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Characterization and use of an untreated Mexican sugarcane bagasse ash as supplementary material for the preparation of ternary concretes

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HIGHLIGHTS

- The addition of untreated sugarcane bagasse ash (UtSCBA) was studied in ternary concretes.
- Microstructure characteristics of ternary concretes containing UtSCBA and fly ash were analyzed.
- Mechanical properties of those ternary concretes were obtained and discussed.

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ABSTRACT

The effects of the addition of a Mexican sugarcane bagasse ash to binary concrete prepared with blended Portland cement (CPC) and fly ash (FA) were studied. The sugarcane bagasse ash was used practically as received (UtSCBA), with the only post-treatment application sieving through a No. 75 μm (ASTM) mesh for four minutes. The characterization of the materials used for the concrete preparation was carried out using RXFE, XRD and SEM/EDS, and the BET methods. Besides the control mixture, three ternary concrete mixtures were prepared: the control mixture (C) with 100% CPC; a mixture with 80% CPC, 20% FA and 0% UtSCBA (T0); a mixture with 70% CPC, 20% FA and 10% UtSCBA (T1); and a mixture with 60% CPC, 20% FA and 20% UtSCBA (T2). The properties of the concretes in fresh and hardened states were studied. In the fresh state, slump, volumetric weight, air content and temperature were estimated, while in the hardened state microstructure, mineral phases, compressive strength, moduli of elasticity and Poisson ratios were investigated. The results indicate that UtSCBA can be considered as a pozzolan even though the LOI content is higher than the maximum allowed in the Standard. UtSCBA particles are heterogeneous (in shape and size) with a specific surface area similar to that of the CPC. Because it has a larger volume of total pores, the use of UtSCBA leads to a reduction of workability and volumetric weight; however, the air content and the temperature in the fresh state are not affected. The results of XRD and SEM/EDS suggest that at early ages both a physical effect of dilution of the CPC and the high carbon content in the SCBA negatively affect the compressive strength of the concretes. However, the pozzolanic reaction of the SCBA is beneficial at later ages. The combination of 10% UtSCBA plus 20% FA did not affect either the development of the strength of the concrete or its modulus of elasticity. On the other hand, the addition of 20% UtSCBA decreased the strength of the concrete at early ages, but after 90 days it was similar to the strength of the control mixture.

1. Introduction

The demand for Portland cement is increasing with the worldwide expansion of urbanization and industrialization; however, Portland cement production has a negative impact on the environment. Studies report that its production is responsible for generating approximately 7% of the world's total CO_2 emissions [1].

One strategy to reduce this problem is to use supplementary cementing materials (SCMs) [2], which is not only an effective measure to protect the environment but also allows for saving resources and energy required in cement production [3,4]. Over the past 30 years important research has been carried out on the

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use of industrial SCMs as a partial replacement for Portland cement; for example, fly ash (FA), silica fume (SF), and blast furnace ground slag (BFGS). With the addition of these materials, the mechanical and durability properties of concrete have been improved [5,6]. Chief among the SCMs, FA is the most-used SCM in the production of binary and ternary concretes, not only for its low cost but also because it is the most characterized and production-controlled material in the construction industry.

It has been demonstrated that despite its slow rate of reaction, when FA is added to concrete it generally provides a significant improvement in the workability of fresh concrete, a higher mechanical strength at later ages and a superior performance when exposed to aggressive media [7,8]. Consequently, the use of FA in concrete increased from 19% in 2010 to 27% in 2013 [9].

Despite the proven benefits of adding FA to concrete, actual trends indicate a significant reduction in its production due to the reduction in the use of coal, the regulatory uncertainties about its use, and the economic slowdown [10]. As a result, the supply of FA is not guaranteed in the near future and the use of alternative SCMs, such as agricultural waste combined with FA, to replace a large percentage of Portland cement has yet been investigated.

In this context, a promising agricultural waste that can be used as a pozzolanic material is sugarcane bagasse ash (SCBA). SCBA is obtained as a by-product of the combustion of the bagasse in boilers and is improperly deposited at open dumps, causing pollution problems [11]. Because SCBA has a high content of SiO_2, it can be used as a supplementary pozzolanic material to partially replace Portland cement in mortars and concretes. However, it has been reported that the addition of SCBA in concrete leads to a significant workability problem during the mixing and placing of the concrete.

The solution to this problem has been addressed in several ways; first, using a large dosage of a high-range superplasticizer (SP) in the mixture [12]; second, by subjecting the SCBA to one or several post-treatments; third, by the combination of SCBA with another SCM; and fourth, by the combination of some the previous options.

The implementation of several post-treatments to improve the properties of the SCBA has been the subject of current research projects [13]. Despite all this research, most of the post-treatments evaluated require a significant amount of energy to operate, causing additional emissions of pollutants to the atmosphere. Among the most common post-treatments applied to the SCBA are re-calcining, grinding, sieving, floating, electrostatic precipitation, and their combination [14,15]. To select a suitable method to post-treat the SCBA and improve its pozzolanicity prior to its use as a SCM in concrete, it is necessary to carry out an extensive study on the availability of low-energy-consuming post-treatments [16]. Studies carried out in Brazil, India, Cuba, Colombia and Thailand suggest that used as a SCM, post-treated SCBA can improve the properties of concrete [17,18]. Additional research has found that the efficiency of the method used to post-treat the ash and its resulting pozzolanic properties are highly dependent on the physical properties of the original ash [19].

Another option to decrease the negative effects on workability caused by using untreated SCBA as a SCM in concrete is its use in combination with FA to prepare ternary concretes, although studies addressing this subject are scarce. Cordeiro et al. [20] investigated the effect of the SCBA in combination with rice husk ash (RHA) on the properties of fresh and hardened concretes. In that study, the SCBA and RHA were ground for 120 min using a vibrating grinder. After grinding, the average particle-sizes of 2.7 μm for the SCBA and 4.3 μm for the RHA were obtained by the authors. They concluded that the combination of the 20% SCBA and 20% RHA in the concrete mixture caused workability problems, while the compressive strength of the concretes was similar to the control mixture using only Portland cement. Jiménez et al. [21] investigated the effect of SCBA in combination with FA on the workability of ternary pastes and mortars. The SCBA was only sieved using the 75 mm ASTM sieve for four minutes. Because of the low-energy post-treatment applied to the ash, the authors decided to name it Untreated Sugarcane Bagasse Ash (UtSCBA). In that study, the authors reported that the addition of UtSCBA produced an increase in the yield stress and viscosity of pastes. In a similar manner, the inclusion of UtSCBA in mortar mixes increased both yield stress and viscosity, which caused a lower percentage of fluidity and a greater consumption of SP than in the simple mortars. The addition of FA in mortars containing UtSCBA has a beneficial effect on workability as FA hinders the negative effects of UtSCBA, yielding a mortar with flow properties like those required to the proper mixing and placing. Results from this research show that the combination of FA and UtSCBA fulfill the necessary requirements for pastes and mortars to be workable; however, there is a need for on-going research which addresses the study of the properties of these concretes in the hardened state.

The main objective of this research then is to investigate the effects of the addition of a "practically as received" sugarcane bagasse ash (UtSCBA) in combination with FA on the properties in the hardened state of ternary concretes.

2. Materials

Sugarcane bagasse ash, FA and blended Portland cement CPC 30R (CPC), according to the Mexican Standard [22], were used in the preparation of the concrete mixtures. The sugarcane bagasse ash was collected from an open dump at the sugar mill "Constancia," which belongs to Grupo Beta San Miguel, located in Tezonapa, Veracruz, México. The ash was collected and sieved through a No. 200 ASTM (75 μm) sieve for four minutes. Because of the low-energy method used to post-treat the ash, it was decided to refer to it as "untreated" (UtSCBA). The fly ash used was Type F (FA), which is available in the American market under the brand AdmixTech®.

As well, both calcareous crushed coarse aggregate and river sand were used in the preparation of the concrete mixtures. The coarse aggregate, with a maximum size of 19 mm, was obtained from a bank of material located in Santa Maria el Tule, Oaxaca, Mexico. Volumetric weight, specific gravity, and adsorption of the coarse and fine aggregates were respectively 1624 kg/m^3, 2.66 and 0.47%, and 1596 kg/m^3, 2.78 and 1.74%. The fineness modulus of the sand was 2.97.

Bi-distilled water and a polycarboxylate-based superplasticizer with a gravity density of 1.07, pH of 6 and a solid content of 30% (PLASTOL 4000)®, which fulfills the ASTM-494 requirements, were used.

2.1. Chemical and mineralogical analysis of the cementitious materials

A chemical analysis of the cementing materials was carried out using X-ray fluorescence spectroscopy (XRF) with an Epsilon 3 XL energy dispersive X-ray spectrometer. In addition, the loss on ignition (LOI) of the cement was estimated at 950 °C in accordance with the ASTM C114-10, whereas the LOIs of the UtSCBA and FA were at 750 °C in accordance with the ASTM D7348-13. The identification of the mineral phases was carried out by X-ray diffraction (XRD) using a Bruker D8 Advance® diffractometer. The equipment, which uses a Cu anode, Ni filter and high-speed detector, was operated at a voltage of 40 kV and a current of 40 mA. The XRD patterns were obtained at a scanning speed of 0.5 s, with an increment of 0.05° in a range between 10 and 70°. For the analysis and interpretation of the results, the software EVA 11.0.0.3® and the ICSD, PDF-maint data base were used.

2.2. Physical properties of the cementitious materials

The density of the UtSCBA and FA was determined in accordance with the ASTM C 188-09. The morphology and texture of the particles of the materials were studied using a high vacuum JEOL® Scanning Electron Microscope (SEM) Model JSM-6490LV in the secondary electron mode which has attached an EDS microanalysis system. The operating voltage of acceleration was 20 kV. The EDS system consists of a WAFER detector built with Lithium-doped Silicon with a 3.5–6 mm diameter and 3 mm thickness, which is controlled by OXFORD's INCA-sight Instruments® software. The particle-size distribution of the materials was estimated using a MICROTRAC S3500®. The equipment was operated in the wet mode using isopropyl alcohol as a dispersant and applying ultrasonic energy by 40 Watts during 60 s. The specific surface area was determined by fisisorcion of nitrogen, a technique also known as the BET method. Equipment from Quantachrome Instruments® (Nova 2000e) was used to obtain adsorption-desorption isotherms.