement in the cementitious composite panels' production process. For the production of these panels were determined extractives content and bulk density of the fibers. The panels were produced with curaua fibers, varying the contents (5%, 10% and 20%). Also, as a methodology, vegetable fibers were treated through immersion in cold water for 24 hours, immersion in hot water for 6 hours, and finally immersed in NaOH solution for 2 hours at a concentration of 1%. The panels were manufactured in the dimensions of 500x500x15 mm, a nominal bulk density of 1.60 g/cm^3 and kept under pressure (4 MPa) for 24 hours. After pressing the panels were conditioned for 28 days for cement cure. As a result, it was observed that the incorporation of 10% curaua fibers is possible as reinforcement in the cementitious matrix, in the manufacture of wood-concrete panels. It was also found that the chemical treatment of the fibers provided the improvement in the physical properties of the composites.

Keywords: *Fiber cement panels, vegetable fibers, curaua, amazonia, composite*

Resumen

El objetivo de este estudio fue caracterizar y evaluar el rendimiento de la fibra amazónica de curauá *(Ananas erectifolius)* como reforzamiento en el proceso de producción de paneles de fibrocemento. Para la fabricación de estos paneles se determinó el contenido de sustancias extraíbles y la densidad aparente de las fibras. Se fabricaron paneles con fibras de curauá, variando su contenido (5%, 10% y 20%). Asimismo, como metodología, se trataron las fibras vegetales a través de la inmersión en agua fría durante 24 horas, inmersión en agua caliente durante 6 horas y, finalmente, se sumergieron en una solución de NaOH durante 2 horas a una concentración del 1%. Los paneles medían 500 x 500 x 15mm, con una densidad aparente nominal de 1,60g/cm^3 y se mantuvieron bajo presión (4 MPa) durante 24 horas. Después de prensarlos, los paneles se acondicionaron durante 28 días para el curado del cemento. Como resultado, se observó que la adición de un 10% de fibras de curauá es idónea para reforzar la matriz cementicia en la fabricación de paneles de madera-cemento. También se encontró que el tratamiento químico de las fibras mejora las propiedades físicas del material.

Palabras clave: Paneles de fibrocemento, fibras vegetales, curauá, Amazonas, compuestos

1. Introduction

The growing volume of forest residues from logging, as well as the wide range of existing fiber plant in Brazil, has driven the search for new alternatives of building components. These materials, despite having potential use, are hardly used on a commercial scale (Ferraz et al., 2011; Wang et al., 2000).

Some countries do not have forest reserves to meet the demand for firewood production, lumber, reconstituted panels, building components from wood, among others, but have significant amounts of other lignocellulosic materials such as vegetable fiber, available in the form of agricultural waste, that can be successfully employed in the production of panels and other building components (Youngquist et al., 1996).

Composite materials reinforced with cellulosic fibers from wood and other fiber sources are alternatives of a promising class of construction products, allowing faster construction, especially when applied in a module manner in construction sites, through the elimination of a series of steps and other problems in the implementation of final changes. Some of the many advantages of using the panels as building elements comprise geometric accuracy range of size, finishing, and easy to install (Matoski et al., 2013). Are environmentally friendly materials, low cost, provide adequate technical performance, and require low level of industrialization for processing (Maden and Gamstedt, 2013). Also, allow to add value to low acceptance of materials such as wood thinning, wood processing waste and other natural fibers (Sá et al., 2010), as well as, can reduce or eliminate undesirable characteristics such as the original size of the raw

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material, natural defects, hygroscopicity and anisotropy (Paula et al., 2009).

Among the vegetable fibers that can be used are the curaua fibers (Ananas erectifolius). This fiber has great potential and high quality due to its strength, softness and reduced specific weight and can be used in automotive companies and construction (Spinacé et al., 2011).

The curaua fibers are used to weave sleeping hammocks, manufacture of ropes, fishing lines, baskets and mats. Their culture is undemanding in relation to soil fertility, has low loss during the dry season in summer, and therefore its cultivation is economically viable (Picanço and Ghavami, 2008; Monteiro et al., 2006).

The use of components originating from wood, as the vegetable fibers, is still not significant in the construction industry due to the lack of understanding of mechanisms and technologies involved in the interface between the cement and lignocellulosic materials for the development of cementitious composite materials reinforced with vegetable fibers (Fan et al, 2012).

Among the possible difficulties in the manufacture of wood, cement composite panels can be mentioned phenolic compounds, acids, soluble sugars, resins and extractives of lignocellulosic fibers that may be responsible for delayed or even total prevention of the handle, as when entering contact the alkaline environment generated by cement, solubilize and react with this, preventing crystallization and hardening (Iwakiri and Prata, 2008; Hofstrand et al., 1985).

To overcome these possible chemical incompatibilities between the cementitious matrix and the fibers with high levels of extractives are used in fiber treatments, the purpose of which is to remove inhibitory chemicals. Some of the most common treatments are: immersion of the particles or fibers in cold water for 24 hours; immersion in hot water for 6 hours; immersion in NaOH solution (Moslemi et al., 1983).

In this context, considering the availability, characteristics and importance of curaua fiber to generate new products, this study aims to evaluate the performance of curaua plant fiber (Ananas erectifolius) as reinforcement in the cementitious composite panels production process, as well as identifying the percentage of fibers to be incorporated into the matrix that maximizes its mechanical properties.

2. Materials and methods

The curaua fibers (Ananas erectifolius) were obtained from the Center for Support of Community Action Projects (CEAPAC), located in the city of Santarem in Pará State and were cut in Pematec Triangel Company, also located in the city of Santarem, with 4 cm length. Subsequently the fibers were passed in the knife mill to breakdown.

After the disaggregation, the fiber was characterized by extractives content and specific bulk density. The extractives content was performed according to NBR 7987 (2012) and the bulk density was determined according to the methodology established by the NBR 6922 (1991).

The production of composite panels was conducted according to the experimental design presented in Table 1.

In the first phase was determined the maximum fiber content such that the percentage thus defined meets the standards of ASTM D1037 (2012). In the second phase, the fiber treatments were performed to evaluate its effect on the panels' properties.

The composite panels were produced, according to ASTM D 1037 (2012) i.e. with dimensions of 50 x 38.5 x 1.5 cm (length, width and thickness, respectively). It was adopted as the target nominal bulk density of 1.60 g/cm^3. There were three replicates per treatment. Following the model adopted by other authors as Soroushiam et al. (2003), the following characteristics were adopted:

- The cement used was Portland CPV ARI, with bulk density of 3,12g/cm^3;
- The ratio water: cement was constant and equal to 1:2.5;
- The chemical additive calcium chloride ($CaCl_2$) in the proportion of 3% relative to the weight of cement, being diluted in water and incorporated as cement cure accelerating agent.

In the second phase sought to determine the effect of the following treatments as shown in Table 2 below

Table 1. Experimental desing

Treatment	Phase	Fiber percentage	Fiber/Cement ratio
1	1	5	0.138 : 2.75
2		10	0.275 : 2.75
3		20	0.55 : 2.75

Table 2. *Treatment of fibers*

Fibers treatment	
Cold water	*Immersion in cold wáter for 24 hours*
Hot water	*Immersion in hot water at 60°C for 6 hours*
NaOH	*Immersion in NaOH solution (1%) for 2 hours*

After mixing the components in a concrete mixer and formation of the mattresses, they were separated by metal plates, clamped and cold pressed with a specific pressure of 4 MPa for 24 hours.

After pressing, the panels passed through the healing process during 28 days in a climatic chamber, then being sectioned for confection of the specimens for determining the physical and mechanical properties. The physical properties were apparent bulk density (EN 323:2002c) and water absorption and thickness swelling (EN 317:2002b), and mechanical properties were modulus of rupture and modulus of bending (EN 310:2002a).

The results were statistically analyzed by means of the Bartlett test, Analysis of variance and covariance and comparison of means by Tukey.

3. Results and discussion

3.1 Properties of fibers

The average result of the extractives content of curaua fibers was 7.07%, and this value is considered relatively high compared to other lignocellulosic materials such as Pinus and Eucalyptus.

In comparison to coconut fibers, Ferraz et al. (2011) obtained an average value of 4.86%, indicating that coconut fibers exert less inhibition on curing and cement hardening. In relation to wood, it is also verified that the Pinus taeda species, the most commonly used Pinus, presents average values lower than the curauá fiber, where Rigatto et al. (2004) obtained average contents of 2.93% and Brand et al. (2011) ranging from 2.24% to 2.90%. Compared with Eucalyptus species, especially Eucalyptus grandis, the literature indicates lower values and similar to the curauá fiber, where Sarto and Sansigolo (2010) found an average value of 6.4%.

The average bulk density value of curaua fibers was 66.57 kg/m^3, this value is considered quite low also when compared to Pinus and Eucalyptus. This result implies high volume of fibers weight at the time of manufacturing products.

This result implies a high volume of fibers per weight at the time of product manufacture, possibly indicating that high percentages of this raw material make it impossible to homogenize the components in the cement matrix, in addition to the low availability of cement per fiber surface area, generating a composite with low mechanical resistance.

Comparing with the average value found by Ferraz et al. (2011), it can be observed that the bulk specific mass of the curauá fiber is similar to coconut fiber (57.94 kg/m^3), and lower than the average values obtained for the wood used in construction such as Pinus (Brito et al., 1982) and Eucalyptus (Ribeiro and Machado, 2005), obtained an average value of 1877.5 kg/m^3 and 1904 kg/m^3 for the bulk mass of Pinus particles. Based on these results, it is assumed that the percentage of fibers to be used in cementitious matrixes should be much lower when compared to wood particles, otherwise a good homogenization of the components besides the low availability of cement by surface area of fiber, resulting in low mechanical strength, which is not desirable in structural building components.

3.2 Properties of panels

3.2.1 Effect of the percentage of curaua fibers

The average results of physical and mechanical properties of the treatments manufactured with different fiber percentages are shown in Table 3. It is noteworthy that due to the low specific mass of the curauá fiber, the treatment with 20% fiber incorporation resulted in a high volume of lignocellulosic material, the amount of cement and water being insufficient for the wetting and agglomeration of the fibers in the formation of the panels, making it impossible to consolidate it.

The average results of the apparent specific mass between the treatments with different percentages of curauá fibers indicated a significant statistical difference, being necessary the application of the covariance analysis to eliminate the influence of this factor on the other properties. The difference in the property can be explained by the fact that the treatment with greater incorporation of a less dense material results in a larger volume, being more difficult its accommodation in the consolidation of the panel, as well as in a slightly larger thickness than with the panels with a percentage of 5%, which directly implies the specific mass.

The average values of water absorption after 2 and 24 hours showed average values from 9.17% to 13.95%, not being detected statistically significant differences between treatments in both immersion intervals. Similarly, there was no statistically significant difference between the mean values for the property swelling in thickness, whose values are framed in the range of 0.35% to 1.64% and met the requirement suggested by Bison process, maximum swelling of 1.20% after 2 hours and 1.80% after 24 hours immersion.

For the swelling, was found no statistically significant difference considering the contents of 5 and 10% fiber. These results are explained by the hygroscopic nature of the fibers and their chemical constitution, since this fiber is rich in hemicellulose, which is in turn more hydrophilic, contributing to the dimensional variation of product.

Regarding the mechanical properties of static bending, it was verified that the treatment with 5% incorporation of curauá fibers showed an average value slightly superior to the treatment with 10% of fibers, and no significant statistical difference was found. This slightly higher result can be justified by the fact that with lower percentage of fibers it is necessary to use a larger amount of cement to generate the composite, where this component directly influences the hardness, giving the composite greater resistance, being used in large scale as structural material in civil construction (Mehta and Monteiro, 2008). Regarding the modulus of elasticity, although no statistically significant difference was found between the different percentages of incorporated fibers, it was observed that the treatment with 10% showed a higher average value, where this result may be a reflection of the fiber characteristic used. None of the treatments reached the minimum requirements of 9 MPa and 3,000 MPa, as suggested by the Bison process for the modulus of rupture and modulus of elasticity, respectively.

Considering that there was no significant statistical difference between the physical and mechanical properties of the above treatments, as well as, seeking to encourage a greater use of curauá fiber for application in cementitious composites, thus reducing the cost of the product and the negative aspect of the emission of dioxide of carbon generated by the cement industries, we chose to incorporate the percentage of 10% of curauá fibers in the panels for the analysis of the influence of the treatments with cold water, hot water and sodium hydroxide.

Table 3. *Physical and mechanical properties of the panels reinforced with curaua fiber*

Percentage	**Physical Properties**					**Mechanical Properties**	
	$ME_{12\%}$ g/cm^3	**AA 2h (%)**	**AA 24h (%)**	**IE 2h (%)**	**IE 24h (%)**	**MOR (MPa)**	**MOE (MPa)**
5%	1.63 a (8.03)	9.17 a (25.86)	9.66 a (24.35)	0.35 a (90.38)	0.65 a (56.27)	3.85 a (49.33)	1853.82 a (55.67)
10%	1.54 b (10.64)	11.94 a (28.47)	13.95 a (26.10)	0.97 a (65.26)	1.64 a (48.75)	3.40 a (50.06)	2313.01 a (55.67)

ME: bulk density; AA: water absorption; IE: swelling in thickness; MOR: modulus of rupture, MOE: modulus of elasticity. Means followed by the same letter in the same column are statistically equal by Tukey test at 95% confidence.

3.2.2 Effect of treatments on curaua fiber

It is observed in Table 4 the results of physical and mechanical properties of the boards produced with the treated fibers.

No statistically significant differences between the apparent bulk density values for panels produced with the treated fibers were observed, indicating that the different chemical treatments, while eliminating or reducing the contents of extractives, did not influence the bulk density of the fibers and thus the bulk density of panels.

The results of water absorption after 2 hours immersion ranged from 4.44% to 13.22%, indicating that the treatment produced using fibers treated in hot water and NaOH showed the best performance in the removal of hydrophilic components. On the other hand, the fibers in natura generated the treatment with greater average absorption, being this, statistically inferior to the others. Similar behavior was observed for the 24 hours immersion interval, whose average values presented variation from 5.07% to 15.37%, indicating that the chemical treatment in the fibers favors the property of water absorption.

The swelling in thickness of the composites after contact with water showed the increase of dimensional stability with removal of extractives. where the average values ranged from 0.22% to 1.02% after 2 hours immersion, and 0.36% to 1.68% after 24 hours. The composites produced with treated fibers were statistically equal to each other and lower compared to control, i.e. the treatment reduced the swelling in thickness.

In general, treatment in the fibers produces composites with greater dimensional stability provided by removing the extractives and therefore better compatibility between the fiber and the cement. All treatments proposed in the work met the requirement of swelling in thickness suggested by the Bison process, which is a maximum of 1.20% after 2 hours immersion, and 1.80% after 24 hours immersion.

It is found that the values obtained for water absorption and thickness swelling of the curauá fiber reinforced panels are lower when compared to the results of the coconut fiber reinforced panels produced by Ferraz et al. (2011), whose values obtained by this author varied from 19.30% to 37.60% for water absorption, and from 0.68% to 2.38% for swelling in thickness. They are also more stable when compared to wood cement panels of Hevea brasiliensis produced by Okino et al. (2004), and those of Schizolobium amazonicum and Cecropia hololeuca studied by Iwakiri et al. (2012).

Regarding the mechanical properties, were not found statistically significant differences for both the modulus of rupture and to the modulus of elasticity between the panels made with treated and untreated fibers, and the treatment produced with fibers subjected to 24 hours of immersion in water at room temperature showed the highest average values. Note also that none of the treatments reached the minimum requirement recommended by the Bison process of 9 MPa for the modulus of rupture and 3.000 MPa for the modulus, indicating that these composites should be applied to purposes requiring no mechanical resistance.

In comparison with the values mentioned in the literature, it is noted that the average values obtained for the modulus of flexural strength and elasticity from the static flexural test of the panels reinforced with the curauá fibers were considerably higher when compared to the reinforced panels with coconut fiber from Ferraz et al. (2011), which obtained values from 1.84 MPa to 2.60 MPa for the modulus of rupture and from 634.3 to 1,783.1 MPa for the modulus of elasticity. However, when compared to Portland cement panels reinforced with wood particles, the values were lower than those obtained by Okino et al. (2004), who evaluated panels of Hevea brasiliensis, those of Iwakiri and Prata (2008) who studied the properties of wood cement panels produced with Eucalyptus grandis, and also those of Iwakiri et al. (2012) using wood particles of Schizolobium amazonicum and Cecropia hololeuca in the cementitious matrix.

Table 4. *Physical and mechanical properties of the panels produced with treated curaua fibers*

Treatment	Physical Properties					Mechanical Properties	
	$ME_{12\%}$ g/cm^3	AA 2h (%)	AA 24h (%)	IE 2h (%)	IE 24h (%)	MOR (MPa)	MOE (MPa)
Control	1.56 a (10.64)	13.22 a (28.47)	15.37 a (26.10)	1.02 a (65.26)	1.68 a (48.75)	3.23 a (50.06)	2185.10 a (55.67)
Cold Water	1.59 a (8.54)	6.12 b (35.66)	7.38 b (30.96)	0.34 b (92.78)	0.51 b (81.41)	4.18 a (31.38)	2711.15 a (36.75)
Hot Water	1.62 a (8.81)	4.44 c (34.84)	5.31 c (31.34)	0.22 b (105.64)	0.41 b (77.41)	3.87 a (20.19)	2210.00 a (31.18)
NaOH	1.62 a (5.93)	4.53 c (25.45)	5.07 c (21.15)	0.22 b (93.49)	0.36 b (84.69)	3.55 a (25.52)	2047.07 a (36.78)

ME: bulk density; AA: water absorption; IE: swelling in thickness; MOR: modulus of rupture, MOE: modulus of elasticity. Means followed by the same letter in the same column are statistically equal by Tukey test at 95% confidence. Values in parentheses refer to the coefficient of variation.

4. Conclusions

Based on the results obtained in this study, it can be concluded that:

- *It is possible to use curauá fibers for the production of cementitious composites.*
- *The analysis of the fiber properties indicated that the species has high content of extractives, which may cause incompatibility with cement, and low bulk density, unfeasible composites with high percentages of incorporation of this lignocellulosic material.*
- *It is possible to incorporate 10% curaua fibers as reinforcement in cementitious matrix, in the manufacture of wood-concrete panels.*
- *The chemical treatment of the fibers promotes an improvement in the physical properties of the composites.*

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