USE OF CACTUS WOOD *CEREUS JAMACARU* AS AGGREGATE IN LIGHTWEIGHT BIOCONCRETE PRODUCTION

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Abstract

It is constant, especially in the civil construction sector, the search for new material sources that meet the assumptions of sustainable development. In this way, the cacti are pointed as a good alternative. Therefore, the objective of the present research was to develop and characterize physically and mechanically lightweight bioconcretes produced with Cereus wood from this lignocellulosic source. *Cereus jamacaru* wood was used after washing in hot water (at 80° C). In the studied matrix, Portland Cement CP V-ARI was used and a water-to-cement ratio of 0.4. To accelerate the cement hydration reactions 3% (relative to the cement mass) of calcium chloride was added. Mixtures with two types of wood particles classified as green and brown were produced and for both cases varying the percentage of compensation water (100 and 200%), cement-to-wood ratio (3,4 and 7) and moulding method (compacting with metal rod or not). A flow table test was used to characterize the fresh mixtures. The mechanical characterization was performed through uniaxial compression test. The density of the composites with the brown particles varied from 892 to 1452 kg/m³ and the compressive strength from 3.38 to 10.51 MPa. The blends with green particles reached between 872 and 1347 kg/m³ of density and between 1.72 and 8.94 MPa of compressive strength. The mixtures with higher cement-to-wood proportions and lower amount of compensating water reached higher compressive strength. The results show that Cactus Wood can be used in the production of bioconcretes with good properties and varied applications in civil construction.

Keywords: Lightweight concrete; Bioconcrete; Cactus Wood; Sustainability; Construction.

1. INTRODUCTION

According to da Gloria [1], the construction industry is one of the great generators of waste and a major consumer of natural resources, and therefore, the search for new resources and technologies able to cause less aggression to the environment is urgent. In this context, the use of alternative lignocellulosic sources for the development of materials is necessary to cause less environmental impacts [2][3]. The main advantages of the lignocellulosic materials are carbon trapping, depending on the application, and the fact that they are renewable.

Cement composites of vegetable biomass are products basically composed of mineral binders combined with vegetal aggregates and other additives [4]. Beraldo [4], also states that the main advantages of using composites are the high availability of raw materials, which are renewable, the lightness of the final product, between 400 and 1500 kg/m³. Others advantages are the resistance to biodegradable agents, good dimensional stability the resistance to impact and the satisfactory mechanical, thermic and acoustic properties. According to Beraldo [5], in some applications, these materials can efficiently replace traditional materials in the construction.

A challenge in the production of cement composites with lignocellulosic materials, which may be called bioconcretes, is the chemical incompatibility between cement and vegetable biomass that can lead to retardation / inhibition of cement hydration reactions. According to Simantupang et al. [6], the extractives present in the wood are the main responsible for this impediment of cement solidification. Beraldo [4] explained that no vegetal species can be added in its natural state to the cement, since the chemical constituents of the plant are very sensitive to the alkaline environment of the cement matrix. The author also showed the importance and effectiveness of applying preliminary treatments in the biomass allied to the use of handle accelerators. In his studies he obtained satisfactory setting and hardening results by using the Brazilian Portland cement CPV-ARI, and 3% of calcium chloride, with biomass previously washed with hot water to reduce the extractives amount.

The water-to-cement ratio is a variable of extreme influence on the resistance of the bioconcrete and according to Andreola [7] the cement hydration will occur completely only if this ratio is greater than 0.38. Because of the high water absorption of the biomass, it is important to have enough water to keep the biomass saturated, to allow the cement hydration and also to guaranty the consistence of the bioconcrete. Another important factor to be analyzed in the production of bioconcrete is the granulometry of the lignocellulosic material that will be used as well as the particle format. Beraldo [5] verified the lack of adhesion between bamboo and cement paste when whole stems of large diameter bamboos, which do not present side shoots, were used. Latorraca [8] concluded that granulometry has a significant influence even in cement pickling and solidification time.

In view of the above, the present research aimed at the development and physical-mechanical characterization of lightweight bioconcretes produced through the use of cactus wood, an innovative lignocellulosic source, as bio-aggregate in order to verify the possibility of use as an alternative material in civil construction.

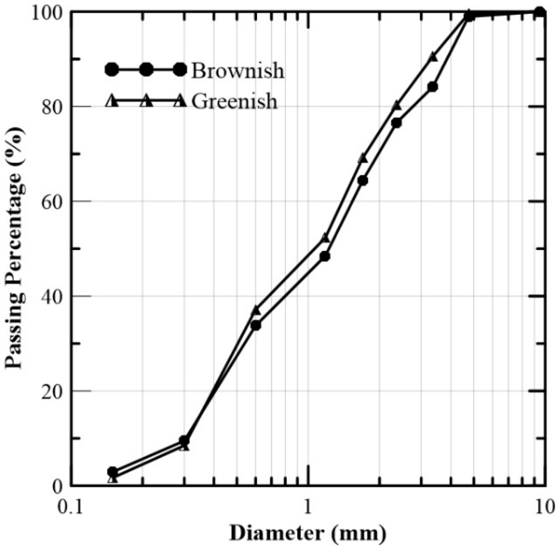
2. EXPERIMENTAL MATERIALS AND METHODS

2.1 Bio-aggregate

The cactus wood used was of the species *Cereus jamacaru* from Barueri - São Paulo, Brazil. The samples were obtained from the base of three years age tree. Manual cutting was performed to remove the samples. The aggregates presented different aspects depending on the stem position which they were extracted. For this research these different woods were separated after extraction: dark green coloration (dark fragments with greater proximity to the leaves of cactus) and brownish coloration (clear fragments coming from a more internal region of the trunk).

The fragments were reduced to smaller size with a hammer mill and all the generated particles whose length exceeded three times the diameter value were discarded due to the possible adhesion damage that they can generate in the final composite. With the remaining particles, particle size analysis was performed.

Figure 1: Granulometric curves of greenish and brownish particles (on the right) and comparison between the light browns of the dark greenish fragments (on the left).



To determine the amount of washes required to reduce the extractives, a wash cycle experiment was performed with a Magnetic Stirrer, IKA brand, model C-MAG HS 7, an Electronic Contact Thermometer, also of the brand IKA, model ETS-D5 and two beakers with a capacity of 500 mL. Firt, 5 g of cactus particles and 300 ml of distilled water were added to the beaker. The water was kept at 80 °C for one hour, its final color was recorded and then a new cycle started. The cycles were repeated until it was noticed that the final water was clear.

In order to characterize physically the bio-aggregate, the test of basic density and water absorption of the wood (NBR 11941 / ABNT 2003) was performed pre-grinding and tests of apparent specific mass (NM 52/2009) and moisture content (NM 9939/2011) after milling. The results for the two types of particles (greenish and brownish) were close enough to be considered the same. The results are expressed in table 1.

Table 1: Physical characterization of the bioaggregate *Cereus Jamacaru*.

Basic density (kg/m³)	**Moisture content (%)**	**Water absorption (%)**	**Apparent Specific mass (kg/m³)**
340	6.30	199.00	250

2.2 Binder and additive

The Brazilian Portland Cement CP V - ARI (cement of high initial strength) was used as binder. The chemical composition and density of the cement can be verified in Andreola et al.[9]. To accelerate the cement hydration, 3% (based on the cement mass) of calcium chloride ($CaCl_2$) was added to the blends.

2.3 Bioconcretes

Table 3 shows the relations cement mass: cactus wood used for the production of cactus bioconcretes (BC). The letters L and F indicate the type of particle used, where L is for brownish and F for greenish. For all mixtures the water -to-cement ratio (w/c) ratio was 0.4.

The composition of these bioconcretes was set as follows: for cement mixtures BCL 100, BCL 200 and BCF 200 the cement consumption and the volume of wood were set following Andreola [7]. The variation in compensating water had the objective to evaluate the necessity of its placement in front of the wood's absorption obtained (almost 200% based on wood mass) and the desired workability. For the mixtures BCL 3, BCF 3 and BCL 4 was fixed the cement: wood ratio following the results obtained by da Gloria [1]. Numbers 3 and 4 indicate the ratio cement mass: wood mass.

Table 2 : Blend Compositions

Blend	Cement comsumption (kg/m³)	Wood volume (%)	Final trace mass				
			Cement	Wood	Water	Compensation water	$CaCl_2$
BCL 100	775.000	45.0	1.000	0.145	0.400	0.145	0.030
BCL200 /BCF 200	775.000	45.0	1.000	0.145	0.400	0.290	0.030
BCL3 /BCF 3	488.093	65.1	1.000	0.333	0.400	0.667	0.030
BCL 4	582.935	58.3	1.000	0.250	0.400	0.500	0.030

The cactus bioconcretes (BC) were produced in a planetary mortar, with a 5-liter capacity vat and stainless steel beater. The water was initially mixed with the calcium chloride in a reserved container forming a homogeneous solution. The cement and wood particles were also mixed separately and were placed first in the equipment. At low rotational speed (136 rpm), during the first minute the was added gradually to the dry materials. After the first minute of mixing the turning of the mortar was interrupted for manual release of the material that was attached to the vats. . Next the mix continued until reach 05 min of total time.

Cylindrical specimens of 5 x 10 cm (diameter x height) were produced. The molds were filled in three layers and the type of compaction was varied: manual with 15 strokes per layer (BCL / BCF 200 and BCL 100) and vibrating table (BCL 3, BCF 3 and BCL 4). The molds were protected against moisture loss until demolding, which happened 24 hours later. Finally, the specimens were placed in a humid chamber at 20 ° C (± 2 ° C) and 95% (± 2%) humidity until they reached the age of 28 days.

During the production of the composites it was observed that there was no segregation or exudation between the blends and that the adhesion between the wood and the other components was ideal.

At fresh state, the property evaluated was the spreading through the flow table test. The consistence index of each mixture was obtained from the average of the diameters reached. Based on the Brazilian standard NBR 5739 (ABNT 2007), the compressive test was performed after 28 days in a Shimadzu-1000 KN universal test machine, at a speed of 0.3 mm / min. The vertical displacements were obtained from the average reading of two Linear variable differential transformers LVDTs. For each mixture, four cylindrical specimens were tested. . The modulus of elasticity was determined according to the requirements of standard NBR 8522 (ABNT 2008).

3. RESULTS

3.1 Extractive Reduction

A gradual variation of the water coloration is observed with washing in hot deionized water. The color change (Figures 7 and 8) is noticeable in each cycle and can be explained by the reduction of extractives of the biomass. It is also possible to observe that the removal of the extractives happens mainly during the first three washing cycles since the color difference between the third and the fourth waste water was not significant.

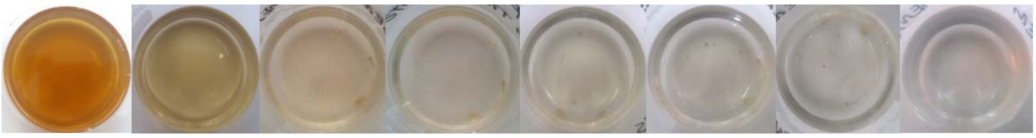


Figure 2 : Comparison of the water coloration at the end of each washing cycle for the greenish (top) and browned (botton) particles.

With the washing cycle experiment it was established that the particles would be submitted to 3 cycles of washes before being used for the bioconcrete production.

3.2 Properties at the fresh state

The pulps achieved good workability as can be seen by analyzing the results of Table 3.

Table 3: Result of the spreading test

Blend	BCL 100	BCL 200	BCF 200	BCL 4	BCF 4	BCF 3
Consistence index (mm)	225.0	282.5	298.5	287.5	257.5	212.5

3.3 Properties at the hardened state

After 24 hours of its production the specimens were demoulded and it was possible to perceive a good homogeneity of the particles in the cementitious matrix.

After 28 days of age the BC were then submitted to the uniaxial test and with the generated data it was possible to generate stress - axial strain graphs for the mixtures.

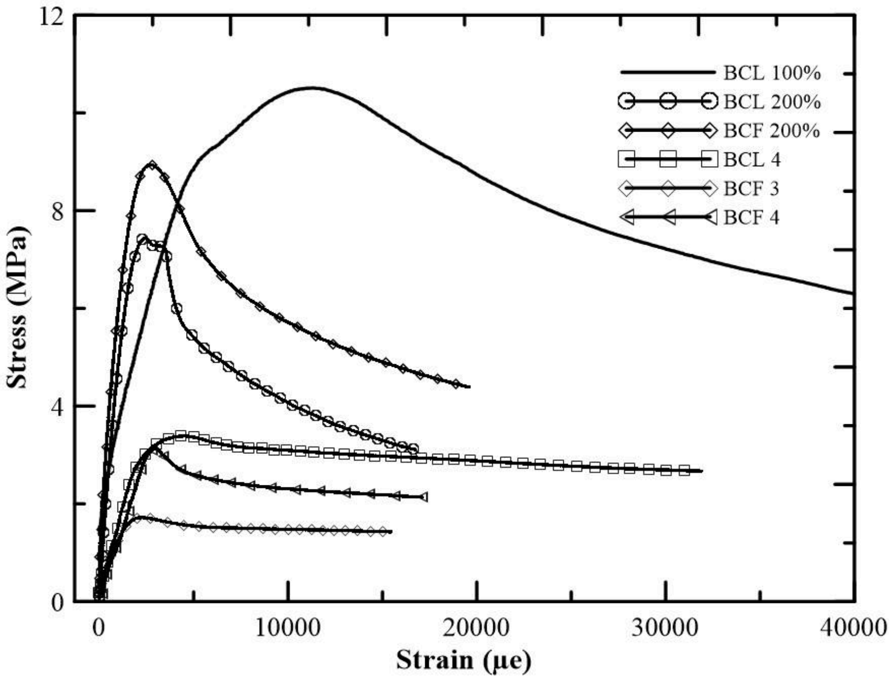


Figure 3: Typical stress-strain curves of BC.

The values of maximum strength as well as the modulus of elasticity and density of the bioconcretes studied are shown in Table 4.

Table 4: Properties of the bioconcretes in the hardened state

Blend	Resistance (MPa)	E (GPa)	Density (kg/m³)
BCL 100	10.512	11.525	1451.600
BCL 200	7.438	10.289	1284.000
BCF 200	8.936	11.978	1347.100
BCL 4	3.387	2.549	997.400
BCF 3	1.720	2.302	872.500
BCF 4	3.135	2.028	999.600

4. DISCUSSION

4.1 Fresh state

The composites with cactus wood and cement studied were demoulded with one day of age indicating that the treatment of washes used, as well as the addition of calcium chloride and the use of cement CP V- ARI were effective in preventing delay / inhibition of cement hydration reactions.

The BCF 200 and BCL 200 with 200% of compensating water and fixed cement consumption and the BCL 4 achieved better workability; the spreading values were between 282.5 and 298.5 mm. This result indicates that the higher quantity of wood in the mixtures negatively influenced the workability.

4.2 Hardened state

The bioconcretes with greenish particles reached bulk density between 872.5 and 1347.1 kg / m³ while the density of the bioconcretes with the brown particles ranged from 997.4 to 1451.6 kg / m³. According to Rilem [10], they can be classified as lightweight materials, since they have a density of less than 1800 kg / m^3. The determinant variables on density were the amount of water and cactus wood (more water and more cactus wood resulted lower densities), and there are indications (analysis BCL 200 versus BCF 200; BCL 4 versus BCF 4) that for similar mixtures with different types of particles, bioconcretes with greenwish particles results in a composite with higher densities.

With the stress versus strain curve generated, it was possible to observe that the composites presented an initial elastic linear behavior, followed by a region of marked nonlinearity until reaching the maximum tension. The rounded aspect of the curve can be explained by microcracking pre-rupture of the bioconcrete that increases the deformations recorded by the LVTDs.

The blends with greenish particles (BCF-x) reached between 1.72 and 8.94 MPa of compressive strength and browned (BCL-x) between 3.38 and 10.51 MPa. There is no data showing any trend in relation to the maximum voltage reached varying only the type of particle.

The specimens with fixed consumption of 775 kg / m³ (BCL 100, BCL 200 and BCF 200) achieved better resistance / density ratio and higher stiffness, that is, lower deformations for a given request, which is a property of great interest in engineering civil. Analyzing the results of the BCL 100 and BCL 200 mixtures, it was observed that by reducing the compensating water in half the bioconcrete had a small gain of density, increase of the MOE, a significant gain of resistance and a great loss of workability.

For the same trace of BCF 3 - in which it was possible to obtain 1.72 MPa of resistance, 2.30 GPa of MOE and 872.5 kg / m³ of density, da Gloria [1] obtained, using wood sawdust, 15.97 MPa of resistance, 4.03 GPa of MOE and 1250 kg / m³. Andreola et. al.[7] studied bioconcrete with bamboo particles and obtained 12.01 MPa of resistance, 4.03 GPa and 1157 kg / m³ of density. These data show that for this trace calculation methodology the composites with cactus wood although less resistant have as main differential the low density that they can achieve and the fact of maintaining a relatively high stiffness. The comparison with the results of the study by Beraldo [5], which also deals with the production of a cementitious composite with bamboo particles, corroborates with the previous analysis.

The traces of the BCL 200 and BCF 200 mixtures - whose results are: 7.44 MPa for maximum strength, 10.29 GPa of MOE, density of 1284 kg / m³ and spreading 282.5 mm; 8.94 MPa for maximum strength, 11.98 GPa of MOE, density of 1347.100 kg / m³ and spreading 298.5 mm - are similar to those of Andreola [7] who working with bamboo particles obtained maximum resistance of 4.20 MPa, MOE of 2.35 GPa and 788.47 kg / m³ of density and 285 mm of scattering. These results show that in cement fixation the cactus bioconcrete obtained better properties than the bamboo, which is probably due to the large amount of fines present in the mixture, which reduced the amount of voids, densified the mixture and consequently increased the other properties.

5. CONCLUSION

The objective of producing light bioconcretes was reached given the low final density of the products. In addition, good physical, mechanical and workability properties (properties of interest in construction) have been reached and it can be concluded that cactus wood can be used as an alternative lignocellulosic source in the production of bioconcretes for use in various purposes in the construction industry.

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