Chapter 27
Mechanical and Durability Study of Steel Fiber-Reinforced Geopolymer Concrete

Abhishek Pulgur Venkatesha Babu, R. K. Chethan Gowda, L. Divakar, C. Vachan, Rajath Raj, C. H. Sri Karan and R. D. Sayabanna

27.1 Introduction

Cement Concrete (CC) is one of the abundantly used material in construction industry according to some estimates its usage is only next to water. The primary composition of the Cement Concrete is Ordinary Portland Cement (OPC) and other naturally available raw materials. The production of OPC is environmentally intrusive process because for every ton of cement production equivalent amount of carbon dioxide is released to atmosphere and also about 50% of raw materials procured are deemed not suitable for OPC production (Meyer 2009; Chen et al. 2010; Peng et al. 2013). These lead to various environmental problems such as global warming, leaching in landfills, natural resource exhaustions, excessive mining, etc. This necessitated the adaption of environmentally friendly materials, industrial byproducts, and waste materials, etc., for production of concrete which has same or better properties as compared to CC. Waste materials such as Flyash (FA), Rice-Husk Ash (RHA), sugarcane bagasse ash, silica fume, Ground Granulated Blast furnace Slag (GGBS), etc., have been either used as replacement to cement or as standalone material to produce Geopolymer Concrete (GPC) or alkali-activated slag concretes (Singh et al. 2015; Provis 2014).

The serviceable life of the concrete structure depends on the durability properties of the concrete. Concrete structures exposed to aggressive environments are not serving the intended life as concrete deteriorates faster under such conditions. The hydration products of OPC are factors which influence the durability properties of

A. Pulgur Venkatesha Babu (✉) · R. K. Chethan Gowda · L. Divakar · C. Vachan · R. Raj · C. H. Sri Karan · R. D. Sayabanna
Department of Civil Engineering, M.S. Ramaiah University of Applied Sciences, Bengaluru 560056, Karnataka, India
e-mail: abhishek.pulgur@gmail.com

H. Drück et al. (eds.), *Green Buildings and Sustainable Engineering*, Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-15-1063-2_27

CC. Geopolymer concrete has good sulfate and acid resistance (Mehta and Siddique 2017; Ban et al. 2017; Wang et al. 2016). The geopolymer concrete incorporated with steel fibers exhibit better flexural strength and tensile strength as compared with GPC without fibers, fiber incorporation also increases the post cracking behavior of concrete increasing the structural integrity of GPC. Most of the GPC are flyash based, the durability studies of GPC with flyash and GGBS have little information in the literature survey, and with this research gap the mechanical and durability properties of the concrete with steel fibers have been investigated.

27.2 Experimental Procedure

27.2.1 Materials Used

In this study, geopolymer concrete is prepared by the 50:50 combination of the GGBS and class F flyash for binder. The GGBS was procured from ACC plant and whereas flyash was procured from Raichur thermal power plant. The chemical properties of the binder were determined using X-Ray fluorescence which is presented in Table 27.1. The physical properties such as specific gravity, specific surface area, soundness and loss of ignition are determined according to relevant IS standards are presented in Table 27.2. Manufactured sand (M-Sand) is used for the fine aggregate and 20 mm down angular granite is used for coarse aggregates, both these were procured from locally available sources. The physical properties such as specific gravity, fineness modulus, water absorption, bulk density were determined and are presented in Table 27.3.

Hooked end steel fibers having aspect ratio of 80 were procured from Chennai was used to prepare Steel fiber-reinforced geopolymer concrete. The impurities present in the steel were tested and are indicated in Table 27.4. The activator used was sodium based which was mixture of 14 M sodium hydroxide and sodium silicate solution. The water glass modulus of the sodium silicate used in the study was about 2.34. The sodium hydroxide solution was prepared from 97% pure NaOH flakes. The ratio of sodium silicate to sodium hydroxide solution was maintained at 2.5.

Table 27.1 Chemical composition of fly ash and GGBS

Sample %	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	SO_3
Fly ash (type F)	56.21	28.50	8.56	1.50	0.28	1.14	0.25
GGBS	30.35	15.75	1.85	36.52	0.36	0.45	0.14

Table 27.2 Physical properties of Binder materials

Materials	Fly ash	GGBS	Relevant standard
Specific gravity	2.0	2.85	IS 4031-part 11-2005
Specific surface area	325 m^3/kg	350 m^3/kg	IS 4031-part 2-1999
Loss on ignition	0.75%	2.1%	IS 1727-1967
Soundness (expansion)	1 mm	1 mm	IS 1727-1967 and IS 4031-1968

Table 27.3 Physical properties of aggregates

Materials	Coarse aggregate	Fine aggregate	Relevant standard
Specific gravity	2.8	2.45	IS 2386-part 3-1963
Bulk density	1685.2 kg/m^3	1623.91 kg/m^3	IS 2386-part 3-1963
Water absorption	0.3%	1.3%	IS 2386-part 3-1963
Fineness modulus	7.17	3.65	IS 2386-part 1-1963

Table 27.4 Mix proportions of GPC

Mixture	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Fly ash (kg/m^3)	GGBS (kg/m^3)	Activator solution (kg/m^3)	Fibre content[a]	Super plasticizer[a]
SF2	1200	600	240	160	200	2	2

[a]Fibre content in % of weight of total binder considered

27.2.2 Methods

The mix proportion of the geopolymer concrete was done according to Patankar et al. (2015) and the mix proportion considered for the study is indicated in Table 27.5, the mix proportion considered for the study had given excellent compressive strength, flexural and tensile characteristics was considered from previous research (Pulgur et al. 2019). The fresh properties of the concrete were determined using slump test which was done accordance to IS 1199-1959 (1959). Geopolymer

Table 27.5 Fresh and mechanical properties of GPC

Mixture	Slump value (mm)	Compressive strength (MPa)		Flexural strength (MPa)		Split tensile strength (MPa)		No. of hammer blows	
		07 days	28 days	07 days	28 days	07 days	28 days	Initial crack	Ultimate failure
SF0	100.5	30.84	38.45	3.81	5.473	2.36	2.7	4	13
SF2	78.75	38.54	47.24	4.84	7.41	3.03	3.47	6	23
CC	120	25.5	45.36	3.84	7.52	2.9	3.38	–	–

concrete specimens were prepared in accordance with IS 516 for compressive strength, flexural strength and split tensile strength. The specimens were cast, covered with plastic sheet and kept in ambient temperature for 24 h and demolded. The specimens were tested for compressive strength on 7 and 28 days according to IS 516-1959, flexural strength in accordance to both IS 516-1959 and split tensile strength on 28 days conforming to IS 516-1959 (1959). The chemical durability properties was conducted in accordance with the Francis et al. (2017), The cube specimens are cured in ambient temperature for 28 days after demolding the initial weight and surface characteristics are noted, then the specimens are immersed in H_2SO_4 and HCl solution whose pH is maintained 1 until the specimens are taken out for testing before which the physical aspects are noted.

27.3 Results and Discussion

27.3.1 Fresh Concrete Mixes

Fiber reinforced geopolymer concrete was prepared using Flyash and GGBS as the binder materials with steel fiber of weight equal to 2% of binder content. Ability of the flow of concrete and resistance to segregation was measured using slump test. The slump values for different trials are tabulated in Table 27.5.

27.3.2 Tests on Hardened Concrete Mixes

Compression test. The compression test was carried out using compression testing machine of capacity of 2000 kN as per IS: 516-1959 (Okoye et al. 2017) guidelines. Cubes of dimension 100 × 100 × 100 mm were casted and cured in ambient condition.

The compressive test for the cubes was carried after 7 days and 28 days. The results are tabulated in Table 27.5. From the results presented in Table 27.5, it can be observed that there is 32% increase in the compressive strength from 7 days to 28 days. Presence of the GGBS as the binder material helps in gaining the appreciable compressive strength in first seven days. Addition of GGBS increases the demolding strength of the concrete.

Flexural Strength of Concrete. The flexural strength test was carried out flexural testing machine IS: 516-1959 guidelines. The beams of dimension 100 × 100 × 500 mm were casted and kept in ambient condition. Test was performed after 7 days and 28 days. The results of flexural test are tabulated in Table 27.5. From Table 27.5, it can be observed that

Durability test on Concrete. Durability test was conducted on specimen of 10 cm cubes. The cubes were first air cured for 28 days and were then shifted to the

Table 27.6 Variation of density and compressive strength

Mix	Acid attack							
	HCl		H_2SO_4		HCl		H_2SO_4	
	% loss in weight				% loss in strength			
	56 days	84 days	56 days	84 days	56 days	84 days	56 days	84 days
SF2	1.52	2.88	0.78	3.35	16.03	20.55	23.82	29.92
CC	13.88	31.8	18	26.52	28	35	32	40

crates containing 1pH solution of HCL and H_2SO_4 (Bakharev 2005; Ganesan et al. 2015). The cubes are placed in the crates for another 28 days. After 56 days loss in density and compressive strength of the concrete blocks were measured and the results are tabulated in Table 27.6. The same procedure was followed after 84 days, i.e., exposure of 56 days. From Table 27.6 it can be observed that there is a decrease in compressive strength of the cube of about 15% when exposed to HCl and 23% when exposed to H_2SO_4. The results of the study are in comparison of the test conducted by Francis et al.

27.4 Conclusions

In the current study, the durability effects of SFRGPC exposed to acidic environment are studied experimentally. The following conclusions are drawn:

- The surface of the geopolymer concrete was intact and no loose material was evident as compared CC specimens
- The geopolymer concrete exhibited good resistance when exposed to various acidic environments both in terms of loss in strength and loss in weight
- The loss in weight was only around 2.88% and 3.35% for the GPC specimens exposed to HCl and H_2SO_4 solutions
- The loss in strength was also around 20 and 30% for the GPC specimens exposed to HCl and H_2SO_4 solutions.

References

Bakharev T (2005) Durability of geopolymer materials in sodium and magnesium sulfate solutions. Cem Concr Res 35(6):1233–1246

Ban CC, Ken PW, Ramli M (2017) Mechanical and durability performance of novel self-activating geopolymer mortars. Procedia Eng. 171:564–571

Chen C et al (2010) Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. J Clean Prod 18(5):478–485

Ganesan N, Abraham R, Raj SD (2015) Durability characteristics of steel fibre reinforced geopolymer concrete. Constr Build Mater 93:471–476

IS 1199 (1959) Methods of sampling and analysis of concrete. Bureau of Indian Standards, New Delhi, India

IS 516 (1959) Methods of tests for strength of Concrete. Bureau of Indian Standards, New Delhi, India

Mehta A, Siddique R (2017) Sulfuric acid resistance of fly ash based geopolymer concrete. Constr Build Mater 146:136–143

Meyer C (2009) The greening of the concrete industry. Cem Concr Compos 31(8):601–605

Okoye FN, Prakash S, Singh NB (2017) Durability of fly ash based geopolymer concrete in the presence of silica fume. J Clean Prod. https://doi.org/10.1016/j.jclepro.2017.02.176

Patankar SV, Ghugal YM, Jamkar SS (2015) Mix design of fly ash based geopolymer concrete. Adv Struct Eng (Elsevier, India)

Peng J et al (2013) Modeling of carbon dioxide measurement on cement plants. Adv Mater Res 610–613(1):2120–2128

Provis JL (2014) Geopolymers and other alkali activated materials: why, how, and what? Mater Struct 47(1–2):1–25

Pulgur A, Divakar L, Chethan Gowda RK, Nagesh B (2019) Influence of steel fibres on mechanical properties of geopolymer concrete. In: Drück H, Pillai R, Tharian M, Majeed A (eds) Green buildings and sustainable engineering. Springer transactions in civil and environmental engineering. Springer, Singapore

Singh B et al (2015) Geopolymer concrete: a review of some recent developments. Constr Build Mater 85:78–90

Wang WC, Wang HY, Tsai HC (2016) Study on engineering properties of alkali activated ladle furnace slag geopolymer. Constr Build Mater 123:800–805