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STUDY ON THE EFFECTS OF SILICA FUME AND GROUND GRANULATED BLAST FURNACE SLAG ON THE HIGH-PERFORMANCE CONCRETE

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Abstract: High Performance Concrete (HPC) is a concrete meeting special combinations of performance and uniformity requirements that cannot be always achieved routinely by using conventional constituents and normal mixing. This leads to examine the admixtures to improve the performance of the concrete. On the other side, cost of concrete is attributed to the cost of its ingredients which is scarce and expensive, this leading to usage of economically alternative materials in its production. This requirement is drawn the attention of investigators to explore new replacements of ingredients of concrete.
The present investigation has revealed that the use of industrial by-products like GGBS, silica fume which are hazardous to the environment may be profitably used as a partial replacement of cement, which leads to economy and durability of the structure. Utilization of industrial by-products in this manner enhances the protection of the environment to a large extent and which eventually leads to "Sustainable Development" and growth of concrete industry.
In the present investigation focuses on characteristics of M30, M40 grade concrete with partial replacement of cement with Silica fume and Ground Granulated Blast furnace Slag (GGBS). The cubes are tested for compressive strengths, cylinders are tested for Split Tensile strengths and beams are tested for Flexural strengths. It is found that by the partial replacement of cement with silica fume and GGBS helped in improving the strength of the concrete substantially compared to normal mix concrete.

Index Terms - **High Performance Concrete, Silica Fume, Ground Granulated Blast Furnace Slag, Effects of silica fume, GGBS on HPC, Mix design, Compressive Strength Results, Split Tensile Strength Results, Flexural Strength Results.**

I. INTRODUCTION

Concrete is a widely used construction material for various types of structures due to its structural stability and strength.
The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. About 1 tonne of CO2 is produced in manufacturing of each tonne of Portland cement (PC). Thus, cement production accounts for about 5% of total global CO2 emissions.
Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material.
The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact.
Sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Therefore, sustainable development is disturbed with protecting the world's resources and sharing its benefits for the betterment of generations to come.
By-products from various industries cause a major environmental problem around the world. In order to encourage waste recycling and prevent waste dumping, a landfill tax has also been imposed in the developed countries. However, the waste dumping is still a serious environmental issue throughout the world. As stated by Mehta (1998), "the goal of sustainable development of the cement and concrete industries is, therefore, very important, and it can be reached if we make a serious effort for complete utilization of cementitious and Pozzolanic by-products produced by thermal power plants and metallurgical industries."
High performance concrete is defined as 'Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, characteristics such as strength, toughness, volume stability or service life in severe environments'.

II. SCOPE AND OBJECTIVES OF THE INVESTIGATION

The primary aim of this investigation was to evaluate the influence of high volumes of SCMs on the properties of HPC. More specifically, the research had the following objectives:

Study of compressive strength, split tensile strength and Flexural strength of M30, M40 conventional concrete by replacing of cement with GGBS, Silica fume.

Tests were conducted on concrete cubes, cylinders and beams to study compressive, split tensile and Flexural strengths. The results are compared with the normal conventional concrete.

III. MATERIALS AND METHODS

3.1 MATERIALS

53 Grade Ordinary Portland Cement (OPC), Fine Aggregates, Coarse Aggregates, Water, Silica Fume, Ground granulated blast furnace slag.

3.2 Cement

Ordinary Portland Cement of Ultratech brand of 53 grade confirming to IS:12269-1987 was used.

3.3 Fine Aggregate

Natural sand as per IS:383-1987 was used.

3.4 Coarse Aggregate

Crushed aggregate confirming to IS: 383-1987 was used. Aggregates of size 20mm and 12.5 mm of Specific gravity2.71 and fineness modulus 7.70 were used.

3.5 Water

The water used for the present investigation was tap water available in the laboratory and the same was analysed according to the standard methods for the examination of water (APHA, 1994) and the values are presented in Table below.

3.6 Mineral Admixtures

3.6.1 Silica Fume:-

Table: **The chemical composition of Silica Fume**

Chemical composi-tion	Silica (Sio2)	Alumina (Al2o3)	Iron Oxide (Fe2o3)	Alkalies as (Na2o+ K20)	Calcium Oxide (Cao)	Magne-sium Oxide (Mgo)
Percen-tage	89.00	0.5	2.5	1.2	0.5	0.6

3.6.2 Ground Granulated Blast Furnace slag:-

Table: The chemical composition of GGBS

Oxides	Sio2	P2O5	CaO	MnO	FeO	Fe2O3
Mass Percentage	11	10	51	08	10	04

3.7 METHODS

- **Tests for properties of fresh concrete**
- **Preparation of the concrete specimens**
- **Mix proportions**

- **Tests for compressive strength**
- **Tests for Split Tensile strength**
- **Tests for Flexural strength**

<u>Tests for properties of fresh concrete</u>

Workability of Concrete is defined as the "property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. The workability of fresh concrete is usually measured by slump test, Compacting factor test, Vee-bee test and flow test.

- AS per the slump test workability of concrete=**<u>50 mm(Medium slump).</u>**
- As per the compaction factor test Degree of workability **<u>=0.8 compaction factor</u>**

<u>Preparation of the concrete specimens</u>

- 150 x 150 x 150 mm cubes were prepared for compression tests.
- For Split tensile strength test 300 mm high 150 mm diameter cylinders were prepared.
- For Flexural strength test 150 x150x 750 mm beams were prepared.

3.8 MIX PROPORTIONS

Mix design is the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain minimum properties notable, workability, strength and durability. The various methods of mix proportioning generally used for the design of Ordinary concrete are all based on the relation between strength and water/cement ratio as well as workability, water/cement and aggregate/ cement rations.
Mix design methods being empirical, minor variations exist in the process of selecting the mix proportions using different methods. In the present work, proportions of high strength & high performance concrete mix design of M30, M40 concrete grades were carried out according to IS 10262:2009 recommendations.

<u>3.9.1 Compressive strength Test</u>

The concrete cubes of 150mm size were cast to test various concrete mixtures for compressive strength. The cubes, after de moulding were stored in curing tanks and on removal of cubes from water at 7 days, 28 days, 90 days the compressive strength test was conducted. The water and grit on the cubes was removed before testing the cubes. The test was carried out as per IS 516:1959.
The specimens, after getting them ready for the test were placed in such a manner that the load is applied on the opposite sides of the specimen as cast. The axis of specimens was aligned with the center of the spherically seated plates. The load was applied gradually without shock under 140 kg/cm2/minute rate of loading until load breaks and no greater load was sustained. This maximum load was noted down.
The compressive strength was calculated by dividing the maximum load by the cross sectional area of the specimen/cube. Three identical specimens were tested in each case and the average of the three values was considered as the compressive strength of specimen.

<u>3.9.2 Split Tensile strength Test</u>

The split tensile strength of all the concrete mixtures in the present study was determined by using the method prescribed by IS 5816:1999. The cylindrical concrete specimens of 150 mm diameter and 300 mm length were cast after curing them for 7 days, 28 days, 90 days. The split tensile strength was conducted on the specimens. The specimens were tested in a compression testing machine by applying loading on the longitudinal direction of specimens. The load was applied gradually (without shock) and the maximum load (at which the specimen splits into two) was noted. Three identical specimens were tested in each case and the average maximum load was considered for computing the split tensile strength.

The split tensile strength (f_t) is calculated from the expression

$$f_t = \frac{2P}{\prod DL}$$

Where ft = splitting tensile strength (MPa)
P = maximum applied load (Newtons)
D = diameter of the specimen (mm)
L = Length of the specimen (mm)

3.9.3 Flexural Strength Test Of Concrete

The flexural strength of all the concrete mixtures in the present study was determined by using the method prescribed by IS 516:1959. The Rectangular concrete beams of 150 mm x 150 mm x750 mm were cast after curing them for 7 days, 28 days, 90 days. The Flexural strength was conducted on the specimens.

Table: Number of specimens tested for the present investigation

S. No	Grade of Concrete	No. of specimens for Compression Test			No. of specimens for Split Tensile Test			No.of specimens for Flexural strength		
		7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
1	M30	30	30	30	15	15	15	15	15	15
2	M40	30	30	30	18	18	18	18	18	18
Total		60	60	60	33	33	33	33	33	33
Total		Cubes 180			Cylinders 99			Beams 99		

IV.RESULTS

Compressive strength Results

Table: Compressive strength of Cement Concrete cubes (M30) at different ages made with partial replacement of silica fume

Grade of concrete	Cement+ Admixture	Compressive strength in N/mm2		
		7 days	28 days	90 days
M30	100% OPC	19	31.73	38.1
	5% SF	20.1	32.04	41.8
	10% SF	22.2	34.6	44.3
	15% SF	21.9	34.2	42.1
	20% SF	21.6	33	41.2

Fig 4.9: Variation of Compressive Strength of Cement Concrete Cubes (M30) at different ages made with partial replacement of Silica fume

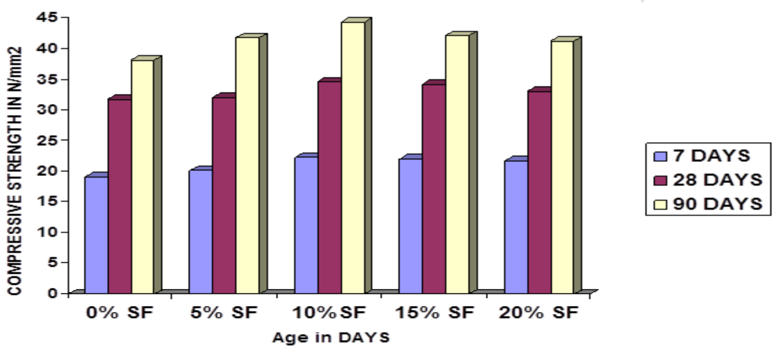


Table: Compressive strength of Cement Concrete cubes (M40) at different ages made with partial replacement of silica fume

Grade of concrete	Cement +Admixture	Compressive strength in N/mm2		
		7 DAYS	28 DAYS	90 DAYS
M40	100% OPC	29	42.8	46.9
	5% SF	30.5	44	49

	10% SF	33	48.9	52.5
	15% SF	32.3	48.5	50.2
	20% SF	29.8	45.03	47.45

Fig 4.10 Variation of Compressive Strength of Cement Concrete Cubes (M40) at different ages made with partial replacement of Silica fume

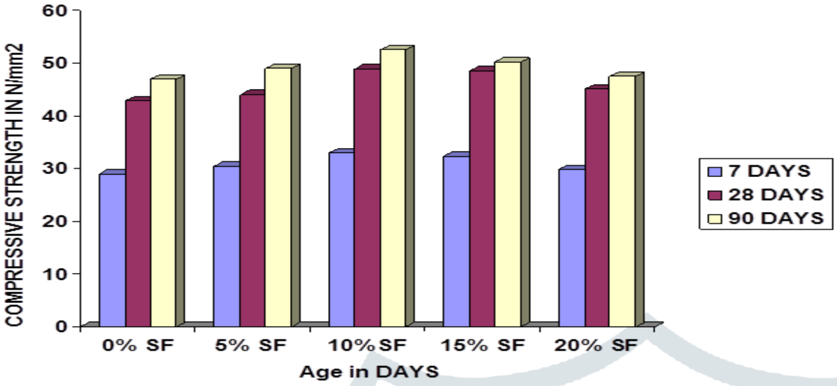


Table: Compressive strength of Cement Concrete cubes (M30) at different ages made with partial replacement of GGBS

Grade of concrete	Cement +Admixture	Compressive strength in N/mm2		
		7 DAYS	28 DAYS	90 DAYS
M30	100% OPC	19	31.73	38.1
	10% GGBS	22	35.09	43.22
	20% GGBS	22	35.05	44.28
	30% GGBS	26	41.02	50
	40% GGBS	24.54	39.46	45.3
	50% GGBS	23.40	38.98	46.51

Fig:4.21 Variation of Compressive Strength of Cement Concrete Cubes (M30) at different ages made with partial replacement of GGBS

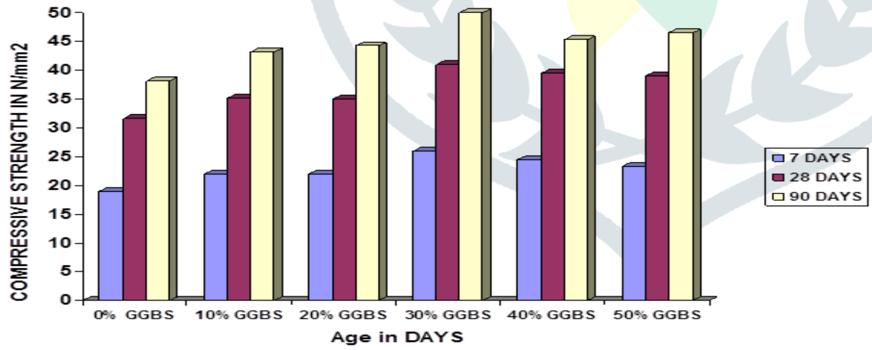
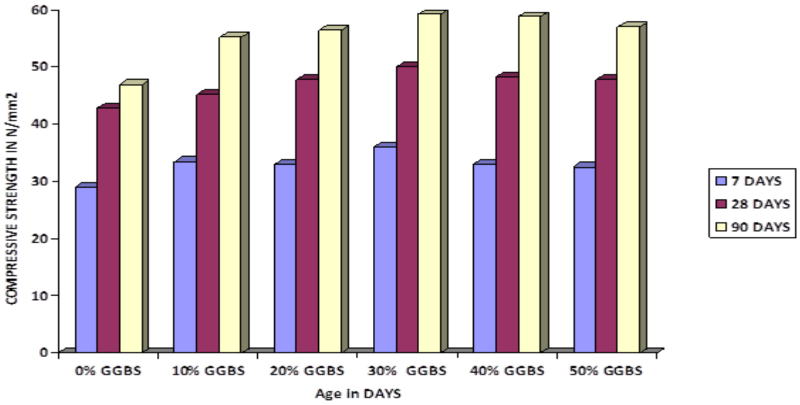


Table: Compressive strength of Cement Concrete cubes (M40) at different ages made with partial replacement of GGBS

Grade of concrete	Cement +Admixture	Compressive strength in N/mm2		
		7 DAYS	28 DAYS	90 DAYS
M40	100% OPC	29	42.8	46.9
	10% GGBS	33.5	45.23	55.12
	20% GGBS	33	47.8	56.4
	30% GGBS	36	50	59.3
	40% GGBS	33	48.2	58.9
	50% GGBS	32.5	47.8	57.1

Fig 4.22: Variation of Compressive Strength of Cement Concrete Cubes (M40) at different ages made with partial replacement of GGBS



Split tensile strength Results

Table: Split Tensile strength of Cement Concrete cylinders (M30) at different ages made with partial replacement of Silica Fume

Grade of concrete	Cement+ Admixture	Split Tensile strength (Mpa)			Percent change in Split tensile strength		
		7 day	28 day	90 day	7 day	28 day	90 day
M 30	100 % OPC	2.52	3.0	3.5	0	0	0
	5 % SF	2.65	3.63	4.05	5.16	21	15.7
	10% SF	3.18	4.09	4.27	26.19	36.33	22
	15% SF	3.15	3.98	4.21	25	32.67	20.29
	20% SF	2.93	3.82	4.02	16.27	27.33	14.86

Fig:4.23 Variation of Split Tensile strength of Cement Concrete cubes (M30) at different ages made with partial replacement of Silica fume

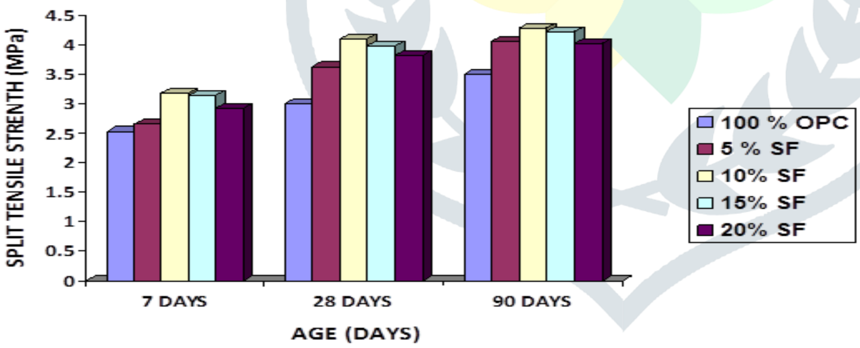
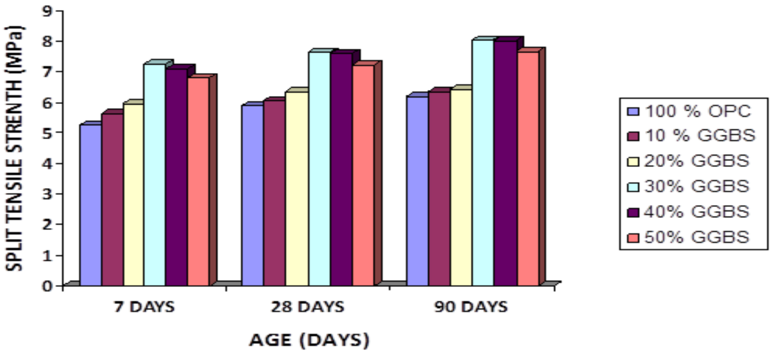


Table: Split Tensile strength of Cement Concrete Cylinders (M40) at different ages made With partial replacement of GGBS

Grade of concrete	Cement+ Admixture	Split Tensile strength (Mpa)			Percent change in Split tensile strength		
		7 day	28 day	90 day	7 day	28 day	90 day
M 40	100 % OPC	5.23	5.9	6.2	0	0	0
	10 % GGBS	5.6	6.05	6.35	7.07	2.54	2.42
	20% GGBS	5.96	6.35	6.43	13.96	7.63	3.71
	30% GGBS	7.25	7.63	8.03	38.62	29.32	29.52
	40% GGBS	7.1	7.6	8	35.76	28.8	29.03
	50% GGBS	6.8	7.23	7.65	30.0	22.54	23.39

Fig 4.24 Variation of Split Tensile strength of Cement Concrete cubes (M40) at different ages made with partial replacement of GGBS



Flexural strength Results

Table: Flexural strength of Cement Concrete beams (M30) at different ages made with partial replacement of Silica fume

Grade of concrete	Cement+ Admixture	Flexural strength (Mpa)			Percent change in Split tensile strength		
		7 day	28 day	90 day	7 day	28 day	90 day
M 30	100 % OPC	3.9	4.5	4.91	0	0	0
	5 % SF	5.15	6.8	7.9	32.05	51.1	60.89
	10% SF	6.06	7.96	8.3	55.38	76.89	69.04
	15% SF	5.92	7.3	8.1	51.79	62.22	64.96
	20% SF	5.5	6.5	7.65	41.02	44.44	55.80

Fig:4.25 Variation of Flextural strength of Cement Concrete cubes (M30) at different ages made with partial replacement of Silica fume

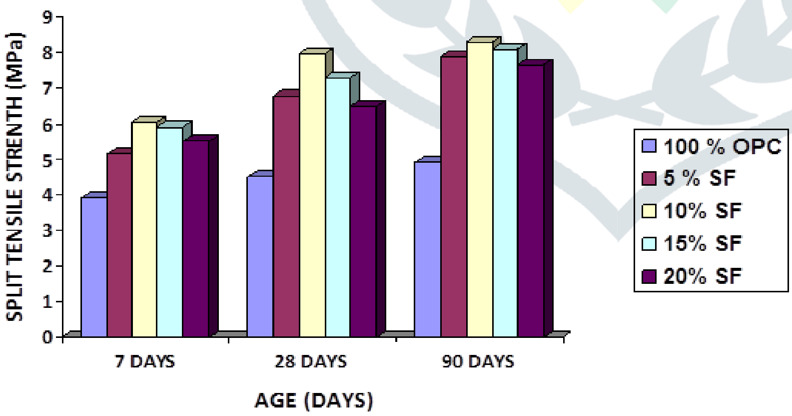
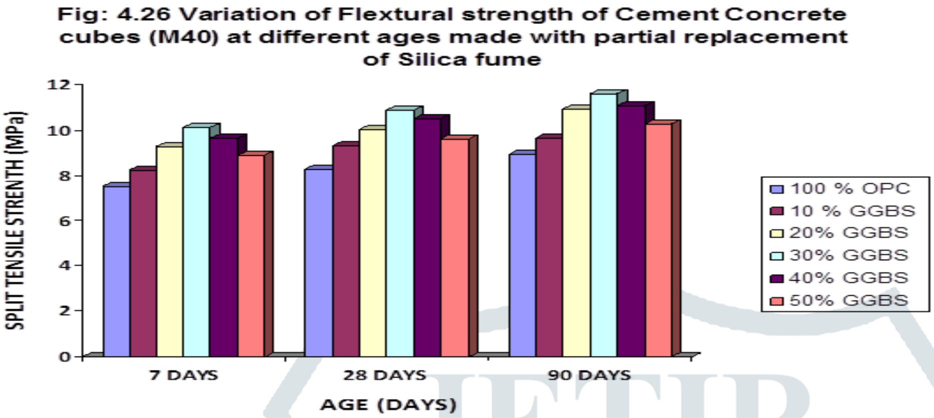


Table:Flexural strength of Cement Concrete beams (M40) at different ages made with partial replacement of GGBS

Grade of concrete	Cement+ Admixture	Flexural strength (Mpa)			Percent change in Split tensile strength		
		7 day	28 day	90 day	7 day	28 day	90 day
M 40	100 % OPC	7.5	8.3	8.96	0	0	0
	10 % GGBS	8.25	9.32	9.63	10	12.29	7.48

	20% GGBS	9.26	10.03	10.94	23.47	20.84	22.10
	30% GGBS	10.12	10.9	11.6	34.93	31.33	29.46
	40% GGBS	9.65	10.5	11.06	28.67	26.51	23.44
	50% GGBS	8.87	9.6	10.25	18.27	15.66	14.40



V. CONCLUSIONS

Based on the detailed investigations performed the following concluding remarks are drawn

Compressive strength

- Compressive strength at different ages (7 days, 28 days, 90 days) of M30, M40 grade concretes produced with the replacement of cement by 10% silica fume is giving higher strengths compared to other percentages(0%, 5%, 15%, 20%).

- Compressive strength at different ages (7 days, 28 days, 90 days) of M30, M40 grade concretes produced with the replacement of cement by 30% GGBS is giving higher strengths compared to other percentages(0%, 10%, 20%, 40%, 50%).

Split Tensile strength

- Split Tensile strength at different ages (7 days, 28 days, 90 days) of M30 grade concretes produced with the replacement of cement by **10% silica fume** is giving higher strengths compared to other percentages(0%, 5%, 15%, 20%).

- Split Tensile strength at different ages (7 days, 28 days, 90 days) of M40 grade concretes produced with the replacement of cement by **30% GGBS** is giving higher strengths compared to other percentages(0%, 10%, 20%, 40%, 50%).

Flexural strength

- Flexural strength at different ages (7 days, 28 days, 90 days) of M30 grade concretes produced with the replacement of cement by **10% silica fume** is giving higher strengths compared to other percentages (0%, 5%, 15%, 20%).

- Flexural strength at different ages (7 days, 28 days, 90 days) of M40 grade concretes produced with the replacement of cement by **30% GGBS** is giving higher strengths compared to other percentages(0%, 10%, 20%, 40%, 50%)

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