Construction and Building Materials 105 (2016) 69–81

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Mechanical and durability properties of mortars prepared with untreated sugarcane bagasse ash and untreated fly ash

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HIGHLIGHTS

- Untreated sugarcane bagasse ash and untreated fly ash were added to mortars.
- Compressive strength and UPV test of those mortars are discussed.
- Electrical resistivity and rapid chloride permeability tests are also highlighted.
- Correlations between mechanical and durability tests are established.
- More reliable predictions of the properties of cementitious materials are needed.

ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 3 November 2015
Accepted 6 December 2015

Keywords:
Compressive strength
Electrical resistivity
Post-treatment
Pozzolans
Rapid chloride permeability test
Ultrasonic pulse velocity

ABSTRACT

Mechanical and durability properties of mortars containing mineral admixtures were analysed. Mortar mixtures were prepared with a water-to-cementitious materials ratio of 0.60 and a cementitious/sand ratio of 1:3.5. A partial replacement of Ordinary Portland Cement (OPC) by 10% and 20% of untreated sugarcane bagasse ash (UtSCBA), and by 10% and 20% of untreated fly ash (UtFA) was used practically "as received". The only post-treatment was to sieve SCBA and FA through No. 200 and No. 100 sieves, respectively. Compressive Strength (CS), Ultrasonic Pulse Velocity (UPV), Electrical Resistivity (ER) and the Rapid Chloride Permeability (RCPT) tests were carried out on cylindrical specimens. The addition of 10% and 20% of UtSCBA and 10% and 20% UtFA to the mortars had the following effects: the CS decreased generally for all the mortars at early ages but after 90 days was similar or surpassed the level of the control; the UPV decreased generally for all the mortars, except for the 10% UtFA mortar which surpassed the control at 180 days; the ER increased generally for all the mortars after only 14 days, especially when UtSCBA was used; the level of permeability decreased generally in all the mortars, but was especially true for the 20% UtSCBA mortar. Correlations between the results of the different tests evidence the need for further investigation of the influence of additives in mortar mixtures in order to develop more reliable predictions on the behaviour of the properties of cementitious materials.

1. Introduction

The use of pozzolanic materials in concrete or mortar mixtures as partial replacement of cement provides a satisfactory solution to environmental concerns and to the loss of durability that some reinforced concrete structures have. Studies have shown that pozzolanic materials have a significant amount of amorphous silica in their chemical composition. When pozzolanic materials are added to the cement, this silica (SiO_2) reacts with the free lime from the hydration of the cement and new silicate hydrate products are formed, thus improving the mechanical and durability properties of the concrete [1].

The use of industrial waste as pozzolanic additions in concrete or mortar mixtures, and in particular the use of fly ash (FA), has

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http://dx.doi.org/10.1016/j.conbuildmat.2015.12.047
0950-0618/

been studied extensively. FA is a by-product of the combustion of pulverized coal in thermal power plants and is gathered by electrostatic precipitators from the combustion gases before they are discharged into the atmosphere. Only flying particles produced from the burning of the coal are attracted to the precipitators. Consequently, most of the FA is formed by silica and alumina rich particles with only a small amount of unburnt coal particles. As a result, FA reacts effectively with hydration products to form more dense and resistant cementitious products, improving in this manner the long-term mechanical and durability properties of concrete.

Research on FA shows that its presence improves the workability of mortars and concretes in their fresh state. In a their hardened state, the presence of FA also improves structural properties; however, this improvement occurs at later ages than in the mortars and concretes which have no FA [2].

FA improves the impermeability and durability of concrete. Some researchers have found that the replacement of 20% of cement with FA in concrete mixtures improved compressive strength and significantly delayed the corrosion initiation period due to the decreased permeability to chloride ions [3,4].

As a result of the variability of both the coal composition and the burning conditions, the chemical properties of FA vary greatly and this variability has a significant impact on the properties of the cementitious materials where FA is used.

Grinding the FA and high-temperature curing have shown to reduce the variability and to improve the mechanical properties of mortars [5]. Recalcination can also be used to improve its pozzolanic activity. Finally, the addition of Calcium Hydroxide and Sodium Silicate to accelerate the cement early hydration and promote setting and hardening of mortars has been investigated [6]. There is an extensive developing body of knowledge on the effects of post-treated FA on alkali-silica reaction resistance, permeability modification, and corrosion resistance of Portland cement based concretes.

Recently, attention has been placed on the study of agricultural waste materials whose use has been shown to improve the mechanical and durability properties of reinforced concrete and mortar.

Some authors have reported that Sugar Cane Bagasse Ash (SCBA) has substantial amounts of Silica (SiO_2), Alumina (Al_2O_3) and Ferric Oxide (Fe_2O_3) [1,7,8] and that these account for over 70% of the constituents of SCBA, indicating that SCBA can also be used as a mineral admixture.

According to Frias et al. [9], the method of capturing the SCBA and the conditions under which it is calcinated influence the chemical and mineralogical composition and pozzolanic material properties.

Cordeiro et al. [10] found that at 800 °C Cristobalite and Calcium were formed. The production of SCBA under controlled conditions helps to prevent the formation of crystalline phases and in this way increases its pozzolanic activity.

Some researchers have shown that a high percentage of the loss on ignition (LOI) of the SCBA has a negative effect on its pozzolanic activity. For example, the development of the compressive strength of mortars with an addition of SCBA with a high LOI value was less than for SCBA mortars with low LOI values [11].

Cordeiro et al. [12] analysed the influence of the particle size of the SCBA on the density and compressive strength and found that the reduction in the particle size of the SCBA resulted in an improvement in the pozzolanic activity.

It has been reported an increase in the compressive strength of concrete and mortar mixtures with an addition of SCBA and it has been also demonstrated that the optimal percentage of cement replacement is 20% [1]. On the other hand, Hernandez et al. [8] observed that a poor curing time of mortar specimens with an addition of SCBA had a negative effect on the compressive strength.

The effect of the addition of SCBA on the properties that determine the durability of mortar and concrete mixtures has received attention in recent research. Ganesan et al. [1] found that the replacement of 20% of cement with SCBA decreased permeability and penetration of chloride ions. Meanwhile, Hernandez et al. [8] 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%.

The results obtained by different researchers show that when post-treated, SCBA and FA have significant pozzolanic activity and can be used as additives in concrete and mortar mixes, because they help to improve mechanical and durability properties.

Unfortunately, all the methods used to activate FA and SCBA demand a lot of energy, making it necessary to investigate whether or not the impairment of the properties of mortars or concretes caused by the use of untreated, "practically as received" ashes, is tolerable.

Therefore, this research proposes to evaluate the mechanical and durability properties of minimally treated SCBA and FA as a partial replacement for cement in mortar mixtures. Compressive Strength (CS), Ultrasonic Pulse Velocity (UPV), Electrical Resistivity (ER) and Rapid Chloride Permeability (RCPT) tests were carried out. The correlations between mechanical and durability testing results were analysed as well.

2. Experimental

2.1. Experimental design

To evaluate the effects of untreated sugarcane bagasse ash (UtSCBA) and untreated fly ash (UtFA) mortars were prepared containing these materials at three levels. Tests of these mortars in fresh and hardened states were carried out. Details of the experimental design and experimental procedures for results in the hardened state are summarized in Table 1.

2.2. Materials

The materials used in this research consisted of Ordinary Portland Cement R-40 (OPC) according with the NMX-C-414-ONNCCE Mexican Standard. The density of the cement was 3.06 g/cm^3. The UtSCBA was collected from a sugar mill located in the community of Tezonapa, Veracruz, México. This ash is generated as combustion by-product of sugar cane bagasse at temperatures between 550 and 700 °C and recovered by sprinkling water during sugar production. The collected ash was homogenized and dried for 24 h in an electric oven at 105 °C. In previous research, sieving and grinding were evaluated in order to select the appropriate low-energy input post-treatment [8,13]. In accordance with the findings of the evaluations of low-level treatments sieving the ash through the ASTM No. 200 (75 μm) sieve for five minutes was chosen for future research. The density of the UtSCBA used was 2.1 g/cm^3.

The UtFA is produced in a thermal plant located at Nava, Coahuila, Mexico, and sieved through ASTM No. 100 sieve for five minutes. The density of the UtFA was 1.98 g/cm^3. Calcareous powder was used as a fine aggregate, which is typically used in Monterrey's metropolitan area. Its density was 2.65 g/cm^3 and its fineness modulus of 2.78. This sand fulfils the recommendations for the use of fine aggregate according to the ASTM C33. Distilled water was used to prepare all the specimens. Mixtures with 10% and 20% of SCBA had workability problems; therefore, the use of a superplasticizer was required. The polycarboxilates based high-range water reducer Plastol Precast LV (ASTM C494 Type A and F) was used to improve the workability of these mixtures (see Table 2 for proportions).

2.3. Methods

2.3.1. Characterization of materials and mixture proportioning

The chemical compositions of OPC, UtSCBA and UtFA were obtained by the use of a XR florescence spectrometer (mass disperse energy) Epsilon 3 XL® (Analytical). The different samples were prepared by mixing each of the materials separately with powdered micronized cellulose and then pressed to obtain pill-shaped samples. Then, the Standard Less Omnia® software was used to quantify the compounds. Particle size distributions were determined by laser ray diffraction in a wet path using a Microgram model S3500, and using the software Microgram Flex version 10.6.1®. The mineral phases were evaluated by XR diffraction using a diffractometer Bruker AXS D8 Advance with radiation Co Kα1 (1.5418 Å). Intervals of 2θ ranging from 10° to 70° and pass size of 0.5 s with increments of 0.05° were