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Flow, water absorption, and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash aggregates

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ABSTRACT

This study focused on investigating the flow, water absorption, and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash (FBA) aggregates. It was also intended to examine the effects of FBA aggregates on the performance of the mortar. The effects of FBA aggregates on the density, compressive strength, dynamic modulus of elasticity and flow characteristics of the mortar were investigated, and the porosity and water capillary absorption of the mortar were measured to evaluate the properties of moisture transport, which may affect the durability of the mortar. It was found from the study that the mortar flow was increased by 10–20% with the replacement by FBA aggregates. The specific compressive strength of the mortar with FBA aggregates was shown to be 5–11% higher than that of the mortar with normal fine aggregates. It was also shown that water would be absorbed more slowly into the mortar with FBA aggregates when the porosity was the same as that of the mortar with normal aggregates.

1. Introduction

As the importance of coal-fired power plants for electricity supply has been emphasized, coal consumption and production have increased at the same time. This trend can be observed globally and many studies to utilize coal production have been conducted. As a result, fly ash, which accounts for 75–80% of coal ash, has widely used as a cement material, admixture, and so on [12,21]. However, most bottom ash, which constitutes 10–15% of coal ash, is still disposed in landfills [30]. In Japan, the amounts of coal ash increased from approximately 8.0 million tons in 2000 to over 10.0 million tons in 2006 [16]. In US, the amount of fly ash and bottom ash generated were 71.7 million tons and 18.1 million tons, respectively, in 2007 while in Europe the amounts of coal ash and bottom ash in the same year was 61.2 thousand tons, 5.7 thousand tons, respectively [1,13]. The high amount of coal ash and bottom ash is causing several environmental problems, including landfill issues and pollution. Upon this background, many studies pertaining to the utilization of bottom ash in concrete have been conducted in the last few decades.

Wei et al. [32] studied the influence of coal combustion by products such as fly ash and bottom ash on the compressive strength, bulk density of concrete and curing temperature. Bakoshi et al. [5] investigated the strength and durability of concrete using bottom ash as a replacement of fine aggregate and found that the use of bottom ash with 10–40% replacement was effective to improve the concrete properties including compressive strength, tensile strength, abrasion resistance, except the freezing and thawing resistance. Cheriaf et al. [10] studied the pozzolanic properties of a coal combustion bottom ash. They found that the pozzolanic activity of bottom ash was very low at early ages, but this activity started at 28 days and accelerated until 90 days [10].

In the research by Canpolat et al. [9], as zeolite, coal bottom ash, and fly ash were substituted as Portland cement replacement materials, the physical and mechanical properties of cement production were investigated through three different combinations of tests. Bai et al. [4] studied the strength and drying shrinkage of concrete using bottom ash as a fine aggregate. They found that the compressive strength concrete with 30% of the fine aggregate replaced with bottom ash was 40–60 MPa compressive strength without any detrimental effects on the permeation or drying shrinkage properties of the structural concrete [4].

Yüksel et al. [34] investigated the influence of bottom ash, granulated blast furnace slag, and a combination of both materials which were substituted as a fine aggregate replacement on the concrete durability. The study concluded that durable concrete can be produced by using granulated blast furnace slag and bottom ash as fine aggregate [34]. Andrade et al. [2] reported the behavior of concrete using bottom ash as a fine aggregate and evaluated the mechanical properties (compressive strength and elastic modulus) and some properties related to moisture transport. Andrade et al. [3] carried out the investigation on the influence of bottom ash substituted for a fine aggregate replacement on the properties of

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fresh concrete, such as water loss by bleeding, setting time, heat evolution and plastic shrinkage.

In light of the background outlined above, this study focused on investigating the flow, water absorption, and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash (FBA) aggregates. The effects of FBA aggregates on the performance of the mortar were also examined in this study. The effects of FBA aggregates on density, compressive strength, dynamic modulus of elasticity and flow characteristics of mortar were investigated, and the porosity and water capillary absorption of the mortar were measured to evaluate the properties of moisture transport, which may affect the durability of the concrete.

2. Experiments

2.1. Material preparation and mix proportion

Type I Portland cement (C) and silica fume (SF) were used as binder materials throughout this investigation, and their chemical and physical properties are listed in Table 1. Normal fine (NF) aggregates (sands) were used in the mixture with NF aggregates, while FBA aggregates (Fig. 1) obtained from the Seocheon thermal power plant, which used a pulverized coal firing boiler system, were used in the mixture with FBA aggregates. The combustion temperature in the boiler system was in a range of 1400–1550 °C. The gradation of FBA aggregates was adjusted in accordance with the gradation of normal aggregates prior to the experiments. The chemical composition of FBA is listed in Table 2. The physical proportion, gradation, and scanning electron microscope (SEM) images of the NF and FBA aggregates are presented in Table 3, Figs. 2 and 3, respectively. The chemical compositions of silica fume and bottom ash were characterized by the Philips energy-dispersive type X-ray fluorescence (XRF) spectrometer (Minipal 2), whereas the chemical compositions of the cement used in this study were acquired from the manufacturer of the cement.

The mix proportion with five mixtures with different water/binder (W/B) ratios (50%, 38%, 30%, 24%, and 20%) used to evaluate the effects of FBA aggregates on normal and high strength mortar is listed in Table 4. The volume proportions of aggregates, silica fume, and superplasticizer for each mixture were adjusted considering workability and strength of the mortar. Note that FBA aggregates replaced NF aggregates at a level of 100% by volume percentage for each mixture with FBA aggregates. Dosages of silica fume and superplasticizer were fixed for each mixture even when the type of aggregates was changed.

2.2. Experimental details

The moisture contents of NF and FBA aggregates were controlled at a surface saturated dry condition (S.S.D.). All batches were mixed in a Hobart mixer in accordance with ASTM C305. The materials except water and superplasticizer were mixed for 1–2 min, water and superplasticizer were then added, and mixing was performed again for 2–3 min.

The flow characteristics of the mortar were measured in accordance with ASTM C1437. The demolded specimens after a single day from the time of manufacturing were cured in a water tank at room temperature. The density and water absorption of the 100 mm × 100 mm cylinder type specimens cured for 28 days were measured. The density and water absorption of the mortar specimens can be calculated as (c.f. ASTM C127; [17]:

$$\text{Density}_{\text{S.S.D.}}\ (\text{kg/m}^3) = \frac{M_{\text{S.S.D.}}\rho_{\text{water}}}{M_{\text{S.S.D.}} - M_{\text{in water}}} \quad (1)$$

Table 1
Properties of binder materials.

	Type I Portland cement (C)	Silica fume (SF)
Chemical composition (wt.%)		
CaO	64.07	1.30
Al_2O_3	4.96	4.00
SiO_2	22.00	90.70
Fe_2O_3	3.66	1.09
K_2O	0.91	2.00
MgO	1.92	–
SO_3	1.92	–
Physical properties		
Specific gravity	3.15	2.20
Surface area (m^2/g)	0.35 (Blaine)	19.62 (BET)

Fig. 1. FBA aggregates used in the experiments (measured in mm).

Table 2
Chemical composition of FBA (wt.%).

CaO	2.40
Al_2O_3	36.00
SiO_2	34.00
Fe_2O_3	16.80
K_2O	5.90
TiO_2	3.80

Table 3
Physical properties of NF and FBA aggregates.

Physical properties	Normal fine (NF) aggregates (crashed sand)	Fine bottom ash (FBA) aggregates
Specific gravity		
(S.S.D.)	2.55	1.87
(O.D.)	2.54	1.77
Water absorption (also, porosity)		
(wt.%)	0.48	5.45
(vol.%)	1.22	10.19
Fineness modulus	2.36	2.34

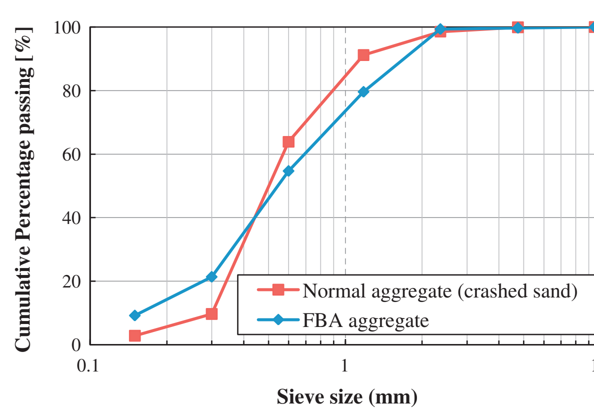

Fig. 2. Gradation curve of the NF and FBA aggregates used in the experiments.