Service life prediction of geopolymer concrete with respective to chloride ion penetration

A Raziya Tasneem¹, B Sarath Chandra Kumar² and Y Himath Kumar³
¹ Pg Student Structural Engineering, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India
² Associate Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India
³ Associate Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India

E-mail: abdulraziya1831@gmail.com, sarath.9b@gmail.com, himathkumar007@kluniversity.in.

Abstract. Geopolymer concrete is an innovative construction material which is produced by the chemical action of inorganic molecules like sodium hydroxide, sodium silicate. This acts as a binding material for the cementation’s material. The cementations material used in the present study is Ground Granulated Blast-furnace Slag (GGBS). In this paper, the service life of the geopolymer concrete structure presented to know the life span. The sodium hydroxide solutions having the molarities of 8M and 10M are used. The ratio of the alkali activators (NaOH and Na₂SiO₃) used is 1:2.5. The normal concrete mix having the water-cement ratio of 0.45 is also cast. The cubes are exposed to the NaCl solution. The specimens exposed to the solutions are drilled in respective depths. The powder is collected from the specimens and are titrated against with AgNO₃ to find the percentage of chloride ion penetration. The compressive strength of the specimens for 28, 56, and 90 days are taken. In this paper it was also observed that as the days increases the percentage of chloride ion penetration decreases.

1. Introduction

The requirement for the concrete as a construction material increases exponentially and thereby, there is an increase in the demand to produce OPC. The environmental issues associated with this product are well known [1]. To reduce these problems, the cement is partially replaced by different materials having binding properties [2-3]. In 1978, Davidovits proposed that binders can be produced by polymer reaction of alkaline liquid with aluminon-silicate material such as fly ash, rice husk, blast furnace slag etc and termed these binders as geopolymer. Geopolymer can be considered as a green material, because it produces less amount of carbon [4].

Geopolymer concrete is generated through the alkali activation (NaOH and Na₂SiO₃) along with fly ash or GGBS combining with aggregates. It has become a very prevalent subject to investigate in modern times. The main purpose for its recognition is that the use of geopolymers conveys the potential of totally substituting Portland cement as the cementitious material [5]. What makes it even more desirable is that its primal component is usually an industrial outcome rich with silica and alumina. Such combinations are found in large quantity of by-products like Fly Ash, Slag, Rice Husk Ash and Metakaolin [6]. The alkali solutions (NaOH and Na₂SiO₃) used for binding the mix is
sodium hydroxide and sodium silicate [7]. It is taken in a ratio of 1:2.5 respectively [8]. The cementitious material used is Ground Granulated Blast-furnace Slag (GGBS). The cubes are cast and are exposed to NaCl solution i.e.; 3.5% of NaCl with respect to water is taken. The cubes are exposed to the solution for 28, 56 and 90 days respectively [9-10]. The present study is carried out to see whether the chloride content is increased or decreased in geopolymer concrete.

1.1. Chloride diffusion
The chloride penetration is a diffusion process, when the concrete is saturated with water and when cement does not react too much with salt. Any reinforcement is in a concrete practically saturated with water, when its core is rather thick and is not too dry (e.g. structures in marine or mountain sites).

1.2. Geopolymer Concrete
The term geopolymer was coined by Davidovits to represent a wide range of material categorized by chains or network of inorganic molecules. The schematic representation of geopolymer concrete is shown in the below figure 1 as illustrated by equation (A) and (B) [11].

![Figure 1. Schematic Formation of geopolymer concrete][12].

2. Materials Used
The materials used are GGBS, coarse aggregate, fine aggregate, alkali solutions like sodium silicate, sodium hydroxide and 10 % of water. The alkali solutions (NaOH and Na$_2$SiO$_3$) having a ratio of 1:2.5. OPC of 53 grades. For conventional concrete water-cement ratio used is 0.45.

2.1. GGBS
The ground granulated impact heater slag shown in figure 2 is a result of iron assembling which when added to concrete improves its properties, for example, usefulness, quality and sturdiness.

2.2. Advantages of GGBS
GGBS gives a useful blend. It has grater siphon capable and compaction qualities. The infiltration of chloride can be diminished. Lower odd of blossoming. Gives greater surface completion and improves style. The structure made of GGBS constituents help in expanding sulphate assault opposition. The warmth of hydration is less contrasted with customary blend hydration. The shading is more even and light. The salt silica response is opposed exceptionally. Unlike bond, GGBS does not create carbon dioxide, sulphur dioxide or nitrogen oxide.
2.3. Sodium Hydroxide (NaOH)
It is also known as caustic soda shown in figure 3, is an inorganic compound with the formula NaOH. It is highly caustic base and alkali that decays at ambient temperature and causes chemical burns. It is available in the form of solid, flakes, granules and in solution. This is highly soluble in water but is insoluble in ether and other non-polar solvents. The molarities used in this experiment are 8M and 10M. The solution is prepared 24 hours before the casting.

![Figure 3. Sodium hydroxide flakes.](image)

2.4. Sodium Silicate (Na2SiO3)
It is also known as water glass or liquid glass shown in figure 4. It is in gel form. The solution is prepared 24 hours before the casting. The alkali solutions are combined and used in the ratio of 1:2.5.

![Figure 4. Sodium silicate.](image)

3. Experimental Procedure

3.1. Casting of cubes
The cubes of dimensions 150mmX150mmX150mm were prepared shown in figure 5, and the specimens were casted for geopolymer concrete were GGBS, fine aggregate, course aggregate and alkali activators (NaOH and Na2SiO3) are mix and conventional concrete of M30 and M40 were cement of grade 53, fine aggregate, course aggregates water along with super plasticizer (BASF mesterease3708) are mixed with the W/C 0.45. The cubes are placed on the vibrator to remove the
voids. After 24 hours the specimens are demoulded and exposed to NaCl solution for 28, 56 and 90 days respectively.

![Figure 5. Casting of Cubes.](image)

### 3.2. Exposed to NaCl Solutions

The NaCl solution is prepared by mixing 3.5% of NaCl with respective to water and let the NaCl dissolve in water for one day. The cast cubed is placed in the solution. A total of 6 cubes of grade M30, 6 cubes of grade M40 and geopolymer cubes i.e.; 6 cubes having morality of 8 Molar and 10 Molar are placed in the solution and let them cure for 28 days, 56 days and 90 days shown in figure 6 [7, 8].

![Figure 6. Cubes Exposed to NaCl solution.](image)

### 3.3. Drilling of cubes

The cubes in figure 7 exposed to NaCl solution are first air-dried for 24 hours and are drilled at various depths. The concrete powder obtained from the cubes is waited and is used for further purpose.

![Figure 7. Drilling of cubes.](image)
3.4. **Titration process**
The cubes were drilled with 4 grams at each successive depth of 5mm, 10mm, 15mm, 20mm and 25mm. The collected powder is titrated against with AgNO$_3$ solution to obtain the results shown in figure 8 [6].

![Titration process](image)

**Figure 8.** Titration process.

4. **Test conducted**

4.1. **Compressive strength test**
The test was conducted according to IS 515-1959. Compressive strength test in figure 9 measures the maximum amount of compressive load of a specimen to find the specified compressive force at a period. The working procedure of the compression testing machine is, it contains two plates, one is fixed and the other is movable. The cube is placed on the fixed plate, with the help of the movable plate the specimen is tightened, and the load is applied. The readings are taken which is shown in the dial gauge which is fixed to the testing machine.

![Compressive strength of cube](image)

**Figure 9.** Compressive strength of cube.

4.2. **Chemical Analysis Test**
The drilled concrete powder from the specimen is collected and 3 grams of the powder is taken in a measuring jar of 100ml and 40 ml of distilled water is added to the powder to make a solution and left for rest to 1 hour. After an hour 10ml of the solution is taken to that 10ml 90 ml of distilled water is added. Now the burette is filled with 50ml of silver nitrate (AgNO$_3$) [13]. The volumetric flask which contains the solution is taken and 2-3 drops of potassium chromite are added and titrated against with AgNO$_3$. When potassium chromite’s are added the solution turns into pale yellow colour and is titrated up to the colour turns into a brick red colour. Finally, the burette readings are collected.

4.3. **Percentage of chloride ion penetration**
The percentage of chloride ion penetration in the concrete powder was finally calculated using the formula [14]
% of chloride in concrete powder = K*N*V/W [8]

Where K = volume of solution taken for titration.
N = normality of AgNO₃ solution, here it is 0.02.
V = volume of AgNO₃ dispended to reach the endpoint.
W = weight of the concrete powder.

5. Results and discussion

5.1. Results for Compressive strength of Cubes
The cubes are exposed to NaCl for 28 days and 56 days are tested under the compressive testing machine and the results are obtained.

Figure 10. Compressive strength for GPC exposed to NaCl solution.

Figure 11. Compressive strength for GPC ambient cured.
Figure 10 and 11 show the strength values of GPC cubes which are exposed to NaCl solution and ambient cured respectively. It shows the strength values of GPC having molarity of 8M and 10M for 28, 56 and 90 days respectively.

![Figure 12. Compressive strength for plane concrete exposed to NaCl.](image)

![Figure 13. Compressive strength of plane concrete water cured.](image)
Figure 12 and 13 shows the strength valued of plane concrete cubes exposed to NaCl solution and water curing respectively. It shows the strength values of M30 and M40 grade of concrete for 28, 56 and 90 days respectively.

5.2. Results for cubes exposed to NaCl solution
The powder taken from the specimen that is titrated as mentioned in the above chemical analysis, the specimen sample gives the percentage of chloride ion penetration. The graphs were drawn as chloride ion penetration versus the depth of penetration.

![Figure 14](image1.png)
**Figure 14.** Chloride ion penetration, 8M GPC (28, 56 and 90 Days).

![Figure 15](image2.png)
**Figure 15.** Chloride ion penetration, 10M GPC (28, 56 and 90 days).
Figure 14 and 15 shows the % of chloride ion penetration in GPC cubes having the molarity of 8M and 10M for 28, 56, and 90 days respectively.

**Figure 16.** Chloride ion penetration, M30 0.45 w/c (28, 56 and 90 Days).

Figure 16 and 17 shows the % of chloride ion penetration in plane concrete of grade M30 and M40 having the w/c ratio of 0.45 for 28, 56 and 90 days respectively.

**Figure 17.** Chloride ion penetration, M40 0.45 w/c (28,56 and 90 days).
6. Conclusion
The following conclusions are drawn for the result obtained from the test conducted for geopolymer concrete and plain concrete. The compressive strength of geopolymer concrete obtained 8M for 28, 56 and 90 days increases by 48.61%, 55.24% and 53.21% respectively and GPC obtained 10M for 28, 56 and 90 days increases by 43.51%, 44.03% and 41.62% respectively, compared to plain concrete exposed to NaCl solution. The compressive strength of geopolymer concrete obtained 8M for 28, 56 and 90 days increases by 49.70%, 50.01% and 50.85% respectively and GPC obtained 10M for 28, 56 and 90 days increases by 50.38%, 49.30% and 50.42% respectively, compared to plain concrete where GPC are ambient cured and plain concrete are water cured. For 28 days of chloride ion penetration GPC and plain concrete cubes gives the highest percentage chloride ion penetration.

7. Reference
[1] Reed M, Lokuge W and Karunasena W 2014 Fibre-reinforced geopolymer concrete with ambient curing for in situ applications Journal of materials science 49 4297-304
[2] Krishnan L, Karthikeyan S, Nathiya S and Suganya K 2014 Geopolymer concrete an eco-friendly construction material Magnesium 1
[3] Lloyd N and Rangan V 2010 Geopolymer concrete with fly ash Proc. of the Second International Conference on sustainable construction Materials and Technologies 1493-1504
[4] Kayali O 2016 Sustainability of fibre composite concrete construction InSustainability of Construction Materials 539-566
[5] Aswani E and Karthi L 2017 A literature review on fiber reinforced geopolymer concrete Int J Sci Eng Res. 8 408-11
[6] Basha BG, Rao BK and Rao CH 2020 Service life prediction of RC structure incorporated with GGBS & silica fume subjected to chloride ion penetration Materials Today: Proceedings
[7] Ch Hema Durga Rajeswari and B Kameswara Rao 2019 Service Life Prediction of High-Performance Concrete Incorporated with GGBS and Silica Fume International Journal of Recent Technology and Engineering 7 448-455
[8] G Rajesh and B Kameswara Rao 2018 Service Life Prediction of High-Performance Concrete with Respect to Chloride Ion Penetration by Incorporated with GGBS International Journal of Recent Technology and Engineering 7 478-483
[9] B Daya Rani and B Kameswara Rao 2019 Service Life Prediction of High-Performance Concrete with Respect to Chloride Ion Penetration by Incorporated with Fly Ash and Silica Fume International Journal of Recent Technology and Engineering 7 484-489
[10] E V Prudhvi sai and B Kameswara Rao 2019 Service Life Prediction of High-Performance Concrete with Respect to Chloride Ion Penetration by Incorporated with Fly Ash International Journal of Recent Technology and Engineering 7 496-501
[11] Kumar BS and Ramesh K 2016 Experimental study on strength properties of metakaolin and GGBS based geopolymer concrete ARPN Journal of Engineering and Applied Sciences 11
[12] Vignesh P and Vivek K 2015 An experimental investigation on strength parameters of flyash based geopolymer concrete with GGBS International Research Journal of Engineering and Technology 2 135-42
[13] Suwito A and Xi Y 2004 Service life of reinforced concrete structures with corrosion damage due to chloride attack InLife-Cycle Performance of Deteriorating Structures: Assessment, Design and Management 207-218
[14] Shyam A, Anwar A and Ahmad SA 2017 A Literature review on study of silica fume as partial replacement of cement in concrete International Journal of Advanced Engineering, Management and Science 3 239801