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Durability Studies of Fly Ash Based Geopolymer Concrete

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ABSTRACT
A detailed study on the durability of geopolymer concrete has been done. Geopolymer concrete is an environment friendly concrete which has lower carbon footprint as compared to that of conventional concrete. In this study, cement has been replaced by fly ash and the properties such as compressive strength, sulphur resistance, acid resistance, water absorption, sorptivity and chloride attack have been studied. Class F fly ash has been used and geopolymer concrete was heat cured for 24 hours under 75◦C. It was observed that use of geopolymer in concrete not only reduces its greenhouse footprint but, also increases its strength and resistivity to harmful acids.
KEYWORDS: Geopolymer concrete, fly ash, compressive strength, control concrete, sulphate resistance, acid resistance, sorptivity.

I. INTRODUCTION

With increasing concern about environment, sustainable development and green design issues have become an important part of civil engineering. Geopolymer concrete is one such step taken towards sustainable development. The manufacturing of conventional concrete releases a considerable amount of carbon di-oxide in the atmosphere. A study shows that its production contributes to 7% of the global CO_2 emissions. Geopolymer concrete is an eco-friendly material of construction which has lower carbon footprint than conventional concrete.

Geopolymer concrete is made from industrial waste materials like fly ash, GGBS etc. which contain alumina-silicate by their alkali activation. Geopolymer not only reduce the greenhouse footprint of the concrete but also enhances its mechanical properties. Geopolymer concrete resists chloride penetration and acid resistance. Also, it has very low creep and shrinkage. Geopolymer has been divided into nine classes among which the class with alumina-silicates is the most popular for use in concrete.

In this study, the properties fly-ash based geopolymer concrete have been studied in detail.The main objectives of this study are to study the change in compressive strength of geopolymer concrete with change in fly ash content, to study durability properties of geopolymer concrete i.e. Permeability, Acid resistance, Sulphate resistance, Chloride attack, Sorptivity after various days of exposure and its comparison with control concrete and to study effect of accelerated corrosion on Geopolymer Concrete and its comparison with control concrete.

II. CONCRETE MIX DESIGN

2.1 Geopolymer concrete:

Mixdesignofgeopolymerconcreteiscalculatedfromthedensityofgeopolymerconcrete.Generally,inthedesignofgeopolymerconcretemix,coarseandfineaggregateshave been taken as 75% of entire mix by mass. This value is similar to that usedinOPC concrete in which they have been in the range of 75% to 80% of theconcretemix by mass. Fine aggregate has been taken as 30% of the total aggregate.Theaveragedensityofflyashbasedgeopolymerconcretehasbeenconsideredsimilartothat of OPC concrete of 2400 kg/m^3 based on literaturesurvey.

The combined mass of fly ash and alkaline liquid arrived from the density of geopolymer concrete. From the combined mass, using ratio of fly ash to alkaline liquid the amount of fly ash and alkaline solution is determined. By taking the ratio of sodium silicate solution to sodium hydroxide solution, find out the mass of sodium silicate solution and sodium hydroxide solution is calculated by above procedure and issued for mix design.

The following parameters were kept constant for various trial mixes based on past work carried out [26].

- Alkaline liquid to Fly Ash ratio =0.4
- Sodium Silicate to Sodium Hydroxide ratio =2.0
- Molarity=M14
- Curing temperature = 75^0C
- Curing Time = 24hours
- Rest Period = 1day
- Admixture Dosage =2%

In order to achieve equivalent compressive strength of M25 grade of control concrete, various permutations and combinations were done by keeping the above parameters constant and varying the fly ash and water content with different mixes. The mix design procedure is as follow:

Mix Design for Fly ash (FA) content= 300kg/m^3

Alkaline solution/Fly ash =0.4
Alkaline solution = 0.4*Fly ash
300 kg = (mass of fly ash + alkaline sol.)/1.4
Mass of FA + alkaline solution = 420 kg
Mass of alkaline solution= 120 kg
Total = density of concrete – (mass of FA + alkaline solution)
= 2400-420
= 1980kg/m^3
% of total aggregate = 82.5%

Fine aggregate = 30% of total aggregate

$\frac{30\times1980}{100}$

= 594.00kg/m^3

Coarse aggregate = 1980−594

= 1386.00kg/m^3

Alkaline liquid = $NaOH + Na_2SiO_3$

$NaOH/Na_2SiO_3$= 2.0
NaOH = 40 Kg/m^3
Na_2SiO_3= 80 Kg/m^3
Extra water = 15%

=45.00kg/m^3

Admixture Dosage(2%) = 6.00kg/m^3
The proportions of various constituents are as shown in table 5.

Table 5: Mix Design of M25 Grade of Geopolymer Concrete

Constituents	Qty. (Kg/m^3)
Fly ash	300.00
Fine aggregate	594.00
Coarse aggregate	1386.00
NaOH	40.00
Na_2SiO_3	80.00
Admixture(2%)	6.00
Water(15%)	45.00

III. TESTING:

4.1.Compressive Strength

The compressive strength of geopolymer concrete has been evaluated on a 2000 kN capacity hydraulic testing machine .For the compressive strength test, cubes of size 150mm x 150mm x 150 mm are tested in compression. Equation of finding out compressive strength of the cube specimens is given below:

Compressive Strength(N/mm^2)= P * 10^3/A
P = Failure load of cube (kN)
A = Area of cube (150 x 150) (mm^2)

2.2. Durability tests:

The following tests were performed on geo polymer and control concrete to study the durability a spect of geo polymer concrete and to compare results with control concrete.

4.2.1. Sulphate resistance:

The test was performed to study the effect of sulphate on concrete. Sulphate may be present in soil or ground water which comes in to the contact of concrete and affect it.

- Test Specimens

Test specimens for compressive strength and change in mass test were 150X150X150mm 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 Parameters

The sulphate resistance of control concrete and geopolymer concrete were evaluated by measuring the residual compressive strength and change in mass after sulphate exposure. Cubes were immersed in solution after 28 days of curing period for a specific exposure period. The test parameters for sulphate resistance test are presented in Table 6.

Table 6:Test Parameters for Sulphate Resistance Test

Parameters to study	**Specimens**	**Exposure period(days)**
Change in compressive strength	Cube150×150×150mm	30,60,90
change in mass	Cubes 150×150×150mm	30,60,90

- Test Procedure

Sodium sulphate (Na_2SO_4) solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the sulphate solution in a tank. To prepare the solution of

5% concentration, for each 100 gm solution 95 gm of water and 5 gm of Sodium sulphate powder is added. After preparation of the solution pH value of the solution is measured by using digital pH meter. In order to maintain the concentration of sodium sulphate throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference sodium sulphate powder or water was added and by trial and error initial pH value is achieved.

- Change in Compressive Strength

The change in compressive strength after sulphate exposure was determined by testing the compressive strength of the specimens after 30, 60 and 90 days of exposure. The specimens were tested in saturated surface dry (SSD) condition. For the SSD condition, the specimens were removed from the sulphate solution, allowed it to dry and then tested in compression testing machine available at laboratory.

- Change inMass

Change in mass of specimens was measured after various exposure period i.e. 30, 60 and 90 days. The weight of each specimen was measured before immersion in the solution. After the exposure period the specimen were taken out and left to air dry for a week in the laboratory ambient condition. Then weights of the specimens were measured using the weighing scale available in laboratory and from that change in mass was calculated.

4.2.2. Acid resistance:

The test was performed to study the effect of sulphuric acid on geopolymer concrete and its comparison with 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 Parameters

The acid resistance of control concrete and geopolymer concrete were evaluated by measuring the residual compressive strength and change in mass after acid exposure. Cubes were immersed in solution after 28 days of curing period for a specific exposure period. The test parameters for acid resistance test are presented in Table 7.

Table 7. Test Parameters for Acid Resistance Test

Parameters to study	**Specimens**	**Exposure period(days)**
Change in compressive strength	Cube150×150 ×150mm	30,60,90
change in mass	Cubes 150×150×150 mm	30,60,90

- Test Procedure

Sulphuric acid (H2SO4) solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the acid solution in a tank. To prepare the solution of 5% concentration, for each 100gm of solution 95gm of water and 5 gm of sulphuric acid (by weight) is added. After preparation of the solution pH value of the solution is measured by using digital pH meter. In order to maintain the concentration of throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference sulphuric acid or water was added and by trial and error initial pH value is achieved.

- Change in CompressiveStrength

Thechangeincompressivestrengthafteracidexposurewasdeterminedbytestingthe compressive strength of the specimens after selected periods of exposure.Thespecimensweretestedinsaturatedsurface dry(SSD)condition. For the SSD condition, the specimens were removed from the acid solution, loose particles were removed using wire brush. Surface preparation was done using cement mortar(1:3) and then tested in compression testing machine available at laboratory.

- Change inMass

Changeinmassofspecimenswasmeasuredaftervariousexposureperiod.Theweightof each specimen was measured before immersion in to the solution. After theexposureperiodthespecimenweretakenoutandlefttoairdryforaweekinthelaboratorycondition.Thenweightsofthespecimensweremeasuredusingtheweighingscaleavailableinlaboratoryandfromthatchangeinmasswascalculated.

4.2.3. Chloride attack:

The effect of chloride on geopolymer and control concrete were studied through this test. Marine structures are subjected to chloride attack and due to the penetration of chloride the reinforcement is subjected to corrosion.

- 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 Parameters

Thechlorideresistanceofcontrolconcreteandgeopolymerconcretewereevaluatedbymeasuringtheresidualcompressivestrengthafterchlorideexposure.Cubeswereimmersedinsolutionafter28daysofcuringperiod.Thetestparametersforsulphateresistancetestarepresentedin Table 8.

Table 8. Test Parameters for Chloride Attack Test

Parameters tostudy	Specimens	Exposure period(days)
Change in compressive strength	Cube150×150 ×150mm	30,60,90

- Test Procedure

Sodium Chloride (Nacl) solution with 3% concentration was used as the standard exposure. The specimens were immersed in the Sodium Chloride solution in a tank. To prepare the solution of 3% concentration, for each 100gm solution 97gm of water and 3gm of Sodium Chloride powder is added. After preparation of the solution pH value of the solution was measured by using digital pH meter. In order to maintain the concentration of sodium sulphate throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference, sodium chloride powder or water is added and by trial and error initial pH value was achieved.

- Change in Compressive Strength

Change in compressive strength after chloride exposure was determined by testing the compressive strength of the specimens after selected periods of exposure. The specimens were tested in saturated surface dry (SSD) condition. For the SSD condition, the specimens were removed from the chloride solution, allowed it to dry and then tested in compression testing machine available at laboratory.

4.2.4. Sorptivity:

Thesorptivitytestisasimpleandrapidtesttodeterminethetendencyofconcreteto absorb water by capillary suction. The test was developed by Hall (1981) and is based on Darcy'slawo fun saturated 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 airovenat 500C. The sides of the specimen were sealed in order to achieve unidirection alflow. Locally availablewaxandresinwith50:50proportions was used as sealant. Weights of the specimen after sealing were taken as initial weight. The in itialmass 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.

4.2.5. Water absorption:

Waterabsorptioncharacteristicofconcreteplaysanimportantrolefor the durability.Thetestwasperformtoevaluatethewaterabsorptioncharacteristicsofgeopolymer and controlconcrete.

- Test Specimens

Testspecimensforcompressivestrengthandchangeinmasstestwere150×150×150mmcubesofcontrolconcreteandgeopolymerconcreteeach.3specimensforeachtestswerepreparedcompressivestrengthandchangeinmass totakeaverageresultofthespecimen.

- TestProcedure

Test specimens were oven dried at 105^0C 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 inovenat 105^0Cand weight after immersion in water.

4.2.6. 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. Then the exposed steel bars were connectedtothepositiveterminalofaconstant30voltDC powersupply,tomakethesteelbarsactasanodes.Thishigh voltagewasusedtoacceleratethecorrosionandshortenth etestperiod.ThenegativeterminaloftheDCpowersource wasconnectedto a stainless steel bar, to make the stainless steel bar act as cathode. Whencrackisinitiatedinthespecimenbystressescausedb ybuildup ofcorrosionproducts,theelectrolyte solution has a free path to the steel. This results in a suddenincreasein current. So, in order to determine the time at which the current was recordedatdifferent timeintervals.

IV. RESULTS:

5.1. Compressive strength:

The results showed that the compressive strength of geopolymer concrete increases with increase in fly ash content and decreases with increase in extra water content. GC-275 (10%) gives strength result 29.33MPa and GC-300(10%) gives 35.55 Mpa strength, hence any range of fly ash content ranges in between these two values can give the target mean strength (31.6MPa). The workability of these mixes were found to be poor and resulted into honeycombing in the test cubes. So in order to increase the workability various mix combination and permutation was done with higher water content. After various combinations GC-300(15%) gave strength of 32.44 MPa with desired workability, so this mix was adopted for casting of all the geopolymer concrete specimens for various studies.

Table 9. Compressive Strength Results of Geopolymer concrete

Sr. No.	Notation	Age of Specimen (Days)	Avg. Comp. Strength
1	GC-250* (10%)	3	18.07
2	GC-275(10%)	3	29.33
3	GC-300(10%)	3	35.55
4	GC-325(10%)	3	36.81
5	GC-350(10%)	3	43.11
6	GC- [illegible]	3	49.18
7	GC- [illegible]	3	37.18
8	GC-285 (12.5%)	3	35.59
9	GC-285(15%)	3	28.89
10	GC-300(15%)	3	32.44

* GC-250 (10%) = Fly Ash content 250kg/m^3

5.2. Sulphate resistance:

A series of tests were performed to study the sulphate resistance of fly ash based geopolymer concrete. The test specimens were soaked in 5% sodium sulfate (Na_2SO_4) solution. The sulfate resistance was evaluated based on visual appearance, change in mass, and change in compressive strength after sulfate exposure up 30, 60 and 90 days period. The results are compared with control concrete specimens. All geopolymer specimens were heat-cured at 75^{0}C for 24 hours. PH value of the solution was checked at 15 days interval and maintained throughout the test period.

Visual appearance:

The visual appearances of test specimens after different exposures are shown in Figure 5. It can be seen from the visual appearance of the test specimens after soaking in sodium sulfate solution for the exposure periods of 30, 60 and 90 days that there was no significant change in the appearance of the specimens compared to the condition before they were exposed. However, white patches were observed on the specimens. There was no sign of surface erosion, cracking or spalling on the specimens.

Table10: Change in Mass of Concrete for sulphate exposure

SodiumSulphate(5%)					
Typeof Concrete	Notation	Wtbefore exposure	Wtafter exposure	%Gain	Exposure Exposure
GC	GC-1M	8.64	8.77	1.54	1Month
	GC-2M	8.58	8.72	1.63	2Month
	GC-3M	8.65	8.82	2.00	3Month
CC	CC-1M	8.77	8.80	0.30	1Month
	CC-2M	8.65	8.68	0.39	2Month
	CC-3M	8.66	8.70	0.42	3Month

Figure 5. Visual Appearance of Geopolymer (Left) and Control (Right) Concrete

Change in Mass

Figure4.3 presents the test results on the change in mass of specimens soaked in sodium sulfate solution for 30,60 and 90 days period as a percentage of the mass before exposure. There was no reduction in the mass of the specimens, as confirmed by the visual appearance of the specimens. There was a slight increase in the mass of specimens due to the absorption of the exposed liquid. The increase in mass of specimens soaked in sodium sulphate solution was 1.54%, 1.6% and 2.00% for geopolymer concrete and 0.30%, 0.39% and 0.42% for control concrete after exposure of 30, 60 and 90 days respectively. To study the effect of the exposure on quality of concrete, Ultra pulse Velocity (UPV) readings were taken. As shown in Figure 6 no significant change in the UPV reading shave been observed for both type of concrete.

Figure 6:ChangeinWeightforsulphateexposure

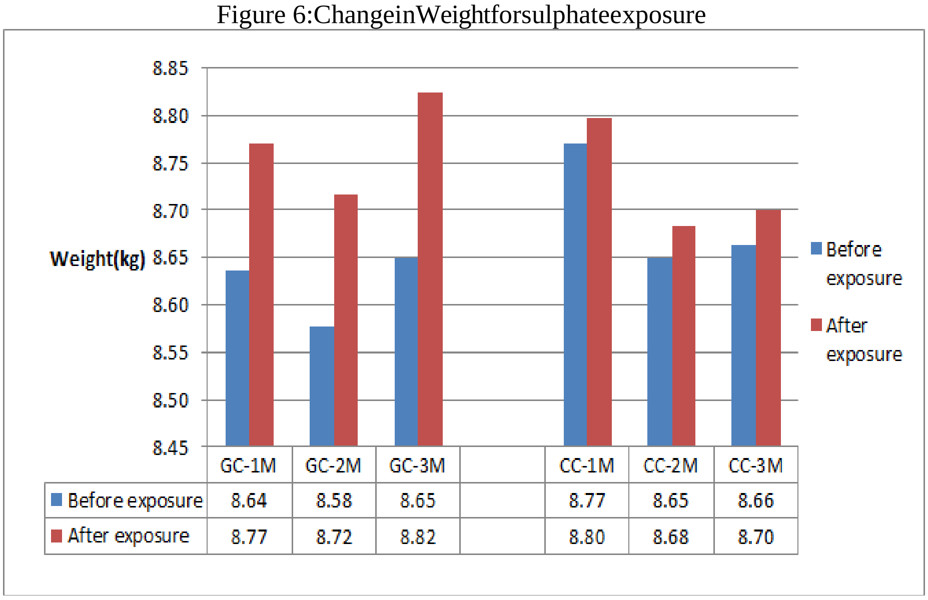


Figure 6:Mass Gain for Sulphate Exposure

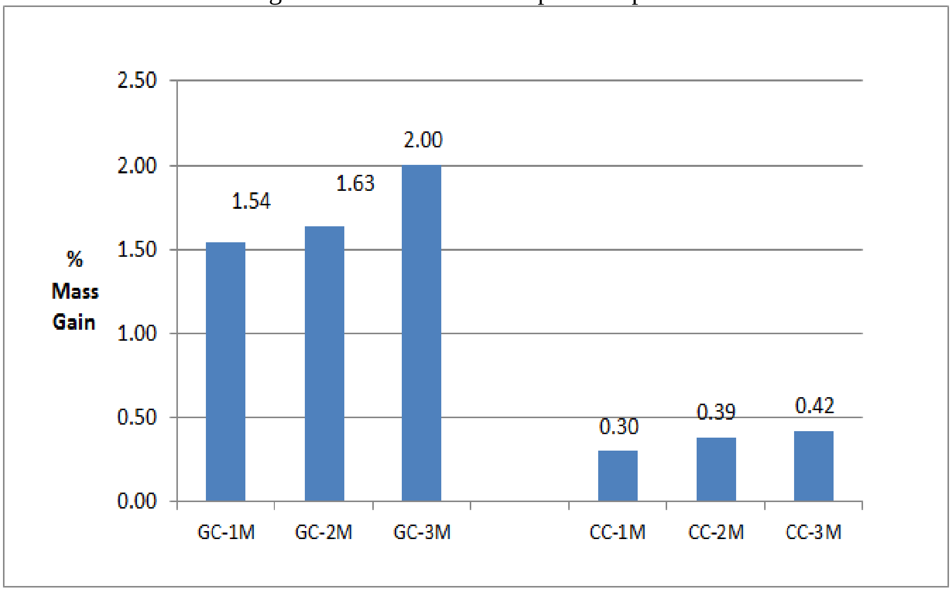
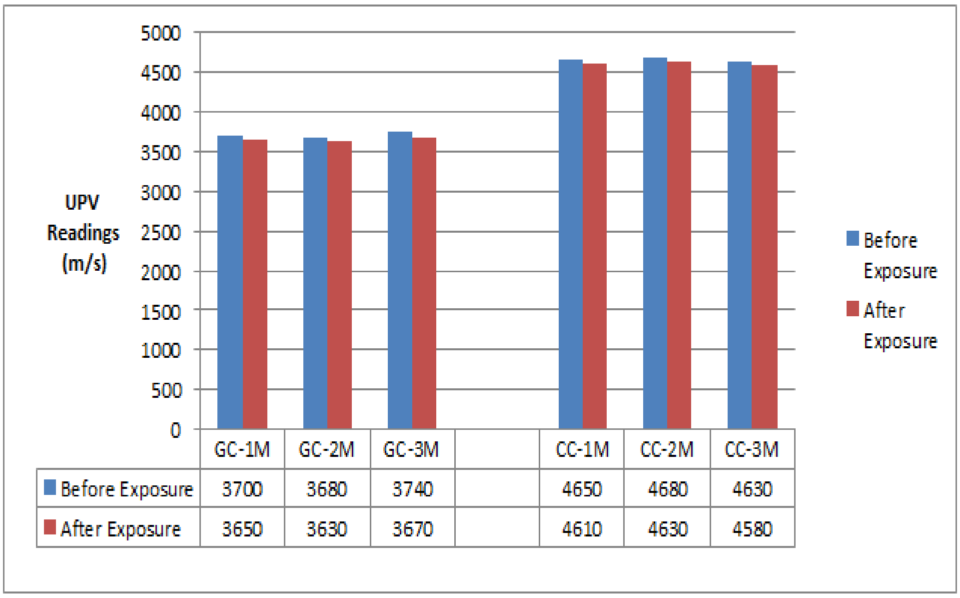


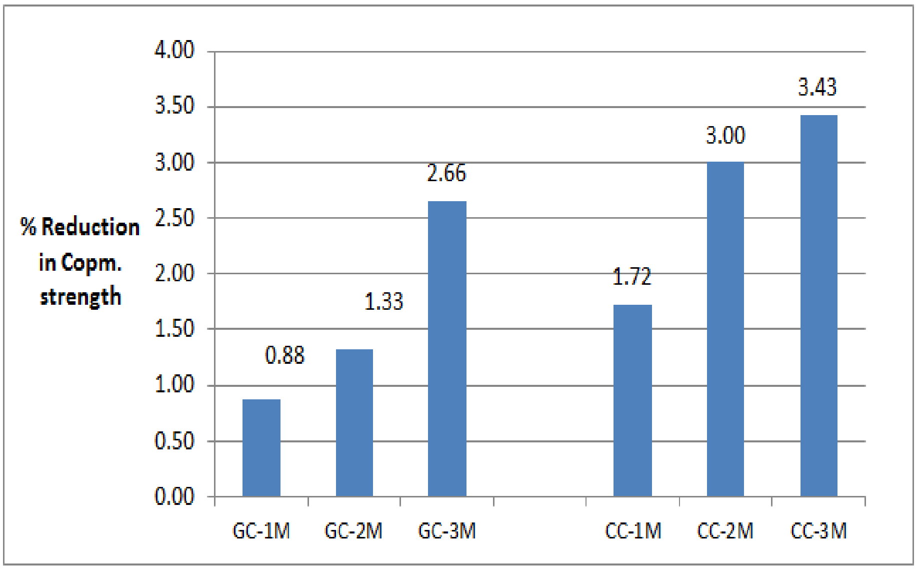
Figure 7: Change in Ultra Pulse Velocity Readings



Change in CompressiveStrength

Change in compressive strength has been determined by testing the concrete specimens after 30, 60 and 90 days of exposure of sodium sulphate solution, respectively. The concrete specimens exposed to sulphate solution have been removed from the immersion tank, were allowed to dry at room temperature and then tested in saturated surface dry condition. 28 day compressive strength of concrete specimens without any exposure has been taken as the reference compressive strength for each type of concrete. Figure 8 presents the test results on the change in compressive strength of concrete specimens exposed to sodium sulphate. No significant change has been observed in both type of concrete due to sulphate exposure.

Figure 8: Change in Compressive Strength for Sulphate Exposure



5.3 Acid Resistance

Acid resistance property of geo polymer concrete mixes has been studied by exposing the concrete specimens in sulfuric acid for 30, 60 and 90 days periods. Various parameter evaluated are visual appearance, change in mass and change in compressive strength after the exposure period of both type of concrete. pH value of the solution was checked at 15 days interval and maintained throughout the test period.

Visual Appearance

Figure 9 compare the visual appearance of the geo polymer and control concrete specimens after soaking in 5% concentrations of sulfuric acid solution for 30, 60 and 90 days. It can be seen that the specimens exposed to sulfuric acid undergoes erosion of the concrete surface. The damage observed in control concrete was significantly higher than the geopolymer concrete for the same exposure period.

Figure 9: Visual Appearance of Geopolymer (Left) and Control (Right) Concrete

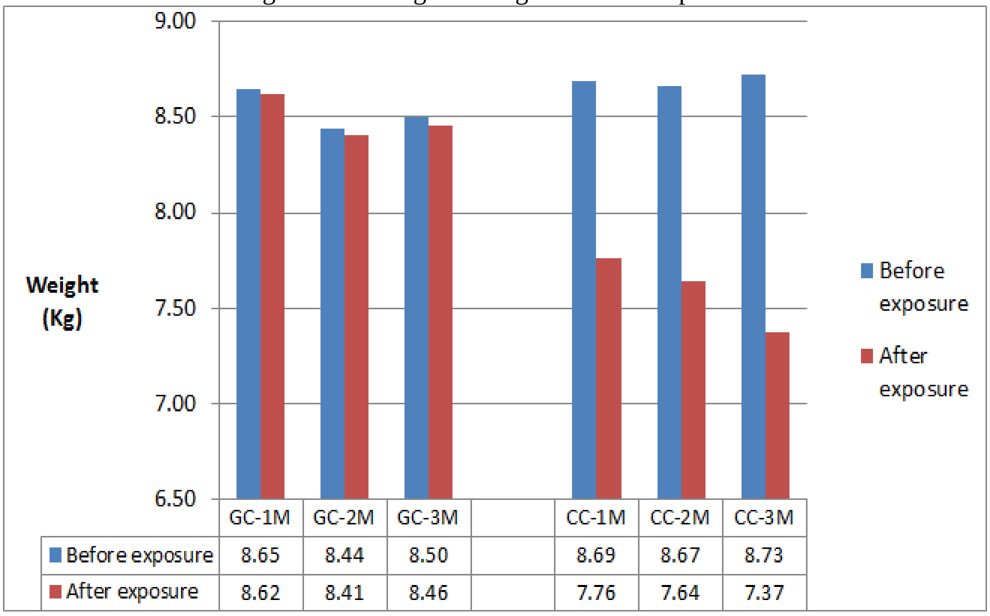
Change inMass

The test results on change in mass of specimens exposed in sulfuric acid for 30, 60 and 90 days exposure periods are presented in Table 11. Percentage change in mass of specimen is calculated with difference in initial weight and weight after the exposure period. Control concrete specimens have significant mass loss compared to geopolymer concrete having same exposure. After4-5 days, coarse aggregates of control concrete were exposed as the surface undergoes erosion. Initial surface erosion was significantly higher for control concrete. Geopolymer concrete shows good resistance to acid and very less mass loss has been observed throughout the test.

Table 11: Change in Mass of Concrete acid exposure

Sulphuric Acid(5%)					
Typeof Concrete	Notation	Wtbefore Exposure	Wtafter exposure	%loss	Exposure Exposure
GC	GC-1M	8.65	8.62	0.31	1Month
	GC-2M	8.44	8.41	0.43	2Month
	GC-3M	8.50	8.46	0.51	3Month
CC	CC-1M	8.69	7.76	10.66	1Month
	CC-2M	8.67	7.64	11.88	2Month
	CC-3M	8.73	7.37	15.51	3Month

Figure 10: Change in Weight for Acid Exposure



Change in Compressive Strength

Change in compressive strength has been determined by testing the concrete specimens after 30, 60 and 90 days of exposure of sulphuric acid solution, respectively. The concrete specimens exposed to sulphuric acid solution have been removed from the immersion tank, were allowed to dry at room temperature and then tested in saturated surface dry condition. 28 day compressive strength of concrete specimens without any exposure has been taken as the reference compressive strength for each type of concrete. Figure 12 presents the test results on the change in compressive strength of concrete specimens exposed to sulphuric acid. High reduction observed in control specimen upto 32% whereas in geopolymer specimen 7.5% reduction has been observed which suggest that the effect of acid exposure on geopolymer concrete is low.

Figure 11: Change in Mass Loss for Acid Exposure

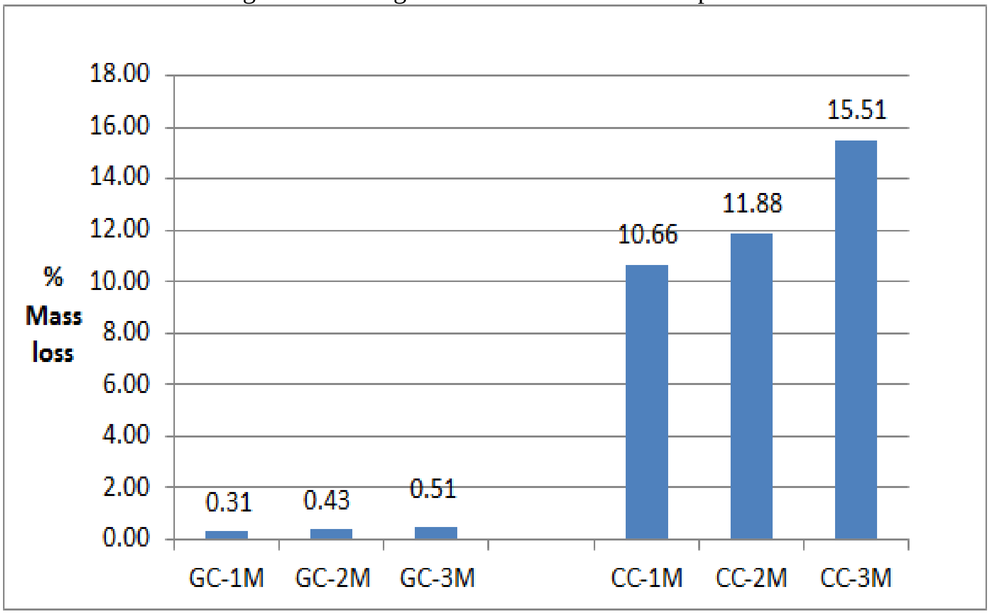
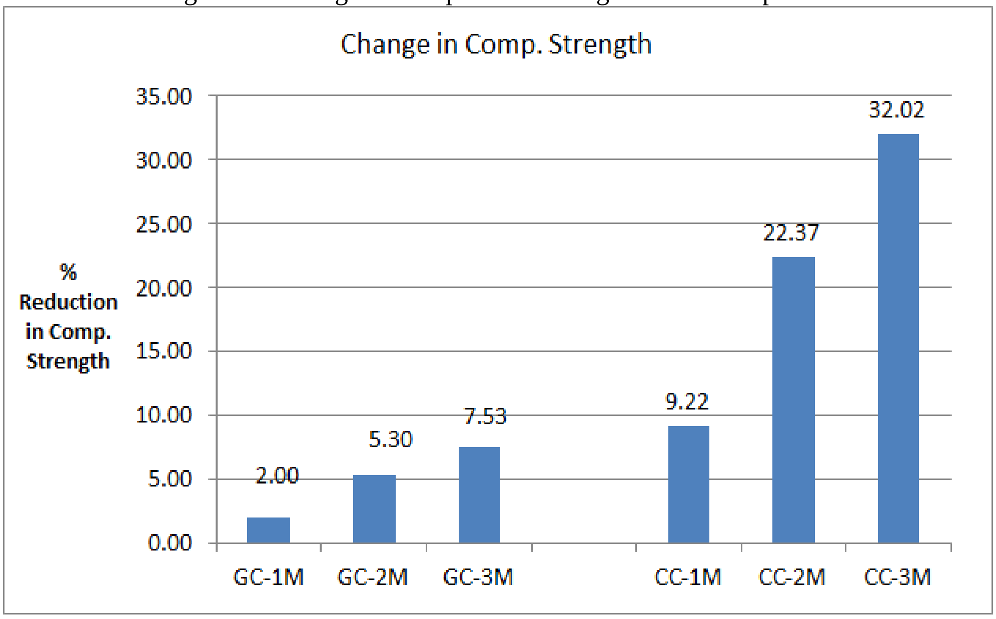


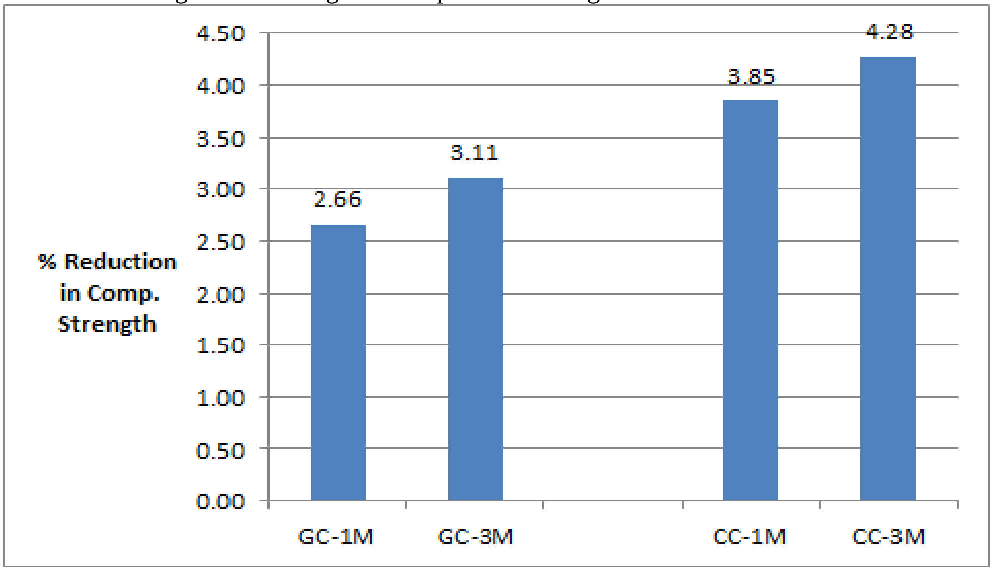
Figure 12: Change in Compressive Strength for Acid Exposure



5.4. Chloride attack

Chloride resistance property of geopolymer concrete mixes has been studied by exposing the concrete specimens in Sodium Chloride solution with 3% concentration for 30 and 90 days periods. There were no reduction in mass and visual appearance observed. With this short exposure period, no major change in compressive strength observed, only slight reduction in compressive strength took place as shown in Figure 13.

Figure 13: Change in Compressive Strength for Chloride Attack



5.5. Sorptivity

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 Table4.4 and Table 4.5 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.

Table 12: 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 13:SorptivityReadingsandCalculationsofGeopolymerConcrete

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 14: Sorptivity of Control Concrete

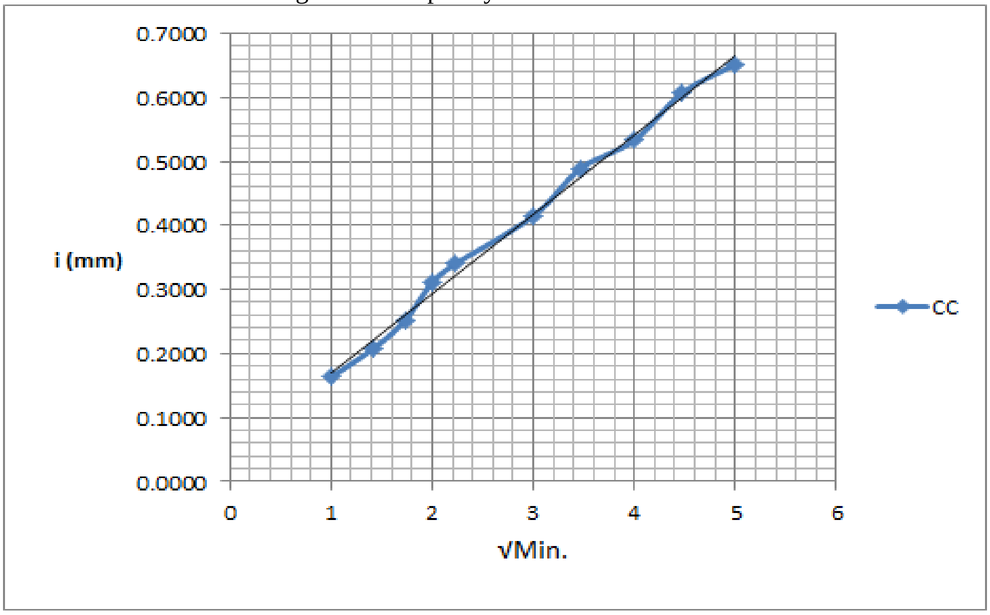
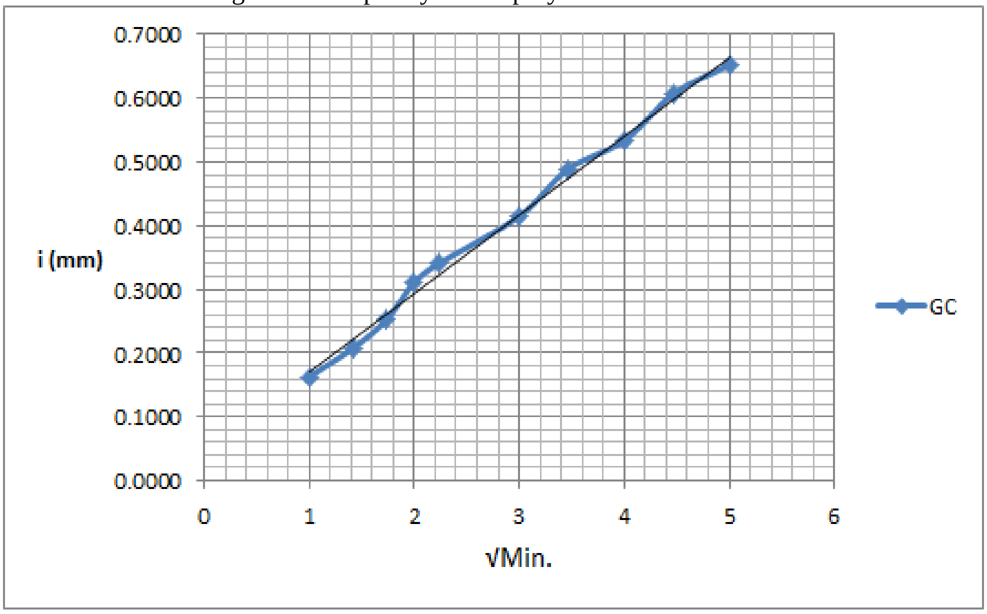


Figure 15: Sorptivity of Geopolymer Concrete



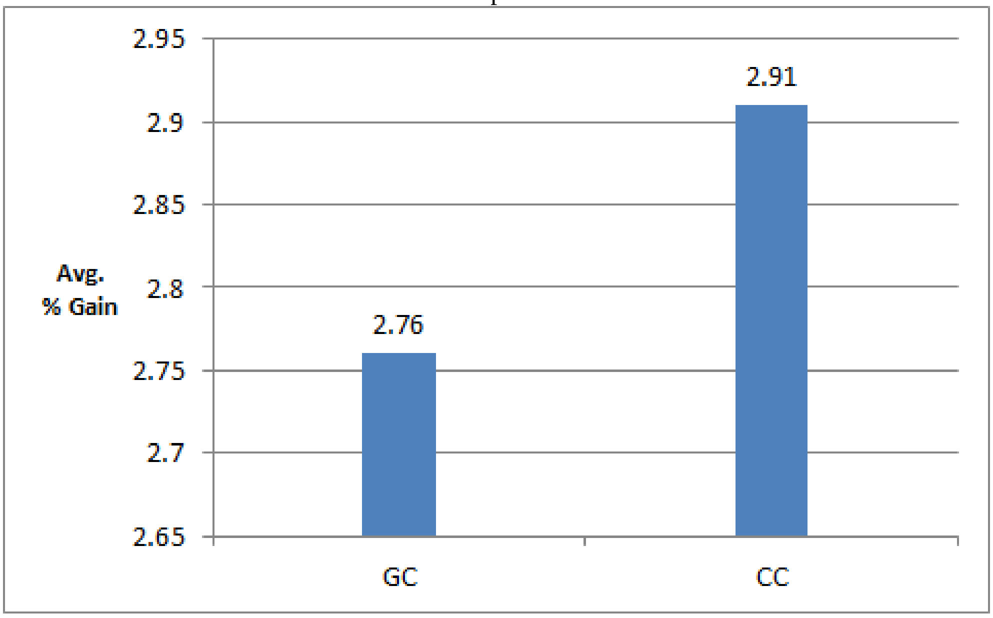
5.6. WaterAbsorption

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 14. 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 14: 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	

16: Water Absorption of Concrete



5.7. Accelerated CorrosionTest

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, comparedtocontrolconcrete.UPVresultsshowsthatthereductionofvelocityreadingsforgeopolymer concrete was7.62%comparedtothatof10.26%thatofcontrolconcrete.

Halfcellpotentialmeterreadingswerealsotakentostudytheextentofcorrosioningeopolymerandcontrolconcretes pecimen.Theinitialreadingsofgeopolymerconcretewere significantly higher than the control concrete, this may be due to thealkalineliquidcomposedofsodiumsilicateandsodiumhydroxide.Eventhoughtheoccurrenceofcracking in geo polymer specimen was delayed, the reading in dicate more corrosionin geo polymer specimen. Hence, these results have beendiscarded.

Table 15: 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 17: Specimen Current Readings

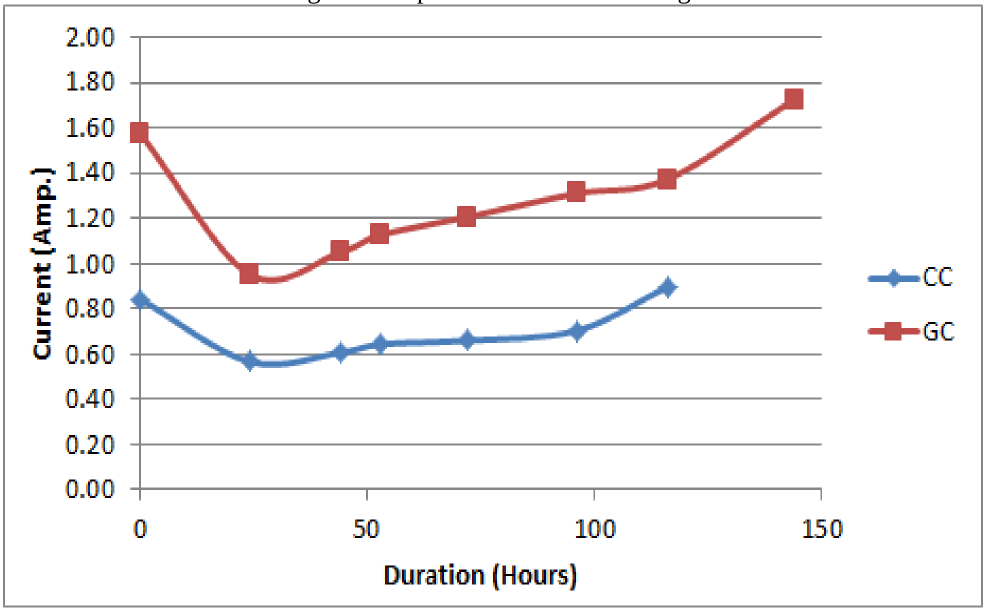


Figure 18: Ultra Pulse Velocity Readings for Accelerated Corrosion Test

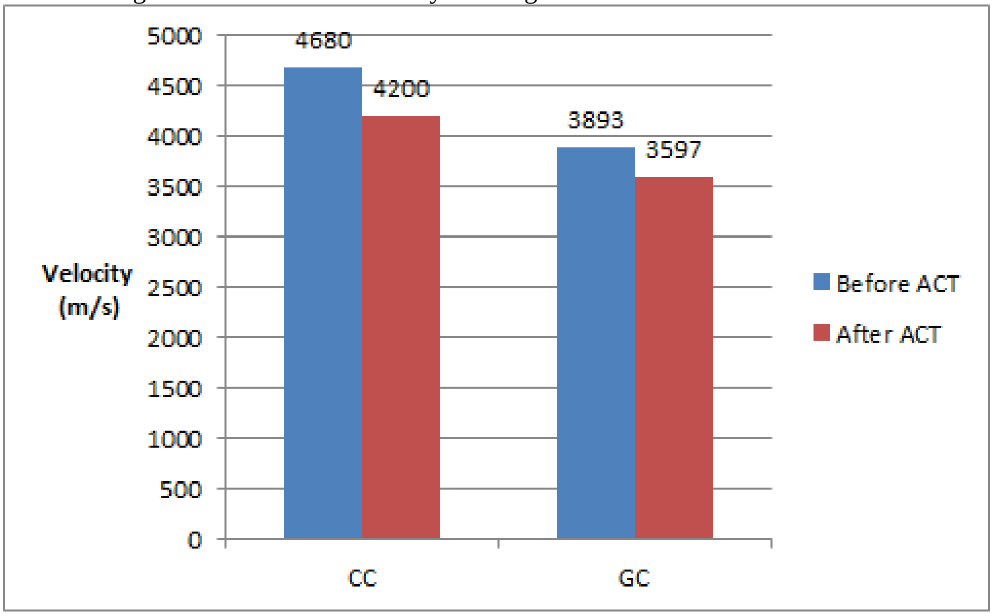
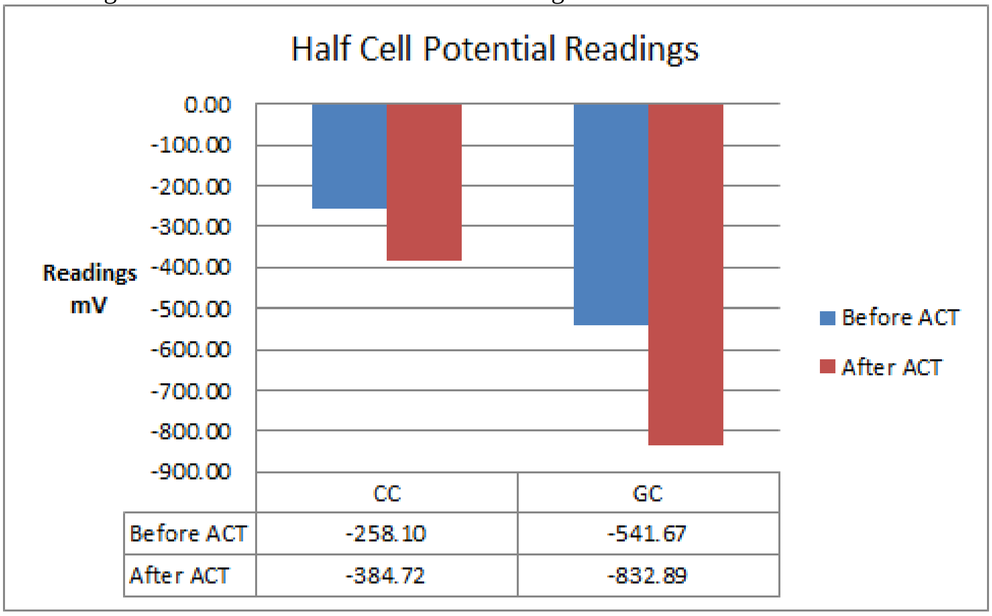


Figure 18: Half Cell Potential Meter Readings for Accelerated Corrosion Test



V. CONCLUSION

- The test results demonstrate that heat-cured fly ash-based geopolymer concrete has an excellent resistance to sulfate attack. There is no damage to the surface of test specimens after exposure to sodium sulfate solution up to three months. There are no significant changes in the mass and the compressive strength of test specimens after various periods of exposure up to three months.
- These test observations indicate that there is no mechanism to form gypsum or ettringite from the main products of polymerization in heat-cured low-calcium fly ash-based geopolymer concrete.
- Exposure to sulphuric acid solution damages the surface of heat-cured geopolymer concrete test specimens and causes a mass loss of about 0.5% after three months of exposure. The severity of the damage depends on the acid concentration.
- The sulfuric acid attack also causes degradation in the compressive strength of heat-cured geopolymer concrete; the extent of degradation depends on the concentration of the acid solution and the period of exposure. However, the sulphuric acid resistance of heat- cured geopolymer concrete is significantly better than that of Portland cement concrete as reported in earlier studies.
- The test result of chloride attack demonstrate that

geopolymer concrete has an excellent resistance to chloride. There are no significant change in mass and the compressive strength after exposure up to three months.

- The Sorptivity curve was found to be less linear 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.
- The test results indicated excellent resistance of the geopolymer concrete to chloride attack, with longer time to corrosion cracking, compared to control concrete. Crack observed in geopolymer concrete specimen at 144 hours compared to 116 hours in control concrete.

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