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Feasibility Study on Fly Ash based Geopolymer Concrete

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Abstract: Concrete is the most widely used building material in the construction of infrastructures such as buildings, highways, dams, and many other facilities. The increasing of worldwide production of ordinary Portland cement to meet infrastructure developments indicates that concrete will continue to be a chosen as the most common material of construction in the future. The production of cement consumes a lot of energy and increase CO_2 emission to the atmosphere. Another alternative to make environment friendly concrete is the development of geopolymer which is an inorganic alumina – silicate polymer, synthesized from materials of geological origin or by product materials such as fly ash which is rich in silicon and aluminum. In this study, 2 mixes were produced to evaluate the effect of key parameters on the mechanical properties of concrete and its behavior. For curing of specimens ambient curing (at room temperature) and oven curing at a temperature of 75^oC have been used. Geopolymer concrete gives better results in workability of concrete as compare to conventional concrete. Test results reveal that fly ash based geopolymer concrete gives better results of compressive strength than ordinary Portland cement. As the fluid to fly ash ratio increases the compressive strength decreases. For oven drying curing increase in compressive strength is more than ambient curing at room temperature as compare to conventional concrete.
Keywords: Compressive Strength, Concrete, Fly Ash, Geopolymer, Rebound Number

I. INTRODUCTION

A. General

The cement industry is India’s second highest payer of Central Excise and Major contributor to GDP (Gross Domestic Product). With infrastructure development growing and housing sector booming, demand for cement is also bound to increase. However, cement industry is extremely energy intensive. After thermal power plants and iron and steel sector, India cement industry is third largest coal user in country. The term 'Geo-polymer' was first introduced by Davidovits in 1978 to describe family of mineral binders with chemical composition similar to zeolites but with amorphous microstructure. Two main constituents of Geo-polymers are source materials and alkaline liquids. The source materials on alumino-silicate should be rich in silicon (Si) and aluminium (Al). They could be by-product materials such fly ash, silica fume, slag, rice-husk ash, red mud, etc. Geo-polymers are also unique in comparison to other alumino-silicate materials.

II. GEOPOLYMER CONCRETE

A. What is Geo-polymer?

Geo-polymers are inorganic, typically ceramic materials that form long range, covalently bonded, non-crystalline (amorphous) networks. Obsidian is example of naturally occurring Geo-polymer.Geo-polymer concrete, in other words, can be termed “No Cement Concrete”. Ordinary Portland cement is main constituent in cement concrete for binding aggregates, coarse and fine, together to make homogeneous mass. Portland cement mixed with water reacts and C-S-H gel formed, whereas in Geo-polymer concrete formation of C-S-H gel is very minimal due to presence of low calcium content in fly ash. The usage of cement is totally nullified in manufacturing Geo-polymer concrete making it more environmental friendly and hence term “No Cement Concrete”.

B. Geo-polymer Production

A coal fly ash sample from Carolina was used in chemical process known as geo-polymerization to produce new binder name geo-polymer. The developed Geo-polymer binder could completely replaced by OPC binder in regular concrete application. Mortar and concrete samples were made to compare strength of geopolymer with OPC concrete. The polymerization process involves a fast chemical reaction under alkaline conditions on silicon-aluminium minerals that results in three dimensional polymeric chain and ring structure. The ultimate structure of Geo-polymer depends largely on ratio of Si to Al (Si:Al), with materials having a ratio of Si:Al between 2 to 3.5 for use in concrete application. A critical feature is that water is added only for workability and this water does not become part of Geo-polymer structure. In other words, water is not involved in chemical reaction and is expelled during curing and drying. In hydration process of OPC, resultant products are predominantly calcium silicate hydrate (C-S-H) gel and calcium hydroxides. Where as in case of Geo-polymer, these do not form. CSH is gel of hydrated CaO-SiO2, which normally contributes mechanical strength to cement. In contrast, formation of three dimensional amorphous alkali alumino-silicate network with general formula of (Na/K)n-((-Si-O2)z-Al- O)n.wH2O which attributes binding properties to Geo-polymeric gel in terms of their elemental composition is calcium. If excess calcium is added, some forms of C-S-H gel will be obtained. But it has significantly lower Ca/Si ratio than CSH gel formed from hydration of Ordinary Portland Cement.

C. Constituents of Geopolymer Concrete

The main constituent of a Geo-polymer concrete is low calcium ASTM class F fly ash, alkaline liquid, coarse and fine aggregates. Unlike ordinary cement concrete wherein cement is mixed in range of 350 kg/m3 to 450 kg/m3 depending upon grade of concrete, an equivalent quantity of fly ash is taken and mixed in case of Geo-polymer concrete. Class F fly ash is obtained from Sophia Power Plant and is used to manufacture Geo-polymer concrete throughout the project.

D. Alkaline Liquid

Locally available silicates and hydroxides of sodium are used to prepare an alkaline liquid. Though silicates and hydroxides of potassium could be used to prepare an alkaline liquid, sodium based silicates and hydroxides are used in this project considering a high cost of potassium based chemicals.

Sodium silicate is a common name for the compound sodium meta-silicate, Na2SiO3, also known as the water glass or liquid glass. It is available in an aqueous solution and in the solid form and is used in cements, passive fire protection, refractoriness, textile and lumber processing, and automobiles. Sodium carbonate and silicon dioxide react when a molten to form sodium silicate and carbon dioxide and chemical equation reads as

$$Na_2CO_3 + SiO_2 \longrightarrow Na_2SiO_3 + CO_2$$

Sodium hydroxide (NaOH), also known as the caustic soda, is caustic metallic base. It is used in many industries, mostly as a strong chemical base in a manufacture of pulp and paper, textiles, drinking water, soaps and detergents and as drain cleaner. Worldwide production in 2004 was approximately 60 million tons, while demand was 51 million tones. Pure sodium hydroxide is white solid available in a form of pellets, flakes, and granules. It is the hygroscopic and readily absorbs carbon dioxide from air, so it should be stored in the airtight container. It is very soluble in water and is highly exothermic when it is dissolved in the water.

A sodium hydroxide solution will leave the yellow stain on fabric and paper. Care should be taken while handling sodium hydroxide pellets or flakes. Gloves and masks should be worn while weighing sodium hydroxide and putting a same in water to dissolve. Sodium silicate and sodium hydroxide are mixed in suitable proportions to obtain an alkaline liquid. 8M, 12M and 14M are the molarities of sodium hydroxide used throughout this research.

E. Curing of Geopolymer Concrete

Steam curing, Heat curing and curing at an ambient temperature are three methods being employed to cure a Geo-polymer concrete. It takes days to cure a concrete in ambient temperature and steam curing requires boiler and fire wood to generate steam. Throughout this project, Heat curing is adopted to cure Geo-polymer concrete elements at 70C to 90C in oven. The heat curing enhances a compressive strength of Geo-polymer concrete by 15% and also attains its full strength in 24 hours. This is in contrast to 28 days curing of cement concrete elements and hence Geo-polymer concrete can also be termed “One day Concrete”.

III. LITERATURE REVIEW

Shri Krishna Gurlhosur, Abdul Samad M Kamdod et. al.[1] studied ‘A Comparative Study Of Green Geopolymer Concrete Using Fly Ash’. The long term properties included in the study were compressive strength, sulfate resistance and sulfuric acid resistance. The alkaline liquid comprised a combination of sodium silicate solution and sodium hydroxide solids in flakes or pellets form dissolved in water. Two different mixing ratios, M15 and M20, was used for the fly ash concrete, cement concrete and mixture of cement + fly ash concrete specimens. The sulfuric acid resistance of concrete was also studied. The concentration of sulfuric acid solution was 5% for soaking concrete specimens. As per the test results, it was observed that higher the average ambient temperature higher was the compressive strength. The test results demonstrate that heat-cured fly ash-based geopolymer concrete has an excellent resistance to sulfate attack. There was no damage to the surface of test specimens after exposure to sodium sulfate solution up to one week. The sulfuric acid resistance of heat-cured geopolymer concrete was significantly better than that of Portland cement concrete.

Brett Temest, Olanrewaju Sanusi[2] studied 'Compressive Strength And Embodied Energy Optimization Of Fly Ash Based Geopolymer Concrete'. In this paper authors have studied the details of mix design and curing regimen for a geopolymer concrete by relating strength development to the quantity of energy that was consumed to activate the fly ash and curing the concrete to elevated temperature. Concrete were produced with the addition of NaOH at the rate of 10%, 13% and 16% of fly ash mass. Cylinder samples were made and batches in room temperature and then cured to 75^0C. It was observed that lower alkalinity activating solutions benefited most from additional curing time, whereas mix produced with higher alkalinity solutions benefited most from additional aging time. Geopolymer cement from fly ash eliminates greenhouse gas sources i.e. resulting in reducing negative environmental impacts. It was also observed that there was less energy consumption than Portland cement concrete with higher compressive strength. Increased curing time at 75^0 C also improved 28 days strength. High temperature curing for an additional day improved compressive strength at an average of 12% in all mixes.

Asha Philip, Ashok Mathew[3] presented 'Experimental Study On Mechanical Properties Of Geopolymer Concrete Using GGBS'. The aim of the study was to develop an environmental friendly construction material using geopolymer concrete. In terms of reducing the global warming, the Geopolymer technology could reduce the CO2 emission in to the atmosphere caused by cement industries about 80%. In this technology, the source material that was rich in silicon and aluminum was reacted with highly alkaline solutions through the process of geopolymerization to produce the binding material. Given paper states to use GGBS (Ground Granulated Blast furnace Slag) in place of OPC and compare its properties with the normal concrete. In the present investigation it was proposed to to study the mechanical properties viz. compressive strength, split tensile strength, flexural strength test on concrete specimen. This study reveals that, GGBS makes significant impact on the strength of geopolymer concrete, the mechanical properties were higher for geopolymer concrete and rate of gain of geopolymer concrete was very fast at first 7 days curing period. Hence give faster construction of products, GGBS based geopolymer concrete has excellent compressive strength and was suitable for structural applications.

IV. MATERIAL PROPERTIES

A. Fly Ash

Fly-ash may be defined as an alumina-silicate source which represents the majority component of geo-polymer concrete quantity wise and has the least unit cost of all the cementing materials used in the mix. Fly-ash plays the important role of reducing brittleness in geo-polymer concrete to a considerable extent so that it can withstand more tensile stress. Fly ash as the solid by-product of the combustion of coal and it is generally extracted from coal-fired power plant through the process of electrostatic precipitation. The Fly-ash used in the thesis work was procured from Paras thermal power station, Vidyut Nagar, PARAS, Tal, Balapur, District AKOLA.

B. Cement

It is a fine mineral powder manufactured with two controlled and precise processes specifically called wet and dry process. Cement is made by grinding together a mixture of limestone and clay, which is than heated at temperature of 1450°c which results, into granular substance called "clinker", combination of calcium, silicate, alumina and iron oxide. In this paper, cement of grade 53 has been used only for conventional concrete.

C. Coarse Aggregates

The aggregate which are retained over IS sieve 20 mm is termed as coarse aggregate. The basic function performed by these aggregates in geo-polymer concrete is to increase the strength of geo-polymer concrete & thus help in making a solid and hard mass of geo-polymer concrete. It helps to reduce the cost of geo-polymer concrete mix prepared by occupying the maximum volume of the concrete. Easily available crushed aggregate of 20mm size are used as coarse aggregates.

TABLE I. PHYSICAL PROPERTIES OF COARSE AGGREGATES

Sr. No.	Properties	Test Result
1	Specific Gravity	2.67
2	Fineness modulus	8.65
3	Bulk density	1545 kg/m3
4	Water absorption	0.55%

D. Fine Aggregates

The aggregates pass through 4.75mm IS sieve is called as fine aggregates. The important function performed by these fine aggregates in geo-polymer concrete is to fill the voids in the concrete so as to make it a homogeneous mix. In addition to this it fills the voids present in the coarse aggregate and reduces shrinkage and cracking of geo-polymer concrete. The nearby available river sand was used in this experimental work.

TABLE II. PHYSICAL PROPERTIES OF FINE AGGREGATES

Sr. No.	Properties	Test Result
1	Specific Gravity	2.6
2	Fineness modulus	2.49
3	Bulk density	1260 kg/m3
4	Water absorption	1%

E. Alkaline Solutions

A combination of sodium silicate solution and sodium hydroxide solution was used as alkaline solution. Alkaline solution in geo-polymer concrete can be defined as an ingredient responsible for dissolution source of silica and alumina leading to the formation of chemical reagent of Alumina-silicate oxides through the complex action of hydroxide ions. The concentration of sodium hydroxide solution is taken as 10 Molarity. The reason is that sodium silicate solution is cheaper than the sodium hydroxide solution. Ratio for sodium silicate to sodium hydroxide solutions was kept as 2.5.

F. Water

Potable water was used in the concrete mix for the given project work. Water is also used in the preparation of NaOH solution for preparing geopolymer concrete and the same was used for curing of normal mix concrete.

V. PREPARATION OF GEOPOLYMER CONCRETE

A. Preparation of Geopolymer Concrete

400 g of sodium hydroxide flakes dissolved in one liter of water to prepare sodium hydroxide solution of 10 M. The mass of NaOH solids in a solution vary depending on the concentration of the solution expressed in terms of molarity (M). The sodium hydroxide solution was mixed with sodium silicate solution to get the desired alkaline solution one day before making the geopolymer concrete. After solution is prepared the composition is weighed and mixed in the dry mix of fly ash, fine aggregate and coarse aggregate to form a fly ash base geopolymer concrete mix concrete mixture and then transferred into the moulds.

B. Mix Proportions

TABLE III. MIX PROPORTIONS

Sr. No.	Constituents	Proportion (kg/m3) of Conventional Concrete	Proportion (kg/m3) of Geopolymer Concrete Mix 1	Proportion (kg/m3) of Geopolymer Concrete Mix 2
1	Fly ash	419	419	419
2	Fine aggregate	714	714	714
3	Coarse aggregate(20mm)	869.25	869.25	869.25
4	Coarse aggregate(10mm)	289.75	289.75	289.75
5	Sodium hydroxide(NaOH)	-	48	52
6	Sodium silicate(Na2SiO3)	-	120	130
7	Water	189	22.5	22.5
8	W/C Ratio	0.45	-	-
9	Solution/Fly ash Ratio	-	0.45	0.5
10	Na2SiO3/ NaOH Ratio	-	2.5	2.5

C. Clasification of Specimens

A total of 45 cubes of 150 mm x 150 mm x 150 mm size has been casted of which 9 cubes of normal mix, 18 cubes for geopolymer concrete mix 1(Ambient temp. and 75°C), and 18 cubes for geopolymer concrete mix 2 (Ambient temp. and 75°C) has been casted. For each mix 3 cubes have been tested for 7 days, 14 days, 28 days.

D. Curing of geo-polymer concrete

Generally, heat curing is recommended for geo-polymer concrete. Heat curing considerable assist the chemical reaction that occurs in geo-polymer concrete. Both curing time and curing temperature changes the compressive strength of geo-polymer concrete. Longer curing time increases the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hrs of curing time beyond the 24 hrs the gain in strength was minor. Higher curing temperature of geo-polymer concrete gains the higher compressive strength. Heat curing can be done by oven heating or steam curing. In case delay in the start of heat curing up to five days did not produce in loses of compressive strength. In the present work, all specimens of geopolymer concrete were kept for ambient curing at room temperature and at oven dry curing at the temperature of 75°C for 24 hours.

VI. RESULTS AND DISCUSSION

A. Slump Cone Results

TABLE IV. SLUMP CONE RESULTS

Sr. No.	Mixes	Slump Value in mm	Average Slump Value in mm
1	Nominal Mix	34	37
		36	
		40	
2	Geopolymer Mix 1	70	74
		74	
		79	
3	Geopolymer Mix 2	95	103
		105	
		109	

It shows that workability is greater in geopolymer concrete as compare to normal concrete and in geopolymer concrete as the fluid/fly ash ratio increases workability increases.

For mix-2 fluid/fly-ash ratio 0.5 is more workable than mix-1 having fluid/fly ash ratio lesser than mix-2 i.e. 0.45. For both the mixes of geopolymer concrete shear slump is obtained while performing slump cone test.

B. Compressive Strength Test Results

Compressive strength is the most important property used to study a concrete. Since other properties of concrete often compare with the compressive strength, it is used as an indicator of the other physical & chemical properties. For each type of mix, 3 cubes were considered and then average of 3 cubes was considered as a final value. The test results of the compressive strength test of normal mix and geo-polymer concrete samples are given below respectively. The table shows the result of 7 days, 14 days and 28 days of all mixes.

TABLE V. COMPRESSIVE STRENGTH TEST RESULTS

Days	Average Compressive Strength of Conventional Concrete (N/mm2)	Average Compressive Strength of Geopolymer Concrete Mix 1 Ambient Temp. (N/mm2)	Average Compressive Strength of Geopolymer Concrete Mix 1 75^0 C Temp. (N/mm2)	Average Compressive Strength of Geopolymer Concrete Mix 2 Ambient Temp. (N/mm2)	Average Compressive Strength of Geopolymer Concrete Mix 2 75^0 C Temp. (N/mm2)
7 Days	17.05	30.58	39.09	28.95	32.82
14 Days	23.25	39.48	49.98	37.56	45.7
28 Days	28.6	43.79	51.13	42.64	49.27

C. Comparative Graphs of both Mixes as per varying Curing Temperature

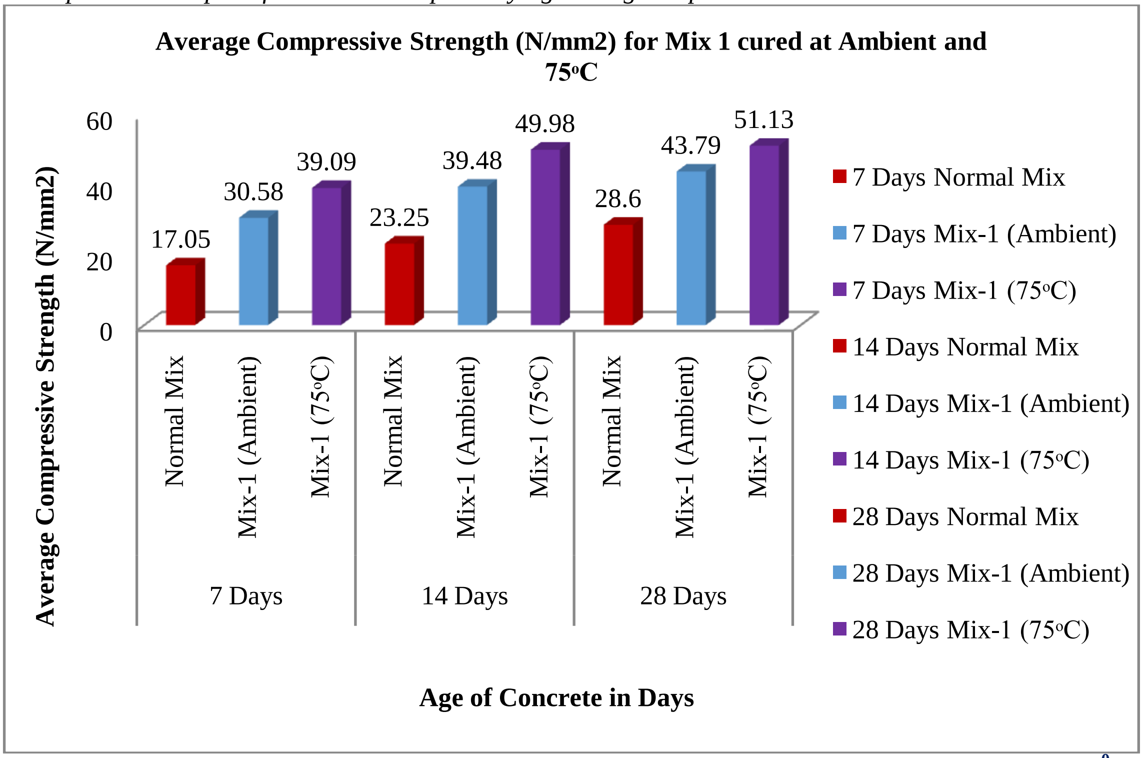

FIGURE I. AVERAGE COMPRESSIVE STRENGTH FOR MIX 1 CURED AT AMBIENT & 75^0 C

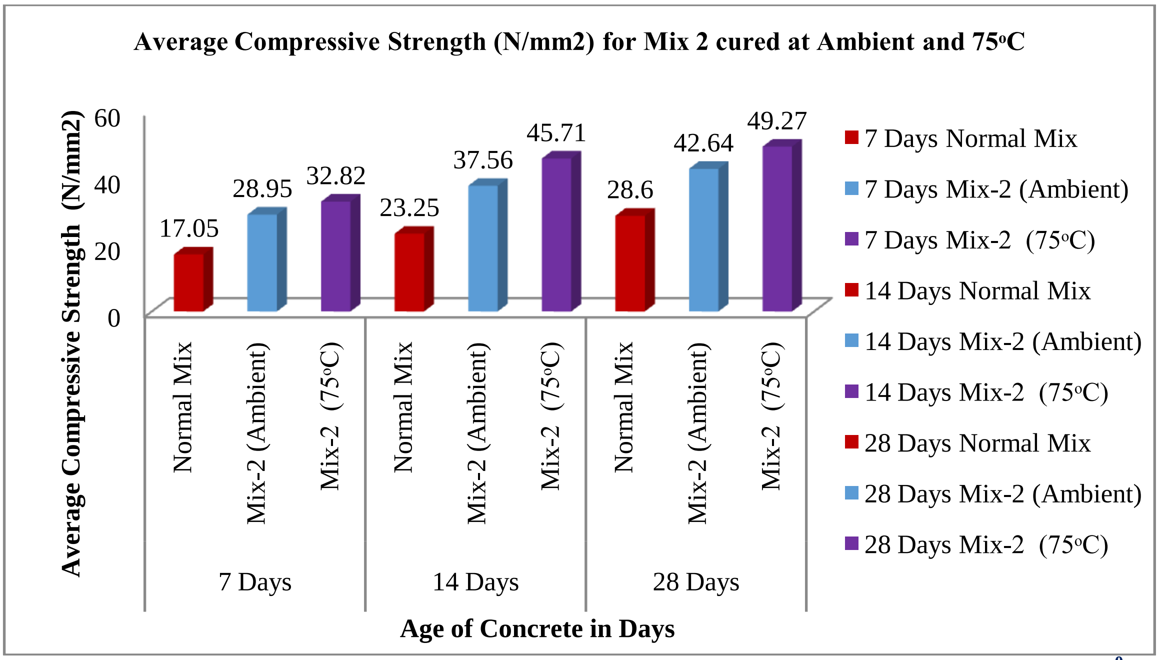

FIGURE II. AVERAGE COMPRESSIVE STRENGTH FOR MIX 2 CURED AT AMBIENT & 75^0 C

Above graphs shows the comparative results of both mixes cured at ambient room temperature and oven drying temperature at 75°C with respect to results of normal conventional concrete individually.

For mix 1, from figure 1 results states that compressive strength for geopolymer concrete is better as compare to normal conventional concrete. But as the mix 1 was divided into two parts as per varying curing temperature one was for room temperature and another was for 75°C, the compressive strength was good for greater temperature than room temperature.

Similarly, for mix 2, from figure 2 results states that compressive strength for geopolymer concrete is better as compare to normal conventional concrete. But as the mix 2 was divided into two parts as per varying curing temperature one was for room temperature and another was for 75°C, the compressive strength was good for greater temperature than room temperature.

In respect to 2 mixes, i.e. mix 1 and mix 2 figure 1 giving more results than figure 2 because for mix 1 fluid to fly ash ratio was 0.45 and for mix 2 fluid to fly ash ratio was 0.5. It states that, as the fluid to fly ash ratio increases the compressive strength decreases.

D. Comparative Graphs of ambient temperature for both mixes and 75°C for both mixes with respect to normal conventional concrete

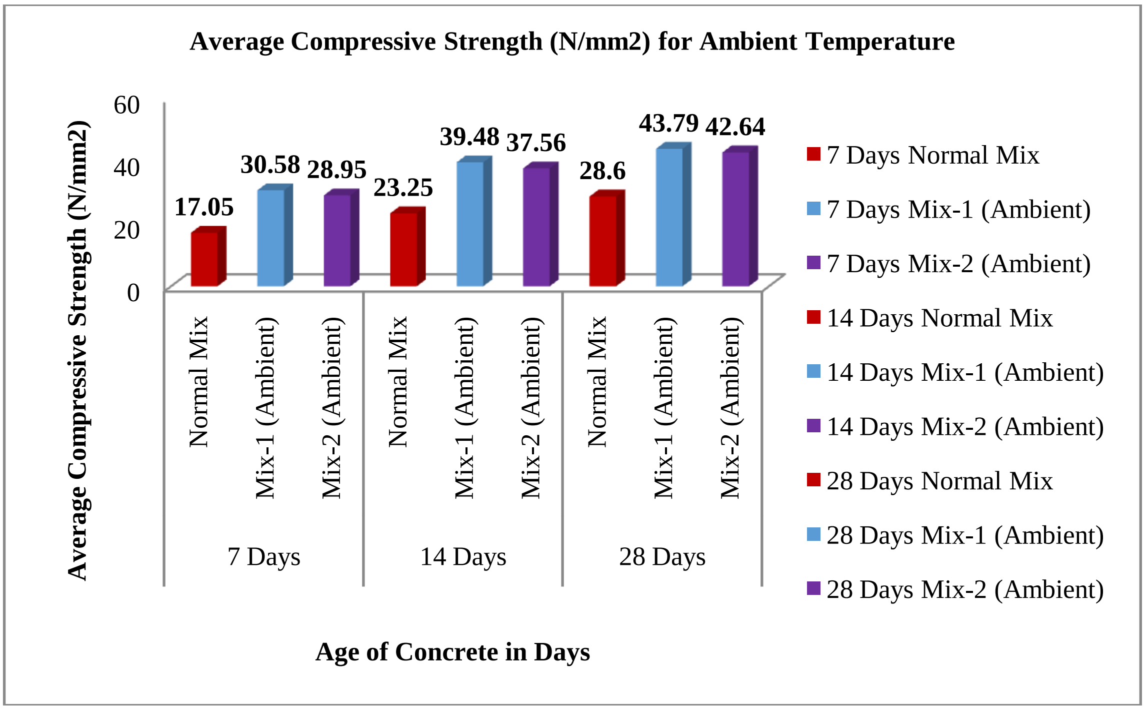

FIGURE III. AVERAGE COMPRESSIVE STRENGTH (N/MM2) FOR AMBIENT TEMPERATURE

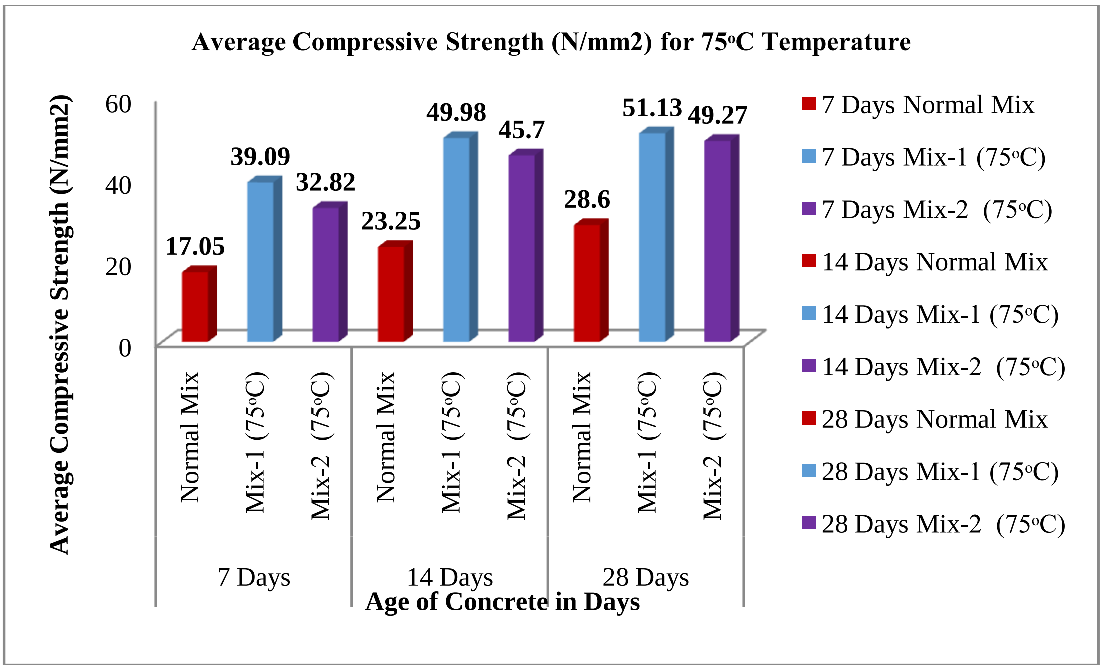

FIGURE IV. AVERAGE COMPRESSIVE STRENGTH (N/MM2) FOR 75°C TEMPERATURE

Above first graph showing the comparative result of normal mix with both mixes were cured at ambient room temperature and second graph showing comparative result of normal mix with both mixes were cured at oven drying temperature of 75°C.

In comparison between normal mix and ambient temperature for both the mixes, compressive strength is greater for geopolymer concrete as compare to normal mix but at the same time for mix 2 compressive strength was lesser.

Figure IV shows comparative results of normal mix with oven drying temperature of 75°C for both mixes. From this graph results reveals that, compressive strength was good for geopolymer concrete with 75^0 C temperature than ambient room temperature.

VII. CONCLUSION

From the above experimental result following conclusions are drawn:

- This project has shown the total elimination of cement from concrete which ultimately becomes "Green concrete".
- The fly ash has considered as waste material and found out to be usefulness through Geopolymer concrete in construction industries and become a valuable material.
- Workability test results shows that, workability of geopolymer concrete is good as compared to normal conventional concrete.
- As the fluid to fly-ash ratio increases workability of geopolymer concrete also increases.
- Comparative results of compressive strength with respect to normal mix shows that compressive strength is better for geopolymer concrete as compared to normal mix.
- The test results of compressive strength for mix-1 were better as compared to mix-2 in geopolymer concrete.
- As the fluid to fly-ash ratio increases compressive strength of geopolymer concrete decreases.
- As the temperature of curing increases the compressive strength increases. Hence the results for oven curing at 75°C as compared to ambient curing was better in geopolymer concrete.
- Increase in compressive strength of geopolymer concrete was 30 to 40% more as compared to normal mix.
- It reduces the emission of carbon-dioxide (CO_2) from the cement manufacturing industries in the environment up to a greater extent.
- Geo-polymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structure after a disaster.

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