Study on Research of Geoplymer Concrete with Fly Ash and Quarrydust

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Abstract— The invention of Geo-polymers has paved the way for construction industry to use Fly ash based Geo-Polymer Concrete with 100 % replacement of cement. Substantial experimental research has been conducted ever since on Geo-Polymer concrete which can prove to the sustainable construction material of the future. This paper reviews various materials used for manufacturing this concrete such as alkaline liquids, fly ash, aggregates and super-plasticizers. The experimental investigations based on my own project report with respect to aspects such as mix design, curing etc. and their impact on properties of Geo-polymer concrete has also been reported. Finally, concluding remarks and suggestions regarding the applications of Geo-polymer concrete are delineated at the end.

Key words: Geopolymer Concrete, Fly ash, Alkaline Activator, Curing, Strength, Applications

I. INTRODUCTION

A. GENERAL

Cement is the second most widely used material in the world after water. Ordinary Portland cement has been traditionally used as a binding material for preparation of concrete. The world-wide consumption of concrete is believed to rise exponentially primarily driven by the infrastructural development taking place in China and India. The production of 1 tonne (2202 lb) of cement directly generates 0.55 tonnes (1211 lb) of chemical CO2 and requires the consumption of carbon fuel to yield an additional 0.40 tonnes (880.8 lb) of CO2.

So, 1 T of Cement = 1T of CO2.

Also, the emission by cement manufacturing process contributes 7% to the global CO2 emission. So it is important to find an alternate binder which has less carbon foot-print than cement. One of the promising alternative is to use fly ash as part or total replacement of cement in concrete. The total replacement of cement has been made possible since the introduction of Geopolymer by Prof. Joseph Davidovits. Prof. Joseph Davidovits in 1979 proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material such as low calcium fly ash to produce binders. Because the chemical reaction takes place in this case is a polymerization process, he coined the term ‘Geopolymer’ to represent these binders. Geopolymer is an inorganic polymer.

There are two main constituents of Geopolymer, namely the source material and the alkaline liquids. The source materials for geopolymer based alumina-silicate should be rich in silicon (Si) and aluminium (Al). These should be natural minerals such as kaolinite, clay, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. could be used as source materials. The choice and combination of the source materials for making geopolymer depends on factors such as availability, cost, and type of application and specific demand of the end users. Here in this study primary source material is flyash and fine aggregate is replaced with quarry dust and alkaline solutions sodium hydroxide and sodium silicate is been investigated.

The alkaline liquids are from soluble alkali metals that are usually sodium and potassium based. The most common alkaline liquid used in geo-polymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate and potassium silicate.

B. OBJECTIVE OF STUDY

To make the world aware of Geopolymer Concrete to be used instead of Conventional Concrete for precast industries as well as for making research in the feasibility to the cast in-situ conditions.

C. RESEARCH SIGNFICANCE

In this thesis, the effort was made to study the strength parameters of fly ash based geo-polymer concrete. To overcome the stress and demand for river sand, researchers have identified some alternatives for sand, namely scale and steel chips, waste iron, crushed granite fine, slag, quarry dust etc. The quarry dust were obtained from quarrying process, the amount produced depends on the rock type, amount of fragmentation by blasting and type of crushing used. Quarry dust is used to replace the fine aggregate some percentages in the production of concrete. It gives better strength. The characteristics of quarry dust were determined in the laboratory as per standard methods. Geo-polymer is inorganic binders, in which the Compressive strength depends on curing time and curing temperature. Geo-polymer concrete reduced CO2 emissions, and makes them a good alternative to ordinary Portland cement. Geo-polymer Concrete is Eco-Friendly.

II. MATERIALS USED

A. FLY ASH

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geo-polymer concrete due to its role in the geo polymerization process. A pozzolan is a material that exhibits cementitious properties when combined with calcium hydroxide. Fly ash is the main by product created from the combustion of coal in coal fired power plants. There are two “classes” of fly ash, Class F and Class C. Each class of fly ash has its own unique properties.

Fig 2.1 Fly Ash

B. QUARRY DUST:

Quarry dust is a waste obtained during quarrying process. It has very recently gained good attention to be used as an effective filler material instead of fine aggregate. Crushed sand less than 4.75 mm is produced from hard granite rock using state of crushing plants.

The amount produced depends on the rock type, amount of fragmentation by blasting and type of crushing used. The product is washed to remove excess fines to get sand of excellent shape and unwanted contamination.

Fig 2.2 Quarry Dust

C. COARSE AGGREGATE

Crushed stone of size 12mm and 20 mm are used as coarse aggregate. The ideal coarse aggregate should be clean, inert, cubical and angular. For this investigation locally available crushed angular aggregate is used.

D. ALKALINE ACTIVATORS

A combination of alkaline silicate solution and alkaline hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

E. CHEMICALS

The chemicals used as alkaline activators are given below:

- Sodium Hydroxide
- Sodium Silicate
- Potassium Hydroxide
- Potassium Silicate

In this project chemicals are the very important constituents. Sodium Silicate and Sodium Hydroxide liquid are obtained commercially from local suppliers. The sodium hydroxide solution was used of 8M 10M 12M. The sodium silicate solution used in most of the studies was the sodium silicate solution in most of the studies was of A53 grade with SiO2-to-Na2O ratio by mass of approximately 2, i.e., SiO2 = 29.4%, Na2O = 14.7%, and water = 55.9% by mass, is recommended.

1) Sodium Hydroxide (NaOH)

The sodium hydroxide solids were of a laboratory grade in pellets form with 99% purity, obtained from local suppliers. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets (a small, rounded, compressed mass of a substance of sodium hydroxide) in water. The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per liter of the solution, where 40 is the molecular weight of sodium hydroxide. The density of sodium hydroxide is 21 g/cc. During the boiling of sodium hydroxide process the amount of heat liberated should be 266 Cal/gr.

2) Sodium Silicate (Na2SiO3)

Sodium silicate solution (water glass) obtained from local suppliers was used. The chemical composition of the sodium silicate solution was Na2O=8%, SiO2=28%, and water 64% by mass. The mixture of sodium silicate solution and sodium hydroxide forms the alkaline liquid. Weight ratio and molar ratio of sodium silicate is 2. The reactions should be defined as hydration/dehydration, precipitation due to these reactions the silicate act as film binder, matrix binder and chemical binder. The combination of sodium hydroxide and sodium silicate act as catalytic.

F. SUPER PLASTICIZER

In order to improve the workability of fresh concrete high-range. Water-reducing naphthalene based super-plasticizer was added to the mixture to increase the workability of the concrete. Super plasticizers are water reducers which are capable of reducing water contents by about 30 percent. However it is to be noted that full efficiency of super plasticizer can be got only when it is added to a mix that has an initial slump of 20 to 30mm. Addition of super plasticizer to stiff concrete mix reduces its water reducing efficiency. Depending on the solid content of the mixture, a dosage of 1 to 3 percent by weight of cement is advisable.

III. MATERIAL PROPERTIES

The materials properties play an important role in the production of concrete. So the properties of materials used in this research work are given below in the tables. In this research work the material used are fly ash and quarry dust and course aggragate.

A. PHYSICAL PROPERTIES OF FLY ASH

S.No	Properties	Results
1	Colour	Whitish Gray
2	Bulk Density(G/Cm3)	0.92
3	Specific Gravity	2.2
4	Moisture (%)	3.90
5	Average Particle Size(µm)	6.92

Table 3.1 Physical Properties of Fly Ash

B. CHEMICAL PROPERTIES OF FLYASH

S.No	Chemical composition	Percentage (%)
1	Silicon dioxide(SiO2)	59
2	Aluminium Oxide(Al2 O3)	21.00
3	Iron Oxide(Fe2O3)	3.7
4	CaO	6.91
5	MgO	1.4
6	SO3	1.00
7	K2O	0.90
8	loss on ignition (LOI)	4.62

Table 3.2 chemical properties of fly Ash

C. PHYSICAL PROPERTIES OF QUARRY SAND

Property	Quarry rock dust
Specific gravity	2.60 (2.54 - 2.60)
Bulk relative density(kg/m3)	1700 (1720 -1810)
Absorption (%)	1.30 (1.20 - 1.50)
Moisture Content (%)	Nil
Fine particles less than 0.075mm (%)	14 (12 – 15)
Sieve Analysis	Zone II

Table 3.3 Physical properties of quarry sand

D. CHEMICAL COMPOSITION OF QUARRY DUST

Constituent	Quarry Rock Dust (%)
SiO2	62.48
Al2O3	18.72
Fe2O3	6.54
CaO	4.83
MgO	2.56
Na2O	Nil
K2O	3.18
TiO2	1.21
Loss of ignition	0.48

Table 3.4 Chemical Composition of Quarry Dust

E. PROPERTIES OF COURSE AGGREGATE

Property	Coarse Aggregate	
	20mm	12mm
Fineness Modulus	8.14	8.14
Specific gravity	2.87	2.83
Bulk Density	1533.33 kg/m3	1517 kg/m3
Percentage of voids	45.24%	47.14%

Table 3.5 Properties of Course Aggregate:

IV. MIX DESIGN

A. CRITERIA

As there is no standard procedure to make the mix design, but some aspects to be followed are:

- Use the same mix design as that of OPC.
- Use coarse and fine aggregates approximately 75% to 80% of the entire mixture by mass.
- Use Low calcium (ASTM Class F) fly ash
- Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, of 0.4 to 2.5. This ratio was fixed at 2.5 in most of the researches as the cost of sodium silicate solution is considerably cheaper than the sodium hydroxide solution.
- Molarity of sodium hydroxide (NaOH) solution in the range of 8M to 16M
- Ratio of activator solution-to-fly ash, by mass, in the range of 0.3 and 0.4. 0.35 was used by most of the researchers
- Super plasticiser is added in the range of 0% to 2% of fly ash, by mass. Extra water, if needed.

B. MIXING AND PLACING

Mixing and placing of geo polymer also plays an important role towards its compressive strength. Coarse aggregate fly ash , quarry dust and then alkaline solution which is combination with superplasticizer is added to dry mix and then mixing is done for 6-8 min After mixing cubes and cylinders are casted in layers and each layer is give 35 blows for proper compaction.

C. CURING METHODS

After the GPC has set. The moulds were demoulded after atleast 24 hours of casting and then it may be given a rest period or it may be kept for curing. Heat curing of low calcium fly ash based GPC is generally used. It enhances the chemical reaction that occurs in the geopolymer paste.

Curing temperature and time are important parameters affecting the compressive strength of geo polymer concrete The optimum temperature of 600C (140 ºF) is observed to increase the compressive strength and the curing time is varied from 4 to 96 hours (4 days). Rapid increase in compressive strength is observed up to 24 hours and then the rise in compressive strength observed was moderate.

Steam curing at 800C (176 ºF) adopted for a period of 4 hours provided enough compressive strength for demoulding the culverts and further steam curing was continued for 24 hours at 800C (176 ºF). Tests have shown that a delay in start of heat curing up to five days did not produce any kind of degradation in the compressive strength.

In fact, such a delay in the start of heat curing substantially increased the compressive strength of geo polymer concrete.

Preliminary tests revealed that fly ash based geo polymer concrete did not harden immediately at room temperature. When the room temperature was less than 300C (86 °F) the hardening did not occur at least for 24 hours. The setting time for geo polymer concrete is more than OPC. The studies have also shown that sunlight curing could help instead of oven curing or steam curing. Sunlight curing showed nearly the same results when compared to that of oven/heat curing.

D. PROPERTIES OF GEOPOLYMER CONCRETE

1) Fresh Concrete Test

The slump test was used to assess workability of the geopolymer mixtures as described in IS: 1199-1959. The workability of concrete increased as the water content in the mixture increased, but there was a decrease in the compressive strength. In addition, some mixtures were assessed using the compacting factor test IS: 1199-1959. The mixtures displayed increasing slump and compaction factor with decreased 7 mm (0.273 inches) angular aggregate content, similar to the behavior of fresh Portland cement concrete

2) Hardened Test on Concrete

The Compressive strength of GPC increased over controlled concrete by 1.5 times (M-25 achieves M-45) i.e. (3625 lbf/in² achieves 6525 lbf/in²) Split Tensile Strength of GPC increased over controlled concrete by 1.45 times and Flexural Strength of GPC increased over controlled concrete by 1.6 times.

3) Compressive Strength

It was noticed from the studies that the compressive strength of all mixes increased with concrete age. It was also noted from the studies that with an increase in the molarity of the sodium hydroxide solution there was increase in the compressive strength of concrete. The ratio of fly ash to alkaline liquid had an influence on the compressive strength as the ratio increased the compressive strength of GPC also increased. From the studies, it was also observed that the water/solids ratios with w/s 0.20 had the highest compressive strength. A decrease in compressive strength was observed as the w/s ratio increased from 0.20 to 0.23. This illustrated that the effect of w/s ratio on geopolymer strength development is similar to OPC concrete. When low water content is used in the geopolymer mixes, the alkaline activator concentration tends to increase in the system. Thus, the available high alkalinity could accelerate the geo-polymerisation process, and increase the concrete's final strength. In the case of aggregate/solids ratios, an increase of a/s ratio was observed to quite significantly decrease the compressive strength. It was observed from the data that an increase of solids or dried alkaline activator is advantageous in producing more alumino-silicate bonds and in improving the final strength of concrete. The concrete also yielded high early strength as compared to that of OPC.

4) Tensile strength

From the studies conducted by various researchers, at early age the results were lower than that of OPC but at the later stage the tensile strength of GPC increased more than that of OPC. The test used for tensile strength of concrete is Indirect Tensile Test or Splitting Tensile Test. The trend in tensile strength is similar to that obtained for compressive strength. Hence, there was a difference in the development in tensile strength of different mixes. As far as the geopolymer concrete mixes based on activated natural pozzolan are concerned, higher strengths were observed at longer ages in comparison with control OPC mixes. The studies showed that the long term tensile strengths of activated geopolymer concrete mixes are higher than those of OPC control mixes. The tensile strength of geopolymer concrete is more sensitive to improper curing than its compressive strength, the same as in OPC concrete. The optimum temperature of curing was 40ºC (104 ºF), the same as that found for compressive strength. Here, note that a higher water to binder ratio resulted in lower tensile strength, the same trend as for OPC mixes.

5) Flexural Strength

From the studies conducted by various researchers, the flexural strength of GPC is Greater than that of OPC. The test used for Flexural strength of concrete is Rupture Test or Flexural Test.

6) Durability Test

From the studies conducted by various researchers, it was observed that GPC yielded more resistance to acid and sulphate attack than that of OPC.

7) Sulphuric Acid Resistance

To study the effects of exposure to acidic environment researchers immersed the specimens in 3% solution of sulphuric acid of 98% purity. Test was carried out at regular intervals after 7 days for a period of 84 days. The solution was replaced at regular intervals to maintain concentration of solution throughout the test period. The evaluations are conducted after 7, 14, 28, 56 & 84 days from the date of immersion. After removing the specimens from the solution, the surfaces are cleaned under the running tap water to remove weak products and loose material from the surface. Later the specimens are allowed to dry and measurements were taken. The results of sulphuric acid resistance test resulted in reduction in the weight of GPC up to 1.31% in 84 days.

V. SCOPES AND RECOMMENDATIONS

A. APPLICATIONS

Geopolymer Concrete can be used in the precast application as there is a need for handling the sensitive alkali solution and also needs a controlled high temperature curing which is required for most of the geopolymer products some precast elements are like precast structural elements, precast decks, precast pavers & slabs for paving, bricks, precast pipes, etc. Geopolymer Concrete can be used for making precast buildings and it can also be used for cast-in-situ for road pavements.

B. SCOPES FOR FUTURE WORK

Studies can be made on its durability property and to improve its workability characteristics. Fiber reinforced Geopolymer composites may be considered a solution to improve flexural strength and fracture toughness. Since there is demand for natural sand, the fine aggregate shall be replaced by quarry dust. Different structural elements like Geopolymer Concrete Beam, Reinforced Geopolymer Concrete Beam, Reinforced

Geopolymer Concrete Columns, Reinforced Beam Column joints shall be cast for the above mentioned concentrations of Sodium Hydroxide solution and curing conditions and tested.

C. LIMITATIONS

The followings are the limitations
Cost of Fly ash, Cost of alkaline solution
High alkalinity of the activating solution.
Practical difficulties in applying Steam/high temperature curing process

VI. Conclusion

Fly ash that is used in GPC is a waste product from the thermal power plant so it is effective in reducing the dumping of the fly ash into landfills OPC can be replaced by GPC wherever the conditions are favourable. GPC can be used in versatile production of precast. The production of versatile, cost-effective and high early strength of geopolymer concrete, it can be used in the precast industry. Geopolymer Concrete can also be used in repair and rehabilitation works. Geopolymer Concrete should be used in infrastructure works like road pavement, bridge girder, culverts, etc. Quarry dust is having a high content of silica, so the natural sand should be replaced by it. As there is a high demand of natural sand as well as the cost is also high. So natural sand should be partially or fully replaced by quarry dust.

In addition to that the Fly ash shall be effectively used and hence no landfills are required to dump the fly ash. The Government of India should take necessary steps like provide fly ash to the nearby cities free of cost means no cost of transportation. As well as to extract sodium hydroxide and sodium silicate solution from the waste materials of the chemical industries, so that the cost of geopolymer concrete could be reduced.

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