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Effect of fly ash fineness on compressive strength and pore size of blended cement paste

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Abstract

This paper presents an experimental investigation on the effect of fly ash fineness on compressive strength, porosity, and pore size distribution of hardened cement pastes. Class F fly ash with two fineness, an original fly ash and a classified fly ash, with median particle size of 19.1 and 6.4 μm respectively were used to partially replace portland cement at 0%, 20%, and 40% by weight. The water to binder ratio (w/b) of 0.35 was used for all the blended cement paste mixes.

Test results indicated that the blended cement paste with classified fly ash produced paste with higher compressive strength than that with original fly ash. The porosity and pore size of blended cement paste was significantly affected by the replacement of fly ash and its fineness. The replacement of portland cement by original fly ash increased the porosity but decreased the average pore size of the paste. The measured gel porosity (5.7–10 nm) increased with an increase in the fly ash content. The incorporation of classified fly ash decreased the porosity and average pore size of the paste as compared to that with ordinary fly ash. The total porosity and capillary pores decreased while the gel pore increased as a result of the addition of finer fly ash at all replacement levels.

Keywords: Fineness; Fly ash; Compressive strength; Porosity; Blended cement paste

1. Introduction

Concrete is one of the most widely used materials in construction. In designing a concrete structure, one of the most important properties which has to be considered, besides the ability of the structure to resist all loads, is its durability. The service life and durability of a concrete structure strongly depend on its material transport properties, such as permeability, sorptivity, and diffusivity which are controlled by the microstructural characteristics of concrete [1]. It is known that the porosity and pore size distribution are the critical components of the microstructure of hydrated cement paste that influence durability. In order to achieve high strength, low permeability, and durable concrete, it is therefore necessary to reduce the porosity of cement paste. It is well known that the incorporation of pozzolanic materials as partial replacement of cement refines the porosity and pore size distribution of the paste. Fly ash is known to be a good pozzolanic material for use in concrete, and many researches have established its effect on the physical properties and pore structure of concrete. However, the pore structure changes due to differences in fly ash fineness are not well established. The present paper, therefore, attempts to provide essential information on the strength and porosity of blended cement with fly ash of two finenesses.

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2. Experimental details

2.1. Materials

Class F fly ash from Mae Moh power plant in the north of Thailand, ASTM Type I portland cement (PC), and tap water were used in this study. Two fly ash finenesses, an original fly ash (OFA) with the median particle size of 19.1 μm and a classified fly ash (CFA) with the median particle size of 6.4 μm were used (Fig. 1). The percentage of OFA retained on sieve No. 325 (45 μm) was 31% and all particles of CFA passed through No. 325 sieve. The Blaine fineness of PC, OFA and CFA were 360, 300 and 510 m^2/kg, respectively. The specific gravities of OFA and CFA were 2.33 and 2.54, respectively.

2.2. Mix proportions and specimens

Fly ashes were used to replace portland cement at dosage levels of 0%, 20%, and 40% by mass of binder. A constant water to binder ratio (w/b) of 0.35 was used throughout the investigation. The pastes were mixed in a mechanical mixer and the specimens were cast in 50 mm cube moulds. The fresh samples were covered with polyethylene sheet to prevent evaporation. After 24 h, the samples were removed from the mould and cured in saturated lime water.

2.3. Compressive strength and mercury intrusion porosimetry

The compressive strength of pastes was tested at 7, 28, 60, and 90 days in accordance with ASTM C 109. Each compressive strength value was the average of three samples. The measurement on total porosity, capillary porosity, gel porosity, and pore size distribution were carried out using a mercury intrusion porosimeter (MIP) with a pressure range from 0 to 33,000 psi (228 MPa) and capable of measuring pore size diameter down to 5.7 nm. The samples were obtained 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 were then evacuated at a pressure of 0.5 Pa at −40 °C for 48 h. Previous studies on hardened cement paste and mortars have shown that the freezing–drying technique is an acceptable procedure for MIP investigation [2,3]. Mercury porosimetry is based on the capillary law governing liquid penetration into small pores. This law, in the case of a non-wetting liquid like mercury and cylindrical pores, is expressed by the Washburn equation [4].

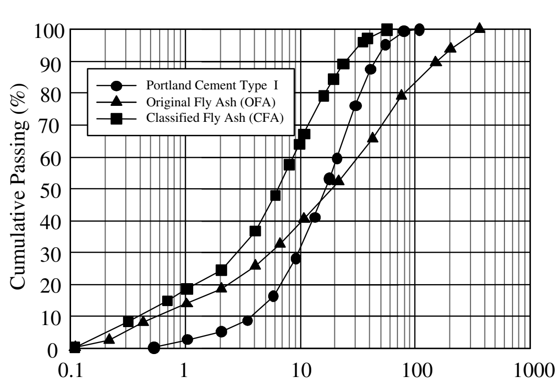

Fig. 1. Particle size distribution of portland cement Type I and fly ashes.

3. Results and discussion

3.1. Compressive strength

Compressive strength of pastes is presented in Table 1. The compressive strength of blended cement paste decreased with an increase in the replacement of fly ash. When fly ash was classified to a reasonably fine fly ash, the rate of compressive strength gain of the blended cement pastes was significantly improved and this conformed with other research studies [5–9]. In fact, the compressive strengths of the CFA paste at 90 days were significantly higher than those of OFA paste and were only slightly lower than that of the PC paste at the same age. This was the result of the packing effect of fine fly ash. The small and spherical fly ash particles filled the voids or airspaces and increased the density [10,11]. The smaller particle size of fly ash with a higher surface area and glassy phase content also improved the pozzolanic reaction [7,12]. Therefore, the CFA made the blended cement paste more homogeneous and denser as well as having a higher pozzolanic reaction than the one containing the original fly ash, and this resulted in an increase in the compressive strength.

3.2. Porosity and average pore diameter of blended cement pastes

Total porosity, capillary porosity (10 nm–10 μm), and gel porosity or small capillary porosity (5.7–10 nm) of

Table 1
Compressive strength and percentage of compressive strength of pastes

Type of paste	Compressive strength (MPa)			
	7-day	28-day	60-day	90-day
PC	60.9	77.6	84.5	84.8
OFA20	45.2	64.5	70.4	74.5
OFA40	30.6	56.6	60.1	61.4
CFA20	47.2	69.3	76.6	81.4
CFA40	44.1	65.3	73.6	78.5

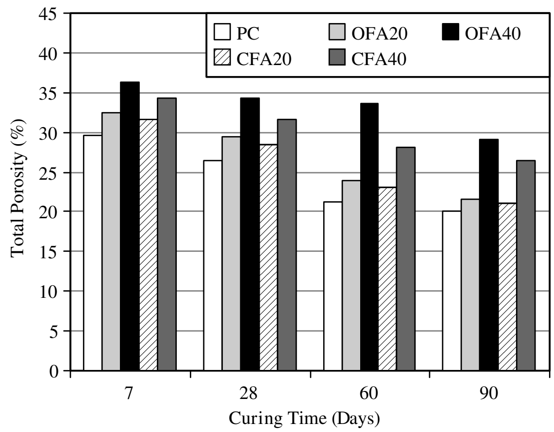

Fig. 2. Total porosity of pastes at 7, 28, 60 and 90 days.

pastes at 7, 28, 60, and 90 days are shown in Figs. 2–4. From Figs. 2 and 3, the results showed that incorporation of fly ash increased the total porosity and capillary porosity of the blended cement pastes at all ages as com-

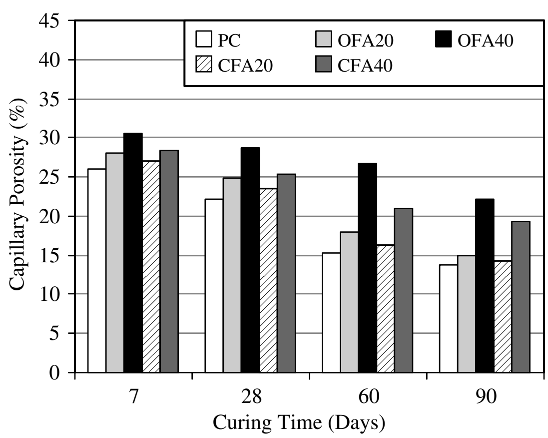

Fig. 3. Capillary pores of pastes at 7, 28, 60 and 90 days.

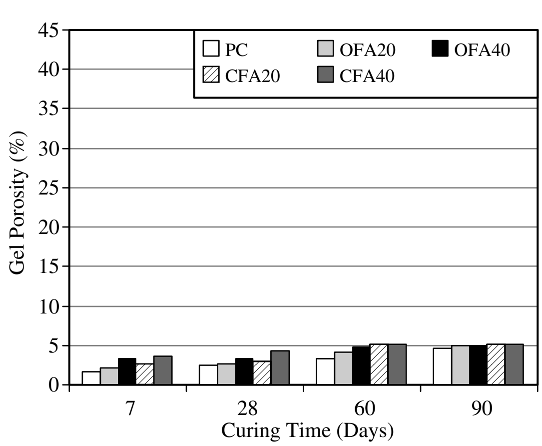

Fig. 4. Gel pores of pastes at 7, 28, 60 and 90 days.

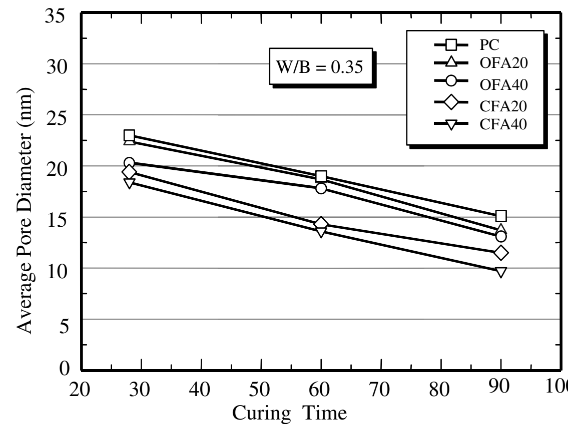

Fig. 5. Average pore diameters of pastes at 28, 60 and 90 days.

pared to that of PC paste. The total porosity and capillary porosity increased with an increase in the replacement of fly ash. The total porosity and capillary porosity of the blended cement paste containing finer fly ash (CFA) was significantly lower than that with coarser fly ash (OFA) but was still larger than that of the PC paste at all replacements and ages. It should be noted here that the compressive strength decreased (see Table 1) while the total porosity and capillary porosity of blended cement paste increased. Similar finding was also reported by other investigations [13–16].

For the gel porosity as shown in Fig. 4, the incorporation of higher replacement level of both OFA and CFA resulted in larger amount of gel porosity as compared to those of PC paste at all ages. The CFA was effective in increasing the gel porosity suggesting the better dispersion in the cement paste.

The results of the average pore diameter of pastes as shown in Fig. 5 showed that the blended cement paste containing OFA had smaller average pore diameter than that of PC paste. The average pore diameter decreased with an increase in the fly ash replacement level. The average pore diameter further reduced with the use of CFA and with an increase in the replacement level. This again confirmed that CFA was more effective in reducing the average pore size as a result of better dispersing and packing of the finer CFA particles.

4. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1. The blended cement pastes containing the original fly ash exhibited higher total porosity and capillary porosity than those of portland cement paste and resulting in lower compressive strength of the blended cement paste as compared to portland cement paste.

2. The blended cement pastes containing the classified fly ash resulted in higher compressive strength, lower total porosity and capillary porosity than those with the original fly ash.
3. The pore size distribution and the average pore diameter of blended cement paste containing fly ash decreased with an increase in fly ash content and fineness.
4. Gel porosity (small capillary porosity) between 5.7 and 10 nm of the blended cement paste containing the classified fly ash were higher than those of the original fly ash and portland cement pastes.

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