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A Brief Analysis of Geopolymer concrete: A New type of Eco-friendly Construction Material for Future

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Abstract - **The requirement of concrete does not terminate for construction industries as well as human beings. Mainly the production of concrete is the primary need for all kind of construction works. At the same time, the availability of raw materials which are used to make concrete keeps on depleting. In order to eradicate the scarcity of natural resources, the alternate binders like Geopolymer concrete play vital role to replace the conventional concrete. The Geopolymer concrete is an inorganic polymer of alumino-silicates which are activated by the alkaline solution. This paper has thoroughly reviewed the performance of Geopolymer concrete and those properties were compared with the Ordinary Portland Cement Concrete. The compressive strength of Geopolymer concrete for different curing condition, concentration of the alkaline solution, alkaline solution to binder ratio, etc. has been discussed. The microstructural and durability studies were also incorporated in this paper which was summarized from the previous research works.**

keywords - **Geopolymer, Alkaline solution, Colloidal Nano silica, Phase changing materials, Ferrogeopolymer, Mechanical properties, Durability, and Microstructural properties.**

I. INTRODUCTION

Concrete is the dominant heterogeneous mixture which is second consumed material in worldwide next to the water. Many of the research work is going on to generate new eco-friendly concrete to minimize the production of traditional concrete by altering their profile. Because of the manufacture of Ordinary Portland Cement, it liberates around 13,000 million tons of CO_2 to the atmosphere that is almost equal to 7% of the greenhouse gases as an annual record [1-2]. Also this cement production, it consumes approximately 1.5 tonnes of natural resources as well as requires an enormous amount of energy of 1700-1800 MJ [3]. The emerging technique to solve this problem is the invention of Geopolymer concrete. The term Geopolymer was initially found by Davidovits to explain the formation of alkali-activated Silica-Oxygen-Alumina-Oxygen bond. This framework has been developed from the Geopolymerization mechanism. The Geopolymerization mechanism consists of dissolution of aluminum and silicon in the alkaline solution and transportation of these species which framing like a three-dimensional network of alumino-silicates called Geopolymer [4]. This complete reaction process takes place with the presence of heat [5]. There are so many factors which influence the mechanical and microstructural properties of fly ash based Geopolymer concrete [6]. Few of these factors are sodium hydroxide or potassium hydroxide concentration, the particle size of source materials, curing method and an alkaline solution to binder ratio, etc. [7-8].

Numerous research works are mainly focused on the effect of curing temperature on the strength properties of Geopolymer concrete. Because the temperature maintained while in the curing process which only ignites the aforementioned rate of chemical reaction in order to decrease the early setting thereby the strength has been kindled [9]. But the variation in compressive strength of Geopolymer concrete was not significantly noticeable beyond the duration of 24 hours curing [10]. Almost 70% of the ultimate strength has been achieved in the curing period of 4 hours. It was very contrast to the conventional hydration process of ordinary Portland cement concrete [11-12]. From the review of previous studies, it was easy to understand that the curing temperature of 60º C to 120 º C for the duration of 20 to 72 hours of curing led to higher compressive strength [13]. Due to the system of heat curing, the application of Geopolymer concrete is narrow down towards prefabricated structural components only [14-15]. So it is necessary to cure the Geopolymer concrete samples at room temperature to meet the strength requirements. Because the curing of specimens at an elevated temperature for longer curing periods will leads to debonding of alkali-activated aluminosilicates which results in the excessive formation of shrinkage cracks. Finally, the Geopolymeric gel which contracts without the transformation from amorphous to crystalline structure [16]. Generally the addition of calcined source like metakaolin in the mixture of Geopolymer solid which has been successfully developed their compressive strength at ambient curing itself [17]. It was observed that from the literature [18], there was a 20% reduction in water absorption and porosity of Geopolymer concrete with the incorporation of steel fibers than the GPC samples without those fiber contents. Nowadays the evolving materials like Nanoparticles as well as Phase changing materials were also added with the Geopolymer concrete to analyze and understand their effects. The addition of Micro-encapsulated phase changing materials which decrease the workability and also it produces weaker bond at the interfacial transition zone because of the formation of more air bubbles [19]. To make sure that the use of Geopolymer concrete for longer duration without any deterioration, it is necessary to test the long term properties. Oliva et al [20] have proved that the excellent resistance to acid attack has been achieved with the Geopolymer concrete than OPC concrete. The Geopolymer mortars can be also used as a repair material with sufficient surface treatment of existing concrete structures.

Sanjay Pareek et al have explained clearly that the adhesion property of Geopolymer mortar which shows a higher value for concrete with the dry surface state than the wet concrete surface. Because the presence of water at the interface could discourage the effect of the alkaline solution so that it leads to a weaker bond.
This review study was mainly developed to elaborately understand the behavior of Geopolymer and their short term as well as short term studies. Hence, the Geopolymer is one of the admirable construction material which can create the sustainable and cement-free concrete in order to save the earth from global warming and also protect the natural resources due to their lesser shrinkage, higher strength and higher resistance to acid attack of by-product based Geopolymer concrete [22].

II. GEOPOLYMER MECHANISM

Geopolymer concrete is made by the exothermic chemical reaction held by the activation of alumina and silica-rich mineral source with the alkaline solution. This Geopolymerization mechanism consists of three processes named as

1. Dissolution of mineral sources
2. Reorientation
3. Polycondensation or Re-precipitation. [23-24]

After the completion of the above-said processes, it forms a polymeric three-dimensional chain-like structure like Si-O-Al-O. These structures can be empirically indicated by Davidovits [25]

III. OBJECTIVES

The main aim of this study has been listed out below

- To produce sustainable and eco-friendly construction material from the industrial by-products to avoid the dumping of those industrial wastes.
- To arrive the better mix proportion of Geopolymer concrete by doing a number of trial mixes.
- To clarify the effect of Geopolymer concrete for different curing temperature with short as well as longer periods.
- For the better understanding of behavior and properties of Geopolymer concrete at ambient curing itself with the help of adding calcium content.
- In order to introduce emerging methods like Nanotechnology and the use of phase changing materials in Geopolymer concrete to minimize energy consumption.

IV. MIX DESIGN

The Mix Design of Geopolymer concrete normally based on trial and error method. Numerous parameters are to be considered while designing a Geopolymer concrete mix such as the volume of aggregates, binder content, sodium hydroxide molarity, the alkaline solution to binder ratio, water to binder ratio and the value of slump, etc. Ramin Hosseini Kupaei et al. have produced the optimum mix design for fly ash oil palm shell (OPS) geopolymer concrete by varying the molarity of sodium hydroxide, fly ash quantity and the surface state of OPS. The selected surface condition of OPS is Air Dry (AD) and Saturated Surface Dry condition (SSD). The concentration of sodium hydroxide has been varied such as 14 and 16. There are thirty-two mixes were prepared by incorporating the above-said materials by constantly maintaining the alkaline solution to fly ash content as 0.34. The authors have found that the SSD condition of Oil Palm Shell has produced higher strength around 7% higher than concrete made with air-dried OPS. This may be arrived due to the presence of water in the saturated surface dry form of oil palm shell. The reduction in strength and workability were noticed by the increasing quantity of fly ash in the oil palm shell geopolymer concrete. The variation in molarity of NaOH from 14 to 16 does not lead to significant strength enhancement i.e. approximately 1-3% strength only increased in case of concrete casted with 16M than 14M. Hence, they have derived the conclusion that the geopolymer concrete prepared with oil palm shell having saturated surface condition has met the required strength of M30 grade by optimizing the mix design of 1:0.74:0.66 (Fly ash: Sand: Oil Palm Shell) for the fixed alkaline solution to fly ash ratio and molarity of sodium hydroxide as 0.34 and 14 respectively. The guidelines for picking the Geopolymer concrete mix design based on the compressive strength and ratio of water to geopolymer solid has been established by Costa et al. [27] in table 1.

T A B L E 1 Mix Design Guidelines for Geopolymer concrete

Compressive strength in N/mm^2	Workability	The ratio of Water to Geopolymer Solids
60	Very low	0.16
50	Low	0.18
40	Normal	0.70
35	Fluid	0.77
30	Fluid	0.74

V. SETTING AND HARDENING

The main factors which affect the setting time of Geopolymer paste are alkaline solution type, temperature maintained while curing and the chemical composition of source material [28]. Cheng and Chiu has reported that normally around 15 to 45 minutes, the Geopolymer paste will set at the temperature of 60_oC.
The presence of calcium content in the source material which reduces the setting time. This calcium which readily reacts with the alkaline solution thereby the initial setting time has been reduced [23].

VI. INFLUENCE OF COARSE AGGREGATE

The behavior of Fly ash based Geopolymer concrete has been analyzed by varying the proportion of aggregate content from 60 – 70% by total volume of concrete and also the mass of fine aggregate were also varied by varying the ratio of fine aggregate to total aggregate content [29]. There are three groups of mixes were prepared M1, M2, and M3. The M1 group of mixes was casted to optimize the percentage of addition of aggregate content. From this optimum results, the other parameters were studied from the M2 and M3 mixes. There was no noticeable slump value observed in all mixes due to high viscosity and cohesiveness of the mix. It kindles the measurement of compaction factor test. For the constant ratio of water-geopolymer solids, the increase in compaction factor was achieved for an increase in alkaline to fly ash ratio. They have concluded that the optimum percentage of 70% of total aggregates and fine aggregate to the total aggregate ratio of 0.35 only increases the strength of Geopolymer concrete up to the curing temperature of 100_{o}C for the duration of 24 hours. Beyond this limit, there was no improvement in the strength value. This indicates that this proportion of fine as well as the total aggregate is sufficient to make enough and efficient bonding and also the polymerization was completed within the duration of 24 hours. The ratio of sodium silicate to sodium hydroxide ratio of 2.5 only, the strength keeps on increasing one. This ratio was universally accepted by many of the researchers. If this ratio increases more than 2.5 means, the amount of sodium hydroxide does not completely meet the dissolution requirements in order to produce the Geopolymer concrete. Moreover, it was reported by many authors that the Modulus of Elasticity of Geopolymer concrete was low when compared to the Ordinary OPC concrete samples. But in this paper, it was proved that Young's modulus, as well as Poisson's of Geopolymer, has been enhanced by 14.4% and 19.2% respectively than the conventional concrete. This higher value increases the elastic properties of GPC concrete. It was achieved by proper and optimum proportioning of aggregate quantity.

VII. MECHANICAL PROPERTIES

This paper depicted the compressive strength of Geopolymer concrete made by blending the fly ash and ground granulated blast furnace slag for the various concentration of sodium hydroxide [30]. Here, the ambient curing was achieved by the incorporation of GGBS which is suitable for the attainment of strength. By constantly maintaining the alkaline solution to binder ratio of 0.35, the variation in compressive strength was observed from 8 to 16 M of sodium hydroxide. They have signified that up to 8M the strength of Geopolymer concrete samples was significantly increased. Beyond that, the strength was reduced. This may be due to the presence of an excess amount of leachable alumino-silicates, it may hamper polymerization reaction. Most of the specimens having more GGBS content attains their 85% of 28-day strength at the duration of 7 days curing itself..

i) Influences of Nano Materials

Nanotechnology is one of the emerging fields in recent days. So this trial was made by the Sudipta Naskar and Arun Kumar Chakraborthy in the order found out the effect of adding nanomaterials like nano silica, carbon nanotube, titanium oxide, etc., on Geopolymer concrete. Geopolymer concrete was made for the grade of M25 with low calcium fly ash having sodium hydroxide concentration of 16. The strength of this concrete was calculated by compression test and also non-destructive tests like rebound hammer and UPV were studied and it was compared with the Indian standard specifications. In order to find the pH value of geopolymer concrete made with and without nanomaterials at the age of 28 days pH meter was used. In all the mixes the water-geopolymer ratio was fixed at 0.25. The casted samples were initially air cured for the duration of 48 hours and then it was kept in the oven for another 48 hours. Then these specimens were retained at ambient temperature up to the required date of testing. The incorporation of 0.75% of nano silica gave better strength only at 7 days but at the age of 28 days, the decrease in strength was observed. The geopolymer concrete made with 0.02% of carbon nanotubes (CNT) does not give satisfying results at both 7 and 28 days. But only the addition of 1% of titanium oxide gives 46.65% higher strength than the control concrete. Based on the rebound hammer test results, the results coincided with the standard values. From the UPV value of Geopolymer concrete, it matches with good quality concrete. The calculated pH value of Geopolymer concrete made with nanomaterials and titanium oxide at 28 days almost similar to the GPC prepared without titanium oxide and control specimens. Finally, the authors have concluded that the combined addition of nanomaterials and titanium oxide gives satisfactory strength results in the low calcium based Geopolymer concrete.

Jumah Musdif Their, Mustafa Özakça [31] have developed the Geopolymer concrete produced with the help of cold-bonded fly ash aggregate (CFA), nano-silica (NS) and steel fiber (SF). The entire work was incorporated with the sodium hydroxide molarity of 12 and all the specimens were cured at ambient temperature. The authors have mainly focused the transport properties like water penetration, water sorptivity and gas permeability at the age of 28 and 90 days. These results are compared with the compressive strength of Geopolymer concrete by doing Regression analysis in order to find the regression coefficient. Finally, they have concluded that the optimum percent of nano-silica and steel fibers are obtained as 2% and 1% respectively. Normally the increasing percent of CFA replaced for natural aggregate which turns down the compressive strength. But the intrusion of nano silica and steel fibers were participated to increase the compression-resisting capacities. This improvement in compression strength was achieved due to the efficient reaction of nano silica which brings up the polymerization reaction product. Logically the porosity of CFA was higher than the natural aggregates.

The Fly Ash-based binders are investigated by adding the colloidal nano-silica at different rates and A.Ravitheja and L.N Kiran Kumar have reported that the primary source for Geopolymer concrete (GPC) is Aluminosilicate which is obtained from the reaction of low-calcium Fly ash with GGBS. In this entire work, the alkaline solution to binder (Fly ash and GGBS) ratio was constantly maintained as 0.45 and the molarity of sodium hydroxide also fixed as 12M. After the completion of casting the GPC cast with colloidal nano-silica were cured at room temperature up to the required date of testing. But the non-nano-silica specimens were kept in a hot air oven at a temperature of 60_{o}C for the duration of 48 hours. After that, the oven cured samples were preserved at ambient until further use. Also the authors have studied the mechanical properties of Fly Ash-based GPC with the addition of nano-silica particles and these results were compared with Fly ash and GGBS based GPC incorporated by colloidal nano-silica. They have arrived that the compressive strength of both mixes was increased up to the addition of 6% of nano-silica (NS). Beyond that, the strength of GPC was decreased because the 6% addition was enough for reaction due to its more surface area. A further count of NS does not involve in the reaction process so that the strength has been decreased. The compressive, tensile and flexural strength of GPC mixes for the addition of 6% colloidal nano-silica, the authors were observed 29%, 50% and 50% more than the control GPC without the NS. It is very important to note that the deformation capacity which is also increased due to the formation of the very high amount of hydrated products.

ii) Effect of Phase Changing Materials

Shima Pilehvar et al. were found out the effect of adding Micro-encapsulated phase changing materials (MPCM) in the solid as well as in the liquid state on mechanical properties of Geopolymer concrete to compare with the Portland cement concrete. The percent of MPCM was calculated based on volume proportion and it was replaced for the fine aggregate. In both concrete mixes (OPC and GPC), the value of slump obtained from the slump cone test has been reduced due to the addition of MPCM for different proportion of 0-20% at an increment of 5%. The compressive strength of concrete made with MPCM has been analyzed by varying the dosage of MPCM and also by varying the curing temperature. Based on the state of MPCM, it does not adversely affect the strength of the concrete. But when the curing temperature increases, the strength reduction was attained. This was occurred due to the lower stiffness and strength of MPCM than the natural fine aggregates. So it was easily got broken if these samples prepared with MPCM under compression testing machine [32]. For the better understanding in the microstructure properties of this concrete prepared with this MPCM, SEM and X-ray micro tomography were conducted. From this test results, it was revealed that the numerous amount of air bubbles were identified in the GPC matrix than OPC. Approximately around 4% and 6% of air voids notified in the total volume of concrete. Thereby, it weakens the bond properties around the interfacial zone. So that the compressive strength may get decreased because of this poor compatibility. The authors have concluded their research work with the recommendation of GPC matrix than OPC in the construction industry if those materials are subjected to change in temperature. Even though these mixes having some negative effects on a strength basis, it satisfies the minimum compressive strength in the range of 25 – 40 Mpa. This was high enough for structural presentations in order to carry the load.

VIII. EFFECT ON DIFFERENT CURING METHOD

C.Y. Heah et al [33] have examined the curing profile on kaoline based Geopolymers. Because the profile of the curing only which defines the strength of the Geopolymer concrete. This study was followed the curing profile of 40$_{o}$C, 60$_{o}$C, 80oC, and 100$_{o}$C for 1 day, 2 day and 3 days which also includes ambient curing. The SEM analysis was also done to evaluate the microstructural behavior. Due to the low reactivity of kaoline, it requires more time for curing to enhance the polymerization process. The curing temperature of 80$_{o}$C and 100$_{o}$C showed similar results. The curing of casted specimens at 80$_{o}$C and 100$_{o}$C for 3 days, the strength was weakened more than the samples cured for 2 days with the same temperature mentioned. Curing at the temperature of 40$_{o}$C and 60$_{o}$C depicted higher strength particularly for longer curing periods in case of kaoline based geopolymers. The best result of compressive strength was obtained at 60$_{o}$C curing for 48h. For this mix, SEM analysis results indicated that the paste gained more growth and later it was very dense which only contributes higher strength. The microstructure of samples cured at 100$_{o}$C was loosely pack, less dense and compact. If the specimens cured at high temperature, it leads to partial evaporation of water which forms microcavities [34].

M.F. Nuruddin et al. were developed to produce Geopolymer concrete for altered curing temperature. The selected source material for this work was fly ash and microwave incinerated rice husk ash (MIRHA). The sodium based alkaline solution was used for all mixes. In this regime, three, unlike curing conditions, were selected such as hot gunny curing, ambient curing, and external exposure curing. The prepared samples were cured under above-said methods and tested in order to analyze the compressive strength and Interfacial Transition Zone (ITZ) with the help of compression testing machine and Field Emission Scanning Electron Microscope (FESEM). In hot gunny curing, the samples were shielded with hot gunny sack for 2 days and this gunny was replaced after the completion of 24 hours. This entire arrangement was secured with plastic sheets to avoid the heat loss. The samples were kept outside to achieve ambient curing. But it should be sheltered from rainfall and direct sunlight. In case of external exposure curing, the samples were put in the transparent chamber that was placed in such a way that the heat radiation from the sunlight should easily penetrate into the chamber. But this should be safeguarded from the rainfall. Due to the company of high moisture content in the hot wet gunny, it decreases the compressive strength. Because it does not maintain the temperature for a longer period. The similar results were obtained in the ambient curing technique. In this method of curing the samples were gained the heat from the outside environment which was used to initiate the polymerization reaction. The blended mixture of 95% of fly ash and 5% of MIRHA gave better performance in hot curing process than the ambient curing way. The external exposure system of curing, it gains the heat from the direct sunlight which ignites the polymerization process. Hence the compressive strength of concrete samples cured at external exposure attained 162% and 102% higher than hot gunny and ambient curing. This much amount of strength was achieved due to the increase in polarization of hydroxyl ions in order to break the Si-O and Al-O bonds and condensed to form poly sialate, poly sialate siloxo, etc. From the microstructure properties analyzed by FESEM, it was observed that the number of microcracks were observed in hot gunny and ambient curing than external exposure curing. This is due to the formation of water film around the aggregates especially in the presence of larger size aggregates. It leads to a weaker bond between the aggregate and Geopolymer paste. But this weaker bond was greatly minimized in the external exposure cured samples which discontinued the microcracks due to strong bond at the interfacial transition zone results in an enormous increase in strength than other two system of curing.

Muhammad Zahid et al were tried to develop the eco-friendly curing procedure to produce Geopolymer concrete because the traditional curing practice of Geopolymer concrete consumes a lot of energy which is one of the major disadvantages of GPC. The Geopolymer concrete was cured with a specially designed solar chamber (SC) and the test results were related with the specimens cured under continuous oven curing (CO) and intermittent oven curing (IO) methods. This solar chamber is employed on the principle of trapping the solar radiation to set the amount of heat and thereby the temperature is maintained inside the box up to 90$_{o}$C. Here chromel alumel 6mm stripped lead thermocouple is used to monitor the surface temperature of the solar cured samples and this entire outer area of this solar chamber is covered by thermocol laminated with plastic sheets in order to avoid the effect of rain. In case of continuous oven curing method, the specimens were kept at a constant temperature of 60₀C for the period of 24 hours. But the intermittent oven curing method composed of three cycles, each cycle consists of 8 hours curing at a temperature of 60₀C and then 16 hours cooling. In all these three methods the casted samples were cured and tested. The test results were indicated that the samples cured under solar cured technique around 56% of strength has been improved than the other two methods and also this system of curing which also deepens the microstructure parameter due to the formation of Geopolymer products. Based on [35] microstructural investigation on Geopolymer concrete it was identified that the formation of crystalline structure changed from amorphous nature to semi-crystalline structure which gave higher strength to the GP concrete if it cured at a higher temperature. In order to understand the microstructural behavior, the XRD diffraction was carried out in this work. The high-intensity peaks of quartz were obtained only for the solar cured samples and also these peaks were increased by enhancing the molarity of NaOH from 5 to 10. The little amount of unreacted fly ash particles were found in the solar conditioned specimens from microstructural studies than the other methods of curing. But in all mix of solar cured samples showed improvement in the degree of Geopolymerization which leads to the denser particle packing.

Parveen et al. have reported the effect on mechanical and microstructural properties of alccofine activated Geopolymer concrete cured at ambient temperature. The experimental values of this research work which would have a significant effect on polymerization lead to increase in strength and microstructural characteristics. The microstructural investigations were done with the help of XRD and SEM analysis. Alccofine (AF) fine material which depends on low calcium silicate slag. Generally the addition alkaline solution for making Geopolymer concrete which results in the sticky and cohesive mix [36]. So it creates the need for water reducing admixture to improve the workability. From this result, it was found that the GPC mix with 10% alccofine and 2% addition of plasticizer which form the mix as less stickiness and better workability. The formation of C-S-H in addition to NASH and CASH is due to the reaction took place between the calcium present in alccofine and the fly ash content. Due to the presence of these CSH, NASH & CASH gels increased the strength of Geopolymer concrete. From the previous kinds of literature, it was observed that the alccofine react with an alkaline solution which produces heat in the matrix and this heat is very much useful for ambient curing. The stress-strain behavior of alccofine incorporated Geopolymer concrete was tested and compared with conventional concrete. The highest strain was recorded in the range of 1.82 – 2.25 x 10^{-2}. All the GPC samples made with alccofine were failed by brittle failure. This was observed due to the formation of a large number of micro-cracks when the load reaches its ultimate load. As per this investigation, the addition of fly ash and enhancement in molarity which affects the water absorption by 9-11% and 5-6% respectively. This reduction in water absorption was observed due to the combined addition of fly ash and microfine alccofine powder. The SEM analysis used to verify the compactness of the concrete matrix. Even though the GPC with 10% alccofine having minor cracks, pores, and holes, it achieved higher compressive, tensile as well as flexural strength at 16 molarity of sodium hydroxide.

IX. MECHANICAL ACTIVATION OF FLY ASH ON GEOPOLYMER CONCRETE

Here [36] the Geopolymer concrete samples were prepared with the processed fly ash and those samples were kept at ambient curing until the date of testing towards the determination of compressive strength changes between the processed and unprocessed fly ash. In order to make the processed fly ash, the raw fly ash was powdered with the help of vibration mill by the use of 10mm diameter steel balls for the duration of 1 hour by fixing the milling medium to powder ratio as 10:1. The morphology, as well as the size of the particles of processed fly ash, has been changed. Due to the addition of this milled fly ash, the compressive strength was greatly increased. The strength of geopolymer concrete made with milled and unmilled fly ash was observed as 45 and 16 N/mm^2 at the age of 28 days of ambient curing. This much amount of strength variation was observed due to the reduction in particle size and change in morphology of processed fly ash. It allows the faster dissolution of particles and quicker setting which increases the packing density of geopolymer concrete leads to an exhibition of higher compressive strength. The reduction in workability has been also noticed owing to the modification in size and spherical shape of fly ash particles which ultimately reduces the ball bearing effect of fly ash.

X. ALKALI ACTIVATED NATURAL POZZOLANA GEOPOLYMER CONCRETE

Dali Bondar (2011) has reported the mechanical strength, drying shrinkage, ultrasonic pulse velocity and modulus of elasticity of alkali-activated concrete casted with natural pozzolan. The selected natural pozzolan which is selected for this work was Taftan andesite. It is one of the most reactive natural pozzolans that is mainly used to manufacture the Ordinary Portland Cement in Iran. These mixes were cured at two different systems like sealed and fog curing with three different temperatures. The designated curing temperature under these two systems is 20±2ºC, 40±2ºC, and 60±2ºC. The rate of the strength of alkali-activated natural pozzolana concrete (AANP) was lesser at early ages but it matches with the strength of OPC if it is cured for a longer duration. The best results have been achieved under a sealed curing condition at 40ºC which is the same as that of OPC concrete mixes.

XI. DURABILITY STUDIES

G. Mallikarjuna Rao and C. H. Kireety [38] observed the durability studies on Fly Ash and GGBS based Geopolymer (GP) mortars. They have examined the resistance of this Geopolymer mortars made with the combination of Fly Ash and GGBS which are subjected to the acidic solutions (Sulphuric acid and Nitric acid) for the altered exposure duration of 7 and 28 days. The authors were found out the loss in mass and also in strength. This experimental study was conducted by considering five different mixes with altering the proportion of Fly Ash and GGBS (100FA-0GGBS, 75FA-25GGBS, 50FA-50GGBS, 25FA-75GGBS & 0FA-100GGBS). For this entire work, the Molarity of NaOH was fixed as 8 for all mixes and also the sodium silicate to sodium hydroxide ratio was fixed at 2.5. The casted Geopolymer samples are kept in the outdoor condition for curing until the date of testing. The range of compressive strength obtained for all the Geopolymer mortar specimens is 3.55 to 61.4 MPa. The lowest strength was observed for the mix of FA100-0GGBS (complete addition of Fly Ash and null use of GGBS).

The strength of GP mortars increased with the addition of GGBS. It was observed that GGBS play a major in the development of strength. In all mixes, 90% of 28-day compressive strength was obtained with 7 days of curing. The main reason for this rapid strength is due to higher calcium content and faster rate of the polymerization process and also it depends on the volume of GGBS added in the mixture. In this paper has focused mainly about the resistance of GP mortars against the immersion of Sulphuric Acis and Nitric Acid solutions after the completion of 28 days curing. The loss in strength and mass was noted for increasing percent GGBS. The proportion of 100GGBS-0FA led to severe degradation in both acidic solutions. the reason for the mass loss was identified that the higher calcium content present in GGBS react with sulphuric acid and produce the gypsum which causes internal voids. The important thing for the reduction in strength was due to the formation of shrinkage cracks would accelerate and conduct the ions through the presence of acidic solutions which leads to deterioration of GP mortars thus leads to strength loss. Finally, they have concluded that the increasing days of immersion the loss in mass as well as in strength keeps on increasing. The higher calcium content in GGBS which is very desirable for enhancing the strength but those are not suitable for durability properties like resistance against acid attack. The authors M. Priyanka and N. Ruben have mentioned that the Geopolymer is formed by mitigating the alumina and silica-rich materials with alkaline solutions. The factors which are affecting the strength of the Geopolymer concrete are curing temperature, curing duration, alkali content, etc. The compressive strength was increased if the alkali content has been increased but strength was decreased for the more addition of silica content in Geopolymer concrete. The curing temperature is one of the main characters for strength development in Geopolymer concrete. The rate of polymerization and also the compressive strength was enhanced by increasing the curing temperature. So many authors have investigated the effect of Geopolymer concrete against acid attack. But they are observed that the deterioration of GPC concrete was mainly based on the extended duration of immersion in acid and concentration of those acids. Olivia, M., & Nikraz, H [39] are inspected the corrosion effect on Geopolymer concrete by adopting Half-cell potential method. The authors were recorded that the corrosion value for severe exposure condition was lesser than the standard value of corrosion for similar environmental exposure.

There is very fewer studies were analyzed about the adhesion properties of geopolymer mortar. Hence, the authors of the paper [21] have mainly focused on the adhesion parameter of geopolymer (GP) mortar on the surface of concrete, steel bars, and plates. This study is much useful for repair works on concrete. This property of geopolymer mortar has shown outstanding results on the dry concrete surface than the wet concrete. The FESEM analysis has been done to understand the adhesion behavior. The pull-outs were also conducted to find out the bond strength of geopolymer mortar to rebars. The adhesion strength of dry concrete coated with geopolymer mortar has been enhanced much after the grinding treatment of concrete surface where the geopolymer mortar is to be applied. From the microstructural investigations, it was clearly observed that the decrease in adhesion strength has occurred in the contact mixture of geopolymer mortar and wet concrete surface. This is due to the presence of water at the interface of geopolymer mortar and the wet concrete surface which lower down the effect of alkaline solution concentration.

XII. GEOPOLYMER CONCRETE PRODUCTS

S. Thirugnanasambandam and C. Antony Jeyasehar [40] have gone through the examination about the ambient cured Geopolymer concrete products like the concrete beam, Railway Sleepers. The Geopolymer concrete specimens were showed better performance than the cement concrete products. The authors extended their research also on Ferrocement roofing channels and domes prepared with cement concrete and Geopolymer concrete. These specimens were tested in a similar manner and finally, they have found that the Ferrogeopolymer elements are showing superior results than the conventional cement concrete elements. In all the production of Geopolymer products, the mix design was followed by IS10292:2009 [41]. The conventional cement concrete specimens are allowed to cure in water until further use. In case of Geopolymer concrete specimens were kept at ambient curing up to the date of testing required. The ultimate load carrying capacity of GPC beam made with steel reinforcement was 44.6kN but it was limited as 41.8kN in the conventional concrete which was 6.7% lower than the Geopolymer concrete. Nowadays faster development is going on railways. So it requires an enormous amount of railway sleepers. So that they have made the sleeper with the grade of M60 as per IS10292:2000 with the water-cement ratio of 0.30. Both the GPC and Conventional sleepers are prestressed by applying yield stress of 2922 N/mm2 with the help of 18 numbers of 6mm diameter. The sleepers were tested as per Indian Railway standards T-39 [42]. The load carrying capacity of GPC sleeper was improved by 10% than control concrete. After the application of ultimate load in GPC sleeper, the 34% increase in deflection has been achieved than the conventional cement concrete one. The Ferrogeopolymer channel, as well as the Ferrogeoplymer dome, showed higher load carrying capacity than the traditional Ferrocement channel and the Ferrocement dome such as 9.3% and 72.16% respectively. In the case of Ferrogeopolymer dome the highest ductility factor of 6.20 was attained. But this ductility ratio has come down in Ferrocement dome having the value of 1.82.

XIII. APPLICATIONS

The Geopolymer concrete which can be successfully used as alternative binding material for Ordinary Portland Cement Concrete. But it requires controlled supervision at the site and also it has many disadvantages such as quick setting, low workability due to high cohesiveness and difficulties to work with the alkaline solution and heat curing, etc. Even though of these drawbacks, it shows higher mechanical, as well as durability properties particularly this type of concrete, contributes higher resistance against acid attacks than OPC concrete. So that it could be used to make wastewater pipes, hydraulic structures like a dam and also for pre-tensioned concrete elements like railway sleepers and poles, etc. [43]

XIV. CONCLUSION

From this aforementioned survey of works of literature on Geopolymer concrete, the following conclusions could be drawn

1. The Geopolymer concrete could be produced by natural pozzolana or artificial by-products but those materials should be rich in aluminum and silicate.

2. Generally, the sodium or potassium based solutions are acted as an alkaline solution. But the combination of sodium hydroxide and sodium silicate solution is cheaper than the potassium-based alkaline solution.
3. The incorporation of a higher concentration of NaOH keeps on enlightening the strength of Geopolymer concrete. This was observed due to the dissolution of OH^- ions react with the silicate and aluminate results in the generation Si-O-Al-O bonds which converted from amorphous to crystalline nature.
4. The addition of increasing molarity of sodium hydroxide in an alkaline solution which enhances the cohesiveness of Geopolymer concrete mixture.
5. In order to meet the workability, the use of extra water will lead to increase the workability but at the same time, it decreases the strength configuration.
6. The other mechanical properties like flexural strength, tensile strength, etc. of the Geopolymer concrete are also follows similar manner as that of compressive strength.
7. Many of the papers have done the experimental investigation on compressive strength of Geopolymer concrete for different curing conditions.
8. From their results, it was observed that the fly ash based Geopolymer concrete should be cured in the presence of heat to attain the required strength.
9. Heat curing can be avoided by the intrusion of Ground Granulated Blast Furnace slag or any other material that should contain more calcium content.
10. The presence of calcium in the Geopolymer concrete which is used in the attainment of needed strength at ambient curing itself.
11. The higher amount of calcium is very useful for the improvement of strength but it brings down the resistance against acid attack.
12. The incorporation of Nanoparticles will dip the compressive strength, flexural strength and also load carrying capacity up to 6% of the weight of binder content.
13. The addition of phase changing materials by replacing the fine aggregate, it produces a weaker bond at the interfacial transition zone by forming numerous air bubbles.
14. The Geopolymer concrete gives better resistance for acid attack, water absorption than traditional Portland cement concrete.

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