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Studies on blended cements containing a high volume of natural pozzolans

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Abstract

This paper presents the results of an investigation on the characteristics of laboratory-produced blended portland cements containing 55% by weight volcanic tuffs from Turkey. Volcanic tuffs from two different resources were used. Using different grinding times, particle size distribution, setting time, compressive strength, and alkali–silica activity of the blended cements were investigated and compared with reference portland cements ground for the same time period. For the compressive strength test, a superplasticizer was used to obtain mortar mixtures of adequate workability at a constant water-to-cement (w/c) ratio of 0.45. Compared to portland cement, the blended cements containing 55% pozzolan showed somewhat lower strengths up to 91 days when the grinding time was 90 min. However, at 91 days, blended cements and portland cements ground for 120 min showed similar strength. Moreover, blended cements containing 55% natural pozzolans showed excellent ability to reduce the alkali–silica expansion.

Keywords: Alkali–silica reaction; Blended cement; Compressive strength; Grinding; Natural pozzolan

1. Introduction

It is well known that the incorporation of pozzolans into cement or concrete systems provides many benefits to properties of both fresh and hardened concrete such as improvement in workability, reduction in the heat of hydration, low permeability, high ultimate strength, and control of alkali–silica expansion. However, most pozzolanic materials, especially natural pozzolans, tend to increase the mixing water requirement for concrete and lower the rate of strength development. Therefore, for structural applications their proportion in blended portland cements is generally limited to 30% or less. Mehta [1] has reported that blended portland cements containing 10, 20 and 30% Santorin Earth, a natural pozzolan from Greece, produced similar or higher compressive strength than the reference portland cement; also, they showed much better durability to alkali–silica expansion and sulfate attack.

The use of pozzolanic materials as a blended component of portland–pozzolan cements production is generally associated with significant savings in energy and cost. Although cost saving was probably the original reason for the development of blended portland cements, impetus to rapid growth in the production of blended cements in many countries of Europe and Asia came as a result of their energy-saving potential [2]. Also, during the production of portland cement clinker a significant amount of CO_2 is released into the atmosphere. It is estimated that the production of every ton of portland cement releases about 1 ton of CO_2, a major greenhouse gas that is implicated in the global warming [3]. World's portland cement clinker production is responsible for about 7% of total CO_2 emissions, therefore a reduction in the portland cement clinker production without decreasing the needed amount of cement for the construction industry can be achieved by incorporating larger than customary proportions of pozzolanic materials into blended portland cements. Studies by Malhotra [4], and Mehta [5] have shown that high-performance concrete mixtures containing high-volume fly ash (>50% fly ash by weight of the blended portland–fly ash cement) can be produced with the help of superplasticizing admixtures. Published literature contains no reports of similar studies with blended cements containing natural pozzolans. One of the objectives of this study is to fulfill this need.

Turkey is rich in volcanic tuff deposits, some of which are currently used in blended cement production by the local cement manufacturers. Almost 155,000 sq. km of the

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Table 1
Chemical composition of raw materials

	Clinker	PA	PB	Gypsum
SiO_2	20.9	62.3	61.7	9.1
Al_2O_3	5.5	15.0	16.2	0.1
Fe_2O_3	2.8	5.1	3.5	0.3
CaO	64.5	4.9	5.0	27.4
MgO	2.7	1.2	1.5	0.5
Na_2O	–	2.2	3.5	–
K_2O	–	1.8	2.4	–
SO_3	0.3	0.2	0.1	40.2
Loss on ignition	1.3	6.3	5.9	22.0
Insoluble residue	0.45	85.4	86.0	–

country is covered by Tertiary- and Quaternary-age volcanic rocks, among which tuffs are the most important [6]. Therefore, the authors decided to investigate the feasibility of producing blended cements containing 55% natural pozzolan from two different Turkish deposits, and test their strength development characteristics in combination with a superplasticizing admixture.

This paper presents the results of an investigation on the blended cements produced in laboratory by intergrinding natural pozzolans, portland cement clinker and gypsum in the proportion 55:42:3 by mass, respectively. Two volcanic tuffs from different regions of Turkey and portland cement clinker were used in the study, and the blended cements were produced with different grinding times of 90 and 120 min. The cements produced were tested for particle size distribution, setting time, and compressive strength. Ability of the blended cements to control the alkali–silica expansions was also determined by a standard accelerated test method.

2. Experimental

2.1. Materials

Chemical composition of the portland cement clinker and gypsum obtained from a cement manufacturer are shown in Table 1.

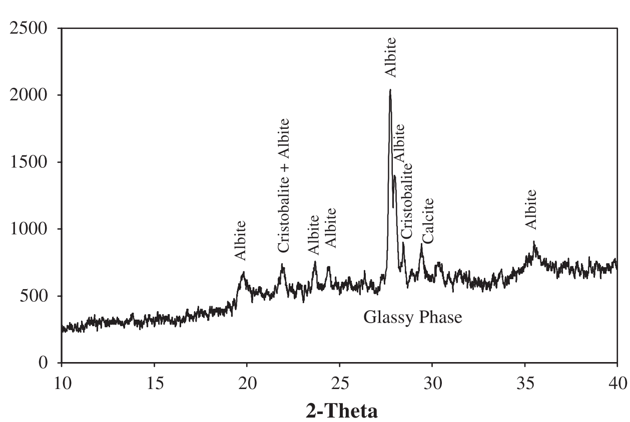

Fig. 1. X-ray diffraction analysis of Pozzolan A.

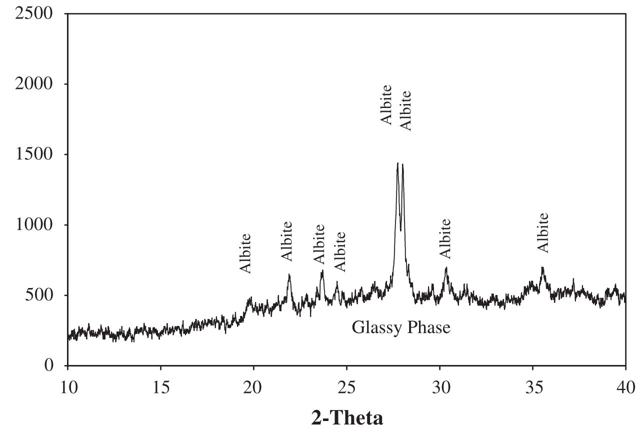

Fig. 2. X-ray diffraction analysis of Pozzolan B.

Two volcanic tuffs from different sources, called Pozzolan A (PA) and Pozzolan B (PB), were used in the study. Pozzolans are received in bulk form and crushed to obtain particles less than 16 mm before intergrinding. Chemical compositions of the pozzolans are shown in Table 1. X-ray diffraction patterns and identified phases of PA and PB are shown in Figs. 1 and 2, respectively. According to the X-ray diffraction data, both pozzolans contain some crystalline minerals and a glassy phase. Judged by the XRD peak intensities, the proportion of crystalline phases seems lower in PB.

The cement clinker, each of the pozzolans and gypsum were ground together in the proportion 42:55:3 by weight, respectively. Before intergrinding, clinker and gypsum were crushed to pass through No. 12 sieve (1.70 mm). A laboratory grinding mill, 450 mm in length and 420 mm in diameter, was used for producing blended cements. A combination of 50- and 20-kg cylindrical steel balls, 30×30 and 20×20 mm in size, respectively, were used as grinding media. For each test, 10-kg raw materials were fed into the mill, so that the raw materials to grinding media ratio was 1:7. This ratio was selected according to studies reported by Bouzoubaa et. al. [7].

Preliminary tests showed that 60 min grinding time was insufficient to grind the reference portland cement clinker to a Blaine fineness of approximately 300 m^2/kg or higher; however 90-min grinding time was found to be adequate. Therefore, one series of blended cements and reference portland cement were produced with grinding times of 90

Table 2
Physical properties of the cements

Cement	Specific gravity	Blaine fineness (m^2/kg)	Passing 45 μm (%)	Median particle size (μm)
PC-90	3.05	296	77.6	19.8
PC-120	3.05	331	81.2	16.9
BCA-90	2.72	471	72.0	23.1
BCA-120	2.75	598	86.1	12.9
BCB-90	2.70	487	74.9	23.4
BCB-120	2.72	567	81.9	16.6

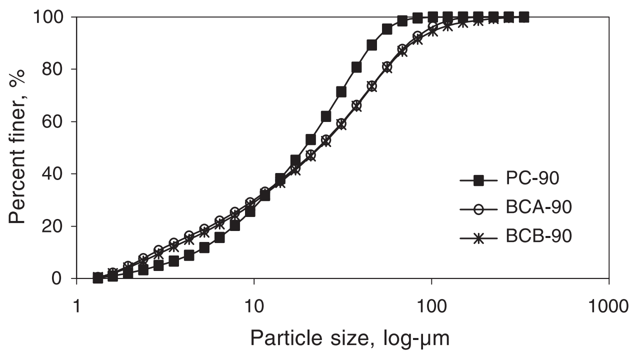

Fig. 3. Particle size distribution curves for the blended cements and portland cement ground for 90 min.

min, and another were produced with 120 min. The blended cements were designated according to the pozzolan type present and the grinding time. For instance, BCA-90 refers to the blended cement (BC) with made PA ground for 90 min grinding. Portland cements were designated as PC-90 or PC-120, depending on the grinding time.

2.2. Methods

The cements were tested for specific gravity, Blaine fineness, percent material finer than 45 μm, normal consistency and setting time in accordance with ASTM standard test methods. The particle size distributions were determined by the Mastersizer/E Malvern laser particle size analyzer with particles suspended in isopropanol. For compressive strength tests at 3, 7, 28, and 91 days of age, mortar mixtures were prepared by using 0.45 water-to-cement (w/c) ratio, and 2.75 sand–cement ratio. A sulfonated naphthalene formaldehyde condensate type superplasticizer in a dry powder, 1.5% by weight of the cement, was used to obtain adequate workability in all mortar mixtures.

The potential expansion due to alkali–silica reaction was evaluated with an accelerated test method (ASTM C 1260), which involves measurement of expansion of mortar bars exposed to 1 N NaOH solution at 80 °C. A local aggregate that is known to be highly reactive in alkali–silica reaction was used in mortar mixtures. Expansion of the mortar bars due to alkali–silica reaction was determined at 14 and 30 days of curing and reported as percent of the initial length.

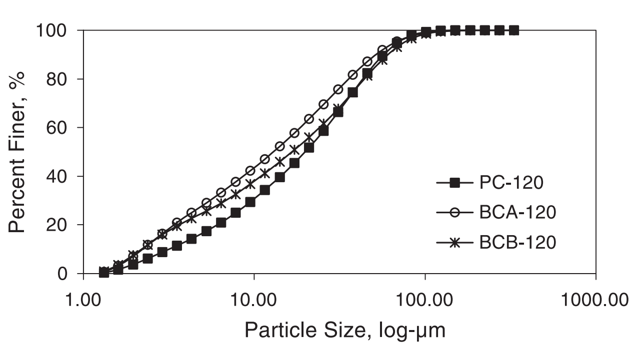

Fig. 4. Particle size distribution curves for the blended cements and portland cement ground for 120 min.

Table 3
Water-to-cement ratio for normal consistency (n.c.), and setting time

	w/c for n.c.	Setting time, min	
		Initial	Final
PC-90	0.24	160	189
PC-120	0.24	155	180
BCA-90	0.37	168	195
BCA-120	0.38	157	190
BCB-90	0.36	115	144
BCB-120	0.37	98	140

3. Results and discussion

3.1. Fineness and particle size distribution

Physical properties of the cements are summarized in Table 2.

A specific grinding time resulted in higher Blaine fineness value for the blended cements when compared to the

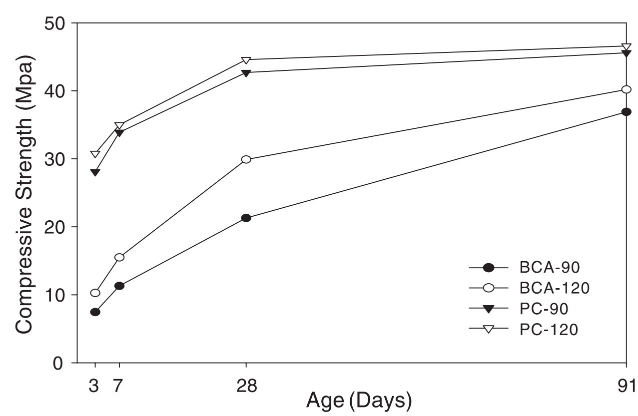

Fig. 5. Compressive strengths of the blended cements with PA and control portland cements.

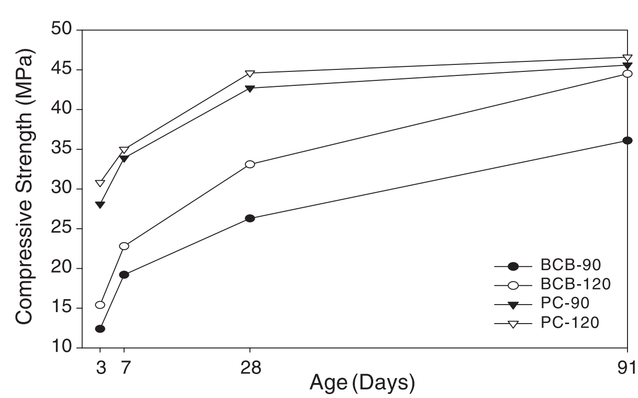

Fig. 6. Compressive strengths of the blended cements with PB and control portland cements.

portland cements. It may be due to easier grindability of natural pozzolans, although this does not seem to have a significant effect on the material finer than 45 μm. Particle size distribution curves for 90-min grinding time are shown in Fig. 3. For particle sizes bigger than approximately 15 μm, blended cements were coarser than portland cement. These coarse particles in blended cements were attributed to the clinker component which was harder to grind than the pozzolans. However, for 120 min of grinding, no coarser phase in blended cements was observed in particle size distribution with respect to portland cement (Fig. 4). Thus, it can be concluded that relatively low intergrinding times may result in a coarser clinker phase for blended cements containing high volumes of natural pozzolans.

3.2. Setting time

Water-to-cement ratios required for normal consistency and setting times of cements are shown in Table 3. The pozzolan addition increased the water demand for the standard consistency by about 50% when compared to portland cements.

The pozzolan addition affected the setting times in different ways according to pozzolan type. The initial and the final setting times of blended cement with PA were higher than that of the reference portland, however, they were lower with PB. The authors are unable to explain this behavior.

3.3. Compressive strength of mortars

The compressive strength data for 3, 7, 28 and 91 days of age for cement BCA and reference portland cement are plotted in Fig. 5 and for cement BCB and reference portland cement are plotted in Fig. 6. The compressive strength up to 91 days age of testing for mortars made with the blended cements containing either of two natural pozzolans was lower than that of the reference portland cements ground for the same time period. The reductions in strengths were considerable at 3, 7 and 28 days; however, the difference narrowed by age 91 days due to progress of the pozzolanic reaction with age in blended cements. For instance, the compressive strength of BCB-120 was found to be only 2% lower than PC-120 at 91 days.

3.4. Alkali–silica activity

The expansion data measured as a percent of the original length at 14 and 30 days of curing are shown in Table 4.

Evidently, compared to the reference portland cement PC-90 and PC-120, the corresponding blended cements with pozzolan additions showed much reduced expansions due to alkali–silica reaction. On the basis of expansion data at 14 and 30 days of curing, it can be concluded that blended cements incorporating 55% natural pozzolans used in this study show negligible alkali–silica expansion when tested according to ASTM C 1260.

Table 4
Alkali–silica expansions (ASTM C 1260)

Cement	Blaine fineness (m^2/kg)	Expansions (%)	
		14 days	30 days
PC-90	297	0.298	0.518
PC-120	330	0.365	0.552
BCA-90	471	0.023	0.078
BCA-120	598	0.016	0.068
BCB-90	487	0.013	0.052
BCB-120	567	0.011	0.057

4. Conclusions

Based on the test results, the following conclusions are drawn on blended cements containing 55% volcanic tuffs used in this investigation:

1. Compared to the reference portland cement clinker, the blended cements containing 55% natural pozzolan produced higher Blaine fineness for the same grinding time. Due to difference in the grindability of clinker and pozzolans, it is suggested that besides the Blaine fineness, particle size distribution may also be determined.
2. In general, compressive strengths of blended cements at all ages of testing up to 91 days were lower than the reference portland cements ground for the same time period. With the cements ground for 120 min, although the compressive strength of mortars made with the blended cement containing PB was lower than that of the reference portland cement by about 35% at 28 days, it was found to be similar at 91 days.
3. Blended cements containing 55% pozzolan showed excellent ability to reduce the alkali–silica expansion.

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