"Experimental Study on Engineering Properties of Fly Ash Based Geopolymer Concrete"

Dipak Balasaheb Kadam[1], Rupali Sanjay Jagtap[2], Dnyaneshwar Rajendra Jagtap[3], Chetan Bajirao Bachhav[4], Suraj Riman Bhosle[5], Santosh R. Nawale[6]

[1]Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon, Ahmednagar, Maharashtra, India
[6]Assistant Professor ME(structure), Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon, Ahmednagar, Maharashtra, India

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Abstract - *The consumption of ordinary Portland cement caused pollution to the environment due to the emission of CO2. Fly ash is a byproduct from the coal industry which is widely available in the world. The properties of Fly Ash based geopolymer are enhanced with few factors that influence its performance. This report presents the Engineering properties of Geopolymer concrete with compressive strength of 30 MPa. The study includes determination of Engineering properties of geopolymer concrete such as modulus of elasticity, Poisson's ratio and modulus of rigidity and comparison of Compressive strength, Splitting tensile strength and Flexural strength of normal concrete with Geopolymer concrete. We have used different types of curing such as thermal curing (at 90° C for 8hrs), sunlight curing and Pond curing, and all tests were carried out pursuant to the relevant Indian Standards.*

Key Words: *Fly ash, Geopolymer concrete, alkaline solution (Na_2O and SiO_2), Solution / Fly ash ratio, Mix 30, Thermal curing*

1. INTRODUCTION

Concrete is one of the most widely used man-made construction material in the world. Compared to the other construction materials, concrete has numerous advantages such as abundant resources, easy operation, mechanical properties, durability, and low cost of production. These characteristics enable concrete to be widely employed in the field of civil Engineering. The global use of concrete is second only to water. As the demand for concrete as a construction material increases, so also the demand for Portland cement. On the other hand, the climate change due to global warming has become a major concern. Cement manufacture requires high temperatures, around 1400 °C, with consequent high energy dispersion and emissions. 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 5%-7% of global warming. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere.

In order to address Environmental effects associated with Portland cement, several efforts are in progress to reduce the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementitious 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.

1.1 General Introduction of Geopolymer Concrete

Davidovits J. [9] who is father of geopolymer, proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash, blast furnace slag, and rice husk ash to produce binders. Two main constituents of Geopolymer are source materials and alkaline liquid. The source material should be alumina-silicate based and rich in both silica and alumina. In Geopolymer concrete, supplementary cementing materials such as Fly ash, Silica fume, Rice husk ash, Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin are used as alternative binders to Portland cement. In this study, fly ash is used as alternative binders.

Geopolymer is an excellent alternative which transform industrial waste products like GGBS and fly ash into binder for concrete. Geopolymer binders are used together with aggregates to produce Geopolymer concrete. They are ideal for building and repairing infrastructures and for pre-casting units, because they have very high early strength. Their setting times can be controlled and they remain intact for very long time without any need for repair. Geopolymer concrete is inorganic polymer composites, which are prospective concrete with the potential to form a substantial element of an environmentally sustainable product by replacing the conventional concrete.80 to 90 percent reduction in CO2 emission can be achieved by the replacement of ordinary Portland cement (OPC) with Geopolymer cement. Geopolymer indicates transformation of geomolecules through geochemical process during diagnosis and can be classified into two major groups, pure inorganic and organic containing synthetic analogues of naturally occurring macromolecule. Geopolymer as initially proposed refers mainly to pure inorganic material but could be extended to include geomaterials with organic content. It is therefore important during Geopolymerisation to consider cross link between inorganic and organic species.

In the past years research has revealed that Geopolymers with high compressive strength, good acid resistance and good fire resistance could be synthesized for a variety of low-cost materials or industrial byproducts, such as Fly ash, Rice husk ash, sugarcane bagasse ash and furnace slag. These characteristics is defining geopolymer promising potentials in civil engineering applications as a "Green" material

In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. The concrete made with such industrial waste is Eco-friendly and so it is called Green Concrete. The properties of geopolymers are largely dependent on the characteristics of the base materials (chemical composition, content of glassy phase, amount of soluble silicon and aluminum, particle size distribution, and presence of inert particles).

1.2 Problem Statement

1. Production of Portland cement is increasing due to the increasing demand of construction industries. Therefore, the rate of production of carbon dioxide released to the atmosphere during the production of Portland cement is also increasing.
2. The main Significance of the Study in the Context of Current Status is to develop the geopolymer concrete using fly ash as source material instead of cement. It is Intended to develop Geopolymer concrete using optimized use of alkaline activators like Sodium silicate and sodium hydroxide with a view to minimize costs.
3. To Utilized Industrial Waste like Fly ash 100% to reduce burden on Environment.
4. To reduce the use of cement which ultimately reduce CO_2 emission from production of Fly ash.
5. Geopolymer can meet a "zero waste" objective; because they can be produced from materials that can utilize 100% recycled industrial waste, such as fly ash, blast furnace slag, Metakaolin, Marble powder etc.

1.3 Objectives

1. To produce Geopolymer concrete by utilising industrial waste such as fly ash.
2. To study the behaviour of geopolymer concrete in fresh state.
3. To study the mechanical Properties of Geopolymer concrete.
4. To optimise water to geopolymer binder ratio on the basis of compressive strength.
5. To study Elastic properties of geopolymer concrete.
6. To compare mechanical properties of geopolymer concrete and cement concrete
7. To solve problem regarding disposal of wastes from mineral extraction and processes of industries.

1.4 Advantages

1. Abundant raw materials resources for production of Geopolymer concrete.
2. Energy saving and environment protection: Geopolymeric raw materials, resulting in 3/5 less energy consumption than Portland cement. In addition, a little CO_2 is emitted.
3. Simple preparation technique: Geopolymer can be synthesized simply by mixing alumino-silicate reactive materials and strongly alkaline solutions, then curing at room temperature/dry temp.
4. Good volume stability: Geopolymer concrete have 4/5 lower shrinkage than Portland cement concrete
5. Reasonable strength gain in a short time: Geopolymer can obtain 50 to 70% of the final compressive strength in the first 24 hours of setting.
6. Ultra-excellent durability: Geopolymer concrete or mortar can withstand hundreds of years weathering attack without too much function loss.
7. High fire resistance and low thermal conductivity: Geopolymer material can withstand 1000° C to 1200°C without losing functions.
8. High Resistance to corrosion of reinforcement in concrete.
9. In terms of global warming: Geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries.

1.5 Limitations

1. Cost is increased due alkaline materials.
2. Usable for high temperature region only.

2. METHODOLOGY

Following parameters are kept constant for the Experimental work as mentioned in the earlier investigation

1) Percentage replacement of cement by fly ash is 100%.
2) Type of alkaline activators used is Sodium Hydroxide and Sodium Silicate.
3) Sodium silicate-to-sodium hydroxide ratio by mass is one.
4) Concentration of NaOH in terms of Morality.
5) Concentration of Na_2O and SiO_2 in sodium silicate solution.
6) Curing time (Duration and Temperature).

Mix design for Geopolymer Concrete

Based on the experimental investigation carried out in the present study which is done by S.V.Patankar et. al. [5] the steps are taken.

3.3.1 Mix Design for M30 Grade of Geopolymer:

Concrete Using Proposed Method- Based on the mix design steps discussed in preceding section, a sample mix proportioning for M30 grade of geopolymer concrete is carried out using proposed method. Following preliminary data is considered for the mix design:

1. Characteristic compressive strength of Geopolymer Concrete (fck) = 30 MPa.
2. Type of curing: Oven curing at 90 °C for 8 h and tested after 7 days
3. Workability in terms of flow: 25–50 % (Degree of workability—Medium)
4. Fly ash: Fineness in terms of specific surface = 320 m^2/kg
5. Alkaline activators (Na_2SiO_3 and NaOH)
(a) Concentration of Sodium hydroxide in terms of molarity = 13 M
(b) Concentration of Sodium silicate solution = 50.32 % solid content
6. Solution-to-fly ash ratio by mass = 0.35
7. Sodium silicate-to-sodium hydroxide ratio by mass = 1.0
8. Fine aggregate
(a) Type: Natural river sand confirming to grading zone-I as per IS 383[13], F.M. = 2.9
(b) Water absorption = Nil
(c) Water content = 2%
9. Coarse aggregate
(a) Type = Crushed/angular
(b) Maximum size = 20 mm
(c) Water absorption = 0.45%
(d) Moisture content = Nil.

Design Steps-

1. Target mean strength Fck = 38.25 MPa
2. Selection of quantity of fly ash From Fig. 1 taken from paper of S.V.Patankar et.al [5], the quantity of fly ash required is 485 kg/m^3 for the target mean strength of 38.25 MPa at solution-to-fly ash ratio of 0.35 and for 3200 m^2/kg fineness of fly ash.
3. Calculation of the quantity of alkaline activators: Calculate the quantity of alkaline activators considering:
Solution / Fly ash ratio by mass = 0:35
i.e.: Mass of (Na_2SiO_3 + NaOH) / Fly ash = 0:35
Mass of (Na_2SiO_3 + NaOH) / 485 = 0:35
Mass of (Na_2SiO_3 + NaOH) = 169.75 kg/m^3
Take the sodium silicate-to-sodium hydroxide ratio by mass of 1
Mass of sodium hydroxide solution (NaOH) = 84.87 kg/m^3
Mass of sodium silicate solution (Na_2SiO_3) = 84.87 kg/m^3
4. Calculation of total solid content in alkaline solution
Solid content in sodium silicate solution = (50.32 / 100) x 84.87 = 42.7 kg/m^3
Solid content in sodium hydroxide solution = (38.50 / 100) x 84.87 = 32.67 kg/m^3
Total Solid content in both alkaline solutions = 74.4 kg/m^3
5. Selection of water content For medium degree of workability and fineness of fly ash of 320 m^2/kg,
Water content = 110 kg/m^3
6. Calculation of additional quantity of water
= [Total quantity of water] – [Water present in alkaline solutions]
= 110 – 94.38
= 15.62 kg/m^3
7. Selection of wet density of geopolymer concrete From Fig. 3[4], wet density of geopolymer concrete is 2,470 kg/m^3 for the fineness of fly ash of 320 m^2/kg.
8. Calculation of fine and coarse aggregate content
(a) Total aggregate content = [Wet density of GPC] – [Quantity of fly ash + Quantity of both solutions + extra water, if any]
= 2470 – [485+169.75 + 15.62] = 1779.63 kg/m^3
(b) Sand content = [Fine-to-total aggregate content in %] x [Total quantity of all-in-aggregate]
= [35/100] x 1779.63 = 622.87kg/m^3
(c) Coarse aggregate content = [Total quantity of all- in-aggregate] – [Sand content]
=1779.63 – 622.87 =1156.76 kg/m^3
9. Mix Proportions for 0.3 S/F

Fly Ash	= 485 kg/m^3
Water	= 15.62 kg/m^3
Fine aggregate	= 622.87 kg/m^3
Coarse aggregate	= 1156.92 kg/m^3
Alkaline solution	= 84.87 kg/m^3

Proportion of Material for Casting:

Fly- ash: FA: CA: Water: Alkaline Solution

1: 1.28: 2.39: 0.03: 0.3

3. RESULTS AND DISCUSSION

3.1- Compressive Strength:

The compressive strength test was performed taking average compressive strength of 2 cubes for all concrete mixes. Chart -1 shows the graphical representation of variation of average compressive strength for 7 and 28 days for cement concrete pond curing, GPC oven curing. Two cubes were cast and tested for compressive strength after 28 days of test period. Here, test period is the period considered after removing the cubes from oven till the time of testing for compressive strength.

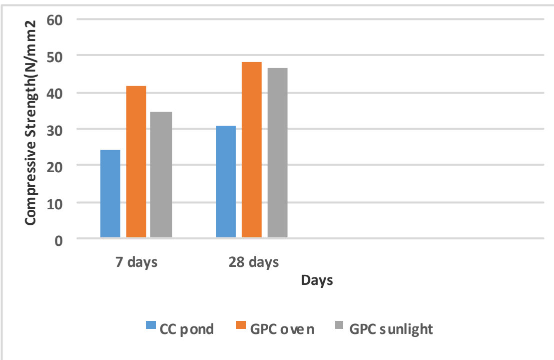

Chart -1: Comparison of Compressive strength of normal and Geopolymer concrete

Table-1: Geopolymer Concrete cubes of size 150mm150mmx150mm

Sr.No.	Solution to Fly Ash ratio	Types of Curing	Days of Testing	Load (KN)	Compressive strength (N/mm^2)
1.	0.30	Oven	7	850	37.78
2.				1040	46.22
3.				945	42
4.			28	1120	49.78
5.				1050	46.67
6.				1085	48.22
7.		Sunlight	7	750	33.33
8.				810	36
9.				780	34.67
10.			28	1290	57.33
11.				820	36.44
12.				1055	46.88

Cement concrete-pond curing: The compressive strength of cement concrete cubes at 28 days pond curing is **30.8 MPa**.

Geopolymer concrete-oven curing: The compressive strength of geopolymer concrete cubes cured at 90 °C in an oven for 8 hours is **48.23 MPa.** To avoid sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature or 28 days in an oven itself.

Geopolymer concrete-Sunlight curing: The compressive strength of Geopolymer concrete cubes at 28 days Sunlight curing is **46.89 MPa.**

It is observed that the compressive strength of M30 grade geopolymer concrete for Thermal and Sunlight curing is 26.08% and 22.5% more than the target strength (38.25 MPa) considered in proposed mix design method which is within the limit of +/−15 % as per IS 456-2000.

Fig.1: Compressive Test

3.2 Flexural Strength:

Table-2: Cement Concrete Beams of size 100mmx100mmx500mm

Sr. No.	Water to cement ratio	Types of curing	Days of Testing	Load (KN)	Modulus of Rupture (N/mm2)
1.	0.45	Pond	7	6.178	2.47
2.	0.45			5.491	2.19
3.	0.45			5.834	2.33
4.	0.45		28	10.86	4.34
5.	0.45			9.81	3.924
6.	0.45			10.33	4.132

Table-3: Geopolymer concrete Beams of size 100mmx100mmx500mm

Sr. No.	S/F ratio	Types of curing	Days of Testing	Avg. Load (KN)	Modulus of Rupture (N/mm^2)
1.	0.35	Oven	7	12.05	4.82
2.			28	12.95	5.18
3.		Sunlight	7	12.4	4.96
4.			28	14.5	5.8

Chart -2 shows a graphical representation of variation of flexural strength for Cement concrete (pond curing) and GPC Thermal and Sunlight curing at the age of 7 and 28 days respectively.

Cement concrete-pond curing: The Flexural strength of cement concrete cubes at 28 days pond curing is **4.13MPa.**

Geopolymer concrete-oven curing: The Flexural strength of geopolymer concrete cubes cured at 90 °C in an oven for 8 hours is **5.18 MPa.** To avoid sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature or 28 days in an oven itself.

Geopolymer concrete-Sunlight curing: The Flexural strength of Geopolymer concrete cubes at 28 days Sunlight curing is **5.8MPa.**

It is observed that the Flexural strength of M30 grade geopolymer concrete for Thermal and Sunlight curing is 35.25% and 51.4 %more than the target strength (3.83 MPa).

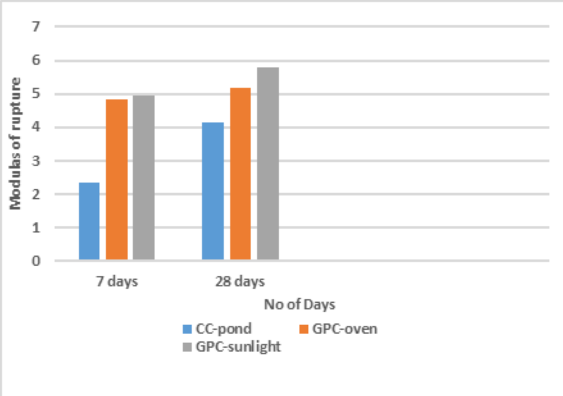

Chart -2: Comparison of Flexural strength of cement and Geopolymer concrete Beams

Fig.2: Flexural Test

3.3- Split tensile Strength:

Chart -3 shows a graphical representation of variation of split Tensile strength for Cement concrete (pond curing) and GPC Thermal and Sunlight curing at the age of 7 and 28 days respectively.

Cement concrete-pond curing: The Split Tensile strength of cement concrete cubes at 28 days pond curing is **4.17 MPa.**

Geopolymer concrete-oven curing: The Split Tensile strength of geopolymer concrete cubes cured at 90 °C in an oven for 8 hours is **4.66 MPa.** To avoid sudden variation in temperature, the concrete cubes were allowed to cool down up to room temperature or 28 days in an oven itself.

Geopolymer concrete-Sunlight curing: The Flexural strength of Geopolymer concrete cubes at 28 days Sunlight curing is **4.95 MPa.**

It is observed that the split Tensile strength of M30 grade geopolymer concrete for Thermal and Sunlight curing is 39% and 65% more than the target strength (3 MPa).

Table-4: Cement concrete Cylinder:

Sr .no	Water to cement ratio	Types of Curing	Days of Testing	Load (KN)	Split Tensile Strength (N/mm²)
1.	0.45	Pond	7	210	2.97
2.	0.45			190	2.69
3.	0.45		28	200	2.83
4.	0.45			255	3.61
5.	0.45			240	3.39
6.	0.45			248	3.5

Table-5: Geopolymer concrete Cylinder:

Sr. no	S/F ratio	Types of Curing	Days of Testing	Load (KN)	Split Tensile Strength (N/mm²)
1.	0.3	Oven	7	295	4.17
2.			28	330	4.66
3.		Sunlight	7	310	4.38
4.			28	350	4.95

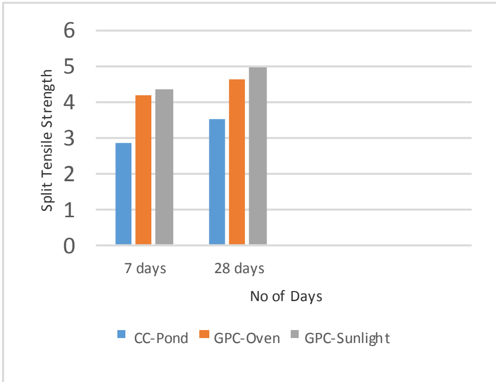

Chart -3: Comparison of Split Tensile Strength of normal and Geopolymer concrete

Fig.2: Split Tensile Test

3.4- Engineering Properties

3.4.1 Modulus of elasticity

The modulus of elasticity (E) is primarily influenced by the elastic properties of the aggregate, age of the concrete, conditions of curing, the type of cement and mix proportions. The modulus of elasticity is normally related to the compressive strength of concrete. The static modulus of elasticity of Geopolymer can be determined by using formulae given by Indian code IS 456: 2000 depending upon compressive strength of concrete. It is given by the following expressions

Es = 5.0Sqrt fcu i.e. Es = 34.72 GPa

Where, Es = Static modulus of elasticity in GPa

fcu = Cube compressive strength of concrete in N/mm^2

3.4.2 Poisson's ratio

At the point of initial cracking the strain on the tension face of a beam in flexure and the lateral tensile strain in compression specimen in uniaxial compression are of the same magnitude. Based on this research finding and using stress strain relation of solid mechanics Neville has derived the formula for Poisson's ratio as follows

μ = fb / fcu

= 0.25 / 48.225

= 0.00518

Where, μ = Static Poisson's ratio

fb = Tensile stress at cracking in flexure in MPa

fcu = Compressive stress at cracking in a compression specimen in MPa

3.4.3 Modulus of Rigidity

The modulus of rigidity (G) of steel fiber reinforcement concrete and polymer modified steel fiber reinforced concrete is obtained from following equation,

G = E/2(1+μ),

= 37.72/2(1+0.00518)

= 17.27GPa

3.4.4 Strain

€= Change in length/ Original length

= 287.3 / 300 = 0.957

3.5. Weight Analysis:

Table 6: Average Weights Analysis of Normal and Geopolymer Concrete

Sr. No.	Particulars	Normal Concrete	Geopolymer Concrete
1.	Cubes (150mm X 150mm X 150mm)	9.18 kg	8.49 kg
2.	Beams (100mm X 100mm X 500mm)	13.5 kg	12.7 kg
3.	Cylinder (150mm dim. X 300mm ht.)	12.7 kg	11.54 kg

4. CONCLUSIONS

1. The details of geopolymer material properties, mix design and the comparison of the mechanical properties of Geopolymer concrete such as compressive strength, flexural strength, split tensile strength with conventional concrete are analyzed.

2. It is observed that the geopolymer concrete of M30 grade having compressive strength is 24.30%, flexural strength is 43.33% and split tensile strength is 52% more than the target strength (38.25 MPa) of normal concrete.

3. The test results shows that the use of fly ash based geopolymer concrete increases the compressive strength, split tensile strength and flexural strength as compared with conventional/Normal concrete.

4. For the analysis of structures, the engineering Properties are very important. The elastic constants are static modulus of elasticity (Es), Poisson's ratio (μ) and modulus of rigidity (G), etc. After performing various tests on Geopolymer concrete we have found out above given properties.

5. By using geopolymer concrete we can solve the problem regarding disposal of wastes from mineral extraction and processes of industries i.e. fly ash.

6. By using Geopolymer concrete can be reduce the CO_2 which emits at the time of production of cement.

7. The weight of Geopolymer concrete somehow light than normal concrete members.

8. Geopolymer concrete can gain 100% strength in 24 h by thermal curing whereas, Cement concrete can gain 100% strength after 28days.

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BIOGRAPHIES

Dipak Balasaheb Kadam
"Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"

Rupali Sanjay Jagtap
"Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"

Dnyaneshwar Rajendra Jagtap
"Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"

Chetan Bajirao Bachhav
"Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"

Suraj Riman Bhosle
"Under Graduate Scholar, Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"

Santosh R. Nawale
"Assistant Professor ME(structure), Department of Civil Engineering, SRES's Sanjivani college of Engineering, Kopargaon"