A Review on Geopolymer Concrete: A Green Concrete

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Abstract - *The use of OPC (Ordinary Portland Cement) and PPC (Portland Pozzolanic Cement) is growing at the faster rate and it is consumed after the water in the world. The production of different cement requires lot of energy and burning of fuel which leads to emissions of various gases such as CO_2. The CO_2 gas is major component for producing global warming and green house effect. There is a need to introduce such type of cement that should reduce the carbon emissions and act as eco friendly cement. Curtain University of technology have done research on geopolymer concrete mix design, structural behavior and durability Geopolymer concrete is actually manufactured by reusing and recycling of industrial solid wastes and by products. Geopolymer concrete uses fly ash to gain the properties of cement and use chemicals to reduce the water demand in preparation of geopolymer concrete. This review paper will deal with the various properties of geopolymer concrete.*

***Key Words*: Geopolymer Concrete (GPC), Ordinary Cement Concrete, Fly Ash, Aqueous Solutions, Precast**

1. INTRODUCTION

1.1. Use of Concrete and Environment Impact

Increasing construction leads to the utilization of various resources which causes harmful effects of emissions on the environment. 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]. Global production of cement estimated over 2.8 billion tonnes according to recent industry data [2]. Associated with this is the emission of carbon dioxide which is responsible for 5-7% of the total global production of carbon dioxide [3]. Significant increases in cement production have been observed now days and were anticipated to increase due to the massive increase in industrialization and infrastructure in India, China and South America [4].

1.2. Geopolymer Concrete Development

Geopolymer concrete does not require any Portland cement for its production. The binder is produced by the reaction of alkaline liquid with the source material rich in alumina and silica. Geopolymer concrete is developed as a heat resistant material by the series of catastrophic fires [5]. After doing the extensive study of geopolymer, it showed as a greener material compared to portland cement concrete. It was found that geopolymer concrete showed good engineering properties [6, 7].

The use of fly ash has eco friendly properties and environmental advantages. The annual production of fly ash in Australia in 2007 was approximately 14.5 million tonnes of which only 2.3 million tonnes were utilized in beneficial ways; principally for the partial replacement of Portland cement [8]. Development of geopolymer concrete will help to make beneficial use of fly ash.

1.3. Geopolymer Concrete Properties

Early high strength gain properties of geopolymer concrete when dry heat or steam cured and although ambient temperature curing is possible for geopolymer concrete [9]. It is used for pre fabrication works of railway sleepers or other pre stressed concrete buildings. The early strength gain property can be exploited in the pre cast industry where steam curing or heated bed curing is common practice and is used to maximize the rate of production of elements. Recently geopolymer concrete has been tried in the production of precast box culverts with successful production in a commercial precast yard with steam curing.

Geopolymer concrete has excellent resistance to chemical attack and shows promise in the use of aggressive environments where the durability of Portland cement concrete may be of concern. This is particularly applicable in aggressive marine environments, environments with high carbon dioxide or sulphate rich soils. Similarly in highly acidic conditions, geopolymer concrete has shown to have superior acid resistance and may be suitable for applications such as mining, some manufacturing industries and sewer systems.

The bond characteristics of reinforcing bar in geopolymer concrete have been researched and determined to be comparable or superior to Portland cement concrete [10, 11].

2. GEOPOLYMER CONCRETE MATERIAL

2.1. Fly Ash: In thermal power plants, where pulverized coal is used for the generation of heat, Fly ash is produced as a byproduct. The production of Fly ash during this year is estimated as 225 million tonnes. Fly ash and bottom ash are produced at the rate of 80% and 20% respectively from a power plant where pulverized coal is burnt [12].

2.2. Alkaline solutions: The alkali solution is the mixture of Sodium Hydroxide (or Potassium Hydroxide) and Sodium Silicate (or Potassium Silicate) to different ratio. In addition to these above mentioned major ingredients, some of the researchers also suggested to use admixtures such as Naphthalene Based Super Plasticizer, and glass powder (Mithanthaya et. al 2015) to improve the fresh and hardened properties of GPC. Due to increase in the concentration of sodium hydroxide solution in terms of molarity (M) makes the concrete more brittle in nature with increased compressive strength [16].

2.3. Basic mixture proportions: There is no standard mix design approaches are yet available for production of GPCs. Djwantoro Hardjito, et al (2004), showed that the geopolymer paste binds together the coarse aggregates, fine aggregates and other un-reacted materials all together to form the GPC, and usual concrete mixing methods are to be used to produce GPC mixes can be often employed for preparation. Mixture proportions are characterized by an alkaline liquid to fly ash by mass of 0.35 and aggregate to total mass proportion of approximately 75% with the nominal strengths. Same as OPC concrete, the aggregates occupy the largest volume, (about 75- 80 % by mass) in GPCs.

2.4. Coarse Aggregates: Coarse aggregate is to be used of 10mm down sized and its specific gravity was found to be 2.77. It also passed the test of aggregate impact value and aggregate crushing value [12].

2.5. Fine Aggregates: Manufactured sand confirms from sieve analysis test is done to decide the zone of the sand. With specific gravity 2.56 is fineness modulus found to be 2.55 its loose density found to be 1620.kg/m3 and its dry compacted density was found to be 1842 kg/m3 [12].

3. FACTORS AFFECTING STRENGTH OF GEOPOLYMERS

The major factors that affect the strength of geopolymer concrete can be briefly discussed below:

3.1. Molarity: The Molarity of Alkali (NaOH solution) plays a very important role in strength gain of geopolymer concrete. Higher the value of NaOH solution more will be the compressive strength of the geopolymer concrete. With the molarity of 8M to 16M the compressive strength achieved by the geopolymer concrete is higher and satisfactory [13].

3.2. Sodium silicate to Sodium hydroxide ratio: The Geopolymer Concrete mix is produced by maintaining the ratio as 2.5 gives a higher compressive strength value. For producing optimum results, a ratio of 1.5 ratio has been suggested [13].

3.3. Water to geopolymer solids ratio: In this parameter the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of the water use in the making of the sodium hydroxide solution and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of binding materials, the mass of sodium hydroxide solids used to make the sodium hydroxide solution and the mass of solids in the sodium silicate solution i.e. the mass of Na_2O & SiO_2. It has suggested using a ratio of 0.17 to 0.18 to get good strength while designing GPC mix [13].

3.4. Fly ash and alkaline activator ratio: Higher the content of fly ash with the higher alkaline content gives the higher value of the compressive strength.

3.5. Rest Period: It is time between the casting and the curing. It is the time from 3 hours to 2 days, inclusion of the 24 hours before the curing starts, or the rest, increases the compressive strength of Geopolymer concrete.

4. GEOPOLYMER CONCRETE PROPERTIES:

4.1. Geopolymer compressive strength: Compressive strength is an essential property of concrete, more the compressive strength more will be the capacity of concrete to bear load. Curing time and high temperature curing leads to the higher strength of the geopolymer concrete, this is due to the fact that higher temperature leads to the higher degree of polymerization and due to this higher strength is observed. Higher the fineness of fly ash higher will be the strength of geopolymer concrete. For different fineness of fly-ash different test results were noted from which it was seen that the maximum strength is generated for that kind of flyash which has fineness 542m^2/kg[13]. With the addition of slag, the curing temperature of geo-polymer concrete get reduces and it can be cured at room temperature also imparts the good strength.

4.2. Durability and Long Term Properties of Geopolymer Concrete: The shrinkage and creep of geopolymer concrete is substantially lower than conventional Portland concrete. The Geopolymer Concrete specimens also showed a higher resistance to sulphate attack after full immersion for 15 weeks in different percentage of magnesium sulphate solution in terms of weight loss and compressive strength as compared with conventional concrete[13]. Geopolymer concrete showed better performance against acid attack with respect to Ordinary Portland Cement. The studies on the effect of corrosion resistance, utilizing activated flyash mortars in construction industry performed well and also indicated reduced corrosion of reinforcing steel bars. Geopolymer materials do not produce any dangerous alkali aggregate reaction, even if it is in the presence of high alkali content.

4.3. Behavior of Geopolymer at Elevated Temperatures: Fire resistance property of geopolymer concrete helps in making the safety of life and property. The ratio of fly ash with the alkaline solution provides the fire resistance property to the geopolymer concrete. The fly ash-based geopolymer displayed increase in strength after temperature exposure. Kong and Sanjayan (2010) observed the behavior of geopolymer concrete under the elevated temperature affected by the size of aggregates used. The aggregate with smaller sized (<10 mm) could lead to spalling and also extensive cracking of geopolymer concrete but the larger aggregate (>10 mm) were more stable with geopolymer concrete.

5. GEOPOLYMER CONCRETE OPPORTUNITIES

5.1. Geopolymer Precast Opportunities: Gourley and Johnson [14] have reported the details of geopolymer precast concrete products on a commercial scale. Precast structures were used for sewer lines, railway sleepers and wall panels. Johnson [14] also reported the good performance of reinforced geopolymer concrete railway sleepers in mainline tracks and excellent resistance of geopolymer mortar wall panels to fire and sewer pipes were also outperformed as compared to ordinary portland cement concrete many times.

AUTHOR NAME	COMPRESSIVE STRENGTH (MPa) 3 DAYS				
	8M	10M	12M	14M	16M
Robina et. al (2015)	-	-	-	-	-
U.R. Kawade et. al (2014)	-	-	-	-	-
Shivaji S. Bidwe et. al (2015)	13.48	15.26	17.03	-	-

Table -1: Compressive Strength for 3 days

AUTHOR NAME	COMPRESSIVE STRENGTH (MPa) 7 DAYS				
	8M	10M	12M	14M	16M
Robina et. al (2015)	24.58	-	26.14	-	27.84
U.R. Kawade et. al (2014)	-	-	29	32	38
Shivaji S. Bidwe et. al (2015)	-	-	-	-	-

Table -2: Compressive Strength for 7days

5.2. Geopolymer Sustainability Opportunity: Coal is often used for the generation of major proportion of the power not only in Australia but also in many other parts of the world such as India, China, and the USA. The huge reserves of good quality coal is produced worldwide and the lower cost of power produced from these resources cannot be ignored. Coal-burning at the power stations leads to the generation of huge volumes of fly ash; most of the fly ash is not effectively used for production. As the need for power increases, the volume of fly ash would increase and it can be used for the preparation of geopolymer concrete. The demand of OPC is increasing day by day so by the use of fly ash for the preparation of geopolymer concrete can be done at higher rate due to the large availability of fly ash.

For the sustainable development of the resources we need to use such type of concrete which do not harm the natural resources and acts as an eco friendly material. The use of fly ash based geopolymer concrete always reduces the global warming by reducing the emissions. A recent life cycle assessment of geopolymer concretes indicates that the global warming potential (GWP) of geopolymer concretes is between 26 and 45% lower compared to ordinary Portland cement concrete[15].

5.3. Geopolymer Economic Opportunity: Fly ash based geopolymer concrete offers several types of economic benefits over the ordinary cement. The price of one tonnes of fly ash is very less as compared to the ordinary cement. Therefore, using the alkaline liquids in geopolymer concrete makes it price about 10 to 30 % cheaper than ordinary cement. In addition, the appropriate usage of one ton of fly ash earns approximately one carbon-credit that has a significant redemption value. One ton low-calcium fly ash can be utilized to manufacture approximately three cubic meters of high quality fly ash-based geopolymer concrete, and hence earn monetary benefits through carbon-credit trade. Furthermore, the very little drying shrinkage, the low creep, the excellent resistance to sulphate attack, and good acid resistance offered by the heat-cured low-calcium fly ash-based geopolymer concrete may yield additional economic benefits when it is utilized in infrastructure applications.

6. COMPARISION OF COMPRESSIVE STRENGHTH OF FLY ASH BASED GEOPOLYMER CONCRETE WITH DIFFERENT MOLARITY OF NaOH

Table -3: Compressive Strength for 28 days

AUTHOR NAME	COMPRESSIVE STRENGTH (MPa) 28 DAYS				
	8M	10M	12M	14M	16M
Robina et. al (2015)	32.36	-	37.25	-	40.21
U.R. Kawade et. al (2014)	-	-	37.4	38.4	41.2
Shivaji S. Bidwe et. al (2015)	29.62	31.39	33.17	-	-

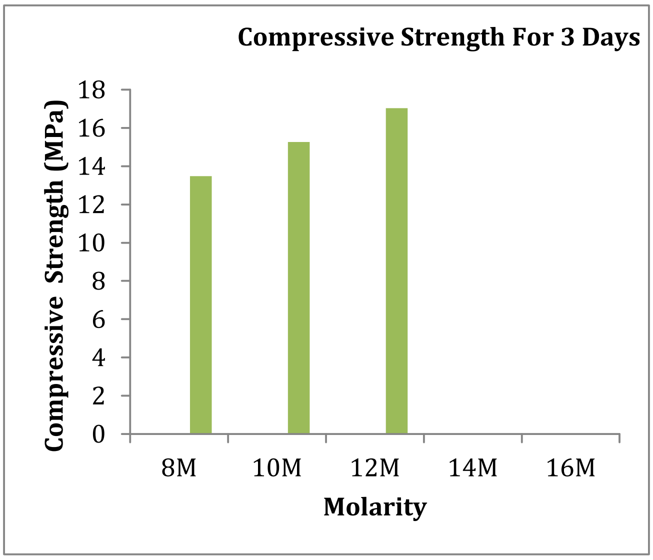

Chart -1: Graphical Representation of Compressive Strength

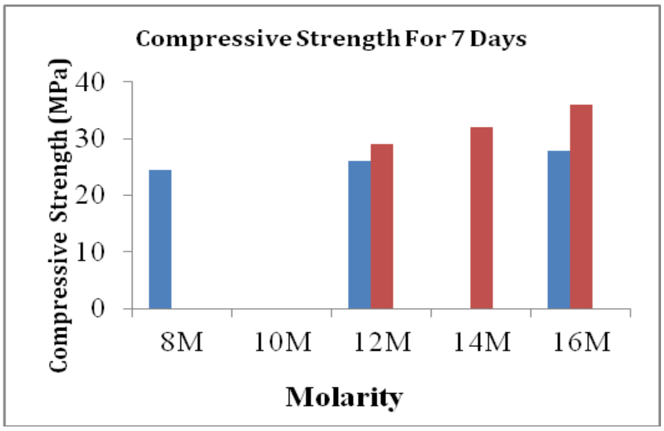

Chart -2: Graphical Representation of Compressive Strength

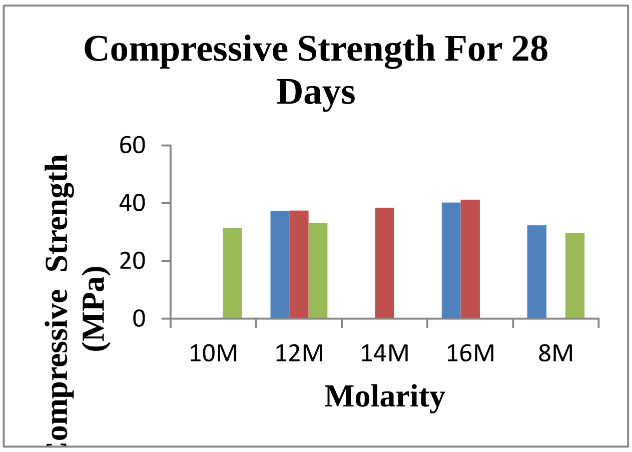

Chart -3: Graphical Representation of Compressive Strength

7. CONCLUSION

Fly ash has been recognized as better material for the preparation of geopolymer concrete and imparts the maximum compressive strength to the geopolymer concrete, due to its favorable features stated above. Significant progress has been made in developing an understanding of the phenomena underlying geopolymerization of aluminosilicates. Fly ash based geopolymer concrete has shown excellent properties and was recommended for structural applications by the researchers and with increasing the value of NaOH molarity the strength of geopolymer concrete gets increased as shown in the above tables. The value of 16M of NaOH has shown the maximum strength with the geopolymer concrete at the age of 3 days, 7 days and 28 days. However, lack of standard specifications and regulations related to processing and application in the industry level hinder its wide use in real structures. It is hoped that concentrating over such issues and needs and researching elaborately in this field will help to emerge fly ash based geopolymer concrete as a commercial and environment-friendly material and ensure the sustainability of construction industry.

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