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RESEARCH ARTICLE

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AN EXPERIMENTAL INVESTIGATION ON REPLACEMENT OF ORDINARY PORTLAND CEMENT USING GEOPOLYMERS IN CONCRETE

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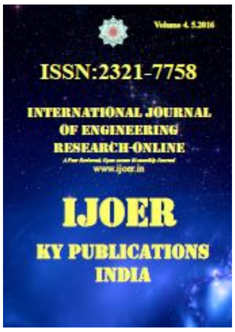

ABSTRACT

Global Warming is the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide emissions from burning fossil fuels or from deforestation, which trap heat that would otherwise escape from Earth. The cement industry is responsible for about 6% of all CO_2 emissions. These efforts include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace (GGBS) slag, rice-husk ash and metakaolin. Alternative but promising gainful utility of FA and GGBS in construction industry that has emerged in recent years is in the form of geopolymer cement concretes (GPCCs). This paper is about fully replacement of Portland cement by geopolymer.

Keywords: Carbon Dioxide, supplementary cementing materials, geopolymer.

INTRODUCTION

Concrete is one of the most widely used construction materials; it is usually associated with Portland cement as the main component for making concrete. The demand for concrete as a construction material is on the increase. On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern during the last decade. The global warming is caused by the emission of greenhouse gases, such as CO_2, to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming (McCaffrey, 2002). The cement industry is responsible for about 6% of all CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. Although the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made in order to reduce the use of Portland cement in concrete. These efforts include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and finding alternative binders to Portland cement.

In 1978, Joseph Davidovits developed Inorganic polymeric materials and coined the term "Geopolymer" for it (1990). Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. Geopolymer mixed concrete develops a glossy surface that can give a good appearance if used in constructing floors and walls. Activation by alkali gives rise to material with varied properties from that of OPC and make flyash based geopolymer concrete more fire resistant and resistant against abrasion and cracking. Since flyash is only a by-product material found from industrial wastes cost of such geopolymer concrete is less than or at most equal to OPC concrete which uses expensive cement as binder material. According to Djwantoro Hardjito "If one considers the impact of the possible carbon dioxide tax on the price of cement and environmental advantage of utilization of flyash, the geopolymer concrete may prove to be economically advantageous". Environmental pollution is the biggest menace to the human race on this planet today. Cement is the main material for the concrete production but the production of cement means the production of pollution because of the emission of CO2 during its production.The use of GGBS will decrease the amount of pollution and it will make eco-friendly concrete. GGBS is a fine powder , so it acts as a binding material in concrete like cement. GGBS can also be used in cases where normal curing is not possible. By heating the geopolymer concrete containing GGBS and flyash it will get binded easily and will attain high early strength. Ground Granulated Blast Furnace Slag is supplied by A.P STEELS INDUSTRIES, KANJIKODE.

SCOPE & OBJECTIVE OF THIS STUDY

It is found from existing literature that considerable work has been carried out on the usage of geopolymers. But to the Author's knowledge, limited work appears to have been reported on competitive study of normal concrete with geopolymer concrete. In this it is proposed to use GGBS and fly ash along with sodium silicate and different molarities of sodium hydroxide (8M, 16M) with M20 grade concrete.

LITERATURE REVIEW

The term 'geopolymer' was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition to zeolites but with an amorphous microstructure. He also suggested the use of the term 'poly (sialate)' for the chemical designation of geopolymers based on silico-aluminate (Davidovits,1988a,1988b,1991; van Jaarsveld et. al., 2002a); Sialate is an abbreviation for silicon-oxo-aluminate.

Davidovits (1988) worked with kaolinite source material with alkalis (NaOH, KOH) to produce geopolymers. The technology for making the geopolymers has been disclosed in various patterns issued on the applications of the so called "SILIFACE-Process". Later, Davidovits (1999) also introduced a pure calcined for 6 hours at 750oc. This calcined kaolinite like other calcined materials performed better in making geopolymers compared to the natural ones.

Xu and Van Deventer (2000) have also studied a wide range of alumino silicate minerals to make geopolymers. Their study involved 16 natural Si-Al minerals which covered the ring , chain, sheet, and framework crystal structures groups , as well as the garnet, mica, clay, feldspar, sodalite and zeolite mineral groups. It was found that a wide range of natural alumino-silicate minerals provided potential sources for synthesis of geopolymer. Among the waste or by product materials, fly ash and GGBS are the most potential source of geopolymers. Several studies have been reported related to the use of these source materials.

Cheng and Chiu (2003) reported a study of making fire resistant geopolymer using granulated blast furnace slag combined with metakaolinite. The combination of potassium hydroxide and sodium silicate was used as alkaline liquids.

J.Pera and J. Ambrose (1999) reported that the reactivity of blended 50/50 normal portland cement/silics management slag blend is lower than the equivalent GGBS blend after 7 and 28 days of age.

Van Jaarsveld (2003) reported that the particle size, calcium content, alkali metal content, amorphous content, and morphology and origin of the flyash affected the properties of geopolymers. It was also revealed that the calcium content in fly ash played a significant role in strength development and final compressive strength as the higher the calcium content resulted in faster strength development and higher compressive strength.

However , in order to obtain the optimal binding properties of the material, fly ash as a source material lower than 5%, Fe2O3 content not higher than 10%, 40-50% of reactive silica content, 80-90% particles with size lower than 45μm and high content of vitreous phase (Fernandez-Jimenez and Palomo, 2003).

Gourley (2003) stated that the presence of calcium in fly ash in significant quantities could interfere with the polymerisation setting rate and alters the microstructure. Therefore, it appears that the use of Low Calcium (ASTM Class F) fly ash is more preferable than High Calcium (ASTM Class C) fly ash as a source material to make geopolymers.

SureshThokchom, Dr.Partha Ghosh and Dr. Somnath Ghosh presents the findings of an experimental investigation to study the effect of alkali content in geopolymer mortar specimens exposed to sulphuric acid. Geopolymer mortar specimens were manufactured from Class F fly ash by activation with a mixture of sodium hydroxide and sodium silicate solution containing 5% to 8% Na2O.

Durability of specimens were assessed by immersing them in 10% sulphuric acid solution and periodically monitoring surface deterioration and depth of dealkalization, changes in weight and residual compressive strength over a period of 24 weeks. Microstructural changes in the specimens were studied with Scanning electron microscopy (SEM) and EDAX. Alkali content in the activator solution significantly affects the durability of fly ash based geopolymer mortars in sulphuric acid. Specimens manufactured with higher alkali content performed better than those manufactured with lower alkali content. After 24 weeks in sulphuric acid, specimen with 8% alkali still recorded a residual strength as high as 55%.

Djwantoro Hardjito and M.Z. Tsen this paper presents the engineering properties of geopolymer mortar manufactured from class F (low calcium) fly ash from Kuching, Sarawak, Malaysia, with potassium-based alkaline reactor. Tests were carried out on 50x50x50 mm cube geopolymer mortar specimens. The results revealed that as the concentration of KOH increased, the compressive strength of geopolymer mortar increases. The range of potassium silicate to KOH solution ratio by mass to produce high strength geopolymer mortar is in between 0.8 – 1.5. This study also found that geopolymer possesses superior thermal stability at least up to 800°C. The setting time of geopolymer was found dependent on the alkaline concentration.

Rafat Siddique (2004) carried out an experimental investigation which deals with concrete incorporating high volume of class F fly ash Portland cement is replaced by 100% respectively with class F fly ash. Tests are performed for both fresh and hardened concrete properties

MATERIALS USED

The study of the properties of various materials like flyash, GGBS, alkaline solutions, coarse aggregate and fine aggregate are done, which were used for casting concrete specimen. The various tests conducted to study the properties of the above said materials are done. The various material used in the project are listed below.

- Slag was collected from A.P. Steels, Kanjikode and it is then grinded to get fine powder form of GGBS.
- Fly ash is collected from Sree Vinayaka Industries.
- Coarse aggregate of size 12 mm and fine aggregate taken from a local supplier are used in the project.
- The solutions of Sodium Hydroxide and Sodium Silicate are used as alkaline solutions in the project. They are collected from Sree Sastha Chemicals, Coimbatore.
- Cement is collected from Ultra Tech Cements, Coimbatore.

TABLE 1 CHEMICAL COMPOSITION OF FLY ASH

Constituents	Percentage of content
SiO_2	46.2
Al_2O_3	26.4
Fe_2O_3	10.7
CaO	7.60
SO_3	1.80

TABLE 2 CHEMICAL PROPERTIES OF GGBS

Components (% mass)	GGBS
Loss on ignition	0.03
Magnesia	8.97
Sulphide sulphur	0.42
Manganese	1.02

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Chloride	0.018
Calcium	38.19

TABLE 3 CHEMICAL COMPOSITION OF GGBS

Constituents	Percentage of content
Carbon	0.23
Sulphur	0.05
Phosphorus	0.05
Manganese	0.58
Free silica	5.27
Iron	93.82

A. Sodium Hydroxide

Generally the sodium hydroxide is available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. Since our geopolymer concrete is homogenous material and its main process to activate the sodium silicate it is recommended to use the lowest cost i.e. up to 94% to 96% purity. In this investigation the sodium hydroxide pellets in 16 molar concentrations where used.

B. Sodium Silicate

Sodium silicate also known as water glass or liquid glass is available in liquid (gel) form. In present investigation sodium silicate 2.0 is used. As per the manufacture, silicates where supplied to the detergent company and textile industry as bonding agent. Same sodium silicate is used for the making of geopolymer concrete. The chemical properties and the physical properties of the silicates are given by the manufacture as follows.

TABLE 4 PHYSICAL AND CHEMICAL PROPERTIES OF SODIUM SILICATE

Chemical formula	Na2O X SiO2 Colour less
Na2O	15.9%
SiO2	31.4%
H2O	52.7%
Appearance	Liquid (Gel)
Colour	Light yellow Liquid (gel)
Boiling Point	1020 C for 40% aqueous solution
Molecular Weight	184.04
Specific Gravity	1.6

C. Properties of Materials

To study the properties of materials, the following tests on materials are carried out:

Fineness modulus of fine aggregate
Fineness modulus of coarse aggregate
Fineness modulus of GGBS
Specific gravity of cement
Specific gravity of fly ash
Specific gravity of fine aggregate
Specific gravity of coarse aggregate
Initial and Final setting time of concrete

Fig. 1 Alkaline solution

Fig. 2 Vicat apparatus mould

Fig. 3 Concrete mixing

Fig. 4 Heating the cube in oven

MIX DESIGN

Mix design is carried out for M20 concrete as per Indian Standard Code method (IS 10262-1982) for concreting the test specimen.

TABLE 5 MIX PROPORTION

Water	Cement	Fine aggregate	Coarse aggregate
191.6	383kg	546 kg	1188kg
0.50	1	1.42	3.10

EXPERIMENTAL INVESTIGATION

A. General

Our present study aims to investigate the potential use of GGBS and fly ash as cement replacing material in concrete. This project will report the hardened state properties such as compressive strength of concrete incorporating fly ash and GGBS as fully replacement for cement and alkaline solutions for water in various molarities. Totally 36 cubes were casted and tested for their strength. The compressive strength is compared with the strength of conventional concrete specimens.

B. *Mixing of Ingredients*

The materials were weighed as per the design mix proportion and they were mixed using concrete mixer. The mixing operation was continued till a good uniform homogenous concrete was obtained. General mixing time of 5-10 min was followed. Weigh batching was done for measuring materials. Use of weigh batching facilitates accuracy, flexibility and simplicity. The ingredients of concrete were weighed in balance. The alkaline solutions such as sodium hydroxide and sodium silicate were made into different molarities of 8M and 16M and they were taken as per the mix design.

C. Preparation of Binder Solution

Binder solution plays a vital role in the binding of the fly ash based geopolymer mortar. Binder solution is a mixture of Sodium Hydroxide and Sodium Silicate. Binder solution is mixed 24 hours prior to the mixing of mortar. Sample calculation of preparation of binder solution for W/B ratio 0.40 is shown below.

Mix ratio:

Fluid: Fly ash + GGBS = 1: 3

Na_2SiO_3: NaOH = 2.33: 1

Fly ash: GGBS = 5: 1

To prepare different molarities of NaOH , first the molecular weight of it has to be considered.

Molecular weight of NaOH = 40

So for 1M solution 40 gms of NaOH pellets has to be diluted.

Like wise for 8M NaOH solution:

To get 1 litre of 8M NaOH solution, 320 grams (8 x 40) of NaOH pellets has to be diluted.

Therefore in 1 lit = 320 gm NaOH

For 16M NaOH solution:

To get 1 litre of 16M NaOH solution 640 grams (16 x 40) of NaOH pellets has to be diluted.

Therefore in 1 lit = 640 gm NaOH

The prepared solutions of NaOH are mixed with Na2SiO3 based on the above given ratio to form the alkaline solution.

D. Casting of Specimens

The mould of standard size 150mm x 150mm x 150mm was selected. Fly ashes, GGBS, alkaline solutions, aggregates were mixed together and cubes having different molarities were casted. They were casted according to the standard procedure with proper compaction and vibration. Immediately after casting the cube, it was placed in an oven and was heated at a temperature of 800C for 2 hours. After that it was allowed to cool and was remoulded. Curing was not needed in this type of concrete.

TESTING OF SPECIMENS

The tests were conducted to determine the strength of the test specimens. The specimens were tested as per IS specifications.

A. Compressive Strength Test

The compressive strength test is the most common test conducted because most of the desirable characteristics properties of concrete and the structural design purpose are qualitatively related to compressive strength. The test was conducted in compression testing machine as per the specifications given in IS 516: 1959 under normal room temperature. The capacity of compression testing machine was 20 tonnes. The cubes were properly held in position such that the load is applied uniformly over the surface. The load was applied gradually till the ultimate load is reached. The ultimate load was noted and from that the compressive strength was calculated using the following formula:

Compressive strength = Ultimate load / Cross sectional area

Cube Compressive Strength = Ultimate Load / a2

Compressive Strength is expressed in N/mm2

RESULTS AND DISCUSSION

A. *General:* The investigation was carried out to determine the strength characteristics of fly ash and GGBS.

B. *Observation:* The replacement of fly ash and GGBS with cement and different molarities of alkaline solutions with water was tried in our project and the results were obtained.

TABLE 6 COMPRESSIVE STRENGTH OF NORMAL CONCRETE

SL.NO.	NO.OF DAYS	AREA mm^2	LOAD (kN)	NORMAL CONC. COMP. STRENGTH (N/mm^2)	LOAD (kN)	8 M CUBES COMP. STRENGTH (N/mm^2)	LOAD (kN)	8 M CUBES COMP. STRENGTH (N/mm^2)
1	7	150x150	304	13.5	580	25.77	215	9.56
2	14	150x150	409	18.18	607	26.98	456	20.56
3	28	150x150	560	24.88	635	28.22	625	27.77

CONCLUSION

From the above experimental study it is found that Geopolymer Concrete with strength of M30 grade can be obtained and it reaches high early strength. One of the great advantages is that no curing is needed for geopolymer concrete in this project. Heat-cured low calcium fly ash-based geopolymer concrete of different moles of Sodium Hydroxide and water to solids ratio can produce compressive strength from 20 N/mm2 to 100 N/ mm2. Also it can be increased by properly selecting the influencing parameters such dosage of chemicals and type of fly ash. It is evident from the obtained results that the strength of the geopolymer concrete is encouraging.

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