



STUDY ON STRENGTH AND DURABILITY PARAMETERS OF GEO POLYMER CONCRETE WITH GGBS FOR 12M AND 14M ALKALI ACTIVATORS

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ABSTRACT

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure leading to second most consumed material next to water in the world. As concrete being a versatile material used for wide varieties under various conditions, ordinary concrete may fail to exhibit the desired quality, performance, and durability. And also to reduce the cost of construction and increase the performance of concrete without losing its original properties is achieved by replacing with suitable pozzalonic material. This paper deals with complete replacement of cement with ground granulated blast furnace slag (GGBS). The main objective of this study is to investigate the strength and durability parameters of geopolymer concrete for 12M and 14M. For each mix standard sizes of cubes, cylinders and prisms were casted and tested. For strength at a age of 3,7,28 days and for durability at a age of 30 days (chemical curing 30 days) The obtained results are then compared to conserve the natural resources along with development of desired characteristics.

Keywords: GGBS, geopolymer concrete, alkaline activators, polymerization, molarity.

1. INTRODUCTION

Geopolymer

Geopolymers are inorganic, typically ceramic, materials that form long-range, covalently bonded, non-crystalline (amorphous) networks. Commercially produced geopolymers may be used for fire- and heat-resistant coatings and adhesives, medicinal applications, high-temperature ceramics, new binders for fire-resistant fiber composites, toxic and radioactive waste encapsulation and as cementing components to make concrete. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in other types of engineering process technologies. According to T.F. Yen [1] geopolymers can be classified into two major groups: pure inorganic geopolymers and organic containing geopolymers, synthetic analogues of naturally occurring macromolecules. In the following presentation, a geopolymer is essentially a mineral chemical compound or mixture of compounds consisting of repeating units, for example silico-oxide (-Si-O-Si-O-), silico-aluminate (-Si-O-Al-O-), ferro-silico-aluminate (-Fe-O-Si-O-Al-O-) or aluminophosphate (-Al-O-P-O-), created through a process of geopolymerization [2].

Geopolymer-Concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with a caustic activator. Commonly, waste materials such as fly ash or slag.

Cement is incorporated with the guide of Ordinary Portland concrete (OPC) as the essential cover which creates tremendous measures of carbon dioxide making threat the earth. Concrete is a champion among the most by and large used advancement materials.

Concrete, the second most utilized material as a part of the world after the water. The demand of concrete is increasing day by day for satisfying the need of development of infrastructure facilities. It is well established fact that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere. Geopolymer is being studied extensively and shows promise as a greener alternative to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer. It has been found that geopolymer concrete has good engineering properties [3].

2. OBJECTIVE AND SCOPE

The main objective of this study is to study the mechanical properties of GGBS concrete for 12 & 14 molarities. In particular the investigation is focused on

Strength parameter

- Compression strength test.
- Flexural strength test.
- Split tensile test.

Durability parameters

- acid attack test.
- sulphate attack test.
- chloride attack test

Scope of present study

Geopolymer cement is being developed and utilized as an alternative to conventional Portland cement for use in transportation, infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial by products to significantly



reduce its carbon footprint, while also being very resistant to many common concrete durability issues. Thus there is a need for a green and eco friendly concrete to fulfill the future necessities and hence geopolymer due to its properties it is believed to be a promising substitute for the future use.

Commercial applications

There exist a wide variety of potential and existing applications. Some of the geopolymer applications are still in development whereas others are already industrialized and commercialized. See the incomplete list provided by the Geopolymer Institute. They are listed in three major categories:

Geopolymer resins and binders

- Fire-resistant materials, thermal insulation, foams;
- Low-energy ceramic tiles, refractory items, thermal shock refractories;
- High-tech resin systems, paints, binders and grouts;
- Bio-technologies (materials for medicinal applications);
- Foundry industry (resins), tooling for the manufacture of organic fiber composites;
- Composites for infrastructures repair and strengthening, fire-resistant and heat-resistant high-tech carbon-fiber composites for aircraft interior and automobile;
- Radioactive and toxic waste containment;

Geopolymer cements and concretes

- Low-tech building materials (clay bricks)
- Low-CO₂ cements and concretes

3. MATERIALS USED

- ground granulated blast furnace slag (GGBS)
- NaOH
- Na₂SiO₃
- Aggregates
 - Coarse aggregate
 - Fine aggregate.
- Sulphuric Acid (H₂SO₄).
- Magnesium Sulphate (MgSO₄).
- Sodium Chloride (NaCl).

3.1 Materials

The materials used for the study are shown in the below.

3.2 GGBS

Granulated Blast Furnace Slag is obtained by rapidly chilling (quenching) the molten ash from the

furnace with the help of water. During this process, the slag gets fragmented and transformed into amorphous granules (glass), meeting the requirement of IS 12089:1987 (manufacturing specification for granulated slag used in Portland Slag Cement). The granulated slag is ground to desired fineness for producing GGBS.



Figure-1. Ground granulated blast furnace slag.

The multi-fold advantages of GGBS

Ensures higher durability of structure. Reduces the temperature rise and helps to avoid early-age thermal cracking and also improve workability. It is off-white in colour and substantially lighter than Portland cement. Resultantly it helps soften the visual impact of large structures such as bridges and retaining walls [4].

Uses of GGBS

- High-rise buildings.
- Marine applications such as dams, shore protection construction.
- Effluent and sewage treatment plants.
- Cement products such as tiles, pipes, blocks, etc.

Physical properties

Table-1. Physical properties of GGBS.

Specific gravity	2.6
Color	White
Surface moisture	Nil
Average particle size, shape	4.75 mm down, round

Chemical properties

Table-2. Chemical Composition of GGBS.

S. No	Chemical composition	% Of composition
1	CaO	37.34
2	Al ₂ O ₃	14.42
3	Fe ₂ O ₃	1.11



4	SiO ₂	37.73
5	Magnesium Oxide(Mgo)	8.71
6	Manganese Oxide(Mno)	0.02
7	Sulphide sulphur	0.39
8	Loss of ignition	1.41
19	Insoluble Residue	1.59
10	Glass content	92.0

3.3 Coarse aggregate

- The Coarse Aggregate Used In This Study To Cast Specimens Was of 20mm



Figure-2. Coarse aggregate.

Table-3. Physical properties of coarse aggregate.

Seive size (mm)	20mm	
	Requirement as per is:383-1970	Percentage passing
80.00	---	---
63.00	---	---
40.00	100%	100%
20.00	85-100%	94.60%
16.00	---	---
12.50	---	---
10.00	0-20%	14.30%
4.75	0-05%	2.85%
2.36	---	---
Specific Gravity		2.82
Water Absorbtion		0.40
Aggregate Impact Value		12%
Bulk Density(Kg/m ³)		1660
Flakiness		14%
Elongation		15%

3.4 FINE AGGREGATE

- The Fine Aggregate Used In This Study to Cast Specimens Was Of Krishna River at Vijayawada, Andhra Pradesh. And The Physical Properties Of The Fine Aggregate Are As Fallows In The Table-4 Listed Beneath.



Figure-3. Fine aggregate.

Table-4. Physical properties of fine aggregate.

S. No	Property	Values
1	Specific gravity	2.65
2	Fineness modulus	2.53
3	Bulk density (Kg/m ³)	1561

3.5 Alkaline activators

Generally alkaline activators combinations that used are potassium hydroxide(KOH) and potassium silicate (K₂SiO₃) or else Sodium Silicate (Na₂SiO₃) and Sodium hydroxide (NaOH) are utilized as basic arrangements. In this paper we have used Sodium Silicate (Na₂SiO₃) and Sodium hydroxide (NaOH) as alkaline activators as per convenience.

Sodium silicate (Na₂SiO₃)

Sodium silicate is the common name for compounds with the formula Na₂(SiO₂). A well-known member of this series is sodium metasilicate, Na₂SiO₃. Also known as waterglass or liquid glass, these materials are available in aqueous solution and in solid form. The pure compositions are colourless or white, but commercial samples are often greenish or blue owing to the presence of iron-containing impurities. Sodium silicate is commonly manufactured using a reaction in liquid phase or in solid phase. Both processes use alkaline and quartz sand as raw materials.

In industry, the various grades of sodium silicate are characterized by their SiO₂:Na₂O weight ratio (weight ratios can be converted to molar ratios by multiplication with 1.032), which can vary between 2:1 and 3.75:1[5]. Grades with this ratio below 2.85:1 are termed alkaline. Those with a higher SiO₂:Na₂O ratios are described as neutral.



Figure-4. Sodium silicate (Na_2SiO_3).

Sodium hydroxide (NaOH)

Sodium hydroxide (NaOH), also known as lye and caustic soda is an inorganic compound [6, 7]. It is a white solid and highly caustic metallic base and alkali of sodium which is available in pellets, flakes, granules, and as prepared solutions at different concentrations [8]. Sodium hydroxide forms an approximately 50% (by mass) saturated solution with water [9]. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents and as a drain cleaner. Worldwide production in 2004 was approximately 60 million tonnes, while demand was 51 million tonnes [10]. Pure sodium hydroxide is a whitish solid, sold in pellets, flakes, and granular form, as well as in solution. It is highly soluble in water, with a lower solubility in ethanol and methanol, but is insoluble in ether and other non-polar solvents. Sodium hydroxide is industrially produced as a 50% solution by variations of the electrolytic chloralkali process. Chlorine gas is also produced in this process. Solid sodium hydroxide is obtained from this solution by the evaporation of water. Solid sodium hydroxide is most commonly sold as flakes, prills, and cast blocks [10].



Figure-5. NaOH flakes.

3.6 Chemicals for durability test

Sulphuric acid (H_2SO_4)

Sulfuric acid (alternative spelling sulphuric acid) is a highly corrosive strong mineral acid with the molecular formula H_2SO_4 and molecular weight 98.079

g/mol. It is a pungent-ethereal, colorless to slightly yellow viscous liquid that is soluble in water at all concentrations [11]. Sometimes, it is dyed dark brown during production to alert people to its hazards [12]. The historical name of this acid is oil of vitrio [13].

Sulfuric acid has a wide range of applications including in domestic acidic drain cleaners [14], as an electrolyte in lead-acid batteries and in various cleaning agents. It is also a central substance in the chemical industry. Principal uses include mineral processing, fertilizer manufacturing, oil refining, wastewater processing, and chemical synthesis. It is widely produced with different methods, such as contact process, wet sulfuric acid process, lead chamber process and some other methods.



Figure-6. Sulphuric acid (H_2SO_4).

Magnesium sulphate (MgSO_4)

Magnesium sulfate is an inorganic salt (chemical compound) containing magnesium, sulfur and oxygen, with the formula MgSO_4 . It is often encountered as the heptahydrate sulfate mineral epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), commonly called Epsom salt, taking its name from a bitter saline spring in Epsom in Surrey, England, where the salt was produced from the springs that arise where the porous chalk of the North Downs meets non-porous London clay. The monohydrate, $\text{MgSO}_4 \cdot \text{H}_2\text{O}$ is found as the mineral kieserite. The overall global annual usage in the mid-1970s of the monohydrate was 2.3 million tons, of which the majority was used in agriculture [15].



Figure-7. Magnesium sulphate (MgSO_4).

Sodium chloride (NaCl)



Sodium chloride [16] also known as salt or halite, is an ionic compound with the chemical formula NaCl, representing a 1:1 ratio of sodium and chloride ions. Sodium chloride is the salt most responsible for the salinity of seawater and of the extracellular fluid of many multicellular organisms. In the form of edible or table salt it is commonly used as a condiment and food preservative. Large quantities of sodium chloride are used in many industrial processes, and it is a major source of sodium and chlorine compounds used as feedstocks for further chemical syntheses. A second major application of sodium chloride is de-icing of roadways in sub-freezing weather.



Figure-8. Sodium chloride (NaCl).

4. LITERATURE REVIEW

Shanker. H. sannu and R. B. Khadiranaikar carried study on performance of geopolymer concrete when subjected to harsh environmental conditions in the study the author chosen grades from M-30, M-40, M-50 and M-60 and the mixes were of 12M and 8M. The ratio of alkaline solution used for the study were 2.50 and 3.50. The specimens used were cubes and cylinders and these specimens were oven cured at a temperature of 60°C. The specimen were immersed in sulphuric acid and magnesium sulphate solution of 10% concentration each. The compressive strength loss of specimens immersed in sulphuric acid ranges from 7 to 23% and specimen immersed in magnesium sulphate had a loss in strength ranging from 3 to 12%. In the split tensile test the specimen immersed in sulphuric acid the loss percentage of strength

ranges from 8 to 45% and for specimens immersed in magnesium sulphate ranges from 7 to 30% [17].

Salmabanu Luhar and Urvashi Khandelwal carried out study on durability of geopolymer concrete and flyash is used instead of cement. Durability test such as chloride attack test, sulphate attack test, acid attack test, sorptivity, water absorption were conducted. The specimens were then heat cured for 24 hours below 75°C. Test results pronounced show that heat cured specimens have excellent resistance to sulphate and chloride attack and minute degradation in sulphuric acid [18].

Bapugouda patil *et al.* conducted study to develop sustainable GPC with use of fly ash and ggbs instead of cement and pond ash and M-sand instead of river sand in this study compressive strength and durability test were compared between GPC and normal strength concrete from the test results it is concluded that specimens immersed in MgSO₄ and NaCl have gained weight and strength increased after a curing period of 28 days. The specimens immersed in HCl have very less deterioration [19].

S. Subbiah ilamvazhuthi and Dr. G. V. T. Gopala Krishna conducted study to bring out the advantageous results of GPC using flyash with polypropylene fiber for a molarity of 8 slump test and compressive test were conducted and specimens were oven cured in the laboratory and found that the concrete has good workability and increase in compressive strength. Durability test such as sulphate test and sulphuric acid test were conducted and the specimens used for these test were cylinders. The specimens showed good resistance to the durability test [20].

5. METHODOLOGY

5.1 Preparation of alkaline solution

The qualities of Geo polymer cement is inspected for blends of 12 & 14 Molarities of NaOH. The atomic weight of NaOH is 40. To get ready 12 Molarity of arrangement, we take 12x40=480gm of sodium hydroxide chips. These chips are weighed and is dissolved completely in distilled water to form 1 liter arrangement. In the same manner, for 14 molarity, we take 14x40=560gm of NaOH flakes are weighed and dissolve in distilled water to make 1 liter of solution. These solutions should be prepared 24 hour prior to their usage in material for experiment. In this study the ratio taken for Sodium hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) is 1:2.

Table-5. Mix proportion.

Materials used	GGBS content	Fine aggregate	Coarse aggregate	Sodium hydroxide	Sodium silicate
Quantity of materials in Kg/m ³	450	585	1318	67.5	135

**Table-6.** Values representing specimens casted for experimental study.

S. No	No of days	Strength specimens						Durability specimens	
		Cubes		cylinders		prism		cubes	
		12M	14M	12M	14M	12M	14M	12M	14M
1	3 days	3	3	3	3	3	3	3	3
2	7 days	3	3	3	3	3	3	3	3
3	28 days	3	3	3	3	3	3	3	3
Total		9	9	9	9	9	9	9	9

- all the strength specimens undergone ambient curing for a period of 3,7,28 days.
- all the durability specimens undergone chemical curing for a period of 30 days.

**Figure-9.** Casting of specimens.**Figure-10.** Curing of specimens.

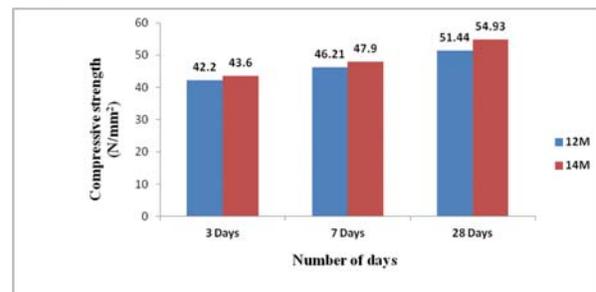
6. RESULTS AND DISCUSSIONS

6.1 Strength

The examples were tried according to IS 516:1959 and the qualities were ascertained for 3,7 and 28 days.

6.1.1 Compressive strength

The specimens used for this test were cubes of standard size 150mm x 150mm x 150mm. for each period of time of each molarity 3 specimens were taken and a total of 9 specimens for 12M and 9 specimens for 14M were taken for all time periods i.e. 3 days, 7 days, 28 days and from the testing it is observed that 14M specimens have good compressive strength compared to that of 12M specimens. And in the percentage of strength increase with respect to time period 14M specimens show good results compared to that of 12M.

**Figure-11.** The above graph representing the test result values of compressive strength.**Table-7.** Results of compressive strength test.

S. No	Molarity	Avg. Compressive strength for 3 days. (N/mm ²)	Avg. compressive strength for 7 days. (N/mm ²)	Avg. compressive strength for 28 days. (N/mm ²)
1	12M	42.72	46.21	51.44
2	14M	43.6	47.9	54.93

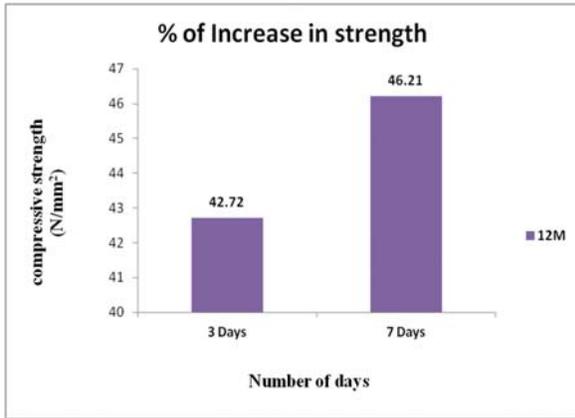


Figure-12. Graph representing the test result values of compressive strength for 3 days and 7 days of 12 m.

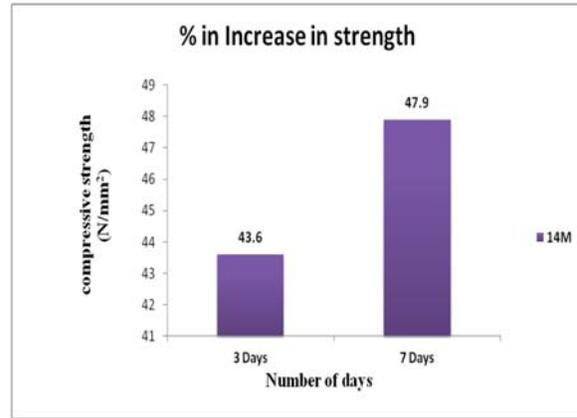


Figure-15. Graph representing the test result values of compressive strength for 3 days and 7 days of 14 m.

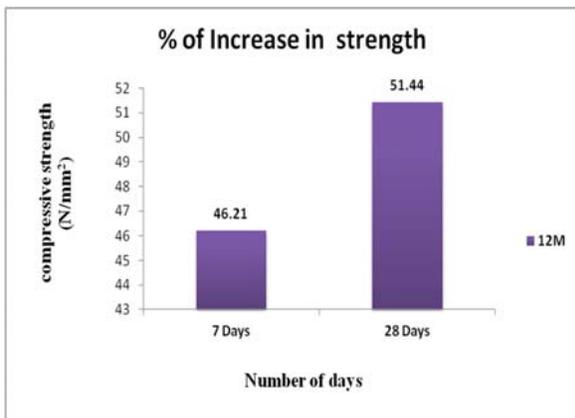


Figure-13. Graph representing the test result values of compressive strength for 7 days and 28 days of 12 m.

- From the above figure no: 10 it is identified that from 3 days to 7 days the percentage of increase in strength is 8.17%.
- From the above figure no: 11 it is identified that from 7 days to 28 days the percentage of increase in strength is 11.32%.

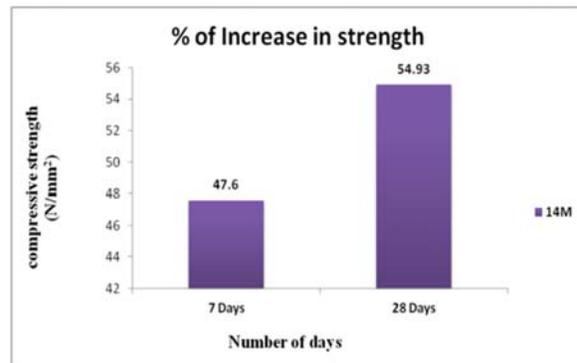


Figure-16. Graph representing the test result values of compressive strength for 7 days and 28 days of 14 m.

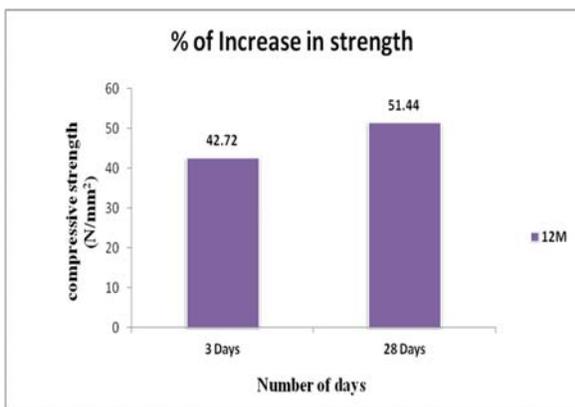


Figure-14. graph representing the test result values of compressive strength for 3 days and 28 days of 12 m.



Figure-17. Graph representing the test result values of compressive strength for 3 days and 28 days of 14 m.



- From the above figure no: 14 it is identified that from 7 days to 28 days the percentage of increase in strength is 14.68%.
- From the above figure no: 10 it is identified that from 3 days to 28 days the percentage of increase in strength is 25.99%.

6.1.2 Split tensile strength

The specimens used for this test were cubes of standard size 150 mm x 150 mm x 300 mm. for each period of time of each molarity 3 specimens were taken and a total of 9 specimens for 12M and 9 specimens for 14M were taken for all time periods i.e. 3 days, 7 days, 28 days the specimens $\{T = 2P/\pi LD\}$ is the formula for calculation of split-tensile strength for 3, 7 and 28 days and the outcomes were tabled and represented beneath .

Table-8. Results of split -tensile strength test.

S. No	Molarity	Avg. split-tensile strength for 3 days (N/mm ²)	Avg. split-tensile strength for 7 days (N/mm ²)	Avg. split-tensile strength for 28 days (N/mm ²)
1	12M	1.66	2.35	2.77
2	14M	2.08	2.77	3.19

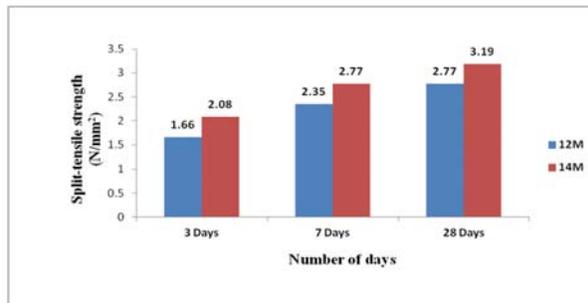


Figure-18. Graph representing the test result values of split-tensile strength.

6.1.3 Flexural strength

The specimens used for this test were cubes of standard size 100 mm x 100 mm x 500 mm for each period of time of each molarity 3 specimens were taken and a total of 9 specimens for 12M and 9 specimens for 14M were taken for all time periods i.e.; 3 days, 7 days, 28 days. $\{T = 2P/bd^2\}$ is the formula for calculation of flexural strength for 3, 7 and 28 days and the outcomes were tabled and represented beneath

Table-9. Results of flexural strength test.

S. No	Molarity	Avg. flexural strength for 3 days (N/mm ²)	Avg. flexural strength for 7 days (N/mm ²)	Avg. flexural strength for 28 days (N/mm ²)
1	12M	4.2	4.7	5.14
2	14M	4.4	4.8	5.21

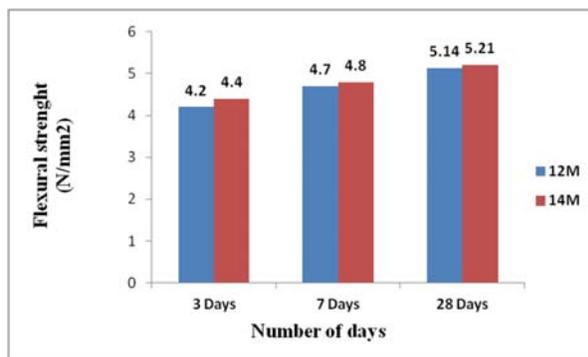


Figure-19. Graph representing the test result values of flexural strength.

6.2 Durability test

The specimens were cured for 30 days and according to IS 516:1959 the qualities were ascertained for 30 days.

6.2.1 Acid attack test

On an average of 3 cubes were used for acid attack test. The acid used for this test is H₂SO₄ acid cubes were taken out from the curing tank after 30 days. Filled the empty tank with 2% concentrated Sulphuric acid solution and cubes were placed into the tank. pH level was maintained constant up to 30 days of immersion of cubes in acid solution. The specimens were taken out from the acid solution and wiped with cotton cloth and dry it for half an hour. The cubes were weighed and the differences in the weights were noted. After that the cubes were tested for compressive strength at the age of 30 days under compressive testing machine.

**Table-10.** Results of acid attack test.

S. No	Type of attack	Molarity	Weight of specimen		% of loss/gain in weight
			Before curing	After curing	
1	Acid attack (H ₂ SO ₄)	12M	9.0	8.84	-1.7
2	Acid attack (H ₂ SO ₄)	14M	9.3	9.0	-3.23

Table-11. Results of acid attack test.

S. No	Type of attack	Molarity	Compressive strength(N/mm ²)		% of loss/gain in strength
			Before curing	After curing	
1	Acid attack (H ₂ SO ₄)	12M	51.44	48.64	-5.44
2	Acid attack (H ₂ SO ₄)	14M	54.93	52.86	-3.77

6.2.2 Sulphate attack test

On an average of 3 cubes were used for Sulphate attack test. The acid used for this test is MgSO₄ acid cubes were taken out from the curing tank after 30 days. Filled the empty tank with 2% concentrated Sulphuric acid solution and cubes were placed into the tank. pH level was maintained constant up to 30 days of immersion of cubes

in acid solution. The specimens were taken out from the acid solution and wiped with cotton cloth and dry it for half an hour. The cubes were weighed and the differences in the weights were noted. After that the cubes were tested for compressive strength at the age of 30 days under compressive testing machine.

Table-12. Results of sulphate attack test.

S. No	Type of attack	Molarity	Weight of specimen		% of loss/gain in weight
			Before curing	After curing	
1	Sulphate attack (MgSO ₄)	12M	8.8	9.1	+3.41
2	Sulphate attack (MgSO ₄)	14M	8.9	9.1	+2.25

Table-13. Results of sulphate attack test.

S No	Type of attack	Molarity	Compressive strength(N/mm ²)		% of loss/gain in strength
			Before curing	After curing	
1	Sulphate attack (MgSO ₄)	12M	51.44	53.54	+4.08
2	Sulphate attack (MgSO ₄)	14M	54.93	56.18	+2.28

6.2.3 Chloride attack test

On an average of 3 cubes were used for Sulphate attack test. The acid used for this test is NaCl acid cubes were taken out from the curing tank after 30 days. Filled the empty tank with 2% concentrated Sulphuric acid solution and cubes were placed into the tank. pH level was maintained constant up to 30 days of immersion of cubes

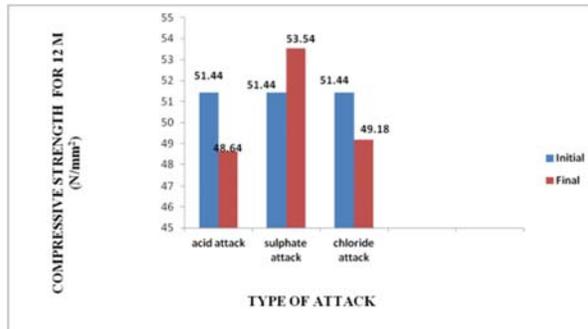
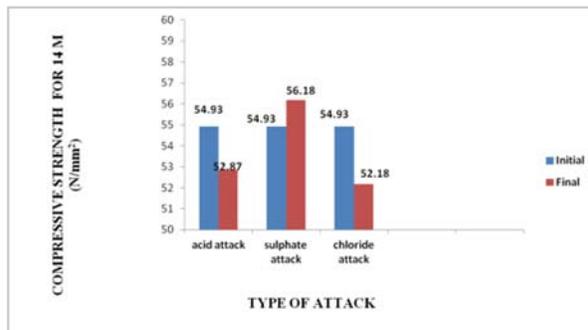
in acid solution. The specimens were taken out from the acid solution and wiped with cotton cloth and dry it for half an hour. The cubes were weighed and the differences in the weights were noted. After that the cubes were tested for compressive strength at the age of 30 days under compressive testing machine.

Table-14. Results of sulphate attack test.

S No	Type of attack	Molarity	Weight of specimen		% of loss/gain in weight
			Before curing	After curing	
1	Chloride attack (NaCl)	12M	9.0	8.76	-2.61
2	Chloride attack (NaCl)	14M	8.6	8.1	-5.87

**Table-15.** Results of sulphate attack test.

S. No	Type of attack	Molarity	Compressive strength(N/mm ²)		% of loss/gain in strength
			Before curing	After curing	
1	Chloride attack (NaCl)	12M	51.44	49.10	-4.55
2	Chloride attack (NaCl)	14M	54.93	52.18	-5.01

**Figure-20.** Graph representing the durability test result values of compressive strength test for 12m.**Figure-21.** Graph representing the durability test result values of compressive strength test for 14m.

7. CONCLUSIONS

- In compressive strength 14M specimen shows better result than that of 12M specimen.
- 12M specimens have less split tensile strength compared to 14M specimen.
- In case of flexural strength 14M has greater strength than 12M specimen.
- In case of durability there is loss of strength and weight in acid attack and chloride attack specimens. But gain in weight and strength in sulphate attack specimens.
- In acid attack loss of strength and weight was less in 12M specimen compared to 14M specimen.
- In sulphate attack 12M specimen have good percentage of gain compared to that of 14M specimens.
- In chloride attack 14M specimen show poor resistance compared to that of 12M specimen.
- Therefore, it was observed that as the molarity increases strength increases, thus 14 M specimens

have good strength compared to that of 12M specimens

- but in durability 12M specimens show good resistance compared to that of 14M specimens.

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