

Effects of size fraction on composition and fundamental properties of Portland cement

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ABSTRACT

To characterize roles of size fraction of Portland cement to its properties, Portland cement was classified into several fractions by air classifier. Then composition and hydration related properties of each Portland cement fraction were investigated. The results show deviation of chemical and mineral compositions occurs during classification. Both fine and coarse Portland cement fractions have undesirable strength contribution. Portland cement fractions falling in the range of 8–24 μm have low water requirement, high hydration rate and highest 28 days compressive strength. Thus Portland cement is recommended to be arranged in middle fraction (8–24 μm), while high activity supplementary cementitious materials (SCMs) and low activity SCMs (or inert fillers) are suggested to be arranged in fine and coarse fractions, respectively, by which Portland cement can be replaced by SCMs (or inert fillers) in larger extent without or with little performance loss.

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1. Introduction

It is reported that different Portland cement fractions have varying characters, including water requirement, hydration and mechanical performance [1]. Many attempts have been made to correlate the particle size distribution (PSD) of Portland cement with their service properties [2]. Some empirical regression models are proposed [3], by which cement strength can be predicted based on its PSD. It is reported that the strength of cement is greatly influenced by cement particles in the range of 3–30 μm [4], cement particles larger than 45 μm are difficult to hydrate, and that larger than 60 μm have mainly a “filling effect” and make practically no contribution to strength development [5,6]. Tsivilis et al. [7] concluded that the best PSD of a Portland cement should be continuous and steep with >65% in the range of 3–32 μm and <10% in the fraction under 3 μm . An increase of very fine particles (under 3 μm) may results in high early strength, but also in high water requirement, undesirable volume changes and deterioration in rheological properties [4]. Other properties affected by size fraction are heat release, capillary porosity percolation, diffusivity, shrinkage and microstructure [8].

Composition and fundamental properties (such as water requirement, hydration degree and strength contribution) of each Portland cement fraction were investigated in present study. The principal objective is to determine which size fractions contribute most to the properties of Portland cement. The results will be very

useful for preparation of high performance blended cement with low clinker content and more efficient utilization of Portland cement clinker.

2. Experiment and results

2.1. Materials and classification

To prepare Portland cement fractions with different PSDs, a commercial Portland cement and a laboratory air classifier was used in the experiment. The chemical composition of the Portland cement is given in Table 1. By changing operational parameters, such as air flow rate, feed rate and rotor speed of the classifier, the Portland cement was classified into eight fractions. PSDs of all fractions measured by laser diffraction method are given in Fig. 1 and Table 2. Since all fractions prepared have a narrow particle size distribution, D_{50} is taken as the mean size of each size fraction.

2.2. Chemical and mineral compositions

Due to grindability difference of cement minerals, the chemical and mineral compositions are likely to vary with the particle size of cement. Taylor proposed that the ratio of C_2S – C_3S increases steadily with the decreases of particle size, while the content of C_3A and C_4AF being little affected [9]. However, Lea chemistry of cement and concrete reported that the ratio of C_2S – C_3S reaches a maximum value in intermediate size range [10].

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Table 1
Chemical composition of the Portland cement used in the experiment.

Material	Chemical composition (%)									
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	LOI	Sum
Portland cement	21.60	4.35	2.95	63.81	1.76	0.51	0.16	2.06	1.19	98.39

Note: LOI, loss on ignition.

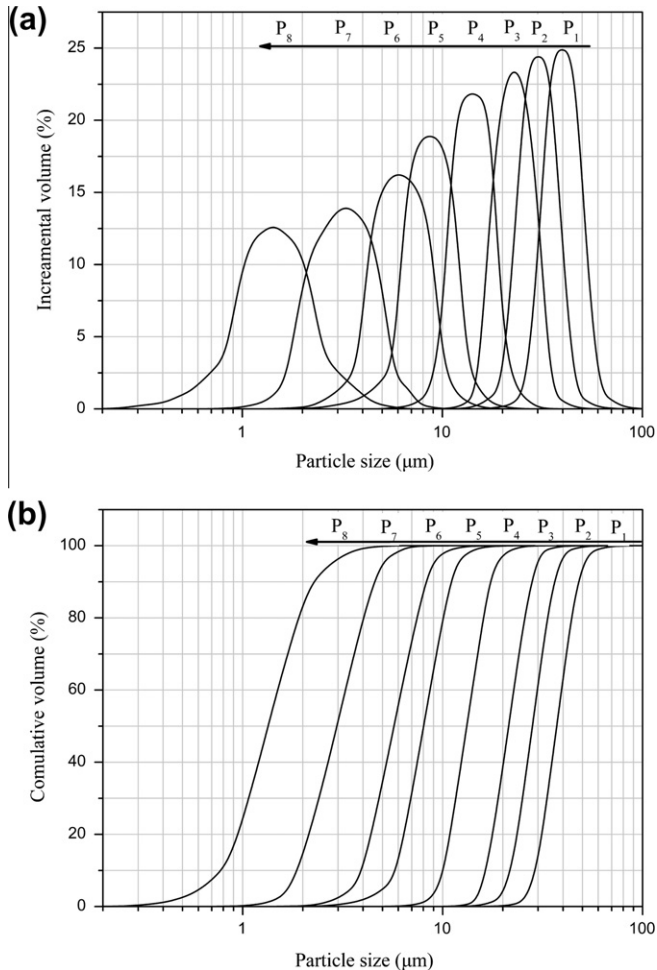


Fig. 1. Particle size distribution of different Portland cement fractions: (a) incremental volume vs. particle size, and (b) cumulative volume vs. particle size.

Table 2
Particle size distribution parameters of different Portland cement fractions.

Fraction	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈
D ₁₀ (μm)	29.45	22.07	16.81	10.29	6.17	4.03	1.90	0.81
D ₅₀ (μm)	36.37	28.27	21.48	13.19	8.24	5.61	3.09	1.50
D ₉₀ (μm)	46.55	35.05	26.84	16.53	11.23	8.11	4.72	2.28

Note: D₁₀, D₅₀ and D₉₀ are the maximum particle diameters when cumulative volume reaches 10%, 50%, and 90%, respectively.

X-ray fluorescence spectroscopy (XRF) analyses were carried out on typical fractions to check if any variation in chemical composition had occurred during the classification. The mineral composition of Portland cement fractions were determined by quantitative X-ray diffraction under conditions of 40 kV, 15 mA, Cu Kα₁, 0.05°/2θ step size, and 3 s/step using *K*-value method, in which α-Al₂O₃ was used as internal standard substance. Meanwhile mineral composition was also calculated according to Bogue's formula.

Table 3 presents that as particle size gets finer, the SiO₂ and CaO contents of cement fractions decrease slightly, while loss on ignition and SO₃ content increase significantly. For instance, the SO₃ content in the finest fraction is over triple of that in the coarsest fraction. It can be seen from Table 4 that mineral composition determined by the two methods shows similar tendency, with the decreases of the mean size of Portland cement fractions the amount of C₃S increases gradually and CaSO₄·2H₂O increases remarkably, while that of C₂S decreases dramatically and C₄AF declines slightly. The results consist with Taylor's findings, and can be illustrated by brittleness index of each cement mineral advocated by Hornain and Regourd [9].

2.3. Water requirement for normal consistency

Water requirement of each Portland cement fraction was determined as necessary quantity of water to obtain a cement paste of normal consistency. No remarkable increase in water requirement was observed for the cement fractions with mean size larger than 8 μm as shown in Fig. 2. For fractions with mean size under 8 μm, however, water requirement increases significantly in parallel with the decreases of mean size. For example, in comparison to the fraction with D₅₀ = 36.37 μm, the water requirement of the fraction with D₅₀ = 13.19 μm only increases by 11.7%, whereas that of the fraction with D₅₀ = 1.50 μm increases by 143.3%.

2.4. Hydration degree and heat evolution

Although water requirements of different Portland cement fractions vary so significantly, cement paste or mortar with equal fluidity are largely used in Practical application, thus hydration related properties of cement paste with certain fluidity (such as normal consistency) were determined in following experiment.

Hydration degree of cement paste of normal consistency was investigated by testing non-evaporable water content. Small pieces taken from different parts of the hardened cement paste were put into ethyl alcohol to terminate their hydration at desire ages, before placed in a furnace at 105 °C for at least 24 h hydrated cement paste was ground. Hydrated cement powder was weighed and heated to 1005 °C for 2 h. Based on that the hydration of 1.0 g of anhydrous cement produces 0.24 g of non-evaporable water, the hydration degree (α) of each cement fraction can be calculated by [11]:

$$\alpha = \frac{W_{105} - W_{1005}}{0.24 \times W_{1005}} \quad (1)$$

where W₁₀₅ and W₁₀₀₅ are the sample weights before and after heating to 1005 °C, respectively.

The hydration degree of each Portland cement fraction is depicted in Fig. 3. It can be seen that the hydration degree of each cement fraction increases gradually as hydration proceeds, and the fine fractions have much higher hydration degree than coarse fractions, especially at early ages. For instance, the hydration degree of the fraction with D₅₀ = 1.50 μm is 18.6% after 5 min hydration, which is nine times higher than that of the fraction with D₅₀ = 36.37 μm. More importantly, the hydration degree of the fractions in the range of 8–24 μm (D₅₀ = 8.24 μm and

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