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Setting process on mortars containing sugarcane bagasse ash

Pega em argamassas com cinzas do bagaço da cana-de-açúcar

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Abstract

This paper presents an experimental study of the effect of partially replace of fine aggregate by sugarcane bagasse ash (CBA) in mortar mixtures in cement reactivity at early ages. The setting times and the initial development of the ultrasonic velocity for mortars produced at various water/cement ratios were evaluated. The objective of this study was to characterize the effects of the partial replacement of fine aggregate by sugarcane bagasse ash in the initial process of cement hydration. Therefore, the CBA used in this study went through different beneficiation processes, by grinding, reburning and sieving, with the objective of improve its features. The results suggest the viability of CBA use to accelerate cement hydration at early ages, with also an observed higher compressive strength.

Keywords: sugarcane bagasse ash, mortar, ultrasound, sustainability.

Resumo

Este trabalho apresenta um estudo experimental do efeito da utilização da cinza do bagaço da cana-de-açúcar (CBC) em substituição parcial do agregado miúdo em misturas de argamassa na reatividade do cimento em idades iniciais, avaliando-se os tempos de pega de misturas de argamassa com variadas relações água/cimento, assim como o desenvolvimento inicial da velocidade dos pulsos ultrassônicos. O objetivo deste trabalho é a caracterização dos efeitos da substituição parcial de agregados miúdos por cinzas do bagaço da cana-de-açúcar no processo inicial da hidratação do cimento. Para tanto, a CBC utilizada neste estudo passou por diferentes processos de beneficiamento, através de moagem, requeima e peneiramento, com o objetivo de melhorar suas características. Os resultados do estudo sugerem a viabilidade do uso de CBC em misturas cimentícias, para aceleração da hidratação nas primeiras idades e maiores resistências à compressão ao longo do tempo.

Palavras-chave: cinza do bagaço da cana-de-açúcar, argamassa, ultrassom, sustentabilidade.

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1. Introduction

Sugarcane is one of the most important crops in the world. One of its by-product is sugarcane bagasse, which is used as fuel in cogeneration boilers. Thus, the sugar and alcohol industry can be regarded as a sustainable and energy efficient sector. The burning process generates a waste known as sugarcane bagasse ash (SBA), which is abundant in silica, with a potential to develop pozzolanic activity and filling effect in concrete and mortar mixtures. Considerable amount of ashes has been produced over the years. It is expected that their production may keep rising due to ethanol growth. The SBA use as a cement or fine aggregate partial replacement in concrete mixtures reduces the environmental impacts caused by rocks exploitation, and by sand extraction. It also reduces CO2 emissions and waste disposal, as well as, the environmental impacts caused by elimination of ash on soils or on other areas. To disposal ash in sugarcane crops as fertilizer is a usual practice. It is believed that all sugarcane residues generated can be discharged through this process. However, this practice ignores agrochemicals used in crops and their permanence on soil even though this process is treated as being environmentally correct [1].

There are several works concerning the SBA use in concrete mixtures as a supplementary cementitious material incorporated as partial cement replacement [2-5]. The usual process of SBA treatment through milling and re-burning aims to increase pozzolanic activity by eliminating organic matter and increasing the amount of fine materials. However, some studies [6 -8] have reported SBA as a material with reduced pozzolanic activity; below the minimum values required by international standards. According to these studies, SBA when burnt in an uncontrolled condition and at high temperatures, shows high levels of organic matter, which indicates that it may be more appropriate to be used as fine aggregate replacement material in concrete mixtures. Cordeiro et al. [9] produced ultrafine ashes to replace part of cement in high performance concrete mixtures, reaching better rheological properties and low chloride ion penetration, with no observed decrease in compressive strength. Tantawy et al. [10] observed an acceleration effect on the setting behavior of mortar mixes with addition of SBA re-burnt in a muffle furnace at 700 ºC for 3 hours. The porosities of their mixes were also lower due to the ash pozzolanic effect. Frías et al. [11] evaluated bagasse ash after re-burnt in controlled temperature, at 400ºC for 20 minutes, and at 800ºC for 60 minutes. Similarly, Cordeiro et al. [12] found better results about pozzolanic activity when SBA was re-burnt for 3 three hours at 350ºC followed by more three hours at 600ºC.

Regardless the treatment process, due to its final granulometry, SBA can alter the cement hydration process at early ages. By filling voids between cement particles, SBA may cause a physical effect [13], which would interfere in the hardening process of concrete mixtures at early ages. The setting and hardening processes are important parameters when to define the times to transport and to vibrate concrete, to remove forms and shores, to finish the concrete surface, among others construction activities. A possible accelerator effect may bring some benefits, mainly related to deadlines and tight schedules.

Figure 1 – Bagasse waste retained in a 2.0 mm mesh sieve

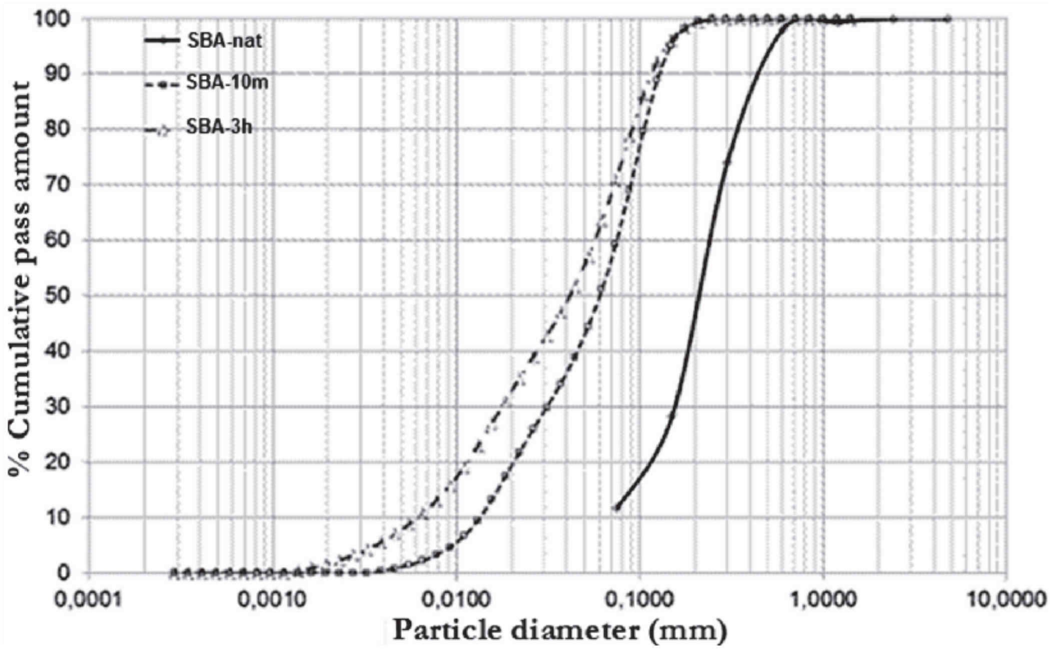
The hydration process and microstructure formation directly influence physical and mechanical properties of concrete and mortar mixtures [14]. It is possible to evaluate the early hydration process and its rate indirectly by the setting times. Initial set is related to the time when concrete changes from fluid to a solid material, while final set is defined when concrete acquires strength. [15]. ASTM C403 [16] procedure indicates the initial and final set times from the penetration resistance of mortar sieved from concrete mixtures. According to Liu et al. [17], this method is not appropriate to field application. One alternative to continuous monitor the concrete physical changes at early ages is to follow the behavior of ultrasonic waves, as cited in several studies [15, 18-20]. The development of the ultrasonic pulse velocity, UPV, in a material is directed related to the microstructure development. Stress waves, such as ultrasound, travel faster in rigid materials.

This work evaluates the effect of partial replace fine aggregate by SBA in mortar mixtures at early ages. Mortar mixtures with water/cement ratios of 0.44, 0.48, and 0.52 were produced in the laboratory. For each mixture, three different SBA treatment processes were used: grinding at a ball mill for 3 hours; grinding at a ball mill for 10 minutes; and re-burning for three hours at 300ºC followed by three hours at 600ºC. Setting times and the development of

Table 1 – Classification of ash treatments

SBA – 10m	SBA – 3h	SBA – R
Ashes ground in ball mill for 10 minutes	Ashes ground in ball mill for 3 hours	Ashes calcined for 3 hours at 300ºC plus 3 hours at 600ºC

Figure 2 – Granulometry of SBA *in natura*, SBA-10m and SBA-3h



ultrasonic pulse velocity for the first 24 hours were analyzed. The results were compared to the behavior of a reference mortar produced without fine aggregate replacement by SBA. The sugarcane bagasse ash used in this study was collected at a major sugar-alcohol industry in Parana State, which has a production capacity estimated of 4.000.000 ton of sugarcane per crop.

2. Materials and experimental program

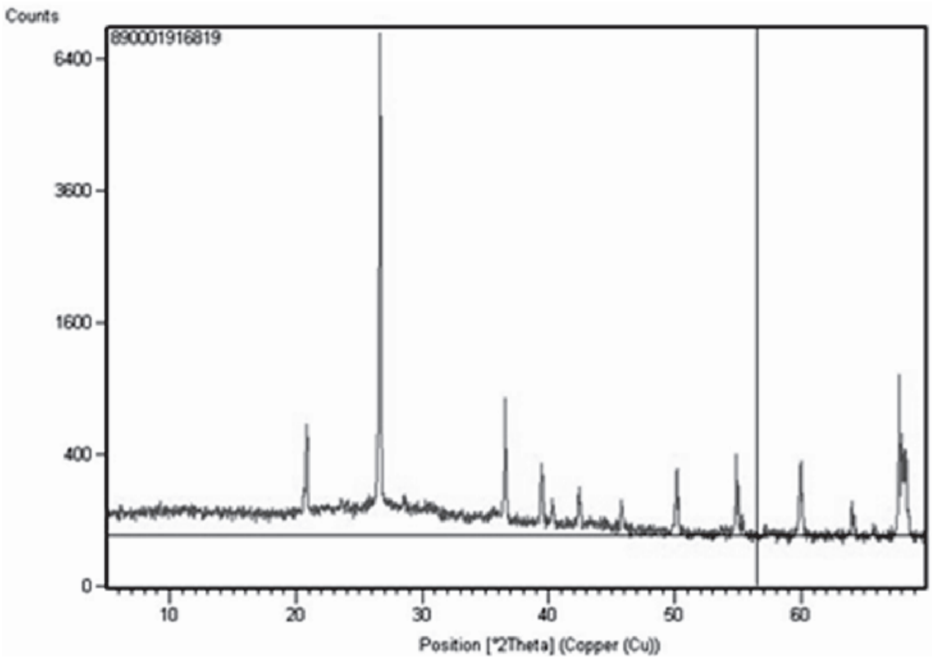
2.1 Sugarcane bagasse ash

Initially, SBA was oven-dried at a temperature of 100ºC to remove moisture, then sieved through a 2 mm mesh, in order to separate wastes of sugarcane bagasse of unburned particles during a complete combustion (Figure 1).
The resulting material was then either grinded for 10 minutes, or for three hours in a ball mill. The former treatment was used only to homogenize SBA, while the latter treatment was used to produce a finer ash. A third treatment was also evaluated, in which SBA was re-burnt in muffle oven at 300ºC followed by three hours at 600ºC, based on Cordeiro et al. [12] studies. Table 1 presents the nomenclature adopted in this work concerning the applied SBA treatments. Figure 2 presents the granulometry of raw SBA before any treatment. The raw material was only sieved through a 2 mm sieve to separate sugarcane bagasse waste (coarse and fine fibrous). Figure 2 also depicts the SBA granulometric curve after milling in a ball mill for 10 minutes and for three hours.
The chemical composition of sugarcane bagasse *in natura* is presented in Table 2. This chemical composition was determined by

Table 2 – Chemical composition of sugarcane bagasse ash *in natura*

Sample Concentration	SBA %
Na_2O	0.09
MgO	1.63
Al_2O_3	2.53
SiO_2	76.55
P_2O_5	0.69
SO_3	0.40
K_2O	1.32
CaO	1.20
TiO_2	0.53
MnO	0.008
Fe_2O_3	2.59
Co_3O_4	0.115
SrO	0.005
ZrO_2	0.015
Cl	0.027
PF	12.31
Total	100.00

Figure 3 –X-ray diffractogram SBA *in natura*



semi-quantitative analysis using X-ray fluorescence spectrometry. The loss on ignition (LOI) test was carried out to determine the percentage of non-mineral substances. LOI was also considered on X-ray fluorescence analyses.

According to the results in Table 2, 76.55% of bagasse ashes are composed by silica (SiO2). Regarding the loss on ignition, the observed value of 12,31% is well above the limit value established by ASTM C 618 [21] to be considered as a pozzolanic material (6%).

The mineral composition of SBA *in natura* was determined by X-ray diffraction technique, by using Rigaku Primini X-Ray fluorescence. The results are presented in Figure 3 and Table 3.

SBA pattern diffractogram revealed the presence of a highly crystalline quartz form (SiO2), with a band of amorphous material in phase 2Θ from 21 to 32º, as shown in diffraction pattern in Figure 3.

In addition, the level of pozzolanic activity (PA) of SBA *in natura* was determined according to pozzolanic activity test method NBR 12653 [22]. The observed results presented in Table 4 indicate that ashes samples reached a value of PA of 4.3 MPA, which is below the value of 6.0 MPa indicated by NBR 12653 [22] to be considered as a pozzolanic material.

However, after SBA processed, its potential to pozzolanic activity reaching percentage strength relative to the control mortar with the strength activity index (cement performance) of 89.4%, 87.5% and 102.3% to SBA ashes -10m, SBA-3h and sample SBA-R, respectively. Strengh activity index greater than 75% after 28 days are indicative of a positive pozzolanic activity for SBA, after treatment.

2.2 Mortar production

A mix of 58% of natural sand and 42% of artificial sand was prepared in order to be classified in the optimal zone of use, with finenesss modulus of 2.65. The maximum aggregate size was 4.75mm. Figure 4 presents the granulometric curves of natural

Table 3 – Amorphicity level of sugarcane bagasse ash *in natura*

Phase	Chemical formula	(%)
Quartz	SiO_2	75.1
Level of amorphicity (%)		24.9

Table 4 – Pozzolanic activity index of ash

Results	Sugarcane bagasse ash
IPA (MPa)	4.3
#325 (%)	1.4
Specific gravity (g/cm³)	2.45
Water (g)	215

and artificial sand, as well as the one for the final composition used (58% natural e 42% artificial).

Initially, three mixtures of reference mortar (without SBA addition) were produced with proportion, in mass, of 1:3 (cement to fine aggregates), with water cement ratios of 0.44, 0.48 and 0.52. Table 5 presents the composition of the different mixtures produced. The cement was CP V ARI (high early strength) with multifunctional high-range water reducer to achieve the desired flowability.

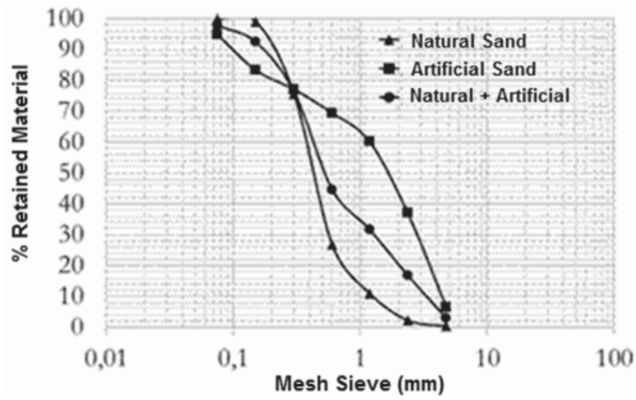
Then, the mortars with SBA addition were produced. In order to preserve the granulometric characteristics, only the fine proportion of the fine aggregates was replaced by SBA, since SBA has a large amount of fines on its composition. Thus, natural and artificial sand were passed through a 150µm sieve, after which the retained material was used while the sieved material was discharged. The fine material that passed through the 150µm mesh was about 7.5% of the total mass. This percentage was further adopted as standard for ash addition. Table 6 presents the composition of mortar mixtures with SBA.

A total of 12 different mortar mixtures were produced: three reference mixes and nine mixes as a product of the combination of three water/cement ratios (0.44, 0.48, and 0.52) and three different types of SBA treatments. Each mixture was twice prepared. For each of the 24 mixes, setting time experiments were performed as well as the development of ultrasonic pulse velocity was monitored.

2.3 Experimental tests

The mortar mixes were initially tested for consistency according to ASTM C230 flow test[23]. For each mix, 15x30 cylindrical specimens were cast for the setting time tests, while 20 cm cube specimens were cast for the UPV test. In all specimens, thermocouples were placed to monitor the initial temperatures.

Figure 4 – Granulometry of natural, artificial sand and natural composition (58%) with artificial (42%)



Initial and final set times were determined by the penetration resistance test according to ASTM C403 [16]. Initial and final set times corresponded to the penetration resistance of 3.5 MPa and 27.6 MPa, respectively.

The development of UPV was carried out according to Irrigaray [20]. A 20 cm cubic device with an external wood structure of 20 mm, as shown in Figure 5, was used. In order to maintain a steady pressure on the ultrasound transducers, these were placed at the center of the cube specimen (10 cm height) inside a 50 mm diameter hole previously made on the wood structure. A 6 mm glass

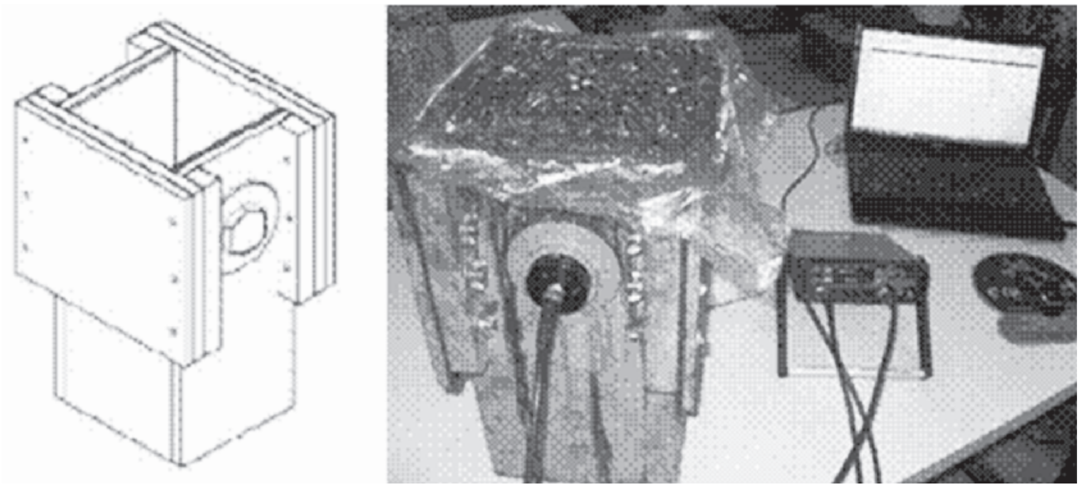
Table 5 – Mixtures of reference mortar (mass)

Material	Ref (0.44)	Ref (0.48)	Ref (0.52)
Natural sand	1.74	1.74	1.74
Artificial sand	1.26	1.26	1.26
Cement	1	1	1
Poly-functional additive	0.01	0.01	0.01
Water	0.44	0.48	0.52

Table 6 – Mortar mixture with SBA (mass)

Materials	SBA (0.44)	SBA (0.48)	SBA (0.52)
Natural sand	1610	1610	1610
Artificial sand	1.166	1.166	1.166
SBA	0.225	0.225	0,225
Cement	1	1	1
Poly-functional additive	0.01	0.01	0.01
Water	0.44	0.48	0.52

Figure 5 – Device to monitor ultrasonic pulse velocity according to Irrigaray (20)



was placed between the concrete and the ultrasound transducers in order to guarantee a plane surface. Prismatic ultrasound transducers of 50 mm diameter and frequency of 54 kHz were used. Once the cubic device was filled with mortar, the transducers were attached and the UPV measurement was initiated. A five minute interval was used to acquire UPV over the first 24 hours.

3. Results and discussions

As expected, the consistency of the fresh mortar increased for mixes with higher water/cement ratio. Figure 6 presents the observed results for all mixes.

Table 7 lists the initial and final set times measured for all mortar mixtures. The development of UPV over time, obtained for the different mortar mixtures are presented in Figures 7 to 9.

The recorded temperatures of each mixture during the first 24 hours are shown in Figures 10, to 12. Table 8 shows the average compressive strength at 28 days obtained for each mortar mixture.

The consistency data presented in Figure 6 indicate that mixtures with partial replacement of fine aggregate by SBA showed lower flow values than the reference mixes regardless the SBA treatment.

Among the mixes with different types of SBA treatment addition, the consistency of mix with re-burnt SBA (SBA-R) was the closest to the consistency of the reference mixtures. On the other hand,

Figure 6 – Consistence index of different mortar mixtures according to ASTM C230 (23)

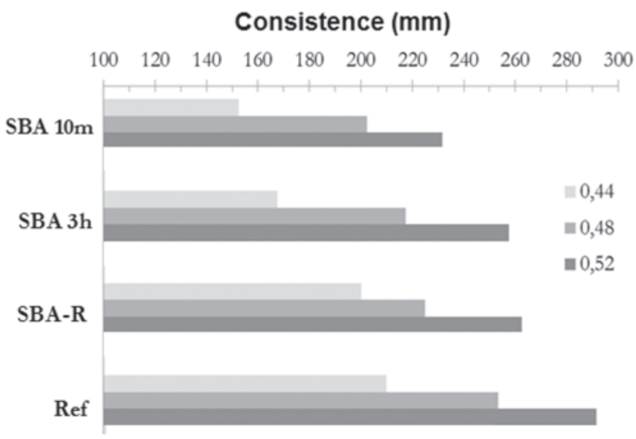


Table 7 – Initial setting time (I.S.) and final setting (F.S.)

Mixture	Mixture (0.44)		Mixture (0.48)		Mixture (0.52)	
	I. S. (h)	F. S. (h)	I. S. (h)	F. S. (h)	I. S. (h)	F. S. (h)
Ref 1	11.2	12.7	9.9	11.6	11.4	13.9
Ref 2	12.0	13.8	12.4	16.0	12.5	15.5
SBA 1 – 10m	7.7	10.5	8.5	11.9	7.5	9.2
SBA 2 – 10m	9.1	11.8	9.4	11.2	9.6	11.9
SBA 1 – 3h	7.8	11.1	9.2	11.7	9.8	11.8
SBA 2 – 3h	8.7	10.7	13.3	16.2	12.5	16.0
SBA 1 – R	8.5	10.3	8.8	10.8	8.9	10.4
SBA 2 – R	9.5	11.5	9.4	11.4	10.0	12.1

Figure 7 – Development of ultrasonic pulse velocity over the time for mixtures with w/c = 0.44

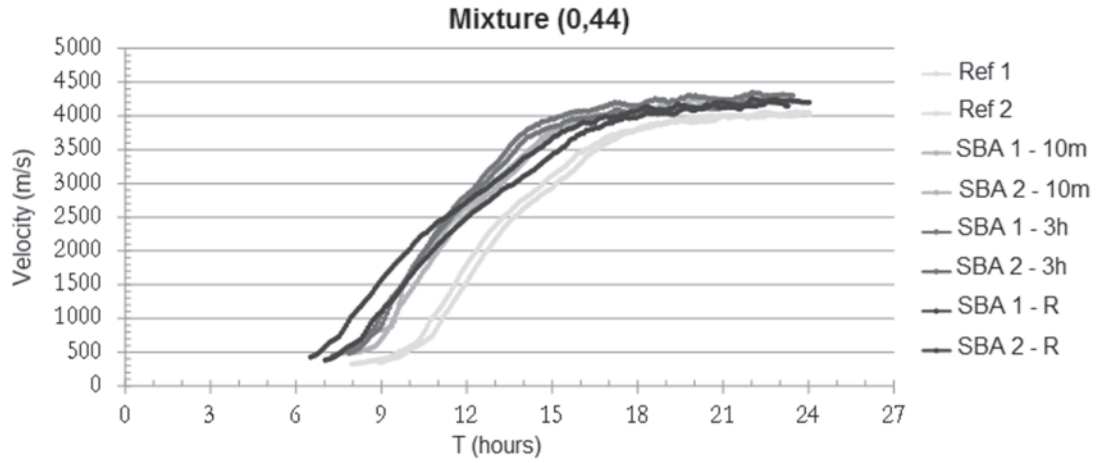


Figure 8 – Development of ultrasonic pulse velocity over the time for mixtures with w/c = 0.48

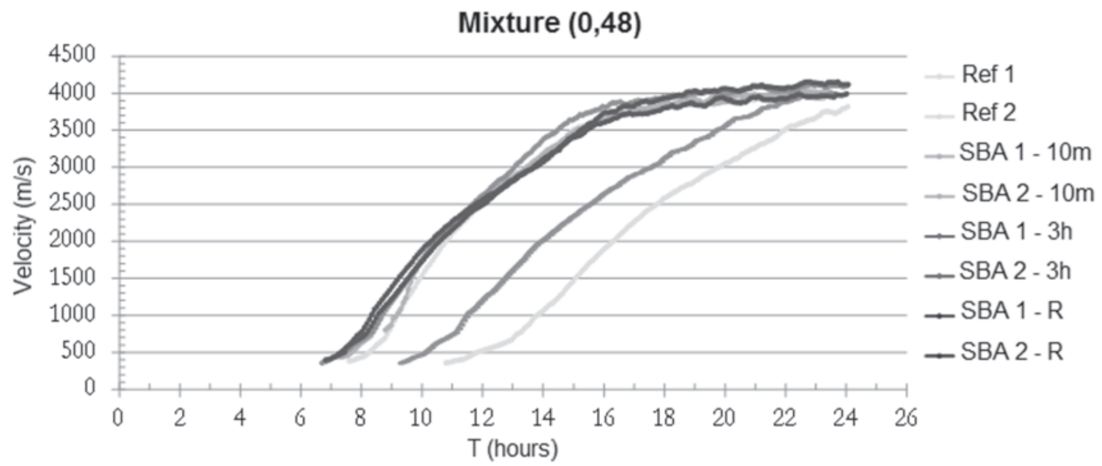


Figure 9 – Development of ultrasonic pulse velocity over the time for mixtures with w/c = 0.52

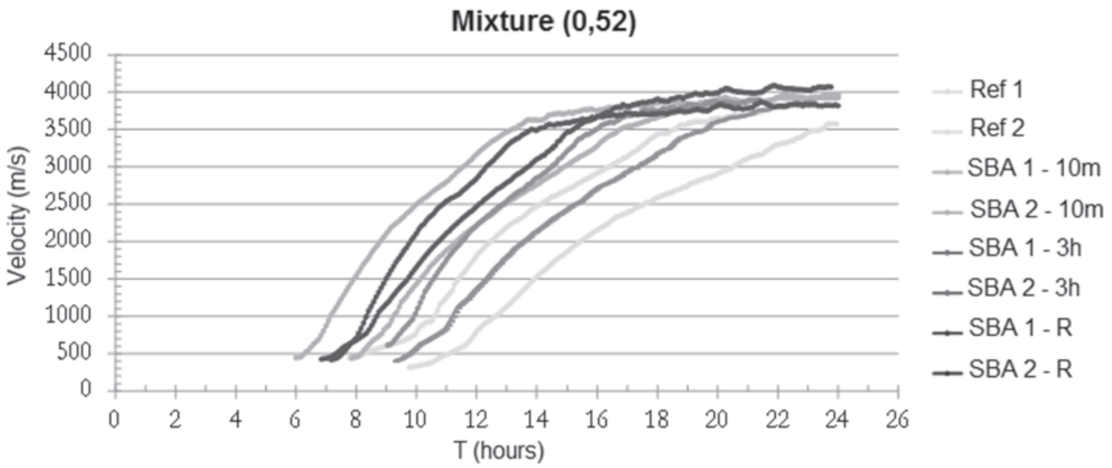


Figure 10 – Temperature history formortar mixtures with w/c = 0.44

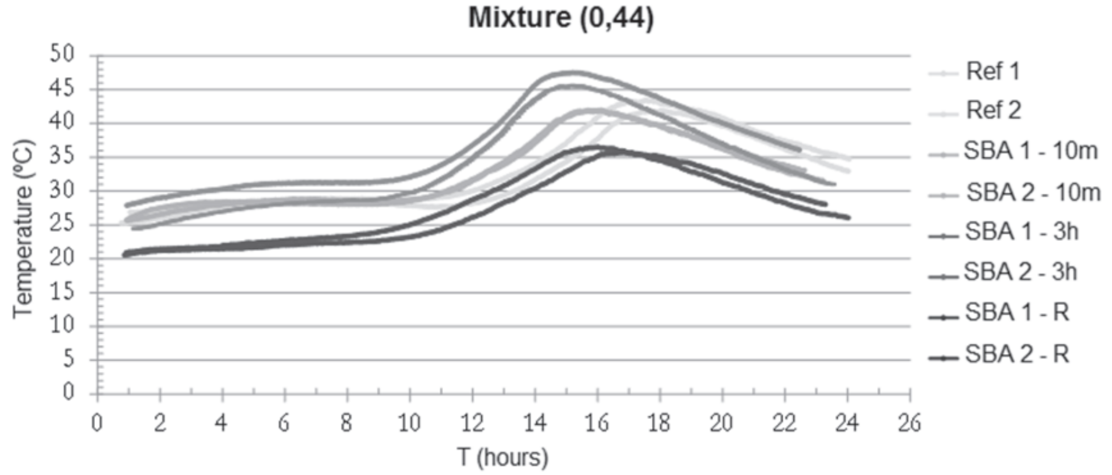


Figure 11 – Temperature history for mortar mixtures with w/c = 0.48

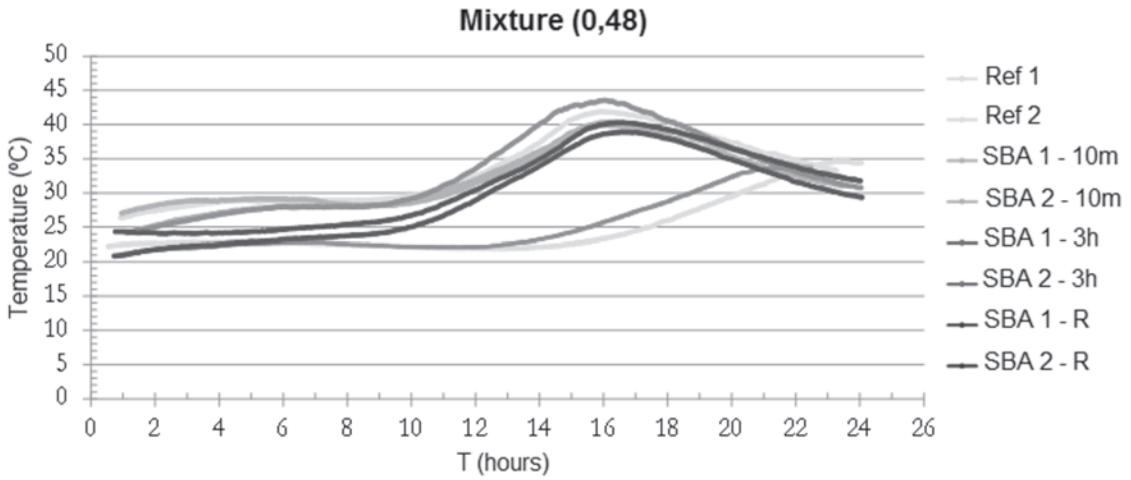


Figure 12 – Temperature history for mortar mixtures with w/c = 0.52

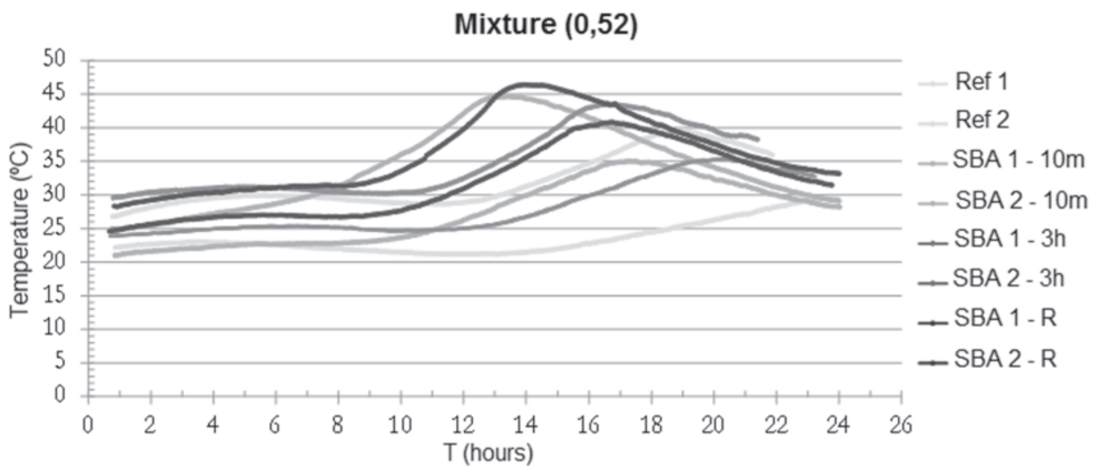


Table 8 – Average compressive resistance at 28 days from mortar mixtures

Mixture	Fc 28 days (MPa)		
	0,44	0,48	0,52
Ref	45.2	43.7	42.2
SBA – 10m	52.1	46.7	43.1
SBA – 3h	53.8	48.4	46.1
SBA – R	54.1	48.8	46.4

mixtures with SBA grinded for 10 minutes (SBA-10) showed the lowest levels of consistency.

The lower consistency of mortars with SBA indicates that this ash has a lower granulometry as compared to the fine portion of the fine aggregate granulometry. However, the duration of SBA grinding did not appear to modify the consistency, since mixtures SBA-3h showed a similar consistency as mixture SBA-10m. The presence of unburned material yields a mixture with lower workability, and higher water demand. For SBA-10 m mixture, the duration of grinding may not have been enough to reduce the organic particles, which may have caused a higher friction among them, and thus reduced workability.

This could also explain the higher consistency for SBA-R mixtures since reburning would enable a smaller amount of organic material.

As far as setting and ultrasound test are concerned, it is clear that the tested mixtures were not at the same temperature. Since 24 mortar mixture were produced throughout a year, according to data presented in Figures 10 to 12, the initial temperatures varied from 20ºC to 30ºC, while the maximum temperatures registered underwent variation of 10ºC among the mixtures, and also between the same mixtures, as can be seen from the temperatures recorded for mixes SBA-1 and SBA-2 for a w/c ratio of 0.52.

It is well known that the rate of the hardening process of cementitious mixtures depends on time and on the temperature history that the mixes are submitted to. At early ages, temperature has a great influence on strength development [24]. Therefore, in order to compensate the temperature effects, maturity functions were used to transform actual ages to equivalent ages (te). The Freisleben-Hansen and Pedersen (FHP) maturity function proposed by ASTM C 1074 [25] , as reproduced in Equation 1, was used. When maturity functions are applied, it is necessary to know the temperature dependence of the mixtures, given by the apparent activation energy (Ea). In this work, the value of 30 kJ/mol for Ea was chosen. This value lies among the ones presented in a broader study with several mixtures [26]. For cement Type I without any supplementary cementitious materials, the reported values are within 22 kJ/mol to 37.9 kJ/mol.

$$t_e = \sum e^{-\frac{E_a}{R}\left(\left(\frac{1}{t}\right)-\left(\frac{1}{t_r}\right)\right)} \Delta t \quad (1)$$

Where:
te – equivalent age at the reference temperature;
Ea – apparent activation energy (J/mol);
R – universal gas constant = 8.314 J/mol-K
t – average mixtures temperature during time interval Δt
tr – reference temperature (20ºC);
Δt – time interval

Thus, the setting times shown in Table 7 were recalculated for each mixture temperature history using Equation 1 with activation energy of 30 kJ/mol. The set times at equivalent ages are presented in Table 9.

It can be observed that, when the influence of temperature is not taken into account, variations between the initial and final set times for the same mixture were recorded. SBA–10m mixtures with w/c of 0.52 showed initial set times of 7.5 and 9.6 hours, according to Table 7. On the other hand, when temperature is considered, these values were 9.7 and 10.5 hours at 20°C.

Results on Table 9 indicate that mixtures with ashes accelerated setting since the initial and final set times were lower than those of the reference mixtures, except for SBA-3h mixture with w/c of 0.48 and 0.52. In these cases, the data were similar. These results demonstrate that when ash was added in the mixture, regardless of the pre-treatment used, they tended to accelerate mortar hardening. The ashes that were reburnt were the ones that resulted in a larger effect on acceleration. This may be attributed to the

Table 9 – Initial and final setting time (te at 20°C)

Mixture	Mixture 0,44 (h)				Mixture 0,48 (h)				Mixture 0,52 (h)			
	I. S.	Mean	F. S.	Mean	I. S.	Mean	F. S.	Mean	I. S.	Mean	F. S.	Mean
Ref 1	15.3	15.7	17.6	18.1	13.5	15.7	13.6	16.9	16.1	14.8	19.8	18.3
Ref 2	16.1	15.7	18.7	18.1	13.7	15.7	13.6	16.9	13.5	14.8	16.8	18.3
SBA 1–10m	10.3	11.2	14.1	15.1	11.6	11.2	11.9	15.7	9.7	10.1	12.6	13.0
SBA 2–10m	12.1	11.2	16.1	15.1	12.2	11.2	11.9	15.7	10.5	10.1	13.3	13.0
SBA 1–3h	11.4	11.4	15.0	14.7	11.9	11.4	13.2	16.8	14.0	14.5	17.8	18.8
SBA 2–3h	11.3	11.4	14.4	14.7	14.6	11.4	13.2	16.8	15.0	14.5	19.9	18.8
SBA 1–R	9.2	9.7	11.5	12.0	10.4	9.7	10.5	13.1	13.2	13.0	15.6	15.7
SBA 2–R	10.2	9.7	12.5	12.0	10.6	9.7	10.5	13.1	12.8	13.0	15.9	15.7

high silica content in the ashes which changes the Ca/Si ratio, and promotes the formation of the silica-rich phases. Also, temperature used to reburn SBA ashes reduced the amount of unburned particles and, at early ages could promote acceleration effects as well as increased reaction of clinquer phases. As far as w/c ratio is concerned, it was observed that the setting process is accelerated at lower values of w/c ratio.

Similarly, to the set times, the ultrasonic pulse velocities measured over the time were transformed into equivalent age at constant temperature of 20ºC. Figures 13 to 15 show the results.

Test of UPV were carried out on two different samples, which implied in different temperatures to each one. By transforming actual time in equivalent time, the UPV development curves over time for each mortar mixture were similar, which facilitated the identification of the behavior at early ages of each mixture during the hardening process. The influence of SBA and its different treatments in the hydration of each studied mortar could be verified.

Results of the ultrasonic pulse velocities appeared to correlate well with the penetration test results. It is possible to observe an acceleration effect on the development of ultrasonic pulse velocities for mixes with SBA when compared to the reference mixtures (without ash). This would indicate acceleration on the hardening process of such mixes. Among the ash treatments, for mixes with w/c ratios of 0.44 and 0.48, the re-burning process was again the treatment that resulted in a higher acceleration. For mixes with

Figure 13 – Development of ultrasonic pulse velocity in equivalent age at 20°C for mixtures with w/c = 0.44

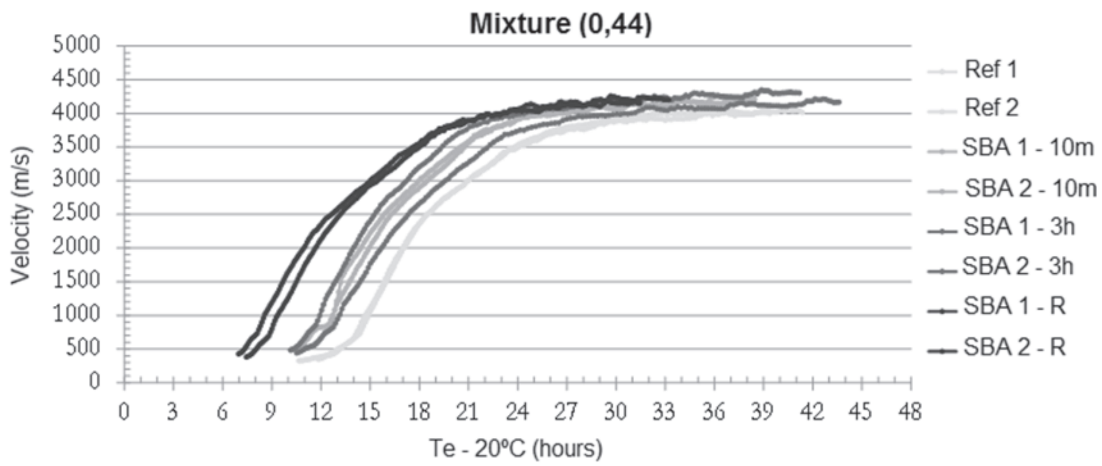


Figure 14 – Development of ultrasonic pulse velocity in equivalent age at 20°C for mixtures with w/c = 0.48

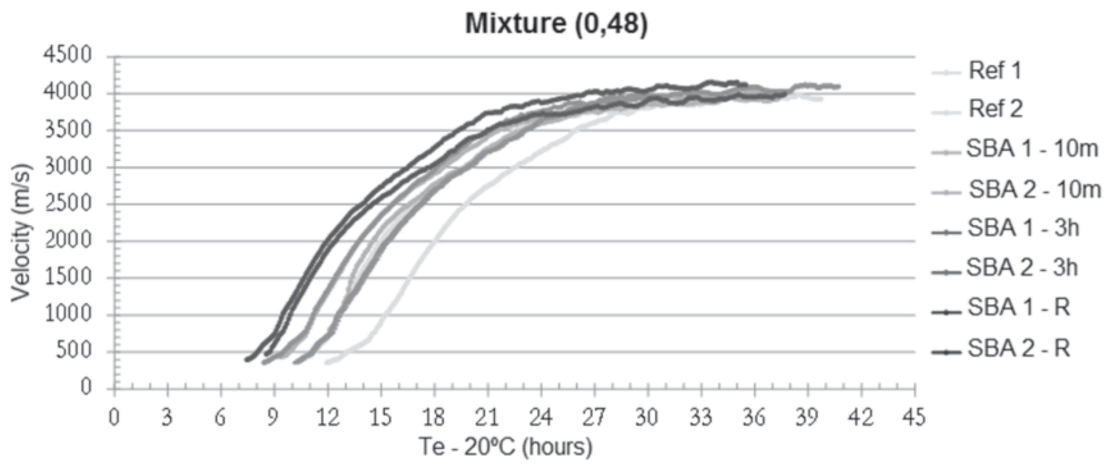
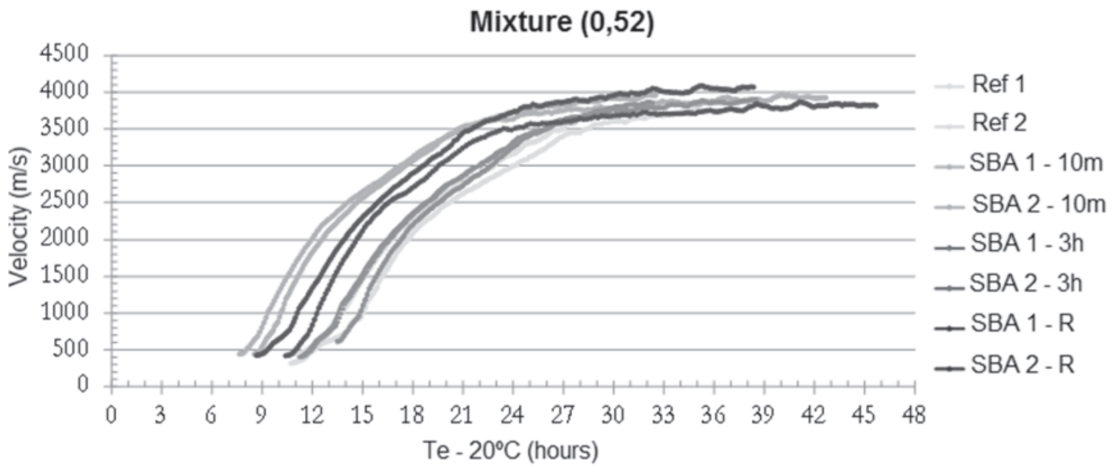


Figure 15 – Development of ultrasonic pulse velocity in equivalent age at 20°C for mixtures with w/c = 0.52



w/c ratio of 0.52, 10 min grinding was the treatment that resulted in a higher acceleration.

Recently, there have been studies that compared the ultrasonic pulse velocity with the final set times of mortar and concrete. Reinhardt and Grosse [27] and Belie et al. [28] studied the hardening process of mortars and concretes through a continuous monitoring of ultrasonic pulse velocities. They demonstrated that the final set occurs around a UPV value of 1500 m/s. Thus, based on these studies, Table 10 presents the final set equivalent times (for a reference temperature of 20ºC) associated to the observed ultrasonic pulse velocity of 1500 m/s, for all mortar mixtures. Once again, it is possible to observe the acceleration effect on final set times for mixtures with presence of SBA.

With regard to compressive strength, the results in Table 8 suggest that the presence of ashes in the mixtures directly influenced this property. It was observed a higher strength in the mixtures containing ash, an increasing about 15% to mixtures with lower water/cement ratio, indicating the possibility of a pozzolanic effect in these mixtures

3.1 Discussion

The addition of SBA in mortar mixtures by replacing about 7.5% of the total fine elements of fine aggregate resulted in a higher compressive resistance on 28 days, and on an acceleration effect on the early cement hydration process. Regardless of the ash treatment or w/c ratio, this acceleration may offer substantial benefits to different applications in building construction, especially to those which require shorter construction times or even on tight schedules.

The SBA used in this work, due to its silico content tended to solubilize when in the presence of the amorphous phase. The presence of organic matter may have contributed to a delay in the hydrated compounds formation. In a short period, few techniques are capable of distinguish this effect and comparative tests may help in the phenomenon identification.

The re-burning treatment used for the SBA, although demanding more energy to its production, could be supported. It provided benefits associated to the acceleration effect and higher compressive strength.

Table 10 – Final setting times to ultrasonic waves velocity of 1500m/s to Te at 20°C

Mixture	Te at 20°C (1500m/s)					
	0,44 (h)	Mean (h)	0,48 (h)	Mean (h)	0,52 (h)	Mean (h)
Ref 1	15.9	16.0	13.8	15.2	16.2	15.7
Ref 2	16.1	16.0	16.7	15.2	15.1	15.7
SBA 1–10m	13.2	13.5	13.4	13.0	10.6	10.9
SBA 2–10m	13.8	13.5	12.6	13.0	11.2	10.9
SBA 1–3h	14.5	13.7	12.4	13.1	15.8	15.4
SBA 2–3h	12.9	13.7	13.8	13.1	14.9	15.4
SBA 1–R	9.6	10.1	11.1	10.9	13.5	13.0
SBA 2–R	10.5	10.1	10.7	10.9	12.5	13.0

Otherwise, its use would be impractical, and as such, grinded ash would be more appropriate to be used according to the identified need. Among the performance of the mixtures with grinded ash, SBA - 3h, which requires a higher consumption of energy and time production, is not justified, once its behavior in the mortar mixtures was similar to mixes with 10 minutes grinding (SBA – 10 m). This latter treatment requires lower energy consumption.
The incorporation of this waste material as partial fine aggregate replacement in concrete and mortar mixtures, regardless of the type of ash treatment, may provide several other benefits in addition to those already mentioned. A sustainable production focused on environmental preservation, waste valuation, to increase products quality and production economic viability is one of the major benefits that can be foreseen.

4. Conclusions

In this study, sugarcane bagasse ashes (SBA) with different treatments were used in mortar mixtures as a partial replacement for the fine elements (less than 150µm) of fine aggregates. The setting process of these mixtures with different water/cement (w/c) was monitored through the penetration resistance test as well as the ultrasonic pulse velocity at early ages.
During setting, temperature control is extremely important, once the cementitious mixtures hardening and solidification processes can be altered. For the different temperatures observed during the process, the maturity method was used to transform actual time in equivalent age (te). All mortars with incorporated ash reached higher compressive strength at 28 days, when compared to the reference mixtures (without ash). Concerning hydration phase at initial ages, mixtures produced with ash, showed an acceleration effect on the hydration process, both by the penetration resistance tests and UPV monitoring.
Mixtures with SBA re-burnt by 06 hours (03 hours at 300°C + 03 hours at 600°C), in general led to the best results. Grinding SBA for 3 hours or for 10 minutes showed a similar behavior, i.e. only to homogenize. It could be identified, that SBA-10m has a viable use, since the mixtures with such ashes showed better results in compared to the reference mixtures, despite the lower performance in comparison to the mixtures with re-burnt ashes. This treatment process is simple, demanding less energy and time for preparation. The use of SBA-R is only feasible to specific buildings, in which the acceleration hydration is crucial, as well as when a higher compressive strength at 28 days is required. The inconvenience of the SBA-10m is its workability, since it has unburned carbon materials. The positive results achieved in this study with the use of SBA in mortar mixtures were probably due to the physical filling effect and/or the pozzolanic activity of the ashes. Further investigations of the physical and chemical characteristics of the ashes used are in development.
The incorporation of sugarcane bagasse ashes is feasible in cementitious mixtures, which the potential to bring benefits to a sustainable production focused on environmental preservation, avoiding the disposal of this waste in nature.

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6. References

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