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Flexural Behaviour of Geopolymer RC Beam with Scrap Steel Slag Coarse Aggregate

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Abstract*: This research work aims adding 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 M40 with 100% scrap steel as coarse aggregate was studied for its flexural behavior and compared with conventional reinforced cement concrete beam with gravel coarse aggregate. The specimens were tested under two-point static loading. The analysis was also carried out using ANSYS software. 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 of study and FE modeling and analysis using ANSYS were comparable to the experimental results.

***Keywords* : Flexural behavior, geopolymer concrete, scrap steel slag coarse aggregate, ANSYS.**

I. INTRODUCTION

With the concern to meet present need of the environment, economy and society many efforts are being made and are successfully applied in the field of construction engineering to reduce the carbon footprint of concrete. Such a resilient form of concrete is the geopolymer concrete [1] which suspends completely the usage of cement. Also its green benefits include ambient curing of the concrete which indeed makes it a revolutionary concrete technology. Since zero carbon built is the need of the hour, this inorganic geopolymer paves the way to future addressing also the water scarcity issues all around by suspending completely the need of water for its curing. Many proven research works of geopolymer concrete [2], [3] are published from all directions and its field application is extending progressively.

In view of adding more sustainability to this green concrete, it was decide to replace its coarse aggregate, the natural gravel which accounts 60-80% of its volume. For which the scrap steel slag was chosen for its more similar properties as that of gravel and is also available in abundance. Steel slag is the solidified complex solution of silicates and oxides obtained as by-product of steel making process. Different types of steel slag are obtained based on the type of furnace in which they are produced. The classification includes, BF (Blast furnace) slag, BOF (Basic Oxygen furnace) slag, EAF (Electric Arc Furnace) slag, LF (Ladle Furnace) slag.

In India 16-18 million tons of steel slag is generated annually and is estimated to reach as high as 200 million tons in near future. But the effective usage of steel slag is not practices in our country and is mostly dumped or landfilled. Securing lands for disposal of steel slag is already an arising problem. Considering the inherit advantage of steel slag over natural gravel in both usage and environment perspective [4], [5], this research work was done replacing the natural gravel coarse aggregate in geopolymer concrete by steel slag. The flexural behavior of such a reinforced geopolymer concrete with scrap steel slag coarse aggregate is presented in this paper.

II. RESEARCH SIGNIICANCE

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 experimental data on the same and compares the flexural behavior with the conventional cement concrete.

III. EXPERIMENTAL PRORAMME

MATERIALS USED

A. Cement

Ordinary Portland cement of grade 43 with specific gravity 3.15 was used. Material complies with the IS 8112-2013requirementss.

B. Fly Ash

Low calcium fly ash – Class F type, obtained in dry state with specific gravity 2.39 from a local coal burning thermal power station was used. Material complies with ASTM C 618 specifications.

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C. GGBS

Commercially available Ground Granulated Blast Furnace Slag (GGBS) was purchased from a local supplier which had specific gravity 2.8 and complied with IS 12089-1987 specifications.

D. Sand

River sand conforming to Zone II of IS 383-1970 with specific gravity 2.6 was used.

E. Gravel

Gravel aggregate of maximum size 20mm conforming to IS 383 – 2016 with specific gravity 2.66 was used.

F. Scrap Steel Slag

Scrap steel slag was obtained from a local Electric arc furnace based scrap steel re-rolling mill. The uneven sized slag balls were crushed down using jaw type crusher to the required grading with maximum aggregate size of 20mm. Figure I shows the scrap steel slag after crushing down to 20 mm size. The aggregate shows a rough surface texture with sharp points. Chemical composition of scrap steel slag is stated in Table I. Table II gives the physical properties of scrap steel slag and gravel aggregate.

Figure I Scrap steel slag

Table- I: Chemical Composition o Scrap Steel Slag

Constituent	%
CaO	48
SiO_2	18
Al_2O_3	7
FeO	10
MnO	15

Also traces of oxides o K, Cl, Cr, M, Ti was found. Free calcium constitutes 2%.

Table- II: Physical Properties of Scrap Steel Slag and Gravel Aggregate

	Scrap steel slag	Gravel
Bulk density, kg/m^3	1260	1380
Fineness Modulus	6	6.23
Specific gravity	2.18	2.66
Water absorption , %	1.5	1

G. Alkaline Activator Solution

The alkaline activator solution was obtained combining 8M Sodium hydroxide solution with sodium silicate solution at a ratio of 2.5. Commercially available high pure materials were used.

H. Super plasticizer

Conplast SP 430 was used as super plasticizer to achieve required workability in this study.

I. Steel Reinforcement

Longitudinal reinforcement was formed with deformed, high yield strength bars of 12 mm and 10 mm diameter. Stirrups are of same bars with 8mm dia. The average yield stress of 12 mm, 10 mm and 8 mm bars are 395 Mpa, 380 Mpa and 245Mpa respectively.

MIX DESIGN

Table III gives the material mix design details. M40 grade of concrete was designed based on IS 10262 – 1982. M 1 – Conventional cement concrete with gravel aggregate. M II – Geopolymer concrete with Scrap Steel slag Coarse aggregate.

Table- III: Mix Design

Material	M I (Kg/m^3)	M II (Kg/m^3)
Cement	311	-
Fly Ash	-	311
GGBS	133	133
Sand	815	815
Gravel CA	1061	-
Scrap steel slag CA	-	870
Water	148	-
Activator solution	-	200
Super plasticizer	7.4	7.4

RC BEAM DETAILS, INSTRUMENTATION AND TESTING

Two beams were casted – M I and M II. M I is the control beam made of cement concrete with gravel coarse aggregate and M II is geopolymer beam made with scrap steel slag coarse aggregate. The beams were 3.2 m long with 125 mm x 250 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 was cast and cured underwater for 28 days. M II after casting was let to open sunlight for ambient curing of 28 days. No water curing was done or M II. Both beams were tested at age of 28 days.

The test beams were simply supported on the testing frame as shown in Figure II . 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.

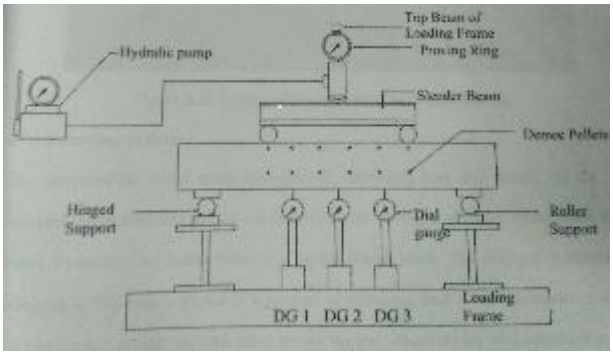

Figure II Beam Test Setup

Figure III MI Beam in Test Setup

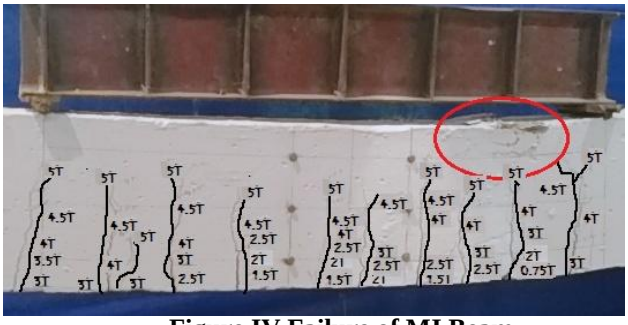

Figure IV Failure of MI Beam

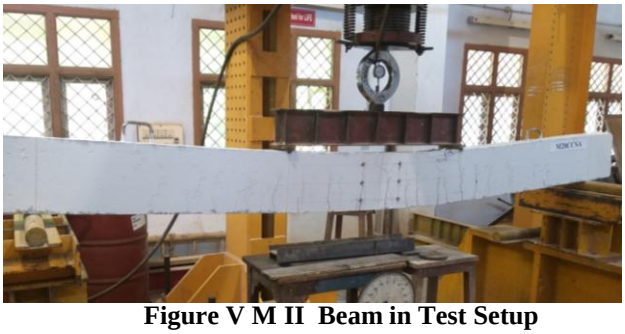

Figure V M II Beam in Test Setup

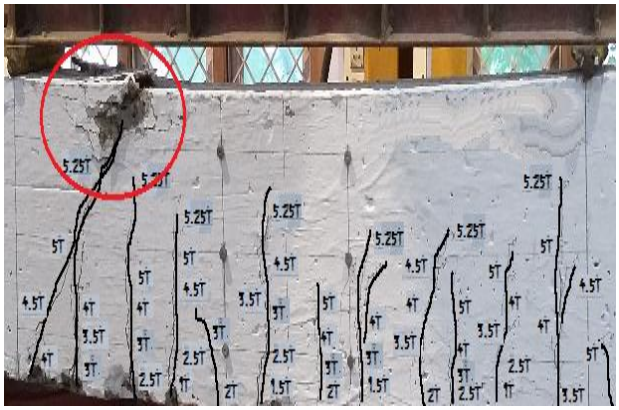

Figure VI Failure of M II beam

IV. RESULTS AND DISCUSSION

A. Compressive strength

The 28 days cube compressive strength of M I and M II was respectively 49 Mpa and 50 Mpa. This gives fairly equal compressive strength values.

B. 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, yielding of tension steel followed by the crushing of concrete in the compression zone with spalling of concrete cover was found resulting in a ductile tension failure. The geopolymer concrete beam with scrap steel slag aggregate had the same failure mode and no significant changes was found when compared with the failure mode of conventional cement concrete beam with gravel coarse aggregate.

Buckling of the longitudinal steel in the compression zone was found in both the beams indicating that the tensile steel has attained its yield strength before failure.

C. Ultimate Load and Deflection

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

Table- IV: Load and Deflection of Beams.

Parameter	M I	M II
First crack load	1 T	0.75 T
Service Load	3 T	3.25 T
Yield Load	4.25 T	4.5 T
Ultimate Load	5.25 T	5.5 T
Max. Deflection	66 mm	76 mm

D. Ductility Behavior

Ductility indicates the capacity of the structural member to undergo deformation inelastically with energy absorption. Displacement ductility which is the ratio of deflection at ultimate load to the deflection at yield load was measured or the beams. M I had ductility of 3.39 and M II had 3.8. This indicates that the geopolymer concrete with scrap steel slag coarse aggregate has improved ductility behavior compared to the conventional cement concrete with gravel aggregate.

E. Numerical Analysis

ANSYS was used to calculate the load displacement response of the beams numerically. Table V reports the ANSYS results which when compared to the results in Table IV show that it has close agreement with the experimental data. Figure VII and VIII show the deflected shape of beams obtained from ANSYS.

Table- V: ANSYS report

Parameter	M I	M II
Ultimate Load	5 T	5.25 T
Max. Deflection	60 mm	71 mm

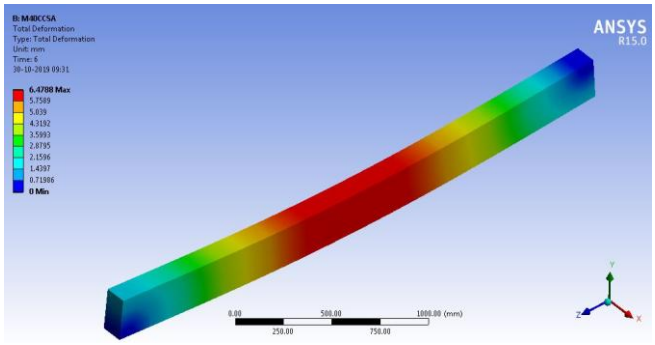

Figure VII Deflected shape of M I

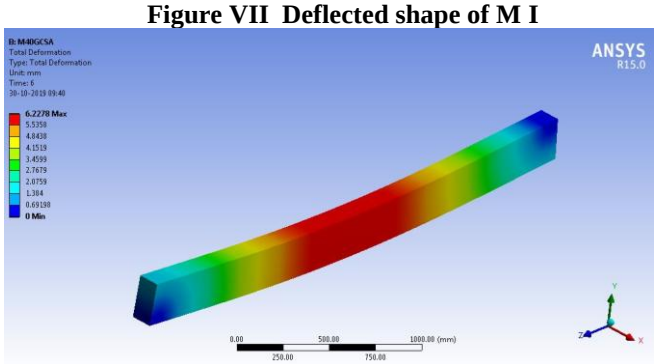

Figure VIII Deflected shape of M II

V. CONCLUSION

- From the experimental and numerical investigations, it is concluded that the flexural behavior of steel slag coarse aggregate geopolymer concrete is comparable and marginally superior to the conventional Cement concrete with gravel coarse aggregate.
- They have close aggrement in terms of compressive strength and has superior flexural response. Failure pattern for both the reinforced concrete were similar and the ultimate load at failure and ultimate deflection were higher for geopolymer concrete with scrap steel slag coarse aggregate than the conventional reinforced cement concrete.
- Geopolymer beam reports improved ductility behaviour in terms of displacement ductility.
- This experimental work encourages the use of scrap steel slag as coarse aggregate in concrete with its inherent structural advantage, easy availability and low cost, if not free.
- This work also recommends long term study of this scrap steel slag coarse aggregate concrete.

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