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ENHANCING THE PROPERTIES OF CONCRETE BY USING ALKALINE SOLUTION AND ITS COMPARATIVE STUDY WITH CONVENTIONAL CONCRETE

S. J. Aher 1,
S.P. Mandhare 2,
S.S. Ghawate 3,
R. Gite 4,
Prof.A. H. Jamale 5
1,2,3,4 UG Scholar,Department of Civil Engineering, Adsul Technical Campus,
Savitribai Phule Pune University, Ahmednagar, Maharashtra, India.
5 UG Guide, Department of Civil Engineering,
Adsul Technical Campus, Savitribai Phule Pune University, Ahmednagar, Maharashtra, India.

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Abstract:
The main aim of this project was to reduce the use of cement so as to produce a CO2 emission free cementitious material and Geopolymer Concrete (GPC) was the best alternative solution present out there. GPC utilizes industrial waste material such as fly ash from thermal power station to provide practical solution to waste management as well as environmental protection method. In this study we have used low calcium fly ash (ASTM class F), along with fly ash, water was enable to bind effectively. Therefore we also have replaced water completely with alkaline solution to hold fly ash, aggregate and sand together. The alkaline solutions we have used are – sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). The main purpose to introduce alkaline solution was polymerization. That is the reason scientist Davidovits named this mix as geopolymer concrete.

GPC required high temperature for curing to happen the polymerization, Thus, the curing of GPC was done at ambient temperature without keeping it in water unlike the conventional concrete. Amongst both the alkali solutions i.e. NaOH and Na2SiO3, sodium hydroxide was used in different molar concentration of 10M, 12M and 14M with keeping silicate to hydroxide ratio constant as 1.5, three different sets of 9 cubes, 3 beams and 3 cylinders were casted.

Keywords: Geopolymer Concrete, Fly Ash, sodium hydroxide, sodium silicate, molarity.

I. INTRODUCTION

The major problem that the world is facing today is the environmental pollution. In the construction industry mainly the production of ordinary Portland cement (OPC) will cause the emission of pollutants which results in environmental pollution. The emission of carbon dioxide during the production of ordinary Portland cement is tremendous because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere.

On the other hand, the climate change due to global warming and environmental protection has become major concerns. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. The environment must be protected by preventing dumping of waste/by-product materials in un-controlled manners.

The geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of global warming, the geopolymer concrete significantly reduce the CO_2 emission to the atmosphere caused by the cement industries. Davidovits (1988; 1994) proposed that an alkaline liquid could be used to react with the Silicon (Si) and Aluminum (Al) in a source material of geological origin or in by product materials such as fly ash and GGBS to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term geopolymer to represent these binders.

Several efforts are in progress to address these issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement.

II. LITERATURE REVIEW

"Geopolymer concrete with fly ash" by N A Lloyd and B V Rangan at Marche Polytechnic University, Ancona, Italy in June 2010.The paper presented brief details of fly ash-based geopolymer concrete. A simple method to design geopolymer concrete mixtures has been described and illustrated by an example. Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster. To ensure further uptake of geopolymer technology within the concrete industry, research is needed in the critical area of durability.

"GPC an eco-friendly construction material" by L. Krishnan, S. Karthikeyan, S Nathiya, K. Suganyaat IJRET: International Journal of Research in Engineering and Technology, in June 2014.The Alkaline liquids used in this study for the polymerization process are the solutions of sodium hydroxide (NaoH) and sodium silicate (Na2SiO3). A 12 Molarity solution was taken to prepare the mix. The cube compressive strength was calculated for 12M solution for different mix Id i.e. F90G10, F80G20, F70G30, and F60G40 (Where F and G are, respectively, Fly Ash and GGBS and the numerical value indicates the percentage of replacement of cement by fly ash and GGBS).The cube specimens are taken of size 100 mm x 100 mm x 100 mm. Ambient curing of concrete at room temperature was adopted. In total 36 cubes were cast for different mix Id and the cube specimens are tested for their compressive strength at age of 1 day, 7 days and 28 days respectively. The result shows that geopolymer concrete cubes gains strength within 24 hours without water curing at ambient temperature. Also the strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix. It was observed that the mix Id F60G40 gave maximum compressive strength of 80.50 N/mm^2.

"A Review on Strength and Durability Studies on Geopolymer Concrete" by Shriram Marathe, Mithanthaya I R, N Bhavani Shankar Rao at Department of Civil Engineering, NMAMIT, Nitte, India.This paper briefly reviews the constituents of geopolymer concrete, its strength and potential applications. The production of OPC requires large amount of energy consumption, also leading to an enormous emission of carbon di-oxide to the atmosphere, which is being a great challenge to the sustainable development. Efforts are needed to develop a environmental friendly civil engineering construction material for minimizing emission of greenhouse gases to the atmosphere. A review summary of the extensive literature survey conducted to know about one such environmental friendly concrete namely geopolymer concrete is presented in this paper. And conclusions were as followed. The creep and shrinkage of geopolymers are substantially lower than conventional Portland concrete. Drying shrinkage strains of fly ash-based Geopolymer concretes were found to be insignificant. The ratio of creep strain to- elastic strain (called creep factor) reached a value of 0.30 in approximately 6 weeks after loading on the 7^{th} day with a sustained stress of 40% of the compressive strength. The GPC specimens also show a higher resistance to sulphate attack after full immersion for 15 weeks in different % of magnesium sulphate solution in terms of weight loss and compressive strength as compared with conventional concrete. The performance of geopolymer materials when exposed to acid solutions was superior to ordinary Portland cement concrete.

"GPC for green environment" by B. Vijaya Rangan at The Indian Concrete Journal in April 2014.The paper describes the results of the tests conducted on large-scale reinforced geopolymer concrete members and illustrates the application of the Geopolymer concrete in the construction industry. Some recent applications in the precast construction and the economic merits are also included. Extensive studies conducted on fly ash-based geopolymer concrete are presented. Salient factors that influence the properties of the geopolymer concrete in the fresh and hardened states are identified. Test data of various short-term and long-term properties of the geopolymer concrete are then presented.

Geopolymer concrete offers environmental protection by means of up cycling low-calcium fly ash and blast furnace slag, waste/by-products from the industries, into a high value construction material needed for infrastructure developments. The paper presented information on fly ash-based geopolymer concrete. Low-calcium fly ash (ASTM Class F) is used as the source material, instead of the Portland cement, to make concrete.Geopolymer concrete has excellent compressive strength and is suitable for structural applications. The salient factors that influence the properties of the fresh concrete and the hardened concrete have been identified. Simple guidelines for the design of mixture proportions are included.

III OBJECTIVES OF INVESTIGATION

- To study the different properties of fly ash and different types of alkaline solutions like NaOH and Na_2SiO_3, etc.
- To cast the concrete blocks, beams and cylinders using geopolymers in different proportions and with appropriate molar solutions.
- To perform test on the concrete blocks, beams and cylinders in order to check it's strength.
- To compare the testing results with the OPC i.e. conventional concrete.

IV CONSTITUENTS OF GEOPOLYMER

1. Fly Ash : The first reference to the idea of utilizing coal fly ash in concrete was by McMillan and Powers in 1934 and in subsequent research (Davis et al., 1935, 1937). In the late 1940s, UK research was carried out (Fulton and Marshall, 1956) which led to the construction of the Lednock, Clatworthy and Lubreoch Dams during the 1950s with fly ash as a partial cementitious material. Fly ash, the most widely used mineral admixture in concrete, is a by-product of combustion of pulverized fuel coal in electric furnace power generating plants at 1250°C to 1600° C. Upon ignition in the furnace, most of the volatile matter and carbon in the coal are burned off. During combustion, the mineral impurities of coal (such as clay, feldspar, quartz and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. In the process, the fused material cools and solidifies into spherical glassy particles called 'FLYASH'.
2. GGBS **:** Blast furnace slag is produced as a by-product during the manufacture of iron as a blast furnace.

It results from the fusion of limestone flux with ash from coke and siliceous and aluminous residue remaining after the reduction and separation of iron from the ore. Slag is rapidly cooled with water to form a glassy disordered structure. If the slag is allowed to cool too slowly this allows a crystalline well-ordered structure to form which is stable and non-reactive. The properties of cementitious and pozzolana materials depend on their chemical composition, their physical state, and their fineness. This is particularly the case with blast-furnace slag. Since it is a by-product of the production of iron, its composition may differ from different sources but is likely to be reasonably consistent from a given source.However, to develop satisfactory properties it is essential that the molten slag be rapidly chilled (by quenching with water) as it leaves the furnace. This causes the slag to granulate, that is, break up, into sand-sized particles. More important it causes the slag to be in a glassy or amorphous state in which it is much more reactive than if allowed to develop a crystalline state by slow cooling. In the latter state, it is suitable as a concrete aggregate but not as a cementitious material. It is important to note that the underground granulated material does not make a good fine aggregate because often the grains are weak, fluffy conglomerates rather than solid particles. To use as a cementitious material, the granulated slag must be ground as fine as or finer than cement. The fineness of grind will (along with the chemical composition and extent of glassiness) determine how rapidly the slag will react in concrete.

3. Alkali Solution : The alkali solution is used for alkalination of GGBS thus leading to polymerization which results in geopolymer binder. Sodium hydroxide and sodium silicate is used as mediums to form alkali solutions. Sodium hydroxide and sodium silicate was purchased from Abhay chemicals, Ahmadnagar. Different concentrations of sodium hydroxide solution were prepared in the Lab. Sodium silicate of 40% concentration and required grade was added to sodium hydroxide solution and the alkali solution was prepared.This solution was prepared 1 day prior to be used and consumed within 36 hours. The solution was prepared and kept covered at room temperature for gel formation.

4. Aggregate : Aggregates provide about 75% of the total volume. They should meet certain requirements with respect to grading, shape, size and strength. Though they are considered inert, they exhibit certain reactivity which is popularly known as AAR (alkali aggregate reactivity or reaction).

Here fine and coarse aggregates were procured from local contractor working on our college site. Various lab tests are conducted on these aggregates to ensure that they are well graded along with other properties essential for in corporating into mix design of concrete.

V METHODOLOGY

1. Procedure for casting:

After procurement and testing on materials, casting of concrete is now on its way. Here, step by step procedure is bulleted below explaining about the mixing and casting of concrete with necessary precautions. They include the following.

- Finalised mix proportions for M20 grade of concrete
- The geopolymer hardener or alkali solution was prepared in the laboratory by mixing sodium hydroxide and sodium silicate in the required proportion as mentioned in the mix design worksheet. The alkali solution was prepared 1 day prior to casting.
- All the apparatus and equipment’s were made ready for casting. They include pan mixer, slump cone apparatus, compaction factor apparatus, tamping rod, buckets, trays, dry and wet cloths, travels, etc.
- After weigh batching, materials are introduced in pan mixer with a sequence. GGBS along with 50% of prepared solution was introduced in the mixer so that alkalination could start. Flyash together with coarse and fine aggregates was introduced in the mixer and mixing was continued for 2 minutes. The remaining

alkali solution was then again added to the mix. Water was added after the alkali solution and super plasticizer was introduced. The wet mixing continued for another 4 minutes until a homogenous mix was achieved.

- Immediately after the mixing was over, it was observed that the concrete was getting more cohesive due to the polymeric chain formation. Slump cone test and compaction factor test was performed to test its workability.
- 150 x 150 x 150 mm cubes and 150 x 300 mm cylinders were thinly coated with oil to prevent adhesion of concrete with inner walls of cubes and cylinders.
- Concrete was poured in 3 layers as per specifications and compacted. In case of cubes each layer was compacted 32 times with 4 along the edges, 4 along diagonals and 4 along midways in both axes. However, in case of cylinders, each layer was compacted 12 times, with 6 along the edges and 6 along both the axes.
- All the cubes were kept on vibrating table and vibrated for 2 minutes to let all the entrapped air escape. Concrete was kept in moulds until it gained sufficient hardness to be demoulded. The demoulded concrete was wrapped in plastic bags and kept for accelerated steam curing at 60° C. other specimens were kept for hot air oven dry curing at 60° C. Specimens were kept for curing continuously for 3 days and after that left for ambient atmospheric curing till 28th day.

2. Observations during casting

- The targeted workability was 75 to 100 mm slump but we achieved 180 mm slump. This could be due to the excess water liberated from the aqueous solution of silicates and hydroxides along with the addition of super plasticizer.
- Colour of geopolymer concrete was quite typical. Due to use of GGBS and fly ash, it was brownish white to white with some shades of musk.
- Due to polymerisation process, the mix was getting difficult to handle.
- During demoulding, it was observed that the setting time of geopolymer concrete is much lower as compared to cement concrete say about days.
- Adopting the method of curing is ambient temperature curing. As GGBS is present, Steam or Hot oven curing is not required
- Touching the mix by bear hands has adverse effects. The high concentration of silicates in its polymerisation stage can cause severe burns on skin.

3. Tests on Fresh Concrete

Following tests were performed on fresh concrete

- Slump cone test
- Compaction factor test
- Cohesiveness test

Each test was performed in lab following all the specifications. Compaction factor test gives more accurate results. Slump cone test revealed that concrete was flow able and pump able.

4. Curing of concrete:

Following are Methods of curing of Geopolymer specimens

- Accelerated steam curing method (warm water method)
- Dry oven curing method
- Ambient temperature Curing

5. Testing of Hardened Concrete:

Test on hardened concrete is done by two types

- Compressive strength
- Split tensile strength

Testing is done with the specifications confirming to IS 516, IS 9013 and IS 14858.Concrete specimen are tested at7, 14, 28 days conducted. On testing all the parameters were kept in mind. Specimens were taken out, stripped and after testing, various failure patterns was observed to study the kind of failure, reasons for such kind of failure, effects and causes of the same and its preventive measures. Photographs and other parameters were noted during failure of specimens for future research and investigation which is beyond the scope of this project. Overleaf illustrated pictures show the failure of cube and cylindrical specimens.

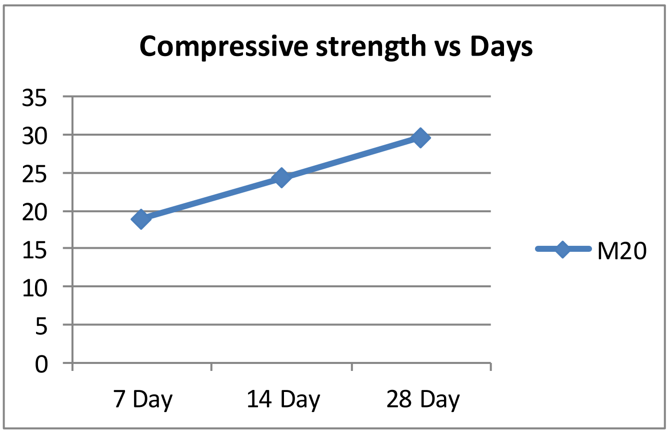
VI RESULT AND DISCUSSION

1.Conventional concrete:

a.Compressive strength:

Compressive strength of geopolymer concrete specimens was determined at 7, 14, 28 days, following all the IS specification. Result of conventional concrete and geopolymer was compared and concluded. Cement is replaced 100% by fly ash and GGBS at a proportion of 60:40 respectively, and water is 100 % replaced by alkaline solution. Result of same are illustrated below in graphical representation.

Figure 1.Compression Testing



Graph: Compressive strength of conventional concrete

Conventional concrete achieved 64% compressive strength after 7 day and 82% after 14 day of its total strength, after 28 day concrete achieved it full strength.

b.Split tensile strength:

Cylinder specimens with dimensions of 150 mm diameter and 300 mm length were produced for the Split tensile strength test. After 24 hours of casting, the specimens were demolded and moved to a curing tank, where they were allowed to cure for 28 days. These specimens were put through their paces on a compression tester. Three cylinders were tested in each category, and the average value is provided Split Tensile strength was calculated as follows as split tensile strength:

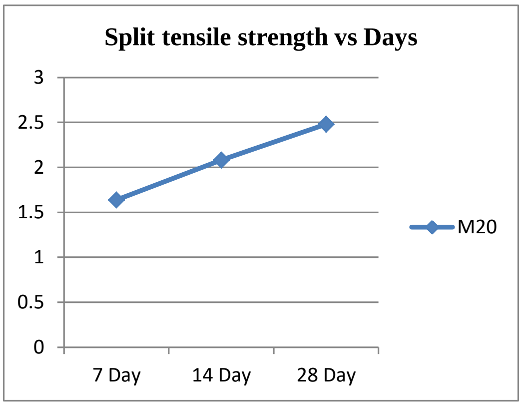
Split Tensile strength (MPa) = 2P / π DL,

Where, P = failure load

D = diameter of cylinder

L = length of cylinder

Figure 2.Split Tensile testing



Graph: Split tensile strength of conventional concrete

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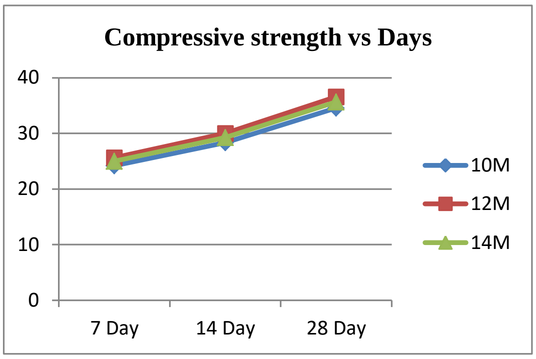
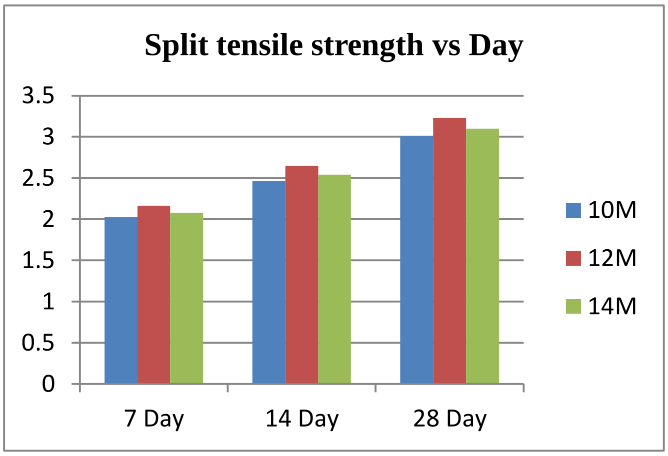
2.Geopolymer Concrete:

a.Compressive strength:



Graph: Compressive strength of geopolymer concrete

b.Split tensile strength:



Graph: Split tensile strength of geopolymer concrete

VII CONCLUSION

1. 12M Geopolymer concrete has maximum compressive strength amongst 10M, 10M and 14M Geopolymer concrete which is 18.94% greater than conventional concrete. i.e. at 28th day it gives **37.4KN/m^2**
2. 12M Geopolymer concrete has maximum split tensile strength amongst 10M, 12M and 14M Geopolymer concrete. It is 23.21% greater than conventional concrete.
3. Initial setting time of Geopolymer concrete is decreased with increased in molarity of sodium hydroxide which can be improve by addition of super plasticizers.
4. Workability of Geopolymer concrete is decreased with increased in molarity of sodium hydroxide.
5. As our aim was, cement can be completely replaced with flyash in order reduce the use of cement.

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