WCTE 2016
World Conference on
Timber Engineering
August 22-25, 2016 | Vienna, Austria

ENABLING COMPRESSED SUGAR CANE BAGASSE BOARD AS CONCRETE SLAB FILLER COMPONENT

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ABSTRACT: Over the years, the search for alternative materials to be applied in civil construction has increased due to economic, socio-environmental and technological factors. A concrete slab filler component is a prefabricated element of inert material whose main function is to reduce a slab's total volume of concrete, thus making the element lighter and cheaper. This research aims to achieve an innovative filler component for concrete slabs, using alternative materials in order to replace traditional ones maintaining high standards of efficiency and durability. Sugar cane bagasse has arisen as an excellent option for this matter. The use of its lignin rich fibres in composites has become increasingly growing thanks to several researches that proved its strength. Thus, the major purpose of this work is to enable compressed sugarcane bagasse boards as filler component in concrete slabs, according to the Brazilian Association of Technical Standards. The prototype underwent a destructive test for analysis of its mechanical properties and general behaviour. As a result, a filler component resistant enough for its function was obtained, being also sustainable although many improvements are still in process.

KEYWORDS: Civil Construction, Slab, Filler Component, Sugar cane, Bagasse.

1 INTRODUCTION

Based on the usage of sugar cane bagasse as a material for civil construction and on the search for new technologies, this project intends to develop a filler component for slab whose performance and features aim to benefit society in economic, technological and environmental terms.

Slab is a structural component whose main function is to transmit the actions of loads to beams or directly to pillars. There are many types of slabs on the market today; however, this research focuses on one way precast slabs, which is the simplest type to work with. Some slabs are filled with inert materials (filler component) in order to reduce their total volume of concrete, thus making a structure cheaper and lighter.

Precast slabs have as filler component Styrofoam or ceramic materials mostly. Both have advantages and disadvantages. The Styrofoam component, despite advantages such as light weight, thermal and acoustic insulation and being a recyclable material, has a major drawback: high cost and propensity to insect's attack; while the ceramic ones deliver optimal adhesion and low probability of cracks and fissures, but another major drawback: high self-weight. The objective is to accomplish a filler component made of an alternative material that is a compromise between Styrofoam and ceramic fillers (figure 1).

Sugar cane (*Saccharum officinarum*) is originally from South Asia, being later introduced in subtropical and tropical countries like Brazil. According to the data obtained by Conab (Brazilian National Supply Company), the harvest of 2013/2014 reached the milestone of 652,015,900 tons of sugar cane. This large scale production generates a large amount of waste. The sugar cane bagasse, which is the resulting material when the cane is press to remove sugar from its cells, is the most abundant agro-industrial by-product in Brazil. For this reason, it is a major need to find intelligent solutions for this issue.

According to researchers, the bagasse is a cellulose, hemicellulose and lignin rich organic matter. These three components confer mechanical and chemical strength to sugar cane fibres, also for being a light material sugar cane bagasse represents an excellent option as alternative material for filler components.

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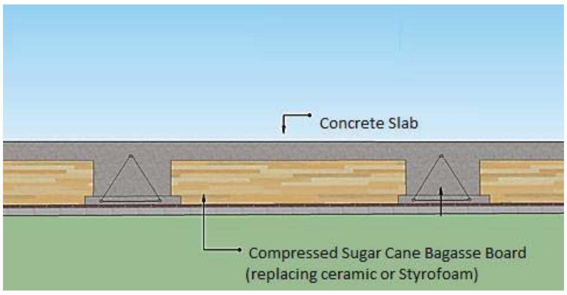

Figure 1: *schematic drawing*

2 MATERIALS AND METHOD

2.1 SUGAR CANE BAGASSE COLLECT

The material was collected at mills around São Luís do Maranhão, Brazil, right after being squeezed. It is important to maintain sugar cane's natural culm shape during the collecting. After that, the material was led directly to the lab, where it received proper treatment.

2.2 TREATMENT, DRYING PROCESS AND MATERIAL SELECTION

The material collected went through a 36 hours long water treatment in order to completely eliminate sugar from its cells so fermentation could be avoided (figure 2). The bagasse was immersed in large containers with pH 7 water. This water was exchanged at regular intervals of 12 hours making a total of 36 hours, when water pH-value, which becomes acid, returns to a ratio close to 7. Paper universal indicator was used to check the pH-value (figure 3). Then, the material was exposed at outdoor temperatures for 24 hours (figure 4) aiming to eliminate the water in excess from its cells before the following kiln-drying process, during a period of 40 hours in general at temperature of 60ºC (figure 5). Intending to confirm the success of drying process, a sample went through weighing once every 6 hours to evaluate its moisture content. When a constant value is reached, the bagasse can be removed from the kiln. After drying process, the material was cut and separated manually into two groups: "dermax" or bark and "comfith" or core. The core, for being the lightest and most fibrous part of sugar cane, was used for this project purpose.

Figure 2: *Sugar Cane bagasse after water treatment*

Figure 3*: paper universal indicator*

Figure 4: *material exposed at outdoor temperatures*

Figure 5*: kiln- drying process*

2.3 DIMENSIONS AND MOLDING

According to Brazilian Association of Technical Standards, a filler component must feature specific dimensions, in centimetres, as depicted on Table 1.

Table 1: *possible dimensions (centimetres) of filler component*

Nominal Height (he)		7,0 (minimum); 8,0; 9,5; 11,5; 15,5; 19,5; 23,5; 28,5
Nominal Width (be)		25,0 (minimum); 30,0; 32,0; 37,0; 39,0; 40,0; 47,0; 50
Nominal Length (C)		20,0 (minimum); 25,0
Locking Tabs	(av)	3
	(ah)	1,5

The following schematic drawing illustrates the proper position of each dimension (figure 6).

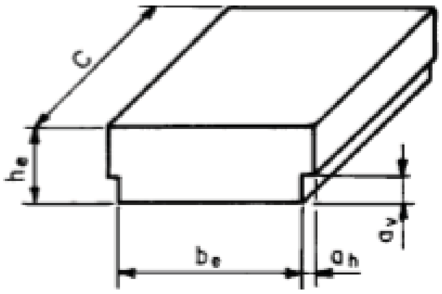

Figure 6*: filler component schematic drawing*

The minimum dimensions of height and width, respectively 7 and 25 centimetres, were chosen for this prototype. The adopted length was 50 cm in order to perfectly fit the filler component in the flexure test equipment as required by the Brazilian Standards.

Given the geometry of the component and its "T" cross section, two boards were produced and later attached to each other. The top part contains a board of 4 cm high, 25 cm wide and 50 cm long. The bottom part contains a board of 3 cm high, same length and 22 cm wide.

The mold used should be made of Teflon in order to prevent material's adhesion on its surface.

2.4 BINDING AGENT

To ensure that sugar cane bagasse fibers remain attached to each other and resistant throughout filler component's life, the use of a binder or any substance with similar function is necessary. However, it should be considered that this binder must not present such a high specific weight that significantly contribute to the self-weight of the resulting element. It also has to ensure the continuity of filler component's inner surfaces, allowing better distribution of stresses throughout them. Two options of binders were considered and tested in this project, being both similar, as they are classified as a polyurethane: a solid product with rigid foam texture. The first option is polyurethane castor oil resin, a waterproof environmental-friendly substance made of a substance called polyol and catalyzer. Its curing process occurs at room temperature although it can be accelerated at high temperatures. Several applications of this resin in wooden materials have proven viable, according to studies conducted at the Wood and Timber Structure Laboratory (LaMEM), Department of Structural Engineering, School of Engineering of São Carlos, USP, in São Paulo, Brazil. The second option is the polyurethane expansive foam, that properly works as an adhesive and filling substance; it is used as an alternative once it is cheap, easily found and applied.

2.5 FILLER COMPONENT PRODUCTION

Two models for filler component's production were stablished. The first method utilizes as binder polyurethane castor oil resin whereas the second one makes use of polyurethane expansive foam. Both results are compared at the end of this paper in order to analyse the best option.

2.5.1 First Method

In this model, the production of filler component was carried out using the polyurethane castor oil resin, which should be added to the bagasse according to the following proportions:

• Top Part: sugarcane bagasse was weighed, as seen in Table 2. The amount of resin used was initially 30% of the mass of bagasse as found in the literature, with the polyol to catalyzer ratio equal to 1:1.5. Then, the mold was filled with the mixture.

• Bottom Part: sugarcane bagasse was weighed, as seen in Table 2. The amount of resin used was initially 30% of the mass of residue as found in the literature, with the polyol to catalyzer ratio equal to 1:2. Then, the mold was filled with the mixture.

Table 2: *materials proportion*

	Bagasse (grams)	Poliol (grams)	Catalyzer (grams)
Top Part	252	47,16	31,44
Bottom Part	254	50,8	25,4

The mold containing the mixture undergoes a pressing process until it reaches the desired thickness. A hydraulic press was used for this purpose. This equipment also accelerated curing process once the boards were heated at a temperature of 100°C while pressing. The result can be seen in Figure 7.

After that, the boards were attached to each other with resin. The central axis must match and respect the distances between the horizontal edges of the boards, 1,5 cm, as seen previously.

Figure 7: sugar cane bagasse and castor oil resin boards before attachment

The prototype's dimensions are illustrated on figures 8 and 9.

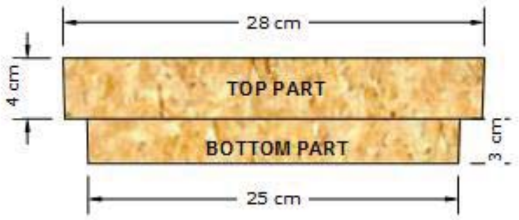

Figure 8: *filler component transversal section*

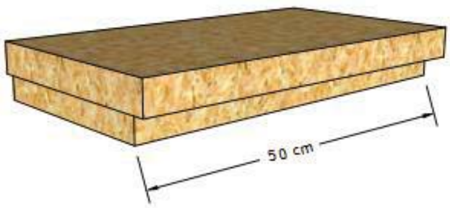

Figure 9: *filler component length*

2.5.2 Second method

Despite the results obtained with sugar cane bagasse and polyurethane castor oil resin filler component, the research and production of new body proofs went on using the second binder, polyurethane foam (figure 10), in order to improve previous results and obtain a comparison in terms of quality and behaviour.

This production method is almost the same as the first one, being modified only the proportion of material since there is an intention of improvement, reducing waste and obtaining a more satisfactory specific weight for the filler component. This new prototype can be seen on figure 11 and 12.

Figure 10: Polyurethane foam

Figure 11: *sugarcane bagasse and polyurethane foam filler component*

Figure 12: *sugarcane bagasse and polyurethane foam filler component*

For polyurethane expansive foam and sugar cane bagasse filler component, the same dimensions (figure 8, 9) were followed. However, instead of two boards of 4 cm and 3 cm, 7 boards of 1 cm height were made and then, attached to each other (figure 13). The top part contains 4 boards of 1 cm high, 25 cm wide and 50 cm long. The bottom part contains 3 boards of 1 cm high, same length and 22 cm wide.

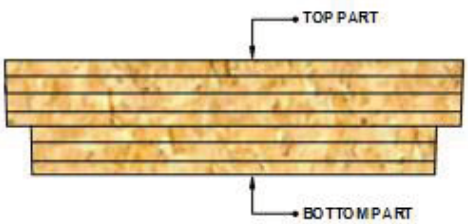

***Figure 13:** filler component composition*

The quantities of material used for each board of 1cm height are described in table 3.

***Table 3:** materials proportion*

	Bagasse (grams)	Polyurethane Foam (grams)
Top Part	169,00	150,60
Bottom Part	189,70	81,50

Figures 14 and 15 show top part total weight and bottom part total weight, respectively, before finishing proceedings.

***Figure 14:** top part weight, before finishing*

***Figure 15:** bottom part weight, before finishing*

2.6 FINISHING STANDARDS CHECK

As predicted by Brazilian Association of Technical Standards, the filler components should present a flat bottom surface and be free from cracks and broken parts which could compromise the component performance or allow concrete leakage. A filler component also must maintain intact its characteristics during use, and the unevenness on the bottom face should be measured and fixed according to the following rules:

a) finishing with plaster: located unevenness up to 3 mm are admitted;

b) finishing with Portland cement mortar: located unevenness of up to 6 mm are admitted.

The gaps, hence, were measured and corrected with plaster. Only the First Method prototype required a repair, so a finishing with plaster was recommended.

3 FLEXURE TEST

Once the production and assembling stages of the filler component are over, this component must undergo a breaking load flexure test. The technical standard published by the Brazilian Association of Technical Standard addressing precast slabs joist and filler on one way slabs points out two models for this test: one for filler components of fragile fracture and the other for components of ductile fracture. Despite the absence of sugar cane bagasse under the list of examples of filler component materials of ductile fracture, the last model was chosen given the behavior of the bagasse mash under flexure and its similarity to the expanded polystyrene (EPS) behavior under the same circumstance.

The equipment required by ABNT NBR 14859-1: 2002 for this test must be able to hold a specimen 50 centimeters long and 30 centimeters wide while simulating the neighboring concrete joists supports positions a filler component would face on a concrete slab setup. The one used in this project can be seen on figure 16, which shows the equipment's brand.

***Figure 16:** EMIC's DL10000, the equipment used to perform the test*

Following the specimen placement, the equipment loading head is placed on the middle of its upper surface, along its major axis, where it applies a progressive load until the specimen's rupture (figures 18, 19 and 20). At this point, the breaking load may be recorded in kgf (kilogram-force) and later converted into kN (kilonewton).

Figure 17: *EMIC's DL10000, with a proper fixture set installed*

Figure 18*: Breaking load test setup (first prototype)*

Figure 19: *Specimen aftermath (first prototype)*

Figure 20: *breaking load test setup (second prototype)*

Under the same standards, the minimum breaking load value required of a concrete slab filler component undergoing the test is 1,0 kN for elements of height equal to, or over, 8 cm. Elements under that height must show a fracture load of at least 0,7 kN, which is the condition under which this research specimens fall.

4 RESULTS

The equipment indicated above (figure 16) generates a *load x strain* graphic for each element tested. It also indicates their rupture load. Thus, drawing a comparison between the prototype of each method was possible

4.1 FIRST METHOD

As stated before, the first method refers to the production of a filler component made of sugarcane bagasse and polyurethane castor oil resin. The graphic *load x strain* below (Figure 21) was obtained while the test was carried out as well as the information on table 3.

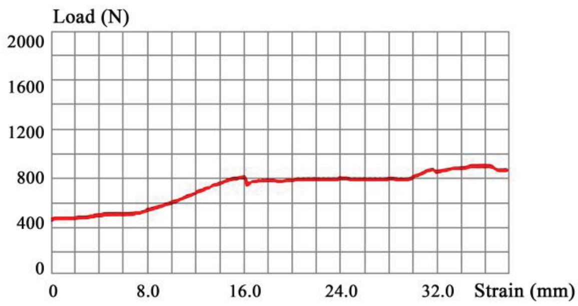

Figure 21*: load x strain chart*

Table 4: *Flexure Test information*

Component length	500mm
Distance between supports	200mm
Fracture Load	91,8 kfg (0,9 kN)

According to that, as the prototype withstands a fracture load higher than 0,7 kN, it is appropriate for its purpose and approved by Brazilian Association of Technical Standard.

With filler component information, such as total volume calculated based on its dimensions on section 2.5.1 and weight, obtained with a precision scale, it is possible to estimate material's specific weight, as seen on table 4.

***Table 5**: filler component characteristics*

Total Volume (m^3)	Weight (kg)	Specific Weigh (kg/m^3)
0,00935	2,60	278,07

4.2 SECOND METHOD

As explained previously, the second method refers to the production of a filler component made of sugarcane bagasse and polyurethane foam. The graphic *load x strain* below (Figure 22) was obtained while the test was carried out as well as the information on table 5.
The same test proceedings were followed for this body proof. The same loads applied to the first method prototype was applied to this one.
However, the equipment used for this test has a limit of applied load, thus the maximum load that could be applied to the body proof was 1,18 kN. As it withstood a load higher than 0,7 kN, it is appropriate for its purpose and approved by Brazilian Association of Technical Standard although given the equipment condition, it was not possible to determine its fracture load.

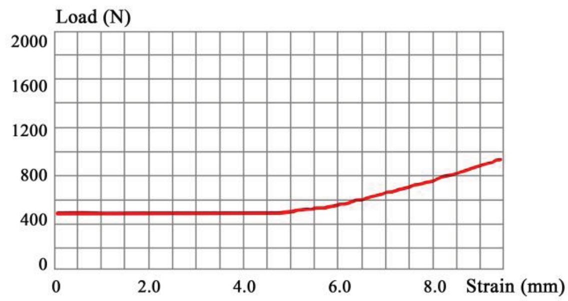

***Figure 22**: stress x strain chart*

***Table 6:** Flexure Test information*

Component length	500mm
Distance between supports	200mm
Fracture Load	Not given

With filler component information, such as total volume calculated based on its dimensions on section 2.5.2 and weight, obtained with a precision scale, it is possible to estimate material's specific weight, as seen on table 7.

***Table 7**: filler component characteristics*

Total Volume (m^3)	Weight (kg)	Specific Weigh (kg/m^3)
0,00935	2,00	213,90

5 DISCUSSION

Comparing both results described on section 4, the second method delivers a lighter and more resistant concrete slab filler component than the first one, although both results are positive and indicate their feasibility.
In order to analyse the differences between the values of specific weight of traditional materials used on filler components, table 8 was composed. The specific weight of ceramic and EPS filler components were obtained from the manufacturer website.

***Table 8:** table of specific weight comparison*

EPS specific weight (kg/m^3)	First prototype specific weight (kg/m^3)	Second prototype specific weight (kg/m^3)	Ceramic specific weight (kg/m^3)
25,00	278,07	213,90	800,00

Therefore, it is easy to conclude that the specific weight of sugar cane bagasse filler component is a compromise between the other ones, as expected.

CONCLUSION

As a conclusion, this research conveys to a positive result. A unidirectional concrete slab filler component made of sugar cane bagasse is feasible, withstanding loads higher than specified by norm in accordance to Brazilian Association of Technical Standards. Also, manufacturing methods are simple and easily executed. Nevertheless, there is certainly room for improvements and production rationalization, which will be chased until the end of this research in July 2016.

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