Innovations in Geotechnical Engineering
Volume 1 Issue 1

A Research on the Experimental Investigation on Geopolymer Concrete and Conventional Concrete with Using Fly Ash as an Admixture

Vinay Tiwari[1], Mayank Gupta[2]
[1]Research Scholar, [2],Assistant Professor, Department of Civil Engineering SIRT-E, Bhopal, Madhya Pradesh, India
****Corresponding Author***
Email Id: er.vinay06@gmail.com

ABSTRACT

Geopolymer concrete is one of the construction materials that have become more popular in recent years due to the fact that it is significantly more environmentally friendly than standard concrete. It is produced using source materials which show pozzolanic properties and made by reacting aluminate and silicate bearing material with an activator. It is recognized that alkali additions to fly-ash or slag can activate these materials to set and harden in their own right thereby forming alkali-activated systems; however, the focus of this study is on the use of chemical pre-treatment of fly-ash to form a geopolymer which will set and harden and could be offered as a viable alternative to Portland cement. This differs basically from other types alkaline activated material (such as activated slag) since the product is polymer instead of calcium silicate hydrate (C-S-H) gel. Considerable research has now been published on the development of geopolymer binders and their properties. However, the geopolymers developed have a wide range of mix designs and additives. The research to date has focused on the properties of these materials, with different variations in performance noted. Little research has been done to understand the chemistry behind these variations and in characterizing the components of fly ash and the additives and how their interaction and relative concentrations determine the performance & properties of geopolymer concrete produced. One possible alternative, as noted above, the use of alkaline additives using industrial by-products containing alumino-silicate materials. Fly-ash is one of most common industrial by-products which is broadly used to upgrade physical, chemical and mechanical properties of cement and concrete. According to study, in India around 75 million tons of fly ash is used as a replacement material in Portland cement, corresponding to approximately 33% of the total production. Worldwide the figures are substantially higher, with China producing over 500 million tons per year. Fly ash is a pozzolanic material which reacts with lime (Ca (OH)2) from Portland cement during hydration to form C-S-H gel. Hence, when used with Portland cement, fly ash will only start to react when Portland cement hydration has taken place. This delay causes the development of strength more slowly at early ages than Portland cement alone. As a consequence, an upper limit of about 40% fly ash replacement can be used to replace Portland cement to maintain acceptable strength and durability

Keywords: *Geopolymer Concrete, Fly Ash, Pozzolanic Material, Strength, Portland cement.*

INTRODUCTION

Ordinary Portland cement (OPC), along with steel is the main construction material used in reinforced concrete structures. However, the manufacturing of hydraulic cement and therefore the concrete manufacture are both energy concentrated and end in considerable CO_2 emissions. Cement production alone is estimated as being responsible for 6-10% of total CO_2 production worldwide, with the production of 1 ton of cement producing 1 ton of CO_2. As substantial numbers of Portland cement are industrial worldwide, even a small reduction in its production could result in significant environmental benefits in terms of CO_2 emission. To date, however, OPC still remains the main cementitious binder in concrete construction hence research into environmentally-friendly alternatives assume even more importance. The use of inorganic residual products from certain manufacturing industries has been used for long as partial replacement for Portland cement. These are most notably fly-ash, rice husk ash, ground granulated blast-furnace slag, waste paper sludge ash, micro-silica etc. A considerable amount of research has now been published on these materials blended with Portland cement in binary and ternary combinations and highlights the improved mechanical and durability properties over plain Portland cement. Presently improvement of cement and concrete materials is aimed at producing high strength and good durability while maintaining an acceptable cost of energy for production. Considering that Portland cement has a high embodied energy and contributes significantly to the total worldwide CO_2 production. There is considerable possibility for the advancement of cement-free binders and represents an area which could impact significantly on the drive for more sustainable construction materials and practices. One possible alternative, as noted above, the use of alkaline additives using industrial by-products containing alumino-silicate materials. Fly-ash is one of most common industrial by-products which is broadly used to upgrade physical, chemical and mechanical properties of cement and concrete. According to study, in India around 75 million tons of fly ash is used as a replacement material in Portland cement, corresponding to approximately 33% of the total production. Worldwide the figures are substantially higher, with China producing over 500 million tons per year. Fly ash is a pozzolanic material which reacts with lime ($Ca(OH)_2$) from Portland cement during hydration to form C-S-H gel. Hence, when used with Portland cement, fly ash will only start to react when Portland cement hydration has taken place. This delay causes the development of strength more slowly at early ages than Portland cement alone. As a consequence, an upper limit of about 40% fly ash replacement can be used to replace Portland cement to maintain acceptable strength and durability.

Geopolymer Concrete

Geopolymer concrete is one of the building materials that have become more popular in recent years due to the fact that it is significantly more environmentally friendly than standard concrete. It is produced using source materials which show pozzolanic properties and made by reacting aluminate and silicate bearing material with a activator. The cement-based concrete utilizes the formation of calcium-silica hydrates (C-S-Hs) for matrix formation and strength whereas geopolymer concrete involves the chemical reaction of alumino-silicate oxides with alkaline solutions with polyciliate yielding polymeric Si–O–Al bonds. In this research work, low calcium fly ash (ASTM Class-F) is used as source material in addition with sodium hydroxide and sodium silicate to form geopolymer paste as the binder, which produces geopolymer concrete. The production of geopolymer concrete is done using the usual concrete technology methods. The aggregate’s role and influence are considered to be same as in the Portland cement concrete. The combined aggregates mass (fine and coarse aggregates) should be somewhere in the range of 70% and 80% of the mass of the geopolymer concrete.

LITERATURE SURVEY

Aleksandar Nikolov et. al. 2017 Natural zeolite is one of the potential raw materials for preparation of geopolymers. In this study, natural zeolite (clinoptilolite) from huge deposit near Beli Plast, Bulgaria was used. Geopolymer pastes and mortars were prepared by using three different alkaline additives— sodium silicate, sodium hydroxide and sodium carbonate. The hardened geopolymers were tested for analyzing of mechanical properties by traditional standard methods. Direct physical methods— thermal analysis (DTA and TGA), X-ray diffraction (XRD), and Scanning Electron Microscopy (SEM) were used for the study of the structure and the composition of the materials. The results presented variable degree of dissolutions of the raw zeolite material when the different additives were used and also showed formation of solid geopolymer materials having qualitatively different structure. Natural zeolite based geopolymers cured at room temperature and used as coating, shown very good adhesion with concrete. Taking account of the results from the studies that were conducted, it was concluded that the formation of a solid material with qualitatively different structure resulted from the mixing of natural zeolite with different types of alkaline additives. The geopolymer paste, if used for surface coating in concrete results in excellent adhesion characteristics and thus making geopolymer based on natural zeolite suitable for coatings and plasters.

Rashidah Mohamed Hamidiet. al. 2016 Utilization of alumino-silicate materials and alkali additives as the starting materials in synthesis of geopolymer matrixes where the former could be fly ash, slag or kaolin whereas the latter commonly used are sodium hydroxide (NaOH) and sodium silicates (Na2SiO3) respectively. In this study work, fly ash was selected as one of the raw materials in preparation of the geopolymer because millions of tons of fly ash generated annually by coal-based thermal power plants and the management of this material are a huge matter of concern. Hence, turning this industrial by-product (fly ash) into a valuable resource material in geopolymer production is one of the ways to address this issue. This study also focused on how the properties of geopolymer concrete get affected by the NaOH concentration. Fixed curing temperature of about 60ºC and curing time of around 1 day were maintained for geopolymer samples preparation. Scanning Electron Microscope (SEM) to observe the morphology, Fourier Transform Infrared Spectroscopy (FTIR) for structural elucidation and determination of the mechanical properties (flexural strength) was carried out by Universal Testing Machine (UTM) to systematically study the influence of NaOH concentration in range of 4M to 18M. On the basis of results of this study, the optimum NaOH concentration of 12M at which the geopolymer exhibited the best mechanical properties was arrived at.

Tanakorn Phoo-ngernkham et. al. 2016 The mechanical performance of fly ash and Portland cement geopolymer activated using sodium hydroxide and sodium silicate solutions was studied in this research work. High calcium Fly Ash (FA) and Ordinary Portland Cement (OPC) having FA:OPC weight ratios of 100:0, 95:5, 90:10, 85:15, and 80:20 were used in preparing the Geopolymer Mortars (GM). Three combinations of sodium Hydroxide Solutions (SH) and sodium Silicate Solutions (SS) viz., SH, SH+SS (SH: SS=2) and SS were prepared for the activation of GMs. Ten molar SH, alkali additive liquid/solid binder ratio of 0.60 and curing at around ambient temperature of 25oC were used for all the mixes. The results indicated that the shear bond strength and the compressive strength of GM depended upon the alkali additives used and also upon the amount of OPC used. The formation of additional Calcium Silicate Hydrate (CSH) along with sodium alumino-silicate hydrate (NASH) gel was the result of the use of SH and SHSS. Whereas, NASH gel was formed the due to the use of SS with only a small amount of CSH. The increase of the OPC content resulted in enhanced compressive and shear bond strengths of GMs because of the formation of additional CSH. The optimum compressive and shear bond strengths resulted from the 15% OPC mixed with SHSS. FTIR and FESEM based analysis had qualitatively proven.

Nour T. Abdel-Ghaniet. al. 2016 In this study, by the activation of blast furnace steel slag (GGBFS) was synthesized using 6% NaOH or using 3% NaOH + 3% Na2SiO3. The geopolymer that was obtained in both these cases exhibited amorphous, homogeneous and tightly-packed structure as well as a high compressive strength which exceeded the compressive strength obtained by conventional mortar. In testing the response toward elevated temperatures, it was seen that the geopolymer which was formed using 3% NH + 3% NS as additives revealed high degree of stability and fire resistance where it retained high strength values even under exposure of temperatures up to about 500ºC. The results clarified, also, that the geopolymer possesses fire resistance and stability higher than those of normal concrete. The current study represented the feasibility of the alkali-activated BFS geopolymer to be used as a fire-resistant coat for substituting the reinforced concrete coat on the lightweight polystyrene panels used for roofs, walls, and the partitions in construction work.

Antonella Petrillo et. al. 2016 Brick represents one of the most used materials for the construction of buildings, but the rising demand of building materials and increased construction and demolition wastes have encouraged the development of new building materials. However, the traditional brick production causes several environmental and human health impacts, so there is a clear need of searching for more efficient and durable alternatives far beyond the limitations of the conventional brick production. The production and utilization of the various alternative materials, such as the geopolymer, represents an immense opportunity for ensuring greater sustainability in the construction industry especially the use of various industrial wastes such as fly ash or the blast furnace slag, as precursors solid. The purpose of this work was to evaluate impacts during the life cycle and describes the basic operations of the geo-polymeric brick manufacturing. The analysis was done using a life cycle approach for identification and quantification of the environmental performance of the process. Study results revealed that the process of geo-polymeric brick making is more energy efficient and also involves reduction of cost in terms of the raw materials.

MATERIAL USED AND METHODOLOGY

Materials for Geopolymer Concrete

1) Fly Ash
2) Fine Aggregate
3) Coarse Aggregate
4) Sodium Hydroxide
5) Sodium Meta Silicate
6) Water

Fly Ash

Fly ash is one of the residual materials produced in the combustion of the coal. Generally, fly ash is obtained from the chimneys of power generation industries, whereas bottom ash is removed from the bottom base of the furnace. In the past years, fly ash was normally released into the atmosphere passing through the smoke stack, but in recent years the pollution control equipment is mandated and now require that this should captured prior to release. Fly ash is generally stored on industrial site at most electric power generation amenities.

Fig. 1: Fly Ash

Fine Aggregate

Sand, gravel, silt and clay are all products of natural and artificial disintegration of rock sand minerals. Sand is obtained from river, lake, glacial, residual, marine and wind-blown deposits. The particle size of fine aggregate is less than 4.75 mm confirming to IS 383:1970. Good quality dry river sand is used in this study. According to IS 383:1970 the fine aggregate is classified into four different grading zones which are Zone-I, Zone-II, Zone-III and Zone-IV.

Fig. 2: Fine Aggregate (Sand)

Coarse Aggregates

Crushed rocks are widely used as coarse aggregate. The shape of particles of crushed rock depends largely on the type of rock and method of crushing. If the aggregate is enough strong and is capable of resisting the influence of weathering without decomposition then it is considered to be physically sound. For this research work the locally available good quality coarse aggregate is used. The size of the coarse aggregate varies from 10 mm to 20 mm, means the material passed from 20 mm IS sieve but retained in 10 mm IS sieve.

Fig. 3. Coarse Aggregate

Water

Potable water free from salts, oils, sugar & any other foreign materials is used for casting and curing of cement concrete. Water plays a vital role in development of strength of concrete, so the quantity and quality of water should be taken care off. Water having pH of 6.0 to 8.0 and not tasting saline and brackish is suitable for use in mixing of concrete. Generally portable water i.e., water not containing any salinity or alkalinity should be used for mixing in concrete.

Experimental Investigation/Methodology Adopted

The following Methodology is adopted in the Research work:

1) Securing conventional ingredients of concrete such as fine aggregate, coarse aggregate and water
2) Collection of typically required materials such as fly ash, alkaline liquids
3) Preparation of samples for testing
4) Conduct of tests on prepared specimen
5) Analysis of results
6) Interpretation and discussions

RESULTS AND DISCUSSION

1) **Tests performed on materials:** Specific gravity of fly ash, consistency of fly ash, initial and final setting time of fly ash, specific gravity of fine and coarse aggregate, water absorption of fine and coarse aggregate, sieve analysis of coarse and fine aggregate.
2) **Testing on prepared samples:** Following tests were performed on prepared samples which are:

   Firstly, compressive strength test of fly ash (Fly Ash Mortar Cubes) using universal testing machine (UTM) for 3 days, 7 days and 28 days compressive strength;

Secondly, slump cone test for the determination of workability was performed for every batch;

Thirdly, compressive strength test for strength characteristics of geopolymer concrete (FlyAsh Concrete Cubes); Total 27 cube specimens were tested using universal testing machine (UTM).

Three of 100 % fly ash (geopolymer concrete) at varying percentage of chemical additives (15%, 20%, 25%), each sample consisting of nine specimens of cube. Out of these nine samples three specimens were tested for 3 days compressive test, three specimens were tested for 7 days compressive test and three specimens were tested for 28 days compressive test.

TABLE 1

Mix Description	Abbreviations used for Each Trail
Geopolymer Concrete (85 % Fly Ash + 15% Chemical Additives)	GC 1
Geopolymer Concrete (80 % Fly Ash + 20% Chemical Additives)	GC 2
Geopolymer Concrete (75 % Fly Ash + 25% Chemical Additives)	GC 3

Compressive Strength

Table 2. Average Compressive Strength of Fly Ash Mortar

Days at Testing is Done	Average Strength of 100 % Fly Ash (N/mm^2)
3 Days	44.34
7 Days	56.36
28 Days	67.56

Slump Value

Table 3. Slump Values of Different Concrete Mixes

Trials	Batch	Slump Value (mm)	Avg. Slump Values (mm)
GC 1	B1	178	175
	B2	172	
	B3	175	
GC 2	B4	167	169
	B5	171	
	B6	168	
GC 3	B7	162	159
	B8	159	
	B9	156	

DISCUSSIONS

In this research work, cement was fully replaced with fly ash and to activate the binding property chemical additives were used which are Sodium Hydroxide Flacks and Sodium Silicate at different percentage to form Geopolymer Concrete was investigated. Various comparative tests were performed on geopolymer (fly ash) and different characteristics were observed as follows:

1) **Initial and Final Setting Time:** In this test, weather effect is observed on geopolymer as in hot weather (May- June) the initial and final setting time was very less and temperature also plays a very important role in the setting, geopolymer requires high temperature (60ºC - 90ºC depends on whether) to set during curing period.
2) **Compressive Strength of Fly Ash (Mortar):** In this test, compressive strength of fly ash mortar (using chemical additives) is compared at 3, 7 and 28 days therefore observed that the compressive strength of fly ash mortar is higher than Ordinary Portland cement i.eopc cement mortar.
3) **Workability:** The workability i.e., the ease of doing work was determined by slump cone test of freshly prepared concrete; in this test it has been observed that the slump value is being decreased from GC 1 to GC 3 i.e. as the percentage of chemical additive is increased the water quantity is decreased, so the workability also decreases.
4) **Compressive Strength of Geopolymer Concrete (Fly Ash Based):** In this test, compressive strength of geopolymer concrete (fly ash + chemical additives at 15%, 20% and 25%) therefore observed that trial GC 2 and trial GC 3 are showing much more compressive strength values at 3, 7 and 28 days the compressive strength of geopolymer concrete with 25% chemical additive i.e. GC 3 is best possible mix.

CONCLUSION

In this research work it has been concluded that,

1) The mean compressive strength of fly ash mortar using chemical additives (NaOH Flacks and Na_2SiO_3) was found more as compared to cement mortar.
2) Increasing of percentage of chemical additives and decreasing the same percentage of fly ash the workability of geopolymer concrete slightly decreases.
3) The compressive strength of geopolymer concrete tends to increase with increase of percentage of chemical additives (NaOH Flacks and Na_2SiO_3) and also increases with the increase in concentration of NaOH (NaOH Flacks + Water) i.e., more the concentration high will be strength.
4) The compressive strength of GC 1 (geopolymer concrete with 15% chemical additives) at 5 N found to be satisfactory and can be opted as low-grade concrete (M15 to M20). In case of GC 2 (geopolymer concrete with 20% chemical additives) at 10 N, the compressive strength was observed optimum and fall under the category of standard grade of concrete (M25). Whereas, in case of GC 3 (geopolymer concrete with 25% chemical additives) at 14 N, the compressive strength was observed very good and also fall under the category of standard grade of concrete (M30 - M40).
5) The compressive strength of GC 2 and GC 3 observed to be increased by 2.68% and 49.11% in 3 days, 0.48% and 65.57% in 7 days and 0.27% and 49.98% in 28 days respectively as compared to CC (OPC 53 grade cement concrete).

REFERENCES

1) N. M. Attwir and S. Kabir, “Reducing Environmental Impacts through Green Concrete Technology,” no. March, pp. 4–6, 2010.

2) Z. Yahya, M. M. A. B. Abdullah, K. Hussin, K. N. Ismail, R. A. Razak, and A. V. Sandu, “Effect of solids-to-liquids, Na2SiO3-to-NaOH and curing temperature on the palm oil boiler ash (Si + Ca) geopolymerisation system,” Materials (Basel)., vol. 8, no. 5, pp. 2227–2242, 2015.
3) K. A. Anuar, A. R. M. Ridzuan, and S. Ismail, “Strength Characteristic of Geopolymer Concrete Containing Recycled Concrete Aggregate,” Environ. Eng., no. February, pp. 81–85, 2011.
4) A. Kumar Patra, M. Chowdhry, and B. K. Prusty, “Effect of Synthesis Parameters on the Compressive Strength of Fly Ash Based Geopolymer Concrete,” Int. J. Environ. Pollut. Control Manag., vol. 3, no. 1, pp. 79–88, 2011.
5) M. R. Karim, M. F. M. Zain, M. Jamil, and F. C. Lai, “Development of a zero-cement binder using slag, fly ash, and rice husk ash with chemical activator,” Adv. Mater. Sci. Eng., vol. 2015, 2015.
6) H. A. Abdel-Gawwad and S. A. Abo-El-Enein, “A novel method to produce dry geopolymer cement powder,” HBRC J., vol. 12, no. 1, pp. 13–24, 2016.
7) T. Sankaralingam, C. Roy, and S. N. Pandey, Resource For High Strength and Durability of Structures at Lower Cost. 2013.
8) M. S. Morsy, S. H. Alsayed, Y. Al-Salloum, and T. Almusallam, “Effect of Sodium Silicate to Sodium Hydroxide Ratios on Strength and Microstructure of Fly Ash Geopolymer Binder,” Arab. J. Sci. Eng., vol. 39, no. 6, pp. 4333–4339, 2014.
9) G. N. Kishore and B. Gayathri, “Experimental Study on Rise Husk Ash & Fly Ash Based Geo-Polymer Concrete Using M-Sand,” IOP Conf. Ser. Mater. Sci. Eng., vol. 225, p. 012273, 2017.
10) D. Kanesan, S. Ridha, and P. Rao, “Formulation of geopolymer cement using mixture of slag and class f fly ash for oil well cementing,” IOP Conf. Ser. Mater. Sci. Eng., vol. 201, no. 1, pp. 5–9, 2017.
11) N. T. Abdel-Ghani, H. A. Elsayed, and S. AbdelMoied, “Geopolymer synthesis by the alkali-activation of blastfurnace steel slag and its fire-resistance,” HBRC J., pp. 1–6, 2016.
12) A. Nikolov, I. Rostovsky, and H. Nugteren, “Geopolymer materials based on natural zeolite,” Case Stud. Constr. Mater., vol. 6, no. August 2016, pp. 198–205, 2017.
13) F. J. López, S. Sugita, M. Tagaya, and T. Kobayashi, “Geopolymers Using Rice Husk Silica and Metakaolin Derivatives; Preparation and Their Characteristics,” J. Mater. Sci. Chem. Eng., vol. 02, no. 05, pp. 35–43, 2014.
14) A. Petrillo, R. Cioffi, C. Ferone, F. Colangelo, and C. Borrelli, “Eco-sustainable Geopolymer Concrete Blocks Production Process,” Agric. Agric. Sci. Procedia, vol. 8, pp. 408–418, 2016.
15) R. M. Hamidi, Z. Man, and K. A. Azizli, “Concentration of NaOH and the Effect on the Properties of Fly Ash Based Geopolymer,” Procedia Eng., vol. 148, pp. 189–193, 2016.
16) K. A. Komnitsas, “Potential of geopolymer technology towards green buildings and sustainable cities,” Procedia Eng., vol. 21, pp. 1023–1032, 2011.
17) P. K. Mehta, “Greening of the Concrete Industry for Sustainable Development,” Concr. Int., vol. 24, no. 7, pp. 23–28, 2002.
18) J. Davidovits, “Properties Of Geopolymer Cements Joseph Davidovits Geopolymer Institute, Cordi-Geopolymère SA, 16 rue Galilée, 02100 Saint-Quentin, France,” Geopolymer Inst., pp. 1–19, 1994.