Long Term Strength Characteristics of Geopolymer Lightweight Concrete Using Industrial By-Products

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Abstract- *An attempt has been made to study the long term strength characteristics of the geopolymer lightweight (GPLW) concrete using the industrial by-products such as class-C flyash and GGBFS as binder materials and processed slag sand and sintered flyash aggregates as replacement to fine and coarse aggregates respectively. Activator solution having SiO_2/ Na_2O ratio of 0.6 was used. Ambient air curing method was adopted in development of geopolymer lightweight concrete with density ranging from 1740Kg/m^3 to 1840Kg/m^3. The strength attained by geopolymer concrete after 28 days is in the range of 26Mpa to 43Mpa and after 180 days is in the range of 30Mpa to 45Mpa under compression and 4Mpa to 8Mpa under flexural loads. Corresponding strengths attained in OPC concrete is 25Mpa, 28Mpa and 8Mpa respectively. Hence GPLW concrete can be used both for structural as well as architectural purposes. The utilization of industrial by-products will help in mitigation of carbon footprint in construction activities.*

Keywords- Class – C Flyash, Geopolymer, GGBFS, Lightweight Concrete, PS Sand, Sintered Fly ash Aggregates.

I. INTRODUCTION

In the modern world, the construction industry needs environmentally sustainable - high performance and simultaneously economical concrete to be developed. All over the globe huge number of construction projects are in progress. Production of OPC requires a great amount of energy and resources, simultaneously polluting the Air, Water and Land. For sustainability, the industrial by-products needs to be utilized for all future civil engineering applications and hence reduce carbon footprint in construction.

Geopolymer was first termed as a 3-dimensional alumino-silicates by Devidovits [1] in 1978-79. In his studies, he found that, coal and lignite fly ash, rice husk ash, palm oil fuel ash, GGBFS, Silica Fumes, limestone, metakaolin and natural pozzolana can be used as supplementary cementing materials to produce geopolymer. Palomo A, et.al in 1999 [2] has said alkali activated fly ash as the cement for the future.

Many researchers are working on developing a sustainable, durable and economical concrete composites by utilizing alternative materials for the production of concrete. The density of conventional concrete is in the range of 2200 – 2600 kg/m^3 whereas the density of lightweight concrete (LWC) is in the range of 300 – 1900 kg/m^3. The lower density of LWC reduces the dead load of structure, has better thermal and acoustic insulation properties and lower cost of haulage and handling.

The LWC is used for many engineering applications such as building construction, bridge deck pavements and architectural elements. Depending on the usage they are classified as structural lightweight concrete, Non load bearing concrete and Insulating concrete. The most common process by which the LWC can be achieved is by use of lightweight aggregates – Lightweight aggregates concrete. Other process includes introduction of air bubbles – Aerated concrete / Foam concrete or by omitting fine aggregates – No-fines concrete. LWC has the advantage of higher strength-to-weight ratio.

II. EXPERIMENTAL STUDY

In this study, an attempt has been made to develop sustainable concrete by utilizing different industrial by-products such as flyash class-C, GGBFS, PS Sand and lightweight sintered flyash aggregates and study the strength characteristics of GPLW concrete.

III. MATERIALS USED AND THEIR PROPERTIES

Reference concrete (CC) was developed using OPC 53 Grade cement to which properties of GPLW concrete were compared. All the constituents used in this study were industrial by-products. Flyash class-C (FAC) and Ground Granulated Blast Furnace Slag (GGBFS) were used as binder source materials and Processed Slag Sand (PSS) and Lightweight Sintered Flyash Aggregates (LWFA) were used as replacement to fine and coarse aggregates respectively. The properties are tabulated in table-I and table-II. Activator solution (AS) having SiO_2/ Na_2O ratio of 0.6 was used. Ambient air curing method was adopted.

IV. METHODOLOGY ADOPTED

The GPLW concrete was synthesized by mixing different proportions of FAC and GGBFS with AS. The activator solution (AS) was prepared by mixing Sodium hydroxide solution of 8M concentration and Sodium Silicate solution in a ratio of 2:1 to arrive at SiO_2/ Na_2O ratio of 0.6. The aggregates in saturated surface dry condition were used for concrete production. A dry uniform mix were prepared before the liquid (water or activator solution) was added. Required numbers of cubes and prism specimen were cast for each mix designations and were cured for a required period of time before testing for compressive strength and flexural strength. The strength characteristics of control concrete and GPLW concrete were compared in this study.

Table I - Binder material Properties

Binder materials	OPC	FAC	GGBFS
Physical properties			
Specific Gravity	3.15	2.38	2.91
Fineness – Specific Surface (m^2/kg)	290	475	358
Residue on 45µ Sieve (%)	NA	10.5	2.3
Chemical properties			
SiO_2 %	18.4	30.73	36
Al_2O_3 %	5.6	17.5	17.59
Fe_2O_3 %	3.2	15.3	1.36
MgO %	1.4	6.7	7.08
CaO %	66.8	20.85	36.45
SO_3 %	3	6.62	0.61
Loss of Ignition, % by Mass	1.8	1.46	2.1

Table II - Aggregates Properties

Aggregate Properties	PSS	SFA
Specific Gravity	2.6	1.49
Fineness Modulus	2.87	6.51
Bulk Density (Kg/litre)		
Loose	1.38	0.89
Rodded	1.54	0.97
Type of Aggregates	Zone-2	12 mm Down

Table III - Mix Designations and Binder proportions

Variation in concrete density (kg/m^3) in different mixes			
Mix	FAC - kg	GGBFS-kg	Density – kg/m^3
F100	446.3	0	1742
F85	379.3	81.8	1757
F75	334.7	136.4	1767
F65	290.1	191	1777
F50	223.1	272.8	1792
F35	156.2	354.7	1807
F25	111.6	409.2	1817
F0	0	545.6	1842

V. MIX PROPORTIONING

The mix proportions for control concrete mix was derived as per ACI absolute volume method of mix proportioning. The proportions for producing GPLWC's were arrived as equivalent volume of materials required for CC. The liquid to binder ratio was kept constant at 0.4 across mixes. The mix designations and corresponding GGBFS / FAC contents are tabulated in table-III. F100 to F0 represents the GPLWC's with different FAC contents. The density of CC was about 1885 Kg/m^3. The lowest density achieved was about 1740 Kg/m^3 for F100 series in which binder was 100 % fly ash and the highest was about 1840 Kg/m^3 for F0 series in which binder was 100 % GGBFS. The density of GPLWC's increases with increase in GGBFS and decreases with increase in flyash. Hence the density of GPWLC's were directly proportional to GGBFS content and inversely proportional flyash content.

VI. RESULTS AND DISCUSSIONS

Cube Specimens of 100*100*100 mm and Prism specimen of 100*100*500 mm were cast as per BIS standards to test for compressive strength and flexural strength. Specimens were able to be demoulded within 24hrs after casting. The GPLWC's specimen were stored inside the laboratory to be air cured at ambient room temperature and CC specimen were water cured for 28 days and further stored with GPLWC's specimen. Tests were conducted after a curing period of 3, 7, 14, 28, 60, 90, 120 and 180 days.

Table-IV Development of Compressive Strength in Different Mixes with Age

Age in Days	Compressive Strength in Mpa							
	CC	F0	F25	F35	F50	F65	F75	F85
3	10.43	20.4	25.63	30.37	29.92	18.87	13.43	6.7
7	13.76	22.76	31.77	30.91	33.59	26.93	19.74	18.77
14	17.04	27.68	32.39	31.35	34.3	32.32	24.48	25.14
28	24.48	27.73	33.38	32.55	42.8	34.22	26.75	26.32
60	25.77	28.35	34.25	33.35	43.26	35.78	32.26	27.18
90	26.34	29.73	35.87	35	43.41	36.45	33.7	27.43
120	27.41	31.55	36.75	35.53	44.21	37.4	34.56	27.8
180	27.51	32.18	38.54	37.38	44.65	38.43	35.25	29.71

Table-V Development of Flexural Strength in Different Mixes with Age

Age in Days	Flexural Strength in Mpa							
	CC	F0	F25	F35	F50	F65	F75	F85
7	6	5.27	5.33	5.27	5.27	5	3.47	2.63
14	6.73	6.13	5.93	5.73	5.73	5	4.87	3.33
28	7.87	7.8	6.07	6.33	7.07	5.6	4.93	3.87
60	7.87	7.87	6.4	6.53	7.2	6.53	5.07	4.13
90	7.87	7.93	6.87	7.07	7.27	6.53	5.47	4.8
180	7.93	8.07	7.13	7.33	7.33	6.6	5.53	4.93

The comparative study of CC and GPLW concretes have been presented. Table-IV and table-V represents the development of compressive and flexural strength with age in different mixes with varying FAC and GGBFS contents. Fig-I and fig-II indicates the development of compressive strength with age in CC and GPLW concrete with different proportions of FAC and GGBFS. Fig-III indicates the comparison of compressive strength developed in CC and GPLWC's at different ages of concrete. Fig-IV and fig-V indicates the development of flexural strength in CC and GPLW concrete with different proportions. Fig-VI indicates the comparison of flexural strength developed in CC and GPLWC's at different ages of concrete.

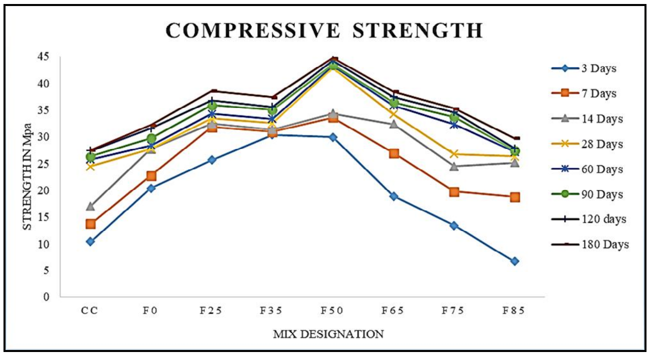

Fig - I Compressive Strength in Different mixes of GPLWC's in comparison with cement concrete

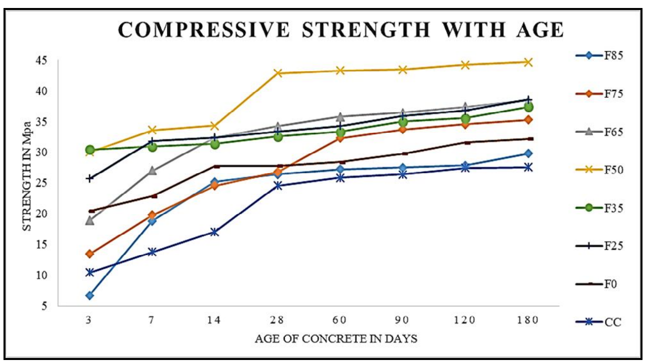

Fig -II Compressive Strength with age in Different mixes of GPLWC's in comparison with cement concrete

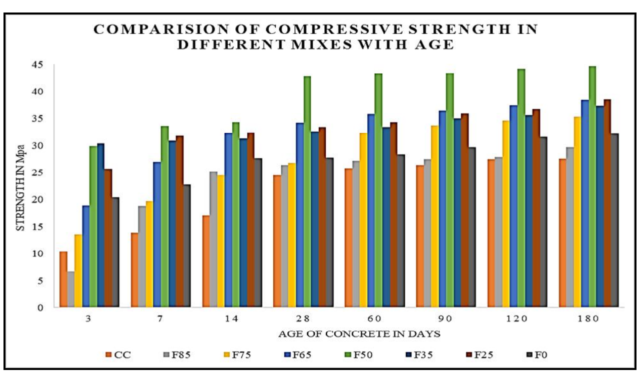

Fig. III Comparison of Compressive Strength in CC and GPLWC's at different age

The compressive strength achieved after 3 days was about 6 to 30 Mpa and after 28 days was about 26 to 43 Mpa for GPLWC's. The compressive strength achieved in CC was 10.4 Mpa after 3 days and 24.5 Mpa after 28 days of water curing, both of which is less than that of GPLWC's. Similarly after 180 days the compressive strength achieved in GPLWC's was about 30 to 45 MPa and in CC was 27.5 Mpa. This indicates that, the GPLW concrete produced with FAC and GGBFS is superior to normal concrete in terms of compressive strength.

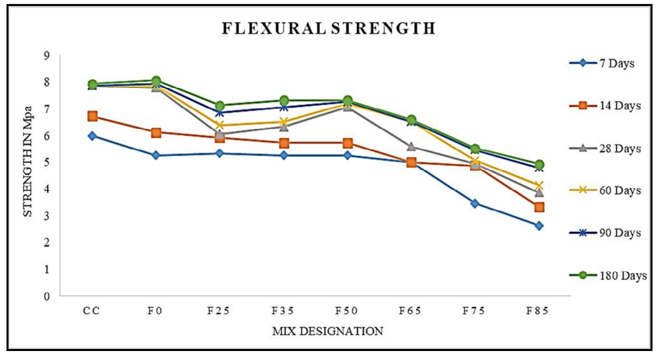

Fig - IV Flexural Strength in Different mixes of GPLWC's in comparison with cement concrete

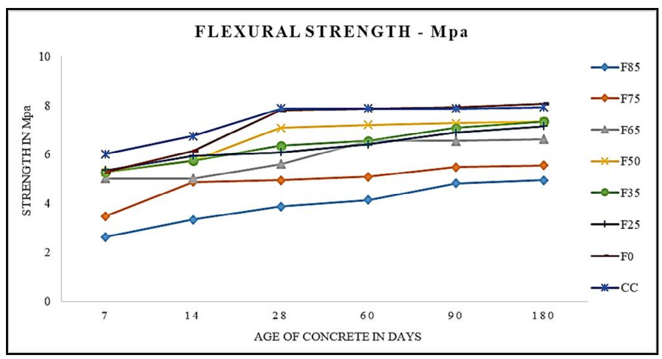

Fig -V Flexural Strength with age in Different mixes of GPLWC's in comparison with cement concrete

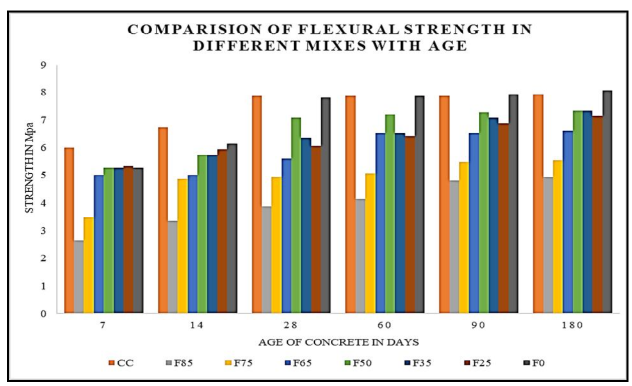

Fig. VI Comparison of Flexural Strength in CC and GPLWC's at different age

Similarly, flexural strength achieved after 7 days was about 3 to 5 Mpa, after 28 days was about 4 to 8 Mpa and after 180 days was about 5 to 8 Mpa for GPLWC's. The flexural strength achieved in CC was 6 Mpa after 3 days and 7.9 Mpa after 28 days of water curing both of which is similar to that of GPLWC's. Also, the flexural strength achieved in CC after 180 days was about 8 Mpa. This indicates that, the CC and GPLW concrete produced with FAC and GGBFS are equivalent in terms of flexural strength behaviour.

With all the combinations of FAC and GGBFS to produce the GPLWCs, after 180 days, the F50 series achieved the highest strength of 44.65 Mpa and lowest of 29.7 Mpa was in F85 series. The compressive strength of F85 series was very close to that of OPC concrete. Beyond 60 days the compressive strengths of F25, F35, F65 and F75 series were found to be very similar. The variation of strength beyond 60 days in these series was about 5%.

VII. CONCLUSIONS

Based on the obtained experimental results, the following conclusions have been drawn:

- Ambient temperature air cured Geopolymer Lightweight concrete with considerable strength properties, was possible to produce using the different industrial by-products such as FAC, GGBFS, PSS and LWFA.
- Depending on the FAC and GGBFS content,
  - The 28 days compressive and flexural strength achieved in GPLWCs were in the range of 26 – 43 MPa and 3.8 – 7.8 Mpa respectively and in CC was about 24.5 Mpa and 7.8Mpa respectively.
  - The 90 days compressive and flexural strength achieved in GPLWCs were in the range of 27.5 – 43.5 MPa and 4 .8 – 7.9 Mpa respectively and in CC was about 26.5 Mpa and 7.9 Mpa respectively.
  - The 180 days compressive and flexural strength achieved in GPLWCs were in the range of 29.7 – 44.5 MPa and 4.9 – 8 Mpa respectively and in CC was about 26.5 Mpa and 7.9 Mpa respectively.
- The GPLW concrete produced with FAC and GGBFS as binder materials was found superior in terms of strength behaviour to that of OPC concrete.
- Within 14 days, all of the GPLWCs attained higher strength than that of 28 days strength of OPC concrete.
- Within 3 days, the GPLWCs with higher GGBFS (F-50, F35, F25) in its binder composition, attained higher strength than that of 28 days strength of OPC concrete.
- The early strength of GPLWCs helps reduce the cost of shuttering works and increases the speed of construction.
- This early strength of GPLWC's can increase the production capacity of precast industry and also due to the lower density of concrete, economic in the lifting, handling and haulage.
- According to the strength requirements for a given structural or architectural application, a suitable mix proportions can be selected.
- Utilization of these industrial by-products can reduce the need for conventional building materials. This reduces the emission of greenhouse gas (CO_2) substantially and hence mitigate carbon footprint in construction activities. Hence GPLWCs can be a Sustainable or Green concrete for future.

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