Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April, 2025
Paper No. ICSECT 154
DOI: 10.11159/icsect25.154

Incorporation of Sugarcane Bagasse Fiber on Concrete and Its Effect on Physical and Mechanical Properties

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Abstract **-** In the following investigation, concrete specimens incorporated with sugarcane bagasse fibers (SCBF) were manufactured to analyze their effects on their physical and mechanical properties. The fibers were collected from the waste generated by the sugar factories in the La Libertad region, Peru. SCBF were incorporated in different concentrations (0.5, 1, 1.5 and 2%) in the concrete mixing process. The effect of the incorporation of SCBF on the density and water absorption of the manufactured specimens were evaluated, also morphological variations were analyzed by Scanning Electron Microscopy (SEM). Likewise, the specimens were subjected to compression tests to verify their resistance. A good integration of the fibers in the concrete matrix was observed, the incorporation of SCBF produces a reduction in the number and size of pores. In addition, the increase in SCBF lightens the concrete, increasing the water absorption capacity. Mechanical tests show that the compressive strength increases with the incorporation of SCBF, reaching a maximum value using 0.5% fiber after 28 days of curing.

Keywords**:** Natural fibers, compressive strength, sugarcane bagasse fiber, concrete, agro-industrial waste

1. Introduction

Concrete is a fundamental material for the construction of homes and the most used material in infrastructure and transportation projects due to its low cost, accessibility, durability, workability and its high resistance to compression [1-3]. However, considerable amounts of natural resources are used in its manufacture and large amounts of carbon dioxide are emitted, with cement being its main component and its industry producing approximately 7% of the carbon dioxide released into the atmosphere [4]. On the other hand, with the rapid industrial and agricultural development, large quantities of organic waste have been generated. The disposal of this waste is a serious environmental problem, since most of the final waste goes to landfills or is burned, which not only reduces the usable surface area of the land, but also pollutes the environment. In particular, sugarcane bagasse is a residue from the sugar industry that ends up being burned, since no appropriate use can be found, which generates the release of toxic gases such as methane, carbon monoxide, nitrogen oxide capable of affecting humans and their environment. [5,6].

To reduce these negative environmental impacts, many researchers have analyzed the feasibility of using natural fibers as reinforcing materials in concrete due to the unique qualities of the fibers, their low cost and their low environmental impact in the search for alternative raw materials for the construction industry [7-9]. Fiber-embedded concrete is similar in cost and time to traditionally produced concrete [10]. The incorporation of natural fibers promises to increase or have a positive effect on the fundamental mechanical characteristics of concrete, since they manage to reduce the porosity in the concrete matrix, generating a more compact structure [11-13].

Jamshaid et al. [14] studied the mechanical characteristics of concrete reinforced with natural cellulosic fibers such as jute, sisal, sugarcane, and coconut. The fibers were incorporated into a concrete matrix in varying proportions from 0.5% to 3% by mass. The results showed that the tensile and compressive strength of the samples increased gradually with increasing proportion of natural cellulosic fibers up to 2%. Further increase in the fiber loading fraction results in deterioration of mechanical properties. Also, Asim et al. [15] used natural fibers of jute, coconut, sugarcane, sisal, and basalt in concrete.

Thermal conductivity tests, scanning electron microscopy (SEM) were performed, and compressive strength was measured. The thermal conductivity results showed that by increasing the percentage of natural fibers in the concrete, the thermal insulation characteristics increased while the compressive strength decreased. Whereas, Krishna et al. [16] used natural coconut fibers to improve the properties of concrete. Coconut fiber delays and controls tensile cracking of composites and also improves ductility and energy absorption capacity. Increased ductility and strength of concrete was achieved by adding 1.5% coconut fiber to the weight of cement. Similarly, Manniello et al. [17] investigated the influence of aspect ratio of reed fibers on tensile characteristics of concrete blocks. Experiments were conducted on cylindrical concrete blocks with a constant amount of 1% fiber and different aspect ratios: 30, 50 and 70 (mm/mm) respectively. The results showed a direct impact of aspect ratio on the ultimate tensile strength of concrete blocks, with higher aspect ratios yielding superior tensile properties. Furthermore, Castillo-Lara et al. [18] studied the mechanical strength of plain cellular concrete and natural fiber-reinforced cellular concrete at volume fractions of 0.5%, 1%, and 1.5%.

The inclusion of fibers improved the compressive and tensile strengths and plastic behavior. The improvement in tensile behavior was greater when treated henequen fibers were used, which was attributed to the increase in fiber-matrix bonding produced by the alkaline treatment. On the other hand, other authors choose to use fiber ashes, such as Xu et al. [19], who presents a review of the physical properties and chemical composition of sugarcane bagasse ashes. The studies indicate that it is a potentially promising construction material. The impact on the properties of fresh and hardened concrete is highlighted, including physical properties, mechanical strength, microstructure, and durability. Likewise, Arshad et al. [20] studied the mechanical properties of plain concrete with silica fume bagasse ash and that reinforced with basalt fiber. They used cement contents of 0%, 5%, 10% and 15%, by mass. The results indicated that the mechanical properties of reinforced concrete generally improve compared to plain concrete

The importance of this research lies in contributing to the advancement in understanding the mechanical behavior of natural fiber reinforced concrete, providing an alternative for reusing sugarcane bagasse waste generated by agro-industrial companies present in the northern region of Peru. The objective of this work was to study the incorporation of sugarcane bagasse fiber in concrete and its effect on its mechanical properties. For this purpose, concrete specimens incorporated with percentages of 0.5, 1, 1.5 and 2% of sugarcane bagasse fiber by mass of cement were manufactured. A morphological study of the manufactured specimens was carried out using scanning electron microscopy, and the variation in density and compressive strength of the specimens was analyzed. The results were compared with control specimens of plain concrete.

2. Materials and Methods

Crushed stone, coarse sand, Portland cement and water were used to prepare the plain concrete. Table 1 shows the physical properties of the aggregates.

Table 1: Physical characteristics of fine and coarse aggregates.

Property	**Fine aggregate**	**Coarse aggregate**
Specific gravity (g/cm^3)	2.57	2.64
Water absorption (%)	2.46	1.21
Humidity content (%)	2.46	1.20
Fineness modulus	2.82	6.99
Uniformity coefficient	5.61	2.47

Fig. 1: Sugarcane bagasse fibers (SCBF).

2.1. Sugarcane bagasse fiber (SCBF) obtaining

The sugarcane bagasse was collected in the district of Laredo, Trujillo, Peru, where it is abundant due to the presence of sugar factories. The fibers were dried in the sun for approximately one week, allowing the humidity of the bagasse to be reduced and facilitating its subsequent processing. After this time, the bagasse was crushed to reduce its size, then going through a sieving process with a 10 mesh (0.85 mm). The fiber obtained was reserved for later incorporation into the different mixtures (Fig. 1).

2.2. Fabrication of concrete test tubes

Concrete specimens measuring 30 cm in height by 15 cm in diameter were manufactured, with a theoretical compressive strength of 210 kg/cm2 at 28 days for the control specimen, using a dosage of 1:2:2. Including the unreinforced control specimen, five variations were prepared, four mixtures were with 0.5%, 1%, 1.5% and 2% of sugarcane bagasse fiber. The sugarcane fiber was introduced into the mix as an additive incorporated in percentage by mass of cement. The mixing process was done manually, gradually incorporating the fiber and mixing for a homogeneous distribution. The pouring process into test tubes was carried out in stages. A first pouring of the mixture of 10 cm was carried out, followed by a homogenization process, introducing a 25 mm steel rod followed by 15 blows with a rubber-headed hammer in order to eliminate bubbles and avoid crabs. This same process was followed in a second stage of pouring at 20 cm and 30 cm. The workability of the mixtures was examined immediately after mixing, the Abrams cone procedure was used. The settlement of the mixtures was in the range of 70 to 82 mm. After 24 hours of drying, the test tubes were removed from the mold to place them in a water tank for the curing process at room temperature until the tests were carried out (Fig. 2).

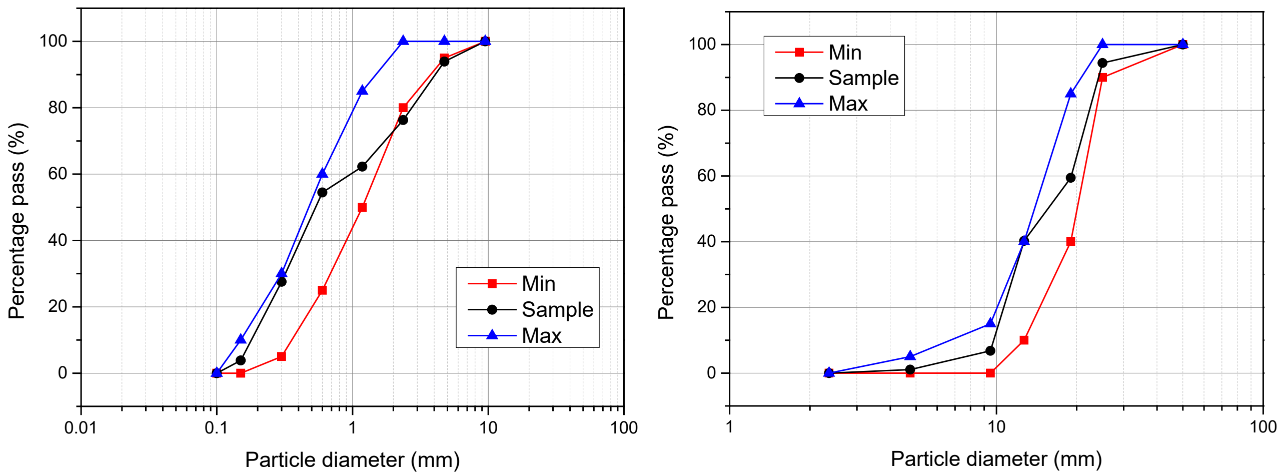
Fig. 2: Curing process of concrete test tubes fabricated.

2.3. Characterization techniques

The moisture content and specific weight were measured using the ASTM C70 and ASTM C127-128 tests, respectively. For the particle size test, ASTM C136 was followed and sieves 1 ½”, 1”, ¾”, ½”, ⅜” and the bottom were used for coarse aggregates, and sieves # 4, 8, 30, 40, 100, 200 and the bottom for fine aggregates. For the measurement of compressive strength, a Forney F-25EX-F-CoPilot hydraulic press was used with a range of 1.33 to 113.398 kgf, where the concrete cylinders were placed in the same direction in which they were made on a metal neoprene plate. The morphology of the foams was obtained in a scanning electron microscope SEM Tescan Vega 3 LMU, the samples were observed using an accelerated voltage of 5 kV. The density of fresh concrete after 28 days was determined according to the ASTM C138 test. While the percentage of water absorption was determined by the ASTM C642-13 test.

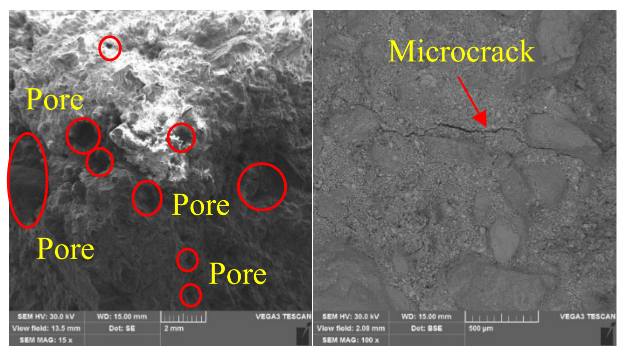
3. Results and Discussion

Fig. 3 shows the granulometric curves (grain size curves) of the fine and coarse aggregates, while Table 1 shows the physical characteristics of the fine and coarse aggregates. The granulometric curves of the aggregates show that the materials are within the estimated limits. The granulometric analysis is complemented by calculating the fineness modulus, uniformity coefficient, among other characteristics. From the results it is observed that the sand has a fineness modulus of 2.82, suitable for the manufacture of concrete, since it is within the established range that goes from 2.70 to 3.50. In addition, its uniformity coefficient was 5.61, its specific gravity was 2.57 g/cm^3, with a moisture content of 2.46 % and an absorption percentage of 2.46 %. On the other hand, for the coarse aggregate, the calculation of the fineness modulus yields a value of 6.99, which is within the established range of 3.5 to 7.8. In addition, its uniformity coefficient was 2.47, its specific gravity was 2.64, with a moisture content of 1.20 % and its absorption percentage was 1.21 %. These characteristics are similar to those of the materials used by other authors [16,21].

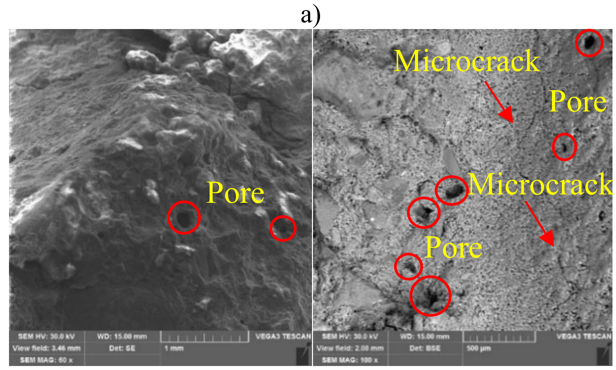


a) b)

Fig. 3: Granulometric curves of a) fine and b) coarse aggregates.



a)



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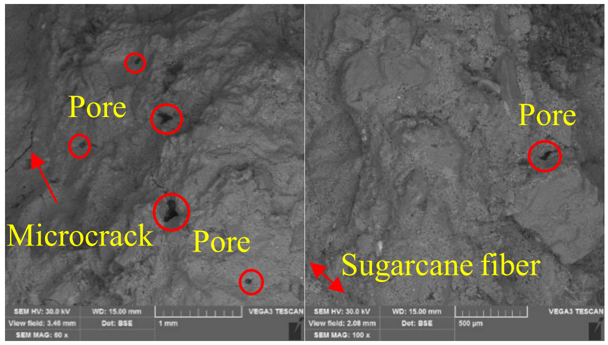

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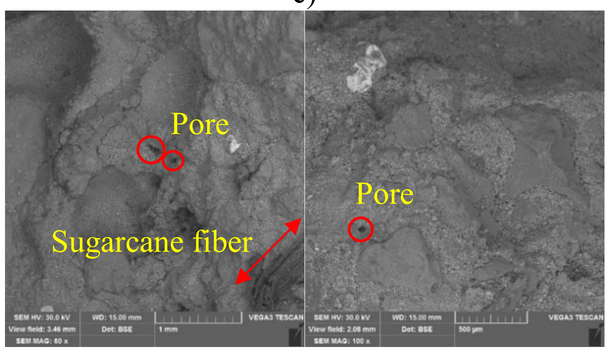

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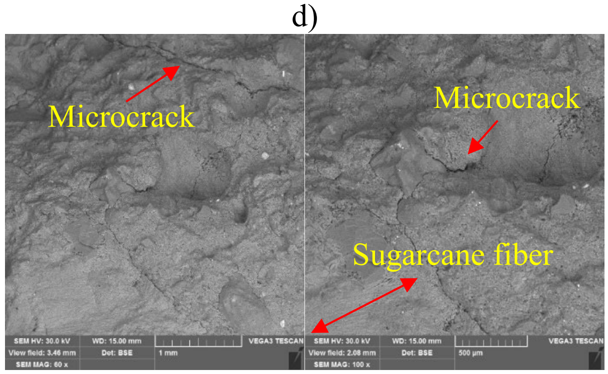

e)

Fig. 4: SEM images of the manufactured specimens incorporated with SCBF: a) 0%, b) 0.5%, c) 1%, d) 1.5%, e) 2%.

Fig. 4 a)-e) represent scanning electron microscopy (SEM) images of the concrete samples with varying percentages of sugarcane bagasse fiber (0%, 0.5%, 1%, 1.5% and 2%). In these figures, it can be observed how the incorporation of sugarcane bagasse fiber produced a decrease in the quantity and size of pores. In addition, the incorporation of sugarcane bagasse fiber did not generate a significant decrease in the number of microcracks within the composite. These phenomena could be due to the uniformity in the dispersion of the fibers in the matrix and their bridging effect in the concrete matrix, which depends on the physical and mechanical characteristics of the fibers [22]. Similar results were found in works where natural fibers were incorporated into cement matrices. Kiamahalleh et al. [22] found that the incorporation of sugarcane fiber produced a decrease in the quantity and size of pores, as well as a reduction in microcracks, however, this effect was only noticeable up to 3% of incorporated fiber. In the SEM analysis carried out by Castillo-Lara et al. [18] To study the impact of henequen fiber on concrete, they observed a structure of air voids with homogeneous sizes despite the high fiber content, suggesting that there may be a considerable amount of air voids connected by the fibers. In the SEM images of Khan et al. [23], The incorporation of coconut fiber generates new interfaces in the matrix that result in a weak bond between the coconut fiber and the matrix. In the micrographs of Saad et al. [24] Cracks were observed between the incorporated fiber and the cement paste, indicating that no chemical reaction occurred between the two, resulting in poor compaction of the concrete. While Zhang et al. [25] presents SEM analysis showing the interfacial separation of the fibers from the cement matrix due to swelling and deswelling of the fibers.

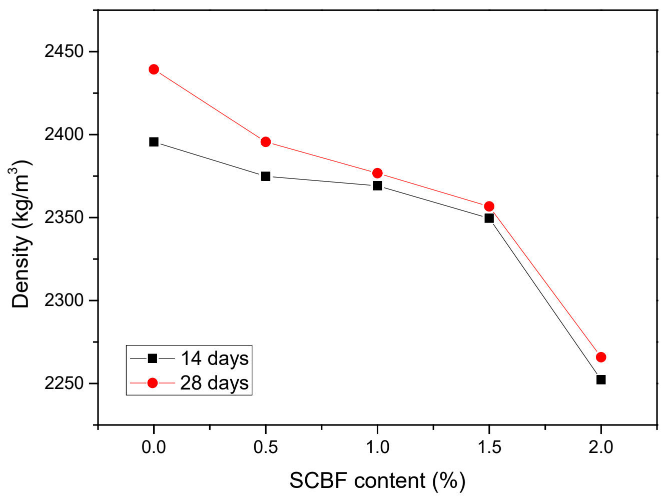

Fig. 5: Density of concrete samples incorporated with SCBF at 14 and 28 days of curing.

The results of the density tests obtained are presented in Fig. 5. These show that the incorporation of sugarcane bagasse fibers in concrete mixtures affects their volumetric density. The density is reduced by up to 7% in a curing time of 28 days, which can be attributed to the low density of the fibers. The density of the control mixture at 28 days was 2439 kg/m^3 and that of the mixtures incorporated with 0.5, 1, 1.5 and 2% SCBF was 2395, 2376, 2357 and 2265 kg/m^3, respectively, values that can be considered within the normal range. These density values are in agreement with those obtained by other authors [7,26,27]. For example, Ahmad et al. [26] found a decrease in density in concrete incorporated with jute fibers, obtaining a density of 2300 kg/m^3 for the samples with 2% SCBF. The authors attribute this to the fact that the incorporated fibers trap more air in the concrete than the control samples. Also, Ahmad et al. [28] found a decrease in density when coconut fiber was incorporated in concrete, reducing up to 2.6% compared to the control when incorporating 2% SCBF.

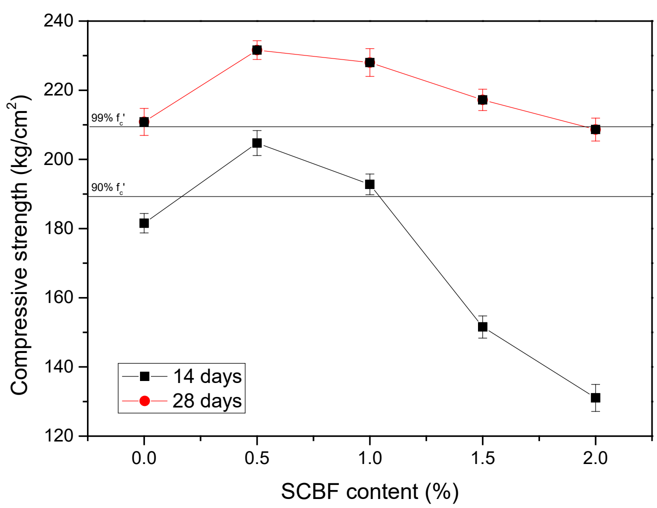

Fig. 6: Compressive strength of concrete specimens incorporated with SCBF at 14 and 28 days of curing.

The results of the compressive strength test of the specimens at 14 and 28 days of curing are shown in Fig. 6. It can observed that the compressive strength of the concrete increased with increasing curing ages. The test also showed a significant increase with the incorporation of 0.5% SCBF which is then reduced with further addition of fibers. The compressive strength is improved by a maximum of 9.8% compared to the reference concrete at 28 days of curing, with value of 231.6 kg/cm^2 (22.7 MPa). It is observed that the incorporation of sugarcane bagasse fibers to the concrete increases its compressive strength, however, as more fiber is added this strength begins to decrease.

As reported by some authors, adding fiber to concrete up to a particular percentage increases the compressive strength of the concrete [8,16,21,23]. Kiamahalleh et al. [22] found that the addition of 2% and 3% of sugarcane fiber improves the compressive strength of concrete by 5% and 16% respectively. This is due to the reduction in the number of pores caused by the incorporation of the fibers. In addition, sugarcane fiber has been used in the manufacture of low-density concrete. For example, Madhwani et al. [29] managed to improve the strength of cellular concrete by adding 1% of sugarcane fiber, while Mydin et al. [30] did so with 4% of fiber. On the other hand, Khalid et al. [12] found improvements in the compressive strength for concrete mixtures incorporated with sugarcane fibers, being the sample with 0.5% of added fiber the one that presented the highest compressive strength in 28 days of curing with 21.3 MPa. It was also reported that the greater the amount of fiber, the lower the strength. This behavior is attributed to voids in the mix and weak interfacial bonds between the fiber and the concrete matrix. The use of small diameter fibers could be a solution to this problem [18], since the increase in the aspect ratio of the fiber causes the strength to decrease due to the lack of fluidity [31]. In addition, it seems that the speed at which the fibers are incorporated and a poor distribution of the fibers in the mix could also limit the compressive strength of the concrete [26].

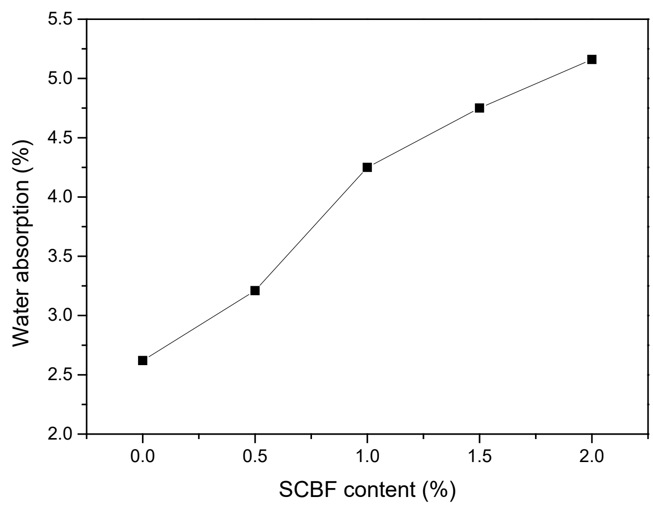

Fig. 7: Water absorption of the SCBF-incorporated specimens after 28 days of curing.

Fig. 7 shows the water absorption of concrete incorporated with sugarcane bagasse fiber after 28 days. The results show an increase in the water absorption capacity with the increase in incorporated fiber. The highest amount of absorption was determined at 5.16 % with the incorporation of 2% SCBF and the minimum amount at 2.62% for the plain concrete. This behavior can be attributed to the fact that the fibers absorb more water in the concrete than the plain concrete [26]; in addition, to the creation of connections between the microcracks and pores of the concrete [32]. These results are in agreement with those obtained by other authors [22, 26,33], for example, Jamshaid et al. [14] found an increase in the water absorption capacity when incorporating different types of natural fibers in concrete, with an approximate 6.7% water absorption when incorporating 2% of sugarcane fiber.

4. Conclusion

The effect of incorporating sugarcane bagasse fiber in concrete on its physical and mechanical properties was studied. studied. It was observed that the increase in SCBF lightens the concrete, reducing its density by up to 7% compared to the the control concrete. The water absorption capacity was increased up to 5.16% with the incorporation of 2% SCBF. Scanning Scanning electron microscopy analysis showed a good integration of the fibers in the concrete matrix, and it was observed observed that the incorporation of SCBF produces a reduction in the number and size of pores. While the results of the compressive strength test show that the incorporation of SCBF improves this property, reaching a maximum value of 231.6 kg/cm^2 (22.7 MPa) with the addition of 0.5% SCBF in 28 days of curing, this effect is reduced by increasing the fiber content. This research demonstrates the potential of the manufactured material, while taking advantage of waste from the sugar industry. However, it is recommended to study other properties of the material to delve deeper into the research.

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