A Study on Water Absorption and Sorptivity of Geopolymer Concrete

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Abstract: *During this study, the water absorption and sorptivity properties of fly-ash based geopolymer concrete were studied in detail. Geopolymer concrete is one among the steps taken towards sustainable construction. It has a lower greenhouse footprint than traditional concrete. The effect of accelerated corrosion on geopolymer concrete was also studied and the results were compared with control concrete. It was concluded through the study that geopolymer concrete is less porous and has a lesser linear curve as compared to control concrete.*

Keywords: *Geopolymer concrete, fly ash, compressive strength, control concrete, water absorption, sorptivity.*

1. Introduction:

Concrete usage around the world is second only to water. Ordinary Portland Cement (OPC) concrete is the most popular and widely used building materials, due to availability of the raw materials all over the world, its ease in preparation and fabrication in all sorts of conceivable shapes. About 1.5 tons of raw materials is needed in the production of every ton of OPC, at the same time about the amount of carbon dioxide released during the manufacturing of Ordinary Portland Cement (OPC) due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. On the other hand, the abundant availability of fly ash worldwide creates opportunities to utilize this by-product of burning coal, as a substitute for OPC to manufacture concrete. It is essential to find alternatives to make environment friendly concrete.

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. According to Davidovits, geopolymerization is age of synthesis that chemically integrates materials containing silicon and aluminum. During the process, silicon and aluminum atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks. By using the fly ash based geopolymer concrete reducing the two environmental related issues i.e. the high amount of released to atmosphere during production of OPC and utilization of Fly ash.

In this study, design mix of M25 grade was used for the tests. Factors such as Alkaline liquid to Fly Ash ratio =0.4, Sodium Silicate to Sodium Hydroxide ratio =2.0, Molarity=M14, Curing temperature =75^{0}C, Curing Time = 24hours, Rest Period = 1day, Admixture Dosage =2% were kept constant during the tests. The main objective of the study was to compare the water absorption capacity and sorptivity of control and geopolymer concrete.

2. Materials:

2.1. Fly ash:

Fly ash used in this study is low calcium Class F fly ash from Dirk India Private Limited under the name of the product POZZOCRETE 60. Physical properties and chemical compositions of the fly ash used along with the specifications are given in Table 1.

Table 1: Properties of class F fly ash

Sr.No.	Particulars	Unit	Specification (IS:3812-1981)[24]	DIRK POZZOCRETE60 (Fly ash)
1	Colour	-	-	Light gray
2	Specific surface area (blaine)	m^2/kg	320	340
3	Lime reactivity	N/mm^2	4.5	5.48
4	Loss on ignition(max)	%	5	1.6

5	$SiO_2+Al_2O_3+Fe_2O_3$	%	70 min. by mass	92.49
6	SiO_2	%	35 min. by mass	57.3
7	MgO	%	5 max. by mass	2.13
8	SO_3	%	3 max. by mass	1.06
9	Na_2O	%	1.5 max. by mass	0.73
10	Total Chlorides	%	0.05 max. by mass	0.029

2.2. Alkaline Liquid

The alkaline liquid used was a combination of sodium hydroxide and sodium silicate solution.

Sodium Hydroxide

Sodium hydroxide is commonly available in flakes or pellets form. Sodium hydroxide (NaOH) in flakes form with 98% purity shown in figure 1 was purchased from local chemical supplier has been used. Sodium hydroxide solution was prepared by dissolving the flakes in water. Tap water available in laboratory was used to prepare NaOH solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar M.

Figure 1: Sodium Hydroxide Flakes

Sodium Silicate

Many types of sodium silicate solution depending upon applications are available in market. Properties of the sodium silicate solution used are given in the Table 2.

Table 2. Properties of sodium silicate solution

Properties	
Na_2O%	16.8
SiO_2%	35.0
Water%	46.3
SiO_2/Na_2O	2.08
Specific gravity(g/cc)	1.48

2.3 Aggregates:

Locally available 10 mm and 20 mm crushed aggregates have been used as coarse aggregates. Locally available river sand was used as fine aggregate in the mixes. The result of sieve analysis for fine aggregate is shown in Table 3.

Table 3. Sieve analysis of fine aggregate

Fine Aggregate				
Sieve Size	Mass retained(gm)	Cumulative mass retain(gm)	Cumulative mass retain(%)	Cumulative Mass passing(%)
4.75mm	0	0	0	100
2.36mm	130	130	13.00	87
1.18mm	19	149	14.9	85.1
600m	86	235	23.5	76.5
300m	508	743	74.3	25.7
150m	180	923	92.3	7.7
Below 150m	64	997	99.7	0

		Total	317.7	
Fineness Modulus=317.7/100=3.18 and Zone III				

2.4 Superplasticiser:

Naphthalene Sulphonate based super plasticiser, supplied by BASF, under the brand name Rheobuild 1125, has been used to improve the workability of the fresh geopolymer concrete.

3. TESTING:

3.1. Sorptivity:

The sorptivity test is a simple and rapid test to determine the tendency of concrete to absorb water by capillary suction. The test was developed by Hall (1981) and is based on Darcy's law of unsaturated flow.

- Test Specimens

Test specimens for compressive strength and change in mass test were 150×150×150mm cubes of control concrete and geopolymer concrete each. 3 specimens for each test were prepared compressive strength and change in mass to take average result of the specimen.

- Test Procedure

The samples were pre-conditioned for 7 days in hot air oven at 500 C. The sides of the specimen were sealed in order to achieve unidirectional flow. Locally available wax and resin with 50:50 proportions was used as sealant. Weights of the specimen after sealing were taken as initial weight. The initial mass of the sample was taken and at time 0 it was immersed to a depth of 5-10 mm in the water. At selected times (typically 1, 2, 3, 4, 5, 9, 12, 16, 20 and 25 minutes) the sample was removed from the water, the stop watch stopped, excess water blotted off with a damp paper towel or cloth and the sample weighed. It was then replaced in water and stop watch was started again.

The gain in mass per unit area over the density of water is plotted versus the square root of the elapsed time. The slope of the line of best fit of these points (ignoring the origin) is reported as the sorptivity. ASTM – 1585 -04 were followed to conduct the test.

3.2. Water absorption:

Water absorption characteristic of concrete plays an important role for the durability. The test was perform to evaluate the water absorption characteristics of geopolymer and control concrete.

- Test Specimens

Test specimens for compressive strength and change in mass test were 150×150×150mm cubes of control concrete and geopolymer concrete each. 3 specimens for each test were prepared compressive strength and change in mass to take average result of the specimen.

- Test Procedure

Test specimens were oven dried at 105^{0}C for 24 hours duration using hot air oven. After oven dry the specimens were immersed in water for 24 hours duration. Absorption characteristic of concrete will be evaluated by difference in weight of specimen after complete drying in oven at 105^{0} C and weight after immersion in water.

3.3. Accelerated corrosion:

Corrosion of reinforcement cause cracking and spalling of concrete and results in to reduction of life of structure. Corrosion resistance is an important factor for the marine and coastal structures. Test is performed to study the corrosion resistance characteristic of geopolymer and control concrete.

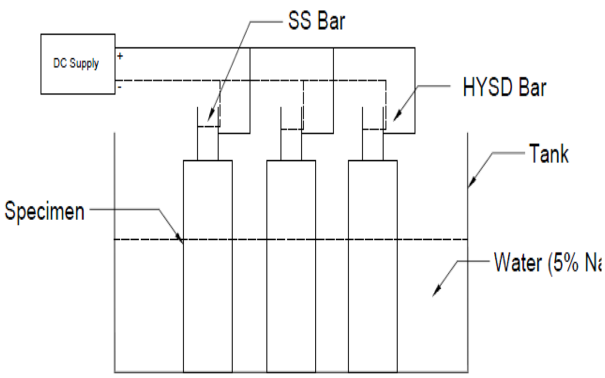
- Test Specimens

Test specimens for compressive strength and change in mass test were 150×150×150mm cubes of control concrete and geopolymer concrete each. 3 specimens for each test were prepared compressive strength and change in mass to take average result of the specimen.

- Test Setup and Procedure

The test specimen were immersed in NaCl solution with 5% concentration upto 2/3 height after 28 days of curing as shown in Figure 2. Then the exposed steel bars were connected to the positive terminal of a constant 30 volt DC power supply, to make the steel bars act as a nodes. This high voltage was used to accelerate the corrosion and shorten the test period. The negative terminal of the DC power source was connected to a stainless steel bar, to make the stainless steel bar act as cathode. When crack is initiated in the specimen by stresses caused by buildup of corrosion products, the electrolyte solution has a free path to the steel. This results in a sudden increase in current. So, in order to determine the time at which the current was recorded at different time intervals.

Figure 2. Accelerated Corrosion Test Setup



Sorptivity property of both type of concrete has been study by performing the at 1, 2, 3, 4, 5, 9, 12, 16, 20 and 25 minutes time interval and change in weight of the specimen after each interval. The Table 4 and Table 5 show the readings and calculations for each interval for control concrete and geopolymer concrete respectively. The Sorptivity curve was found to be less linear compared to that of control concrete. The rate of absorption, which has significant effect on durability property of concrete, was found less in geopolymer concrete than the control concrete.

4. RESULTS:

4.1. Sorptivity

Table 4: Sorptivity Readings and Calculations of Control Concrete

Time (Min.)	Weight (kg)	Gainin wt.(kg)	Cumulativegain inWt(kg)	Vol.of water(mm^3)	Surface area(mm^2)	i(mm)	Time ($min^{0.5}$)
0	8.403	0.000	0.000	0.000	22500	0.000	0
1	8.407	0.004	0.004	3666.667	22500	0.163	1.00
2	8.408	0.001	0.005	4666.667	22500	0.207	1.41
3	8.409	0.001	0.006	5666.667	22500	0.252	1.73
4	8.410	0.001	0.007	7000.000	22500	0.311	2.00
5	8.411	0.001	0.008	7666.667	22500	0.341	2.24
9	8.413	0.002	0.009	9333.333	22500	0.415	3.00
12	8.414	0.002	0.011	11000.000	22500	0.489	3.46
16	8.415	0.001	0.012	12000.000	22500	0.533	4.00
20	8.417	0.002	0.014	13666.667	22500	0.607	4.47
25	8.418	0.001	0.015	14666.667	22500	0.652	5.00
Sorptivity=0.124mm/$min^{0.5}$							

Table 5: Sorptivity Readings and Calculations of Geopolymer Concrete

Time (Min.)	Weight (kg)	Gainin wt.(kg)	Cumulativegain inWt(kg)	Vol.of water(mm^3)	Surface area(mm^2)	i(mm)	Time ($min^{0.5}$)
0	8.520	0.000	0.000	0.000	22500	0	0
1	8.523	0.003	0.003	3000.000	22500	0.1333	1.00
2	8.524	0.002	0.005	4666.667	22500	0.2074	1.41
3	8.525	0.001	0.006	5666.667	22500	0.2519	1.73
4	8.526	0.001	0.007	6666.667	22500	0.2963	2.00
5	8.526	0.000	0.007	6666.667	22500	0.2963	2.24
9	8.528	0.001	0.008	8000.000	22500	0.3556	3.00
12	8.529	0.001	0.009	9000.000	22500	0.4000	3.46
16	8.530	0.001	0.010	10000.000	22500	0.4444	4.00
20	8.531	0.001	0.011	11000.000	22500	0.4889	4.47
25	8.531	0.001	0.012	11666.667	22500	0.5185	5.00
Sorptivity=0.090mm/$min^{0.5}$							

Figure 3: Sorptivity of Control Concrete

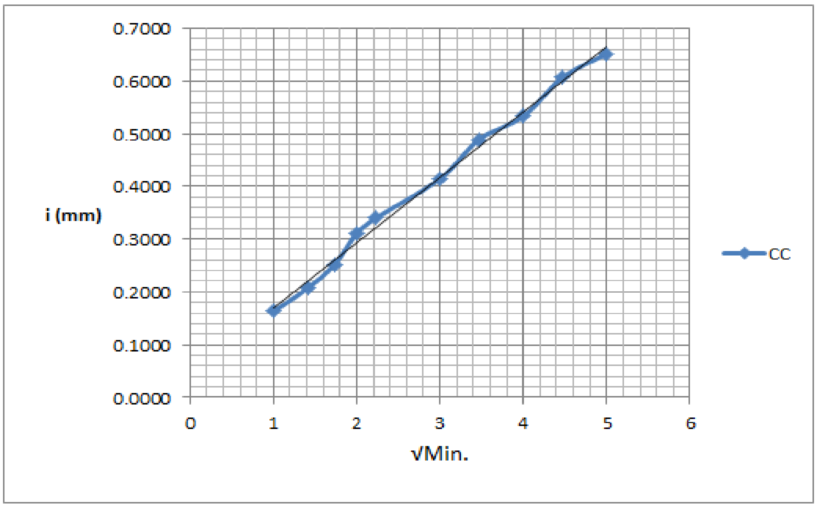
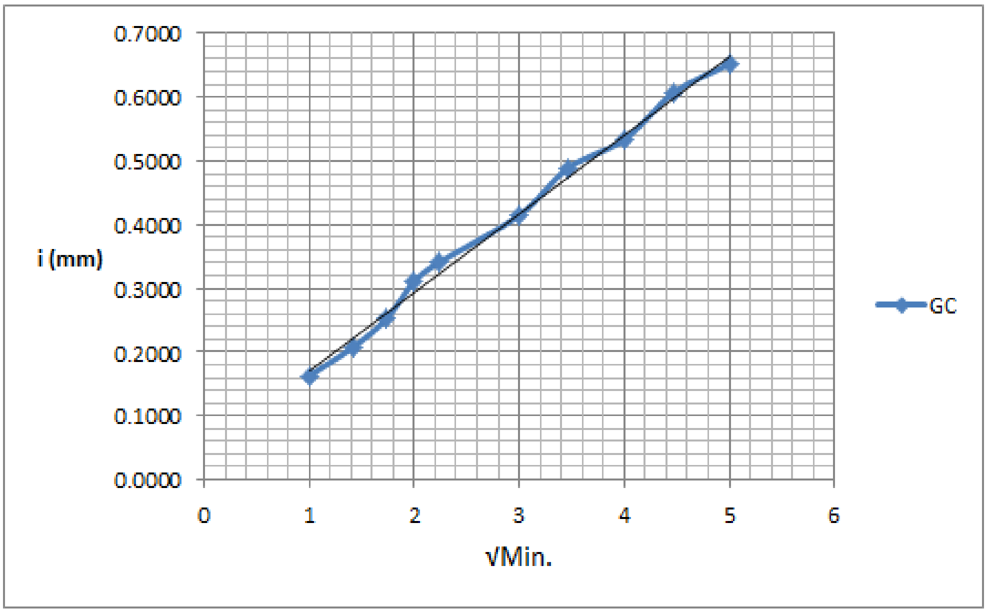


Figure 4: Sorptivity of Geopolymer Concrete



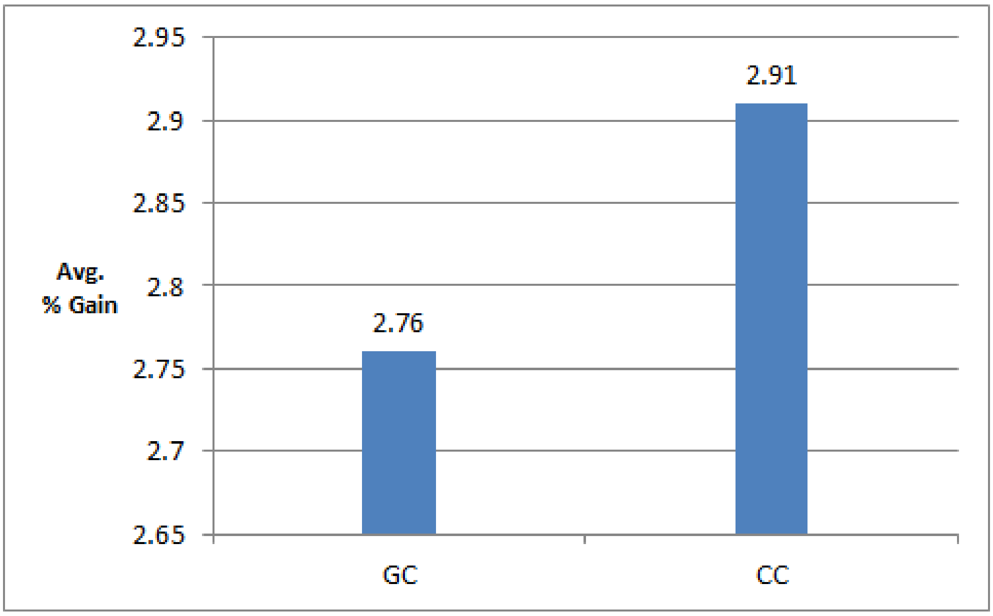
4.2. Water Absorption

Water absorption characteristics of the concrete plays an important role for the durability of the structure. Ingress of water detoriates concrete and in reinforced concrete structure, corrosion of the bars took place which results it no cracking and spalling of the concrete and ultimately reduce the life span of the structure. Test results of water absorption test are shown in Table 6. The result indicates that the water absorption of geopolymer concrete is less compared to control concrete. Although the difference in % of gain in weight is very less.

Table 6: Water Absorption Test Results

Typeof Concrete	Notation	Initial Wt.(kg)	OvenDry Wt.(kg)	Wt.after immersion	Gain %	Avg.gain %
GC	GC-1M	8.35	8.27	8.51	2.90	2.76
	GC-2M	8.30	8.22	8.44	2.68	
	GC-3M	8.25	8.17	8.39	2.69	
CC	CC-1M	8.60	8.47	8.68	2.48	2.91
	CC-2M	8.59	8.46	8.69	2.72	
	CC-3M	8.47	8.23	8.52	3.52	

Figure 5: Water Absorption of Concrete



4.3. Accelerated Corrosion Test

This study evaluated the corrosion based durability characteristics of low calcium fly ash based geopolymer concrete and its comparison with control concrete subjected to the marine environment. The resistance of corrosion has been evaluated by measuring current readings of the specimen at regular interval and also by visual inspection has been done. Ultrasonic Pulse Velocity (UPV) readings were also taken to study the change in concrete quality due to the corrosion incorporated. Comparison of Current readings and UPV readings is shown in Figure 17 and Figure 18 respectively.

The crack initiation of control concrete were observed after 116 hours by change in current as well as visual observation. Geopolymer specimen took longer time with crack initiation after 144 hours. The test results indicated excellent resistance of the geopolymer concrete to chloride attack, with longer time to corrosion cracking, compared to control concrete. UPV results shows that the reduction of velocity readings for geopolymer concrete was 7.62% compared to that of 10.26% that of control concrete.

Half cell potential meter readings were also taken to study the extent of corrosion in geopolymer and control concrete specimen. The initial readings of geopolymer concrete were significantly higher than the control concrete, this may be due to the alkaline liquid composed of sodium silicate and sodium hydroxide. Even though the occurrence of cracking in geopolymer specimen was delayed, the reading indicate more corrosion in geopolymer specimen. Hence, these results have been discarded.

Table 7: Current Readings

Unit	Current(Amp.)	
Specimen	CC	GC
Hours	-	-
0	0.84	1.58
24	0.57	0.95
44	0.61	1.05
53	0.64	1.13
72	0.66	1.21
96	0.70	1.31
116	0.90	1.37
144	-	1.73

Figure 6: Specimen Current Readings

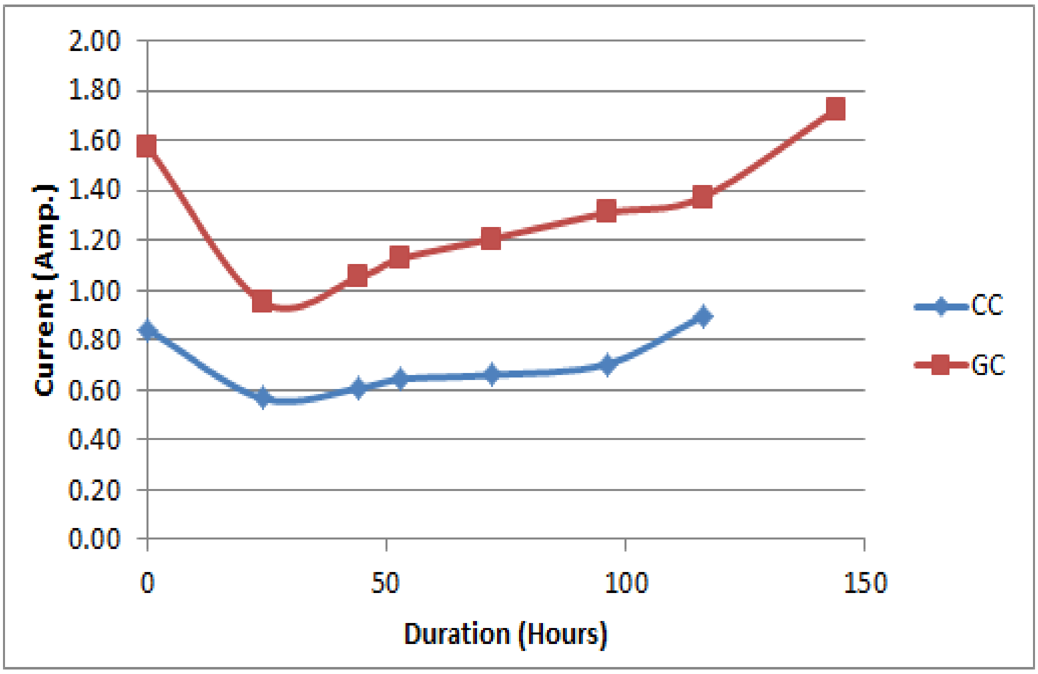


Figure 7: Ultra Pulse Velocity Readings for Accelerated Corrosion Test

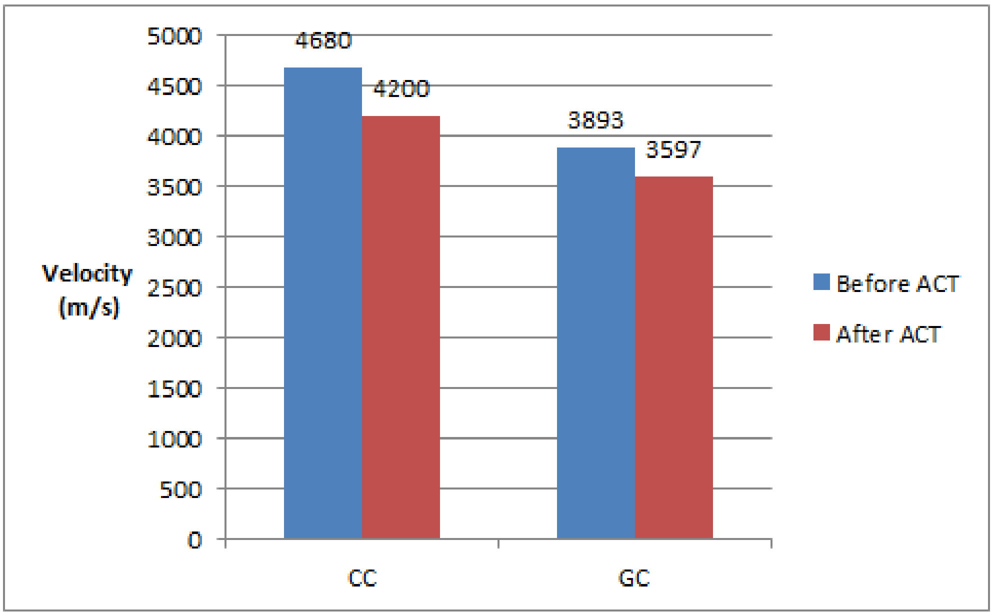
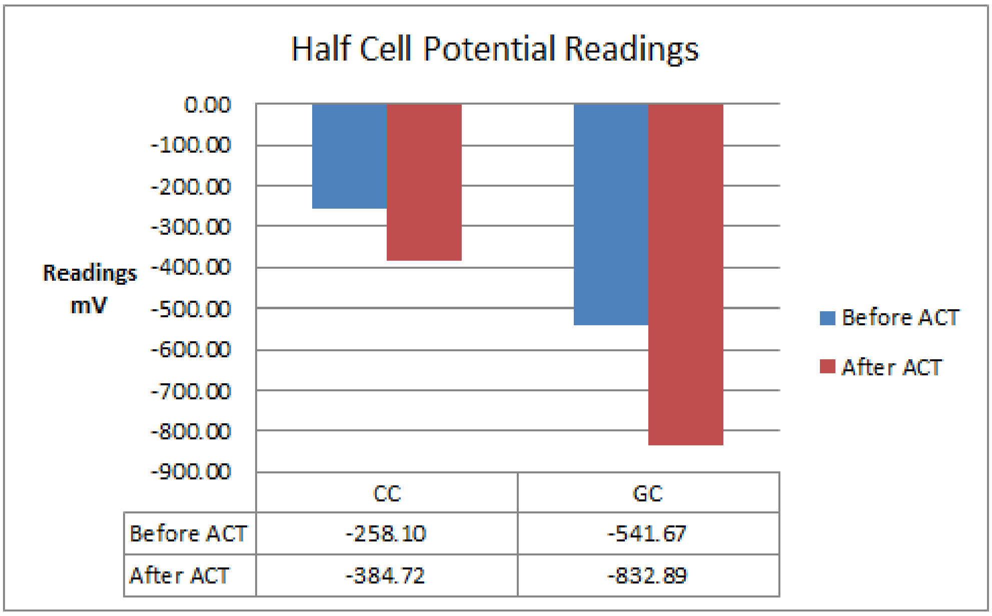


Figure 8: Half Cell Potential Meter Readings for Accelerated Corrosion Test



CONCLUSION:

The mix design of M25 geopolymer concrete was used in the study. The results were compared to that of control concrete. It was found thattThe Sorptivity curve is less linear as compared to that of control concrete. That means the rate of absorption of geopolymer is less. Test results of water absorption test shows that the porosity of geopolymer concrete is less as fly ash is fine than OPC and results in to less water absorption than the control concrete. Accelerated Corrosion test was also performed on cylinders of 150 mm diameters and 300 mm height with stainless steel bar and HYSD bar embedded in it. Impressed current technique was adopted with 30V constant power supply. Corrosion resistance was evaluated by change in current, half cell potential meter readings, UPV results and visual inspection. The results showed that the corrosion occurrence in geopolymer concrete takes longer time than control concrete.

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