IC-NOCMAT 2007 Maceió

International Conference on Non-Conventional Materials and Technologies:
Ecological Materials and Technologies for Sustainable Building
Maceió, Alagoas, Brazil, 14th-17th October 2007
In Honour of Professor R.N.Swamy

MECHANICAL PROPERTIES AND DURABILITY OF MORTARS CONTAINING ULTRAFINE SUGAR CANE BAGASSE ASH

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Abstract: Recent researches have shown the high potentiality of the use of sugar cane bagasse ash (SCBA) as mineral admixture in mortars and concretes. The SCBA is a by-product of sugar and alcohol industry, and it presents different physical-chemical characteristics according to bagasse characteristics and burning conditions. The mechanical grinding of the particles is an alternative to offer homogeneity to the ash's physical characteristics. In this work, the bagasse ash's grinding was carried out in a semi-industrial production. It was used a hammer mill with dry operation in closed circuit. The ultrafine ash produced was used as partial substitute of the Portland cement in mortars with water-cementations material ratios (w/c) of 0.5. The mortars produced had 0%, 10%, 20% and 30% of ash as cement replacement, in mass, and the properties analyzed were (1) workability with the flow table test; (2) axial compressive strength at the ages of 1, 7, 14, 21 and 28 days; (3) total water and capillary absorptions after 28 days of curing; (4) pore size distribution at the age of 28 days; (5) gas permeability at the ages of 1, 7, 14, 21 and 28 days; and (6) pore size distribution. The results indicate that the grinding operation is an efficient method to produce sugar cane bagasse ash. Besides that, the results indicate that the mortars with sugar cane bagasse ash as admixture show positive effects in both mechanical properties and durability, when compared to those from the reference mixture. Therefore, the SCBA is a promising mineral admixture for use in concrete, mortars and pastes.

Keywords: *sugar cane bagasse ash; grinding; mortar; mechanical properties; durability.*

1. INTRODUCTION

The sugar cane is a plant originally from Meridian Asia and it is typically cultivated in countries that have tropical and subtropical climate, in order to obtain sugar and alcohol [1]. The sugar agro industry is the oldest economical activity in Brazil [1]. Nowadays, this country is recognized world widely as the major producer of sugar cane and its products, being responsible for a production of 455 million tones in 2006 [2]. During the processes of sugar and alcohol productions, many residues are generated, that are already being reused nowadays. The use of these by-products that stands out is at the production of energy by the burning of the bagasse, due to the great amount this material that is generated and to its low calorific power of 7,74 MJ/kg, with humidity of 50% [3]. About 95% of the bagasse produced is burnt in order to produce energy, by generating steam [4]. Therefore, a great amount of sugar cane bagasse ash (SCBA) is generated during the production of energy.

The SCBA is composed basically by silica (SiO_2). For this reason, this by-product is a potential mineral admixture to be used in concretes. Since the SCBA does not present many nutrients and it is hard to be degraded [5], there isn't a specific destination for this material. Searching ways of reusing this by-product, many researches were carried out, using the SCBA as admixture in pastes [6-8], mortars [9] and concretes [10-11]. Generally, the ash presents pozzolanic properties and it changes the behavior of these materials.

This work studies the use of SCBA in mortars as parcial substitute of cement Portland, with replacement, in mass, of 0%, 10%, 20% and 30%. The mortars studied had 0.5 water-cementations material ratios (w/c). Mechanical properties and durability, namely, axial compressive strength, total and capillary absorptions, pore size distribution, gas permeability and pore structure test, besides the workability (through the flow table test), were analyzed. In order to assure better pozzolanic characteristics of the SCBA, the as-received material was submitted to ultrafine dry grinding, by the use of a hammer mill in pilot-scale closed circuit.

2. MATERIALS

The as-received SCBA sample was collected at an agroindustry that produces sugar cane and alcohol in the State of Rio de Janeiro (Brazil). Table 1 presents a summary of the physical characteristics and the chemical composition of both SCBA and Portland cement (PC) used in the mortars. Figure 1 shows the X-ray diffraction (XRD) pattern of SCBA, where the predominance of silica as cristobalite and quartz is evident. The SCBA was ground in closed circuit using a hammer mill, operating in dry mode. In this case, the grinding was performed in a pilot-scale mill operating continuously in closed circuit with a dynamic air classifier [10]. The mill operates at 2200 rpm with the classifier set for a product finer than about 30 μm. The circuit production rate was about 0.15 t/h. The Figure 2 shows the particle size distribution of ground SCBA. In the preparation of mortars, standard natural sand [12] and deionized water were also used. In the Figure 3 is possible to observe the morphological aspects of the ground SCBA from the scanning electron microscopy (SEM).

Table 1 – Physical and chemical properties of the SCBA and Portland cement

Physical properties		
Characteristic	SCBA	PC
Density (kg/m³)	2530	3170
Blaine specific surface area (m²/kg)	196	308
Median particle size, D_{50} (µm)	76.3	16.9
% Passing 45 µm	67.4	8.4

Chemical composition (wt %)		
	SCBA	PC
SiO_2	78.34	20.85
Al_2O_3	8.55	4.23
Fe_2O_3	3.61	5.25
CaO	2.15	63.49
Na_2O	0.12	0.16
K_2O	3.46	0.40
SO_3	-	2.38
MnO	0.13	< 0.05
MgO	1.65	-
P_2O_5	1.07	-
L.O.I*	0.42	1.05

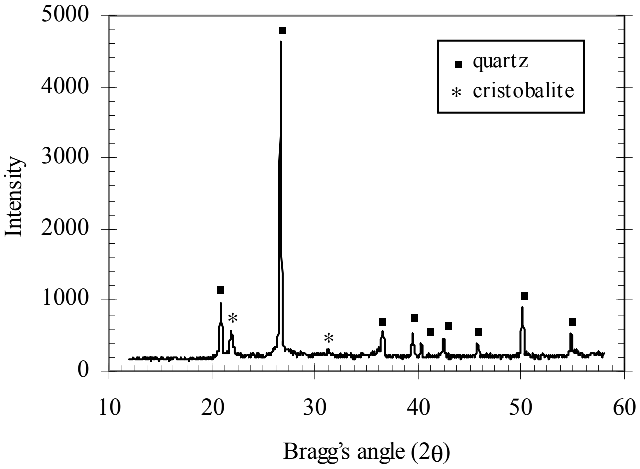


Figure 1 - X-ray diffraction pattern of as-received SCBA.

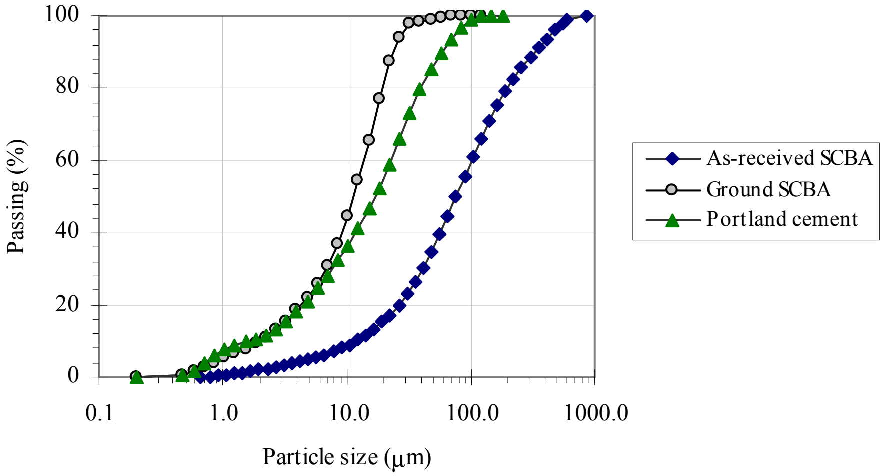


Figure 2- Particle size distribution of as-received SCBA, ground SCBA and Portland cement.

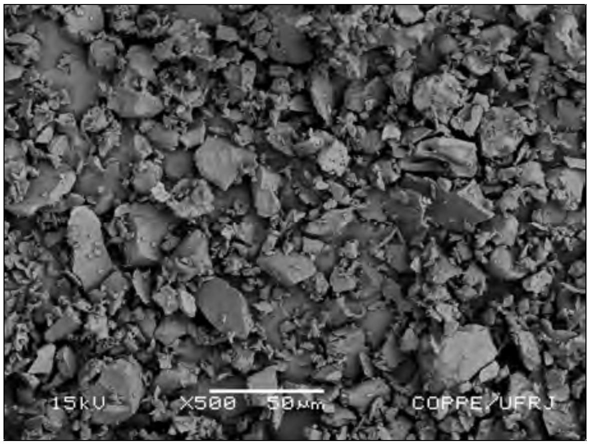
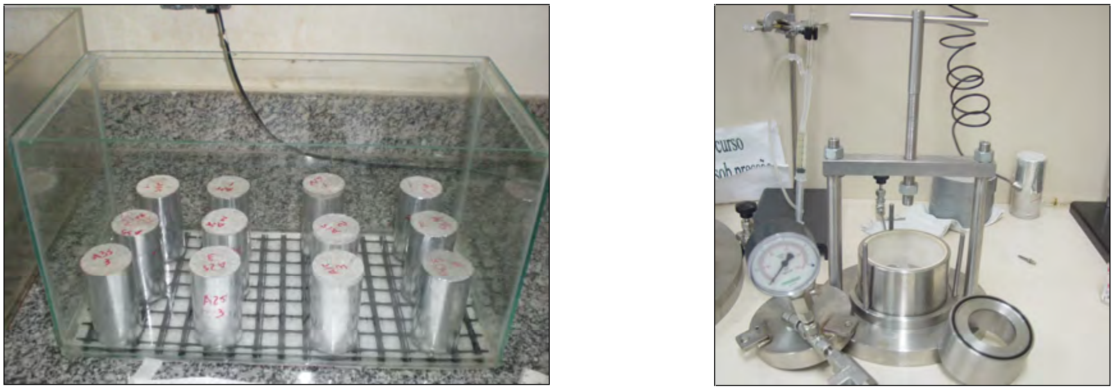


FIGURE 3 – SEM IMAGE OF THE GROUND SCBA.

3. METHODS

The mortars were produced with water-cementitous material ratios (w/c) of 0.5, and cementitious material-sand ratios of 1:3. Besides the reference mixture, with no substitution, three mixtures were produced, each with 10%, 20% and 30% of replacement, in mass, of cement for ultrafine SCBA. The flow of the mortars was determined through the flow test, according to the Brazilian standard ABNT NBR 7215 [13]. The axial compressive strength tests of the mortars were carried out at the ages of 1, 7, 14, 21 and 28 days, according to the prescriptions of ABNT NBR 5739 [14], with cylindrical specimens with 50 mm diameter and 100 mm height. It was used a servohydraulic machine, with displacement rate of 0,05 mm/min. The Young's modulus was calculated according to the ABNT NBR 8522 [15].

The durability of the mortars was investigated by total water absorption, capillary sorption, permeability and pore size distribution tests. The absorption test was carried out in accordance to the American standard ASTM C642/97 [16]. It allows calculating the absorption after immersion and the specific weight of the hardened mortar. The water capillary sorption was determined according to the test (shown in the Figure 4-a) prescribed at ABNT NBR 9779 [17]. The specimens for the absorption test were prismatic, with 50 mm width, 50 mm length and 20 mm height, whereas those used at the capillary absorption tests were cylindrical, with 50 mm diameter and 100 mm height. They all, at the age of 28 days, were dried at 40 º C in a ventilated oven until constant mass was achieved. The drying process in a lower temperature than the one suggested by the standards (105ºC) is preferred because it keeps the integrity of the hydration compounds of the Portland cement [10]. For the capillary absorption test, the specimens had their sides covered with waterproof tape, in order to maintain the direction of the flow.



(A) (B)

FIGURE 4 – WATER CAPILLARY SORPTION TEST (A) AND GAS PERMEAMETER USED IN THE STUDY (B).

Although permeability is an important property, there is not a standard test to determine it. At the present study, it was used the procedure proposed by Cabrera & Lynsdale [18]: the specimen is placed inside of the permeameter, shown in Figure 4-b, and a gas flow is forced, vertically, through the mortar. The gas used is nitrogen. Through the modified Darcy's law (for compressible fluid) – Eqn. 1, it is possible to obtain the intrinsic permeability (k) of the material.

$$k = \frac{2\,\eta\, Q\, h \cdot P_2}{A\left(P_1^2 - P_2^2\right)} \qquad (1)$$

Where η - fluid's (nytrogen) viscosity (Ns/m²)
Q - flow rate (m³/s)
h - specimen's height (m)
A - specimen's cross-sectional area (m²)
P_1 - upstream pressure (N/m²)
P_2 - downstream pressure (N/m²)

The Darcy's law is only applied when the flow is one-directional. In order to have this condition covered, it is essential that the specimen has its sides sealed. Therefore, the specimens had their sides covered by aluminum adhesive tape and they were placed inside of a silicon rubber ring, when put inside of the permeameter. During the test, the flow rate is measured by the use of a flowmeter and a chronometer. The intrinsic permeability is obtained from this value. The specimens were cylindrical, with 50 mm diameter and 25 mm height, and they were dried at the same conditions as those used at the absorptions tests.

The pore structure test was carried out using an Autopore II 9215 mercury intrusion porosimeter. In order to obtain the equivalent pore radius (r), the Washburn's equation (Eqn. 2) is used. The samples were cut from cylinders, with 50 mm diameter and 25 mm height, that were previously dried as the samples used at absorptions tests.

$$k = \frac{-2\gamma \cos\theta}{P} \qquad (2)$$

Where γ - surface tension (assumed to be 0.483 N/m)

θ - contact angle between mercury and pore wall (assumed to be 130º)
P - net pressure across mercury meniscus at the time of cumulative intrusion measurement

4. RESULTS AND DISCUSSION

As result for the flow table test, the reference mixture and the one with 10% of cement replacement for SCBA presented the same value, 200 mm; whereas the mixtures with 20% and 30% of replacement presented, respectively, flows of 203 and 204 mm. It is possible to observe an increase of the mortars's flow with the increase of the addition of the SCBA. This behavior can be explained by the contamination of the ash by quartz (from the sand), which allows better movement amongst cement grains [10].

The typical stress-axial strain curves obtained after 28 days of curing for mortar are shown in F igure 5. For the Young`s modulus, the reference mixture presented the value of 29.7 ± 3.1 GPa, whereas the mixtures with 10%, 20% and 30% of SCBA presented, respectively, 26.9 ± 3.4 , 24.6 ± 5.7 and 26.3 ± 3.6 GPa. The Figure 6 shows the evolution of compressive strength of the mortars as time goes by. At the first day, the compressive strengths are practically the same. After this age of curing, the replacements up to 20% of cement for SCBA do not present significant changes at the compressive strengths; while the mixture with 30% of SCBA stands out, presenting lower values of compressive strength.

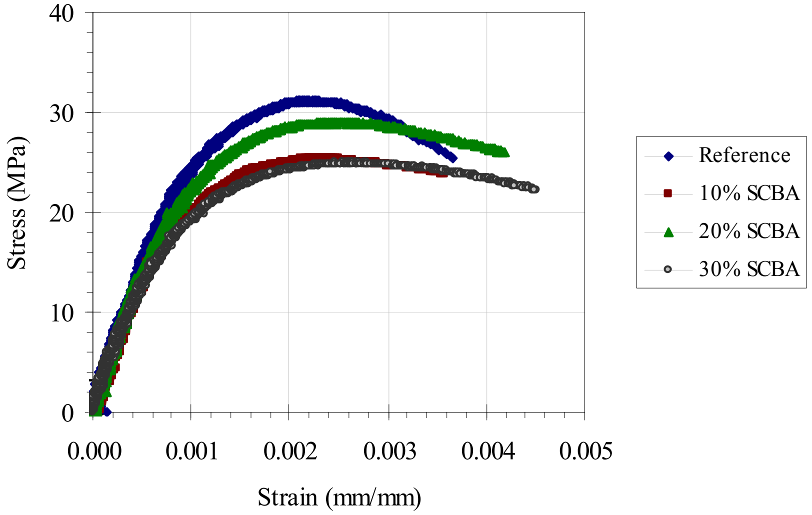


FIGURE 5 – TYPICAL STRESS VERSUS STRAIN CURVES OF REFERENCE AND SCBAS (10%, 20%, AND 30%) MORTARS AT THE AGE OF 28 DAYS OF CURING

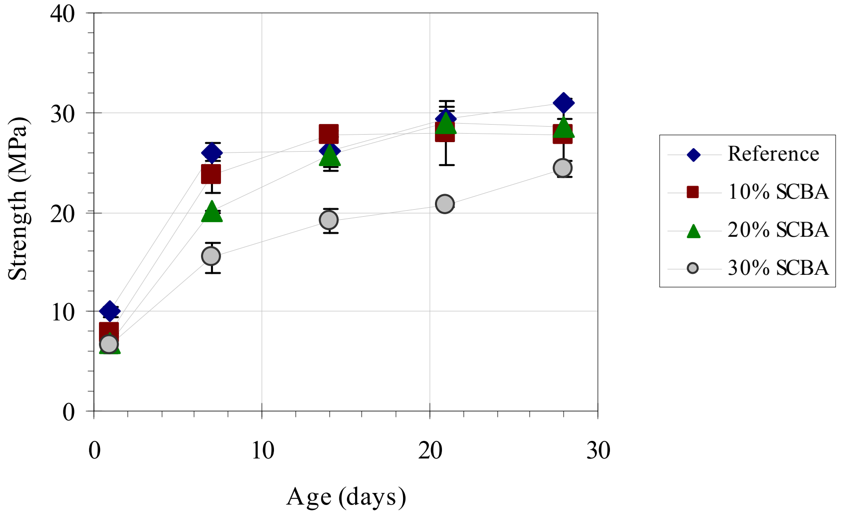


FIGURE 6 – EVOLUTION OF COMPRESSIVE STRENGTH OF MORTARS WITH CURING TIME

The results obtained from the absorption test are shown in Table 2. The substitution of 10% of cement Portland for ultrafine SCBA has positive result for the absorption, presenting a slight decrease of its value when compared to that from the reference mortar. On the other hand, the mortars with 20% and 30% substitutions present higher value of total water absorption, having the tendency of increasing as the value of substitution does it so. The values of specific weight remain practically the same, as the percentage of substitution increases. The water capillary sorption against square root of time curves of the mortars are presented in Figure 7. For the long-term capillary sorption, there are not significant differences when the SCBA mortars are compared. However, these mixtures present higher sorption than that of reference mortar. For short-term, it is possible to observe a tendency of increasing of the values of sorptivity as the amount of substitution does it so, mainly for the mortars with 20% and 30% of ultrafine SCBA. The Figure 8 presents the sorption values used to obtain the sorptvities from the linear regression.

TABLE 2 – VALUES OF ABSORPTION, SPECIFIC WEIGHT AND SORPTIVITY (STANDARD DEVIATIONS BETWEEN PARENTHESES).

Property	Reference	10% of SCBA	20% of SCBA	30% of SCBA
Total water absorption (%)	6.43 (± 0.10)	6.19 (± 0.37)	8.01 (± 0.10)	8,19 (± 0.10)
Specific weight (kg/m³)	2390 (± 22)	2391 (± 41)	2418 (± 14)	2407 (± 21)
Sorptivity ($kg/m^2t^{0.5}$)	0.646	0.648	0.768	0.925

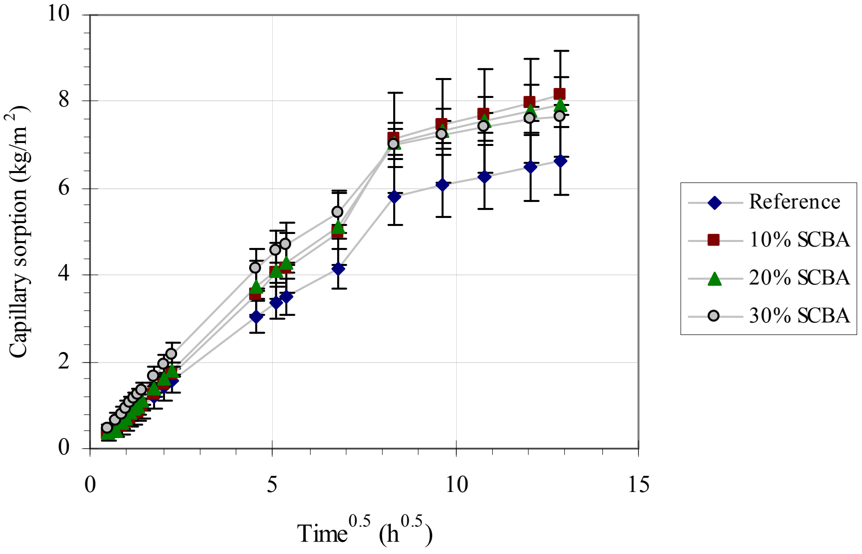


FIGURE 7 – WATER CAPILLARY SORPTION AGAINST SQUARE ROOT OF TIME FOR MORTARS.

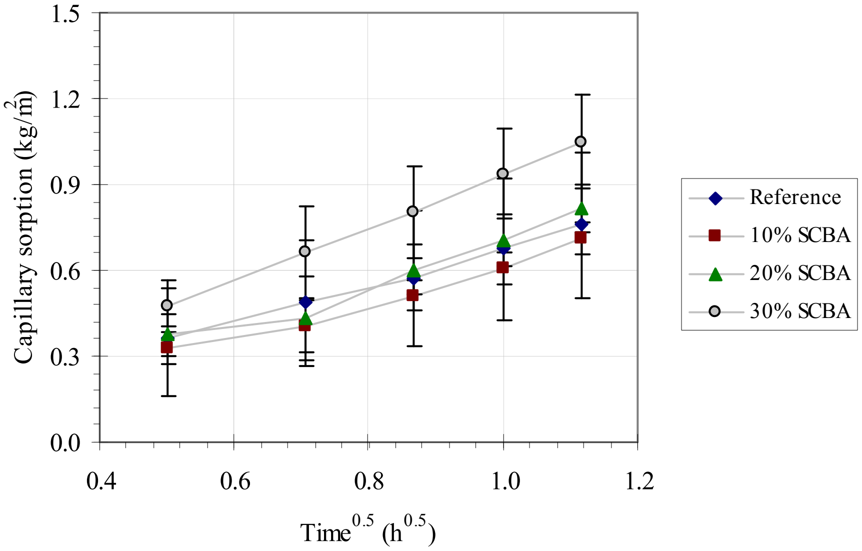


FIGURE 8 – WATER CAPILLARY SORPTION AGAINST SQUARE ROOT OF TIME FOR MORTARS AFTER 1.3 HOURS

The changes of the mortar's gas permeability are shown in the graph of Figure 9. As expected, as the specimens get older, the intrinsic permeability decreases, especially from the age of one day on. Comparing the mixtures, we can say that for the early ages, the substitution of cement Portland for ultrafine SCBA increases the intrinsic permeability, mostly for the percentage of replacement of 30%, with which it is observed a change in the degree of magnitude. It is worth noting that when analyzing the intrinsic permeability of mortars and concretes, usually, the degree of magnitude is the parameter considered, instead of the exact value. While for the early ages the mixtures exhibit increase of the permeability as the percentage of the substitution does so, at the age of 28 days, they presented practically the same permeability. The pore size distribution curves of the mortars are reported in Figure 10. The addition of ultrafine SCBA has slight effect at the pore structure. The mortars with 10% and 20% of SCBA exhibit smaller volume of pores than the reference mixture and the one with 30% of replacement. Regarding the pore size, the volume of the micropores (pore diameter smaller than 2 nm) in the 10% and 20% SCBAs mortars are higher in comparison with the reference. Nevertheless, the content of macropores (pore diameter higher than 100 nm) in these two mixtures is smaller than the other mortars. No substantial differences of pore size can be observed when the 30% SCBA mortars is compared with the reference mortar.

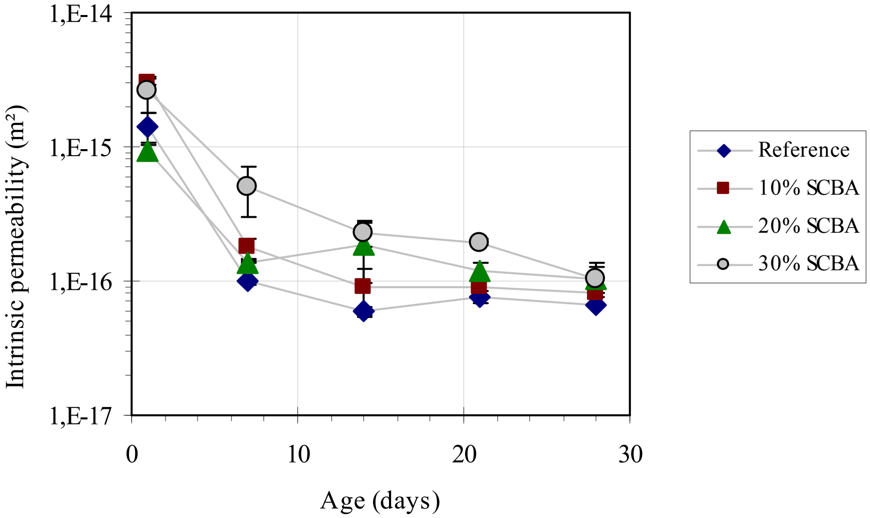


FIGURE 9 – EVOLUTION OF INTRINSIC PERMEABILITY WITH CURING TIME

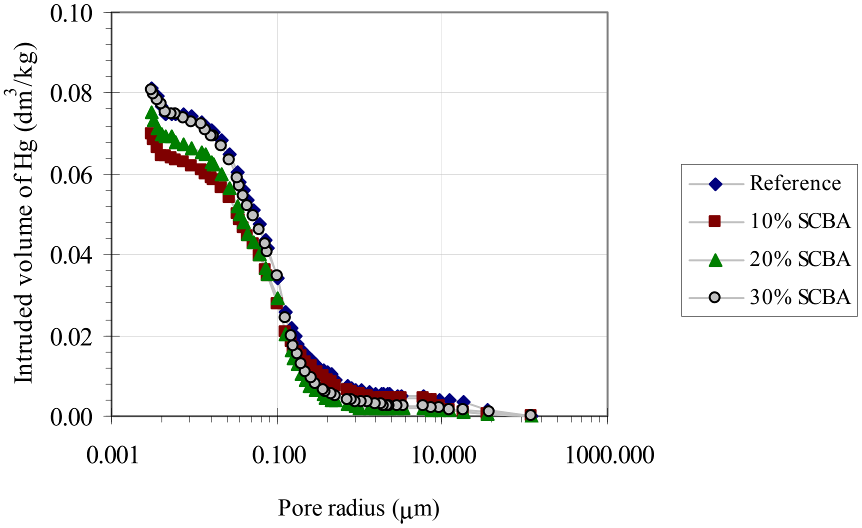


FIGURE 10 – PORE SIZE DISTRIBUTION CURVES OF THE MORTARS.

5. CONCLUSIONS

The grinding procedures applied at this study were adequate for the production of the ultrafine SCBA. In general, the obtained results indicate the possibility of substitution of Portland cement for ultrafine SCBA up to 20% without negative effects for the properties of the mortars. An improvement of the cement replacement by ultrafine SCBA was the increase of the mortars' flow. The results of compressive strength at the age of 28 days were close, except for 30% SCBA mixture. The absorption values increased with the addition of SCBA, except for the replacement of 10%, when this property was slightly improved. The water capillary sorption increased also with the substitution of cement for SCBA, when compared with the reference mixture, although, the values for all three mortars with SCBA were practically the same.

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