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Flexural behavior of post tensioned geopolymer concrete beams

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Abstract
The aim of the research work is to presents the result of experimental studies concerning the flexural behavior of post tensioned geopolymer concrete beams. In this study the flyash based geopolymer concrete mix design was obtained for M50 grade. The fluid to flyash ratio was fixed as 0.45. The ratio of sodium silicate to sodium hydroxide was 2.5 and the concentration of the solution is 14 molar. The preliminary tests were carried out for the geopolymer concrete and conventional concrete and optimizing the mix design. A total of four beams of size 125 × 250 × 3200 mm were cast and tested in the laboratory. Of which two of them are geopolymer concrete and the remaining two beams are conventional concrete. All the beams were tested under static monotonic loading and the results were presented. Comparison was made between conventional concrete and geopolymer concrete.

Keywords: Geopolymer, Steam curing, Flyash, Post tensioning, Flexural behaviour.

1. Introduction
1.1 General
In blended cement concrete, various industrial by products such as flyash, slag, silica, fume, etc., are used as mineral admixtures to certain percentages as supplementary cementations materials to improve the strength and durability of concrete structures. In addition to this industrial waste product such as flyash, rise husk ashes are particularly important resources to supplement the Portland cement.

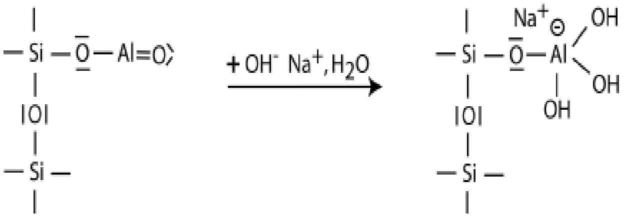
On the other hand, India produces about 70 million tons of coal ash per year from burning about 200 million tons of coal per year for electric power generation. Flyash is one of the promising pozzolanic materials that can be blended with Portland cement for the production of durable concrete. The geopolymer mortar / concrete are produce by totally replacing the ordinary portland cement (OPC) by flyash. Consumption of flyash in the manufacture of geopolymer is an important strategy in making concrete more environmental friendly [1].

In building and slab-on-ground construction, unbounded tendons are typically prefabricated at a plant and delivered to the construction site, ready to install. The tendons are laid out in the forms in accordance with installation drawings that indicate how they are to be spaced, what their profile (height above the form) should be, and where they are to be stressed. After the concrete is placed and has reached its required strength, usually between 3000 and 3500 psi the tendons are stressed and anchored. The tendons, like rubber bands, want to return to their original length but are prevented from doing so by the anchorages. The fact the tendons are kept in a permanently stressed (elongated) state causes a compressive force to act on the concrete. The compression that results from the post tensioning counteracts the tensile forces created by subsequent applied loading (cars, people, and the weight of the beam itself when the shoring is removed). This significantly increases the load-carrying capacity of the concrete.

1.2 Geopolymer
Davidovits (1999) proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as flyash and rice husk ash. He termed these binders as geopolymers [2]. Palomo *et al.* (1999) suggested that pozzolans such as blast furnace slag might be activated using alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. In this scheme the main contents to be activated are silicon and calcium in the blast furnace slag. The main binder produced is a C-S-H gel, as the result of the hydration process. In this work, low-calcium (ASTM Class F) flyash-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The flyash-based geopolymer paste binds the loose coarse

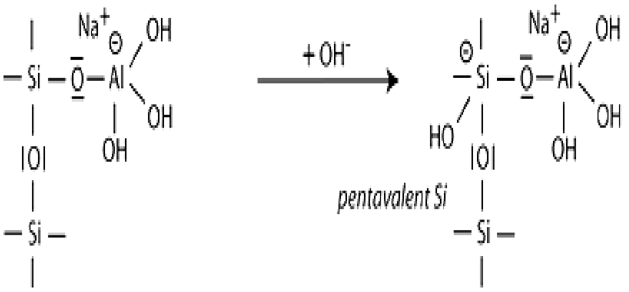
aggregates, fine aggregates and other un-reacted materials together to form the geopolymer, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods [3].

1.3 Chemical Reaction of Geopolymer Concrete
The chemical mechanism can be interpreted in the following way, with NaOH or KOH (steps 1 to 6-7):



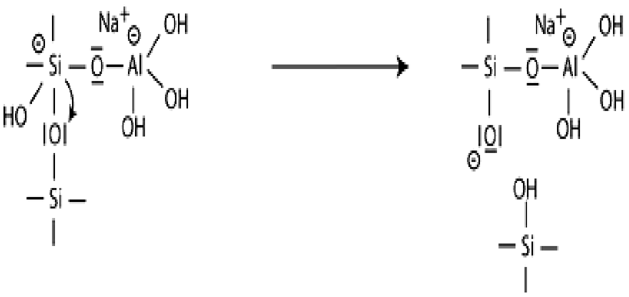
(1)

Step 1: alkalinsation and formation of tetravalent Al in the side group sialate - Si-O-Al-$(OH)_3$-Na^+,



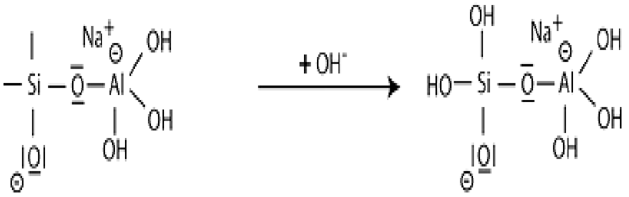
(2)

Step 2: alkaline dissolution starts with the attachment of the base OH- to the silicon atom, which is thus able to extend its valence sphere to the penta-covalent state,



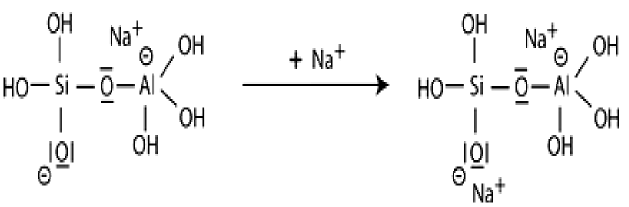
(3)

Step 3: the subsequent course of the reaction can be explained by the cleavage of the siloxane oxygen in Si-O-Si through transfer of the electron from Si to O, formation of intermediate silanol Si-OH on the one hand, and basic siloxo Si-O- on the other hand.



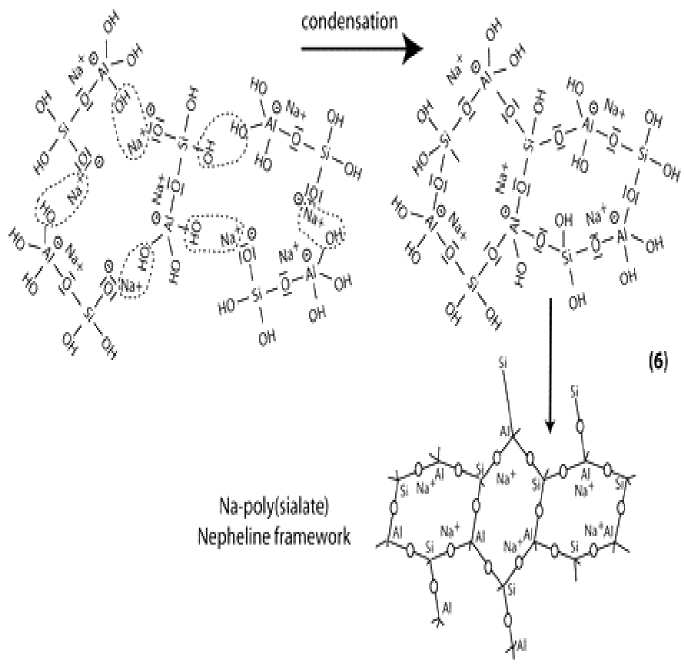
(4)

Step 4: further formation of silanol Si-OH groups and isolation of the ortho-sialate molecule, the primary unit in geopolymerization.

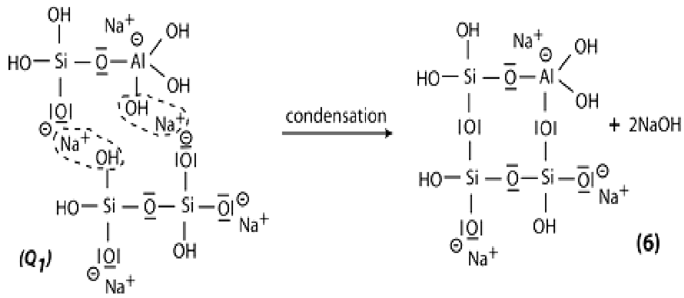


(5)

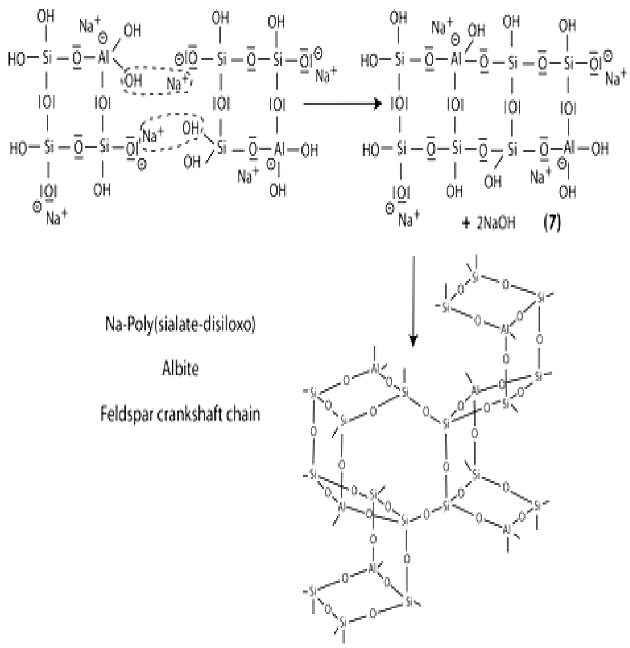
Step 5: reaction of the basic siloxo Si-O- with the sodium cation Na^+ and formation of Si-O-Na terminal bond.



Step 6a: condensation between ortho-silicate molecules, reactive groups Si-ONa and aluminum hydroxyl OH-Al, with production of NaOH, creation of cyclo-tri-silicate structure, whereby the alkali NaOH is liberated and reacts again and further poly condensation into Na-poly (silicate) nepheline framework.



Step 6b: in the presence of water glass (soluble Na- polysiloxonate) one gets condensation between di-siloxonate Q_1 and ortho-silicate molecules, reactive groups Si-ONa, Si-OH and aluminum hydroxyl OH-Al-, creation of ortho-silicatee-disiloxo cyclic structure, whereby the alkali NaOH is liberated and reacts again.



Step 7: further polycondensation into Na-poly (sialate-disiloxo) albite framework with its typical feldspar crankshaft chain structure.

The flyash based geopolymer concrete covers the material and the mixture proportions, the manufacturing process, the fresh and hardened state characteristics, the influence of various parameters on the fresh and hardened state concrete, the utilisation of the material in structural members, and the long-term behavior [4]. The paper presented a summary of the extensive studies carried out by the authors on the flyash-based geopolymer concrete. Low-calcium flyash is used as the source material, instead of the Portland cement, to make concrete. Flyash-based geopolymer concrete has excellent compressive strength and is suitable for structural applications. The salient factors that influence the properties of the fresh concrete and the hardened concrete have been identified. The elastic properties of hardened concrete and the behaviour and strength of reinforced structural members are similar to those of Portland cement concrete. Therefore, the design provisions contained in the current standards and codes can be used to design reinforced flyash-based geopolymer concrete structural members [5].

Lloyd and Rangan [6] conducted a study on geopolymer concrete with flyash. For their study, they used low calcium (ASTM Class F) flyash as their base material. The observations are made with the effect of water - geopolymer solids. They concluded that geopolymer possess excellent properties and is well suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after disaster.

Hardjito and Rangan [7] studied flyash based Geopolymer Concrete. The material used was low calcium ASTM class F dry flyash obtained from power station. The calcium content of the flyash was about 2 percent by mass. They observed the compressive strength data and concluded that flyash based geopolymer concrete has good compressive strength and is suitable for structural application. The flyash based geopolymer concrete also showed excellent resistance to sulphate attack and the elastic properties of hardened concrete and the behaviour and the strength of reinforced structural members are similar to the Portland cement concrete.

The fresh geopolymer concrete was easily handled upto 120 minutes without any sign of setting. The addition of high range water reducing admixture improved the workability of concrete. They concluded that higher concentration of sodium hydroxide solution and curing temperature in the range of 30ºc to 90ºc results in a higher compressive strength of geopolymer concrete. Higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete. The rest period between casting of specimens and the commencement of curing up to 60 minutes has no effect on the compressive strength of geopolymer concrete [8].

Rangan *et al.* [9] carried out experiments on Reinforced low - calcium flyash based Geopolymer concrete beams and columns. Heat-cured low-calcium flyash - based geopolymer concrete has advantages such as excellent structural properties, low creep, very little drying shrinkage, excellent resistance to sulfate attack, and acid resistant. Heat-cured low-calcium flyash - based geopolymer concrete has an excellent compressive strength and is suitable for structural applications. The elastic properties of hardened concrete and the behaviour and strength of reinforced structural members are similar to those of Portland cement concrete. Therefore, the design provisions contained in the current standards and codes can be used to design reinforced flyash-based geopolymer concrete structural members.

Kunal kupwade - patil and Erez Allouche [10] conducted test on the effect of alkali silica reaction in geopolymer concrete. In their study, alkali silica reaction occurs due to chemical reactions between hydroxyl ions in the pore water within the concrete matrix and certain forms of silica. This reaction could lead to strength loss, cracking, volume expansion and potentially failure of the structure. The results suggest that the extent of alkali silica reactions owing to the presence of reactive aggregates in flyash based geopolymer concrete is substantially lower than OPC based concrete, and well below the ASTM specified threshold.

1.4 Post-Tensioning

Post-tensioning allows extremely long span bridges to be constructed without the use of temporary intermediate supports. This minimizes the impact on the environment and avoids disruption to water or road traffic below. In stadiums, post-tensioning allows long clear spans and very creative architecture. Post-tensioned rock and soil anchors are used in tunneling and slope stabilization and as tie-backs for excavations. Post-tensioning can also be used to produce virtually crack-free concrete for water-tanks.

Post-tensioning is a method of reinforcing (strengthening) concrete or other materials with high-strength steel strands or bars, typically referred to as tendons. Post-tensioning applications include office and apartment buildings, parking structures, slabs-on-ground, bridges, sports stadiums, rock and soil anchors, and water-tanks. In many cases, post tensioning allows construction that would otherwise be impossible due to either site constraints or architectural requirements.

FFU synthetic sleepers are manufactured

3. Experimental Investigations

3.1 Class "F" Type Flyash

The burning of harder, older anthracite and bituminous coal typically produces Class F flyash. This flyash is not pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F flyash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can leads to the formation of geopolymer.

3.2 Aggregates

Only tested aggregate should be used. Aggregate should always be obtained from the same source. Shape and size of course aggregate may vary for different deliveries from same crusher. The aggregates shall conform to IS: 383 [11] and the aggregates shall have 30% abrasion and 30% impact value suitable for wearing surfaces when tested in accordance with IS:2386 (Part-IV) [12].

3.3 Activated Solution

The combination of sodium silicate and sodium hydroxide solution can be used as the alkaline liquid. The concentration of sodium hydroxide may vary in the range 8M to 14M however 12 molar solutions is adequate for most applications. The sodium silicate is in the form of a gel. The pallet formed sodium hydroxide is diluted and mixed with sodium silicate is the activator solution for this project. The sodium silicate and sodium hydroxide are taken in the ratio of 2.5.

$$\frac{\text{sodium silicate}}{\text{sodium hydroxide}} = 2.5$$

The ratio between fluid to flyash was fixed as 0.45, since the workability is good.

$$\frac{\text{sodium silicate} + \text{sodium hydroxide}}{\text{flyash}} = 0.45$$

Reactions occur at a high rate when the alkaline liquid contains soluble silicate. The mixed alkaline solution for M50 grade concrete as shown in Fig. 1.

Fig 1: Alkaline Solution

The concrete strength attained more than 50 MPa, it was decided to use geopolymer goncrete for prestressed concrete beams by using post tensioning technique.

3.4 Specimen Details

In this study four beams of size 3200 x 250 x 125 mm were cast (Two conventional concrete and two geopolymer concrete beams). At the time of casting hollow ducts of 60 mm size with grouting provisions were installed for post tensioning operations. The ducts were placed at a constant eccentricity of 40 mm at both ends of the beam, spiral rings of 6 mm diameter at a length of 600 mm was placed. It gave the shear capacity to take care of end anchorage. The details of beam and arrangements are shown in Figs.2 and 3.

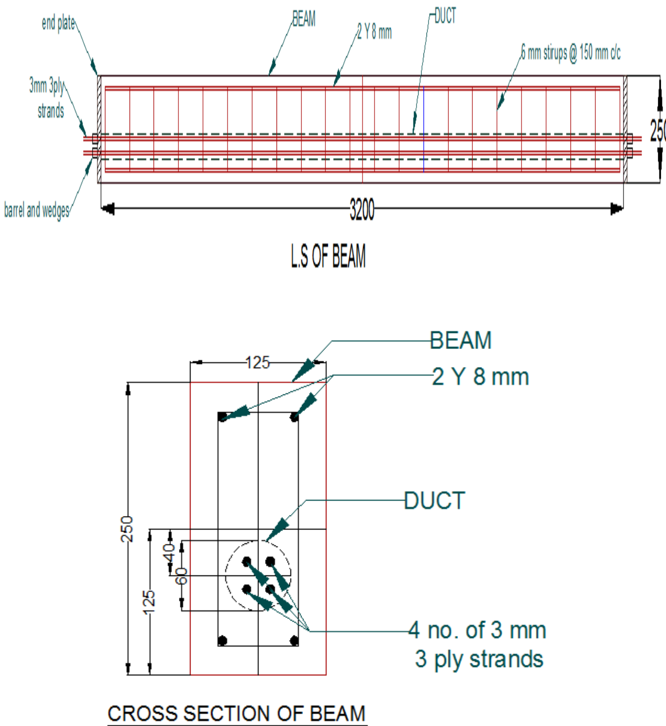


Fig 2: Details of beam

Fig 3: Arrangement of Duct before Casting

3.5 Casting of Prestressed Geopolymer Concrete beam

The flyash and the aggregates were first mixed together in the pan mixer for about 3 minutes. Then the alkaline liquid mixed with super plasticizer (Conplast SP 430) was added with the dry mixes in the pan mixer itself. The workability of the fresh concrete was measured by conducting slump test and was about 50 mm. All the specimens were cast using geopolymer concrete and conventional concrete of grade M50. Each specimen was cast in three layers by using a needle vibrator. The casting process is shown in Fig.4.

Fig 4: Casting of Post Tensioned Beam

3.6 Curing of Geopolymer Concrete

Steam curing substantially assists the chemical reaction that occurs in the geopolymer concrete. Both curing time and curing temperature influence the compressive strength of the concrete. The geopolymer concrete specimens undergoes a steam curing (60ºC) of 24 hours. Before steam curing the concrete specimens were wrapped with polythene papers for the affection hot water into the specimens. The specimen placed inside the steam chamber is shown in Fig.5.

Fig 5: Specimens kept in steam curing chamber

3.7 Post Tensioning of Beams

Compressive forces were induced in a concrete structure by tensioning steel tendons of strands placed in ducts embedded in the concrete. The tendons were installed after the concrete was placed. The strands were properly anchored by end blocks. The end blocks are rigid steel plates of size 125 × 250 mm and thickness of 20 mm as shown in Fig.6.

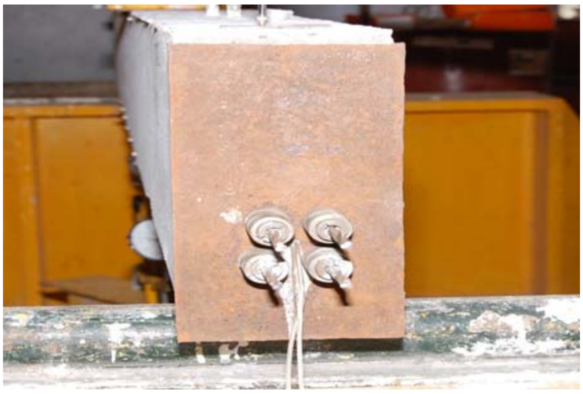


Fig 6: Post tensioned beam with end anchorage

3.8 Grouting

All the beams were grouted manually with cement paste through the holes placed inside the beams.

3.9 Experimental Setup

The beams were tested under two point loading which was monotonically increased. The schematic view and load set up are shown in Figs.7and 8. The load deflection behaviors of post tensioned beam are shown in Fig.9 and 10. From the experimental results, it is found that the flexural behavior of OPC and GPC post tensioned beams are same. The results are presented in Table 1.

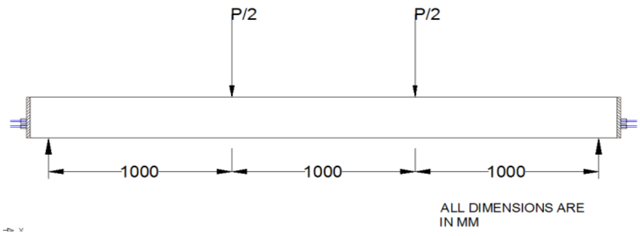


Fig 7: Schematic View of Test Setup

Fig 8: Load setup

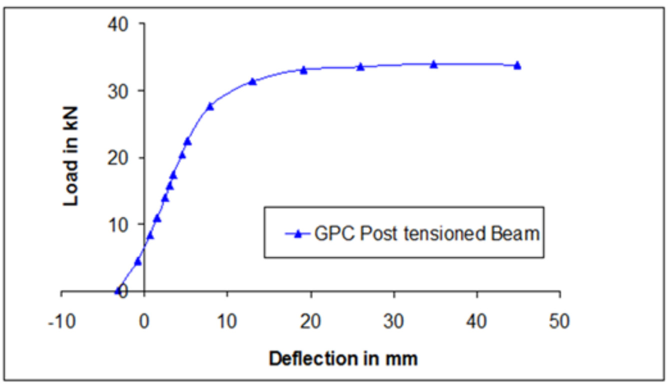


Fig 9: Load - Deflection of GPC Post Tensioned Beam

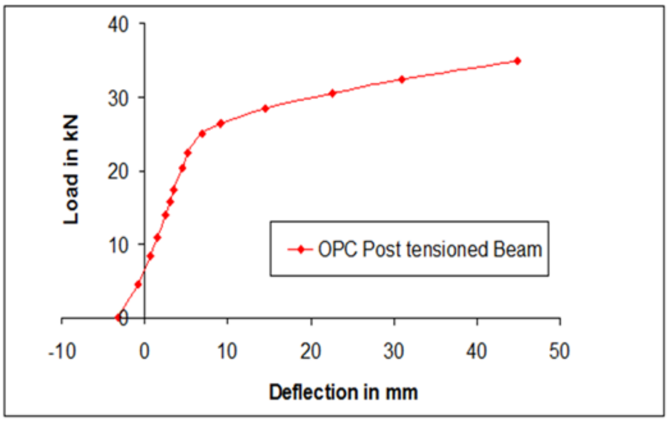


Fig 10: Load – Deflection of OPC Post Tensioned Beam

Table 1: Experimental results

OPC				GPC			
First crack		Yield stage in kN	Ultimate stage in kN	First crack		Yield stage in kN	Ultimate stage in kN
Load in kN	Deflection in mm			Load in kN	Deflection in mm		
15.00	20.00	32.50	80.00	20.00	21.00	40.00	90.00

The crack pattern of the beam is shown in Fig.11. It is found that all beams were failed by flexure only. None of the beam exhibit pre mature or brittle failure.

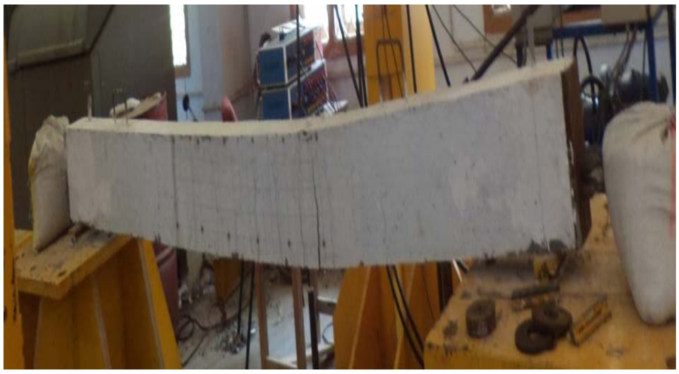


Fig 11: Crack Pattern of GPC Post Tensioned Beam

4. Conclusion

This work represents the static behavior of post tensioned geopolymer concrete beam. The binder in this concrete was low calcium flyash. A mixture of sodium hydroxide and sodium silicate was used as the activator for the polymerization process. Based on the experimental work the following conclusions are drawn.

(i) As the age of geopolymer concrete increases the strength of concrete increases.

(ii) The initial cracks were obtained by visual examination only. The initial cracks were obtained at 15 kN for conventional concrete, whereas the geopolymer initiates the first crack at 20 kN.

(iii) The flexural behaviour of post tensioned conventional concrete beam and geopolymer concrete beams are similar. The maximum ultimate load from experimental work for both geopolymer and conventional concrete was almost same.

(iv) The geopolymer concrete beam deflects more than the ordinary concrete, nearly 18% more deflection at given load level.

(v) From the experimental work it is conclude that the geopolymer concrete behaves as similar to conventional concrete. From the report was identified several economic benefits of using geopolymer concrete. Geopolymer concrete is 25% economically beneficial than ordinary concrete.

(vi) The cracks of the concrete beams occurs at the centre are well distributed in flexure zone only. None of the beam exhibit shear failure.

(vii) From the experimental work it is conclude that the behavior of geopolymer concrete is similar to conventional concrete.

5. References

1. Lloyd N.A and Rangan B.V, Geopolymer Concrete with Flyash. *Second International Conference on Sustainable Construction Materials and Technologies,* 2010; 3:1493-14504.
2. Djwantoro Hardjito, Steenie E. Wallah, Dody M. J. Sumajouw, and Vijaya Ranga B, Flyash Based Geopolymer Concrete, *ACI Material Journal*, 2004; 101:467- 462.
3. Palomo A, Grutzeck M.W, Alkali-activated fly ashes a Cement for the Future. *Cement and Concrete Research,* 1999; 29:1323-1329.
4. Davidovits J, Geopolymers: Inorganic Polymeric New Materials, *Journal of Thermal Anal,* 1991; 37:1633-1656.
5. Davidovits J, High Alkali Cement for 21st Century Concretes Technology: Past Present and Future, *ACI Detroit, USA,* 1994, SP, 144(19):383-397.
6. Lloyd N and Rangan B.V, Geopolymer Concrete – Sustainable Cementless Concrete, *Proceedings of Tenth ACI International Conference on Recent Advances in Concrete Technology and Sustainability,* 2009; 7: 33-53.
7. Hardjito D and Rangan B.V, Development and Properties of Low Calcium Flyash-Based Geopl oymer Concrete Research Reprot GCI, Faculty of Engineering Curtin University of Technology, Perth;2005.
8. Malhotra VM, High Performance High-Volume Fly Ash Concrete, *ACI Concrete International*, 2002; 24(7):1-5.
9. Rangan B, V, and Wallah S.E, Low – Calcium Fly Ash-Based Geopolymer Concrete: Long- Term Properties, Research Report GC2, Faculty of Engineering Curtin University of Technology, Perth, 2006.
10. Kunal kupwade – patil and Erez Allouche, Effect of Alkali Silica Reaction in Geopolymer concrete, *World of coal ash conference,* May, 9-12, Denver, CO, USA, 2011.
11. IS 383:1970 Specification for Coarse and Fine Aggregates from Natural Sources for Concrete.
12. IS 2386-1: 1963 Methods for Test for Aggregate for Concrete.