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ABSTRACT

Biomass has gained in importance as an energy source in recent years. One of the crops that presents interesting opportunities with regard to biomass is sugar cane. In Brazil, sugar cane production is increasing for alcohol and sugar manufacture. Some by-products, such as sugar cane straw, also are obtained during harvesting. Due the calorific value of the sugar cane straw, its use as biomass is increasing. After the straw is burned to produce energy, an ash is obtained: sugar cane straw ash (SCSA). This waste needs an appropriate destination and, since the recent publication of successful studies using biomass derived-ashes as pozzolanic material, the present study aimed to assess the pozzolanic reactivity of sugar cane straw ash. The pozzolanic activity was assessed using a new and simple recently proposed method: evaluation of the electrical conductivity of calcium hydroxide (CH) and pozzolan suspensions, in which solid CH is initially present. These results were compared to those of two other well-established techniques: Fourier transformed infrared spectroscopy and thermogravimetric analysis. The evaluation by all three techniques is similar and shows that sugar cane straw ash is a good pozzolanic material: high lime fixation values for CH:SCSA mixes were determined by thermogravimetric analysis and unsaturation respect to CH in 3.5:6.5 CH:SCSA suspension was achieved at 60ºC. According to this behaviour, a bright future for SCSA as a replacement for Portland cement is expected.

INTRODUCTION

Biomass has become an interesting source of energy in the last years. In the early 21st century, concern about the availability of non-renewable resources and CO_2 emissions motivated an increase in research about biomass as an alternative energy source[1]. The transformation of

biomass into energy also allows the production of new inorganic materials for different applications[2-4]. In some cases, advanced materials based on porous silica nanoparticles have been obtained[5,6]. One agricultural product that supplies biomass is the sugar cane. In Brazil, the sugar cane crop has increased in recent years for the manufacture of alcohol and sugar, making Brazil the largest producer worldwide[7]. In numbers, the harvest of sugar cane in Brazil was 632 million tons in 2014/2015, which represents an increase of 64% in the last ten years[8]. Formerly, the sugar cane harvest was performed using a burning process in the cultivation area; however, an Agro-Environmental Protocol[9] was created in order to end this procedure. As a consequence, mechanized harvesting gained in importance. In the mechanized process, a by-product composed of green and dry leaves is generated — sugar cane straw — of which about 140 kg is obtained per ton of sugar cane produced[9,10]. Initially, the straw was left on the field, but some authors recognized that the calorific value of the sugar cane straw could be used as biomass, in the same way as the sugar cane bagasse that is obtained from alcohol/sugar production[9,11]. Recent studies have assessed the collection of this by-product from the field[9,12] and new practices for burning it to produce energy[13]. However, after obtaining energy from the sugar cane straw by burning, waste is generated: sugar cane straw ash (SCSA). There is currently no mechanism for the valorization of this residue and, due to expected increases in sugar cane production and studies on the use the straw as an energy source, the production of SCSA will likely increase in the coming years.

A good valorization method for this biomass-derived waste could be the partial replacement of Portland cement as a pozzolanic material. Some biomass-derived ashes have been successfully tested in cement and concrete as pozzolanic materials: rice husk ash[14] and sugar cane bagasse

ash[15]. A pozzolan is an amorphous silica or alumina/silica material that reacts with calcium

hydroxide (portlandite generated from Portland cement hydration) in an aqueous medium, and

generates cementing gels similar to those found for Portland cement[16]. The advantages of using

biomass wastes such as pozzolans to partially replace Portland cement are technological

(improving compressive strength and durability) and ecological (reducing both Portland cement

consumption and the disposal of ashes in landfills)[17].

The pozzolanic reactivity of a material can be assessed via studies of calcium hydroxide

consumption using several techniques. Previously, reports on the reactivity of SCSA studied the

behavior of Portland cement blends[18] and kinetic parameters[19]. In this paper, the pozzolanic

activity of SCSA obtained from an auto-combustion process was assessed by means of electrical

conductivity measurements as proposed by Tashima et al.[20]. This method consists of monitoring

the electrical conductivity of suspensions composed of calcium hydroxide/pozzolan for seven

days.

The SCSA reactivity results obtained by electrical conductivity measurements of suspensions

were compared to those from other well-established techniques: Fourier transformed infrared

spectroscopy (FTIR) and thermogravimetric analysis (TGA). The main advantage of electrical

conductivity measurement is the easy preparation and relatively low cost of the test compared to

the two other techniques for evaluating the pozzolanic potential of a material. In addition, SEM

images were obtained in order to show the pozzolanic reaction products between SCSA and

calcium hydroxide. This study aimed to assess the pozzolanic activity of SCSA and valorize this

biomass waste, as well as to compare the results of a recently proposed and simple technique to those from other well-established methods.

MATERIALS AND METHODS

Materials. Sugar cane straw was obtained from a sugar cane plantation near to Ilha Solteira (Sao Paulo, Brazil). The straw was burned in an auto-combustion process with a maximum temperature of 700ºC. In this process, the sugarcane straw is initially ignited, and them the combustion heat maintains the process without any fuel added. The temperature was measured in different points and at several times. After burning, the SCSA was collected from the bottom of the furnace, and passed through sieves in order to remove unburned particles. Finally, it was milled for 30 minutes in a planetary ball mill to reduce the particle diameter. Calcium hydroxide of high purity (>95% purity), supplied by Panreac S.A, was used for all pozzolanic reactivity tests.

Equipment. Electrical conductivity measurements were carried out using a Crison micro CM2201 instrument. pH measurements were obtained using a Crison micro PH2001 pH meter. In order to maintain the test temperature, a Julabo SW22 shaking water bath was used. Thermogravimetric analysis was performed using a Mettler Toledo TGA850 instrument, in a temperature range of 35–600ºC at a heating rate of $10ºC.min^{-1}$ in an N_2 atmosphere (75 $mL.min^{-1}$ gas flow), where the samples were tested in sealed 100 μL pin-holed aluminum crucibles.

Fourier transformed infrared spectroscopy was performed using a Bruker TENSOR 27 in the wavenumber range between 400 and 4000 cm^{-1}. SEM images of the calcium hydroxide/SCSA pastes were obtained using a JEOL JSM-6300 microscope. The chemical composition of SCSA was obtained through X-ray fluorescence (XRF) by means of a Philips Magix Pro XRF instrument.

Methods. Electrical conductivity measurements were performed as proposed by Tashima et al.[20]. This followed method differs from others previously reported[21-24]: the main difference is related to the presence or not of solid calcium hydroxide in the tested suspensions. Some techniques[21-23] are based in the preparation of a saturated solution in $Ca(OH)_2$, and the decreasing in electrical conductivity is measured when pozzolan is added. Other technique[24] is based in the same type of measurement, however, the initial $Ca(OH)_2$ solution is unsaturated. In the test used in the actual study, there is an amount of undissolved $Ca(OH)_2$ in the initial suspension. In this way, two simultaneous processes take place: the consumption of dissolved $Ca(OH)_2$ and the dissolution of solid $Ca(OH)_2$.

In tests according to Tashima´s method, 1g of solid (the mixture of calcium hydroxide (CH) and pozzolan) and 50 mL of deionized water were combined in an Erlenmeyer flask. The CH:SCSA suspensions (also named "systems" in the manuscript) were assessed at 40, 50 and 60ºC for seven days in six different proportions: 2:8, 2.5:7.5, 3:7, 3.5:6.5, 4:6 and 4.5:5.5 (by mass). In addition, suspensions at 30ºC were also studied, where the relative amount of calcium hydroxide was decreased compared to the tests at higher temperature. At this temperature the following

proportions were evaluated: 0.5:9.5, 1:9, 1.5:8.5, 2:8, 2.5:7.5 and 3:7. The results of the loss of electrical conductivity (Lc) tests are presented as the percentage decrease in electrical conductivity, as reported by Tashima et al.[20]. This parameter clarifies the electrical conductivity results and also takes in account the influence of the ions released by the pozzolan. The pH of the suspensions was measured before the addition of the SCSA and at the end of the test (7 days). At the end of the test, the suspensions evaluated at 40ºC were filtered, and the solid part retained on the filter was analyzed by TG.

TG and FTIR studies were carried out for two CH:SCSA pastes with proportions by mass of 3:7 and 5:5 at a constant water/binder rate of 0.80. The CH:SCSA pastes were assessed after 1, 3, 7 and 28 days of curing at a temperature of 40ºC with relative humidity higher than 95%. At each curing time point, the pastes were milled in an agate mortar and mixed with acetone in order to stop the hydration process. They were then filtered and dried in a laboratory incubator for 30 min at 60ºC. SEM images of the fractured surface of the 3:7 paste were obtained after 28 days of curing at 40ºC. After each curing age the SEM pastes were prepared by breaking samples and taking regular fracture images. They were the placed in acetone for one hour and, finally, dried for 30 minutes in a laboratory incubator at 60ºC.

RESULTS AND DISCUSSION

Sugar cane straw ash characterization. The chemical composition of SCSA obtained from XRF analysis is shown in Table 1. SCSA presents a SiO_2 content of 36.5%, which is lower than

published values for sugar cane bagasse ash[15]. Al_2O_3 and Fe_2O_3, other oxides that are important in the pozzolanic reaction[25], are found in minor amounts: 2.8% and 3.4%, respectively. The CaO content is 16.4%, percentage much lower than that found for blast furnace slag or class C fly ash[16]. SCSA does not harden when mixed with water, suggesting that its hydraulic behavior could be negligible.. The total alkali content (K_2O plus Na_2O) was 8.1%, which is considered high. However, such high values are very common in ashes produced by burning biomass[26]. C-S-H gel formed in the Portland cement hydration or in the pozzolanic reaction has the ability to incorporate alkali ions (Na^+ or K^+)[27]. However, in the presence of reactive aggregates, alkali-silica expansion could take place when alkali-rich pozzolanic additions are used[28]. Finally, the amount of LOI is relatively high (15.5%), due to the presence of organic matter — the combustion was incomplete and some cellulosic compounds remained. Regarding the phases present in SCSA, the XRD pattern showed the presence of an amorphous phase, and crystalline phases mainly composed of quartz (SiO_2) and calcite ($CaCO_3$), which probably originate from the soil where the sugar cane straw was collected. It is therefore likely that the SiO_2 and CaO are present as crystals in the SCSA and do not take part in the pozzolanic reaction. Studies to determine the percentage of insoluble SCSA residue by acid and base treatment presented a value of 16.5%, which means that the SiO_2-crystalline phase in the pozzolan represents about 45% of the total SiO_2.. The mean particle diameter (D_{med}), median particle diameter (D_{50}) and 90% passing particle diameter (D_{90}) of the SCSA were 14.7, 7.0 and 38.8 μm, respectively. Specific surface area was 0.595 m2/g and specific gravity was 2.25.

Table 1. Chemical composition of SCSA by percentage

SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	K$_2$O	Na$_2$O	Cl	MgO	SO$_3$	P$_2$O$_5$	Others	LOI
36.5	2.8	3.4	16.4	7.9	0.2	0.4	7.3	4.4	4.0	1.2	15.5

Electrical Conductivity Measurements. The principle of this test is based on the limited

solubility of calcium hydroxide (CH) in water. Calcium hydroxide yields a saturated water

solution if the quantity of dissolved hydroxide is lower than the amount of added hydroxide.

Under these conditions, the concentration of Ca^{+2} and OH^- remains constant at a given

temperature. Thus, the electrical conductivity of the suspension has a high value. If a pozzolan is

added to the suspension, a reaction between Ca^{+2}/OH^- ions and the reactive fraction of the

pozzolan takes place. This reaction decreases the concentration of ions and, consequently, the

electrical conductivity tends to diminish. However, the dissolution of solid calcium hydroxide

present in the suspension maintains a constant concentration of Ca^{+2} and OH^-. While the solution

remains saturated due to the dissolution of calcium hydroxide the electrical conductivity remains

constant. When the solid calcium hydroxide is exhausted, the solution becomes unsaturated and

the electrical conductivity starts to decrease. The time taken to achieve an unsaturated state

depends on the CH/pozzolan proportion and the pozzolan reactivity. Highly reactive pozzolans

reach the unsaturated state more quickly.

The results of the loss of electrical conductivity (Lc) tests for suspensions studied at 30, 40, 50

and 60ºC over seven days are shown in Figure 1. Two types of curves can be seen in the

graphics. In one case CH remains in the saturated state, and the Lc value is static during the 4–

168 hours testing period. In the other, an increase in the Lc value during the testing period is

seen. This occurs when unsaturation is achieved because the pozzolanic reaction fixed the entire

solid CH phase. The Lc value increases, for all systems, in the first 4 hours due to the addition

of SCSA addition to the suspension when adsorption of dissolved ions onto SCSA particles takes

place. For the suspensions studied at 60ºC (Figure 1a), the 2:8 system presented a Lc value of

over 70% after only 24 hours, which represents a rapid consumption of the solid CH. For the

2.5:7.5 system, the Lc value is lower than the 2:8 system after 24 hours (almost 40%), however,

the suspension is also shown to be unsaturated. The 3:7 suspension presented an increase in the

Lc value after 48 hours, whereas the 3.5:6.5 and 4:6 systems only showed a rise in the Lc value

after 96 and 168 hours, respectively. The 4.5:5.5 system did not show any increase in Lc at this

temperature, which means that the pozzolan could not consume all of the solid calcium

hydroxide and the unsaturated state was not achieved. It is well-known that chemical reactions

(e.g. pozzolanic reaction) usually are slower when the temperature decreases. Thus, as expected,

the loss in the conductivity of suspensions studied at 50ºC (Figure 1b) showed a slower

unsaturation process than the suspensions tested at 60ºC. The 2:8 system presented an Lc value

of 40% in the first 24 hours. The 2.5:7.5 and 3:7 systems presented an increase in the Lc value

after 48 and 72 hours, respectively, whereas the final three suspensions (3.5:6.5, 4:6, 4.5:5.5) did

not show any loss of conductivity. For the suspensions tested at 40ºC (Figure 1c), only the 2:8

system presented an increase in the Lc value after 48 hours, taking a much longer time to reach

the unsaturated state than at the higher temperatures. The 2.5:7.5 and 3:7 systems also showed an

increase in the Lc value, after 72 and 120 hours, respectively. As in the test at 50ºC, 3.5:6.5, 4:6,

and 4.5:5.5 suspensions remained saturated until the end of the test. According to the criteria

proposed by Tashima et al.[20], SCSA can be classified as a pozzolan with medium reactivity. This

behavior is similar to that found for low densified silica fume (DSF-H). For testing at 30ºC

(Figure 1d), considering that CH:SCSA suspensions of 3.5:6.5 did not reach unsaturation at 40ºC or 50ºC, lower CH:SCSA systems were tested (0.5:9.5, 1:9 and 1.5:8.5). For these suspensions tested at 30ºC, an increase in the Lc value was found for 0.5:9.5 (4 hours), 1:9 (4 hours), 1.5:8.5 (48 hours), 2:8 (72 hours) and 2.5:7.5 (144 hours). However, the 3:7 suspension did not show any increase in the Lc value, meaning that SCSA could not consume enough calcium hydroxide to turn the suspension unsaturated at this temperature.

Additionally, pH measurements were carried out in order to assess the change in the concentration of OH⁻. Thus, the pH of calcium hydroxide suspensions before the addition of SCSA and the pH of the suspension at the end of the test were measured. In general terms, a significant decrease in pH was observed from the testing time at which unsaturation was reached, indicating that the OH⁻ concentration diminished. For samples in the saturated state, only minor changes in pH were observed, suggesting that the OH⁻ concentration remained constant. Figure 2 shows these variations in pH (ΔpH). It can be observed that for a given CH:SCSA proportion, a higher testing temperature results in a higher ΔpH. A straight line is shown for ΔpH = 0.2 meaning that below this value the suspension remained saturated. As an exception, the ΔpH of the 4:6 CH:SCSA sample at 60ºC was below this value: in this case, the Lc value was at the limit of unsaturation (see Fig. 1a), and consequently, the change in pH value was also at the limit.

Figure 3 shows the DTG curves of the solid residue obtained by filtration of the suspensions after the end of electrical conductivity measurements at 40ºC. The main peak in the range 125–150ºC is from the dehydration of pozzolanic reaction products (mainly calcium silicate hydrates, C-S-

H). The aim of this test is to assess the peak in the range 500–600ºC, which results from the

dehydroxylation of the calcium hydroxide, according to the following equation

$$Ca(OH)_2 \rightarrow CaO + H_2O$$
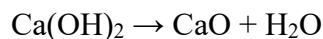
If this peak appears in the DTG curve, it means there is calcium hydroxide remaining in the solid

residue after filtration, meaning that SCSA could not achieve an unsaturated suspension. From

these results, it can be seen that only the 3.5:6.5 and 4:6 suspensions presented a peak at 500–

600ºC, where the SCSA could not react with enough calcium hydroxide to result in an

unsaturated suspension, confirming the results of the electrical conductivity measurements

(Figure 1c). The suspensions 2.5:7.5 and 3:7 did not show calcium hydroxide in their DTG

curves, also in good agreement with the electrical conductivity measurements.

Fourier transformed infrared spectroscopy. FTIR spectra of the 3:7 and 5:5 ratio CH:SCSA

pastes after 1, 3, 7 and 28 days curing at a temperature of 40ºC are shown in Figure 4. The main

vibration bands detected in this test were at 3641 (O-H vibration), 1030, 956 and 443 cm^{-1} (Si-O

vibration). For the raw materials, the vibration band at 3641 cm^{-1} is related to calcium hydroxide

(CH), and the peak at 1030 cm^{-1} is from the amorphous phase of the pozzolan (SCSA). For the

pastes, the four selected vibration bands have important roles in the pozzolanic reaction. With

increasing curing age, the vibration band at 956 and 443 cm^{-1} increases, whereas the other two

peaks, at 3641 and 1030 cm^{-1}, decrease. This results from the consumption of calcium hydroxide

(vibration band at 3641 cm^{-1}) by the amorphous phase of SCSA (vibration band at 1030 cm^{-1})

with curing. Consequently, a new vibration band resulting from the pozzolanic reaction appears

at 956 cm^{-1}. In both pastes, from the first day of curing the vibration band at 1030 cm^{-1} is

reduced in intensity, showing dissolution of the amorphous network of the SCSA (dissolution of

SiO_4 units), occurred mainly during the early part of the reaction. For the 5:5 CH:SCSA paste,

the vibration band at 3641 cm^{-1} reduced from the first to the third day of curing, and remained

practically constant afterwards. This means that the SCSA could not consume all of the calcium

hydroxide after 28 days of curing, and the pozzolanic reaction occurred mainly in the first seven

days. The vibration band at 956 cm^{-1} was practically unchanged from days 1 to 28. For the 3:7

CH:SCSA paste, the peak at 3641 cm^{-1} almost disappeared after one day of curing. This suggests

that the SCSA consumed almost all of the calcium hydroxide after this time. The peak at 875 cm^{-1} is related to C-O bond vibration from the carbonate anion. This peak appeared on the pure

SCSA spectrum due the presence of calcite (see Figure 4). In the CH:SCSA pastes, this peak is

related to carbonate from the ash and from calcium hydroxide, and its intensity was maintained

practically constant for all curing times, showing that the sample did not carbonated. The FTIR

studies show that SCSA presents good reactivity, since the pozzolanic reaction at both CH:SCSA

proportions took place at early curing ages.

Thermogravimetric analysis. The DTG curves of the 5:5 and 3:7 CH:SCSA pastes from 1 to

28 days of curing at 40ºC are shown in Figure 5. The main peaks of these analyses are in the

range 125–175ºC, which represents the dehydration of products from pozzolanic reaction, and at

500–575ºC, resulting from the dehydroxylation of calcium hydroxide. In the 5:5 paste the 500–

575ºC peak reduced from days 1 to 3 of curing and remained practically constant until 28 days,

meaning that the pozzolanic reaction occurred in the first three days. The peak near to 150ºC

increased from days 1 to 3 of curing, and did not show any changes after this time. This behavior

is due the pozzolanic reaction, which consumes the calcium hydroxide and forms cementing gels

(mainly C-S-H). For the 3:7 paste, on the first day of curing there was no peak at 550ºC, as a result of complete calcium hydroxide consumption by the SCSA. Since the pozzolanic reaction took place within the first day, the peak related to the gel from this reaction (near to 150ºC) remained practically constant from 1 to 28 days of curing time. These results of thermogravimetric analysis are in accordance with those from the FTIR studies.

Table 2 shows the mass loss of pozzolanic reaction products (P_P) and calcium hydroxide (P_{CH}), as well the lime fixation of all pastes in the curing time studied. For the paste with a CH:SCSA proportion of 5:5, the lime fixation[29] had a high value after one day of curing (81.46%), suggesting the good pozzolanic reactivity from the SCSA. After three and seven days, the lime fixation had similar values (92.76% and 92.29%, respectively) and after 28 days of curing, the lime fixation did not significantly change. Therefore for the 5:5 CH:SCSA paste, the major pozzolanic reaction took place in the first day of curing. In the 3:7 CH:SCSA paste the lime fixation was 100% within the first day of curing. At this proportion, the SCSA was able to consume all of the calcium hydroxide in only one day of curing. These DTG curves and lime fixation values show that the reactivity of the SCSA is of interest for potential applications. Concerning the mass loss from dehydration of the pozzolanic reaction products (P_P), in both pastes studied, the values did not vary significantly with the curing time. Since the SCSA presents good reactivity, the major part of pozzolanic reaction occurred in the first day of curing, resulting in only minor changes in the mass loss related to the dehydration of pozzolanic reaction products. These minor changes can be related to changes in water bonds of the C-S-H gels during the curing time. In previous studies[30], more important changes in the mass loss related to

formed hydrates at 20ºC were observed after the calcium hydroxide was completely combined,

differently to that found at 40ºC.

Table 2. Mass loss related to the dehydration of pozzolanic reaction products (P_P) and calcium

hydroxide (P_{CH}), and lime fixation of CH:SCSA pastes

CH:SCSA	Curing time (days)	P_P (%)	P_{CH} (%)	Lime fixation (%)
	1	12.58	2.14	81.46
	3	14.03	0.90	92.76
5:5				
	7	13.47	0.89	92.29
	28	13.94	0.17	98.50
	1	13.50	0	100
	3	14.44	0	100
3:7				
	7	15.05	0	100
	28	15.39	0	100

Comparison of results from different techniques. The results of the three techniques for

samples cured at 40ºC were compared. The three studies showed a high consumption of calcium

hydroxide by the 3:7 CH:SCSA paste in the first days of testing. In electrical conductivity

studies, the Lc started to increase after 120 hours, whereas FTIR and TG studies showed no

presence of calcium hydroxide after three days of curing. For studies with higher amounts of

calcium hydroxide (4.5:5.5 for electrical conductivity studies and 5:5 for FTIR/TG studies), the

SCSA did not consume all of the calcium hydroxide in the first seven days of curing. For the

4.5:5.5 system, the Lc did not increase during the test, which means that the solution remained

saturated. The DTG curve of the filtered material presented small amounts calcium hydroxide.

FTIR/TG studies showed that the calcium hydroxide was not totally consumed after seven days

of curing. In general, the results from the electrical conductivity studies are similar to those

found by the FTIR and TG techniques. The new method proposed by Tashima et al.[20] has the

advantage of being simpler and cheaper, and also gave interesting results on pozzolanic

reactivity behavior.

Scanning electron microscopy. SEM images of 3:7 pastes after 28 days of curing at 40ºC are

shown in Figure 6. These images show a substantial presence of gel formed by the pozzolanic

reaction. In addition, calcium hydroxide particles were not identified, indicating that all of it had

been consumed by the SCSA (Figure 6a and Figure 6b). In Figure 6c, cementing gel is the main

product. This gel is rich in calcium and silicon (spot A, mass percentage: SiO_2 = 35.7%; CaO =

35.2%) and showed a Ca/Si atomic ratio of 1.06. In addition a quartz particle can be seen

surrounded by cementing gel (spot B). In Figure 6d, fibrillary C-S-H is highlighted. This phase is

rich in calcium and silicon, and also contained aluminum and iron (spot C, SiO_2 = 38.3%; CaO =

38.2%), with a Ca/Si atomic ratio of 1.07. This fibrous phase also appeared in Figure 6b.
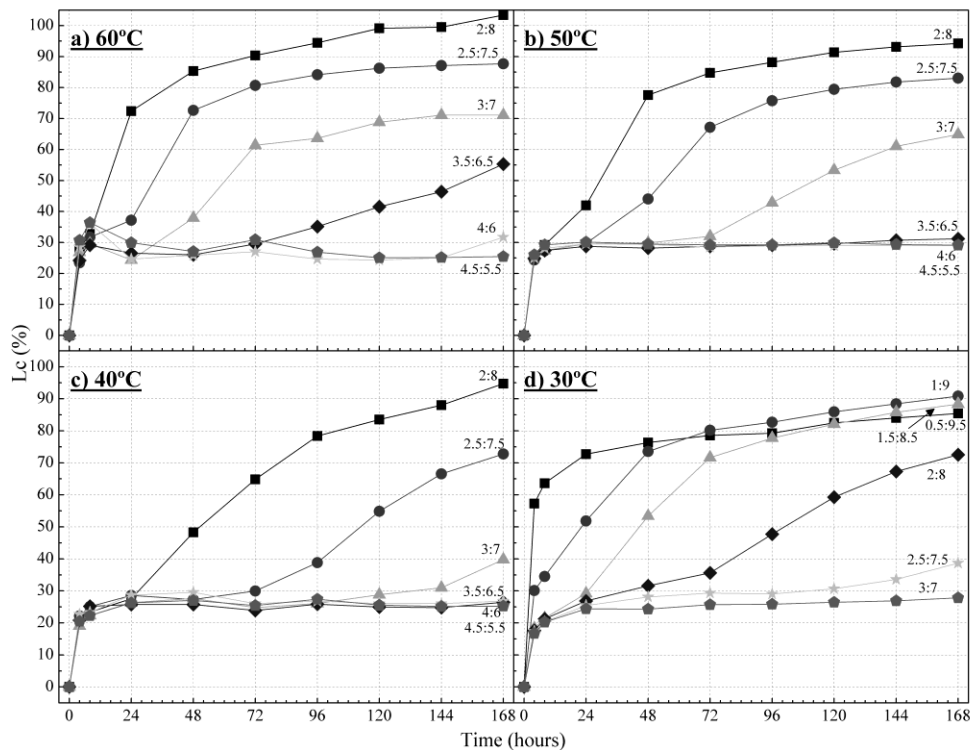
Figure 1. Loss of Electrical Conductivity (Lc) of suspensions studied at a) 60ºC; b) 50ºC; c) 40ºC and d) 30ºC.
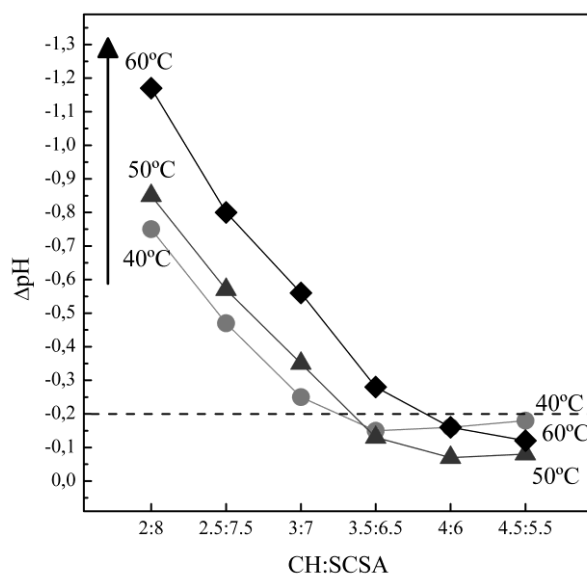

Figure 2. pH variation (ΔpH) of the CH:SCSA suspensions at each temperature studied.
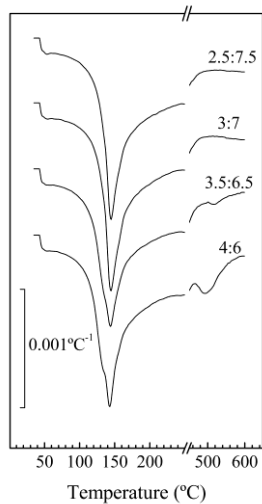
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Figure 3. DTG curves of the solid part of the suspensions after electrical conductivity
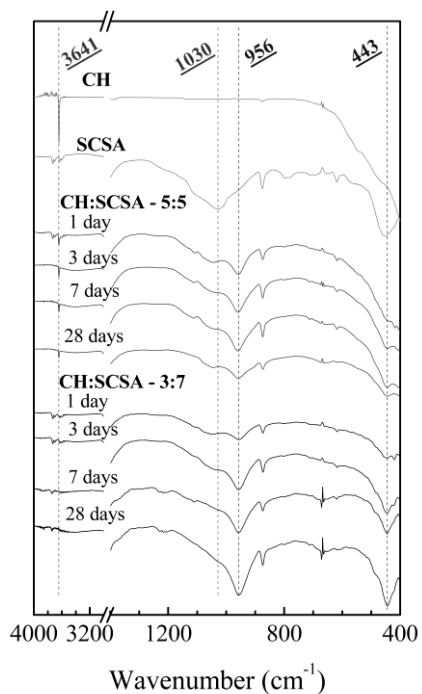
measurements at 40ºC.

Figure 4. FTIR spectra of 3:7 and 5:5 CH:SCSA pastes after 1, 3, 7 and 28 days of curing at
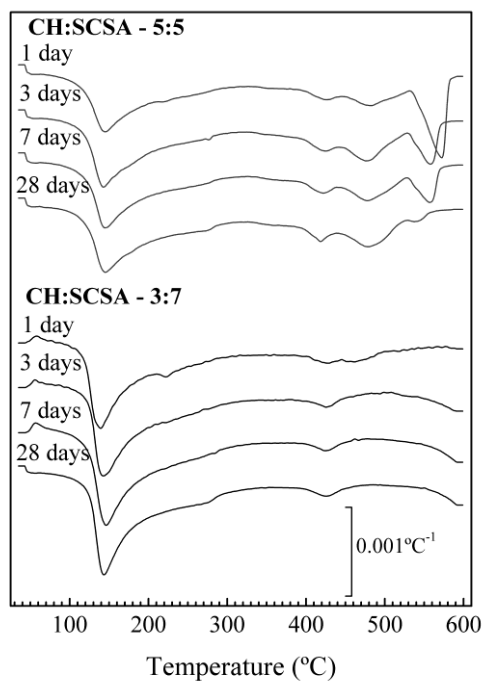
40ºC.

Figure 5. DTG curves of 5:5 and 3:7 CH:SCSA pastes from 1 to 28 days of curing at 40ºC.
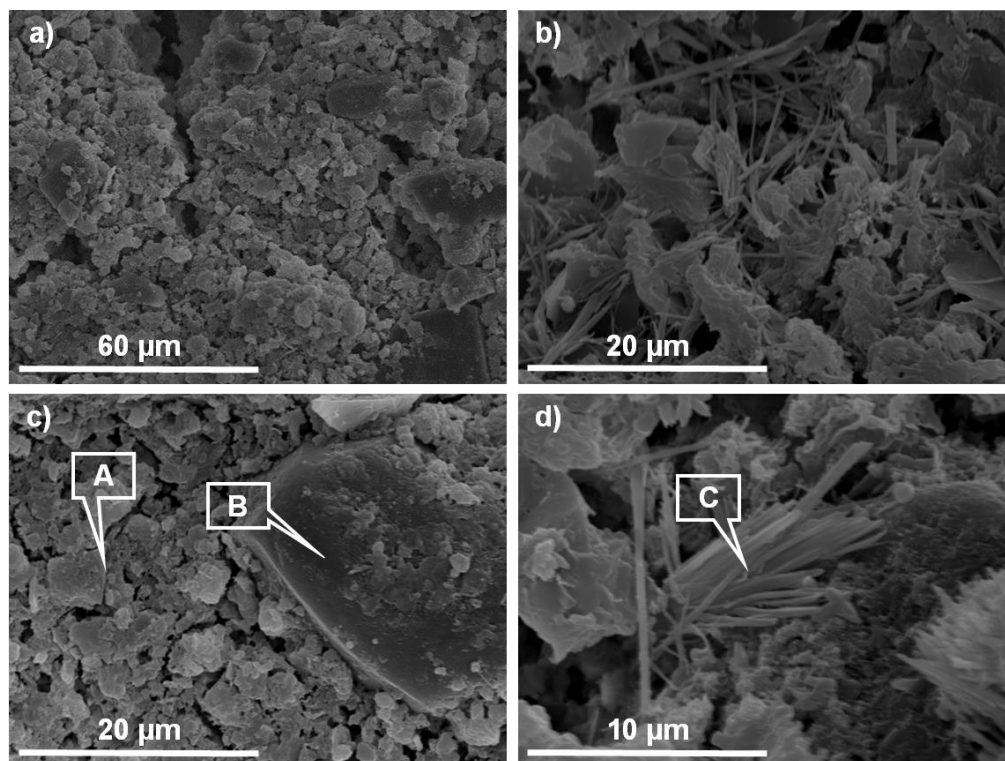
Figure 6. SEM images of 3:7 CH:SCSA paste after 28 days of curing cured at 40ºC.

CONCLUSIONS

There is good potential for the valorization of sugar cane straw ash as a pozzolanic material. An increase in the use of biomass is inevitable because of the need for sustainable energy sources. The wastes generated from biomass burning show interesting properties as construction materials, and SCSA seems likely to be used in the same way due to the promising results concerning its reactivity. In addition, the valorization of the ash in building construction has a sustainable profile, since non-renewable materials, such as Portland cement, can be replaced. The three techniques used in this study presented similar results for SCSA reactivity. The electrical conductivity technique has the advantage of being simpler and cheaper than TGA and FTIR

studies. The evaluation by thermogravimetric analysis shows high pozzolanic reactivity of SCSA in CH:SCSA mixes, finding values of lime fixation, for 5:5 proportion, higher than 80% after 1 day of curing at 40ºC and higher than 98% after 28 days. FTIR studies on CH:SCSA pastes yielded important qualitative data: diminution of vibration bands related to raw materials ($3641 cm^{-1}$ for CH and $1030 cm^{-1}$ for SCSA) and increase of vibration band related to pozzolanic reaction products ($956 cm^{-1}$). Electrical conductivity measurements let to classify the ash as medium reactivity type, accordingly to Tashima´s method, similar to densified silica fume. Measurements of pH on these suspensions showed that a decrease in 0.2 units or higher confirms reaching unsaturated state of the aqueous suspension. This study showed the potential for valorization of a biomass waste and assessed its pozzolanic reactivity using an interesting recently proposed technique.

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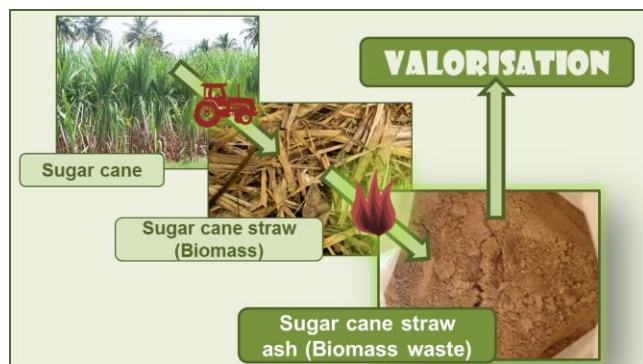
Pozzolanic reactivity studies on a biomass-derived waste from sugar cane production: sugar cane straw ash (SCSA)

João C. B. Moraes[†], José L. P. Melges[†], Jorge L. Akasaki[†], Mauro M. Tashima[†], Lourdes Soriano[‡], José Monzó[‡], María V. Borrachero[‡], Jordi Payá[*,‡].

The possibility of valorisation of an agroindustry residue, the sugar cane straw ash, as pozzolanic material was successfully assessed by different characterization techniques.