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Effect of Aggressive Chemical Environment on Fly Ash Based Geopolymer Concrete

[1]K.CHINNASUBBARAO, [2]G.SHANI PRIYANKA

[1]*(M.Tech) Structural Engineering, Dept. of Civil Engineering*
[2]*Associate Professor, Dept. of Civil Engineering*
Priyadarshini Institute of Technology & Management

Abstract:- Concrete is the most widely used building material around the world because of the availability of raw materials, the simplicity in preparation and the moulding into different shapes. One of the main ingredients in a normal concrete mixture is Portland cement. It leads to the release of significant amount of CO2 and other greenhouse gases to pollute the atmosphere. Reuse and recycle of industrial solid wastes and by products in concrete is necessary to produce even "greener" concrete. The use of fly ash is more environmental friendly due to the reduced CO2 emissions and costs compared to OPC, which requires the burning of large quantities of fuel and the decomposition of limestone and can result in significant CO2 emissions. The test results indicate that the heat-cured fly ash-based geopolymer concrete has an excellent resistance to acid and sulphate attack when compared to conventional concrete. Thus we can say that the production of geopolymers have a relative higher strength, excellent volume stability and better durability. The experimental results reveal that the poisson's ratio was in the range of 0.20 to 0.24 and modulus of elasiticity was in the range of 27 to 29 N/mm2.

Keywords- Geopolymer Concrete, Molarity, Sodium Hydroxide, Sodium Silicate, Modulus of Elasticity.

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1. INTRODUCTION

Concrete is the most widely used construction material in the world. It is often referred to as the universal material. Its annual consumption is around 20 billion tons per year, which is equivalent to 2 tons per every living person, speaks of immense potential which can affect the economy of a country [1]. Producing one tonne of cement requires about 2 tonnes of raw materials (shale and limestone) and releases 0.87 tonne (≈ 1 tonne) of CO2, about 3 kg of Nitrogen Oxide (NOx), an air contaminant that contributes to ground level smog and 0.4 kg of PM10 (particulate matter of size 10 μm), an air borne particulate matter that is harmful to the respiratory tract when inhaled. The global release of CO2 from all sources is estimated at 23 billion tonnes a year and the Portland cement production accounts for about 7% of total CO2 emissions.

The cement industry has been making significant progress in reducing CO2 emissions through improvements in process technology and enhancements in process efficiency, but further improvements are limited because CO2 production is inherent to the basic process of calcinations of limestone. Due to the production of Portland cement, it is estimated that by the year 2020, the CO2 emissions will rise by about 50% from the current levels. Therefore, to preserve the global environment from the impact of cement production, it is now believed that new binders are indispensable to replace Portland cement [2]. In this regard, the geopolymer concrete is one of the revolutionary developments related to novel materials resulting in low-cost and environmentally friendly material as alternative to Portland cement.

Geopolymer binders might be a promising alternative in the development of acid resistant concrete since it relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity [3]. Geopolymersis a type of inorganic polymer composite, that are produced and hardened even at ambient temperature under highly alkaline conditions, in the presence of alkali hydroxide and silicate solution.Polymerization takes place when reactivealuminosilicatesare rapidly dissolved and free SiO4 and AlO4 tetrahedral units are released in solution. The geopolymer concrete (GPC) was superior to plain Portland cement concrete (PPCC) when these mixes were subjected to sodium sulphate and magnesium sulphate solutions [4]. In the present study a class F, fly ash was used to synthesize an alkali activated concrete (Zeopolymer concrete, GPC) without use of OPC, and study its strength and durability properties under different chemical environment.

1.1. Geopolymers

The geopolymer technology was first introduced by Davidovits in 1978. Geopolymers is an inorganic polymeric materials formed by activating silica aluminum rich minerals with alkaline hydroxide or alkaline silicate solution at ambient or higher temperature level [5]. The chemical composition of geopolymer is similar to natural zeolitic materials, but the microstructure is amorphous.

1.2. Constituents of Geopolymer

There are two main constituents of geopolymers, namely the source materials and alkaline liquid.

Source materials

Any material that contains mostly Silicon (Si) and Aluminum (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Several mineral and industrial by- product materials have been investigated in the past. The calcined source materials such as fly ash, slag, calcined kaolin demonstrated a higher compressive strength when compared to non-calcined materials [6]. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, but to date its utilization is limited. Currently, 90 million tonnes of fly ash are being generated annually in India. By exploring use of the fly ash based geopolymer concrete two environment related issues are tackled simultaneously i.e. the high amount of CO2 released to the atmosphere during production of OPC and utilization of this fly ash. The production of geopolymer concrete is carried out using the conventional concrete technology methods.

Alkaline liquids

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). However, potassium hydroxide and potassium silicate can also be used. Alkaline liquid plays an important role in the polymerization process [7]. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides.

1.3. Objectives

There are three main objectives of this research.
1. To develop Geopolymer concrete using Fly ash as a source material.
2. To calculate the density of Geopolymer concrete.
3. To study the effect of sodium hydroxide concentration on strength and durability properties of fly ash based Geopolymer concrete.

2. Experimental investigation

2.1 Materials

The following materials have been used in the experimental study [8]

a) Fly Ash (Class F) collected from Raichur Thermal power plant having specific gravity 2.10.

b) Ground granulated blast furnance slag collected from Jindal steel factory, Bellary having specific gravity 2.84.

c) Fine aggregate: Sand confirming to Zone –III of IS:383-1970 having specific gravity 2.61 and fineness modulus of 2.73.
d) Coarse aggregate: Crushed granite metal confirming to IS:383-1970 having specific gravity 2.72 and fineness modulus of 6.40.

e) Water : Clean Potable water for mixing

f) Alkaline Media: Specific gravity of
i) Sodium Hydroxide (NaOH)= 1.16
ii) Sodium Silicate (Na2SiO3) = 1.57
g) Superplasticizer : Conplast (SP-430)

Tests were conducted on specimen of standard size as per IS: 516-1959 and IS:5816-1999 [15 and 16]. Details of tests conducted and specimens used are given in Table 1.

TABLE I DETAILS OF SPECIMEN USED AND TEXTS CONDUCTED

Type of tests conducted	Size of specimen	No. of specimen cast for each grade
Compresive strength	150x150x150mm	5
Split tensile strength	100x200mm	5

2.2 Mix Design of Geopolymer Concrete

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m3 [9].

2.3. Mixing, Casting, Compaction and Curing of Geopolymer Concrete

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes. In preparation of NaOH solution, NaOH pellets were dissolved in one litre of water in a volumetric flask for concentration of NaOH (12M). Alkaline activator with the combination of NaOH and Na_2SiO_3 was prepared just before the mixing with fly ash. The ratio of alkaline liquid to fly ash by mass varies with the grade of concrete [10].

The fly ash and alkaline activator were mixed together in the mixer until homogeneous paste was obtained. This mixing process can be handled within 5 minutes for each mixture with different molarity of NaOH. Fresh fly ash based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of conventional slump test. Heat curing of geopolymer concrete (GPC) is generally recommended, both curing time and curing temperature influence the compressive strength of GPC [11]. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept in ambient air curing.

2.4 . Modulus of Elasticity

The Young's modulus or elastic modulus, Ec of fly GPCC was determined as the tangent modulus measured at the stress level equal to 40 percent of the average compressive strength of concrete cylinders. Ec of Portland Pozzolana cement concrete (PPCC) was measured at the stress level equal to 30% of the average compressive strength of concrete cylinders. Tests were carried out accordance with the IS: 516-1959 [12]. For each mixture, 150x300 mm concrete cylinders were prepared. All the specimens were provided with sulphure capping. The tests were performed in a 250 tones capacity servo controlled UTM. Two LVDTs (Linear Voltage Difference Transducers) were used to measure the axial deformation of the concrete cylinders.

Fig.1 Set up for measuring modulus of elasticity

2.5 Poisson's Ratio

Poisson's ratio is calculated by measuring lateral deformation while generating the stress-strain curves. In this study, circumferential extensometers were used to detect the lateral strain of the concrete cylinder. The circumferential extensometer is a specially designed "clip gauge" for measuring the average lateral expansion along the whole circumference of the

cylinder, and it is advantageous over the normally used electrical strain.
gauge which can only catch the length change of a small portion of the total cylinder circumference. Given the remarkable heterogeneity of the concrete and highly localized deformation, the circumferential extensometer is apparently much more reliable to provide accurate and consistent average circumferential deformations, which can then be converted easily into the lateral strains. A solid stainless steel rod with a diameter of 250mm was used to verify the accuracy of the circumferential extensometer, which was installed right at the mid-height of the rod together with an LVDT along the circumferential direction.

3. STRUCTURAL BEHAVIOUR OF GEOPOLYMER CONCRETE

Yost et al. (2013) conducted an experimental program on the structural performance of geopolymer concrete beams. They observed that the GPC beams perform similar to OPC beams of comparable strength and aggregate content. GPC beams failed in a more brittle manner than the OPC concrete beams. The researchers suggested that the same analysis and design procedure which established for OPC concrete beams can be used for the case of GPC beams to check the flexural and shear strength. The performance of GPC columns has been studied also to ensure that this material is capable to perform as a structural material in columns. Rahman et al. (2011) investigated the behaviour of GPC columns under combined axial load and biaxial bending using twelve reinforced concrete slender columns. They observed that the failure of the columns was identical to that of OPC under the same loading conditions.

4. RESULTS AND DISCUSSIONS

4.1. CHANGE IN WEIGHT

Cubes each GPC and OPC were immersed in 0.005 & 0.05 M sulphuric acid, 10% sodium sulfate solution and 10% sodium chloride solution fortest period of 30,60 and 90 days. The change in weight of geopolymer concrete cubes exposure to sulphuric acid, sodium chloride and sodium sulphate solution were observed for GPC concrete cubes and were compared with the weight of unexposed/untreated GPC cube. All the exposedspecimens[15] recorded weight loss and it was observed that the weight loss in case of acid attack was more in compare to sulphate and chloride. The results of change in weight is presented in fig.11

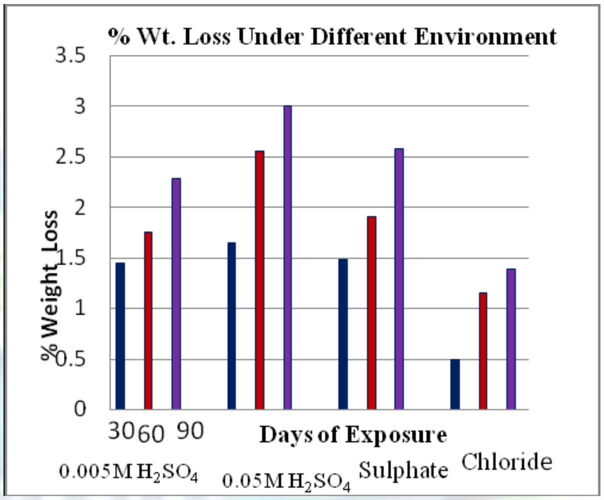

Fig 2. Change in weight

4.2 EFFECT ON COMPRESSIVE STRENGTH

Cubes each GPC and OPC were immersed in0.005 & 0.05 M sulphuric acid, 10% concentration of sulphuric acid, sodium sulfate solution and sodium chloride solution for the test period of 30,60 and 90 days.

4.3. EFFECT OF AGGRESSIVE ACID ENVIRONMENTS ON COMPRESSIVE STRENGTH

The effect on compressive strength on both GPC and OPC sample cubes exposed to 0.005 Molar solutions of sulphuric acids for 30 , 60& 90 days were compared.
The deterioration observed was connected to depolymerisation of the aluminosilicate , which in some cases lead to a significant loss of strength. Due to low calcium content in fly ash, thegeopolymer concrete exhibits high resistance to acid immersion. The GPC cubes[14] exposed to sulphuric acid undergoes erosion of the surface while in case of ordinary Portland cement; sulphuric acid attack leads to deposition of a white layer of gypsum crystals on the acid-exposed surface of the specimen. The compressive strength[13] of OPC cubes were found decreases more in comparison to GPC. (Fig.12-14)

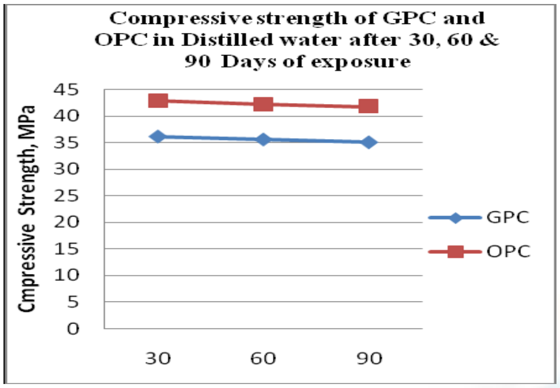

Fig 3: Compressive strength of GPC and OPC in distilled water.

4.4 EFFECT OF SULPHATE & CHLORIDE SALTS

The effect of sulphate and chloride salts on compressive strength of both GPC and OPC cubes were presented in table-2& 3. Results shows that compressive strength for both types decreases on exposure of 30, 60 &90days duration while the decrease in case of OPC is more in comparison to GPC which shows that Geoploymer concrete exhibit significant resistance to sulphate and chloride attack. (Fig.).

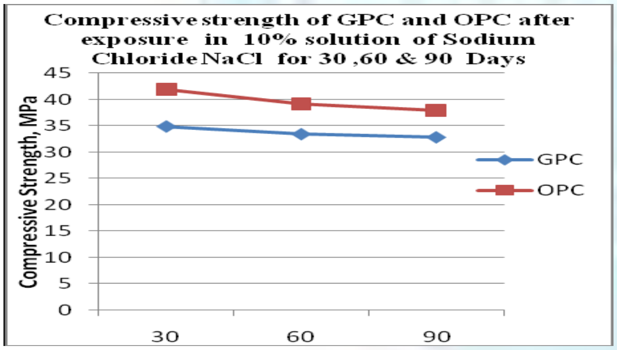

Fig 4: Effect of sulphate and chloride salts

5. CONCLUSIONS

Geopolymer concrete has many superior properties compared with its counterpart OPC concrete. The chemical composition of GPC and the curing conditions play important roles in its mechanical properties. GPC is an environmentally friendly sustainable construction material which is becoming increasingly popular. For a particular compressive strength, GPC exhibits higher tensile strength compared to OPC concrete, which is suitable for structural applications. Higher bond strength is shown between reinforcement and GPC. It has excellent resistance to sulphate attack, fire and good resistance to acids. It has low creep and low drying shrinkage. At the moment, standards and codes for OPC concrete are being used in the design of GPC structural members. However, more attention should be paid to the structural design in regards to brittleness of GPC. The GPC and PPCC mixes indicated minor changes in weight and strength when the specimens were exposed to sulphuric acid and magnesium sulphate. The compressive strength loss for the specimens exposed in suplhuric acid was in the range of 10 to 40% in PPCC, where as it was about 7 to 23% in GPCs. The compressive strength loss for the specimens exposed in magnesium sulphate was in the range of 5 to 25% in PPCC, where as it was about 3 to 12% in GPCs. The split tensile strength loss for the specimens exposed in suplhuric acid was in the range of 15 to 25% in PPCC, where as it was about 8 to 45% in GPCs.

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