Experimental Study on the Mechanical and Durability Performance of Geopolymer Concrete Using GGBS and Metakaolin

A. Divya and S. Saranya

1 Introduction

The geopolymer technology is proposed by Davidovits which provides significant application in the concrete industry as an alternative material to the Portland cement [1]. In order to reduce the CO_2 emission from the cement manufacturing industry, geopolymer concrete is one of the best options to reduce environmental pollution [2–4]. It also helps in utilizing a huge amount of industrial waste effectively, to avoid disposal problems. The supplementary cementious material used in geopolymer concrete is rich in silicon and Aluminium [5–9]. These compounds react with the highly alkaline solution by geopolymerisation to produce the binding material [10–12]. The process comprises of chemical reaction in high alkaline conditions on Si–Al minerals to forms a three-dimensional polymeric chain and ring structure involving the Si–O–Al–O bonds [12–18]. Geopolymer concrete is the latest environment friendly construction material for sustainable development in construction industry. This attempt results in reducing CO_2 emission from the manufacturing industry and effective utilization of industrial waste by utilizing them as concrete material [1, 5, 6, 19–21].

A. Divya (✉) · S. Saranya
Department of Civil Engineering, Sona College of Technology, Salem, India
e-mail: divya.a@sonatech.ac.in

S. Saranya
e-mail: saranya@sonatech.ac.in

B. B. Das et al. (eds.), *Recent Developments in Sustainable Infrastructure (ICRDSI-2020)–Structure and Construction Management*, Lecture Notes in Civil Engineering 221, https://doi.org/10.1007/978-981-16-8433-3_58

2 Geopolymer Concrete Materials

GGBS used in this experimental work was obtained from Local industry. Metakaolin with specific gravity 2.50 was utilized. Sodium silicate and sodium hydroxides were used as activators to react with the aluminium and the silica in GGBS and metakaolin. Sodium hydroxide solution of 12 M concentration was prepared by dissolving hydroxide flakes with 97% purity in the water. The river sand having the fineness modulus 2.76, specific gravity 2.54 and conforming to grading zone-II as per IS: 383-1970 was used. The coarse aggregate used in this research work was 20 mm of maximum size with fineness modulus and specific gravity are 6.45 and 2.60 respectively.

2.1 Construction of Geopolymer Concrete

For the design of geopolymer concrete, from the entire mass of concrete 75% of the concrete mass is considered by total aggregates (fine and coarse). Conventional concrete is casted in the similar way with aggregate range of 75–80% by the mass of concrete in which fine aggregate occupies 30% of the total aggregates. It is observed from the literature, the average density of geopolymer concrete is 2400 kg/m^3 similar to OPC concrete. With the density of concrete, the combined mass of alkaline liquid and cementious material is derived. The mass of alkaline liquid and GGBS was determined by assuming the ratios of alkaline liquid to GGBS as 0.35. The ratio of sodium silicate to sodium hydroxide solution was fixed as 2.50 approximately. In this present work, the concentration of NaOH solution is considered as 12 M. The mix ratio of corresponding proportion is given in the Table 1.

Table 1 Mix proportioning of geopolymer concrete

Mix ID	GGBS (kg/m^3)	Metakaolin (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	NaOH solution (kg/m^3)	Na_2SiO_3 solution (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
Mix 1	442.44	–	540	1260	45.1	112.6	39.43	11.83
Mix 2	398.2	44.24	540	1260	45.1	112.6	39.43	11.83
Mix 3	353.96	88.48	540	1260	45.1	112.6	39.43	11.83
Mix 4	309.71	132.73	540	1260	45.1	112.6	39.43	11.83
Mix 5	265.47	176.97	540	1260	45.1	112.6	39.43	11.83

2.2 Development of Geopolymer Concrete

Sodium hydroxide flakes of 480 g are liquefied in one litre of water to prepare sodium hydroxide solution of 12 Molarity. The mass of NaOH solids in a solution will be influenced by the concentration of the solution expressed in terms of molar. The mass of NaOH solids was measured as 361 g per kg of NaOH solution of M concentration. The alkaline solutions are mixed together one day prior to the casting of geopolymer concrete. The solid constituent aggregates, GGBS and Metakaolin were dry mixed manually for about 3 min. After one day the alkaline solution is mixed with other concrete materials in a controlled environment and transferred into the moulds as early as possible as the setting times are very less. It is observed that the concrete were very hard to handle.

2.3 Casting and Curing

The fresh concrete is immediately transferred into the mould after mixing. Cube specimen of size of 150 × 150 × 150 mm, cylinders with diameter 150 mm and height 300 mm, and beams of 500 mm × 100 mm × 100 mm were made ready to study the compressive, tensile, flexural and durability study of geopolymer concrete. After casting, all the specimens were kept at room temperature to induce the geopolymerisation process till the date of testing. Figure 1 shows the Geopolymer cube specimen at 28 days.

Fig. 1 Geopolymer cube specimen

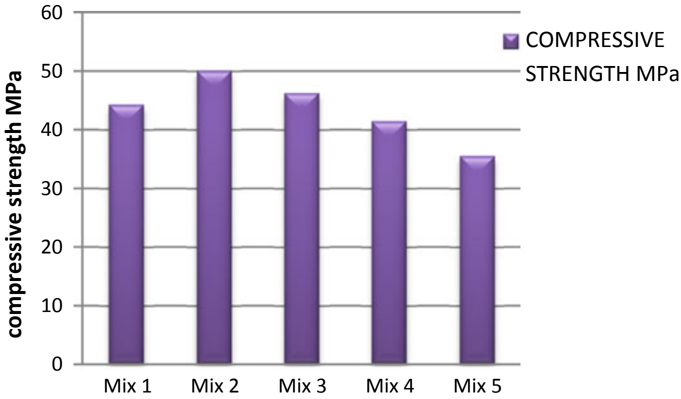

Fig. 2 Compressive strength of geopolymer concrete

3 Experimental Investigation

3.1 Compressive Strength Test

The compressive strength of geopolymer concrete is determined by cube specimen. It is observed that the geopolymer concrete can withstand high load carrying capacity. From the graph it is observed that the concrete with GGBS and Metakaolin are acting as good binding materials. The compositions Mix 2 possess a higher compressive strength than the other combination. Figure 2 shows the comparison of the compressive strength of geopolymer concrete.

3.2 Tensile Strength Test

From the observation, it is noted that the tensile strength of geopolymer concrete increases with increase in percentage of GGBS at later days. It was found that split tensile strength shows improved strength of MPa for 10% replacement of metakaolin than the other mix. The tensile strength shows that the cementitious replacement gives equivalent strength as that of conventional concrete. Figure 3 shows the tensile strength of geopolymer concrete at 28 days.

3.3 Load Versus Deflection Behaviour of GPC Beams

The Geopolymer beams of size 1000 × 100 × 150 mm with reinforced with two lower bars allowing for an effective depth of 130 mm with cover of 20 mm. The

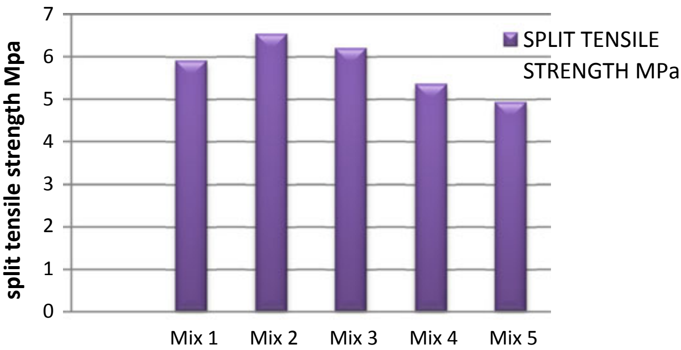

Fig. 3 Tensile strength of geopolymer concrete

beams were tested under ultimate load in two-point bending over a span of 900 mm and a shear span of 300 mm providing a shear span-to-depth ratio of 2. The load was applied in increments of 2 kN until the tensile reinforcement yielded. Deflection was observed for every corresponding load. The mid span deflection was recorded at each load step using a dial gauge which had a least count of 0.01.

When the maximum load was obtained, the concrete cover started to fall for the beams of Geopolymer and Conventional concrete in the compression zone. Figure 4 shows the failure pattern of the Geopolymer beam. It was observed that the first crack appeared close to the mid span of the beam.

Figure 5 shows the comparison of the load carrying capacity of geopolymer and conventional reinforced beam. The ultimate load of conventional and geopolymer beams are 72 kN and 91 kN respectively at the age of 28 days. It is observed that the initial and final crack capacity of Geopolymer concrete is higher than the conventional concrete.

Fig. 4 Failure pattern of geopolymer concrete

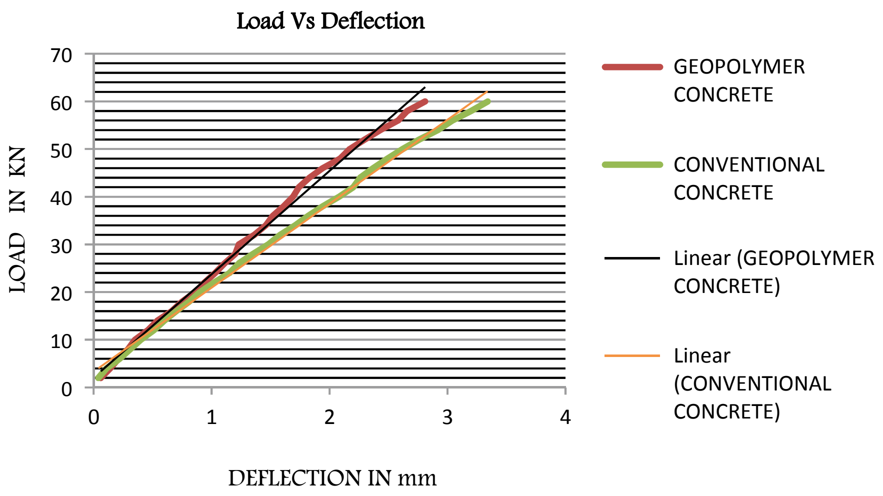

Fig. 5 Load versus deflection behaviour of concrete

3.4 Half-Cell Potential Measurement

The half-cell potential measurement is an electrochemical technique used to determine the severity of corrosion in the reinforced concrete structures. After the initial curing of 28 days, the cylinder was again subjected to curing by salt water solution in the ratio 100:3.8 upto 2/3rd height of the cylinder. After 4 days, the water was removed and half-cell potential readings were taken. After the readings were taken the specimen were again subjected to salt water curing. By this way half-cell potential readings were taken every 4 days until it reached 90% probability of corrosion.

The corrosion behaviour of geopolymer and conventional concrete is shown in Fig. 6. In comparison to the values of ASTN C876, the experimental values obtained

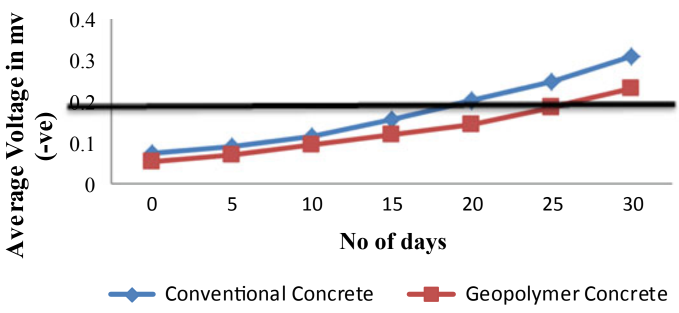

Fig. 6 Corrosion measurement by half-cell potential

from the cylinders shows that conventional concrete cylinder is subjected to corrosion earlier than Geopolymer concrete.

3.5 Accelerated Corrosion Test

An accelerated corrosion test is to determine the corrosion resistance of concrete. The salt water produces a corrosive attack to the concrete and corrosion is induced in a shorter time period by using digital multi meter.

The connection is made that the positive by is connected to the steel plate and the negative is connected to the steel reinforcement of the cylindrical specimen, which acts as electrode. Figure 7 shows the setup of accelerated corrosion test.

Figure 8 explains that the rate of corrosion of Geopolymer concrete is slower when compared to the conventional concrete.

Fig. 7 Acceleration corrosion test

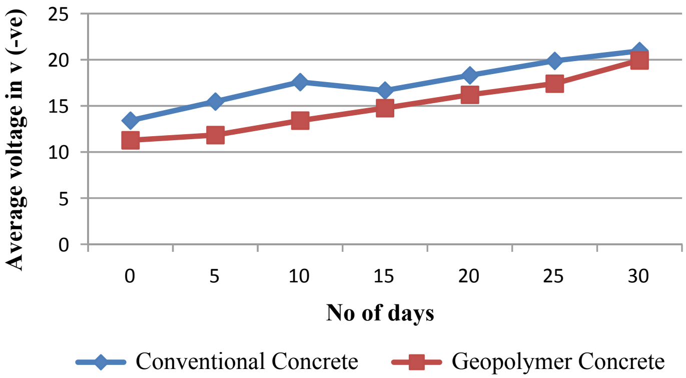

Fig. 8 Acceleration corrosion teat results

4 Conclusion

An attempt has been made to test the various properties of geopolymer concrete. Based on the experimental work, the following conclusions are made:

- The Compressive strength of the geopolymer concrete escalated with the increase in GGBS content in the concrete.
- The compressive strength of geopolymer concrete increases with an increase of age of concrete.
- The Ultimate load of the reinforced concrete beam for conventional concrete is 72 kN and Geopolymer concrete is 91 kN. The load carrying capacity of Geopolymer concrete RC beam is 23% higher than the conventional RCC beam.
- In half cell potential measurement, no corrosion occurs for Geopolymer concrete at 30 days as per ASTM C876 specifications.
- The Accelerated Corrosion test results shows that the current passing through the Geopolymer concrete is lower, when compared to the conventional mix.
- By proper proportioning of GGBS and Metakaolin and by selecting appropriate parameters, desirable strength of geopolymer concrete can be achieved.
- Since Geopolymer concrete exhibits good durability characteristics, it can be used as an alternate material to ordinary concrete.
- Geopolymer concrete is Eco-Friendly since complete replacement of cement is made.

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