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Characterization of Mixed Mortars with Partial Replacement of Sand with Sugarcane Bagasse Ash (SCBA)

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Abstract

This paper analyzes the effect of partial sand replacement by sugarcane bagasse ash in mixed mortars utilizing a 1:2:9 mix proportion by volume for cement, lime and fine aggregate. The ash is characterized by its particle distribution, pozzolanic activity, chemical composition, bulk density, moisture content and loss on ignition. The mortars are then produced with a constant water/cement ratio of 2.64 and a partial replacement of sand with sugarcane bagasse ash using different substitution percentages (0%, 5%, 10%, 15% and 20%). The mortars are characterized in the plastic state: water retention, bulk density and air content, and in the hardened state: capillary coefficient, tensile strength by bending test, axial compressive strength and flexural and longitudinal Young's modulus. The statistical analysis of the results showed that the ash can be incorporated into mortars without causing significant alterations in its properties.

Keywords

Mortars, Sugarcane Bagash Ash

1. Introduction

The construction industry is undoubtedly essential to a nation's growth, playing a vital role within society by fulfilling its infrastructural needs (Ibrahim, Roy, Ahmed & Imtiaz, [1]). However, the fulfilment of these needs has been consuming the natural resources of Earth at a relentless pace due to the manufacture of an enormous amount of material. Sand and cement are widely used in the construction industry and their feedstock needs to be extracted from the soil through mining. The literature (Brown & Lugo, [2]) posits that the extraction of such

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feedstock generally induces detrimental impacts on the environment and results in long term environmental degradation. The degraded areas no longer present the ability to replace the soil's organic matter, nutrients, biomass and propagules stock, altering the biological, physical and chemical characteristics of the explored site, making the soil sterile.

The best way to reduce the reliance on these resources and to conserve the environment, is by adopting alternative solutions, such as the use of industrial waste as feedstock (Alwaeli, [3]), which can reduce the demand of natural resource extraction in addition to allowing for the potential discovery of materials with similar or even superior properties.

The large amount of industrial waste produced all over the world results in an extreme need for recycling, not only due to the raise on landfills disposal cost which reflects on the product cost, but also as a consequence of zero waste initiative, which should be the final aim of every future human activity (Faraone, Tonello, Furlani & Maschio, [4]).

The waste incorporation as an alternative solution has shown satisfactory results in the literature, especially the utilization of sugarcane bagasse ash within the construction business (González-López *et al.*, [5]; Chen, Sun, Gau, Wu & Chen, [6]; Lima, Varum, Sales & Neto, [7]; Souza, Teixeira, Santos, Costa & Longo, [8]; Akram, Memon & Obaid, [9]; Cordeiro, Toledo Filho, Tavares & Fairbairn, [10]). Previous studies analyze the characteristics of the ash and its possible application in constructions through additions and partial replacements of aggregate and binders in concrete, cement paste, mortars, ceramic materials and soil blocks.

Sugarcane bagasse is the main byproduct of sugarcane processing, which is widely utilized as boiler's fuel in order to generate energy and such process generates waste such as bottom and fly ash. Considering that in the 2013/2014 harvest season around 652 million tons of sugarcane were crushed and that all bagasse was used to generate energy, then approximately 3.9 million tons of sugarcane bagasse ash were produced (Conab, [11]).

A portion of this amount of ash returns to canebrake soil, even though it is a nutrient poor material with a difficult deterioration and it may contain heavy metals which can contaminate aquifers and the soil. The literature highlights that this practice is common amongst sugarcane farmers and it is considered environmentally friendly, however it seems that the use of pesticides is ignored; the combination of ash, filter cake and vinasse with pesticides is highly prejudicial to the soil (Sales & Lima, [12]). When the ash is not properly disposed of, it can cause contamination of adjacent terrains, aquifers and can create health issues, resulting in severe social and environmental problems. Thus, since this waste does not have another use, the best option is to dispose of it in landfills (Frías, Villar & Savastano, 2011). The need for reducing the areas utilized for this waste's disposal adds to the need to reduce the environmental impacts caused by it. This paper seeks to assist in this effort by analyzing the effects of the partial replacement of sand with sugarcane bagasse ash in mortars utilizing a 1:2:9 mix proportion by volume for cement:lime:fine aggregate. Firstly the ash was characterized to obtain its physical and chemical properties and then the bottom ash was used as a partial sand replacement at 5 different percentage values.

2. Materials and Methods

2.1. Materials

Cement, lime, fine aggregate, bottom sugarcane bagasse ash and water were utilized to produce the mixed mortars. The cement used was Portland, class 32 (CP II Z-32), fabricated in the state of Parana, Brazil. The material presented a bulk density of 2.97 g/cm^3, initial and final curing time of 290 - 363 (h:min) respectively and Blaine surface area of 3526 (cm^2/g). The lime was the hydrated CH III type of the brand Mottical, made in the state of Parana; its bulk density was 2.60 g/cm^3 and its Blaine surface area was 1314 (cm^2/g). The sand used as fine aggregate was obtained in the city of Maringa, Parana and presented a bulk density of 2.64 g/cm^3 and a fineness modulus of 2.91.

The ash was obtained from a sugar plant located in the south of Brazil, (**Figure 1**), collected from the boiler's bottom and transported in plastic bags. Prior to the characterization procedure of the ash, the material was sieved with a 0.6 mm sieve in order to remove leaves and any portion of bagasse that was not completely burnt.

2.2. Mix Design

For the experimental procedure a 1:2:9 mix proportion by volume for cement:lime:fine aggregate was chosen

Figure 1. Bottom ash in a sugar plant.

and, in order to facilitate the mortar's production process, the mix was converted to mass proportion.

The mix proportion by mass (kg), a total of 2.5 kg of dry components was chosen, according to the recommendation of NBR 13,276 [13] and afterwards the fine aggregate was replaced by the SCBA, as is shown in **Table 1**.

To obtain the necessary water volume, a consistency index of 260 ± 5 mm (NBR 13276 [13]) was used, resulting in a water/cement ratio of 2.64. As the sand replacement with SCBA caused a reduction in the mortar consistency due to the fineness and high specific surface area of the ash, it was necessary to add the Sika Viscocrete 20HE superplasticizer to improve the workability of the M3 and M4 mortars, once their consistency indexes were not within the stipulated range.

2.3. Fabrication of Mortars

A laboratory mixer was used to mix the mortar's components; firstly, the dry materials, except the cement, were added to the bowl followed by the water; then the components were mixed at a low velocity for 4 minutes. The mass of the mortar was measured and then it was stored for 16 to 24h (NBR 13276 [13]). After this maturation interval, the mixture had its mass obtained to verify the water loss by evaporation and afterwards the cement and the water replacement were mixed to the mortar for another 4 minutes at a low velocity.

3. Methods

3.1. SCBA Characterization

The SCBA particle size distribution was obtained by the combination of sieve analysis and sedimentation (NBR 7181 [14]). The pozzolanic activity was assessed by the Chapelle Method modified by Raverdy *et al*. [15], NBR 15895 [16]. The bulk density of the ash sample was determined using the procedure described within the NBR 6508 [17]. To obtain the moisture content of the ash sample, firstly its mass was measured, then it was kept in a drying oven for 24 h and, afterwards, the mass of the dry sample was obtained (NBR NM 24 [18]). The loss on ignition was determined through the sample's calcination in a muffle furnace using a temperature of 950˚C ± 50˚C during 50 minutes (NBR NM 18 [19]). To obtain the chemical composition of the samples the X-ray Rigaku spectrometer was utilized, with a Pd Kα radiation, a current of 1.2 mA and a voltage of 40 kV. The contaminants present in the ash were analyzed through leachate (NBR 10005 [20]) and solubilized (NBR 10006 [21]) samples analysis and compared to the Brazilian range limits (NBR 10004 [22]); to obtain these results an Atomic Absorption Spectroscopy (EAA 52 VarianSpectraa-240FS) and an Ion Chromatograph (Metrohm–850 Professional IC) were used. In order to know the microstructure of the SCBA, a sample was analyzed with a scanning electron microscope (SEM), this experiment took place at the Central Complex of Research Support (COMCAP) of the State University of Maringa (UEM).

Table 1. Mix composition for 2.5 kg of dry components.

Mortarsformulation	Replacement percentage (%)	Materials Cement (g)	Lime (g)	Sand (g)	SCBA (g)	Water (ml)	Superplasticizer (ml)
M0	0	176	217	2107	0	365	0
M1	5	176	217	2002	105	365	0
M2	10	176	217	1896	211	365	0
M3	15	176	217	1791	316	365	0.2
M4	20	176	217	1686	421	365	0.2

3.2. Mortar Characterization

In order to characterize the mortars, experiments in the plastic and hardened state were carried out.

For the plastic state properties such as water retentivity (NBR 13277 [23]), bulk density and air content (NBR 13278 [24]) were obtained. For the hardened state several experiments were carried out; to determine the capillary coefficient (NBR 15259 [25]) the mortar's samples were cast in prismatic molds of dimensions 40 × 40 × 160 (mm) according to the NBR 13279 [26] and the masses of the samples were measured after 10min and 90min. The tensile strength obtained by bending tests (NBR 13,279 [26]) counted on the application of a uniformly distributed load in the cross section located at the center-point of the prismatic sample which was simply supported (**Figure 2(a)** and **Figure 2(b)**). Using the halves of the fractured samples, the axial compressive strength of the hardened mortar was tested. The flexural and longitudinal Young's modulus were determined according to the ASTM E 1876-09 (Astm [27]) using an impulse excitation of vibration in either longitudinal (E long) (**Figure 3(a)**) and flexural (E flex) (**Figure 3(b)**) modes. For the experiment, mortar cylinder samples with a diameter of 5cm and a height of 10 cm were casted according to the ABNT NBR 7215 [28].

The parameters adopted for the hardened state experiments included laboratory conditions such as air temperature of (23 ± 2)˚C and relative humidity of (60 ± 5)% and curing time of 48h.The samples were tested when they were 28 days old.

4. Results and Discussion

4.1. SCBA Characterization

The grain size distribution curve of the SCBA, shown in **Figure 4**, reveals that 51% of the sample was retained in the sieve with diameter of 0.06 mm and passed the 0.2 mm and according to the NBR 6502 [29] classification, this means that the ash could be compared to a fine sand. The sample presented a small variation in the diameter values, indicating uniformity of the particles.

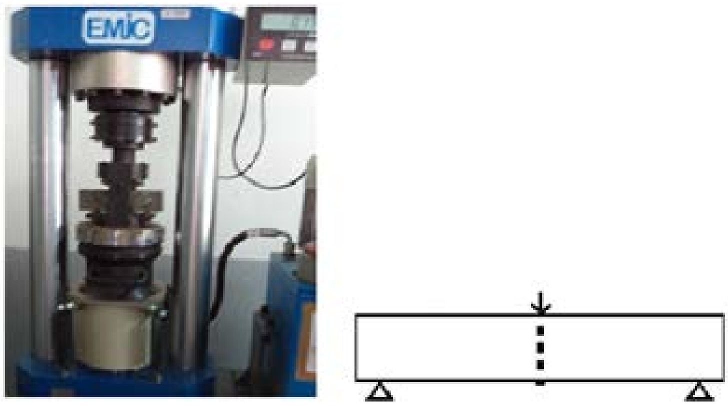
The analysis of the SCBA pozzolanic activity showed a low concentration of calcium hydroxide per gram of ash (101 mg $Ca(OH)_2$/g), meaning that the sample did not present relevant pozzolanic activity, as it is shown in the report of the experiment, which was carried out in the Technological Research Institute (IPT-SP).

The SCBA bulk density (2.75 g/cm³) was similar to the sand result; this outcome was already expected as previous research which used ash from four different plants all presented bulk density results similar to the fine aggregate, around 2.65 g/cm³ (Sales & Lima, [12]).

The SCBA moisture content was 0.16% and the loss on ignition was 9.56%; the literature brings a similar value of 10% for the loss on ignition in previous studies (Agredo, Gutiérrez, Giraldo & Salcedo, [31]). It is important to highlight that the slight difference between values can be justified by the amount of organic matter present in the ash.

The chemical composition of the ash samples can be observed on **Table 2**, which shows are levant presence of silica (57.41%) and a lower percentage of iron oxide (21.79%). When these results are compared to previous studies, it was noticed that the ash analyzed in this paper presented a smaller amount of silica, once percentages as high as 66% were found (Frías, Villar & Savastano, [32]). This variation could be attributed to differences between soils, fertilization methods, burning method of the bagasse and others.

The solubilized sample analysis indicated the presence of heavy metals in the SCBA, which exceeded the limits of the Annex G of the NBR 10004 [22], as it is shown on **Table 3**. Using the Annex F of the same code, it



(a) (b)

Figure 2. (a) Equipment used for experiments; (b) Load point for the determination of the tensile strength by bending test.

(a) (b)

Figure 3. (a) Longitudinal (E long); (b) Flexural (E flex) Young's modulus.

Table 2. Chemical composition of the SCBA.

Element	Chemical Formula	Concentration (%)
Si	SiO_2	57.41
Fe	Fe_2O_3	21.79
Ti	TiO_2	6.41
Al	Al_2O_3	4.31
K	K_2O	4.05
Ca	CaO	1.96
P	P_2O_5	1.14
Mg	MgO	1.03
V	V_2O_5	0.72
Cl	Cl	0.46
Mn	MnO	0.37
S	SO_3	0.25
Zr	ZrO_2	0.11
Cu	CuO	-
Zn	ZnO	-

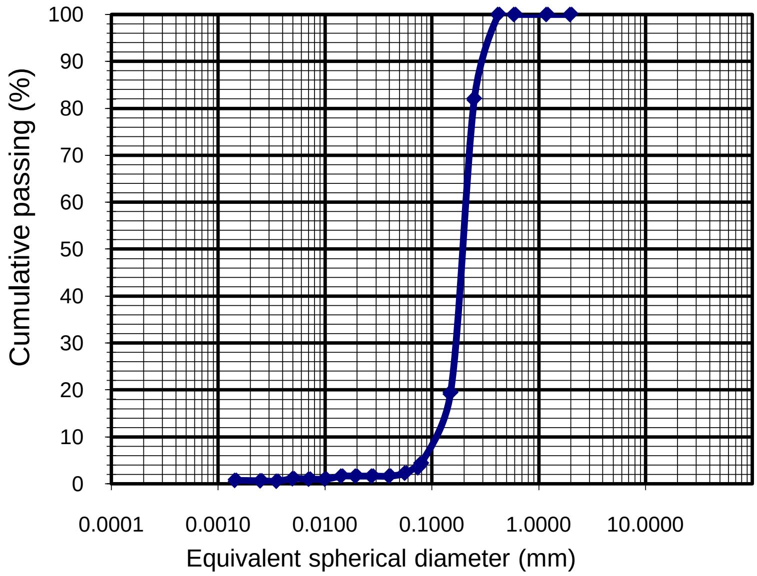


Figure 4. Particle size distribution of the SCBA, Castro [30].

Table 3. Chemical elements found in the solubilized sample of SCBA whose concentration exceed the limits of Brazilian codes.

Components	Limits (mg/l)	SCBA
Aluminum	0.2	0.79
Lead	0.01	0.12
Cadmium	0.006	0.005
Manganese	0.1	0.02

was possible to observe that the leachate sample analysis results were within the limits stablished for organic compounds. Thus, the SCBA sample could be classified as a "non-hazardous waste-class II A-non-inert" (NBR 10004 [22]) which means that the ash may present properties such as biodegradability, combustibility or water solubility. Previous studies presented the same ash classification (Sales & Lima, [12]).

4.2. Mortar Characterization

Through the analysis of the water retentivity results, it was possible to observe that, even though the sand replacement with SCBA reduced the consistency of the mortar, it increased the mortar's ability of retaining water (**Figure 5**). This is considered a positive improvement as a higher water retentivity would reduce water loss from the mortar to absorbent surfaces, allowing the complete hydration of the cement and the lime. In addition, this characteristic could influence the available time to apply and regularize the mortar, it could also improve its performance. Finally, the water retentivity could affect properties on the hardened state due to its influence in the binder's reaction during the curing.

The sand replacement with SCBA also caused a raise in the bulk density of the mortars M1 and M2 when compared to M0 (**Figure 6**). This increase could be explained by the higher bulk density of the ash in comparison to the fine aggregate and by the filling of the voids between sand grains with ash grains. It is important to highlight that the decrease of the bulk density of M3 could be related to the addition of superplasticizer, which aid the incorporation of air, resulting in a lower bulk density. To reinforce the pattern that the higher the sand replacement with ash the higher the bulk density, the results for M4 were superior to M3, even though both had superplasticizer addition.

As the sand replacement by SCBA increased, the air content of the mortars decreased (**Figure 7**). This could be explained by the filling of the voids between sand grains with ash grains, avoiding the entrance of air. The air

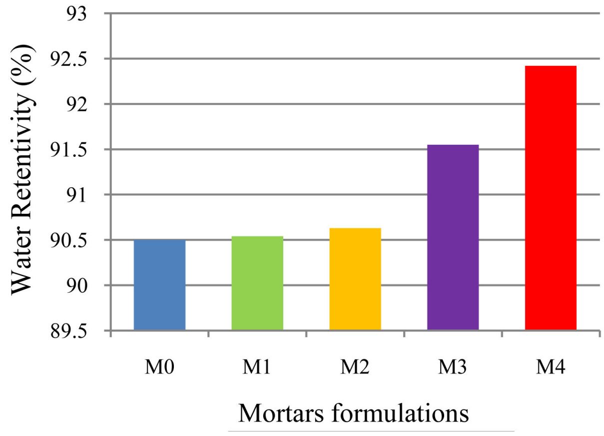


Figure 5. Water retentivity of the mortars.

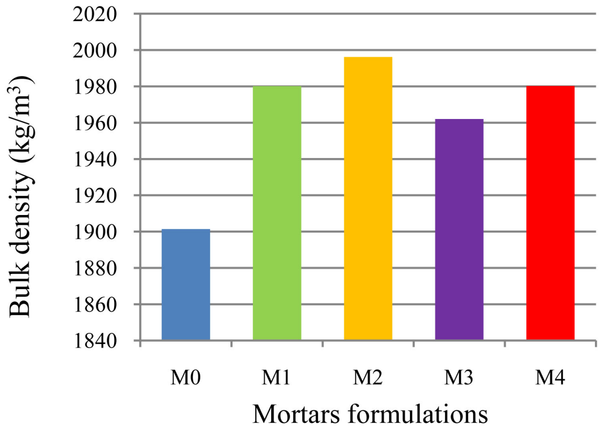


Figure 6. Bulk density of the mortars.

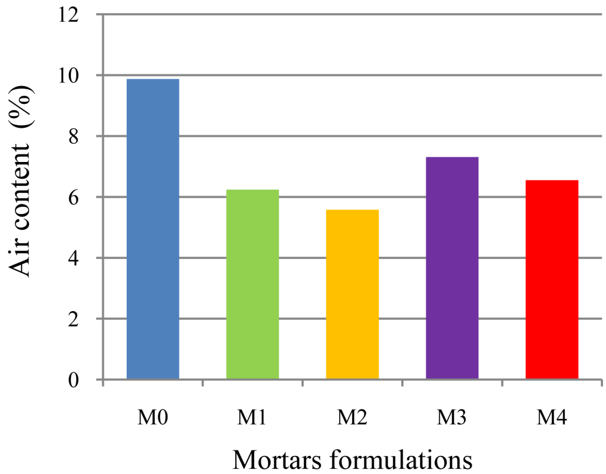


Figure 7. Air content of the mortars.

content increased in the mortar M3 due to the addition of superplasticizer which is responsible for air incorporation. When the mortar M4 is compared to the M3, it is possible to observe a reduction in the air content, which could indicate an excess of fine material.

The presence of SCBA caused a slight rise in the water absorption, turning the mortar into a more permeable material (**Figure 8**). The permeability in plastering mortars can influence the protection level that this material will provide against weather variations and condensation in the walls. It is supposed that this increase happened because of the high porosity of the mortars with the ash, resulting in a higher water absorption due to capillary action.

The axial compressive strength results of all the mortars with sand replacement with SCBA were higher than the one found for M0 (**Figure 9**), while only the mortars M1 and M2 presented a growth of the tensile strength by bending test results in comparison to the M0. Both axial compressive strength and tensile strength by bending test are important properties for a plastering mortar, however, a low tensile strength by bending test could cause a higher impact in other properties and cause pathological manifestations such as cracking. The overall increase of the strengths could be connected to the decrease of the workability and the air content and the raise of the bulk density of the mortars.

The flexural and longitudinal Young's modulus of the mortars M1 and M2 were slightly higher than the M0 (**Figure 10**); this property influences directly the mortar's ability of mortars, absorbing deformations. Similarly to the previous results, it was observed a decrease of this property for the mortar M3, followed by an increase for the mortar M4, possibly due to the fact that both mortars presented the same quantity of superplasticizer but M4 had a higher quantity of ash.

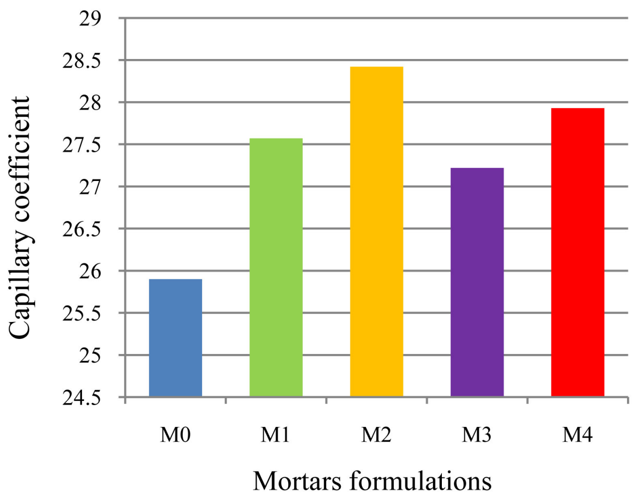


Figure 8. Capillary coefficient of the mortars.

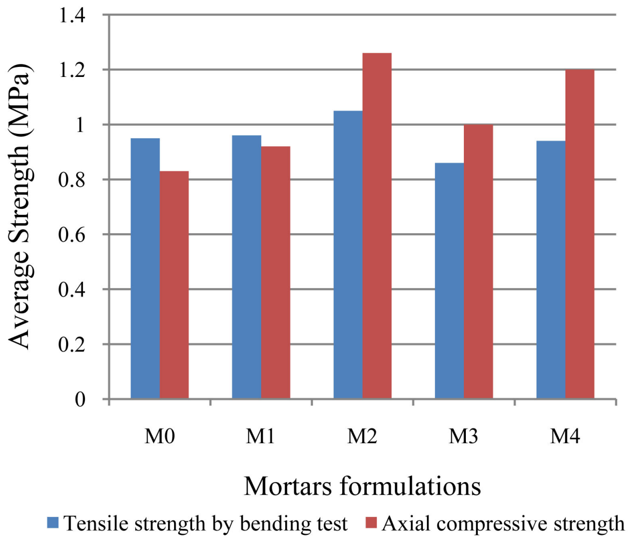


Figure 9. Average strength of the mortars.

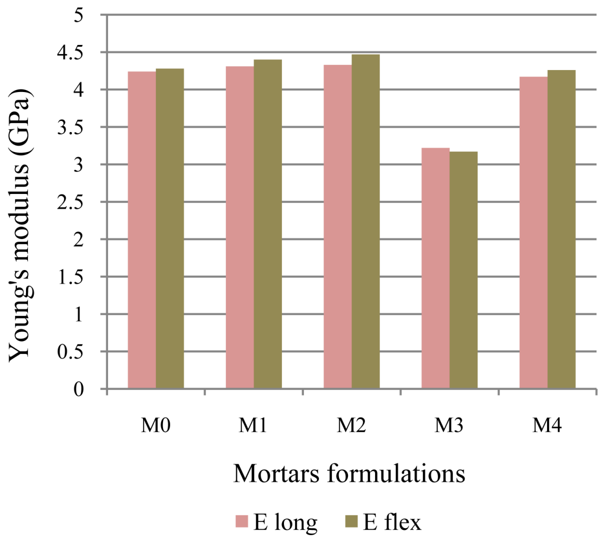


Figure 10. Young's modulus of the mortars.

5. Conclusions

The employment of sugarcane bagasse ash for the production of mortars seems to be an interesting waste utilization, resulting in a reduction in the need for disposal areas for the ash, reducing the utilization of sand and the environmental impact caused by your extraction.

- The partial sand replacement with SCBA caused a decrease in the mortar workability, however it was corrected by the utilization of superplasticizer.
- The SCBA use showed advantages such as the increase of water retentivity and the bulk density; the latter improvement caused an increase of the strengths as well.
- It was observed as a disadvantage, the slightly raise of the mortars permeability due to a higher porosity caused by the waste presence.
- The utilization of superplasticizer caused a reduction in the strength results; however its presence improved the workability and reduced the permeability and the Young's modulus.

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