Development of Geopolymer Lightweight Concrete using Industrial By-products

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Abstract: **An attempt has been made in this research work to develop the geopolymer concrete composite using the industrial by-products such as fly ash class-C, GGBFS, PS sand and sintered fly ash aggregates to achieve the required strength. The different combination of fly ash and GGBFS as binding materials were studied in this work. The ambient cured geopolymer concrete was developed to mitigate the carbon footprint in building construction. The density of concrete was in the range of 1740Kg/m^3 to 1840Kg/m^3. The higher the GGBFS content higher the density. The strength developed in geopolymer concrete after 28 days of curing is in the range of 25 Mpa to 45 Mpa. Hence this Light Weight Geopolymer concrete can be used as structural concrete for buildings.**

Keywords**: Geopolymer, Class – C Fly ash, GGBFS, PS Sand, Sintered Fly ash Aggregates.**

I. INTRODUCTION

In the modern world, the challenges faced by the Civil Engineering Industry, is to develop high performance construction material at reasonable cost with the lowest possible environmental impact. India has become the second largest country in both production and consumption of cement next only to China. Manufacturing of Ordinary Portland Cement - OPC is highly energy consuming process and also requires huge quantity of natural resources. The production of OPC releases large amount of CO_2 in to the atmosphere, i.e., with all the modern technology of cement manufacturing process available, for every ton of Portland cement production, about 0.8 ton of CO_2 is released to atmosphere. The decade (2014 – 2024) is known as international decade for sustainability. It envisages adoption of industrial by-products such as fly ash, GGBFS composites in civil engineering applications.

Geopolymer is one in which cement is completely replaced (100%) by many suitable cementitious materials. Geopolymer binders have emerged as an environmental friendly, possible alternative to OPC binders due to their reported high early strength and durability [1] - [6]. The strength development in Geopolymer relies on alumina-silicate rather than calcium silicate hydrate bonds as in OPC concrete. Geopolymer was invented by Devidovits [7] in 1979 as a 3-dimensional alumina silicates. He states that, supplementary cementing materials which are coal and lignite fly ash, rice husk ash, palm oil fuel ash, GGBFS, Silica Fumes, limestone, metakaolin and natural pozzolana can produce geopolymer.

The Geopolymer is synthesized by mixing one or more supplementary cementing materials, in known proportions, with alkaline solution of Sodium Silicate and Sodium Hydroxide. Sodium Hydroxide either in Pellets form or in Solution form - Lye, is available commercially. Sodium hydroxide solution with required molar concentration is prepared for the work and is mixed with Sodium silicate solution and used as activator solution.

II. EXPERIMENTAL STUDY

An attempt has been made here to develop the geopolymer concrete composite using the industrial by-products such as fly ash class-C, GGBFS, PS sand and sintered fly ash aggregates to achieve the required workability and strength.

A. Materials Used and their properties

Locally available cement – OPC 53 Grade is used to develop a control concrete, to which the geopolymer concrete strengths are compared. The Fly ash Class C (FAC), a by-product from Neyveli Thermal power plant and Ground Granulated Blast Furnace Slag (GGBFS), a by-product of Iron and steel industry has been used as geopolymer source materials. Fine Aggregate used is another by-product from steel industry, Processed Slag Sand (PSS). Sintered Fly ash Aggregates (SFA) another by-product from thermal power plant has been used as Coarse Aggregates. Activator Solution (AS) is a combination of Sodium Silicate and Sodium Hydroxide solutions procured in commercial grade. The physical and chemical properties of these materials are tabulated in table-I and table-II.

B. Methodology adopted

The Geopolymer has been synthesized by mixing FAC and GGBFS in different proportions with AS of Sodium Silicate and Sodium Hydroxide. Commercially available Lye (Caustic Soda), Sodium Hydroxide in solution form and

Sodium Silicate solutions has been used in this study. Sodium hydroxide solution of 8M concentration has been prepared for the work and mixed with Sodium Silicate solution in a ratio of 2:1 and has been used as activator solution. The fine and coarse aggregates in saturated surface dry condition was used for concrete production. The binder and aggregates have been dry mixed to achieve uniform mix. Then the liquid, activator solution was added and mixed till a workable mixture is obtained.

TABLE I - PROPERTIES OF THE BINDER MATERIALS USED

Binder materials	OPC	FAC	GGBS
Physical properties			
Specific Gravity	3.15	2.38	2.91
Fineness – Specific Surface (m2/kg)	290	475	358
Residue on 45µ Sieve (%)	NA	10.50	2.30
Chemical properties			
SiO_2 %	18.40	30.73	36.00
Al_2O_3 %	5.60	17.50	17.59
Fe_2O_3 %	3.20	15.30	1.36
MgO %	1.40	6.70	7.08
CaO %	66.80	20.85	36.45
SO_3 %	3.00	6.62	0.61
Loss of Ignition, % by Mass	1.80	1.46	2.10

TABLE III - PROPERTIES OF THE AGGREGATES USED

Aggregate Properties	PSS	SFA
Specific Gravity	2.60	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

C. Mix Proportioning

Mix proportioning of materials for Cement Concrete has been derived as per ACI absolute volume method of concrete mix design. The Geopolymer Concrete mix proportions are based on the volume of materials required to produce the cement concrete. The difference being the binder materials and liquid. The liquid – binder ratio was maintained at 0.4 for all mix proportions. Table-III shows the mix designations and their mix proportions of different mixes under study.

The density of cement concrete obtained is about 1885 Kg/m^3. The density of geopolymer concrete with 100 % fly ash and no GGBFS is about 1740 Kg/m^3 and that of GPC with 100% GGBFS has a density of about 1840 Kg/m^3. The density of GPC increases with increase in GGBFS content in binder material. The low density of concrete is due to the utilisation of sintered fly ash aggregates, one of the light weight aggregates as coarse aggregates. Hence the development of sustainable light weight concrete (LWC) using different industrial by-products has been achieved.

D. Results and Discussions

Cube Specimens of 100*100*100 mm were cast as per BIS standards to test for compressive strength. Tests have been conducted after a curing period of 3 days, 7 days, 14 days, 28 days and 56 days. Specimens have been demoulded after 24hrs of casting and stored under the shade, to be air cured at ambient temperature. The comparative study of Geopolymer concrete and Cement Concrete have been presented.

Table-IV represents the development of strength with age in different mixes with varying fly ash and GGBFS ratios. The CC represents to Cement Concrete. F100 to F0 represents the Geopolymer concrete with varying the fly ash content from 100% to 0%. Fig-1 and fig-2 indicates the compressive strength development in geopolymer concrete with different proportions of fly ash and GGBFS in the mix proportions.

TABLE-III MIX PROPORTIONS OF MATERIALS

Mix Proportions	**Volume**	**CC**	**F100**	**F85**	**F75**	**F65**	**F50**	**F35**	**F25**	**F15**	**F0**
	m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
Cement - Kg	187.50	590.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fly ash - Kg		0.00	446.25	379.31	334.69	290.06	223.13	156.19	111.56	66.94	0.00
GGBFS -Kg		0.00	0.00	81.84	136.41	190.97	272.81	354.66	409.22	463.78	545.63
Water /AS - lit	236.25	236.25	236.25	236.25	236.25	236.25	236.25	236.25	236.25	236.25	236.25
PS Sand - Kg	221.42	575.69	575.69	575.69	575.69	575.69	575.69	575.69	575.69	575.69	575.69
SFA -Kg	324.83	484.00	484.00	484.00	484.00	484.00	484.00	484.00	484.00	484.00	484.00

TABLE-IV STRENGTH DEVELOPMENT IN DIFFERENT MIXES WITH AGE

Mix / Age	CC Mpa	F-85 Mpa	F-75 Mpa	F-65 Mpa	F-50 Mpa	F-35 Mpa	F-25 Mpa	F-0 Mpa
3 Days	10.43	6.70	13.43	18.87	29.92	26.38	25.63	20.40
7 Days	13.76	18.77	19.74	26.93	32.26	30.12	31.77	22.76
14 Days	17.04	26.32	24.48	32.32	35.30	33.22	33.58	28.35
28 Days	24.48	27.18	33.70	34.22	42.80	35.24	36.54	29.73
56 Days	25.77	25.14	22.26	37.78	43.59	28.69	32.39	30.45

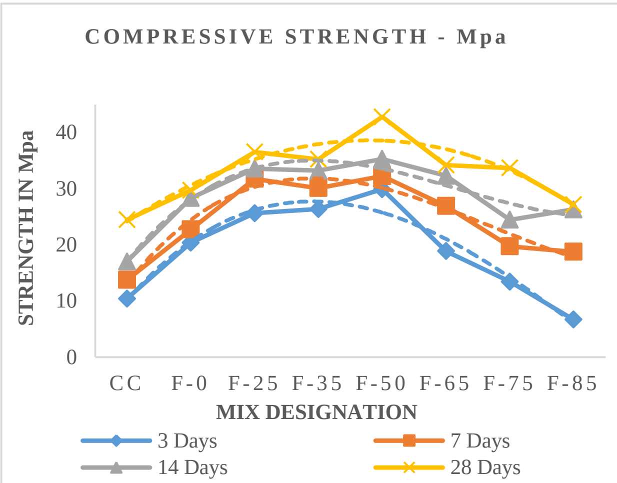

Fig. 1 Development of Strength in Geopolymer concrete with varying fly ash and GGBFS ratio in comparison with cement concrete

The minimum compressive strength achieved is 6.7 Mpa at 3 days and a maximum compressive strength achieved is 42.8 Mpa at 28 days. Table IV and the figs – 1 and 2, indicates that up to 28 days of curing, there is a steady increase in strength development.

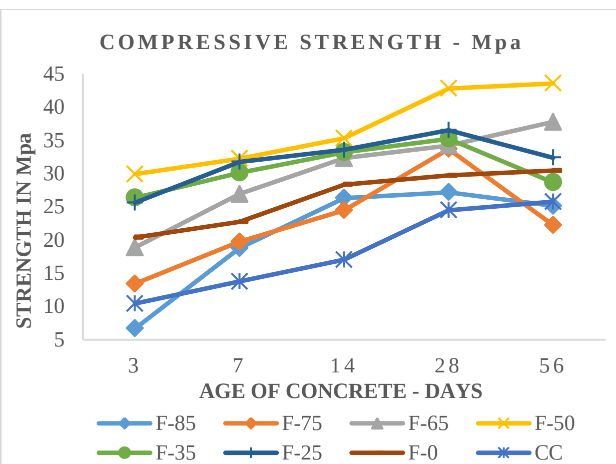

Fig. 2 Development of Strength with age in Geopolymer concrete in comparison with cement concrete

Between 28 days and 56 days, most of the geopolymer series shows a reduction in strength of about 10% to 20%, with exception of CC, F-65, F-50 and F-0. This may be due to the secondary chemical reactions within the microstructure of geopolymer concrete.

The compressive strength of cement concrete was 10.4 after 3 days of water curing and 24.5 Mpa after 28 days of water curing, which is less than that of geopolymer concrete. This indicates the geopolymer concrete produced with Class-C fly ash and GGBFS is superior to normal concrete.

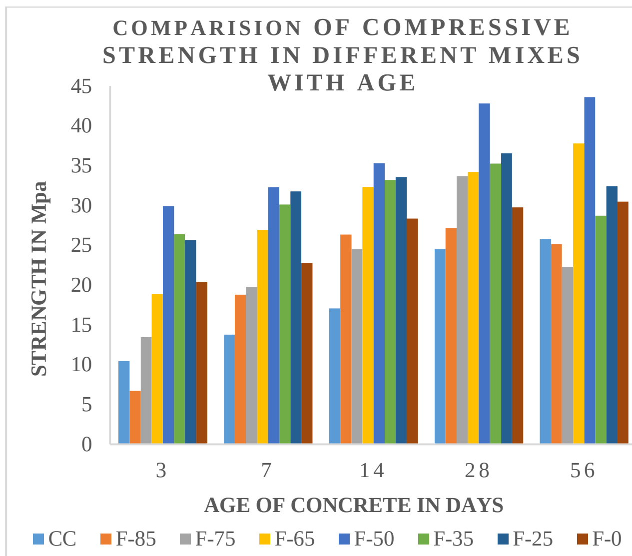

Fig. 3 - Comparison of Strength development in Geopolymer concrete and cement concrete with reference to age of concrete

It has also been noticed that, the strength of geopolymer concrete varies with variation in the percentage of GGBFS content in the binder material. If the molar concentration is varied, the strength of GPC also varies. Also the ratio of sodium silicate and sodium hydroxide will alter the strength properties of GPC. It has also been noticed during this investigation that, the use of modern superplasticizers does not provide any benefit in case of GPCs, instead they negatively affect the workability properties of GPCs.

III. CONCLUSIONS

The following conclusions have been drawn based on the experimental results:

- It is possible to prepare a light weight geopolymer concrete of considerable strength using the combinations of GGBS and fly ash, under ambient temperature curing.
- The compressive strength of the concrete is in the range of 7-45 MPa for different combinations of GGBS and fly ash. This wide range of strength is useful to select the required percentage of GGBS for structural applications.
- The variation of strength is sensitive to the percentage of Fly ash and GGBS in all the combinations.
- Increased use of industrial by-products reduces the energy intensive manufacturing process of conventional building materials. This reduces the greenhouse gas emission and hence reduce carbon footprint of buildings.

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