Finite Element Analysis of Geopolymer Concrete Incorporating Copper Slag as Fine Aggregate

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Abstract— The present paper mainly focuses on analytical study of geopolymer concrete (GPC) incorporating copper slag (CS) as fine aggregate. The beams were analyzed by using Ansys R15.0. Fly ash and ground granulated blast furnace slag were used as geopolymer binders. In our present investigation the specimens of the GPC with incorporating copper slag as the fine aggregate in the proportions of 0%,10%, 20%, 30%, 40% are made, and the parameters such as compressive stress, Max. Equivalent stresses (Von-Misses stress), Max. Normal Stress, Max. Normal Elastic Strain, Max. Shear Stress, Max. Shear strain and Max. central deflection, flexural properties were found. The present study has given a final conclusion that the performance of reinforced geo polymer concrete (RGPC) beams was better than that of equivalent grade of reinforced conventional concrete beams.

Key words: Reinforced Geopolymer Concrete Beams, Ansys R15.0, Copper Slag(CS), Max.Equivalent Stresses (Von-Misses Stress), Max. Normal Elastic Strain, Max.Shear Stress, Max.Central Deflection

I. INTRODUCTION

Concrete is the most widely used construction material after water in the world and ordinary Portland cement (OPC) is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of CO_2 is released into the atmosphere for every ton of OPC produced [1]. The mechanical properties of Geo-polymer concrete (GPC) mixes with different aggregates blending and also combination of sodium hydroxide and sodium silicate solution was used as alkaline activator and conclude that optimum fine aggregate blending and also all Flexural Strength (FS) of all mixes were found. [2]. In terms of reducing the global warming, the geo polymer technology can reduce the CO_2 emission in to the atmosphere, caused by cement and aggregate industries is about 80% [3]. In this geo polymer technology, the source material is rich in silicon (Si) and Aluminium (Al) is reacted with a highly alkaline solution through the process of geo polymerization to produce the binding material. In our investigation, we are replacing the by-products such as fly ash and GGBS as a part of cement and copper slag as a part of sand to produce geopolymer concrete. [4]. Beams strengthened with Copper Slag Fiber Reinforced Polymer and the beams were modelled using ANSYS and the obtained results were compared. [5]. An Analytical Investigation of Bonded copper slag Fiber Reinforced Polymer Sheets with Reinforced Concrete Beam Using Ansys which has been used to study the strengthened behavior of the beam and gave the conclusion as the Deflections in the beams retrofitted with copper slag gave better results [6]. The models which are analyzed has shown the same structural response and failure modes as found in the experimental investigation [7]. The load deflection relationships, ultimate load, flexural properties were obtained and compared with the experimental results available in literature and obtained results shows good agreement with the experimental results for comparative study of experimental and analytical results strengthened beams in flexure. [8]. A theoretical and experimental study on mechanical properties and flexural strength of fly ash-geo polymer concrete using young's modulus, Poisson's ratio stress-strain relation and with two-point loading and as FEM and concluded after the results there were approximate values by comparing both the theoretical and experimental study.

II. EXPERIMENTAL STUDY

The experimental investigation was focused on the effect of various proportions of copper slag on GPC and determine the parameters such as Compressive Strength, Ultimate Deflection, flexural properties, Max.Equivalent stresses (Von-Misses stress), Max.Normal Stress, Max.Normal Elastic Strain, Max.Shear Stress, Max.Shear strain and Max.central deflection. Sand and CS were used as fine aggregate and CS chemical composition are listed in Table 1. Super plasticizer of SP-430 was used to improve the workability of mixtures.

A. Materials

Composition	% by mass
SiO_2	43.20
Al_2O_3	12.60
Fe_2O_3	1.30
CaO	40.20
Na_2O_3	0.90
K_2O	0.60
TiO_2	-
MgO	1.45
GNO_3	-

Table 1: Chemical composition of CS

Crushed granite stones of the size 20 mm and 10 mm were used as coarse aggregate and the river sand was used as fine aggregate. The bulk specific gravity in oven dry condition and the water absorption of the coarse aggregate 20 mm and 10mm were 2.58 and 0.3% respectively. The bulk specific gravity in oven dry condition and water absorption of the sand were 2.62 and 1% respectively and also the fineness modulus is 2.59.

B. Mix proportion

In this study, mechanical properties of geopolymer concrete (GPC) incorporating copper slag(CS) as fine aggregate with the replacement levels of 0%, 10%, 20%, 30% and 40% of copper slag was studied. The design mix proportions of GPC values are shown in Table 2.

Constituents	Content of concrete per m^3
GGBS	242
Fly ash	242
20 mm aggregate	914
10mm aggregate	610
SS Solution	121
SH Solution	48
Super plasticizer	3.386

Table 2: GPC mix proportions per m^3

The changing values of sand and copper slag according to different proportions are shown in Table 3.

Constituents	Proportions per m^3				
	0%	10%	20%	30%	40%
Sand	648.5	583.6	518.8	453.95	390
Copper slag	0	64.85	129.7	194.55	260

Table 3: Mix proportions of sand and CS

C. *Reinforcement Details*

Reinforced beams were casted for earlier specified proportions of geo polymer concrete. Reinforcement has four main bars of 12mm dia (2 bars at top and two bars at bottom) and stirrups of 8mm dia at 150mm c/reinforcement is of Fe500 grade steel. The beams so casted were cured for 28 days. The beams were tested after curing for two-point loading in a manually operated loading frame having capacity of 1000kN.

The same experimental beams were analyzed with the loading conditions obtained experimentally by using Ansys R15.0. The values of Ultimate load taken for analyzing is as shown in Table 4 and the values of concrete properties is as shown in Table 5.

Specimen ID	Ultimate Load at 28 Days (KN)
0%CS	190
10%CS	212
20%CS	226
30%CS	232
40%CS	239

Table 4: Ultimate load

Mix Proportion	Poisson's ratio	Unit weight (kg^3)	Young's Modulus (Gpa)
100% S	0.210	2362.949	38.495
10% CS + 90% S	0.220	2394.455	42.586
20% CS + 80% S	0.234	2410.208	44.330
30% CS + 70% S	0.239	2441.714	45.612
40%CS+6 0%S	0.242	2457.467	46.718

Table 5: Mechanical Properties of Geo Polymer concrete

III. ANALYSIS

A. *Geometrical design in CATIA*

By using Catia software, firstly a solid rectangular path has been taken according to the dimension of the experimental beam and reinforcement has been placed as in the case of experimental beam as shown in Figure 1. The positions of loading conditions and supports has been imposed.

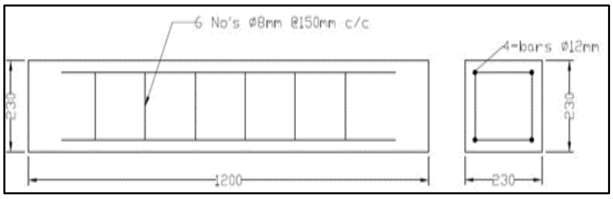

Fig. 1: Beam Considered For the Study

B. *Assigning of properties to the Geometrical model*

The Geometrical model designed in catia has been imported to Ansys Workbench R15.0. The properties such as Density, Poisson's Ratio, Young's modulus of concrete and Grade of Steel obtained experimentally has been assigned to the model. The values of Density, Poisson's ratio and young's modulus of concrete is as shown in Table 5.

C. *Meshing*

The geometrical model is divided into number of elements by using isoperimetric meshing is as shown in Figure2.

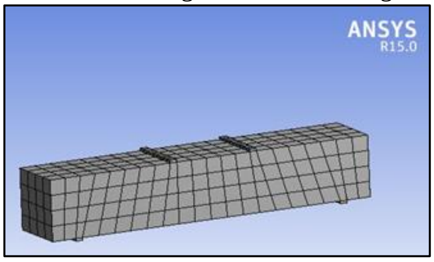

Fig. 2: Isoperimetric Meshing of the beam

D. *Boundary conditions and Loads*

The boundary conditions as in the case of simply supported beam has been assigned to the model and the maximum load obtained experimentally for each proportion is assigned to the geometrical model. The maximum load obtained at 28 days of curing for each proportion is shown in the Table 4.

E. *Solution*

The parameters which are to be found such as Deflection, compressive stress, flexural properties, Max.Equivalent stresses (Von-Misses stress), Max.Normal Stress, Max. Normal Elastic Strain, Max.Shear Stress and Max.Shear strain can be obtained upon selection.

IV. RESULTS AND DISCUSSION

A. *Deflection*

From Table 6, the deflection values have been decreased for proportions from 0%CS and attained better results in 40%CS. This is due to the fine material of CS which fills the voids and increases the compressive strength of the concrete which in turn increases the other mechanical properties. The Analytical deflection values have found similar to that of experimental values. And deformation is shown in Figure 3.

Specimen ID	Exp. Ultimate deflection	Analytical ultimate deflection
0%CS	14.76	13
10%CS	13.06	11.03
20%CS	11.89	10.25
30%CS	11.23	9.9025
40%CS	10.56	9.75

Table 6: Experimental and Analytical Deflection at 28 Days of Curing

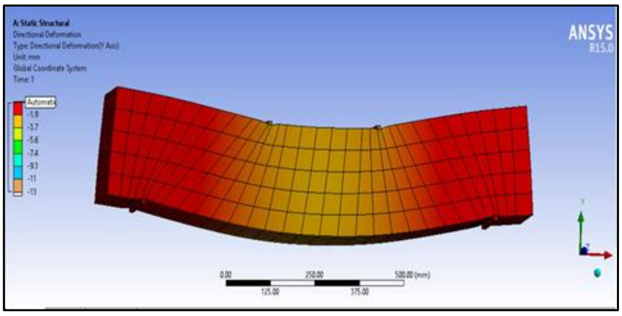

Fig. 3: Deflection of Beam

B. Max.Equivalent Stresses (Von-Misses stresses)

From Table7, it can be noticed that the values of max. Equivalent stresses increased in Y-direction from 0% CS to 40% CS. The increase in the stress is due to increase in the load carrying capacity. But in with 40%CS grade for the small range of loading the stress taken is very high. The stresses shown in Figure 4.

Max. Von misses Stresses For 28 Days	
Specimen Id	Max. Von Misses Stress
0%	754.41
10%	852.52
20%	908.81
30%	932.94
40%	961.09

Table 7: Maximum Equivalent Stresses at 28 days of Curing

Fig. 4: Max.Von-Misses Stresses

C. Max.Normal Elastic Strain

From Table 8, it can be noticed that values of maximum normal elastic strain in Y-direction increased from 0%CS to 40%CS. It is to be noted that the CS40% has attained higher strain value at lower load compared to that of GPC.

Specimen Id	Normal Elastic Strain For 28 Days		
	X-Direction	Y-Direction	Z-Direction
0%	0.00094	0.00156	0.000125
10%	0.0011077	0.0017514	0.000155
20%	0.00118	0.00186	0.000165
30%	0.0012122	0.0019166	0.00017
40%	0.00124	0.000197	0.000175

Table 8: Max.Elastic Strain

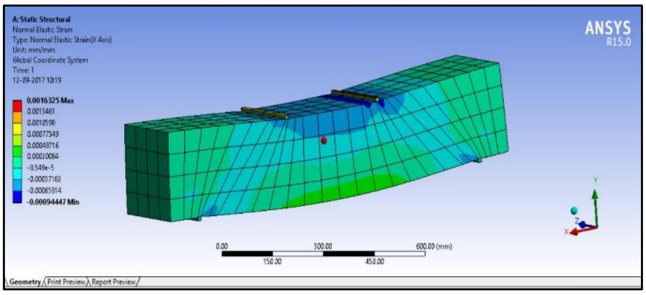

Fig. 5: Max. Elastic Strain

D. Max. Shear Stress

From Table 9, it can be noticed that values of maximum shear stress in XZ-plane has increased from 0%CS to 40% at the bottom of supports. The maximum shear stress occurs at the XZ-plane and at bottom near supports due to which the loading is in vertical direction so it supposed to fail first at the bottom region. The Max. Shear stress is indicated in Figure 6.

Specimen Id	XY-Plane	YZ-Plane	XZ-Plane
0%	361.27	31.061	22
10%	410.66	41.347	29.737
20%	437.78	44.077	31.701
30%	449.41	45.247	32.543
40%	462.97	46.613	33.525

Table 9: Max. Shear Stress

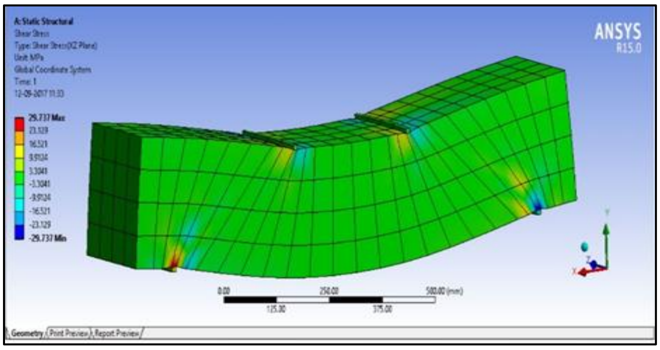

Fig. 6: Max. Shear Stress

V. CONCLUSIONS

Based on the results of this Analytical investigation, the following conclusions can be drawn:

1) It is clearly seen that the load carrying capacity of geo polymer concrete increased with the increase of copper slag replacement.
2) The significant improvement in mechanical properties upto 40% CS replacement is mainly due to the fine material of CS which fills the voids and increases the compressive strength of the concrete which in turn increases the other mechanical properties.
3) The deflection is maximum at the center increasing gradually from the ends as we have checked the deflections at L/2 and at L/3 distances.
4) The compressive strength, equivalent stresses, normal stresses, flexural properties have been gradually enhanced with the increase of the % of copper slag.
5) It is noted that shear stress values have increased proportionally with the increase of ultimate load.
6) The results of maximum central deflection for the beams with different proportions has been occurred and compared with analytical results and obtained that there was an approximate value that are coinciding with the experimental results.

REFERENCES

[1] Davidovits J. Geopolymers: Man-Made Geosynthesis and the Resulting Development of Very Early High Strength Cement, Journal of Materials Education, 16 (1994) 91-139.
[2] C. Sreenivasulu, J.Guru Jawahar, M.Vijaya Sekhar Reddy and D.Pavan Kumar,"Effect of Fine aggregate Blending on short-term mechanical properties of geo

polymer concrete, Asian Journal of Civil Engineering (BHRC), Volume-17,Issue-5(2016),PP-537-550.

[3] C.Sreenivasulu, A.Ramakrishnaiah, and J.Guru Jawahar, Mechanical properties of geo polymer concrete using granite slurry as sand replacement, Intenational Jornal of Advances in Engineering and Technology,April-2015, Volume-8,Issue-2,PP-83-91

[4] Shaishav R. Viradiya1, Tarak P. Vora "Comparative study of experimental and analytical results of FRP strengthened beams in flexure", IJRET: International Journal of Research in Engineering and Technology Volume-3, Issue- 4, April -2014, PP. 555-559.

[5] Santhakumar. R and Chandrasekaran" Analysis of Retrofitted Reinforced Concrete Shear Beams using Carbon Fiber Composites", Electronic Journal of Structural Engineering, 4 (2004), PP. 66-74.

[6] Lavate. R.S, Patil. A. T, Patil A. M, Hargude. N.V, "Dynamic Response Analysis of Fiber Reinforced Composite Beam", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684, PP: 38-47.

[7] Omran H.Y, Zangeneh.P and EL-Hacha. R, "Finite element modelling of steel-concrete composite beams strengthened with prestressed CFRP plate" International institute for FRP, December- 2009, PP. 187-192.

[8] Jayalin.D, Prince Arulraj.G, Karthika.V: "Analysis of composite beams using Ansys", IJERT: International Journal of Research in Engineering and Technology Volume-4, Issue-9, Aug-2015, PP-11-15.

[9] T. Subramanian, J. Jayalakshmi:" Analytical Investigation of Bonded Glass Fibre Reinforced Polymer Sheets with Reinforced Concrete Beam Using Ansys", IJAIEM: International Journal of Application or Innovation in Engineering & Management, Volume-4, Issue-5, May 2015,ISSN-2319-4847 PP-105-112.

[10] Mst.Sumaiya Khatun, Md. Mashfiqul Islam,Md. Rashed UI Islam, Jannatul Ferdous Doal, Mosarauf Hussan, Ashiffa Siddique "Finite Element Analysis of Steel Fiber Reinforced Concrete(SFRC): Validation of Experimental shear capacities of beams" Procedia Engineering 90 (2014) 89 – 95.

[11] Osman M. Ramadan, Sayed M. Abdelbaki Ahmedm. Saleh and Abdul Kareem Y. Alkhattabi:"Modelling of Reinforced Concrete Beams with and without opening by using Ansys", Journal of Engineering and Sciences, Assiut University, Volume-37, Issue No-4, July (2009) PP-845-858.

[12] Osman M. Ramadan, Sayed M. Abdelbaki, Ahmed M. Saleh And Abdul kareem Y. Alkhattabi:" Theoretical and Experimental Study On Mechanical Properties and Flexural Strength of Fly ash-Geopolymer Concrete", Construction and Building Materials 106 (2016) 65–77

