Durability of mortars containing sugarcane bagasse ash

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Abstract. This research examines the durability properties of mortars containing sugarcane bagasse ash (SCBA) replacing Portland Cement (PC) by weight of binder. Mortar mixtures were prepared with a water-to-cementitious materials ratio of 0.60 and a cementitious/sand ratio of 1:2.75. A partial replacement of (PC) by 10% and 20% of (SCBA) was used. Compressive Strength, Electrical Resistivity, and Accelerated corrosion tests were investigated. The results showed that the addition of 10% SCBA to the mortar mixtures improves the compressive strength, increases the electrical resistivity more than the mixture control and delays first crack occurrence, therefore we may conclude it is a durable mortar. The results of electrical resistivity allow us to infer that the M3 mixture at late ages will reach the condition of low risk of corrosion. The SCBA used in this research does not require a high-energy-demanding posttreatment to be used in combination with PC for the preparation of durable mortars.

1. Introduction
Low durability and short service life are some of the main problems in reinforced concrete structures. Several researches have been directed towards the utilization of agricultural wastes ashes as cement replacement to produce concrete and mortars of standard quality, improve the durability and reduce negative environmental effects [1]. Sugar cane bagasse ash (SCBA) is obtained as a by-product of the combustion of the bagasse in boilers and it is improperly deposited at open dumps, causing pollution problems. Because SCBA has a high content of SiO₂, it can be used as a supplementary pozzolanic material to partially replace Portland cement in mortars and concretes. Few studies have been reported on the use of SCBA and its effect on durability of blended cement concrete and blended cement mortars. Ganesan et al., [2] evaluated the effects of SCBA content as a partial replacement of cement on physical and mechanical properties of hardened concrete. The test results indicate that up to 20% of ordinary Portland cement can be optimally replaced. The advantages of such replacement were a reduction in water permeability and appreciable resistance to chloride permeation and diffusion. Hernandez et al., [3] found that the higher the content of the SCBA, the higher the content of chlorides in surface layers of mortar specimens, which led them to conclude that the addition of 10% and 20% of SCBA reduced the diffusion coefficient by about 50%. Otherwise, Cordeiro et al., [4] evaluated the effects of “ultrafine sugar cane bagasse ash” as partial replacement (10, 15 and 20%) of cement on properties of high-performance concretes. The results indicate that the cement replacement of up to 20% is possible in high performance concrete with the improvement of the properties and with very low chloride-ion penetration. In another investigation, Cordeiro et al., [5] found that the SCBA is a potential pozzolanic material; however, its effective application in mortar and concrete requires first...
the controlled use of grinding and classification processes to allow it to achieve the fineness and homogeneity that are required to meet industry standards. The results obtained by different researchers show that pozzolana activity of SCBA depends significantly on its particle size and fineness. Unfortunately, all the methods used to improve pozzolana activity of SCBA demand a lot of energy, making it necessary to evaluate the effects of untreated sugar cane bagasse ash (practically as received) as a partial replacement of cement on properties of concretes and mortars. Therefore, this research proposes to evaluate the durability properties of minimally treated SCBA partial replacement for cement in mortar mixtures. Compressive Strength, Electrical Resistivity, and Accelerated corrosion tests were investigated. Two mortar mixtures containing 10% and 20% Admix Tech® Class F Fly Ash (FA) were prepared as a reference; the FA meets the requirements described in the ASTM C 618 standards.

2. Experimental program

2.1 Materials and Methods

Two wastes were used in the preparation of the mortars mixtures. The SCBA used in the present study is an agrowaste product of the sugar industry obtained from the Constancia sugarcane mill, located in Tezonapa, Veracruz, Mexico. The SCBA was collected directly from the landfill and the only post-treatment was to sieve it using a No. 200 sieve (75 µm) for four minutes. The FA used throughout the investigation is commercially available in the market as an industrial waste (Admix Tech). The cement used for all the stages of the research project was commercial grade composite Portland cement CPC30R (PC), which met the NMX -C-414-ONNCCE standards [6]. The densities of both SCBA and FA used were 2.24 and 2.27 g/cm³, respectively, and the density of Portland cement was 2.94 g/cm³. The chemical composition of the principal mineral wastes and PC was determined using X-ray fluorescence spectroscopy (XRF) with an Epsilon 3XL energy dispersive X-ray spectrometer, Table 1.

| Element/Compound          | SCBA  | FA   | PC   |
|---------------------------|-------|------|------|
| Aluminium Oxide (Al₂O₃)   | 13.62 | 20.58| 5.77 |
| Calcium Oxide (CaO)       | 2.36  | 4.83 | 50.76|
| Iron Oxide (Fe₂O₃)        | 5.52  | 2.78 | 2.19 |
| Silicon Dioxide (SiO₂)    | 59.56 | 61.10| 23.86|
| LOI at 1000 °C            | 10.78 | 3.69 | 3.07 |

2.2 Mixture design

The standard for the design of mortars (ASTM C311-04) indicates that mixtures should be elaborated with 2.75 parts of sand for one part of cement with a water to cement ratio of 0.485, which can be modified to achieve a flow of 110 ± 5%. Based on the above and the results of preliminary tests, it was decided for the final design to add one part of powder materials (cement, SCBA, FA) to 2.75 parts of graded standard sand by weight. To ensure that the flow of the control mortar mixture (M0) complies with the flow set by the standard, the water ratio was fixed at 0.56. The mixture dosages are shown in Table 2.

2.3 Samples preparation

The mortar mixtures were prepared under laboratory conditions. The fresh mortar was characterized through a series of tests including flowability (ASTM C1437-01), air content (ASTM C231/C231M-09b), volumetric weight (ASTM C138/C138M-09) and temperature (ASTM C1064/C1064M-08).
Table 2. Mortar mixtures proportions (wt. %)

| Mixtures | PC  | FA  | SCBA |
|----------|-----|-----|------|
| M0       | 100 | 0   | 0    |
| M1       | 90  | 10  | 0    |
| M2       | 80  | 20  | 0    |
| M3       | 90  | 0   | 10   |
| M4       | 80  | 20  | 0    |

Then 9 prisms (50×50×50mm), 6 prisms (75×75×200mm) and 6 prisms (50×50×50mm) with a 10mm and 50 mm steel bar embedded in length for each mixture were cast, Figure 1.

![Prisms for compressive strength test](image1)
![Prisms for resistivity test](image2)
![Prisms for accelerate corrosion test](image3)

**Figure 1. Prisms for tests**

The prisms were demolded after 24 h and cured by immersion in a Ca(OH) saturated solution at 23.0 ± 2.0 °C until the time of the test: the compressive strength determination (ASTM C109/C 109M) was done at 28, 56 and 90 days of age, and the electrical resistivity test (RILEM TC-154) was carried out for 9 weeks. The prisms with the embedded steel bar were cured for 28 days. After the curing period, prisms were exposed to the aggressive solution (using a 5% NaCl solution) for the accelerate corrosion test.

2.4 Durability tests

2.4.1 Electrical resistivity. Concrete electrical resistivity is now an established non-destructive technique that is often used to assess concrete durability [7]. Resistivity measurements were made once a week (for 9 weeks). A Resipod model 38 mm® device from Proceq was used, Figure 2.

2.4.2 Accelerate corrosion test. In normal conditions, the evolution of steel corrosion is slow. In order to accelerate this process and evaluate the durability of the mortar, the specimens were exposed to chlorides using the cycles consisting of a 3-day immersion in a 3.5% NaCl solution followed by a 4day drying period at 115°C in an oven Figure 3. The conditions of prisms were continuously monitored and the first crack initiation time of first crack was recorded. This is used as a measurement of the specimen’s relative resistance against chloride attack and reinforcement corrosion [8]. In addition, the half-cell potential method was used. This method evaluates the corrosion risk of steel reinforcement based on the corrosion potential $E_{corr}$ measured by the half-cell potential technique. The half-cell potential method can only provide a qualitative assessment of corrosion risk of steel reinforcement embedded in concrete [9] Figure 4.
3. Results

3.1 Properties of mortar mixtures in the fresh state

Table 3 presents the values of fluidity, air content, volumetric weight and temperature

| Mixture | Flowability (mm) | Air content (%) | Volumetric weight (Kg/m³) | Temperature (°C) |
|---------|------------------|-----------------|--------------------------|-----------------|
| M0      | 205.75           | 2.4             | 2.25                     | 20              |
| M1      | 210.00           | 3.1             | 2.20                     | 20              |
| M2      | 212.75           | 3.3             | 2.15                     | 19              |
| M3      | 213.25           | 3.6             | 2.10                     | 19              |
| M4      | 215.50           | 3.8             | 2.00                     | 19              |

All mortar mixtures achieved a flow value of 110 ± 5% mm and they complied with the standard. The SCBA mixtures have more air content because they have more porous particles than the PC and the FA mortar mixtures [3]. A reduction of the volumetric weights of the mortars occurs when the cement replacement increases. This reduction is caused by the lower densities of the ashes. The temperatures of the mixtures remained practically unchanged.

3.1.1 Compressive strength Test. Figure 5 shows the compressive strength test results. The readings show an increase of compressive strength with age for all the mortar mixtures. The beneficial effect of SCBA used was present in the mortar mixture M3; in this mixture the highest compressive strength values were obtained. Some authors have reported that the addition of SCBA can increase the compressive strength of concrete at later ages (28 and 90 days) when compared with a control group [10]. The main cause of the increase of compressive strength in mortar mixtures containing SCBA is the pozzolanic reaction between the SiO₂ and CH from the hydration process of PC.

3.1.2 Electrical Resistivity Test. The electrical resistivity measures the capacity of a porous medium (such as mortar) for transporting the electric charge in a finite volume. The electrical resistivity will be higher the denser the medium. Figure 6 shows the average electrical resistivity values vs. time for mortar mixtures prisms. The evolution of resistivity vs. time showed very similar trends on the mixture M0, M1 and M2 specimens for all the time of exposure. However, a significant beneficial effect of the addition of SCBA in the mortar (M3 y M4) is observed.
The addition of CBC to the mortar mixtures let increase the resistivity values in those mixtures. The increase was due, in the first place, to a chemical reaction of calcium hydroxide produced during the hydration of the cement with the silicon dioxide of the CBC. The reaction resulted in Calcium Hydrated Silicate that densified the mortar matrix [11]. In addition, the particles of the unreacted CBC performed as a filler. Both the chemical reaction and the physical effect of the CBC particles reduced the porosity of the M3 and M4 mixtures, reduced the pore interconnectivity and improved their electrical resistivity [12]. The use of ashes in concrete refined the pores and, thereby, the permeability and corrosion get reduced [13].

3.2 Accelerated corrosion test
The durability of the prisms with the embedded steel bar was evaluated by means of two techniques: the corrosion potential $E_{corr}$ measured by the half-cell potential technique, but the $E_{corr}$ parameters are used to determine the “probability” of corrosion; instead, the visual inspection technique is evidence that corroborates the real damage caused by corrosion of steel. The condition of prisms was monitored each week and the occurrence time of the first crack was recorded. Figure 7 shows the deterioration of prisms submitted to immersion cycles in a 3.5% NaCl solution and drying.
In the prism made with the M0 mixture, the first crack occurred in week 3; in the prism of the mixture M1, the crack was visible in week 4, and the first crack of the prism made with the mixture M2 occurred in week 6. The specimens that showed no visible damage at the end of the exposure period were those made with the mixtures M3 and M4. The above corroborated the results obtained both in the electrical resistivity tests and in the corrosion potentials.

4. Conclusions
In the specimens made with the mixture of Portland cement (90%) and sugar cane bagasse ash (10%), the visible damage (appearance of the first crack) was the one that took longer to appear; therefore, it can be deduced that they are more durable than the control specimens. In this work, the durability was evaluated only with respect to the time of appearance of the first crack and under accelerated conditions. To determine the durability of the mortars in terms of time in years, it will be necessary to perform tests to determine the chloride diffusion coefficients of these mortars; with these coefficients and with the characteristics of the reinforcing steel, its life time can be predicted. The addition of 10% SCBA to the mortar mixtures improve the compressive strength and increase the electrical resistivity.

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