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EFFECT OF TEMPERATURE ON PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETE CONTAINING SILICA FUME

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ABSTRACT

Fire is one of the natural hazards which attack building construction.The damage in buildings which continuously exposed to fire are caused due to its high temperature. Thus the effect of high temperatures on physical and mechanical properties of concrete was investigated. In this study ordinary Portland cement has been partially replaced by ratios of silica fume. The heat treatment temperature varied from 100 to 600°C by increments of 100°C for three hours without any load. Concrete specimens were treated at each temperature level. The specimens were heated under the same condition for each temperature level. Comparison between physical and mechanical properties during heat treatment were investigated. All specimens were moist-cured for 28 days after casting. Tests were carried out on specimens cooled slowly to room temperature after heating. Results of this investigation indicated that the replacement of ordinary Portland cement by 10% silica fume by weight improved the compressive strength by about 64.6%, but replacment of ordinary portland cement by silica fume by ratios 20 and 30% improved the compressive strength by only 28% at 600°C. This could be attributed to the additional tobermorite gel (CSH phase) which formed due to the reaction of silica fume with $Ca(OH)_2$.

Introduction

Heat-resistant materials are usually used for structural purposes. The need for such building materials is particularly important in the chemical and metallurgical industries and for the thermal shieldings of nuclear power plants. Concrete must at times resist the effects of induced high temperatures, but in most instances it is desired to avoid deterioration of the concrete's physical properties, as much as possible. This work aimed to investigate the effect of high temperatures on the physical and mechanical properties of concrete containing silica fume. Previous studies [1–4] investigated the following: the thermal stability of concrete has been assessed by means of strength measurements taken at the elevated temperatures or after cooling;

concretes with pozzolanic materials added in the mixer in order to replace Portland cement seem to be more sensitive to exposure to heating; the microfillers materials such as fly ash, silica flour and calcined shale dust were used as thermal stabilizers of Portland cement and the high-strength concrete subjected to high temperature appeared to be more suitable to spalling than normal strength concrete.

Experimental Work

All tests were carried out using Portland cement. The concrete specimens were made with cement:sand:aggregate ratios 1:2:3 by weight and water/(cement + silica fume) ratio of 0.4. The ordinary Portland cement has been partially replaced by silica fume of ratios 10, 20 and 30% by weight. After 28 days of moist curing, the specimens were dried at a temperature of 105 ± 5°C for 24 hours in an electric furnace. The furnace temperatures were controlled by an electroinc controller. Next, they were kept for three hours in each of the investigated temperatures in an electronic controller furnace, in the range between 200 to 600°C at intervals of 100°C. After heat treatment was complete, concrete samples and the furnace were cooled to the indoor room air temperature and they were applied to various tests. The physical properties were measured before the specimens were mechanically tested. Groups of three specimens were used to determine the residual compressive strength according to BS1881 [5]. Groups of three specimens were also used to detect the residual splitting tensile strength [6]. For studing the phase deformation in hardened cement paste, X-ray diffraction using Nickel-filter Cu-Kα radiation generated at 40KV , 20mA were used.

Results and Discussion

In this study, the aggregate is thermally stable within the temperature range of exposures. The unstable component of the concrete under investigation is the portland cement paste. Heterogeneity of concrete due to its components, both in micro and macroscale, causes a large number of phenomena and physico-chemical processes during heat treatment. Therefore, the moisture is removed at a faster rate which affects the surrounding phase of cement paste when exposed to high temperatures. Mainly due to flow resistance and high temperature, steam creates a high pressure in the paste. In consequence, the so-called conditions for internal autoclaving are formed in cement paste. The temperature range between 100–300°C is the most favourable for the formation of such conditions because in this temperature range steam is liberated most intensively [7]. Additional hydration of unhydrated cement grains is the results of steam effect under the condition of internal autoclaving. This is indicated by a decrease in phases (C3S + β-C2S) and an increase in the $Ca(OH)_2$ phase due to recrystallization of amorphous $Ca(OH)_2$ which is confirmed by means of the X-ray diffraction analysis, as shown in Fig.(1). The addition of silica fume improves both the mechanical characteristics and durability of concrete. This is due to physical effects of silica fume in concrete , which can fit into the spaces between cement grains as a result of its fineness; and due to chemical reaction of silica fume with the hydrated product, because of its high surface area and high content of amorphous silica [8].

Figure 2 shows the change of porosity of concrete specimens, made with different silica fume contents, with increasing temperature of heat treatment. In general, in all concrete specimens,

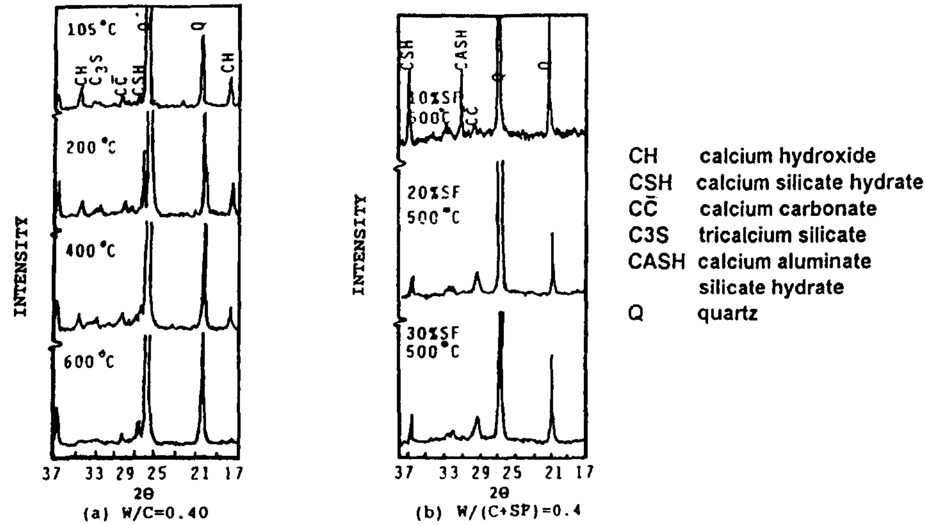

FIG. 1.
X-ray diffraction of concrete thermally treated at various temperatures.

the porosity increases with increasing temperature of thermal treatment. Evidently, the concrete specimens containing 10% silica fume show the lower porosity values at all temperatures; this result is mainly associated with the formation of a more dense structure of the concrete specimens containing 10% silica fume which shows higher thermal stability. With increasing

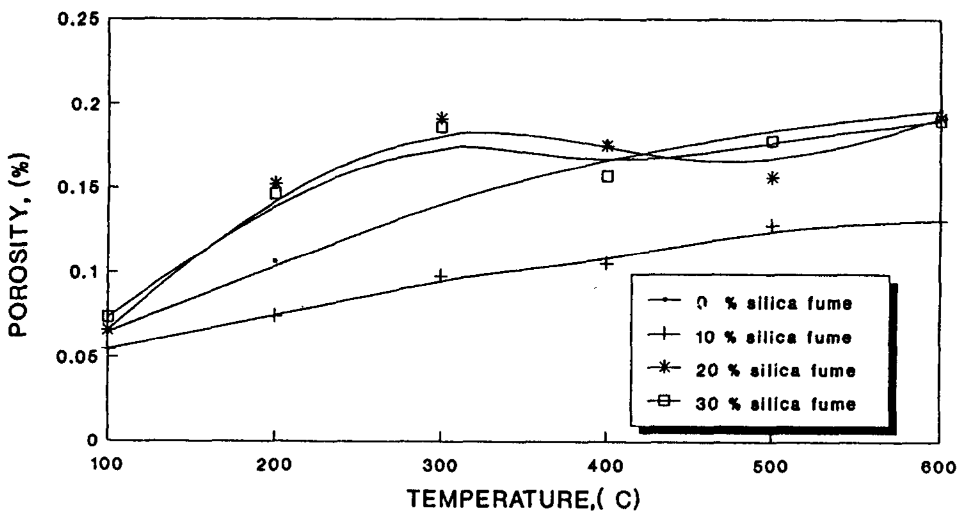

FIG. 2.
Change of porosity of heat treated concrete containing SF with temperature.

silica fume content of concrete (made with 20 and 30% silica fume), however, higher porosity values were obtained. This result is related to the formation and enlargement of microcracks and/or the increased degree of crystallinity of the formed hydrates leading to a sort of opening of the pore system of concrete specimens.

Figure 3 demonstrates the water absorption values of the various concrete specimens containing 0, 10, 20,and 30% silica fume as a function of temperature of heat treatment. The results indicate the same changes in the water absorption values similar to those of the porosity values with increasing temperature of heat treatment. Furthermore, the concrete specimens containing 10% silica fume give the lowest values of water absorption as compared with those obtained from concrete specimens containing higher silica fume contents (20 and 30%) at different temperatures of heat treatment. These results indicate that concrete specimens containing 10% silica fume give lower porosity and water absorption values.

Figure 4 illustrates the change of weight of concrete containing silica fume with increasing temperature. In general, the loss of weight increases with increasing temperature during heat treatment. This result is mainly associated with the decomposition of the formed cement hydrates. In addition, as the silica fume increases from 0 to 20% the weight loss increases for each temperature of heat treatment, since larger amounts of calcium silicate hydrates are formed in concrete containing silica fume contents. For the concrete specimens made with 30% silica fume, however, no further loss in concrete weight is noticed indicating that no more calcium silicate hydrates are formed on increasing the silica fume content above 20% and the excess silica fume remains free in the concrete specimens.

Figure 5 shows the relation between compressive strength of thermally treated concrete with different silica fume contents and at different temperature. A continuous decrease in compressive strength appears with increasing temperature of concrete specimens made without silica fume. Evidently, on addition of silica fume to concrete the thermal stability increases with retained strength values up to 350°C for concrete containing 10% silica fume, but to about

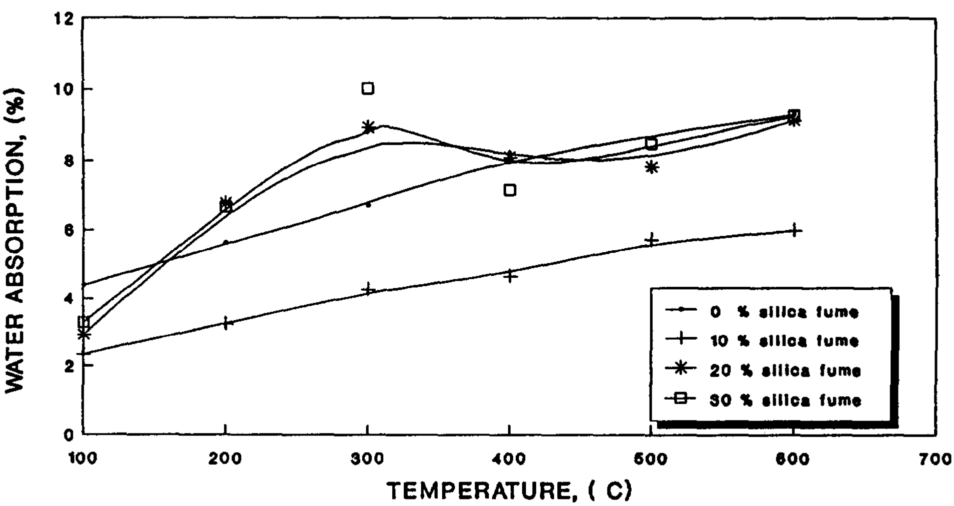

FIG. 3.
Change of concrete water absorption containing sillica fume with temperature.

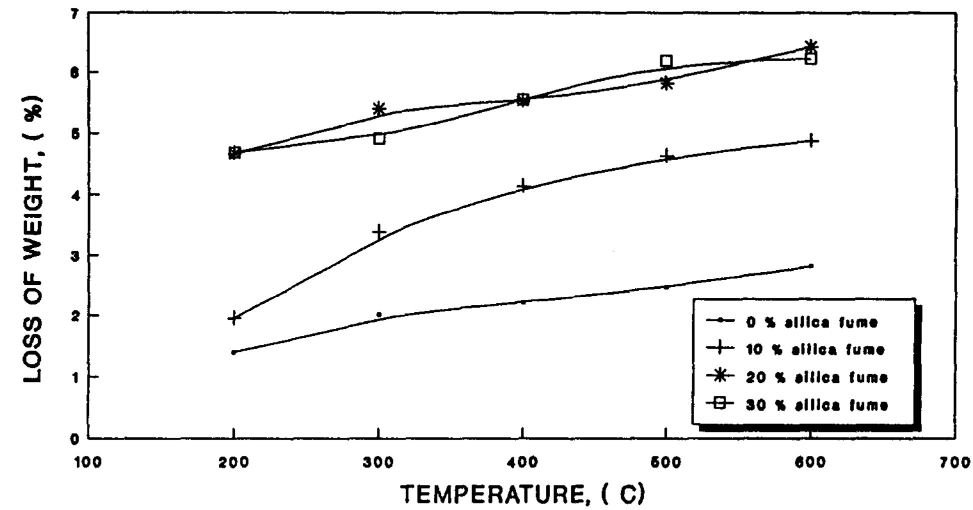

FIG. 4.
Change of concrete weight containing silica fume with temperature.

200°C for concrete containing 20% and 30% silica fume. Heat treatment at higher temperature, however, leads to a notable decrease in compressive strength. Obviously, the concrete specimens made with 10% silica fume possess the highest strength at all temperatures during heat treatment. It is clear from Fig.1 that more CSH hydrates are formed with stronger binding forces and sufficient thermal stability during heat treatment. This result is also associated with

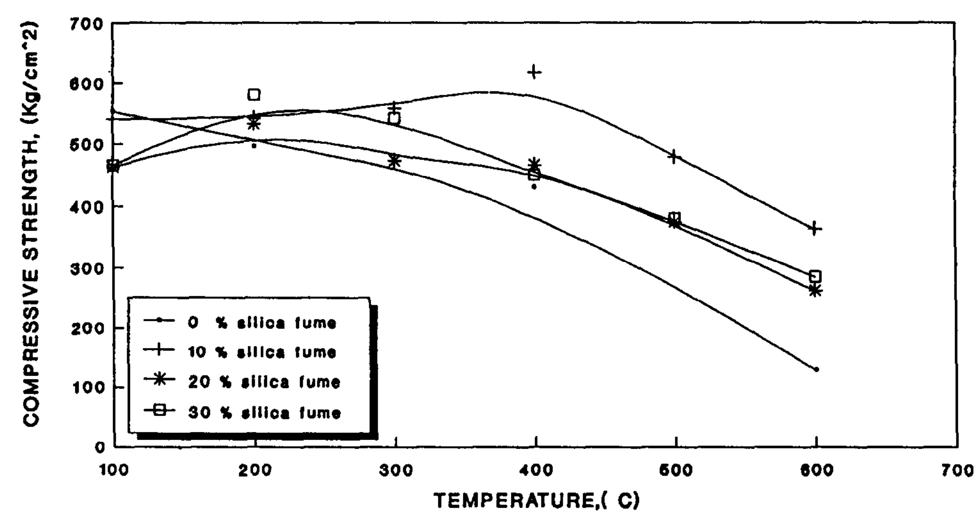

FIG. 5.
Relation between concrete compressive strength containing SF with temperature.

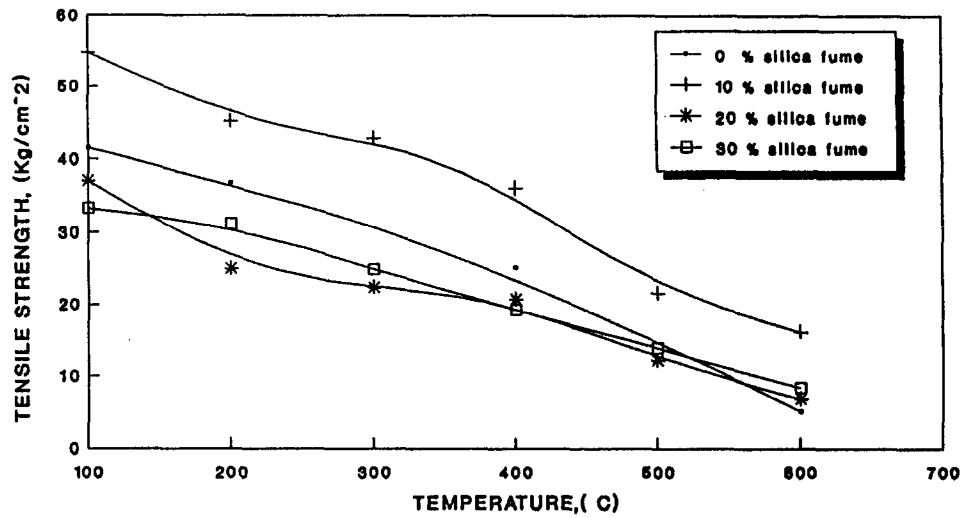

FIG. 6.
Relation between concrete tensil strength containing SF with temperature.

relatively lower porosity values of concrete specimens as compared with those obtained for concrete specimens having silica fume contents of 20 and 30%. The latter concrete specimens possess relatively high porosity values leading to lower strength values with increasing temperature, as observed in Fig.(2). The addition of 10% silica fume improves the compressive strength by 64.6% for specimens thermally treated at 600°C, but the rise in compressive strength is only 25% for concrete specimens having higher silica fume contents of 20 and 30% at the same temperature.

Figure 6 shows the effect of high temperature on the tensile strength of hardened concrete. It is clear that, the tensile strength decreases as the temperature of thermal treatment increases. This result is mainly related to the thermal decomposition and/or the stability of the formed hydrates which act as the main binders between the concrete constituents. Evidently, the concrete specimens made with a W/(C + SF) ratio of 0.40 and containing 10% silica fume possess relatively higher values of tensile strength; this is due to the relatively low porosity of these concrete specimens and/or their high thermal stability of the CSH phases produced as a result of the reaction between free $Ca(OH)_2$ and active silica fume.

Conclusions

The main conclusions derived from this study may be summarized as follows:

1. The addition of silica fume to ordinary concrete leads to the consumption of $Ca(OH)_2$ obtained during cement hydration.
2. Concrete specimens containing 10% silica fume possess lower porosity values at all temperatures of thermal treatment.

3. Concrete specimens made with 10% silica fume possess the highest compressive strength values at all temperatures of thermal treatment as more CSH is formed with stronger binding forces and a sufficient thermal stability.
4. The improvement in compressive strength for concrete specimens containing 10% silica fume and treated at 600°C is 64.6%.

References

1. P.J.E. Sullivan and G.A. Khoury, ACI, SP 92–10 (1986).
2. J.Papayianni and T.Valiasis, Mater. and Struc.,24 (1991).
3. N.G.Zoldners and H.S. Wilson, ACI Publication SP–39 (1973).
4. G. Sanjayan and L.J. Stocks,ACI Mater. Journal, 90(2) (1993).
5. BS 1881, Part 4, "Methods of Testing Concrete for Strength" (1970).
6. I. Soroka,"Portland Cement Paste and Concrete", Chemical Publishing Co., Inc., New York (1980).
7. J. Piasta, Z. Sawicz and L. Rudzinski, Mater. and Struc., 17(100) (1984).
8. R.J. Detwiler and P.K. Mehta, ACI Mater. Journal, 86(6) (1989).