EXPERIMENTAL INVESTIGATION ON EFFECT OF HIGH TEMPERATURE ON M-20 GEOPOLYMER CONCRETE

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Abstract: Concrete is one of the most widely used construction material. The global use of cement concrete is second only to the use of water. The demand for concrete as a construction material is increasing day to day. The production process of cement releases some harmful substances, which adversely effect on environment. Design and experimental investigation on development of geopolymer concrete is important because increase in use of geopolymer concrete leads to reduction in use of regular cement concrete and ultimately production of cement. Also the fly ash and ground granulated blast furnace slag is used and the problem of dumping of these materials ultimately gets solved.

In this experimental research cement is totally replaced by use of fly ash and ground granulated blast furnace slag (GGBS), and are activated by use of Alkali Activated Solution to form a cementious paste. Effect of elevated temperature is experimentally observed for various combinations of FA and GGBS and compared with ordinary cement concrete. From the experimental work it is observed that the geopolymer concrete with use of 40% fly ash and 60% GGBS gives 35% more strength than target strength. When geopolymer concrete and ordinary cement concrete is exposed to elevated temperature ranging from 300º C to 700º C in variation of 200º C; comparatively geopolymer concrete has maximum 52% strength reduction, while on other hand ordinary cement concrete has maximum 67% strength reduction.

Keywords: Fly ash, Ground granulated blast furnace slag, Alkali activator solution, Geopolymer concrete

I. INTRODUCTION

The cement industry is having major contribution in GDP by paying India’s second highest Central Excise. With infrastructure development, the demand for cement is also increase. Production of portland cement is the most energy consuming process after aluminum and steel, as it consumes 4GJ per tonne of energy. The Indian cement industry is the third largest user of coal in the country after thermal power plants and steel sector. The manufacturing of Portland cement is an energy intensive process and releases a large amount of greenhouse gas to the atmosphere. The climate change due to global warming, one of the greatest environmental issues has become 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. CO_2contributes to near about 67% of global warming.’[7]

Production of cement requires high energy and also releases some harmful substances. The global release of CO2 from all sources is estimated at 23 billion tonnes a year and the Portland cement production accounts for about 7% of total CO2 emissions. The cement industry has been showing remarkable progress in reduction of CO2 release through improvements in production technology and enrichment in process efficiency, but further improvements are limited because CO2 production is genetic to the basic process of calcinations of limestone. Mining of limestone has bad effect on land-use patterns, local water system and surrounding air quality and thus remains as one of the main reasons for the high environmental impact of the industry. Also dust release during the production of cement is major issue. The industry produces millions of tonnes of dry material, if 0.1% of this is lost to the atmosphere, it can cause adverse impact to environment.

Geopolymer cement concrete is a polymer produced by combining materials rich in silica and alumina (like fly ash) with sodium/potassium silicate and sodium/potassium hydroxide. Fly ash plays important role in geopolymer cement, as it has high content of silica and alumina. Fly ash used in construction industry mostly is a byproduct from coal based power plants. The burning of coal, generates fly ash. Many coal based power plants in India have been retiring due to thrust towards cleaner energy production and this may lead to scarcity of fly ash in future. Hence, it is needed to reduce the use of cement as to reduce production of cement.

II. EASE OF USE

A. Geopolymer concrete

The geopolymer technology has considerably good results for construction industry as an alternative binder to Portland cement. In construction industry applications a water resistant binder with sufficient strength is desirable .In addition the production technology necessitates an adequate processing time.Though after shaping procedure the material should be demoded immediately to enable beneficial production. Therefore the binder should show a late beginning of setting, but it should be possible to accelerate strength development when the material is shaped. The form of cementitious material using silicon and aluminum activated in a high alkali solution was developed. This material is usually based on fly ash as binder material and is termed geopolymer or alkali-activated fly ash cement. The mortar and concrete made from this geopolymer possess similar strength and appearance to those from ordinary Portland cement. Basically geopolymer concrete requires oven curing for 24 hours, because from previous research on geopolymer concrete it is seen that water curing leads to reduction in compressive strength. 'Geopolymer shows many excellent properties such as high compressive strength, low creep, good acid resistance, low shrinkage, fire resistance and other mechanical properties.' [1]

III.EXPERIMENTALWORK

B. Material selection

For development of geopolymer concrete selection of appropriate material is very important. As strength of concrete is widely depend on material and its properties hence it is needed to select the material which will give high strength and good properties. Following are the materials selected for development of geopolymer concrete.

a) Fly Ash: Fly ash is a by-product of pulverized coal blown into a fire furnace of an electricity generating thermal power plant. According to the survey, the total fly ash production in the world is about 780 million tons per year but utilization is only about 17–20 %. In India more than 220 million tons of Fly ash is produced annually. Out of this, only 35–50 % fly ash is utilized either in the production of Portland pozzolonna cement. The silica content normally varies from 50-60% and alumina content varies from 20 to 30% for a typical Class F fly ash. A typical chemical composition of Fly Ash is shown in Table1.

b) Ground Granulated Blast Furnace Slag (GGBS): While manufacturing of steel and iron GGBS is a byproduct which has large problem of disposal. Blast furnace slag is formed in the processes of iron manufacture from iron ore, combustion residue of coke, and fluxes such as limestone and other materials. If the molten slag is rapidly chilled by immersion in water, a vitreous Ca–Al–Mg silicate fine grain glass is formed with ahighly cementitious in nature. Due to presence of SiO_2andAl_2O_3 in GGBS it can be used in geopolymer as a base material.

c) Water: Even though water has no role in chemical reaction, but it has effect on fresh and hardened Geopolymer concrete. The water use for development of geopolymer concrete should be potable water and free from chemical or organic impurities.

d) Alkaline Solution: Alkaline solution for Geopolymer is a combination of sodium silicate/potassium silicate and sodium hydroxide/potassium hydroxide. There are no fixed guidelines for the proportion of sodium silicate/potassium silicate to sodium hydroxide/potassium hydroxide. Ratios of0.4 & 2.5 were used by in previous research. Some research suggested that higher ratio of sodium silicate solution-to-sodium hydroxide solution by mass, results in higher compressive strength of Geopolymer concrete. Sodium hydroxide is effective in dissolving the minerals within fly ash. The important parameter to be considered is molarity of NaOH. If proportion of Sodium Silicate to Sodium hydroxide is considered as 2.5 and high molar sodium hydroxide (8M-16M) is used than molar ratio of SiO2/Na2O in alkaline solution will be in the range of 1.33 to 1.070. A research by Davidovits (Davidovits 2013) stated that 'fly ashes comprised molar ratio of SiO2/Na2O was below1.20 with an average of 1.0 and most of them propose to use pure NaOH of 8M to12M without considering safety.'[2] Also use the sodium hydroxide solution after 24 hours from mixing with water, as it gives more strength. A higher ratio of SiO2/Na2O is recommended. In this study ratio of Sodium Silicate and Sodium Hydroxide is kept as 2.0 with 4M sodium hydroxide. 'Lower ratio of SiO2/Na2O and higher molar sodium hydroxide generates higher compressive strength, but hazardous to work.'[1]

C. Mix Design

There are no special codal provisions for design of geopolymer concrete. From literature available it is clear that geopolymer concrete is can be designed as similar to regular cement concrete. In this study deign of geopolymer concrete is carried out with the help of IS 10262- 2009. As geopolymer concrete itself explains that it is concrete without use of cement hence the quantity of cement calculated from design procedure is totally replaced by supplementary cementitious material like FA, GGBS or any other.

- Characteristic compressive strength of concrete(fck)
  = 20 Mpa
- Target mean strength(fck')
  = fck + 1.65S

From table no. 1 (Clause- 3.2.1.2 A-3 and B-3), IS 10262-2009

For M-20, S= 4.0 Mpa
Therefore,
fck = 20 + 1.65 x 4
= 26.6 Mpa

- Selection of quantity of fly ash
  From ISSN-2250-3153,
  RatioofActivatorsolutiontoFlyashis0.35bymas

s. From previous research and literature available, ratio of Sodium Silicate to Sodium Hydroxide is keptas2.0.

- Selection of quantity of water

Selection of Quantity of Water Workability of geopolymer concrete is depending on total quantity of water including water present in both alkaline solutions and the degree of workability. Select the total quantity

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of water required to achieve desired workability based on fineness of fly ash.

From IS 10262-2009,
Maximum water content = 185 Kg/m^3
Water required to develop M-20 concrete = 145 Kg/m^3

- Calculation of quantity of aggregate Total quantity = Wet density – (Q. of Geopolymer binder + Additional water)

Fine aggregate = (Ratio of fine to coarse aggregate) X Total quantity

Average mass density of geopolymer concrete = 2600 Kg/m^3

D. Experimental Results

Material required for 2 blocks = 0.00675 m^3

Dry volume of concrete = 54% extra of wet volume

= 0.0104 m^3

Results obtained from concrete trials for compression with 150 X 150 X 150 mm size blocks.

IV. RESULTS

Table 1 Compression test results

Sr. No.	% FA	% GGBS	Compressive Strength (N/mm^2)	Average Compressive Strength N/mm^2
Trial 1	100	0	14.60	13.16
			13.52	
			11.36	
Trial 2	80	20	18.20	18.06
			19.40	
			16.56	
Trial 3	60	40	24.90	26.56
			28.30	
			26.50	
Trial 4	40	60	35.75	35.67
			34.44	
			36.84	

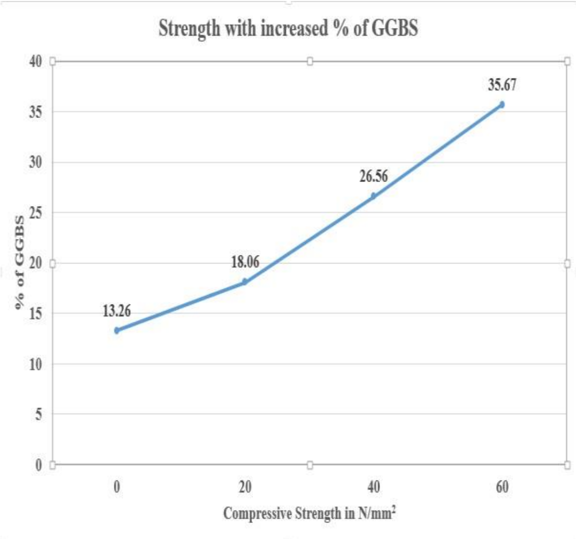

Fig. 1 Graphical Representation of strength variation with increase in % of GGBS

V. TEMPERATURE EFFECT ONCONCRETE

Interest in the behavior of concrete at a high temperature mainly results from the many cases of fires taking place in buildings, high-rise buildings, tunnels, and drilling platform structures. During a fire, the temperature may reach up to 1100◦C in buildings and even up to 1350◦C in tunnels, leading to severe damage in a concrete structure. However, in some special cases, even much lower temperature, may cause explosive destruction of concrete, thus endangering the bearing capacity of the concrete element.

The increase in temperature results in water evaporation, C-S-H gel dehydration, calcium hydroxide and calcium aluminates decomposition, etc. Along with the increase in temperature, changes in the aggregate take place. 'Due to those changes, concrete strength and modulus of elasticity gradually decreases, and when the temperature exceeds ca. 300◦C, the decline in strength becomes more rapid. When the 500◦C threshold is passed, the compressive strength of concrete usually drops by 50% to 60%, and the concrete is considered fully damaged.'[8]

Fig. 2 Concrete Specimens kept in furnace for checking temperature effect

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Fig. 3 Concrete surface cracks after exposed to 700^{0}C

Table no. 2 Compressive Strength of specimen when concrete exposed to 300^{0}C.

Sr. No.	Strength of concrete specimen (N/mm^2)	
	Ordinary cement concrete	Geopolymer concrete
1	18.09	25.07
2	19.4	25.72
3	20.05	26.59
Average	19.18	25.79
% reduction in strength	14.94	1.26 (increase)

Table no. 3 Compressive Strength of specimen when concrete exposed to 500^{0}C

Sr. No.	Strength of concrete specimen (N/mm^2)	
	Ordinary cement concrete	Geopoly m er concrete
1	12.21	20.00
2	13.52	22.01
3	14.60	23.11
Aver age	13.44	21.71
% reduction in strength	40.39	14.76

Table no. 4 Compressive Strength of specimen when concrete exposed to 700^{0}C

Sr. No.	Strength of concrete specimen (N/mm^2)	
	Ordinary cement concrete	Geopolym er concrete
1	6.32	12.21
2	9.16	11.34
3	7.19	12.86
Averag e	7.56	12.14
% reduction in strength	66.47	52.34

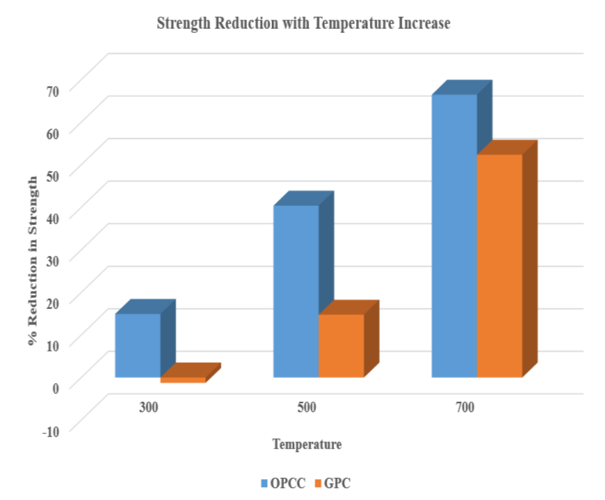

Fig.4 Graphical Representation of Strength Reduction with Temperature

VI. CONCLUSION

The objective of the present work is to design the geopolymer concrete which gives strength of 20Mpa. The concrete gives higher strength when cement is replaced by 40% GGBS and 60% fly ash.

1. Increase in quantity of GGBS leads to increase in strength of concrete.
2. Ordinary cement concrete loses its 14.94% strength, while geopolymer concrete gains 1.26%strength, when concrete exposed to temperature of 300^{0}C for 24 hours.
3. While exposing to temperature of 500^{0}C, Ordinary cement concrete loses its 40.39% strength, while geopolymer concrete loses 14.76%strength.
4. When concrete exposed to temperature of 700^{0}C, Ordinary cement concrete loses its 66.47% strength, while geopolymer concrete gains 52.34%strength.

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