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Proposal for a fiber cement panel with the addition of sugarcane bagasse

Propuesta de panel de fibrocemento con adición de bagazo de caña

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Abstract

The objective of the study is to propose a fiber cement panel based on sugarcane bagasse that complies with the basic requirements for non-compressed fiber cement, without using special equipment for its manufacture, reducing the processes by half without compromising the quality of the product. No crusher, kiln, hydraulic press or vacuum pump were used to produce the panels; water was used to clean the fibers and sodium silicate was used as a mineralizing agent; results were compared with NMX standards for structural mortars and fiber cement slabs together with manufacturing processes from previous research on natural fibers to obtain a methodology that optimizes the process. It is demonstrated that it is feasible to produce fiber cement panels that comply with the minimum regulatory requirements by reducing processes, without damaging the physical-mechanical values of the fiber cement. The best performance results show a MOR of 6.70 MPa and a density of 1560 kg/m^3 for a panel with 6% cane bagasse added to the dry mass of cement, a water/cement ratio of 0.95 by volume and sand/cement of 2.5 by mass. Opportunities are generated to experiment with counterpart fibers based on the tools, processes and recommendations of the project.

Composite material, Fiber cement, Cane bagasse fiber, Sodium silicate

Resumen

El objetivo del estudio es proponer un panel de fibrocemento a base de bagazo de caña que cumpla con los requisitos básicos para fibrocementos no comprimidos, sin utilizar equipos especiales para su manufactura, reduciendo los procesos a la mitad sin comprometer la calidad del producto. Para elaborar los paneles no hay necesidad de emplear: trituradora, horno, prensa hidráulica o bomba de vacío; para la limpieza de las fibras se utilizó agua y como agente mineralizante silicato de sodio; se contrastaron resultados con normas NMX para morteros estructurales y placas de fibrocemento junto con procesos de manufactura de investigaciones previas sobre fibras naturales para obtener una metodología que optimice el proceso. Se demuestra que es viable producir paneles de fibrocemento que cumplan con los requisitos mínimos normativos reduciendo procesos, sin perjudicar los valores físico-mecánicos de éste. Los resultados de mejor desempeño arrojan un MOR de 6.70 MPa y una densidad de 1560 kg/m^3 para un panel con 6% de adición de bagazo de caña respecto a la masa seca del cemento, una relación agua/cemento de 0.95 en volumen y arena/cemento de 2.5 en masa. Se genera oportunidades para experimentar con fibras homólogas basándose en las herramientas, procesos y recomendaciones del proyecto.

Material compuesto, Fibrocemento, Fibra de bagazo de caña, Silicato de sodio

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Introduction

In recent years, environmental concerns have stimulated extensive research on environmentally friendly materials. Putting attention to the use of fibers obtained from renewable plant sources for composite materials (Biagiotti, *et al.*, 2008; John & Thomas, 2008; Faruk, *et al.,* 2012). The combination of interesting mechanical and physical properties, in addition to environmental benefits, has been the main driver behind their use as an alternative to traditional reinforcements (Ardanuy, *et al.*, 2015).

Whereby although brittle building materials have long been reinforced with plant fibers (PV) since ancient times, the concept in cement-based reinforcement materials was first studied in the 1940s, when these were evaluated as possible substitutes for asbestos fibers due to their toxicity (Tonali, *et al.*, 2011).

Therefore, the applications of cement-based composites with PV have been defined in the construction area as non-structural elements, such as: thin walls, thin sheet products for partition walls, building envelopes or roofs, flat sheets, roof tiles and prefabricated components in general (Roman, *et al.*, 2008).

Despite the above, bagasse fibers (BC) have less scientific documentation with respect to fiber cement panels, so most of them follow a series of base or standard processes in their production, unlike other PVs such as wood chips, wool or cellulose, conifers and other lignocellulosic materials such as rice husks, cotton stalks, hemp, coconut fiber, jute, sisal, etc. Therefore, it is important to create more alternative uses and methods (Fernández Rodríguez & Díaz Hernández, 2017).

Being able to use a new manufacturing methodology in coating dividing elements for this type of fiber, means replicating in a plausible way panels with half of the recommended processes but manually, with few elements, especially in communities that have this type of agro-industrial waste; therefore the method would be useful in future homologous projects for other PVs with similar characteristics in order to contrast the feasibility of the method and its limits.

Research on the treatment of BC share similarities from its cutting, separation, cleaning, drying and mineralization, all of them with different mechanical, physical or chemical means in the process, for example to define the morphology of the fiber commonly a cutting, chopping or grinding is done in addition to the one that the bagasse already has at the time of leaving the sugar mills (Lozano Zamora & Rojas Fraile, 2019), then the fiber is sieved and sifted by machinery with a certain dimension; For washing and elimination of the remaining sugars, it is subjected to cycles of rinsing with hot and cold water (Cabral, *et al.* , 2018) or otherwise with substances such as calcium hydroxide for cleaning, which also serves as a coating against aggressive agents (Osorio Saraz, *et al.*, 2007; Nawrath Barros, 2015); as for chemical stabilization, so that the fiber is not affected by the alkalinity of the cement, sodium silicate is commonly used (López Barrios & Valencia Gualdron, 2006), the aforementioned calcium hydroxide or even without any agent to protect it; finally, for the drying of the fiber, forced draft ovens are used, in order to have a constant temperature control.

For the manufacture of panels, the process generally consists of the mixing of materials, addition of accelerators, casting, vibrating, pressing and curing. The making of the cementitious paste is usually carried out with motorized mixers since the fibers make it difficult to elaborate a homogeneous mortar, some use accelerants such as calcium chloride in this step since the cellulose present in the fibers delays the setting, (Osorio Saraz, *et al.*, 2007) after that, fixed or disassembled molds are used which can be metallic, acrylic or wood; then a pressing with machinery or dead weight is applied for a short period of time. There are certain proposals that combine this with vacuuming to eliminate excess moisture from the paste (Khorami & Ganjian, 2011); finally, the piece is cured by immersing it in water or using curing chambers with high humidity for a period of one month.

The techniques and considerations that were taken based on the preliminary results and the information provided by the different investigations with cementitious materials and natural fibers will be handled within the development.

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Materials and methods

A series of tests were carried out to design, experiment and characterize the materials to be used, from the tools, mix composition, element thickness, casting, vibrating and curing, in order to obtain an adequate result that complies both in physical and mechanical characteristics according to the non-compressed fibrocement standard NMX-C-234-ONNCCE-2015.

A CPC 30R RS cement was used for the design of a rapid strength mortar. Along with river sand from the material bank "El Cuervo" in Huajúmbaro, Michoacán; the stone that passed the ASTM No. 4 mesh (4.75 mm opening) was used, this same contains an amount of 78% (Table 1) of silica based on x-ray fluorescence analysis (Arreola Sánchez, 2013).

Huajúmbaro Arena "El Cuervo"			
Component	%	Component	%
SiO2	78.185	CaO	1.015
AlO3	11.557	Na2O	2.666
TiO2	0.203	K2O	3.577
Fe2O3	1.567	PXC/PPI	1.19
MgO	0.239	BaO	0
MnO	0.03	P2O5	0.036
Sum = 100.29			

Table 1 Chemical composition of the river sand in Huajúmbaro *(Arreola Sánchez, 2013)*

Dry sugarcane bagasse with a relative humidity of 11.7% from the Lázaro Cárdenas sugar mill in Taretan, Michoacán was used; it was processed at the mill to be used as boiler fuel; a series of rollers and machinery squeezed it and crushed it five times until leaving a fiber with little sugar and with lengths of 1.0 to 3.0 cm and thicknesses of 1 to 15 mm, in addition to containing a high amount of fines. In order not to affect the setting and the decrease in strength of the mortar, the fiber was sieved with an ASTM No. 4 mesh in order to eliminate randomly dispersed pellets and fragments in the bagasse; the fiber used was the one retained by the ASTM No. 8 mesh in order to eliminate the high amount of fines.

The fiber was washed with water at room temperature, being submerged for 24 h and then rinsed, squeezed manually and left to dry, then to be used in the mixture, it was left to saturate again one day before being made for the same period of time (Figure 1).

Figure 1 Sifting and cleaning of sugarcane bagasse.

So that the BC does not degrade in the alkaline medium at the time of integration into the cement matrix, it is previously impregnated with sodium silicate 20º Be with a concentration of 22% w/w, a higher range was used than other research whose values ranged between 15-17% w/w (Juarez Alvarado, 2002) due to the fact that a fiber rinse with boiling water was not used.

For the binder, a type I mortar was designed based on the (NMX-C-486-ONNCCE-2014) with a cement/sand dosage of 1:2.5 in mass with respect to previous tests showing a better resistance with the sand used in this project (Mondragón Martínez, 2021); so that the fluidity was acceptable in the control without going out of the norm, a water/cement ratio in volume of 0. 95, which allowed a value of 130% in the flow table; this was used in all the test groups to maintain a good consistency when working the mix with mineralized BC.

Next, a panel morphology was used with 25.0 cm x 25.0 cm slabs in accordance with the standards for fiber cement slabs, with a thickness of 1.0 cm; BC fiber was then added in percentages of 3.0, 6.0 and 12.0% with respect to the dry mass of the cement. Before mixing with the prepared mortar, the fiber is treated as follows: once the fiber is saturated with water, the excess is emptied without squeezing for 5 minutes, then it is submerged and impregnated with sodium silicate for 5 minutes while the fiber is shaken, immediately the excess liquid is drained for 3 minutes, in order to eliminate excesses, after which it is added to the previously mixed mortar (Figure 2).

The previous water saturation helps that both the fibers and the sodium silicate do not detract hydration from the mortar and cause a drop in its quality, in addition to facilitating its handling and curing.

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Figure 2 BC saturated in water and subsequently impregnated with sodium silicate

The mixing of the components that make up the composite was carried out with a mixing shovel using a 19 L bucket as a container, as shown in Figure 3, following the following sequence:

1. Cement + Sand - mixed 30 seconds manually with a spoon until the composition was homogeneous.
2. Addition of Water - 30 seconds at medium speed with the mixer with circular movements.
3. Addition of treated BC fiber - 30 seconds at medium speed with the same movement but with an up and down motion.
4. 20 seconds at fast speed with the same motion.
5. Check the consistency, making sure that there are no fiber clumps, if there are, repeat step

Figure 3 Mixing of components

The specimens were poured into previously greased disassembled metal molds, which after being filled with the mixture were compacted by manual impact vibration, dropping it to a height of approximately 10 cm, 15 times per side (60 blows in total), then the excess mortar was leveled with the edge of a ruler that was moved in the longitudinal and transversal direction slowly through the mold with a continuous and fast transversal movement to avoid pulling out pieces of mixture and fiber, then it was tamped with an acrylic prism in parallel on the four sides of the mold and proceeded again to vibrate them.

Finally the ruler was passed again with the same procedure to eliminate surplus. They were demolded after 24 h and were superficially moistened with a sprinkler to be later left inside a sealed container in order to maintain favorable humidity and temperature conditions for their curing. The tests were carried out at 7 and 28 days of curing (Figure 4).

Figure 4 Panel manufacturing process

Subsequently, once the specimens are cured, tests are made to obtain the modulus of rupture (MOR) to five plates in a Forney brand universal machine, with a constant acceleration of 0.30 t/min supported on two smooth rods with a diameter of 20 mm and a separation between them of 200 mm for each of the four test groups in transverse and longitudinal direction (Figure 6), averaging the values and performing the test in a time of approximately 30 seconds, noting the maximum load when the rupture is recorded, all based on what is marked by the standard and using equation 1.

$$MOR = \frac{eFl_s}{2be^2} \quad (1)$$

Where: F is the ultimate load (N); l_s is the distance between the centerlines of the supports (mm); b is the width of the test specimen (mm) and e is the thickness where the failure passes (mm).

They are subjected to vertical bending tests as marked in the standard with the following arrangements and instructions as shown in Figures 5, 6 and 7.

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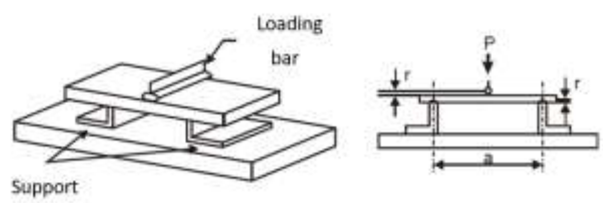


Figure 5 Bending test apparatus (NMX-C-234-ONNCCE-2015)

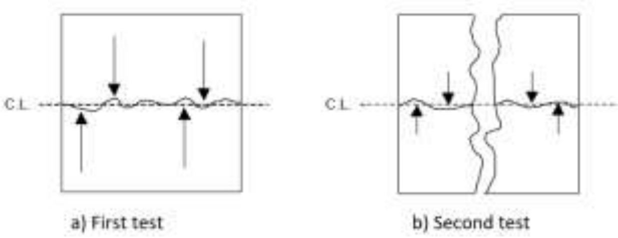


Figure 6 Transversal and longitudinal arrangement for testing by plate (NMX-C-234-ONNCCE-2015)

Where: r are the upper faces of the round supports with a radius of 20 mm; a is the distance between supports for this case will be 200 mm.

Figure 7 Attachment and arrangement for bending test (NMX-C-234-ONNCCE-2015)

Finally, permeability tests were performed which consisted of placing an acrylic frame of 20.5 cm x 25.5 cm x 5.0 cm on top of a panel, this was repeated for each test group taking only one panel from each batch which were cut to a measure of 25.0 cm x 20. 0 cm according to the standards (Figure 8) and this was sealed in the part that made contact with the plate, then water was placed until a height of 20 mm was obtained on the upper face of the panel, it was left for 24 h in ambient conditions without moving the specimen to finally report, at the end of this time, if visually drops were present on the lower face (Figure 9). In this test the panels may show traces of moisture on the bottom of the plate, but in no case should water droplets be observed.

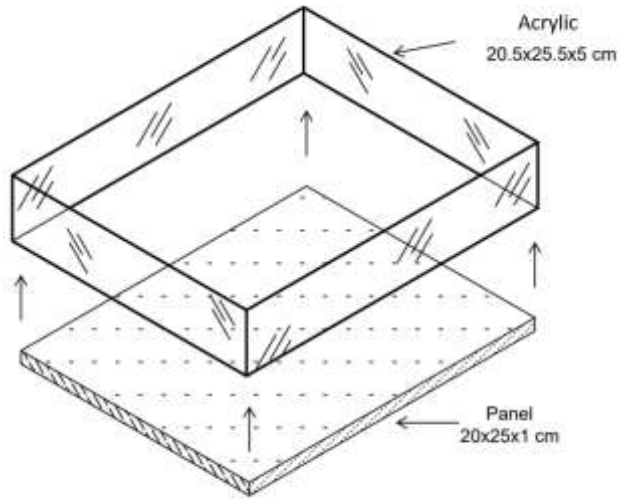


Figure 8 Permeability test frame assembly and dimensions

Figure 9 Performance of permeability test on control specimen (control)

Results and discussion

After testing the specimens with the different dosages of BC and control specimens (Table 2), it is observed that the test group with 6% addition of BC fibers is the one that shows the highest modulus of rupture at 28 days; with respect to the values at 7 days, the specimen containing 3% BC is shown as the best specimen, but its resistance shows a decrease of 32.

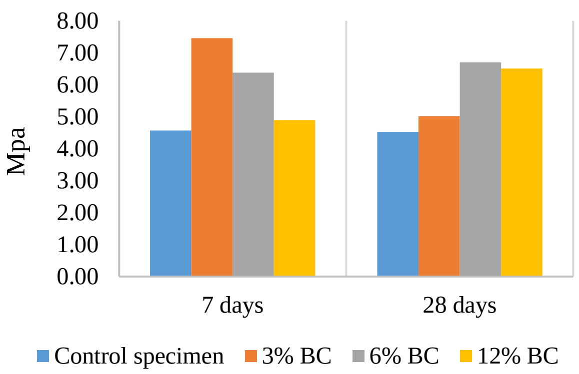
The remaining specimens with the addition of BC show an improvement in flexural strength with respect to the control, none of them worsens or decreases below the value of the same once the month is reached, which indicates that the fibers fulfill their function as reinforcement without reducing the panel mechanically (Table 3) (Graph 1).

Dosage to manufacture a panel				
Components	Witness	3% BC	6% BC	12% BC
Cement (gr)	357	350	340	320
Sand (gr)	892	875	850	800
Water (ml)	339	332	323	304
Fiber (gr)	0	10.50	20.40	38.40

Table 2 Dosage of each test group to produce a 25x25x1 cm panel

MOR results for the test groups		
Mix	MOR prom. 7 days (MPa)	Average MOR at 28 days (MPa)
Witness	4.56	4.53
3% BC	7.46	5.02
6% BC	6.37	6.70
12% BC	4.90	6.51

Table 3 Average modulus of rupture of the different specimens and cores at 7 and 28 days.

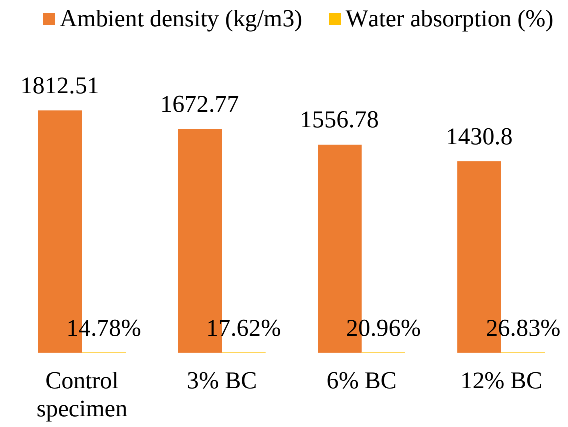


Graph 1 Average modulus of rupture of the different specimens and samples at 7 and 28 days

As for the ambient density, the values are shown in Table 4, in which all of them show a decrease in density as the amount of fiber addition increases, as well as the water absorption capacity (Graph 2).

MOR results for the test groups		
Mix	Ambient density (kg/m^3)	Water absorption (%)
Witness	1812.51	14.78
3% BC	1672.77	17.62
6% BC	1556.78	20.96
12% BC	1430.80	26.83

Table 4 Density and absorption capacity of the test groups



Graph 2 Physical properties of the panels

The permeability test showed that none of the specimens with the addition of BC passed the 24 h test, since they showed water droplet formation before the end of the test (Figure 10). The higher the concentration of BC, the shorter the time in which drops appear, with times of appearance ranging from 20 h to only 7 h (Table 5).

Figure 10 Photographic report of the visual inspection of the four analysis groups in the permeability test

24 h permeability test report	
Mix	Droplet formation
Witness	None
3% BC	20 h
6% BC	12 h
12% BC	7 h

Table 5 Comparative table of the test groups to permeability for 24 h

According to the above results MOR was classified as a type B fiber cement board, which is used for boards in interior applications, such as interior walls, floors, ceramic substrate or walls, which can be subjected to heat, moisture but not freezing as shown in (Table 6).

Applications and categories of NT flat plates for category B
Application
1. Substrate for internal walls or floor tiles.
2. Ceilings.
3. Interior substrate for walls to be painted or wallpapered.
4. Mezzanine or base floors (internal).

Table 6 Possible uses for non-compressed fiber cement boards (NMX-C-234-ONNCCE-2015)

According to the minimum MPa values established by the standard, the fiber cement manufactured with this proposal is classified in Class 1; the standard does not specify its use, it only classifies it in that category (Table 7)

Minimum performance requirements	
Category B in ambient condition (MPa)	
Class 1	4
Class 2	7
Class 3	13

Table 7 Minimum MPa values (NMX-C-234-ONNCCE-2015)

There are more applicable tests according to NMX-C-234, but they are not of high relevance they are considered of lower hierarchy and as the category is type B it is not necessary to perform the other tests.

Conclusions

The fiber cement panel composed of BC and mortar, denotes adequate MOR values for its use, being supported by the marked in the NMX-C-234-ONNCCE-2015, with results above 4 MPa, which is designated as Class 1, getting very close to a class 2 panel of 7 MPa, having the possibility to perform as a standard panel category B with uses such as: substrate for internal walls or floor tiles, ceilings, interior substrate for walls to be painted or wallpapered and mezzanine or floor base (internal), but nevertheless by not successfully passing the permeability test, considered as a higher grade, which is below the flexural test, the objective is semi-complete, exposing a new problem: how to increase the impermeability, in order to guarantee its durability, which is implicit in the failed test of the test groups with BC. It is remarked that even so, the mechanical values reflected by the method used, which leaves out several of the usual processes carried out for woody fibers, did not impair the final flexural performance of the panels.

The general objective of the feasibility of being able to produce a fiber cement panel based on sugarcane bagasse and mortar using a smaller amount of resources and procedures for its production is partially confirmed, for which it is now necessary to modify the process, in such a way that it allows improving the impermeability, in order to complete the control requirements that guarantee the permanence of the element.

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