

Effects of the fineness of limestone powder and cement on the hydration and strength development of PLC concrete



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HIGHLIGHTS

- Limestone powder accelerated cement hydration by providing nucleation site.
- Limestone addition up to 15 wt% improved the compressive strength compared to Plain by formation of new hydration products.
- Large surface area of cement clinker is more effective to enhance the strength than that of limestone powder.

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ABSTRACT

Portland limestone cement (PLC) have been widely used in the world because of its environmental impact, which is less carbon dioxide emissions by using less amount of cement clinkers. Moreover, formation of monocarboaluminates as fillers in cement can improve dense concrete microstructures by reacting with C_3A . Also, larger nucleation sites from limestone powder can enhance strengths due to the active cement hydration. Thus, in this study, the effects of the fineness and replacement of limestone powder on the hydration and strength properties of concrete were investigated by X-ray diffraction (XRD), setting times, isothermal calorimetry, compressive strength and mercury intrusion porosimetry techniques. The obtained results showed that the addition of limestone powder accelerated cement hydration by providing nucleation sites for the hydration products, and as a result, the fineness of cement and limestone powder strongly influenced on the hydration reaction and the strength development.

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1. Introduction

Cement and concrete, the two most widely used construction materials, often causes major environmental problems due to the large amounts of CO_2 emission produced during their manufacturing. In order to reduce the CO_2 emission level, multiple researches on the mineral addition of ground granulated blast-furnace slag, fly ash, silica fume, or limestone powder to ordinary Portland cement (OPC) have been conducted. In particular, limestone powder is widely used as a mineral admixture in concrete because of its natural availability as well as technical and economic advantages [1,2].

The effects of limestone powder addition on the hydration and strength properties of OPC have been studied by various research groups, which found that its presence increased the hydration rate of Portland cement during early age stages [3,4]. In addition, Portland Cement Association [5] provided the research on the hydra-

tion and setting times, heat evolution, microstructures as well as effects of particle size distribution on the mechanical properties of PLC concrete. The study of the hydration kinetics and compressive strength of the PLC paste and mortars produced by various curing methods revealed that the negative effect of cement dilution on the mechanical properties of the obtained mortars caused by the limestone powder addition could be alleviated by the increase in limestone powder fineness [6].

Since increasing the fineness of limestone powder results in a greater number of nucleation sites, the hydration reaction of tri-calcium silicate (C_3S), a major component of Portland cement, can be accelerated by the presence of limestone powder [7–9], while other cement hydration reactions remain limited [10]. In other words, the surface of limestone filler particles plays an important role in providing nucleation sites for the precipitation of hydration products. The sites from the limestone powder were able to reduce the energy barrier and can promote hydration product formation much faster from the pore solution [11].

In addition, the use of fillers with large surface areas can lead to low capillary porosity and thus increase the compressive strength

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[12]. Stark et al. [8] found that the addition of 6 wt% of limestone powder significantly affected the hydration of the main cement components, which are C_3S , tricalcium aluminate (C_3A), and tetra-calcium aluminoferrite (C_4AF) as well as the early cement strength measured during the first 4 days. Lecomte et al. [4] investigated the effect of grinding on the properties of PLC and found that adding limestone filler increased material sorptivity and changed porosity characteristics.

In order to extend the application of PLC in the cement and concrete industry, various studies on the concrete using limestone powder have been recently conducted. Various PLC mix proportions were provided with the test results such as mechanical and physical properties of samples [13]. Blending GGBFS and limestone powder was used to improve PLC hydration with various mix proportions [14]. In order to investigate the contribution of limestone for the cement hydration, calorimetric analysis was used with defined M-values [15].

However, only few researches for practical use such as large amount of limestone powder use in concrete have been conducted. Generally, the compressive strength and other mechanical properties of PLC containing more than 15 wt% of limestone powder were lower than those of OPC concrete.

The purpose of this study is to investigate the effect of fineness of limestone powder and cement on the physical properties of PLC to obtain the efficient mix proportions of PLC in this study.

2. Experiment

2.1. Materials

ASTM Type I Portland cement (PC1) was used as plain cement in this study. Its mineralogical composition calculated using the Bogue formula was 53.9 wt% of C_3S , 19.8 wt% of di-calcium silicate (C_2S), 5.9 wt% of C_3A , and 10.3 wt% of C_4AF , and the surface area and density of PC1 were $345 \text{ m}^2/\text{kg}$ and 3142 kg/m^3 , respectively. The utilized limestone powder (LP1) contained 96.9 wt% of CaCO_3 , while its density was equal to 2810 kg/m^3 . Both the cement and limestone powder components were ground by using a ball mill. The surface areas of the resulting fine cement (PC2) and limestone powder (LP2) were $444 \text{ m}^2/\text{kg}$ and $5980 \text{ m}^2/\text{kg}$, respectively. The chemical composition and physical properties of all materials used in this work are summarized in Table 1.

Both fine and coarse aggregates used in this study were complied with ASTM C33. The saturated surface dry (SSD) density of the utilized coarse aggregates was 2600 kg/m^3 , while their maximum size was 25 mm. The fine aggregates were placed inside an oven heated to a temperature of 105°C for 24 h in order to achieve the SSD density of 2700 kg/m^3 before concrete mixing. The particle size distributions of the utilized cement and limestone powder, which were obtained by laser diffraction, are shown in Fig. 1. The particle size distributions of the raw materials were measured by laser diffraction from Beckman Coulter LS 230. Wet analysis using ethanol was conducted by the instrumental analysis for the size particle distribution.

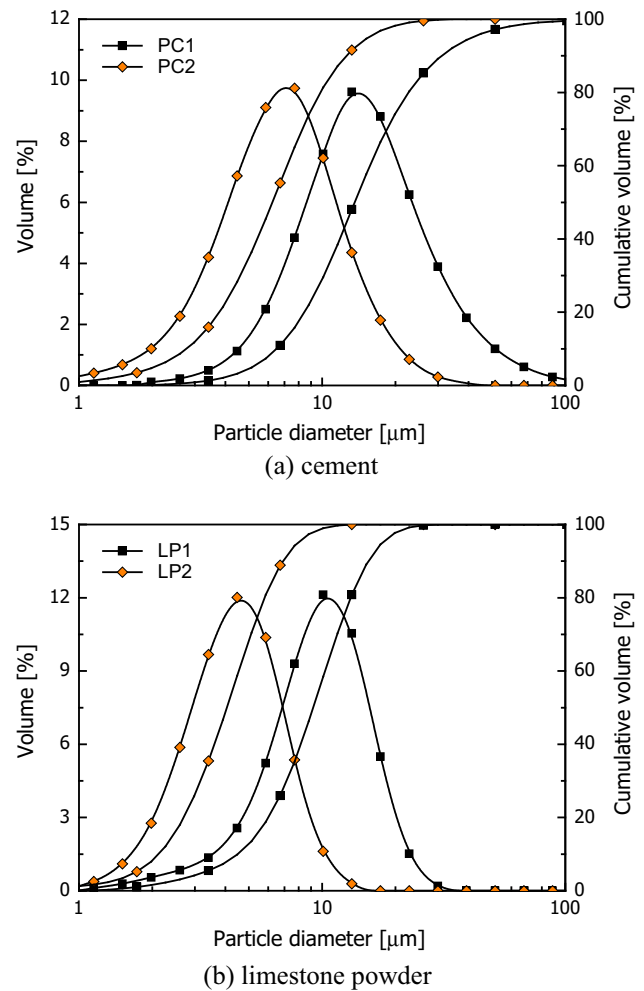


Fig. 1. Particle size distributions of materials used.

2.2. Mixture proportions and methods

The utilized mixture proportions for concrete are shown in Table 2. The addition of 15 wt%, 25 wt% and 35 wt% of limestone powder as well as the fineness of cement and limestone powder was investigated to evaluate the effect of limestone powder on the hydration reaction and strength development. The water-to-binder ratio, binder content, and coarse-to-fine aggregate weight ratio were fixed to 0.47, 360 kg/m^3 , and 1.27, respectively. A super-plasticizer of the polycarboxylate type was used to obtain a slump with a desired size (150 mm). Binders including cement and limestone powder were premixed for 30 min by using a V-type mixer.

Concrete specimens for the compressive strength test were cast in cylindrical molds with sizes of $100 \times 200 \text{ mm}$ for 24 h followed by de-molding and curing in water at a temperature of $20 \pm 1^\circ\text{C}$. Compressive strength tests were conducted in accordance with the ISO 1920-4 standard after aging for 3, 7, and 28 days.

Table 1
Chemical and physical properties of cement and limestone powder.

	Chemical composition (wt%)						Density (kg/m^3)	Surface area (m^2/kg)	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3		Blaine	BET
PC1	21.1	4.4	3.4	62.7	2.3	2.3	3142	345	—
PC2	21.2	4.3	3.3	62.8	2.5	2.2	3189	444	—
LP1	1.3	0.7	0.9	54.3	1.0	0.4	2810	—	1040
LP2	1.1	0.8	0.9	54.7	0.9	0.4	2887	—	5980

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