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Development of the fire resistance and mechanical characteristics of silica fume-blended cement pastes using some chemical admixtures

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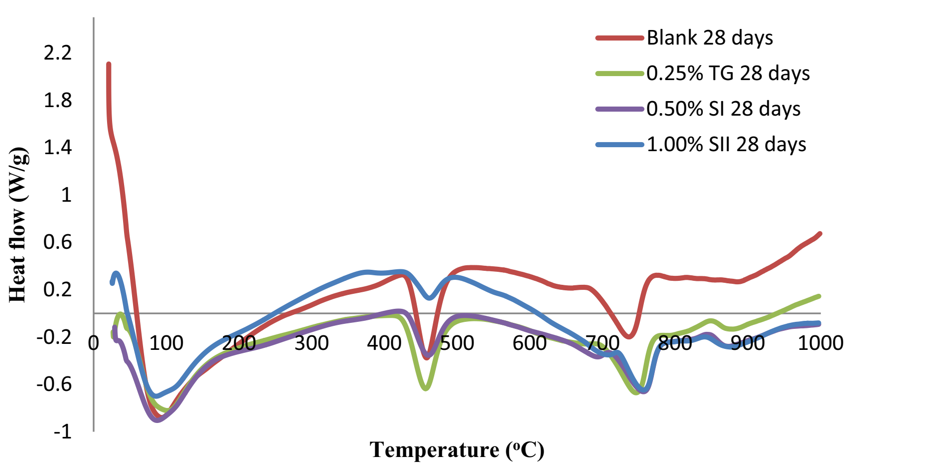
HIGHLIGHTS

- The used admixtures enhancing both fire resistance and mechanical properties of silica-fume blended pastes.
- The water reduction% of the prepared admixtures reaches 52.1% and 54.36%.
- The compressive strength enhanced by (31.6% for TG, 50.3% for SI and 53.9 for SII).
- Fast cooling in water causes the higher losses of strength than slow cooling in air for all temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the fire resistance and mechanical properties of blended cement pastes were improved using three different admixtures namely; phenol formaldehyde sulfonilate (SI), and low phenol content phenol formaldehyde sulfonilate (SII) and sikament-TG (TG). The fire resistance tests were studied by measuring the weight loss percentages for some selected pastes (optimum dose) at each firing temperature. The phase composition and microstructure of the formed hydrates were examined using scanning electron microscopy, X-ray diffraction and differential scanning calorimetry analysis. The results show that the doses of 0.25% TG, 0.50% SI and 1.00% SII are the optimum doses. Moreover, in case of air cooling, the compressive strength of the hardened pastes admixed with the optimum doses increases by firing the specimens up to 500 °C, then decreases by firing the specimens at temperatures up to 700 °C, but still higher than the compressive strength at room temperature.

1. Introduction

The enormous needs of concrete in the high-rise buildings, nuclear reactors pressure vessels, reservoir for hot crude oil,

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liquefaction vessels, hot water and coal gasification increases the risk of exposing the concrete to fire.

Concrete structures have a good fire resistance, which is the main reason why concrete is so extensively utilized as building materials. Concrete is non-burnable and is an effective insulator against heat transmission which helps in decreasing the degree of harm [1].

So studying the effect of elevated temperatures on the cement paste is a very important issue as the cement is the main components of concrete. Fire causes deterioration of concrete leading to strength reduction, generate deformations while the fire and expansion through cooling process, which cause stresses and strains on the building structural, leads to decrease the service life time of structure [2].

There are a lot of factors that can affect the strength of concrete at a high temperature like, material properties including cement pastes, mineral admixtures [3], aggregates and thermal compatibility between them and also, heating rate, temperature exposure period [2], moisture content, applied load and finally cooling mode after heating [2,4,5].

It was found that concrete subjected to early steps of fire has no remarkable loss of qualities; on the contrary, fire may develop its mechanical strength till a certain temperature in behalf of the increase in its degree of hydration. On other hand, the mechanical ability of concrete falls down onwards this temperature as a result of decomposition of hydration products, and formation of microcracks [3]. The decomposition of calcium hydroxide (CH), as an example, leads to formation of CaO and H_2O, has a very harmful effect due to several factors; the creation of microcracks which appears at 400–460 °C [3,6], the strength loss during heating and finally lime expansion during the cooling process [3]. As the CaO combines with water and returns back to CH with a significant expansion.

Nevertheless, we can control the damaging effects of high temperatures on concrete structure by considering some precautions as selecting the suitable materials, changing the cooling materials and cooling rate [7].

So the fractional replacement of cement by mineral additives, like silica fume, fly ash, metakaolin, granulated blast furnace slag (GBFS), is of great effect which can enhance the fire resistance properties.

Silica fume (SF) can be namely (Condensed silica fume, Micro silica and Volatilized silica). It is a side-product of the production of silicon or ferrosilicon in smelters using electric arc furnaces. It has a thermal insulation and high-temperature resistance properties

SF reacts with CH by a mode of pozzolanic reaction leading to formation of further amount of calcium silicate hydrate (CSH) which stabilizing the concrete structure, since CSH has higher thermal stability than that of CH. The formation of this extra CSH leads to increase the compressive strength of concrete [4,5,8].

Also, due to the physical properties of SF, it can fit in the spaces between cement grains as it is a very fine particle which lead to micro-cracks filling which decrease the pores size and finally the total porosity.

SF-blended cements have high sensitivity in existence of chemical admixtures. The aim of adding chemical admixtures is to make concrete more satisfactory for any required applications. So instead of using special cements, we can improve the properties of the concrete by using suitable chemical admixtures. The main role of these admixtures is to lower the water/cement ratio (W/C ratio) with maintaining the workability. This improves the rheological properties due to dispersion effect of anhydrate and hydrated cement particles [9] and increases the compressive strength of cement system [5,10–12].

The SF blended cement pastes containing admixtures give large number of advantages such as increasing the compressive strength and toughness, decreasing the permeability to enhance durability, preventing generation of cracks and increased chemical attack, abrasion and fire resistance [5,13,14].

The influence of SF with admixtures on high-temperature resistance was demonstrated by several researchers. Exposing concrete to high temperature up to 800 °C produces variables results which are related to the factors illustrated above. In previous work, it was reported that the compressive strength of fired cement pastes (OPC + 10% SF + different dosages of sulphonated naphthalene formaldehyde (SNF) superplasticizer) with different delaying time additions rises till 600 °C, then cutback up to 800 °C. The maximum value of compressive strength is about 132 MPa for 1.0% SNF with delayed addition 7.5 min at 600 °C [5]. The effect of different wt% of SF on the characteristics of cement pastes at high temperatures was studied, the results confirmed that the cement paste containing 15% SF (best wt%), has a good firing resistance as the compressive strength increase up to 600 °C till reach to about 80 MPa, Beyond this temperature, the compressive strength decrease [8].

The present research aimed to study the effect of two prepared polymeric admixtures (SI and SII) on the mechanical properties of SF blended cement at room and elevated temperatures up to 800 °C and compare the results with that obtained from commercial admixture (TG) to point out the effect of the admixtures on the improvement of the fire resistance of concrete and evaluate the efficiency of our prepared admixtures.

2. Materials and experimental techniques

2.1. Materials

2.1.1. Cement and silica fume

The cement used in this study is Ordinary Portland cement (OPC) blended with 7.5% Silica fume by weight. The OPC was manufactured in Suez Cement Company, Suez, Egypt. The silica fumes (SF) was supplied from Sika Egypt Company, El-Obour City, Egypt. The chemical oxide composition and the physical properties of OPC and SF are recorded in Table 1 and Table 2; respectively.

The phase composition of the cement was calculated using Bouge's equation and was 52.0% C_3S, 19.2% β-C_2S, 8.8% C_3A and 11.1% C_4AF.

2.1.2. Chemical admixtures

In this study, we used three different admixtures. Two of them were prepared laboratory namely, phenol formaldehyde sulfanilate (SI), and low phenol content phenol formaldehyde sulfanilate (SII); which were prepared at the Surface Active Agents Lab, Petrochemical Department, Egyptian Petroleum Research Institute (EPRI), Cairo, Egypt. The third one was a commercial sikament-TG (TG) which was supplied from (Sika Egypt Company, El-Obour City, Egypt).

To prepare SI admixture, 96 g of sulfanilic acid sodium salt, 133 g of phenol and 400 ml water were added to a reaction vessel equipped with a stirrer, and 20% aqueous sodium hydroxide (NaOH) was added to adjust pH 9. Thereafter, the mixture was stirred and heated to 90 °C, and then 168 g of 37% aqueous formaldehyde was then added drop wisely into the reactor. The reaction was completed after 3.5 h. The mixture was then cooled to room temperature and adjusted to pH 11.0 with 20 wt% aqueous NaOH.

While to prepare the SII admixtures, the same steps was repeated as reported above; except that the phenol content was reduced to half the weight of SI (66.5 g of phenol).

The structure of the synthesized polymers was shown in Fig. 1 and confirmed by using FT-IR spectroscopic as shown in Fig. 2a–b.