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Review

Influence of coal bottom ash as fine aggregate on fresh properties of concrete

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ABSTRACT

This paper investigates the influence of the use of coal bottom ash as a replacement for natural fine aggregates on the properties of concrete in the fresh state. Tests for water loss through bleeding, and the determination of the setting times and plastic shrinkage, were carried out in order to evaluate the material in the presence of bottom ash. The influence of the porosity of bottom ash on the potential water absorption and water loss of the material, as well as on the water consumption of concretes produced with bottom ash, is also discussed. The results showed that in the fresh state the concretes produced with the bottom ash are susceptible to water loss by bleeding and the higher the percentage of bottom ash used as a natural sand replacement the lower the deformation through plastic shrinkage. The results also showed that the setting time is affected by the presence of bottom ash in the concrete. In conclusion, different forms of bottom ash mix result in concretes with different properties in the fresh state, but the behavioral tendencies are maintained when bottom ash is employed as a replacement for natural aggregates.

Contents

1. Introduction

Results reported in the literature are promising regarding the use of bottom ash as a partial or total fine aggregate replacement for natural sand [1–6]. Thermoelectric power stations produce a great quantity of residues from burning coal [1–4]. These residues, mainly fly ash and bottom ash, have a very effective potential use in mortar and concrete.

Due to the high porosity of coal bottom ash, there is a certain difficulty in determining the exact water/cement ratio. Thus, many assumptions are based on an estimated quantity of water which does not participate in the processes of material lubrication and the filling of void spaces. This water present inside the bottom ash grain through capillary retention, would not contribute to the formation of capillary pores [7–10]. Although the water absorption by the bottom ash alters the water intended for the workability of the concrete, this effect makes it act as a porous aggregate functioning as a reservoir of water for future hydration of the cement [5,6,11–14]. The plastic shrinkage of the concrete is directly affected by the quantity of water available in it, which may be lost through bleeding (settlement), changing the relative humidity and the internal capillary pressure [15–18]. The use of a porous material which can promote a supply of water internally to the concrete, without permitting that there is an excessive capillary attraction force, makes the system less susceptible to deformations or cracking through plastic shrinkage, which is of great interest.

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This paper presents the results of a study using bottom ash in common concretes as a replacement for natural sand, analyzing the performance in fresh state regarding bleeding, setting time, heat evolution and plastic shrinkage.

2. Materials

- *Cement*. The cement used was CPV – ARI (high initial resistance), according to the Brazilian standard NBR 5733/91 (similar to type III ASTM C 150-05). Table 1 shows the chemical and physical characteristics of the cement used.
- *Natural fine aggregates*. A natural siliceous sand was used, classified within the optimum zone according to the Brazilian standard NBR 7211/2005, with a specific mass of 2.63 g/cm^3 and a fineness modulus of 2.50.
- *Natural coarse aggregates*. A granite gravel was used, classified within the range 9.5/25.0 (d/D), according to the Brazilian standard NBR 7211/2005, with a specific mass of 2.70 g/cm^3 and a maximum size of 19 mm.
- *Bottom ash*. Collected from the settling pond of the Jorge Lacerda thermoelectric power station, which generates 840,000 tons of bottom ash annually, in Santa Catarina, southern Brazil. The chemical and physical characteristics are given in Table 1.

The chemical composition of the bottom ash was analyzed by X-ray energy dispersive spectrometry (EDS). The calcium content is very low (2.07%) and the sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ reaches 89.5%, which means that this ash belongs to ASTM Type F ash. In a previous study [7], the chemical composition of this bottom ash was investigated by ICP and ICP-AES and it was found to contain MgO (0.6%). The sum CaO + MgO content is very low <1.4%.

The grain size distribution of the bottom ash and natural sand are shown in Fig. 1 and the scanning electron micrograph in Fig. 2. All of the natural sand replacement was carried out by volume, adding bottom ash in the same volume as the natural sand.

3. Experimental program

The concrete mixes were prepared according to two forms of bottom ash addition: (a) equivalent volume replacement, correcting bottom ash quantities according to the moisture content – CRT3; (b) non-equivalent volume replacement, without replacement of bottom ash according to the moisture content of the aggregate – CRT4.

Table 1
Chemical and physical characteristics of Portland cement and bottom ash

Content (%)	Cement	Bottom ash
Chemical analysis		
SiO_2	18.13	56.0
Al_2O_3	4.28	26.70
Fe_2O_3	2.54	5.80
K_2O	–	2.60
CaO	59.80	0.80
TiO_2	–	1.30
SO_3	3.14	0.10
Na_2O	–	0.2
MgO	5.25	0.60
CaO free	1.47	–
Loss on ignition	3.29	4.6
Physical tests		
Blaine (cm^2/g)	4.098	–
Initial setting time (h:min)	1:30	–
Final setting time (h:min)	2:37	–
Specific gravity (g/cm^3)	3.12	1.674

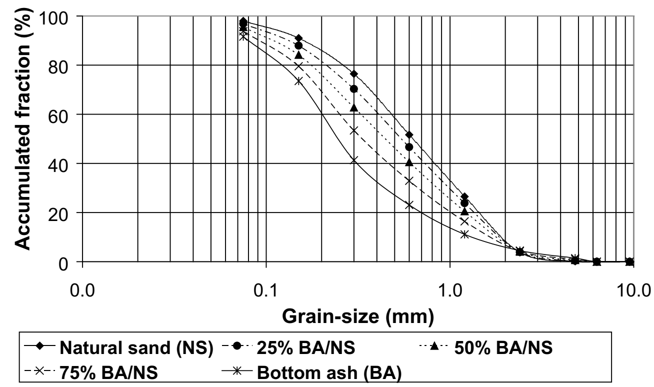

Fig. 1. Grain size distribution curves for bottom ash/natural sand (BA/NS) mix.

The second form of proportion (CRT4) enabled the maintenance of mechanical properties, based on the results obtained for the reference concrete with 100% of natural sand. However, to achieve this, a greater quantity of cement was required, due to the lower quantity of fine aggregates per volume of concrete.

Table 2 shows the consumption of the material of the concretes with bottom ash. The workability was specified for a slump of 80 ± 10 mm. The fresh density was determined by the gravimetric method. The test for water loss by bleeding was carried out in a controlled temperature room at 22 ± 2 °C and $60 \pm 5\%$ relative humidity. The water was collected from molded samples in a glass container with an exposed area of 140×190 mm^2 using a syringe to hold the water removed without small particles. The evaluation of the bleeding was carried out for a period long enough to collect water from the surface of the sample. When between two measurements no quantity of water was collected the test was considered completed. Zero time was counted from the time of placing the sample in the test container. One minute before each reading the container with the concrete samples was inclined at an angle of approximately 15°, promoting the positioning of surface water on one side of the container to facilitate its collection. The water was collected at 12-min intervals, long enough to deal with several samples simultaneously.

The setting time of the concrete was determined under the same ambient conditions as the bleeding test, and simultaneously with the plastic shrinkage test. The measurements were carried out according to the French standard NF EM 196-3 (1990), using the test apparatus with a Vicat needle adjusted to receive an extra mass of 700 g, ensuring that the needle was not blocked by fine aggregate grains. The evaluation of setting was carried out after sieving of the concrete in a sieve with an open mesh of 4.8 mm to remove coarse aggregates. The measurement of heat evolution in mortar samples with the same composition as the concrete, except for the presence of coarse aggregates, was carried out using a semi-adiabatic calorimeter [19,20]. The temperatures were collected using type-K thermocouples, and stored in a Data Logger connected to a PC. The plastic shrinkage test consisted of monitoring the linear deformation of a prismatic sample of $70 \times 70 \times 500$ mm^3. Immediately after concrete manufacture, the sample was taken to a climatic chamber for molding in the plastic shrinkage monitoring equipment. The equipment for the measurement of deformation consisted of an LVDT – Linear Variable Differential Transducer, fixed to a metal plate in contact with the concrete sample. This plate was fixed to the sample by four screws inserted into the fresh concrete. The plastic shrinkage measurement was carried out through the displacement of the metal plate. The LVDT was connected to a signal amplifier which downloaded the data to a Data Logger coupled to a microcomputer.