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Experimental Investigation on Mechanical Properties of High-Performance Concrete with Supplementary Cementitious Materials

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Abstract
High-Performance Concrete (HPC) does have preferable mechanical characteristics and performance relative to that of the standard concrete strength and ability. Even so, the massive requirement for cement, the tremendous ecological influence, and the preliminary expense were considered downsides, which constrain its broader implementation. The integration of Supplementary Cementitious Materials (SCMs) into HPC is indeed an appropriate means for minimizing the quantity of cement required whereas bringing attention to sustainable development as well as expense. The contemporary experimental analysis was conducted to investigate the flexural behavior of Grade M60 HPC by cement substitution incorporating Fly Ash (FA) as well as Silica Fume (SF) with a view to responding to such aforementioned concerns. In addition, specimens are generated to estimate the compressive strength of HPC with these SCMs. Fly ash and Silica Fume substitutes range between 10 to 30 percent. The grade M60 concrete for the HPC mix is engineered according to the BIS specification. The mixture composition was achieved on the basis of the varying testing combinations by adjusting the SCM concentration. Concrete workability was accomplished by adjusting the exact dosage of the superplasticizer. The fresh-state and hardened characteristics of HPC are evaluated using the analysis of a number of experiments, including workability, compressive strength, split tensile strength, and flexural strength tests conducted in the research lab. Apart from that, dealing with mix development as well as hardness characteristics, the durability characteristics of HPC is furthermore evaluated including the analysis of a water permeability and chloride ions penetration test performed in the lab. The analysis revealed that SCM substitution displayed better mechanical characteristics relative to the control specimens. Efforts have been done to also contrast the compressive strength of 7, 14 and 28 days cured specimens, the split tensile and the flexural strength of the concrete sustaining the water-cement proportion to 0.3.

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I. INTRODUCTION

In terms of its durability, structural integrity as well as economic concerns, Concrete is perhaps the most extensively employed construction product globally. However, the standard concrete is lacking its applications in due course and is being supplemented eventually by high-performance concrete. High-performance concrete (HPC) is a product that achieves specific configurations of durability and homogeneity criteria that can not necessarily be accomplished with traditional materials and conventional mixing and positioning and curing activities on a constant basis. It is the most significant component in the construction field. The efficiency is perfect in durability and also regarding the characteristics of fresh concrete as well as the mechanical strength of concrete. Recently, almost all research is underway to enhance the properties of concrete as

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regards durability, performance, and overall quality as structural components. The requirement for HPC is to fulfill specific purposes including longevity, stiffness modulus, and tensile strength. Superplasticizers are often employed to manufacture HPC with standard components as well as using mineral admixtures such as SF, FA and metakaolin to maximize durability besides flowability, and to reduce concrete's water-binder proportion in fresh condition. Mineral admixture enhances strength in the concrete. The cost of concrete would be minimized by reducing the cement volume, thereby contributing to the utilization of ecologically alternate resources in its processing. The CO2 intensity polluting the environment is controlled attributed to the reduction of the cement volume and this contributes to an eco-friendly approach. Some of the major implementations of high-performance concrete were frameworks providing a prolonged operational lifetime including long-span bridge structures, high towering structures, dams, tunnels, etc. High-performance concrete allows strengthened and prestressed structural trusses to function longer in roadway bridges, as well as improved independent truss capabilities owing to the usage for HPC lead to a reduction in the number of steel beams expected.

Supplementary cementitious materials including FA, blast-furnace slag (BFS), and SF remain by-products of the industries that have been commonly employed for multiple purposes in concrete (Juenger and Siddique, 2015). While considerable analysis of this area has been accomplished, there is still enough provision for deeper investigations. FA, an industrial waste by-product, often emerged effectively for overcoming the problems of limiting industrial waste and renewable development. The usage level, however, remains under 50 percent (Zhang et al., 2015). While to resolve the issue of FA's pozzolanic process retardation, SF inclusion is expected to accelerate the pozzolanic reaction through a premature phase as SF fundamental particles help to fill the pores within wider cement material, sand, and certain fillers. Several researchers also carried out analyses to model the characteristics of concrete that is self-compacting, standard as well as high-performance concrete (HPC). (Mousavi et al., 2012) estimated compressive strength for HPC utilizing computing for a genetic interpretation. (Erdal, 2013) implemented the HPC strength prediction Decision graphs.

II. LITERATURE REVIEW

The HPC created with silica and calcium carbonate mixture aggregate demonstrates (Xing et al., 2011) that by adopting silica aggregate reports of improved performance in elevated-temperature concrete than utilizing calcareous aggregate with respect to compressive strength. Comparable interaction for the tensile strength has been exhibited. Furthermore, the authors conclude that the existence of the aggregate appears to provide a little effect on the development of the high-temperature elasticity modulus. Some of the key distinctions among traditional concrete and HPC, despite the concrete formulation, are the greater binder composition and the greater utilization of supplementary cemented materials in the latter case. All factors, and the lower water/binder proportion generally utilized, encourage the persistence yet while aging of a considerable amount of anhydrous stages. Furthermore, fibers are also widely used in HPC. Of such context, irregular and arbitrarily generated fiber reinforcing in a concrete framework will completely regulate the fracture development and thus offer adequate assistance for a certain type of self-healing process as it is assumed that narrow cracking will be repaired easier (Snoeck and De Belie, 2015).

(Muthukumar and Sirajudeen, 2016), conducted an empirical analysis on high-performance concrete considering the proportion of M50 grade mixes. High-performance concrete accomplished mostly by, 100% substitute of the fine aggregate by crusher rinse gravel and selective substitution of cement by micro silica by 5, 10, 15, 20 and 25 percent.

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Glenium b233 was introduced to the concrete mix for workability. Data collected from the analysis was evaluated and contrasted with a reference specimen. Effect evidence specifically indicates a 7- and 28-day percentage improvement in compressive strength, tensile strength and flexural strength for concrete grade M-50. In this experimental procedure, the application of micro silica, crusher washed sands and superplasticizer represents a fundamental growth in compressive in addition to tensile properties. Cement was substituted by 20 percent with micro silica, but strength improved by 16.5 percent. The endurance of the HPC is attainable through the application of micro silica.

III. MATERIAL AND METHODS

Ordinary Portland cement 53 grade referring to IS 12269 – 1987 is applied with a specific gravity of 3.18 and a fineness density of 10 percent providing the initial and final settlement time of 34 minutes and 260 minutes respective. Locally available river sand supporting IS 383 -1970 grading zone II has been used as fine aggregates collected via a sieve of dimension 4.73mm having a specific gravity of 2.7 and 3.91 fineness module. Coarse aggregate supporting to standardized average size aggregate 12 mm according to IS 383 -1970 with a specific gravity of 2.75 and water retention of 0.5 percent has been used. For improved workability for high-performance concrete, Conplast SP430-Sulphonated Naphthalene Polymers has been used as a superplasticizer. Fly ash contains significant quantities of silicon dioxide (SiO_2) with a specific density of 2.3 metric tons every cubic meter and a density of 1.0 metric tons for every cubic meter. The silica fume employed verified the ASTM-C (1240-2000), which has a specific mechanism to fly ash, is extremely helpful in lowering the water-to-cement proportion expected for practical concrete in combination with superplasticizers. In particular, the specific gravity of silica fume is on the scale of 2.2 to 2.3. Silica fume is an ultrafine substance with circular particles fewer than 1 μm in diameter and size of almost 0.15 μm.

Concrete 150 mm cubes were cast and evaluated according to IS: 516 – 1959 at 7, 14, and 28 days and average compressive strength is recorded. Concrete cylinders with a diameter of 150 mm and a height of 300 mm were cast and examined according to the IS: 5816-1999 and maximum split tensile strength is documented. Concrete beams of 500x700 mm size have been cast and evaluated according to IS: 516-1959 and an average flexural strength is recorded.

IV. MIX PROPORTION

The concrete mix was developed at the curing age of 28 days for compressive strength of 60 MPa, as recommended by the BIS 10262: 2009 code. By modifying the water – binder ratio and superplasticizer dose, the workability of the fresh concrete was determined dependent on the different sample mixes. The water-binding proportion was set at 0.3 and the superplasticizer dose was set at 1.5%. In addition, the cement was substituted by two separate mineral admixtures of fly ash and silica fume. The amount of replacement varies with the weight of cement from 0 to 30 percent. As there are no particular procedures for developing acceptable standards for HPC mix, a generalized technique concerning structural blend composition including the relevant documentation for HPC is implemented utilizing the BIS approach as shown in Table 1.

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Table 1: Mix Proportion of Concrete specimen

MIX	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (liters)	Super Plasticizer (%)	FA (BY %OF CEMENT)	SF (BY%OF CEMENT)
Control	620	550	1135	186	1.5	0	0
M1	620	550	1135	186	1.5	10	2.5
M2	620	550	1135	186	1.5	20	5-
M3	620	550	1135	186	1.5	30	10
M4	620	550	1135	186	1.5	30	15

V. RESULTS AND DISCUSSION

The fresh concrete workability is established by incorporating slump outcomes as shown in table 2. The samples were molded and cured to test concrete's endurance and durability attributes.

Table 2: Test result for workability

MIX	Slump(mm)	Compaction factor
Control	60	0.92
M1	56	0.87
M2	58	0.89
M3	59	0.91
M4	57	0.90

Table 3: Hardened state test result

MIX ID	Compressive Strength (MPa)			Split Tensile Strength (MPa)	Flexural Strength (MPa)
	7 Days	14 Days	28 Days	28 Days	28 Days
Control	36.5	45	66.9	4.923	5.207
M1	29.5	40	61.2	4.817	4.793
M2	33.7	43.1	63.5	4.843	4.821
M3	36	44.8	66.4	4.910	5.153
M4	32.7	42.1	65.3	4.895	4.983

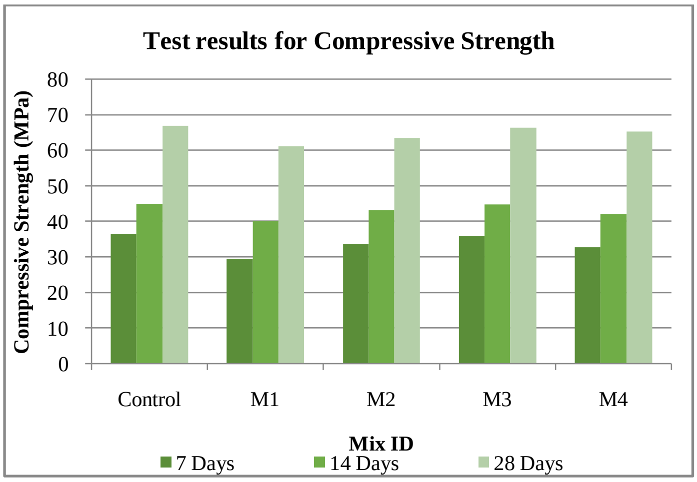

Figure 1: Compressive strength test result

At 7, 14 and 28 days of age, all samples have been tested to evaluate the compressive strength, split tensile strength, and flexural strength of the concrete as shown in table 3. Concrete durability was tested by performing the permeability and chloride penetration tests in labs. For the above test of concrete grade M60 for FA and SF respectively, the optimal level of cement substitution is 30 per percent and 10 percent. This might be attributable to the perception that it is owing to the pozzolan response and replacement consequences of SCMs that the endurance characteristics decline. Consequently, the analysis indicates that the substitution of the FA 30 percent and SF 10 percent

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would be ideal for better results in order to achieve an optimum structural life span.

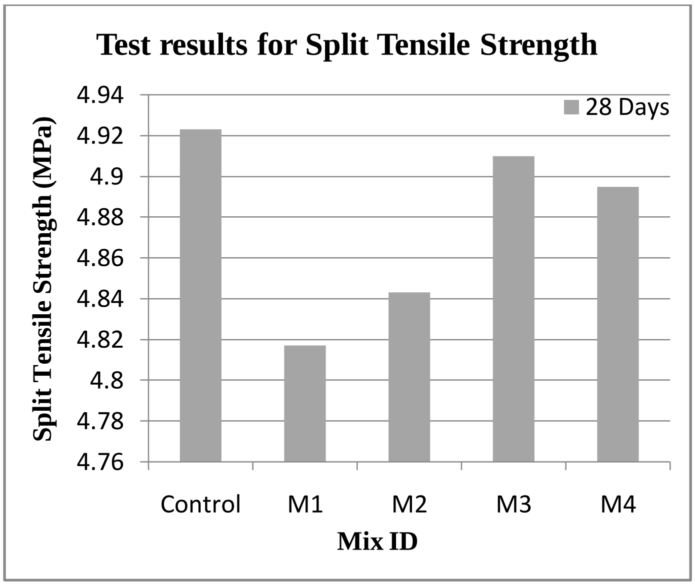

Figure 2: Split tensile strength test result for 28 days

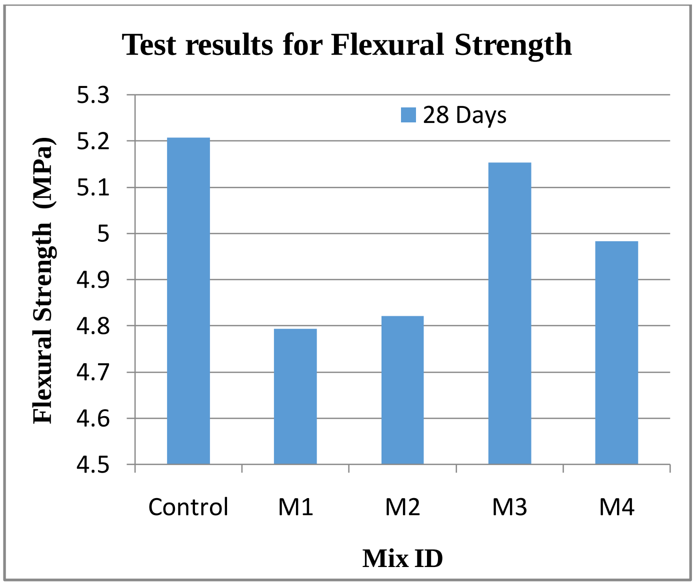

Figure 3: Flexural strength test result for 28 days

Table 4 displays the effects of the water permeability check. For the Rapid Chloride Permeability Test (RCPT), 1374 coulombs and 591 coulombs were chloride penetration in reference mix and other sample mix selected randomly from the group. Particularly in comparison to these mixtures, the chloride penetration in concrete is quite minimal by cement substitutions using SF 591 coulombs signifying less concrete's permeability according to the standards. Importantly, the presence of FA and SF obviously lowers concrete pores and renders the concrete impenetrable.

Table 4: Water permeability test

Mix	Permeability of water (cm)	Average (cm)
Control	4.6	4.6
M1	4	4.2
M2	4.1	
M3	4.5	
M4	4.3	

VI. CONCLUSION

Mostly from the experimental analysis on high-performance concrete utilizing SCMs, it is inferred that HPC with 30 percent FA and SF with a proportion of 10 percent have achieved superior strength in all dimensions of strength including compressive, tensile, and flexural relative towards other mixture designs. As the curing duration increases the compressive strength tends to increase. Concrete's compression failure pattern is attributable mostly to the crippling of the coarse rough aggregate and is not so of the link degradation. The results of the durability test display rather little penetration intensity for water permeability test and a medium to quite low RCPT range. Replacing cement with silica fume up to 10 percent leads to increased strength, values for both grades of M60. There is a decline in compressive strength, tensile strength and flexural strength over a curing duration of 28 days above 10 percent. As the level of replacement increases, there is a reduction in workability and therefore water ingestion would be greater for larger substitutes. The use of fly ash and silica particles provides remarkable outcomes in concrete properties.

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