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Geopolymer Concrete: An Eco-friendly Alternative to Cement Concrete

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Abstract—*Nowadays, environmental issues resulted from cement production have become a major cause of concern. To develop a sustainable future, it is encouraged to limit the use of cement as a construction material as on one hand it is costly and on the other, it adversely affects the environment. Thus, geopolymer is a promising substitute as an alternative to Ordinary Portland Cement (OPC) for developing various sustainable products in making building materials, concrete, fire resistant coatings and fibre reinforced composites. Geopolymer concrete is hardened cementitious paste which results from the reaction of a source material rich in silica and alumina with alkaline solution. The various studies by different research workers have revealed that the geopolymer concrete results in early compressive strength, low permeability, good chemical resistance, excellent fire resistance behavior and economically cheaper than cement concrete. This paper describes the utilization, properties and benefits of fly ash, rice husk ash and ground granulated blast furnace slag based geopolymer concrete. Geopolymer concrete has a great potential in construction considering carbon credit, waste disposal and limited availability of non-renewable resources. Therefore, geopolymer concrete is sure to play major role in construction industry.*

Keywords*: Geopolymer concrete, Eco-friendly construction material, Fly ash,Rice husk ash, Ground granulated blast furnace slag, Alkaline solution, Compressive strength, Chemical resistance, Economically cheaper.*

1. INTRODUCTION

Concrete is one of the most widely used construction material in the worldwide construction industry. Ordinary Portland cement (OPC) is generally used as the primary binder to produce concrete. As demand of construction industries is increasing, production of Portland cement is also increasing. As per current scenario, annually global production of OPC is exceeding 2.6 billion tons worldwide and growing at the rate of 5 percent annually. The main constitute for the production of OPC is Lime stone and there is an acute shortage of limestone may come after 40 years. Generally, while producing one ton of cement, one ton of carbon dioxide will be emitted to the atmosphere, which is a major cause of environmental pollution. Furthermore, huge quantity of energy is also required for the production of cement. Hence to reduce the pollution and to conserve non-renewable resources a sustainable initiative is required to be proposed. The critical element for sustainable growth is the development of alternative cements to replace conventional Portland cement [1]. Recently, another class of cementitious materials has been developed from alumino-silicate activated in a high alkali solution. The mortar and concrete made from geopolymers possess similar mechanical performance and appearance properties to those from Portland cement [2].

2. GEOPOLYMER CONCRETE

The term "geopolymer" was firstly investigated by a French Professor Davidovits in 1978 to represent a broad range of materials which are members of the family of inorganic polymers.

Geopolymer materials represent an innovative technology that is generating huge amount of interest in the construction industry considering carbon credit, waste disposal and limited availability of non-renewable resources. Geopolymer concrete is a sustainable and eco-friendly construction material and an alternative to Portland cement concrete which does not require the presence of Portland cement as binder.

Geopolymerization is a process of polymerizing silica and alumina using alkaline solution that results in three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymer concrete is prepared by activating the source materials rich in silicon and aluminium such as fly ash, rice husk ash, GGBS etc. with high alkaline solution (sodium silicate and sodium hydroxide). These Silicon (Si) and Aluminium (Al) presents in source material are reacts with an alkaline liquid and subsequently polymerizes into 3D molecular chains and become the binder.

This paper gives the brief description on constituents of geopolymer concrete, physical properties, necessity, applications and limitations of geopolymer concrete.

3. CONSTITUENTS OF GEOPOLYMER CONCRETE

Geopolymer concrete is prepared by mixing binder and alkaline solution with fine aggregate and coarse aggregate. The role of binder plays mainly by the materials which are rich in silica and alumina such as fly-ash, rice husk ash, ground granulated blast furnace slag etc. and the alkaline solution is the mix of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate in different ratio.

Source Materials

Fly ash is the fine particulate waste material resulting from the combustion of coal in a fire furnace of an electricity generating thermal power plant. It is typically rich in alumina and silica that makes it pozzolonic material. Low-calcium (Class F) fly ash is preferred as a source material than high-calcium (Class C) fly ash. The presence of calcium in high amount interferes with the polymerization process and alters microstructure of concrete [3].

Rice husk ash is a by-product from the burning of rice husk at a temperature lower than 600°C. It is rich in silica about 90%. The strength and durability of concrete is increased with an increase in silica content**.**

Ground granulated blast furnace slag (GGBS) is obtained by quenching molten iron slag from a blast furnace in water, dried and then ground into a fine powder. GGBS is a non metallic and granular material consisting essentially of silicates and aluminates of calcium. Addition of ground granulated blast furnace slag in concrete results in enhancement of concrete workability, density and durability.

Alkaline Solutions

Alkaline solution plays an important role in the geopolymerization process. Sodium or potassium based hydroxide and silicates can be used as alkali activators. Polymerization occurs at a high rate when the alkaline liquid contains soluble silicate as compared to the use of alkaline hydroxides only.

4. GEOPOLYMER CONCRETE PROPERTIES

Compressive Strength

Reddy *et al* [2] evaluated that higher concentration of sodium hydroxide (NaOH) solution inside the fly ash based geopolymer concrete will result in higher compressive strength of concrete because as the concentration of NaOH increases the bond between aggregate and paste of concrete becomes stronger.

Motorwala *et al* [4] stated that the combined use of potassium hydroxide (KOH) and sodium hydroxide (NaOH) was helped in achieving a more rigid structure and hence improved the strength characteristics. It was also observed that with the increase in sodium silicate-to-sodium hydroxide ratio by mass, compressive strength increased.

Usman and Pandian [5] studied the effect of fly ash and rice husk ash-based geopolymer concrete with steel fiber on the properties of concrete. The study revealed that 10% replacement of fly ash with rice husk ash was suitable for production of geopolymer concrete. The addition of steel fibre did not affect the compressive strength of the geopolymer concrete. The workability of fresh concrete decreased with replacement of fly ash by rice husk ash and with addition of steel fibre.

Ramani P V and Chinnaraj P K [6] stated that it is possible to produce geopolymer concrete of substantial strength and durability using ground granulated blast furnace slag (GGBS) and black rice husk ash (BRHA). He observed that the addition of black rice husk ash beyond 10 % had a retarding effect on the compressive strength yet the strengths are well above the target for up to 20% replacement levels.

Durability

Brahammaji and Muthyalu [7] concluded that geopolymer concrete mixes resisted acid attack in a better way as compared to conventional concrete at all ages of exposure to HCl, H_2SO_4 and $MgSO_4$.The results evaluated that loss of weight and compressive strength due to exposure is less in geopolymer concrete as compared to conventional concrete.

Luhar and Khandelwal [8] investigated that heat-cured fly ash based geopolymer concrete has an excellent resistance to sulfate and chloride attack with longer time to corrosion cracking compared to conventional concrete. In geopolymer concrete specimen cracks were observed at 144 hours compared to 116 hours in normal concrete.

Rangan B V [9] evaluated that heat-cured low-calcium fly ash-based geopolymer concrete shows excellent resistance to acid and sulfate attack and also undergoes low creep and very little drying shrinkage.

5. FEASIBILITY AND ECONOMIC BENEFITS OF GEOPOLYMER CONCRETE

Bhavin *et al* [10] stated that it is feasible to use geopolymer concrete as alternative to conventional cement concrete. Based on the work carried out in the project, cost of 1 cubic meter production of normal concrete is Rs. 4562 against a cost of Rs. 3187 of geopolymer concrete. However it was also concluded that the compressive strength of normal concreteof M20 grade block is 21.7MPa against a 62 MPa of geopolymer concrete. In addition to it geopolymer concrete also provides resistance in corrosive environment.

Lloyd N A and Rangan B V [11] investigated that fly ash-based geopolymer concrete is estimated to be about 10 to 30 percent cheaper than that of Portland cement concrete. Furthermore, heat-cured low-calcium fly ash-based geopolymer concrete exhibits very little drying shrinkage, low creep, excellent resistance to acid and sulphate attack. In encapsulation fly ash-based geopolymer concrete may yield additional economic benefits when it is utilized construction industry.

6. APPLICATIONS OF GEOPOLYMER CONCRETE

Rangan [12] stated that geopolymer concrete has excellent resistance to chemical attack. As such, this advantage of geopolymer concrete is particularly applicable in aggressive marine environments, environments with high carbon dioxide or sulphate rich soils. Likely, in highly acidic conditions, geopolymer concrete has shown to have superior acid resistance and may be suitable for applications such as manufacturing industries and sewer systems.

Gourley and Johnson [3] reported that geopolymer concrete can be used for making precast concrete products on a commercial scale. The products included sewer pipes, railway sleepers, and wall panels.

7. LIMITATIONS

In addition to various advantages of geopolymer concrete in several fields, some of the important limitations of geopolymer concrete may have to overcome before its wide acceptance in the field.

In geopolymer concrete development of strengths is directly dependent on the purity of the resource materials. Thus, it becomes difficult to maintain the homogeneity in the source materials such as fly ash and purity of alkaline materials obtained from different manufacturers. High alkalinity environment possess health hazards to the workers. Therefore, production of geopolymer concrete requires great care in contrast to Portland cement concrete.

8. CONCLUSION

Geopolymer concrete offers environmental protection by means of upcycling waste/by-products from the industries, into a high value construction material required for infrastructure developments. Fly ash-based geopolymer is superior than normal concrete in many features such as compressive strength, exposure to aggressive environment (acid attack) and exposure to high temperature. It also undergoes very little drying shrinkage. Study shows that geopolymer concretes produced with different combination of fly ash and GGBS are able to produce structural concretes of high grades (more than M40 MPa) by self curing mechanisms. The geopolymer concrete mixes can be prepared easily using equipment similar to those used for production of conventional cement concretes.

Therefore, considering these advantages it can be concluded that in near future geopolymer concrete may find a sustainable and eco-friendly alternate to normal cement concrete.

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