Thermochimica Acta 498 (2010) 1–6

Contents lists available at ScienceDirect

Thermochimica Acta

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

Review

The effect of the content of unburned carbon in bottom ash on its applicability for road construction

Prvoslav D. Trifunovic[a], Slobodanka R. Marinkovic[a,*], Rade D. Tokalic[a], Srdjan D. Matijasevic[b]

[a] Faculty of Mining and Geology, University of Belgrade, Djusina 7, 11000 Belgrade, Serbia
[b] Institute for the Technology of Nuclear and Other Raw Materials, Franse d Eperea 86, 11000 Belgrade, Serbia

A R T I C L E I N F O

Article history:
Received 10 June 2009
Received in revised form 26 October 2009
Accepted 31 October 2009
Available online 12 November 2009

Keywords:
Unburned carbon
Recycling of bottom ash
Road construction
Differential thermal analysis
Thermogravimetric analysis

A B S T R A C T

The content of unburned carbon is an important characteristic of bottom ash which could make it unsuitable for incorporation as aggregate for road construction. In this work, the effect of the content of unburned carbon in the bottom ash from the Serbian power plant "Nicola Tesla" on its applicability for road construction was examined. Four samples with different contents of unburned carbon, *i.e.*, raw bottom ash, two size fractions obtained from it (2–5 and <2 mm) and bottom ash treated by the "float–sink" method, were investigated. When these materials were used as a component in the mixture: fly ash–Portland cement–bottom ash–water for road construction, it was found that only mixtures containing bottom ash with a lower carbon content (size fraction <2 mm and treated) were employable. The content of unburned carbon in the mentioned materials was determined by simultaneous DTA/TGA. This method was also used to investigate the composition of the hardened mixtures.

Contents

1. Introduction

Significant amounts of waste coal ashes are produced during combustion of coal in thermal power plants. For ecological and economical reasons, there is intensive research to find ways of increasing the use of these waste materials, especially if they can be utilized in bulk, such as for sub-base and base materials for road construction.

Two kinds of coal ashes are distinguished: fly ash (FA) and bottom ash (BA). There are three principal differences between them:

1. The contents of the oxides: SiO_2, Al_2O_3 and Fe_2O_3 are greater in FA, which consequently may exhibit pozzolanic properties, but BA is a more or less inert material, *e.g.*, bottom ash usually does not exhibit pozzolanic properties;
2. FA has a lower unburned carbon (coal) content;
3. FA consists of finer (powdery) particles than BA, the particles of which are coarse (sized between sand and gravel), fused and with a glassy texture [1,2].

According to the mentioned characteristics, FA could be applied as a partial substitute for Portland cement (PC) and BA as the entire source of aggregate, or blended with natural aggregates (sand and gravel) [2] in road construction.

The content of unburned carbon in the ashes is an important factor for their applicability in road construction.

It was reported in the literature [3] that a high percentage of carbon decreases the pozzolanic activity of fly ash.

Bottom ash, with a higher content of unburned carbon, has a more porous and vesicular texture and consequently is crushed more easily under compacting and loading. There are literature data [4] that show that bottom ash is not a suitable aggregate for most highway construction applications.

It is well known [5–7] that the carbon content is closely related to the particle size distribution in ash. The amount of unburned

* Corresponding author. Tel.: +381 11 3219108; fax: +381 11 3235539.
E-mail address: slobodankamarinkovic@gmail.com (S.R. Marinkovic).

0040-6031/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.tca.2009.10.022

Table 1
Chemical compositions of the fly ash and bottom ash.

	Fly ash (%)	Fly ash specifications (ASTM 618) (%)	Bottom ash (%)
SiO_2	52.27	–	42.09
Al_2O_3	22.34	–	14.72
Fe_2O_3	6.05	–	5.56
$SiO_2 + Al_2O_3 + Fe_2O_3$	80.66	50.0 minimum, Class C70.0 minimum, Class F	62.37
CaO	6.64	less than 10%, Class F more than 10%, Class C	2.64
MgO	4.41	–	2.69
SO_3	2.74	5.0 maximum	1.98
P_2O_5	0.08	–	0.08
TiO_2	1.07	–	0.70
Na_2O	0.41	1.5 maximum	0.33
K_2O	1.36	–	0.90
CaO free	–	–	–
Loss on ignition (L.O.I.)	2.04	6.0 maximum	6.23

carbon decreases with increasing fineness of the ash particles. Due to this, raw bottom ash and various size fractions obtained from it by sieving contain different contents of unburned carbon. Also, it is known that unburned carbon particles are characterized by a lower density than the bottom ash particles and, consequently, the float–sink method may be applied to reduce the carbon content in bottom ash [7,8].

In this work, a sample of raw bottom ash from the Serbian power plant "Nicola Tesla" and samples obtained from it by sieving and treatment by the float–sink method, which thus contained different contents of unburned carbon, were mixed with fly ash, Portland cement and water. After 7 days, the compressive strength and composition of the hardened mixtures were determined.

The aim of the work was to establish the effect of the content of unburned carbon in bottom ash on its applicability as the entire source of aggregate for road construction in the mixture (fly ash–Portland cement–bottom ash–water).

2. Experimental

Fly ash and bottom ash, both by-products or waste materials, from the "Nicola Tesla" thermal power plant, the biggest in Serbia, were used in this work.

The chemical composition of these materials (presented as oxide equivalents) was determined by classic chemical analysis.

The mineralogical composition of the fly ash and bottom ash was investigated by X-ray diffraction analysis, using a Philips PW 1729 X-ray generator and a Philips PW 1710 diffractometer.

The grain size distribution of the bottom ash was determined by sieving through sieves of mesh size 5, 4, 3, 2.5 and 2 mm.

Four samples of bottom ash: S_1, S_2, S_3 and S_4 were used. The S_1 sample was untreated-raw bottom ash. Samples S_2 (2–5 mm size fraction) and S_3 (less than 2 mm size fraction) were obtained by sieving the bottom ash sample. Sample S_4 (treated bottom ash) was prepared from the raw bottom ash by the float sink method.

The float–sink method consisted of immersion of the bottom ash in tap water and separation of the floating material (unburned carbon) by filtration. These operations were performed five times.

The four samples of bottom ash were examined by differential thermal analysis (DTA) and thermogravimetric analysis (TGA) in order to determine their content of unburned carbon. The DTA and TGA examinations were performed using a Netsch STA 409 simultaneous differential thermal and thermogravimetric analyzer. All experiments were performed in an air atmosphere by heating the samples at a constant rate of 10 °C/min in the temperature interval 0–1000 °C.

Mixtures of the four bottom ash samples (S_1, S_2, S_3 and S_4) with fly ash, Portland cement and water (W) were investigated in the manner described below with view of determining their suitability for road construction.

Cylindrical specimens of the mentioned mixtures (with a diameter of 10.2 cm and a height 11.7 cm) were made by means of compression (so-called Proctor specimens). The mass ratios of fly ash:Portland cement and of fly ash + Portland cement:bottom ash were 3:1 and 1:1, respectively, in all mixtures. The required amount of water in the mixtures, *i.e.*, the optimum moisture content, was determined in preliminary research, according to the procedure for the standard Proctor test (SRPS U.B1.012 and SRPS U.B1.038), valid in Serbia. These values were: 47.22, 49.05, 45.80 and 45.99% of the mass of the solid phase in the mixtures with the four bottom ash samples: S_1, S_2, S_3 and S_4, respectively.

After preparation, the specimens were kept under wet condition (about 100% moisture content) at temperature 20 ± 2 °C for 7 days.

The specimens were made in triplicate and designated as:

$$S'_1: \quad \text{FA–PC–BA}(S_1)\text{–W}; \qquad S'_2: \quad \text{FA–PC–BA}(S_2)\text{–W};$$

$$S'_3: \quad \text{FA–PC–BA}(S_3)\text{–W}; \qquad S'_4: \quad \text{FA–PC–BA}(S_4)\text{–W}.$$

The compressive strength of the Proctor-sized specimens (S'_1, S'_2, S'_3 and S'_4) were measured after 7 days.

The specimens crushed during determination of their compressive strength were then pulverized and studied by DTA/TGA analysis in order to determine their composition. The DTA/TGA examinations were performed under the same conditions as those employed for the bottom ash.

3. Results and discussion

The chemical compositions of the fly ash and bottom ash are given in Table 1. The requirements (according to ASTM 618) for the potential use of fly ash as a pozzolan in the construction industry are also shown in Table 1.

Based on the results presented in Table 1, it is evident that the fly ash from the "Nicola Tesla" Power Plant can be classified as a class F fly ash and that it satisfies the chemical requirements for use as a pozzolon in the construction industry, because the content of pozzolan oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) in this fly ash was greater (80.66%) than the minimum content of these oxides (70%) required by ASTM 618. Also, the contents of SO_3 and Na_2O, as well as the L.O.I. are in accordance with ASTM 618 (Table 1).

The bottom ash from the "Nicola Tesla" Power Plant can be classified as a class F ash according to its content of the oxide CaO, but the sum of the oxides: $SiO_2 + Al_2O_3 + Fe_2O_3$ was lower (62.37%) and the L.O.I. higher than regulated by ASTM 618 (Table 1) for a pozzolan. Consequently, it is a relatively chemically inert material.

Based on the X-ray diffraction study, it could be stated that the major crystalline phase in the fly ash was quartz-SiO_2. The other crystalline phases present in small amounts in the fly ash, were mulite-$Al_6Si_2O_{13}$, anhydite-$CaSO_4$, feldspar-$NaAlSi_3O_8$,