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Research Article

GEOPOLYMER – A POTENTIAL ALTERNATIVE BINDER FOR THE SUSTAINABLE DEVELOPMENT OF CONCRETE WITHOUT ORDINARY PORTLAND CEMENT

NAZNEEN[1]*, SUNDEEP C DAGGUBATI[2,3] AND VEMURI LAKSHMINARAYANA[4]

[1]Assistant Professor-Civil Engineering, Aarupadai Veedu Institute of technology, Chennai, India

[2]UG student, Civil Engineering, Department of Civil Engineering, Aarupadai Veedu Institute of Technology, Vinayaka Missions University, Kancheepuram, Chennai, India

[3]M.Eng. Std – Civil Engineering, University of Canterbury, NZ

[4]Principal, Aarupadai Veedu Institute of Technology, Chennai, India

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ABSTRACT

Production and utilisation of the two hundred year old Portland cement harmed our environment enough and this is quite evident from the results of several impact assessment studies conducted till to date. Deterioration and damage to our environment could be substantial if the dependence on such an energy intensive and versatile material is not reduced. The quest for sustainable alternatives that would substitute or completely replace this polluting binder in the concrete already started. Extinction of the age old practice of producing cement (binder) from pollution causing methods and materials seems to be predictably possible in the near future. Inorganic polymer compounds called as "Geopolymers" are proving to be the materials possessing the potential to become appropriate alternatives to Portland cement. Extensive studies are being conducted worldwide on the use of Geopolymer as an alternative to Portland cement in making the most widely used manmade material which is nothing but the concrete. This paper seeks to provide a context for development of this alternative binder, its properties, advantages and limitations. This attempt has been made based on the available literature and other reliable sources of information.

INTRODUCTION

Traditional concrete consists of Ordinary Portland Cement (OPC) and it is the main binder which holds the aggregates together to form a solid, hard and a durable building material. This OPC production has a high embodied energy and it is a great source of gases causing global warming (Gartner, 2004). It is estimated that for every kilogram of OPC that is manufactured, an emission which is equivalent to 0.66 to 0.82 kg of CO_2 is emitted in to the atmosphere (Li, *et al*., 2011). Calcination of lime and the need to heat other raw materials to elevated temperatures are the key activities which makes the production of OPC so energy intensive (Huntzinger, *et al*., 2009). Hence, it is clear that the effects of continued usage of OPC as the binder in making concrete are devastating to our environment. OPC is the pollution causing compound which needs to be replaced soon either completely or substantially with a sustainable alternative binder to ensure that the construction activities are in full swing. Global construction industry could progress well without much botheration about the compliance to rules, regulations and environmental issues arising due to various infrastructural developments depending on concrete if the emission problem related to it is solved.

A polycondensation reaction of aluminosilicate materials which are available in plenty in almost all the parts of the world results in the formation of an innovative binder called as a "Geopolmer" (Vladimir, *et al*., 2014). These are inorganic materials whichare cementitious in nature. The inherent binding ability of these compounds develop a good bonding

***Corresponding authors email: nazneen@live.in**

capability by acting like an adhesive in a mixture containing natural aggregate and other conventional by-products which are normally used in making a building material like concrete. A number of studies are being conducted considering this material's superior characteristics and properties over the concrete mix which is formed from only Ordinary Portland Cement. Notable applications among these are the encapsulation of industrial or hazardous waste and construction of Civil Infrastructure. These are the major aspects which are drawing the attention of Civil and Environmental Engineers who are extensively researching about sustainable, alternative and eco-friendly materials (Gourley, 2003; Barbosa, *et al*., 2000; Bakri, *et al*., 2011).

ORIGIN OF GEOPOLYMER

The quest for this inorganic polymer which the present world calls as "Geopolymer" seems to have actually started in the early 1970's when a team of researchers at Geopolymer Institute in France started their path breaking research of synthesising fire resistant ceramic like material. The revolutionary step was to fabricate this material without the need to bake the material at high temperatures. Davidovitswas one among the researchers and he attributed this kind of synthesis of the material to a chemical reaction that is capable of converting a clay mineral in to a complex stable compound. He also genuinely acknowledged the earlier researchers who synthesised various materials using the polycondensation reaction along with alkaline solutions but he mentioned clearly that they were unable to develop those materials to such an extent that they would find extensive implementation in the industry. The researcher collaborated with a America's leading cement manufacturer and started producing geopolymeric cement exclusively in 1984. This cement was said to be formed from acid-resistant cementitious materials (Davidovits, 2002).

SYNTHESIS OF A GEOPOLYMER

To obtain a Geopolymer with the desired mechanical properties which are consistent and long lasting there are three vital steps that are to be followed and they are thermal activation, alkali activation and polycondensation. Sodium or Potassium hydroxide in the form of an alkali solution is commonly used in the synthesis of a geopolymer and these are termed to be the reactants. Besides these materials fly-ash, ground granulated slags and other aluminosilicate amorphous materials can be used as binders. In short, when a solid aluminosilcate reacts with alkali hydroxide solution to form a synthetic alkali aluminosilacate, a geopolymer is said to be formed. Properties which these synthetic materials possess is greatly affected by the materials from they are formed and the process in which they are made (Xu and Deventar, 2000).

Sodium/Potassium Hydroxides + Silicates + Aggregates = Geopolymer Concrete

Availability of a wide range of source materials which form Geopolymer Concrete resulted an ambiguous situation and the label "Geopolymer" started seeming more generic. It becomes tough to utilise or predict the performance of various materials that fall under the source materials category due to their similarity between physical and chemical characteristics as they are not proven to be consistent constituent materials. While it is important to establish the outcome and characteristics of Geopolymerformed from various source materials, it is an encouraging observation to the note that there is a consistent stability in the basic Geopolymer matrix and the durability usually lasts long as the reaction products completely stay inert after the Geopolymerisation (Fig. 1) (James and John 2000).

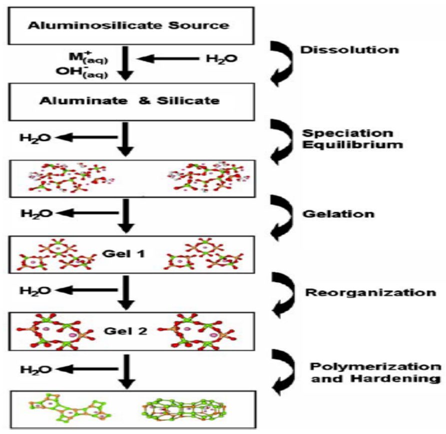

Fig. 1 A conceptual model for geo-polymerisation.

Source: Geopolymer technology: The current state of the art. Advances in Geopolymer Science & Technology P. Duxson *et al*., (2007).

ADVANTAGES OF GEOPOLYMER BINDER OVER OPC

The literature survey which was conducted revealed that the application of Geopolymer as an alternative to Ordinary Portland Cement already delivered the desired positive results which we engineers expect the concrete to possess. In some cases it was even reported that the concrete formed from the Geopolymeric binder exhibited superior properties when compared to the concrete which is made from OPC besides reducing the greenhouse emission and contributing to an effective waste management. Strong bonding phase and exceptional durability,

Table 1 Mechanical properties of geopolymer production concrete

Mix	Compressive Strength (MPa)	Std Deviation	Tensile Strength (MPa)	Flexural Strength (MPa)	Shrinkage (micro strain)	Elastic Modulus (GPa)	Poisson's ratio
32 MPa	38. 1	3.7	4.5	6.2	300	31.8	0.20
40 MPa	55.6	4.3	6.0	6.6	230	38.5	0.24

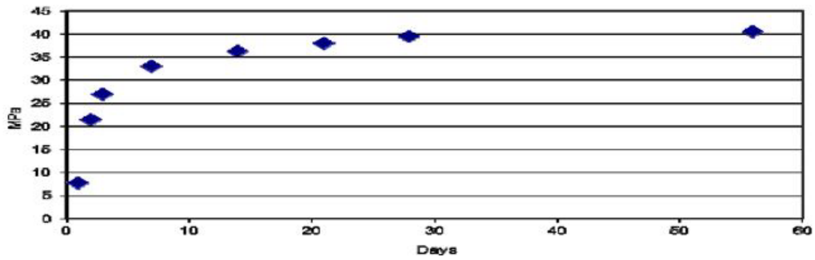

Fig. 2 Compressive strength development Source: James Aldred & John Day, AECOM Australia (2012), Article Online ID: 10003700.

High initial and overall strength and 80% less CO_2 emission, utilisation of cheaply available industrial by-products were commonly observed to be its advantages(George and Peter, 2008).

Though there is a common perception that Geopolymer requires heat curing and assumed to be gaining the required strength slowly, a test conducted on Geopolymer specimens in Australia revealed that they acquired the desired the quite rapidly and that too these specimens achieved it within 7 days. Temperature above 20°C was prevalent and it did not affect much. The summary of properties of these specimens and the development of design strength is shown below (Table 1) and (Fig. 2).

The results of this study reconfirms that the concrete made from Geopolymers usually tend to have higher tensile and flexural strength than that of traditional concrete. The reason for this can be attributed to the Geopolymer gel and aggregate bonding which seems to be much stronger than OPC and other constituent materials. Several precast works were done and the Geopolymer concrete was successfully used in the construction of retaining walls, precast beams, bridge decks and water tanks. The study revealed that this kind of concrete proved to be resistant to chloride and other chemical attack. There were no problems due drying shrinkage and the team engineers suggested for a large scale implementation of this material to promote sustainability and reduce greenhouse gases (James and John, 2000). The rebar bond with the Geopolymer matrix was also extensively studied and was found to be comparable to that of the OPC's bond with the reinforcing bars. These studies show that Reinforced Concrete can also be made possible using this material as a binder (Sofi, *et al.*, 2007; Sarkar, *et al.*, 2007).

Recycled aggregates can be used without any hesitation unlike in Portland Cement Concrete and the studies showed that waste from demolition can be used in high volume in a Geopolymer Concrete (Pacheco, *et al.*, 2012). Encapsulation of hazardous waste in the Geopolymer's binding matrix is another fascinating advantage. It takes care of these pollutants by converting the resultant compound in to an inert material (Davidovits, 2002). The following graph shows the amount of such hazardous which was locked (Fig. 3).

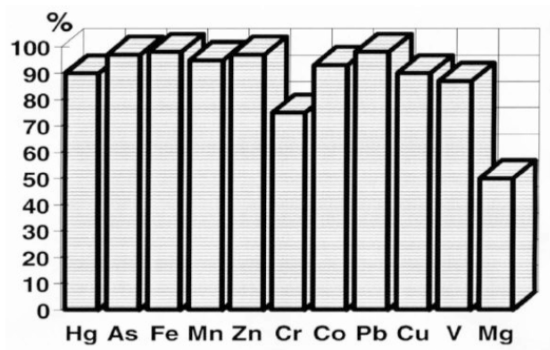

Fig. 3 Amount of pollutant encapsulation.

Source: Prof. Joseph Davidovits (2002). Environmentally Driven Geopolymer Applications.

The equivalent CO_2 emissions were also reported to be 9% less than OPC in making Geopolymer concrete (Louise and Frank, 2013). Due to the constituent materials which are naturally fire resistant in nature, Geopolymer concrete tends be resistant to fire damage and these properties were also extensively studied. It has been established that the Geopolymers with granulated blast furnace slag in them are resistant to fire attacks effectively (Cheng and Chiu, 2003). Also Carbon fiber reinforced Geopolymer composites were tested and were found to be extremely robust in resisting fire damages (Richard, 1996).

Geopolymer was also considered to be a material suitable for repair and rehabilitation and the studies conducted on this area also yielded positive results which favour the employment of Geopolymer in this field. Some among those results are as follows: Reinforced Concrete beams can be bonded with carbon fabrics successfully with the use of Geopolymers. It was also found to be extremely durable under UV light. Many researchers concluded that Geopolymers greatly affect the structural performance of repaired elements in appositive way. In this way a concrete that is made from the Geopolymer concrete could be used to retrofit, strengthen and repair damaged structural memebers effectively (Balaguru, *et al.*, 1997).

LIMITATIONS

In depth understanding of the rheological geopolymer binders is lacking and the knowledge regarding it is still vague (Barger, *et al.*, 2001). The effect of activator nature on their rheology is also unknown. Several conclusions from the literature also raises a concern about the rate at which these binder systems set in varying site conditions. Certain Geopolymers prepared from activators that contain sodium compounds in them showed less resistance to fire and the structural elements which were cast using such Geopolymer concrete seemed much vulnerable than the elements which were casted using OPC as the binder. But the presence of potassium silicate compound instead of sodium related compound seemed to have brought much thermal stability (Bakharev, 2005). This kind of uncertainties which arise due to inability to specify and employ a particular source material to obtain a desired property seems to be hindering the current advancement and adoption of Geopolymer concrete. Generic labelling of the compounds forming geopolymer as activators and binders without much understanding and investigation about their properties might be the reason for this. A fundamental flaw from which a Geopolymer is said to be suffering is that nanoporosity durability flaw which ultimately makes it placement difficult (John Harrison, 2009).

CONCLUSION

The motivation to find alternative binder systems like the Geopolymers comes from the fact that Portland Cement is being consumed very large amounts and also due to its ill effects on our environment. Portland cement may also extinct like the dodo bird on fine day but for a good cause. However, it must be admitted undoubtedly that very few of these alternative binders have been able to compete against Portland Cement. Continuous research and development in the field of alternative binder systems is very crucial at this point of time. Based on the available information, it is quite evident that Geopolymer qualifies to be an alternative binder which could eliminate the usage of Portland Cement to a maximum extent. The New Zealand cement industry was one of the first industry sectors to voluntarily come forward to help in the reduction of CO_2 levels in 1995. New Zealand has widely distributed pozzolan materials. Utilising these naturally available cementitious materials would also reduce the burden on our Environment instead of baking limestone alone. (South and Hinczak, 2001). A similar collaborative initiative to locate and identify source materials which aid in the manufacture of sustainable building materials like geopolymers would ensure the country a safe environment to live in and prosper. Besides improving the ability to procure the alternative materials, enough stress should also be kept on figuring out ways in which these new alternative binders would consistently give desired and durability properties.

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