

## Study on the Durability of GGBS and Metakaolin based Geopolymer Concrete

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**ABSTRACT:** The objective of this research work was to produce a carbon dioxide emission free cementitious material. The geopolymer concrete is such a vital and promising one. In this study, geopolymer is prepared from 'Ground Granulated Blast Furnace Slag' (GGBS) a powder from grinding the by-product of slag waste from blast furnace of steel plants and metakaolin from industry. The Alkaline liquids used in this study for the polymerization process are the solutions of sodium hydroxide (NaOH) and sodium silicate ( $Na_2SiO_3$ ). A 8 Molarity and 10 Molarity solutions was taken to prepare the mix. The cube compressive strength was calculated for different mixes. The cube specimens are taken of size 150 mm x 150 mm x 150 mm. Ambient curing of concrete at room temperature was adopted. In total 180 cubes were casted for their compressive strength at age of 28 days respectively. The test data indicate that on exposure to 5% Sodium Sulphate, Sulphuric Acid and Sodium Chloride, the losses in weight, and strength of geopolymer concrete (GPC) are significantly much less than those for cement concrete. Thus the geopolymer concrete is considered to be an environmentally pollution free construction material.

**Keywords:** Geopolymer concrete, GGBS, Metakaolin, Alkali Activators, Ambient curing, Sodium Sulphate, Sulphuric Acid, Sodium Chloride.

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### I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its low cost, excellent durability, easy availability of its constituent materials, easy formability to any shape, etc. Among all constituents of concrete ordinary Portland cement (OPC) is the main ingredient which binds the aggregates together. However, the manufacturing of OPC is an energy intensive process and the production of OPC is responsible for almost 5% of total global CO<sub>2</sub> emissions, which is the main cause of global warming. In another estimate it was found that the production of one tone of OPC releases approximately one tone of carbon dioxide to the atmosphere. Due to an increase in global population and urbanization the increasing use of concrete in construction is unavoidable in near future. This concern has led to the use of new sustainable OPC less binder for concrete and supplementary cementations materials (SCMs) as a partial replacement of a large amount of OPC in the concrete. [1-2]

Geopolymer is emerging cement less binder purported to provide a sustainable and environmentally friendly alternative to OPC. The term geopolymer was initially introduced by Davidovits (1991) [3]. Geopolymer is synthesized from materials of geological origin (e.g., metakaolin) or industrial by-products, such as fly ash and slag, which are rich in silica and alumina with alkaline activators. In one estimate it was found that the production of fly ash-based geopolymer requires approximately 60% less energy and has at least 80% less CO<sub>2</sub> emissions compared to the manufacture of OPC. [4] So far, extensive research and development on geopolymer concrete and composites have been undertaken worldwide with hopes to promote geopolymer as an ultimate sustainable construction material for the future [5,6,7].

GPC being a new material of construction, requires to be assessed for both strength and durability characteristics. The GPC utilizes industrial by-product of blast furnace slag from steel plants. The test data in this paper is expected to enable the engineers to examine the durability aspects of the GPC from GGBS which is obtained after grinding the slag and Metakaolin. The new concrete produced from the industrial by-product slag would not only have low carbon footprint with low 'embodied energy' and 'low carbon dioxide emission', but also it is more durable material with higher and faster strength development capability.

### II. MATERIALS

Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin were used in this investigation. Commercially available GGBS and Metakaolin used during the experiments.

The Properties of GGBS and Metakaolin are given in Table 1, 2 and 3. Coarse aggregates of sizes 10 mm and river sand as fine aggregate were used. Physical properties of gravels and sand are given in Table 4 and 5. Distilled water was used in all the experiments. Master Gienium Sky 8233 from BASF India, super plasticizer were used as admixtures are given in Table 6. The alkali activators used were solutions of sodium hydroxide,

potassium hydroxide and sodium silicate.

**Table 1** Physical properties of GGBS.

Parameter	GGBS	IS : 12089 – 1987
CaO	37.34%	---
Al <sub>2</sub> O <sub>3</sub>	14.42%	---
Fe <sub>2</sub> O <sub>3</sub>	1.11%	---
SiO <sub>2</sub>	37.73%	---
MgO	8.71%	Max. 17%
MnO	0.02%	Max. 5.5%
Sulphide Sulphur	0.39%	Max. 2%
Loss of Ignition	1.41%	---
Insoluble Residue	1.59%	Max. 5%
Glass Content (%)	92%	Min. 85%

**Table 2** Physical properties of Metakaolin

Colour	Pink / Off-white
Pozzolan Reactivity mg Ca (OH) <sub>2</sub> / gm	900
Average Particle size	1.4 micron
Brightness (ISO)	75 ± 2
Bulk Density (Gms / Ltr)	320 to 370
Specific Gravity	2.5

**Table 3** Chemical Properties of Metakaolin

Al <sub>2</sub> O <sub>3</sub>	>39.0 %
Fe <sub>2</sub> O <sub>3</sub>	<0.8%

**Table 4** Sieve analysis of aggregates

BS sieve size (mm)	Percentage passing of aggregates of different size	
	10 mm (aggregate)	Fine aggregates (aggregate)
20	100	100
12.5	100 %	100
10	94.62 %	100
4.75	15.40 %	99.6
2.36	2.89 %	99
1.18	--	92.6
0.60	--	48.6
0.3	--	8.2
0.15	--	2
Pan	--	0

**Table 5** Physical properties of gravels and sand

Sample	Sp. Gravity	Water absorption (%)	Fineness modulus
10 mm aggregate	2.74	0.33	--
Sand	2.50	0.30	2.2

**Table 6** Properties of GLENIUM B233 Superplasticiser

Specific Gravity	1.09
Chloride ion content	Less than 0.2%
Recommended Dosage	0.5 to 1.5 liter per 100kg of cementations material
pH	7+/-1
Aspect	Yellowish free flowing liquid

\*Data taken from the product brochure of the supplier.

### Preparation of alkalis

Solutions of sodium hydroxide (8 M and 10 M each) were prepared separately. The solutions prepared were left for 24 hours before mixing with sodium silicate. The mixtures of sodium hydroxide and sodium silicate solutions were used for geopolymerization process.

### Mix proportion of geopolymer concrete

The geopolymer concrete was prepared by conventional method as OPC concrete. Since the density of geopolymer concrete is almost equal to that of OPC concrete (2400 kg/m<sup>3</sup>), aggregates also occupy 75% by mass in geopolymer concretes. In the present mix design of geopolymer concrete, coarse and fine aggregates were taken as 75% by mass of the entire mixture. Fine aggregates were 36% by mass of the total aggregates. The ratio of sodium silicate to sodium hydroxide solution was kept 2.5. 8 M and 10 M NaOH solution was used. To improve the workability of fresh geopolymer mix, Master Gienium Sky 8233 super plasticizer was used in all the mixes.

### Casting of geopolymer concrete mixes

The conventional techniques used in OPC concrete were adopted. First fine and coarse aggregates were saturated surface dry (SSD) and then mixed together in concrete mixer for about 3 min. The alkali solution was mixed with super plasticizer and then added to the dry materials and mixing continued for 2 min. The whole mixture was then transferred into a concrete mixer and mixing continued for 3 – 5 min. The fresh geopolymer concrete formed pellets when homogeneously mixed in a concrete mixer and were very stiff in consistency as far as workability was concerned; however, adequate compaction was achieved. The mixture was casted in a 150 mm X 150 mm X 150 mm steel mould in three layers, and each layer given 60 strokes with compacting rod. Nine cubes were casted for each mix beside the trial mixes. The casted samples were left in the laboratory at room temperature for 28 Days.

### Casting Procedure

Generally the fine aggregate, coarse aggregate and fly ash are weighed to the required quantities and then they are mixed in dry condition for 2-3 minutes and then the alkaline solutions prepared (combination of sodium hydroxide and sodium silicate) are to be taken to required quantity is added to the dry mix. This mixing is done for 5-7 minutes in the mixer for proper bonding of all the materials. After the mixing is done the mix is filled in the cube moulds of size 150 mm X 150 mm X 150 mm in 3 layers with equal compacting and these cubes are kept on a vibrating table so that no voids are formed. [8]

## III. EXPERIMENTAL STUDY

### Mix Design of Geopolymer Concrete

In the design of geopolymer concrete (GPC mix), coarse and fine aggregates together were taken as 75% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75% to 80% of the entire mixture by mass. Fine aggregate was taken as 30.8% of the total aggregates. From the past literatures it is clear that the average density of Cementations materials based geopolymer concrete is similar to that of OPC concrete (2400kg/m<sup>3</sup>). Knowing the density of concrete, the combined mass of alkaline liquid and Cementations materials can be arrived. By assuming the ratios of alkaline liquid to Cementations materials as 0.45, mass of metakaolin and mass of alkaline liquid was found out. To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. Extra water (other than the water used for the preparation of alkaline solutions) used

respectively to achieve workable concrete. The mix proportion for geopolymer concrete is given in Table 7 and the different combinations of GGBS and Metakaolin investigated are given in Table 8.

### Preparation of Geopolymer Concrete

To prepare 8 molarity and 10 molarity concentration of sodium hydroxide solution, 320 and 400 grams (molarity x molecular weight (40)) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The solids constituents of the GPCC mix i.e. kaolinite clay, GGBS and the aggregates were dry mixed in the mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 4 minutes. Finally extra water was added to achieve workable GPCC mix. In this experimental work a total of 180 numbers of Geopolymer concrete specimens were cast with various mix ratios as shown in Table - 8. The specimens are of 150 mm side. Before casting machine oil was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the moulds and compacted thoroughly using a tamping rod. The top surface was finished using a trowel. The GPC specimens were removed from the mould after 1 or 2 days based on setting of specimens. The specimens were left at room temperature till the day of testing. Compressive strength test was conducted using a 3000 kN Compression testing machine. The test was conducted as per the relevant Indian standard specifications.

**Table 7** Material requirements for 1 m<sup>3</sup> of GPC

GGBS + Metakaolin Kg/m <sup>3</sup>	Fine Aggregate Kg/m <sup>3</sup>	Coarse Aggregate Kg/m <sup>3</sup>	Sodium hydroxide Kg/m <sup>3</sup>	Sodium silicate Kg/m <sup>3</sup>	Super plasticizer Kg/m <sup>3</sup>
414	660	1166	53	133	8.28

**Table 8** Combinations of GGBS and Metakaolin

Mix ID	GGBS	Metkaolin
M1	100%	0%
M2	70%	30%
M3	50%	50%
M4	30%	70%
M5	0%	100%

### Durability tests

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

#### 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 for compressive strength and change in mass test were 150 X 150 X150 mm 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. 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. [9] Sodium sulphate (Na<sub>2</sub>SO<sub>4</sub>) 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 7 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.

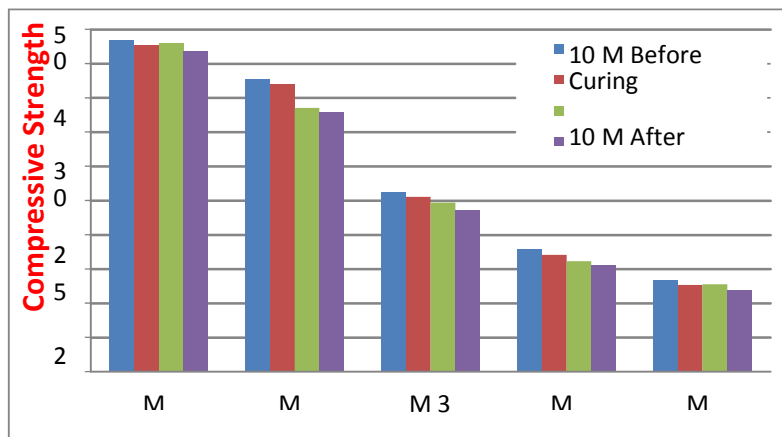
#### Changes in Compressive Strength

The change in compressive strength after sulphate exposure was determined by testing the compressive strength of the specimens after 30 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.

**Table 9** Change in Compressive Strength due to sulphate exposure

S. No.	Mix ID	Compressive Strength (N/mm <sup>2</sup> )			
		10 M Before Curing	10 M After Curing	8 Before Curing	8 M After Curing
1	M 1	48.39	47.65	48.04	46.85
2	M 2	42.72	41.95	38.504	37.85
3	M 3	26.16	25.54	24.6672	23.62
4	M 4	17.87	17.06	16.125	15.5
5	M 5	13.3	12.65	12.75	11.94



**Figure 1** Compressive Strength due to sulphate exposure

### Changes in Mass

Change in mass of specimens was measured after various exposure period i.e. 30 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.

**Table 10** Change in Mass due to sulphate exposure

S. No.	Mix ID	Weight of Specimens (grams)			
		10 M Before Curing	10 M After Curing	8 Before Curing	8 M After Curing
1	M 1	8603	8653	8536	8555
2	M 2	8532	8570	8594	8600
3	M 3	8197	8243	8465	8475
4	M 4	8238	8293	8427	8432
5	M 5	8259	8325	8504	8520

### Acid resistance

The test was performed to study the effect of sulphuric acid on geopolymer concrete and its comparison with control concrete. Test specimens for compressive strength and change in mass test were 150 mm×150 mm

× 150 mm 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. 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. [10]

**Test Procedure**

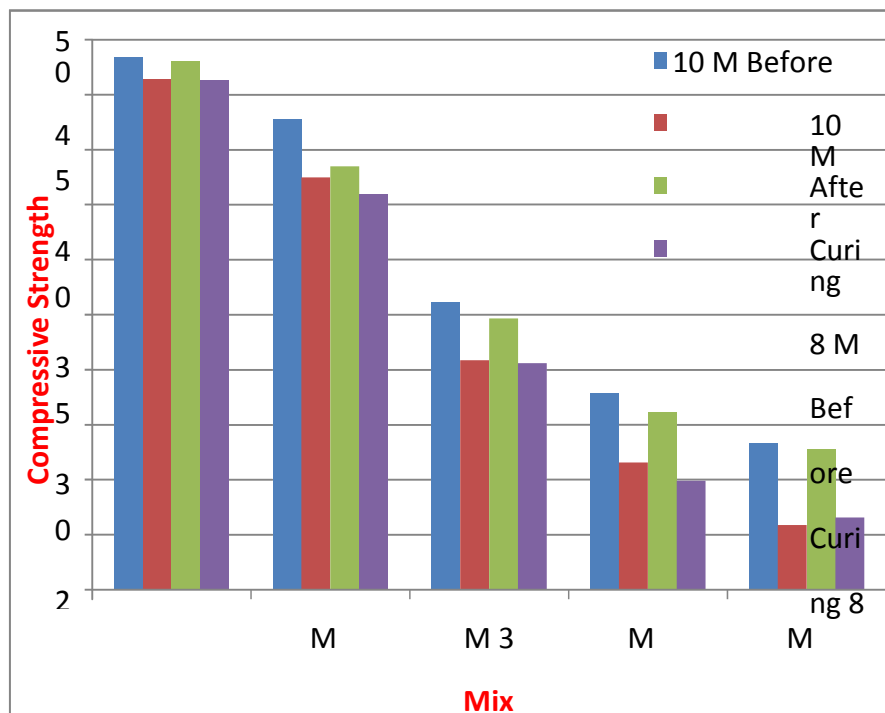
Sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the acid solution in a tank. To prepare the solution of 5% concentration, for each 100 gm of solution 95 gm of water and 5gm of sulphuric acid (by weight) 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 7 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 Compressive Strength**

The change in compressive strength after acid 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 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.

**Table 11** Change in Compressive Strength due to Acid exposure

S. No.	Mix ID	Compressive Strength (N/mm <sup>2</sup> )			
		10 M Before Curing	10 M After Curing	8 M Before Curing	8 M After Curing
1	M 1	48.39	46.35	48.04	46.3
2	M 2	42.72	37.49	38.504	35.936
3	M 3	26.16	20.85	24.6672	20.58
4	M 4	17.87	11.56	16.125	9.88
5	M 5	13.3	5.85	12.75	6.54



**Figure 3** Change in Compressive Strength due to Acid exposure

**Change in Mass**

Change in mass of specimens was measured after various exposure period. The weight of each specimen was measured before immersion in to the solution. After the exposure period the specimen were taken out and left to air dry for a week in the laboratory condition. Then weights of the specimens were measure during the weighing scale available in laboratory and from that change in mass was calculated.

**Table 12** Change in mass due to Acid exposure

S. No.	Mix ID	Weight of Specimens (grams)			
		10 M Before Curing	10 M After Curing	8 M Before Curing	8 M After Curing
1	M 1	8997	8630	8720	7890
2	M 2	8532	8256	8650	8320
3	M 3	8298	7823	8223	8102
4	M 4	8242	7756	8452	7910
5	M 5	8257	7625	8675	7235

**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 for compressive strength and change in mass test were 150×150×150 mm 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. [9]

**IV. TEST PARAMETERS**

The chloride resistance of control concrete and geopolymer concrete were evaluated by measuring the residual compressive strength after chloride exposure. Cubes were immersed in solution after 28days of curing 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. To prepare the solution of 5% concentration, for each 100 gm solution 95 gm of water and 5 gm 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 chloride throughout the test, the pH value of the solution was measured at every 7 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.

**Table 13** Change in Compressive Strength due to chloride exposure

S. No.	Mix ID	Compressive Strength (N/mm <sup>2</sup> )			
		10 M Before Curing	10 M After Curing	8 M Before Curing	8 M After Curing
1	M 1	48.39	47.95	48.04	47.63
2	M 2	42.72	42.29	38.504	38.04
3	M 3	26.16	25.86	24.6672	23.95
4	M 4	17.87	17.25	16.125	15.268
5	M 5	13.3	12.56	12.75	12.284

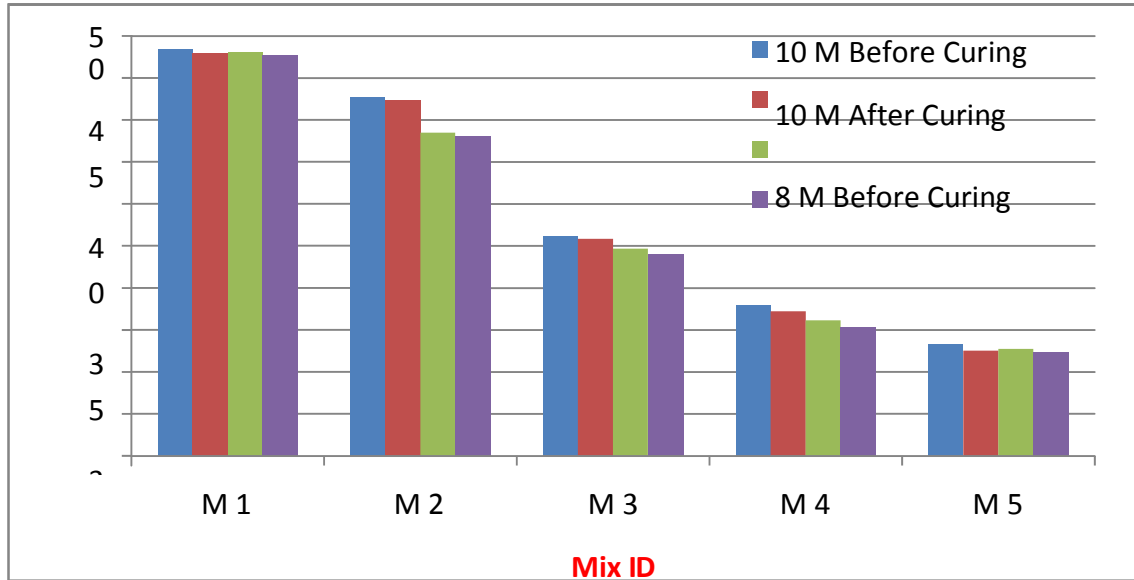


Figure 5 Compressive Strength due to chloride exposure

### Changes in Mass

Change in mass of specimens was measured after various exposure period. The weight of each specimen was measured before immersion in to the solution. After the exposure period the specimen were taken out and left to air dry for a week in the laboratory condition. Then weights of the specimens were measure during the weighing scale available in laboratory and from that change in mass was calculated.

Table 14 Change in mass due to chloride exposure

S. No.	MIX ID	Weight of Specimens (grams)			
		10 M Before Curing	10 M After Curing	8 M Before Curing	8 M After Curing
1	M 1	8600	8645	8720	8726
2	M 2	8530	8550	8425	8430
3	M 3	8193	8210	8500	8520
4	M 4	8239	8250	8645	8690
5	M 5	8259	8302	8734	8746

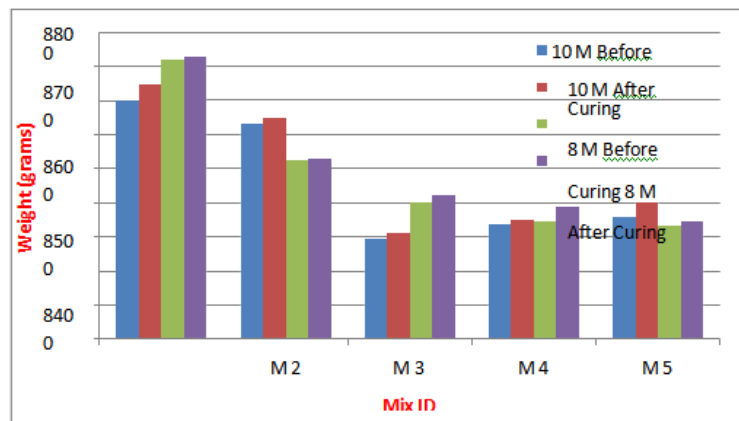


Figure 6 Change in mass due to chloride exposure



## V. CONCLUSION

The test results demonstrate that ambient cured GGBS and Metakaolin based geopolymer concrete has an excellent resistance to sulphate attack. There is no damage to the surface of test specimens after exposure to sodium sulphate solution up to one month. There are no significant changes in the mass and the compressive strength of test specimens after the exposure. Exposure to sulphuric acid solution damages the surface of ambient cured geopolymer concrete test specimens and causes a mass loss after the exposure. The severity of the damage depends on the acid concentration. The sulphuric 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. The test result of chloride attack demonstrates that geopolymer concrete has a good resistance to chloride. There are no significant change in mass and the compressive strength after exposure up to three months. The strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix.

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