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Study of Corrosion of Steel Bars in Ggbs Based Geopolymer Concrete

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Abstract: In modern construction concrete and steel are the important materials in RC Buildings. In that, steel plays a major role in strength and durability properties of the structures. The Chloride ion present in the concrete form a passive layer over the embedded steel in concrete causes breakdown. Corrosion of steel occurs due to chemical attack and environmental attack. Steel losses its strength due to corrosion and it needs to be protected. Geo-polymer concrete is a new alternative to conventional concrete. The engineering and construction industry has successfully engaged in challenge for consuming "Sustainable green and recycled products" in manufacture of concrete. In order to reduce the environmental problem related to disposal of Ground Granulated Blast Furnace Slag (GGBS) has potential to be used as concrete material. In this research paper, we deal with prediction of corrosion rate with various methods and also the mechanical properties of the GGBS based Geo-polymer Concrete.

Keywords: GGBS, Steel bars, Induced Corrosion, Corrosion rate, Half-Cell Potential, Accelerated corrosion Test.

I. INTRODUCTION

Environmental pollution is one of the biggest problems the world faces today. CO_2 emission by the concrete industry is one of the major contributors in greenhouse gases. The cement industry is responsible for about 6% of all CO_2 emissions. Cement (OPC) production is drastically increased during recent years and its production creates environmental and impose ecological issues. Production of one ton of Portland cement emits approximately one ton of CO_2. In order to reduce this an alternative binder which are rich in silica and alumina like industrial by products such as fly ash, ground granulated blast furnace slag GGBS, rice husk, metakaolin etc used in place of OPC to reduce CO_2 emission.

The GGBS based geo-polymer is used as the binder, as an alternative of Portland or some other hydraulic cement paste, to produce geopolymer concrete. The geopolymer glue formed by combination of source material and alkaline activator solution binds the free coarse aggregates and fine aggregates together to make the geopolymer concrete, with or without the presence of admixtures. The making of geopolymer concrete is carried out by using the usual concrete technology methods. In the normal concrete, the aggregates occupy the major volume, i.e. about 75-80% by mass. In this study 78% volume occupied by aggregates in geopolymer concrete.

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The silicon and the aluminium present in the GGBS are activated by a mixture of sodium hydroxide and sodium silicate solutions to make the geopolymer paste that binds the aggregates.

The engineering and construction industry has successfully engaged in a challenge for consuming, "Sustainable, green and recycled products" in manufacture of concrete. Ground Granulated Blast Furnace Slag (GGBS) has potential to be used as concrete material in place of Binder. It is been well recognized that the major cause for the reduction in the overall performance of any type of concrete is due to lack in durability and corrosion resistivity and hence based on that, studies are conducted.

II. LITERATURE SURVEY

Osborne [1998] studied the performance and long term durability of GGBS concrete and compared it with Portland cement concrete and concluded that there are many technical and financial uses and recommendations are given for effective use of GGBS in concrete. Several research studies were done on accelerated corrosion tests for determining corrosion resistance of reinforced concrete. While many researches had chosen a constant voltage setup(Deb and Pradhan 2013, Kishore Kumar *et al.2012*), several other researchers employed constant current setup. One of the studies (El Maaddawy *et al.* 2003) employed impressed current techniques to determine the corrosion resistivity of concrete.

III. MATERIALS

A.Materials Used

Binder:

Cement: Portland cement is the common type of cement used .In this, Ordinary Portland cement is used for concrete.

Ground Granulated Blast Furnace Slag(GGBS): It comprises mainly of calcium oxide, silicon di-oxide, aluminium oxide, magnesium oxide. It has the same chief chemical elements as ordinary Portland cement but in different proportions and the addition of GGBS in geopolymer concrete (GPC) increases the strength of the concrete and also curing of Geo-Polymer concrete at room temperature is possible. The figure shows the GGBS in powder form. Chemicals Present in GGBS are calcium oxide (30-50%), silicon di-oxide (28-38%), aluminium oxide (8-24%), magnesium oxide (1-18%), Manganese oxide (0.68%), titanium dioxide (0.58%), potassium dioxide (0.37%), sodium di oxide (0.27%).

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Aggregates: Aggregates provide strength and durability to the concrete. Coarse aggregates of 12mm size were used and the specific gravity was 2.74. Fine aggregate used is M-sand.
Water: By the process of hydration, cementitious material reacts with water and form a paste. This cement paste fills the voids and makes the aggregate together. Low water cement ratio makes a durable, strong concrete.
High water cement ratio makes high slump concrete.
Alkaline solution: The important constituent of GPC is alkaline liquid. NaOH is available in pellets form. It is dissolved in water a day prior to use to make required molarity / concentration .8M = (8 x 40 = 320gm).Na_2SiO_3 is available in brownish coloured.
Super plasticizer: To achieve the workability for concrete, superplasticizers are used. In this, Conplast SP430 is used.

Water: Generally, water is used to achieve workability for concrete. In this 12% water is used.

B. Mixture Proportions

The mix proportioning for M25 grade concrete has been done as per IS10262. As a result of various trial mixes, the ratio of ingredients obtained as **1: 1.8: 3.2.** The concrete quantities for various materials are given in Table 2 and 3

C. Curing Condition

Chemical Ambient curing process has been adopted throughout the study.

Table 1. Quantities of Conventional Concrete

Materials		GPC Kg/m^3	OPC Kg/m^3
Binder	GGBS	330	-
	Cement	-	350
Fine Aggregate		822	780.2
Coarse Aggregate		1342	1220
NaOH		55	-
Na_2SiO_3		179	-
Water		10% of Binder	175

IV. EXPREMENTAL PLAN

The various tests are done for the corrosion study of both the concrete as well as the reinforcement bars and durability studies as well are done as follows

4.1. Engineering properties

4.1.1 Tensile strength test

Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to know the tensile strength of concrete to determine the load at which the concrete members may crack. The equation for finding the tensile strength is,

ft = [(2*P) / (3.14*D*L)]

Where ft is the tensile strength of concrete (MPa),
P is the load, at which concrete fails,
D is the diameter of the cylinder
L is the length if the cylinder

4.2. Durability tests

4.2.1 Acid attack test

Some chemical environments can deteriorate the concrete even if it is a high-quality concrete. Sulphuric acid can be formed by sulphurous gases which forms during combustion react with moisture and forms sulphuric acid. Also, the bacteria present in the sewage converts in to sulphuric acid. During the reaction of sulphuric acid with concrete, calcium sulphoaluminate will forms and it crystallise and causes expansion and disruption of concrete. For the acid attack test, three specimens of cubes 150mm x150mm x150 mm after curing were taken. Note the initial weights of the cubes before immersing in the solution. Specimens were immersed in the solution of 5% of sulphuric acid. The pH of 3 was maintained throughout the test. After 28, 56 and 90 days, specimens have to keep for 1 day for drying. After drying, check the weight of the specimens and also, the compressive strength of the specimens by testing it in compressive testing machine. Compare the decrement of weights and compressive strength with conventional concrete.

4.2.2sulphate attack test

Sulphate attack can happen in two ways-internal and external attacks. External sulphate attack can happen through environments like soil, water which penetrates to concrete structures. Internal sulphate attack can happen either by high sulphate content or from aggregates contaminated with gypsum. Ettringite formation will happen when sulphate reacts with hydrated compounds in concrete and it leads to expansion and results in cracking and spalling of concrete. The specimens after curing were weighed and noted as the initial weight of the specimens. Then, the specimens were immersed in the 5% of sodium sulphate solution. After 28, 56 and 90 days, specimens were taken out from the solution and allow it to dry. Check the weight of the specimen as final values of specimens. Also, the compressive strength and compare it with initial compressive strength.

4.2.3 Chloride attack test

Chloride attack is the primarily cause of corrosion of reinforcement. Calcium chloride and sodium chloride leaches calcium hydroxide and cause concrete disintegration. For the chloride attack, specimens were immersed in 5% of sodium chloride solution. Before immersing, dry weights of the specimens are to be noted. After particular days, take out the specimens and keep it for drying. Weigh the specimens and check the variation in the weights. Also check the compressive strength and find the percentage change in the compressive strength of the specimens It is seen that the surface is smooth and chloride did not penetrate to the concrete.

4.3. Corrosion Studies:

4.3.1 Rapid chloride penetration test

In this test, the chloride ion penetration is tested by passing current. The procedure for the RCPT test is given in ASTM C 1202.It indicates the resistance of concrete to chloride ion penetration.

The cylinder is cut into the disc cylinders of 50 mm thickness and 100 mm thickness diameter using cutting machine. Then the sample's lateral side is coated with epoxy resin and rest it for dry. Specimens are kept in vacuum chamber for 3 hours and then saturated it with water. After that, the specimens are inserted into the cells and seal it tight using epoxy resin so that it will be water tight and keep it for one day for drying. One cell is connected to cathode terminal that is filed with 3% of sodium chloride solution. Other cell is connected to anode filled with 0.3N of sodium hydroxide solution. Specimens are subjected to 60V potential continuously for 6 hours. Current and temperature readings being measured in every 15 minutes, from which total charge passed is calculated.

4.3.2 Half Cell Potential

The Half-Cell Potential method was conducted as per ASTM C 876. This method is used to monitor the probable corrosion of reinforcement in concrete by electrochemical method. In this test, a voltmeter was connected between reinforcing steel bar and CSE(Copper-Copper Sulphate Electrode)reference electrode on the surface of concrete and Half-Cell Potential is measured. The specimens were cured for 28 days and then subjected to different environment such as ambient room temperature and submerged in sodium chloride solution over a period of 90 days.

4.3.3 Salt Spray Test

The Salt spray test was carried out in accordance with ASTM B117-16. This method is used to accelerate the corrosion process in the concrete and to determine which concrete has better corrosion resistivity in chloride environment. The specimen is subjected to a total period of 168 hours. The actual test conditions are as follows: Chamber temperature: 34.2°-34.7°C, pH of Solution: 6.5, Air Pressure: 15 psi, Concentration of Sodium Chloride: 5.3%, Collection of solution per hour: 1.3 ml.

V.RESULTS AND DISCUSSION

A.Splitting Tensile Strength

Tensile strength is the measure of the ability of a material to withstand a longitudinal stress, expressed as the greatest stress that the material can stand without breaking. To understand the effect of bottom ash as fine aggregate on tensile strength of cement concrete, cylinder specimens of size 100mm diameter and 200mm length were casted, then testes at the age of 7, 28 and 90 days. The test was conducted as per standards of IS 5816 and the results are computed as follows.

Table 2. Tensile Strength values N/mm^2

Sp.ID/ No. of days	7 days N/mm^2	28 days N/mm^2	90 days N/mm^2
OPC	2.9	3.5	3.89
GPC	5.2	5.56	5.68

- The GGBS Based Geopolymer concrete has major increase in the tensile strength in comparison with Ordinary Portland Cement Concrete.
- Based on the mechanical strength of concrete the following observations are made.

B.Acid attack test

The samples kept in 5% of sulphuric acid solution and the pH values were maintained and checked for weight and compressive strength. It's noticed that there is a change in weight as the outer layer gets degraded. Also, there is a decrease in the compressive strength of the sample as compared to the initial strength. As per standards of ASTM C – 267 the test where conducted and the specimen where kept in.

Table 3: Percentage of change in strength in acid attack

Mix Proportions	% of change		
	28 days	56 days	90 days
OPC	8.1	13	15
GPC	12.9	16	22.3

Fig. 1: 56 day Specimen of Acid Attack

- In acid attack there is much decrease in weight and for Geopolymer concrete There is 22.3% change in strength at 90mdays testing.

C.Sulphate attack test

In sulphate attack, sulphate reacts and there will be disruption of cement paste that leads to loss in strength and cohesion. Samples were immersed in 5% of magnesium sulphate solution after curing. The test has been done as per the standards of ASTM C 1012-10.

Table 4: Percentage of change in strength in sulphate attack

Mix Proportions	% of change		
	28 days	56 days	90 days
OPC	3.16	4	4.79
GPC	2	3.8	4.81

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- The Change in strength of Geopolymer concrete is the same as that of conventional concrete at 90 days

Fig. 2: Sulphate resistance specimen at 90 days

D. Chloride Attack Test

The chloride resistance of control concrete and BA concrete were evaluated by measuring the residual compressive strength after chloride exposure. Cubes were immersed in solution after 28days ofcuring period. Sodium Chloride (Nacl) solution with 5% concentration was used as the standard exposure.The specimens were immersed in the Sodium Chloride solution in a tank. The test where carried as per IS code specifications.

Table 5. Percentage of change in strength in Chloride attack

Mix Proportions	% of change		
	28 days	56 days	90 days
OPC	3.16	4.8	6.43
GPC	3.03	4.67	6.6

As per test results the Geopolymer concrete is durable and resistant to Acid attack, Sulphate and salt water penetration.

E. Rapid chloride penetration test

In this test, the chloride ion penetration is tested by passing current. The procedure for the RCPT test is given in ASTM C 1202.It indicates the resistance of concrete to chloride ion penetration. The cylinder is cut into the disc cylinders of 50 mm thickness and 100 mm thickness diameter using cutting machine. Then the sample's lateral side is coated with epoxy resin and rest it for dry. Specimens are kept in vacuum chamber for 3 hours and then saturated it with water. After that, the specimens are inserted into the cells and seal it tight using epoxy resin so that it will be water tight and keep it for one day for drying. One cell is connected to cathode terminal that is filed with 3% of sodium chloride solution. Other cell is connected to anode filled with 0.3N of sodium hydroxide solution. Specimens are subjected to 60V potential continuously for 6 hours. Current and temperature readings being measured in every 15 minutes, from which total charge passed is calculated.

Average current flowing through one cell is calculated by,

$$I = 900^* [I0 + 2^*[I30 + I60 + I90 + I120 + I150 + I180 + I210 + I240 + I270 + I300 + I330 + I360]]$$

where I0 = Initial current reading in mA.
I30 = Current reading at 30 minutes in mA.
I60 = Current reading at 60 minutes in mA.
I90 = Current reading at 90 minutes in mA.
I120 = Current reading at 120 minutes in mA.
I150 = Current reading at 150 minutes in mA.
I180 = Current reading at 180 minutes in mA.
I210 = Current reading at 210 minutes in mA.
I240 = Current reading at 240 minutes in mA.
I270 = Current reading at 270 minutes in mA.
I300 = Current reading at 300 minutes in mA.
I330 = Current reading at 330 minutes in mA.
I360 = Current reading at 360 minutes in mA

Table 6. Rcpt results

Mix Proportions	Rapid Chloride Penetration Test		
	28 days	56 days	90 days
OPC	1100	1250	1300
GPC	864	923	989

Table 7. Chloride Permeability Based on Charge Passed

Charges passed (columbs)	Chloride pearmiability
>4000	High
2000 – 4000	Moderate
1000 - 2000	Low
100 – 1000	Very low
<100	negligible

Table 10 shows the classification of these samples into different categories of chloride ion permeability from negligible to very low. The results show that the samples are resistant to chloride penetration, where the Geopolymer concrete is resistant with the category of very low and the Ordinary Portland cement concrete are low. Thus Geopolymer concrete is resistant to chloride attack since they are less permeable, less porous.

F. Half Cell Potential

The samples were kept under 5% NaCl solution and readings were taken at specific intervals. In this case, we can see the accelerated corrosion rate as compared to the other environments in chloride induced environment. The most common chemical salt is the sodium chloride. Sodium chloride deposited on atmospherically exposed surface acts as a hygroscopic material (It extracts moisture from the air), which then increases the corrosion in non-immersed areas. This can be correlated to high voltage values in case of chloride environment than in the ambient room temperature. The test results are given in Table 8.

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Table 8. Half Cell Potential Resullts

No. Of Days	Corrosion Potential (mV)							
	Ambient Temperature				5% NaCl Solution			
	GPC		OPC		GPC		OPC	
	Fe 500	Fe 550	Fe 500	Fe 550	Fe500	Fe 550	Fe 500	Fe 550
0	-3.3	-3.1	-3.8	-3.7	-3.3	-3.1	-3.8	-3.7
7	-4.4	-4.2	-4.2	-4.6	-34.3	-33.8	-37.1	-35.8
14	-6.2	-6.0	-6.9	-7.3	-46.4	-45.9	-49.9	-48.5
28	-10.2	-9.3	-10.7	-9.7	-61.1	-59.9	-63.4	-62.9
56	-23.6	-22.3	-22.8	-21.4	-89.2	-87.4	-91.8	-90.2
90	-43.2	-42.8	-42.30	-41.7	-129.3	-127.1	-132.3	-128.8

G. Salt Spray Test

The samples were tested in salt spray chambers for a period of 168 hours and then taken out and visually inspected Then the concrete is broken and the reinforcement inscribed in the concrete is checked for any corrosion. The corrosion of steel bars in OPC is more compared to the GGBS concrete. There was no corrosion observed in GGBS concrete containing Fe 550 steel bars and small amount of corrosion in Fe 500 bars after removing the concrete shell.

This shows the chloride resistivity of GGBS based Geopolymer Concrete.

- The actual test conditions are as follows:
  - Chamber temperature: 34.2°-34.7°C,
  - pH of Solution: 6.5,
  - Air Pressure: 15 psi,
  - Concentration of Sodium Chloride: 5.3%,
  - Collection of solution per hour: 1.3 ml.
  - Test Period: 168 hours

Fig. 3: Salt Spray test Specimen after 168 hours test

VI. CONCLUSION

The Following conclusions were drawn from the above investigation:

1) HCP was measured for different cylindrical specimens exposed to different environments for a period of 90 days such as ambient temperature surroundings and chloride environment. HCP measurements increase with increasing days and Geo-polymer concrete had significantly low HCP measurements than Conventional concrete which shows the corrosion resistivity of GGBS concrete.
2) When the cylindrical specimens were subjected to salt spray test for a period of 168 hours. The Geo-polymer concrete showed good resistance and compared to conventional concrete.
3) From the weight loss method, The corrosion rate of the cylindrical specimens subjected to SST are given and from that it is evident that Fe 500 bars present in both Geo-polymer concrete and Conv. Conc. Did not show promising results as they started corroding at an early period in the test. At the end of test period corrosion rates for cylindrical specimens Geo-polymer concrete cyl. Specimens showed a corrosion rate of 26% less than that of the conventional concrete.
4) Based on the STS test results it is also evident that the Geo-polymer concrete has better resistance to chloride environment than the conventional concrete although at certain points of time conventional concrete also showed good resistance to chloride penetration.

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