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The Effect of High Temperature on Mortars Containing Silica Fume

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Abstract: In this research the effect of high temperature on the compressive strength of silica incorporated mortar specimens have been studied. For this purpose prismatic mortar specimens containing 0, 5 and 10% silica fume substituted for cement with different w/b ratios and cured at different ages were prepared. The compressive strength before and after exposure to high temperatures of 300 and 600°C were recorded. It was observed that silica fume incorporated mortars has no potential effects in the face of fire hazardous.

Key words: Compressive strength, mortar, silica fume, w/b ratio, high temperature

INTRODUCTION

Fire is one of the hazards that attack buildings. The damages of building which continuously exposed to fire are due to its high temperature. one of the basic reasons why Portland cement concrete is so widely used in building construction is that it can help satisfy the cardinal need for public safety in the face of hazards of fire better than most its competitors. Concrete is a combustible and a reasonable insulator against the transmission of heat. These qualities alone help to confine the fire and limit the extent of the damage (Klieger and Lamond, 1994; Buchanan, 2001).

In recent years the use of high strength concrete ranges in compressive strength from 60 Mpa to as high as 170 Mpa has become more prevalent. Concrete structures such as high-rise buildings, coal gasification vessels and shells of nuclear reactors are using these materials and for producing this kind of concrete one of the essential materials that used is silica fume. Silica fume leads to the densification of cement paste by acting as a micro filler and filling the small voids between coarser cement particles (Caldarone, 2008). Silica fume has also a chemical action in concrete by reacting with portlandite to produce further amount of C-S-H gel which is the main responsible product for the strength in concrete (Khayat and Aitcin, 2002).

The effect of high temperature on concrete depends on the degree of hydration of cement, moisture content, permeability as well as the rate and time of exposure to elevated temperature. There are different opinions at which, how silica fume incorporating systems behave under fire (Jahren, 1989).

Sancak *et al*. (2008) tested normal weight and light weight concretes containing 0, 5, 10% silica fume and they stated that concretes containing higher silica fume has a lower strength than that of control concretes without silica fume after exposure to high temperatures of 100, 400, 800 and 1000°C. Similar results have obtained by Behnood and Ziari (2008) in the case of high strength concrete exposed to 600°C. They showed that concrete specimens containing 6 and 10% silica fume have a lower compressive strength by 6.7 and 14.1%, respectively with respect to the ordinary concrete. This behavior of concrete is due to the dense structure of high strength concrete and fine pore structure in silica fume concrete, which the rate of water vapor can seep through the cement paste can be slower than that of non silica fume concrete. As a result, excessive vapor pressure can develop causing internal cracking, strength reduction and sometimes explosive spalling, especially when the moisture content of the concrete is high (Jahren, 1989).

On the other hand Saad *et al*. (1996) showed that the specimens containing 10% silica fume possess higher strength than ordinary specimens after exposure to 600°C. In evaluating the residual properties of thermally damaged concrete (Biolzi *et al*., 2008) showed that concrete containing 10% micro silica has a higher residual strength than control concrete after exposure to temperatures of 250, 500 and 750°C and both concretes showed higher strengths up to 250°C.

The packing densities of C-S-H gel are not affected by exposure to high temperatures up to 300°C. Moreover, the increase in total pore volume at this temperature is lower than that of lower temperatures (De-Jong and Ulm, 2007).

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Jahren (1989) reviewed 25 references pertaining to fire resistance of silica fume concrete to conclude that there is little evidence to proof that silica fume can have potential effect on the fire resistance concrete.

From the previous, we noticed that there are contradictory results regarding the effect of high temperature on the strength characteristics of cement based materials containing silica fume. The objective of this research study is studying the effect of high temperature on the compressive strength of mortars having different w/b ratios and containing different percentages of silica fume as a cement replacement. The significance of the study is evaluating the residual properties of mortars containing silica fume.

MATERIALS AND METHODS

This project was performed at Ege University Concrete lab. Izmir, Turkey in 2006. In this research normal Portland cement, type PC 42.5 was used. The silica fume was obtained from Sika firm, the chemical composition of the cement and silica fume are given in the Table 1: Natural sand passing through sieve No. 4, having specific gravity of 2.7 and fineness modulus of 2.64 was used. Sikament FF-N (trade mark) available in 7.5 kg capacity gallons, having density of 1.21 kg L^{-1} was used to compensate the flow loss of the mixes.

Mortar mixtures having w/b ratios of 0.4, 0.5 and 0.7 and containing 0, 5 and 10% of silica fume as a cement replacement were prepared. While the water content was not constant the super plasticizer was used in ratios of 0.8 to 3% to compensate the loss of workability due to the incorporation of silica fume. The proportion of cement to fine aggregate was 1:2.75. The mixing process was performed according to ASTM 305 recommendations. The flow of each mixture was determined in accordance with ASTM C109, however, the flow values of 0.7 w/b ratio mixtures was greater than the standard range.

Table 1: Chemical composition of cement and silica fume

Item (%)	Cement type PC 42.5	Silica fume
SiO_2	20.42	93.00
Al_2O_3	5.11	1.40
Fe_2O_3	3.48	1.00
C	1.00	
CaO	64.13	0.10
MgO	0.99	1.50
Na_2O	Not determined	0.40
K_2O	0.80	1.00
S		0.10
SO_3	2.84	0.50
Loss on ignition	1.04	
Insoluble residue	0.42	
free CaO	1.02	
C_3S	54.32	
C_2S	17.57	
C_3A	7.64	
C_4AF	10.59	

Specimen preparation and test methods: From each mixture 28 mortar prismatic specimens of 40×40×160 mm dimensions were prepared. All prisms were casted into two layers each was compacted with an electric compactor. The specimens were left in the molds for 24 h. In the room temperature, after that they cured in water for 7, 28 and 90 days. Before testing all specimens were air dried for 7 days. The heating equipment used in this test was an electrical oven with an average heating rate of 7° min^{-1}. From each mixture nine specimens were placed in the furnace and the furnace was heated to desired temperatures of 300 and 600°C for 24 h. After heating the specimens were allowed to cool in room temperature before subjecting to compression test. The compression test was performed according to ASTM C349 using the portions of prisms broken from flexure.

RESULTS AND DISCUSSION

Performance of specimens at ambient temperature: The compressive strength of 7, 28 and 90 days moist cured mortar specimens incorporating silica fume show a significant increase in strength compared with corresponding strength of the control specimens without silica fume. Moreover, by increasing silica fume content from 5 to 10% by weight of cement, the compressive strength increases. The only exception of this is the 7 day moist cured specimens having w/b ratio of 0.4 (Fig. 1).

Performance of specimens after 24 h exposure to 300°C: After exposure to 300°C the compressive strength of nearly all specimens increase significantly compared to corresponding specimens tested at 20°C. This increase is superior for specimens containing silica fume (Fig. 1, 2). Specimens containing 10% silica fume and having w/b ratios of 0.7 and 0.5 show higher compressive strength than that containing 5% silica fume. On the other hand the specimens containing 5% silica fume and having w/b ratio of 0.4 show greater compressive strength than the specimens containing 10% silica fume. This relation is true for all curing ages. The highest compressive strength values were obtained for specimens that had been moist cured for 90 days and having w/b ratio of 0.4.

The increase in strength after exposure to 300°C is most likely due to further hydration of non hydrated cement in the system which leads to producing more C-S-H which by turn makes the system denser.

Performance of specimens after 24 h exposure to 600°C: As shown in the Fig. 3, 24 h exposure to 600°C results in a great decrease in compressive strength in both silica fume and non silica fume incorporated specimens and it can be noted that, for all w/b ratios, the silica fume

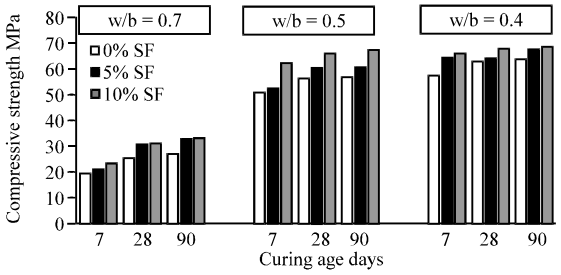

Fig. 1: The compressive strength of specimens containing different percentages of silica fume at different curing ages tested at ambient temperature

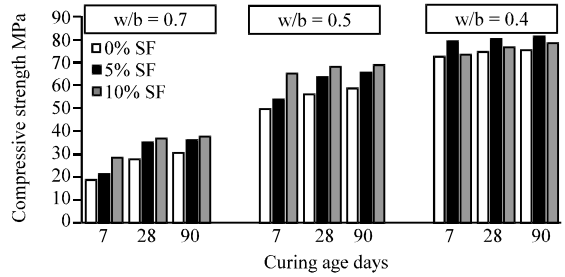

Fig. 2: The compressive strength of specimens containing different percentages of silica fume at different curing ages tested after exposure to 300°C

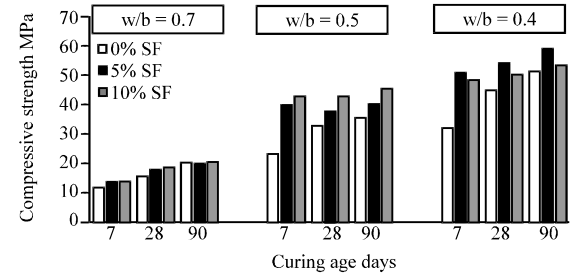

Fig. 3: The compressive strength of specimens containing different percentages of silica fume at different curing ages tested after exposure to 600°C

contained specimens show higher residual strength than control specimens with no silica fume. Moreover, 7 days moist cured specimens show greater loss in strength than 28 and 90 days moist cured specimens with respect to corresponding control specimens in Fig 1. The maximum residual compressive strength value was recorded for 5% silica fume contained specimens that were moist cured for 90 days and had w/b ratio of 0.4. The reduction in strength after exposure to this temperature is probably due to the decomposition of calcium hydroxide which increases the porosity of the system, furthermore the built up vapor pressure in the system due to high temperature causes micro cracks which leads to decreasing the strength.

Despite of the dense structure and high strength, no sapling detected for the specimens exposed to high temperature. This phenomenon is most likely due to the low water content of the specimens because they were air dried for 7 days prior to exposure to temperature and the size effect which in small sized specimens the vapor seep out more easily.

The higher residual strength of silica fume contained specimens after exposure to high temperature can be due to the pozzolanic effect of silica fume during the hydration process which leads to producing high amounts of C-S-H and by turn increasing the strength (Khayat and Aitcin, 1992). Furthermore silica fume is acting as a micro filler and strengthening the micro structure of the system (Caldarone, 2008).

CONCLUSION

For the materials used and test procedure applied the following conclusions may be drawn:

- Before exposure to high temperatures, for all curing ages the silica fume incorporated mortar specimens show higher compressive strength than that without silica fume. The increase in strength is more pronounced for specimens containing higher silica fume
- After exposure to 300°C the compressive strength of nearly all specimens increase, this increase is superior for specimens containing silica fume
- Both silica fume and non silica fume specimens show a dramatic decrease in strength after exposure to 600°C. Once again, the silica fume contained specimens have a higher residual strength than the non silica fume contained specimens
- None of the specimens spalled after exposure to high temperature

REFERENCES

Behnood, A. and H. Ziari, 2008. Effect of silica fume addition and water to cement ratio on the properties of high strength concrete after exposure to high temperatures. Cem. Concr. Compos., 30: 106-112.

Biolzi, L., S. Cattaneo and G. Rosati, 2008. Evaluating residual properties of thermally damaged concrete. Cem. Concr. Composites, 30: 907-916.

Buchanan, A.H., 2001. Structural Design for Fire Safety. John Wiley and Son Ltd., England, pp: 421.

Caldarone, M., 2008. High-Strength Concrete: A Practical Guide. Taylor and Francis Group, London.

De-Jong, M.J. and F.J. Ulm, 2007. The nanogranular behavior of CSH at elevated temperatures (up to 700°C). Cement Concrete Res., 37: 1-12.

Jahren, P.A., 1989. Fire resistance of high-strength/dense concrete, with particular reference to the use of condensed silica fume: A review. Proc. Int. Conf. High-Strength Concrete, 114: 1013-1050.

Khayat, K.H. and R.C. Aitcin, 2002. Fume in Concrete: An Overview. American Concrete Institute, USA.

Klieger, P. and J. Lamond, 1994. Significance of Tests and Properties of Concrete and Concrete-Making Materials. ASTM International, USA.

Saad, M., S.A. Abo-El-Enein, G.B. Hanna and M.F. Kotkate, 1996. Effect of temperature on physical and mechanical properties of concrete containing silica fume. Cem. Concr. Res., 26: 669-675.

Sancak, E., Y.D. Sari and O. Simsek, 2008. Effects of elevated temperature on compressive strength and weight loss of the lightweight concrete with silica fume and superplasticizer. Cement Concrete Compos., 30: 715-721.