A Comparative Study on Strength and Durability Aspects of fly ash- GGBS based Geopolymer Concrete over Conventional Concrete

Miss. Sapna Rathod
M.Tech Student
Department of Civil Engineering,
S.G. Balekundri Institute of Technology,
Belagavi 560064, India.

Mr. Girish Hombal
Asst. Professor
Department of Civil Engineering,
S.G. Balekundri Institute of Technology,
Belagavi 560064, India.

***Abstract*— Concrete is known to be the most versatile, durable and reliable construction material. It is the second most used material after water which inculcates huge quantity of Portland cement. Production of Ordinary Portland Cement is the second major generator of carbon dioxide, which pollutes the atmosphere.**

The main aim of this study is concern towards the environment. Geopolymer is the factor which neither uses Portland cement nor releases greenhouse gases. In the present study the feasibility of industrial by-products i.e.; Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) powder as eco-friendly and sustainable is studied. The Alkaline solutions used are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The study includes casting of Geopolymer concrete and conventional concrete specimens and tested for different ages for both strength and durability. The results show that Geopolymer concrete gives good strength compared to conventional concrete. Thus, the Geopolymer concrete can be considered to be an environmentally pollution free construction material.

Keywords*— Geopolymer Concrete, Sodium Silicate, Sodium Hydroxide, Fly ash, Ground granular blast furnace slag, Compressive strength, Flexural strength, and ambient curing.

I. INTRODUCTION

Davidovits [1] first introduced the word Geopolymer in 1978 to present the wide scope of material characterisation by series or web of organic molecules. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. For the Any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. To impart a proper unbreakable binding forum this mechanization chiefly depends on the utilisation of industrial waste products or natural materials. Metakaolin, low calcium ASTM Class F fly ash, combination of metakaolin and fly ash, organic Al-Si minerals, combination of calcined and non-calcined minerals, combination of GGBS and metakaolin are investigated as source materials. Geopolymer are hardened material with three dimensional structures similar to aluminosilicate glass structures. The main source materials aluminium and silicone provided by industrial waste products or thermally organic activated minerals polymerizes impulsively and spontaneously into networks of organic particles or molecules for the formation of Geopolymer paste [2].

At the preliminary stage of mixing the alkaline energized solution melts the ions of aluminium and silicon from the amorphous segment of feed stock. This segment includes the poly-condensation of adjacent silicon and alumina particles come in effect. Whereas the hydroxyl ion creates bond with oxygen ejecting water particles by itself. Water is only used to promote flowability during formation of geopolymer concrete. The reaction of water is negligible in the process of geopolymerisation and fades away during post mixing processes. This different nature of water enhances both the chemical and mechanical properties of GPC and shows better resistance against salt attacks, acid attacks, temperature, water ingression.

Geopolymer concrete mainly composites of source materials enhanced with alumina and silica such as fly ash and ground granulated blast furnace slag, catalytic liquid system combined of sodium hydroxide and sodium silicate, fine aggregates such as manufacture sand and coarse aggregates, exposed to ambient curing or heat curing. The complex material hence obtained is fragile and solid in nature, gives significant results in compression. Low dry shrinkage and creeping are some of the characteristic of geopolymer concrete kept for heat curing. GPC also increases the mechanical properties of the concrete. It has shown best results in resisting acid and chloride penetration. Geopolymer concrete prepared with lesser fluid binder ratio shows best durability properties against thawing and freezing. Under the action of acid solution on Geopolymer concrete, it engrosses cracks on the outer layer, but remains structurally inert.

II. MATERIALS USED

1. Fly ash - Class-F fly ash was procured from “West Coast Paper Mills”, Dandeli (Karnataka) and is used as one of the primary raw materials.

Table 1: Physical properties of Fly ash

Specific gravity	Fineness (m^2/kg)	LOI (%)
2.25	320	2.4

Table 2: Chemical composition of Fly ash

Al_2O_3 (%)	Fe_2O_3 (%)	SiO_2 (%)	MgO (%)	SO_3 (%)	Na_2O (%)	Chlorides (%)	CaO (%)
24	8.97	58.82	0.83	1.8	0.89	0.06	2.9

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2. GGBS - GGBS was procured from "JSW Steels", Bellary.

Table 3: Physical properties of GGBS

Physical form	Bulk density (kg/m^3)	Specific gravity	Specific surface (m^2/kg)	LOI (%)
Milky white powder	1165	2.75	413	0.18

Table 4: Chemical composition of GGBS

Glass (%)	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Sulphite sulphur (%)	Insoluble residue (%)	LOI (%)
92	37.73	37.34	14.42	1.11	0.39	1.59	1.41

3. Alkaline solution - The present study utilizes sodium hydroxide procured from "Laxmi Chemicals", Belagavi in the form of pellets (specific gravity 2.14). The sodium hydroxide is easily available and economical. Sodium silicate solution was also procured from "Laxmi Chemicals", Belagavi.

3.1 Preparation of alkaline solution

In this investigation, 8 molar concentration of sodium hydroxide solution was selected based on the trial mix results to check for strength characteristics and durability characteristics of Geopolymer mix. For the present study the ratio of NaOH: Na_2SiO_3 is 1:2.

The NaOH solution should be handled properly with special care and precautions as high exothermic reactions occur during the process which may affect the human skin and eyes.

III. METHODOLOGY

1. *Mix proportion*

As there are no code provisions for the mix design of geopolymer concrete, the density of geo-polymer concrete is assumed as 2400 Kg/m^3. The rest of the calculations are done by considering the density of concrete. The total volume occupied by fine and coarse aggregate is adopted as 75% i.e. 0.75x2400=1800 kg/m^3. The mass of geopolymer binders (fly ash and GGBS) and the alkaline liquid = 2400 – 1800 = 600 kg/m^3. Take the alkaline liquid-to-fly ash+GGBS ratio by mass as 0.60; the mass of fly ash + GGBS = 600/ (1+0.60) = 375 kg/m^3 and the mass of alkaline liquid = 600 – 375= 225 kg/m^3.

The ratio of sodium silicate(Na_2SiO_3) solution-to-sodium hydroxide(NaOH) solution was adopted as 1:2; by further calculation the mass of sodium hydroxide (NaOH)solution = 75kg/m^3; the mass of sodium silicate solution = 150kg/m^3. The sodium hydroxide solids (NaOH) is mixed with water to make a solution with a concentration of 8 Molar. Superplasticizer was added to maintain adequate workability.

2. *Test Methods*

The methodology for casting Geopolymer specimens is same as that of conventional concrete. The coarse, fine aggregates, fly ash and GGBFS were first dry mixed for about 3-4 minutes and then the solution was added and it was mixed for about 4-5 minutes until it resulted in homogenous concrete mix. Immediately after mixing, the concrete was tested for its flowability and then concrete was poured into the moulds for prism specimens of size 150mm x 150mm x 700mm and cube specimens of size 100mm x 100mm in three layers, each layer being tamped 25 times and then vibrated in vibrating machine so that no voids are there. After demoulding Geopolymer specimens were given ambient curing at room temperature and concrete specimens were immersed in water.

Preliminary mix:

Initially cubes were casted for 7 & 28 days for three molarities (12M, 10M, and 8M), each molarity for all the three proportions (50:50, 60:40, and 70:30). Based on the strength results of these specimens one final proportion was finalized and casting was done for the final mix.

Final mix:

The mix finalized from the strength results of the trial mixes was 8M (60:40), for this the further casting process was carried out for 7, 14, 28 & 56 days. In total, approximately 200 cubes and 18 prisms were prepared.

IV. RESULTS AND DISCUSSIONS

1. *Compressive strength*

Sl. no:	Days	Geopolymer concrete		Conventional concrete	
		Weight (kg)	Avg. compressive strength (MPa)	Weight (kg)	Avg. compressive strength (MPa)
1	7	2.536	36.67	2.713	32.33
2		2.503		2.720	
3		2.480		2.727	
4	14	2.478	37.33	2.784	34.67
5		2.495		2.728	
6		2.510		2.708	
7	28	2.521	41.00	2.656	38.00
8		2.473		2.594	
9		2.503		2.662	
10	42	2.516	39.67	2.644	39.00
11		2.547		2.675	
12		2.600		2.650	
13	56	2.404	42.00	2.742	38.67
14		2.636		2.692	
15		2.650		2.570	
16	84	2.368	44.00	2.642	42.00
17		2.522		2.698	
18		2.450		2.676	

Fig 1: variation of compressive strength of GPC and CC

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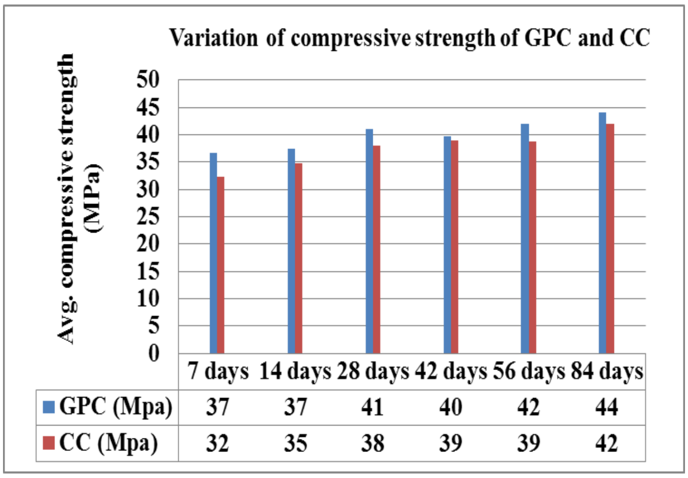
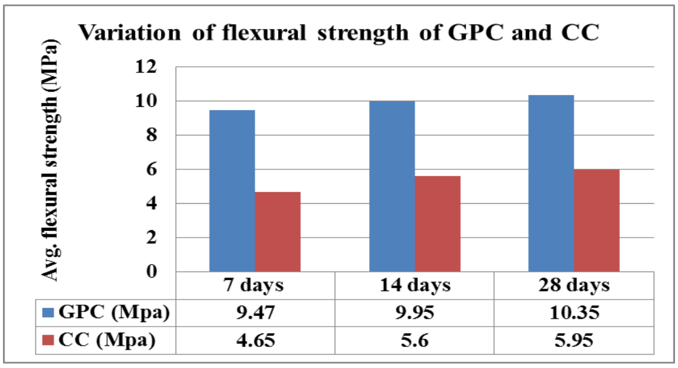


The Geopolymer concrete achieved the required strength in 7 days only. The percentage increase of Geopolymer concrete strength when compared to normal concrete strength was 13.51% at the age of 7 days, 5.405% for 14 days, 7.32 for 28 days, 2.5% for 42 days, 7.14% for 56 days and 4.55% for 84 days. The strength obtained by conventional concrete at the age of 28 days has been already achieved by Geopolymer concrete in 7 days itself and the strength obtained at the age of 84 days was achieved in 56 days only by Geopolymer concrete.

2. Flexural strength

Sl.no:	Days	Geopolymer concrete		Conventional concrete	
		Weight (kg)	Avg. flexural strength (MPa)	Weight (kg)	Avg. flexural strength (MPa)
1	7	41.06	9.47	40.732	4.65
2		40.69		42.018	
3		40.80		40.794	
4	14	41.29	9.95	40.740	5.60
5		40.43		42.200	
6		40.35		40.934	
7	28	41.46	10.02	41.020	5.95
8		40.56		42.320	
9		41.20		41.560	

Fig 2: variation of flexural strength of GPC and CC



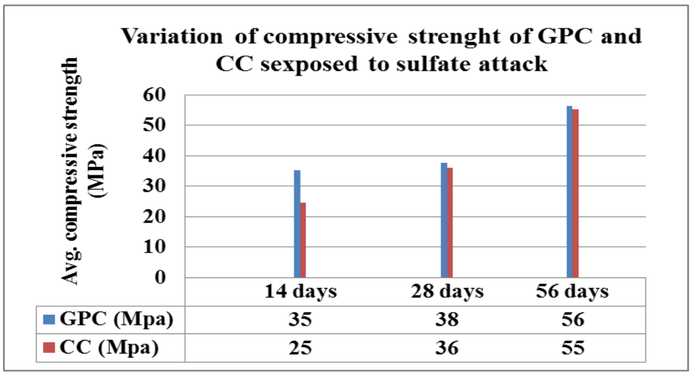
The percentage increase in the Geopolymer concrete when compared to the conventional concrete was 50.89% for 7 days, 43.72% for 14 days and 42.51% for 28 days.

3. Durability tests

3.1 Magnesium sulfate tests

Sl. no:	Days	Geopolymer concrete		Conventional concrete	
		Weight (kg)	Avg. compressive strength (MPa)	Weight (kg)	Avg. compressive strength (MPa)
1	14	2.460	35.33	2.742	24.67
2		2.536		2.720	
3		2.505		2.721	
4	28	2.590	37.67	2.634	39.33
5		2.530		2.798	
6		2.580		2.650	
7	56	2.494	56.33	2.814	55.33
8		2.568		2.656	
9		2.510		2.620	

Fig 3: variation of compressive strength of GPC and CC exposed to sulfate attack

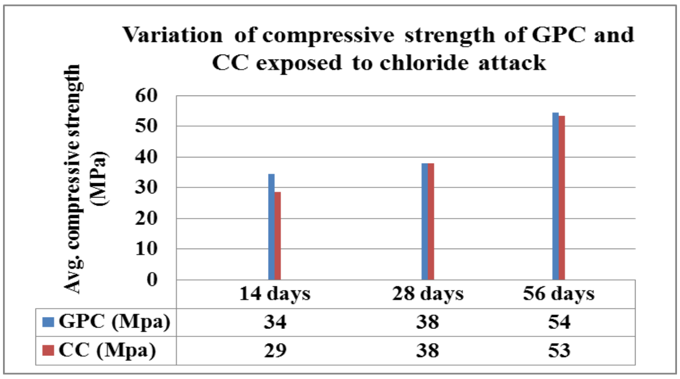


When the specimens were immersed in magnesium sulfate solution for 56 days there was no harm to the outer surface and after soaking it in the solution for 56 days. We could see no symptoms of fracture, corrosion and spalling on the surface of the cube samples whereas this was not seen in plain concrete. The effect of magnesium sulfate attack on the plain concrete was severe and the evolution of ettringite and expansive gypsum cause rupture, expansion and spilling of concrete.

3.2 Sodium chloride tests

Sl. no:	Days	Geopolymer concrete		Conventional concrete	
		Weight (kg)	Avg. compressive strength (MPa)	Weight (kg)	Avg. compressive strength (MPa)
1	14	2.544	34.33	2.732	28.67
2		2.670		2.731	
3		2.600		2.716	
4	28	2.550	38.67	2.740	38.00
5		2.518		2.808	
6		2.530		2.714	
7	56	2.472	54.33	2.680	53.33
8		2.516		2.750	
9		2.620		2.772	

Fig 4: variation of compressive strength of GPC and CC exposed to chloride attack

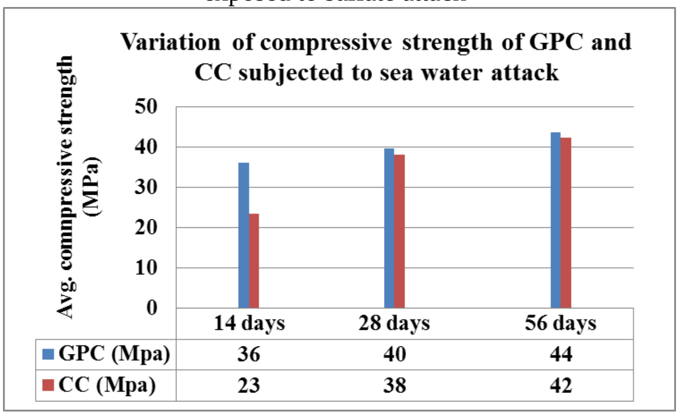


The gain in strength of Geopolymer concrete shows excellent resistance against chloride attack. When the specimens were immersed in sodium chloride solution for 56 days there was no harm to the outer surface and after soaking it in the solution for 56 days, and the visual appearance of the cube samples showed that there was accumulation of white deposits on the outer layer of the specimens because of the exposure conditions. We could see no symptoms of fracture, corrosion and spalling on the surface of the cube samples. Geopolymer concrete showed minor increment in the mass of cube samples whereas plain concrete showed reduction in the mass of samples.

3.3 Sea water tests

Sl. no:	Days	Geopolymer concrete		Conventional concrete	
		Weight (kg)	Avg. compressive strength (MPa)	Weight (kg)	Avg. compressive strength (MPa)
1	14	2.518	36.00	2.718	23.33
2		2.460		2.782	
3		2.502		2.786	
4	28	2.562	39.67	2.770	38.00
5		2.576		2.738	
6		2.620		2.764	
7	56	2.510	43.67	2.786	42.33
8		2.550		2.620	
9		2.583		2.612	

Fig 5: variation of compressive strength of GPC and CC exposed to sulfate attack



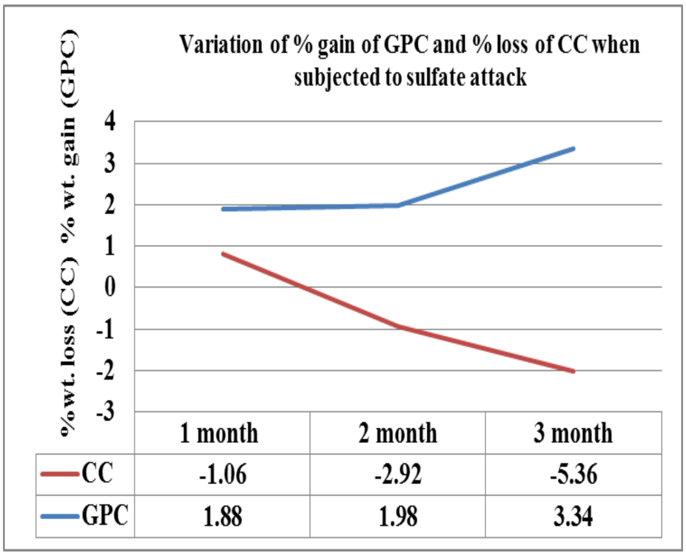
The gain in strength of Geopolymer concrete shows excellent resistance against seawater. When the specimens were immersed in sea water for 56 days there was no harm to the outer surface and after soaking it in the solution for 56 days, and the visual appearance of the cube samples showed that there was accumulation of light green deposits on the outer layer of the specimens. We could see no symptoms of fracture, corrosion and spalling on the surface of the cube samples. Geopolymer concrete showed minor increment in the mass of cube samples whereas plain concrete showed reduction in the mass of samples.

4. Weight loss/gain test results

***4.1** Due to Magnesium sulfate attack*

Sl. no:	Month	Geopolymer concrete Avg. % wt. gain	Conventional concrete Avg. % wt. loss
1	1st	1.88	1.06
2			
3			
4	2nd	1.98	2.92
5			
6			
7	3rd	3.34	5.36
8			
9			

Fig 6: variation of compressive strength of GPC and CC exposed to sulfate attack



The figure above represents that there is gain in weight of Geopolymer concrete specimens and loss in weight of conventional concrete specimens when exposed to magnesium sulfate solution for the duration of three months. The weight gain percentage with period was very less. In the first month the percentage in weight gain for Geopolymer concrete was 1.88%, 1.98% for the second month and 3.34% for the third month respectively. There was loss in weight of normal concrete throughout the exposure of duration. The loss in first month was 1.06%, 2.92% for second month and 5.36% for the third month respectively.

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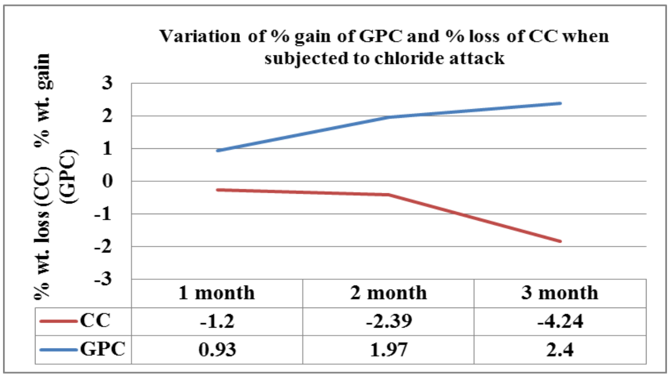
4.2 Due to Magnesium chloride attack

Sl. no:	Month	Geopolymer concrete Avg. % wt. gain	Conventional concrete Avg. % wt. loss
1			
2	1st	0.93	1.20
3			
4			
5	2nd	1.97	2.39
6			
7			
8	3rd	2.40	4.24
9			

Fig 7: variation of compressive strength of GPC and CC exposed to sulfate attack

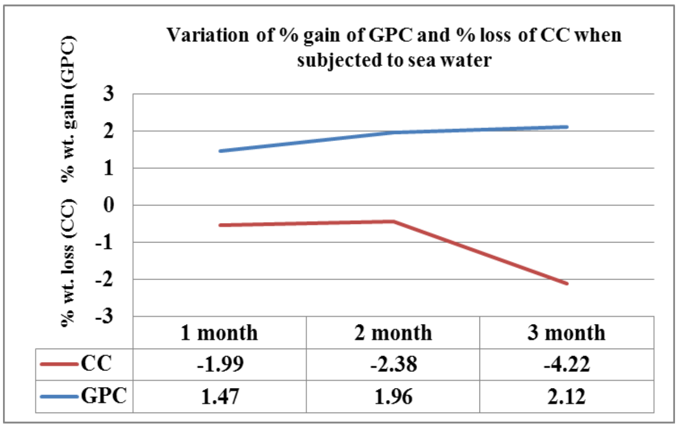


The figure above represents that there is gain in weight of Geopolymer concrete specimens and loss in weight of conventional concrete specimens when exposed to magnesium sulfate solution for the duration of three months. The weight gain percentage with period was very less. In the first month the percentage in weight gain was 0.93%, 1.97% for the second month and 2.4% for the third month respectively. There was loss in weight of normal concrete throughout the exposure of duration. The loss in first month was 1.2%, 2.39% for second month and 4.24% for the third month respectively.

4.3 Due to Magnesium sea water attack

Sl. no:	Month	Geopolymer concrete Avg. % wt. gain	Conventional concrete Avg. % wt. loss
1			
2	1st	1.47	1.99
3			
4			
5	2nd	1.96	2.38
6			
7			
8	3rd	2.12	4.22
9			

Fig 8: variation of compressive strength of GPC and CC exposed to sulfate attack



The figure above represents that there is gain in weight of Geopolymer concrete specimens and loss in weight of conventional concrete samples when exposed to magnesium sulfate solution for the duration of three months. The weight gain percentage with period was very less. In the first month the percentage in weight gain was 1.47%, 1.96% for the second month and 2.12% for the third month respectively. There was loss in weight of normal concrete throughout the exposure of duration. The loss in first month was 1.99%, 2.38% for second month and 4.22% for the third month respectively.

V. CONCLUSIONS

From this investigation, the conclusion can be made that;

- Ambient cured Geopolymer concrete prepared with fly ash and GGBS arrive at the demandable strength for the mentioned period.
- It shows many applications in structural field because of its required gain of strength at the prescribed age.
- The Geopolymer concrete achieved the required strength just in 7 days w.r.t compressive strength.
- The percentage increase of Geopolymer concrete compressive strength when compared to normal concrete compressive strength was 13.51% at the age of 7 days, 7.32 for 28 days, 7.14% for 56 days and 4.55% for 84 days.
- The compressive strength obtained by conventional concrete at the age of 28 days has been already achieved by Geopolymer concrete in 7 days itself.
- The strength obtained by conventional concrete at the age of 84 days was achieved in 56 days only by Geopolymer concrete.
- The flexural strength of Geopolymer concrete also increased with age and the percentage increase in the Geopolymer concrete as to conventional concrete was 50.89% for 7 days, 43.72% for 14 days and 42.51% for 28 days.
- The gain in strength of Geopolymer concrete shows the best resistance against sulphate attack.
- There were no symptoms of fracture, corrosion and spalling on the surface of the cube samples whereas the effect of magnesium sulphate attack on the plain concrete was severe and it showed all the above mentioned symptoms.

- The effect of magnesium sulphate solution on the Geopolymer concrete is less compared to plain concrete.
- The gain in strength of Geopolymer concrete shows excellent resistance against chloride attack and sea water attack.
- The visual appearance of the cube samples showed that there was accumulation of white deposits on the outer layer of the specimens because of the Chloride attack and it also revealed that there was no harm to the edges of the cube samples.
- Geopolymer concrete showed minor increment in the mass of cube samples whereas plain concrete showed reduction in the mass of samples when exposed to chloride attack.
- Geopolymer concrete showed gain in weight whereas conventional concrete showed loss in weight when exposed to magnesium sulphate solution, sodium chloride solution and sea water.

Fly ash and GGBS based Geopolymer concrete develops strength of 35 N/mm^2 at the age of 7 days itself, which later shows more increment for 28 and 56 days.

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