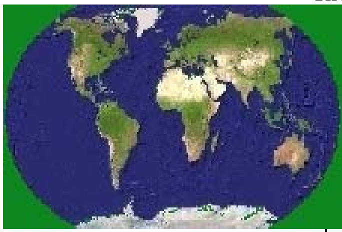

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R. Balamuralikrishnan
Senior Lecturer, Department of Built and Natural Environment, Caledonian College of Engineering, Sultanate of Oman.

Correspondence:
R. Balamuralikrishnan
Senior Lecturer, Department of Built and Natural Environment, Caledonian College of Engineering, Sultanate of Oman.

Fatigue behaviour of geopolymer concrete beams

R. Balamuralikrishnan

Abstract
The aim of the research work is to presents the result of experimental studies concerning the fatigue behaviour of geopolymer concrete beams. In this study the fly ash based geopolymer mix design was obtained for M40 grade concrete. The fluid to fly ash ratio was fixed as 0.45. The ratio of sodium silicate to sodium hydroxide was 2.5 and the concentration of solution is 14 molar. The preliminary tests were carried out for the geopolymer concrete and optimizing the mix design. A total of four beams of size 125 × 250 × 3200 mm were cast and tested in the laboratory. All the beams were tested under fatigue loading (compression cyclic) with help of hydraulic actuator. Comparison is made between reinforced concrete and geopolymer concrete and results are presented.

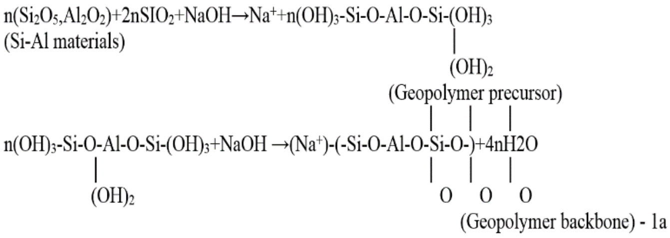
Keywords: Geopolymer, Flyash, Activator solution, Fatigue behaviour, Stream curing, S-N curve.

1. Introduction
Cement is a major industrial commodity that is 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 greenhouse gases carbon dioxide contributes 65% of global warming. The cement industry is responsible for about 6% of all carbon dioxide emissions, because of production of one ton of Portland cement emits approximately one ton of carbon di oxide into the atmosphere. Cement production is also highly energy- intensive, after steel and aluminum. Although the use of Portland cement is still unavoidable several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues [1]. In blended cement concrete, various industrial by products such as fly ash, 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 fly ash, 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. 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 [2].

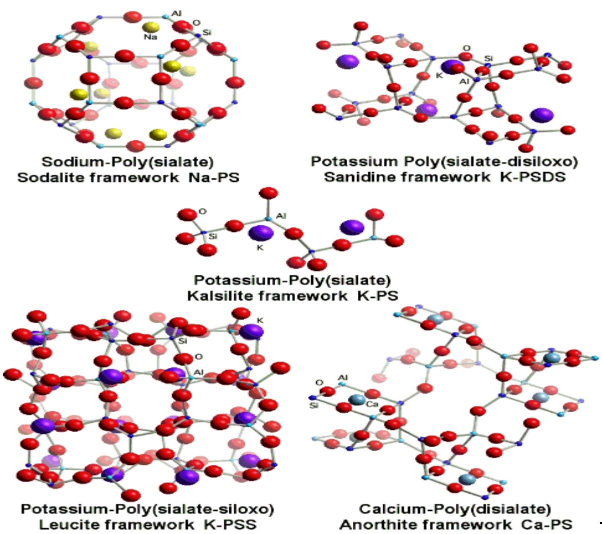
A tone of Portland cement production involves emission of about a tone of CO_2 which is a green house gas causing global warming. Among the greenhouse gases, CO_2 contributes about 65% of global warming [3].

Geopolymer materials represent an innovative technology that is generating considerable interest in the construction industry, particularly in light of the on-going emphasis on sustainability. In contrast to Portland cement, most geopolymer systems rely on minimally processed natural materials or industrial by products to provide the binding agents. Since Portland cement is responsible for upward of 85 percent of the energy and 90 percent of the carbon dioxide attributed to a typical ready-mixed concrete [4], the potential energy and carbon dioxide savings through the use of geopolymers can be considerable. Consequently, there is growing interest in geopolymer applications in transportation infrastructure.

Geopolymers are inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolite materials, but the microstructure is amorphous instead of crystalline. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Davidovits [5] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. Geopolymer concrete is concrete which does not utilize 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 polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a 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 1a.



The last term in the equation 1b 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. This below reactions called the polysialite reaction which produces geopolymers.



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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 [6]. 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 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 fly ash-based geopolymer concrete structural members [7].

2. Experimental Investigations

The materials of geopolymer concrete consists of

- Low calcium fly ash
- Aggregates
- Activator solution

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. Flyash also contains environmental toxins in significant amounts, including arsenic, barium, beryllium, boron, calcium, chromium, cobaly, copper, fluorine, lead, manganese, nickel, selenium, strontium, thallium, vanadium and zinc. The SEM analysis of flyash particles is given below. Geopolymer concrete can be manufactured by using low calcium fly ash (ASTM class F).these types of fly ash has silicon and aluminium 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 µm. the presence of calcium in high amounts may interfere with the polymerization process and alter the microstructure. The SEM photocopy of flyash is shown Fig. 1.

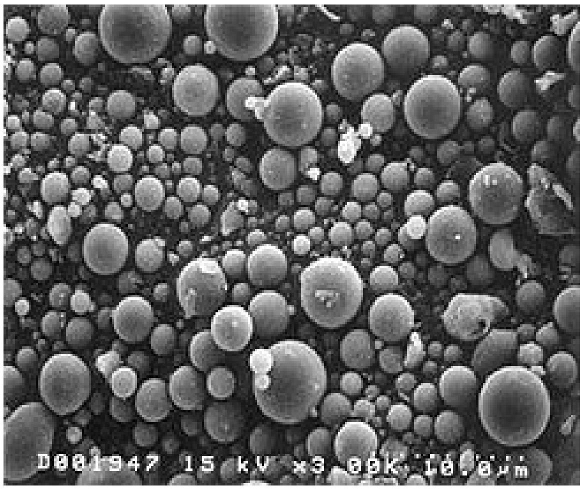

Fig 1: Scanning Electron Microscope (SEM): Fly ash particles

2.1 Aggregates

The shape of the aggregate affects the workability of concrete. As per IS 383-1970 [8] the fine aggregate of specific gravity is 2.64, confined zone II is been used. For attaining more strength to concrete 12 mm sieved coarse aggregate are used in this project.

2.2 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 to 14M, however 8 molar solution is adequate for most applications [9]. 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.

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

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

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

The mixed alkaline solution for M40 is shown in Fig.2.

Fig 2: *Alkaline solution*

2.3 Specimen Details

In this study work 4 beams of size 3200 x 250 x 125 mm were used (Two conventional concrete and two of geopolymer concrete). All the beams are designed as under reinforced beams, 2 numbers of 16 mm CTD bars as bottom reinforcement and 2 numbers of 10 mm CTD bars as the top reinforcement. 8 mm dia stirrups were fastened as the shear reinforcement at 150 mm c/c. [10]. The design of the under reinforced beam is given in appendix A. The longitudinal section of the typical beam is shown in Fig.3.

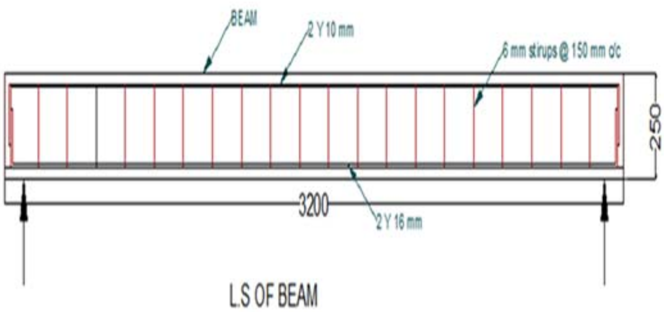

Fig 3: Longitudinal section of beam

2.4 Mixing, Casting And Compaction

The fly ash and the aggregates were first mixed together in the pan mixer for about 3 minutes. Then the alkaline liquid was the added with the dry mixers in the pan mixer itself. The workability of the fresh concrete was measured by conducting slump test. All the specimens were cast using geopolymer concrete and conventional concrete. Cubes of sizes 100 x 100 x 100 mm and cylinders of size 100 x 200 mm and 150 x 300 mm were cast to determine the compressive strength. Each specimen was cast in three layers by compacting manually as well as by using vibrator table. The cast specimens are shown in Fig. 4.

Fig 4: Casting of geopolymer concrete

2.5 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. The ordinary concrete beams are cured in curing chamber for 28 days. Specimens placed in the curing chambers are shown in Fig.5.

Fig 4.5: Specimens placed in steam curing chamber

2.6 Test Programe

The beams are tested under fatigue loading with hydraulic actuator in the form of compression cyclic loading condition.

Fatigue is the condition whereby a material cracks or fails as a result of repeated (cyclic) stresses applied below the ultimate strength of the material. A perusal of the broken parts in almost any scrap yard will reveal that the majority of failures occur at stresses below the yield strength [11]. This is a result of the phenomenon called fatigue which has been estimated to be responsible for up to 90% of the in-service part failures which occur in industry. If a bar of steel is repeatedly loaded and unloaded at say 85% of its' yield strength, it will ultimately fail in fatigue if it is loaded through enough cycles. Also, even though steel ordinarily elongates approximately

30% in a typical tensile test, almost no elongation is evident in the appearance of fatigue fractures. Basic fatigue testing involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at various values of constant amplitude alternating stress levels. The data are condensed into an alternating Stress, S, verses Number of cycles to failure, N, curve which is generally referred to as a material's S-N curve. As one would expect, the curves clearly show that a low number of cycles are needed to cause fatigue failures at high stress levels while low stress levels can result in sudden, unexpected failures after a large number of cycles. Fatigue failures generally involve three stages:

- Crack Initiation,
- Crack Propagation, and
- Fast Fracture

Fatigue failures often occur quite suddenly with catastrophic (disastrous) results and although most insidious for metals, polymers and ceramics (except for glasses) are also susceptible to sudden fatigue failures. Fatigue causes brittle like failures even in normally ductile materials with little gross plastic deformation occurring prior to fracture. The process occurs by the initiation and propagation of cracks and, ordinarily, the fracture surface is close to perpendicular to the direction of maximum tensile stress. Basic fatigue testing involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at various values of constant amplitude alternating stress levels. The data are condensed into an alternating Stress, S, verses Number of cycles to failure, N, curve which is generally referred to as a material's S-N curve. As one would expect, the curves clearly show that a low number of cycles are needed to cause fatigue failures at high stress levels while low stress levels can result in sudden, unexpected failures after a large number of cycles.

Fatigue is a process of progressive structural change in a material subjected to transient loads, stresses or strains. Fatigue strength is defined as the maximum transient stress range (*S*) that may be repeated without causing failure for a specified number of loading cycles (*N*). The stress range is defined as the algebraic difference between the maximum and the minimum stress in a stress cycle: $S = f_{max} - f_{min}$; that is: the transient stress. Most ferrous materials exhibit an 'endurance limit' or 'fatigue limit' below which failure does not occur for an unlimited number of cycles, *N*. In general, the concrete material fatigue performance exceeds that of the steel and is not considered in design.

The *S-N* approach requires numerous fatigue test data points and exhibits considerable scatter and therefore numerous repeated tests are needed to develop the 'best-fit' relationship that describes the fatigue behaviour of the material with a reasonable confidence level. There has been a significant amount of research studying fatigue of reinforcing steel and multiple empirical equations have been developed to describe its behaviour. Most correspond to the same general form of the equation 1c.

$Sm \times N = k$ ---1c

In this work the load range was set between P_{max} to P_{min} whrere P_{max} is 75 % of the ultimate load and P_{min} is 10% of the P_{max}. Cubes and cylinders of geopolymer concrete are tested in hydraulic compression testing machine in accordance with Indian standards. Specimens of cubes of size 100x100x100 mm and cylinders of size 100x200 mm are used for determining the compression strength. The schematic view of test setup is shown in Fig.6.

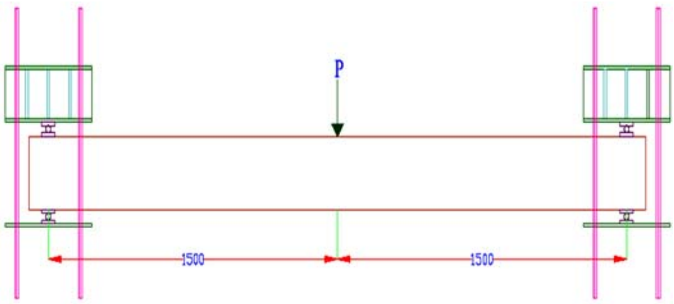

Fig 6: Schematic view of test setup

2.7 Experimental Setup

The test setup used in this thesis was single point load placed at the centre of the beam the load range was set between P_{max} to P_{min} whrere P_{max} is 75% of the ultimate load and P_{min} is 10% of the $P_{max.}$ when the cyclic load is applied at the centre, 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} values are fixed on the basis of the literatures. The experimental work setup is shown in Fig. 7.

Fig 7: Experimental test setup

P_{max} = 75 % of P_u
P_{min} = 10% of P_{max}
Where, P_{max} = maximum load applied on the beam
P_{min} = minimum load applied on the beam
P_u = ultimate load

3.0 Results and Discussion

The fatigue test was carried out for both conventional and geopolymer concrete beams. The beams were subjected compression cycles. The conventional concrete beams failed at 1151 cycles and geopolymer beams failed at 1364 cycles.

Where,
P_u = 53.9 kN
P_{max} = 40.4 kN
P_{min} = 4.04 kN
Amplitude = 18.18 kN
Frequency = 0.5 Hz are input data used for the testing.

The load vs deflection curves for geopolymer concrete and conventional reinforced concrete are shown in Figs.8 and 9.The load vs number of cycles curve for geopolymer concrete and conventional reinforced concrete are shown in Figs.10 and 11.The S – N curve for geopolymer concrete and conventional reinforced concrete are shown in Figs.12 and 13.

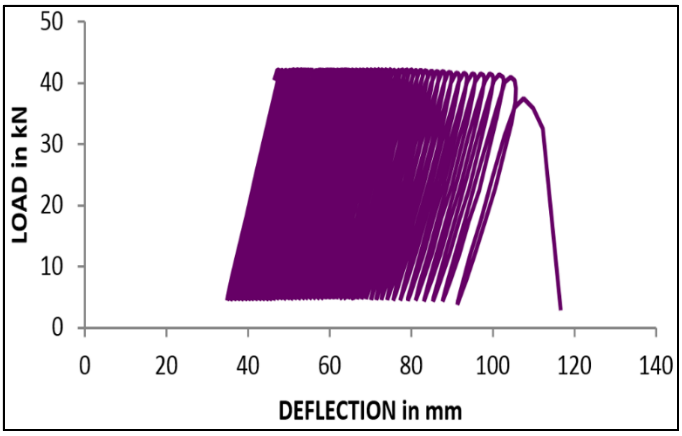

Fig 8: Load vs deflection curve for conventional concrete

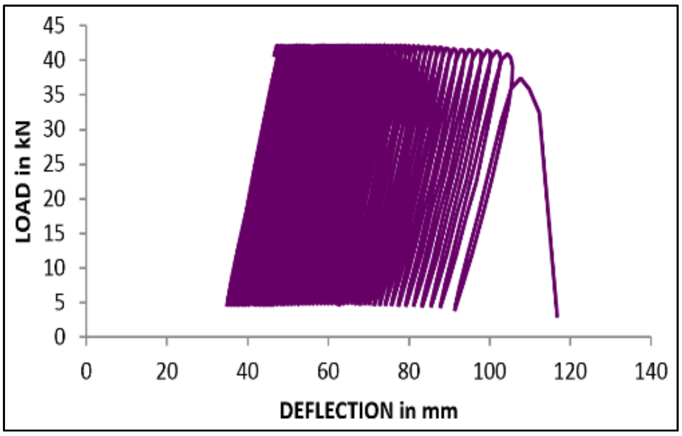

Fig 9: Load vs deflection curve for geopolymer concrete

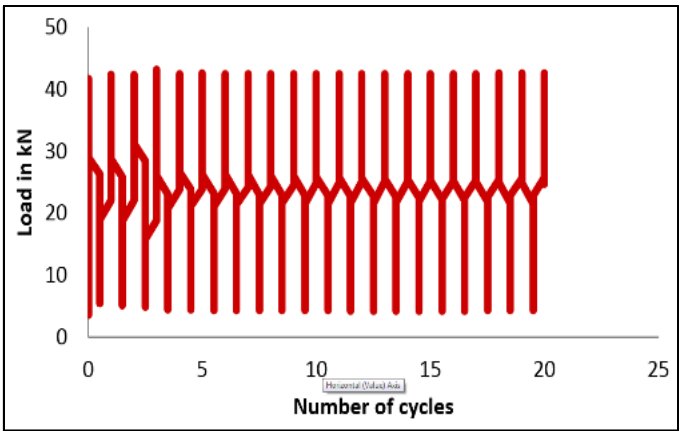

Fig 10: Load vs. no. of cycles for normal concrete

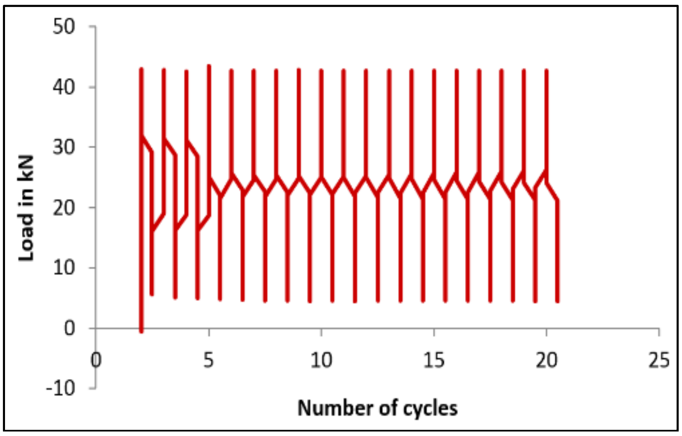

Fig 11: Load vs. no. of cycles for goepolymer concrete

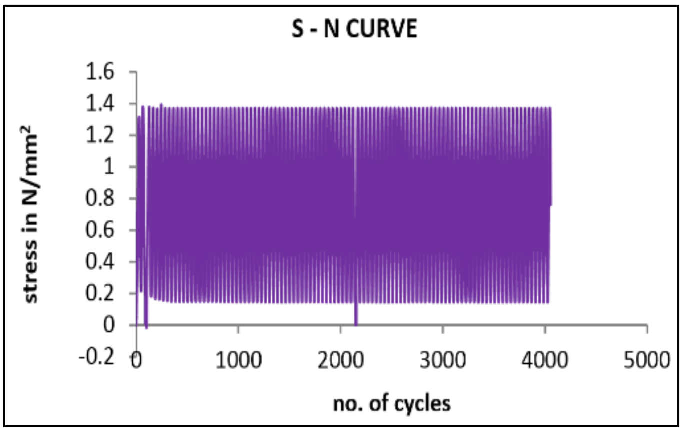

Fig 12: S - N curve for conventional concrete

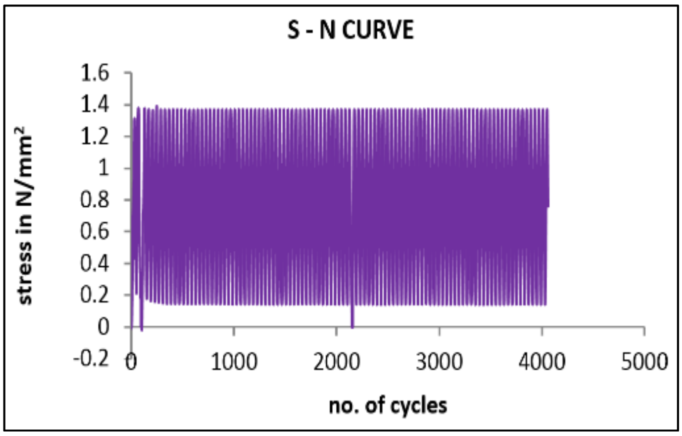

Fig 13: S - N curve for geopolymer concrete

The failure pattern of beams is shown in the Fig. 14.

Fig 5.7: Failure pattern of conventional concrete beam

4. Conclusions

This work represents the fatigue behaviour under compression cyclic loading of geopolymer concrete. 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.

- The mix design for geopolymer concrete grade of M40 was obtained in the ratio 1 : 1.4 : 2.65: 0.45
- As the age of geopolymer concrete increases the strength of concrete increases.
- The initial cracking of conventional reinforced beams occurred at 103 cycles and for the geopolymer concrete was 128 cycles.

- The numbers of cycles for the fatigue failure for geopolymer concrete are lesser than the conventional reinforced concrete beams, nearly 15%.
- The geopolymer concrete takes more fatigue loads 1332 cycles than the conventional concrete beams 1151 cycles.
- The S–N curve for both conventional reinforced and geopolymer concrete is similar.
- The cracks of the concrete beams occurs at the centre were well distributed in flexure zone only. None of the beam exhibit shear failure.
- From the experimental work it is conclude that the behavior of geopolymer concrete is similar to conventional concrete.

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