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Use of Industrial Waste in SCGPC – Experimental Investigations on Strength And Durability Characteristics

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Abstract: The aim of the present study is to develop the concrete by using the industrial waste and assessing the fresh & hardened properties of concrete. In this work, the materials used in the concrete are fly ash, ground granulated blast furnace slag (GGBS) as fully replacement of cement. Self Compacting Geopolymer Concrete (SCGPC) is considered as modern construction material in concrete technology. As the name replies, it does not need any compaction efforts, to achieve full compaction and utilizes Supplementary Cementitious Materials (SCM) in addition with alkaline solutions like sodium hydroxide and sodium silicate and super plasticizer as a binder for matrix formation and strength. In the present study, fly ash based SCGPC replaced with various percentages of GGBS was developed. The concrete specimens were cured both oven curing and ambient curing. For assessing the workability properties – Slump Cone test, V – Funnel test and L – Box test were carried out as per EFNARC guidelines and for assessing the strength properties – Compressive strength test, Flexural strength test and Split tensile test were conducted. The results indicated that with the addition of GGBS by replacing fly ash in SCGPC, the workability characteristics are decreased and strength was increased with the increase in GGBS content. The results also indicated that the SCGPC was suitable for use at both oven and ambient temperature curing. The durability tests were conducted on specimens and found that the durability increases with the increase of GGBS content.

Keywords: Geopolymer; Alkaline activators; GGBS; fly ash; Super plasticizer

I. INTRODUCTION

The production of Ordinary Portland Cement (OPC) is increasing 9% annually. OPC production is a critical review due to high amount of carbon dioxide (CO2) gas released into the atmosphere and OPC is also one among the most energy – intensive construction material. The current contribution of green house gas emission from OPC production is about 1.6 billion tonnes annually or about 8% of the total greenhouse gas emissions to the earth's atmosphere. Geopolymer concrete is an innovative constructive material that does not need OPC as a binder. Instead, the Supplementary Cementitious Materials (SCM) such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA), Silica Fume (SF), etc, that the materials are rich in alumina (Al) & silicon (Si) are activated using Alkaline Activator Solution (AAS) to produce the Geopolymeric binder [1]. Davidovits propose that an AAS react with the silicon (Si) and the alumina (Al) is a source material of either geological origin or an industry waste as by-product materials such as fly ash, ground granulated blast furnace slag, rice husk ash, etc, to produce binders. Because the Geo- polymerization process takes place in that, he coined as the term 'Geopolymer' to represent these binders [2].

Self compacting Geopolymer concrete (SCGPC) can be considered as an advanced and innovative construction material and can be regarded as a revolutionary development in the field of concrete technology. It is an innovative type of concrete that can achieve the combined advantages of both GPC and Self Compacting Concrete (SCC). As the name implies, it does not need any compacting efforts to achieve full compaction and SCGPC that is produced by a polymeric reaction of alkaline liquid with a by-product material utilizes Supplementary Cementitious Materials such as Fly Ash, Ground Granulated Blast Furnace Slag, Silica Fume, Rich Husk Ash, Meta kaolin, etc., together with alkaline solution as a binder for matrix formation and super plasticizer to increase workability. The sustainable production of self compacting Geopolymer binder hinges on controlling the mix proportion, determining the right quantities of Sodium Hydroxide (NaOH) (or) Potassium Hydroxide (KOH) and Sodium Silicate (Na2SiO3) (or) Potassium Silicate (K2SiO3) solution required to activate the source material and optimizing the super plasticizer (SP) dosage. The water expelled from the Geopolymer matrix during the curing and further drying period, leaves behind non-pores in the matrix, which provide benefits to the performance of Geopolymer. The water in a low calcium fly ash

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based Geopolymer mixture therefore plays an indirect role in the chemical reaction takes place; it merely provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in an OPC concrete mixture during the hydration process. However, a small proportion of calcium rich source materials in order to accelerate the setting time and to alter the curing time adopted for the Geopolymer mixture. In that situation, the water released during the geopolymerisation reacts with the calcium present to produce hydration products [3].

The fly ash based Geopolymer concrete for curing in ambient condition can be proportioned for desirable fresh & hardened properties using GGBS as a part of binder. Whereas, heat curing process requires special arrangements which is energy consumption process and may not be feasible for applying in cast-in-situ concreting. The geopolymerisation process is mainly influenced by the Chemicals of the AAS and the source materials [4, 5].

The influence of different super plasticizer dosage on the Compressive strength & Micro structural characteristics of Inter-facial Transition Zone (ITZ) prepared with fly ash based self compacting geopolymer concrete that the specimens prepared with different dosage of SP 3%, 4%, 5%, 6% and are cured at 70°C for a duration of 48 hrs, the results revealed that the 6% SP dosage has the Compressive strength of 51.52Mpa tested at 28 days. The Compressive strength of concrete has increased with a decrease in the thickness of ITZ and this relationship depends on the dosage of SP use [6].

The effect of extra water, curing time & temperature on the fresh & Hardened properties of self compacting geopolymer concrete stated that the inclusion of water beyond certain limit resulted in bleeding and segregation of fresh concrete and decrease the compressive strength of concrete and also longer curing time improves the geopolymerisation process resulting in higher compressive strength [7, 8].

The concentration variation of sodium hydroxide had the least effect on the fresh properties of SCGPC. By increasing the concentration, the workability of fresh concrete was slightly reduced, however, the corresponding compressive strength was increased. A concrete sample with sodium hydroxide concentration of 12M gives maximum compressive strength [9]. The deterioration of concrete structures might be the result of the action of aggressive waters, such as sea water or the corrosion of steel reinforcement in the case of reinforced concrete. It is to be noted that the durability of Concrete is independent of its intrinsic characteristics, is variable according to the type of exposure in the environment of marine and degree of immersion [10].

II. MATERIALS

A. Fly ash

Fly ash is a by-product obtained during the combustion of coal in Thermal Power Plants. In the present study, Low calcium (Class F) fly ash obtained from Raichur Thermal Power Plant, Karnataka, India. Fly ash was used as a source material for producing the SCGPC. The chemical compositions of fly ash are given in table 1.

B. GGBS

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron from steel industry. GGBS consists essential silicates and alumina-silicates of calcium. GGBS obtained from JSW steel Ltd, Bellary. The chemical compositions of GGBS are given in table 1.

Table -1: Chemical Compositions of Fly ash & GGBS

Oxide	**Fly ash (%)**	**GGBS (%)**
CaO	3.2	37.34
Al2O3	30.6	14.42
Fe2O3	1.5	1.11
SiO3	61.12	37.73
MgO	0.75	8.71
Na2O	1.35	----
LOI	0.79	1.41
MnO	----	0.02

C. Aggregates

Well graded locally available fine aggregates passing 4.75 mm and coarse aggregate of passing 12.5 mm sieve are used in the present work.

D. Preparation of Alkaline Activator Solution (AAS)

The preparation of alkaline activator solution plays a major role in production of Geopolymer concrete. The AAS is the combination of sodium hydroxide (NaOH) solution and sodium silicate (Na2SiO3) solution. The solids must be dissolved in water to make a solution with the required concentration expressed in terms of molarity (M). The concentration of NaOH solution can vary in the range between 8M to 16M; however, 12M solution is adequate for most of the applications. The NaOH for 12M is 12x40 (Molecular weight) = 480gms should dissolve in 1 liter of water. After mixing the NaOH flakes in water its molecular weight reduces to 361gms for 12 Molarity. For 12 M

NaOH solutions, for 1 liter of water we require 36.1% of NaOH flakes and 63.9% of water. It is recommended that the alkaline liquid is prepared at least 24 hours before to use.

E. Super plasticizer

In order to achieve superior workability and required flow-ability of the fresh concrete, a commercially available super plasticizer named as Conplast SP430 supplied by Fosroc construction solutions, India, and a specified amount of extra water was also used in the mix. The ordinary drinking water available in concrete laboratory was used for this purpose.

III. EXPERIMENTAL WORK

A. Objective of the study

The main objective of the present study is developing & assessing the self compacting Geopolymer concrete by using the industrial waste.

B. Mix proportions of SCGPC

In this work, the mix design of SCGPC is purely different to that of OPC concrete. The production of SCGPC was carried out by using the trial and error method. In GPC, generally the mass of combined aggregates may be taken about 70% to 80%. With regard to alkaline liquid to fly ash ratio by mass of fly ash, values in range of 0.35 to 0.5 are recommended. In the beginning, a total number of 17 trial mixes of SCGPC were produced to assess the workability characteristics and study the influence of various parameters on the Compressive strength. Finally the ratio of alkaline liquid to fly ash was kept 0.5 as constant and the ratio of the sodium silicate solution to sodium hydroxide solution was kept 1.0 as constant for all mix proportions. The addition of extra water improved the workability characteristics of SCGPC mixtures, however the addition of water beyond the limit results bleeding and segregation of fresh concrete & decreased the compressive strength of SCGPC. In the present study, 12% of extra water, SP%, VMA% by mass of fly ash was taken. The mix proportions of SCGPC were given in table 2.

Table 2:- Mix proportions

Coarse aggregate (kg/m^3)	950
Fine Aggregate (kg/m^3)	860
Binder (kg/ m^3)	420
NaOH Solution (kg/ m^3)	108
Na2SiO3 Solution (kg/ m^3)	108s
AAS/Binder	0.5
NaOH / Na2SiO3	01:01
SP (%)	1
VMA (%)	0.05
Extra water (%)	12

C. Mixing, Casting and Curing

The components of SCGPC i.e., fine aggregate; coarse aggregate, fly ash, GGBS, was dry mixed in the pan mixer about 2 min. Then the dry mix followed by the wet mix where by the liquid part of the mixture i.e., sodium hydroxide solution, sodium silicate solution, AAS solution, SP, extra water mixed with VMA for another 2 min. After mixing, the fresh concrete was then filled into steel moulds and allowed to fill all the spaces of the moulds by its own self weight without any compacting efforts. After casting the specimens were put for curing. Here the curing methodology is purely different that to curing of OPC concrete. After casting the specimens along with moulds kept for drying in both oven curing at 70^{o}C and/or ambient curing temperature.

IV. RESULTS & DISCUSSIONS

A. Fresh Properties

The fresh properties required by SCGPC are flow ability or filling ability, passing ability and resistance to segregation. The tests performed on SCGPC are Slump flow, T-50cms flow, V-Funnel, L-Box satisfying the EFNARC guidelines. The values are tabulated in table 3 and the results plotted are as shown in figures 1(a), 1(b), 1(c), 1(d).

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Table 3: Fresh properties of SCGPC

% of GGBS Replaced with fly ash	Mix Design Ation	Slump flow in mm	T-50cm in sec	V-Funnel in sec	L-Box
0	M1	676	3	13	0.92
20	M2	670	4	14	0.88
40	M3	664	5	15	0.87
60	M4	647	6	19	0.86
80	M5	620	8	22	0.78
100	M6	575	8	26	0.73

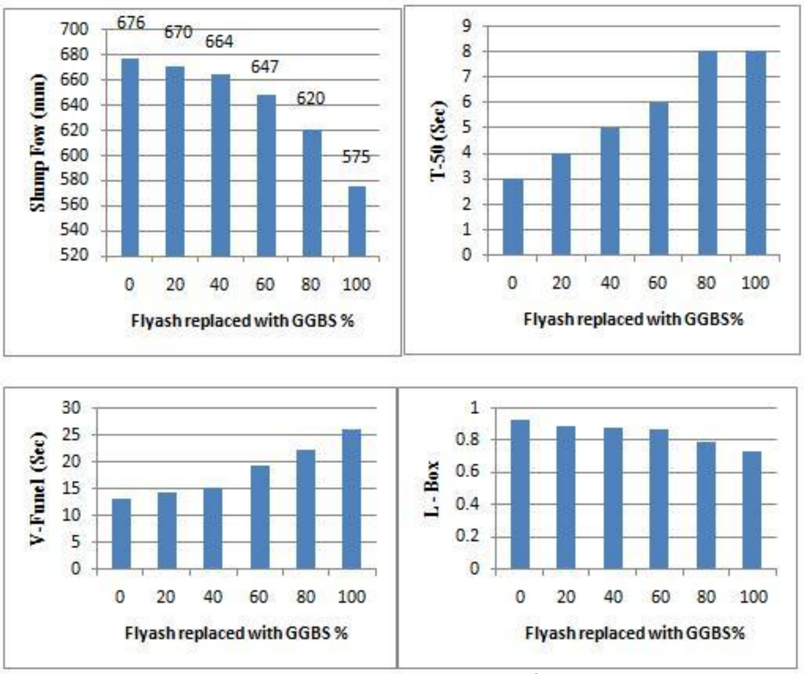

Figure 1 Fresh Properties of SCGPC

B. Hardened Properties

The hardened properties for the specimens cured in both heat curing & ambient temperature curing are assessed for compressive strength, split tensile strength, flexural strength by using respective test methods. The values are tabulated in table 4 andthe results plotted are as shown in figures 2(a), 2(b) and 2(c). In bar chart the Blue colour bars indicate the ambient temperature cured specimens' strength and Red colour bars shows that the heat cured specimens' strength.

Table 4 Hardened properties of SCGPC specimens

% of GGBS replaced with fly ash	Compressive Strength Mpa		Split Tensile Strength Mpa		Flexural StrengthMpa	
	Ambient Curing	Heat Curing	Ambient Curing	Heat Curing	Ambient Curing	Heat Curing
0	26.66	27.2	3	3.15	2.5	3.15
20	40.22	42.5	3.15	3.2	2.6	3.23
40	45.66	55.6	3.8	3.42	2.54	3.48
60	56.22	58.2	4.61	3.52	2.75	3.58
80	72	74.42	3.86	3.56	2.6	3.62
100	74.66	76.8	4.25	4.2	2.72	4

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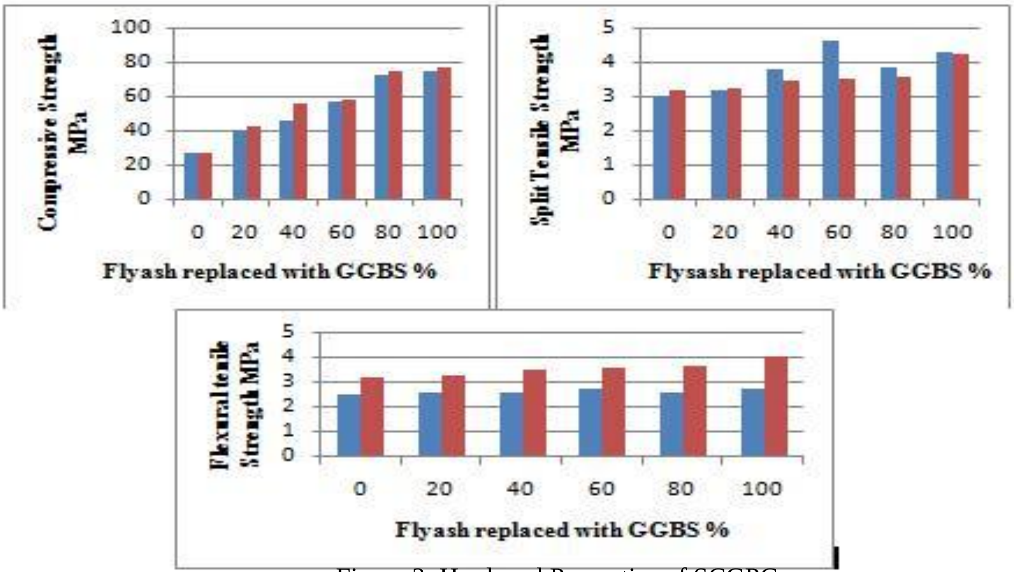

Figure 2: Hardened Properties of SCGPC

C. Durability Properties of SCGPC

In the present study, tests were performed on concrete cube specimens of size 70.6 mm3. The SCGPC specimens are immersed in 5% HCL and 5% H2SO4 solutions. The deterioration of SCGPC specimens can be estimated by finding out the appearance of the specimen, weight loss of the specimen and also the reduction in compressive strength of the specimens when they are kept in HCL and H2SO4 solution were identified for 28 days respectively. The weight loss of SCGPC specimens of different mixes in HCL solution H2SO4 solution are shown in table 5. The Compressive strength loss of SCGPC specimens of different mixes in HCL solution H2SO4 solution are shown in table 6.

Table 5 Weight loss of SCGPC specimens

MIXES	weight of specimens before acid immersion in gms (28 days)		weight of specimens after acid immersion in gms (28 days)		Weight loss in gms (28 days)	
	HCL	H2SO4	HCL	H2SO4	HCL	H2SO4
M1	868	859	830	816	38	43
M2	913	902	886	869	33	33
M3	893	886	874	862	19	24
M4	855	855	838	834	17	21
M5	882	895	871	882	11	13
M6	865	886	861	879	4	7

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Table 6:- Compressive Strength loss of SCGPC specimens

MIXES	Compressive strength of specimens before acid immersion in N/mm^2 (28 days)		Compressive strength of specimens after acid immersion in N/mm^2 (28 days)		Compressive strength loss in N/mm^2 (28 days)	
	HCL	H2SO4	HCL	H2SO 4	HCL	H2SO 4
M1	29.01	30.01	27.01	27.01	2	3
M2	36.01	35.01	34.01	33.01	2	2
M3	48.01	48.01	47.01	46.01	1	2
M4	59.01	59.01	58.01	58.01	1	1
M5	60.01	56.02	60.01	55.03	0	0.99
M6	66.02	67.02	66.01	67.02	0	0

CONCLUSION

In this present study, the fresh & hardened properties of Low-calcium fly ash based SCGPC assessed with different replacements of GGBS. From experimental results, the following conclusions are drawn:

- Economical benefits are achieved by elimination of curing process and reducing form-work &labour cost as compaction is not required.
- In respect of fresh properties of concrete, with the replacement of GGBS,in fly ash based SCGPC, the workability was reduced.
- In respect of hardened properties, with the replacement of GGBS, in fly ash based SCGPC, the strength was increased.
- Mix 4 (i.e 60% fly ash is replaced with GGBS), is ideal by considering the self compacting and strength properties of concrete.
- SCGPC is more durable for chemical attacks as well as strength criteria.

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