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Thermo-mechanical properties of concrete containing high-volume mineral admixtures

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Abstract

This paper reports the results of a study conducted to evaluate the influence of high-volume class C fly ash (FA), blast furnace slag (BFS) and both FA + BFS on the thermal conductivity (TC), compressive strength, water absorption and density of concrete. TC decreased with the increase of FA, BFS and FA + BFS as replacement for Portland cement. The reductions in TC due to FA, BFS and FA + BFS were, respectively, up to 39%, 18% and 31%. The addition of FA, BFS and FA + BFS in the concrete had a decreasing effect on TC. Their addition also decreased compressive strength as a function of replacement percent. However, this reduction in compressive strength decreased with increasing curing period.
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Keywords: High-volume fly ash; High-volume blast furnace slag; Thermal conductivity; Compressive strength

1. Introduction

The knowledge of thermal conductivity (TC) and other thermal transport properties of construction materials involved in the process of heat transfer is essential in predicting the temperature profile and heat flow through the material. The TC of concrete, being one of the most commonly used construction materials, is very important. Heat transfer problems in concrete are complicated. In order to facilitate better understanding of the effect of each constituent of concrete on the TC of concrete, one must study the heat transfer through each of the constituents of concrete and its relative importance and contribution to the overall thermal behavior of the concrete [1].

A review of an earlier investigation reveals that the TC of concrete increases with increasing cement content [2]. In addition, it is affected by the type of aggregate [1,3]. Porosity and moisture content have a significant influence on TC. The TC of rocks, commonly used as aggregates in concrete, ranges from 1.163 to 8.6 W/mK [2,3]. The mineralogical character of aggregate would greatly influence the TC of concrete, because the TC of rocks changes with both its composition and degree of crystallization. Basalt and dolerite have the lowest TC; granite, limestone and dolomite are in the intermediate range, whilst quartzite and sandstone show the highest TC. Rock with crystalline structure shows higher TC than amorphous and vitreous rocks of the same composition [3,4]. Thus, concrete made up of aggregate of lower TC demonstrates less TC whereas the more conductive aggregate produces more conductive concrete with a greater conductivity [5,6]. Thus, aggregate type can increase the TC of concrete by nearly twice [1]. Also, concrete in moist state is 70% more conductive than in the oven-dried state [1,5]. Since the TC of crystalline silica is about 15 times that of amorphous silica [7], it is natural for concretes with amorphous silica to have lower conductivity than those containing crystallized silica [8,9]. The amorphous calcium-silicate-hydrate in the cement paste, which is the continuous phase in concrete taken as a composite, may also contribute to lowering the TC.

Mineral admixtures for concrete also have an effect on the TC of concrete. Silica fume (SF) decreases the TC of cement paste [10] and a low volume of SF, fly ash (FA) and blast furnace slag (BFS) also decrease the TC of mortar [11] and lightweight aggregate concrete [12]. However, the

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effect of high-volume FA and BFS on the TC of concrete has not been reported previously.

Demirboga and Gul [12], Akman and Tasdemir [13], and Blanco et al. [14] reported that TC decreases due to density decrease of concrete. Lu-Shu et al. [15] mathematically modeled a relationship between density and TC, and reported that TC increased with increasing density.

The relative performance of FAs in concrete depends upon the composition of cement used. In addition, the age of the test is an important factor influencing the relative performance of the various cementing materials [16]. Results of numerous studies have indicated that FA slows the rate of hardening and reduces the early compressive strength of concrete [17].

Taşdemir et al. [18] reported that BFS concrete tends to lower strengths at early ages than ordinary portland cement (PC) concretes, but at later ages they may have the same or greater strength than the ordinary PC concretes. Reeves [19] has shown that in the use of BFS, the heat of hydration is generated more slowly than ordinary PC. Thus, the rate of gain of strength is also more gradual than that of ordinary PC [20].

Table 1
Chemical analysis and physical properties of PC, FA, BFS (%)

Component		PC (%)	FA (%)	BFS (%)
SiO_2		19.80	30.6	39.56
Fe_2O_3		3.42	5.5	0.33
Al_2O_3		5.61	14.8	10.82
CaO		62.97	36.8	37.68
MgO		1.76	2.5	6.79
SO_3		2.95	4.9	0.33
Sulphide (S^{-2})		0.17	—	—
Chlor (Cl^-)		0.04	—	0.125
Undetermined		0.30	—	3.99
Free CaO		0.71	11.5	—
LOI		0.36	2.4	—
Specific gravity (g/cm^3)		3.15	2.4	2.86
Specific surface (cm^2/g)		3410	3200	4000
Compressive strength (MPa)	2 days	24.5	—	—
	7 days	42.0	—	18
	28 days	44.4	—	—

2. Research significance

Very limited information is available about the effect of mineral admixtures on the TC of the concrete. There are many studies related to the effect of high-volume mineral admixture on the mechanical properties of concrete, but the effect of high-volume FA and BFS on the TC of concrete has not been reported previously. Thus, the effect of high volumes of mineral admixture on the TC of concrete also needs to be investigated.

3. Experimental investigation

ASTM Type I, PC, from Set cement factory in Ankara, Turkey, was used in this study. Class C FA, BFS, and aggregate were obtained from Afşin Thermal Power Plant, Iskenderun Iron-Steel Factory in Hatay-Iskenderun and Aras River in Erzurum in Turkey, respectively. In order to eliminate the variation of aggregate and cement, each was taken from the same batch throughout the investigation. The chemical composition and physical properties of the materials used in this study are summarized in Table 1.

First group: Separately, FA–PC and BFS–PC mixtures were prepared adding 0%, 50%, 60% and 70% FA or BFS replacement for PC (Table 2).

Second group: 25% FA + 25% BFS, 30% FA + 30% BFS or 35% FA + 35% BFS replacement for PC. For each mixture, three specimens of $110 \times 160 \times 40\,mm^3$ prisms and of 100 mm diameter and 200 mm height cylinders were prepared and stored in lime-saturated water at $20 \pm 3\,°C$ until the time of testing. Cylinder specimens were tested for compressive strength in accordance with ASTM C 109 at 3, 7, 28 and 120 days curing periods. For each curing period, three specimens were used to determine compressive strength.

Prisms specimens were dried at the age of 28 days in an oven at $110 \pm 10\,°C$ and weighed at 24 h intervals until the loss in weight did not exceed 0.5% in 24 h (ASTM C 332) for TC. Since the conductivity of air is lower than that of water, Steiger and Hurd [30] reported that when unit weight of concrete increased by 1% due to the water

Table 2
Mixture proportions

Mixtures		PC (%)	FA (%)			BFS (%)			FA + BFS (%)		
		100	50	60	70	50	60	70	25 + 25	30 + 30	35 + 35
w/c		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Water (kg/m^3)		167.5	167.5	167.5	167.5	167.5	167.5	167.5	167.5	167.5	167.5
Cement (kg/m^3)		350	175	140	105	175	140	105	175	140	105
Fly ash (kg/m^3)		—	175	210	245	—	—	—	87.5	105	122.5
Blast furnace slag (kg/m^3)		—	—	—	—	175	210	245	87.5	105	122.5
Aggregates sizes (mm)	0–4 kg/m^3	740	740	740	740	740	740	740	740	740	740
	4–8 kg/m^3	458	458	458	458	458	458	458	458	458	458
	8–16 kg/m^3	577	577	577	577	577	577	577	577	577	577
Superplasticizer (%)		1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

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