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Workability and Flexural Behavior of Geopolymer Lightweight Concrete using Industrial By-products

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ABSTRACT

In this research paper, an attempt has been made to develop the geopolymer lightweight concrete 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. The use of fly ash and GGBFS in different ratios as binder material were studied in this work. The geopolymer lightweight concrete was developed at ambient curing. The liquid – binder ratio was maintained at 0.4 for all the mix under study. The workability of concrete was measured with help of slump cone test, compaction factor test and flow test using inverted slump cone. The workability test results indicate the present geopolymer concrete under study can be termed as self-compacting and self-levelling concrete. The density of this concrete was in the range of 1740Kg/m3 to 1840Kg/m3. The higher the GGBFS content better is the workability and density. The compressive and flexural strength developed in geopolymer concrete after 28 days of curing is in the range of 27 Mpa to 43 Mpa and 5 Mpa to 8 Mpa respectively. Hence this Lightweight Geopolymer concrete can be produced with required workability and strength. This green concrete utilization in large scale can reduce the cost of the building.

Keywords: Geopolymer, Class – C Fly ash, GGBFS, PS Sand, Sintered Fly ash Aggregates, Flexure, Workability

I. INTRODUCTION

In the modern era, the civil engineers are faced with the challenges of developing high performance construction materials with economy and environmentally sustainable. India is now the second largest country in both production and consumption of cement next only to China. Ordinary Portland cement (OPC) manufacturing process consumes high energy and natural resources. The OPC manufacturing process has been technologically advancing over the past years. About 0.8 ton of CO2 is released to atmosphere for every ton of Portland cement produced. The utilization of industrial by-products in civil engineering applications has become more and more important to reduce the carbon footprint. Devidovits [1] in 1978-79 is the one who termed these 3-dimensional alumino-silicates as Geopolymer (GP). He states that, supplementary cementing materials such as coal and lignite fly ash, rice husk ash, palm oil fuel ash, GGBFS, Silica Fumes, limestone, metakaolin and natural pozzolana can produce geopolymer. Palomo A, et.al in 1999 [2] has said alkali activated fly ash as the cement for the future. In the recent years, enormous research works were being undertaken on geopolymer composites with many suitable cementitious materials and different by-products as fine and coarse aggregates.
Geopolymer composites have emerged as an environmental friendly alternative to OPC composites. Many researchers [3] - [7] have reported as geopolymer composites possess high early strength and better durability. Recently several researchers [13]-[20] have used different by-products as cement, fine aggregate and coarse aggregate replacement materials in production of concrete.

The geopolymer is synthesized by activating one or more supplementary cementing materials with help of activator solution (AS). Activator solution can be prepared using silicates and hydroxides of sodium or potassium. Most commonly used are Sodium Silicate (SS) and Sodium Hydroxide (SH). Sodium hydroxide solution (SHS) of known molar concentration is prepared and mixed with Sodium Silicate solution (SSS) to form the activator solution (AS).

II. METHODS AND MATERIAL

2.1 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.

The Geopolymer concrete has been synthesized by mixing FAC and GGBFS in different proportions with AS. The AS has been prepared using SHS of 8M concentration and SSS in 2:1 ratio. 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.

Workability tests such as Slump, Compaction Factor (CF) and Flow tests were conducted on fresh concrete. The compressive and flexural strength tests were conducted on hardened concrete. These test results established for different mix proportions were also compared with the Ordinary Portland Cement Concrete.

2.2 Materials Used and their properties

Control mix is developed using Ordinary Portland cement – OPC 53 Grade and the properties of which are compared with geopolymer concrete properties. The binder and aggregates used in this study were industrial by-products. Fly ash Class-C (FAC) and Ground Granulated Blast Furnace Slag (GGBFS) has been used as geopolymer source materials. Processed Slag Sand (PSS) and Lightweight Sintered Fly ash Aggregates (LWSFA) have been used as fine and coarse aggregates. Activator Solution (AS) is a combination of SSS and SHS procured in commercial grade. The properties of these materials are tabulated in table-1 and table-2.

2.3 Mix Proportioning

Concrete mix design as per ACI absolute volume method has been adopted to arrive at mix proportioning for Cement Concrete (CC). The mix proportions for Geopolymer Concrete (GPC) were considered as equivalent volume of materials required for the cement concrete. The difference being FAC and GGBFS used as binder materials and AS used as liquid. The liquid to binder ratio was maintained at 0.4 for all mix proportions which is 236.3 litres per cubic meter of water and Activator Solution for CC and for GPCs respectively. The liquid to binder ratio was maintained at 0.4 for all mix proportions which is 236.3 litres per cubic meter of water and Activator Solution for CC and for GPCs respectively. Table-3 shows the series designations for different mixes and their material proportions. The CC represents the Cement Concrete. F85 to F0 represents the GPCs with different FAC contents varying from 85% to 0%. F85 series contains 85% FAC and 15% GGBFS. Similarly F0 series contains 100% GGBFS. The table-3 shows the densities of different mixes with varying ratios of FAC and GGBFS. It has been noticed that as the GGBFS content is increased, the density of GPC also increased.

TABLE-1 PROPERTIES OF THE BINDER MATERIALS USED

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	10.50	2.30
Chemical properties			
SiO2 %	18.40	30.73	36.00
Al2O3 %	5.60	17.50	17.59
Fe2O3 %	3.20	15.30	1.36
MgO %	1.40	6.70	7.08
CaO %	66.80	20.85	36.45
SO3 %	3.00	6.62	0.61
Loss of Ignition, % by Mass	1.80	1.46	2.10

TABLE-2 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 Rodded	 1.38 1.54	 0.89 0.97
Type of Aggregates	Zone-2	12 mm Down

TABLE-3 MIX PROPORTIONS OF MATERIALS FOR CONCRETE

Components	Volume - m^3	Materials in Kg/m^3 in Different Series							
		CC	F85	F75	F65	F50	F35	F25	F0
Cement-Kg	0.188	590.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fly ash-Kg		0.0	379.3	334.7	290.1	223.1	156.2	111.6	0.0
GGBFS-Kg		0.0	81.8	136.4	191.0	272.8	354.7	409.2	545.6
PS Sand-Kg	0.221	575.7	575.7	575.7	575.7	575.7	575.7	575.7	575.7
SFA -Kg	0.325	484.0	484.0	484.0	484.0	484.0	484.0	484.0	484.0
Density-Kg/m^3		1,886.6	1,757.1	1,767.0	1,777.0	1,791.9	1,806.8	1,816.7	1,841.6

III. RESULTS AND DISCUSSION

The workability tests on fresh concrete were conducted to study the flow behaviour of CC and GPCs. The table-4 represents the different workability test results and the comparative study is represented by the fig-1, fig-2 and fig-3. The F100 mix (100% replacement of cement with FAC) found to be very stiff and difficult to work with, even at liquid-binder ratio of 0.45 and 0.5. This may be due to the higher surface area of fly ash requiring higher liquid content to achieve the required workability. Lesser the FAC content better was the workability. The workability of GPC series F0 and F25 were equivalent to the workability of CC. It has also been noticed during this investigation that, the use of superplasticizers does not provide much benefit in case of GPCs, instead they negatively reduces the workability properties of GPCs.

Specimens of 100*100*100 mm cubes to test for compressive strength and 100*100*500 mm prisms to test for flexural strength were cast as per BIS standards for CC and GPCs. Demoulding of specimens were carried out after 24hrs of casting. The GPC specimens were stored in shade and were air cured at ambient temperature. The CC specimens were water cured for 28 days. Comparative study of GPCs and CC have been presented here. Tests have been conducted after a curing period of 7, 14 and 28 days. Table-5 and table-6 represents the compressive strength and flexural strength respectively, achieved in different mixes. Fig-4 and fig-5 indicates the compressive and flexural strengths of CC and GPCs. The 28 days compressive and flexural strength achieved in CC mix is 24.48 Mpa and 7.93 Mpa respectively. The 28 days minimum compressive strength achieved in GPC mixes is 27.18 Mpa in F85 series and a maximum of 42.8 Mpa in F50 series. Similarly, The 28 days minimum flexural strength achieved in GPC mixes is 4.93 Mpa in F85 series and a maximum of 7.8 Mpa in F0 series.

TABLE-4 WORKABILITY TESTS RESULTS IN DIFFERENT MIXES

Series	Slump mm	CF %	Flow mm
CC	285	0.99	520
F0	265	0.99	520
F25	260	0.99	500
F35	252	0.98	480
F50	250	0.98	460
F65	240	0.98	450
F75	225	0.97	400
F85	178	0.97	375

TABLE-5 COMPRESSIVE STRENGTH IN DIFFERENT MIXES

Compressive Strength in Mpa			
Series	**7 days**	**14 days**	**28 days**
CC	13.76	17.04	24.48
F0	22.76	28.35	29.73
F25	31.77	33.58	36.54
F35	30.12	33.22	35.24
F50	32.26	35.30	42.80
F65	26.93	32.22	34.22
F75	19.74	24.48	33.70
F85	18.77	26.32	27.18

TABLE-6 FLEXURAL STRENGTH IN DIFFERENT MIXES

Flexural Strength in Mpa			
Series	**7 days**	**14 days**	**28 days**
CC	6.00	6.60	7.93
F0	5.27	6.13	7.80
F25	5.33	5.93	6.40
F35	5.27	5.73	6.33
F50	5.27	5.73	7.07
F65	5.00	5.60	6.53
F75	3.47	4.87	5.47
F85	2.63	3.33	4.93

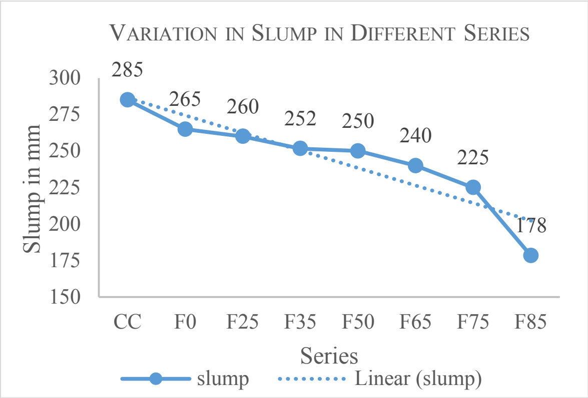

FIG. 1 - COMPARISON OF SLUMP VALUES IN CC AND GPCS

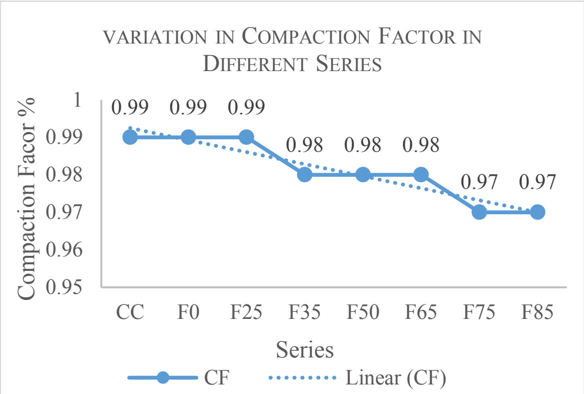

FIG. 2 - COMPARISON OF COMPACTION FACTOR IN CC AND GPCS

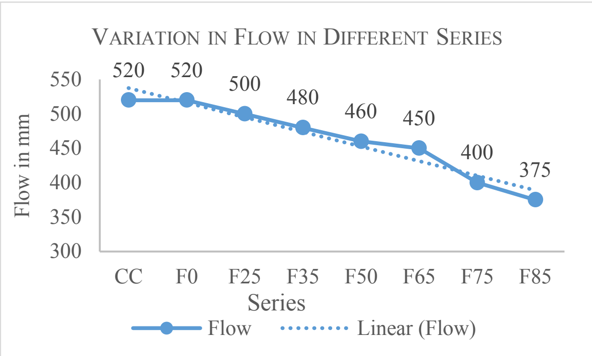

FIG. 3 - COMPARISON OF FLOW IN CC AND GPCS

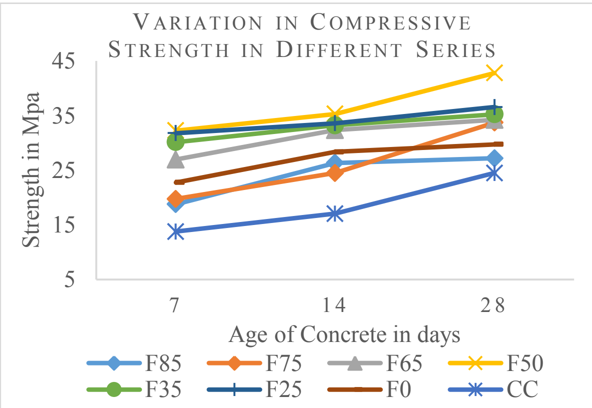

FIG. 4 - COMPARISON OF COMPRESSIVE STRENGTH IN CC AND GPCS

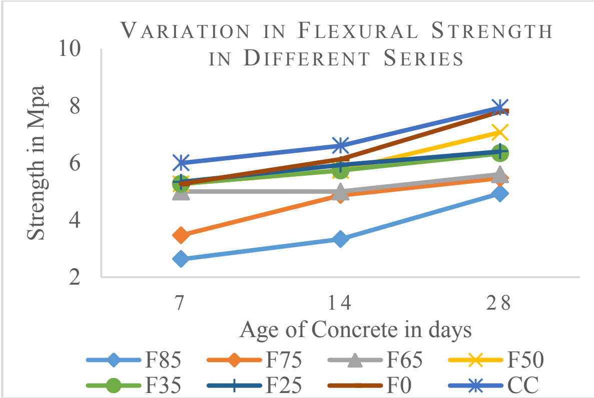

FIG. 5 - COMPARISON OF FLEXURAL STRENGTH IN CC AND GPCS

It has also been noticed that, as the FAC content in the binder material varies the strength of GPCs also varies. The comparison of properties of CC and GPCs, both in fresh and hardened state, indicates that the geopolymer concrete produced with Class-C fly ash and GGBFS is superior to cement concrete. The ratio of FAC and GGBFS needs to be carefully selected for the required workability and strength properties.

IV. CONCLUSION

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

- It is possible to produce lightweight geopolymer concrete of required workability and considerable strength using the combinations of industrial by-products such as FAC, GGBFS, PS sand and sintered fly ash aggregates, cured at ambient temperature.
- The workability achieved in this study can be compared with that of self-levelling and self-consolidating concrete. The workability of GPC increases with reduction in FAC content.
- The 28 days compressive strength and flexural strength of the GPCs were in the range of 27- 43 MPa and 4.93- 7.8 Mpa, depending on FAC and GGBFS content in the mix.
- The strength varies with variation in the percentage of FAC and GGBFS. Lower the FAC content higher is the strength achieved.
- Use of industrial by-products reduces the carbon di-oxide emission and hence GPCs can be termed as sustainable concrete or Green concrete.

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