Study on Durability Properties of Geopolymer Aggregate Concrete

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ABSTRACT

Stones collected from a quarry are the most widely used coarse aggregate in construction. As a result of the intensive use of natural resources, the need for coarse aggregate in the building sector has expanded. It has required research into alternate building materials. The goal of this study is to identify an alternate coarse aggregate material utilising Ground Granulated Blast Furnace Slag (GGBS) clinker and to assess the hardened characteristics of non-conventional aggregate concrete in M25 grade. Durability qualities such as water absorption, sorptivity, acid resistance, and sulphate resistance were also assessed to assure the reliability of its use in harsh situations. Overall, this study's geopolymer aggregate concrete has the potential to be used as lightweight coarse aggregate in concrete.

Keywords: Eco friendly, Geopolymer aggregate, GGBS, light *weight concrete, Durability properties*.

1. Introduction

Concrete is the most used building materials with portland cement as principal component. The primary binder in typical concrete is ordinary Portland cement (OPC). Coarse to medium grained particle material used in construction includes sand, gravel, crushed stone, slag, recycled concrete and geopolymer aggregates. These are the most significant strip-mined materials in the world. Concrete aggregate is utilised in concrete for its cost-effectiveness, crack reduction, and, most significantly, structural strength. Concrete is the substance that gives it its strength, hardness and durability. Fine and coarse aggregates make about 65-75 percent of the volume of concrete are critical components in the manufacturing process. They will be labelled as natural or manufactured depending on their origin. Natural aggregates are derived from quarries or riverbeds, whereas artificial aggregates are derived from industrial operations such as a furnace. This is owing to its appealing properties of high compressive strength and the ability to be moulded into any shape. Natural aggregates resources are depleting at an alarming rate as a result of rising demand for building activities in India and throughout the world in recent years. As a consequence of their intensive use to fulfil the rising demand for civil engineering projects, natural resources are diminishing at an alarming rate. Developing activities are carried out despite the scarcity of natural resources. This causes the depletion of natural resources to accelerate and the expense of erecting structures to pose a severe danger to the construction sector. Coarse aggregate alternative, ground-granulated blast-furnace slag (GGBS) was used. GGBS is created by quenching molten iron slag, a byproduct of the iron and steel industry. It is created by drying and grinding a glassy and granular material into a fine powder in a furnace with water or steam.

Aggregate qualities have a significant impact on the durability performance of concrete in construction. It is a generic word that characterises the aggregate's resistance to environmental, physical, and cyclical loading conditions, and it is impacted by temperature, load, moisture, and chemical exposure.

Durability is essential for sustainable concrete building. Concrete construction frequently display severe early deterioration due to use of improper materials, poor construction procedures, curing and mix designs. Global issue that costs public and business sectors billions of dollars each year. Assessing the durability of concrete to estimate its service life is difficult. Concrete testing examines whether or not a thing works and how well it functions. Durability testing determines how long a product will last and under what conditions. Although it is not so concise, it may be thought of as a quality test that is done over time.

2. Materials

2.1 Cement

Cement (OPC 53 grade) was used in the experimental work. The physical properties ofcement are determined as per IS: 4031-1988 and given in Table 2.1.

Table 2.1 Physical properties of cement

Sl.No	Descriptions	OPC- 53 grdae
1	Standard consistency (%)	30
2	Setting Time (minutes)	
	a) Initial	100
	b) Final	265
3	Specific Gravity	3.10
4	Compressive strength (MPa)	27

2.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS obtained from JSW Steel, Andhra Pradesh**.** Physicalproperties of GGBS are determined as per IS: 12089 and given in Table 2.2

Table 2.2 Physical properties and chemical properties of GGBS

S.No	Properties	
	Physical properties	***GGBS***
1	Specific Gravity	2.90
2	Fineness % passing on	87(150µm sieve)
	Chemical Properties*	***GGBS***
4	SiO_2	43.4
5	Al_2O_3	12.5
6	Fe_2O_3	0.82
7	TiO_2	0.5

8	CaO	40.3
9	MgO	0.75
10	Na_2O	0.26
11	K_2O	0.35
12	Mn_2O_3	0.14
13	SO_3	0.34
14	Loss on ignition	2.1

2.3 Fine aggregate

The experiment used locally available sand with a thickness of 4.75mm. Table 2.3 shows the fine aggregate parameters determined according to IS: 2386-1963. Table 2.3 shows the fine aggregate sieve analytical findings.

2.4 Coarse aggregate

During the experimental work, crushed granite stone was employed as coarse aggregate. For experimental purposes, coarse aggregate passing through 20mm and retaining through 4.75mm must be employed. The parameters of coarse aggregate are calculated according to IS: 2386- 1963 and are shown in the table. 2.3. Table 2.3 shows the Sieve analysis findings for coarse aggregate.

Table 2.3 Properties of Fine Aggregate and Coarse Aggregate

Sl.No	Properties	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.61	2.68
2	Fineness modulus	3.60 (Zone II)	8.64
3	Bulk density (kg/m^3)	1724	1561
4	Water Absorption (%)	0.75	0.6

2.5 Alkaline Solution

As an alkaline solution, a solution of sodium silicate and sodium hydroxide was utilised. The sodium silicate solution A53 was utilised, with a SiO2 and Na2O mass ratio of roughly 2.5, i.e. (Na2O=15.5%, SiO2 =31.0%, and water 53.5% by mass). Sodium hydroxide in flake or pellet form with a purity of 97-98% was utilised. To create the solution, the sodium hydroxide (NaOH) solids were dissolved in water. The sodium hydroxide solution concentration was kept constant at 10 molar. The mass of NaOH solids in a solution varies with solution concentration reported in units of molar M. A NaOH solution with a concentration of 10M, for example, had 10x40=400 grammes of NaOH. The sodium hydroxide-to-sodium silicate ratio was kept constant at 2.5. To make the alkaline liquid, the sodium silicate solution and sodium hydroxide solution were mixed together at least one day before usage.

2.6 Mixture Proportions

The mixes were proportioned in line with the IS10262:2019 technique for geopolymer aggregate concrete of M25 grade. Geopolymer aggregate components have a significant impact on final product qualities. The mechanics of hardened geopolymer aggregate concretes are closely connected to elements such as the composition of the source materials, the kind and concentration of the activator, and the aggregate size. Additionally, the percentage of each component to the aggregate is crucial in the development of strength-supporting structures within the geopolymer aggregate matrix. As performance criteria, the compressive strength of hardened concrete and the workability of new concrete are considered.

2.7 Manufacturing Process Of GPA

- GPA was prepared using geopolymer stones produced from cementitious materials and commercially available sodium hydroxide (10M) solution.
- To determine optimal mix design and process conditions.
- Dry components were combined in mortar mixer with a continual addition of NaOH solution until a homogenous mix was achieved.
- Following mixing, geopolymer mix was run through pelletizer to generate clinker stones.
- Under the condition of Oven Curing, manufactured Geopolymer stones were crushed and sieved into different sizes three days after casting. Figures 2.1 through 2.4 depict the work procedure.

Figure 2.1 GPA mixture.

Figure 2.2 casting of GGBS aggregate.

Figure 2.3 GGBS cylinder.

Figure 2.4 GGBS aggregate.

2.8 Durability test on geopolymer aggregate concrete

Sorptivity, water absorption, sulphate resistance, and acid resistance tests had been performed. The capacity of concrete to withstand weathering, chemical attack, and abrasion while retaining its desirable engineering properties is referred to as durability. It is well known that durability extends the service life of a construction. A concrete structure's service life and durability are heavily influenced by material transport qualities such as permeability, sorptivity, and diffusivity. Because the process of deterioration such as carbonation, chloride and sulphate attack is driven by fluid movement in concrete, permeability inhibits degradation of concrete in aggressive environments.

2.8.1 Water Absorption Test

Water absorption test for determining rate of water absorption. 100 x 200 mm cylinders were submerged in water for 28 days following casting for this test. The specimen sides were waxed and sealed by plastic sheet before first mass was obtained. Specimen placed in tray with water to depth of 2 to 5 mm. After removing and inflating off the excess surface water, mass of specimen was measured at required intervals as shown in figure 2.5. Absorption value calculated using formula, absorption,

$$I = mt/(a*b)$$

where,

mt is the change in mass at time
't',a is the area of the specimens
d is the density of water.

Figure 2.5 Water Absorption test on GPA concrete

2.8.2 Sorptivity Test

ASTM C 1585-04 was used to conduct the sorptivity test. In early absorption measurements, the permissible coefficient variation was set at 6%. Sorptivity is measurement of capillary force produced by concrete pore structure which causes fluids to be pulled into concrete structure. During the test, 100 mm diameter and 50 mm thick concrete slices are employed. Specimen sides are waxed and sealed by plastic sheet before first mass was obtained.

Specimen placed in tray with water to depth of 2 to 5 mm. After removing and inflating off excess surface water, mass of specimen measured at required intervals.

Sorptivity value calculated using formula,

$$s = I/t0.5$$

where, s is sorptivity in mm/min, t is elapsed time in minutes and I is cumulative absorption which is given by,

$$I = ấm/Ad$$

where, ấm is increase in mass, A is surface area of specimen through which waterpenetrates and d is density of the medium, i.e. water. Cumulative absorption value plotted against square root of time and sorptivityis obtained from slope of best fitting line of plot. Sorptivity test done on GPA concrete samples is shown in figure 2.6

Figure 2.6 Sorptivity test on GPA concrete

2.8.3 Acid Resistance Test

After 28 days from day of casting, acid resistance of GPC evaluated on 100 mm cubes. Initial weight of specimens were recorded and cubes submerged in 3% hydrochloric acid (HCl) and 3% sulfuric acid (H_2SO_4) separately for 30 days. Concentration of solution remained constant. Specimens removed from acid water after 30 days. Cube surface were cleaned and their weight are recorded, and tested using compression testing equipment with capacity of 1000 kN at consistent rate of loading of 140 kg/cm^2/min. Losses in weight and the compressive strength of GPC cubes are calculated. GPC specimens immersed in acids are shown in figure 2.7

Figure 2.7 GPA concrete specimen immersed in H_2SO_4 and Hcl acids

2.8.4 Sulphate Resistance Test

The detailed descriptions for sulphate resistance test was developed in compliance with ASTM C 642. Sulphate resistance of geopolymer concrete assessed by measuring residual compressive strength and mass change after sulphate exposure. Sulphate resistance tests were performed on 150x150x150 mm and 100x200 mm cylinders. Geopolymer concrete specimens of all categories were submerged to a depth of 30mm in 3% sodium sulphate solution and 3% sodium chloride solution, as illustrated in Figures 2.8 and 2.9. On the third day following casting, the geopolymer concrete examples were submerged in a magnesium sulphate solution. On 14 and 28 days, the specimens were fully submerged in these solutions, with four times the volume of specimens. The solution was refreshed once a week to maintain the concentration. The solution was also mixed once a week to avoid deposits on the base. The effects of this solution on the specimen were periodically examined using visual examination, weight change measurement, and a strength test. In the compression testing machine, the cubes' surfaces were cleaned, weighed, and tested.

Figure 2.8 GPA concrete immersed in sodium sulfate solution

Figure 2.9 GPA concrete immersed in sodium chloride solution

3 RESULTS AND DISCUSSION

The experimental data are explained and provided in form of tables and graphs in this chapter. GPA aggregate qualities and durability characteristics are thoroughly described.

3.1 Artificial aggregate material properties

Produced geopolymer coarse aggregate properties were identified. Results from the test compared to both of natural aggregate used in concrete and specifications for coarse aggregate specified by Indian standards. To comply with exposure classification, Los Angeles abrasion value allowable limits not exceed 35%. Moreover, flakiness value under 35 is suggested for coarse aggregate.

Abrasion value of geopolymer coarse aggregate found half that of natural aggregate. Both aggregate are tested for abrasion in accordance with Indian standards. Geopolymer coarse aggregate takes more space in Los Angeles abrasion machine because of lighter density. It is advised that testing for abrasion, use the same volume of geopolymer and natural aggregate.

Significant variation in aggregate density, geopolymer aggregate exhibits greater water absorption and porosity than natural aggregate. Overall, it should be emphasised that synthetic geopolymer coarse aggregate met requirements and results are equivalent of natural coarse aggregate.

3.2 Durability test properties

3.2.1 Water absorption

The water absorption values for various Geopolymer aggregate Concrete mixes were measured on 150 mm x 200 mm squares and discussed.

Table 3.1 Water absorption values of GPA concrete

S. No	Mix	Water absorption in %
1.	CC	1.45
2.	GPA	1.04

A water absorption test on GPA concrete was carried out. Table 3.1 displays the absorption %. Figure 3.1 depicts the range in water absorption for GPA concrete mixtures.

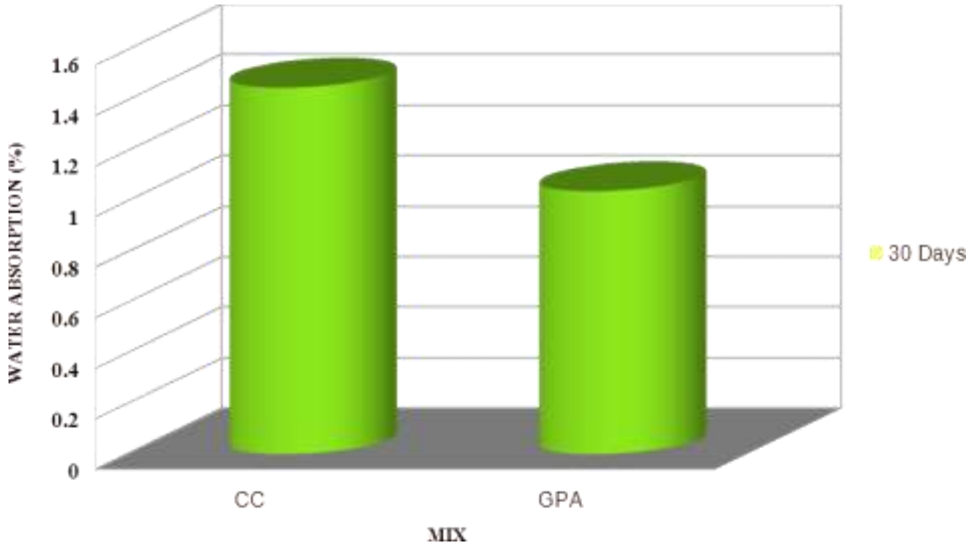

Figure 3.1 Water absorption of GPA concrete

The following findings were reached as a result of studies. According to Table 3.1, the GGBS replace GPA concrete absorbed less water than the control specimen. The average water absorption in GPA concrete specimens is just 0.75%, indicating a 42.58% reduction in water absorption as compared to control specimens. As a result, GPA concrete has a lower absorption value, implying greater strength and durability.

3.2.2 Sorptivity

Figure 3.2 shows absorption value plotted against square roots of time, with the blue line representing conventional concrete and the red line representing GPA concrete.

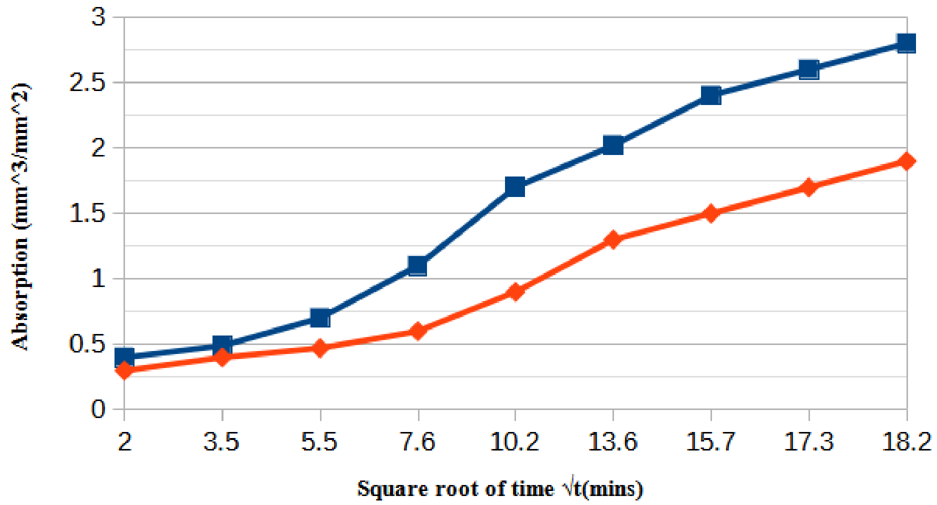

Figure 3.2 Absorption Vs Square root of time

Slope of absorption curve for each combination produces sorptivity value, which is shown in Table 3.2. Figure 3.3 depicts variance in sorptivity for GPA concrete blends and standard concrete.

Table 3.2 Sorptivity values of GPA concrete

S. No	Mix	Sorptivity (mm/min$^{1/2}$)
1.	CC	0.1571
2.	GPA	0.1062

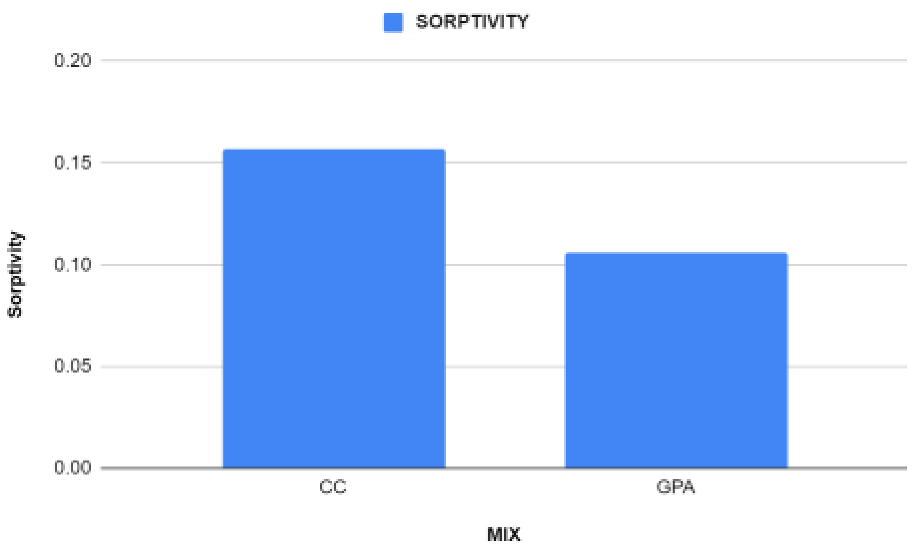

Figure 3.3 Sorptivity of GPA concrete

As compared to control specimen, addition of GPA reduced sorptivity to minimum value of 0.1062. Sorptivity was reduced by almost 47.9%.

3.2.3 Acid Resistance Test

Weight and compressive strength loss of GPA concrete specimen after 30 days of immersion in 3% H_2SO_4 solution are provided in Table 3.3, and the variations in weight and strength losses are illustrated in figures 3.4 and 3.5.

Table 3.3 Weight and strength losses of GPA concrete on exposure to H_2SO_4

S. No	Mix	Weight loss (%)	Strength loss (%)
		30 days	**30 days**
1.	CC	0.25	3.3
2.	GPAC	0.1	2.9

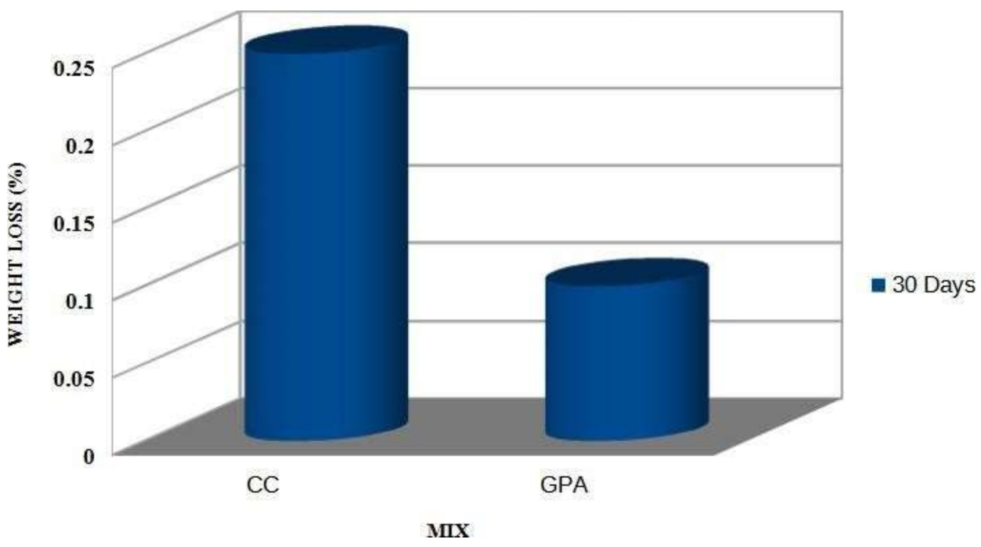

Figure 3.4 Weight loss of GPA on exposure to H_2SO_4

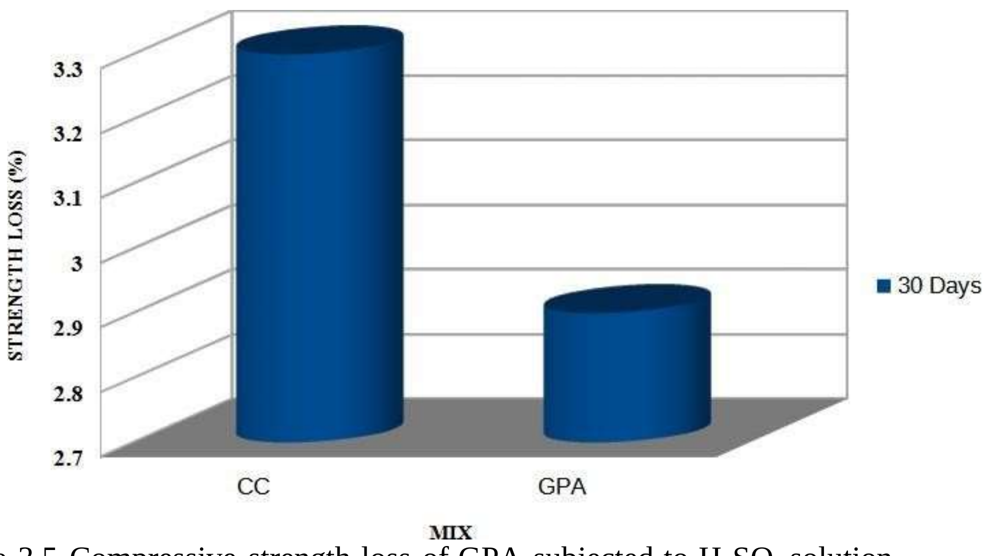

Figure 3.5 Compressive strength loss of GPA subjected to H_2SO_4 solution

Weight and compressive strength losses of GPC after 30 days of immersion in 3% Hcl solution are provided in Table 3.4 and difference in strength and weight losses are illustrated in figure 3.6 and 3.7.

Table 3.4 Weight and strength losses of GPA concrete on exposure to Hcl

S. No	Mix	Weight loss (%)	Strength loss (%)
		30 days	30 days
1.	CC	1.8	2.1
2.	GPA	1.15	1.8

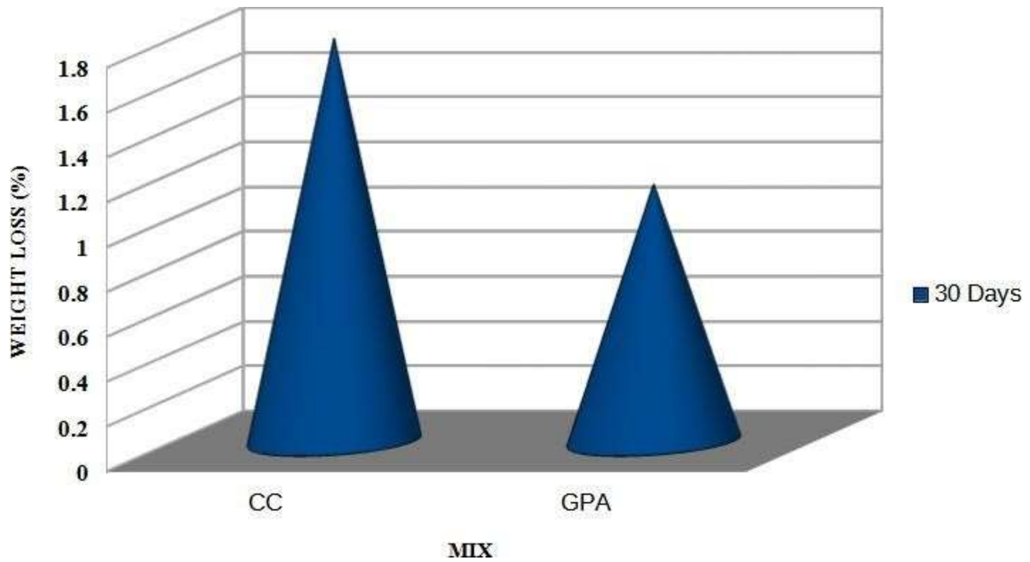

Figure 3.6 Weight loss of GPC on exposure to HCl

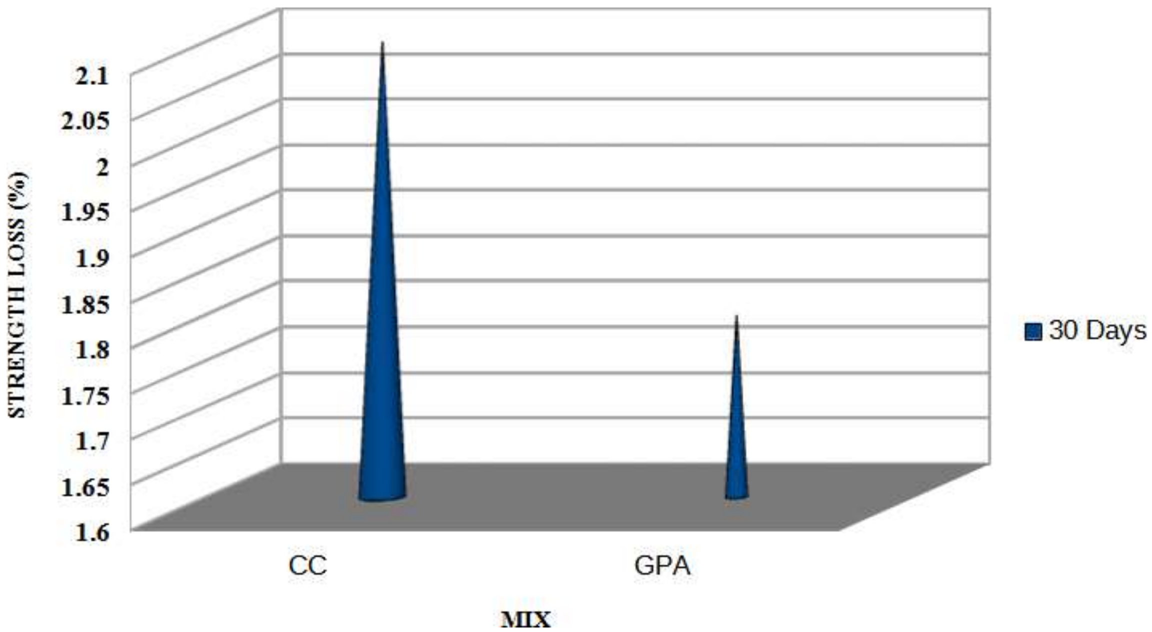

Figure 3.7 Compressive strength loss of GPA on exposure to Hcl

Percentage of strength and weight loss of GPA after 30 days of exposure to 3% solutions of H2SO4 and HCl suggest addition of GPA had good effect on acid resistance of GPA concrete specimen showed fewer losses than control specimen.

The current study shows that, even when exposed to a comparably higher concentration of H2SO4 and HCl, the performances of conventional added GPA samples are comparable to that of the GGBS-based Aggregate concrete, while they performed significantly better than the conventional concrete from the previous literature. Nevertheless, because to their low structural compactability, GPA specimens did not offer much resistance to H_2SO_4 and HCl, and displayed larger weight and compressive strength losses at conclusion of 30 day exposure period.

3.2.4 Sulphate Resistance Test

Weight and compressive strength loss of GPA concrete specimen after 30 days of immersion in 3% solution of sodium sulphate are provided in Table 3.5, and the variations in weight and strength losses are illustrated in figure 3.8 and 3.9.

Table 3.8 Weight and strength losses of GPA concrete on exposure to Sodium sulphate solution

S. No	Mix	Weight loss (%)	Strength loss (%)
		30 days	30 days
1.	CC	3.5	6.31
2.	GPA	1.4	1.91

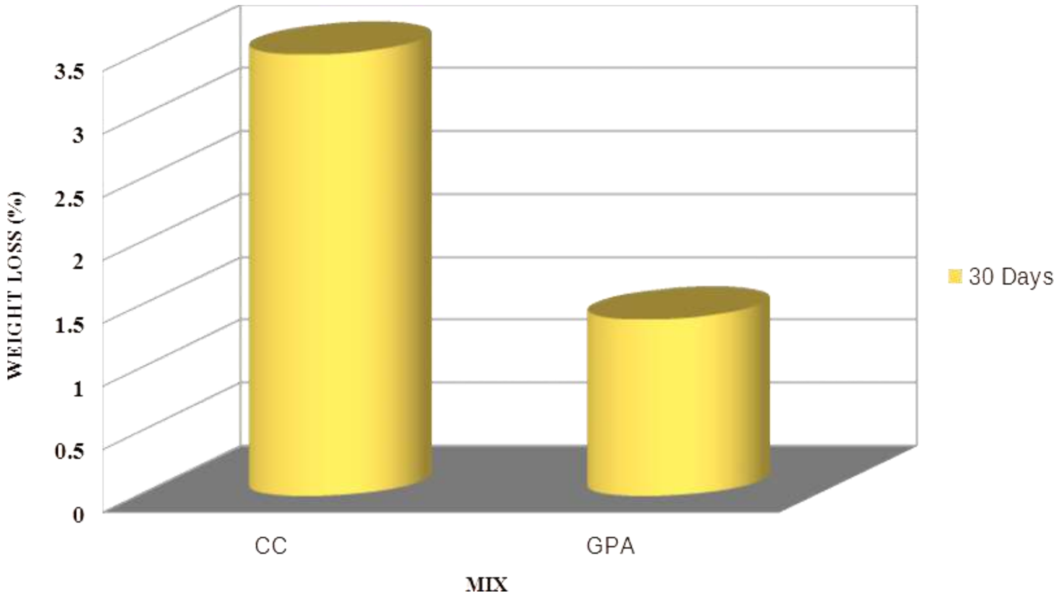

Figure 3.8 Weight loss of GPA on exposure to Sodium Sulphate solution

Strength increase between 28 days in conventional concrete is 63 percent, which is significant when compared to the value of roughly 6 percent in GPA concrete. As a result, research proved that GPA concrete achieves its full strength faster than standard concrete.

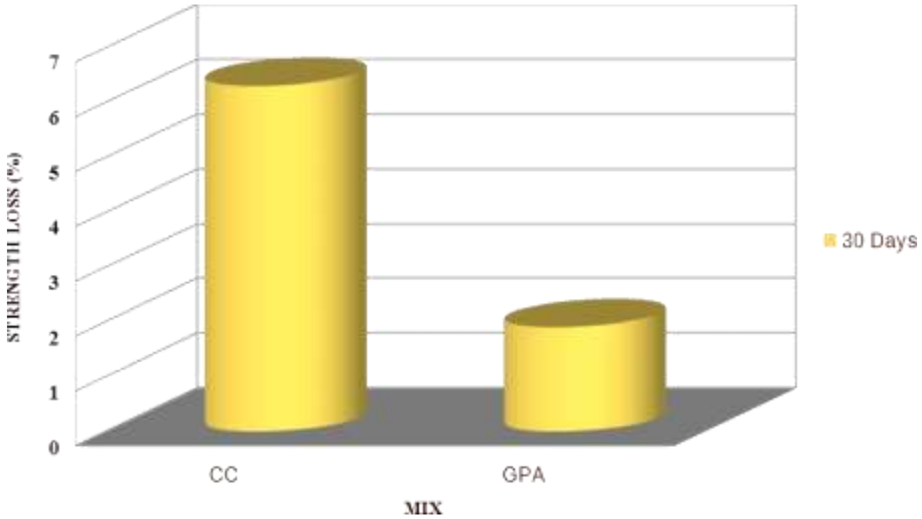

Figure 3.9 Strength loss of GPA on exposure to sodium sulphate solution

Weight and compressive strength loss of GPA concrete specimen after 30 days of immersion in 3% solution of sodium chloride are provided in Table 3.8, and the variations in weight and strength losses are illustrated in figure 3.10 and 3.11.

Table 3.9 Weight and strength losses of GPA concrete on exposure to Sodiumchloride solution

S. No	Mix	Weight loss (%)	Strength loss (%)
		30 days	**30 days**
1.	CC	4.6	6.1
2.	GPA	1.5	1.8

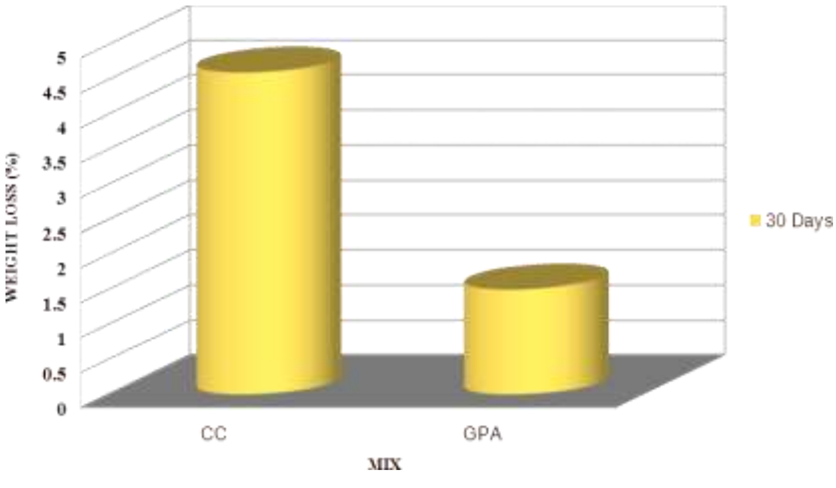

Figure 3.10 Weight loss of GPA on exposure to Sodium chloride solution

Table 3.8 shows the weight and strength reductions of the GPA and CC specimens after 30 days of exposure. At the end of 30 days, there were slight weight changes ranging from -0.4 to 1.35 percent, but there was a considerable strength loss of roughly 12.2 percent in CC concrete specimens, whereas the strength loss in GPA concrete specimens was essentially negligible.

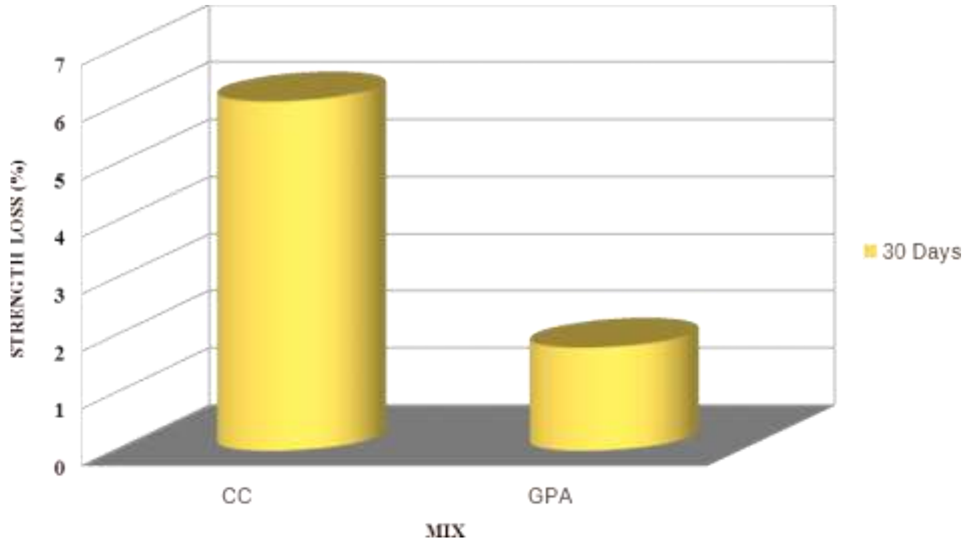

Figure 3.11 Strength loss of GPA on exposure to Sodium chloride solution

4. Conclusion

Concluded that geopolymer coarse aggregate suitably used as replacement of conventional coarse aggregate in concrete.

- Density of geopolymer coarse aggregate concrete is lesser when compared to conventional aggregate concrete, utilized in which light weight concrete applications.
- From the durability studies of water absorption test, observations indicated that 42.58% of geopolymer aggregate concrete is less compared to conventional aggregate concrete.
- In Sorptivity test, observations indicated that 47.9% of geopolymer aggregate concrete is less compared to conventional aggregate concrete.
- In Acid resistance test, observations indicated that 28.6% of geopolymer aggregate concrete is less in weight and strength loss compared to conventional aggregate concrete.
- In Sulphate resistance test, observations indicated that 31% of geopolymer aggregate concrete is less in weight and strength loss compared to conventional aggregate concrete.

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