AN EXPERIMENTAL INVESTIGATION OF GEOPOLYMER CONCRETE AT ELEVATED TEMPERATURE AND AGAINST AGGRESSIVE CHEMICAL ENVIRONMENT

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ABSTRACT:

The present paper reports result of an investigational program accompanied to revision the behavior of geopolymer concrete subjected to severe ecological conditions. The grades chosen for the investigation were M-30, M-40, M-50 and M-60, the mixes were designed for molarity of 8M and 12M. The alkaline solution used for present study is the combination of sodium silicate and sodium hydroxide solution with the ratio of 2.50 and 3.50. The geopolymer concrete cubes of 150×150×150 mm were cast. Three cubes were tested for compressive strength at the age of 7 days and 28 days by universal testing machine. Then the specimen were subjected to the elevated temperature 200o c, 400o c, 600o c, 800o c and 1000o c in an electric air heated muffle and after cooling were tested for the compressive strength. Six cubes were immersed in each solution of sodium sulphate, sulfuric acid, and sodium chloride for 30 days and 60 days. The test reveal the properties of geopolymer concrete and its applicability at elevated temperature and against aggressive environment such as acid attack, sulphate attack and chloride attack when compared to conventional concrete. Thus we can say that the production of geopolymers have a relative higher strength, excellent volume steadiness and better resilience.

1. INTRODUCTION

Global warming has emerged today as life-threatening issue for the world. As concrete is one the most consumed material after water on the earth for infrastructure & construction industries, a commendable contribution cam be made by optimizing the use of cement and natural resources in concrete manufacturing. Geopolymer concrete is one of the major developments in recent years leading to utilization of fly ash in large quantities and thus reducing cement consumption and ultimately reducing emission of CO2 in order of one tonne per a tonne of cement. Mechanical &Durability properties of concrete structure is another important parameter affecting the sustainability of concrete technology in addition to minimizing use of virgin material .In the context of increased awareness regarding the ill-effects of the over exploitation of natural resources, eco-friendly technologies are to be developed for effective management of these resources. Construction industry is one of the major users of the natural resources like cement, sand, rocks, clays and other soils. The ever increasing unit cost of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit const of its production. At the same time, increased industrial activity in the core sectors like energy, steel and transportation has been responsible for the production of large amounts like fly ash, blast furnace slag, silica fume and quarry dust with consequent disposal problem.

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO2 emission caused due to cement industries. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Metakaolin or calcined Kaolin, low calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined minerals and non-calcined minerals, combination of fly ash and metakolin, combination of granulated blast furnace slag and metakaolin have been studied as source materials. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.

Ever since the introduction of geopolymer binders by Davidovits in 1978, it has generated a lot of interest among engineers as well as in the field of chemistry. In the past few decades, it has emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. Though geopolymers can be manufactured from various source materials rich in silica and alumina such as fly ash, silica fume, ground granulated blast furnace slag and metakaolinetc, fly ash based geopolymers have attracted more attention. Geopolymer binders might be a promising alternative in the development of acid resistant concrete since it relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity.

2. OBJECTIVE:

The main objective of this study is to investigational program accompanied to revision the behavior of geopolymer concrete subjected to severe ecological conditions.

Current Research

Traffic median barriers are used by Departments of Transportation (DOTs) along highway systems to confine vehicular flow in prescribed pathways and to prevent errant vehicles from entering into the wrong lane or going out of the roadway. Like many other infrastructure elements, median barriers are subjected to environmental loads as well as mechanical loads. This is particularly true when such structures are deployed in coastal areas, where they are exposed to relatively high concentration of chlorine ions.

Geopolymer concrete with appropriate chemical and physical properties6-8 can be used as a alternative binder to the Portland cement in severe exposure conditions. Kupwade-Patil et al.8, 9 demonstrated that carefully selected fly ash can be used to develop GPC with significantly higher resistance against the chloride induced corrosion and alkali-silica reaction in comparison to concrete derived from TYPE I cement. The use of locally available fly ash in order to construct a geopolymer median barrier provides a novel application of GPC binder technology, in a large scale application for the beneficent use fly ash.

In addition to outstanding mechanical properties and durability characteristics, technology is considered 'green and eco-friendly', as the use of fly ash as a offers a significantly lower CO2 footprint compared with that associated with the production of Portland Cement3, 6, 10 as well as a beneficial use of industrial byproducts, energy conservation, and conservation of virgin materials.

The design and detail specifications for median barriers are provided by the American association of state highway and transportation officials (AASHTO). These have been periodically modified so as to incorporate changes in the vehicular type and loading mandated on federal and state highways. By 2009, AASHTO its revised Load Resistance Factor Design (LRFD) which is a design guide for bridges and their fixtures11. This update superseded the NCHRP Report 35012, which had been the accepted method for safety hardware device testing and acceptance since

1993. The LRFD (2009) incorporates the various vehicular loads and crash conditions assure roadside safety performance of traffic barriers. To ascertain the compatibility of the geopolymer bridge barrier, it was imperative to design it according to the prevailing code of practice i.e. AASHTO LRFD and AASHTOMASH. Fabrication also followed current construction practices used in the production of OPC median barriers.

3. EXPERIMENTAL METHODOLOGY

Materials

The following materials have been used in the experimental study (Veeresh, 2011)

1. Fly Ash (Class C) collected form Raichur Thermal power plant having specific gravity 2.00.
2. Fine aggregate: Sand confirming to Zone –III of IS:383-1970 having specific gravity 2.51 and fineness modulus of 2.70.
3. Coarse aggregate: Crushed granite metal confirming to IS:383-1970 having specific gravity 2.70 and fineness modulus of 5.85.
4. Water : Clean Potable water for mixing
5. Alkaline Media: Specific gravity of
   a. Sodium Hydroxide (NaOH) = 1.16
   b. Sodium Silicate (Na_2SiO_3) = 1.57

Tests were conducted on specimen of standard size as per IS: 516-1959. Details of tests conducted and specimens used are given in table 1.

Table 1: Details of specimen used and tests conducted

Type of tests conducted	Size of specimen	No. of specimen cast for different grades
Compressive strength	150x150x150mm	5
Split tensile strength	100x200mm	5

Mix design of geopolymer concrete

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 7% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m3 (Rangan, 2008). The details of mix design and its proportions for different grades of GPC are given in Table 3 to 6.

Mixing, Casting, Compaction and Curing of Geopolymer ConcreteGPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes. (Figure 1 and 2)

In preparation of NaOH solution, NaOH pellets were dissolved in one litre of water in a volumetric flask for two different concentration of NaOH (8 and 12M). Alkaline activator with the combination of NaOH and Na2SiO3 was prepared just before the mixing with fly ash. The addition of sodium silicate is to enhance the process of geopolymerization (HuaXu, J.S.J.van Deventer, 2000). The ratio of fly ash/ alkaline activator and Na2SiO3 / NaOH used in the current study was 2.5 and 3.5 for all the mixes. The fly ash and alkaline activator were mixed together in the mixer until homogeneous paste was obtained. This mixing process can be handled within 5 minutes for each mixture with different molarity of NaOH. Fresh fly ash based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of conventional slump test. Heat curing of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC . For easy working of fresh GPC mixes superplasticizerConplast SP-430 was used. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept at 60°C for 24 hours in an oven as shown in Figure 3.

Table 2: Slump values for different grades of GPC

Grade	Na2SiO3/NaOH	Slump (mm)	Grade	Na2SiO3/NaOH	Slump (mm)
M-30	2.5	135	M-30	3.5	145
M-40	2.5	130	M-40	3.5	140
M-50	2.5	110	M-50	3.5	130
M-60	2.5	95	M-60	3.5	110

Table 3: Mix proportions of GPC mix with molarity of 8M (Na2SiO3/ NaOH as 2.5)

Materials		Mass (kg/m3)			
		M-30	M-40	M-50	M-60
Coarse aggregates	20 mm	277.20	277.20	277.20	277.20
	14 mm	369.60	369.60	369.60	369.60
	7 mm	646.80	646.80	646.80	646.80
Fine sand		554.40	554.40	554.40	554.40

Fly ash	380.69	394.29	408.89	424.62
Na2SiO3/ NaOH	2.50	2.50	2.50	2.50
SiO2/Na2O	2.00	2.00	2.00	2.00
Sodium hydroxide solution	48.95	45.06	40.89	36.40
Sodium silicate solution	122.36	112.65	102.22	91.00
Super Plasticizer	5.70	5.91	6.13	6.37
Extra water	38.06	39.42	40.88	42.46

Table 4: Mix proportions of GPC mix with molarity of 8M (Na2SiO3/ NaOH as 3.5)

Materials		Mass (kg/m3)			
		M-30	M-40	M-50	M-60
Coarse aggregates	20 mm	277.20	277.20	277.20	277.20
	14 mm	369.60	369.60	369.60	369.60
	7 mm	646.80	646.80	646.80	646.80
Fine sand		554.40	554.40	554.40	554.40
Fly ash		380.69	394.29	408.89	424.62
Na2SiO3/ NaOH		3.50	3.50	3.50	3.50
SiO2/Na2O		2.00	2.00	2.00	2.00
Sodium hydroxide solution		38.07	35.05	31.80	28.31
Sodium silicate solution		133.24	122.67	111.31	99.08
Super Plasticizer		5.70	5.91	6.13	6.37
Extra water		38.06	39.42	40.88	42.46

Table 5: Mix proportions of GPC mix with molarity of 12M (Na2SiO3/ NaOH as 2.5)

Materials		Mass (kg/m3)			
		M-30	M-40	M-50	M-60
Coarse aggregates	20 mm	277.20	277.20	277.20	277.20
	14 mm	369.60	369.60	369.60	369.60
	7 mm	646.80	646.80	646.80	646.80
Fine sand		554.40	554.40	554.40	554.40
Fly ash		380.69	394.29	408.89	424.62
Na2SiO3/ NaOH		2.50	2.50	2.50	2.50
SiO2/Na2O		2.00	2.00	2.00	2.00
Sodium hydroxide solution		48.95	45.06	40.89	36.4
Sodium silicate solution		122.36	112.65	102.22	91
Super Plasticizer		5.70	5.91	6.13	6.37
Extra water		38.06	39.42	40.88	42.46

Table 6: Mix proportions of GPC mix with molarity of 12M (Na_2SiO_3/ NaOH as 3.5)

Materials		Mass (kg/m3)			
		M-30	M-40	M-50	M-60
Coarse aggregates	20 mm	277.20	277.20	277.20	277.20
	14 mm	369.60	369.60	369.60	369.60
	7 mm	646.80	646.80	646.80	646.80
Fine sand		554.40	554.40	554.40	554.40
Fly ash		380.69	394.29	408.89	424.62
Na_2SiO_3/ NaOH		3.50	3.50	3.50	3.50
SiO_2/Na_2O		2.00	2.00	2.00	2.00
Sodium hydroxide solution		38.07	35.05	31.80	28.31
Sodium silicate solution		133.24	122.67	111.31	99.05
Super Plasticizer		5.70	5.91	6.13	6.37
Extra water		38.06	39.42	40.88	42.46

4. RESULTS AND DISCUSSIONS

Workability

The workability of the geopolymer concrete decreases with increase in the grade of the concrete as presented in Table 2, this is because of the decrease in the ratio of water to geopolymer solids. As the molarity of the NaOH solution increases the workability of the geopolymer concrete decreases, because of the decrease in the water content. Thus we can say that as the grade of the concrete increases, the mix becomes stiffer decreasing the workability.

Sulphuric acid and magnesium sulphate attack on GPC and PPCC specimens

Visual appearance

From figure 4 it can be seen that the specimens exposed to sulphuric acid undergoes erosion of the surface. In the case of ordinary Portland cement, sulphuric acid attack manifests itself by deposition of a white layer of gypsum crystals on the acid-exposed surface of the specimen. Whereas, geopolymer cement tested, unlike Portland cement, no gypsum deposition can be detected visually. Figure 5 clearly indicates that there is no change in shape and remained structurally intact without visible cracks. Specimen surfaces received white deposits throughout the duration of exposure. These deposits were soft and powdery during, early stage of exposure, it became harder with time. The visual examination of normal concrete subjected to sulphate test has received less deposit of white and less deterioration on the surface of concrete.

Figure 1: Mixing of sodium silicate and sodium hydroxide solution

Figure 2: Mixing of ingredients **Figure 3**: Curing of specim

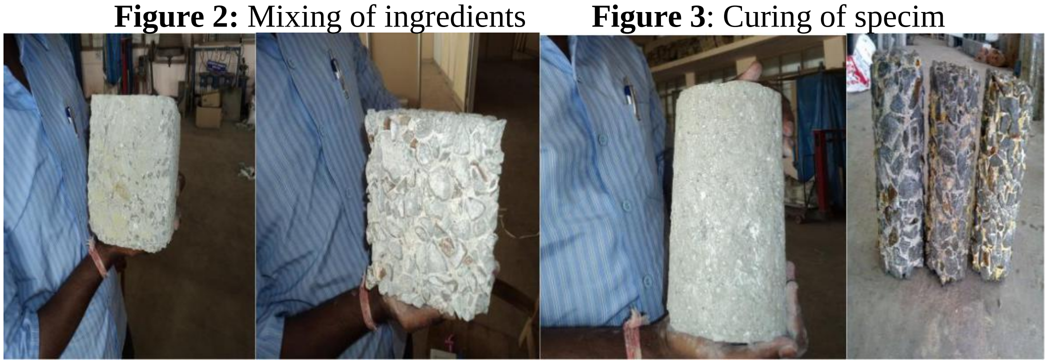

Figure 4: GPC and PPCC specimens exposed to Sulphuric acid solution after 45 days

Figure 5: GPC and PPCC specimens exposed to magnesium sulphate solution after 45 days

Weight change

There is a slight mass gain during first week of exposure due to mass of solution absorbed by concrete. The mass loss on exposure to sulpuric acid in GPC was about 3%, where as in PPCC it was observed to be 20 to 25% for 45 days of exposure. In case of normal concrete, the hydration compounds were neutralised by sulphuric acid and gradually the binder disintegrated, thus exposing the aggregates. There was a slight increase in the mass of specimens due to the absorption of the exposed liquid. The increase in mass of specimens soaked in magnesium sulphate solution was approximately 1.2% for cubes 1.5% for cylinder after 45 days of exposure. It has been observed that there was a decrease in mass loss in normal concrete specimen upto 1%. Negligible change in mass of geopolymers on exposure to sulphates, as seen in the present case, was also reported (Bakharev, 2005 (b)).

Experimental Investigation and Comparison of Results

Crack analysis of the barrier's FE model predicted the first crack to appear at a load of 30 Kip, whereas the initiation of cracking during the test was observed to occur at 26

Kip. This suggests a close agreement with the FE approximation. The load characteristics of the GPC barrier are shown in Figure 11. As the load reached 30 Kip, the first crack fully propagated on the tensile face of the barrier with the development of a second crack. When the applied load reached 32 Kip, a crack was observed at the right support while the crack at the central tensile zone(first crack) developed further. The flexural load was completely transferred to the rebar 41 Kip, when the concrete fully cracked, which was accompanied with loud sound. The steel was visible at this point and the load dropped to 22 Kip. As the load further, the rebar failed when the load reached 26 Kip. This marked the end of the test.

5. CONCLUSIONS

With the elimination of the use of Portland cement, the emission of CO2 has been greatly reduced which results in the reduction of Environmental pollution. The reduced CO2 emissions of GPC make them a good alternative to OPC. Geopolymer concrete is more environments friendly; it has the potential to replace ordinary Portland cement concrete and due to high early strength it shall be effectively used in the precast industries. Due to use of the industrial waste, Geopolymer concrete is an economical product and it also affects the cost of Geopolymer concrete.

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