Numerical Study on Flexural Behavior of Alkali-activated Slag Concrete Beam by ANSYS

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ABSTRACT

Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate-bearing materials with a caustic activator, such as fly ash or slag from iron and metal production. It can be a suitable substitute for ordinary Portland cement (OPC). Geopolymer concrete is considered green concrete because of the reduced CO_2 emission and due to the usage of waste materials for manufacturing. Several investigations are happening on the topic of geopolymer concrete in structural members like beams, columns and slabs. This work focuses on the numerical analysis of the flexural behaviour of alkali-activated reinforced slag concrete beam under cyclic loading. Numerical study was conducted using finite element tool, ANSYS. For this, a numerical model was developed and modeled. Thereafter, cyclic load was applied on the same beam to obtain the load-deformation curve. From this curve, the first crack load, ultimate load, maximum deformation, ductility index and energy absorption capacity were obtained.

Keywords: Alkali activated reinforced slag concrete, Green concrete, ANSYS

1 Introduction

Ordinary Portland Cement (OPC) is the most widely used cementitious material in the construction industry. As we know, the production of OPC emits large amount of CO_2 which is a greenhouse gas and adversely affects the environment. Prediction forecasts that the worldwide consumption of cement will continue to increase yearly by 2.5 to 5.8% during the second and third decades of the 21st century [1]. Cement and concrete industry being the primary contributors of CO_2 gas emission.

In addition to the environmental problems caused by the cement industry and the large amounts of energy consumed in the Portland cement production process, PPC has many durability problems, such as sulphate attack, alkali aggregate reaction, and low fire resistance. Hence, the development of eco-friendly construction materials as an alternative for PCC has become one of the main objectives of the scientific community.

Geopolymer is an innovative and eco-friendly alternative for Portland cement which showed higher mechanical and durability properties than Portland cement, confirmed through various studies. Geopolymer refers to materials which are characterized by chains or networks or inorganic molecules. Geopolymer cement concrete is made from utilization of waste materials such as fly ash and ground granulated blast furnace slag (GGBS). Fly ash is the waste product generated from thermal power plant and ground granulate blast furnace slag is generated as waste material in steel plant. Both fly ash and GGBS are processed by appropriate technology and used for concrete works in the form of geopolymer concrete. The use of this concrete helps to reduce the stock of wastes and also reduces carbon emission by reducing Portland cement demand. The main constituent of geopolymers source of silicon and aluminium which are provided by thermally activated natural materials (example. kaolinite) or industrial byproducts (example. fly

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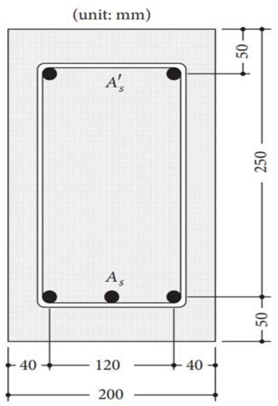
ash or slag) and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create hardened binder. It is also called as alkali-activated cement or inorganic polymer cement. Fly ash, GGBS, fine aggregate, coarse aggregate and an alkali activator are the materials required for the production of this concrete. Alkali activator is a combination of solutions of alkali silicates and hydroxides, besides distilled water. The role of alkaline activator solution is to activate the geopolymeric source materials containing Si and Al such as fly ash and GGBS.

The mechanical properties of geopolymer concrete had been conducted in several studies. Flexural property is an important characteristic in the reinforced concrete components. Four point static bending test is experimentally done to study the flexural behavior of reinforced concrete beam. In this study, the numerical analysis of alkali activated slag concrete under four-point static bending test is validated according to Sung *et al.* [2]. The alkali activated slag reinforced concrete is then analyzed for its flexural behavior under cyclic loading using Ansys software.

Lee *et al.* [2] conducted the experimental evaluation of reinforced concrete beam made of Alkali Activated Slag (AAS) concrete in terms of flexure and shear. In this study, it is concluded that the elastic modulus and the strain at maximum stress of AAS concrete were slightly smaller than that of normal OPC concrete. The stress- strain behavior of this geopolymer concrete is clearly shown in this paper. Saranya *et al.* [3] investigated the performance of reinforced (reinforcement using steel fibres) geopolymer concrete under cyclic loading. How the load will be taken in beam according to the percentage variation in steel fibres. Du *et al.* [4] investigated the flexural behavior of performance-based alkali-activated slag-fly ash concrete beams. Experimental study on flexural behavior of beam using the slag-based AAC is done. Four-point static bending tests were performed to investigate the effects of concrete strength, rebar ratio, and beam depth on the flexural performance. The historical background, environmental impact, constituent materials, reactions mechanism, hydration products, compressive strength, stress-strain behavior, elasticity modulus, Poisson's ratio, tensile strength, bond characteristics with reinforcing steel bars, and behavior under elevated temperature are reviewed in detail for alkali-activated slag concrete by Amer *et al.* [1]. Bashir *et al.* [5] studied the effect of mesh size on crack propagation. Two specimens with embedded cracks in a flat plate of Inconel-600, under the same load and environment are used. Several investigations are happening on the topic of geopolymer concrete in understanding the performance of structural members like beams, columns and slabs. This work focuses on the numerical analysis of the flexural behaviour of alkali-activated reinforced slag concrete beam under the cyclic loading.

2 Analysis of Alkali Activated Slag Concrete Beam under Cyclic Loading

The reinforced alkali activated slag concrete beam (AAS) is designed according to the geometric specifications taken from Sung *et al.* [2]. The size of concrete is 200×300mm with an effective side cover of 40mm and top cover of 50mm. There are three numbers of tension bars and two numbers of compression bars (both of grade SD500) having 25mm diameter each. The stirrups used of diameter 10mm at 70mm centre to centre distance. The reinforcement details and dimensions of specimen are shown in figure 1(a) and figure 1(b).



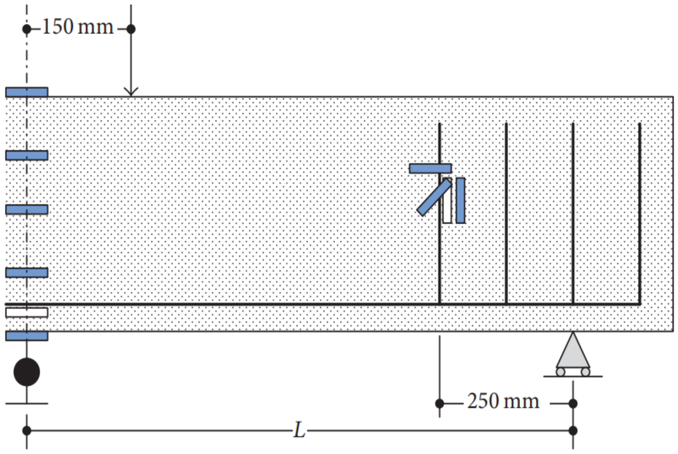


Figure 1 (a): *Details of reinforcement*

Figure 1(b): *Geometric details of specimen*

SOLID185 is used to model the beam. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The steel reinforcement was modelled using the Link8 element. This Link 8 element contains two nodes with three degrees of freedom at each of these nodes with translations in the nodal x, y, and z-direction. The steel element used for FEM modelling was assigned to be an elastic-plastic material and identical in tension and compression. The modeled beam is shown in figure 2.

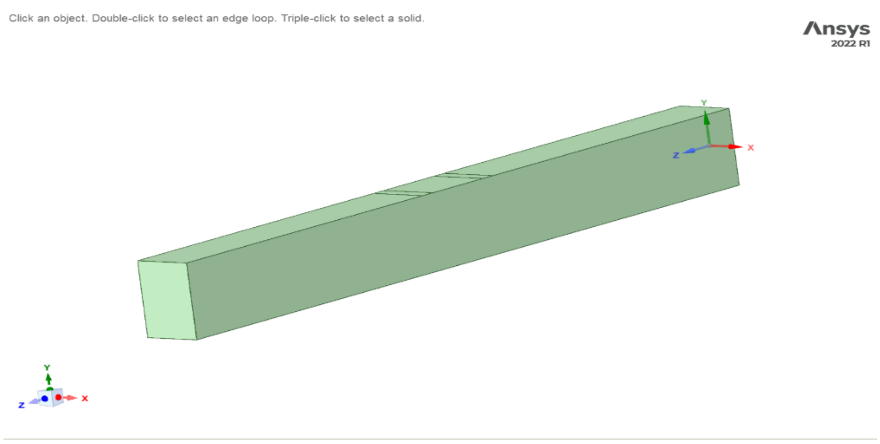


Figure 2: *Geometry of the model*

The material can be either added by open Engineering Data and press the Engineering Data Sources button to show the full list of materials in the database and navigate to the materials to be used in every new model or by adding in the form of commands. Here, the properties of reinforced AAS concrete beam are listed in table 1.

Table 1: *Material Properties*

Sl.No	Properties	Value	Unit
1	Density	2300	kg/m^3
2	Young's Modulus	31.5	GPa
3	Poisson's ratio	0.18	-
4	Compressive strength	55.3	MPa
5	Tensile strength	3.9	MPa

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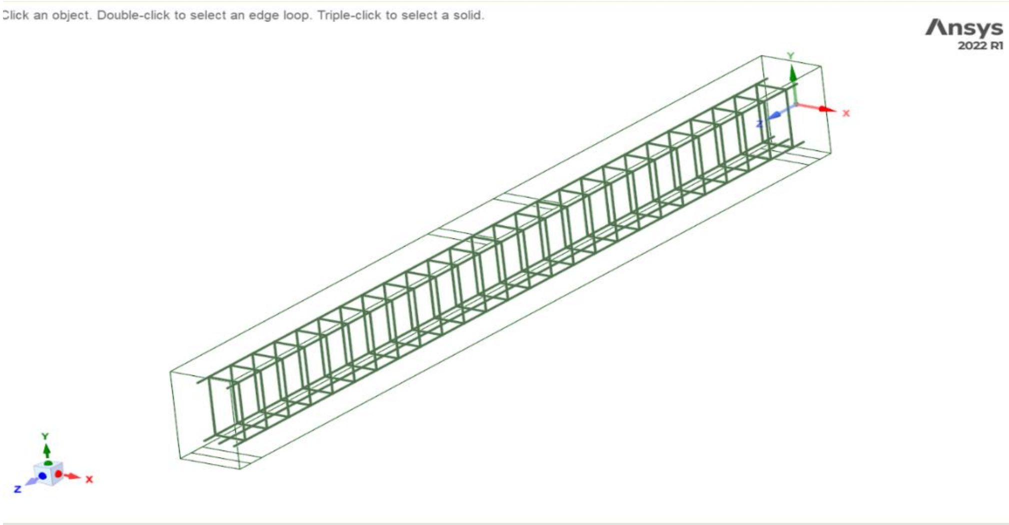

Figure 3: *Reinforcement in AAS concrete beam model*

Modelling in ANSYS can be done using the Space Claim or Design Modeler software pack. In practice many prefer Solid works for physical modelling of a part over Space Claim/ Design Modeler. Here, the modelling work is done in space claim and modelling is completed in geometry building stage. The reinforcement in the modeled beam is shown in figure 3.

For the modeled beam, it includes 15046 number of nodes and 11512 number of elements. The meshing of the beam was done by using rectangular shape size of the mesh is kept as 25mm throughout the surface of specimen. Figure 4 shows the model in ANSYS after providing meshing.

The simply supported condition was provided by giving remote displacement option in ANSYS (U_x, U_y constrained).

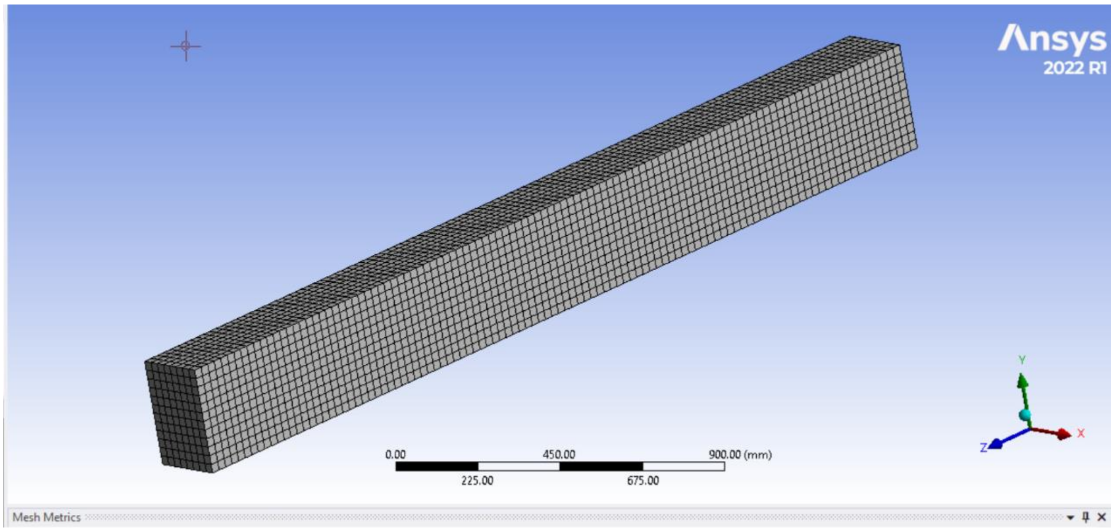

Figure 4: *Meshing in beam*

Here displacement convergence method is used to get the load-deformation curve. So, displacement is given in steps where the number of steps given as 41 with a step end time of 16 second. The displacement is provided in step to get the cyclic load pattern. This load pattern was given as specified in Saranya *et al.* [3]. The input displacement data given in ANSYS is shown in figure 5.

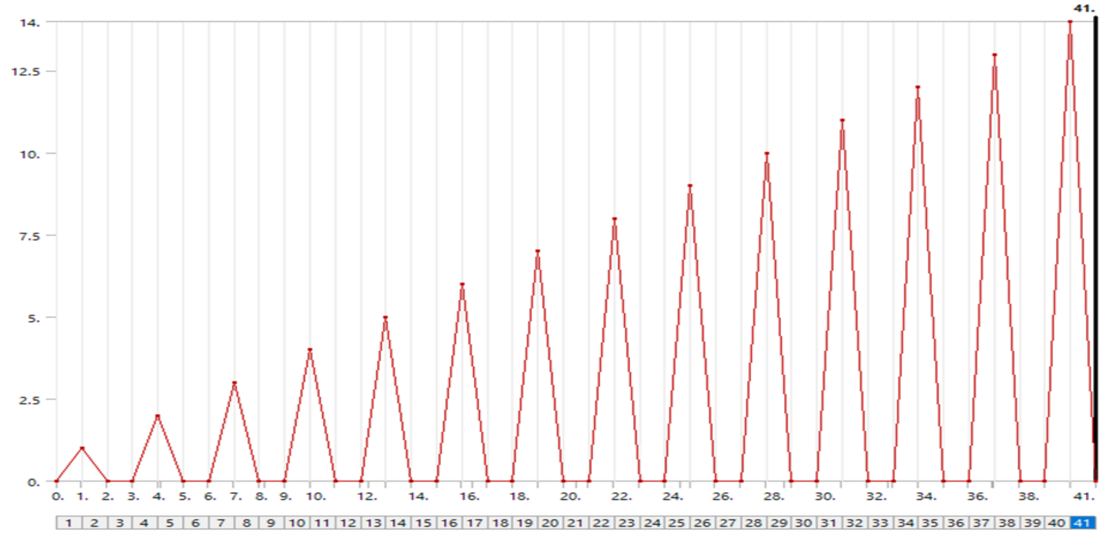

Figure 5: Cyclic load pattern given in ANSYS

3 Results and Discussions

Displacement convergence method is used. In this method, the input is given as displacement in steps and the corresponding load will be produced. Finally, an ultimate load is reached where we get the maximum deformation. The deformations of the beam under cyclic loading is shown in figure 6. The total deformation pattern is shown in figure 7.

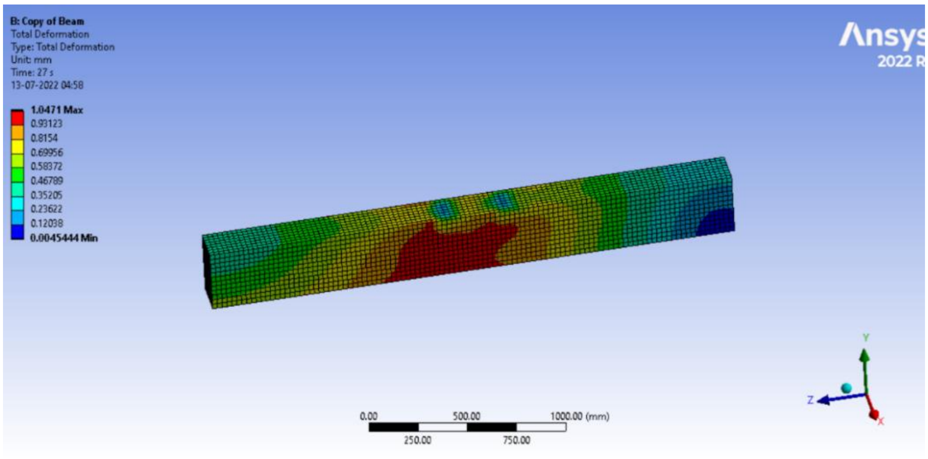

Figure 6: *Total deformation of first cycle*

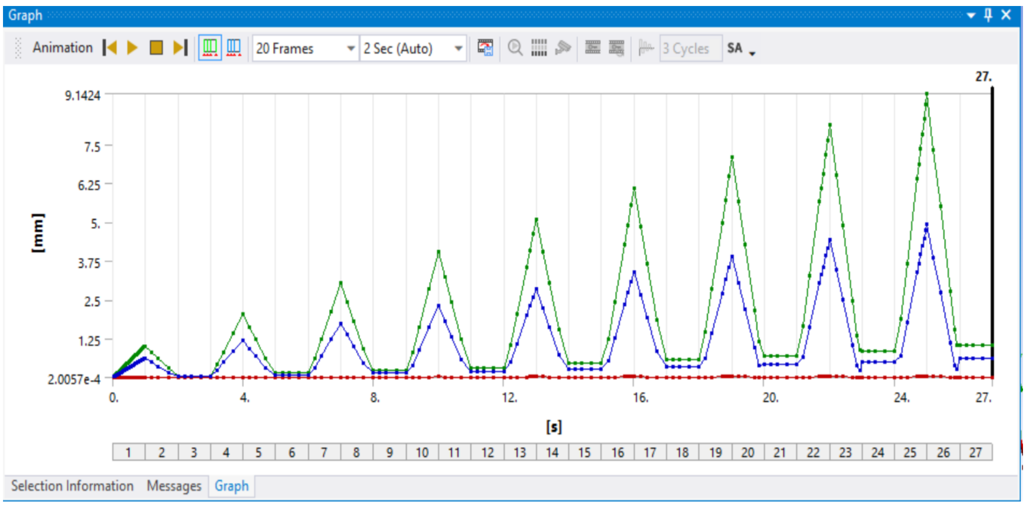

Figure 7: *Total deformation of cyclic load*

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The load at which the load-deflection curve deviates from linearity is taken as first crack load. The first crack load, ultimate load and the deflection corresponding to ultimate load obtained from numerical study is given in table 2.

Table 2: *First crack load, Ultimate load and Deflection*

Specimen	First crack load (kN)	Ultimate Load (kN)	Deflection at ultimate load (mm)
AAS concrete	21.37	78.85	9.14
OPC (Saranya *et al.*) [3]	18.5	53.2	8.8

Reinforced AAS concrete beam exhibited an increase of 15% in first crack load when compared with OPC concrete beams. The maximum ultimate load obtained for AAS concrete beam is 78.85 kN which is 48% more than that of OPC concrete beam. When comparing the deflection values corresponding to ultimate load, a higher value of deflection is observed in geopolymer concrete adding an advantage to it.

Load-deformation curve for the concrete beam under cyclic loading is shown in figure 8. The obtained values from numerical study were found to be better when compared to OPC concrete beam.

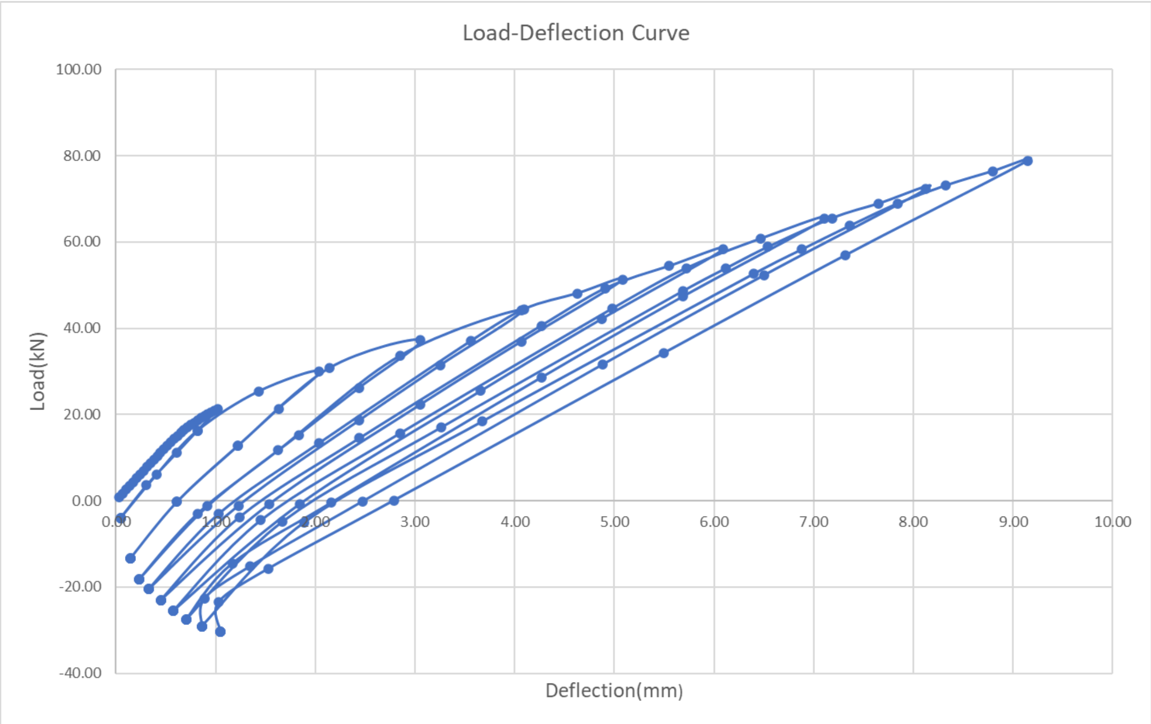

Figure 8: *Load-Deflection curve for cyclic loading*

From figure 8, it is observed that all the curves are linear up to first crack. The maximum load in each cycle is increased.

The area under the load-deflection curve provides energy absorption capacity, which is tabulated in table 3. The energy absorption capacity of AAS concrete beam showed an improvement of 6% to that of OPC concrete beam.

Ductility index is the proportion between deflection at the ultimate load (Δ_u) and the deflection at the yielding load (Δ_y). The ductility index calculated from load-deflection curve is tabulated in table 3. The ductility index of AAS concrete was found to have an increment of 45% compared with cement concrete.

Table 3: *Deflection, ductility index and Energy absorption capacity*

Specimen	Deflection at ultimate load, Δ_u (mm)	Deflection at yield load, Δ_y (mm)	Ductility index, μ	Energy absorption capacity (kNm)
AAS concrete	9.14	2.14	4.27	0.284
OPC	8.8	3.0	2.93	0.268

4 Conclusion

OPC concrete is the widely used construction materials in the construction industry which emits a huge amount of CO_2 gas in the atmosphere. The emission of CO_2 gas adds on to greenhouse effect. So, it is high time to switch into a better alternative for OPC concrete. Geopolymer concrete is proved as a better alternative for OPC concrete which utilizes the wastes such as fly ash, slag etc. Several experimental studies had been conducted to evaluate the mechanical and durability of geopolymer concrete. This study conducted a numerical investigation to evaluate the flexural behavior of reinforced alkali activated slag (geopolymer) concrete beams under cyclic loading. The study was initially validated based on the experimental work done by Sung *et al.* [2]. Then, cyclic load was given on the geopolymer concrete to analyse the behavior of the beam. The first crack load was obtained as 21.37 kN which shows an increment of 15% when compared to OPC concrete. The maximum deformation for the geopolymer concrete was found to be 9.14 mm. There was an increment of 48% increase in the ultimate load, 6% of improvement in energy absorption capacity and 45% increase in ductility index. Thus geopolymer concrete showed a good agreement with cyclic load. Hence, it can be concluded that the geopolymer concrete can be used as better alternative for OPC concrete even in the case of cyclic loading.

5 Publisher's Note

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How to Cite

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