A STUDY ON INFLUENCE OF MOLARITY AND VARYING PERCENTAGE OF GGBS ON GREEN CONCRETE, STRENGTH AND DURABILITY OF HARDENED GEOPOLYMER CONCRETE

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Abstract - *This present work reports the results of the laboratory tests conducted to investigate the effect of sodium hydroxide concentration along with the increasing percentage of GGBS on the fresh properties and compressive strength of geopolymer concrete. The experiments were conducted by varying the concentration of sodium hydroxide from 10 M to 12 M for mix designs M_1 (100FA0GGBS) M_2 (75FA25GGBS) M_3 (50FA50GGBS) M_4 (25FA75GGBS) M_5 (0FA100GGBS). Test methods such as Slump test was used to assess the workability characteristics of GPC. The test specimens were cured at 60°C for a period of 24 hours and then kept in room temperature until the day of testing. Compressive strength test was carried out at the ages of 7 and 90 days. At the age of 90 the specimens were subjected to durability tests. Hydrochloric acid was used for the acid attack and magnesium sulphate was used for sulphate attack. Test results indicate that concentration variation of sodium hydroxide had least effect on the fresh property of GPC. Concrete samples with sodium hydroxide concentration of 12 M produced maximum compressive strength compared to 10 M. With the increase in the percentage of GGBS the compressive strength of geopolymer concrete is also increased. The concrete samples with 12 M concentration with 100% GGBS percentage showed better resistance towards both acid and sulphate attack. Hence concrete mix M_5 with 12 Molarity considered durable concrete.*

Keywords : Geo-Polimer, Fly-ash, GGBS, Acid attack, Compressive strength, Workability, Sodium Hydroxide concentration.

I. INTRODUCTION

Development in the field of Science and Technology is considered as a continuous process for improving infrastructure all around the globe. Each day an innovative techniques are implemented in the field of construction for achieving high durability, safety, economical and sustainable construction. Concrete is considered to be the most consumed material besides water. Ordinary Portland Cement (OPC) mainly utilized as main binding material for the manufacture of the concrete. The use of ingredients such as fine aggregate, water and coarse aggregate is responsible for concrete's strength, toughness and compactness. Concrete is widespread due to many reasons such as concrete has an excellent resistance towards the water surfaces and it behaves as an impermeable member and also the concrete possess greater strength and gives a long term life span because of its good strength and durability. Furthermore the cement is a cheap material which is available widely and easily on market even the fine and coarse aggregate are also available easily. As a matter of fact the fly–ash and GGBS is considered to be the waste material the geopolymer concrete can be cheaper than the Portland cement concrete and also because some peculiar properties can also further enhanced the economic benefits of geopolymer concrete. Fly–ash is the unwanted product produced from process of coal combustion in thermal power - station which is obtainable at enormous scale all around the globe with the presence of alumina (AI) and silicon (SI) as the chief constituents. Hence fly–ash has enormous potential as a cement replacement. The chemical mechanical and physical properties are the influential aspects to the strength of the geopolymer concrete. Physical properties are primarily turn to the quality and the type of material utilized in the manufacture of concrete. Alkaline solution i.e sodium- hydroxide (NaOH), sodium-silicate (Na_2sio_3) along with water are commanding elements for chemical properties. Among the various types of by-product or waste material GGBS and fly–ash is considered to be the most promising source of geo-polymer. The implementation of fly–ash and GGBS as source materials been reported in various studies and researches. In the present study proportion of fly-ash and GGBS is varied along with the molarity of the alkaline solution is also varied in order to get the idea about the strength aspect of the geopolymer concrete.

II. MATERIALS

Materials utilized in the preparation of geopolymer concrete are,

1. Fly – ash.
2. GGBS.
3. M-sand.

4. Coarse aggregates.
5. Sodium hydroxide.
6. Sodium silicate.
7. Water.

1. Fly-Ash

Geopolymer concrete is composed of alumino-silicate centered source materials admixed with alkaline solution. In the present study class F fly-ash is used. Because class F fly-ash is alkali activated and it has low calcium content. The low calcium class F fly-ash is attained from the KPTCL bellary thermal power – station Kudatini Bellary taluk, Bellary district, Karnataka. Table 1 shows Physical properties of fly ash

Table 1 : Physical properties of fly ash

Sl No	Properties	Values
1	Specific gravity	2.27
2	Fineness Modulus	3.59

2. Ground Granulated Blast-furnace Slag

Ground granulated blast-furnace slag (GGBS) is the waste product produced in the coarse of the production of iron and steel. The waste slag is cooled, dried and at that point of time the slag is grounded into a fine powder. This powder is popularly known as Ground Granulated Blast-furnace Slag. In the current study GGBS is obtained from Ultratech cement ltd, Solarium city, Doddanakundi, Bangalore Table 2 shows Physical properties of GGBS.

Table 2 : Physical properties of GGBS

Sl No	Properties	Values
1	Specific gravity	2.83
2	Fineness Modulus	3.59

3. M-Sand

Manufactured sand is a product which is produced from crushing of aggregates. M-sand can be preferably utilized as fine aggregates during concrete production. For this study superior quality of m-sand is utilized manufactured sand for the project is obtained from the davangere district. Mainly 2 tests i.e specific gravity and water absorbtion tests were performed to establish the quality of the obtained m-sand Table 3 shows Physical properties of M-Sand.

Table 3 : Physical properties of M-Sand

Sl No	Test	Value
1	Specific gravity	2.59
2	Water absorption	1.8%

4. Coarse Aggregate

Crushed stones were used as coarse aggregates in this present study. Crushed stones are considered to be the excellent option as a coarse aggregate in concrete production. They are obtained by crushing of stones like granite, sandstone. Locally obtainable crushed granite stones of size 20 mm and 12 mm down size was utilized in the existing study Table 4 shows Physical properties of coarse aggregate.

Table 4 : Physical properties of Coarse Aggregate

Sl No	Test	Value
1	Specific gravity	2.64
2	Water absorption	0.27%

5. Sodium Hydroxide

The NaOH generally existing in market as in the form of pellets and flakes. The cost of the NaOH is mainly depending upon its purity. The purity of NaOH available in market is about 96% to 99%. In the current study 10 M and 120M NaOH solution was prepared with the use of NaOH pellets of 97% Fig 1 shows Sodium hydroxide Pellets. For this study sodium hydroxide pellets with 97% purity was obtained from Davangere scientific supplies, Davangere. Table 5 shows Chemical composition of Sodium Hydroxide.

Table 5 : Chemical composition of Sodium Hydroxide

Sl no	Chemical formula	Percentage
1	Carbonate (Na_2Co_2)	02
2	Chloride (Cl)	00.01
3	Sulphate (SO_4)	00.05
4	Lead (Pb)	00.001
5	Iron (Fe)	00.001
6	Potassium (K)	00.1
7	Silicate (SiO_2)	00.05
8	Zinc (Zn)	00.02
9	Molarity	10M and 12M

6. Sodium Silicate

Sodium silicate is widely identified as water glass which is existing in gel form and as well as solid form in the market. The strength of geopolymer concrete is largely depending upon the ratio between silicates to hydroxide Fig 2 shows Sodium silicate. In the present study the SiO_2 and Na_2O ratio is kept as 2.5 and the sodium silicate is obtained from Davangere scientific supplies, Davangere.

7. Water

Normal water is utilized in the present work. There are 2 main role of water in this experiment one being the water to be utilized for the preparation of alkaline solution and another being used during mixing of concrete for achieving good workability. The water which is present in the geopolymer mix does not play any kind of role in chemical reaction. On the other hand the water does provide the workability to the concrete.

Fig 1 : Sodium hydroxide Pellets

Fig 2 : Sodium Silicate

III. PREPARATION OF ALKALINE SOLUTION

In this existing work the mix design is carried out for both 10 molar and 12 molar. To prepare 10M of NaOH solution the required weight of sodium hydroxide pellets to be added to the water is calculated in the mix design calculation. The exact technique to achieve 10 molar is by mixing of 400 gms (10 * 40) of solid sodium hydroxide pellets with approximately 500 ml water. After the complete mixing of pellets in water i.e the solid pellets are dissolved check if the prepared NaOH solution is about 1 ltr. If solution found to be falling short of 1 liter mark add water till the solution become 1 liter. The chemical reaction between water and sodium is an exothermic reaction hence there will be huge amount of heat will be released. So the precautionary care must be taken during the alkaline solution preparation. Similar procedure can be adopted for the preparation of 12 M NaOH solution. But for achieving 12 Molar 480gms of sodium hydroxide to be mixed with the 1 litter water.

IV. Mix Design

Mix design for 10M Geopolymer concrete (G-60-10-24)

G-Geopolymer
60^0 C- Temperature
10-Molarity
24 Hour-Curing

1) Alkaline solution
AL/FA = 0.35
Assuming amount of binder material = 360 kg
Where,
AL =Alkaline solution
FA = Fly-ash
AL = 0.35 X 360 = 126 kg/m^3

2) Water
Geopolymer solids = W/GPC = 0.23
   a. NaOH solution
   b. Na_2SiO_3 solution

The Silicate to hydroxide ratio is kept as 2.5

a. NaOH solution preparation
NaOH solution = AL / (2.5+1)
= 126 / 3.5 = 36 kg/m^3
NaOH solid Mass = 0.303 X 36 = 10.98 kg/m^3
NaOH water Mass = 36 – 10.98 = 25.09 kg/m^3

b. Na_2SiO_3 solution preparation
Na_2SiO_3 solution = 126 – 36 = 90
Mass of solid Na_2SiO_3 = 0.44 X 90 = 39.6 kg/m^3
Mass of water in Na_2SiO_3 = 90 – 36.9 = 50.4 kg/m^3

$$\frac{(W_{free} + \text{water in NaOH} + \text{Water in } Na_2SiO_3)}{(BM + \text{NaOH solid} + Na_2SiO_3 \text{ solids})} = 0.23$$

Where,
W_{free} = Free water
BM = Binding material

$$\frac{(W_{free} + 25.09 + 50.4)}{(360 + 10.908 + 39.6)} = 0.23$$

W_{free} = 18.92 kg/m^3

3) Calculation of Mass of Ingredients

a. For Mix design = M 1 (100 % Fly-ash)
   a) Vol of concrete = 1 m^3

   b) Vol of FA = ((mass of Fly-ash) / (sg of FA)) x (1^{-3})
   = (360 / (2.27 x 1000)) = 0.1585 m^3

   c) Vol of aggregate
   e = a – b – ((W_m / W_{sg}) x 10^{-3}) – ((OH_m / OH_{sg}) x 10^{-3}) – (($SiO_{3\,m}$ /$SiO_{3\,sg}$) x 10^{-3})

W_m = mass of free water
W_{sg} = sg of water
OH_m = mass of NaOH sol
OH_{sg} = sg of NaOH
$SiO_{3\,m}$ = mass of Na_2SiO_3
$SiO_{3\,sg}$ = sg of Na_2SiO_3

e = 1 – 0.1585 – (18.92 / 1000) – (36 / (1.31 x 1000)) – (90 / (1.2 x 1000))
e = 1 – 0.1585 – 0.1214
e = 0.7201

a) Mass of Coarse aggregate = 0.7201 x 2.64 x 0.62 x 1000 = 1178.659 kg/m³
b) Mass of Fine aggregate = 0.7201 x 2.59 x 0.38 x 1000= 708.722 kg/m³

Table 6 shows the mix proportions of the various mix design implemented in the present study.

Table 6 : Mix Proportions of various mix designs

Mix design	Molarity	Alkaline liquid to Fly-ash ratio	Fly-ash (Kg/m³)	GGBS (Kg/m³)	Water (Kg/m³)	NaOH (Kg/m³)	Na_2SiO_3 (Kg/m³)	Fine Aggregate (Kg/m³)	Coarse Aggregate (Kg/m³)
M_1	10	0.35	360	-	18.92	36	90	709	1179
	12	0.35	360	-	21.49	36	90	706	1174
M_2	10	0.35	270	90	18.29	36	90	753	1252
	12	0.35	270	90	21.49	36	90	750	1248
M_3	10	0.35	180	180	18.92	36	90	724	1204
	12	0.35	180	180	21.49	36	90	722	1200
M_4	10	0.35	90	270	18.92	36	90	732	1217
	12	0.35	90	270	21.4	36	90	722	1200
M_5	10	0.35	-	360	18.92	36	90	740	1230
	12	0.35	-	360	21.49	36	90	737	1226

V. RESULTS AND DISCUSSION

1. WORKABILITY

Each mix design of concrete shall be tested for consistency immediately after mixing. The slump cone test was conducted in order to test the workability of concrete Table 7 shows slump test results on fresh concrete. Fig 3 shows the varation of workability of geopolymer concrete. As the percentage of GGBS increase it was found that the mix was becoming more and more stiff.

Table 7 : Slump test result on fresh Geopolymer concrete

Sl No	Mix design	Molarity	
		10M	12M
1	M_1	110	107
2	M_2	95	94
3	M_3	87	90
4	M_4	79	75
5	M_5	73	69

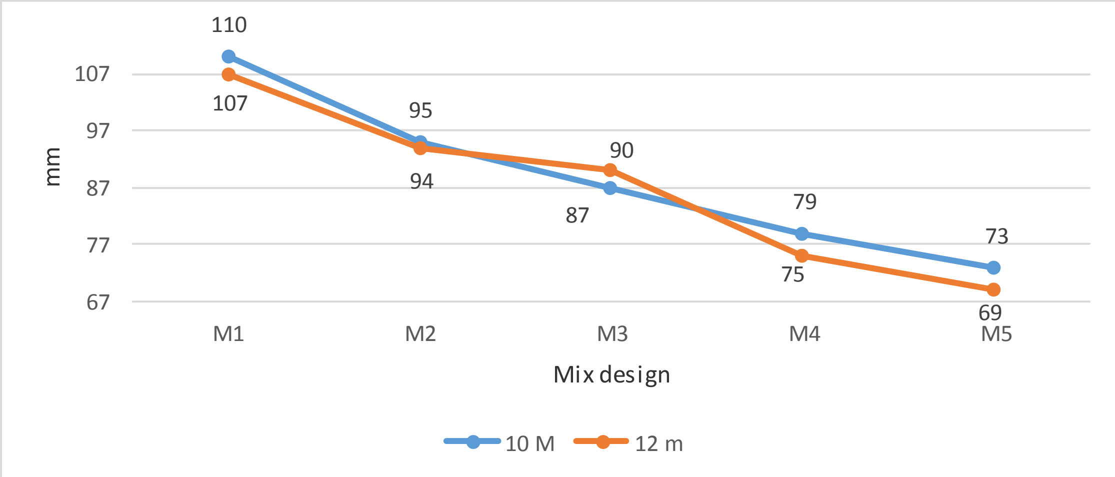

Fig 3 : Variation of Workability of Geopolymer concrete

2. COMPRESSIVE STRENGTH TEST ON GEOPOLYMER CONCRETE

To assess the strength of geopolymer concrete the compressive strength test is conducted. Here geopolymer concrete cubes are tested for its strength in hardened state at the age of 7 days and 90 days as per IS : 516 – 1959. For each mix design a total of 16 cubes were casted 8 each for 12M and 10M respectively. These cubes were tested for compressive strength and average of 3 cubes of 7 days and average of 3 cubes for 90 days are taken as compressive strength of one mix design at 7th and 90th day strength respectively Table 8 shows compressive strength test results on geoploymer concrete. Fig 6 shows the varation of compressive strength of geopolymer concrete. The compressive strength of the geopolymer concrete was constantly increasing with the increase in the percentage of GGBS.

Table 8 : Compressive test result on Geopolymer concrete

Mix design	Molarity	Specimen	Weight (Kg)	F_{ck} (N/mm^2)	Avg 7th day Compressive strength (Mpa)	Weight (Kg)	F_{ck} (N/mm^2)	Avg 90th day Compressive strength (Mpa)
M_1	10	1	8	17.35	17.43	7.65	22.22	22.08
		2	7.88	16.44		7.89	23.56	
		3	8.12	18.5		7.61	20.44	
M_1	12	1	7.4	26.2	26.07	7.16	32.89	34.70
		2	7.26	24.89		7.34	35.55	
		3	7.63	27.11		7.63	34.67	
M_2	10	1	7.12	19.55	21.78	7.95	29.33	29.18
		2	8.06	23.11		7.34	29.78	
		3	7.63	22.67		7.63	28.44	
M_2	12	1	7.89	32	30.67	7.26	36.88	37.18
		2	7.30	30.67		7.4	36.44	
		3	7.12	29.33		7.63	38.22	
M_3	10	1	7.07	25.78	28.29	7.90	34.67	34.67
		2	7.23	29.33		7.90	32	
		3	7.36	29.78		7.98	37.33	
M_3	12	1	8.13	32.89	33.48	7.07	42.67	42.81
		2	8.12	35.56		7.96	41.78	
		3	7.94	32		8.03	44	
M_4	10	1	7.16	34.22	33.77	7.94	42.67	43.55
		2	7.4	34.67		7.98	44.88	
		3	7.28	32.44		7.61	43.11	
M_4	12	1	8.2	34.67	39.11	7.99	48	48.73

		2	8.26	40.89		8.31	52	
		3	8.38	41.78		7.74	48.88	
M_5	10	1	7.94	39.55	39.70	7.88	47.11	46.37
		2	7.62	38.67		7.80	45.33	
		3	8.03	40.8		7.70	46.67	
M_5	12	1	7.46	41.33	42.37	7.64	51.11	51.85
		2	7.87	43.55		7.54	55.11	
		3	7.59	42.22		7.80	49.33	

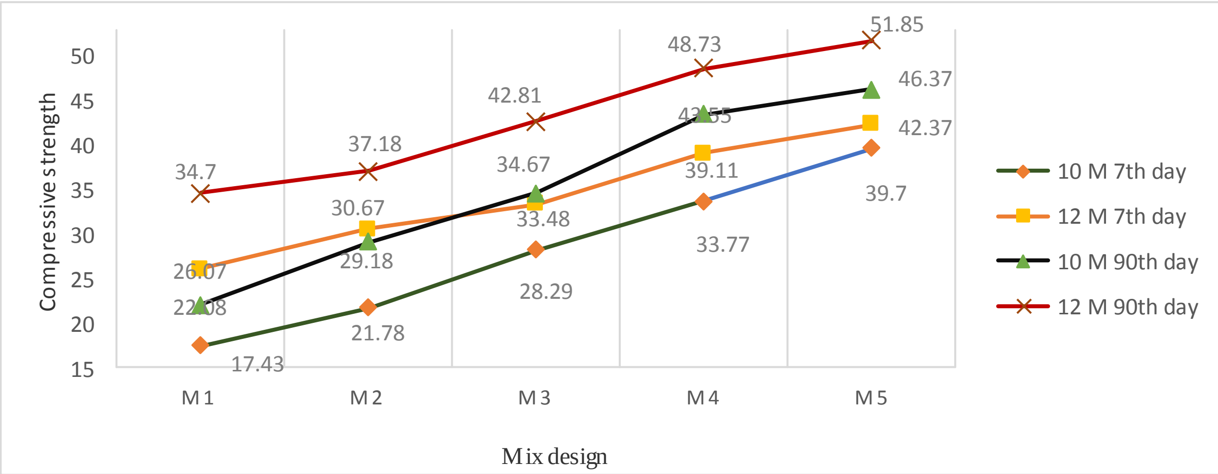

Fig 4 : Variation of Compressive strength test result

3. DURABILITY TESTS ON GEOPOLYMER CONCRETE

The specimen were air cured for 90 days and then tested for their durability character. The HCl is used as the acidic medium and the $MgSo_4$ is used as the basic medium in the present study. The tank was filled with 5 % concentrated Hydrochloric acid solution for acid attack and 5 % concentrated Magnesium Sulphate solution is filled in another tank for Sulphate attack then the specimen cubes were placed in acid and Sulphate tank for 28 days. After 28 days the cubes were taken out and dried of with cotton cloth and allowed dry for 30 min. then cubes were weighed and the percentage of weight loss is calculated. Then the specimens were tested for its compressive strength Table 9 shows result of durability tests result on geoploymer concrete Fig 5 shows the Change in weight after durability tests gropolymer concrete and Fig 6 shows Loss of compressive strength after durability test on geopolymer concrete.

Table 9 : Durability tests on Geopolymer concrete

Mix design		M_1		M_2		M_3		M_4		M_5	
Molarity		10M	12M	10M	12M	10M	12M	10M	12M	10M	12M
Weight (kg)	Initial	7.63	7.96	7.84	7.72	7.84	7.65	7.95	7.78	7.97	7.92
	After acid attack	7.18	7.56	7.54	7.48	7.64	7.50	7.79	7.67	7.82	7.84
Change in Weight (%)		-5.89	-4.98	-3.74	-3.11	-2.55	-1.84	-1.92	-1.34	-1.48	-0.93
Weight (kg)	Initial	8.13	7.80	7.50	7.81	7.66	7.92	7.70	7.90	8.15	7.99
	After Sulphate attack	8.52	8.11	7.79	8.08	7.90	8.15	7.92	8.08	8.31	8.08
Change in Weight (%)		+4.71	+4.09	+3.96	+3.36	+3.11	+2.92	+2.89	+2.17	+1.97	+1.24
Compressive strength (Mpa)	Initial	22.08	34.70	29.18	37.18	34.67	42.81	43.55	48.73	46.37	51.85
	After acid attack	15.11	24.44	22.22	29.78	28.89	37.33	37.78	44	41.33	48.44
Loss of Compressive strength (%)		31.56	29.56	23.85	19.90	16.67	12.80	13.24	9.70	10.86	6.57
Compressive	Initial	22.08	34.70	29.18	37.18	34.67	42.81	43.55	48.73	46.37	51.85

strength (Mpa)	After Sulphate attack	16	25.77	22.67	30.22	29.33	38.22	38.22	44.89	41.78	49.33
Loss of Compressive strength (%)		27.53	25.04	22.30	18.71	15.40	10.72	12.23	7.88	9.89	4.86

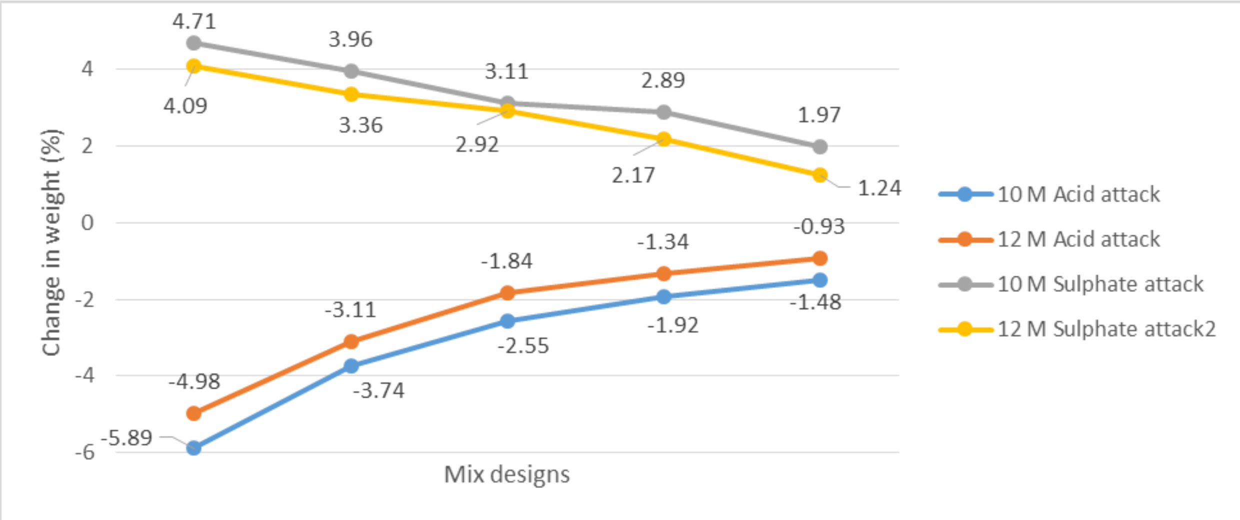

Fig 5 : Change in weight after durability test on GPC

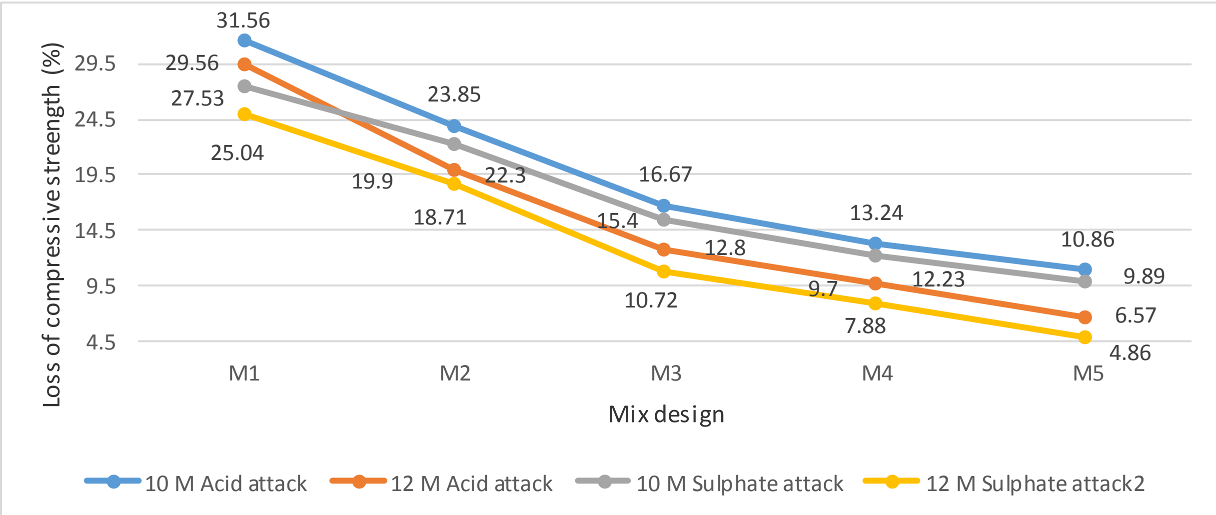

Fig 6 : Loss of compressive strength after durability test on GPC

VI. CONCLUSIONS

In this present study the following conclusions are made:

1. Fly-ash and GGBS can be used effectively as 100% replacement for OPC.
2. M-sand can be used as replacement of natural river sand.
3. The molarity of NaOH solution does not have a significant effect on the workability parameter of the geopolymer concrete.
4. As the percentage of GGBS increase it was found that the mix was becoming more and more stiff.
5. On the present investigation it was witnessed that with the increase in the molarity of alkaline solution there was an increase in compressive strength of geopolymer concrete.
6. During this experimental study it was observed that the concrete hardens quickly due to polymerization so it is advisory for the use of admixtures.

7. The compressive strength of the geopolymer concrete was constantly increasing with the increase in the percentage of GGBS.
8. Compressive strength of mix M_5 with 12 Molar alkaline solution shows the best result in the present study.
9. During the durability tests the percentage of change in weight of specimen was decreased with the increase in the percentage of GGBS.
10. In terms of compressive strength the concrete mix with higher percentage of GGBS (M_5) had an effective resistance towards both Acid and Sulphate attack when compared to the higher fly–ash concrete mix (M_1).

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