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REVIEW ON GEOPOLYMER CONCRETE AN ECO-FRIENDLY SOLUTION

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Abstract:

The eco-friendly concept in concrete evolved from the desire of decent intellectuals of developing nations to reduce greenhouse gas emissions and need to conserve the resources in nature such as limestone, rocks, river sand etc. which are used for the expansion of - infrastructure for human beings, further to enhance the utilisation of waste materials that lead to air, land and water pollution. Geopolymer concrete (GPC) is a unique construction material that is favourable to the environment which promotes sustainable development and a long life cycle without destruction of natural resources. Environmental, technical and economic benefits have increased the demand of eco-friendly concrete.

The current example of investigation is in progress to create geopolymer structures that advance a lower epitomized energy, lower carbon dioxide fastener and that have properties like Portland concrete. It is a versatile material being used for railroad sleepers, utility poles, footways, marine structures etc. This paper reviews the research done by the scientists globally in the domain of materials made of GPC and investigates some of their qualities, limitations and possible applications.

Key Words: Geopolymer, Eco-friendly, Fly Ash, Compressive Strength

Introduction:

Cement industry has largely shaped the modern built environment. Concrete is delivered from a mixture of chemically active material cement, rigid inclusions like coarse and fine aggregates. Water is added for initiating the hydration process. Commonly used aggregates such as crushed stone, gravel and sand make up 60 to 80% of the concrete mix. Cement industry single-handedly contributes to about 5% of global carbon dioxide (CO_2) emissions **[1]**. Concrete is found to be the second most devoured substance after water and the extraction and preparation of crude materials for concrete has few negative impacts such as degradation of land, dust, commotion, visual contamination, loss of productive farmland and huge water consumption to manage dust and to clean the aggregates.

Thus, the popularity of concrete also carries with it a great environmental cost. Limestone has to be heated to higher temperatures of about 1500°C to produce cement. This extreme heating process needs an enormous amount of fuel, which eventually leads to chemical decomposition of limestone forming calcium oxide, used in the final cement product, liberating carbon dioxide gas into the environment. It has been seen that during the production of one ton of OPC about one ton of CO_2 is delivered into the climate [25].Construction industry is conscious about the ecological consequences of cement and concrete production, designing the need to develop an eco-friendly concrete.

Davidovits in 1978 formulated the word geopolymer to signify a wide span of materials depicted by networks or chains of inorganic compounds. In contrast to conventional Portland cement, calcium- silicate-hydrates (CSH's) are not formed by geopolymers for framework development and strength, instead polycondensation of silica and alumina reactants take place to achieve the structural strength. Supplanting cement from the framework with by-products, for example, fly debris and Ground Granulated Blast Furnace Slag-GGBS in GPC opens the door for 100% disposal of cement from concreteand hence helps in limiting the worry of planetary temperature boost.

Low-calcium fly debris (LCF) is a material made of aluminosilicate that is for the most part used for the assembling of geopolymer compounds [2]. The nature of raw and hardened geopolymer material is found to depend on the amount of calcium compound present in it. Quick formation of a calcium silicate hydrate (CSH) phase was found to result in rapid hardening of the material [3]. In light of these past observations, it has been concluded that lesser calcium content of the source material resulted in a delay in the setting time and made it more effective against chemical attack. Hence, replacement of high-calcium fly ash (HCF) with LCF is a better option in setting up a functional and strong GPC. The existence of high amounts of calcium in fly ash has also been found to affect the polymerization process [26]. GPC diminishes the CO_2 outflows by 80% and hence there is an incredible potential for reducing the reserves of industrial wastes.

Composition of Geopolymer Concrete (GPC):

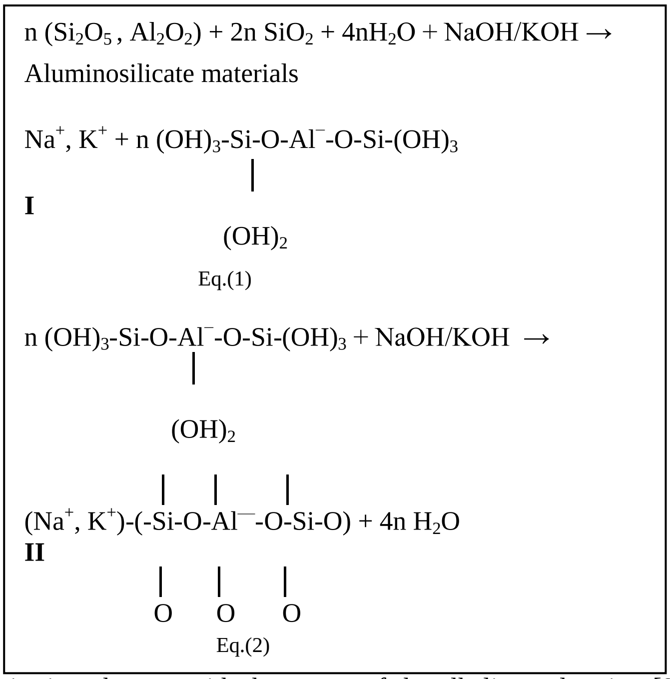
Among the various classes of geopolymers, the one with the most prominent application which can totally replace Portland cement in construction are the aluminosilicate materials [27]. Geopolymers are produced using source materials, fine and coarse aggregates and an Alkaline Activator Solution. The source materials are thermally triggered natural materials (for example kaolinite) or industrial by-products such as fly ash, GGBS etc. which are rich in aluminium (Al) and silicon (Si). Geopolymers made from various source materials show various properties. Basic Activator Solution is a reactant fluid which comprises of a combination of arrangements of sodium or potassium silicates and hydroxides or a combination of these that is water dissolvable.

It has been observed that GGBS is more activated by sodium silicate solution whereas Fly ash is activated in a better way by Sodium Hydroxide [30]. This alkaline solution helps to activate the source materials and hence called as alkali-activated cement. Activation of aluminosilicates present in any of the source materials using the alkali activator solution leads to the formation of geopolymer with chemical structure as:

$$M_n\{—(SiO_2)_q—AlO_2—\}_n$$

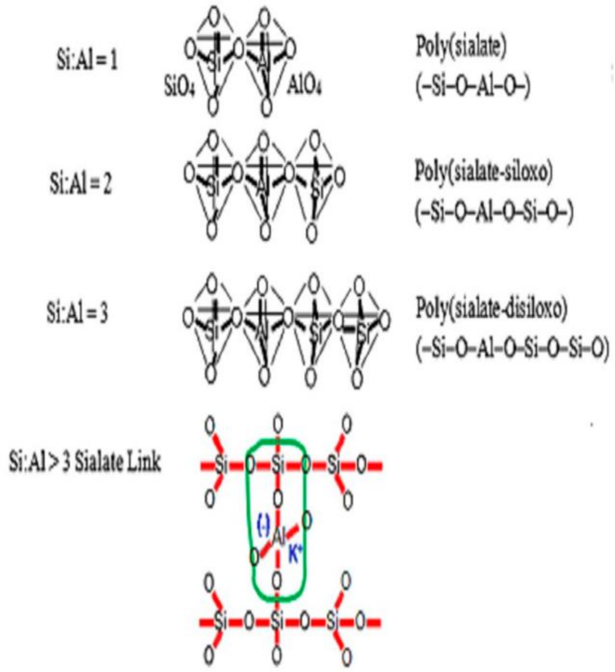
Where M addresses a soluble base metal cation, n is the level of polycondensation, and q refers to the Si/Al proportion. The structure and mechanical properties of the geopolymers are decided by the raw material composition and the concentration of alkaline solutions. Geopolymerisation refers to a consolidated procedure for the manufacture of geopolymers, which include several steps such as dissolution, reorientation, polymerisation and condensation [4].

The polymerization process incorporates two phases. In Phase I, dissolution of alumino-silicates material takes place due to the presence of water and alkaline activator, outcome of which is development of tetrahedral monomers of aluminates and silicates. In Phase II, 3-D geopolymer structure is formed by the polymerisation of the monomers [5, 6]. Formation of oligomers from monomers enhances the dissolution of reactants to a greater extent which results in a saturated solution containing a complex mixture of silicate, aluminate and alumino-silicate species which polymerise into an amorphous gel. Further condensation and hardening of the gel results in the formation of geopolymers. The time of hardening is found to be very short. The initial four hours of setting contributes to 70% of the ultimate compressive strength. During solidification water is completely eliminated and the material eventually attains its final form [7].



The extent of polymerisation changes with the nature of the alkali metal cation [8]. For K^+ cation (1.33A°) the degree of polymerisation is high because of its bigger dimension and lesser charge density compared to that of Na^+ cation (0.97A°) [8, 10]. Geopolymer thus obtained after this exothermic process has a long complex network consisting of a specific tetragonal network of aluminates (AlO_4) and silicate groups (SiO_4) linked alternatively by sharing all oxygen atoms.

The negative charges of the SiO_4 and AlO_4 tetrahedra are balanced by the cations such as Na^+ and K^+ present in the cavities of the framework. The properties of the geopolymer highly depend on the value of Si/Al ratio. If the ratio is greater than 3 geopolymers form a linear 2D network and hence exhibit adhesive and rubbery properties. If the ratio is less than 3 cross linked 3D networks will be formed and the material formed will be stiff and brittle.



Here, water is available just to encourage functionality and doesn't turn into an aspect of the subsequent geopolymer structure. That is, water doesn’t take part in the chemical reaction and is removed during the processes such as drying and curing. This is in contradiction to the hydration reactions that result in the generation of primary products of hydration such as calcium hydroxide and calcium silicate hydrate upon mixing Portland cement with water. This distinction imposes a greater effect on the chemical as well as mechanical characteristics of the subsequent GPC, and also makes it more resistant to water, heat and other means of chemical attack [27, 23]. GPC’s quality is also influenced by the time and temperature during curing. Heat has to be applied for the polymerization process to happen depending on the nature of source materials and activating solution, even though few systems are designed in such a way that curing happens at room temperature [27, 11]. Due to higher consistency the behaviour of fresh GPC mixture is rigid. The addition of super plasticizer will make the mortar more flexible and workable.

Literature Review:

It has been observed that concrete is a significant material for engineering and inclusion of some other materials may alter the characteristics of concrete and there is a greater demand for concrete with high compressive strength [12]. Greenhouse gases are emitted into the environment during crushing and heating of natural aggregates at elevated temperatures in the procedure for manufacture of concrete mix. Sequence of catastrophic fires transforms GPC into a heat resistant material. Geopolymers were found to solidify quickly at room temperature and up to 20 MPa compressive strength was attained in a single day [28]. Results of several studies have shown that GPC exhibits good engineering properties.

Trials on geopolymer mortars revealed that the significant part of 28-day strength was obtained in the initial curing for 2 days [24]. Analysis of several parameters contributing to the compressive strength of GPC implied that with gain in the temperature, curing time, resting time and strength of sodium hydroxide solution, compressive strength also upsurged [13]. A longer curing time was found to enhance the polymerisation process and resulted in the development of a concrete with higher compressive strength. It was ascertained that up to a curing time of 24 hours, strength of the concrete increased rapidly. Workability was found to be improved by adding naphthalene based super-plasticizer, but admixtures up to a level of 4% depicted in lowering the strength in compression of GPC. A 33% reduction of strength in compression was observed with surge in the ratio of water to geopolymer solids. Higher compressive strength was attained using sodium hydroxide solution of 14 M concentration.

It has been reported that presence of any one of the soluble silicates such as sodium or potassium silicate along with the alkaline liquid increased the rate of reaction in comparison to the use of only alkaline hydroxides [14]. Greater compressive strength of 19 MPa was attained for a ratio of 0.33 for alkali solution to alumina-silicate by mass and with a curing period for 72 hours at 35^{o}C [15].

The compressive strength of 150mm size geopolymer concrete cubes manufactured using Indian fly ash were examined for its durability aspects related to acid, chloride and sulphate attacks [16]. The test results disclosed the excellent properties of GPC and its structural applications which will help to minimise global warming. The variations in strength of geopolymer concrete using alkali solutions of different molarities were studied [17]. Results revealed that an ambient curing of GPC specimens for 28 days using 12 M solution helped in attaining ideal strength during compression, split elasticity and flexural strength. It was found that on completing 28 days of hot curing using 12M solutions the compressive strength, split elasticity and flexural strength were 1.25 times, 1.18 times and 1.058 times respectively greater than the GPC specimens with different molarities. Major part of the investigations have demonstrated that the concentration of NaOH utilized plays out an inevitable part in acquiring strength of the flyash debris based geopolymers.The impact of potassium hydroxide and potassium silicate on the compressive strength of low calcium fly debris based geopolymer concrete was contemplated [18].

They also performed a comparative study on the compressive strength using different molar KOH solutions at divergent curing temperatures. Studies were carried out using 8M, 10M and 12M molar solutions of potassium hydroxide at varied curing temperatures of 60°C, 70 °C and 80°C. Test results indicated that an optimum molarity and curing temperature of 12M and 70°C respectively for a given proportion attained maximum compressive strength.

The compressive strength utilizing new and solidified low-calcium flyash debris based Geopolymer mortar examples were analysed [19]. From the results it was concluded that the compressive strength of Geopolymer mortar enhanced with rise in molarity of alkaline activator. Compressive strength in the order of 1.6MPa – 20MPa was attained in 28 days with specimens with activator/flyashratio of 0.4 and cured at a temperature of 65°C for a single day.The compressive strength of fly ash based GPC was studied using Alkaline Activator solution (AAS) of different molarities [29].

Molarities of NaOH arrangement utilized were 10 M, 12 M and 14 M with ambient curing. Tests to determine the compressive strength were carried out on 7, 14 and 28 days old concrete specimens. Tests outcome revealed that as the molarity of sodium hydroxide (NaOH) solution increases, it helps in escalating the compressive strength of GPC. An ideal compressive strength was attained using NaOH solution of 12 M concentration. Mechanical properties of geopolymer paste were examined based on alterations of the alkali activator ratio [22]. NaOH and Na_2SiO_3 were utilized for the formulation of alkali activator. Geopolymer paste made using 8M NaOH, and a mass ratio of 2.5 (Na_2SiO_3 to NaOH) proved to be the best composition as it produced a compressive strength of 98.6 MPa. Similar investigation of the compressive strength of GPC and conventional concrete (CC) using M-sand as fine aggregate with different proportions was done [20].

They inferred that GPC displayed relatively better strength and can be a replacement material for CC. Studies on the effect of time, temperature and molarity of sodium hydroxide on compressive strength of fly debris based GPC were done and it was noticed that for all temperatures, as the molarity of sodium hydroxide rises an escalation in the compressive strength of GPC was observed, yet a striking change isn't observed at and above 60°C [21].

Advantages of GPC:

- Highly durable, good compressive and tensile strength
- Resistant to Fire (up to 2400^{o}F)
- Heat of hydration is low relating to cement concrete.
- As per ASTM 1202C, the chloride permeability of this concrete rates ‘low’ to ‘very low’. Hence greater safety can be provided to reinforced steel against corrosion with reference to conventional cement concrete.
- Chemical resistance is high
- High durability
- Low creep and drying shrinkage

Applications:

GPC has been utilised for the construction of walkways, water storage tanks, precast bridge decks etc. The Brisbane West Wellcamp Airport, world’s largest project on geopolymer concrete was constructed using 40,000m^3 (100,000 tonnes) of GPC, which makes it a great application in the world which saved around 6,600 tonnes of carbon emissions in its construction. Coatings of geopolymers have been used by the U.S. military for designing pavements in order to withstand the heat released during vertical takeoff and landing of aircraft. The University of Queensland's Global Change Institute (GCI), World's first Structural Building has been developed by utilizing geopolymer concrete.

Limitations:

The polymerization reaction depends on temperature and if the reaction is performed between 60-85^{o}C the attainment of strength is found to be better. This limits the utilization of geopolymers for large scale operations. Higher alkalinity of the activating solution is associated with a safety risk, as it requires more processing, which results in an increased consumption of energy and production of greenhouse gases. Efflorescence has been observed on the surface of the product in case of unreacted alkali, which was more prominent during the winter season. Thus, the practical utilisation of geopolymer concrete is limited in transportation infrastructure to precast applications. Current trend of research is to focus on the development of user-friendly geopolymers that can replace the use of alkaline activators which are highly caustic. There are no proper code standards and regulations yet, which hinders in the implementation of its various applications.

Conclusions:

Geopolymer solid shows critical potential to be a prospective material; since it isn't just naturally cordial yet in addition has great mechanical properties. GPC has high potential because of its improved sturdiness, chemical and thermal protection from heat and early age strength. Taking into account of the lower internal energy (almost 20% to 30 % less) and lesser emissions of CO_2 of geopolymer based composites in comparison to those of conventional Portland cement concretes, the new composites can be viewed to be more environment friendly and henceforth their practical utilities should be created and empowered.

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