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Enhancement of the properties of fly ash based geopolymer paste by incorporating ground granulated blast furnace slag

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HIGHLIGHTS

- Difficulties to use fly ash based geopolymer practically exist due to its high setting time.
- An attempt to reduce the setting time of fly ash based geopolymer by adding GGBFS.
- Significant improvement of setting time and compressive strength is observed.

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ABSTRACT

Research efforts have been made continuously to establish fly ash based geopolymer as an alternative binder material for the production of fresh concrete because production of Ordinary Portland Cement degrades the environment by huge emissions of carbon-di-oxide and also by consuming lot of natural resources. But most of the study reveals, fly ash based geopolymer paste needs more time to get set when it is cured at ambient temperature. As a result, it is quite impractical to use fly ash based geopolymer paste as an alternative to Ordinary Portland Cement in faster construction. In this study, an effort has been made to enhance the properties of fly ash based geopolymer paste by incorporating ground granulated blast furnace slag at various percentage levels. Microstructure of the geopolymer paste is studied using Scanning Electron Microscopy. Result of this investigation shows that significant improvement on setting time and compressive strength can be obtained by adding ground granulated blast furnace slag in the mixes.

1. Introduction

The growing demand of infrastructural development in the developing countries leads to consume more concrete. To meet the demand of the production of concrete, large quantity of Ordinary Portland Cement (OPC) is used as main binder material. But production of OPC requires large quantity of natural resources and it is also energy extensive process and also releases huge amount of carbon-di-oxide in the environment. As a result, environmental degradation and protection of natural resources are becoming very important issues to be taken care of to promote sustainability in the construction industries. Therefore, usage of supplementary cementitious materials in concrete has got a great momentum to protect the environment. Apart from this, using an alternative binder material like geopolymer, to produce concrete with desired specifications may be another solution to promote sustainability in construction field. In the seventeenth century, Prof. Davidovits invented “geopolymer” as materials characterized by chains or networks of inorganic molecules [1,13–15]. OPC paste normally gains strength by the development of C-S-H gel whereas geopolymer helps to gain strength by the poly-condensation of silica and alumina precursors. Materials rich in silica (Si) and aluminium (Al) and alkaline liquids are the main constituents of geopolymer. Fly ash, silica fume, slag, rice husk ash, etc. are examples of silica-alumina rich materials, which are by-product materials from different industries. Using by-product materials from other industries help to minimize the environmental problems, which was created due to the dumping problems. The geopolymerization process has been described by the following stages: under high alkaline condition, dissolving of oxide minerals from the alumina-silica rich source materials, transportation/orientation of dissolved oxide minerals followed by coagulation/gelation, and poly-condensation to develop 3-D stable network of silico-aluminates structures [2]. Based on the types of chemical bonding,

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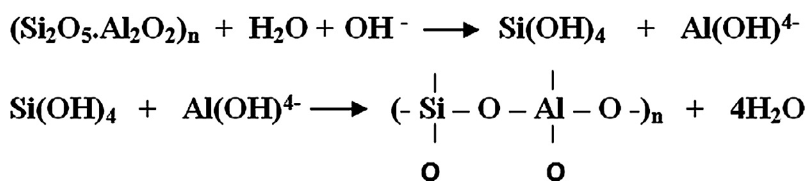
mainly three types of structures can be established from the 3-D alumino-silicate stable network: sialate (–Si–O–Al–O–), sialate-siloxo (Si–O–Al–O–Si–O) and sialate-disiloxo (Si–O–Al–O–Si–O–S i–O) [3].

The schematic formation of geopolymer material is described below [4].



Study on the mechanical and physical properties of fly ash based geopolymer by varying solid to liquid ratio using sodium hydroxide as the only activator was carried out and reported optimum solid/ liquid ratio of 4 for getting highest compressive strength [5]. Investigation on the effect of silica and alumina contents on setting, phase development, and physical properties of high calcium fly ash (Class C) based geopolymers reveals that setting of geopolymer was accelerated with the increase of both alumina and silica [6]. Whereas setting time of fly ash based geopolymer with use of potassium hydroxide (KOH) for different fly ash to alkaline solution ratio reported that as the ratio increases, the setting time decreases [3]. Two different temperatures (65 °C and 85 °C) as curing temperature and three different durations (2 h, 5 h and 24 h) of heat curing were used to determine the properties of class F type of fly ash based geopolymer varying the concentration of sodium hydroxide solution and concluded that the optimal concentration of NaOH solution was 6 M and observed that an increase in the curing temperature increased the compressive strength [7]. Different curing conditions on the properties of high calcium fly ash based geopolymer were investigated and observed high early compressive strength for temperature curing [8]. This experimental investigation reported that fly ash based geopolymer requires more time to be set and highest compressive strength was found for the mix produced with 14 M sodium hydroxide solution and the ratio of sodium silicate to sodium hydroxide solution 1.5 [9].

Too high setting time is one of the barriers to use fly ash based geopolymer effectively in construction industries presently. Although most of the researchers concluded that fly ash based geopolymer paste will show less duration for setting and high strength with heat curing. But heat curing is also not acceptable since practically it is not possible in many cases. Therefore, in this paper an experimental investigation has been carried out to improvise the setting and compressive strength of fly ash based geopolymer by introducing ground granulated blast furnace slag in the mixes.

2. Experimental programme

In the present investigation, fly ash, ground granulated blast furnace slag(GGBFS), Alkali Solutions (combination of sodium hydroxide solution and sodium silicate solution), and distilled water were used as materials for the casting of samples.

2.1. Materials

2.1.1. Fly ash

Fly ash is a by-product material of thermal power plants, which is being produced by the combustion of pulverized coal in the furnaces. Based on the CaO content, fly ash is classified into two types. These are Class C (high CaO content) and Class F type (Low CaO content) of fly ash. For this research work, class F type of fly ash was used. Chemical composition of fly ash used in this work is shown in Table 1.

2.1.2. Ground granulated blast furnace slag (GGBFS)

Ground-granulated blast furnace slag (GGBFS) is also a by-product material of iron and steel production, which is obtained by quenching molten iron slag from a blast furnace in water or steam. After quenching, granular product used to be dried and ground into a fine powder and the process produce a glassy type of material. Chemical composition of GGBFS used in this work is shown in Table 1. In this study, GGBFS is incorporated at 10%, 20%, 30%, 40% and 50% level to the total binders.

2.1.3. Alkali solutions

Liquid mixture of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Commercially available sodium silicate (Na_2SiO_3) solution was used in this study. Chemical composition of sodium silicate solution used is Na_2O – 8.5%, SiO_2 – 28.0% and Water – 63.5% by mass. For the present study, commercially available NaOH flakes with 98% purity were used for the production of alkaline solution. In this study, the ratio of sodium silicate solution to sodium hydroxide solution and the ratio of alkali solution to binder (fly ash + GGBFS) were kept constant as 1.0 and 0.4 respectively. Alkali solution i.e. mixture of sodium silicate solution and sodium hydroxide solution was prepared 24 h prior to use in mix.

2.1.4. Water

In the present investigation, distilled water was used for the preparation of NaOH solution with different concentrations.

2.2. Methods

In this section, procedures to perform the tests to study the influence of GGBFS in fly ash based geopolymer paste have been discussed.

Table 1
Chemical composition of fly ash and GGBFS (percentage by weight).

Constituents	Fly ash	GGBFS
CaO	0.73	34.07
Al_2O_3	32.24	16.98
Fe_2O_3	2.84	1.26
SiO_2	58.90	32.57
MgO	0.89	9.69
Na_2O	0.35	0.20
K_2O	1.12	0.08
SO_3	0.50	0.84
Insoluble residue	2.28	4.01
Loss of ignition	0.03	0.02