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A Study on Performance of Geopolymer Concrete

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Abstract: The major problem that the world facing today is global warming the cement industry is one of the major reasons for emission of greenhouse gases, such as CO_2 which causes global warming. A lot of energy and natural resources are consumed in production of Ordinary Portland cement (OPC). Geopolymer concrete (GPC) is one of the processes that reduces cement usage and increases the usage of industrial by-products in concrete. In the present study, OPC is fully replaced by pozzolanic materials and alkaline liquids such as Sodium hydroxide (NaOH) and Sodium silicate (Na_2Sio_3) to produce the Geopolymer concrete. The present investigation is to study the effect of pozzolanic materials and concentration of NaOH. The experimental programme is divided into two phases. In Phase-1, two mixes were taken one is Fly ash based GPC and other is GGBS based GPC with 10M concentration and out of these two mixes the optimum mix GGBS based GPC is taken for further study. In Phase-2 the mix GGBS based GPC is considered and concentration of NaOH is varied (i.e. 6M, 8M, 10M, 12M and 14M) to study the compressive strength. The test specimens prepared were concrete cubes of size 100×100×100 mm and cured under sunlight. The GPC specimens were tested for their compressive strength at the ages of 7, 14, 28 and 56 days. The sorptivity and XRD analysis were also carried out after 28 days of curing. The results show that the GGBS based GPC specimens gives higher compressive strength and lesser sorptivity than the Fly ash based GPC in phase-1 study and in phase-2 with the increase in concentration of NaOH the compressive strength increased and sorptivity value decreased. The XRD analysis also carried out to study the minerals of GPC.

Keywords: Ordinary Portland cement (OPC), Geopolymer concrete (GPC), GGBS, XRD Analysis.

I. INTRODUCTION

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO_2 emission caused due to cement industries. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous [1]. Any material that contains mostly silicon (Si) and aluminum (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Metakaolin or calcined Kaolin, low calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined minerals and non-calcined minerals, combination of fly ash and metakolin, combination of granulated blast furnace slag and metakaolin have been studied as source materials[2]. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate. In the past few decades, it has emerged as one of the possible alternatives to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. The temperature during curing is very important, and depending upon the source materials and activating solution, heat often must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature [3]. 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 as shown in Fig.1.

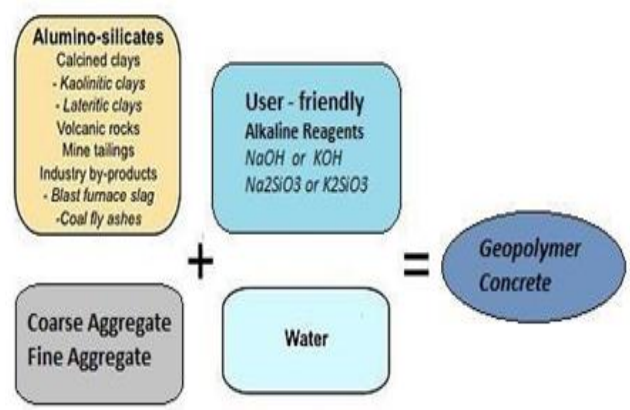

Fig.1. Geopolymer concrete.

A. Necessity of Geopolymer Concrete

Concrete is one of the widely used materials all over the world. Ordinary Portland cement (OPC) is used as the primary binder to produce the concrete. The demand of concrete is increasing day by day for the need of development of infrastructure facilities. However, it is well known 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. Environmental pollution is the biggest menace to the human race on this planet today. It means adding impurity to environmental. It has a severe effect on the ecosystem. There are many reasons which cause pollution. In our construction industry, cement is the main ingredient/ material for the concrete production. But the production of cement means the production of pollution because of the emission of CO_2 during its production [4]. There are two different sources of CO_2 emission during cement production. Combustion of fossil fuels to operate the rotary kiln is the largest source and other one is the chemical process of calcining limestone into lime in the cement kiln also produces CO_2. In India about 2,069,738 thousand of metric ton of CO_2 are emitted in the year of 2010. The cement industry contributes about 5% of total global carbon dioxide emissions [5]. And also, the cement is manufactured by using the raw materials such as limestone, clay and other minerals. Quarrying of these raw materials is also causing environmental degradation. To produce a ton of cement, about 1.6 tons of raw materials are required and the time taken to form the limestone is much longer than the rate at which humans use it. On the other side the demand of concrete is increasing day by day for its ease of preparing and fabricating in all sorts of convenient shapes. So, to overcome this problem, the concrete to be used should be environmental friendly. To produce environmentally friendly concrete, we have to replace the cement with the industrial byproducts such as fly-ash, GGBS (Ground granulated blast furnace slag) etc. In this respect, the new technology geopolymer concrete is a promising technique.

II. PAST RESEARCH ON GEOPOLYMER MATERIAL

In geopolymers, the polymerization process involves a chemical reaction under highly alkaline conditions on Al-Si minerals, yielding polymeric Si-O-Al-O bonds as proposed by Davidovits the chemical composition of geopolymers is similar to zeolite, but shows an amorphous microstructure. The structural model of geopolymer material is still under investigation; hence the exact mechanism by which geopolymer setting and hardening occur is not yet clear. The mechanism of geopolymerization may consist of dissolution, transportation or orientation, and polycon densation, and takes place through an exothermic process. The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as met akaolin (calcined kaolin), fly ash, slag etc., yield higher compressive strength when compared to those synthesized from non-calcined materials, such as kaolin clay. The source material used for geopolymerization can be a single material or a combination of several types of materials. A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator, with the activator liquid-to-source material ratio by mass in the range of 0.25-0.30. Because heat is a reaction accelerator, curing of fresh geopolymer is carried out mostly at an elevated temperature. When curing at elevated temperatures, care must be taken to minimize the loss of water. However, curing at room temperature has successfully been carried out by using calcined source material of pure geological origin, such as metakaoli. The geopolymer material can be used in various applications, such as fire and heat resistant fibre composites, sealants, concretes, ceramics, etc., depending on the chemical composition of the source materials and the activators. Davidovits suggested that the atomic ratio of Si-to-Al of about 2 for making cement and concrete. Geopolymer can also be used as waste encapsulation to immobilize toxic metals.

A. Fly Ash-Based Geopolymer Concrete

In the authors' experimental work, geopolymer is used as the binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, the aggregates occupy the largest volume, i.e. about 75-80 % by mass, in geopolymer concrete. The silicon and the aluminum in the low-calcium fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials.

III. REVIEW OF LITERATURES

A. Introduction

In carrying out the project work various codes, journals, books etc. are referred. A comprehensive literature survey on various aspects of Geopolymer Concrete (GPC) has been provided to understand the nature of GPC from engineering application's point of view, so that, a rational technical plan for development of GPC with given alumina-silicate sources can be formulated. The science of GP has not yet reached the stage where GPC mix can be made by user by just adding water as it has happened in the case of Portland cement technology. However, enough qualitative information is available on the mechanical strength so that, GPC mixes can be developed to achieve the desired level of strength for use in structures. Literature review done on this topic is briefly presented below.

B. Literature Reviewed

N A Lloyd et al., [1] studied the Geopolymer concrete with Fly ash, to produce the Geopolymer concrete the Portland cement is fully replaced with fly ash. Test data are used to identify the effects of salient factors that influence the properties of the geopolymer concrete and to propose a simple method for the design of geopolymer concrete mixtures. Test data on various short-term and long-term properties of the geopolymer concrete and the results of the tests conducted by large-scale reinforced geopolymer concrete member's show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments. A simple method to design geopolymer concrete mixtures has been described and illustrated by an example. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined. To ensure further uptake of geopolymer technology within the concrete industry, research is needed in the critical area of durability. Current research is focusing on the durability of geopolymer in aggressive soil conditions and marine environments.

V.Supraja et al., [2] has done Experimental study on Geopolymer concrete incorporating GGBS, to produce the Geopolymer concrete the Portland cement is fully replaced by GGBS and alkaline liquids that are NaOH and Na_2Sio_3 are used for the binding of materials. Using different molars of sodium hydroxide solution, i.e. 3M, 5M, and 7M and 9M are taken to prepare different mixes. Two different curing are carried, i.e. oven curing at 500^{o}c and curing directly by placing the specimens to direct sunlight. The result shows that there is no significant increase in the strength of oven cured specimens after 3 days of oven curing and the strength of Geopolymer concrete is increasing with the increase of the molarity of sodium hydroxide. They concluded that the compressive strength is increased with the increase in the molars of sodium hydroxide. After 3 days of curing the increase in the compressive strength is not significant and compared to hot air oven curing and curing by direct sunlight, oven cured specimens gives higher compressive strength but sun light curing is convenient for practical conditions.

Kolli Ramujee et al., [3] studied the development of Low Calcium Fly ash Based Geopolymer Concrete. The Portland cement is fully replaced with Fly ash and alkaline solutions that are (NaOH and Na_2Sio_3) are used to make geopolymer paste which binds the aggregates to form geopolymer concrete. The author also made an attempt to develop the mix design for Geopolymer concrete in medium grade and relative comparison has been made with equivalent mix proportions of the grade of OPC Concrete in both heat cured and ambient cured conditions. About 7 different mixes for each grade is cast, tested and optimized. The design parameters like alkaline liquid to fly ash ratio and water to the Geopolymer solids ratio were proposed to develop the Geopolymer concrete of standard grade. From the investigation, it is clear that the water/binder ratio 0.21and Alkaline liquid to fly ash ratio of 0.40 are suggested for G40 which indicates improvement in compressive strength of geopolymer concrete can be achieved by decreasing water binder ratio. The compressive strength attained at 28 days for GPC under ambient curing is almost equal to compressive strength achieved by Geopolymer concrete at 7 days. Because of the slow reactivity of fly ash at ambient temperature, considerable heat must be applied to increase the Geopolymerization process. The increase in concentration of NaOH results in an increase of compressive strength and it is recommended 16M concentrations for medium grade.

More Pratap Kishanrao et al., (2013) [4] had conducted the tests on the design of geopolymer concrete. This study is continuing, to investigate the behavior of such geopolymer concrete under high temperatures ranging from 100^{o}C to 500^{o}C. Cubes of size 100mm × 100mm × 100mm are tested for their residual compressive strengths after subjecting them to these high temperatures. In the present investigation, Class-F fly ash and blast furnace slag are used in equal proportion (50% each) as cementitous materials for the preparation of GPC mixes. A mixture of analytical grade Sodium hydroxide and Sodium silicate solution is used in the present investigation as the catalytic liquid. The effect of exposure to any particular elevated temperatures in terms of reduction in the compressive strength of the mix, compared to the strength of the same mix at room temperature is quantified in terms of a Residual Compressive Strength Coefficient. The results showed that the compressive strength and weight are lost after exposed to elevated temperature. The behavior of the residual compressive strength of Geopolymer concrete cubes after exposure to various elevated temperatures decreases. They concluded that the geopolymer concrete gains about 60-70% of the total compressive strength within 7 days. The behavior of the residual compressive strength of Geopolymer concrete cubes after exposure to various elevated temperatures tested at normal room temperature and while further increment of temperature, there is a loss in compressive strength graded.

Mohd Mustafa Al Bakri Abdullah et al., [5] has studied on Fly Ash-based geopolymer lightweight concrete using foaming agent and by this he reports the results of his investigation on the possibility of producing foam concrete by using a geopolymer system. Class C fly ash was mixed with an alkaline activator solution (a mixture of sodium silicate and NaOH), and foam, was added to the geopolymer mixture to produce lightweight concrete. The reactive were mixed to produce a homogeneous mixture, which was placed into a 50 mm mould and cured at two different curing temperatures (60°C and room temperature), for 24 hours. After the curing process, the strengths of the samples were tested on 1, 7, and 28 days. The water absorption, porosity, chemical composition, microstructure, XRD and FTIR analyses were studied. The results showed that the sample which was cured at 60°C (LW2) produced the maximum compressive strength for all tests. Also, the water absorption and porosity of LW2 were reduced by 6.78% and 1.22% after 28 days, respectively. The SEM showed that the LW2 sample had a denser matrix than LW1 (room temperature). This was because LW2 was heat cured, which caused the geopolymerization rate to increase, producing a denser matrix. However for LW1, micro cracks were present on the surface, which reduced the compressive strength and increased water absorption and porosity. Finally the conclusions are made that the specimens which are heat cured (temperature at 60^{o}C) showed better results than the specimens cured at room temperature and when the porosity and water absorption decreases the compressive strength increases.

Prakash R. Vora et al., (2013) [6] conducted the studies on Parametric Studies on compressive strength of Geopolymer Concrete by casting 20 geopolymer concrete mixes to evaluate the effect of various parameters affecting its compressive strength in order to enhance its overall performance. Various parameters i.e. ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, curing temperature, dosage of super plasticiser, rest period and additional water content in the mix have been investigated. Two concrete mixes Mix-1 and Mix-2 with the alkaline liquid to fly ash ratio 0.35 and 0.4 have been cast using the ingredients. The effect of alkaline liquid to fly ash ratio by mass on compressive strength of concrete at age 3 days has been evaluated by comparing results of both mixes. The test specimens have been cured for 48 hours at 750^{o}C in an oven. The effect of addition of super plasticiser on compressive strength of concrete has been observed by comparing results of Mix-5. Concrete mixes 5 have been cast using 2%, 3% and 4% dosage of admixture, respectively. Their results shows that compressive strength increases with increase in the curing time, curing temperature, rest period, concentration of sodium hydroxide solution and decreases with increase in the ratio of water to geopolymer solids by mass & admixture dosage, respectively. They concluded that the wide variety of parameters affect the compressive strength of the geopolymer concrete. Therefore, parametric study of various factors affecting the compressive strength of the geopolymer concrete is strongly recommended first before conducting any further investigations related to mechanical properties and durability of the geopolymer concrete in order to get the desirable benefits from the further investigations.

Shankar H. Sanni et al., (2012) [7] conducted study on performance of geopolymer concrete under severe environmental conditions by considering M-30, M-40, M-50 and M-60, the mixes were designed for molarity of 8M and 12M. The alkaline solution used for present study is the combination of sodium silicate and sodium hydroxide solution with the ratio of 2.50 and 3.50. The test specimens were 150mm×150mm×150mm cubes, 100mm×200mm cylinders heat-cured at 60°C in an oven. The GPC have inorganic polymer of alumina-silicates as the binder whereas the conventional concretes have Portland cement (P-C) generated C-S-H gel. Durability of specimens were assessed by immersing GPC specimens in 10% sulphuric acid and 10% magnesium sulphate solutions separately, periodically monitoring surface deterioration and depth of de-alkalization, changes in weight and strength over a period of 15, 30 and 45 days. There is a slight mass gain during first week of exposure due to mass of solution absorbed by concrete. The mass loss on exposure to sulphuric acid in GPC was about 3%, where as in PPCC it was observed to be 20% to 25% for 45 days of exposure. The increase in mass of specimens soaked in magnesium sulphate solution was approximately 1.2% for cubes 1.5% for cylinder after 45 days of exposure; it has been observed that there was a decrease in mass loss in normal concrete specimen up to 1%. Their result shows that the heat-cured fly ash-based geopolymer concrete has an excellent resistance to acid and sulphate attack when compared to conventional concrete. They concluded that the GPC do not have Portland cement, they can be considered as less energy intensive, since Portland cement is highly intensive energy material next only to Steel and Aluminium. Compressive strength loss for the specimens exposed in sulphuric acid was in the range of 10% to 40% in PPCC, where as it was about 7% to 23% in GPCs.

Daniel L Y Kong et al., (2010) [8] conducted a study on effect of elevated temperatures on geopolymer paste, mortar and concrete made using fly ash as a precursor. The geopolymer was synthesized with sodium silicate and potassium hydroxide solutions. Various experimental parameters have been examined such as specimen sizing, aggregate sizing, aggregate type and super plasticizer type. The study identifies specimen size and aggregate size as the two main factors that govern geopolymer behavior at elevated temperatures (800°C). Aggregate sizes larger than 10mm resulted in good strength performances in both ambient and elevated temperatures. Strength loss in geopolymer concrete at elevated temperatures is attributed to the thermal mismatch between the geopolymer matrix and the aggregates. A minimum of six specimens (100mm×200mm) cylinders for each type were tested for 3 days compressive strength after casting. However it is found that the paste specimens underwent 73.4% strength loss after elevated temperature exposures. Paste specimens cast into 25mm×25mm×25mm cube moulds recorded a 6.4% strength gain. The results show that the elevated temperature strength is dependent on the size of the geopolymer paste specimens. The size of the aggregates is an important factor in determining the geopolymer concrete behavior under elevated temperatures. They concluded that the smaller sized aggregates (<10 mm) promote spalling and extensive cracking in the geopolymer concrete while geopolymer concretes containing larger aggregates (>10 mm) are more stable in elevated temperatures. The rate of expansion of the aggregate with temperature is an influential factor in the performance of geopolymer concrete under elevated temperatures.

Ganapati Naidu et al., [9] studied on Strength Properties of Geopolymer Concrete with addition of GGBS. In this study an attempt is made to study the strength properties of geopolymer concrete using low calcium fly ash replacing with slag in 5 different percentages. Sodium silicate and sodium hydroxide of 8 molarities of solutions were used as alkalis in all 5 different mixes. With maximum (28.57%) replacement of fly ash with slag (Mix No. 5), achieved a maximum compressive strength for 28 days. The same mix (Mix No. 5) is shown 43.56 MPa after exposure of 500°C for 2 hours. By the study they concluded that for higher concentrations of GGBS result in higher compressive strength of geopolymer concrete. Mixing of GGBS was tested up to 28.57%, beyond that immediate setting was observed. Compressive strength of geopolymer concrete increases with increase in percentage of replacement of fly ash with GGBS fly ash was replaced by GGBS up to 28.57%, beyond that fast setting was observed. A maximum of 25% loss in compressive strength was observed when geopolymer concrete exposed to a temperature of 500°C for two hours and 90% of compressive strength was achieved in 14 days. Based on the study they concluded that the percentage of GGBS increases the compressive strength increases and initial setting time decreases. So, the average density of geopolymer concrete was equal to that of OPC concrete.

Mr. Bennet Jose Mathew et al., [10] conducted study on the Strength, Economic and Sustainability Characteristics of Coal ash - GGBS based GPC. GPC is manufactured using industrial waste like fly ash, GGBS is considered as a more eco-friendly alternative to OPC based concrete. The feasibility of production of geopolymer concrete using coarser bottom ash is evaluated in this study. Additionally, the effect of replacement of fly ash with bottom ash at varying percentage on strength of Geopolymer concrete is also studied. The effect of curing methodology on strength of fly-ash - GGBS based geopolymer concrete has also been evaluated. Economic impact and sustainability studies were conducted on both OPC based concrete and geopolymer concrete. By this study the conclusions are made that the bottom ash – GGBS based geopolymer concrete gives very low strength probably due to large particle size, geopolymer concrete can be prepared at comparable cost with OPC based concrete provided transportation system for raw materials is well established and the embodied energy of fly ash- GGBS based geopolymer concrete is 40% less than that of OPC based concrete. They also concluded that the Sodium hydroxide (39%) and sodium silicate (49%) together contributes a lion's share to embodied energy of geopolymer concrete while in OPC cement contributes nearly 94% of the total embodied energy.

S.V.A. Silva et al., [11] studied on the development of fly ash based geopolymer concrete. For this the experimental investigation carried out to develop geopolymer concrete based on alkali activated fly ash by Sodium Hydroxide with Sodium Silicate. Effects of the factors such as method of curing and concentration of NaOH on compressive strength as well as the optimum mix proportion of geopolymer paste, mortar and concrete were investigated. The specimens of the geopolymer paste and mortar are tested for compressive strength respectively after 7 days of casting when cured for 5 hours at 800°C. By the results they indicated that the increase of water content of all three forms of geopolymer resulted in decrease of the compressive strength. Strength development of geopolymer at room temperature was also studied and found that only half of the compressive strength of the heat cured sample was achievable even after 28 days. Fly ash based geopolymer mortar solid block and a concrete interlocking paving block were developed using the optimum mix proportions obtained. The conclusions are made that there was a rapid strength development during first 3 days of heat cured geopolymer samples. The time taken for the strength gain in ambient cured samples was much higher than that of the heat cured samples. That was may be due to the slow speed of polymerization at low temperatures and fly ash based geopolymer concrete can be efficiently used to manufacture relatively high strength interlocking paving blocks.

Malathi V et al., (2012) [12] conducted a study on the strength of fly ash based geopolymer concrete under heat curing by using two kinds of systems which were considered by using 100% replacement of cement by ASTM class F Fly ash. The beams were made with geopolymer concrete having compressive strength in the range of M20 - M35 by heat curing. The ratio between sodium hydroxide and sodium silicate solution is 1:2.5. The specimen was cured at 60°C for 24 hrs. The compressive strength test was performed after the curing period and strain was also measured using LVDT. An empirical formula is derived for fly ash based geopolymer concrete using the results from this work. The compressive strength of test cylinder size 300mm×150mm diameter was measured for GPC after 24 hrs heat curing at 60°C. Eight beams of beam 100mm×100mm×500mm were cast. The beams were tested at two points loading. For each mixture four 100×300mm concrete cylinders were made. Four of these cylinders were used to determine the elastic modulus and poisons ratio. Four other cylinders were tested to determine the average compressive strength. Their results shows that there was increase in load carrying capacity of beam for increase in grades and the compressive strength of fly ash based geopolymer concrete is high as in the case of Portland cement concrete. They concluded that modulus elasticity of GPC with compressive strength in the range of 20 to 35 Mpa were similar to those of OPC concrete and the poisons ratio of GPC with compressive strength in the range of 20 to 35 Mpa falls between 0.19 and 0.22 which are similar to that of OPC concrete.

IV. RESULTS AND DISCUSSIONS

With the genetic information available on geopolymer, a rigorous trial-and-error method was adopted to develop a process of manufacturing geopolymer concrete following the technology currently used to manufacture Ordinary Portland Cement concrete. Many trails are done using different materials like Rice husk ash, Metakaoline, Fly ash, GGBS 3.5 mm, and GGBS 90 micron to react with the alkaline solution in geopolymer concrete. After some failures in the beginning, the trail-and-error method yielded successful results with regard to manufacture of GGBS based geopolymer concrete and Fly ash based geopolymer concrete. Rice husk ash, metakaoline and 3.5 mm GGBS are used for trial mixes which are light in weight and absorbing more water and not achieving the strength compared to the Fly ash based geopolymer concrete. Geopolymer concrete doesn't require water curing as it is giving good strength when it is cured in sunlight (Ambient curing). When the GGBS of size 3.5 micron based geopolymer concrete hasn't given the minimum strength as it has no workability and GGBS has the properties similar to sand and its microstructure is week compared to 75 micron GGBS. The decrease in water content favors the formation of Geopolymerization process, which demands for increase of concentration of Sodium hydroxide and sodium silicates

A. Sorptivity Test

Phase-1 Sorptivity Test: The sorptivity test of GPC by varying the source material which is rich in silica as shown in Fig.2.

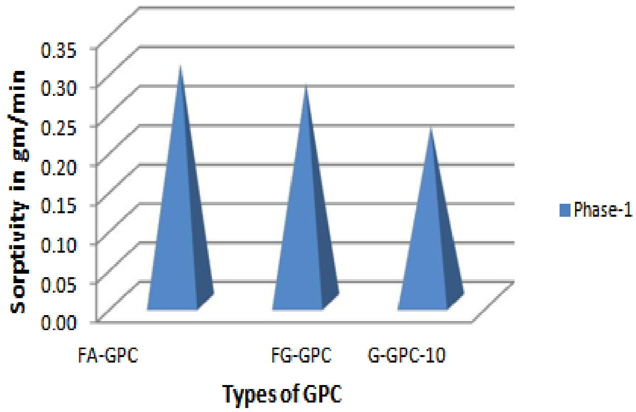

Fig.2. Phase-1 Sorptivity test results.

Geopolymer concrete specimens G-GPC-10 manufactured with 100% GGBS resulted in lesser values of sorptivity when compared to the 100% Fly ash and 50% Fly ash + 50% GGBS based geopolymer concrete as in the case of FA-GPC and FG-GPC specimens respectively. This may be attributed to the fact that alkali content in the mix gives better reactivity with the GGBS resulting in denser microstructure. FA-GPC specimen recorded 0.30 mm/min$^{0.5}$ sorptivity whereas specimens of G-GPC-10 showed comparatively lower corresponding values of 0.23 mm/min$^{0.5}$ respectively. Formation of microstructure in G-GPC10 is better than the FA-GPC due to the crystalline structure of GGBS reacting with alkaline solution, which reducing the Sorptivity.

Phase-2 Sorptivity Test: The sorptivity test of GGBS based GPC by varying the with Molarity of Sodium Hydroxide as shown in Fig.3.

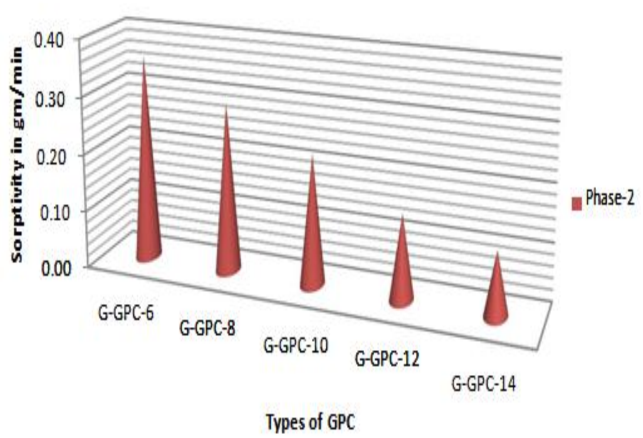

Fig.3. Phase-2 Sorptivity test results.

Geopolymer concrete specimens G-GPC-14 manufactured with 14 Molar of NaOH resulted in lesser values of sorptivity when compared to the 12, 10, 8 and 6 Molars of NaOH, as in the case of G-GPC-12, G-GPC-10, G-GPC-8 and G-GPC-6 specimens respectively. This may be attributed to the fact that higher molar NaOH content in alkaline solution of the mix gives better reactivity with the GGBS resulting in denser microstructure. G-GPC-14 specimen recorded 0.11 mm/min$^{0.5}$ sorptivity whereas specimens of G-GPC-12, G-GPC-10, G-GPC-8 and G-GPC-6 showed comparatively higher corresponding values of 0.36, 0.29, 0.23 and 0.15 mm/min$^{0.5}$ respectively. Compressive strength after 28 days was found maximum for G-GPC-14 specimen who contained 14 M NaOH. When the sorptivity decreases the strength increases due to the increase in crystalline structure.

B. Compressive Strength

Phase-1 Compressive Strength:

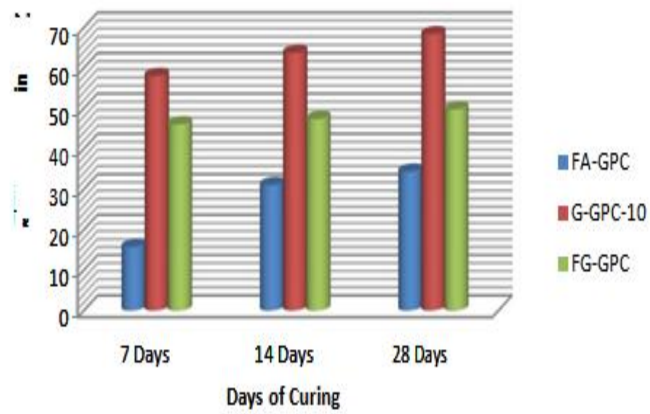

Fig.4. Phase-1 compressive strength results.

From the graph we can observe that there is a gradual increase in G-GPC-10 with the age and it gives the higher strength than the FA-GPC and FG-GPC as shown in Fig.4. Initial setting time of Fly ash based GPC is slower than the GGBS based GPC which attaining higher strength. The fly ash GPC is slower in drying as it takes a minimum of 48 hours to get de-mould. Water consumption of GGBS based GPC is little more than the Fly ash GPC. When the molarity of concentration, increased the workability of the concrete is increasing.

Phase-2 Compressive Strength:

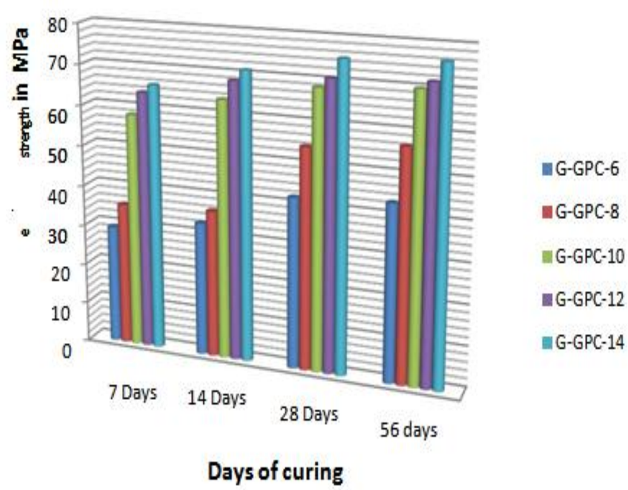

Fig.5. Phase-2 compressive strength results.

We observed that the compressive strength is increased with the increase in the molarity of sodium hydroxide as shown in Fig.5. From the Fig.6 it is clear that after G-GPC-10 the rate of increase in the strength is decreased and that may not exceed more than the G-GPC-14. So, 10M, 12M can be the optimum strengths that can be considered.

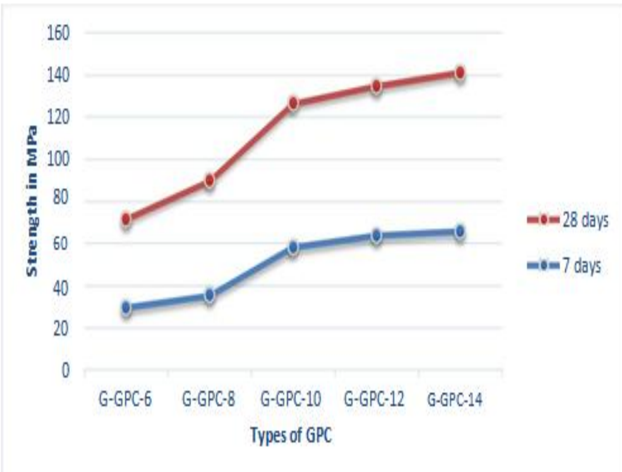

Fig.6. Phase-2 Rate of Increase in Strength.

C. X-ray Diffraction

The result of an X-Ray diffraction study of the GPC is shown the following Figs.7 and 8.

Phase-1 Comparisons of Chemical Compounds:

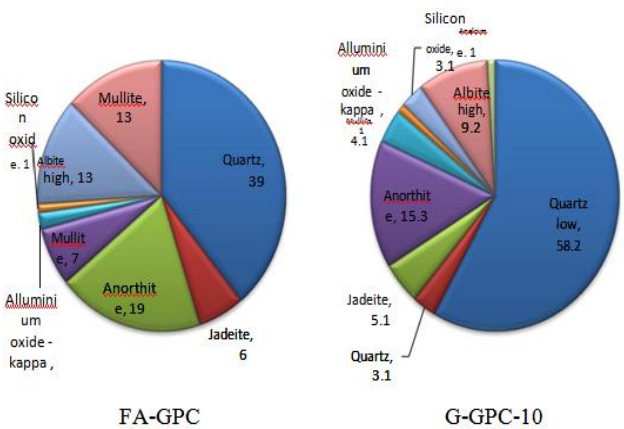

Fig.7. Phase-1 Contents of compounds in Pie Chart.

The G-GPC specimen's exhibit peaks of Quartz. Peaks of Silicon Oxide are also observed. In the above Pie chart the Quartz and Silicon oxide are in higher contents GGBS based GPC than the FLY Ash based GPC. The mix G-GPC-10 containing Quartz and Silicon Oxide higher, than the FA-GPC, which helped in strengthening the concrete Analcime is an extra compound that found in the G-GPC-10, which also increases the strength of the concrete.

Phase-2 Comparisons of Chemical Compounds: XRD analysis of the G-GPC's Specimen showed the presence of Quartz, Analcime, Anorthite, Mullite, Jadeite and Albite The G-GPC specimen exhibits peaks of syngenite. Peaks of Thenardite are also observed. Thenardite occurred due to reaction between Na ions form the NaOH solution with sulfate ions leading to the formation of sodium sulfate decahydrate. The presence of the Anorthite phase indicates that calcium from the aggregate is reacting with the sodium silicate along with the alumina silicate forming Anorthite and Albite. Albite can be associated with the strength enhancement region of the geopolymer matrix. Thenordite is a compound which de-hydrates the material and resists the water absorption; it is also proved practically by the sorptivity test.

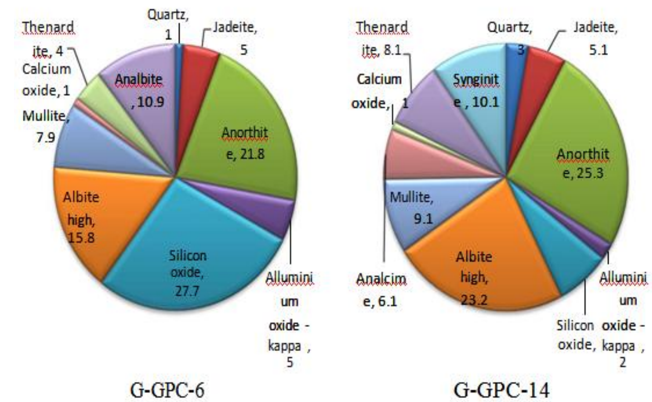

Fig.8. Phase-2 Contents of compounds in Pie Chart.

V. CONCLUSION

Based on limited experimental investigations of geopolymer concrete, the following conclusions are made regarding the resistance of Geopolymer concrete:

- The compressive strength attained by GGBS based Geopolymer concrete is more than the Fly ash based Geopolymer concrete.
- The Sorptivity and XRD analysis proves that GGBS based GPC absorbs less water due to its crystalline structure.
- The reaction of GGBS in geopolymer concrete with alkaline solution attains higher strength and less sorptivity confirms GGBS is the best suitable material in Geopolymer concrete compared to fly ash.
- The increase in molarity of NaOH leads to less voids and good crystalline structure that result in less water absorption.
- NaOH plays a major role in attaining the strength of the concrete; hence it is recommended 10M concentrations for medium grade.
- The rate of increase in strength after 10 Molar concentrations is decreased so, considering 10M and 12M as the optimum dosage for GPC mix.
- Based on the molar concentration the grades of concrete can be designed and implemented in construction.
- The geopolymer concrete can be innovative supplementary to OPC in construction material but judicious decisions are to be taken by engineers.

VI. REFERENCES

[1] N A Lloyd and B V Rangan., Geopolymer Concrete with Fly Ash, Second International Conference on Sustainable

Construction Materials and Technologies Volume 3, 2010, pp. 1493-1504.

[2] V. Supraja, M. Kanta Rao., Experimental study on Geo-Polymer concrete incorporating GGBS, International Journal of Electronics, Communication & Soft Computing Science and Engineering ISSN: 2277-9477, Volume2, Issue 2.

[3] Kolli Ramujee and M. Potharaju., Development of Low Calcium Flyash Based Geopolymer Concrete, IACSIT International Journal of Engineering and Technology, Vol. 6, No. 1, February 2014.

[4] More Pratap Kishanrao., Design of Geopolymer Concrete, International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 5, May 2013

[5] Prakash R. Voraa, Urmil V. Daveb., Parametric Studies on Compressive Strength of Geopolymer Concrete, Science direct Procedia Engineering 51 (2013) 210 – 219

[6] Mohd Mustafa Al Bakri Abdullah, Kamarudin Hussin, Mohamed Bnhussain, Khairul Nizar Ismail, Zarina Yahya and Rafiza Abdul Razak., Fly Ash-based Geopolymer Lightweight Concrete Using Foaming Agent, Int. J. Mol. Sci. 2012, 2013, 7186-7198; doi:10.3390/ijms13067186.

[7] Shankar H. Sanni, Khadiranaikar, R. B., "Performance of geopolymer concrete under severe environmental conditions", International Journal of Civil and Structural Engineering, Volume 3, No 2, 2012.

[8] Prof.M.A.Bhosale, Prof.N.N.Shinde., Geopolymer Concrete by Using Fly Ash in Construction, IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN : 2278-1684 Volume 1, Issue 3 (July-August 2012), PP 25-30.

[9] Muhammad Aamer Rafique Bhutta, Ph.D., Warid M. Hussin, Ph.D., Mohd Azreen, Ph.D., and Mahmood Mohd Tahir, Ph.D., Sulphate Resistance of Geopolymer Concrete Prepared from Blended Waste Fuel Ash, ASCE.

[10] Ganapati Naidu. P, A.S.S.N. Prasad, S. Adiseshu, P.V.V. Satayanarayana., A Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S, International Journal of Engineering Research and Development eISSN : 2278-067X, pISSN : 2278-800X.

[11] Mr. Bennet Jose Mathew, Mr. M Sudhakar, Dr. C Natarajan., "Strength, Economic and Sustainability Characteristics of Coal Ash–GGBS Based Geopolymer Concrete", International Journal of Computational Engineering Research (ijceronline.com) Vol.3 Issue. 1.

[12]. Daniel L.Y. Kong a, Jay G. Sanjayan., "Effect of elevated temperatures on geopolymer paste, mortar and concrete", Cement and Concrete Research 40 (2010) 334–339.