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A Complete Study on Behaviour of Geo-Polymer Concrete with Admixtures

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ABSTRACT

Concrete is made up of cement, aggregates, water & additives is the world's most consumed construction material since it is found to be more versatile, durable and reliable. Concrete is the second most consumed material after water which required large quantities of Portland cement. The production of Ordinary Portland Cement (OPC) causes havoc to the environment due to emission of CO2 as well as mining also results in unrecoverable loss to the nature. Hence, there is the need to find an alternative material to the existing most expensive cement-concrete. Geopolymer concrete (GPC) is an innovative construction material which shall be produced by the chemical action of inorganic molecules. This paper presents the progress of the research on making geopolymer concrete using fly ash and metakaolin with different activator ratios from 2 to 3. These materials react with alkaline solution and produce alumino silicate gel that acts as the binding material for the concrete. This GPC is an excellent alternative construction material to plain cement concrete without using any amount of ordinary Portland cement. In our present investigation the specimens of the GPC with different activator ratios from 2 to 3 are made, and the tests like compressive test, split tensile test and flexural strength are conducted on them. At the end of the investigation it is found that the mechanical properties of the specimens have been increased with increase of activator ratio from 2 to 3.

Keywords: ***Geopolymer concrete, fly ash, metakaolin, sodium silicate, sodium hydroxide.***

INTRODUCTION

After wood, concrete is the most often used material by the community. Concrete is conventionally produced by using the ordinary Portland cement (OPC) [1-3] as the primary binder. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the amount of energy required to produce OPC is only next to steel and aluminium. On the other side, the abundance and availability of fly ash worldwide create opportunity to utilise this by-product of burning coal, as partial replacement or as performance enhancer for OPC. Fly ash in itself does not possess the binding properties, except for the high calcium or ASTM Class C fly ash. However, in the presence of water and in ambient temperature, fly ash [4] reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. This pozzolanic action [5] happens when fly ash is added to OPC as a partial replacement or as an admixture. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60-65% by mass (Malhotra 2002; Malhotra and Mehta 2002), can be regarded as a landmark inthis attempt. In another scheme, pozzolans such as blast furnace slag and fly ash

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may be activatedusing alkaline liquids to form a binder and hence totally replace the use of OPC in concrete. In this scheme, the alkalinity of the activator can be low to mild or high. In the first case, with low to medium alkalinity of the activator, the main contents to be activated are silicon and calcium in the by-product material such as blast furnaceslag. The main binder produced is a C-S-H gel, as the result of a hydration process.In the later case, the main constituents to be activated with high alkaline solution aremostly the silicon and the aluminium present in the by-product material such as lowcalcium (ASTM Class F) fly ash (Palomo, Grutzeck et al. 1999). The binderproduced in this case is due to polymerisation. Davidovits (1999) in 1978 named the later as Geopolymers, and stated that these binders can be produced by a polymericsynthesis of the alkali activated material from geological origin or by-product materials such as fly ash and rice husk ash.

New Age Concrete:

Improvement of quality of structural materials is a general trend which may be observed in our civilization. At different periods that trend has a steady continuous function or of a step function. High Performance Concretes appeared a few years ago and now develop rapidly representing a new generation of composite materials in building and civil engineering. Without any doubt their application will be increased in many kinds of structures where special requirements are imposed. Although Portland cement demands are decreasing in industrial nations, it is increasing dramatically in developing countries. Cement demand projections shows that by the year 2050 it will reach 6000 million tons.

Portland cement production leads to major CO2 emissions, results from calcinations [6] of limestone (CaCO3) and from combustion of fossil fuels, including the fuels required to generate the electricity power plant, accounting for almost 0.7 tonnes of CO2 per tonne of cement which represents almost 7% of the total CO2 world emissions. This is particularly serious in the current context of climate change caused bycarbon dioxide emissions worldwide, causing a rise in sea level and being responsible for a meltdown in the world economy. Since Portlandcement is used mostly in concrete production,the most important building material on Earth (10.000 billion tons per year), partial replacement by pozzolanic by-products and mineral additions will allow relevant carbon dioxide emissions reductions. Investigations about the pozzolanic properties of fly ash, calcined clays and calcined agriculture wastes were already carried out. Pozzolanic admixtures react with Ca(OH) generating additional CSH phases, resulting in a more compact concrete with increase durability. Some supplementary cementitious material, like fly ash has very slow hydration characteristics thus providing very little contribution to early age strength while others like metakaolin possess a high reactivity with calcium hydroxide having the ability to accelerate cement hydration. Since current concrete structures present a higher permeability level that allows aggressive elements to enter, leading corrosion problems using pozzolanic admixtures not only reduce carbon dioxide emissions but also allow structures with longer service life, thus lowering their environmental impact.

Nevertheless, studies on the durability performance of concrete containing pozzolanic by-products are recent and still scarce. Even scarcer about the durability performance of concrete that contains blended reactive pozzolans. This paper presents experimental data about the strength and durability performance of metakaolin, fly ash based concrete [2].

Need For Geo Polymer Concrete

Portland cement is under critical review due to high amount of carbon dioxide (CO2) released into atmosphere. However it is necessary to search for alternative low emission binding agent for concrete to reduce the environmental impact caused by manufacturing of cement. This is done by using the industrial by-products as binder’s .The new technology geo-polymer concrete is a promising technique. In terms of reducing the global warming the geo-polymer technique could reduce the CO2 emission to the atmosphere.

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Fly ash Based Geo Polymer Concrete

In this work, fly ash-based geopolymer is used as the binder, instead of Portland orany other hydraulic cement paste, to produce concrete. The fly ash-based geopolymerpaste [7] binds the loose coarse aggregates, fine aggregates and other un-reactedmaterials together to form the geopolymer concrete, with or without the presence ofadmixtures. The manufacture of geopolymer concrete is carried out using the usualconcrete technology methods.As in the OPC concrete, the aggregates occupy the largest volume, i.e. about 75-80% by mass, in geopolymer concrete. The silicon and the aluminium in the lowcalcium (ASTM Class F) fly ash are activated by a combination of sodium hydroxideand sodium silicate solutions to form the geopolymer paste that binds the aggregatesand other un-reacted materials.

GEO-POLYMER

Geo-polymer is also known as inorganic polymer is one such material that uses the industrial by-product materials instead of cement and these are activated by alkaline liquids such as sodium silicate and sodium hydroxide.Davidovits (1988) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a bi-product material [8] such as fly ash, rice husk ash etc to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term Geo-polymer to represent the binders. Geo-polymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete.

The main difference between geo-polymer concrete and Portland cement concrete is the binder. Silicon and Aluminum oxides in the bi-product material react with alkaline liquids to form geo-polymer paste that bonds the coarse aggregate and fine aggregate materials together to form a Geo-polymer concrete. Coarse and fine aggregates occupy about 75-80% mass of Geo-polymer concrete. The influence of aggregates such as grading, angularity and strength are considered to be same in case Portland cement concrete [Lloyd and Rangan, 2009].

Studies have been carried on fly ash based geo-polymer concrete. The compressive strength and workability of geo-polymer concrete are influenced by the proportions and the properties of the constituent materials that make geo-polymer paste.

B. VijayaRangan, DjwantoroHardjito, Steenie E. Wallah, and Dody M.J. Sumajouw Faculty of Engineering and Computing, Curtin University of Technology, GPO Box U 1987, Perth 6845, Australia .(This paper presents test data on fly ash-based geo-polymer concrete. The paper covers the material and the mixture proportions, the manufacturing process, compressive strength.

Research results [Hardjito and Rangan, 2005] have shown the following:

- Higher concentration (in terms of Molarity) of sodium hydroxide solution results in higher compressive strength.
- Higher ratio of sodium silicate –to- sodium hydroxide solution by mass results in higher compressive strength.
- As the H_2O to Na_2O molar ratio increases the compressive strength of Geo-polymer concrete decreases.

Advantages Of Geo Polymer Concrete

- Increased strength and durability
- Rapid strength gain
- Increased fire and cold resistance
- Low shrinkage and creep
- Strong chemical resistance
- Also economical
- Environmental friendly

Applications Of Geo Polymer Concrete

- Construction and repair of highways, roads, and airport runways
- Construction of marine structures
- Constructions in cold regions
- Construction of sewers and landfills

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Materials Used In Geo Polymer Concrete

- Fly ash.
- Metakaolin
- Sodium hydroxide
- Sodium silicate
- Aggregates

Flyash

Fly ash used in the experiments is taken from V.T.P.S., IBHRAHIMPATNAM. Physical properties are checked in laboratory and the chemical properties are reported here for ready reference as obtained.

Fly ash is a burnt and powdery derivative of inorganic mineral matter that generates during the combustion of pulverized coal in the thermal power plant. The burnt ash of the coal contains mostly silica, alumina, calcium and iron as the major chemical constituents. Depending on the burning temperature of coal, the mineral phases in crystalline to non-crystalline structures such as quartz ($SiO2$), mullite ($3AlO32H2O$),hematite ($Fe2O3$), magnetite ($Fe3O4$), wustite (FeO), metallic iron, orthoclase ($K2OAl2O36SiO2$) and fused silicates usually occur in the burnt coal ash. Silica and alumina account for about 75 to 95 % in the ash. The classification of thermal plant fly ash is considered based on reactive calcium oxide content as class-F (less than 10 %) and class-C (more than10%). Indian fly ash belongs to class-F. The calcium bearing silica and silicate minerals of ash occur either in crystalline or non-crystalline structures and are hydraulic in nature they easily reacts with water or hydrated lime and develop pozzolanic property. But the crystalline mineral phases of quartz and mullite present in the ash are stable structures of silica and silicates, and are non-hydraulic in nature. Usually the fly ash contains these two mineral phases as the major constituents.

Therefore, the utilisation of fly ash in making building materials like fibre cement sheets largely depends on the mineral structure and pozzolanic property. Fly ash is broadly an aluminium-silicate type of mineral rich in alumina and silica [3].

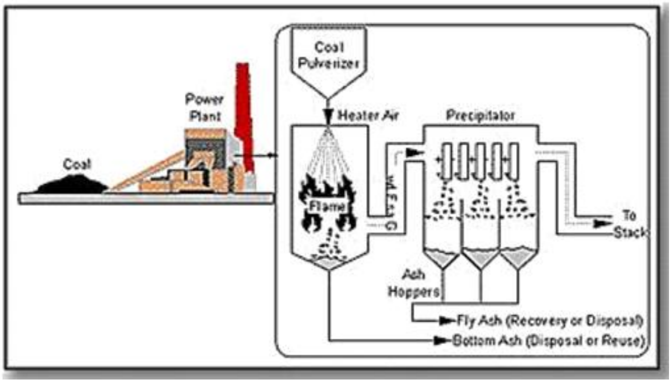

Fig 1: Fly ash manufacturing process

Fig2 :Flyash

The usage of blended cement is growing rapidly in construction industry due to the considerations of cost saving and environmental protection. Increasing the use of by-products such as Fly Ash for partially replacing the Portland cement in concrete not only reduces the amount of cement used, but also significantly enhances the properties of concrete, reduces the emission of $CO2$ and conserves the existing resources. Inclusion of Fly Ash in concrete greatly improvesconsistency. Research work done on Metakaolin has shown that the partial replacement of Portland cement with Metakaolin [9] in concrete significantly affects consistency and early strength. However, unlike Fly Ash increased replacement levels of Metakaolin increases water demand due to its high chemical activity and high specific surface. Concrete containing fly ash more than about 50% of total cementitious materials is classified as high volume fly ash concrete. The addition of fly ash in concrete improves certain properties such as workability,

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later age strength development characteristics. The major disadvantage observed in such concrete is the slower development of strength. This drawback can be addressed by adding super pozzolanic materials such as silica fume, Metakaolin and rice husk ash. This type ofternary blending of cementitious materials may improve the quality of concrete in different dimensions.

Aggregates

Fine Aggregates

The fine aggregate used in the project was locally supplied and conformed to grading zone II as per IS: 383:1970. It was first sieved through 4.75mm sieve to remove any particles greater than 4.75mm. Locally available dry aggregate satisfying the requirementsLocally available dry aggregate satisfying the requirements of ASTM C33-08 was used in the concrete mixes. The sand obtained from river beds or quarries is used as fine aggregate. The fine aggregate along with the hydrated cement paste fill the space between the coarse aggregate.

The specific gravity of the fine aggregate (sand) used in the investigation was 2.66 and the fine aggregate used in this present investigation comes under ZoneII.

Coarse Aggregate

Locally available coarse aggregate having the maximum size of (10 -12mm) was used in this project.

Metakaolin

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Rocks that are rich in kaolinite are called as china clay or kaolin. This is traditionally used in the manufacture of porcelain. The sizes of the particles of metakaolin are smaller than cement particles. These particles are not as fine as silica fume.Kaolinite is a layered silicate mineral between the layer of SiO2 and Al2O3.Whenthis is heated, the water in between the layers gets evaporated and the kaolinite [7] is activated to undergo reaction with cement. When this is calcined between 600° to850°C the kaolin is transformed to an amorphous phase known as metakaolin.

Fig 3: Metakaolin

Preparationof Alkaline Activator Solution

The alkaline solutions used are Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Sodium silicate solution is directly available in the market. Sodium hydroxide flakes are available and to make hydroxide solution first the volumetric flask of 1liter capacity are to be taken and the flake are to be added slowly according to the required molarities to the distilled water.Now for obtaining 8M (8 molarity) solution first sodium hydroxide flakes of 480 gm are taken in a flask and then distilled water is added slowly for dissolving the flakes. And then 1 litre solution is prepared. While flakes are dissolved heat is evolved. Molarity = moles of solute/litre of solution.

8M = 8 x molecular weight

=8x40

= 320 gm of flakes to be dissolved in 1 lit of distilled water.

Fig 7: Activator Solution

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The sodium silicate solution and the sodium hydroxide solution are to be prepared at least one day prior to the use. These two solutions are to be mixed together and then added to aggregates for proper mix.

Mixing& Casting

The conventional method used for the casting of normal concrete cubes is adopted for preparing geo-polymer concrete cubes.

Mix sodium hydroxide solution and sodium silicate solution together at least 20 minutes prior to adding the liquid to the dry materials. Mix all dry materials in the pan mixer for about three minutes. After casting of specimens compaction is done [5]. Specimens are compacting on a vibrating table for 10 seconds.Three different mixes were developed in this study, for each mix 27 cubes of 150mm,27 cylinders of diameter 150mm x height 300mm and 27 beams of 500mm x 100mm x 100mm were cast to study compressive, split tensile and flexural strengths of each mix.

Fig 8: Mixing of GPC

Curing

After demoulding of specimens, they were left in room temperature. The average temperature during the curing period of the specimen was 23o C. Fig 4 shows the specimens under Ambient curing [10].

Fig 9: Specimens under Curing

Testing

The specimens were tested as per IS 516:1959 and strengths were calculated for 3, 7,28days.

The specimens are wiped clean and they are placed under universal testing machine and load is applied continuously. The load is increased gradually until the specimen fails and the maximum load is recorded for each specimen.

Compressive strength=Average Load/area of cross section

Fig10 : Testing of specimens

RESULTS

Compressive Strength

The compression strength on cubes were conducted according to IS Specifications (IS: 516 – 1959).

Compressive strength=Average Load/area of cross section

Activator Ratio	Compressive Strength for 3 days	Average value in Tonnes **for ratio's**			Average value in N/mm^2 **for ratio's**		
		1:2	1:2.5	1:3	1:2	1:2.5	1:3
1:2	16 , 15, 16.5						
1:2.5	16, 17.5, 17	15.8	16.83	19.66	7.02	7.48	8.73
1:3	19, 21, 19						

Table 7: Compressive Strength values for 3 days

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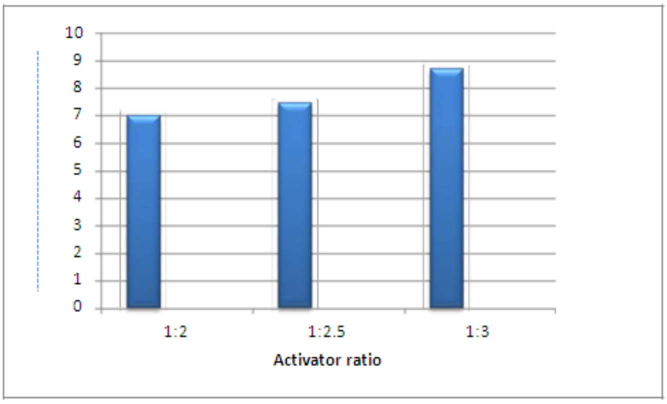

Fig 11:Compressive strength at the age of 3 days for different Activator ratios

Activator Ratio	Compressive Strength for 7 days	Average value in Tonnes for ratio's			Average value in N/mm^2 for ratio's		
		1:2	1:2.5	1:3	1:2	1:2.5	1:3
1:2	25, 22, 22.5	23.16	24.33	25.33	10.81	10.3	11.25
1:2.5	25, 25, 23						
1:3	26, 25, 25						

Table 8: Compressive Strength values for 7 days

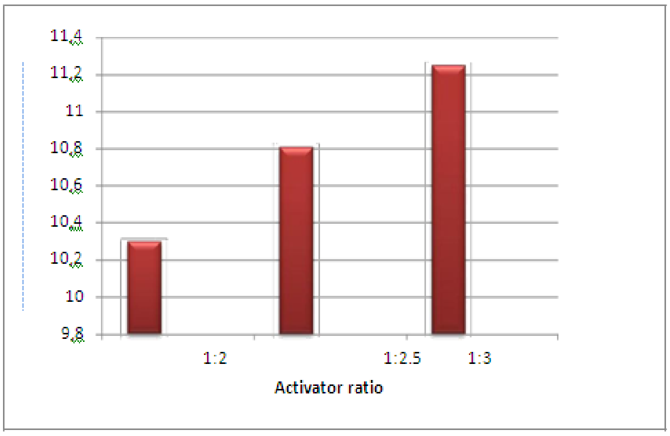

Fig 12:Compressive strength at the age of 7 days for different Activator ratios

Activator Ratio	Compressive Strength for 28 days	Average value in Tonnes for ratio's			Average value in N/mm^2 for ratio's		
		1:2	1:2.5	1:3	1:2	1:2.5	1:3
1:2	26, 25, 25.5	25.5	26	28.83	11.3	11.56	12.84
1:2.5	25.5, 27, 25.5						
1:3	30, 28, 28.5						

Table 9: Compressive Strength values for 28 days

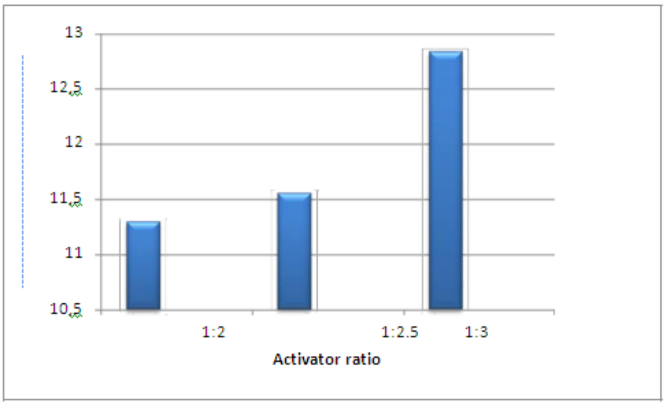

Fig 13:Compressive strength at the age of 28 days for different Activator ratios

CONCLUSION

- The compressive strength, Split tensile strength, Flexural strength of flyash based GPC specimens increased with the increase in Activator ratio i.e., 1:2, 1:2.5 and 1:3.
- The strength of all GPC specimens improved with the increase I curing time.
- The percentage increase in compressive strength with the control specimen for ratios 1:2, 1:2.5, 1:3 is 6.55%, 16.71%, for 7 days 4.95%, 4.07% and 2.3%, 11% for 28 days.
- The percentage increase in split-tensile strength with the control specimen for ratios 1:2, 1:2.5, 1:3 is 21%, 30.43%, for 7 days 4.06%, 3.12% and 3.125%, 18.18% for 28 days.
- The percentage increase in flexural strength with the control specimen for ratios 1:2, 1:2.5, 1:3 is 0 %, 9%, for 7 days 14.9%, 0% and 0%, 39.52% for 28 days.

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