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Utilization of plastic waste in Geopolymer concrete: State of the art review

Shemal V. Dave[1], Ankur C. Bhogayata[2], Dr. N.K.Arora[3]

[1]P.G. Student, Structure Engineering, Marwadi Education Foundation
[2]Associate Professor & Head, Civil Engineering Department, Marwadi engineering college
[3]Principal, Lukhdhirji Engineering College, Morbi, Gujarat, India

Abstract: *A considerable growth in the production of plastic leading togeneration of huge quantity of plastic waste. Reusing this as a sustainable construction material may be an ideal solution. This paper represents some of the recent developments in the field of utilization of waste material forgreen and sustainable construction material called Geopolymer concrete.It also reveals possibilities of utilization ofplastic waste as a constituent, from the work done so far. From the review of past research works it can be concluded that utilization of plastic waste materials shows scope towards development of green concrete which resembles thecement concrete.*

1. INTRODUCTION

Since the dawn of human civilization, we are utilizing natural resources for our comfort, betterment and especially to get evolve. In early stages we were utilizing natural resources in its natural form. Due to advancement in science, we forged natural resources as per our needs. When these resources reach to end of their life, we consider them as waste materials. Today tons of waste is floating all over the world, which leading to waste disposal muddle. Manufacturing industries are growing haphazardly which results in immense amount of organic and inorganic waste. Disposal of these waste is a major problem that we are facing right now.

Plastic is one of the most consumptive material all over the world. Plastic was invented in late 20th century. What makes plastic so special is its strength, durability, low cost, ease of manufacture, versatility that also makes it problematic when it comes to its end of life. Plastic waste might be used as a partial or total replacement of fine aggregates as well as course aggregates to obtain desired properties of Geopolymer concrete.

Utilization or reusing/recycling of these waste as a construction material is a partial solution to environmental problem. Use of these materials not only helps in getting them utilized in cement, concrete and other construction materials, but also helps in reducing the cost of cement and concrete manufacturing, and also has numerous indirect benefits such as reduction in landfill cost, saving in energy, and protecting the environment from possible pollution effects.

Concrete is being widely used as a construction material all over the world. Generally concrete ingredients are cement, sand and aggregates which are used globally for making concrete. Ordinary Portland cement production is the second major source of generation of carbon dioxide after automobile. Hence, it is necessary to look for an alternative material. Geopolymer is an innovative, green and sustainable construction material which is produced by the chemical action of inorganic material. Flyash which is rich in silica and alumina reacted with alkaline solution producing alumina silicate gel that acts as a binding material for concrete. Geopolymer can be casted without using ordinary Portland cement. Geopolymer concrete which already is a green and sustainable construction material by blending it with waste material we can achieve an ultimate green concrete. This paper emphasize the constituents of Geopolymer concrete and its potential application.

1.1 BRIEF OF GEOPOLYMER CONCRETE

Davidovits in 1988 proposed that an alkaline liquid could be used to react with the silicon-(Si) and the aluminium-(Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Due to the chemical action that takes place in this case is a polymerization process, he named the term "Geopolymer" to represent these binders. Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Geopolymer concrete is being widely studied extensively and shows promise as a substitute to Portland cement concrete. Research shifted from the chemistry domain to engineering applications and commercial production of Geopolymer concrete. There are two main constituents of Geopolymer, namely the source materials and the alkaline liquids. The source materials for Geopolymer based on alumina-silicate must be rich in silicon-(Si) and aluminium-(Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, waste materials such as silica fume, fly ash, rice-husk ash slag, red mud, could be used as basematerials. The alkaline liquids are from soluble alkali metals that are mostly sodium or potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate.

1.2ADVANTAGES OF GPC OVER PCC

Geopolymer concrete is considered to be an innovative material that is a viable alternative to traditional Portland cement concrete. There are numerous advantages of Geopolymer over Plain cement concrete.

1.2.1 High compressive strength:

Geopolymer concrete has higher compressive strength than ordinary Portland cement. It also has a properties of rapid strength gain and it cures very quickly which makes Geopolymer concrete an excellent option for quick builds. Geopolymer concrete has upper hand over ordinary Portland cement concrete when it comes to resist tensile forces. In other words Geopolymer concrete has high tensile strength and is less brittle than ordinary Portland cement. It also can resist higher moment than OPC which makes it suitable for earthquake resistance building.

1.2.2 Very low creep and shrinkage:

Shrinkage may be define as the contracting or shrinking of concrete in its hard form because of loss in capillary water. This shrinkage is a responsible factor for an introduction of tensile stresses in concrete which may cause cracking, deformation of concrete even before the concrete is subjected to any amount of external force. Geopolymer has very less amount of water and have very less pores than OPC which prevents losses of capillary water so it will not experience significant shrinkage.

Creep is defined as deformation or change in shape of structure subjected to sustained load. Basically, long term pressure or stress on concrete can make it change shape. The creep of Geopolymer concrete is very low.

1.2.3 Resistant to heat and cold:

Generally normal concrete face layer crack and spalling when it comes under excessive temperature. But Geopolymer can withstand at higher temperature without any damage. Geopolymer can withstand up to 1200° Celsius without any sign of damage. As for cold temperatures, it is resistant to freezing. The pores are very small but water can still enter cured concrete. When temperatures dip to below freezing that water freezes and then expands this will cause cracks to form. Geopolymer concrete will not freeze.

1.2.4 Chemical Resistance:

Concrete pore structure and its permeability is a first line of defence against aggressive chemicals. Geopolymer have very little numbers of pores compare to OPC. So it has a very strong chemical resistance. Acids, toxic waste and salt water will have a less effect on Geopolymer concrete.Corrosion is not likely to occur with this concrete as it is with traditional Portland concrete.

1.2.5 Environment friendly:

Geopolymer cement uses very low energy materials, like fly ashes, slags and other industrial wastes and a small amount of high chemical energy materials (alkali hydroxides) to bring about reaction only at the surfaces of particles to act as a glue.

2. LITERATURE REVIEW OF RECENT DEVELOPMENT IN GPC

Several authors have reported their work on Geopolymer concrete.

Muhammad FadhilNuruddin, Sobia Anwar Qazi and Nasir Shafiqinvestigated on Utilisation of waste material in geopolymeric concrete, they proposed that the flexural strength of geopolymeric concrete was comparable to OPC concrete. External exposure curing conditions were found to be the best curing regime for geopolymeric concrete given that it showed the highest value of compressive strength in comparison with similar concretes cured under ambient curing in their study. The compressive strength of the geopolymeric concrete under external exposure conditions developed up to 28 days however; there was no significant increase in strength beyond this time. The best performing geopolymeric concrete mix design, based on the results of compressive strength tests and a microstructure study, was the concrete mix cured under external exposure conditions. This mix comprised

Table: 1 Mix design for Geopolymer concrete

Sr. No.	Material	Mass	Unit
1	Fly Ash	350	kg/m^3
2	Sodium Hydroxide (NaOH)	41	kg/m^3
3	Sodium silicate (Na_2SiO_3)	103	kg/m^3
4	Table sugar	10.5	kg/m^3
5	Extra water	35	kg/m^3
6	Fine aggregate	645	kg/m^3
7	Coarse aggregate	1200	kg/m^3

H.R. Prajapati and their fellows worked on Aspects of durability of Geopolymer concrete containing metallized plastic waste their study include The performance of Geopolymer concrete was studied, using test of oxygen permeability and water sorptivity. In oxygen permeability test ingress of gases and water vapour occurs while in water sorptivity test ingress of water and hazardous liquid occurs. Experimental work was done on fly ash and waste metallized polymer plastic based Geopolymer concrete by different sodium silicate to sodium hydroxide ratio 1, 2 and 3, different molar content of sodium hydroxide 8molar, 10molar and 16molar , percentage of metallized polymer plastic waste 0%, 0.5%, 1.0% and 1.5% and cured with hot air at 100°C for 24hr. they concluded that Molar content of Sodium hydroxide (NaOH) when increased from 8M to 16M then Oxygen permeability and Water sorptivity of Geopolymer concrete decreases. Sodium silicate (Na_2SiO_3) to Sodium hydroxide (NaOH) ratio when increased from 1 to 3 then Oxygen permeability and Water sorptivity of Geopolymer concrete decreases. Metallized polymer plastic waste increased from 0% to 1.5% and then Oxygen permeability and Water sorptivity of Geopolymer concrete decreases.

M. I. Abdul Aleem and P. D. Arumairaj studied on Geopolymer concrete in their paper they concluded that User-friendly Geopolymer concrete can be used under conditions similar to those suitable for ordinary Portland cement concrete. These constituents of Geopolymer Concrete shall be capable of being mixed with a relatively low-alkali activating solution and must be curable in a reasonable time under ambient conditions. The production of versatile, cost-effective Geopolymer concrete can be mixed and hardened essentially like Portland cement. Geopolymer Concrete shall be used in repairs and rehabilitation works. Due to the high early strength Geopolymer Concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized. The Geopolymer Concrete shall be effectively used for the beam column junction of a reinforced concrete structure. Geopolymer Concrete shall also be used in the Infrastructure works. In addition to that the Flyash shall be effectively used and hence no landfills are required to dump the flyash. The government can make necessary steps to extract sodium hydroxide and sodium silicate solution from the waste materials of chemical industries, so that the cost of alkaline solutions required for the Geopolymer concrete shall be reduced.

D. Hardjito and their fellows published an invited paper, Brief review of development of Geopolymer concrete in American Concrete Institute, Los Vegas. The authors' experimental results show that the H_2O-to-Na_2O molar ratio in the mixture composition is a significant parameter affecting the compressive strength of fly ash-based Geopolymer concrete, whereas the influence of the Na_2O-to-SiO_2 molar ratio is insignificant. As the H_2O-to-Na_2O molar ratio increased the compressive strength of Geopolymer concrete decreased. Also, the compressive strength decreased when the water-to Geopolymer solids ratio by mass increased. Note that the total mass of water in the mixture is the sum of water contained in the sodium silicate solution, the mass of water in the sodium hydroxide solution, and the mass of extra water, if any, added to the mixture. The mass of Geopolymer solids in the mixture is the sum of the mass of fly ash, the mass of sodium hydroxide flakes, and the mass of solids in sodium silicate solution. Geopolymer concrete shows significant potential to be a material for the future, because it is not only environmentally friendly but also possesses excellent mechanical properties, both in short term and long term, and durability.

DjwantoroHardjito and their research teams studied on Geopolymer concrete: Turn waste into environmentally friendly concrete they represented experimental data to show the influence of various salient parameters on the compressive strength of Geopolymer concrete. Limited test results also reveal that Geopolymer concrete undergoes very little drying shrinkage and moderately low creep, and possesses excellent resistance to sulphate attack. They also pinpointed that Geopolymer concrete is an environmentally friendly and energy-efficient construction material with an enormous potential in many infrastructure applications. The binder in this concrete is produced by synthesizing waste materials that are rich in silicon and aluminium such as low calcium (class F) fly ash.

Er Bharat Bhushan Jindal briefly studied Geopolymer concrete in their paper they mentioned that Fly ash-based Geopolymer is better than normal concrete in many aspects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature. Study shows that Geopolymer concrete is more resistant to corrosion and fire, has high compressive and tensile strengths, and it gains its full strength quickly (cures fully faster). It also shrinks less than standard concrete. Thus, owing to these structural advantages it may be concluded that in near future Geopolymer concrete may find an effective alternate to standard cement concrete.

N A Lloyd and B V Rangan published a paper on Geopolymer concrete: A review of development and opportunities,This paper presents the results from studies on mix design development to enhance workability and strength of Geopolymer concrete. The influence of factors such as, curing temperature and régime, aggregate shape, strengths, moisture content, preparation and grading, on workability and strength are presented. The paper also includes brief details of some recent applications of Geopolymer concrete. They pin pointed that Basic mixture proportions characterized by 75% aggregate to total mass, alkaline liquid to fly ash of 0.35 (analogous to water to cement ratio) and elevated temperature curing results in a high strength Geopolymer concrete. Ambient curing of Geopolymer has been trialedand further mixture trials with ambient curing are presently being researched. Temperature specification for curing should be correlated to actual specimen temperature for high and very high strength Geopolymer concretes, monitoring temperature may be warranted if strength is critical and when steam curing, placement of the steam vents or hoses and control thermocouples as well as specimens is important. The introduction of a rest day, that is ambient curing for 24 hours prior to steam curing, resulted in elevated compressive strengths of the order of 20%. As with Portland cement concrete, strength was increased and workability and ease of compaction decreased with a reduction in added water. Strength gain at one day is around 80% of the 28 day strength when cured for 24 hours. As with Portland cement concrete, the aggregate moisture content can be accommodated by adjusting the total water added to a Geopolymer concrete mixture without sacrificing strength or workability. Additionally, the effect of aggregate particle shape and grading on the properties of Geopolymer concrete is similar to that of Portland cement concrete. The paper presented brief details of Geopolymer precast concrete products.

The economic benefits and contributions of Geopolymer concrete to sustainable development are also outlined.Mix design for same shown in following table.

Table: 2 Mix design for Geopolymer concrete

Material	Nominal 40MPa mixture (kg/m^3)	Nominal 60Mpa mixture (kg/m^3)	Nominal 75Mpa mixture (kg/m^3)
20 mm aggregate	641	641	641
7 mm aggregate	641	641	641
Sand	549	549	549
Flyash	404	404	404
NaOH solution	41	41	41
Na_2SiO_3 solution	102	102	102
Super Plasticizer	6	6	6
Added water	25.5	17	13.5

Zainab Z. Ismail and Enas A. AL-Hashmi worked on Use of waste plastic in concrete mixture as aggregate replacement, they have mentioned that,the compressive strength values of all waste plastic concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic ratio at all curing ages. This may be attributed to the decrease in the adhesive strength between the surface of the waste plastic and cement paste. In addition waste plastic is hydrophobic material which may restrict the hydration of cement.The dry density values of waste plastic concrete mixtures at each curing age tend to decrease below values for the reference concrete mixture, but they remain averaged to that of the reference concrete mixtures. At 28 days curing age, the lowest dry density (2223.7 kg/m3) exceeds the range of the dry density of structural lightweight concrete.The slump values of waste plastic concrete mixtures showed a tendency to decrease below the slump of the reference concrete mixture. In spite of this decline in the slump of those mixtures, those mixtures are easyto work based on the consideration that workabilityhas a broad range from very low to high workability for different applications, The flexural strength values of waste plastic concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic ratio. A concrete mixture made of 20% waste plastic has the lowest flexural strength at 28 days curing age, viz. 30.5% below the value of the reference concrete mixture.

R. A. Patel, AnkurBhogayta and their fellows worked on Flexural response of Geopolymer concrete beam containing metalized plastic waste, the beam was analysed using stress strain behaviour model proposed by Collins et. al. (Structural Design Considerations for High Strength Concrete, ACI concrete international 15(5):27-34) and compared with test results.They have highlighted that as the analytical model which is applicable to reinforced concrete given by Collins is able to predict ultimate flexural strength of Geopolymer concrete containing metallized plastic waste, indicating its flexural response is similar to reinforced concrete.For balance reinforced beam moment resistance capacity was nearly same in analytical and experimental.For analytical study moment resistance capacity was decreased 12.92%, 4.54% and 3.72% in shear reinforced beam, over reinforced beam and under reinforced beam respectively as compare to experimental.

AnkurBhogayta and their fellows worked on Strength Properties of Concrete Containing Post Consumer Metalized Plastic Wastes in their experimental work,aconventional concrete with 0.45 water/cement ratio was prepared and plastic pellets were added by 0.5%, 1% and 1.5% by concrete volume. Compressive strength, split tensile strength and surface tensile test were performed on the samples. The test results reviled the reduction of strength properties up to 60%. It could be observed that the plastic beyond 1.5% proportion could make the concrete not suitable for construction work except where the lean concrete could be used. They have also added that, the most suitable water to cement ratio was found as 0.45. It could be noticed that increase in water to cement ratio reduces the cement content and ultimately more reduction of basic strength properties could be expected.

3. DISCUSSION

Based on various papers, it is observed that there is significant advantage in the usage of fly ash in concrete for the development of environmental friendly and sustainable concrete called Geopolymer concrete, which obtained from partially or fully replacement of Portland cement in concrete, while maintaining excellent mechanical properties with enhanced durability performance. As Geopolymer concrete is a small step towards green concrete, by blending it with plastic waste might be one step forward towards ultimate green concrete which shall prove healthy to environment. Plastic waste might be utilized as a partial or total replacement of fine aggregates, coarse aggregates or could be added as filler materials.

4. CONCLUSION

Based upon above literature review it can be concluded that over the last decades, satisfactory research has been conducted on mechanical, chemical and durability aspects of Geopolymer concrete varying in proportions, curing temperature, curing time and additives. Also very satisfactory work has been conducted on different aspects of cement concrete, blended with plastic waste. However, a need of explicit data is felt from the literature review on utilization of plastic waste in Geopolymer concrete.

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