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Durability of Geopolymer Lightweight Concrete using Industrial By-products against Acid and Sulphate Attack

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ABSTRACT

The study presents the durability of the geopolymer lightweight (GPLW) concrete when exposed individually to 10% Sulfuric acid, 5% Sodium Sulphate solution and 5% Magnesium Sulphate solutions up to 90 days period. Class-C flyash and GGBFS were used as binder materials. Processed Slag sand was used as replacement to fine aggregates and sintered flyash aggregates as replacement to coarse aggregates. The GPLWC specimen were immersed in acid and Sulphate solutions after air curing for 90 days. The strength results of both OPC and GPLW concrete were compared. The compressive strength attained by GPLWC after 90 days was about 27Mpa to 43Mpa and after 180 days was about 30Mpa to 45Mpa. The corresponding compressive strengths in OPC concrete was 26Mpa and 28Mpa respectively. After 60 days and 90 days of exposure to sulphate solutions, the compressive strength decrease was in the range of -10% to 33% and -4% to 38% respectively for GPLWC and about 9% and 16% respectively for OPC concrete. Over the same period of exposure to 10% H2SO4 solution, the compressive strength had decreased and was about 13% to 44% and 14% to 48% respectively for GPLWC and about 10% and 20% respectively for OPC concrete. It is observed that, the selection of binder material is very important, as it adversely effects the strength of concrete to a greater extent.
Keywords: Class-C Fly ash, Geopolymer, GGBFS, Lightweight, PS Sand, Sintered Flyash Aggregates

I. INTRODUCTION

The durability of concrete is determined by its ability to endure the physical and environmental surroundings without losing the functional properties and structural integrity. Concrete is susceptible to attack by sulfuric acid and other sulphates formed in sewage or surrounding atmosphere due to chemical reactions. Geopolymer composites have emerged as an environmental friendly alternative to OPC concrete. Many researchers [3]-[9] have reported as geopolymer composites possess high early strength and better durability. Recently several researchers [14]-[20] have used different by-products as replacement materials, for cement, fine aggregate and coarse aggregate, in production of concrete.

1.1 Sulphate attack

Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium. They occur in soil or ground water. Because of solubility of calcium sulphate is low, ground waters contain more of other sulphates and less of calcium sulphate. Ammonium sulphate is frequently present in agricultural soil and water from the use of fertilizers or from sewage and industrial effluents. Decay of organic matters in marshy land, shallow lakes often leads to the formation of H_2S, which gets transformed into sulphuric acid by bacterial action. Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete.

The sulphate attack is a common occurrence in natural or industrial situations. Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products. Of all the sulphates, magnesium sulphate causes maximum damage to concrete. A characteristic white powdery appearance is the indication of sulphate attack. The term sulphate attack denotes an increase in the volume of cement paste in concrete or mortar due to the chemical reaction between the products of hydration solution containing sulphates.

II. EXPERIMENTAL STUDY

The study presents the durability of the geopolymer lightweight (GPLW) concrete when exposed individually to 10% Sulfuric acid, 5% Sodium Sulphate solution and 5% Magnesium Sulphate solutions up to 90 days period.

1.2 Materials Used and their properties

OPC 53 Grade cement was used to develop the Reference concrete (CC). The properties of GPLW concrete were compared with the properties of CC. The constituents used were FAC, GGBFS, PS sand and LWFA, all of which were industrial by-products. The binder source materials used were Flyash class-C (FAC) and Ground Granulated Blast Furnace Slag (GGBFS). Processed Slag Sand (PSS) was used as fine aggregates and Lightweight Sintered Flyash Aggregates (LWFA) was used as coarse aggregates. The physical and chemical properties are tabulated in Table-1 and Table-2. Activator solution (AS) was having a ratio of SiO_2/ Na_2O of 0.6 and was prepared using combination of commercially available Sodium Silicate and Sodium Hydroxide solutions. Ambient curing was used to develop the GPLWC.

TABLE 1 - PROPERTIES OF THE BINDER MATERIALS USED

Binder materials	OPC	FAC	GGBFS
Physical properties			
Specific Gravity	3.15	2.38	2.91
Fineness – Specific Surface (m^2/kg)	290	475	358
Residue on 45µ Sieve (%)	NA	10.5	2.3
Chemical properties			
SiO_2 %	18.4	30.73	36
Al_2O_3 %	5.6	17.5	17.59
Fe_2O_3 %	3.2	15.3	1.36
MgO %	1.4	6.7	7.08
CaO %	66.8	20.85	36.45
SO_3 %	3	6.62	0.61
Loss of Ignition, % by Mass	1.8	1.46	2.1

TABLE 2 - PROPERTIES OF THE AGGREGATES USED

Aggregate Properties	PSS	SFA
Specific Gravity	2.6	1.49
Fineness Modulus	2.87	6.51
Bulk Density (Kg/litre)		
Loose	1.38	0.89
Rodded	1.54	0.97
Type of Aggregates	Zone-2	12 mm Down

2.1 Methodology

For the durability studies on CC and GPLWC, 10% Sulfuric acid solution was considered for acid attack, 5% Sodium sulphate and 5% Magnesium sulphate solutions were considered for Sulphate attack.

After ambient curing period of 90 days independent specimen were immersed in 10% Sulphuric Acid, 5% Sodium sulphate and 5% Magnesium sulphate solutions. The specimens were removed from respective solutions after a period of 60 and 90 days. These specimens were first washed under running water and allowed to dry. They were checked physically for any visible deformations. The size and shape of specimens were checked carefully. The loss of weight and cube compressive strength were determined for different mixes of GPLWC. These results was compared with the CC.

2.2 Mix Proportioning

The ACI absolute volume method of mix proportioning was adopted to arrive at mix proportioning for control concrete (CC). For GPLWC the mix proportions were equivalent to the volume of materials required for producing CC. The liquid-binder ratio adopted in the study was 0.4 across CC and GPLWC. The mix designations and corresponding binder proportions are tabulated in Table-3. The GPLWC F100 to F0 represents different FAC and GGBFS proportions. The densities of CC and GPLWC were 1887 Kg/m^3 and about 1742 Kg/m^3 to 1842 Kg/m^3. As the GGBFS proportions increases the density of GPLWC increases.

The CC represents the Cement Concrete. F85 to F0 represents the GPLWCs with different FAC contents varying from 85% to 0%. F85 series contains 85% FAC and 15% GGBFS. Similarly F0 series contains 0% FAC and 100% GGBFS. The densities of different mixes are also shown in Table-3. It has been noticed that as the GGBFS content is varied, the density of GPLWC also varies.

TABLE 3 - MIX DESIGNATIONS, BINDER PROPORTIONS AND DENSITIES

Variation in concrete density (kg/m^3) in different mixes			
Mix	FAC - kg	GGBFS-kg	Density – kg/m^3
F100	446.3	0	1742
F85	379.3	81.8	1757
F75	334.7	136.4	1767
F65	290.1	191	1777
F50	223.1	272.8	1792
F35	156.2	354.7	1807
F25	111.6	409.2	1817
F0	0	545.6	1842

III. RESULTS AND DISCUSSIONS

Cube specimens of 100*100*100 mm were cast for CC and GPLWC to test for compressive strength. The specimens were demoulded within 24 hrs from casting. The GPLWC specimens were stored under the shade at ambient temperature for air curing. The CC specimens were water cured for 28 days. Comparative study of GPLWC and CC have been presented here.

3.1 Strength characteristics of GPLWC

Compressive strength tests were conducted after a curing period of 3, 7, 14, 28, 60, 90, 120 and 180 days. Table-4 represents the compressive strengths achieved in different mixes. Fig-1 indicates the comparison of compressive strengths of CC and GPLWCs. From the results, it was concluded that, with respect to their strength properties, the GPLWC were superior to CC.

TABLE-4 STRENGTH DEVELOPMENT WITH AGE IN DIFFERENT MIXES

Age in Days	Compressive Strength in Mpa							
	CC	F0	F25	F35	F50	F65	F75	F85
3	10.43	20.40	25.63	30.37	29.92	18.87	13.43	6.70
7	13.76	22.76	31.77	30.91	33.59	26.93	19.74	18.77
14	17.04	27.68	32.39	31.35	34.30	32.32	24.48	25.14
28	24.48	27.73	33.38	32.55	42.80	34.22	26.75	26.32
60	25.77	28.35	34.25	33.35	43.26	35.78	32.26	27.18
90	26.34	29.73	35.87	35.00	43.41	36.45	33.70	27.43
120	27.41	31.55	36.75	35.53	44.21	37.40	34.56	27.80
180	27.51	32.18	38.54	37.38	44.65	38.43	35.25	29.71

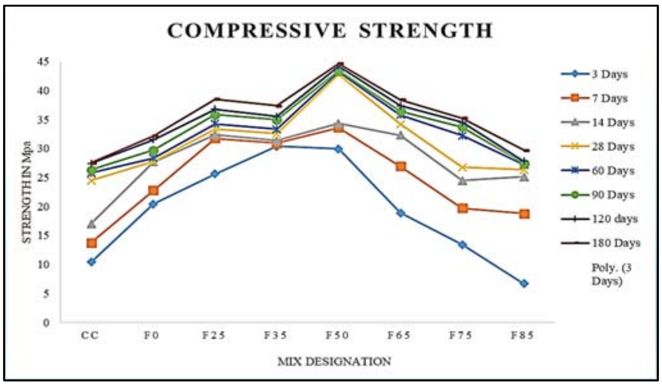


FIG-1: STRENGTH DEVELOPMENT OF CC AND GPLWC WITH AGE IN DIFFERENT MIXES

3.2 Effect of Sulfuric acid on GPLWC

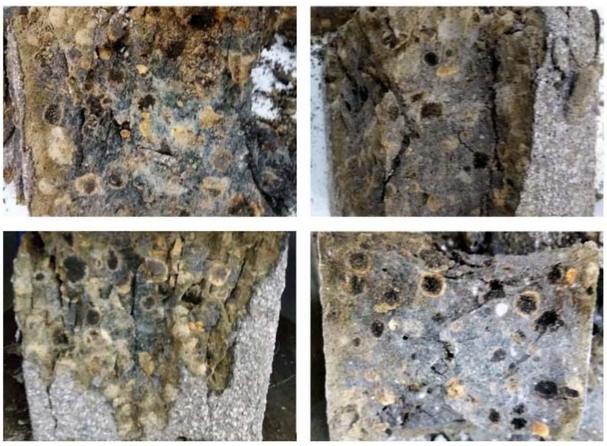
Table-5 represents the compressive strength before immersion in acid, i.e. after 90 days of ambient air curing, the corresponding loss in weight and compressive strengths after 60 and 90 days of immersion. The specimens after the test period, were checked physically. The shape and size of the specimens were not affected by the acid solution i.e. the dimension loss were negligible in all the mix designations.

We have noticed the strength loss and negative weight loss with duration of exposure to acid in all the mixes. The negative weight loss means there was an increase of weight after immersion into acid.

TABLE-5 EFFECT OF 10% H_2SO_4 SOLUTION ON COMPRESSIVE STRENGTH

10% H_2SO_4 Soln	CC	F0	F25	F35	F50	F65	F75	F85
0 Days Exposure	26.34	29.73	35.87	35.00	43.41	36.45	33.70	27.43
60 Days Exposure	23.84	24.79	23.72	30.14	24.18	25.72	29.26	23.75
Weight loss in %	-0.25%	-2.04%	-1.02%	-2.96%	-2.21%	-3.53%	-4.43%	-5.92%
Strength loss in %	9.48%	16.63%	33.88%	13.89%	44.29%	29.45%	13.18%	13.42%
90 Days Exposure	21.13	20.05	23.09	30.01	22.43	22.38	26.81	17.80
Weight loss in %	-1.58%	-2.57%	-1.94%	-2.68%	-2.46%	-2.17%	-1.05%	-2.67%
Strength loss in %	19.79%	32.58%	35.64%	14.26%	48.33%	38.60%	20.46%	35.10%

A- BEFORE EXPOSURE B- AFTER EXPOSURE



C- SPECIMEN AFTER TESTING FOR COMPRESSIVE STRENGTH

FIG-2: EFFECT OF 10% H_2SO_4 SOLUTION ON GPLWC SPECIMEN

This can be attributed to voids getting filled up with acid solution. The increase in weight after 60 days exposure was about 0.25% in CC and in the range of 1% to 6 % in GPLWC. Similarly after 90 days exposure the weight gain was about 1.6% and in the range of 1% to 2.7 % respectively.

In Fig-2-A and B, shows the specimen before and after exposure to acid. The top surface deteriorations were observed in specimens exposed to acid. The specimen immersed in acid lost the smooth surface and small indentations were formed due to the acid attack, exposing the coarse aggregates. Fig-2-C indicates the acid ingression into the mass of specimen. The depth of peripheral ingression varied between 5mm to 15mm.

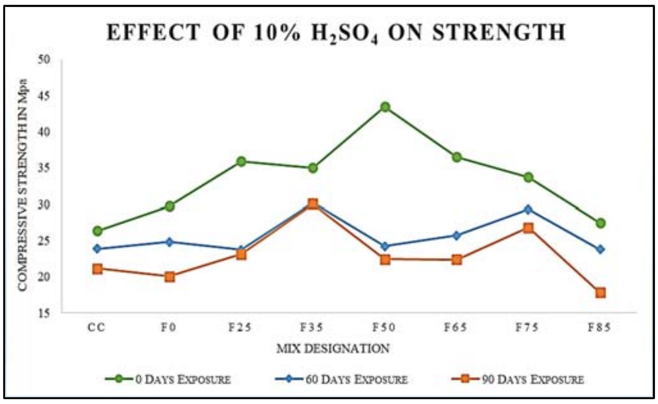


FIG-3: EFFECT OF 10% H_2SO_4 ON STRENGTH IN DIFFERENT MIXES

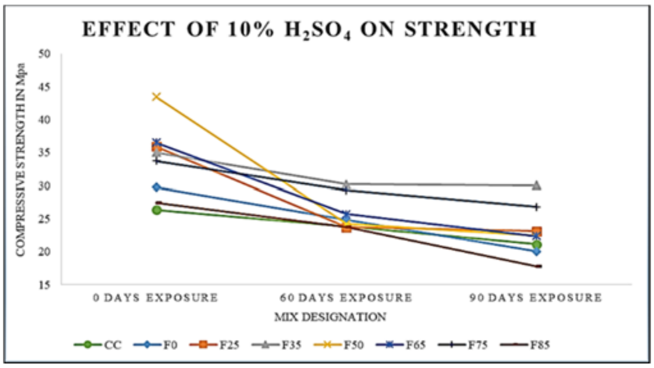


FIG-4: STRENGTH REDUCTION WITH AGE OF EXPOSURE TO 10% H_2SO_4 SOLUTION IN DIFFERENT MIXES OF GPLWC AND CC

From the Table-5, Fig-3 and Fig-4, due to the exposure to acid solution, the strength loss among the GPLWC were in the range of 13% to 44% after 60 days exposure and 14% to 48 % after 90 days exposure. The strength loss in the CC mix was about 9.5% after 60 days exposure and about 20% after 90 days exposure. It was noticed that, the GPLWC-F50 series was most affected, with highest strength loss of about 48% and the GPLWC-F35 series was least affected with strength loss of about 14%.

3.3 Effect of Sulphate solution on GPLWC.

Table-6 and Table-7 represents the compressive strength before immersion in sulphate solutions, i.e. after 90 days of ambient air curing, the corresponding loss in weight and compressive strengths after 60 and 90 days of immersion.

The specimens after the test period, were checked physically. The shape and size of the specimens were not affected by the sulphate solutions i.e. the dimension loss were negligible in all the mix designations. We have noticed the strength loss and negative weight loss with duration of exposure to sulphate solutions in all the mixes. The negative weight loss means there was an increase of weight after immersion into sulphate solutions. This can be attributed to voids getting filled up with sulphate solutions.

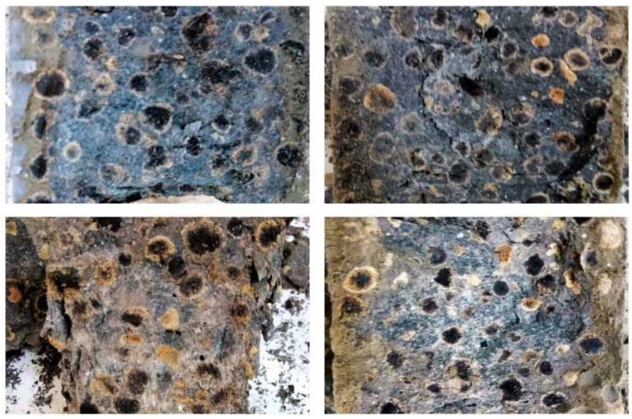
3.3.1 Effect of Sodium Sulphate solution

The increase in weight after 60 days exposure was about 2.5% in CC and in the range of 2% to 6 % in GPLWC. Similarly after 90 days exposure the weight gain was 2.6% and in the range of 2.7% to 6.2 % respectively. In Fig-5-A and B, shows the specimen before and after exposure to Sodium Sulphate solution. The surface of the specimens were unaffected by the sulphate solution. Fig-5-C indicates the sulphate ingression into the mass of specimen. The depth of peripheral ingression varied between 3mm to 10mm.

TABLE-6 EFFECT OF 5% Na_2SO_4 SOLUTION ON COMPRESSIVE STRENGTH

5% Na_2SO_4 Soln	CC	F0	F25	F35	F50	F65	F75	F85
0 Days Exposure	26.34	29.73	35.87	35.00	43.41	36.45	33.70	27.43
60 Days Exposure	24.53	25.92	25.41	30.21	30.12	38.06	35.38	29.93
Weight loss in %	-2.45%	-2.04%	-2.91%	-3.52%	-4.04%	-3.94%	-5.35%	-5.80%
Strength loss in %	6.88%	12.82%	29.18%	13.69%	30.61%	-4.42%	-4.99%	-9.13%
90 Days Exposure	23.44	22.64	25.12	29.36	27.44	31.71	28.60	28.46
Weight loss in %	-2.63%	-2.57%	-2.87%	-2.59%	-3.80%	-2.68%	-6.18%	-5.95%
Strength loss in %	11.00%	23.85%	29.99%	16.11%	36.80%	13.02%	15.13%	-3.75%

A- BEFORE EXPOSURE B- AFTER EXPOSURE



C- SPECIMEN AFTER TESTING FOR COMPRESSIVE STRENGTH

FIG-5: EFFECT OF 5% Na_2SO_4 SOLUTION ON GPLWC SPECIMEN

From the Table-6, Fig-6 and Fig-7, due to the exposure to Sodium Sulphate solution, the strength loss among the GPLWC were in the range of -9% to 30.6% after 60 days exposure and -3.7% to 37% after 90 days exposure. The strength loss in the CC mix was about 6.9% after 60 days exposure and about 11% after 90 days exposure.

It was noticed that, the GPLWC-F50 series was most affected, with highest strength loss of about 37% and the GPLWC-F35 series was least affected with strength loss of about 16%. It was also noticed the increase in strength after exposure to sulphate solution in F-85, F-75 and F-65 series. The negative trend in strength loss was reversed with increase in duration of exposure.

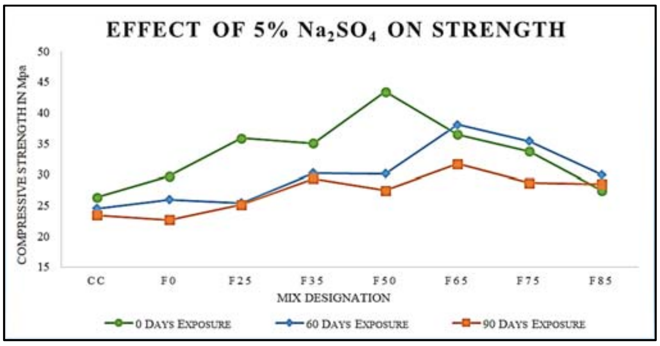


FIG-6: EFFECT OF 5% Na_2SO_4 SOLN ON STRENGTH IN DIFFERENT MIXES

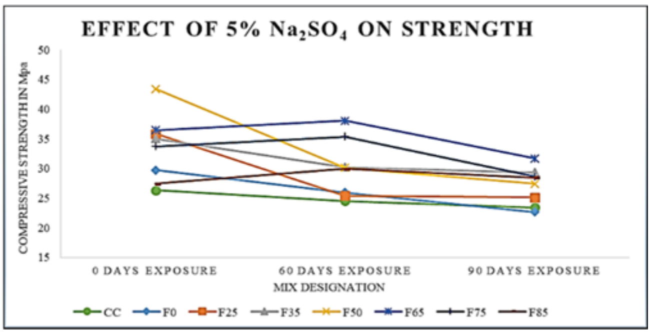


FIG-7: STRENGTH REDUCTION WITH AGE OF EXPOSURE TO 5% Na_2SO_4 SOLUTION IN DIFFERENT MIXES OF GPLWC AND CC

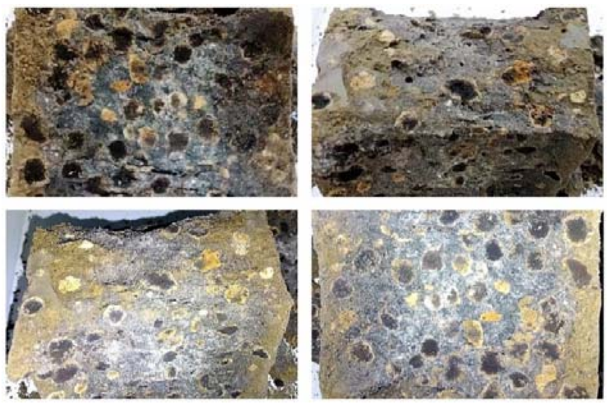
3.3.2 Effect of Magnesium Sulphate Solution

The increase in weight after 60 days exposure was about 3% in CC and in the range of 1% to 5.3 % in GPLWC. Similarly after 90 days exposure the weight gain was 3% and in the range of 2% to 5.5 % respectively. In Fig-8-A and B, shows the specimen before and after exposure to Magnesium Sulphate solution. The surface of the specimens were unaffected by the sulphate solution. Fig-8-C indicates the sulphate ingression into the mass of specimen. The depth of peripheral ingression varied between 5mm to 12mm.

TABLE-7 EFFECT OF 5% $MgSO_4$ SOLUTION ON COMPRESSIVE STRENGTH

5% $MgSO_4$ Soln	CC	F0	F25	F35	F50	F65	F75	F85
0 Days Exposure	26.34	29.73	35.87	35.00	43.41	36.45	33.70	27.43
60 Days Exposure	23.88	26.49	26.38	31.02	29.08	33.19	35.80	30.23
Weight loss in %	-2.94%	-2.04%	-1.47%	-2.63%	-4.38%	-1.01%	-5.34%	-5.32%
Strength loss in %	9.35%	10.91%	26.48%	11.39%	33.01%	8.96%	-6.22%	-10.20%
90 Days Exposure	22.20	23.59	26.20	30.61	27.22	30.40	28.68	28.47
Weight loss in %	-3.09%	-2.57%	-1.91%	-2.53%	-3.99%	-3.18%	-5.48%	-5.29%
Strength loss in %	15.71%	20.65%	26.97%	12.54%	37.29%	16.61%	14.90%	-3.79%

A- BEFORE EXPOSURE B- AFTER EXPOSURE



C- SPECIMEN AFTER TESTING FOR COMPRESSIVE STRENGTH

FIG-8: EFFECT OF 5% $MgSO_4$ SOLUTION ON GPLWC SPECIMEN

From the Table-7, Fig-9 and Fig-10, due to the exposure to Magnesium Sulphate solution, the strength loss among the GPLWC were in the range of -10% to 33% after 60 days exposure and -3.8% to 37.3% after 90 days exposure. The strength loss in the CC mix was about 9.3% after 60 days exposure and about 15.7% after 90 days exposure

It was noticed that, the GPLWC-F50 series was most affected, with highest strength loss of about 37% and the GPLWC-F35 series was least affected with strength loss of about 12.5%. It was also noticed the increase in strength after exposure to sulphate solution in F-85 and F-75 series. The negative trend in strength loss was reversed with increase in duration of exposure.

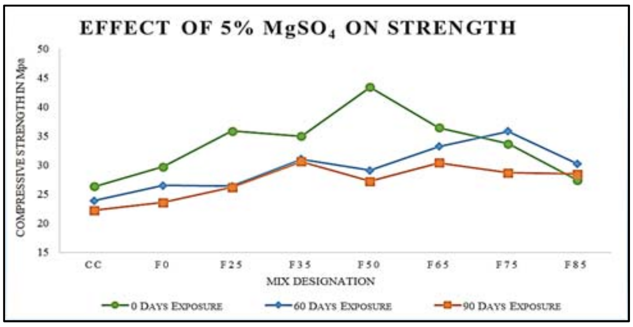


FIG-9: EFFECT OF 5% $MgSO_4$ SOLN ON STRENGTH IN DIFFERENT MIXES

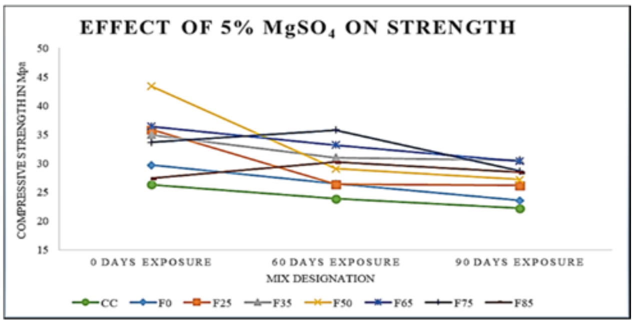


FIG-10: STRENGTH REDUCTION WITH AGE OF EXPOSURE TO 5% $MgSO_4$ SOLUTION IN DIFFERENT MIXES OF GPLWC AND CC

3.4 Discussion on results

The compressive strength test results clearly indicate that the developed GPLWC possess superior strength properties compared to the CC, whereas the durability test results indicates a different trend. Not all GPLWC possess better resistance to acid and sulphate attack as reported by most of the researchers. Most of the research carried out on durability aspect was with utilization of combination of class-F flyash, GGBFS, metakaolin and silica fumes as binder materials. Very limited study has been done on class-C flyash as main composition to produce geopolymer concrete.

The chemical composition of the binder materials used will alter the end results on strength and durability. Different researchers from different parts of the world have used different combinations of materials to develop the Geopolymer concretes. After analysing the test results, it was concluded that, the strength and durability of GPLWC depends on type and source of materials used for the development of concrete.

IV. CONCLUSIONS

The following conclusions have been drawn based on the experimental results:

- The 90 days and 180 days compressive strengths of the GPLWC were in the range of 27.4 to 43.4 MPa and 29.7 to 44.7 MPa respectively, depending on FAC and GGBFS content in the mix. The developed GPLWC possess superior strength properties compared to the CC
- The strength loss in concrete after exposure to 10% H_2SO_4 solution in different mixes of GPLWC were in the range of 13% to 44% after 60 days exposure and 14% to 48 % after 90 days exposure. The strength loss in the CC mix was about 9.5% after 60 days exposure and about 20% after 90 days exposure.
- The strength loss in concrete after exposure to 5% Na_2SO_4 solution in different mixes of GPLWC were in the range of -9% to 30.6% after 60 days exposure and -3.7% to 37% after 90 days exposure. The strength loss in the CC mix was about 6.9% after 60 days exposure and about 11% after 90 days exposure.
- The strength loss in concrete after exposure to 5% $MgSO_4$ solution in different mixes of GPLWC were in the range of -10% to 33% after 60 days exposure and -3.8% to 37.3% after 90 days exposure. The strength loss in the CC mix was about 9.3% after 60 days exposure and about 15.7% after 90 days exposure.

- The **F-35** series, with 35% FAC and 65% GGBFS, was found to possess better strength and durability properties. The 3 days strength was about 30MPa, which was about 93% of 28 days strength and about 81% of 180 days strength. The strength loss due to H_2SO_4 / Na_2SO_4 / $MgSO_4$ was only about 16% after 90 days of exposure.
- Second best was **F-75** series, with 75% FAC and 25% GGBFS. Because of higher flyash content strength development is slow. The 28 days strength of about 26.75MPa which was 76% of 180 days strength (35.25MPa). The strength loss due to H_2SO_4 / Na_2SO_4 / $MgSO_4$ was only about 20% after 90 days of exposure.

V. ACKNOWLEDGMENT

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