Mechanical properties of fly ash based geopolymer concrete with addition of GGBS

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Concrete plays important role in the construction industry worldwide. New technologies have helped to develop new types of construction and alternative materials in the concrete area. Cement is the major component in production of concrete. But manufacturing of cement causes air pollution and it is dangerous in the present day scenario. In view of these environmental issues, investigations have been carried out for alternative materials replacing the cement in concrete. Geopolymer concrete is a new type of concrete material, which has recently emerged as a future concrete. Geopolymer concrete is commonly formed by alkali activation of industrial alumina silicate byproducts such as fly ash (FA) and ground granulated blast furnace slag (GGBS). In the present investigation, mechanical properties of geopolymer concrete with fly ash and partially replacing GGBS under ambient temperature (27°C) curing are studied. Five different grades of concrete viz., M20, M30, M40, M50, M60 duly varying percentage of GGBS 9%, 20%, 27.5%, 38% and 43% were considered. Eight molarity (8M) sodium hydroxide (NaOH) was fixed for the study. Alkaline activator to binder (Fly ash + GGBS) ratio was kept constant at 0.5. Further, ratio of sodium silicate to sodium hydroxide solution was taken as 2.5. Standard cubes, cylinders and prisms were considered in the investigation. Mechanical properties were obtained and recorded. The results received from the present study were encouraging.

1. INTRODUCTION

Cement is major integral constituent in the production of traditional concrete. Cement industry accounts considerable share for CO_2 emissions due to high environmental carbon footprint of cement. The carbon foot print is a measure of the amount of CO_2 released through combustion and expressed as tons of carbon emitted per annum (Flower, D.J.M and Sanjayan, J.G) [1]. The production process of cement and concrete has some unfavourable effects on the environment. Technology is pacing the way worldwide to reduce carbon footprint while using less or no Portland cement. Utilization of industrial waste material such as fly ash, GGBS (ground granulated blast furnace slag), silica fume etc., for replacement for Portland cement will lead to substantial reduction greenhouse gas emissions. Thus, replacing these type of materials offers distinct benefits viz., reduces release of CO_2 emission to the atmosphere, reduces the embodied energy (Venkatarama Reddy B.V.) [2] in concrete and minimizes the land required to dispose the industrial wastes. In view of this, geopolymer concrete has become core area to explore the alternative solution to conventional concrete. Studies have given rise to good sustainable concrete. Geopolymer concrete is produced without cement. The basic ingredients of geopolymer concrete are fly ash and GGBS. The term geopolymer was introduced in the year 1991 (Davidovits)[3]. Geopolymerization is the process of inorganic alumina silicate polymeric gel resulting from reaction of amorphous alumina silicates with alkali hydroxide and silicate solutions. Fly ash is a pozzolanic material contains rich in Silica (Si) and Alumina (Al). When these compounds are activated by highly alkaline solution and soluble silicates liquids under elevated temperature curing yields binders Si-O-Al (geopolymers) similar to C-S-H bond similar to conventional concrete. Since, it requires temperature curing about 60°C for 24 hours, for achieving required strength become hindrance in practical application. To overcome this issue research has been emphasized on the use of GGBS for partial replacement of fly ash. GGBS which contains substantial amount of calcium imparts heat of hydration required for geopolymerization process. Thus geopolymer concrete with fly ash and GGBS shows encouraging results without temperature curing.

2. RESEARCH SIGNIFICANCE

It is necessary to make geopolymer concrete as it is main potential application for concrete industry. The present study establishes performance of geopolymer concrete as structural grade for concrete application. This paper aims at optimal percentage replacement of GGBS to meet target strength of different grades (M20, M30, M40, M50, and M60) of concrete. A comprehensive assessment of mechanical properties has been evaluated for making geopolymer concrete as a structural grade concrete.

3. LITERATURE REVIEW

Ambily P.S et al. [4], studied the geopolymer concrete under ambient curing condition unlike temperature curing carried by earlier researchers. In their experimental programme, Ground Granulated Blast Furnace Slag (GGBS) was used as partial replacement for Fly Ash. The replacement ratios were adopted are 25%, 50% and 75% and 100%. Ganapathi Naidu P, et al. [5], made similar observations as indicated above. They found that as the percentage of GGBS increases, compressive strength also increases. Pradeep. J, et al.[6], in their investigation studied for percentage of binder i.e. Fly Ash + GGBS and varied 23%, 26%, 27% 29% & 31%. Bhikshma. V, Naveen Kumar. T [7], have studied the compressive strength of geopolymer concrete for various replacements of GGBS (10%-45% for various molarities 8M, 12M, 16M) under ambient curing temperature (27^0 C) and obtained the strengths in the range of 21-72 MPa.

4. EXPERIMENTAL PROGRAMMES

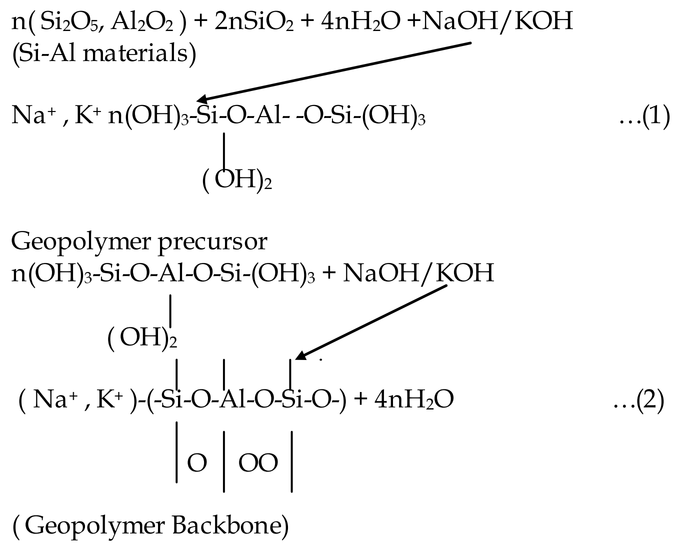
4.1. Geopolymerization process

Chemical reaction between solid alumino silicate oxides and alkali metal silicate solutions at highly alkaline conditions and mild temperatures yielding amorphous to semi crystalline polymeric structures which consist of Si–O–Al and Si–O–Si bonds.

The geopolymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows:

$$M_n [-(SiO_2)_z-AlO_2]_n . wH_2O$$

where, M = the alkaline element or cation such as potassium, sodium or calcium
n = the degree of polycondensation or polymerization
z = 1,2,3 or higher



Mechanism includes three stages. (i) Dissolution of Si and Al atoms from the source material through the action of hydroxide ions; (ii) Condensation of precursor ions into monomers; (iii) Polymerization of monomers into polymeric structures.

In the present investigation different grades of concrete viz., M20, M30, M40, M50 and M60 have been considered. Based on the previous studies, the percentage replacement of GGBS9%, 20%, 27.5%, 38% and 43% were fixed and considered for the above concrete grades respectively in the present study. Fly ash used in the experimental work was a low-calcium fly ash. The silica and alumina are constitutes about 85% of the total mass and its ratio is about 1.5. Properties of fly ash and GGBS are presented in Table 1.

Locally available clean river sand was used as a fine aggregate (Fineness modulus - 2.65, Specific gravity 2.62) confirming to zone II of IS 383:1970. Similarly well graded coarse aggregates having size 4.75 mm - 20 mm were used. A mixture of Sodium hydroxide (NaOH) and Sodium Silicate

Table 1. Properties of Fly Ash and GGBS

S.No	Characteristics	Percentage by Mass	
		Fly Ash	GGBS
1	Loss on Ignition	1.90	2.10
2	Silica, SiO_2	52.16	42.32
3	Alumina, Al_2O_3	36.93	15.66
4	Calcium, CaO	4.67	34.53
5	Iron, Fe_2O_3	4.23	3.68

Figure 1. Freshly mixed geopolymer concrete

Figure 2. Demoulded cubes, cylinders and prisms

(Na_2SiO_3) was used as alkali activator. Sodium hydroxide is in the form pellets having purity 98%. Commercial grade Sodium Silicate having Na_2O 13%-15% and SiO_2 28% -34% were used. To improve the workability poly carboxyl ether based high performance super plasticizer Glenium B233 (BASF Chemicals India) was used. The dosage of super plasticizer is taken as 0.5% by mass of fly ash and GGBS.

Based on the mix design guidelines proposed by B.V. Rangan, Curtain University, Australia [8], several trial mixes were conducted. Finally, a standard design mix has been adopted in the present experimental work. In the mix design, combined aggregate (Coarse and Fine aggregate) taken as 70% of total mass concrete. Molarity of sodium hydroxide (NaOH) was considered as 8M in the present investigation. Alkaline activator to binder (Fly ash + GGBS) ratio was kept constant 0.5. Alsoratio of sodium silicate to sodium hydroxide solution was taken as 2.5. The mix proportions are presented in Table 2.

The sodium silicate solution and the sodium hydroxide solution were mixed together prior to 24 hours of casting. Standard mixing method is adopted for making geopolymer concrete. The fine and coarse aggregates in saturated surface dry condition were first mixed with the fly ash and GGBS about 2 to 3 minutes. At the end of this mixing, the alkaline solution together was added to the dry materials and the mixing continued for another four minutes. The freshly mixed geopolymer concrete as shown in Figure 1.

The workability was measured by means of conventional Slump test and compaction factor tests. Immediately after mixing, the fresh concrete was transferred in to moulds. Standard 30 cubes (150mmx150mmx150mm), 30 Cylinders (150mm Dia&300mm Length) and 15 Prisms (100mmx100mmx500mm) have been considered in the present investigation. After 24 hours, specimens were de moulded and kept under air dry condition at 27°C in laboratory as shown in the Figure 2.

Cube Compressive strength at 7 and 28 days were determined. Further, splitting tensile and flexure strength were obtained at age of 28 days. Tests were carried as per provision laid in IS 516 and IS 5816.

Table 2. Mix proportions of geopolymer concrete (kg/m³)

Grade of Concrete	Molarity (M)	GGBS (%)	Fly Ash	GGBS	F.A	C.A	Na_2O SiO_2	NaOH Pellets	Water
M20	8	9.0	437	43	740	915	171	18	51
M30	8	20.0	384	96	749	926	171	18	51
M40	8	27.5	348	132	756	933	171	18	51
M50	8	38.0	298	182	763	943	171	18	51
M60	8	43.0	274	206	767	948	171	18	51

Table 3. Test results of compressive strength

Grade of Concrete	GGBS (%)	Density (kg/m^3)	Compressive Strength (N/mm^2)	
			7 Days	28 Days
M20	9.0	2212	16.00	28.33
M30	20.0	2231	24.37	40.40
M40	27.5	2265	32.97	50.46
M50	38.0	2309	41.94	59.90
M60	43.0	2343	51.57	71.07

Table 4. Test results of splitting tensile and flexural strength

Grade of Concrete	GGBS (%)	Splitting Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
M20	9.0	1.88	3.01
M30	20.0	2.55	3.67
M40	27.5	3.11	4.27
M50	38.0	3.63	4.93
M60	43.0	4.24	5.43

5. RESULTS AND DISCUSSIONS

5.1. Compressive strength

Compressive strengths for 7 and 28 days test obtained are in the range of 16 to 52 MPa and 28 to 71 MPa respectively. The results were presented in Table 3. Further, it is observed that Compressive strength at 7 days is about 60-70% of 28 days strength which is on par with conventional concrete. The failure pattern of cube specimen under compression is as shown in the Figure 3.

Results reveal that the rate of gain of strength development is increased with increase in GGBS content. This may be due to the more heat of hydration available due to addition of GGBS for geopolymerization process which results in early strength development. Density results are same as that of conventional concrete. Further, increase in percentage of GGBS results in denser microstructure of concrete.

Figure 3. Failure mode of cube specimen

5.2. Splitting tensile and flexural strength

The results were presented in Table 4. The 28 days test results of splitting tensile strengths are in the range of 1.9 to 4.2 MPa for grades M20 - M60 respectively. The results are about 7% - 9% of the compressive strength. Similarly, flexural strength results obtained are in the range of 3.0 - 5.5 MPa.

Figure 4. Tested cylinder specimen

Table 5. Comparison of flexural strength results

Grade of concrete	Experimental results (N/mm^2)	Theoretical Values (N/mm^2)			Fraction 'k' = $f_{ct}/\sqrt{f_{ck}}$
		IS 456 2000 $f_{ct} = 0.7*\sqrt{f_{ck}}$	ACI 318 $f_{ct} = 0.62*\sqrt{f_{ck}}$	Canadian $f_{ct} = 0.60*\sqrt{f_{ck}}$	
M20	2.93	3.13	2.77	2.68	0.656
M30	3.67	3.83	3.40	3.29	0.669
M40	4.27	4.43	3.92	3.79	0.675
M50	4.93	4.95	4.38	4.24	0.698
M60	5.43	5.42	4.80	4.80	0.701

*f_{ct} = Flexural strength, f_{ck}= Characteristic Compressive strength,
k = Constant (Fraction)

Flexural strength is measured as fraction of compressive strength. Flexural strength fraction (k) obtained is presented in Table 5 is compared with various country specifications. Further percentage of split tensile strength with respect to the characteristic compressive strength is marginally lower than the values suggested as in case of conventional concrete. These short falls in splitting tensile and flexural strengths may be due to the dry curing of geopolymer concrete as against the moist curing in case of conventional concrete. It is observed that geopolymer concrete cylinder specimens were failed similar to that of conventional concrete which is shown in Figure 4.

6. CONCLUSIONS

- The average density of fly ash and GGBS based geopolymer concrete is same as that of ordinary Portland cement concrete.
- The workability of the geopolymer concrete observed is similar to that of conventional concrete.
- The 28 days compressive strengths results are more than the values recommended by IS 456-2000.
- Experimental results of flexural and splitting tensile strength revealed insignificant variation compared to conventional concrete.
- Mechanical properties of fly ash and GGBS based geopolymer concrete are comparable with conventional concrete.

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