FLEXURAL BEHAVIOUR OF GEOPOLYMER REINFORCED CONCRETE BEAM WITH PARTIAL REPLACEMENT OF COARSE AGGREGATE BY USING STEEL SLAG

Mr.Md Parvez Affani[1] Gundu Usha Sree[2]

[1]Assistant Professor, Global Institute of Engineering and Technology, Moinabad-Chilkur Rd, Hyderabad, Telangana 501504

[2]M. Tech Student, Global Institute of Engineering and Technology, Moinabad-Chilkur Rd, Hyderabad, Telangana 501504

Abstract *The flexural behaviour of geopolymer concrete with partial replacement of coarse aggregate by steel slag. Geopolymer concrete, known for its environmentally friendly properties and high durability, offers a sustainable alternative to traditional cement-based concrete. The incorporation of steel slag, a byproduct of steel manufacturing, aims to enhance mechanical properties and promote recycling within the construction industry. The flexural behaviour of geopolymer reinforced concrete beams with partial replacement of coarse aggregate by steel slag is to evaluate how these materials influence the structural performance and durability of the concrete. By integrating steel slag, a byproduct of steel manufacturing, into the concrete mix, the research aims to explore potential enhancements in flexural strength, ductility, and crack resistance. Additionally, the study seeks to assess the environmental benefits of using industrial waste materials, promoting sustainability in construction practices. Ultimately, the findings aim to provide insights into optimizing geopolymer concrete formulations for improved structural applications, contributing to the development of eco-friendly construction materials that maintain or exceed the performance of conventional concrete. Various mixes were prepared by replacing coarse aggregate with steel slag at different replacement levels (0%, 20%, 30%, and 50%).*

Key parameters such as flexural strength, modulus of rupture, and crack propagation were evaluated through standardized testing methods. The results indicate that partial replacement with steel slag improves the flexural performance of geopolymer concrete, particularly at moderate replacement levels (20%-50%). The enhanced bonding between the geopolymer matrix and steel slag aggregates contributes to improved load-bearing capacity and reduced crack formation. Geopolymer RC beam of grade M35 with 10%,20%,30%,40% and 50% scrap steel as coarse aggregate was studied for its flexural behavior and compared with conventional reinforced cement concrete beam with gravel coarse aggregate. Specimens were tested under two-point static loading. The study derived that in all stages, the performance of the geopolymer beam with scrap steel slag was marginally better than the conventional beam with gravel coarse aggregate. The ultimate load carrying capacity, deflection service load and ductility factor of geopolymer RC beam with scrap steel slag coarse aggregate was comparable to the conventional cement concrete RC beam and is vi marginally higher. It is also found that conventional RC theory can be used in the calculation of moment capacity, deflection and crack width of the geopolymer beam. This study of work encourages the use of steel slag as coarse aggregate in concrete with its inherent structural advantage, easy availability and low cost, if not free.

Keywords- GPC, Fly ash, GGBS, Alkaline liquids, Steel slag.

1. INTRODUCTION

India. OPC is used as the primary binder to produce the concrete. The demand of concrete is increasing day by day for the need of development of infrastructure facilities. However, it is well known that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere. The global cement industry contributes around 2.8 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made (artificial) greenhouse gas emissions to the atmosphere. It is essential to find alternatives to make eco-friendly concrete . In this situation; detailed study of Geopolymer concrete, which is the concrete with zero cement in concrete naturally, becomes very important. Therefore, an attempt has been made in the present investigation by casting Geopolymer concrete mixes with 100% replacement of OPC with processed fly ash in each concrete mix. It is an alternative to make environmentally friendly concrete is the development of inorganic alumina-silicate polymer, called Geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that is rich in silicon and aluminium.

Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, but to date its utilization is limited. Currently, 90 million tons of fly ash is being generated annually in India. By exploring use of the fly ash based geopolymer concrete two environment related issues are tackled simultaneously i.e. the high amount of CO2 released to the atmosphere during production of OPC concrete and Utilization of this fly ash. The production of geopolymer concrete is carried out using the OPC technology methods.

The fly ash based Geopolymer concrete consists 75% to 80% by mass of aggregate, which is bound by a geopolymer paste formed by the reaction of the silicon and aluminium within the fly ash and the alkaline liquid made up of sodium hydroxide and sodium silicate solution with addition of super plasticizer. Hence, the effect of various parameters affecting the compressive strength i.e. ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, curing temperature, rest period and additional water content in the Geopolymer concrete mixes has been investigated in order to enhance its overall performance.

Geopolymer is an eco-friendly replacement of OPC and possess strength and durability similar to or greater than the OPC. Geopolymer concrete is a combination of fly ash or GGBS or both along with hydroxide and silicate solutions. In this paper a combination of both fly ash and GGBS were used to make geopolymer concrete along with sodium hydroxide and sodium silicate solutions. This paper focuses on the study of reinforced geopolymer concrete columns. The objectives of this paper are to experimentally study the ultimate load and deflection of geopolymer columns with varying reinforcement under axial loading and eccentric loading. The experimental study included testing of six geopolymer concrete short columns. In addition the mechanical properties of geopolymer concrete were studied. The mechanical properties include compressive strength, and split tensile strength. The final results showed that Geopolymer concrete column with reinforcement percentage of 3.21% showed higher load capacity of 392 kN, minimum deflection of 4.35 mm and higher stiffness of 90.1 kN/m2.

Objectives of the study

The objectives of study is to analyse the flexural behaviour of geopolymer reinforced concrete beams with partial replacement of coarse aggregate using steel slag include:

1. Evaluate Flexural Strength: To determine the flexural strength of geopolymer concrete beams with varying percentages of steel slag as a coarse aggregate replacement.

2. Contribute to Sustainable Practices: To provide insights into the feasibility of using industrial by-products like steel slag in construction, promoting sustainable material practices in concrete production. These objectives aim to enhance the understanding of geopolymer concrete's structural capabilities and its potential role in sustainable construction.

2. LITERATURE REVIEW

V.B.Vithiyaluxmi , Dr. P. Senthamil Selvi,et.,aI.(2021) This study aims to study further sustainability to the cement - less geopolymer concrete by replacing its natural gravel coarse aggregate by an industrial by-product, scrap steel slag. Geopolymer RC beam of grade M35 with 30% scrap steel as coarse aggregate was studied for its flexural behaviour and compared with conventional reinforced cement concrete beam with gravel coarse aggregate. Specimens were tested under two-point static loading. The study derived that in all stages, the performance of the geopolymer beam with scrap steel slag was marginally better than the conventional beam with gravel coarse aggregate.

B. Sarath Chandra Kumar ,K. Ramesh,et.,aI.(2018) Geopolymers are showing great potential and several studys have critically examined the various aspects of their viability as binder system. Geopolymer concretes (GPCs) are new class of building materials that have emerged as an alternative to Ordinary Portland cement concrete. In this paper, studies carried out on the behaviour of ambient temperature cured reinforced GPC flexural members are reported. A total of twelve beams were tested in flexure having varying combinations of GGBS and Metakaolin in the binder phase were considered.

Y.Himath Kumar,B.Sarath Chendra Kumar,et.,aI.(2017) Geopolymer concrete is proven to have an excellent engineering properties with reduced carbon footprint. It not only greenhouse gas emission but also utilize large amount of industrial waste material such as fly ash. If structure have a minimum cover thickness, concrete spalling and corrosion of reinforcement occurred in the structure. Due to this reason, the element life is reduced and also the structure will be collapsed.

3. METHODOLOGY AND MATERIALS USED

Geopolymer is used as alternate to Concrete and which is prepared by mixing Fly ash. GGBS and Sodium hydroxide solution. Also, the course aggregate is partially replaced by steel slag to know the flexural strength of beam.

The materials used as follows
a. Geopolymer concrete
b. Fly ash
c. GGBS
d. Fine aggregate
e. Coarse aggregate
f. Steel slag
g. Alkali activator solutions
h. Sodium hydroxide solution
i. Alkaline liquid

Geopolymer concrete

The main constituents of geopolymer are the source materials and the alkaline liquid. The source materials for geopolymer based Alumino-silicate should be rich in silicon and aluminium. Also, the natural minerals are Kaolinite, Clays, Micas, and Alousite, Spinel, etc. Alternatively, by product materials such as Fly ash, Silica fume, Slag, Rice husk ash, red mud, etc. The alkaline liquids are formed, by soluble alkali metals like sodium or potassium as base.

Fly Ash

Class-F Fly ash collected from coal-fired power stations. Its spherical in nature, ranging in diameter from less than 1µm to no more than 150µm and fineness is defined by not more than 35% retained on a 45µm sieve. Class-F fly ash as containing a minimum amount of silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus 70 % iron oxide (Fe_2O_3), whereas Class-C fly ash must contain a minimum of 50% of the same chemical constituents. Class-F fly ash will normally have a low calcium oxide (CaO) content (less than 10%), while Class C fly ashes may contain more than 10% and often15-30% calcium oxide. For this investigation a low calcium Class-F fly ash is used. But, Fly ash is a fine, grainy particle obtained as a waste from the combustion of coal in thermal power plants.

Ground Granulated Blast furnace Slag (GGBS)

Ground Granulated Blast furnace Slag (GGBS) is the by-product of iron making process and is produced by water quenching of molten blast furnace slag. GGBS is ground to improve its reactivity during cement hydration. It contains mainly inorganic constituents such as silica, calcium oxide, magnesium oxide, Al_2O_3 and Fe_2O_3. Generation of blast furnace slag varies considerably from 430-650 kg/tone of hot metal. Two types of blast furnace slag such air-cooled slag and granulated slag are being generated from the steel plants. In India, around 40% of this slag is produced in the form of granulated slag.

Fine Aggregate

The sand used conforms to grading zone II of IS 383:1970. Coarse and fine aggregates used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete . The properties of aggregate used are listed below:

Specific gravity of fine aggregate = 2.66

Fineness modulus of coarse aggregate= 7.12

Coarse Aggregate

The crushed aggregate was used from local quarry.

Specific gravity of coarse aggregate = 2.71

Fineness modulus of coarse aggregate= 7.12

Steel Slag:

Slag is a co-product of the iron and steel making process. Iron cannot be prepared in the blast furnace without the production of its co-product; blast furnace slag. Steel can be prepared in the Basic Oxygen Furnace (BOF) or in an Electric Arc furnace (EAF) by leaving its by-product steel slag. This slag, which floats on the surface of molten steel, is then poured off. The main constituents of iron and steel slags are silica, alumina, calcium, and magnesia, which together make about 95% of the total composition and minor elements forms 5% of total composition.

Alkali activator solutions

In looking at the alkaline liquids used in Geo polymerization, various researchers have found that different combinations of alkali-silicates and alkali-hydroxides are Ideal. The Geo polymerization reactions occur at a higher rate than when hydroxides are used as activators. The reaction between alkaline solutions containing sodium hydroxide (NaOH) or potassium hydroxide (KOH) was also studied. When activating multiple natural Al-Si minerals, higher extent of dissolution was observed when in NaOH than in KOH.

Sodium Hydroxide

Sodium hydroxide solution of 12 molar was used. The solution was purchased from a local supplier. A 12 molar solution indicates that $12 \times 40 = 480$ grams of sodium hydroxide per litre of solution.

Alkaline liquid

It is recommended that the alkaline liquid is prepared by mixing sodium silicate and sodium hydroxide solutions allowing the mix for a minimum period of 24 hours to the opcreaction of polymerization. The sodium silicate solution is commercially available in different grades. The Sodium silicate solution (Na_2SiO_3)with Sodium Hydroxide (NaOH) ratio by mass of 2.5 is used.

The sodium hydroxide with 97- 98% purity in pellet form is commercially available.

4. EXPERIMENTAL STUDY

MIXING, CASTING & CURING

The geopolymer concrete is manufactured by adopting the conventional techniques used in the manufacture of Conventional concrete. The Fly ash and the Fine aggregate which are dry mixed together in 50-litre capacity Pan-mixer for three minutes. The Saturated surface dry coarse aggregate is added and mixed with the fly ash and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch. The chemical solution is added and the entire batch mix for four minutes. The fresh concrete is cast and compacted by the usual methods used in the case of Conventional concrete. The workability of fresh concrete is measured by means of the conventional slump test. The slump measured is 130 mm. The prepared concrete is kept in moulds of specimen cube size 100 x 100 x 100 mm. After casting the specimens, they are kept in rest period in room temperature for one day.

The term 'Rest Period' is coined to indicate the time taken from completion of casting of test specimen to the start of curing at an elevated temperature. The geopolymer concrete is de-moulded and then placed in an autoclave for steam curing for 24 hours at a temperature of 60oC. The compressive strength of geopolymer concrete cubes increase with the increase in age. The density of geopolymer concrete is around 2350 kg/m3, which is less to that of conventional concrete. After casting the specimens are covered using vacuum bagging film. A boiler is used to generate the steam at a specified temperature of 60o C. The curing at 60o C is done in the steam curing chamber 24 hours.

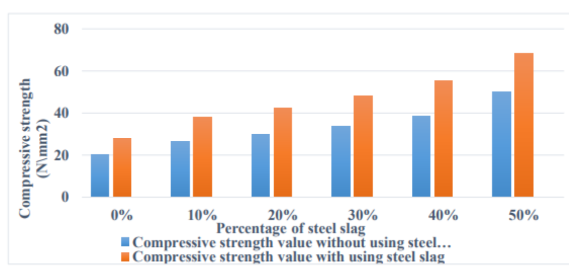
EXPERIMENTAL STUDY

The test program consists of casting and testing of four beams. Size of the beams 125 X 250 X 3200 mm, out of which two are control cement concrete and geopolymer concrete beams. The beams designed as under reinforced section. It is reinforced with 2-12 dia at bottom, 2-10 dia at top using 6 mm diameter stirrups @ 150 mm c/c. The control cement concrete beams cast using M35 grade (1:0.5:1.0 with water cement ratio of 0.45) and Fe 415 grade steel. Ordinary Portland cement, natural river sand and the crushed granite of maximum size 20 mm are used for control concrete. High yield strength deformed (HYSD) steel bars of 12 and 10 mm diameters with mean strength of 433 N/mm2 is used. The elastic modulus of the concrete is found as 2.20 x104 N/mm2 and the Poisson ratio found as 0.12. The control beams and geopolymer concrete beams are designated as RCC-I, RCC-II and GPC-I, GPC-II respectively. The companion cubes (100 mm size) and cylinders (100 mm diameter x 200 mm height) are also cast along with the beams and tested.

Test 1 Compressive strength
Test 2 Flexural strength
Test 3 Split tensile test

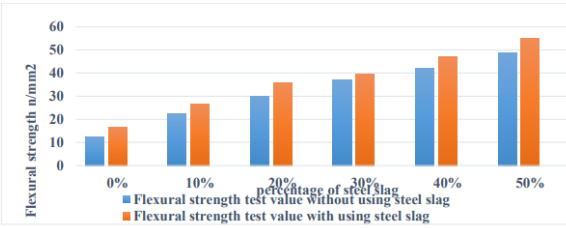
5. RESULTS AND ANALYSIS

Compressive strength values for without using steel slag and with using steel slag



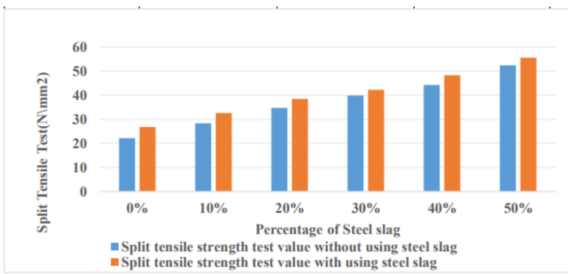
Compressive strength values for without using steel slag and with using steel slag

Flexural strength test values for without using steel slag and with using steel slag



Flexural strength test value for without using steel slag and with using steel slag

Split tensile strength test values for without using steel slag and with using steel slag



Split Tensile Strength test values for without using steel slag and with using steel slag

6. CONCLUSIONS

From this study the following conclusions were made

1. From the experimental and numerical study, it is concluded that the flexural behaviour of 50% added steel slag geopolymer reinforced beam is comparable and superior to the conventional geopolymer reinforced beam.

2. The compressive strength and split tensile strength of 50% added steel slag geopolymer reinforced concrete is superior to the conventional geopolymer reinforced beam.

3. They also have superior compressive strength and flexural response. Failure pattern for both the reinforced concrete were similar.

4. The ultimate load at failure and ultimate deflection were higher for GPC (Geopolymer reinforced concrete) beam with 50% added steel slag than the conventional geopolymer reinforced beam

5. The compressive strength results achieved are almost slightly difference for GPC and Conventional concrete, which indicates that GPC concrete behaves similar to Conventional concrete.

6. In geopolymer concrete the high grades mixes are less workable when compared with lower grade concrete.

7. The load deflection characteristics, crack patterns and failure modes for of Reinforced conventional concrete beams and Geopolymer concrete beams are almost similar.

8. For geopolymer beams the transverse strength is slightly more when compared with Reinforced conventional concrete beams.

9. Various possibilities could have caused the failure of concrete first followed by rupture of geogrids ribs.

10. The physical and mechanical properties of the geogrids have a great impact on the peak and post peak behaviour of reinforced beams in flexure. Biaxial geogrids with ribs aligned in the both directions yield better post-peak flexural behaviour in comparison to others in terms of load and deflection capacity.

11. Biaxial geogrid normal strength reinforced beams attained a 20% increase in load capacity and along with substantial increase in post peak deflection.

12. There is a clear correlation between concrete strength, tensile properties of the geogrid.

13. In both ordinary conventional concrete and geopolymer concrete specimens with geogrid performs better when compared to the specimen without geogrids.

14. As the strength of both ordinary conventional concrete and geo polymer concrete is comparatively same, So the conventional concrete can be replaced by geo polymer concrete considering the environmental conditions such as global warming, emission of CO2 etc.

REFERENCES

1. V.B.Vithiyaluxmi, Dr.P.Senthamilselvi. "Flexural Behaviour Of Geopolymer Reinforced Concrete Beam With Partial Replacement Of Coarse Aggregate By Using Steel Slag" Volume: 08 Issue: 04 Apr 2021.

2. B. Sarath Chandra Kumar, & K. Ramesh. "Analytical Study on Flexural Behaviour of Reinforced Geopolymer Concrete Beams by ANSYS." IOP Conference Series: Materials Science & Engineering. Vol. 455, Issue 1, 2018

3. Y. Himath Kumar & B. Sarath Chandra Kumar "Study on Strength & Durability Parameters of Geopolymer Concrete with GGBS for 12M & 14M Alkali Activators," ARPN Journal of Engineering & Applied Sciences, Vol. 12, Issue 4, 2017, pp. 1202- 1212.

4. Y. Himath Kumar & B. Sarath Chandra "Effect of Molarity on Compressive Strength of Geopolymer Mortar with GGBS & Metakaoline," International Journal of Civil Engineering & Technology, Vol. 8, Issue 4, 2017, pp. 935-944.

5. B. Vijaya Rangan "Fly Ash-Based Geopolymer Concrete," Proceedings of the International Workshop on Geopolymer Cement & Concrete, Allied Publishers Private Limited, 2010.

6. Y. Himath Kumar & V. Keerty "Experimental Studies on Properties epithetical Geopolymer Concrete with GGBS & Fly Ash," International Journal of Civil Engineering & Technology, Vol. 8, Issue 1, 2017, pp. 602-609

7. Bakharev T (2006). Thermal behaviour of geopolymers prepared using class F fly ash & elevated temperature curing. Cement Concrete Res., 36: 1134-1147.

8. Anurag Misra, Rohit Ramteke Madan Lal Bairwa, Study on Strength & Sorptivity characteristics on fly ash concrete. Journal of Engineering & Applied Sciences. 2007;2(5)54-59

9. Barbosa, V. F. F., K. J. D. MacKenzie, C. Thaumaturgo. (2000). "Synthesis & Characterisation of Materials Based on Inorganic Polymers epithetical Alumina & Silica: Sodium Polysialate Polymers." International Journal of Inorganic Materials 2(4): 309- 317.

10. Bakharev ,Chindaprasirt, P., Chareerat, T., &Sirivivatnanon, V. (2005). Workability & strength of coarse high calcium fly ash geopolymer. Cement & Concrete Composites, 29(3), 224-229.

11. Davidovits, J. (1991). Geopolymers: Inorganic Polymeric New Materials. Journal of Thermal Analysis, 37, 1633-1656.

12. Davidovits, J. (1994). Properties of Geopolymer Cements. Paper presented at First International Conference on Alkaline Cements & Concretes, Kiev State Technical University, Kiev, Ukraine.