Flexural Behaviour of Geopolymer Concrete Beams under Cyclic Loading

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Abstract : The aim of the research work presents the result of experimental and analytical studies of the compression cyclic behaviour of geopolymer concrete beams. In this study the conventional concrete for M40 grade was performed. Then geopolymer concrete of M40 grade trail mix design was finalized. The fluid to fly-ash ratio was fixed as 0.50. The ratio of sodium silicate to sodium hydroxide was 2.5. The concentration of sodium is 8 molar, the compressive and preliminary test are to be carried out for geopolymer concrete. A total of four beams of size 125mm x 250mm and a length of 3200mm to be casted. Two beams of geopolymer concrete with fluid to fly ash ratio as 0.50, remaining two beams of conventional concrete. All the beams are to be tested under compression cyclic loading and the results provides the comparison between the geopolymer concrete beams and conventional beams.

***Index Terms* – geopolymer concrete, fly ash, reinforced concrete, cyclic flexural load**

I. INTRODUCTION

Cement is major industrial commodity that manufactured commercially in over 120 countries. In fact twice as much concert is used in construction around the world than the total of all other building materials. The environmental issues associated with the production of OPC are well known. Among the green house carbon dioxide contributes 65%of global warming. The cement industry is responsible for 6% of all carbon dioxide emission, because of production of one ton of Portland cement emit approximately one ton of carbon dioxide into the atmosphere. Cement production is also highly energy-intensive, after steel and aluminium. Although the use of Portland cement is still unavoidable several effort are in progress to supplement the use of Portland cement in concrete in order to global warming.

In blended cement concrete, various industrial by product such as fly ash, slag, silica etc., are used as mineral admixture 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 fly ash, ,rise husk ashes are particularly important resource to supplement the Portland cement. On the other hand, India produce about 70 million tons of coal as per year from about 200 million of coal per year for electric power generation. Fly ash is one of the promising pozzolanic materials that can be blended with Portland cement for the production of durable concrete. The geopolymer mortar / concrete is produce by totally replacing the ordinary Portland cement OPC by fly ash. Consumption of fly ash in the manufacture of geopolymer is an important strategy in making concrete more environmental friendly.

Geopolymer materials represent an innovative technology that is generating considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability.in contrast to Portland cement, most geopolymer systems rely on minimally processed natural materials or industrial by produce to provide the binding agents. Since Portland cement is responsible for upward of 85% of the energy and 90% of the carbon dioxide attributed to a typical ready-mixed concrete (Marceau etal-.2007), the potential energy and carbon dioxide saving through the use of geopolymer can be considerable. Consequently, there is growing interest in geopolymer application in transportation infrastructure.

High performance geopolymer cement are used commercially elsewhere in the world due to superior performance top Portland cement. These cements are stronger, fireproof, and waterproof. They bond strongly to most materials, do not appreciably expand or contract, are foam able, and resistant to salts, acids and alkalis. They also require less energy to make and are more environmentally benign. Additionally, geopolymer cement can be produced in ways that make it useful for addressing a range of everyday and extreme challenges. Geopolymers require 30% to 60% less energy to make 9, 10 and about less carbon dioxide into the atmosphere.

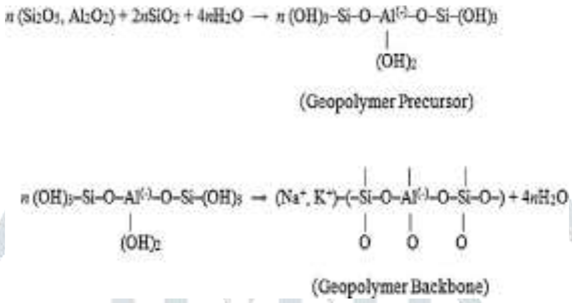
Geopolymer are inorganic polymers, the chemical composition of the geopolymer material is similar to natural zeolite materials, but the microstructure is instead of crystalline. The polymerization process involves a substantially fast chemical reaction under alkaline condition on si-al mineral that result in a three dimensional polymeric chain and ring structure consisting Si-O-Al-O bonds.

II. GEOPOLYMER CONCRETE

Davidovits 1994 proposed that an alkaline liquid could be used to react with the silicon (Si) and aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binder. Because chemical reaction that take place in this case is a polymerization process, he coined the term Geopolymer to represent these binder. Geopolymer concrete is concrete which does not need any Portland cement in its production. Geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer concrete.

The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite, clay, etc. Alternatively by-product materials such as fly ash, silica fume, slag, rice -husk, red mud, etc. could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquid are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geo polymerization is a combination of sodium hydroxide (NAOH) or potassium hydroxide (KOH) and sodium silicate.

Geopolymer is used as the binder, instead paste, to produce concrete. The geopolymer paste binds the loose coarse aggregate, fine aggregates and other un-react materials together to form the geopolymer concrete.as in the Portland cement concrete, the aggregates occupy the largest volume, that is approximately 75% to 80% by mass, in geopolymer concrete. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that results in three dimensional polymeric chain a ring structure consisting of Si-O-Al bonds. The schematic formation of geopolymer material can be shown as described by the following equations.



The last term in the equation 2 reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water expelled from the geopolymer matrix during curing and further drying periods, leaves behind Nano pores in the matrix, which provide benefits to the performance of geopolymers. The structure of geopolymer as below reaction is called the polysialate reaction which produces geopolymer.

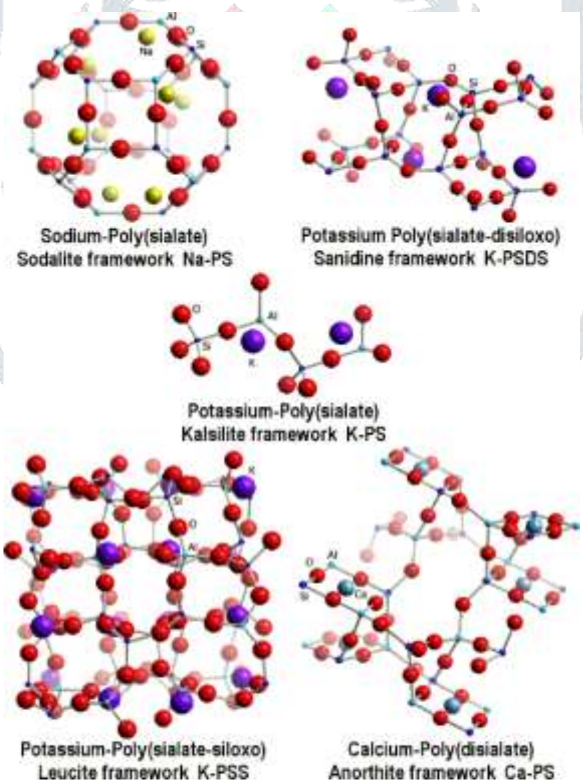


Fig.1 Framework of Geopolymer Materials

III. LITERATURE SURVEY

Silva A, Silva F J and Thaumaturgo C has studied the fatigue behaviour of geopolymer concrete. The geopolymer cement concrete was developed through adequate portions of geopolymer components. Its characteristics were compared with Portland cement concrete (PCC), through of the establishment of some parameters of design, as consumption of binder, water/aggregate ratio and mortar content. The concrete mechanical performance was evaluated with emphasis to the fatigue behavior, were tested the effects of different tensile strength maximum (increasing and decreasing). The results of fatigue tests had shown that GCC presents a better performance when compared to PCC. Its fatigue strength was 15% higher than that of PCC, when 70% of rupture tension of the concrete in static bending was applied tension of about 80% static bending resulted 96% increases, when compared to GCC.

Lloyd N A and Rangan B V has studied geopolymer concrete with fly ash. Geopolymer concrete results from the reaction of a source material that is in silica and alumina with alkaline liquid. A summary of the extensive studies conducted on fly ash-based geopolymer concrete is presented. Geopolymer concrete has excellent properties and is well-suited to manufactures precast concrete product that are needed in rehabilitation and retrofitting of structures after a disaster. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined. Current research is focusing on the durability of geopolymer in aggressive soil condition and marine environments.

Vijayarangan B, Djwantorohardjito has studies on fly ash based geopolymer concrete. This paper presents test data on fly ash -based geopolymer concrete. The paper covers the materials and the mixture proportions, the manufacture process, the fresh and hardened state characteristics, the influence of various parameters on the fresh and hardened state concrete, the utilization of the material in structural members, and the long term behavior. The paper presented a summary of the extensive studies carried out by the authors on the fly ash-based geopolymer concrete. Low calcium fly ash is used as the source material, instead of the Portland cement, to make concrete. Fly ash- based geopolymer concrete has excellent compressive strength and is suitable for structural applications. The elastic properties of hardened concrete and behavior 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 fly ash-based geopolymer concrete structural members.

Vijai K, Kumutha R and Vishnuram B G studied the effect of types of curing on the strength of geopolymer concrete. This paper presents results of an experimental study on the density and compressive strength of geopolymer concrete. The experiments were conducted on fly ash based geopolymer concrete by varying the types of curing namely ambient and hot curing. The ratio of alkaline liquid to fly ash was fixed as 0.4. For all the samples the rest period was kept as 5 days. For hot curing, the temperature was maintained at 60^0C for 24 hours in hot air oven. The compressive strength test was conducted for each sample and the results showed that there is an increase in compressive with the increase ambient cured specimens. For hot cured sample the increase in compressive strength with age was very less as compared to that of specimens subjected to ambient curing. The density of geopolymer concrete was around 2400 kg/m^3 which is equivalent to that of conventional concrete. The compressive strength of hot cured concrete is much higher than that ambient cured concrete.

Nigro E, Di Ludovico M and Bilotta A has discussed on the external bonding of fiber reinforced polymer composites has become a popular technique used worldwide for strengthening existing reinforced concrete structures. A key factor the effectiveness of such technique is the bond of FRP reinforcement to the concrete substrate; numerous experimental works have been carried out to investigate such aspect. In respectively, have been used to determine the maximum force which can be carried out by external reinforcement, the bond stress-slip relationship and the fracture energy of the interface law.

However, experimental data concerning cyclic tests on both FRP sheet and plate applied on concrete specimens are still lacking. Thus a series of single shear test under both monotonic and cyclic actions, without inversion of sign, have been performed on concrete prismatic specimens (characterized by a low compressive strength in order to simulate the application on existing structures to be strengthened) reinforced with CFRP sheets and plates. In order to evaluate and compare the influence of cyclic external on the bonding behaviors of both sheets plate reinforcement the monotonic and cycle tests have been reported and analyzed in the paper in term of force-displacement curves, axial strain and shear stresses recorded during tests along the FRP reinforcement.

IV. EXPERIMENTAL INVESTIGATION

4.1. General

In this thesis work the cyclic behavior of conventional concrete and geopolymer concrete beams are been compared. The compressive strength of conventional concrete and geopolymer concrete was selected as M40.

4.2. Materials of Geopolymer concrete

The materials geopolymer concrete consists of

a. Low calcium fly ash
b. Aggregates
c. Activator solution

a. Low calcium fly ash

Fly ash particles are almost totally spherical in shape. The pozzolanic reaction between fly ash and lime generates less heat, resulting in reduced thermal cracking when fly ash is used to replace Portland cement. Fly ash also contains environmental toxins in significant amounts, including arsenic, barium, beryllium, boron, calcium, chromium, copper, Fluorine, lead, manganese, nickel, selenium, strontium, thallium, vanadium and zinc. The analysis of fly ash particle in given below. Geopolymer concrete can be manufactured by using low calcium fly ash (ASTM class F). These type of fly ash has silicon and aluminum oxides about 80% by mass. The calcium content is less than 5%. The carbon content of the fly ash is less than 2%. The particle size distribution reveals that 80% of the fly ash was smaller than 50 micron. The presence of calcium in high amounts may interfere with the polymerization process and alter the microstructure.

b. Aggregates

The shape of the aggregate affects the workability of concrete. As per 383-1970 the fine aggregate of specific gravity is 2.64, confined zone II is been used. For attaining more strength to concrete 12mm sieved coarse aggregate are used in this project. The details of sieve analysis and specific gravity of fine and coarse aggregate of used materials are mentioned in the Table No 1 to 4.

c. Activator 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 to14M, however 8 molar solution is adequate for most applications. The sodium silicate is in the form of a gel. The pellet formed sodium hydroxide is diluted and mixed with sodium silicate is the activator solution for this project. The sodium silicate and hydroxide are taken in the ratio of 2.5.

Sodium silicate / sodium hydroxide = 2.5

The ratio between fluids to fly ash was fixed as 0.45, since the workability is good.

(Sodium silicate + Sodium hydroxide) / Fly ash = 0.45

C. Specimen details

In this thesis work 4 beam of size 125mm x 250mm x 3200mm were used (two conventional concrete and two geopolymer concrete). All the beams are designed as under reinforced beams, 2 number of 16mmdiameter bars as bottom reinforcement and two numbers of 10mm bars as the top reinforcement. 8mm diameter of bars as stirrups ware fastened as the shear reinforcement at 150mm c/c. the design of the typical beam is shown in Figure 2.

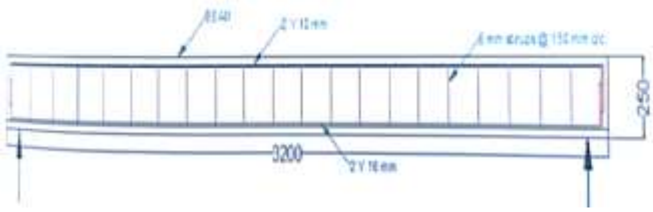


Fig.2 Longitudinal Section of Beam

D. Mixing, Casting and Compaction

The fly ash and the aggregate were first mixed together in the pan mixer for about 3 minutes. Then the alkaline liquid was the added with the dry mixer in the pan mixer itself. The workability of the fresh concrete was measured by conducting slump test and is about 6mm. All the specimens were cast using geopolymer concrete and conventional concrete. Cubes of size 150 x 150 x 150 mm and cylinder of size 150mm x 300mm were casted to determine the compressive strength. Each specimen was casted in three layers by compacting manually as well as by using vibrator table. The specimens are shown in Figure 3.

Fig.3 Casting of Geopolymer Concrete Beams

E. Curing of Geopolymer Concrete

Steam curing substantially assists the chemical reaction that occurs in the geopolymer concrete. Both curing time and curing temperature influencing the compressive strength of the concrete. The geopolymer concrete specimens undergoes a steam curing 60^0C of 24 hours. The ordinary concrete beams are cured in curing as 28 days.

F. Test producer

The test setup used in this project load was applied by two point load method at the on third of the beam from both sides. The load range was set between P_{max} to p_{min}. Where P_{max} is 85 % of the ultimate load and p_{min} is 10% of the $P_{max.}$ When cyclic load is applied at one third distance of the span of the beam was deflected and comes back to its original position. In this work the load range is fixed at the tension zone only. The maximum and minimum load was fixed below the zero level or neutral level of the beam. The P_{max} and p_{min} value are fixed on the basis of the literatures. The experimental work setup is shown in Figure 5.

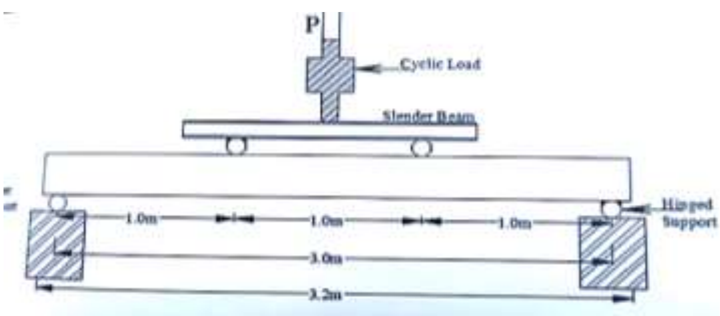


Fig.4 Schematic View of Test Setup

Fig.5 Experimental Test Setup

V. MATERIAL TESTS

5.1 Results of various tests performed on materials

Table 1 Sieve Analysis of Fine Aggregate

S.No	IS Sieve Size	Aperture size	Weight retained in (g)	% of weight retained	Cumulative % of weight retained	Cumulative % of passing
1	4.75	4.75	6.5	0.65	0.65	99.35
2	2.36	2.36	8.5	0.85	1.50	98.50
3	1.18	1.18	53.5	5.35	6.85	93.15
4	600 µ	0.6	408.5	408.5	47.7	52.3
5	300 µ	0.3	371.5	37.15	84.85	15.15
6	150 µ	0.15	141	14.1	98.95	1.05
7	75µ	.075	10	1.0	99.95	0.05p

Table 2 Specific Gravity of Coarse Aggregate

S.No	Empty weight (W1)	Weight of sample + Weight of bottle (W2)	Weight of sample + Weight of bottle + weight of water (W4)	Weight of bottle + Water (W4)	Specific Gravity
1	56	162	263	198	2.58
2	56	163	263	198	2.55
3	56	162	264	198	2.65
Average value					2.62

Table 3 Specific Gravity of Fine Aggregate

S.No	Empty weight (W1)	Weight of sample + Weight of bottle (W2)	Weight of sample + Weight of bottle + Weight of water (W4)	Weight of bottle + Water (W4)	Specific Gravity
1	668	1258	1847	1474	2.72
2	668	1262	1846	1474	2.70
3	668	1206	1809	1474	2.65
Average value					2.62

Table 4 Specific Gravity of Cement

S.No	Empty weight (W1)	Weight of sample + Weight of bottle (W2)	Weight of sample + Weight of bottle + Weight of water (W4)	Weight of bottle + Water (W4)	Specific Gravity
1	56	117	208	167	3.05
2	56	116	207	167	3.00
3	56	117	209	167	3.21
Average value					3.14

VI. INPUT DATA

6.1 Using stroke control (Displacement control)

P_{max} = 85 % of P_u

P_{min} = 10% of P_{max}

P_u = 53.9 KN

$P_{max=}$ 45.80 KN and Max. Deflection = 41.6mm

P_{min} = 4.80 KN and Deflection = 4.13mm

Amplitude = 20.61 mm

Frequency = 0.5 Hz

6.2 Design of beam

Size of beam = 125mm x 250mm

Length of beam = 3200mm

fck = M40

fy =Fe 415

Clear cover 25mm

A_{st} = 524.07 mm2

Using 2 no's of 16mm diameter bars.

X_u = 80.6mm

$X_{u\ max}$ = 105mm

Min A_{st} = 204.16mm^2

Therefore provide 6mm diameter bars at 150 mm c/c.

6.3 Concrete Mix Design

Mix design for conventional concrete

Size of aggregate = 12.5mm

Minimum cement content = 320 kg/m^3

Maximum w/c ratio = 0.40

Type of exposure = Severe

Degree of quality control = Good

Maximum cement content 450 kg/m^3

Specific gravity coarse aggregate = 2.78

Specific gravity fine aggregate = 2.62

Specific gravity cement = 3.14

Target strength = 48.25 N/mm^2

Mix ratio = 1: 2.29: 2.13: 0.40

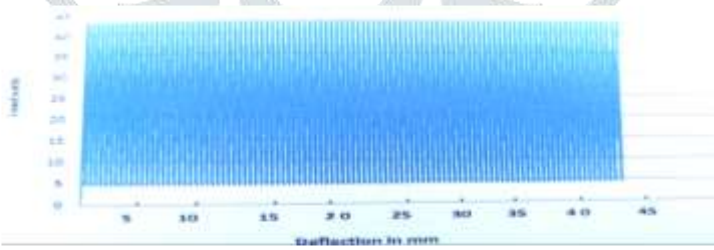


Fig.6 Load vs Deflection Curve

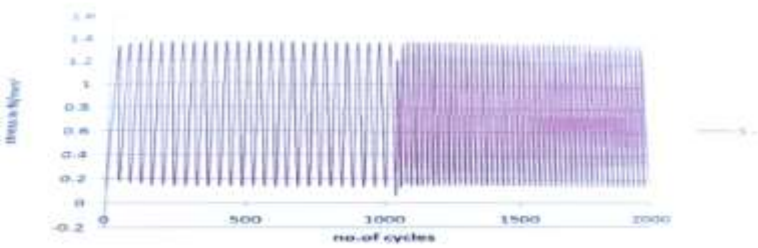


Fig.7 S-N Curve

Fig.8 Deflection of GPC Beams under Cyclic Loading

VII. RESULT AND DISCUSSIONS

This project work represents the flexural behavior under compression cyclic loading of geopolymer concrete. The binder in this concrete was low calcium fly ash. A mixture of sodium hydroxide and sodium silicate was used as the activated for the polymerization process. Based on the experimental work the following conclusions are drawn.

a) The mix design for geopolymer concrete grade of M40 was obtained in the ratio 1: 2.12: 2.31: 0.40
b) As the age of geopolymer concrete increases the strength of conventional concrete.
c) The geopolymer concrete beams take more cyclic 2714 cycles than the conventional 2316 for failure of beams.
d) The S-N curve for both conventional concrete and geo polymer concrete little variation.
e) From the experimental works it was concluded that the behaviour of geopolymer concrete as an elastic materials is similar to conventional concrete.

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