Research Article Impact Factor: 4.226 ISSN: 2319-507X
Watile R. K., IJPRET, 2015; Volume 3 (8): 535-545 IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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SPECIAL ISSUE FOR
NATIONAL LEVEL CONFERENCE
"SUSTAINABLE TECHNOLOGIES IN CIVIL ENGINEERING"

DEVELOPMENT AND APPLICATION OF GEOPOLYMER CONCRETE: A SUSTAINABLE APPROACH

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Accepted Date: 13/03/2015; Published Date: 01/04/2015

Abstract: Geopolymer is an inorganic non-metallic material newly developed in recent years. The critical element of sustainable growth in the construction industry is the development of alternative cements. This review of the history of Geopolymer concrete research in the last few decades highlights the role of both the development of innovation and application of Geopolymer concrete.

Keywords- Fly ash, Geopolymer, Concrete, Applications, Limitations

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Access Online On:

www.ijpret.com

How to Cite This Article:

Watile R. K., IJPRET, 2015; Volume 3 (8): 535-545

PAPER-QR CODE

INTRODUCTION

Recent years have seen a great development in construction industry and demand of concrete increases. As demand for concrete as a construction material increases the production of Portland cement will also increase. However, production of Portland cement is an energy intensive process and releases a large amount of green house gas to the atmosphere. It is estimated that the production of cement will increases from about 1.5 billion tons in 1995 to 2.2 billion tons in 2010 [1]. The production of Portland cement is consequently one of the largest global sources of combustion and chemical process related carbon dioxide emissions, accounting for 6 -7 % of global carbon dioxide production, because the production of one ton of Portland cement emits approximately one ton of CO_2 [2-3]. In order to minimize the effect, needs a sustainable approach by providing a mean to limit waste and recycle material. The use of recycled materials and by products has ecological effects that benefit the environment. These efforts include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rise husk ash and metakaolin, and finding alternative binder to Portland cement.

1. DEVELOPMENT OF GEOPOLYMER CONCRETE

The term 'Geopolymer' was first discovered by Chelokovski in 1950 and then called Geopolymer by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure.

2.1 Synthesis of Geopolymer

The word syntheses exist a large number of raw materials sources rich in alumina and silicon with the potential for procuring Geopolymer. Among the materials predominant fly ash, calcined clays, Puzzolans Kaolins, illite/smectile, Metakolin and slag. Unlike Ordinary Portland cement Geopolymer do not form calcium-silicate-hydrates (C-S-H) for matrix formulation and strength. Davidovits suggested the use of the term poly (sialate)' for the chemical designation of Geopolymers based on silico-aluminate; Sialate is an abbreviation for silicon-oxo-aluminate. Poly (sialates) are chain and ring polymers with $Si4^+$ and $AL3^+$ in IV-fold coordination with oxygen and range from amorphous to semi-crystalline with the empirical formula:

$$M_n\,(-(SiO_2)_z - AlO_2)_n .\, wH_2O \qquad \text{...... (1)}$$

Where "z" is 1, 2 or 3 or higher up to 32; M is a monovalent cation such as potassium or sodium, and "n" is a degree of polycondensation. Davidovits has also distinguished 3 types of polysialates, namely the Poly (sialate) type (-Si-O-Al-O), the Poly(sialate - siloxo) type (-Si-O-Al-

O-Si-O) and the Poly(sialate-disiloxo) type (-Si-O-Al-O-Si-O). [4-6] The structures of these polysialates can be schematised as in Figure 1.1.

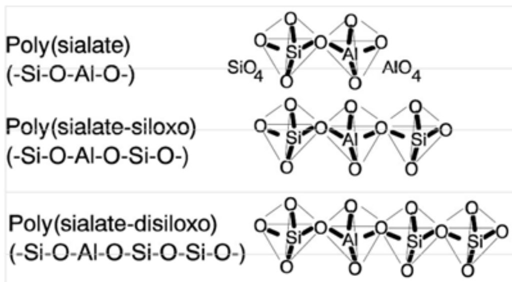

Figure 1.1 Chemical structures of polysialates

Geopolymerization involves the chemical reaction of alumino-silicate oxides (Si_2O_5, Al_2O_2) with alkali polysilicates yielding polymeric Si – O – Al bonds. Polysilicates are generally sodium or potassium silicate supplied by chemical industry or manufactured fine silica powder as a by-product of ferro-silicon metallurgy. Equation 2 shows an example of polycondensation by alkali into poly (sialatesiloxo).

(-)

$$(Si2O5,\ Al2O2)_n + {}_nSiO2 + {}_nH2O\ \ NaOH,\ KOH \longrightarrow {}_n(OH)3\text{-Si-O-Al-O-Si-(OH)3}$$

(OH)$_2$

(-) (-)

$${}_n(OH)3\text{ -Si-O-Al-O-Si-(OH)3}\ \ NaOH,\ KOH \longrightarrow (Na,K)^{(+)} -(\text{-Si-O-Al-O-Si-O-}) + {}_nH_2O$$

| | | |

(OH)2 O O O

| | | ..... (2)

Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium silicate-hydrates (CSHs) for matrix formation and strength, but utilize the poly condensation of silica and alumina precursors and a high alkali content to attain structural strength. Therefore, geopolymers are sometimes referred to as alkali activated alumino silicate binders [7]. However, Davidovits also stated that using the term 'alkali-activated' could create significant confusion and generate false granted ideas about Geopolymer concrete [8-9]. For example, the use of the term 'alkali-activated cement' or 'alkali-activated fly ash' can be confused with the term 'Alkali-aggregate reaction (AAR)' , a harmful property well known in concrete. The last term of Equation 2 indicates that water is released during the chemical reaction that occurs in the formation of Geopolymer.

2.2 Alkaline solutions

A combination of sodium silicate solution and sodium hydroxide / potassium hydroxide solution can be used as the alkaline liquid [10]. Xu et. al [11] have also studied a wide range of aluminosilicate minerals to make geopolymers. Their study involved sixteen natural Si-Al minerals which covered the ring, chain, sheet, and framework crystal structure groups, as well as the garnet, mica, clay, feldspar, sodalite and zeolite mineral groups. It was found that a wide range of natural alumino-silicate minerals provided potential sources for synthesis of geopolymers. Amir Kamalloo et. al. [12] study the effect of R_2O/Al_2O_3 (where R=Na or K), SiO_2/Al_2O_3, Na_2O/K_2O and $H2O/R_2O$ molar ratios on the compressive strength of Metakaolin base geopolymers. For alkaline solutions, they used sodium or potassium hydroxide. The test results have shown that potassium hydroxide (KOH) gave better results in terms of the compressive strength and the extent of dissolution.

2.3 Fly Ash

Fly ashes are fine and glassy powder that are recovered as a result of coal combustion during production of electricity. It is being regarded as Coal Combustion Waste. Composition of fly ash depends on fly ash source, but all fly ashes includes substantial amounts of silicon dioxide (SiO2) which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed, calcium oxide (CaO), aluminum oxide (Al2O3) and iron oxide (Fe2O3). Magnesium, potassium, sodium, titanium, and sulphur are also present in lesser amount. Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite and various iron oxides [13-14].Two main types of fly ashes: Class F fly ash and Class C fly ash exist. Table 1 summarizes the distinct difference in properties and composition of class C fly ash and class F fly ash.

Table 1 ***Properties and Composition of Fly Ash***

Properties/Composition	Class C Fly Ash	Class F Fly Ash
Early Strength(<28days)	Very effective, Can replace cement 1:1	Effective, May replace cement as high as 1:2
Reduce Permeability	Effective	Very Effective
Quartz	Found	Found
Resistance to sulfate attack	Less Effective	Very Effective
Mulllite	Not Found	Found
Tricalcium	Found	Not Found
Aluminate	Not Found	Found

The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. Source of coal always determine the chemical composition of the fly ash [15]. Burning of harder, older anthracite and bituminous coal typically produces Class F fly ash while Class C fly ash result from combustion of younger lignite or sub bituminous coal. Class F fly ash has been investigated to contains less than 20% CaO while Class C fly ash contains more than 20% CaO [16]. Fly ash has been proven to be one of the starting materials in the synthesis of geopolymer and fly ash based geopolymer concrete exhibit properties for application in construction field. Scott [17] et al confirms the usability of fly ash in the procurement of Geopolymer. Fly ash based geopolymer is generally synthesized by preparing a solution of sodium hydroxide and potassium hydroxide separately then added to the liquid commercial sodium silicate (water glass); this solution may then be added to the powdered fly ash, the same way water is add to Portland cement. Follow by curing at a temperature ranging between 60^oC and 90^o C depending on the properties of the fly ash used[18]. Oh Jae et al., [19] reported the compressive strength (14 days compressive strength) of the two main types of fly ash based Geopolymer. Author reported that "the major difference in chemical composition between the high strength and low strength samples is the calcium content of the raw materials. In the absence of sodium hydroxide, it was clearly observed that the use of water glass immediately reduced the Workability of Ca-rich sample paste, leading to a large reduction in the compressive strength. In the presence of sodium hydroxide, the addition of water glass largely enhanced the compressive strength in Ca-rich fly ash pastes". The study also reviewed that high calcium content in Class C fly ash seems to reduce the compressive strength of the synthesized geopolymer. Suresh et al., [20] manufactured geopolymer mortal with Class F fly ash and varied the percentage of alkali activator. The study reviewed out that geopolymer mortar specimens manufactured by activation with higher alkali content (%Na2O) resulted in lower water absorption, apparent porosity and water sorptivity and high compressive strength (28 days compressive strength). Residual compressive strength after exposure in sulphuric acid had a direct relationship with alkali content. Specimens with higher alkali content recorded higher residual compressive strength. Anurag et al [21] conducted an experiment on fly ash based geopolymer concrete by varying the concentration of NaOH and curing time. Compressive strength (28 days compressive strength), water absorption and tensile strength tests were conducted on each of the samples. Results of the investigation indicated that there was an increase in compressive strength with increase in NaOH concentration. Strength was also increased with increase in curing time, although the increase in compressive strength after 48hrs curing time was not significant. J. Temuujin et. al**.** [22] conclude that compressive strength of fly ash based geopolymer mortar depend on the strength of the geopolymer binder and bonding exhibits excellent between the geopolymer binder and aggregate. Increasing the proportion of aggregate in the mortar reduced the amount of geopolymerisation but did not significantly impact on compressive strength. It is proposed that compressive strength of geopolymer mortars with high levels of aggregate can be increased by optimising the amount of alkali. M. Olivia et**.** al**.** [23] concludes Fly ash geopolymer concrete exhibits low water absorption and sorptivity. Geopolymer could be classified as a concrete with average quality according to water permeability coefficient values. A water/binder ratio and well-graded aggregate are some important parameters that influence the water penetrability of low calcium fly ash geopolymer concrete. It is found that the higher water/binder ratio, then the lower water absorption and AVPV, sorptivity and water permeability. It is recommended to have low water/binder ratio

and a better grading to reduce the capillary porosity and the overall porosity of geopolymer concrete P. Chindaprasirt et. al. [24] studies the basic properties i.e. workability and strength of geopolymer mortar made from coarse lignite high calcium fly ash. The results revealed that the workable flow of geopolymer mortar was dependent on the ratio by mass of sodium silicate to NaOH and the concentration of NaOH. The geopolymer samples with high strength were obtained with the following practices: the delay time after moulding and before subjecting the sample to heat was 1 h and the optimum curing temperature in the oven was 75°C with the curing duration of not less than two days. A. Kotwal et. al**.** [25] carried out experimental program to establish a relationship between the activator composition and the properties of geopolymer mortar in fresh and hardened states. Concentrations of sodium hydroxide and sodium silicate were ascertained that are advantageous for constructability and mechanical behavior and indicate that there is potential for the concrete industry to use fly ash based geopolymer as an alternative to portland cement but there is a need to investigate the long term properties to determine if geopolymer mortar can be applied in structural building applications.

2. APPLICATION OF GEOPOLYMER CONCRETE

Geopolymer concrete products and cast in situ structures have been developed and trialled. Geopolymer concrete produced and successfully trialled on sewer pipes, railway sleeper, cemetery crypts, box culverts, and wall panels [26]. Wagners EFC Team have designed, tested and supplied EFC geopolymer concrete for the production of 33 large floor beams that form suspended floor plates of the new Global Change Institute (GCI) building at the University of Queensland St Lucia Campus [27]. Wagners in Australia is supplying a proprietary geopolymer concrete for both precast and in-situ applications successfully utilizes in field of precast girder, precast bridge deck, light pavement, retaining wall, water tank, boat ramp [28]. In addition, their chemical resistance enlarges their use in marine applications, sewage pipes and in mine tailings [29]. Also a research focuses on the adaptability of into geopolymer concrete structural members used primarily to support compressive loads. In accordance with the experimental data, it is pertinent to point out that there is a promising scope in the applicability of Geopolymer concrete as structural elements in the construction field [30-31]. In Australia the newly complete Brisbane West WellCamp Airport (BWWA) held a community open day. 70000 tonnes geopolymer concrete for airport become the greenest airport in the world, more than 30000 cubic meters of the world's lowest carbon, cement free geopolymer concrete. Wegners earth friendly concrete was used to save more than 6600 tonnes of carbon emission in construction of airport [27].

3. LIMITATIONS OF GEOPOLYMER CONCRETE

Geopolymer binders cover a wide range of possible source materials and activators. Some binders within this generic group are not viable alternatives to traditional Portland cement based concrete. The low shrinkage and heat of hydration as well as the high tensile strength means that the material may have technical advantages over traditional concrete with practical limitations like bringing the base material fly ash to the required location; high cost for the alkaline solution;

safety risk associated with the high alkalinity of the activating solution and difficulties in applying steam curing /high temperature curing process.

4. CONCLUSION

Geopolymer materials can be used as replacement of Portland cement; these are environmentally friendly and need only moderate energy for being obtained. The main product of reaction in the geopolymer materials was amorphous alkali aluminosilicate. The type of material was dependent on the activation history. The paper presented a summary of the extensive studies regarding development and successful applications; carried out by the authors on the fly ash-based geopolymer concrete. Low-calcium fly ash is used as the source material, instead of the Portland cement, to make concrete. Fly ash-based geopolymer concrete has excellent compressive strength and is suitable for structural applications with some limitations.

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