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Effect of fly ash fineness on microstructure of blended cement paste

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Abstract

This research demonstrates the effect of fly ash fineness on pore size and microstructure of hardened blended cement pastes. Two sizes of fly ash, original fly ash and classified fly ash were used to replace Portland cement type I paste. Test results indicated that the pore sizes of hardened blended cement paste were significantly affected by the rate of replacement and the fineness of fly ash. The replacement of cement by original fly ash decreased the pore sizes of blended cement paste and the incorporation of classified fly ash resulted in a further decrease in the pore sizes of blended cement paste. The X-ray diffraction (XRD) results showed that the blended cement paste with classified fly ash was more effective at reducing the intensity of $Ca(OH)_2$ than that with the original fly ash. The scanning electron microscope (SEM) results revealed that the hardened blended cement paste containing finer fly ash produced a denser structure than the one containing coarser fly ash.

Keywords: Fineness; Fly ash; Pore size; Microstructure; Blended cement paste

1. Introduction

Concrete is a composite material which has a complex microstructure and exhibits a wide range of scale lengths from nanometers to millimeters [1]. Aggregates are the biggest materials in concrete and have particle size in millimeters. At the micrometer scale, the cement paste is a composite of unhydrated residues of cement grains and hydration products (C–S–H, $Ca(OH)_2$, and capillary pore). Hydrated cement paste contains large capillary pores with diameters between 50–10,000 nm, medium capillary pores with diameters of 10–50 nm and gel pores with diameter of less than 10 nm [2]. It is well known that the service life of a concrete structure is strongly dependent on its material transport properties, which are controlled by the microstructure characteristics of concrete. It is generally recognized that the incorporation of pozzolanic materials as a partial replacement for Portland cement in concrete is an effective means for improving the properties of concrete. Pozzolanic materials react with calcium hydroxide during hydration reaction and forms calcium silicate hydrate. This can reduce the size of the pores of crystalline hydration products, make the microstructure of concrete more uniform and improve the impermeability and durability of concrete. These improvements can lead to an increase in the service life of a concrete structure.

Fly ash is a waste product from the combustion of pulverized coal in electricity power plants. It is estimated that more than 3.5 million tons of fly ash has been produced annually in Thailand since 2001, however, only half has been utilized. The utilization of fly ash is still limited due to lack of understanding of the characteristics of fly ash itself and the properties of concrete containing fly ash. Many researchers have already reported on the influence of fly ash on the properties of concrete such as compressive strength, sulfate resistance, durability and so on. However, few researches were found, which deal with the fineness of fly ash on pore structure and microstructure of blended cement paste. An understanding of the influence of fineness

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of fly ash on pore structure and microstructure of cement paste could lead to an increase in the use of fly ash in concrete. In this paper, pore structure and microstructure of fly ash cement pastes with different fly ash finenesses are investigated.

2. Experimental program

2.1. Material properties

Fly ash from Mae Moh power plant in the north of Thailand, Portland cement type I (PC) and tap water were used in this study. The chemical composition of Portland cement type I (PC), original and classified fly ashes (OFA and CFA) are given in Table 1. The total amount of the major components SiO_2, Al_2O_3, and Fe_2O_3 in OFA and CFA are 81.54% and 79.44%, respectively. They can be classified as class F fly ash in accordance with ASTM C 618. It should be noted that there is no significant difference in the chemical composition of OFA and CFA. Two fly ash sizes of OFA with median particle size of 19.1 μm and CFA with median particle size of 6.4 μm were used to replace Portland cement. Physical properties of PC, OFA, and CFA are shown in Table 2 and particle size distributions are shown in Fig. 1. Particle shapes of PC, OFA, and CFA by SEM are shown in Fig. 2.

The X-ray diffraction patterns (XRD) of OFA and CFA are shown in Fig. 3. There is little difference between the XRD patterns of OFA and CFA. It is known that fly ashes consists of a glassy matrix with crystalline phases like quartz, mullite, hematite, anhydrite, lime, and so on. In the Mae Moh fly ash, quartz is commonly found as the crystalline compound in OFA and CFA. In addition, traces of hematite and mullite are also noticeable. Chindaprasirt et al. [3] studied the glassy phase content of the Mae Moh fly ash and found that the glassy phase content of

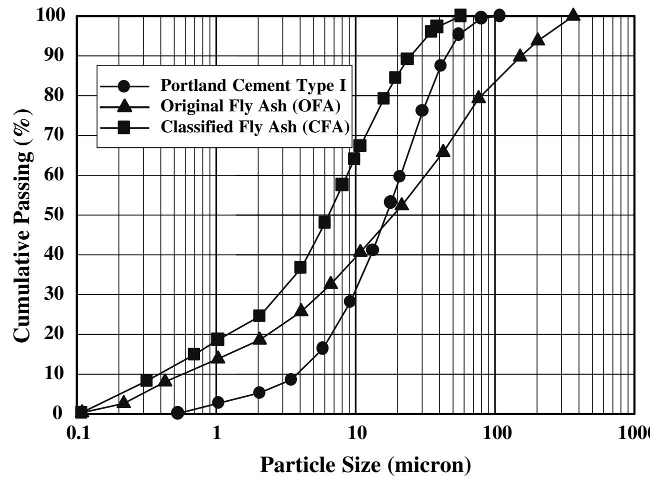

Fig. 1. Particle size distribution of PC type I and fly ashes.

the fine fly ash (about 85–90%) was higher than that of the coarser fly ash (about 70–75%). This result agreed with Berry et al. [4], who showed that the glassy phase was found to increase in the fine fly ash as compared to the original fly ash.

2.2. Mix proportion

Fly ashes were used to replace Portland cement at the rate of 0, 20, and 40% by weight of binder. The water to binder ratio (W/B) was constantly 0.35 throughout the investigation. The pastes were mixed in a mechanical mixer and were cast in 50 mm cube molds and compacted by tamping rod, and were sealed by plastic to prevent water loss. 24 h after casting, specimen were removed from the molds and cured in saturated lime water.

2.3. Mercury intrusion porosimetry

Measurement on pore size distribution of paste was carried out using mercury intrusion porosimeter (MIP) with a pressure range from 0 to 33,000 psi (228 MPa), capable of measuring pore size diameter down to 5.7 nm. By carefully breaking the hardened blended cement paste cubes with a chisel, the representative samples of 3–6 mm pieces weighing between 1 and 1.5 g were taken from the middle of the specimen. The samples were frozen at −195 °C by immersion in liquid nitrogen for 5 min and evacuated at a pressure of 0.5 Pa at −40 °C for 48 h [5–7]. Mercury porosimetry is expressed by the Washburn equation [8]. A constant contact angle of 140° and a constant surface

Table 1
Chemical composition of PC type I and fly ashes

Chemical composition (%)	Portland cement type I	Original fly ash	Classified fly ash
SiO_2	20.90	45.69	44.72
Al_2O_3	4.76	24.59	23.69
Fe_2O_3	3.41	11.26	11.03
CaO	65.41	12.15	12.67
MgO	1.25	2.87	2.63
SO_3	2.71	1.57	1.28
Na_2O	0.24	0.07	0.07
K_2O	0.35	2.66	2.87
LOI	0.96	1.23	1.42

Table 2
Physical properties of PC type I and fly ashes

Sample	Median particle size (μm)	Retained on a sieve No. 325 (%)	Specific gravity	Blaine fineness (m^2/kg)
Portland cement type I	14.1	4.8	3.15	360
Original fly ash	19.1	31.0	2.33	300
Classified fly ash	6.4	0	2.54	510