A Review on Durability Studies of Geopolymer Concrete and Mortar under Aggressive Environment

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Abstract

Concrete prepared with Ordinary Portland Cement (OPC) is well known in the world for its reliability durability and versatility. OPC concrete is the second most used material next to water. Even though OPC is so popular in construction, it is not eco friendly due to enormous energy consumption in its production and due to emission of enormous CO_2. This is posing a serious challenge in sustainable development. Efforts are needed to develop a environmental friendly civil engineering construction material for minimizing emission of green-house gases to the atmosphere. The Endeavour to develop a environment friendly concrete had offered many alternatives. One eminent among them is geopolymer concrete. This paper presents a review summary of detailed literature survey conducted on geopolymer concrete. In geopolymer concrete, the inorganic alumino-silicate polymer gel synthesized from source materials rich in silicon and aluminium, such as low calcium (class F) fly ash, Ultra-Fine GGBS, High calcium Fly ash, M-Sand and Fly Ash , Recycled Aggregates and Metakaolin and GGBS which binds the loose aggregates, and other un-reacted materials in the produced geo-polymer mix. Geopolymer cement, because of it environment friendly nature becomes a most suitable alternative to OPC. This is because, with the usage of geopolymer cement, Portland cement can be dispensed with in making concrete. This paper briefly reviews the durability studies such as resistance to acid, high temperature, resistance to sulphate and chloride of geopolymer concrete.

Keywords: *Geo-polymer, Durability, Elevated temperature, Sulphate attack, Chloride attack.*

I. INTRODUCTION

In making a concrete, Portland cement is the main and major ingredient. But production of one ton of Portland cement results in emission of approximately one ton of CO_2 into the atmosphere. This makes cement industry as one of the major polluting industries. The major components of geopolymer cement can be broadly divided into two categories; they are alkaline liquids and the source materials. The source materials need to be alumino silicate materials like slag, rich husk ash, metakaolin, fly ash, red mud, activated bentonite clay etc. The alkaline activation on these source materials will result in formation of geopolymer cement. The source materials for geopolymers based alumino-silicate should be rich in silicon and aluminium such as natural pozzolana, like fly ash, blast furnace slag, and calcined kaolinite clays. Sodium or potassium based soluble alkali metals are used to make alkaline liquids. Normally sodium hydroxide with sodium silicate at liquid ratio of 2.5 is used as a alkaline liquids. Sodium is preferred over potassium mainly because it is cheaper. As there is polymerization process when alkaline liquid reacts with Silicon (Si) and Aluminium (Al) in fly ash when producing biders, Davidovits termed these binders as "geopolymer". The geopolymer concrete is made by mixing of geopolymer and aggregates. Geopolymerization involves the chemical reaction of alumino-silicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yielding polymeric Si–O–Al bonds. This review briefs about the durability studies on GPC for exposure to elevated temperature, resistance to sulphates, chlorides and acid.

II. EFFECT ON TEMPERATURE

Chandan Kumar, et al. (2014) conducted experimental investigations to assess the performance of geopolymer concrete at elevated temperature. Three cubes were selected as specimens. These were tested by universal testing machine at the age of 7 and 28 days for compressive strength. Then elevated temperature test was performed on these 200^{o}C, 400^{o}C, 600^{o}C, 800^{o}C and 1000^{o}C

In an electric air heated muffle. After cooling these specimens, compressive strength was tested. Geopolymer concrete composite showed deterioration in its properties when exposed to temperatures above 200^{0}C.Geopolymer concrete showed reduction in strengths in compression when exposed to high temperatures. This reduction was about 6.27%, 19.94%, 34.76%, 42.31% and 60.12 % at 200°C, 400°C, 600°C, and 800°C and 1000°C degree respectively.

The Construction Research centre in the University Teknologi Malaysia had carried out experimental investigation on geopolymer mortars by exposing it to extreme dry were cycles to assess its performance. Palm oil fuel ash (POFA) and pulverized fuel ash (PFA) from agro industrial waste were combined to produce geopolymer mortars as cement replacement. These geopolymer mortars activated by alkaline solution were studied. Tests were carried out using both OPC specimens and Geopolymer specimens. To study the resistance of geopolymer mortars against aggressive weather conditions, Dry-wet cycle test was conducted. The result of the tests established better resistance of geopolymer mortars compared to OPC mortars due to elimination of cement in the mixture.In the residual compressive strength is reduced 40% after 30 dry-wet cycles. The reduction of residual compressive strength was reduced significantly higher than geopolymer mortars.

A low calcium Processed fly ash was used as a source material procured from coal based National thermal power station, Eklahare., Nashik. The authors Satpute Manesh B et al. (2012) confirmed that the temperature and curing time significantly improves the compressive strength, although the increase in strength may not be significant for curing at more than 600°C. In the activation of geopolymer concrete curing temperature and its duration are also important. Higher compressive strength was developed at the curing time range of 6 to 24 hours. However, beyond 20 hours the increase in strength is not significant. At 120°C the rate of strength is faster compared to at 60°C. But compressive strength is not significant beyond 120°C. Daniel and sanjayan (2010) Conducted experimental investigation to assess the performance of Geopolymer paste, mortar and concrete using Australian fly ashes at the elevated temperature. Different parameters have been examined such as specimen size, aggregate size and aggregate type and super plasticizer type. The study resulted that the influence of specimen size is more when compared to the aggregate size in the thermal behavior at elevated temperature at 800°C. Aggregate size greater than 10 mm resulted in good strength performances in both ambient and elevated temperatures.

Bakharev T, (2005) reported a after a full detailed research work on the study of thermal stability of properties firing to around 800-° 1200°C of materials prepared using Class F fly ash geopolymer using potassium and sodium as activators. Compressive strength and shrinkage measurements were found in the studies. The materials were prepared in the water binder ratio as 0.09- 0.35 using compaction pressures up to 10 MPa and curing temperatures 80°C to 100°C. When compared to sodium and potassium silicate, potassium silicate as activator was better in compressive strength on heating and deterioration was started at 1000°C.

The fire responses of geopolymer matrix were measured by Balaguru (1997). When compared the results with organic matrix composites (Used in infrastructure, military and transportation applications), it was established that geopolymer matrix did not release smoke or ignite burn even under extended heat exposure. Sixty percent of flexural strength was retained by geopolymer matrix after simulated fire exposure. From this experiment, it is further established that geopolymer coating could be used to protect transportation infrastructure and composite to strengthen concrete structures. It is concluded that geopolymers have better fire resistance than organic polymers.

III. RESISTANCE TO SULPHATE:

Tang L et al. (2014) conducted experimental investigations to study the resistance to sulphates of fly ash based GPC. The variations are effected of the following to assess the experimental results a) structural morphology b) compressive strength c) dynamic elastic modulus d) weight and e) volume. Scanning electron microscope (SEM) technique was used to study the attack of sulphate on the microstructure of the specimen. Damage mechanism during erosion process can be explained by dynamic elastic modulus. To assess the resistance of concrete to sulphate attack, one of the major criterions suggested is dynamic elastic modulus. The better resistance of GPC to sulphate attack is mainly because of the following two aspects.

1. Slowing down the corrosion of sulphate due to much denser microstructure and
2. More stable polymerization.

There were experimental investigations on performance of fly ash based geopolymer concrete done by Bhagia Maria Joshy et al. (2014) by subjecting it to severe environmental conditions. The results established that this geopolymer concrete's resistance to sulphate attack is excellent. Even after exposure of these specimens for up to 90 days to sodium sulphate solution, there is no damage to the surface. The compressive strength loss was between 7% to 38% when exposed to sodium sulphate.

Kumaravel S et al (2013) investigated the resistance of geopolymer concrete to sulphates. The cylinders are prepared with different concentration of

12M, and 14 Mole of NaOH. Geopolymer concrete was tested with different concentration of NaOH for sulphate resistance. When compared to initial weight, there were increase of of 6%, 7%, 4% and 10% in specimen of 8M, 10M, 12M and 14M respectively. The compressive strength of GPC specimens immersed in Na_2SO_4 about 90 days is reduced. The 8M, 10M, 12M, and 14 Mole specimens show reduction in strength of 11%, 16%, 10% and 18% respectively with respect to control specimen. From this, it is found that salt resistance of geopolymer concrete made from 12M NaOH concentration showed the least reduction in weight and strength when compared to 8M, 10M and 14M NaOH concentration used for GPC.

There was a investigation conducted to study the effects of aggressive chemical environment on durability of GPC by Neetu Singh et al (2013). The test result established that the GPC (heat cured fly ash based) has excellent resistance to sulphate attack. Even after exposure up to 90 days, there is no major reduction in mass and the compressive strength. When exposed to sulphate salt for various periods up to 90 days, the decreased in GPC is lesser compared to OPC which confirmed its significant resistance to sulphate attack.

IV. RESISTANCE TO CHLORIDE:

Fly ash based GPC were subjected to severe environmental conditions using chloride in an experimental investigation conducted by Bhagia Maria Joshy et al. (2014). The test established that this GPC has excellent resistance to chloride attack. There was no damage to the surface of the test specimen after exposing it up to 90 days to sodium chloride solutions. There is no significant change in the mass and the compressive strength of test specimens after an exposure period of 90 days. This result proves that GPC is best in sea water area. When compared to OPC, this GPC has excellent mechanical properties and durability. Due to its excellent compressive strength, this GPC is suitable for structural application. The compressive strength loss between 8% to 41% when this GPC were exposed to sodium chloride.

V. RESISTANCE TO ACID:

The resistance to geopolymer concrete to sulphuric acid was investigated by Kumaravel S et al (2013) by immersing into solution for 90 days. The solution was kept at room temperature and regular stirring was done. In order to maintain the concentration of the solution throught the test period, regular replacement is done. When acid concentration increases, the weight of GPC decreases. Even after 90 days of immersion in acid, same effect is reflected.

The durability of GPC against aggressive chemical environment was investigated by Neetu Singh et al (2013). When tested with suphuric acid attack, there was degradation in the compressive strength. The extent degradation is based on two main factors namely the concentration of acid solution and the duration of exposure. But, when compared with resistance of Portland cement concrete against sullphuric acid attack, the performance of GPC is much better. When exposed to suphuric acid attack, GPC cubes undergo only erosion of surface whereas deposition of white layer of gypsum crystals happened on the acid exposed surface of OPC specimen. The lower calcium content in the source material of GPC concrete is main possible factor for its better performance compared to OPC concrete when exposed to sulphuric acid attack, The calcium content in OPC concrete is much higher due to lime being one of source material. Hence it is well established by this study this study that GPC concrete has excellent mechanical properties and durability against aggressive environment compared to OPC concrete.

There was a study by Suresh Thokchom et al.(2009) on resistance of fly ash based Geopolymer mortars in sulphuric acid. The program was to immerse for 18 weeks period in 10% sulphuric acid solution. The samples of Geopolymer mortars having Na_2O ranging from 5% to 8% selected for this study. The evaluation of resistance is on the following namely 1. Residual alkalinity 2. Effect on compressive strength 3. Changes in weight 4. Visual appearance. The evaluation was carried out at regular intervals during study period, it was observed that there is very low weight loss (0.41% to 1.23%) and the higher weight loss happened on samples having higher percentage of Na_2O The samples almost lost alkalinity. The loss of compressive strength was 28% when Na2O at 8% and 52% when Na2O at 5%. So it is established that geopolymer mortars has better durability and excellent mechanical properties under sulphuric acid environment.

VI. CONCLUSIONS

When compared to OPC, this GPC has excellent mechanical properties and durability. Due to its excellent compressive strength, this GPC is suitable for structural application. Geopolymer concrete has no visible signs of surface deterioration, formation of pores on the surface and spalling of concrete after immersion in aggressive solution for 30,60 and 90 days of exposure. The better performance of GPC than that of OPC in acidic environment might be attributed to the lower calcium content of the source material. The heat-cured fly ash based Geopolymer concrete has an excellent resistance to sulfate attack. There is no damage to the surface of test specimens after exposure to sodium sulfate solution up to 90 days. Heat cured GPC has an better resistance to chloride attack. Which is proved that GPC best in sea water area. The compressive strength loss between 8% to 41% when this GPC were exposed to sodium chloride. . The compressive strength loss between 7% to 38% when this GPC were exposed to sodium sulphate.

It can thus be concluded that Geopolymer concrete possesses excellent mechanical properties and durability for aggressive environment compare to OPC.

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