EXPERIMENTAL STUDY OF FLY ASH BASED LIGHTWEIGHT GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF COARSE AGGREGATE BY ARTIFICIAL LIGHTWEIGHT EXAPANDED CLAY AGGREGATE

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Abstract – *Fly ash based lightweight geopolymer concrete (LWGPC) is an innovative construction material which combine both the advantages of lightweight concrete and geopolymer concrete. Fly ash based lightweight geopolymer concrete provides the eminent solution to decrease the dead load of the structure and decrease the co_2 which emits at the time production of cement. The main focus of this experimental study is to produce fly ash based lightweight geopolymer concrete with partial replacement of coarse aggregate by artificial lightweight expanded clay aggregate (LECA) with different replacement level of 0%, 25%, 50%, 75% and 100% by volume. In this experimental study, the binder is class F fly ash and the alkaline activators are sodium silicate and sodium hydroxide in different molarities. The experimental tests including workability in the form of slump, wet and dry density, water absorption, compressive strength and shear strength at the age of 7 and 28 days with hot air oven curing at 70°C were studied. The results show that it is possible to produce fly ash based lightweight geopolymer concrete successfully used as structural lightweight concrete.*

Key Words: Fly ash based lightweight geopolymer concrete, alkaline activators, artificial lightweight expanded clay aggregate, compressive strength, shear strength, density, water absorption,

1. INTRODUCTION

Environmental pollution is the most severe problem that the world is facing today. In the construction industry, the production of ordinary Portland cement (OPC) causes emission of pollutants which result in environmental pollution. The production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. Among the greenhouse gases, CO_2 contributes about 70% of global warming. The contribution of ordinary Portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% to 8% of the total greenhouse gas emissions to the earth's atmosphere. The use of geopolymer technology is one of these alternatives. Geopolymer binders produced from alkaline activator with pozzolanic material (such as fly ash) react in highly alkaline conditions. The resulting gel binder reacts to produce geopolymer concrete (GPC). The geopolymerization technology can reduce the CO_2 emissions by 80-90 % as compared with OPC, extremely low costs while offering excellent mechanical and chemical resistance properties.

Lightweight concrete can be prepared either by injecting air or by omitting the finer sizes of the aggregate or by replacing them with hollow, cellular, or porous aggregate. The density of lightweight concrete usually ranges from 300 to 1800 kg/m3 whereas the density of geopolymer concrete is approximately 2400 kg/m3. Lightweight concrete has been categorized into three groups. [1] no-fines concrete, [2] aerated/foamed concrete, [3] lightweight aggregate concrete, [1] No-fines concrete contains a small amount of aggregate, if any. The coarse aggregate should be a single-size material, with nominal maximum sizes of 10 mm and 20 mm being the most common. The use of blended aggregates (10 and 7 mm; and 20 mm and 14 mm) showed satisfactory performance. However, since this type of concrete is characterized by uniformly distributed voids, it is not suitable for reinforced or pre-stressed concrete used in construction .[2] Foamed concrete is produced by using either cement paste or mortar in which large volumes of air are entrapped by using a foaming agent. Such foamed concrete has high flow ability, low weight, and minimal consumption of aggregates, controlled low strength, and excellent thermal-insulation properties. [3] Lightweight aggregate concrete consists of lightweight aggregate. Aggregates having bulk density less than 1200 kg/m3 are comes under lightweight aggregates. There are two types of aggregates natural and artificial LWA (Lightweight Aggregate). Natural aggregate like are volcanic tuff, Dialomite, perlite and lava slag. Artificial aggregates are fly ash pebbles, expanded glass, and cinder aggregate and Lightweight expanded clay aggregate (LECA). LECA are expanded clay aggregates manufactured by clay or brick powder which is heated at a high temperature (900° to1200°C) in a rotary kiln.

Light weight geopolymer concrete finds huge range of applications for which there is a narrow research work done. In this study, light weight aggregates are used in the geopolymer concrete replacing different proportions of

LECA by conventional aggregates and the development of mix calculation to get required strength at low density. This research provides the effect of GPC with LECA of different proportions by showing results in the form of Density water absorption compressive strength and shear strength.

2. EXPERIMENTAL PROGRAM

As design code does not exist for the mix design of geopolymer concrete. In the case of Portland cement concrete the density is in the range between 2200 to 2600 kg/m^3. The density of geopolymer concrete 2400 kg/m^3 was considered for 1m^3 fly ash based lightweight geopolymer concrete. The fly ash 450 kg/m^3 was considered for 1 m^3 fly ash based lightweight geopolymer concrete. The solution of sodium silicate (Na_2SiO_3) with Na_2O = 16.85%, SiO_2 =38.15% and water 45% by mass was used and sodium hydroxide (NaOH) with 14M was used. Solution to fly ash ratio was used 0.35 by mass. The sodium silicate to sodium hydroxide ratio was 2.0 by mass. The water was 120 kg/m^3 adopted for 1m^3 fly ash based lightweight geopolymer concrete. The weight of water was calculated present in the solution of sodium silicate and sodium hydroxide and subtracts water from the total water (120kg/m^3). Remaining density was calculated and 35% fine aggregate was considered and 65% coarse aggregate of remaining density and partial replacement of coarse aggregate by artificial lightweight expanded clay aggregate (LECA) as 0%, 25%, 50%, 75% and 100% by volume. For each mix cubes specimens and shear specimens were cast.

3. MATERIALS AND THEIR PROPERTIES

3.1 Fly Ash

Fly ash is an industrial by product generated at coal electricity generating power plant that contain silica alumina and calcium based minerals. Fly ash of rattan India power limited Amravati is used in dry powder form. Its chemical composition and physical properties given in table 1 and table 2.

Table -1: Chemical Properties

Chemical Composition	% by mass
Silica (SiO_2)	64.3
Alumina (Al_2O_3)	29
Iron Oxide (Fe_2O_3)	3.3
Lime (CaO)	1.40
Magnesia (MgO)	1
Titanium Oxide (TiO_2)	0.5
Sulphur Trioxide (SO_3)	0.2
Loss on Ignition	0.30

Table -2: Physical Properties

Physical properties	Test Result
Specific gravity	2.13
Density (Kg/m^3)	980
Particle size (µ)	10 to 100
color	Dark grey
Fineness: passing 45µ (%)	65

3.2 Alkaline Liquids

In the present experimental study, sodium based alkaline activators are used. The most common alkaline liquid used in geopolymerization is a combination of sodium hydroxide (NaOH) and sodium silicate ($Na2SiO_3$). The sodium silicate solution purchased from Samarth chemical industry khamgaon, with Na_2O = 16.85%, SiO_2 =38.15% and water 45% by mass.

Sodium hydroxide in flakes form purchased from Samarth chemical industry khamgaon. The sodium hydroxide solution is prepared by dissolving the flakes in water the mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar.in this experimental study NaOH with concentration of 14M was used.

3.3 Aggregate

In the present experimental study, coarse aggregate along with partial replacement of artificial lightweight expanded clay aggregate (LECA) and fine aggregate as locally available river sand. The following properties of fine aggregates, coarse aggregate and artificial lightweight expanded clay aggregate were determined as per IS: 2386-1963 given in table 3.

Table -3: Properties of Aggregate

Physical Properties	Fine Aggregate	Coarse Aggregate	LECA
Specific Gravity	2.65	2.60	1.59
Bulk Density (Kg/m^3)	1720	1620	290

Water Absorption (%)	1.23	1	14.23

3.4 Water

Potable laboratory tab water was used for mixing of fly ash based lightweight geopolymer concrete.

4. MIXING, CASTING AND CURING OF FLY ASH BASED LIGHTWEIGHT GEOPOLYMER CONCRETE SPECIEMENS

Fly ash based lightweight Geopolymer concrete mixed by adopting the conventional techniques used in the mixed of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together in the mixer machine for about 3 to 4 minutes. The aggregates were prepared in saturated surface dry condition. The alkaline solution was then added to the dry materials and the mixing continued for further about 4 to 5 minutes to manufacture the fresh concrete shown in fig-1. The fresh concrete was cast into the moulds immediately after mixing in three layers for cubical specimens of size 100 X 100 X100 mm and shear specimens of size shown in Fig-2 each layer was given 25 to 30 manual strokes using a temping rod. After 24 hours from casting fly ash based lightweight geopolymer concrete specimens were cured by hot air oven curing. The specimens were cured at 70°C for 24 Hours shown in figure 1 and specimens were allowed to cool up to room temperature then specimens were removed from mould and kept in room temperature up to testing.

Fig -1: Fresh concrete and Hot air oven curing

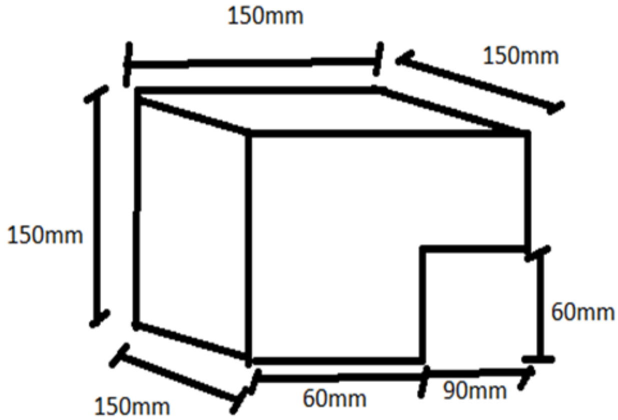

Fig -2: Shear Specimen

5. TESTING AND RESULTS

5.1 Workability Test

Workability is the property of freshly mixed concrete that determines the ease with which it can be properly mixed, placed, consolidated and finished without segregation. The workability of the fresh fly ash based lightweight geopolymer concrete was measured by means of the conventional slump test as per IS: 1199(1989) shown in fig-3. Results shown in chart 1 and tabulated in table 4.

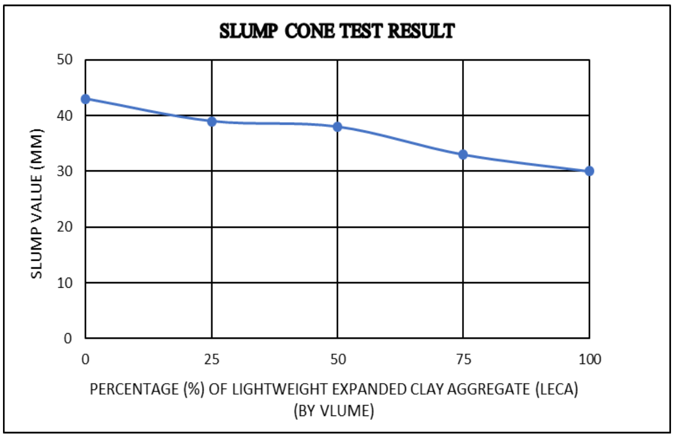

Chart -1: Slump Cone Results

Table -3: Slump Cone Results

Sr. No.	% of LECA (by volume)	Slump Cone Test Results (mm)
1	0	43
2	25	39
3	50	38
4	75	33
5	100	30

Fig -3: Slump Cone Test

5.2 Density Test

The density of both fresh and hardened fly ash based lightweight geopolymer concrete cubes made with different replacement of coarse aggregate by artificial lightweight expanded clay aggregate (LECA). The wet density was calculated with fresh concrete and dry density was calculated at the age of 28 Days. The density of fly ash based lightweight geopolymer concrete was calculated by formula

Density = (mass of concrete sample/volume of concrete sample)

For wet and dry density three sample for each parameter was casted and test was performed. The result was taken as the average of these three sample. The results shown in chart-2 and tabulated in table 4.

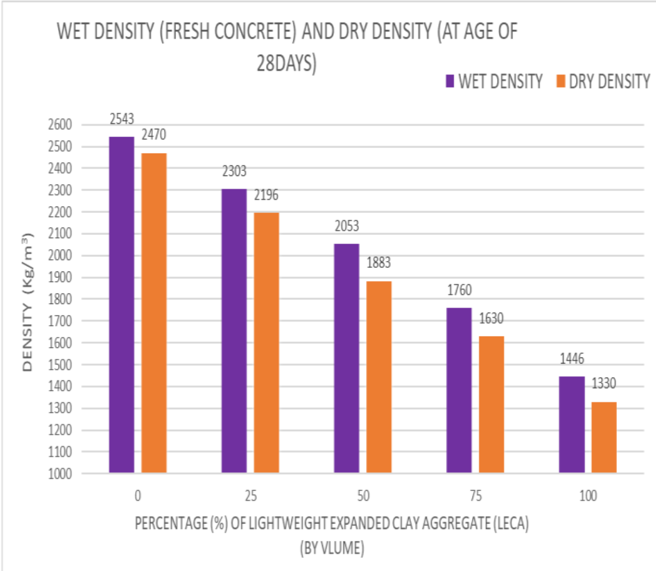

Chart -2: Wet and Dry Density Results

Table -4: Wet and Dry Density Results

Sr. No.	% of LECA (by volume)	Wet Density (kg/m^3)	Dry Density (kg/m^3)
1	0	2543	2470
2	25	2303	2196
3	50	2053	1883
4	75	1760	1630
5	100	1446	1330

5.3 Compressive Strength

Compressive strength is an essential property for all concrete as it also depends on curing time and curing temperature. When the curing time increase the compressive strength also increases. The compressive strength test was conducted at the age of 7 and 28 days with hot air oven curing. The compressive strength test was performed as per IS: 516 –1959 shown in fig-4. The compression testing machine of 3000 kN capacity was used. The effects of partial replacement of coarse aggregate by lightweight expanded clay aggregate with hot air oven curing at 70°C on compressive strength. The results are shown in chart-3 and tabulated in table-5.

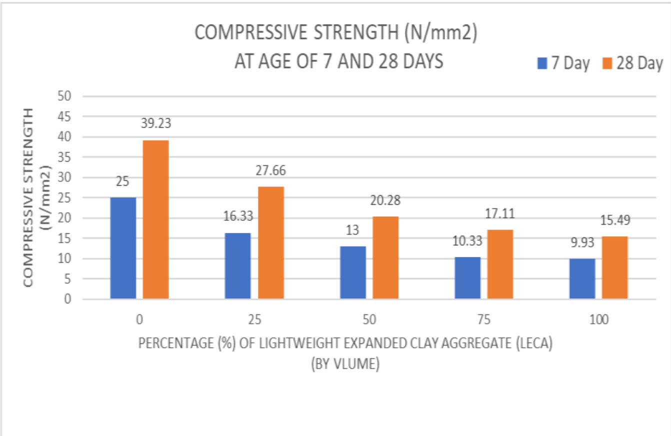

Chart -3: Compressive Strength Results

Table -5: Compressive Strength Results

Sr. No.	% of LECA (by volume)	Compressive strength (N/mm^2) at age of 7days	Compressive strength(N/mm^2) at age of 28days
1	0	25	39.23
2	25	16.33	27.66
3	50	13	20.28
4	75	10.33	17.11
5	100	9.93	15.49

Fig -4: Compressive Strength Test

5.3 Shear Strength

For shear test compression testing machine of capacity 3000 KN was used and shear specimen was tested under two point loads with special arrangement. This load produced ultimate shear crack. Total 15 numbers of shear specimens were casted shown in fig-5. Three sample for each parameter was casted and shear test was performed at the age of 28 days. The results are presented in chart-4 and tabulated in table 6.

Fig -5: Shear specimens

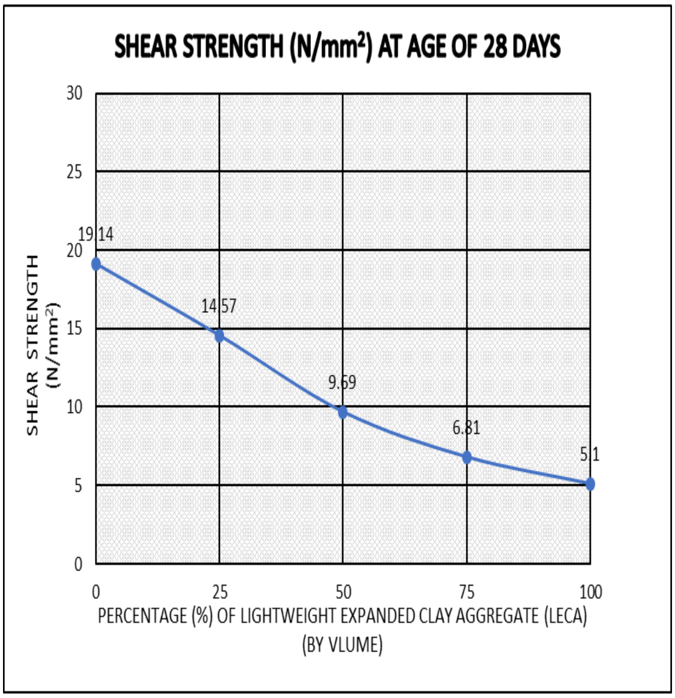

Chart -4: Shear Strength Results

Table -6: Shear Strength Results

Sr. No.	% of LECA (by volume)	Shear strength (N/mm^2) at age of 28days
1	0	19.14
2	25	14.57
3	50	9.69

4	75	6.81
5	100	5.10

5.3 Water Absorption Test

The cured fly ash based lightweight geopolymer concrete specimens initially weighed for weight W1 kg. The specimens kept in hot air oven at temperature of 100°C for a period of 24 hours. The specimen removed from oven and allowed to cool to room temperature and weighed for weight W2. The oven dried specimen immersed in water bath and kept undisturbed for 24 hours allowing the water to fill all the voids with in the specimen. The specimen remove from water bath and allowed for surface dry condition. The specimen at saturated surface dry condition and weighed for weight W3. The % water absorption can be calculated by formula.

% water absorption = [(W3-W2)/ W2]*100

For water absorption three sample for each parameter were casted and water absorption test was performed at the age of 28days. The results are presented in chart-5 and tabulated in table 7.

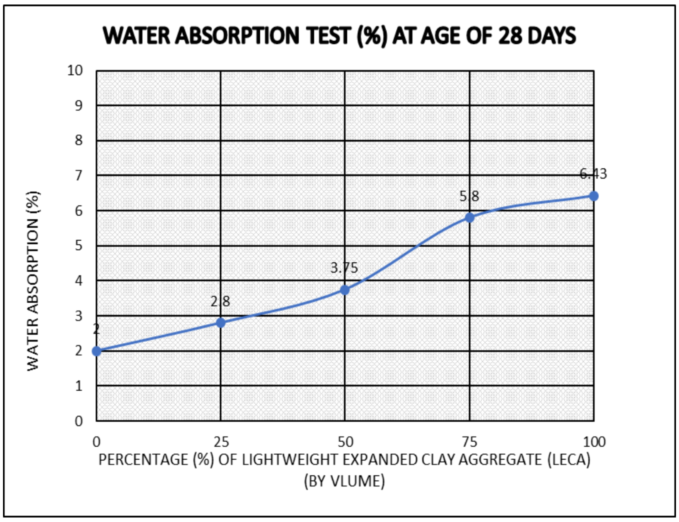

Chart -5: Water Absorption Results

Table -7: Water Absorption Results

Sr. No.	% of LECA (by volume)	Water Absorption (%)
1	0	2
2	25	2.8
3	50	3.75
4	75	5.8
5	100	6.43

6. CONCLUSIONS

The following conclusions are drawn based on the experimental results.

1. In the experimental study the results indicated that the use of lightweight expanded clay aggregate to produce fly ash based lightweight geopolymer concrete.

2. The workability of fly ash based lightweight geopolymer concrete in fresh state increases with increasing percentage of lightweight expanded clay aggregate (by volume).

3. The results shows that the increasing percentage of lightweight expanded clay aggregate (by volume) compressive strength and shear strength decreases.

4. By increasing percentage of lightweight expanded clay aggregate (by volume), the water absorption of fly ash based lightweight geopolymer concrete increases.

5. It is observe that the increasing percentage of lightweight expanded clay aggregate. The wet and dry density of fly ash based lightweight geopolymer concrete decreases.

6. By using fly ash based lightweight geopolymer concrete we can be reduce the dead load of the structure.it can be reduce the CO_2 which emits at the time of production of cement.

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