Geopolymer concrete for sustainable development: A brief review

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Abstract:Sustainable concrete is a growth towards green and eco-friendly concrete construction practices to solve global environmental problems (e.g. global warming, energy related insecurity, climate change and water stress). With infrastructure development growing and the housing sector prospering, the demand of cement is also bound to increase in coming times. The growing worldwide demand for concrete is a great opportunity for the development of new generation of geopolymer cement and concrete of all types due to the fact that there are lower carbon emissions during their manufacturing process while also being highly resistant to many concrete durability issues. Geopolymer concrete is a cement-less construction material which is produced by chemical reaction of inorganic molecules and it requires an aluminosilicate source material such as Fly ash (FA), Metakaolin, GGBFS (Ground Granulated Blast Furnace Slag), Red mud etc. along with an user friendly alkaline activating solution; sodium or potassium soluble silicates and hydroxides which polymerize these source materials and activate silicon and aluminium to create hardened binder at relatively low temperatures. Therefore, the main objective of the present paper is to outline the essentials of geopolymer concrete briefly and also authors have sincerely attempted to review selective past works from literature based on properties, advantages and implementation of geopolymers for a sustainable environment and a greener future.
Keywords: *geopolymer; geopolymer concrete; sustainability; green technology; concrete*

1. INTRODUCTION

Sustainable development is the lay out principle for meeting human development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and economy services based upon which the economy and society depend. The desired output is a state of society where living conditions and resources are used to continue to meet human needs without undermining the power of integrity and stability of the natural system in a future generation.

Concrete is versatile and most commonly used construction material around the globe. Concrete is generally made up of three basic components: cement, aggregate and water. A major constituent of concrete is cement, which has its own environmental impacts. The cement industry is one of the largest producers of carbon dioxide; creating up to 8% of worldwide man-made emissions of this gas. According to the most recent survey of Portland Cement Association (PCA) members, an average of 927 kg of carbon dioxide for every 1000 kg of Portland cement produced in the U.S. Carbon dioxide emissions from cement production represent 3.8% of global carbon dioxide releases from fossil fuel burning. There is a growing interest in reducing carbon emissions and climate change problems related to concrete from industrial sectors. Several studies have been carried out to mitigate the use of cement content in concrete to solve global environmental issues and increase the utilization of industrial wastes. Types of industrial wastes include FA, GGBFS Metakaolin and Red mud etc. which can be reused to produce Geopolymers that may replace cement and could be applied in infrastructure constructions.

1.1. Geopolymers

Geopolymer is a substitute material produced through the alkaline activation of aluminosilicates at ambient or slightly elevated temperature, having an amorphous to semi crystalline polymeric structure with Si4+ and Al3+ cations tetrahedrally coordinated and connected by oxygen bridges [Davidovits 2005; Duxon *et al*.2007]. Geopolymers are a subset of the broader class of alkali-activated binders, which also included materials formed by alkali, silicate, carbonate or sulphate activation of metallurgical slags and giving a product that is predominately calcium silicate hydrate [Shi *et al*.2006].

1.2. Geopolymer Concrete

Geopolymer concrete is cement-less construction material which is produced by chemical reaction of inorganic molecules and it requires an aluminosilicates source material such as FA, GGBFS etc. along with a user friendly alkaline activating solution; Sodium or Potassium soluble silicates and hydroxides which polymerize these source materials and activate Silicon and Aluminium to create hardened binder at relatively low temperature. Two main constituents of Geopolymer concrete are: Source materials and alkaline activators. The result is a network formed by covalent bonds in a three-dimension structure consisting silicon, aluminium and oxygen. Several materials can be used as raw material for geopolymer concrete production [Pereira *et al*. 2019]. The alkaline activators such as Sodium or Potassium hydroxides and silicates are used to activate these aluminosilicate source materials. Compared to NaOH, KOH showed a greater level of alkalinity. The ratio of potassium hydroxide and sodium hydroxide when it is equal to 1 show near same mechanical properties of geopolymer concrete [Chavan *et al*. 2017]. Geopolymer concrete is seen as a potential alternative to Ordinary Portland Cement (OPC) concrete and an opportunity to use of industrial by-products and natural ashes in concrete such as Fly ash, GGBFS and Cement kiln dust etc. [Mehta *et al*. 2020].

2. Essential requirements for production of geopolymer concrete

2.1.Aluminosilicate Raw materials

In geopolymer concrete, the source or raw materials which are rich in silica and alumina are activated by alkaline activators to form an Al-O-Si tetrahedral geopolymer structure. Several raw materials can be used for production of geopolymer concrete such as: FA, GGBFS, Metakaolin and Red Mud. FA is a by-product of thermal power plants. FA is used as raw material in preparation of geopolymer concrete and possesses similar properties as the normal Portland cement. During the past decade, it has been mostly used as a pozzolanic material to increase the mechanical, physical and chemical properties of concrete. GGBFS is a cementitious material and is obtained by extinguishing molten iron slag from a blast furnace in water or stream. According to a past study, it was found that the addition of 25% GGBFS with 5% of glass powder under 4 M sodium hydroxide (NaOH) concentrations the concrete exhibited higher strength [Bansal *et al*.2018]. Metakaolin is the anhydrous calcined form of clay mineral kaolinite and its particle size is smaller than cement. Many studies in the past established Metakaolin based geopolymer concrete had better corrosion resistance property. The compressive strength and split tensile strength improve up to 15% with the increase content of Metakaolin [Narmatha *et al*. 2016]. Red mud or red sludge is a highly alkaline waste material composed mainly of iron oxide which is generated as a waste product from aluminum industry. The solubility of red mud decreases with NaOH as the temperature and pressure increases [Nie *et al*. 2016].

2.2. Alkaline Solution

Alkaline solutions are the second most preferable component in geopolymer concrete. Various chemicals used as the alkali activator include Sodium hydroxide or silicate and Potassium hydroxide or silicate. Sodium hydroxide (NaOH) is widely used for manufacture of geopolymer as compared to potassium hydroxide (KOH) for the purpose of increasing dissolution process. The weight ratio of 2.5 between sodium silicate $Na2SiO_3$ and sodium hydroxide NaOH is favorable for the strength development of geopolymer concrete specimens of any grade [Sanni *et al*. 2013]. It creates a high pH environment and accelerates the reaction processes. The increment of compressive, flexural strength was obtained with increment in molarity of NaOH [Kumar *et al*. 2019].

2.3. Aggregates

A geopolymer concrete with proper proportioning of total aggregate content and ratio of fine aggregate-to-total aggregate can have better engineering properties than the properties of ordinary Portland cement-based concrete [Joseph *et al*. 2012]. In design of Geopolymer concrete mix, the proportion of coarse and fine aggregates is usually taken as 77% of entire mixture by mass to produce a strong geopolymer matrix.

2.4. Curing Conditions

Several works have implemented the methods of curing of geopolymer concrete specimens which includes oven heating curing, membrane curing, steam curing, hot gunny curing, room temperature and water curing respectively. Among these various methods oven/elevated curing proved to be more preferable method for geopolymer concrete [Mohammed *et al*. 2017]. Increase in duration and temperature of oven curing increases the compressive strength of geopolymer concrete [Madhukar *et al*. 2012]. It was reported in past works that condition of curing has a good influence on the mechanical and physical properties of geopolymer. For better geopolymerisation, the curing temperatures between 40- 85 degree Celsius was required [Heah *et al*. 2011]. It is also observed that better strength resulted out of longer duration of curing but the increment in strength minimized when curing time was extended beyond 24 hours [Singh *et al* .2015].

3. Properties of Geopolymer Concrete

3.1. Workability

Wang *et al*. 2019 on their experiment worked on FA and GGFBS combination based geopolymeric recycled aggregate concrete (GRAC) and demonstrated that combination of 50% FA and 50% GGFBS with a 0.5 water-to-binder ratio could exhibit excellent workability properties. Zein *et al.* 2017 studied on the increment of workability by using retarder admixture (Plastocrete RT6 Plus). The authors found that that the setting time of the geopolymer concrete will be increased by adding more retarder admixture, thus increasing its workability. Likewise, Zhang *et al*. 2018 stated that with the increment of slag content and molarity of NaOH solution, decreases workability and setting time of geopolymer concrete. But in contrast, some studies and test results also demonstrated that increment of workability occurs with increase in concentration of sodium hydroxide solution for all alkaline solution-to-FA ratios [Patankar et al. 2014]. Mathapatiet *et al*. 2018 in a paper presented that replacement of FA by 30% of Metakaolin in geopolymer concrete reduces the workability. Workability reduces due to porous nature of Metakaolin.

3.2. Compressive Strength

Padmakar *et al*. 2017 stated that mix proportion of 30% Metakaolin and 70% of GGBFS seems to have good compressive strength; this may occur due to increase in alkaline reaction between constituents of GGBFS and Metakaolin. Nemade*et al*. 2013 found that with increase in content of red mud there will be gradually decrease in compressive strength and splitting tensile strength, optimum percentage of replacement of cement by weight 25% got nearly equal to the results of controlled concrete. Budh*et al* .2014 found that compressive strength of geopolymer concrete increases with the increase of molarity of NaOH solution. Guades *et al.* 2016 found that the compressive strength of fly ash based geopolymer concrete was higher than the conventional concrete by up to 6 times.

3.3. Durability

Singh *et al*. 2016 stated that with addition of red mud in the geopolymer concrete increases its resistance to sulphuric acid attack because of its greater alkalinity and lesser calcium content. Due to good properties and sustainability characteristics, Red mud based geopolymer concrete can be used as partial replacement of ordinary Portland cement. Nagalingam *et al*. 2019 investigated that increasing quantity of Metakaolin in the GGBFS based geopolymer concrete; a decrease in value of water absorption was noted. Gulsan *et al*. 2018 studied the effects of chemical attacks (5% sulphuric acid) on durable properties of slag based geopolymer concrete and fly ash based geopolymer concrete with respect to Ordinary Portland Cement based concrete. The results concluded that Slag based geopolymer specimens showed a little surface deterioration with grey to white color change. FA based geopolymer specimens showed a moderate surface deterioration with no color change and OPC based concrete specimens showed the greatest surface deterioration with grey to white color change. Ali *et al*. 2017 stated that the durability properties of geopolymer concrete are predominant to that of Ordinary Portland Cement based concrete within the considered exposure.

4. Geopolymer concrete for sustainable development

Concrete is the final product which is resulting from mixing binder (usually cement), aggregates and admixtures (if any required). However, the main drawback of Portland cements which needs to be overcomed is high carbon emissions. The main component of concrete is cement, which has its own environmental footprint. Emission of carbon dioxide takes place during manufacture of cement both directly when calcium carbonate is heatedand also through the extensive use of energy with its production. Considering the drawbacks of Ordinary Portland Cement (OPC) and to reduce global warming, Geopolymer concrete have great potential to substitute OPC in construction purposes.Geopolymer concrete is regarded as a class of eco-friendly construction materials which is superior substitute for sustainable development, and ideally characterized by following advantages:

- Superior corrosion resistance.
- Extreme compression and tensile strength.
- The fire resistance capacity is greater as compared to OPC.
- The dry shrinkage is very low regard to OPC.
- Geopolymer concrete is now mostly used for building of pavement, marine structures (because of resistance capacity for various chemical attacks), electric power poles etc.
- Low consumption of energy
- Low carbon concrete.
- Extreme acid resistance.
- Abundance of local raw materials.

On this basis, Geopolymer concrete is a veritable building material which can be considered as a replacement of Ordinary Portland Cement concrete in the infrastructure fields.In one of the studies it was seen that the cost production of GPC is lesser than the cost production of OPC [Thaarrini *et al*. 2016]. However, this material has not fully been widely used in various applications. But the growing demand of geopolymer across multiple numbers of industries, regarding to its heat and fire resistance is estimated to accelerate the growth of the overall market in the next few years. There are no popularity applications of geopolymer concrete in transportation areas, even though the geopolymer application is rapidly advancing in Europe and Australia. Pyrament which is blended Portland geopolymer cement successfully used for rapid pavement repair. The ability of geopolymerisation has emerged as a possible solution for immobilization and stabilization of toxic materials.Surprisingly a little is known about the nature of these reactions which requires further research.

5. Perspectives and Conclusion

The main objective of this paper is to describe a new class of eco-friendly construction material known as geopolymer Concrete which shows significant potential to be a future material as it possesses superior mechanical properties with respect to traditional cement-based concrete. This new sustainable approach/technology can be used for practical purposes like fire resistant panels, immobilization of radioactive waste, low cost bricks. Due to early setting time geopolymers, itcould be effectively used in precast infrastructure industries. However, there is a lack of information related to geopolymers and their behavior as whole therefore efforts related to successful commercialization of geopolymer concrete and solid waste management should be encouraged at a larger scale in developing countries like India.

6. References

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