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Effect of limestone powder on high temperature resistance of self-consolidating micro-concrete

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ABSTRACT

In this study, an experimental investigation was performed to evaluate the influence of elevated temperatures on the mechanical properties of self-consolidating micro-concrete containing the mineral additives. The ordinary Portland cement (OPC) was used as binder, and limestone powder was used as mineral additive materials. The OPC were partially replaced by 0, 10, 20 and 30% of mineral admixture. The blended concrete paste was prepared using the water-binder ratio of 0.5 wt% of blended cement and natural sand. The hardened specimens were thermally treated at 20, 200, 400, 600, 800 and 1000 ^{o}C for 2 hours. The compressive strength, tensile strength and loss of density of self-consolidating micro-concretes were compared with those of the pure ordinary Portland concrete. The results showed that the addition of limestone powder to OPC improves the performance of the produced blended micro-concrete when exposed to elevated temperatures.

Keywords: Mineral admixture, limestone powder, micro-concrete, high temperature, self-consolidating.

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). On the other hand, 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 micro-concrete subjected to heat, containing limestone powder. These properties are very important for a safe design of self-consolidating concrete and in the repair of concrete structures.

EXPERIMENTAL PROGRAM

The blended micro-concrete mix was prepared using ordinary Portland cement (OPC) that was partially substituted by 0, 10, 20 and 30 percent limestone powder (LP). Their chemical properties are given in Table 1. The experiments were carried out on self-consolidating micro-concrete specimens. The micro-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 micro-concretes. The fresh concrete were first cured at 100% relative humidity for 24 hours and then cured in water for 28 days. The hardened micro-concretes 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 were compared with those of the pure ordinary mortar.

Table 1. Chemical properties of OPC and mineral admixtures

Component, %	**OPC**	**LP**
CaO	63.6	51.4
SiO_2	16.6	2.96
Al_2O_3	4.72	1.13
Fe_2O_3	3.27	0.2
S+A+F	-	*4.3*
MgO	1.91	1.0
Na_2O	0.34	0.03
K_2O	1.06	0.14
SO_3	4.72	0.03
Cr_2O_3	0.04	-
TiO_2	0.41	0.07
LOI	2.69	42.9
Specific gravity	3.07	2.72
Fineness (specific surface), cm^2/g	3312	2427

Coefficient of thermal expansion measurements were carried out on 5x5x25 mm prismatic specimens by using the DIL 402 CD/4/G type dilatometer according to ASTM E 831-03 (2003) . The linear change in the length of each specimen was measured by the instrument under temperatures from 20 to 1000 ^{o}C at a heating rate of 5 $^{o}C/min$. The specimens were dried in the oven at 50 ^{o}C until they maintained a constant weight before the CTE measurement. In other words, the moisture content of the concretes was kept as oven dry in all the measurements. The sample and standard are put into the furnace, provided with contact ceramic rods, and the initial reading on the dial indicators is taken.

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 LP 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 micro-concrete 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.

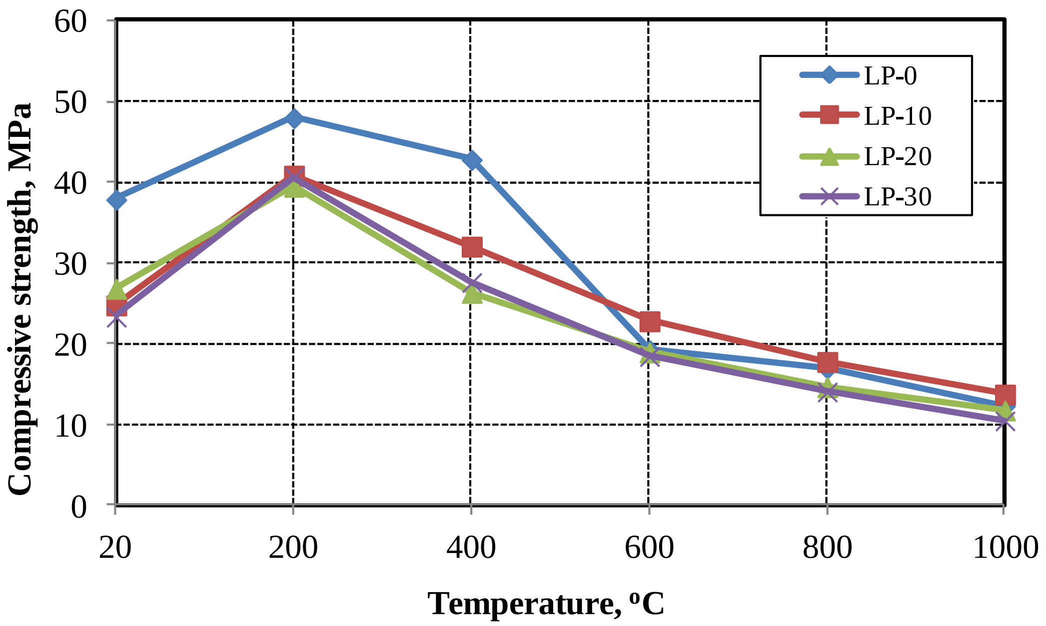

Figure 1. Compressive strength of micro-concrete at elevated temperature

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.

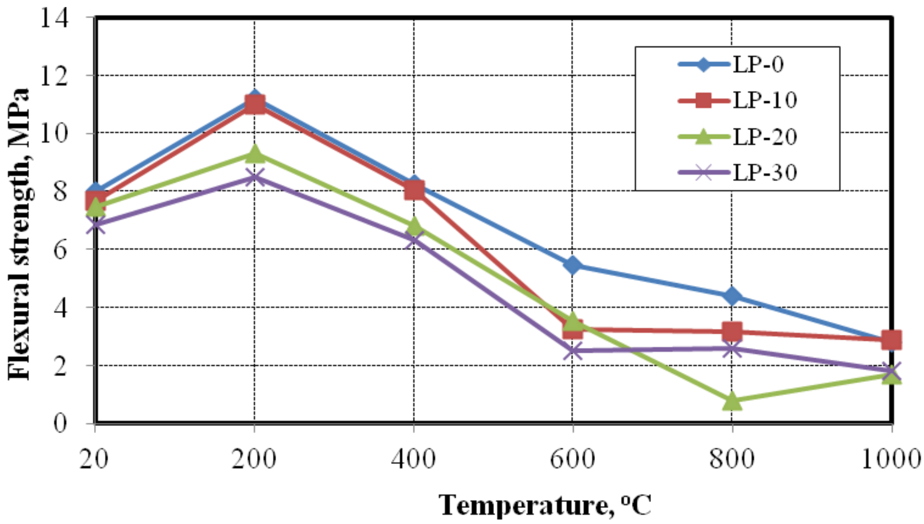

Figure 2. Flexural strength of mortars at elevated temperature for LP, SF and BP

When the mineral admixture contents are compared, the compressive strength of mortar specimens containing the 10% of LP are about the same with the pure specimens after 600 °C. This increase may be due to the hydrothermal interaction of the mineral particles and free lime during hydration reaction. In flexural strength (Fig. 2), the addition of LP does not make a contribution to pure specimens. The flexural strength was decreased by use of LP up to 20% at all the elevated temperature values. However, there is not much difference on flexural strength of specimens with LP of 10% at 20, 200, 400 and 1000 °C. The tensile strength of concrete is important because it determines the ability of concrete resist to cracking.

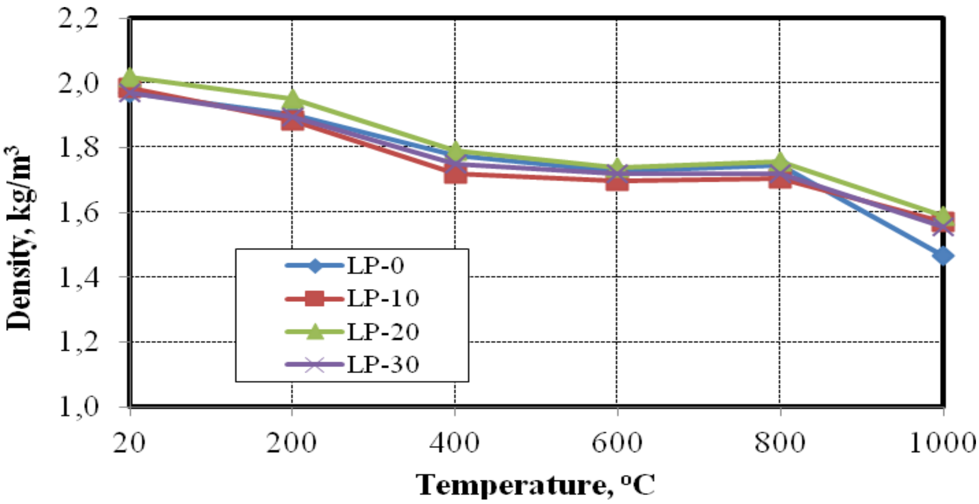

Figure 3. Density of mortars at elevated temperature for LP

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. On the other hand, the density of the micro-SCC was the same in all the ratios of LP for each elevated temperature. However, there is a decrease in density of control series at the highest elevated temperature.

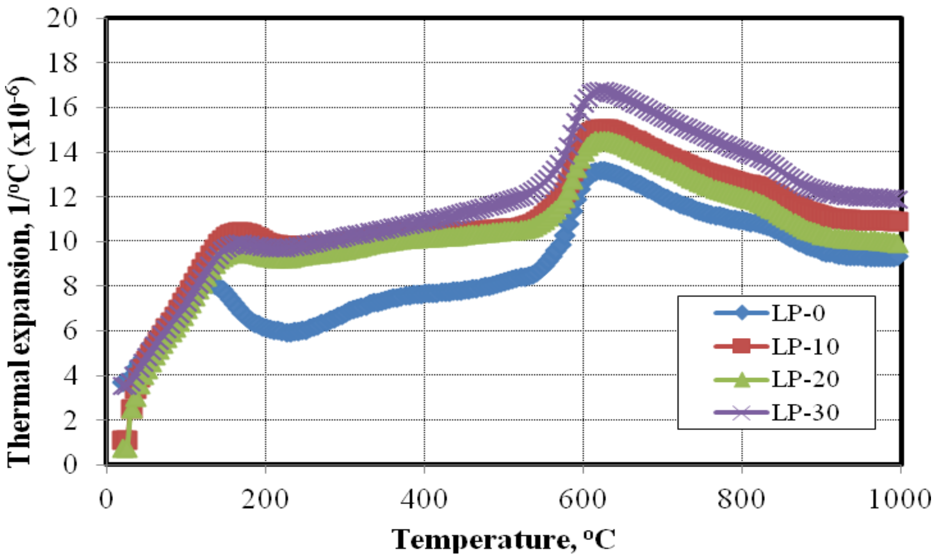

Figure 4. CTE of micro-concrete depending on LP content

The CTE of self-consolidating micro-concrete produced with different content of LP is given in Fig. 4. As seen, there is no regularly increase or decrease in the CTE with the increase of LP from 0 to 30% at low temperature (below 100 °C). It was probably due to the internal vapor stress in the hydrated cement matrix and internal capillarity water. When the increase of CTE was limited at 120 °C, it decreased at 150 and 200 °C because of the evaporation of free internal water in the C–S–H gel. Decomposition of C–S–H gel resulted in an increase of CTE between 250 and 500 °C. The CTE of micro-concretes was, however, enhanced significantly between 550 and 650 °C because of the transition of quartz in the natural sand. Similar definitions were made by Kodur and Sultan (2003). Authors measured the thermal expansion of high strength concrete using the dilatometric methods. They defined that thermal expansion of high strength concrete, produced with siliceous aggregate, increases with temperature up to about 550 °C. Above 900 °C, CTE values of specimens decreased suddenly because of shrinking specimens. The lowest CTE was obtained on control specimens while the highest CTE values are measured on the micro-concrete with 30% of LP content. Probably, this was due to evaporation of CO_2 from $CaCO_3$ at about 900 °C.

CONCLUSION

In the study, effect of limestone powder content on compressive strength, flexure strength, density loss and coefficient of thermal expansion of hardened self consolidating micro-concrete specimens that exposed to high temperature from room temperature to 1000 ^{o}C gradually was investigated. The results showed that the replacing of the OPC with limestone powder causes to increase in thermal expansion of micro-concrete. However, compressive strength of the specimens does not changed by use of LP in ratio of 10% over 600 ^{o}C.

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