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# Effect of grinding method and particle size distribution on the properties of Portland-pozzolan cement

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## HIGHLIGHTS

- In PPC, the presence of Trass improved the particle size distribution.
- Durability properties of cements were not affected by fineness significantly.
- The use of cements with high fineness seems not economically beneficial.

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## ABSTRACT

This paper describes the influence of the producing method (Inter-grinding or separate grinding) and particle size distribution (PSD) on properties of Portland-pozzolan cements (PPC). Experiments were carried out on cement paste including normal consistency, time of setting, $Ca(OH)_2$ content, and heat of hydration, on cement mortar including potential alkali-silica reaction, and on concrete including compressive strength, sorptivity, electrical resistivity, and rapid chloride permeability. In this study, 10 types of cements including two types of Portland cement (PC), and eight types of Portland-pozzolan cement (PPC) were used. The results show that PPC provided better mechanical and durability properties compared to PC properties. This was evident especially in PPC containing 25% Trass. Also, the durability properties of cements were not affected by increase of fineness significantly. Particle size distribution (PSD) of PPC varied for each method of production, which was largely due to the amount of Trass in the PPC. Finally, it was concluded that physical properties of cements obtained by Inter-grinding were slightly better than that of separate grinding; however, durability properties were not affected by grinding method. Also, for achieving the same percentage of 45-μm residue, Inter-grinding is less energy-demanding than separate grinding (shorter grinding time is required). In addition, the use of cements with high fineness seems not economically beneficial due to its low effect on long term properties.



## 1. Introduction

The bulk of the cementitious binder used in concrete is Portland cement clinker, the manufacture of which is an energy-intensive process. Approximately 2% of world energy is spent in this process [1]. It is often stated that the production of 1 ton of cement results in emission of 0.8 ton of $CO_2$ [2]. In fact, estimations show that the manufacture of Portland cement is responsible for about 5–8% of global $CO_2$ emissions [3].

On the other hand, the concrete industry is one of the major consumers of natural resources. In order to reduce energy consumption, $CO_2$ emissions, and to increase their production, cement plants produce blended cements, comprised of supplementary cementitious materials (SCMs) such as slag, natural pozzolans, fly ash, and limestone [4–6].

According to Mehta [7], the use of supplementary cementitious materials has increased from 10% in 1990 to about 15% in 2005, and it is viable to increase this number to about 50% in 2020. SCMs are beneficial not only in the sense that they contribute to sustainability and reduction in $CO_2$ emissions, but also due to the potential ability of these materials to enhance the properties and performance of concrete.

Blended cements are produced by two different methods, either by Inter-grinding of Portland cement clinker, SCM, and gypsum, or by blending the separately grinded Portland cement (clinker + gypsum) and SCM [6,8–11]. A good understanding of the grinding technology is an essential step in the development of a multi-component cement. Whether separate grinding or Inter-grinding is

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preferred depends on the type of SCM used, economical considerations (energy consumption), replacement levels, the necessary fineness, and the required strength and durability properties of the blended cement.

The main difference between Inter-grinding and separate grinding of a multi-component cement is that during Inter-grinding, the components interact with one another. The physical interactions among the constituents are mostly due to the relative difference in grindability. These interactions can help or hinder the grinding process, and influence the relative content of each component in different size fractions and the particle size distribution of the ground products. As a result of these interactions, particle size distribution (PSD) of interground blended cements is different than that of separately ground cements. Schiller and Ellerbrock [12] found that the PSD of any constituent is greatly influenced by the grindability of others. A component which is harder to grind becomes concentrated in the coarser fractions, while a component which is easier to grind becomes concentrated in the finer fractions. PSD is vital with respect to the rheology and the early-age hydration process which determine the properties of fresh concrete, such as water demand, heat release, strength development, and early-age volume change [13]. It has been shown that Inter-grinding requires less energy than separate grinding, especially for the production of high-fineness products [14].

Generally, despite the considerable effect of grinding method and PSD on the early age properties of cement-based materials, limited researches have been performed and published on this issue, especially about the durability aspects of concrete. Accordingly, this paper aims to study the effects of grinding method and PSD on the mechanical and durability properties of Portland-pozzolan cements (PPC).

## 2. Experiments

### 2.1. Materials

The natural pozzolan used throughout this work was Trass pozzolan obtained from Jadjroud area, which is used to produce a Portland-pozzolan cement by Tehran cement factory. Trass is a volcanic tuff which hardens hydraulically in combination with lime and water. Tuffs are generally pyroclastic rocks which arise from explosive volcanic eruptions. Fig. 1 shows the SEM image of Trass particles.

The clinker used was an ordinary Portland cement clinker. Chemical and physical characteristics of the clinker, gypsum, and Trass are shown in Table 1.

To produce cements, the materials were crushed to 2-mm maximum size by a jaw crusher before feeding to the mill. The grinding process was carried out in a one-compartment laboratory-type ball mill of 20-kg raw mix capacity. In each step of grinding process, a fixed amount of 20 kg of materials were poured into the laboratory-type ball mill. Also, the grinding time which is directly related to energy consumption was recorded for each mixture.

In this study, 10 types of cements including two types of Portland cement (PC), and eight types of Portland-pozzolan cement (PPC) were used. The Portland-pozzolan cements were prepared using clinker, gypsum (4% by weight of clinker), and

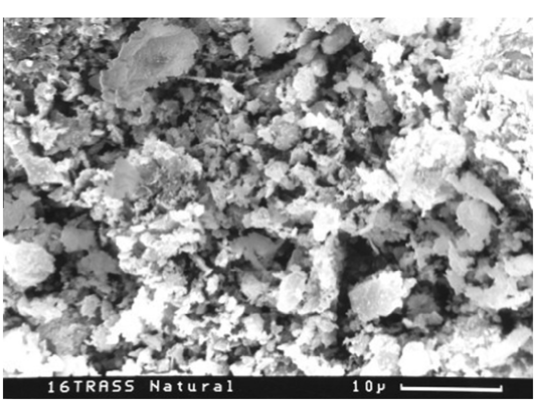


**Fig. 1.** Trass particles.

**Table 1**
Chemical and physical characteristics.

| | Clinker (C) | Gypsum (G) | Trass (T) |
|---|---|---|---|
| Calcium oxide (CaO) (%) | 64.2 | 39.53 | 2.99 |
| Silicon dioxide ($SiO_2$) (%) | 22.35 | – | 69.38 |
| Magnesium oxide (MgO) (%) | 2.05 | 0.64 | 1.61 |
| Aluminium oxide ($Al_2O_3$) (%) | 4.71 | 0.7 | 12.66 |
| Ferric oxide ($Fe_2O_3$) (%) | 2.95 | 0.42 | 2.16 |
| Sulphate oxide ($SO_3$) (%) | 0.75 | 28.1 | – |
| Potassium oxide ($K_2O$) (%) | 0.584 | – | 1.905 |
| Sodium oxide ($Na_2O$) (%) | 0.185 | – | 1.513 |
| Titanium oxide ($TiO_2$) (%) | 0.15 | – | – |
| Phosphorus oxide ($P_2O_5$) (%) | 0.05 | – | – |
| LOI (%) | 1.41 | 7.4 | 7.43 |
| Free water (%) | – | 0.18 | – |
| Combined water (%) | – | 7.13 | – |
| $SiO_2$ + insoluble water (%) | – | 6.6 | – |
| Specific gravity (gr/cm$^3$) | 3.15 | 2.31 | 2.32 |

Trass (25% and 35% by weight of binder). Portland cements were produced by Inter-grinding 96% clinker and 4% gypsum, with Blaine finenesses of 3200 ± 100 cm$^2$/g and 4000 ± 100 cm$^2$/g. For both cases, the percentage of 45-μm residue was determined by Alpine sieving apparatus, and this value was considered as a criterion in categorizing PPC. The percentage of 45-μm residue for PC with 3200 ± 100 cm$^2$/g and 4000 ± 100 cm$^2$/g Blaine fineness were obtained to be 7% and 2.8% respectively. Portland-pozzolan cements were produced by two methods of Inter-grinding and separate grinding.

In the separate grinding method, PPC with different Trass contents were produced by grinding PC and Trass separately, then blending them uniformly; however, in the Inter-grinding method, they were produced by Inter-grinding clinker, gypsum, and Trass. In both methods, the process of grinding was continued until the 45-μm residue content (determined by Alpine sieve) reached 7% and 2.8% respectively. Cements and their designations, grinding methods, fineness values, and grinding times are presented in Table 2. It should be noted that Blaine fineness and grinding time related to separately ground cements were calculated by weighted mean of the ingredients to reach the content of 45-μm residue to 7% and 2.8%.

Also, the particle size distributions of cements are presented in Fig. 2. For all concrete mix designs, the coarse aggregate used was crushed calcareous stone with a maximum size of 19 mm and natural sand was used as fine aggregate. The coarse aggregate had a specific gravity and water absorption of 2510 kg/m$^3$ and 1.90%, respectively, and the fine aggregate had a water absorption of 2.75% and a specific gravity of 2570 kg/m$^3$.

The gradings of the coarse and fine aggregates according to the BS 882 Standard [15] are presented in Fig. 3. The naphthalene-based superplasticizer, Rheobuild, with a specific gravity of 1200 kg/m$^3$, was employed to achieve the desired workability.

### 2.2. Mixture proportion

The concrete production was carried out in a 50 l mixer. The water-to- binder (w/b) ratio was 0.5 having a constant total binder (cement + pozzolan) content of 350 kg/m$^3$. The Slump of concrete was kept constant at 9 ± 2 cm. The mixture proportions for concrete specimens are summarized in Table 3.

### 2.3. Testing procedure and specimen preparation

The particle size distribution of the cements was measured by laser diffraction. Also, Blaine fineness values were determined according to ASTM C 204 [16]. The amount of water necessary for the cements to have normal consistency was determined according to ASTM C187 [17]. Then, the pastes having normal consistency were used to determine the setting time (According to ASTM C191) [18].

The free $Ca(OH)_2$ content of the hardened cement pastes was determined at various ages (3, 7, 14, and 28 days) using a NETZSCH STA429. Fresh pastes were filled into plastic syringes to prevent moisture loss and carbonation, and then the pastes in syringes were cured at 60 ± 1 °C to accelerate the reactions.

The heat of hydration of cements was determined at 1, 3, 7 and 28 days according to ASTM C186 [19].

The potential expansion due to alkali–silica reaction was evaluated with an accelerated test method (ASTM C 1567) [20]. For this purpose, known highly reactive siliceous limestone sand from Shahriar Dam was used as AAR reactive aggregate. Cement mortars were prepared with a cementitious materials: graded aggregate ratio of 1: 2.25 by mass.

Mortar prisms (25 × 25 × 285 mm) were demoulded 24 h after casting, and were then immersed in water at 23 ± 2 °C and stored in a climatic chamber at 80 ± 2 °C for 24 h. After this period, the initial length of each prism was measured (zero point or initial point), after which the prisms were immersed in a 1 M NaOH