Experimental Investigation Flyash Based Light Weight Geopolymer Concrete Using Expanded Polystyrene (EPS)

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Abstract - The main objective is to produce lightweight geopolymer concrete using expanded polystyrene (EPS) beads as partial replacement of the fine aggregates for building components. The selection of EPS bead aggregate was made mainly due to its low density, closed cellular structure, hydrophobic and energy absorbing characteristics. Also, to study the strength characteristics of light weight geopolymer concrete using different combinations. Previously, several studies were conducted on mix details, strength properties, drying shrinkage, compaction and finishing etc. of the geopolymer concretes .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 m^3. 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.

Key Words: *Lightweight Geopolymer concrete, Geopolymer, Expanded polystyrene (EPS) , Fly Ash, Polymerisation*

1.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. Every year the production of Portland cement is increasing with the increasing demand of construction The survey shows the total production of fly ash in the world is about 780 million tons per year after 2010. In India more than 100 million tons of fly ash is produced annually, out of which 17 – 20 % fly ash is utilized either in concrete as a part replacement of cement or workability improving admixtures or in stabilization of soil. There are environmental benefits in reducing the use of Portland cement in concrete, and using a byproduct cementations material, such as fly ash, silica fume, ground granulated blast furnace slag, rise husk ash, etc. as a partial substitute. With silicon and aluminum as the main constituents, fly ash has great potential as a cement replacing material in concrete.

Geopolymer concrete is a new material in which cement is totally replaced by the pozzolanic materials that is rich in Silicon (Si) and Aluminum (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature. Geopolymers were developed as a result of research into heat resistant materials after a series of catastrophic fires. The research yielded non- flammable and non-combustible geopolymer resins and binders.

Geopolymers can be synthesized using waste materials like industrial slag, fly ash, volcanic ash and along-with alkali activators. These materials have excellent compressive strength, ranging from 30MPa to 120 MPa, depending on the starting materials, method of preparation and the added aggregates. Such properties make these materials a very attractive choice for a range of potential applications. Currently, geopolymer can be considered as the materials still in their embryonic stage, but these materials are developing very fast. Although the geopolymer technology wasdeveloped more than 30 years ago, patents and licences closely guarded it. Also, Geopolymeric materials were developed as technology rather than science; hence there is avery little fundamental understanding of these materials.Geopolymerization is the process of combining many small molecules known as oligomers into a covalently bonded network.The geo-chemical syntheses are carried out through oligomers which provide the actual unit structures of the three dimensional macromolecular edifice.

2. Experimental Study

The chapter describes the details of experimental programs for the measurements of strength properties of geopolymer concrete mixes using EPS. The basic tests carried out on concrete samples are discussed in this chapter, followed by a brief description about mix deign and curing procedure adopted. At the end, the various tests conducted on the specimens are discussed.

The materials that were used for lightweight geopolymer concrete throughout the experimental work are Fly Ash, Fine Aggregate, Coarse Aggregate Expanded Polystyrene (EPS).Preliminary test on this materials are also conducted.

2.1 Mix Design

Based on the experimental investigation carried out in the present study the following mix proportioning method is proposed. Data Required for Mix Design:

- Characteristic compressive strength of Geopolymer Concrete (f_{ck})
- Fineness of fly ash in terms of specific surface in m^2/kg
- Workability in terms of flow
- Oven curing (heating) 60 °C for 24 h and tested after 7 days
- Fineness modulus of fine aggregate
- Water absorption and water content in fine and coarse aggregate

Following design steps are used to select the suitable mix proportion of fly ash basedgeopolymer concrete.

1. Target mean strength (fck) for mix design
2. Selection of Quantity of Fly ash (F)
3. Calculation of the quantity of alkaline activators
4. Calculation of total solid content in alkaline solution
5. Selection of quantity of water
6. Correction in Water Content
7. Calculation of additional quantity of water
8. Selection of wet density of geopolymer concrete
9. Selection of fine-to-total aggregate content
10. Calculation of fine and coarse aggregate content
11. Actual quantity of materials required on the basis of field condition

2.2 Final Mix Proportions

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 is shown in Table 1.

Table 1: Ingredients for light weight geopolymer concrete with EPS for alkaline solution (Na-based and K-based) ratio as 1

Ingredient	Unit	Weight	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	Kg/ m^3	390	390	390	390	390
C.A	Kg/ m^3	1273.4	1273.4	1273.4	1273.4	1273.4
F.A	Kg/ m^3	685.68	651.4	617.11	582.83	548.54
EPS	Kg/m^3	10.11	0.51	1.01	1.52	2.02
Na_2SiO_3or K_2SiO_3	Kg/m^3	68.25	68.25	68.25	68.25	68.25
NaOH or KOH	Kg/m^3	68.25	68.25	68.25	68.25	68.25
Extra water	Kg/ m^3	34.41	34.41	34.41	34.41	34.41
Super plasticiser	Kg/m^3	11.7	11.7	11.7	11.7	11.7

Table 2: Ingredients for light weight geopolymer concrete with EPS for alkaline solution (Na-basedand K-based) ratio as 1.5

Ingredient	Unit	Weight	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	Kg/m^3	390	390	390	390	390
C.A	Kg/m^3	1273.41	1273.41	1273.41	1273.41	1273.41
F.A	Kg/m^3	685.68	651.4	617.11	582.83	548.54
EPS	Kg/m^3	10.11	0.51	1.01	1.52	2.02
Na_2SiO_3or K_2SiO_3	Kg/m^3	81.90	81.90	81.90	81.90	81.90
NaOH or KOH	Kg/m^3	54.60	54.60	54.60	54.60	54.60
Extra water	Kg/m^3	34.41	34.41	34.41	34.41	34.41
Super plasticiser	Kg/m^3	11.7	11.7	11.7	11.7	11.7

Table 3: Ingredients for light weight geopolymer concrete with EPS for alkaline solution (Na-based)ratio as 2

Ingredient	Unit	Weig	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	Kg/m^3	390	390	390	390	390
C.A	Kg/m^3	1273.4	1273.41	1273.41	1273.41	1273.41
F.A	Kg/m^3	685.6	651.4	617.11	582.83	548.54
EPS	Kg/m^3	10.1	0.51	1.01	1.52	2.02
Na_2SiO_3	Kg/m^3	91.0	91.0	91.0	91.0	91.0
NaOH	Kg/m^3	45.5	45.5	45.5	45.5	45.5
Extra wate	Kg/m^3	34.4	34.41	34.41	34.41	34.41
Super plasticiser	Kg/m^3	11.7	11.7	11.7	11.7	11.7

Table 4: Ingredients for light weight geopolymer concrete with EPS for alkaline solution (Na-based)ratio as 3

Ingredient	Unit	Weight	5% EPS	10% EPS	15% EPS	20% EPS
Flyash	Kg/m^3	390	390	390	390	390
C.A	Kg/m^3	1273.41	1273.41	1273.41	1273.41	1273.41
F.A	Kg/m^3	685.68	651.4	617.11	582.83	548.54
EPS	Kg/m^3	10.11	0.51	1.01	1.52	2.02
Na_2SiO_3	Kg/m^3	102.37	102.37	102.37	102.37	102.37
NaOH	Kg/m^3	34.13	34.13	34.13	34.13	34.13
Extra water	Kg/m^3	34.41	34.41	34.41	34.41	34.41
Super plasticiser	Kg/m^3	11.7	11.7	11.7	11.7	11.7

2.3 Test Conducted

1. Compressive Strength.
2. Spilt Tensile Strength
3. Nondestructive testing (NDT)
   i. Rebound Hammer test.
   ii. Ultrasonic Pulse Velocity.

3. Performance Analysis

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

Sr. No.	EPS content	Na-based		K-based	
		Peak load in N	Compressive strengthafter 7 days in N per mm^2	Peak load inN	Compressive strengthafter 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

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

Sr. No.	EPS content	Na-based		K-based	
		Peak load in N	Compressive strengthafter 7 days in N per mm2	Peak load in N	Compressive strengthafter 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

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

Sr. No.	EPS content	Na-based		K-based	
		Peak load in N	Compressive strength after 7 daysin N per mm2	Peak loadin N	Compressive strength after 7 daysin 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

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

Sr. No.	EPS content	Na-based		K-based	
		Peak load in N	Compressive strengthafter 7 days in N per mm2	Peak load inN	Compressive strengthafter 7 days in N per mm2
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

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

Sr. No.	EPS content	Na-based		K-based	
		Peak load in N	Compressive strengthafter 7 days in N per mm2	Peak load in N	Compressive strengthafter 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

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

Sr. No.	EPS conte nt	Na-based		K-based	
		ak load nN	Compressive strengthafter 7 days in N per mm2	Peak load inN	Compressive strengthafter 7 days in N per mm2
1	5%	239	55.07	1289	57.27
2	10%	103	49.02	1169	51.96
3	15%	989	43.96	1078	47.92
4	20%	94.2	30.85	721.9	32.09

Table 11:Compressive strength of LWGC specimens with EPS at ambient temperature and alkalineratio as 2

Sr. No.	EPS content	NaOH	
		Peak load in N	Compressive strength after 7 days in N/mm^2
1	5%	1120	49.78
2	10%	1026	45.60
3	15%	894.3	39.75
4	20%	712.5	31.67

Table 12: Compressive strength of LWGC specimens with EPS at ambient temperature and alkalineratio as 3

Sr. No.	EPS content	NaOH	
		Peak load in N	Compressive strength after 7 days in N/mm^2
1	5%	944.5	41.98
2	10%	803.1	35.69
3	15%	684.6	30.43
4	20%	592.1	26.32

Table 13: Tensile strength of specimen

Sr.No.	Peak Load (KN)	Tensile strength (N/mm2)
1	142.5	8.42
2	135.7	7.67
3	161.4	9.13

Table 14: Compressive strength by using Rebound Hammer

Sr. No.	EPS Content in %	Rebound Number	Compressive strengthN/mm^2
1	5	48	60
2	10	43	48
3	15	35	38
4	20	28	26

Table 15: Ultra-sonic pulse velocity test

Sr. No.	Time recorded(sec)	Pulse velocity (km/sec)
1	97.8	3.06
2	92.5	3.26
3	94	3.19

4. CONCLUSIONS

The numbers of cube for experimental study conducted was 56 and number of cylinder conducted was 6. From the above experimental study following conclusion are made.

- 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 120ºC.
- The compressive strength of K-based activator geopolymer concrete is higher than Na- based activator geopolymer concrete at ambient temperature and oven curingtemperatures of 90ºC and 120ºC.
- Na-based activator geopolymer concrete gave higher compressive strength than K- based activator at ambient temperature for 20% EPS content and alkaline ratio 1.
- The compressive strength of all the combination of Na-based specimens having alkaline ratio as 2 is less than that of 1.5 and 1.
- The Compressive strength of all the combination of Na-based specimens having alkaline ratio as 3 is less than that of 2, 1.5 and 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 2100kg 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 90ºC and 120ºC the percentage increase in the value of modulus of elasticity was observed to be 32.07% and 25.53%, respectively

- The result obtain by NDT test using rebound hammer was 60 N/mm^2, 56N/mm^2, 48N/mm^2, 34N/mm^2 for 5% EPS , 10%EPS, 15%EPS and 20% EPS, 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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