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Influence of Mineral Additives on Resistance of Concrete at Elevated Temperature

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Influence of mineral additives on resistance of concrete at elevated temperature

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Concrete containing mineral admixtures is used extensively throughout the world for their good performance and for ecological and economic reason. They save energy, conserve resources and have many technical benefits. In this study, an experimental investigation was performed to evaluate the influence of elevated temperatures on the mechanical properties of self-consolidating concrete containing the mineral additives as powder material. The ordinary Portland cement (OPC) was used as binder, and limestone powder, silica fume and brick powder was used as mineral additive materials. The OPC were partially replaced by 0, 10, 20 and 30% of each type of mineral admixture. The blended concrete paste was prepared using the water-binder ratio of 0.5 wt% of blended cement. The experiments were carried out on mortar specimens. In addition, superplasticizer admixture and natural sand in size of 0-1 mm were used in the production of mortars. The fresh mortars were first cured at 100% relative humidity for 24 hours and then cured in water for 28 days. The hardened concrete mortars were thermally treated at 20 (room temperature), 200, 400, 600, 800 and 1000 ^{o}C for 2 hours. The compressive strength, tensile strength and loss of density of self-consolidating concrete mortars were compared with those of the pure ordinary Portland concrete. The results showed that the addition of mineral additives to OPC improves the performance of the produced blended concrete when exposed to elevated temperatures.

Keywords: Mineral admixture, mortar, high temperature.
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1. Introduction

Under normal conditions, most concrete structures are subjected to a range of temperature no more severe than that imposed by ambient environmental conditions. However, there are important cases where these structures may be exposed to much higher temperatures. Concrete is well known for its capacity to endure high temperatures and fires, owing to its low thermal conductivity and high specific heat (Arioz, 2007). However, it does not mean that fire as well as higher temperatures does not affect the concrete. Characteristics such as color, compressive strength, elasticity, concrete density and surface appearance are affected by high temperature (Morsy et al., 2009; Xu et al., 2001; Savva et al., 2005; Saad et al., 1998). Therefore, improving concrete's fire resistance is a field of interest for many researchers lately. According to their studies, it is possible to improve fire resistance of concrete in few ways. One of the very efficient methods is cement replacement with pozzolanic materials (Demirboğa et al., 2007; Aydın, 2008; Wang, 2008). Concrete containing different types of mineral admixtures is used extensively throughout the world for their good performance and for ecological and economic reason (Xiao, 2006; Kalifa et al., 2001). The most used common mineral materials are fly ash, ground granulated blast furnace slag, silica fume, limestone powder and rice husk ash (Aydın et al., 2008; Morsy et al., 2008).

The scope of this study is to provide experimental data on the residual mechanical and physical properties of blended cement self-consolidating concrete subjected to heat, containing different type of mineral admixtures such as limestone powder, silica fume and brick powder. These properties are very important for a safe design of self-consolidating concrete and in the repair of concrete structures.

2. Experimental program

The blended concrete mix was prepared using ordinary Portland cement (OPC) that was partially substituted by 0, 10, 20 and 30 percent limestone powder (LP), silica fume (SF) and brick powder (BP). Their chemical properties are given in Table 1. The experiments were carried out on self-consolidating mortar specimens. The blended concrete paste was prepared using the water-binder ratio of 0.5 wt% of blended cement. In addition, superplasticizer admixture (2% of binder) and natural sand in size of 0-1 mm were used in the production of mortars. The fresh mortars were first cured at 100% relative humidity for 24 hours and then cured in water for 28 days. The hardened concrete mortars were thermally treated at 20 (room temperature), 200, 400, 600, 800 and 1000 ^{o}C for 2 hours except for heating and cooling duration. The compressive strength, tensile strength and loss of density of self-consolidating concrete mortars were compared with those of the pure ordinary mortar.

3. Results and discussions

The compressive strength of thermally treated mortar specimens after cooling to room temperature was determined. The results shown in Figure-1 indicate the residual compressive strength of each specimen containing the different type of mineral admixture is different at elevated temperatures. It shows a relative increase in the compressive strength of each specimen thermally treated up to 200^{o}C as compared to its original compressive strength before heating. This increase in compressive strength may be due to the shrinkage of specimens by driving out of free water. At high temperatures, above 200 ^{o}C, the thermal effect might cause water migration whereas dehydration of moisture supply from outside is insufficient. Internal stress and thus micro and macro cracks are generated due to the heterogeneous volume dilatations of ingredients and the buildup of vapor in the pores. Therefore, at higher temperature, especially above 200 ^{o}C, the observed decrease in compressive strength of blended mortar containing 0, 10, 20 and 30% mineral admixture, may be due to internal thermal stress generated around pores which generate micro-cracks, and thus thermally expansion of the specimens.

The compressive strength decreased suddenly after 200 ^{o}C. This was because of weakening of the cement paste-aggregate bond; and weakening of the cement paste due to an increase in porosity on dehydration, partial breakdown of the C-S-H, chemical transformation on hydrothermal reactions, and development of cracking. A number of material and environmental-related factors affect the response of concrete materials to elevated-temperature conditions. As many of the aggregate materials are thermally stable up to temperatures of 300°C to 350°C, which includes the temperature range considered for most applications, the compressive strength of concrete at elevated temperature is dependent in large measure on the interaction between the cement pastes and aggregate.

When the mineral admixtures are compared, the mortar specimens containing the SF are more durable to high temperature, especially over 400 ^{o}C. However, all the mineral admixtures in ratio of 10% are affected on enhancement of high temperature resistance of specimens according to pure specimens. This increase may be due to the hydrothermal interaction of the mineral particles and free lime during hydration reaction. Similar results were observed in residual flexural tensile strength of the specimens (Fig. 2). The tensile strength of concrete is important because it determines the ability of concrete to resist cracking.

The density of thermally treated mortar specimens after cooling to room temperature was determined by Archimedes principle. It was decreased by increasing of temperature value (Fig. 3). In general, the lowest density values were obtained at the highest temperature. Micro-cracking due mainly to thermal incompatibility of the hardened cement paste and aggregate which increases porosity and decreases density (Bažant, 1996; Zadražil et al., 2004). This process takes place throughout whole temperature interval.

4. Conclusion

In the study, effect of mineral admixture type of compressive, flexure and density of hardened concrete mortar specimens that exposed to high temperature from room temperature to 1000 ^{o}C gradually. The results showed that the replacing of the OPC with limestone powder, silica fume and brick powder improves the performance of the produced blended SCM when exposed to elevated temperatures, especially over 400 ^{o}C.

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Table 1. *Chemical properties of OPC and mineral admixtures*

Component, %	OPC	SF	BP	LP
CaO	63.6	1.48	4.56	51.4
SiO_2	16.6	74.7	50.7	2.96
Al_2O_3	4.72	0.46	23.8	1.13
Fe_2O_3	3.27	0.84	8.32	0.2
S+A+F	-	*76.0*	*82.8*	*4.3*
MgO	1.91	3.64	2.28	1.0
Na_2O	0.34	0.85	0.98	0.03
K_2O	1.06	5.05	4.34	0.14
SO_3	4.72	2.48	0.98	0.03
Cr_2O_3	0.04	2.83	0.03	-
TiO_2	0.41	0.63	1.1	0.07
LOI	2.69	5.97	2.45	42.9
Specific gravity	3.07	2.44	2.73	2.72
Fineness (specific surface), cm^2/g	3312	14000	3954	2427

Figure 1. *Compressive strength of mortars at elevated temperature for LP, SF and BP*

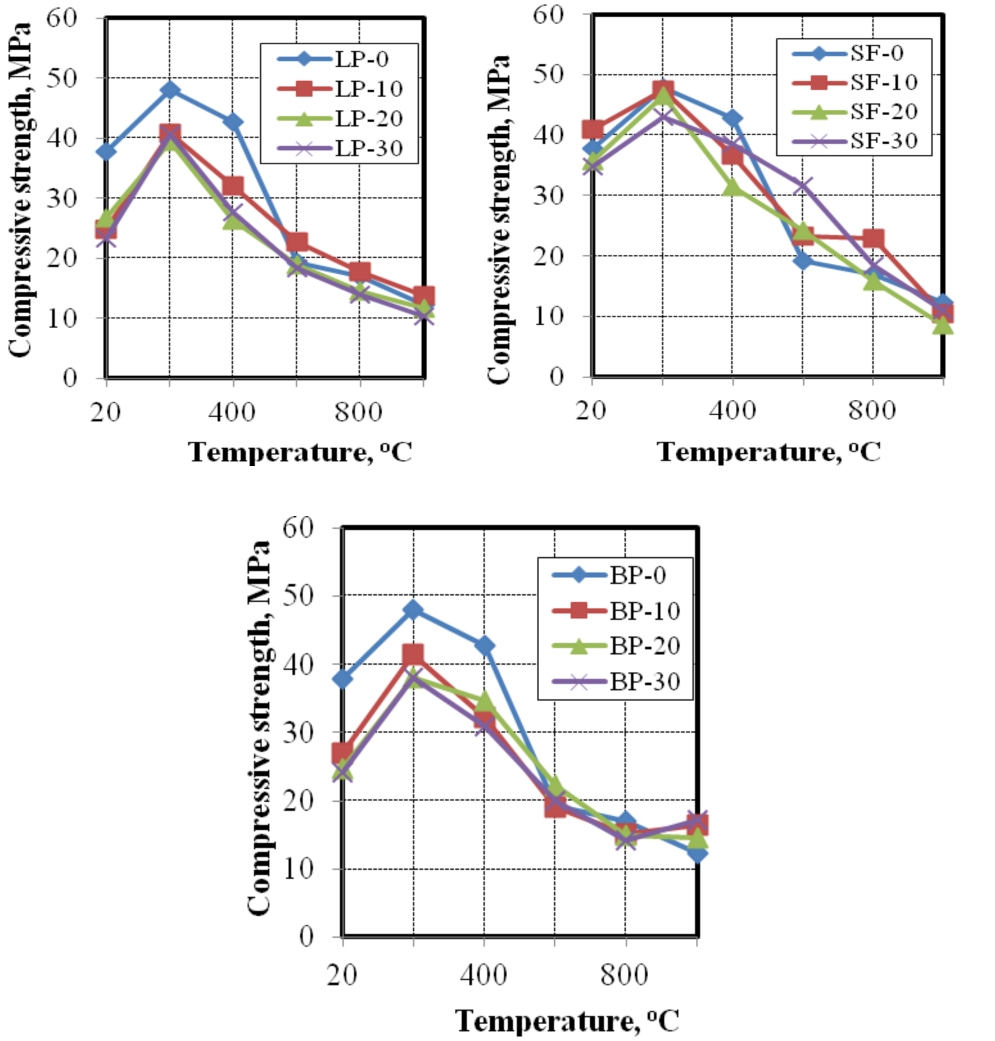

Figure 2. *Flexural strength of mortars at elevated temperature for LP, SF and BP*

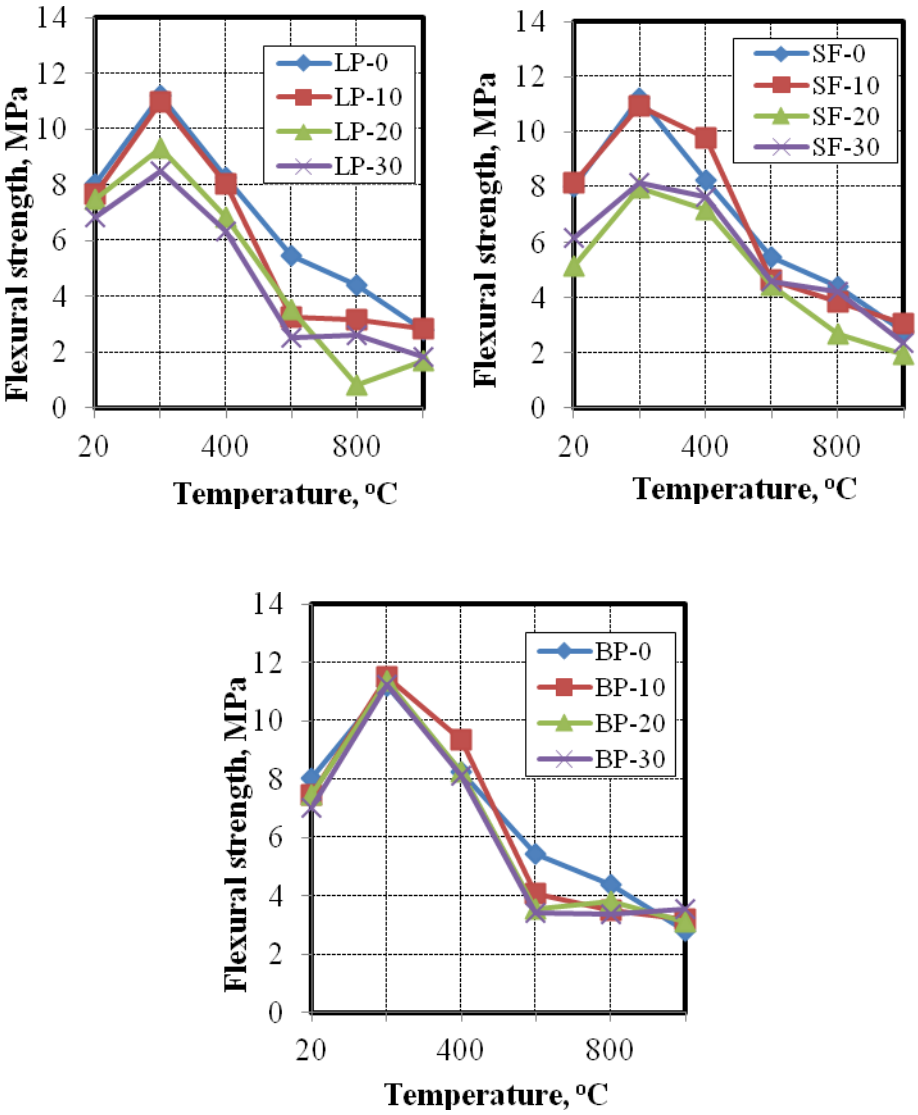

Figure 3. *Density of mortars at elevated temperature for LP, SF and BP*