Comparative Study of Processed and Unprocessed Flyash in Geopolymer Concrete

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Abstract- *Geopolymer concrete is an emerging construction material that uses a by-product material such as fly ash as a complete substitute for cement. Geopolymer concrete is eco-friendly material which is used as the alternate for the Portland cement. In this experimental study comparison of processed and un-processed fly ash is done. Geopolymer concrete is result from the reaction of fly ash and alkaline solution. Alkaline solution results from sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH).This alkaline solution act as binder in concrete mixture. During this experiment the test results are depends upon variation of different parameters like grade of concrete and type of fly ash used. Ratio of Na_2SiO_3 to NaOH is taken as 2. Solution to fly ash ratio by mass is taken as 0.35.*

Keywords- Flyash, sodium silicate, sodium hydroxide, molarity, rebound hammer and compressive strength.

I. INTRODUCTION

Concrete is the widely used construction material that makes best bridges, roads, foundations, architectural structures, block walls, fences and poles. It is one of the most widely used construction material which is usually associated with Portland cement as the main ingredient for making concrete. It is estimated that the production of cement is 4.65 billion metric tonnes produced in 2016 globally. With 502 million tonnes per year of cement production capacity as of 2018, India is the second largest producer in the world. The cement production capacity is estimated to touch 550MT by 2020. As of September 2018, all India capacity was around 480 MT. On the other hand, the climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases such as carbon dioxide, methane, nitrous oxide, ozone to the atmosphere by human activities. Several efforts are in progress to reduce the use of Portland cement in concrete in order to address the global warming issue. This includes the utilization of alternative cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and the development of alternative binders to Portland cement. In this respect, the geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In global warming, the geopolymer technology could significantly reduce the carbon dioxide emission to the atmosphere caused by cement industries.

Use of geopolymer concrete (GPC) instead of OPC concrete is suitable because CO_2 equivalent emission is nearly 9% less than OPC concrete. Fine aggregate, coarse aggregate, pozzolanic powder and alkaline activator solution are the materials used for making of GPC.Durability of GPC is nothing but ability to resist weathering action, chemical attack, abrasion or any process of deterioration.Geopolymers possess good mechanical properties as well as fire and acid resistance. It is observed that durability of GPC is vary with various parameters like molarity of sodium hydroxide solution and ratio of alkaline solution.In this experimental work, pozzocrete 60, pozzocrete 63 and pozzocrete 100 type of processed fly ash are used. The use of this advanced pozzolanic fly Ash material provides an effective reduction of the mixing water required and superior strength development, allowing high replacement rates that are not possible with normal cement additions. We also used unprocessed fly ash of fineness passing through IS sieve 150 micron
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II. REVIEW OF LITERATURE

Monita and Hamid R. Nikraz (2011) studied the strength characteristics, water absorption and water permeability of low calcium fly ash based geopolymer concrete. Mixtures with variations of water/ binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio were investigated. Results showed that a good quality concrete was obtained by reducing the water/binder ratio and aggregate/binder ratio; and the water absorption of low calcium fly ash geopolymer was improved by decreasing the water/binder ratio, increasing the fly ash content, and using a well-graded aggregate.

Modified guidelines for nix design of geopolymer concrete which was relevant to IS 10262-2009 was presented by Anuradha R. et al (2012). Also authors examined the applicability of existing mix design with the geopolymer concrete. In this study 100% cement was replaced by class F fly ash and 100% sand was replaced by M- sand.

S. Jaydeep and B. J. Chakravarthy (2013) prepared an optimum mix for geopolymer concrete using admixtures. Concrete cubes of size 150×150×150mm were prepared to find out compressive strength at 7 and 28 days. Results showed that the addition of sodium silicate solution to the sodium hydroxide solution as an alkaline activator enhanced the reaction between the source material and solution. Oven cured specimen gives the higher compressive strength as compared to direct sunlight curing. It was also observed that geopolymer concrete is more advantageous, economical and eco-friendly method when compared with conventional concrete.

P. K. Jamdade and U. R. Kawade (2014) studied the strength of geopolymer concrete by using oven curing. In this study geopolymer concrete is prepared by mixing sodium silicate and sodium hydroxide with processed fly ash. The concrete is cured at different condition and different temperatures i.e. 60 ^{O}C, 90 ^{O}C and 120 ^{O}C so as to increase the strength of concrete. It was observed that higher curing temperature resulted in larger compressive strength of geopolymer concrete, even though an increase in the curing temperature beyond 60^{0}C did not increase the compressive strength substantially. Also longer curing time improved the polymerization process resulting in higher compressive strength of geopolymer concrete.

YasirSofi and Iftekar Gull (2015) intended to study the properties of fly ash based Geopolymer concrete. M20 grade GPC can be formed by adopting nominal mix of 1:1.5:3 (fly ash: fine aggregates: coarse aggregates) by varying alkaline liquid to fly ash ratio from 0.3 to 0.45. The compressive strength, tensile strength and flexural strength tests were conducted on geopolymer concrete and parameters that affect it are analyzed and proved experimentally. The durability properties like permeability and acid attack are also studied. From the test results, it was concluded that geopolymer concrete possesses good compressive strength and offers good durability characteristics. With the increase of alkaline liquid to fly ash ratio strength decreases and alkaline liquid to fly ash ratio less than 0.3 is very stiff.

Experimental investigation has been carried out by Dr. Patankar (2015) for the gradation of geopolymer concrete and a mix design procedure is proposed on the basis of quantity and fineness of fly ash, quantity of water, grading of fine aggregate and fine to total aggregate ratio. Sodium silicate solution with Na_2O= 16.37%, SiO_2= 34.35% and H_2O= 49.28% and Sodium hydroxide solution having 13M concentration were maintained constant throughout the experiment. Water to geopolymer binder ratio of 0.35, alkaline solution to fly ash ratio of 0.35 and sodium silicate to sodium hydroxide ratio of 1.0 by mass were fixed on the basis of workability and cube compressive strength.

III. MATERIALS AND METHODOLOGY

The physical and chemical properties of materials, mixture proportions, the mixing process and the curing conditions of geopolymer concrete were discussed in this chapter.In the present study, mix design procedure for geopolymer concrete by Prof. S.V. PATANKAR is used which is developed on same lines of IS 10262-2009 for different grades of concrete. The current practice used in the manufacture and testing of Ordinary Portland cement concrete was followed. An optimum mix design is then developed keeping in mind the economic advantages of using locally available materials.

1. Materials

The main ingredients of geopolymer concrete are fly ash, alkaline solution, coarse aggregate, fine aggregate and water.

1.1 Fly ash- Fly ash or flue ash, also known as pulverized fuel ash, is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases. We used pozzocrete 60 having particle size maximum 18 % ROS (Residue over Sieve) on 45 micron sieve. Pozzocrete 63 having particle size 90% less than 45 micron and specific density approx. 2.3 metric ton per cubic meter. Pozzocrete 100 having particle size less than 5% retained on 25 Micron are used. All this three processed flyash are taken from Dirk India Pvt. Ltd., Eklahare, Nasik, Maharashtra. We also used unprocessed type of fly ash having 37.18 % residue retained on 45 Micron IS sieve. This unprocessed fly ash is taken from Bhusawal, Maharashtra.

1.2 Alkaline Solution-A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium based solutions were selected because they are cheaper than Potassium based solutions. The sodium hydroxide solids were in pellet form with specific gravity 2.13 and 97% purity. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molarity M. We kept molarity of NaOH solution as 13M throughout the experiment. To create 13M solution, we used 604 gm of sodium hydroxide pellets in 1 liter of water. The sodium hydroxide solution as prepared one or two days prior to the concrete batching to allow the exothermically heated liquid to cool to room temperature. The sodium silicate solution and sodium hydroxide solution were mixed just prior to the concrete batching. We used sodium silicate to sodium hydroxide ratio as 2 (S. Patankar-2015).

1.3 Coarse Aggregate-In this experimental study, we used two types of coarse aggregates. We use these two types of aggregates to analyze the behavior of geopolymer concrete. These aggregates are ordered from local supplier.

Table 1. Coarse Aggregate Type

C.A. Type	Size (mm)	Fineness Modulus
Coarse aggregate I	20	7.15
Coarse aggregate II	12.5	6.8

1.4 Fine Aggregate-Fine aggregate means the aggregate which passes through 4.75mm sieve.In this experimental study we are using locally available river sand as a fine aggregate.

Table 2. Physical Properties of Fine Aggregate

Particle Shape & Size	Rounded & Below 3.1mm
Specific Gravity	2.53
Fineness Modulus	3.4
Bulk Density	1460 M^3

2. Methodology

2.1 Mix Design Procedure

2.1.1 Design of M20 grade of Concrete

Molarity of NaOH = 13M,
Ratio of $Na_2SiO_3/NaOH$ =2

Table 3. Quantity of Materials Required Per Cubic Meter for M20 Grade of Geopolymer Concrete

Ingredients	Fly ash	NaOH	Na_2SiO_3	Fine Aggregate	Coarse Aggregate	Total Water	Extra Water
Quantity (kg/m^3)	280	32.67	65.33	740.1	1374.45	100	62.5

2.1.2 Design of M30 grade of Concrete

Table 4. Quantity of Materials Required Per Cubic Meter for M30 Grade of Geopolymer Concrete

Ingredients	Fly ash	NaOH	Na_2SiO_3	Fine Aggregate	Coarse Aggregate	Total Water	Extra Water
Quantity (kg/m^3)	405	47.25	94.5	678.03	1937.25	110	57.45

2.1.3 Design of M40 grade of Concrete

Table 5. Quantity of Materials Required Per Cubic Meter for M40 Grade of Geopolymer Concrete

Ingredients	Flyash	NaOH	Na_2SiO_3	Fine Aggregate	Coarse Aggregate	Total Water	Extra Water
Quantity (kg/m^3)	520	60.67	121.3	631.22	1172.28	120	22.5

2.2 Preparation of Specimen

All fly ash, coarse aggregate, fine aggregate and alkaline solution is measured with digital balance. The water is measured with measuring cylinder of capacity 1 liter and 500 ml. The sodium hydroxide solution of 13M is prepared one day prior of casting. The ingredients are thoroughly mixed over a G.I. sheet. The sand, fly ash, coarse aggregate and fine aggregate are measured accurately and were mixed in dry state for normal concrete. The dry concrete mix is then thoroughly and uniformly mixed till uniform and homogenous mixing in dry is observed. Selected percentage of alkaline solution is spread over the concrete mix and mixed thoroughly for five minutes. Then required amount of water is added carefully to achieve workability of concrete. The fresh concrete was placed in the moulds by trowel. Moulds of size 150 x 150 x 150mm are used. It is ensured that the representative volume was filled evenly in all specimens to avoid segregation, accumulation of aggregates etc. While placing concretes, the compaction in vertical position was given to avoid gaps in moulds. Moulds are cleaned and oiled from inside for smooth demoulding.

Concrete is mixed thoroughly and placed in the mould in three layers and compacted by electrically operated

Table vibrator with suitable fixing frame. It is vibrated till concrete woes out of mould. The vibration is continued till fly ash slurry just ooze out on surface of moulds. Care is taken of cement slurry not to spill over, due to vibration and segregation. Care is taken not to add extra fly ash, alkaline solution or extra water for achieving good surface finish. The additional concrete is chopped off from top surface of the mould for avoiding over sizes etc. The density of fresh concrete is taken with the help of weigh balance. Identification marks are given on the specimens by embossing over the surface after initial drying. The specimens were demoulded after 24 hours of casting and immediately stored in the oven for 1 day at 60^0C temperature. After demoulding the concrete specimen are allowed to become air dry in laboratory until the day of testing.

2.3 Compression Strength Test

These specimens are tested by compression testing machine after 7 days curing or 28 days curing. Load should be applied gradually at the rate of 140 kg/cm^2 per minute till the Specimens fails.

The compressive strength of specimen was calculated by formula

$$F_{cu} – P_c / A$$

Where,
P_c= failure load in compression, N
A= Loaded Area of cube, mm^2
F_{cu}= Compressive strength, N/mm^2

Fig.3.1. Compression Test

Fig.3.2. Compression Test Result

2.3.1 Rebound Hammer Test

Rebound Hammer test is a Non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. First the rebound number of concrete cube is taken and then the compressive strength is tested on compression testing machine.

Table 6. Quality of Concrete for different values of rebound number

Average Rebound Number	Quality of Concrete
>40	Very Good Hard Layer
30 to 40	Good layer
20 to 30	Fair
<20	Poor concrete
0	Delaminated

IV. RESULT

4.1Rebound Hammer Test

Table 7. Test Result

Type of Flyash	Concrete Grade	Cube Name	Rebound Number
P60	M20	P60-M20-6	44
	M30	P60-M30-1	46
	M40	P60-M40-4	41
P63	M20	P63-M20-5	43
	M30	P63-M30-9	38
	M40	P63-M40-3	41
P100	M20	P100-8	37
	M30	P100-2	39
	M40	P100-7	42
Unprocessed	M20	M20-1	34
	M30	M30-4	37
	M40	M40-11	38

4.2 Compression Test

Table 8. 7^{TH} Day Compressive Strength

Type of Flyash	Concrete Grade	Cube Name	Test Result (N/mm^2)
P60	M20	P60-M20-7	11.1
	M30	P60-M30-3	14.3
	M40	P60-M40-1	17.6
P63	M20	P63-M20-3	15.6
	M30	P63-M30-4	21.3
	M40	P63-M40-5	24.4
P100	M20	P100-M20-2	12.1
	M30	P100-M30-7	14.8
	M40	P100-M40-3	17.3
Unprocessed	M20	M20-2	10.9
	M30	M30-5	12.4
	M40	M40-12	16.1

Here we can see that 7 days compressive strength gain in geopolymer concrete have observed to be about 55.5% for P60, 78% for P63, 60.5% for P100 and 54.5%for unprocessed flyaash in case of M20 grade of concrete. P63 concrete have higher strength than the other P60, P100 and unprocessed flyash concrete.

For M30 grade of concrete there is a strength gain of 47.6 % for P60, 71% for P63, 49.3% for P100 and 41.3% for unprocessed flyash.

For M40 grade of concrete there is a strength gain of 44 % for P60, 61.5% for P63, 43.25% for P100 and 40.25% for unprocessed flyash.

Table 9. 14^{TH} Day Compressive Strength

Type of Flyash	Concrete Grade	Cube Name	Test Result (N/mm^2)
P60	M20	P60-M20-2	14.3
	M30	P60-M30-2	19.4
	M40	P60-M40-8	24.2
P63	M20	P63-M20-1	21.7
	M30	P63-M30-2	32.2
	M40	P63-M40-7	37.4
P100	M20	P100-1	14.1
	M30	P100-3	20.2
	M40	P100-5	25.3
Unprocessed	M20	M20-3	11.2
	M30	M30-6	16.2
	M40	M40-10	18.5

Here we can see that 14 days compressive strength gain in geopolymer concrete have observed to be about 71.5% for P60, 108.5% for P63, 70.5% for P100 and 56% for unprocessed for M20 grade of GPC. P63 concrete have greater compressive strength gain rate in between 7 to 14 days than P60, P100 and unprocessed.

For M30 grade of concrete there is a strength gain of 64.6 % for P60, 107.3% for P63, 67.3% for P100 and 54% for unprocessed flyash.

For M40 grade of concrete there is a strength gain of 60.5 % for P60, 93.5% for P63, 63.25% for P100 and 46.25% for unprocessed flyash.

Table 10. 28^{TH} Day Compressive Strength

Type of Flyash	Concrete Grade	Cube Name	Test Result (N/mm^2)
P60	M20	P60-M20-3	18.4
	M30	P60-M30-6	26.1
	M40	P60-M40-9	35.4
P63	M20	P63-M20-4	23.6
	M30	P63-M30-5	343
	M40	P63-M40-1	43.7
P100	M20	P100-M20-3	19.2
	M30	P100-M30-9	31.1
	M40	P100-M40-6	39.4
Unprocessed	M20	M20-4	14.3
	M30	M30-7	25.2
	M40	M40-9	31.1

Here we can see that after 28 days only P63 concrete have attained the desired compressive strength. After 28^{th} day P60 have 92%, P63 have 118%, P100 have 96% and 71.5% for unprocessed flyash of M20 grade of concrete.

For M30 grade of concrete, strength achieved is 87% for P60, 114% for P63, 103% for P100 and 84% for unprocessed flyash.

For M40 grade of concrete there is a strength gain of 88.5 % for P60, 109% for P63, 98.5% for P100 and 77.7% for unprocessed flyash.

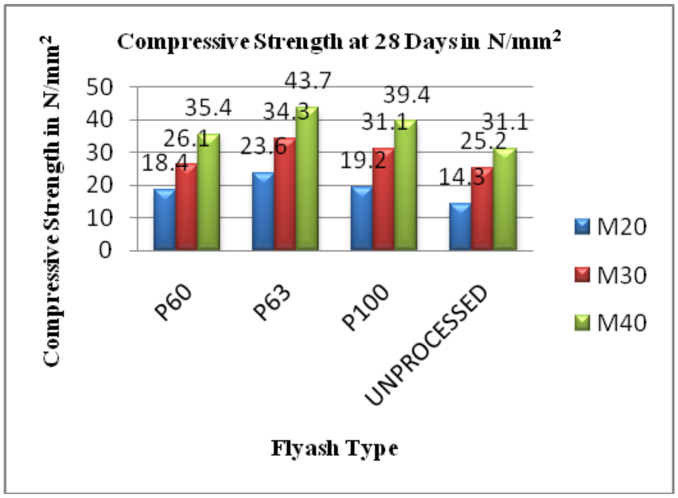

Fig.5.1 Compressive Strength at 28 Days in N/mm^2

Geopolymer concrete compressive strength for P63 type of fly ash has been found more dominating in terms of both strength gain rate and ultimate compressive strength than that of P60, P100 and unprocessed type of fly ash. The strength achieved by M30 grade of concrete on 28 day of P63 grade of flyash is 34.3 Mpa.

V. CONCLUSIONS

From the experimental work carried out the following conclusions were made

1. Test result show that as the change in concrete grade, the compressive strength result changes. Also Compressive strength achieved by processed fly ash is much better than unprocessed fly ash.
2. The strength achieved by unprocessed flyash is much lesser than processed type of flyash. This is obtained due to sandy nature of unprocessed flyash.
3. Workability of geopolymer concrete was found to be very stiff before addition of extra water. When extra water was added to the geopolymer concrete mix, it was workable.
4. The density of concrete with P63 type of flyash is higher than that of other type of flyash.
5. The Compressive strength achieved for P63 concrete is about 13% higher than desired strength of M30 grade of concrete.
6. The Compressive strength achieved for P63 concrete is about 6% higher than desired strength of M40 grade of concrete.
7. Compressive strength of P63 type of processed flyash is observed greater than all other types of processed and unprocessed flyash.
8. The Split Tensile Strength results for P63 concrete are observed greater than P60, P100 and unprocessed fly ash Concrete.
9. In rainy weather, 2% moisture content is observed in geopolymer concrete.
10. The compressive strength and split tensile strength of geopolymer concrete increases with increase in fineness of fly ash up to P63 and then decreases with further increase in fineness of fly ash i.e. for P100.
11. Geopolymer concrete can be used as innovative construction material by saving in natural resources, sustainability and all other geopolymer concrete properties.
12. Geoplymer concrete is an excellent alternative solution to the CO_2 producing ordinary Portland cement concrete.

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