Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

MECHANICAL PROPERTIES OF FLY ASH BASED GEOPOLYMER CONCRETE WITH ADDITION OF GGBS

V. BHIKSHMA and T. NAVEENKUMAR

Dept of Civil Engineering, University College of Engineering, Osmania University, Hyderabad, India

Concrete plays an important role in the construction industry worldwide. New technology has made for easier development of new types of construction and alternative materials in the concrete area. Cement is the major component in the production of concrete, but its manufacture causes environmental issues and thus there is a need for alternative materials. Geopolymer concrete is a new type of material with that potential, commonly formed by alkali activation of industrial alumina silicate byproducts, such as fly ash and ground granulated blast furnace slag (GGBS). For this paper, mechanical properties of geopolymer concrete with fly ash and GGBS cured under ambient temperatures were studied. Five different grades of concrete were considered. The results were encouraging: The workability of the geopolymer concrete was similar to that of conventional concrete. Experimental results of flexural and splitting tensile strength revealed insignificant variation compared to conventional concrete. The mechanical properties of fly ash and GGBS-based geopolymer concrete were comparable with conventional concrete.

Keywords: Ground granulated blast furnace slag, Geopolymerization, Ambient curing, Concrete strength.

1 INTRODUCTION

Cement is the major integral constituent in the production of traditional concrete. The cement industry accounts for a considerable share for CO_2 emissions due to cement's high environmental carbon footprint (a measure of the amount of CO_2 released through combustion, and expressed as tons of carbon emitted per annum (Flower and Sanjayan 2007)). Technology is paving the way worldwide to reduce the carbon footprint by using less or no Portland cement. Utilization of industrial waste material such as fly ash, ground granulated blast furnace slag (GGBS), silica fume etc., as a replacement will lead to substantial reductions in greenhouse gas emissions. It will also reduce the embodied energy (Venkatarama Reddy and Jagadish, 2003) in the concrete and minimize the land required to dispose the industrial wastes.

Consequently, geopolymer concrete has become a core area for exploring alternative solutions to conventional concrete. The term geopolymer was introduced in the year 1991 (Davidovits 1991), and studies have established an excellent sustainable concrete. Geopolymer concrete is produced without cement, with basic ingredients of fly ash and GGBS. 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 rich in Silica (Si) and Alumina (Al). When these compounds are activated by highly-alkaline solutions and soluble silicates liquids under elevated temperature curing, they yield binders Si-O-Al (geopolymers) similar to C-S-H bonds in conventional concrete. Since it requires temperature curing of about 60°C for 24 hours to achieve the required strength, it is impractical. To overcome this issue, research has been emphasized on the use of GGBS for partial replacement of fly ash. GGBS, which contains a substantial amount of calcium, imparts heat for 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 because it has enormous potential applications for the concrete industry. This study examines the performance of geopolymer concrete as a structural grade for concrete application, aiming for the optimal percentage replacement of GGBS to meet target strength of different grades of concrete (M20, M30, M40, M50, and M60). A comprehensive assessment of mechanical properties has been evaluated for making geopolymer concrete as a structural-grade concrete.

3 LITERATURE REVIEW

Amdbily et al. (2011) studied geopolymer concrete under ambient temperature curing. In their experimental programme, Ground Granulated Blast Furnace Slag (GGBS) was used as partial replacement for fly ash. The replacement ratios were 25%, 50%, 75%, and 100%. Ganapathi et al. (2012) made similar observations, finding that as the percentage of GGBS increases, the compressive strength also increases. Pradeep et al. (2012) studied the percentage of binder, i.e., fly ash + GGBS, at 23%, 26%, 27% 29% and 31%. Bhikshma and Naveenkumar (2013) studied the compressive strength of geopolymer concrete for various replacements of GGBS (10% to 45% for various molarities 8M, 12M, 16M) under ambient curing temperature (27°C), and obtained the strengths in the range of 21-72 MPa.

4 EXPERIMENTAL PROGRAMS

In the present investigation different grades of concrete i.e., M20, M30, M40, M50 and M60 have been considered. Based on the previous studies, the percentage replacements of GGBS at 9%, 20%, 27.5%, 38% and 43% were fixed and considered for the above concrete grades. The fly ash used was a low-calcium fly ash. The silica and alumina 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 of 4.75 mm to 20 mm were used. A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used as an alkali activator.

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

Sodium hydroxide was in the form of pellets having a purity of 98%. Commercial-grade sodium silicate having Na_2O 13%-15% and SiO_2 28% -34% were used. To improve the workability, polycarboxyl ether-based high performance super plasticizer i.e., Glenium B233 (BASF Chemicals India), was used. The dosage of super plasticizer was taken as 0.5% by mass of fly ash and GGBS.

Based on the mix design guidelines proposed by Hardjito and Rangan (2005), several trial mixes were conducted. Finally, a standard design mix was adopted. In the mix design, combined coarse and fine aggregates were used as 70% of total mass concrete. The molarity of sodium hydroxide was 8M. The alkaline activator to binder (Fly ash + GGBS) ratio was kept constant at 0.5. Also the ratio of sodium silicate to sodium hydroxide solution was taken as 2.5. The mix proportions are presented in Table 2:

Table 2. Mix Proportions of geopolymer concrete (kg/m^3).

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

The sodium silicate solution and the sodium hydroxide solution were mixed together prior to 24 hours of casting. A standard mixing method was adopted for making geopolymer concrete. The fine and coarse aggregates in a saturated surface dry condition were first mixed with the fly ash and GGBS for about 2 to 3 minutes. Afterward, the alkaline solution was added to the dry materials and the mixing continued for another four minutes. The workability was measured by means of conventional slump test and compaction factor tests. Immediately after mixing, the fresh concrete was transferred into molds. Standard 30 cubes (150 mm x 150 mm x 150 mm), 30 cylinders (150 mm diameter and 300 mm length) and 15 prisms (100 mm x 100 mm x 500 mm) were considered. After 24 hours, specimens were de-molded and kept to air dry at 27°C in the laboratory. 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.

5 RESULTS AND DISCUSSIONS

5.1 Compressive Strength

Compressive strengths for 7 and 28 days obtained were in the range of 16 MPa to 52 MPa and 28 MPa to 71 MPa respectively. The results are presented in Table 3. Further, it was observed that compressive strength at 7 days is about 60-70% of 28 days, on par with conventional concrete. Results revealed that the rate of gain in strength development was increased with the increase in GGBS content. This may be due to the increased heat of hydration available due to the addition of GGBS in the geopolymerization process, resulting in early strength development. Density results were the same as that of conventional concrete. Further, an increase in the percentage of GGBS results in a denser microstructure of concrete.

Table 3. Compressive strength of geopolymer concrete.

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

5.2 Splitting Tensile and Flexural Strength

The results are presented in Table 4. The 28-day test results of splitting tensile strengths are in the range of 1.9-4.2 MPa for grades M20-M60 respectively. The results are about 7% to 9% of the compressive strength. Similarly, flexural strength results obtained are in the range of 3.0-5.5 MPa. Flexural strength is measured as a fraction of compressive strength. Flexural strength fraction (k) obtained is presented in Table 5, compared with various country specifications. Further, the 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 shortfalls in splitting tensile and flexural strengths may be due to the dry curing of geopolymer concrete, as opposed to moist curing in the case of conventional concrete.

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

Table 5. Comparison of flexural strength for different specifications.

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)

6 CONCLUSIONS

- The average density of fly ash and GGBS-based geopolymer concrete was the same as that of ordinary Portland cement concrete.
- The workability of the geopolymer concrete observed was similar to that of conventional concrete.
- The 28-day compressive strength results were more than the values recommended by IS 456-2000.
- The 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 were comparable with conventional concrete.

References

Ambily, P. S., Madheswaran, C. K., Sharmial, S., and Muthaiah, S., Experimental and analytical investigations on shear behavior of reinforced geopolymer concrete beams, *International Journal of Civil and Structural Engineering*, Vol. 2, No. 2, 673-88, September, 2011.

Bhikshma, V., and Naveenkumar, T., Strength characteristics of fly ash-based geopolymer concrete with addition of GGBS, *ICEAS*, 1192-1199, International Conference on Engineering and Applied Science, Osaka, Japan, 7-9, November, 2013.

Davidovits, J., Geopolymer: Inorganic polymers new materials, *Journal of Thermal analysis*, 37, 1633-56, 1991.

Flower, D. J. M, and Sanjayan, J. G., Greenhouse gas emissions due to concrete manufacture, *International Journal of Life Cycle Assessment* 12(5), 282-8, 2007.

Ganapathi Naidu, P., Prasad, A. S. S. N, Adiseshu, S., and Satyanarayana, P. V. V., A study on strength properties of geopolymer concrete with addition of GGBS, *International Journal of Engineering Research and Development*, Issue 4, Vol. 2, 19-28, July, 2012.

Hardjito, D., and Rangan, B. V., Development and properties of low-calcium fly ash-based geopolymer concrete, *Research Report GC-1*, Faculty of Engineering, Curtin University of Technology, Perth, Australia, 2005.

Pradeep, J., Sanjay, R., and Aswath, M. U., Experimental study on flexural behavior of fly ash and GGBS-based geopolymer concrete beams in bending. *International Journal of Emerging trends in Engineering and Development*, Issue 2, Vol. 6, September, 2012.

Venkatarama Reddy, B.V., and Jagadish, K. S., Embodied energy of common and alternative building technologies, *Energy and Buildings*, Vol. 35, 129-137, 2003.