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A Brief Review on Geopolymer Concrete

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Abstract
Portland cement concrete industry has grown universally in recent years. The demand for concrete as a construction material has increased due to increase of infrastructure. However, Portland cement concrete generates problems such as durability and carbon dioxide emission. There are many ways to reduce environmental pollution (carbon dioxide) caused by the production of Portland cement and by the increasing of waste material. Around 120 million tonnes of fly ash get assembled every year at the thermal power stations in India. It becomes a serious problem due to inadequacy of land disposal. Cement is totally replaced by the pozzolanic material that is rich in Silicon and Aluminium like fly ash referred to as "Geopolymer concrete" which is a contemporary material. Geopolymer concrete was actually manufactured by reusing and recycling of industrial solid wastes and by products. Fly Ash, a byproduct of coal obtained from the thermal power plant is plenty available worldwide. Fly ash is used as ingredients in concrete which enhance the properties of concrete and utilization of fly ash is helpful for consumption. This paper presents a brief history and review of geopolymer technology with the aim of introducing the technology and the vast categories of materials that may be synthesized by alkali activation of alumino silicates.

Keywords
Fly Ash, Carbon dioxide, Alkaline activators, Geopolymer Concrete, Strength and Durability, Applications.

I. Introduction

In the context of increased awareness regarding the ill effects of the over exploitation of natural resources, eco friendly technologies are to be developed for effective management of these resources. Concrete usage around the world is second only to water. Cement is conventionally used as the primary binder to produce concrete. The environmental problems associated with the production of cement are well known [1]. The amount of the carbon dioxide released during the manufacture of cement due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of cement produced. Hence, it is imminent to find an alternative material to the existing most expensive most resource consuming Portland cement. OPC is extensively used in India due to its low cost and easy availability. Concrete can be cast in almost any desired shape, and once hardened, can become a structural (load bearing) element. On the other hand it also affects environment, also there are many negative influence of OPC. For example emissions of airborne pollution in the form of gases, noise, dust, and vibration when operating machinery and during blasting in quarries, devouring of large quantities of fuel during manufacture and release of CO_2 from the raw materials during manufacture. Due to all such reasons it is needed to be replaced by non-producing CO_2 materials such as fly ash and various supplementary materials. [2]. As such, geopolymer concrete has been introduced to reduce this problem. Fly ash is plentifully available to replace totally manufactured cement and make a concrete like material. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be manufactured without using any amount of ordinary Portland cement [3]. The advancement of geopolymer concrete is an important step towards the production of environmentally friendly concrete. Geopolymer is a type of amorphous alumino silicate cementitious material that exhibits the ideal properties of rock forming minerals, i.e., hardness, chemical stability and longevity [4]. Geopolymerization involves a heterogeneous chemical reaction between solid aluminosilicate oxides and alkali metal silicate solutions at highly alkaline conditions and mild temperatures yielding three dimensional amorphous to semi-crystalline polymeric and ring structures, which consist of Si–O–Al and Si–O–Si bonds.

The schematic formation of polycondensation material by alkali into poly (sialatesiloxo) can be shown as described by equations (A) and (B).

$$n(Si_2O_5,Al_2O_2) + nSi_2 + nH_2O \xrightarrow{NaOH.KOH} n(OH)_3 - Si - O - \underset{\underset{(OH)_2}{\downarrow}}{\overset{-}{Al}} - O - Si - (OH)_3 \quad (A)$$

$$n(OH)_3 - Si - O - \underset{\underset{(OH)_2}{\downarrow}}{\overset{-}{Al}} - O - Si - (OH)_2$$

$$\xrightarrow{NaOH,KOH} (Na^+, K^+) - (\underset{\underset{O}{|}}{\overset{|}{Si}} - O - \underset{\underset{O}{|}}{\overset{|}{Al}} - O - \underset{\underset{O}{|}}{\overset{|}{Si}} - O-) + nH_2O$$

(B)

The last term in equation (B) signifies that water is released during the chemical reaction that occurs in the formation of geopolymers. This water is expelled from the mixture during the curing process leaves behind discontinuous nano pores in the matrix, which provide prosperity to the accomplishment of geopolymers [5]. The water in a geopolymer mixture plays no role in the chemical reaction that takes place; it merely provides the workability to the mixture during manipulation. This is in resemblance to the chemical reaction of water in a Portland cement concrete mixture during the hydration process [6]. Geopolymers exist to the group of strong and durable cementitious materials that harden at temperatures below 100°C.

II. Objective

The main target of this study is to analyze the carbon dioxide free cementitious material, various properties and their effects on Geopolymer concrete.

III. Literature Review

Yasir Sofi and Iftekar Gull intended to study the properties of fly ash based Geopolymer concrete. M20 grade GPC can be formed by adopting nominal mix of 1:1.5:3 (fly ash: fine aggregates: coarse aggregates) by varying alkaline liquid to fly ash ratio from 0.3 to 0.45. The compressive strength, tensile strength and flexural strength tests were conducted on geopolymer concrete and parameters that affect it are analyzed and proved experimentally. The durability properties like permeability and acid attack are also studied. From the test results, it was concluded that geopolymer concrete possesses good compressive strength and offers good durability characteristics. With the increase of alkaline liquid to fly ash ratio strength decreases and alkaline liquid to fly ash ratio less than 0.3 is very stiff.

P. K. Jamdade and U. R. Kawade studied the strength of Geopolymer concrete by using oven curing. In this study Geopolymer concrete is prepared by mixing sodium silicate and sodium hydroxide with processed fly ash. The concrete is cured at different condition and different temperatures i.e; 60^0C, 90^0C and 120^0C so as to increase the strength of concrete. It was observed that higher curing temperature resulted in larger compressive strength of Geopolymer concrete, even though an increase in the curing temperature beyond 60^0C did not increase the compressive strength substantially. Also longer curing time improved the polymerization process resulting in higher compressive strength of Geopolymer concrete.

Arya Aravind and Mathews M Paul carried out research on mechanical properties of Geopolymer concrete reinforced with steel fiber. This study focuses on the compressive strength and split tensile strength of geopolymer concrete reinforced with steel fiber. Experiments were performed using the Box–Behnken experimental design. Box–Behnken experimental design is a type of response surface methodology. Response surface methodology is an empirical optimization technique for evaluating the relationship between the experimental outputs and factors called X_1, X_2, and X_3. For obtaining the results for Box Behnken design, analysis of variance has been calculated to analyze the accessibility of the model and was carried in Microsoft Office Excel 2007. It can be concluded that compressive strength of geopolymer concrete is gradually increased with prolonged curing period also with the increase of sodium silicate to sodium hydroxide liquid ratio by mass. Split tensile strength of geopolymer concrete increased as percentage of steel fiber increased. Another important observation was obtained that curing under normal sunlight yielded strength of 16 N/mm^2.

Kamlesh. C. Shah conducted research on strength parameters and durability of fly ash based Geopolymer concrete. In this study, two concrete mixes are to be worked out; GPC Mix-1 fly ash concrete and OPC Mix-2 Concrete mix having OPC equivalent to amount of cementitious material used in GPC Mix-1. Different parameters were used such as alkaline liquid to fly ash ratio of 0.40 ,0.45 and 0.50, ratio of NaOH to Na_2SiO_3 2.0 and 2.5, molarities of NaOH; 10M ,12M, 14M and 16M. Compressive strength test, split tensile test, pull out test and durability test were performed under ambient temperature curing conditions i.e; 60^0C, 90^0C and 120^0C. Higher average compressive strength, tensile strength and pull out strength of 52.25, 4.10 and 10.25 N/mm^2 were observed for concrete GPC Mix-1 as compared to that of concrete OPC Mix-2. The test results showed that oven cured fly ash based geopolymer concrete have an excellent resistance to sulfate attack, salt attack and acid attack as compared to ambient curing. Minor increase in the mass of concrete specimens of mix has been observed due to the absorption of the sulfate, acid & salt for concrete Mix-1.

S. Jaydeep and B. J. Chakravarthy prepared an optimum mix for Geopolymer concrete using admixtures. Concrete cubes of size 150×150×150mm were prepared to find out compressive strength at 7 and 28 days. Results showed that the addition of sodium silicate solution to the sodium hydroxide solution as an alkaline activator enhanced the reaction between the source material and solution. Oven cured specimen gives the higher compressive strength as compared to direct sunlight curing. It was also observed that geopolymer concrete is more advantageous, economical and eco-friendly method when compared with conventional concrete.

Shankar H. Sanni and R. B. Khadiranaikar carried out investigation on the variation of alkaline solution on mechanical properties of geopolymer concrete. The grades preferred for the investigation were M30, M40, M50 and M60; the mixes were designed for 8 molar. The alkaline solution used was the combination of sodium silicate and sodium hydroxide solution with the varying ratio of 2, 2.5, 3 and 3.5. The test specimens were 150x150x150 mm cubes and 100x200 mm cylinders heat-cured at 60°C in an oven. The results revealed that the workable flow of geopolymer concrete was in the range of 85 to 145mm and was dependent on the ratio by mass of sodium hydroxide and sodium silicate solution. The freshly prepared geopolymer mixes were cohesive and their workability increased with the increase in the ratio of alkaline solution. It was concluded that the strength of geopolymer concrete can be improved by decreasing the water/binding and aggregate/binding ratios. Compressive strength and split tensile strength obtained were in the range of 20.64-60N/mm^2 and 3-4.9 N/mm^2.

Benny Joseph and George Mathew carried out the influence of aggregate content on the engineering properties of Geopolymer concrete. Influence of other parameters such as curing temperature, period of curing, ratio of sodium silicate to sodium hydroxide, ratio of alkali to fly ash and molarities of sodium hydroxide were also discussed. Based on the study carried out, it can be concluded that a geopolymer concrete with proper proportioning of total aggregate content and ratio of fine aggregate to total aggregate, along with the optimum values of other parameters, have better engineering properties than the corresponding properties of ordinary cement concrete. Compared to ordinary cement concrete, 14.4% enhancement in modulus of elasticity and 19.2% enhancement in Poisson's ratio could be achieved in geopolymer concrete.

Aminul Islam Laskar and Rajan Bhattacharjee investigated the variation of workability of fly ash based Geopolymer concrete with the variation of lignin based plasticizer and poly-carboxylic ether based superplasticizer. It has been observed that there exists a critical value of molar strength of sodium hydroxide beyond which superplasticizer and plasticizer have adverse effect on workability of fly ash based geopolymer concrete. There is an increase in slump below the critical molar strength of sodium hydroxide. Lignin based first generation plasticizer shows better performance in terms of workability over third generation superplasticizer below the critical value of molar strength. It was also observed that there is a good correlation between the rheological parameters and slump for fly ash based geopolymer concrete incorporating plasticizer and superplasticizer.

Monita and Hamid R. Nikraz studied the strength characteristics, water absorption and water permeability of low calcium fly ash based geopolymer concrete. Mixtures with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio were investigated. Results showed that a good quality concrete was obtained by reducing the water/binder ratio and aggregate/binder ratio; and the water absorption of low calcium fly ash geopolymer was improved by decreasing the water/binder ratio, increasing the fly ash content, and using a well-graded aggregate. No significant change was observed in water permeability coefficient for the geopolymer with different parameters.

Steenie Edward Wallah used low-calcium fly ash as its source material, alkaline activators and aggregates normally used for Ordinary Portland cement concrete. Four series of test specimens with different compressive strength were prepared to study the drying shrinkage of this concrete. Results obtained were compared with the calculated results of drying shrinkage as predicted by Gilbert Method which is normally used for Ordinary Portland cement concrete. Results showed that the heat cured fly ash-based geopolymer concrete undergoes very low drying shrinkage. The drying shrinkage strain at one year as calculated using Gilbert Method was much higher, about five to seven times, compared to the measured drying shrinkage strain.

IV. Limitations

- Geopolymer concrete did not harden immediately at room temperature as in conventional concrete.
- Geopolymer concrete specimens took a minimum of 3 days for complete setting without leaving a nail impression on the hardened surface.

These two limitations of geopolymer concrete mix was eliminated by replacing 10% of fly ash by OPC on mass basis with alkaline liquids resulted in Geopolymer Concrete Composite and are considered as drawbacks of this concrete to be used for practical applications [7].

V. Advantages

- The price of fly ash is low.
- Better compressive strength.
- Fire proof i.e; higher resistance to heat.
- Low permeability.
- Eco-friendly.
- Magnificent properties within both acid and salt environments.

VI. Conclusion

From the past research studies, it can be sequel that:

The reduced CO_2 emissions of Geopolymer cements build them a good alternative to Ordinary Portland Cement.

Geopolymer cement produces a substance that is comparable to or better than traditional cements with respect to most properties.

Higher concentration of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.

Geopolymer concrete has excellent properties within both acid and salt environments.

Low calcium fly ash based geopolymer concrete has excellent compressive strength, exposure to aggressive environment, workability, exposure to high temperature and is suitable for structural applications.

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