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Influence of activation of fly ash on the mechanical properties of concrete

Yasmin Hefni *, Yehia Abd El Zaher, Mona Abdel Wahab

Structural Engineering Department, Ain Shams University, Egypt

HIGHLIGHTS

- Fly ash as a partial replacement for cement reduces concrete strength at early ages.
- Fly ash improved concrete strength at the ages of 56 up to 180 days.
- Fly ash extremely enhanced all concrete strengths after exposure to elevated temperatures.
- Activation of fly has a pronouncing effect on improving concrete properties at early ages.
- Glass fibers enhances the splitting and flexural strength.

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ABSTRACT

The use of high volume fly ash as a partial replacement of cement in concrete reduces environmental pollution and conserves natural resources. This study presents the results of an experimental investigation to find out the effect of chemical activation of class F fly ash to overcome the low early strength problem. The replacement ratio of Portland cement with fly ash was 40%. Four different chemical activators were used in the study; 2.5% Na_2SO_4, 2.5% NaOH, 3.0% (Na_2SiO_3 and CaO) by ratio (1:8) and 4% Aquis Na_2SiO_3. Concrete strength was investigated at room temperature and after exposure to elevated temperature. Glass fibers were added by ratio 0.7% to improve concrete ductility. Test results indicated that aquis Na_2SiO_3 activator is the superior activator for fly ash in view of enhancing concrete compressive, splitting tensile and flexural strengths at early ages. Besides, a significant increase in concrete strength was obtained at elevated temperatures. Adding glass fibers in the ratio of 0.7% by weight of cementitious material with activated FA by using aquis Na_2SiO_3 greatly enhances the splitting tensile and flexural strengths at normal and elevated temperature.

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1. Introduction

Fly ash is a byproduct of pulverized coal combustion in electric power generating plants. It reacts aggressively with calcium hydroxide to form compounds with cementitious value which increases concrete strength. Nowadays fly ash spreads in Egypt as a result of burning coal at coal mills at most of cement plants to produce heat energy. Selecting fly ash in concrete will attain environmental, economic and also structural benefits as increasing strength and fire resistance of concrete structures.

Adding fly ash to concrete improves mechanical properties of concrete al late ages but obtains lower strength up to 28 days. The reduction in early strength is a function of replacement percent [1,2]. The mechanical properties and abrasion resistance showed continuous and significant improvement at the ages of 91 and 365 days due to the pozzolanic reaction of fly ash [2]. However, class F fly ash can be suitably used up to 50% level of cement replacement in concrete for use in precast elements and reinforced cement concrete construction [2]. Potha et al. [3] and Azhar et al.[4] concluded that adding fly ash in concrete by large doses improved the concrete strength at late ages at normal and after exposure to elevated temperatures. Strength improvement at elevated temperature may be attributed to the relatively porous structure and the reduction in thermal conductivity. The obstacles of using fly ash in repair techniques such as jacketing are the extended setting time and the slow strength development.

Different methods of activation have been developed to overcome the low early strength of fly ash concrete and to enhance the reactivity. There are three methods of activation of pozzolans;

* Corresponding author.
E-mail address: yasmin_hefni@hotmail.com (Y. Hefni).

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thermal, mechanical, and chemical activation. Chemical activation method has the lowest cost to strength ratio compared to the others activation methods and it is superior in improving strength [5]. Mainly two different methods of chemical activation commonly utilized include alkali activation and sulfate activation [6,7]. Alkali activation using calcium hydroxide $Ca(OH)_2$ or sodium hydroxide NaOH and sulfate activation using calcium sulfate $CaSO_4{\cdot}2H_2O$ or sodium sulfate Na_2SO_4 [8] are the most common chemical activation techniques. Other techniques of activation include calcium chloride $CaCl_2$, sodium silicate Na_2SiO_3 and calcium oxide CaO [8,9,10]. Gopalsamy et al. [8] studied the effect of using a mixture of CaO and Na_2SiO_3 in the ratio of 1:8, respectively, for fly ash activation. Activation by using Aquis Na_2SiO_3 produces silica gel that could change to gel with solid properties when the gel loses water gradually. In fact this gelatinization is the process of transformation from linear structure to reticular structure. Gelatinization process could be expressed by the following equation [11]:

$$Na_2SiO_3 + nH_2O \rightarrow 2NaOH + SiO_2.(n-1)H_2O.$$

Saraswathy et al. [12] experimentally investigated the effect of chemical activation of fly ash by using chemical treatment with sodium hydroxide solution on concrete strength and corrosion resistance. Test results indicated that using activated fly ash up to critical level of 20–30% replacement improved concrete strength and corrosion resistance. Owens et al. [13] investigated the effect of chemical activations on high volume fly ash pastes (50% fly ash replacement of PC) by using sodium sulfate, calcium sulfate and sodium hydroxide at a dosage of 1% of weight of binder, 10% weight of binder and 1 Molar, respectively. Two different temperature regimes were utilized. One was the treatment of samples at 20 °C for 7 days while the other was the treatment at 60 °C for the initial 24 h and 200 °C for the remaining 6 days. Test results indicated that the addition of sodium and calcium sulfate improved compressive strength of the mixes treated at 60 °C after 1 day curing by 10% and 27%, respectively when compared to the un-activated mix. The sodium sulfate and sodium hydroxide activated mixes showed no strength gain at 3 and 7 days. The calcium sulfate activated mix outperformed the un-activated mix at 3 and 7 days.

On the other hand, the use of glass fibers improves the tensile strength, imparts the concrete ductility and better crack arrest and propagation. Reddy and Vijayan [14], Sudheer et al. [15] and Ravikumar and Thandavamoorthy [16] concluded that glass fibers improve the concrete fire resistance. This may be attributed to the lower thermal resistance of glass fibers (0.05 W·m·°C) which is lower than concrete. This could explain the better fire resistance of fiber reinforced concrete as fibers isolate the inner matrix of concrete and reduce crack propagation and fire intrusions through cracks.

2. Research significance

The objective of this study is to experimentally investigate the effect of chemical activation of fly ash on the mechanical properties of concrete at normal and after exposure to elevated temperatures. Four different chemical activators were used in the study; 2.5% Na_2SO_4, 2.5% NaOH, 3% (Na_2SiO_3 and CaO) by ratio (1:8) and 4% Aquis Na_2SiO_3. The success of promoting the pozzolanic action of fly ash by chemical activation will help in maximizing the benefits of using fly ash in wide range of applications in concrete industries. Also, investigating the effect of adding glass fibers on chemically activated fly ash concrete at normal and elevated temperatures is a major part of the study.

3. Experimental study

The experimental program was designed to achieve the objectives of the study through the following two stages:

1. Stage I: Investigating the effect of chemical activation of fly ash (FA) by using four types of chemical activators. Fly ash was used by partial replacement of 40% of cement weight. The proposed ratio was chosen based on an earlier study for the authors [17]. The compressive, splitting tensile and flexural strengths were investigated at room temperature and after exposure to elevated temperatures.
2. Stage II: investigating the effect of adding glass fibers to high volume chemically activated fly ash concrete on mechanical properties such as compressive, tensile and flexural strengths; Younge's modulus and pull out strength; at normal and after exposure to elevated temperatures.

3.1. Materials

3.1.1. Cement

Ordinary Portland cement (CEM I 42.5N) complying with ES 4756-1/2007 [18].

3.1.2. Aggregates

Natural siliceous sand with fineness modulus 2.85 was used as fine aggregate and crushed limestone in two sizes; S1 (5–20 mm particle size) and S2 (10–25 mm particle size) was used as coarse aggregate. All used aggregates complying with ECP 203/2007 [19].

3.1.3. Water

Clean tap water (free from organic matters) complying with ECP 203/2007 [19].

3.1.4. Admixtures

High range water reducing admixture complying with ASTM C 494 Type F [20].

3.1.5. Fly ash

Type F fly ash with light grey spherical particles, less than 10% retained on sieve 45 μm, and specific gravity of 2.0. The chemical oxide composition ($SiO_2 + Al_2O_3 + Fe_2O_3$) of the used fly ash was 92.47% and loss of ignition (LOI) value was 1.1%.

3.1.6. Glass fibers

E-glass single filament fibers with diameter of 13 μm, and two lengths of 6 mm and 18 mm in the ratio of 1:1.

3.1.7. Sodium silicate

Manufactured directly in a solution from by the wet process where the silica leached out under pressure by concentrated caustic soda solution. The percent of Na_2O and SiO_2 of Liquid sodium silicate were 14.7 and 29.4 and density of the activator was 1.5 g/cm^3.

3.1.8. The sodium hydroxide

Solution of NaOH was prepared by dissolving sodium hydroxide pellets of purity 97% in deionized water at least 1 day prior to mixing.

3.1.9. Sodium sulfate

Commercially available Na_2SO_4 as powder (99% pure).

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