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A Review on Fly Ash based Geopolymer Concrete.

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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 conducted by various researchers on the 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.*

Keywords: *Geopolymer Concrete, Fly ash, Alkaline Activator, Curing, Strength, Applications.*

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I. Introduction

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 CO_2 and requires the consumption of carbon fuel to yield an additional 0.40 tonnes (880.8 lb) of CO_2. So, 1T of Cement ≈ 1T of CO_2. [1]

Also, the emission by cement manufacturing process contributes 7% to the global CO_2 emission. [2] 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. [3] [1]

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.

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.

II. Research Significance

The authors wish 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.

III. Materials

1.1. Fly ash

One constituent of geopolymer is the source material. The source materials are the materials which contain silicon and aluminium like fly ash, ground granulated blast furnace slag, silica fume, metakaolin, rice husk ash, etc.

In most of the studies fly ash is used as source material. Fly ash plays the role of an artificial pozzolan. Fly ash are of two types ASTM class C and ASTM class F. Low calcium (ASTM class F) fly ash is used as source material than high calcium (ASTM class C) fly ash. The presence of calcium in high amount may be interfering with the polymerization process. The other characteristics that influence the stability of fly ash to be a source material for Geopolymer are particle size, amorphous content, loss of ignition as well as morphology, and origin of fly ash. [4]

3.2. Alkaline Liquid

The most common alkaline liquid used in geo-polymersiation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate and potassium silicate. Out of which in most of the studies sodium is used instead of potassium alkalis as the cost of sodium is less than that of potassium. The sodium hydroxide solution was used of 8M 10M 14M. 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. [5]

3.3. Aggregates

Combined aggregate was used in Geopolymer concrete. Local aggregates comprising 20mm (0.78 inches), 10 mm (0.39 inches), 7mm (0.273 inches) coarse aggregates in saturated surface dry (SSD) condition were used. The coarse aggregate (CA) were crushed granite and basalt type aggregates Fine aggregates used are mostly locally available grit sand and river sand. Coarse and fine aggregate used by the concrete industry are suitable to manufacture Geopolymer concrete. Coarse and fine aggregates of approximately 75%to 80% of the entire mixture by mass. [5] This value is similar to that used in OPC concrete.

3.4. Superplasticizer

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. [6]

IV. Mix Design

As there is no standard procedure to make the mix design, researchers [7] stated as follows that

- 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.

V. Mixing And Placing

Mixing and placing of geo polymer also plays an important role towards its compressive strength. Fine aggregate coarse aggregate fly ash and GGBS 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 are casted in layers and each layer is give 35 blows for proper compaction.

VI. 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 60^0C (140 ^{0}F) is observed to increase the compressive strength and the curing time is varied from 4 to 96 hours (4 days). [8] Rapid increase in compressive strength is observed up to 24 hours and then the rise in compressive strength observed was moderate. [5]

Steam curing at 80^0C (176 ^{0}F) 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 80^0C (176 ^{0}F) [9]. 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. [10]

Preliminary tests revealed that fly ash based geo polymer concrete did not harden immediately at room temperature. When the room temperature was less than 30^0C (86 ^{0}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. [4]

VII. Properties Of Geopolymer Concrete

7.1. 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 [10]

7.2. Hardened Test on Concrete

The Compressive strength of GPC increased over controlled concrete by 1.5times (M-25 achieves M-45) i.e. (3625 lbf/in^2 achieves 6525 lbf/in^2) Split Tensile Strength of GPC increased over controlled concrete by1.45 times and Flexural Strength of GPC increased over controlled concrete by 1.6 times. [6]

7.3. 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 aluminosilicate bonds and in improving the final strength of concrete. The concrete also yielded high early strength as compared to that of OPC [10]

7.4. 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. [10]

7.5. 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.

7.6. 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.

7.7. 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. [5]

VIII. 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.

IX. 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

X. 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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