AN EXPERIMENTAL STUDY ON EFFECT OF PARTIAL REPLACEMENT OF NORMAL WEIGHT AGGREGATES WITH COMBINATION OF LIGHTWEIGHT AGGREGATES IN FLY ASH BASED GEOPOLYMER CONCRETE

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ABSTRACT – The density of Geopolymer Concrete (GPC) made with normal weight aggregates lies in the range of 2300 to 2500 kg/m^3. The usage of normal weight aggregates increases the self-weight of the concrete structure resulting in lager sections in designing of structural elements. By using Lightweight Aggregates (LWA), the density of the concrete is reduced which tends to reduce the size of the load on the structure, foundation size and construction cost. In the present study, Lightweight Aggregate Geopolymer Concrete (LWAGPC) is produced by using combination of lightweight aggregates Pumice+LECA (P+L), Pumice+Sintagg (P+S) and LECA+Sintagg (L+S) as a partial replacement of natural crushed aggregates varying from 0 to 20% for each combination. Fresh properties of LWAGPC are studied by conducting slump cone test. Hardened properties of GPC are assessed by conducting compressive strength test, split tensile strength test and flexural strength test on specimens subjected to oven curing for 3hours, 12hours and 24hours. Comparison between three combinations is studied for compression, split tensile and flexural strength properties.

***Key Words*: Lightweight Geopolymer Concrete, Pumice, LECA, Sintagg, Oven Curing**

1. INTRODUCTION

Geopolymer concrete is being studied extensively and found as a greener alternative to Portland cement concrete. Geopolymer concrete is made by reacting alumina silica rich materials with alkaline based solution. In geopolymer concrete no cement is used, instead fly ash and alkaline solution are used to make the binder necessary to combine ingredients of concrete.

Lightweight concrete can be produced by including large quantities of air in the aggregate or in the matrix or between the aggregate particles. Lightweight aggregate concrete is produced by using porous lightweight aggregates. Lightweight aggregate concrete is an important and versatile material in present construction. The use of lightweight aggregate (LWA) in construction industry will increase in near future.

1.1 Objectives

1. To develop the geopolymer concrete with higher (14M) concentration of NaOH solution by using lightweight aggregate.
2. To study the effect of partial replacement of normal weight aggregate with combination of lightweight aggregates by volume in GPC.
3. To study the effect of oven curing with respect to time.

1.2 Geopolymer Concrete

In 1978, Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or industrial by product materials to produce binders. Because, the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders.

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc., could be used as source materials.

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3).

1.3 Demand for Natural Aggregates

Global demand for construction aggregates is expected to grow 4.7 percent annually through 2011 to 26.8 billion metric tons. For non-building construction market, more than 70 percent of worldwide aggregate demand is accounted in 2006. In India, demand for construction aggregates is amounted to 1.1 billion metric tons in 2006, making the country the third biggest aggregates market in the Asia/Pacific region. The most commonly used product type is crushed stone, making up 40 percent of total 2006 aggregates demand. Gravel accounts for the next largest share of demand, followed by sand and other aggregate materials.

1.4 Lightweight Concrete

Lightweight concrete generally referred to as:
1. Aerated Concrete (or) Cellular Concrete (or) Foamed Concrete.
2. No fines Concrete.
3. Lightweight aggregate Concrete.

1.5 Lightweight Aggregate

LWAC has been widely investigated and developed in a wide range of unit weight and suitable strengths for various applications as both structural and non-structural material. LWAC is having many advantages such as low density, good thermal insulation, good fire resistance and reduced cost of transport. There are different types of LWAs, they are Diatomite, Pumice, Scoria, Volcanic cinders, tuff, Expanded clay, Sintagg, LECA, Shale, Slate, Perlite, Vermicelite.

In the present study Pumice, LECA and Sintagg aggregates are used as lightweight aggregates.

1.6 DETAILS OF SPECIMENS

- Cubical specimens of size 100 mm × 100 mm × 100 mm are casted for the determination of compressive strength.
- Cylindrical specimens of size 100 mm × 200 mm are casted for the determination of split tensile strength.
- Beams of size 500 mm × 100 mm × 100 mm are casted for the determination of flexural strength.

2. LITERATURE REVIEW

D Hardjito and S E Wallah (2005) presents the results of a study on GPC. The paper also reports the stress-strain behaviour of the concrete with compressive strength in the range of 40 to 65 MPa. Tests were carried out on 100 mm×200 mm cylindrical GPC specimens. Test results show that a good agreement exists between the measured stress-strain relations of fly-ash based GPC and those predicted by a model developed originally for Portland cement concrete.

N Sivalinga Rao et al (2013) presented a paper on Fibre Reinforced Light Weight Aggregate with partial replacement of natural aggregate with pumice. The compressive strength of concrete is found to decrease as the pumice content is increased from 0 to 100 percent. The compressive strength of pumice concrete is seen to increase with the fibre content and reaches an optimum value at 1.5% of fibre content. The optimum value is achieved at the combination of 20% pumice content with 1.5% of fibre content.

Sonia, Subashini R (2016) examined the structural behaviour of Lightweight concrete (LWAC) using LWA, LECA and normal weight aggregates. Investigated on concrete mix M25 by the effect of partially and fully replacement of the coarse aggregate by LECA with various % such as 20%, 40%, 60%, 80% and 100% and fly ash % such as 15%, 20%, 25% used as partial replacement for cement in concrete. This paper concentrated compressive and split tensile strength of the LWAC. In strength performance of 15% replacement of fly ash content with 40% replacement of coarse aggregates concrete for better results to ensure its optimal proportions.

Arvind Kumar, DilipKumar (2014) A mix design was done for M25 Grade of concrete by IS method. Ordinary Portland cement of 43 Grade was selected and prepared by mixing sintered fly ash with cement and water. The maximum compressive strength is attained at 12% replacement of Sintered fly ash aggregate in concrete while the minimum strength is attained at 20%. The maximum flexural strength was attained at 8% replacement, while the minimum strength was attained at 20% replacement.

3. MATERIALS

3.1 Fly Ash

Fly Ash is a finely divided residue that results from the combustion of ground (or) pulverized coal and is transported from boilers by flue gases is known as "fly ash".

3.2 Alkaline Solution

A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator, with the activator liquid-to-source material ratio by mass in the range of 0.35-0.5. In this present study combination of sodium silicate solution and sodium hydroxide (NaOH) solution is used as the alkaline liquid.

3.3 Fine Aggregate

The size of fine aggregate is below 4.75mm. The fine aggregate used is natural sand obtained from the river Godavari confirming to grading zone-II of table 3 of IS 10262: 2009.

3.4 Coarse Aggregate

Locally available natural crushed stone with maximum nominal size of 20 mm, 10 mm and 6 mm have been used as coarse aggregate.

3.5 Lightweight Aggregate

a) Pumice

The cellular structure of pumice and its low density is created by the formation of bubbles or voids when gases contained in molten lava flowing from volcanoes become trapped on cooling. It is chemically inert and usually has a relatively high silica content. They are light enough and yet strong enough to be used in natural state. Pumice is mined, washed and then used.

Fig :1 Pumice Stone

Table -1: Physical Properties of Pumice

S.No	Property	Value
1.	Specific gravity	0.712
2.	Fineness modulus	7.844
3.	Bulk density(Kg/m^3)	522
4.	Aggregate size (mm)	20
5.	Water absorption	33.53
6.	Shape	Crushed aggregates

b) LECA

LECA means Light Expanded **C**lay **A**ggregate. LECA consists of small, lightweight, bloated particles of burnt clay. The thousands of small, air-filled cavities give LECA its strength and thermal insulation properties. The base material is plastic clay which is extensively pretreated and then heated and expanded in a rotary kiln. Finally, the product is burned at about 1100°C to form the finished LECA product.

Fig :2 LECA

Table -2: Physical Properties of LECA

S.No	Property	Value
1.	Specific gravity	0.44
2.	Fineness modulus	5.09
3.	Bulk density(Kg/m^3)	357
4.	Aggregate size(mm)	16
5.	Water absorption	10%
6.	Shape	Round Pellets

c) Sintagg:

Sintered Fly Ash is one of the most important type of structural lightweight aggregate used in modern times. Fly Ash is finely divided residue, comprising of spherical glassy particles, resulting from the combustion of powdered coal. By heat treatment these small particles can be made to combine, thus forming porous pellets or nodules which have considerable strength.

Fig :3 Sintagg

Table -3: Physical Properties of Sintagg

S.No	Property	Value
1.	Specific gravity	1.28
2.	Fineness modulus	6.43
3.	Bulk density(Kg/m^3)	800
4.	Aggregate size(mm)	10
5.	Water absorption	<16%
6.	Shape	Round Pellets

3.6 Water

This is the least expensive but most important ingredient of concrete. The water, which is used for making solution, should be clean and free from harmful impurities such as oil, alkali, acid, etc. in general, the distilled water should be used for making solution in laboratories. Distilled water was used for preparing NaOH solution of 14M.

4. EXPERIMENTAL INVESTIGATION

4.1 General

As said in the introduction, GPC is the combination of fly ash and alkaline solution. Alkaline solution preparation is explained below. Quantities of ingredients used in LWAGPC are calculated based on the density of concrete. Total 13 castings are done for different mix proportions and the effect of oven curing on LWAGPC is studied for 3 H, 12 H and 24 H. The properties of the fresh concrete like workability with slump cone test and hardened concrete like compressive strength, split tensile strength and flexural strength of specimens for each mix are studied.

4.2 Preparation of Alkaline Solution

Alkaline solution is a combination of NaOH solution and sodium silicate gel. In alkaline solution the concentration of sodium hydroxide solution and the ratio of sodium silicate solution to sodium hydroxide solution influence the strength of the concrete. It is strongly recommended that the alkaline solution must be prepared 24 hours prior to use and also if it exceeds 36 hours it turns to semi-solid state.

4.3 Preparation of NaOH Solution

The molecular weight of NaOH is 40. For 14M concentrated NaOH solution 14 x 40 = 560 grams of NaOH pellets are dissolved in distilled water till the volume of solution becomes one litre. The mass of NaOH solids is measured as 42.01% in one-kilogram solution of 14 M.

For any mix all the quantities other than 20mm are same and are shown in table 4

Table -4: Quantities required to prepare mix

F.A (kg)	A.L (Kg)	Pellets (Kg)	Water (Lts)	Na_2SiO_3 Gel (Kg)	Sand (kg)	12mm (kg)	6mm (Kg)
39.2	19.6	2.35	3.25	14.00	41.18	19.22	9.61

Replacement of 20mm normal weight aggregate with Combination of lightweight aggregates Pumice, LECA and Sintagg

Table -5: Quantities table per mix

S.No	% replacement	20mm Aggregate (Kg)	(P+S) (Kg)	(P+L) (Kg)	(L+S) (Kg)
1	0	67.255	0	0	0
2	5% (2.5%+2.5%)	63.729	0.525 + 0.944	0.525 + 0.383	0.383 + 0.944
3	10% (5%+5%)	60.417	1.052 + 1.891	1.052 + 0.765	0.765 + 1.891
4	15% (7.5%+7.5%)	57.053	1.578 + 2.837	1.578 + 1.145	1.145 + 2.837
5	20% (10%+10%)	53.703	2.105 + 3.786	2.105 + 1.53	1.53 + 3.786

4.4 Mixing and Casting

The object of mixing is to coat the surface of all aggregate particles with geopolymer paste and to blend all the ingredients of GPC in to a mass. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. In the present study total 117 cubes, cylinders and beams are casted pertaining to 13 different mix proportions.

4.5 Curing and Testing of Specimens

In the present study all the specimens were placed in the oven after demoulding for curing at a temperature of 70°C for 3 H, 12 H and 24 H. For studying the hardened properties of GPC, compression, split tensile and flexural strength tests are conducted.

5. RESULTS AND DISCUSSIONS

5.1 Slump Cone Test:

The slump values are increased with increase in percentage of LWA. The increase in percentage of lightweight aggregate content increases the workability of the geopolymer paste because soaking of aggregates is done before casting. Hence, there is an increase in slump value.

5.2 Compressive Strength

The compressive strength of LWAGPC is calculated by conducting compression test on cube specimens subjected to oven curing for 3 H, 12 H and 24 H. The results are shown below.

Table -6: Compressive Strength Test Results

S.No	% of LWA (P+S)	Density (kg/m^3)	Compressive Strength(N/mm^2)		
			3H	12 H	24 H
1	0	2350	27.50	52.33	45.83
2	5	2314	29.67	35.12	32.83
3	10	2297	32.26	38.83	37.00
4	15	2268	41.83	48.30	46.00
5	20	2232	35.00	42.00	39.00

Referring to table 6, GPC with (P+S) exhibited better results for 15% than the other percentages. The compressive strength of geopolymer concrete with all (P+S) percentages increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 1.5 to 5% lesser than that of conventional GPC.

Table -7: Compressive Strength Test Results

S.No	% of LWA (P+L)	Density (kg/m^3)	Compressive Strength (N/mm^2)		
			3 H	12 H	24 H
1	0	2350	27.50	52.30	45.83
2	5	2295	30.60	49.20	42.92
3	10	2277	32.20	49.60	43.30
4	15	2235	27.17	39.67	38.50
5	20	2211	25.00	35.60	35.33

Referring to table 7, GPC with (P+L) shown better results for 10% than the other percentages. The compressive strength of GPC with all percentages of (P+L) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 2 to 6% lesser than that of conventional GPC density.

Table -8: Compressive Strength Test Results

S.No	% of LWA (L+S)	Density (kg/m³)	Compressive Strength (N/mm²)		
			3 H	12 H	24 H
1	0	2350	27.50	52.30	45.83
2	5	2347	28.83	30.13	37.00
3	10	2321	33.60	37.40	43.50
4	15	2295	35.50	49.66	52.67
5	20	2260	34.10	43.16	44.00

Referring to table 8, GPC with (L+S) shown better results for 15% than the other percentages. The compressive strength of GPC with all percentages of (L+S) increased up to 24 hours of oven curing It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 0.1 to 3.9% lesser than that of conventional GPC.

5.3 Split Tensile Strength

The split tensile strength of GPC is calculated by conducting split tensile test on 100 mm x 200 mm cylindrical specimens. The test results are shown in tables.

Table -9: Split Tensile Strength Test Results

S.No	% of LWA (P+S)	Density (kg/m³)	Split Tensile Strength (N/mm²)		
			3 H	12 H	24 H
1	0	2297	3.28	3.43	4.24
2	5	2289	1.38	1.77	1.53
3	10	2278	1.68	1.97	1.93
4	15	2254	2.16	2.46	2.36
5	20	2223	2.08	2.38	2.21

Referring to table 9, GPC with 15% (P+S) shown better results than the other percentages. The split tensile strength of GPC with all percentages of (P+S) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 0.3 to 3% lesser than that of conventional GPC density.

Table- 10: Split Tensile Strength Test Results

S.No	% of LWA (P+L)	Density (kg/m³)	Split Tensile Strength (N/mm²)		
			3 H	12 H	24 H
1	0	2297	3.29	3.43	4.24
2	5	2278	1.70	2.77	2.44
3	10	2261	2.29	3.26	2.54
4	15	2224	1.82	2.29	2.16
5	20	2202	1.59	2.10	1.76

Referring to table 10, GPC with 10% (P+L) exhibited better results than the other percentages. The split tensile strength of GPC with all percentages of (P+L) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 0.8 to 4% lesser than that of conventional GPC density.

Table -11: Split Tensile Strength Test Results

S.No	% of LWA (L+S)	Density (kg/m³)	Split Tensile Strength (N/mm²)		
			3 H	12 H	24 H
1	0	2297	3.29	3.43	4.24
2	5	2291	2.05	2.49	2.12
3	10	2282	2.16	2.61	2.18
4	15	2259	2.28	3.27	2.37
5	20	2238	2.19	3.05	2.28

Referring to table 11, GPC with 15% (L+S) exhibited better results than the other percentages. The split tensile strength of GPC with all percentages of (L+S) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 0.6 to 2.6% lesser than that of conventional GPC density.

5.4 Flexural Strength

Total 117 specimens are tested pertaining to 13 mix proportions. The test results are shown in tables.

Table -12: Flexural Strength Test Results

S.No	% of LWA (P+S)	Density (kg/m³)	Flexural Strength (N/mm²)		
			3H	12 H	24 H
1	0	2369	5.15	6.82	8.90
2	5	2326	6.68	7.50	6.91
3	10	2300	6.14	6.43	6.29
4	15	2294	5.87	6.35	6.11
5	20	2287	5.65	6.23	5.98

Referring to table 12, GPC with 5% (P+S) shown better results than the other percentages. The flexural strength of GPC with all percentages of (P+S) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 2 to 3.5% lesser than that of conventional GPC density.

Table -13: Flexural Strength Test Results

S.No	% of LWA (P+L)	Density (kg/m³)	Flexural Strength (N/mm²)		
			3H	12 H	24 H
1	0	2369	5.15	6.82	8.90
2	5	2315	7.06	9.40	7.97
3	10	2271	6.90	8.65	6.98
4	15	2247	6.38	6.77	6.63
5	20	2236	4.14	5.91	5.20

Referring to table 13, GPC with 5% (P+L) exhibited better results than the other percentages. The flexural strength of GPC with all percentages of (P+L) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 2 to 5.6% lesser than that of conventional GPC density.

Table -14: Flexural Strength Test Results

S.No	% of LWA (L+S)	Density (kg/m³)	Flexural Strength (N/mm²)		
			3H	12 H	24 H
1	0	2369	5.15	6.82	8.90
2	5	2351	7.10	7.93	7.64
3	10	2326	7.22	8.23	8.01
4	15	2301	7.32	8.40	8.15
5	20	2289	7.27	8.31	8.06

Referring to table 14, GPC with 15% (L+S) exhibited better results than the other percentages. The flexural strength of GPC with all percentages of (L+S) increased up to 12 hours of oven curing. It is also observed that the density value decreases with increase in % of LWA. Density of LWAGPC is 0.7 to 3.4% lesser than that of conventional GPC density.

5.5 Comparison of Strengths for Different Combinations of LWA

Comparison is done for different combination of LWA's having optimum period.

Table -15: Compressive Strength for cured specimens

S.No	% Replacement of LWA	Compressive Strength(N/mm²)		
		(P+S) (12 H)	(P+L) (12 H)	(L+S) (24 H)
1	5	35.12	49.20	37.00
2	10	38.83	49.60	43.50
3	15	48.30	39.67	52.67
4	20	42.00	35.60	44.00

Referring to table 15, it is observed that (P+L) combination exhibited better values than (P+S) and (L+S) combinations for 5% and 10% of replacement. On the other hand, (L+S) combination shown better results than (P+S) and (P+L) combinations in case of 15% and 20% replacement

Table -16: Split Tensile Strength for 12 H cured specimens

S.No	% Replacement of LWA	Split Tensile Strength(N/mm²)		
		(P+S)	(P+L)	(L+S)
1	5	1.77	2.77	2.49
2	10	1.97	3.26	2.61
3	15	2.46	2.29	3.27
4	20	2.38	2.10	3.05

Referring to table 16, it is observed that (P+L) combination exhibited better values than (P+S) and (L+S) combinations for 5% and 10% of replacement. On the other hand, (L+S) combination shown better results than (P+S) and (P+L) combinations in case of 15% and 20% replacement.

Table -17: Flexural Strength for 12 H cured specimens

SNo	% Replacement of LWA	Flexural Strength(N/mm²)		
		(P+S)	(P+L)	(L+S)
1	5	7.50	9.40	7.93
2	10	6.43	8.65	8.23
3	15	6.35	6.77	8.40
4	20	6.23	5.91	8.31

Referring to table 17, it is observed that (P+L) combination exhibited better values than (P+S) and (L+S) combinations for 5% and 10% of replacement. On the other hand, (L+S) combination shown better results than (P+S) and (P+L) combinations in case of 15% and 20% replacement.

5.6 Graphs:

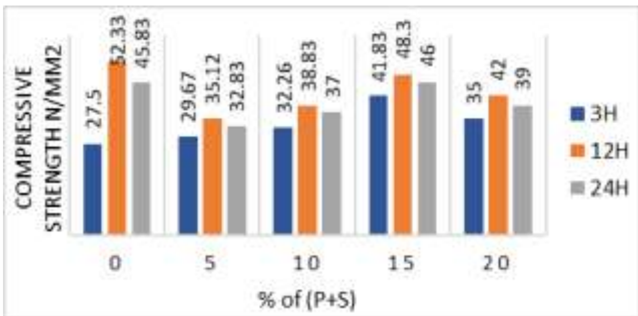

Chart -1: Compressive Strength Variation for different % of (P+S) in Oven Curing

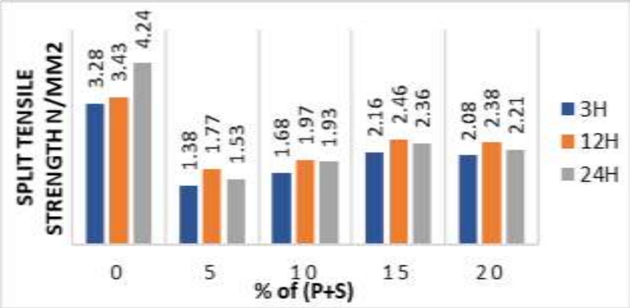

Chart -2: Split Tensile Strength Variation for different % of (P+S) in Oven Curing

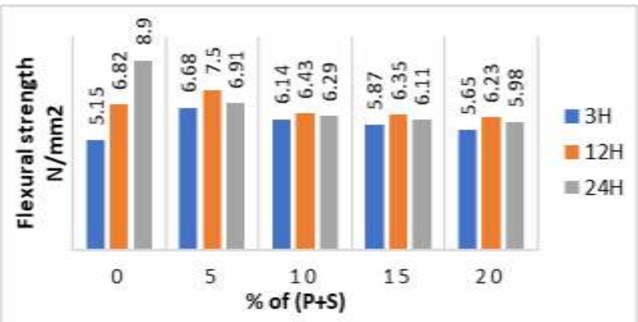

Chart -3: Flexural Strength Variation for different % of (P+S) in Oven Curing

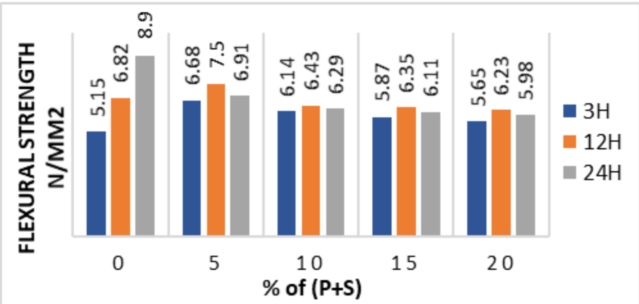

Chart -4: Compressive Strength Variation for different % of (P+L) in Oven Curing

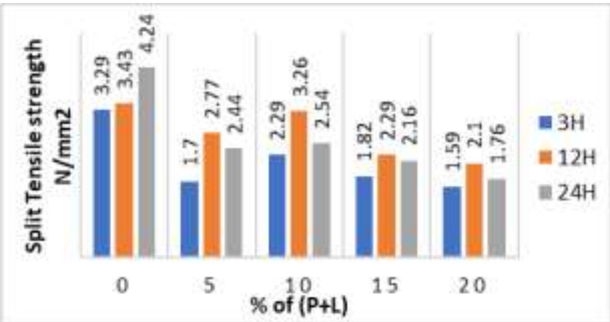

Chart -5: Split Tensile Strength Variation for different % of (P+L) in Oven Curing

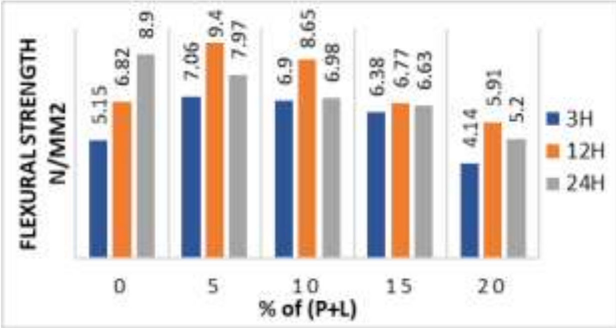

Chart -6: Flexural Strength Variation for different % of (P+L) in Oven Curing

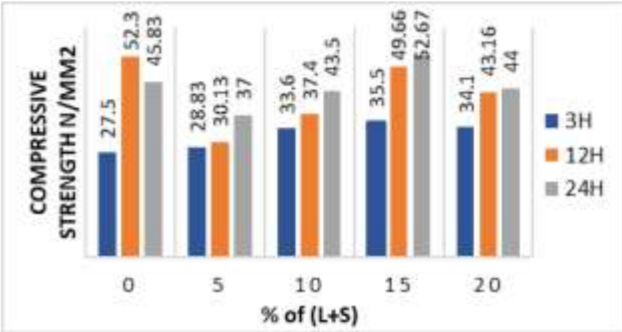

Chart -7: Compressive Strength Variation for different % of (L+S) in Oven Curing

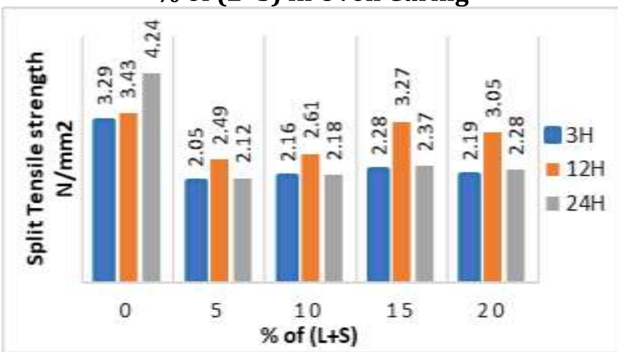

Chart -8: Split Tensile Strength Variation for different % of (L+S) in Oven Curing

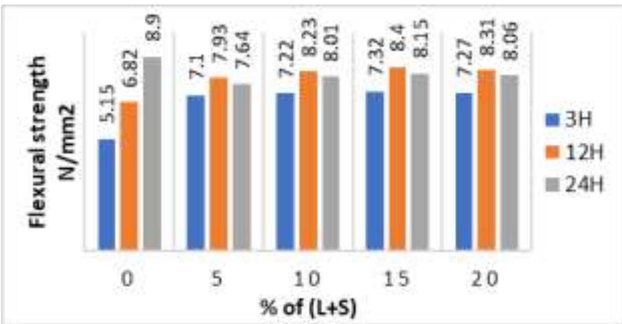

Chart -9: Flexural Strength Variation for different % of (L+S) in Oven Curing

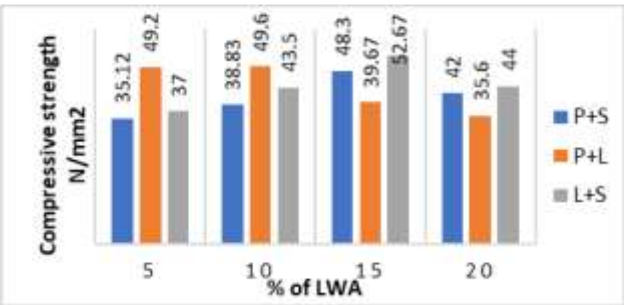

Chart -10: Comparison of Compressive Strength Values in Oven Curing

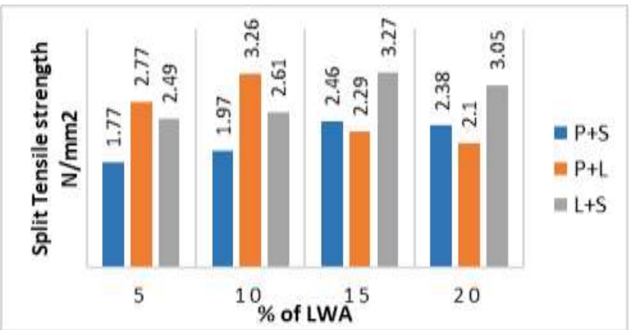

Chart -11: Comparison of Split Tensile Strength Values in Oven Curing

Chart -12: Comparison of Flexural Strength Values in Oven Curing

6. CONCLUSIONS

1. The density of GPC with combination of LWAs has relatively reduced compared to density of conventional GPC. It is observed that the density reduces from 0.3 to 5% in case of (P+S), 0.8 to 6% in case of (P+L) and 0.1 to 3.9% in case of (L+S).
2. The density of LWAGPC decreases with the increase in % of replacement.
3. Pumice, LECA and Sintagg being porous in natur2e, have more water absorption capacity when compared to natural coarse aggregates, which in turn affects the workability. To overcome this drawback, soaked aggregates are used.
4. Compressive strength of LWAGPC is found to increase up to 15% of replacement, 10% of replacement at 12 hours and 15% of replacement at 24 hours in case of (P+S), (P+L) and (L+S) respectively. Further increase in percentage, reduces the compressive strength.
5. Split Tensile strength of LWAGPC is found to increase up to 15% of replacement, 10% of replacement and 15% of replacement in case of (P+S), (P+L) and (L+S) respectively. Further increase in %, reduces the split tensile strength.
6. Flexural strength of LWAGPC is found to increase in 5% replacement in case of (P+S) and (P+L). In case of (L+S), it is observed that 15% replacement is optimum. Further increase in replacement reduces flexural strength in all the three cases.
7. For all the percentages of replacement, in the three cases, split tensile strength and flexural strength are found to increase up to 12 hours of oven curing and further curing decreases the strengths. So, it may be concluded that 12 hours of oven curing may be optimum period for LWAGPC.

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7. REFERENCES

1. Hardjito,D et al., “Introducing fly ash based Geopolymer Concrete: Manufacture and Engineering Properties”, Curtin University of Technology, Australia, 2005.

2. Lloyd,N,A and Rangan,B,V., “Geopolymer Concrete with flyash”, Curtain University of Technology, Australia, 2010.

3. Bhikshma,V et al., “An experimental investigation on properties of geopolymer concrete (No cement concrete)”, Asian Journal of Civil Engineering (Building and Housing) Volume 13, Issue 6, 2011.

4. Omar A. Abdulkareem et al., “Mechanical and Microstructural Evaluations of Lightweight Aggregate Geopolymer Concrete before and after Exposed to Elevated Temperatures”, 2013.

5. Sivalinga Rao,N et al., “Fibre Reinforced Light Weight Aggregate (Natural Pumice Stone) Concrete”, International

Journal of Scientific and Engineering Research, Volume 4, Issue 5, 2013.

6. Devi Pravallika,B., Venkateswara Rao,K., "The Study on Strength Properties of Light Weight Concrete using Light Weight Aggregate", International Journal of Science and Research, Volume 5, Issue 6, 2016..

7. Sonia,T ., Subashini,R., "Experimental Investigation on Mechanical Properties of Light Weight Concrete Using Leca", International Journal of Science and Research, Volume 5, Issue 11, 2015.

8. Zaid Topiwala et al., "Compressive Strength analysis of Lightweight Aggregate Concrete with Sintered Fly Ash Aggregates", International Journal of Modern Trends in Engineering and Science, Volume 4, Issue 4, 2017.

9. Arvind Kumar and DilipKumar., "Density of Concrete with Sintered Fly Ash Aggregate", International Journal for innovative Research in Science and Technology, Volume 1, Issue 7, 2014.

10. "Concrete Technology Design and Practice" by M.S.Shetty.

11. Concrete Technology by Nevelli and brooks.

12. FIP manual by John Derrington and Jan Bobrowski.

13. Guide for structural lightweight aggregate concrete ACI committee report 2017.