Journal of Engineering Science and Technology Review 6 (1) (2013) 25-32

Review Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Flyash Based Geopolymer Concrete – A State of the Art Review

G. Saravanan[1,*], C. A. Jeyasehar[2] and S. Kandasamy[3]

[1]*Department of Civil Engineering, A. C. College of Engineering and Technology, Karaikudi, India*
[2]*Department of Civil and Structural Engineering,Annamalai University, Annamalainagar, India.*
[3]*Department of Civil Engineering, A.C.College of Engineering and Technology, Karaikudi, India.*

Received 20 May 2012; Accepted 20 January 2013

Abstract

Concrete usage around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. But the amount of carbon dioxide released during the manufacture of OPC due to the calcinations of lime stone and combustion of fossil fuel is in the order of 600 kg for every ton of OPC produced. In addition, the extent of energy requires to produce OPC is only next to steel and aluminum. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize (by – product of burning coal, regarded as a waste material) as substitute for OPC to manufacture concrete. Binders could be produced by polymeric reaction of alkali liquids with the silicon and the aluminum in the source materials such as fly ash and rice husk ash and these binders are termed as Geopolymer. In Geopolymer Concrete, fly ash and aggregates are mixed with alkaline liquids such as a combination of Sodium Silicate and Sodium Hydroxide. United Nation's Intergovernmental panel on Climate Change (IPCC) prepared a report on global warming during April 2007 which enlists various methods of reduction of CO2 emissions into atmosphere. As per that report, unmindful pumping of CO2 into the atmosphere is the main culprit for the climate change. Large volume of fly ash is being produced by thermal power stations and part of the fly ash produced is used in concrete industry, low laying area fill, roads and embankment, brick manufacturing etc. The balance amount of fly ash is being stored in fly ash ponds. Hence it is imperative on the part of Scientists and Engineers to devise suitable methodologies for the disposal of fly ash. Disposal of fly ash has the objective of saving vast amount of land meant for ash pond to store fly ash. Further, use of fly ash as a value added material as in the case of geopolymer concrete, reduces the consumption of cement. Reduction of cement usage will reduce the production of cement which in turn cut the CO2 emissions. Many researchers have worked on the development of geopolymer cement and concrete for the past ten years. The time has come for the review of progress made in the field of development of geopolymer concrete. Consequently 102 papers pertaining to the ingredients and technology of geopolymer concrete have been reviewed in this state of the art paper.

KeyWords: OPC; Binders; flyash; geopolymer concrete; silicon and aluminium.

1.Introduction

Geopolymer is an alkali aluminosilicate binder formed by the alkali silicate activation of aluminosilicate materials. During 1950s Glukhovsky [1] developed alkali activated cements. He worked predominantly with alkali activated slags containing large amounts of calcium, where as Davidovits[2] pioneered the use of calcium- free system based calcined clay. Alkali activation of aluminosilicates can produce X-ray amorphous aluminosilicate gels, or geopolymers, with excellent mechanical as well as chemical properties. The structural backbone of these aluminosilicate (geopolymeric) gels has historically been depicted as consisting of a three dimensional frame work of SiO4 and AlO4 tetrahedra interlinked by shared O atoms. The negatively charged and tetrahedrally coordinated Al (III) atoms inside the network are charge-balanced by alkali metal cations such as Na, K and Ca. These gels can be used to bind aggregates, such as sand and natural rocks, to produce mortars and concretes. In other words, geopolymers are inorganic binders that function as the better-known Portland cement. Over the last decade, much research has been conducted on the chemical, mechanical and micro structural aspects of geopolymers [3-6]. But inadequate research focus is given to the study of the interactions between aggregates and geopolymeric binders.

2. Flyash properties and strength analysis

A mechanistic model accounting for reduced structural reorganization and densification in the microstructure of geopolymer gels with high concentrations of soluble silicon in the activating solution has been researched by Peter Duxon et al [7]. Balaguru et al [8] developed a fire proof composite made with an inorganic matrix and high strength fibers for use in aircraft interiors.

The objective of this research is to eliminate fire related deaths in air craft accidents. The focus areas are processing

* E-mail address: g_srvnn@yahoo.co.in
ISSN: 1791-2377

variables, fiber types, and mechanical properties of the composite at room and elevated temperature. Hardijito et al [9] presented the effect of mixture composition on the compressive strength of flyash based geopolymer concrete. Van Jaarsveld et al [10] analyzed the technology of geopolymerisation and demonstrated that, in certain cases, the properties of geopolymeric materials are superior to existing cementitious systems. The effects of flyash content and fiber volume fraction on the rheological and impact behaviors of short fiber reinforced flyash geopolymer composites were systematically investigated by Zhang Yunsheng et al [11].

Sofi et al [12] investigated the engineering properties of inorganic polymer concretes (IPCs) with compressive strength of 50 MPa. Kaps and Buchwald [13] view that increasing attention has been paid in the last few years on geopolymeric binders containing metakaolin, fly ash and other alumino-silicate materials. Domone [14] in his unique research study for revealed that collected the data from more than seventy recent studies on the mechanical properties of hardened self compacting concrete with small amount of flyash and analysed and correlated to produce comparisons with the properties of equivalent strength normally vibrated concrete (NVC).

Metakaolinite based geopolymer has been synthesized by Hongling Wang et al [15] at about 20ºC from metakaolinite under activation of NaOH solution [4 to 12 mol/L) and sodium silicate solution. The effect of concentration of NaOH solution on the mechanical and chemical properties of the geopolymer was investigated by means of X-ray diffraction, scanning electron microscopy and infrared spectrometry.

Kraiwood Kiattikomol et al [16] evaluated the properties of ground coarse flyashes, from five sources of Thailand, the shapes, sizes and chemical compositions of which are completely different. Faguang leng et al [17] used Nernst-Einstein equation to calculate the diffusion coefficient of chloride ions of high performance concrete (HPC), and analyzed the property of resistance to chloride ion of HPC with flyash or blast furnace slag.

Wong et al [18] investigated the effect of flyash on strength and fracture properties of the interfaces between the cement mortar and aggregates. The basic properties like workability and strength of geopolymer mortar made from coarse lignite high calcium flyash were investigated by Chindaprasirt et al [19[.

Swanepoel and Strydom [20] emphasized that more focus should be given to the study of utilizing waste products. Fly ash a waste product of the electricity and petrochemical industries was investigated as basic ingredient of a new geopolymeric material.

3.Durability of geopolymer materials.

Bakharev [21] reports the results of the study of the elevated temperature curing on phase composition, micro structure and strength development in geopolymer materials prepared using Class F fly ash and sodium silicate and sodium hydroxide solutions.

The durability of geopolymeric materials manufactured using a class F flyash and alkaline activators when exposed to a sulphate environment. The tests involved immersions for a period of 5 months in to 5% solutions of sodium sulfate and magnesium sulfate, and a solution of 5% sodium sulfate+ magnesium sulfate. The main parameters studied were the evolution of weight, compressive strength, products of degradation and micro structural changes. The degradation was studied by Bakharev [22] using X-ray diffraction, Fourier transform infrared spectroscopy and scanning electron microscopy. The performance of geopolymer materials when exposed to acid solutions was superior to ordinary Portland cement paste. Zhang Yunsheng et al [23] analysed two aspects of studies: [1] synthesis of geopolymer by using slag and metakaolin, [2] immobilization behaviours of slag based geopolymer in a presence of Pb and Cu ions. Djwantoro Hardijito et al [24] described the effects of several factors on the properties of flyash based geopolymer concrete, especially the compressive strength. The test variables included were: the age of concrete, curing time, curing temperature, quantity of super plasticizer, the rest period prior to curing, and the water content of the mix.

Bakharev [25] investigated the durability of geopolymer materials manufactured using class F fly ash and alkaline activators when exposed to a sulphate environment. The material prepared using sodium hydroxide had the best performance, which was attributed to its stable cross-linked aluminosilicate polymer structure. High strength cements can be synthesized by alkali activation of materials rich in Al2O3, and SiO2. In this study, amorphous aluminosilicate polymers produced by sodium silicate activation of metakaolinite were studied by Matthew Rowies and Brain Connor [26]. The specimen size and shape effects on the compressive strength of higher strength geopolymer concrete were investigated by Tokyay and Ozdemir [27] using different sized cylinders having constant length-to-diameter ratio (l/d),different sized cubes, and cylinders with varying l/d for compressive strength levels. Mozaffari et al [28] studied waste paper sludge ash which requires relatively higher proportions of water than Portland cement when used as a single binder. This high water demand may be reduced by the addition of secondary binders such as ground granulated blast furnace slag, which improves the hydration properties of the mixes. Shang and Song [29] attempted to generate information about the strength and deformation behaviour of plain concrete under biaxial compression. Concrete cubes were tested under biaxial compressive stresses. Two light weight aggregate concretes namely Structural Light weight Concrete (SWLC) 35 and (SWLC) 50 of 35 and 50 MPa 28 days cube strength were cast by Haque et al [30]. The light weight aggregates are used in concrete it also gives remarkable strength were studied. Atis et al.[31] analysed roller compacted concrete made with and without flyash which enjoyed numerous application in dams, roads and large floors construction in Europe, Japan, Australia and United states since 1970s.

Gunduz [32] analysed Cellular hollow light weight masonry (CHLM) blocks produced by adding flyash, scoria, perlitic pumice and cement. This could be used as a substitute for concrete hollow blocks in building industry. CHLM blocks were produced according to BS 1881 specifications. Andini et al [33] employed coal flyash for the synthesis of geopolymers. The alkali metal hydroxide (NaOH or KOH) necessary to start polycondensation has been added in the right proportion as concentrated aqueous solution. The condensation of each alkali metal solution has been adjusted in order to have the right liquid volume to ensure constant workability. Aluminosilicate geopolymers with SiO_2 / Al_2O_3 ratios ranging from 0.5 to 300 have been prepared from mixtures of dehydroxylated kaolinite with either Al2O3 or fine Acrosil with the ratios Na2O/SiO2 constantly used throughout by Ross Fletcher et al. [34] Inorganic polymers based on alumina and silica polysialate units were synthesized by Valaria Barbosa et al [35]. A series of geoplymer composites was prepared containing 10-20% volume of various granular inorganic fillers ranging from waste demolition materials through mineral tailings to engineering ceramics. Geopolymers are similar to zeolites in chemical composition but they reveal an amorphous microstructure. Hua Xu and Van Deventer [36] studied by the amount of Al available for geopolymer reaction during synthesis appears to have a dominant effect in controlling setting time, accordingly, increasing the Sio2/ Al2O3 ratio leads to longer setting times. The mechanism of Al speciation and hydrolysis in geopolymer systems are investigated by Luqian Weng et al [37] based on the partial charge model together with preliminary experimental validationShuheng Zhang et al [38] examined the effects of five kinds of water soluble organic polymers on the mechanical and physical properties of uncalcined kaolinite geopolymer. The inorganic polymer namely geopolymer has emerged as a promising material in various fields due to its better properties with respect to ceramics and cement based materialsCheng and Chiu [39] explained the use of granulated blast furnace slag as an active filler in the making of geopolymers. During the work it was found that geopolymer setting time correlates well with temperature, potassium hydroxide concentration, metakaolinite and sodium silicate addition. Metakaolinite based geopolymer composite containing 5-30% (volume fraction) polytetra-floroethylene was synthesized using composed aqueous NaOH and sodium silicate at room temperature. Flexural strength, compressive strength and elastic modulus of the composite were measured by Hongling Wang et al [40) Surface deterioration of exposed transportation structures is a major problem. In most cases, surface deterioration could lead to structural problems because of the loss of cover and ensuing reinforcement corrosion. To minimize the deterioration, various types of coatings have been tried by Balaguru [41]. Bahanja and Sengupta [42] published a mathematical model developed using statistical methods to predict the 28 day compressive strength of silica fume concrete with water to cementitious material (w/c) ratios ranging from 0.3 to 0.42 and silica fume replacement percentages from 5 to 30.Eddie Cheng and Marc Lipman [43] studied different topologies using advanced measures of vulnerability, namely strength and toughness. One of the first popular system topologies was the Boolean n-cube and it has been experimented and studied.

A long term investigation was made by Husian Al-Khait and Nijad Fattuhi [44] on the compressive strength of various concretes, subjected to Kuwait hot and environmental conditions. The main parameters investigated include W/C ratio, cement type and content, admixture and its dosage. The processing, intrinsic microstructure and properties of geopolymer materials and geopolymer composite made with basalt fibers (chopped and fiber waves) have been investigated by Waltraud Kriven et al [45]. Curing of geopolymers was achieved by one of three routes, viz., pressure less curing, warm pressing, and curing in a high pressure autoclave.Douglas Comrie and Waltrud Kri ven [46] conducted an experiment using six potassium-based geopolymer composites fabricated in 6” cube moulds. Molten diferrous silicide was poured in to the moulds at 1425º C where it was solidified and ejected to formnew shaped metal part and it can with stand more temperature.

Luca Bertlini et al [47] reported the results of a research aimed at studying the effect of replacing part of Portland cement with flyash and bottom ash, both from municipal solid waste incinerators (MSWIs). Flyash was subjected to a washing treatment to reduce the chloride content, while bottom ash was subjected to dry or wet grinding under water. Van Deventer and Lukey [48] termed the fundamental nanostructural exploration of the relationships between zeolites, traditional cements and geopolymers, with a view to optimize the geopolymer synthesis process.Douglas Comrie et al [49] stated hazardous waste can be rendered innocuous through chemical (waste stabilization) or physical (waste encapsulation) methods. Physical properties of solidified waste and sand mortar mixes have been examined on the basis of compressive strength testing. Waste treatment can be effected through both physical and chemical processes. Geopolymers are fire resistant, blast resistant, and acid resistant and could become the building and construction industry’s materials of the future. This overview [50] concludes the following 1) Economics and environmental benefits 2)Focus and out comes in future environmental conditions.Sagoe-Crentsil and Brown [51] have continued the research on recent developments in mineral polymer, (ie geopolymer), binder technology which points to a wide range of potential engineering applications within mineral processing and mining sectors.Bankowski et al [52] created geopolymer matrix using potential stabilization method for brown coal flyash obtained from electrostatic precipitate and collected from ash disposal ponds, and leaches conducted on both types of geopolymer stability ratio of flyash to geopolymer was varied to do in different compositions on leaching rates.Intermediate level wastes are immobilized in monolithic solids of low dispersibility. Alkali activated binders known as geopolymers are investigated by Khalil and Merz [53]. Monolithic solids gives more strength when added activated binders like sodium silicate and sodium hydroxide.

Tolerance of the solidified matrix to water was quite adequate. Samples maintained their shape, dimensions and strength to the end of experiments.Geopolymers are made by adding aluminosilicates to concentrated alkali solutions for dissolution and subsequent polymerization to form a solid. They are amorphous to semi- crystalline three dimensional aluminosilicate networks. Perera et al [54] have used several applications and their wide spread use is restricted due to lack of long term durability studies like macro cell test and detailed scientific understanding.

Geopolymer composites reinforced with short polyvinyl alcohol fibers have been manufactured using the extrusion technique. The extruded products were thin plates with 6mm thickness. Zongjin Li et al [55] demonstrated that short fiber reinforced composites could be extruded without additional rheological modifier. Bending test have been conducted with the extruded samples to investigate their mechanical properties. Geopolymer materials are being developed[56] as an alternating cementing system that will provide a number of significant advantages over traditional Portland cements, namely i) superior durability, ii)use of raw materials sourced within New Zealand industrial wastes and by products and iii) environmental benefits through its novel manufacturing process, eliminating carbon dioxide emission. Van Deventer et al [57] analysed high performance materials for construction, waste immobilization and an ever growing range of niche applications are produced by the reaction sequence known as ‘geopolymerisation’. In this process an alkaline activating solution reacts with a solid aluminosilicate source with solidification possible within minutes and very rapid early strength development.When crystalline aluminosilicates partially dissolve in a concentrated alkaline medium, an amorphous geopolymeric gel is formed interspersed with undissolved crystalline particles. Some aluminosilicates dissolve more readily than others to give an equilibrium ratio of aluminium to silicon in the gel. Hua Xu et al [58] studied the kaolinite and stilbite mixture used to investigate the relative reactivity of different minerals when present in different ratios.

All the papers together [59] with the present state of knowledge of flyash concrete should leave no doubt that flyash can offer a positive, eco-friendly and sustainable cementitious material for regeneration and rehabilitation of India's infrastructure. India, like many other developing countries, faces an insatiable demand for material and energy resources. Continued population explosion, rapid industrialization and wide spread urbanization demand enormous resources and supply of construction materials to rejuvenate the infrastructure facilities required to enhance the quality of life.The accelerated pozzolanic activity of various siliceous materials, like silica fume, fly ash (as received and fine ground), quartz, precipitated silica, metakaolin and rice husk ash (RHA; various fineness and carbon content), has been determined by Agarwal [60]. The compressive strength of accelerated tests has been compared with cubes cured in water at 7 and 28 days. Silica fibers have been indented by Semjonov and Kurkjian [61] with a diamond having a cube- corner tip. The tensile strength of fibers indented with loads from 0.2 to 10 g were 465-130 Mpa respectively. The indentor most commonly used (Vickers) unfortunately gives rise to flaws which are much larger (15 – 20Чm) than 1Чm.An extensive laboratory based investigation made by Jones and McCarthy [62] the use of unprocessed, run of station, low –lime flyash in foamed concrete, as a replacement for sand. By using low-lime fly ash can significantly enhance many of the properties of foamed concrete, including rheology and compressive strength development, whilst providing almost complete immunity to sulfate attack.Lutz Franke and Kritsada Sisomphon[63] were used pozzolanic components in concrete mixtures has several considerable benefits. However, the description of under standing on many of the properties of such concretes and structures is still doubtful, especially concerning the steel corrosion protection capacity. An amorphous silica by-product was investigated as a possible supplementary cementing material, standard ASTM tests for the SCM as well as specific surface area measurement, electron microscopy, Fourier transform infrared spectroscopy, X-ray Diffraction, Sif nuclear magnetic resonance spectroscopy, thermal analysis, cement paste and mortar cube strength studies were conducted by Anderson et al [64]. Laurent Trotignon et al [65] released cement based materials play important role in the design and performance of future deep radioactive waste disposals. The type of materials selected for engineered barrier systems is an important issue: protection of waste packages against corrosion and chemical degradation may be greatly enhanced by a proper choice and dimensioning. Bertil Persson [66] gave the out lines experimental laboratory any field studies on creep of young or mature high performance concrete (HPC) carried out between 1991 and 1999. For this purpose, about 400cylinders made out of eight mix compositions of HPC were studied in the laboratory. Half the number of HPC was sealed: half of the studies were carried out on air-cured HPC.Ground granulated blast furnace slag is increasingly used in concrete construction due to technical and economical benefits. Haque and Chulilung [67] described the Strength development of 3 grades of plain cement concretes, Portland blast furnace slag (slagment) concretes and concretes in which 15 and 35% of slagment was replaced by flyash (ternary blends). These concretes were cured in standard and nonstandard curing conditions using standard and nonstandard cylindrical specimens.

4. Effect of admixtures on geopolymers

The effects of replacing cement by flyash and silica fume on compressive strength, stress- strain relationship, and fracture behavior of concrete were investigated by Lam et al [68].Two geopolymer systems were prepared by alkali activation of flyash and the kaolin at room temperature with alkaline silicate solutions was analyzed by Lee and Van Deventer [69]. The system I was synthesized using a less concentrated alkaline silicate solutions than system II. Fundamental research was made by Van Jaarsveld et al [70] in to the geopolymerisation process is increasing rapidly because of the potential commercial application of this technology. Taylor and Tait [71] have investigated the effects of flyash on the fatigue resistance of cement mortars. Mehmet Gesoglu et al [72] presented a new insight in to the effects of physical and chemical properties of the flyash on the characteristics of the cold- bonded flyash light weight aggregates. Songpiriyakiji [73] has observed the compressive strength of flyash based geopolymer mortar prepared using Sodium hydroxide and sodium silicate solution as alkaline activators.An increasing demand for utilization of large scale industrial waste as added value products has projected geopolymer technology to the fore front of solidification /stabilization applications over and above its potential as a 'green' alternative to concrete. Phair and Van Deventer [74] examines the effect of alkali metal silicate precursor solutions on geopolymerisation.

Chalee.et.al.[75] have investigated the effect of W/C ratio on cover depth required against the corrosion of embedded steel of flyash concrete in marine environment up to four year exposure.

The early strength development of 'BRECEM' concrete made from 50-50 mixtures of calcium aluminate cement and ground granulated blast furnace slag (GGBS), using 100 mm cubes at w/c ratios of 0.35 and 0.45 has been studied by Keith Quillin et al. [76]

The effect of corrosion resistance was studied by Miranda et al [77] utilized activated flyash mortars in construction industry which performed well and also reducing corrosion of reinforcing steel in flyash concrete.

Cao et al [78] investigated the sulfate resistance of Portland cements. Four Portland cements of different characteristics and blended cements containing flyash, ground granulated blast furnace slag and silica fume were used in this work. Gorst and Clark [79] identified the resistance to thaumusite form of sulfate attack (TSA) of concrete mixer. However, there have been no data to indicate how TSA affects the nature and strength of the bond between reinforcing steel and concrete and hence the load carrying capacity of reinforced concrete elements. Randomly oriented short fibers have been shown to increase tensile strength and retard crack propagation of cement based materials for diverse applications, especially in aggressive environments as established by De Gutierrez et al [80]. Yuanjing Zheng et al. [81] investigated the interaction between coal and straw ash and the effect of coal quality on flyash and deposit properties; straw was co-fired with three kinds of coal in an entrained flow reactor .A series of geopolymers were made using KOH and NaOH alkaline solution by curing in auto clave at 1000psi and 80ºC for 24 hours. Samples were made using only KOH or NaOH. Waltrud Kri ven and Jonathan Bell [82]was researched the multiple alkali sources can act in a synergistic fashion to create a sample of optimal properties.Nabil Al- Akhras [83] investigated the effect of metakaolin (MK) replacement of cement on the durability of concrete to sulfate attack. The degree of sulfate attack was evaluated by measuring expansion of concrete prisms, compressive strength reduction of concrete cubes, and visual inspection of concrete specimens to cracks. The MK replacement of cement increased the sulfate resistance of concrete.Duxson et al [84] released statistical analysis of a systematic series of geopolymers with varying alkali type (sodium and potassium) and Si / Al ratio after 7 and 28 days ageing has been used as a basis of observing the development of mechanical properties with time. Minimal changes in the compressive strength of specimens was generally observed in specimens of different alkali or between 7 and 28 days of ageing. However ,mixed alkali specimens with high Si/Al ratio exhibited significant increase in strength, while pure alkali specimens displayed decrease in strength.The effect of dissolution medium variables, such as medium composition, ionic strength and agitation rate, on the swelling and erosion of Hyromellose (hydroxypropylmethylcellulose) matrices of different molecular weights were examined by Nicole Kavanagh and Owen Corrigan[85]. High strength concrete (HSC) was produced by Muhammad Shoaib Ismail and.Waliuddin [86] using locally available materials. The effect of rice husk ash (RHA) passing #200 and #300 sieves as a 10 - 30% replacement of cement on the strength of HSC. The RHA was obtained by burning rice husk, an agro-waste material which is abundantly available in the developing country.

The specimen size and shape effects on the compressive strength of high strength concrete were investigated by Tokyay and Ozdemir [87] on different sized cylinders having constant length-to-diameter ratio, different sized cubes and cylinders with various l/d for 40,60, and 75 Mpa compressive strength levelsThe early strength development of ' BRECEM' concretes, made from 50-50 mixtures of calcium aluminate cement and ground granulated blast furnace slag , using 100 mm cubes at w/c ratios of 0.34 and 0.45, has been studied by Keith Quillin et al.[88]. BRECEM concretes showed good strength development at both w/c ratios weather water cured or air cured. The compressive strength of mixture made with bottom and fly hospital ash are compared statistically with those of micro silica and conventional concretes in order to evaluate and conventional concrete in order to evaluate the effectiveness of reusing hospital incinerator ash. Nayef Al- Mutairi et al [89] results showed that the concrete cube recipe and temperatures influence the compressive strength values.The long- term strength development and the durability characteristics of this light weight concrete are being monitored in both the severe hot and dry and hot-coastal and salt-laden exposure conditions prevalent in Kuwait. The early results of the investigation suggested by Al-Khaiat and Haque [90] the compressive strength of this concrete is less sensitive to lack of initial curing.

5. Corrosion studies on fly ash based geopolymer concrete.

An accelerated corrosion test of steel bar located inside fly ash based geopolymer concrete specimens was conducted and the test results were compared by Sarawut Yodmunee and Wanchai Yodsudjai [91]. The behavior of Portland cement with and without 30% flyash additive in aggressive solutions was studied by Miletic et al [92]. This paper considers the surface corrosion of hardened cement paste test samples prepared, cured in water for 21 days, and then exposed to an aggressive environment.Addition of fiyash has beneficial effects on some mechanical properties of concrete, as well as on the corrosion process induced by the chloride ion. Montemor et al [93] investigated the effect of flyash addition on the corrosion process occurring in reinforced concrete exposed simultaneously to carbon dioxide and chloride. Reinforcement corrosion in concrete structures during the last three decades has been reported by Shamsad Ahamed [94]. It is one of the major durability problems, mainly when yhe rebar in the concrete is exposed to the chlorides either contributed from the concrete in gradients or penetrated from the surrounding chloride-bearing environment. The use of flyash to replace a portion of cement has resulted significant savings in the cost of cement production were analyzed by Velu Saraswathy and Ha-Wong Song [95]. Flyash blended cement concretes require a longer curing time and their early strength is low when compared to ordinary Portland cement concrete.

Tae- Hyun Ha et al [96] investigated the influence of mineral admixture, namely flyash on the corrosion performance of steel in mortar and concrete was studied and evaluated by some accelerated short- term techniques in sodium chloride solution.Solid- particle erosion studies were conducted on a representative geopolymer. Steady-state erosion rates were obtained and the material-loss mechanism was studied by Goretta et al [97] by scanning electron microscopy. Three repair materials including cement repair, geopolymeric repair and geopolymeric repair with steel slag were prepared. Their mechanical performances such as compressive strength, bond strength and abrasion resistance were examined experimentally by Shuguang Hu et al [98].Glasses and glass- ceramics were prepared by melting municipal solid waste incinerator fly ash and their corrosion properties were evaluated by Young Jun Park and Jong Heo[99]. Corrosion of both materials proceeded in two different steps. At the initial stage, the corrosion process is a diffusion- controlled process. A long term corrosion study were conducted by Scott. Civjan et al [100] to determine the effectiveness of calcium nitrite, silica fume, flyash, ground granulated blast furnace slag and disodium tetrapropenyl succinate in reducing corrosion of reinforcing steel in concrete. Mixture proportions included single, double, and triple combinations of these admixtures,

The extensive use and addition of mineral admixtures and the recent modifications in the physico-chemical characteristics of Portland cements have introduced a large number of variables that need to be addressed by Omar Saeed Baghabra Al-Amoudi [101]. Further more, the effect of cations associated with sulfate ions on these variables is inconclusive and extensively debated in the literature.

6. Miscellaneous topic

The distinction between manufactured and natural limestone cannot be made with the naked eye, and only can be determined by microscopic analysis was made by Ian Lawton [102]. They appear to provide a wealth of such analysis, apparently confirmed by other experts, suggesting that the samples of pyramid limestone they have been able to test are indeed manufactured.

7. Conclusion

The summary of the geopolymer study started in 2001, the published literature contained only limited knowledge and know-how on the process of making low calcium (ASTM ClassF) flyash- based geopolymer concrete. Most of the literature dealt with the use of metakaolin or calcined kaolin as the source material for making geopolymer paste and mortar. Moreover, the exact details regarding the mixture compositions and the process of making geopolymers were kept undisclosed in the patent and commercially oriented research documents. After some failures in the beginning, the trail and error method yielded successful results with regard to manufacture of low-calcium (ASTM Class F) flyash based geopolymer concrete. Once this was achieved tests were performed to quantify the effect of salient parameters that influence the short-term properties of fresh and hardened geopolymer concrete.

References

1. Glukhovsky.V.D., "Ancient, modern and future concretes", Proceedings of the first International conference on alkaline cements and concretes VIPOL Stock company Kiev. (1994), pp 1 – 9.
2. Davidovits .J, "Geopolymers : inorganic polymeric new materials' ,Journal of Thermal Analysis 37 (1991) 1633-1656
3. Davidovit . J., "Geopolymers : Inorganic polymeric new materials", Journal of Materials Education , Vol. 16 ,(1994), pp. 91 – 139.
4. Van Jaarsveld . J.G.S ,and Van Deventer. J.S.J., "The potential use of geopolymeric materials to immobilize toxic metals". Part I. Theory and applications, Miner Eng. 10 (1997) 659- 669.
5. Palomo .A, Grutzeek ..M.W , Blanco. M.T, "Alkali activated fly ashes --- a Cement for the future", Cem. Concr. Res . 29 (1999) 1323 – 1329.
6. Roy. D..M , "Alkali activated cements : opportunities and challenges", Cem. Concr Res. 29 (1999) 249-254
7. Peter Duxon , John L.Provis, Grant C.Lukey , Seth W. Mallicoat, Waltraud M. Kriven, Jannie S.J. Van Deventer," Under standing the relationship between geopolymer composition, microstructure and mechanical propertiesColloids and Surfaces "A. Phsicochem. Eng. Aspects 269 (2005) 47-58
8. Balaguru.P, Hammell.J.A, and Foden.A, "Mechanical Characterization and durability Study of Geopolymer Composites". www.geo org.
9. Hardijito.D, Wallah.S.E,. Sumajouw.D.M.J,and Rangan.B.V, "Properties of Geopolymer Concrete with Fly ash as Source Material: Effect of mixture Composition" www.geo org.
10. Van Jaarsveld .J.G.S, Van Deventer J.S.J, Lukey.G.C,"The characterisation of source materials in fly ash- based geopolymers", Materials letters 57 (2003) 1272- 1280
11. Zhang Yunsheng, Sun Wei, Li Zongjin, Zhou Xiangming, Eddie, Chau Chungkong, "Impact properties of geopolymer based extrudates incorporated with fly ash and PVA short fiber".
12. Sofi .M, Van Deventer J.S.J, Mendis .P.A, Lukey. G.C," Engineering properties of inorganic polymer concretes (IPCs)", Cement and Concrete research 37(2007) 251- 257
13. Kaps.Ch, Buchwald.A, "Property controlling influences on the generation of geopolymeric binders based clay".www.geopolymer strength properties
14. Domone.J "A review of the hardened mechanical properties of self-compacting Concrete",Cement and Concrete composites 29(2007) 1-12
15. Hongling wang ,Haihong Li, Fengyuan Yan, 'Synthesis and mechanical properties of metakaolinite –based geopolymer"r, Colloids and Surfaces A. Phsicochem. Eng. Aspects 268(2005) 6
16. Kraiwood Kiiattikomol, Chai Jaturapipitakkul, Smith Songpiriyakij, Seksun Chutibtim ," A Study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials", Cement & Concrete Composites 23 (2001) 335-343
17. Faguang Lang , Naiqian Feng , Xinying Lu," An Experimental study on the properties of resistance to diffusion of chloride ions of fly ash and blast furnaceslag cvoncrete'\, , Cement and concrete Research 30 (2000) 989-992.
18. Wong .Y. L., Lam . L, Poon C.S, Zhou. F.P, "Properties of fly ash-modified cement mortar- aggregate interfaces" , Cement and concrete Research 29 (1999) 1905 -1913
19. Chindaprasirt.P, Chareerat . T, Sirivivatnano"Workability and strength of coarse high calcium fly ash geopolymer" , Cement & Concrete Composites 29 (2007) 224-229
20. Swanepoel .J.C, Strydom.C.A, "Utilisation of fly ash in a geopolymeric material", Applied Geochemistry 17 (2002) 1143-1148
21. Bakharev.T, "Geopolymeric materials prepared using class F fly ash and elevatedtemperature curing", Cement and concrete Research 35 (2005) 1224-1232.
22. Bakharev. T, "Resistance of geopolymer materials to acid attack ", Cement and concrete Research 35 (2005) 658-670
23. Zhang Yunsheng, Sun Wei, Chen Qianli, Chen Lin, "Synthesis and heavy metal immobilization behaviors of slag based geopolymer", Journal of Hazardous Materials 143 (2007): 206-213
24. Djwantoro Hardijito, Wallah Steenie E., Sumajouw .Dody M.J.,and Rengan .B.V " Factors influencing the compressive strength of fly ash based geopolymer concrete",vol.6, No.2,2004: 88-93.
25. Bakharev.T, "Durability of geopolymer materials in sodium and magnesium sulfate Solutions", Cement and concrete Research 35 (2005) 1233-1246
26. Matthew Rowies and Brain O'Connor ,"Chemical optimization of the compressive strength of aluminosilicate geopolymers synthesized by sodium silicate activation of metakaolinite". www.geoplymer.org
27. Tokyay..M, and Ozdemir.M, "Specimen shape and size effect on the compressive strength of higher strength concrete", Cement and concrete Research , Vol.27,No 8,pp 1281-1289, 1997
28. Mozaffari.,E, O'Farrell.M, Kinuthia. J.M.,Wild. S, "Improving strength development of wastepaper sludge ash by wet-milling", Cement & Concrete Composites 28 (2006) 144 -152,
29. Shang.H.S and Song.Y.P, "Experimental study of strength and deformation of plain concrete under biaxial compression after freezing and thawing cycles", Cement and concrete Research 36 (2006) 1857-1864
30. Haque.M.N, Al-Khaiat.H, Kayali. O, "Strength and durability of light weightConcrete", Cement & Concrete Composites 26(2006) 144 -152,

31. Atis.C.D, Sevim .U.K, Ozcan .F, Bilim.C, Karahan.O, Tanrikulu.A.H, Eksi. "A,Strength properties of roller compacted concrte containing a non- standard highcalcium fly ash",,Materials letters 58 (2004) 1446-1450
32. Gunduz.L, "Use of quaret blends containing fly ash, scoria, perlitic pumice andcement to produce cellular hollow light weight masonry blocks for non-load bearing walls",Construction and building materials (In press)
33. Andini. S, Cioffi. R, Colangelo.F, Grieco.T, Montagnaro. F, Santoro. L, "Coalfly ash as raw material for the manufacture of geopolymer - based products www.geoplymer.org
34. Ross A. Fletcher, Kenneth J..D Mackenzie, Catherine L. Nicholson, Shiro Shimada , "The coposition range of aluminosilicate geopolymers",Journal of European Ceramic Society 25 (2005)1471- 1477
35. Valeria F.F. Barbosa, Kenneth J.D. Mackenzie, "Thermal behavior of inorganicgeopolymers and composites derived from sodium polysialate", Matrials research Bulletin 38 (2003) 319-331
36. Hua Xu , Van Deventer .J.S.J, "The geopolymerisation of alumino-silicateMinerals" , International Journal of mineral Processing 59 (2004) 247-266
37. Luqian Weng , Kwesi Sagoe- Crentsil, Trevor Brown, Shenhua Song, "Effects of aluminates on the formation of geopolymers", Materials Science and Engineering B 117 (2005) 163-168
38. Shuzheng Zhang, Kecheng Gong, Jianwen Lu , "Noval modification method for inorganic geopolymer by using water soluble organic polymers" , Materials letters 58 (2004) 1292-1296
39. Cheng .T.W , Chiu. J.P, "Fire-resistant geopolymer produced by granulated blast furnace slag", Minerals Engineering 16,(2003) 205-210
40. Hongling Wang , Haihong I, Fengyuan Yan, "Reduction in wear of metakaolinite –based geopolymer composite through filling of PTFE", Wear 258 (2005)1562-1566
41. Balaguru.P, "Geopolymer for protective coating of Transportation Infrastructueres ",(1998) Final report FHWANJ, 0-12
42. Bhanja. S, Sengupta.B, "Investigations on the compressive strength of silica fume concrete using stastical methods", Cement and concrete Research.Vol. 32 (2002) 1391-1394.
43. Eddie Cheng, Mare J. Lipman, "Vulnerability issues of star graphs, alternating group graphs and spilit –stars: strength and toughness", Discrete Applied Mathematics 118 (2002)163-179.
44. Husian Al-Khaiat, Nijad Fattuhi, "Long term strength development of concrete in arid conditions", Cement & Concrete Composites 23 (2001) 363-373.
45. Waltrud M. Kri ven , Jonathan Bell and Mathew Gordon, " Microstructure and Microchemistry of fully-reacted geopolymers and geopolymer matrix Components", www.geoplymer.org.
46. Douglas C.Comrie and Waltrud M. Kri ven , Composie cold ceramic geopolymer in a refractory application , www.geoplymer.org
47. Luca Bertolini, Maddalena Carsana, David Cassago, Alessandro Quadrio Curzio Mario Collepardi, " MSWI ashes as mineral additions in concrete", Cement and concrete Research.Vol. 34 (2004) 1899-1906
48. Van Deventer J.S.J and Lukey G.C, "Nanostructural Characterisation of Advancedgeopolymericmaterials', Cement and concrete Research.Vol. 37 (2005) 1909- 1926
49. Douglas C.Comrie,John H.Peterson and Douglas J.Ritcey, "Applications of geopolymer technology to waste stabilization", www.geoplymer.org
50. "Advanced &Composite materials", Over view- research , www.geoplymer.org
51. Sagoe- Crentsil.K and Brown T.J, " Bayer Process Waste Stream as Feedstock Material for Geopolymer Binder Systems", www.cmmt.csiro.au/research/papers/abstract. /771-772
52. Bankowski.P, Zou.L, Hodges.R, "Reduction of metal leaching in brown Geopolymers", www.geoplymer.org
53. Khalil.M.Y and Merz. E," Immobolisation of intermediate level wastes in Geopolymer", Journal of Nuclear Materials Volume 211, Issue 2, (1994) 141-148
54. Perera. D. S, Blackford. M.G, Vance.E.R, Hanna.J.V, Finnie.K.S, Nicholson. C.L, " Geopolymers for the Immobilisation of radioactive Waste", www.geoplymer.org
55. Zongjin Li, Yunsheng Zhang and Xiangming Zhou, "Short Fiber Reinforced Geopolymer Composites Manufactured by Extrusion", www.geoplymer.org
56. "Building innovation through geopolymer technology", www.geoplymer.org
57. Van Deventer. J.S.J,Provis . J.I, Duxson. P, Lukey .G.C, "Reaction mechanismsin the geopolymeric conversion of inorganic waste to useful products", Journal of Hazardous Materials A139 (2007)506-513.
58. Hua Xu, Jannie, Van Deventer. J.S. J, "Microstructural characterization of geopolymers synthesized from kaolinite/ stilbite mixtures using XRD, MAS- NMR, SEM/ EDX, TEM/ EDX, and HREM", Cement and concrete Research.Vol. 32 (2002)1705-1716
59. "Flyash and its use in concrete", April 2003, The Indian Concrete Journa 975 - 995
60. Agarwal . S.K, "Pozzolanic activity of various siliceous materials", Cement and concrete Research.Vol. 36 (2006) 1735-1739.
61. Semjonov. S.L, Kurkjian . C.R, "Strength of silica optical fibers with micron size Flaws", Journal of Non-crystalline Solids 283 (2001) 220-224
62. Jones .M.R, McCarthy, "Utilising unprocessed low-lime coal fly ash in foamed Concrete", Fuel 84 (2005) 1398-1409,
63. Lutz Franke, Kritsada Sisomphon, "A new chemical method for analyzing freecalcium hydroxide content in cement material", Cement and concrete Research.Vol. 34 (2005) 1161-1165.
64. Anderson. D, Roy. A, Seals.R.K, Cartledge. F.K, Akhter. H., Jones. S.C, "A preliminary assessment of the use of an amorphous silica residual as supplementary cementing material", Cement and concrete Research.Vol. 30 (2007) 437-445.
65. Laurent Trotignon, Hugues Peycelon, Xavier Bourbon, "Comparison of performance of concrete barriers in a clayey geological medium", Physics and Chemistry of the Earth 31(2006) 610-617.
66. Bertil Persson, "Correlating laboratory and field tests of creep in high performance Concrete ", Cement and concrete Research.Vol. 31, (2001) 389-395
67. Haque. M. N and Chulilung. T, "Strength development of slag and blended Concrete", Cement and concrete Research.Vol. 20, No.1 (1990) 120-130.
68. Lam.L, Wong. Y.L and Poon. C.S , "Effect of fly ash and silica fume on compressive and fracture behaviors of concrete" , Cement and concret Research.Vol. 28, No.2 pp. 271-283,1998.
69. Lee. W.K.W, Van Deventer.J.S.J, "The effects of inorganic salt contamination on the strength and durability of geopolymers" , Colloids and Surfaces Phsicochem. Eng. Aspects 211(2002) 115-126.
70. Van Jaarsveld. J.G.S, Van Deventer .J.S.J, Lukey. G.C, "The effect of composition and temperature on the properties of fly ash- and kaolinite – based geopolymers", Chemical Engineering Journal 89 (2002) 63 – 73.
71. Taylor . P.C, Tait.R.B , "Effects of fly ash on fatigue and fracture properties of hardened cement mortar" , Cement & Concrete Composites 21 (1999) 223-232
72. Mehmet Gesoglu, Turan Ozturan, Erhan Guneyisi , "Effects of fly ash properties on characteristics of cold –bonded fly ash light weight aggrecates", Construction and Building Materials 21(2007) 1869 – 1878.
73. Songpririyakij.S, "Effect of Temperature on Compressive Strength of Fly ash -based Geopolymer Mortar". www.geoplymer.org
74. Phair.J.W, Van Deventer.J.S.J, "Effect of silicate activator pH on the leaching and material characteristics of waste based inorganic polymers", Minerals Engineering. Vol.3, pp 289-304, 2001.
75. Chalee.W, Teekkavanit.M, Kiattikomol.K , Siripanichgorn. A, Jaturapittakkul.C, " Effect of W/C ratio on covering depth of fly ash concrete in marine environment", Construction and Building Materials 21 (2007) 965-971.
76. Keith Quilin , Geoff Osborne , Amal Majumdar, Bahadur Singh, "Effects of w/c ratio and curing conditions on strength development in BRECEM concretes", Cement and concrete Research.Vol. 31, (2001) 627-632
77. Miranda.J.M, Fernandez-Jime.A, Gonza lez. J.A, Palomob.A, "Corrosion resistance in activated flyash mortars", Journal of hazardous materials 137 (2006)1656-1663
78. Cao. H.T, Bucea. L, Ray. A, & Yozhatlian. S, "The Effect of Cement Composition and pH of Environment on Sulfate Resistance of Portland Cements and Blended Cements", Cement & Concrete Composites 19 (1997) 161 – 171.
79. Gorst.N.J.S and Clark.L.A, "Effects of thermal behaviour on bond strength of reinforcement in concrete", Cement & Concrete Composites 25 (2003) 1089 – 1094.

80. De Gutierrez.R.M, Diaz. L.N, Delvasto. S," Effect of pozzolanas on the performance of fiber – reinforced mortars", Cement & Concrete Composites 27 (2005) 593 -598.\
81. Yuanjing Zheng, Peter Arendt Jensen , Anker Degn, Bo sander , Helle Junker, "Ash transformation during co-firing coal and straw", Science &Direct, Fuel 86 (2007) 1008 -1020
82. Waltrud M. Kri ven and Jonathan Bell, "Effect of Alkali Choice on Geopolymer Properties", www.geoplymer.org
83. Nabil M. Al- Akhras, "Durability of metakaolin concrete to sulfate attack", Cement and concrete Research.Vol. 36 (2006 1727-1734
84. Duxson. P, Mallicoat. S.W, Lukey .G.C, Kriven . W. M, Van Deventer. J.S.J, "The effect of alkali and Si/Al ratio on the development of mechanical properties of metakaolin- based geopolymers", Colloids and Surfaces A Physico chemistry Engineering , ASPECTS 292 (2007) 8-20
85. Nicole Kavanagh and Owen I. Corrigan , "Swelling and erosion properties of Hydroxylpropyl methylcellulose (Hypromellose) matrices – influence of agitation rate and dissolution medium composition", www.geoplymer.org
86. Mohammed Shoaib Ismail and Waliuddin , "Effect of rice husk ash on high strength concrete", Construction and Building Materials vol.10,(1996) No:7 pp521-526
87. Tokyay. M and Ozdemir. M, "Specimen shape and size effect on the compressive strength of hiher strength concrete", Cement and concrete Research.Vol. 27, No,8 (1997) pp 1281-1289
88. Laney and Bill.E, "Geopolymer- modified, gypsum - based construction materials", Construction and Building Materials vol.12(2007) pg 1- 15
89. Nayef Al-Mutairi, Mohammed Terro, Abdul- Lateef Al- Khaleefi, "Effect of recycling hospital ash on the compressive properties of concrete: statistical assessment and predicting model", Building and Environment 39 (2004) 557-566
90. Al-Khaiat.H and Haque. M.N, "Effect of initial curing on early strength and physical properties of a light weight concrete", Cement and concrete Research Vol. 28, No 6, (1998) pp 859-566.
91. Sarawut Yodmunee and Wanchai Yodsudjai, "Study on corrosion of steel bar in fly ash based geopolymer concrete", International conference on Pozzoloana, Concrete and Geopolymer, www.geoplymer.org
92. Miletic.S, Ilic. M and Joanic .P "Application of energy – dispersive analysis to Portland and Portland fly ash cement corrosion", Cement and concrete Research.Vol. 28, No.11,pp 1545-1553,1998.
93. Monetemor. M..F, Cunha..M.P, Ferreira. M.G, Simoes. A.M, "Corrosion behaviour of rebars in fly ash mortar exposed to carbon dioxide and chlorides",Cement & Concrete Composites 24 (2002) 45- 53.
94. Shamsad Ahamed, "Reinforcement corrosion in concrete structures, its monitoring and service life prediction - a review", Cement & Concrete Composites 25(2003) 459- 471.
95. Velu Saraswathy and Ha-Wong Song , "Electro chemical studies on the corrosion performance of steel embedded in activated fly ash blended concrete", Electrochimica Acta 51 (2006) 4601 – 4611.
96. Tae-Hyun Ha , Srinivasan Muralidharan , Jeong- Hyo Bae , Yoon-Cheol Ha , Hyun-Goo Lee , Kyung-Wha Park , Dae-Kyeong Kim, "Accelerated short – term techniques to evaluate the corrosion performance of steel in fly ash blended concrete",Building and Environment 42 (2007) 78 – 85.
97. Goretta.K.C, Nan Chen, Routbort, J.L , Luckey. G.C and Van Deventer. J.S. " Erosion of a Geopolymer", Energy Technology Division, Argonne National Laboratory, Argonne, Illinois 60439-60538
98. Shuguang Hu , Hongxi Wang , Gaozhan Zhang , Quigjun Ding , "Bonding andabrasion resistance of geopolymeric repair material made with steel slag", Cement & Concrete Composites. In Press
99. Young Jun Park and Jong Heo, "Corrosion behavior of glass and glass- ceramics made of municipal solid waste incinerator fly ash", Waste Management 24 (2004) 825- 830
100. Scott A. Civjan, James M. LaFave, Jonna Trybulski, Daniel Lovett, Jose Lima, Donald W. Pfeifer, "Effectiveness of corrosion inhibiting admixture combinations in structural concrete", Cement and Concrete composites 27 (2005) 688-703.
101. Omar Saeed Baghabra Al-Amoudi, "Sulfate Attack and Reinforcement Corrosion in Plain and Blended Cements Exposed to sulfate Environments", Building and Environment,Vol. 33, No.1, (1998) pp 53-61
102. Ian Lawton, "The Geopolymer theory of Pyramid construction: Time for a look at the Geopolymer theory", www.geoplymer.org