A Study on Geopolymer Concrete

T. Yeswanth Sai, K. Athira, and V. Sairam

Abstract Cement free concrete is an emerging field in modern construction industry. This technology is highly recommended due to the reduction in greenhouse gas emission. In the last few decades, the environmental CO_2 footprint is increasing day by day due to the high consumption of cement. To overcome this issue, the other pozzolanic materials are incorporated instead of cement. Geopolymer concrete is an innovative construction material that utilizes fly ash as one ingredient. Geopolymer concrete also reduces global emission of CO_2 by approximately 2.1 billion tonnes per year. It can also be referred to as cement-free concrete. It is also known as greener construction technology. The fly ash is non-binding material, and it is activated by an alkaline solution to produce the binding material. The main objective is to achieve the sustainable fly ash-based geopolymer concrete and to carry out the mechanical properties like compressive strength, split tensile strength and flexural strength and durability properties when exposed to acid, sulphates, chlorides and water absorption for M30 grade at 7, 14, 21 and 28 days.

Keywords Geopolymer concrete · Compressive strength · Water absorption · Durability

1 Introduction

1.1 Materials Used and Mix Proportioning

The materials used in geopolymer concrete are low calcium fly ash (source or base material) or class F fly ash, fine aggregate passing through 4.75 mm sieve of zone 2, coarse aggregate of size 20 mm. The properties of geopolymer concrete are designed in comparison with M30 grade nominal concrete. The specific gravity of fine and coarse aggregates is 2.71 and 2.73, respectively. The chemical composition of fly

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Table 1 Chemical composition of class F fly ash

SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	CaO	LOI
57.30%	27.13%	8.06%	2.13%	1.06%	0.73%	0.03%	1.60%

Table 2 Mix proportioning of concrete

Mix	Cement	Water (L)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Admixture	Class-F fly ash
OPC (M1)	438 kg/m^3	197	685	1079	125 ml/1 bag of cement	0
GPC (M2)	0	27.55	619.06	1149.68	NaOH-19.95 kg/m^3 and Na_2Sio_3-118.25 kg/m^3	475 kg/m^3

ash is given in Table 1. The alkali activators used are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The mix proportioning of the control mix (M1) and geopolymer concrete (M2) is given in Table 2. The mix design was done in accordance with [1]

2 Methodology

2.1 Synthesis and Tests

The sodium hydroxide solution and the sodium silicate solution were mixed to prepare the alkaline activator solution to enhance the reaction between source material and the activator [2]. The geopolymer concrete is casted by adopting the conventional technique used in the manufacture of portland cement concrete as per IS: 516 [3]. The workability of the fresh concrete was taken as 100 mm slump [4]. The geopolymer concrete takes 2–3 days to get harden. Normal water curing has been adopted for both nominal as well as geopolymer concrete [5]. For strength tests, the demoulded specimens were cured in water for 7, 14, 21 and 28 days. For durability, the demoulded cubes were cured in sodium sulphate for 7, 14, 21 and 28 days. Similarly, the demoulded cylinders are cured in sodium chloride and beams in sulphuric acid. The compressive, split tensile and flexure strength test on hardened fly-ash-based geopolymer concrete were performed on standard compression testing machine and universal testing machine, respectively, for the water cured specimens in accordance with IS:516 [3]. The prolonged curing enhances the polymerization process and results in higher compressive strength.

3 Results and Discussion

Mechanical and durability properties of geopolymer concrete: After curing of 7, 14, 21 and 28 days, the compressive, tensile and flexure strength developed are shown in Tables 3, 4 and 5. The strength gain percentage of geopolymer concrete as compared to nominal concrete mix is shown in Figs. 1, 2 and 3. Compressive strength at early curing period shows 17% increment in strength, whereas at the later stage of curing shows only 8.2% increment in compressive strength. It shows a parabolic trend in strength gain. Similarly, tensile strength shows 32.82% of enhancement at 7th day strength and 24.93% at 28th day but there is a sudden drop in strength gain at 14th day curing in the comparative study which is better than nominal concrete. Flexural strength shows maximum strength gain at 14th day curing, whilst early strength gain shows 21.7%, 28th day flexural strength gives only 13.18% strength gain as compared to the nominal M30 concrete mix (Table 6).

Compressive strength (N/mm²) and water absorption (sulphate solution): Cubes were cured in sulphate solutions for 7, 14, 21 and 28 days. Compressive strength and water absorption were found and compared with nominal concrete.

Table 3 Compressive strength (N/mm^2)

Number of curing days	Compressive strength (N/mm^2)	
	OPC (M1)	GPC (M2)
7	20.73	24.29
14	24.14	28.59
21	26.95	31.84
28	34.07	36.88

Table 4 Tensile strength (N/mm^2)

Number of curing days	Tensile strength (N/mm^2)	
	OPC (M1)	GPC (M2)
7	1.98	2.63
14	2.87	3.43
21	3.06	4.00
28	3.77	4.71

Table 5 Flexural strength (N/mm^2)

Number of curing days	Flexure strength (N/mm^2)	
	OPC (M1)	GPC (M2)
7	2.07	2.52
14	2.43	3.24
21	3.46	4.08
28	4.55	5.15

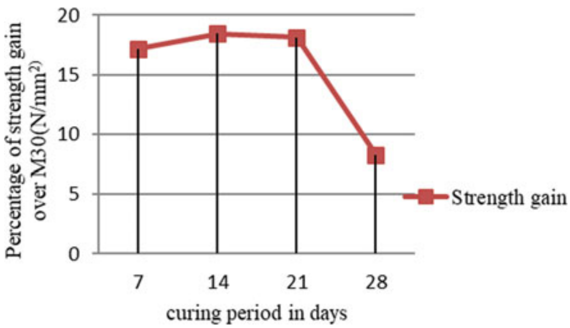

Fig. 1 Compressive strength (N/mm^2) gain pattern of geopolymer concrete compared to M30 concrete mix

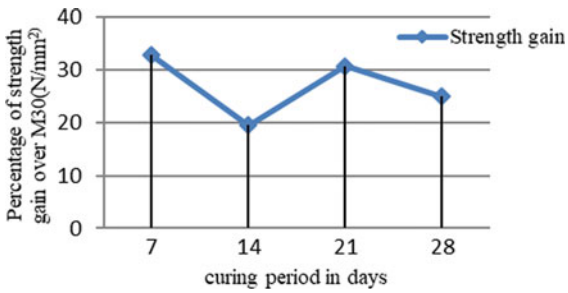

Fig. 2 Tensile strength (N/mm^2) gain pattern of geopolymer concrete compared to M30 concrete mix

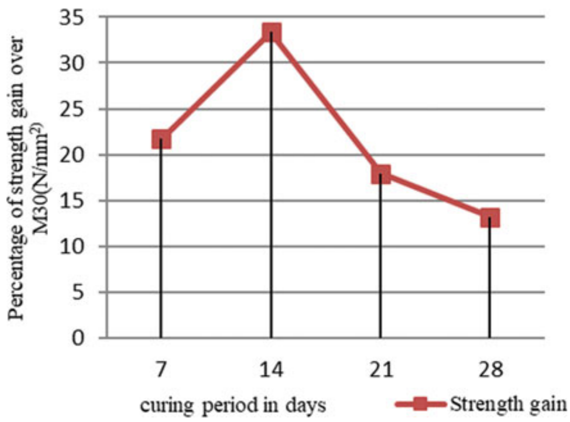

Fig. 3 Flexural strength (N/mm^2) gain pattern of geopolymer concrete compared to M30 concrete mix

Table 6 Compressive strength (N/mm^2) and water absorption (sulphate solution)

Days	Compressive strength (N/mm^2)		Water absorption (%)	
	OPC (M1)	GPC (M2)	OPC (M1)	GPC (M2)
7	24.80	28.60	0.985	0.755
14	29.83	33.46	1.535	0.935
21	35.46	38.89	1.880	1.285
28	40.10	44.02	2.290	1.410

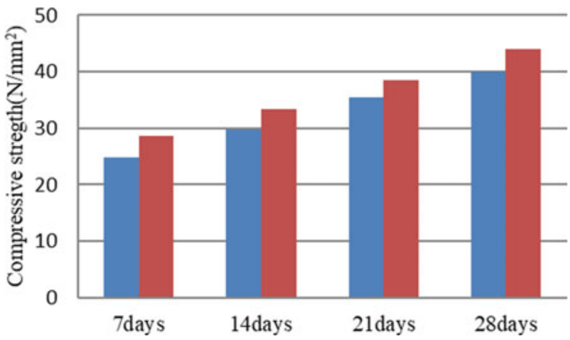

Fig. 4 Compressive strength (N/mm^2) versus curing in days

Percentage increases in compressive strength for 7, 14, 21 and 28 days are 15.3%, 12.1%, 9.6% and 9.7%, respectively. Maximum percentage increment is observed after 7 days curing. This might be due to the higher rate of early strength gain and capacity to resist sulphate attacking geopolymer concrete. But in the later stage of curing, the pattern of increment is more or less constant (Fig. 4).

Split tensile strength (N/mm^2) and water absorption (chloride solution): The resistance to chloride attack is also a major concern of offshore, coastal and chemically prone structures. The OPC and GPC cylinders were cured in sodium chloride solution for 7, 14, 21 and 28 days. After the curing periods, the specimens were tested for split tensile strength and water absorption. Table 7 and Fig. 6 represent the test results. There was a sharp increase of 26% in split tensile strength of control mix at 28 days. The geopolymer attained a sharp increase in split tensile strength after 21 days about 38%. The water absorption rate increased drastically at 14 days testing for both OPC and GPC mixes about 115% and 212%, respectively. But the overall water absorption of GPC mix was lower than OPC mix by about 30% at 28 days (Fig. 5).

Flexural strength (N/mm^2) and water absorption (sulphuric acid solution): The acidic environment condition was created with the help of sulphuric acid. The flexural strength of the GPC mix increased 41% with respect to OPC mix at 28 days. The rate of water absorption test showed a decrease at 28 days of curing to about 13% (Fig. 6).

Table 7 Split tensile strength (N/mm^2) and water absorption (chloride solution)

Days	Split tensile strength (N/mm^2)		Water absorption (%)	
	OPC (M1)	GPC (M2)	OPC (M1)	GPC (M2)
7	1.93	2.56	0.9	0.449
14	2.07	2.86	1.94	1.402
21	3.01	3.96	2.03	1.490
28	3.82	4.02	2.40	1.671

Table 8 Flexural strength (N/mm^2) and water absorption (sulphuric acid solution)

Days	Flexural strength (N/mm^2)		Water absorption (%)	
	OPC (M1)	GPC (M2)	OPC (M1)	GPC (M2)
7	3.89	4.38	1.08	0.75
14	4.08	5.48	1.4	0.86
21	4.44	6.58	2.27	1.78
28	4.83	6.83	2.60	2.26

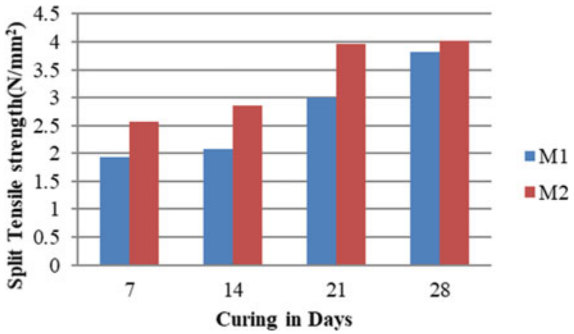

Fig. 5 Split tensile strength (N/mm^2) versus curing in days

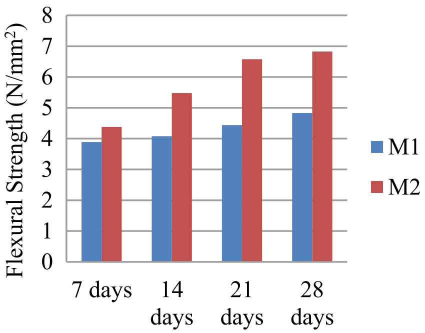

Fig. 6 Flexural strength (N/mm^2) versus curing in days

Water absorption (%): The water absorption rate is gently decreasing in geopolymer concrete as the curing period proceeds. After 28th day curing in sulphate solution, water absorption dropped to 38.42%. This indicates a reduction in porosity. The water absorption shows maximum decrease in the chloride and sulphuric acid solution at the early stages of curing (Fig. 7).

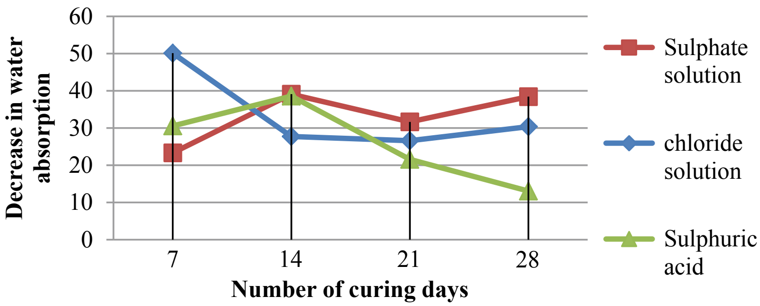

Fig. 7 Water absorption (%)

4 Conclusions

- Geopolymer has competitive compression, tension and flexural strength when compared to conventional concrete. Compressive strength gain is maximum at 7th day curing, whereas flexural strength gain is at 14th day curing. Split tensile strength shows a sudden drop at 14th day curing and shows maximum strength gain at 7th day curing. All the cases show a drop in strength gain in the later stage of curing compared to the initial strength gain patterns.
- Compressive strength can be increased by increasing the concentration of sodium hydroxide.
- Fly ash-based geopolymer concrete has excellent durability, and it is suitable for many structural applications. Resistance to sulphate attack is better than nominal concrete in every curing stage on an average of 11.73% in terms of compressive strength. Similarly, average enhancement of resistance to chloride attack in terms of split tensile strength is 26.9% and acid attack in terms of flexural strength is 34.1%.
- The water absorption results show that the porosity of geopolymer concrete is less as fly ash is finer than OPC, and results in less water absorption are the control concrete. The drop in water absorption indicates reduction in porosity.
- To overcome the delay in setting due to sodium silicate gel, heat curing is recommended.

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