Fly Ash Based Light Weight Geopolymer Concrete Using EPS

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Abstract- *this paper presents the strength characteristics of light weight geopolymer concrete by using Expanded Polystyrene (EPS) as partial replacement of sand. The light weight geopolymer concrete is manufactured from class F(low calcium) P-60 grade of flyash, alkaline solutions i.e. sodium hydroxide(NaOH) and sodium silicate (Na_2SiO_3),or Potassium Hydroxide(KOH) and Potassium Silicate(K_2SiO_3), fine and coarse aggregate, expanded polystyrene. Super plasticizer is also added for suitable workability. The concentration of NaOH or KOH used in the experiment is 14M. Alkaline solution ratio, sodium silicate to sodium hydroxide or potassium silicate to potassium hydroxide ratio is considered as 1 and 1.5 for two different combinations. The test was carried out on 150 X 150 X 150mm cubes of light weight geopolymer concrete specimens after 7 days of oven curing. The cubes were oven cured at 90°C and 120°C for 8 hours. Specimens of each combination were also cured at ambient temperature for 7 days. Results showed that for given proportion to get maximum compressive strength the optimum molarity of alkaline solution is 14M and optimum curing temperature is 120°C with sodium silicate to sodium hydroxide ratio as 1.5. Whereas results also showed that for given proportion of potassium silicate to potassium hydroxide ratio of 1.5 which is cured at optimum curing temperature of 120°C and optimum molarity of 14M gives more compressive strength as compared to sodium hydroxide and sodium silicate.*

Keywords- Light Weight Geopolymer Concrete, Mix Design, Flyash, Alkaline Solution, Sodium Silicate, Sodium Hydroxide, Potassium Silicate, Potassium Hydroxide, heat cured, Compressive Strength, Expanded Polystyrene, EPS

I. INTRODUCTION

Concrete, as a major construction material, is being used at an ever increasing rate all around the world. Almost all of this concrete is currently made using OPC, leading to a massive global cement industry.A new material that has been introduced in the construction field called Geopolymer concrete in which cement is totally replaced by Fly ash rich in Aluminium (Al) and Silicon (Si). When the polymerisation process of highly alkaline liquids is activated, the materials start to bind with aggregates in concrete.

Expanded Polystyrene (EPS) is a lightweight material that is used in various Engineering, industrial, commercial as well as household applications. It has density that is about a couple of hundredth of that of soil. It has compressive strength comparable to medium clay and has good thermal insulation properties with stiffness. It is mainly use to reduce settlement below embankments, reducing lateral pressure on sub-structures, reducing stresses on rigid buried conduits and related applications, sound and vibration damping. EPS is very light in weight and has grainy form which is used as aggregate to create a light weight structural concrete. It has unit weight varying from 1200 to 2000 kg per m³. As polystyrene aggregate is light weight and high density, concrete can be created by partially replacing sand (fine aggregate) in the normal weight concrete mixtures with equal volume of the chemically coated crushed polystyrene granules.

II. EXPERIMENTAL WORK

The experimental work is divided into two parts. The first part consist of light weight geopolymer concrete containing sodium based combinations, where two different sodium silicate to sodium hydroxide ratios of 1 and 1.5 are considered and for each ratio the geopolymer concrete specimens are heated at 90^{o}C and 120^{o}C temperatures as well as at ambient temperature. Thus a series of twelve cubes are conducted in the first part. The second part is similar to the first part in every aspect except the alkali activators where potassium silicate and potassium hydroxide are used. For each series, in both parts, 3 cubes of 150 x 150 x 150mm geopolymer concrete specimens are conducted and the average value is shown in the results. In all specimens a constant activators to flyash ratio of 0.35 is considered.

A. Materials:

The materials which are used to make Light weight Geopolymer concrete is included in this chapter. Following are the constituents of Geopolymer concrete:

- Flyash- rich in Silica and Aluminium

- Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH)
- Sodium Silicate (Na_2SiO_3) or Potassium Silicate (K_2SiO_3)
- Coarse aggregates and Fine aggregates.
- Expanded Polystyrene (EPS)
- Super plasticizer

i. Flyash:

Flyash is the residue obtained from combustion of pulverized coal collected by the mechanical or electrostatics separators of the fuel gases of thermal power plants. Its composition varies with the type of fuel brunt, load on boiler and type of separator etc. Flyash (FLA) Pozzocrete 60 is used in concrete in dry powder form. Colour of Flyash is light gray .The Physical & Chemical properties of Flyash are shown in the tables below.

Table 1: Physical properties of Flyash

Sr. No.	Test	Unit	IS-Specification IS- 3821 (2003)	Typical Test result
1	Fineness - Specific Surface by Blaine's Permeability Method (Min.)	m^2 per kg	320	420
2	Lime Reactivity (Minimum)	N per mm^2	4.5	6.99
3	Moisture Content (Max.)	%	2	0.18
4	Autoclave Expansion (Max.)	%	0.8	0.025
5	Compressive Strength At 28 days – Pozzocrete + Cement Mortar Plain Cement Mortar	N per mm^2	-	47.8, 94.51% 50.50

Table 2: Chemical properties of Flyash

Sr. No	Chemical properties	Values	Requirements as Per IS- 3821 (2003)	Typical Test result
1	Loss on Ignition (Max.)	%	5	0.92
2	$SiO_2 + Al_2O_3 + Fe_2O_3$	%	70 min. by mass	92.99
3	SiO_2	%	35 min. by mass	57.29
4	MgO	%	5 max. by mass	1.46
5	SO_3	%	3 max. by mass	0.59
6	Na_2O	%	1.5 max. by mass	0.51
7	Total Chlorides	%	0.05 max. by mass	0.025

ii. Sodium Hydroxide (NaOH):

Sodium hydroxide (NaOH) is also known as lye or caustic soda, which is an inorganic compound. It is a white solid and highly caustic metallic base and alkali of sodium which is available in pellets, flakes, granules, and as prepared solutions at different concentrations. Sodium hydroxide solution was prepared from concentration of 14M using NaOH flakes of 97% purity and tap water which was prepared a day prior of the casting.

Fig. 1. sodium hydroxide solution of 14M concentration

iii. Potassium Hydroxide (KOH):

Potassium hydroxide isan inorganic compound with the formula KOH, and is commonly called caustic potash. It is colorless solid is a prototypical strong base. It has many industrial and niche applications, most of which exploit its corrosive nature and its reactivity toward acids. Potassium hydroxide can be found in pure form by reacting sodium hydroxide with impure potassium. It is usually sold as translucent pellets, which will become tacky in air because KOH is hygroscopic.

iv. Sodium Silicate (Na_2SiO_3):

Sodium silicate is the common name for compounds with the formula $(Na_2SiO_2)nO$. A well-known member of this series is sodium metasilicate Na_2SiO_3 is also known as water glass or liquid glass. Sodium silicate is one of the important solutions which are used in this experiment. It is in gel form i.e. at least 40-45% solid content of the solution.

Fig. 2.sodium silicate solution in gel form

v. Potassium Silicate (K_2SiO_3):

Potassium silicate is the name for a family of inorganic compounds. The most common potassium silicate has the formula K_2SiO_3, samples of which contain varying amounts of water. These are white solids or colorless solution. It is strongly alkaline. These are used for woodwork protection against fire, horticulture, industrial uses like metal cleaning formulations, various uses in the fabrication of welding rods or even of cosmetics, etc. It is also in gel form.

Fig. 3 potassium hydroxide flakes and potassium silicate solution

vi. Aggregates:

Aggregates are the most mined materials in the world. An aggregate is a main component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Locally available fine and coarse aggregate is used which is sieved. The fine aggregate used in this experiment is of sieve 2.36mm, 1.18mm and below. Similarly, the coarse aggregate is of sieve 16mm and 10mm.

vii. Expanded Polystyrene:

Expanded polystyrene (EPS) geofoam is a lightweight material that has density about a hundredth of that of soil. It has good thermal insulation properties with stiffness and compression strength comparable to medium clay. In this experiment, locally available EPS from industry which is of size 3-5 mm is used. Fine aggregate (sand) is partially replaced with EPS by volume.

Fig. 4mixing of aggregate, Fly ash and EPS

B. Mix Design

Expanded polystyrene (EPS) geofoam is a lightweight material.With the help of previous research work, the mix proportioning of light weight geopolymer concrete is designed with different trials. Four different combination as partial replacement of sand with EPS is considered in the experimental work. It consists of 5%, 10%, 15% and 20%. The details of mix design for the given combination with different alkaline solutions ratio is shown below in tables.

Fig. 5 mixing of all the ingredients of light weight geopolymer concrete

Table 3: Ingredients for light weight geopolymer concrete with EPS for alkaline ratio as 1

Ingredient	Unit	Weight	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	kg per m^3	390	390	390	390	390
C.A	kg per m^3	1273.41	1273.41	1273.41	1273.41	1273.41
F.A	kg per m^3	685.68	651.4	617.11	582.83	548.54
EPS	kg per m^3	10.11	0.51	1.01	1.52	2.02
Na_2SiO_3 or K_2SiO_3	kg per m^3	68.25	68.25	68.25	68.25	68.25
NaOH or KOH	kg per m^3	68.25	68.25	68.25	68.25	68.25
Extra water	kg per m^3	34.41	34.41	34.41	34.41	34.41
Super plasticiser	kg per m^3	11.7	11.7	11.7	11.7	11.7

Table 4: Ingredients for light weight geopolymer concretewith EPS for alkaline ratio as 1.5

Ingredient	Unit	Weight	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	Kg per m^3	390	390	390	390	390
C.A	Kg per m^3	1273.41	1273.41	1273.41	1273.41	1273.41
F.A	kg per m^3	685.68	651.4	617.11	582.83	548.54
EPS	kg per m^3	10.11	0.51	1.01	1.52	2.02
Na_2SiO_3 or K_2SiO_3	kg per m^3	81.9	81.9	81.9	81.9	81.9
NaOH or KOH	kg per m^3	54.6	54.6	54.6	54.6	54.6
Extra water	kg per m^3	34.41	34.41	34.41	34.41	34.41
Super plasticiser	kg per m^3	11.7	11.7	11.7	11.7	11.7

Fig. 6. Hand mixing of concrete and filling it in the mould

III. RESULTS AND DISCUSSION

Compression tests on three specimen of each mix were conducted on CTM and the average value is shown in Table. The specimens were heat cured at ambient temperature,90°C and 120°C. Concentration of NaOH and KOH was 14M for the specimens. Rest period of one day is provided due to which the compressive strength is increased. The specimen was kept in oven for 8 hrs heat curing. Demoulding of specimen was done before keeping the specimens in the oven. The results of all the specimens tested are shown below in Tables.

Fig. 7. Specimens at the time of compressive testing in CTM machine

Table 5: Compressive strength of LWGC specimens with EPS at 120°C and alkaline ratio as 1

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm^2*	*Peak load in N*	*Compressive strength after 7 days in N per mm^2*
1	5%	1380	61.33	1435	63.79
2	10%	1283	57.02	1334	59.30
3	15%	1085	48.22	1128	50.15
4	20%	774	34.40	805	35.78

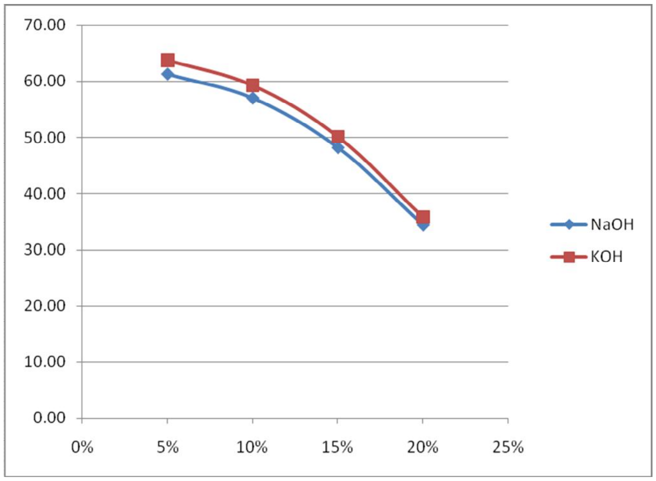

Fig. 8. Correlation between compressive strength to EPS content of Na and K-based Specimens at 120°C and Alkaline ratio as 1

Table 6: Compressive strength of LWGC specimens with EPS at ambient temperature and alkaline ratio as 1

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm2*	*Peak load in N*	*Compressive strength after 7 days in N per mm2*
1	5%	998.7	44.39	1029	45.72
2	10%	876.4	38.95	902.7	40.12
3	15%	765.9	34.04	786.3	34.95
4	20%	620.2	27.56	598.5	26.60

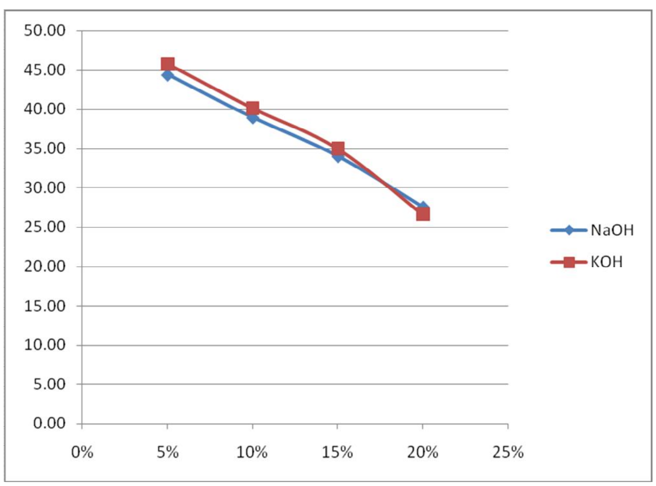

Fig. 9. Correlation between compressive strength to EPS content of Na and K-based Specimens at ambient temperature and Alkaline ratio as 1

Table 7: Compressive strength of LWGC specimens with EPS at 90°C and alkaline ratio as 1

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm2*	*Peak load in N*	*Compressive strength after 7 days in N per mm2*
1	5%	1191	52.93	1239	55.05
2	10%	1086	48.27	1129	50.20
3	15%	996.3	44.28	1036	46.05
4	20%	686.7	30.52	786.1	34.94

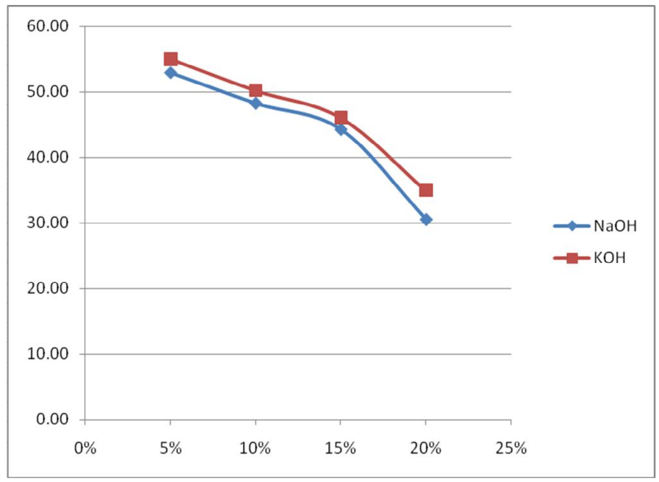

Fig. 10. Correlation between compressive strength to EPS content of Na and K-based Specimens at 90°C and Alkaline ratio as 1

Table 8: Compressive strength of LWGC specimens with EPS at 120°C and alkaline ratio as 1.5

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm^2*	*Peak load in N*	*Compressive strength after 7 days in N per mm^2*
1	5%	1479	65.73	1523	67.71
2	10%	1382	61.42	1410	62.65
3	15%	1035	46.00	1180	52.44
4	20%	782.8	34.79	814.1	36.18

ISSN **[ONLINE]: 2395-1052**

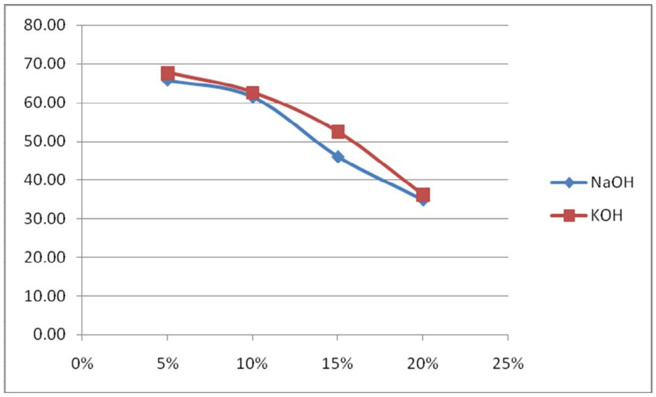

Fig. 11. Correlation between compressive strength to EPS content of Na and K-based Specimens at 120°C and Alkaline ratio as 1.5

Table 9: Compressive strength of LWGC specimens with EPS at ambient temperature and alkaline ratio as 1.5

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm2*	*Peak load in N*	*Compressive strength after 7 days in N per mm2*
1	5%	1089	48.40	1186	52.71
2	10%	963.7	42.83	1002	44.54
3	15%	713.3	31.70	797.2	35.43
4	20%	548.5	24.38	592.4	26.33

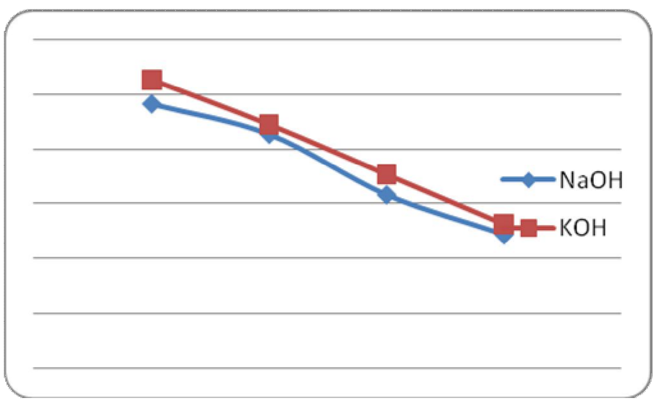

Fig. 12. Correlation between compressive strength to EPS content of Na and K-based Specimens at ambient temperature and Alkaline ratio as 1.5

Table 10: Compressive strength of LWGC specimens with EPS at 90°C and alkaline ratio as 1.5

Sr. No.	EPS content	NaOH		KOH	
		Peak load in N	*Compressive strength after 7 days in N per mm²*	*Peak load in N*	*Compressive strength after 7 days in N per mm²*
1	5%	1239	55.07	1289	57.27
2	10%	1103	49.02	1169	51.96
3	15%	989	43.96	1078	47.92
4	20%	694.2	30.85	721.9	32.09

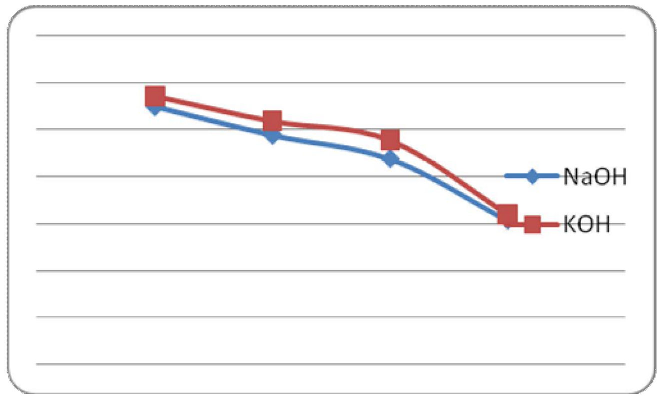

Fig. 13. Correlation between compressive strength to EPS content of Na and K-based Specimens at 90°C and Alkaline ratio as 1.5

IV. COST ANALYSIS

Cost comparison for 1 m^3 of various geopolymer concrete is shown in Tables. It shows that the cost is reduced when the EPS content in concrete is increased. Cost analysis for $1m^3$ is shown below.

1	Fly ash cost per kg	=Rs. 3/-
	Quantity of fly ash required	= 390 kg
	Total cost required for $1m^3$	=390 x 3
		=Rs. 1170
2	Cost of sodium silicate per kg	= Rs. 39
	Quantity for $1m^3$	=68.25kg (Ratio=1)
		= 81.90 kg (Ratio=1.5)
	Total cost required	=Rs. 2661.75 (Ratio=1)
		= Rs. 3194.1 (Ratio=1.5)

3 Cost of sodium hydroxide per kg =Rs. 32

Quantity for $1m^3$ =68.25 kg (Ratio=1)

= 54.60 kg (Ratio=1.5)

Total cost required =Rs.2184 (Ratio=1)

=Rs.1747.2 (Ratio=1.5)

4 Cost of potassium silicate per kg =Rs. 79

Quantity for $1m^3$ =68.25 kg (Ratio=1)

= 81.90 kg (Ratio=1.5)

Total cost required =Rs.5391.75 (Ratio=1)

= Rs. 6470.1 (Ratio=1.5)

5 Cost of potassium hydroxide per kg = Rs. 66

Quantity for $1m^3$ =68.25 kg (Ratio=1)

= 54.60kg (Ratio=1.5)

Total cost required =Rs.4504.50 (Ratio=1)

= Rs. 3603.6 (Ratio=1.5)

6 Cost of coarse aggregate per kg =Rs. 0.82

Quantity for $1m^3$ =1267.5 kg

Total cost required =Rs.1039.35

7 Cost of fine aggregate per kg =Rs. 1.2

Quantity for $1m^3$ =682.5 kg

Total cost required =Rs. 819

Table 11: Cost comparison of Na-based activator specimens with Na_2SiO_3 to NaOH = 1:

Sr.No	Materials	C.S	5%	10%	15%	20%
1	Fly ash	1170	1170	1170	1170	1170
2	Na_2SiO_3	2661.75	2661.75	2661.75	2661.75	2661.75
3	NaOH	2184	2184	2184	2184	2184
4	C.A	1039.35	1039.35	1039.35	1039.35	1039.35
5	F.A	819	778.05	737.1	696.15	655.2
6	EPS	-	2.5	5	7.5	10
	Total (Rs.)	**7874**	**7836**	**7797**	**7759**	**7720**

Table 12: cost comparison of Na-based activator specimens with Na2SiO3 to NaOH = 1.5:

Sr.No	Materials	C.S	5%	10%	15%	20%
1	Flyash	1170	1170	1170	1170	1170
2	Na_2SiO_3	3194.1	3194.1	3194.1	3194.1	3194.1
3	NaOH	1747.2	1747.2	1747.2	1747.2	1747.2
4	C.A	1039.35	1039.35	1039.35	1039.35	1039.35
5	F.A	819	778.05	737.1	696.15	655.2
6	EPS	-	2.5	5	7.5	10
	Total (Rs.)	**7970**	**7931**	**7893**	**7854**	**7816**

Table 13: Cost comparison of K-based activator specimens with K^2SiO^3 to KOH = 1:

Sr.No	Materials	C.S	5%	10%	15%	20%
1	Flyash	1170	1170	1170	1170	1170
2	K_2SiO_3	5391.75	5391.75	5391.75	5391.75	5391.75
3	KOH	4504.5	4504.5	4504.5	4504.5	4504.5
4	C.A	1039.35	1039.35	1039.35	1039.35	1039.35
5	F.A	819	778.05	737.1	696.15	655.2
6	EPS	-	2.5	5	7.5	10
	Total (Rs.)	**12925**	**12886**	**12848**	**12809**	**12771**

Table 14: Cost comparison of K-based activator specimens with K^2SiO^3 to KOH = 1.5:

Sr.No	Materials	C.S	5%	10%	15%	20%
1	Flyash	1170	1170	1170	1170	1170
2	K_2SiO_3	6470.1	6470.1	6470.1	6470.1	6470.1
3	KOH	3603.6	3603.6	3603.6	3603.6	3603.6
4	C.A	1039.35	1039.35	1039.35	1039.35	1039.35
5	F.A	819	778.05	737.1	696.15	655.2
6	EPS	-	2.5	5	7.5	10
	Total (Rs.)	**13102**	**13064**	**13025**	**12987**	**12948**

V. CONCLUSION

- The Light Weight Geopolymer concrete containing Potassium (K)-based activator gave highest compressive strength of 67.71 N per mm^2 for 5% EPS content at oven curing Temperature 120°C.
- The compressive strength of K-based activator geopolymer concrete is higher than Na-based activator geopolymer concrete at ambient temperature and oven curing temperatures of 90°C and 120°C.
- Na-based activator geopolymer concrete gave higher compressive strength than K-based activator at ambient temperature for 20% EPS content and alkaline ratio 1.
- It is observed that specimens with Na_2SiO_3 to NaOH or K_2SiO_3 to KOH ratio as 1.5 gave higher compressive strength than that of ratio as 1.
- The compressive strength of Na-based lightweight geopolymer concrete having 5%, 10%, 15% and 20% EPS is reduced by 3.33%, 9.67%, 32.35% and 48.84% and K-based lightweight geopolymer concrete is reduced by 4.64%, 11.76%, 26.14% and 49.04% as compared to normal geopolymer concrete.
- The compressive strength of geopolymer concrete is 1.5 times greater than conventional concrete.
- The overall density of geopolymer concrete is reduced from 2400 kg per m3 to 2100 kg per m3 by using EPS beads.
- The density for 20% EPS obtained was 2138 kg per m3 and density for 5% EPS was 2290 kg per m3
- The density of light weight geopolymer concrete compared to normal geopolymer concrete is reduced by 4.58%, 6.83%, 8.08% and 10.91% for 5% EPS, 10% EPS, 15% EPS and 20% EPS respectively.
- The light weight geopolymer concrete specimens with Na-based activator exhibited more surface cracks than that of K-based activator.
- Results indicate that lightweight geopolymer concrete having 10% EPS can be effectively used as part replacement of fine aggregates in making lightweight geopolymer concrete.
- From cost analysis, it is observed that Na-based activator light weight geopolymer concrete is less costly than that of K-based activator concrete.
- The results were experimentally compared and it shows that for 5% EPS there was 25.7% increase in the value of modulus of elasticity for ambient curing. Similarly for 90°C and 120°C the percentage increase in the value of modulus of elasticity was observed to be 32.07% and 25.53%, respectively.
- The floating and segregation of EPS beads can be minimized by using low slump of mix and fast setting of geopolymer with hardener.

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