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

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Abstract - *This research work 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. 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 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 investigation 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, GCBS, Alkaline liquids, Steel slag

1. INTRODUCTION

India also is facing the problem of depletion on natural resources such as limestone, which is the most important ingredient to produce cement, and in turn the concrete in India. . Ordinary Portland cement (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 aluminum. 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 CO_2 released to the atmosphere during production of OPC and Utilization of this fly ash. The production of geopolymer concrete is carried out using the conventional concrete 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 aluminum within the fly ash and the alkaline liquid made up of sodium hydroxide and sodium silicate solution with addition of superplasticizer. 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.

2. RESEARCH SIGNIFICANCE

`Approximately no research data on the flexural behavior of reinforced concrete using scrap steel slag coarse aggregate in geopolymer concrete is cited at present. Reinforced geopolymer concrete with scrap steel slag coarse aggregate attains comparable strength and serviceability and in cases, marginally higher than that of the conventional reinforced cement concrete with natural gravel coarse aggregate. This research work provides satisfactory detailed numerical data on reinforced geopolymer beam

3. MATERIAL COLLECTION

3.1 Fly ash

Class F fly ash collected from coal- fired power stations. Its spherical in nature, ranging in diameter from less then 1μm to no more then 150μm and fineness is defined by no more then 35% retained on a 45μm sieve. Class F fly ash as containing a minimum amount of silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3) of 70%, whereas class C fly ash must contain a minimum of 50% of the same chemical constituents. Class F fly ashes 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.

3.2 Ground Granulated Blast Furnace Slag (GCBS):

Granulated blast furnace slag (GBFS) is the by-product of iron making process and is produced by water quenching of molten blast furnace slag. GBFS is ground to improve its reactivity during cement hydration. It contains mainly inorganic constituents such as silica, calcium oxide, magnesium oxide, Al2O3 and Fe2O3. 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. The activity of GBFS is determined by the quantities and the properties of amorphous glass, as well as the chemical compositions. Fine grinding and mechanical activation was suggested to improve the reactivity of the blended cement constituents. Fine grinding leads to generation of larger surface area for better reaction.

3.3 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. Physical characteristics such as porosity, density, particle gradation, are affected by the cooling rate of the slag and its chemical composition. The chemical composition and cooling of molten steel slag have a great effect on the physical and chemical properties of solidified steel slag.

3.4 Alkaline liquids:

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. Higher concentration (in molar units) of sodium hydroxide results in higher compressive strength and higher ratio of sodium silicate-to-sodium hydroxide ratio by mass results in higher compressive strength.

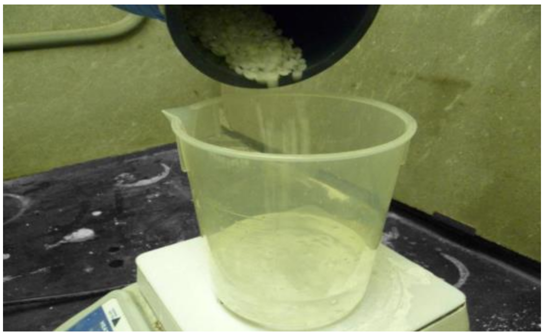

Fig -1: Alkaline activator

4. MIX PROPORTION

MATERIAL	M I (Kg/m3)	M II (Kg/m3)
Fly ash	311.87	311.87
GGBS	133.66	133.66
Sand	629.60	629.60
steel slag (CA)	-	365.07
Gravel (CA)	1216.89	851.82
Activator solution	191.58	191.58

where, M I indicates Geopolymer reinforced beam with 0% steel slag ;

M II indicates Geopolymer reinforced beam with 30% steel slag .

5. RC BEAM DETAILS, INSTRUMENTATION AND TESTING:

Two beams were casted – M I and M II. M I is the conventional beam made of Geopolymer reinforced beam with 0% steel slag and M II is geopolymer reinforced beam made with 30% steel slag coarse aggregate. The beams were 1 m long with 150 mm x 150 mm cross section. The beams were designed to be under reinforced. The tensile zone reinforcement consisted two 12 mm bars and the compression zone had two 10 mm bars. Shear reinforcement was made with 8mm stirrups at 150 mm spacing along the length of the beam. M I and M II after casted for 28 days was let to open sunlight for ambient curing. No water curing was done both beam. Both beams were tested at age of 28 days. The test beams were simply supported on the testing frame as shown in Figure. Load was applied through a slender beam to transmit load equally at two points through bearings on the top of the beam. Load was increased gradually and the corresponding deflection in the beam was measured at the middle and two loading points by high accuracy dial gauges. Loading was continued and data were recorded until the beam suffered flexural failure by crushing in the compression zone. Figure III and V show the beams loaded in test setup. Figure IV and VI clearly show the failure pattern of beams.

Fig 2– M I beam in test setup and failure mode

Fig 3– M I beam in test setup and faulire mode

5.1 RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH:

The 28 days cube compressive strength of M I and M II was respectively 42.67 Mpa and 60.64 Mpa. M II has higher compressive strength then M I .

CRACK PATTERN AND FAILURE MODE.

Both the beams suffered the same failure response. Their structural response was typical with cracks arising from the tension zone and propagating vertically to the compression zone. No horizontal cracks was found which is indicative of the fact that no bond failure has occurred.In both the beams, the geopolymer concrete beam with 0% and 30% steel slag aggregate had the same failure mode and no significant changes was found when compared with the failure modes. Fig IV shows the crack pattern of geo-polymer reinforced beam with 0% steel slag at ultimate load of 30.7 KN and Fig VI shows the crack pattern of geo-polymer reinforced beam with 30% steel slag at ultimate load of 55.6 KN.

ULTIMATE LOAD AND DEFLECTION

The Ultimate load and deflection of the beams are presented Table. In all the stages of loading, M II sustained higher loads prior to failure compared to M I which indicates superior flexural behaviour. Excessive deflection was suffered by M II indicating its improved ductility.

Parameter	M I	M II
First crack load	14 KN	29.3 KN
Ultimate load	30.7 KN	55.6 KN
Max. Deflection (mm)	5.2	7

6. CONCLUSION

- From the experimental and numerical investigations, it is concluded that the flexural behaviour of 30% added steel slag geopolymer reinforced beam is comparable and superior to the conventional geopolymer reinforced beam.
- They also have superior compressive strength and flexural response. Failure pattern for both the reinforced concrete were similar.
- The ultimate load at failure and ultimate deflection were higher for geopolymer reinforced beam with 30% added steel slag than the conventional geopolymer reinforced beam .

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