Effect of Delay Time and Duration of Steam Curing on Compressive Strength and Microstructure of Geopolymer Concrete

Visalakshi Talakokula, R. Singh and K. Vysakh

Abstract Ordinary Portland cement (OPC) is conventionally used as a primary binder to produce concrete. The amount of carbon dioxide released during the manufacture of OPC is a matter of great environmental concern in view of global warming. Thus, alternative concrete technologies have become an area of increasing interest in research community. On the other hand, fly ash (FA), abundantly available by-product of coal fired thermal power plants poses great environmental problems in terms of its safe disposal. Therefore, use of FA as a replacement of cement in concrete production is one alternative, which is being widely used in the construction field. Geopolymer is a type of amorphous alumino-silicate cementitious material. This paper reports the results of an experimental study on the effect of delay time and duration of steam curing on the compressive strength and microstructure development of FA based geopolymer concrete specimens prepared by thermal activation of FA with sodium hydroxide and sodium silicate solution.

Keywords Compressive strength · Concrete · Geopolymer · Microstructure · Steam curing

1 Introduction

Concrete with 100 % fly ash (FA) replacement can be obtained through Geopolymerization, which can be synthesized by polycondensation reaction of geopolymeric precursor and alkali polysilicates. Geopolymerization is an innovative technology that can transform several alumino-silicate materials into useful products

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called inorganic polymers. Materials rich in silica such as fly-ash, slag, rice husk and alumina such as clay are the primary requirements for geopolymerization.

Addition of FA to concrete has become a common practice in recent years. FA is a fine residue from powdered coal combustion that acts as a pozzolanic material [1] i.e. the particles react with water and lime to produce cementitious products [2, 3]. Reasons for FA replacements of cement in various proportions include economy and enhancement of certain properties of fresh concrete (workability and pumpability) as well as hardened concrete [3]. Studies have been published concerning the effect of FA on concrete porosity and resistivity, pore solution chemistry, oxygen and chloride ion diffusivity [3–6], carbonation rates [7, 8] and passivation [9], mechanical properties of concrete [10, 11]. In order to produce fly ashes with stable properties and adequate quality, many power plants have implemented their own sophisticated quality control measures. The property improvement of FA blended cements has been extensively studied and it is found that their physical and mechanical properties match those of OPC [6, 12–14].

2 Details of FA Utilized

Figure 1 shows the scanning electron microscopy (SEM) image of FA in which the spherical shape of the FA particles can be clearly seen in the SEM image. The major components of FA are silica, alumina, ferric oxide and calcium oxide. The current standard, ASTM C-618 [15] defines two classes of FA based on bulk chemical composition and, specifically, in terms of the sum $Al_2O_3 + SiO_2 + Fe_2O_3$. As per the standard, this sum is between 50 and 70 % for Class C FA and 70 % or greater for Class F FA. The higher percentage of more reactive calcium oxide in Class-C FA makes it advantageous to use for higher strength gain. To know the class of FA used in the present study, the sample was characterized by X-ray diffraction (XRD), composition analysis. XRD is a non-destructive analytical

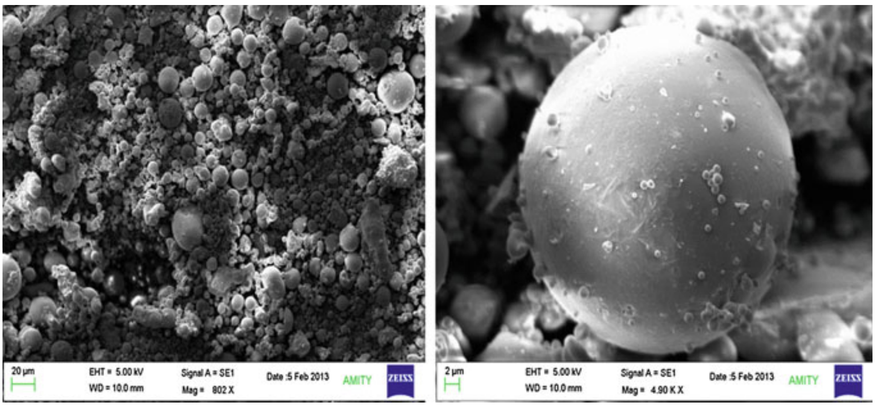

Fig. 1 SEM images of FA

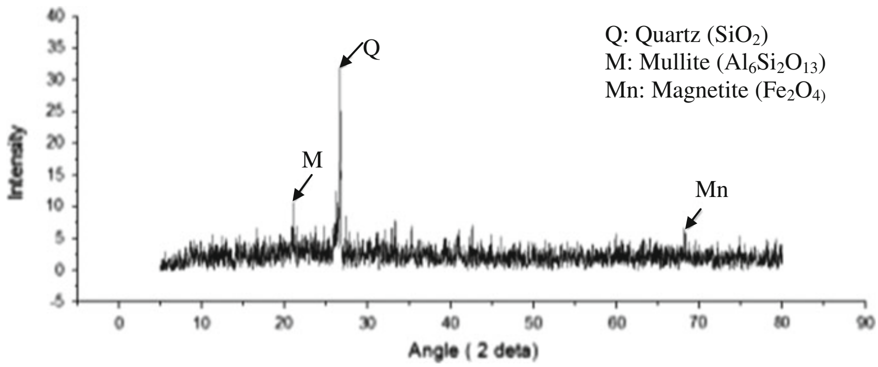

Fig. 2 XRD spectrum of FA

technique which reveals information about the crystal structures, Fig. 2 shows the XRD diffractograms of the investigated sample. The figure presents the comparative diffractograms of a sample of FA. The symbols on figures indicate the positions and peak intensities of the powder diffraction standard from international centre for diffraction database. As seen from the figure, XRD analysis indicates predominance of Quartz (SiO_2), along with Mullite ($Al_6Si_2O_{13}$) and Magnetite (Fe_2O_4), which confirms that the sample of FA analysed belongs to Class C FA.

3 Experimental Procedure

In this investigative study six cubes were made of M30 grade concrete mix with 100 % replacement of cement with FA. The alkaline liquid required for the mix preparation is prepared by mixing sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) at room temperature. The mixture of chemicals is left at room temperature for 24 h before being used for the concrete mix preparation. Cubes of size 150 × 150 × 150 mm^3 were casted as per IS: 516-1959 [16] using the chemical mixture. Table 1 shows the details of mix proportions adopted. After casting, steam curing was done for two different cycles (i) 2 h delay and for 18 h at 100 °C and (ii) 2 h delay and for 3 h 100 °C.

4 Steam Curing at Atmospheric Pressure

The temperature during curing is very important, and depending upon the source materials and activating solution, often heat must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature. In this study, two aspects of a steam-curing cycle is adopted.

Table 1 Details of mix proportions

Characteristic compressive strength	M30
Maximum size of aggregate	20 mm
Specific gravity of FA	2.2
Specific gravity of fine aggregate	2.6
Specific gravity of coarse aggregate	2.6
Zone of sand	Zone I
Specific gravity of NaOH	1.46
Specific gravity of sodium hydroxide	1.6

5 Results

After steam curing, the specimens were tested as per IS: 516-1959. The compressive strength results obtained are as shown in Fig. 3. It can be clearly seen from figures that the compressive strength of the cubes is found to be lower for a curing period of 3 h as compared to the curing period of 18 h. The maximum compressive strength attained is only about 50 % of the design strength.

6 Microstructural Study

To understand the microstructural changes occurring during these curing periods, SEM images were obtained before and after curing. Figures 4, 5 and 6 show clear variation in the microstructure of the samples. For the samples before curing (Fig. 4), a gel medium is formed due to the addition of the alkaline liquid with dispersion of FA particles can be seen.

Figure 5 shows the image of a sample with 2 h delay followed by 18 h cycle of steam curing at 100 °C, the fly ash particles are seen to be broken and the structure of it is destroyed due to the prolonged steam curing cycle. It can also be observed that the structure has a large number of disintegrated particles leading to the reduction in compressive strength. Figure 6 showing the sample after 2 h delay

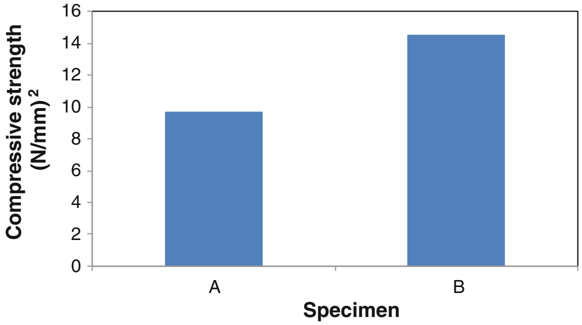

Fig. 3 Results of compressive strength for two different curing regimes

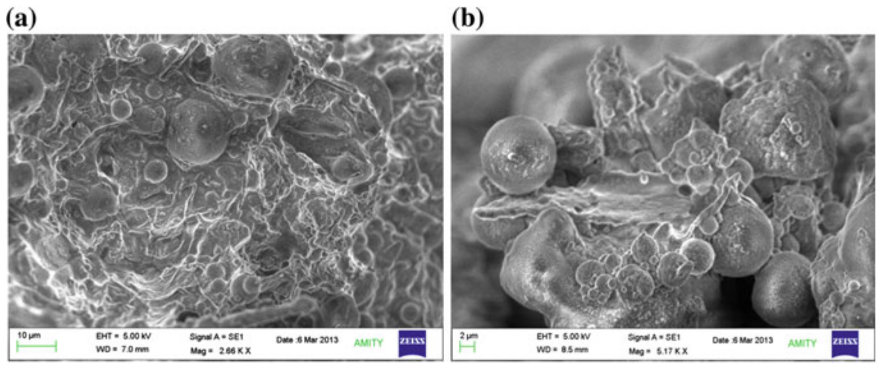

Fig. 4 SEM image of 100 % fly ash concrete sample before curing at different magnifications **a** 10 μm, **b** 2 μm

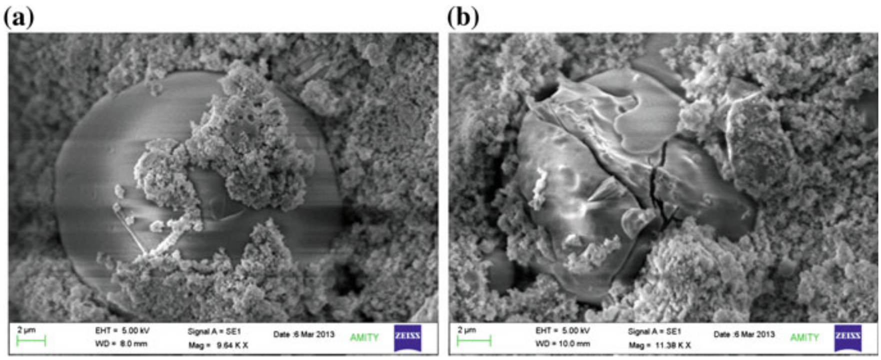

Fig. 5 SEM image of 100 % fly ash concrete sample after 2 h delay and 18 h steam curing cycle at 100 °C **a** 10 μm, **b** 2 μm

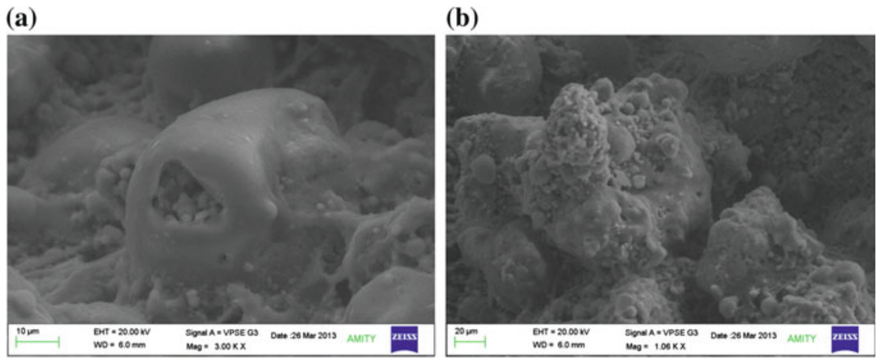

Fig. 6 SEM image of 100 % fly ash concrete sample after 2 h delay and 3 h steam curing cycle at 100 °C at different magnifications **a** 10 μm, **b** 2 μm

followed by 3 h steam curing at 100 °C. In this image the fly ash particles are seen to be well bonded. The granular particles form a continuous mass, and this fact combined with the better bonding between fly ash particles leads to a higher compressive strength.

7 Conclusions

The experimental results concluded that FA based geopolymer specimens has greater compressive strength for a steam curing cycle of 2 h delay followed by 3 h curing at 100 °C as compared to steam curing cycle of 2 h delay followed by 18 h curing at the same temperature. When the curing period is prolonged the FA particles were found to be broken.

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