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An Experimental Investigation on the behaviour of Portland Cement Concrete and Geopolymer Concrete in acidic environment

Kolli Venkata Manjeeth, J. Sri Kalyana Rama
[1]*(Student, Civil Engineering Department, BITS PILANI HYDERABAD CAMPUS)*
[2]*(Lecturer, Civil Engineering Department, BITS PILANI HYDERABAD CAMPUS)*

ABSTRACT : *The degradation of concrete by acid attack has been a major problem which needs to be addressed with the utmost concern. This acid attack is primarily in the form of acid rain in low concentrations. This attack not only depends upon the type of the acid, but also on the concentration of the acid and the vulnerability of concrete. Portland cement concrete has high alkaline content and may be prone to acid attack by acidic media. The emergence of new alternative materials needs to address this issue by resisting acid attack to a large extent. Geopolymer materials are polymer minerals which are based on alumina and silica compounds and are a family of zeolites. The mechanism of corrosion of geopolymer concrete is tougher compared to that of conventional concrete. An experimental study was conducted to analyze the acid attack resistance of geopolymer concrete and Portland cement concrete. Durability of the concrete specimens were analyzed by immersing them in ph 1, ph 3 and ph 5 solutions for a period of 5 weeks and evaluating their resistance in terms of change of mass and compressive strength at regular intervals of one week each. Results indicated that Geopolymer concrete was highly resistant to sulphuric acid.*

Keywords*-Geopolymer Concrete, Alumina, Silica, Sulphuric Acid.*

I. INTRODUCTION

Durability of concrete is the most crucial property which evaluates the life of concrete. Interactions of concrete with external environment is one of the major factors which determines the durability of concrete. Among environmental factors like thaw, abrasion and corrosion and acid attack, acid attack is the most threatening parameter. There are many chemical attacks like acid attack, alkali attack, chloride attack, sulphate attack etc. [1]. The extent of deterioration of an acid attack on concrete depends on the chemical character of anions present. Aggregate type and concrete also influence the extent and intensiveness of acid attack. Limestone aggregate is more susceptible to acid attack and aggregate including siliceous materials are more resistant. Even the type of cement used in concrete also influences the acid attack. The integrity of hardened Portland cement binders is highly dependent on maintaining the high levels of alkalinity which normally stabilize the gel compound responsible for cementitious properties. Acids react with alkaline components of the binder (calcium hydroxide, calcium silicate hydrates and calcium aluminate hydrates) lowering the degree of alkalinity. The rate of penetration is thus inversely proportional to the quantity of acid neutralizing material, such as the calcium hydroxide, C-S-H gel, and limestone aggregates. In practice, the degree of attack increases as acidity increases; attack occurs at values of pH below about 6.5, a pH of less than 4.5 leading to severe attack. The rate of attack also depends on the ability of hydrogen ions to be diffused through the cement gel (C-S-H) after calcium hydroxide ($Ca(OH)_2$) has been dissolved and leached out.

The geopolymer technology was first introduced by Davidovits in 1978[2]. His work considerably shows that the adoption of the geopolymer technology could reduce the CO_2 emission caused due to cement industries. Geopolymer are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolite materials, but the microstructure is amorphous [3]. Any material that contains mostly silicon (Si) and aluminum (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Davidovits found that geopolymer cements has very low mass loss of 5%-8% when samples were immersed in 5% sulphuric acid and hydrochloric acid solutions. In contrast, Portland cements were completely destroyed in the same environment. He studied the resistance of geopolymer materials prepared from fly ash against 5% sulphuric acid up to 5 months exposure and concluded that geopolymer materials have better resistance than ordinary cement counterparts [4]. He has also shown that geopolymer composites possesses excellent durability properties in a study conducted to evaluate the long term properties of fly ash based geopolymer. The geopolymer has a very good resistance in acid media in terms of weight loss and residual compressive strength [5].

II. SPECIMEN PREPARATION AND TEST PROCEDURE

For batching, all material was collected and stored at room temperature. All aggregates were maintained in SSD (Saturated Surface Dry) condition for at least 20 hours before the experiment. The importance of SSD is to eliminate the absorption of alkali activator solution by the aggregates. The SSD condition is attained by soaking aggregates by soaking them in water for 24 hours and then drying on a tray. The nominal size of coarse aggregate was found to be 20mm and the nominal size of fine aggregate was found to be 4.5 mm after proper sieving and grading. The specific gravities of coarse and fine aggregates were 2.72 and 2.64 respectively. The alkali activator solution used consisted of NaOH solution of 98% purity and its molarity was 16M. The Na_2SiO_3 solution had 34.64%SiO_2, 16.27% Na_2O and 49.09% water. During mixing, all components excluding alkali activators were initially dry mixed for 2 minutes and then wet mixed with addition of alkali activator. Then, the concrete was cast into cube moulds for testing of compressive strength. Normal concrete is preferred to be cured in water. But on the other hand, geopolymer concrete is cured at room temperature and the moulds are covered so as to not let heat escape ensuring that heat expelled from the moulds by the chemical reaction is sufficient for heat curing. This process is self-curing.

III. DESIGN MIX

Table 1 (Design mix of normal and geopolymer concrete)

Volume of normal Concrete	0.0215217 m3
Mass of normal Concrete	51.652 kg
Water : Cement: FA: CA	0.4:1:1.65:2.92
Fine Aggregate	14.275 kg
Coarse Aggregates	25.27 kg
Cement	8.652 kg
Water	3.46 lt
Volume of geopolymer Concrete	0.0215217 m3
Mass of geopolymer Concrete	51.652 kg
Flyash: FA: CA	1:1.65:2.92
Fly ash	8.8 kg
Fine Aggregate	11.93 kg
Coarse Aggregates	27.84 kg
Alkali Activator	3.08 kg
Mass of NaOH sol	0.88 kg
Mass of Sodium Silicate sol	2.2 kg
Mass of Sodium Silicate solids	0.803 kg
Mass of NaOH solids	0.387 kg
Mass of water in alkali activator	1.89 lt

IV. CORROSION MECHANISM

The whole mechanism of corrosion in concrete at different concentrations of sulphuric acid is of two steps. The first step is by an ion exchange reaction between cations and hydronium ions followed by an electrophilic attack of acid protons on Si-O-Al bonds [6]. In geopolymer concrete, the exchanged calcium ions diffuse towards acid solution reacting with sulphate ions resulting in formation of gypsum crystals. Deposition of gypsum crystals inside corroding matrix provides a protective effect inhibiting the total process of deterioration [7]. Concrete is usually highly alkaline and is easily attacked by acid solutions. As the pH of the solution decreases, the stability of the cement binder is disturbed and may lead to severe degradation of the material. In case of geopolymer concrete, the gypsum layer formed provides a protective effect not initiating any kind of degradation [8]. The first step of any corrosion process involves in the formation of shrinkage cracks which become wide enough later to allow diffusion of sulphate anions which react with the calcium ions thereby leading to deposition of gypsum crystals. The content of calcium in geopolymer concrete balances the negative charge of Al in the coordination structure [9]. Therefore knowing that the extent of damage is dependent on the amount of CSH one may expect that a decrease in the calcium content of geopolymer cements results in a higher acid resistance by reducing the amount of CSH and producing a more protective corroded layer [10].

V. EXPERIMENTAL VALUES

Table 2 (Compressive Strength values in different concentrations of sulphuric acid)

Solution Conc	Ph 1	Ph 4	Ph 7
Week 0	NC- 40.87 GC- 45.88	NC- 40.87 GC- 45.88	NC- 40.87 GC- 45.88
Week 1	NC- 37.61 GC- 41.87	NC- 38.18 GC- 42.67	NC- 39.65 GC- 44.16
Week 2	NC- 33.19 GC- 38.65	NC-37.54 GC- 41.87	NC- 38.55 GC- 43.58
Week 3	NC-30.81 GC- 36.46	NC- 36.56 GC- 39.15	NC- 38.15 GC- 41.65
Week 4	NC-29.1 GC- 34.64	NC- 34.68 GC- 38.84	NC- 37.48 GC- 40.98
Week 5	NC-26.47 GC- 32.59	NC- 32.95 GC- 37.83	NC- 35.18 GC- 38.89
Week 6	NC-23.08 GC-30.79	NC- 29.48 GC- 36.15	NC- 34.59 GC- 37.45

Table 3 (Mass loss values in different concentrations of Sulphuric acid)

Solution Conc	Ph 1	Ph 4	Ph 7
Week 0	NC- 2.36 GC- 2.38	NC- 2.36 GC- 2.38	NC- 2.36 GC- 2.38
Week 1	NC- 2.3 GC- 2.42	NC- 2.34 GC- 2.40	NC- 2.36 GC- 2.38
Week 2	NC- 2.24 GC- 2.45	NC-2.28 GC- 2.36	NC- 2.36 GC- 2.36
Week 3	NC- 2.18 GC- 2.50	NC- 2.25 GC- 2.35	NC- 2.32 GC- 2.36
Week 4	NC-2.11 GC- 2.32	NC- 2.20 GC- 2.34	NC- 2.29 GC- 2.36
Week 5	NC-2.01 GC- 2.24	NC- 2.19 GC- 2.30	NC- 2.25 GC- 2.34
Week 6	NC-1.95 GC-2.20	NC- 2.10 GC- 2.25	NC- 2.20 GC- 2.30

VI. GRAPHS

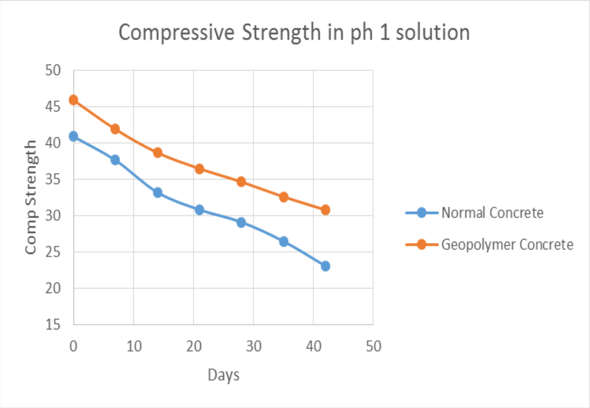

Figure 1 (Compressive Strength of NC and GC in Ph 1 solution)

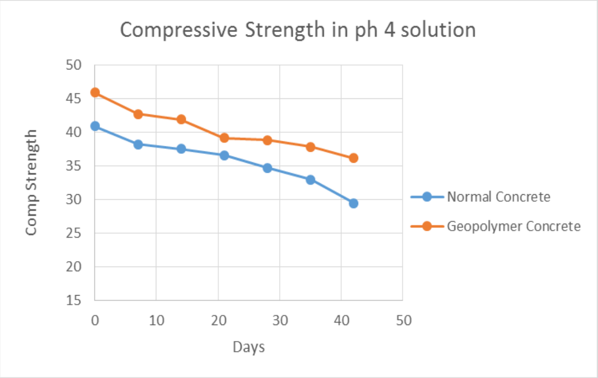

Figure 2 (Compressive Strength of NC and GC in Ph 4 solution)

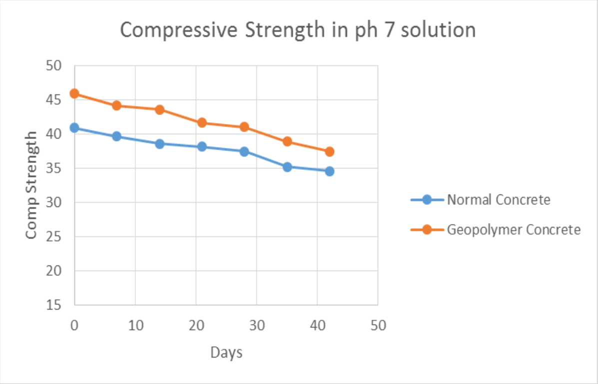

Figure 3(Compressive Strength of NC and GC in Ph 7 solution)

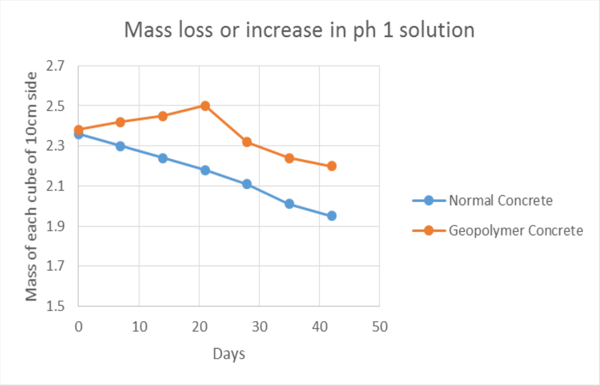

Figure 4 (Mass loss of NC and GC in Ph 1 solution)

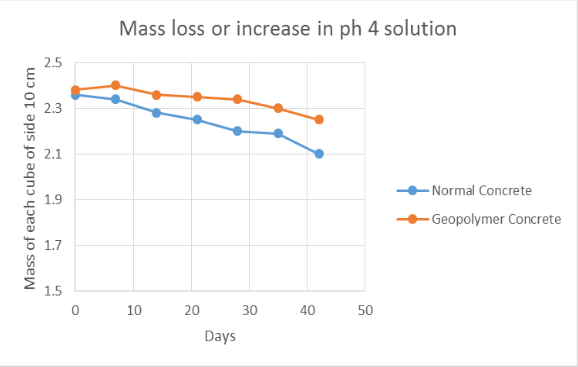

Figure 5(Mass loss of NC and GC in Ph 4 solution)

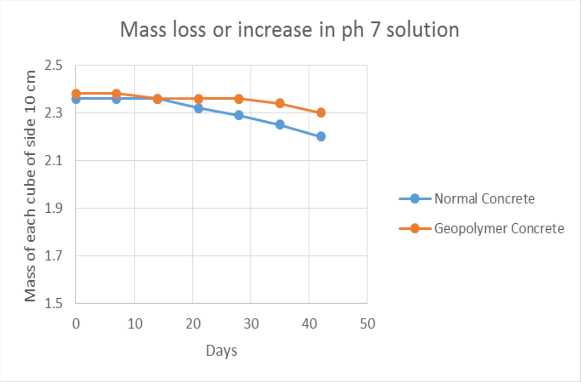

Figure 6(Mass loss of NC and GC in Ph 7 solution)

VII. DISCUSSION

Extent of corrosion at pH 1:

The graphs of compressive strength and mass loss in immersion in ph 1 over a period of 6 weeks confirms us that the best acid attack process occurs at the highest acidity point. At ph 1, acidic nature is at its best and attacks the concrete to a large extent due to which we observe huge decrease in compressive strength of normal concrete and geopolymer concrete. However, geopolymer concrete has shown better acid attack resistance when compared to the normal concrete. On the other hand in mass loss, geopolymer concrete shows increase in mass for a certain amount of time due to deposition of gypsum crystals in the geopolymer matrix and on the outer surface forming a layer of inhibition, which is not the case in normal concrete. But, at the end of 6 weeks, it can be said that mass loss for geopolymer concrete is less when compared to normal concrete. So, we can conclude that geopolymer concrete is best used in ph 1 solution acid attack.

Extent of corrosion at pH 4:

At pH 4, the tested concrete cubes were corroded to considerably lower extents than at pH 1 confirming that the intensity of the aggression is significantly dependent on the pH value of the acid solution. The results of corrosion mass loss versus exposure time and compressive strength vs exposure time are presented. After 6 weeks of exposure to sulphuric acid solution, GC and PPC paste specimens were corroded to considerable depths, but geopolymer cubes showed better resistance to the attack. The gradual deposition of corrosion products resulted in gradual decrease of corrosion rates. As the acid concentration decreases, the acid attack vigorousness also becomes less thereby showing less corrosion rate compared to Ph 1. This can be evident from the graphs.

Extent of corrosion at pH 7:

At Ph 7, the concrete cubes were corroded to quite lower extents. The graphs show the decrease in mass loss and compressive strength during the 6 weeks of exposure. At relatively higher pH values, e.g. 7, the acid content of the solution is comparatively very less (based on a logarithmic relationship). During the first few weeks of exposure therefore, the very less acid content of the solution or part of which close to the acid exposed surface of the specimens can be easily neutralized. Hence, there is very less or minimal corrosion rate and therefore the mass loss percentage and compressive strength change is also very low compared to the other two solutions.

VIII. CONCLUSION

The relationship between the mass loss experienced by all concrete specimens subjected to sulphuric acid and the reduction in their 28-day compressive strength is shown and it is observed that compressive strength declined as mass loss increased. This directly proportional relationship can be attributed to the fact that immersing concrete specimens in sulphuric acid results in loss of cement paste and its structural integrity, weakening of the concrete matrix, as well as a reduction in the specimen’s diameter. The loss of weight of cement mortars increases with the increasing values of acid concentration. Geopolymer mortar specimens manufactured from fly ash with alkaline activators remained structurally intact to a better extent than normal or conventional concrete and did not show any recognizable change in colour in Sulphuric acid. The loss of weight was observed to be lower in geopolymer mortar specimen when compared with conventional cement mortar. It is observed that the percentage loss of Compressive strength of all Geopolymer Concrete mixes are considerably lower than that of Conventional concrete mixes at all ages of acid exposure. The better performance of geopolymer materials than that of Portland cement concrete in acidic environment might be attributed to the lower calcium content of the source material as a main possible factor since geopolymer concrete does not rely on lime like in Portland cement concrete. It can thus be concluded that Geopolymer concrete possesses excellent mechanical properties and durability for aggressive environment compare to PPC.

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