

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013

Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)

On 12th to 14th December Organized by

Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

STRENGTH AND BEHAVIOUR OF GEOPOLYMER CONCRETE BEAMS

Ruby Abraham, Deepa Raj S, Varghese Abraham

Professor, College of Engineering, Thiruvananthapuram-695016, India

Associate Professor, College of Engineering, Thiruvananthapuram-695016, India

Assistant Engineer, Kerala Water Authority, Kollam, India

ABSTRACT

This paper presents the results of the experimental investigations carried out to determine and to compare the flexural behavior of geopolymer concrete (GPC) beams with conventional concrete beams of same grade. A total of twenty beams consisting of twelve GPC beam specimens and eight PCC beam specimens were considered in this study. The beams were designed as under reinforced with tensile reinforcement ratios 0.55%, 0.83%, 1.02% and 1.3%. The beams were tested under two point monotonic loading. Performance aspects such as load carrying capacity, first crack load, ultimate load, load-deflection behavior, moment-curvature behavior, crack width, crack spacing and the modes of failure of both types of beams were studied. The test results showed that the geopolymer concrete exhibits better performance compared to conventional concrete of same grade.

1. INTRODUCTION

Demand for concrete as a construction material is increasing day by day. The main ingredient of conventional concrete is ordinary Portland cement. There are two major drawbacks with respect to its sustainability. About 1.5 tons of raw materials are needed for the production of every ton of Portland cement and at the same time, about one ton of carbon dioxide is released into the environment during its production. Hence the production of Portland cement is an extremely resource and energy intensive process[1]. Recently another form of cementitious materials (Alkali activated aluminosilicates) was developed and was termed as 'geopolymer'. The term geopolymer was introduced by Davidovits in the year 1978. The main ingredients of geopolymer were materials which are rich in alumina and silica like, fly ash, rice husk ash, metakaolin and an alkaline solution. The primary difference between Portland cement concrete (PCC) and geopolymer concrete is that in GPC, cement is completely avoided and the binder used is alkali activated aluminosilicate. In future, fly ash production will increase, especially in the countries such as China and India. Accordingly, efforts to utilize this by-product material in concrete manufacturing are important to make concrete more environment friendly [2]. For instance, every million

tons of fly ash that replaces Portland cement helps to conserve one million ton of limestone, 0.25 million tons of coal and over 80 million units of power, notwithstanding the abatement of 1.5 million tons of CO₂ to the atmosphere[4].

Experimental investigations were carried out to investigate the flexural behaviour of Reinforced Geopolymer Concrete Beams (GPB) and Reinforced Conventional Concrete Beams (RCB) with varying tensile reinforcement ratio.

2. EXPERIMENTAL PROGRAMME

2.1 Constituent Materials

The materials used were, fly ash, fine aggregate, coarse aggregate, alkaline solution, super plasticizer, cement and water. Low-calcium Class F fly ash obtained from Tuticorin Thermal Power Plant in Tamil Nadu was used as the base material for Geopolymer concrete. Coarse aggregate of nominal size 20 mm with fineness modulus 6.92 and locally available river sand with fineness modulus 3.16 and conforming to zone II of IS 383 (1970) were used . Alkaline solution comprises a mixture of sodium silicate solution and sodium hydroxide solution. Sodium silicate solution with SiO₂ to Na₂O ratio of 2 (Na₂O=14.7%, SiO₂=29.4% and water=55.9%) by mass was used. Ordinary Portland Cement of 53 grade conforming to IS 12269-1987 was used for conventional concrete. Superplasticizers was also used to obtain workability of more than 100mm slump for GPC.

2.2 Mix Design

Since there is no codal recommendation for the design of GPC, the mix design was done by trial and error method [3,5]. Mix proportion corresponding to a compressive strength of 30MPa was adopted from the trial mixes. A mix design for M₃₀ PCC was also done as per IS 10262-2009 for comparison purpose. The final mix proportion for both mixes are shown in Table 1.

TABLE 1.
MIX PROPORTIONS OF GPC AND
PCC

Materials	GPC (Kg/m ³)	PCC (Kg/m ³)
Coarse aggregate	1294	1266
Fine aggregate	554	598
Fly ash	408	Nil
Cement	Nil	426
Sodium silicate solution	103	Nil
Sodium hydroxide solution	41	Nil
Superplasticizer	10.2	Nil
Water	14.5	192

2.3 Preparation of specimens

Concrete specimens such as beams of size 125mmx175mmx1200mm, cubes of size 150mm, cylinders of size 150mm diameter and 300mm height and prisms of size 100mmx100mmx500mm were prepared from Geopolymer concrete and conventional concrete . All the beams were designed as under reinforced sections. The variable considered in this study was four different values of tensile reinforcement ratios. The reinforcement ratios are 0.55% (2nos 8mm),0.83% (3nos 8mm),1.02% (2nos10mm&1no 6mm) and

1.3% (3nos 10mm). Two 6mm diameter bars were provided in the compression side of all the beams. Two legged stirrups of 6mm diameter @ 100mm c/c is used as stirrups for all the beams. The spacing of stirrups in the bending zone is 165mm c/c. The aggregates prepared in saturated-surface-dry condition were first mixed with fly ash for about three minutes. The alkaline liquid was mixed with the superplasticizer and the extra water. The liquid component of the mixture was added to the dry materials and the mixing continued for another four minutes. After measuring the workability, the mix was poured into the beam mould. It was compacted thoroughly in four layers to enable full compaction and achieve maximum compressive strength. After casting, all GPC specimens were kept at room temperature for one day. After one day the specimens were placed inside the oven and cured at 60°C for 24 hours without demoulding. After 24 hours of curing the specimen was taken out from the oven, demoulded and kept in laboratory ambient conditions till testing day. In the case of PCC, after casting all specimens were kept in the mould for 24 hours. After this time the specimens were demoulded and immersed in water for 28 days for curing.. Geopolymer concrete beams and conventional concrete beams with reinforcement ratios 0.55%, 0.83%, 1.02% and 1.3% are designated as GPB1,GPB2,GPB3,GPB4 ,RCB1, RCB2, RCB3 and RCB4 respectively.

2.4 Testing of Specimens

The hardened properties such as compressive strength, splitting tensile strength, modulus of elasticity and flexural strength were determined by testing standard cubes, cylinders and prisms. The beams were simply supported and subjected to two point static loading. The span of the beam was kept as 990mm. Load was applied using 250kN hydraulic jack and was measured using load cell of 100kN capacity. The deflection at the mid-span was observed for each load increments of 2.0kN using LVDT. (Linear Variable Differential Transformer) Figure1 and Figure 2 show the schematic diagram of test set up and experimental setup respectively. The load was increased in stages till the failure of the specimen and at each stage of loading, deflection at mid-span using LVDTs across the depth of the beam at 20mm below the top and 20mm above the bottom, was noted. The deformations obtained from LVDT readings were used to calculate strains. Crack width was also measured using a crack detection microscope of range 0 to 3mm and with a least count of 0.02mm.

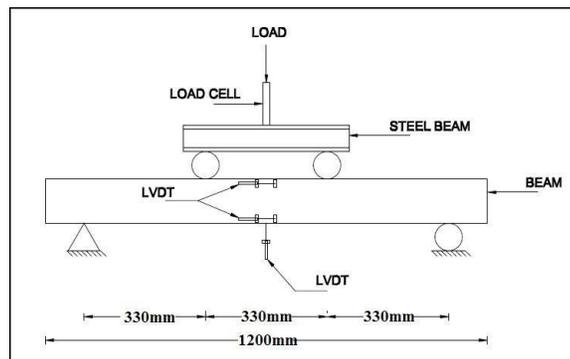


FIGURE 1. SCHEMATIC REPRESENTATION OF TEST SETUP



FIGURE 2. TEST SETUP FOR LOADING

3. TEST RESULTS AND DISCUSSIONS

Table 2 summarizes the fresh and hardened properties of the two mixes. From the table it can be observed that GPC exhibits enhanced mechanical properties than conventional concrete. This may be due to better bonding of the geopolymer paste than cement paste.

TABLE 2. FRESH AND HARDENED PROPERTIES

Properties	GPC	PCC
Slump (mm)	120	92
Compacting factor	0.90	0.89
Compressive strength (N/mm ²)		
7 th day	32.60	23.3
28 th day	38.62	39
Split tensile strength (N/mm ²)	3.56	3.12
Flexural strength (N/mm ²)	4.46	3.79
Modulus of elasticity (N/mm ²)	39992	26678

3.1 Load Deflection and Moment curvature behavior

The recorded values of load and deflection were used to draw the load deflection and moment curvature plots. From these graphs, the energy absorption capacity, displacement ductility factor and curvature ductility factor were determined.

Figure 3 shows the load-deflection behaviour of geopolymer concrete beams and conventional concrete beams with different reinforcement ratios. From the figure the following observations can be made. The deflection of all the beams until the initiation of cracks increased linearly and was proportional to the load. After the initial cracking, deflection increased nonlinearly until the maximum load was reached. The load at the end of the initial linear zone in the load-deflection curve was considered as the first crack load. It can also be observed that the load deflection behaviour of both GPB and RCB were similar in nature.

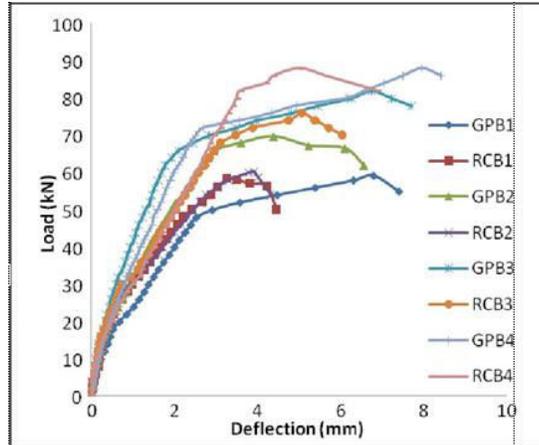


FIGURE 3. LOAD-DEFLECTION CURVES

The moment curvature relation is related to the distribution of moments and the maximum value of curvature is related to maximum value of strain in concrete. The moment curvature plots obtained from the experimental results for the combination of GPB₁ and RCB₁, GPB₂ and RCB₂, GPB₃ and RCB₃, GPB₄ and RCB₄ beams are shown in Figure 4. Figure shows that the curve was linear up to the first crack moment. There after GPB beams show highly nonlinear behavior. After yielding of steel, curves became highly nonlinear for all the beams.

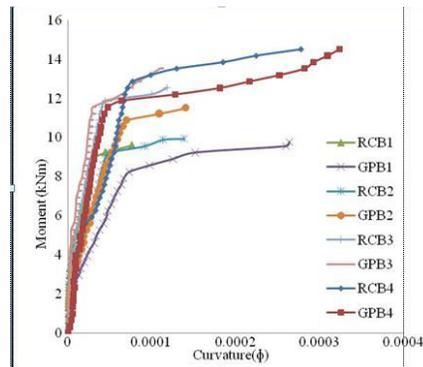


FIGURE 4. MOMENT-CURVATURE DIAGRAMS

3.2 First crack load and Ultimate load and Energy absorption Capacity

The values of first crack load and ultimate load and energy absorption capacity are tabulated in Table 3. The GPB beams showed slightly higher cracking load compared to RCB beams. For GPB₁ the increase in the first crack loads was 7.46% than RCB₁. For GPB₂ first crack load increased by 8.1% than RCB₂. For GPB₃ the increase in the first crack loads were 10% than RCB₃. The first crack load was same for both the RCB₄ and GPB₄ beams. The GPB beams with higher reinforcement ratio showed increase in first crack load compared to GPB beams with lower reinforcement ratio. For GPB₁ the increase in the ultimate load was 1.72% than RCB₁. For GPB₂ the ultimate load increased by 15.76% than RCB₂. For GPB₃ the ultimate load increased by 7.89% than RCB₃. The ultimate load was same for both RCB₄ and GPB₄.

The area under the load deflection curve indicates the energy absorption capacity. It can be seen that energy absorption capacity of the GPB beams are relatively better than that of the RCB beams. The higher load carrying capacity and the larger deflections undergone by the GPB beams increased the

energy absorption capacity of the GPB beams.

TABLE 3.
FIRST CRACK LOAD, ULTIMATE LOAD AND ENERGY ABSORPTION CAPACITY

Beam	First Crack Load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)	Energy absorption Capacity (kNmm)
GPB ₁	18	59.25	6.814	320.181
RCB ₁	16.75	58.25	3.273	122.392
GPB ₂	20	69.75	4.397	216.347
RCB ₂	18.5	60.25	3.92	161.797
GPB ₃	22	82	6.762	433.70
RCB ₃	20	76	5.071	269.756
GPB ₄	24	88	7.98	531.781
RCB ₄	24	88	5.016	284.583

3.3 Crack patterns and Failure mode

Cracks were not observed initially when the load was increased linearly at the beginning of the test. As expected, flexure cracks initiated in the bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. The width and the spacing of cracks varied along the span. At ultimate stage, most of the cracks traversed up to the top of the beams. In all, the crack patterns observed for reinforced geopolymer concrete beams were almost similar to those of conventional concrete beams. The cracks at the mid-span opened widely near failure. The failure mode of both GPB and RCB beams was similar to that of an under-reinforced concrete beam. The crack patterns of geopolymer concrete beams and conventional concrete beams are shown in Figure 5.

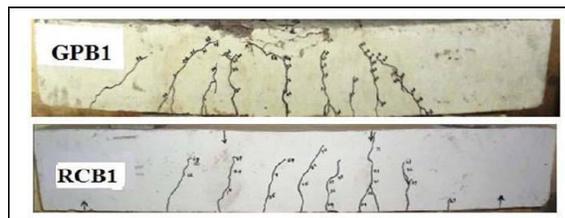


FIGURE 5. CRACK PATTERN

3.4 Ductility index

The ductility index calculated from the load deflection graph and moment curvature plot are tabulated in Table 4. The ductility index is calculated as the ratio of deflection at ultimate load to the deflection at yield load. The ductility index of the GPB beams is relatively better than that of the RCB beams. The beam RCB₄ has the least displacement ductility 1.14 and beam GPB₁ has highest displacement ductility of 5.12. The percentage increase in displacement ductility index for GPB₁ was 71.81% than RCB₁. Similarly for GPB₂ the displacement ductility was 63.41% higher than RCB₂. The percentage increase in displacement ductility index for GPB₃ and GPB₄ was 132.43% and 26.32% than RCB₃ and RCB₄ respectively.

Curvature ductility is the ratio between the curvature at ultimate load and yield load. The failure of an under reinforced beam is termed as tension failure, because the primary cause of failure is the yielding in tension of the steel. The large increase in the curvature, prior to collapse, is indicative of a typical ductile mode of failure. From Table 4 it can be observed that the curvature ductility values of all the GPB beams

were better than that of corresponding conventional concrete beams. For GPB₁ the curvature ductility was 5.83% higher than RCB₁. For GPB₂ the curvature ductility was 2.5% higher than that of the RCB₂. Similarly for GPB₃ and GPB₄ the percentage increase of curvature ductility was 42.36% and 11.29% than RCB₃ and RCB₄ respectively.

TABLE 4. DUCTILITY INDEX AND CRACK WIDTH

Beam	Crack Width		
	Displacement Ductility factor	Curvature Ductility Index	in mm at First crack Load
GPB ₁	5.12	8.17	0.02
RCB ₁	2.98	7.72	0.06
GPB ₂	2.68	3.68	0.02
RCB ₂	1.64	3.59	0.04
GPB ₃	4.30	4.94	0.02
RCB ₃	1.85	3.47	0.04
GPB ₄	1.44	1.38	0.02
RCB ₄	1.11	1.24	0.02

3.5 Crack width and Crack spacing

During testing, the crack widths were measured using crack detection microscope of least count 0.02mm at each 2kN increment of load. At each loading, crack width of 3 to 4 major cracks were noted. The crack width at first crack load of all tested specimens are tabulated in Table 4. The crack width values at maximum service load for each specimen was checked for serviceability limits as specified by the code. From the table, it is clear that the crack widths of all the GPB beams were less than that of the RCB beams. For GPB₁ crack width was decreased by 20% than RCB₁. For GPB₂ crack width was decreased by 14.29% than RCB₂. For GPB₃ crack width was decreased by 9.09% than RCB₃. Similarly for GPB₄ crack width was decreased by 9.52% than RCB₄. From the table, it can be concluded that the crack width of all the tested Geopolymer specimens were less than that of corresponding conventional concrete specimens.

4. CONCLUSION

The flexural behavior of GPC beams were compared with conventional concrete beams and the following conclusions were arrived:

- i. Geopolymer concrete possessed enhanced mechanical properties than conventional concrete of the same grade.
- ii. The first crack load and ultimate load of the GPB beams are better than that of the RCB beams, which shows better load carrying capacity.
- iii. All the beams fail in flexural mode. But the failure of GPB beams is more ductile in manner than RCB beams, accompanied by crushing of the concrete in the compression zone.
- iv. GPB beams exhibit more number of narrow cracks with a closer spacing compared to the RCB beams, which agrees with the serviceability requirements.
- v. Energy absorption capacity of the GPB beams is relatively better than that of the RCB beams, as a result of the higher load carrying capacity and the larger deflections undergone by the

- GPB beams, which shows better ductility.
- vi. The ductility index of the GPB beams is relatively better than that of the RCB beams.
 - vii. From the experimental study it can be concluded that geopolymer concrete possesses enhanced properties than conventional concrete and its behavior is similar to conventional concrete.

REFERENCES

- [1] Louise K Turner, Frank G, Collins, 2013 "Carbon dioxide equivalent ($\text{CO}_2\text{-e}$) emissions between Geopolymer and OPC cement concrete" Construction and Building materials, vol.43, pp.125-130.
- [2] Davidovits J., 1991. "Geopolymers: inorganic polymeric new materials", Journal of Thermal Analysis, 37, pp. 1633–1656.
- [3] Hardjito, D. and Rangan, B. V., 2005. "Development and Properties of Low- Calcium FlyAsh-based Geopolymer Concrete." Research Report GC-1, Faculty of Engineering, Curtin University of Technology, Perth, Australia.
- [4] Raijiwala D.B., Patil H.S., 2011. "Geopolymer concrete : A concrete of next decade", Journal of Engineering Research and Studies, vol.2, pp. 19-25
- [5] Vijaya Rangan B., 2006. "Studies on Low Calcium Fly Ash Based Geopolymer Concrete", Indian Concrete Journal, pp.9-17