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Strength and Durability Properties of High Performance Steel Fiber Reinforced Concrete

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A B S T R A C T

Use of fiber in concrete has acquired more popularity in the last ten years. Researchers have shown that by adding steel fibers with smaller diameter in concrete mix, the brittle behavior of HSC/HPC can be eliminated. The use of super plasticizer and cementing materials like silica fume & GGBS having a pozzolanic reaction and filler effect will develop the interface of the materials, and improves the strength of the concrete which will lead to economical HPC with improved durability. In the present experimental investigation, High Performance Concrete of grade M60 is studied by using 10% silica fume & 30% GGBS as replacement by weight of cement and with varying steel fibers by volume of concrete. Natural sand is completely replaced by M-sand. Steel fibers having aspect ratio of 50 are used. The proportion of steel fibers is varying in range 0.5%, 1%, 1.5%, 2.0% by total volume of concrete. The strength properties such as compression, split tensile, flexural, and durability properties such as water absorption, sorptivity, acid resistance are studied. The results showed that 10% of silica fume and 30% GGBS as replacement to cement, natural sand is replaced 100% with M-sand and with 1.5% of steel fiber to the HPC gives the good strength and durability properties of the concrete.

I. INTRODUCTION

In today's concrete industry, the most important challenge to deal with is achieving residential and infrastructure requirements of the society in sustained manner. The major reasons among sustainability can be summarized as: climate vary in many regions of the world, intense weather patterns that are happening with higher frequencies. According to scientists, this phenomenon is due to high range of emission of green-house gases like carbon dioxide (CO2) etc. The two industries which produces huge amount of CO2 in the world are the Portland cement and the transportation industry.

Concrete industry consumes more range of raw materials like sand, gravel, crushed rocks and fresh water. At an annual rate of 1.6 billion metric tons of Portland cement and modified Portland cement is being consumed by concrete industry. Large amount of clay and limestone is consumed during production of cement.

Evidently, when the structures deteriorate large amount of energy, materials, along with financial resources will be wasted. In general, the concrete structures will be designed in such a way that its service life should be around 50 years. The structures with the service life of around 100 years are being designed with the help of HPC mixtures. With this background and by the use of energy and materials will give best result in resource productivity that's declared by economists, business people, and scientists around the world.

Concrete is one of the most important items among the materials in all types of civil engineering works. Since the adoption of concrete as a building material lot of researches and studies have been made to improve the quality strength and durability of concrete by the same time efforts are also being made to economize concrete construction compared to other materials .

Recycling of waste products leads to a cost-effective method. It is usually done by partial replacement for the aggregates in fresh concrete mixtures and cement replacement materials like 15% to 20% fly ash or 30 %to 40% slag by weight etc. by the construction industry.

To produce high performance concrete suitable admixtures are added as cementitious material with conventional materials and technology.

II. LITERATURE REVIEW

- Sravani et. al., (2015). An attempt has made to study about the effect of silica fume, GGBS and steel fibers on mechanical properties of High Performance Concrete due.

  A. The paper concluded that

  B. The compressive strength of M70 high grade concrete is increased 2.64%, when 10% of cement was replaced by silica fume in by weight.

C. The failure of ordinary concrete and silica fume concrete is sudden, by the addition of steel fibers the failure is transformed from sudden failure to gradual failure.

D. The compressive strength of M70 grade high strength concrete gradually increases up to 0.75% addition of fibers by volume. Further the addition of steel fibers with 10% replacement of cement by micro silica gradually reduces the compressive strength.

- Ramesh et. al., (2015)

In this experimental study High Strength Concrete Mixes of grade M60 were made and investigated on its strength parameters. The paper concluded that Preparation of trial mix and test the compressive strength at 7 days will give the actual idea about the mix proportion. Increase the percentage of silica fume 5 % gives the target strength 60.92 N/mm2. Finally replacement of cement with silica fume 5 % showed good result in compression strength test.

- P D. Kumbhar et. al., (2014).

An attempt is made to investigate a new mix design procedure for HPC, the paper concludes that,

A. For tropical climatic conditions due to huge variations in relative humidity and temperatures the existing mix design methods of HPC is widely not applicable prevailing in different regions of tropical countries.

B. Various parameters are involved in the mix design process are not mentioned in the existing methods and are generally left to the judgment of designer.

C. The mix design is based on parameters like w/c ratio, ambient relative humidity and temperature, desirable contents of various ingredients, coarse to fine aggregate ratio suitable for tropical climatic conditions etc.

D. The mix design is based on parameters like w/c ratio, ambient relative humidity and temperature, desirable contents of various ingredients, coarse to fine aggregate ratio suitable for tropical climatic conditions etc.

- V Priyadharshini et. al., (2014).

In this experimental study an attempt is made to study High Performance Concrete using Quarry dust as Fine aggregate. The paper concluded that when adding 0.5% and 1% of fiber content compressive strength and tensile strength of the mix will increase. When 1.5% of steel fiber was added strength decreased because of accumulation of fiber. When adding more fiber in concrete, bonding between the fibers will increase and accumulation of fiber will occur called as balling effect. From the experimental investigation it was found that the optimum fiber content is 1%.

- R Vijayasarathi et. al., (2014)

In this study strength and durability aspects were studied of GGBS based HPC. The paper concluded that compressive strength was observed to be 56.4 to 61.5 Mpa for 28 days and 67.9 to 72 Mpa and lowest value belonged to GGBS of 60% and 50% GGBS is optimum.

III. RESEARCH SIGNIFIGANCE

In the present experimental investigation, High Performance Concrete of grade M60 is studied by using 10% silica fume & 30% GGBS as replacement by weight of cement and with varying steel fibers by volume of concrete. Natural sand is completely replaced by M-sand. Steel fibers having aspect ratio of 50 are used. The proportion of steel fibers is varying in range 0.5%, 1%, 1.5%, 2.0% by total volume of concrete. The strength properties such as compression, split tensile, flexural, and durability properties such as water absorption, Sorptivity, acid resistance are studied.

IV. EXPERIMENTAL PROGRAM

In the present experimental investigation, High Performance Concrete of grade M60 is studied by using 10% silica fume & 30% GGBS as replacement by weight of cement and with varying steel fibers by volume of concrete. Natural sand is completely replaced by M-sand. Steel fibers having aspect ratio of 50 are used. The proportion of steel fibers is varying in range 0.5%, 1%, 1.5%, 2.0% by total volume of concrete. The strength properties such as compression, split tensile, flexural, and durability properties such as water absorption, Sorptivity, acid resistance are studied.

V. MATERIALS USED

Cement

The cement is tested and the test results are shown in Table below. The OPC 53 grade Birla super cement is used in this investigation.

TABLE 1. PHYSICAL PROPERTIES OF ORDINARY PORTLAND CEMENT

Properties	**Results**	**Requirements as per IS**
Specific gravity	3.16	3.15
Normal consistency	33%	IS 12269-1987
Initial setting time	45min	Not less than 30 min as per IS 12269-1987
Final setting time	260min	Not less than 600 min as IS 12269-1987

The different tests are conducted on fine aggregate (M-sand) and the results obtained are tabulated in table 2 and 3. The tests are conducted as per IS: 2386, 1963.The M-sand was conforming to zone-II requirement.

TABLE2. TESTS ON FINE AGGREGATE (M-SAND)

Properties	**Results**
Specific gravity	2.66
Fineness modulus	2.82
Water absorption	0.76%

Coarse Aggregate

In this investigation we have used 12.5mm down size for coarse aggregates and they are tested as per IS 2386. The results are shown in table below:

TABLE 3. TESTS ON COARSE AGGREGATE

Property	**Results**
Specific Gravity	2.65
Fineness Modulus	2.946
Water Absorption	0.39%

Water

Ordinary potable tap water has been used for mixing and curing the concrete specimen at the site.

Ground Granulated Blast Furnace Slag (GGBS)

GGBS is mineral admixture is used as partial replacement of cement in the concrete to reduce the cost of mix, to improve the workability of the fresh concrete mix, and to increase the strength and durability of the concrete. It acts as pozzolanic material in the concrete. It is broadly used in Europe countries and next in United States and in Asia. Ground granulated blast Furness slag is collected from Bharath RMC Hoskote, Bengaluru. The specific gravity of GGBS is 2.68.

Silica Fume

- Micro Silica is a non-crystalline polymorph of Sio2, silica.
- It is an ultrafine by-product of the silicon and ferrosilicon alloy production and having average particle diameter of 150 nm in spherical shape.
- This average size of particle about 0.15µm and it is nearly 100 times smaller than the particle size of cement.
- It acts as a pozzolanic material in high performance concrete.
- The specific gravity of silica fume is generally in the range of 2.2 to 2.3.
- Silica fume is collected from Kengeri Industrial Area, Bengaluru.
- The specific gravity is 2.21.

Steel Fiber

Steel fiber is used to increase the tensile property of the concrete. When the fiber reinforcement is in the form of short discrete fibrous they act effectively as rigid inclusions in the concrete matrix. Here, the crimped type of steel fiber are used and having its aspect ratio 50 (i.e. l/d=25/0.5).

Superplasticizer

The superplasticizer utilized is Conplast SP430. It is manufactured by BASF development chemical India Pvt. Ltd, Mumbai. The item has been basically created for high performance concrete where the most durability and performance is needed.

To give magnificent speeding up of quality addition at early ages and real increments in quality at all ages by essentially decreasing water is a request in a concrete mix. Especially appropriate for precast concrete and other high early strengths prerequisites. It helps in reduction of permeability of concrete and improves durability by increasing ultimate strengths.

VI. DETAILS OF MIX PROPORTION

Materials Required	**Weight kg/m^3**
Cement	325.05
GGBS	162.52
Silica Fumes	54.175
Total Powder Content	541075
Fine Aggregate	716
Coarse Aggregate	1043.6
Water In Litres	147.75
Water Cement ratio	0.3
Superplasticizer in %	0.8

VII. REULTS AND DISCUSSIONS

Compressive Strength

The compressive strength of different mixes, such as CC, HPC, HPC 0.5F, HPC 1.0F, HPC1.5F & HPC 2.0F are cured & tested at 7, 28 & 56 days are tabulated. The results are shown in figure 1. 150mm cubes are tested in compression testing machine as per IS 516 1975.

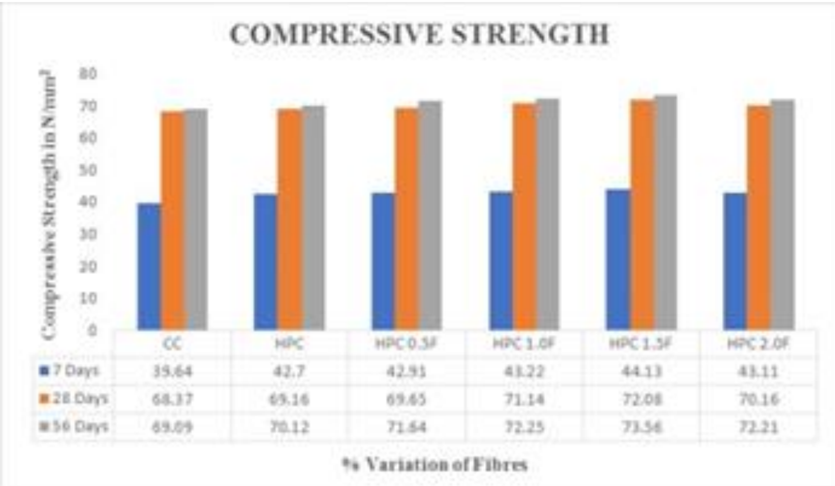

Fig. 1 Variation of Compressive Strength of M60 Grade of Concrete

Observation and Discussion on Compressive Strength

By this experimental study we observed that the compressive strength of concrete varied with the replacement of cement by finer cementitious materials Silica fume, GGBS and with addition of steel fiber in varying percentages. Compressive strength increased for HPC and other mixes with steel fibers. The optimum percentage of steel fibers is 1.5% & the mix HPC 1.5F showed compressive strength of 72.08N/mm2 at 28 days. HPC with 1.5 % of steel fiber after 28 days compressive strength is 5.42% more than conventional concrete. When compared with HPC the optimum mix showed 4.22% increase in strength .For HPC 2.0F, compressive strength decreased compared with 1.5% fibers, but it is more than that of conventional mix. The strength was 70.16N/mm2 for 2% fibers. There is an increase in compressive strength of all mixes at 56 days from 28 days strength showing hydration and pozzolanic action of mineral admixtures. From 7 days to 28 days there is almost 38- 42% increase in strength for all the mixes. Pozzolanic action of admixtures and steel fibers has contributed the strength gain for HPC.

Split Tensile Strength

The of split tensile strength results of normal concrete and HPC (10% of silica fume and 30% of GGBS) and HPC with 0.5-2.0% of steel fiber is determined at 7 days, 28 days & 56 days. Cylinders of size (150×300) mm were tested. The results are shown in figure 2.

Observation and Discussion on Split Tensile Strength

The split tensile strength for conventional concrete was found as 4.18 N/mm2,6.73 N/mm2& 6.78 N/mm2 at 7, 28 & 56 days respectively.HPC mix showed increased strength from CC and the values are 4.58 N/mm2, 6 .88 N/mm2, 6.91 N/mm2 at 7, 28 & 56days .A further increment of strength was observed with the increase of steel fibers. It can be observed that the split tensile strength is more for concrete with 1.5 % of fiber (HPC 1.5F) when compared with split tensile strength of all mixes. HPC with 1.5 % of steel fiber after 28 days tensile strength is 3.92% more than HPC mix without fibers. Introduction of steel fiber to the concrete improved its tensile strength. Split tensile strength was decreased for 2.0% fibers compared with 1.5% fibers. The strength was 6.84N/mm2. The steel fibers having a property of tensile strength that arrest cracks. The combination of mineral admixture and fiber gives a rise in strength while compared to conventional mix.

Fig. 2 Variation of Split Tensile Strength of M60 Grade of Concrete

Flexural Strength

The of Flexural strength test of M60 grade with standard size (100×100×500)mm beams were determined at 28days. The results are shown in 3.

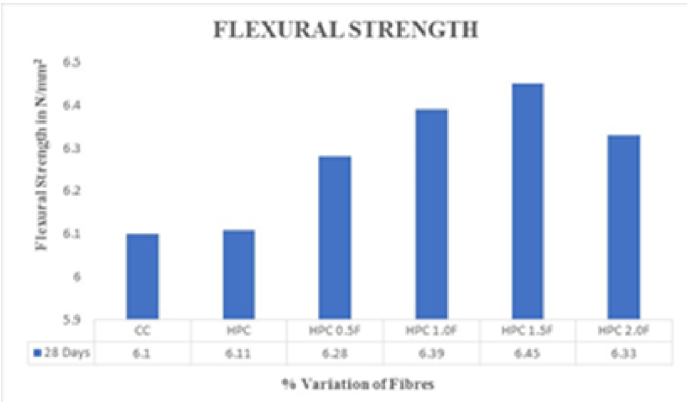

Fig. 3 Variation of Flexural Strength of M60 Grade of Concrete

Observation and Discussion on Flexural Strength

From the experimental study we observed that the flexural strength of concrete mixes, CC, HPC, HPC 0.5F, HPC 1.0F, HPC 1.5F & HPC 2.0F was determined at 28 days. Optimum mix was HPC with 1.5% of steel fiber after 28 days, gave flexural strength 5.56% more than HPC. All mixes with fibers showed strength more than that of non fiber mix. Compared to conventional concrete, the development of cracks was delayed in fiber mix HPC. The fiber improves tensile property of the matrix and arrests development of internal micro-cracks. The fibers interlock and entangle around aggregate particles and act as a crack arrestor restricting the development of cracks.

Water Absorption

Cube specimens are prepared using M60 grade of concrete mix by the use of replacement materials GGBS and Silica fume with incorporation of steel fiber. Specimens of size (150 ×150×150)mm were casted for the test and cured for 28 days. The results are shown in Fig. 4

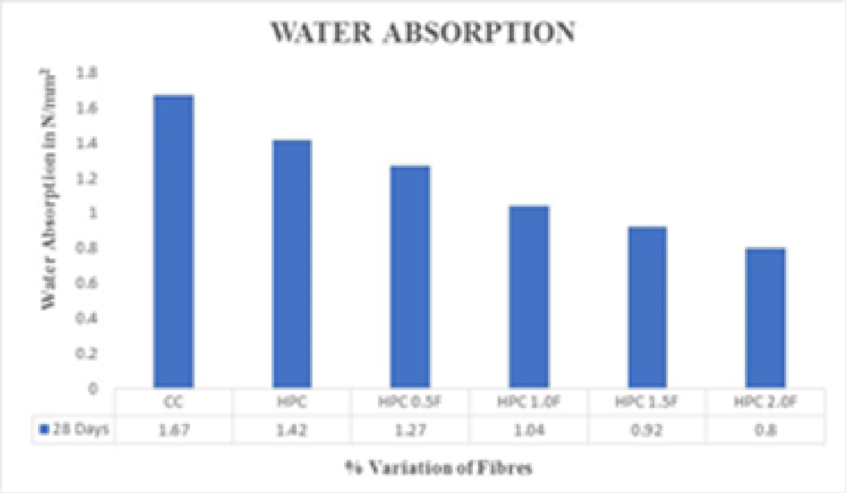

Fig. 4 Variation of Water Absorption of M60 Grade of Concrete

Observation and Discussion on Water Absorption

The water absorption of HPC is reduced 17.6% as compared to conventional concrete due to the addition of silica fume, GGBS in concrete helps in C-S-H reaction. These pozzolanic materials which give better microstructure and reduce porosity of the specimens lead to less absorption of water. It is observed that water absorption gradually decreases as the fiber content increases. Also HPC mix showed better result compared with CC. since, HPC will shows good effect on water absorption due to the dense packing of HPC mix with steel fiber leads to decrease the micro cracks and gives less water absorption.

Sorptivity Test

Cube specimens are prepared using M60 grade of concrete mix by the use of replacement materials GGBS and Silica fume with incorporation of steel fiber. Specimen if size (150 ×150×150)mm were casted for the test. Sorptivity test was done after 28 days of curing and the results are showed in fig. 5.

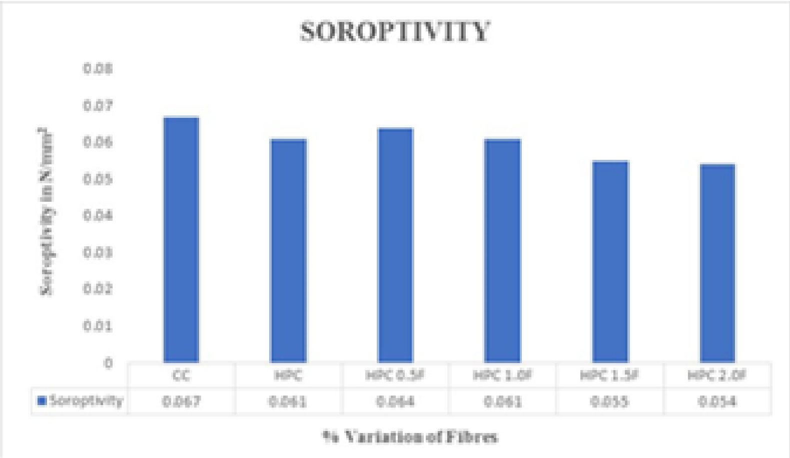

Fig. 5 Variation Sorptivity of M60 Grade of Concrete

Observation and Discussion on Sorptivity

The Sorptivity is depending on the permeability and porosity of the concrete and the strength of capillary forces. Sorptivity is directly proportional to permeability of specimen, the capillary forces and inversely proportional to effective of porosity. The surface moisture in concrete is reduced due to strong micro structure of GGBS and silica fume, GGBS considerably reduces the content of Ca(OH)2 crystals in the aggregate paste interface, which makes the microstructure of transition zone dense and strong. Sorptivity of concrete decreased for HPC and mixes with fibers compared to conventional concrete .This can be due to of presence of fine particle of silica fume and GGBS reduced surface pores thus reducing penetration of water. The presence of fibers might have made concrete matrix reduced in micro cracks thus reduction in Sorptivity. Hence HPC and HPC with fibers showed improved durability properties compared with conventional mix.

Acid Resistance

Cube specimens are prepared using M60 grade of concrete mix by the use of replacement materials GGBS and Silica fume with incorporation of steel fiber. Specimen if size (150 ×150×150) mm were casted for the test. Acid resistance test results were showed in Fig. 6 & 7.

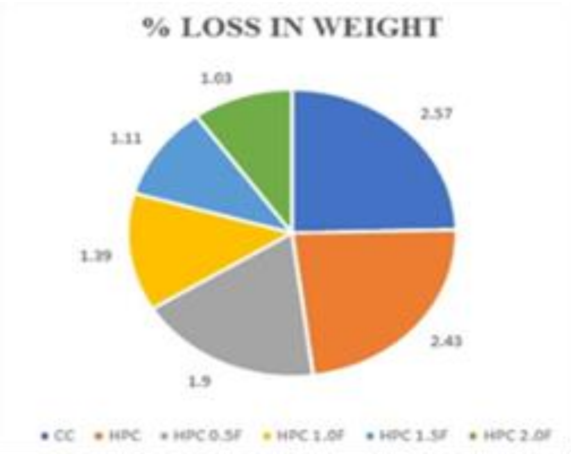

Fig. 6 Percentage loss in Weight for M60 Grade of HPC

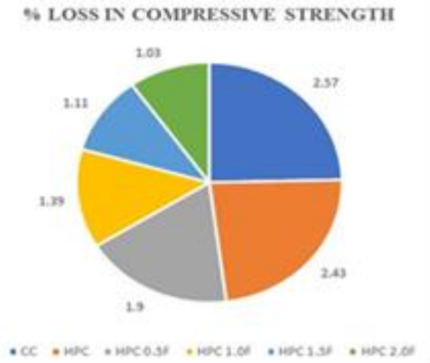

Fig. 7 Percentage loss in Compressive Strength for M60 Grade of HPC

Observations and Discussions on Acid Resistance Test

The loss in compressive strength and loss in weight of HPC were decreased as increase in percentage of steel fiber. Since, addition of silica fume and GGBS gave low permeability which results in good resistance to acid effect. The loss in compressive strength for HPC is 4.45 % less as compared to conventional concrete. And it is decreased as the increment in fiber content 0.5% up to 2.0%. The usage of steel fibers and silica fumes leads to increase in acid resistance of the HPC. This is due to dense packing between the cement paste and aggregates. From the test results it is observed that the loss in weight and loss in compressive strength of concrete was more in conventional concrete, as the steel fiber quantity increases it shows resistance to acid attack which shows good durable property.

VIII. CONCLUSIONS

1. The workability of concrete increases, which depends on silica fume and due to GGBS as partial replacement of cement.

2. As the 100% of replacement of fine aggregate by M-sand can be accepted as the concrete gave good workability, strength and durability, but workability decreases as the addition of steel fiber to the concrete.

3. The compressive strength of HPC increased 1.15% as compared to conventional concrete. The values were 68.37 N/mm2 for CC and 69.16 N/mm2 for HPC at 28 days

4. The introduction of fiber in the concrete reduced cracks in the surface of specimens.

5. As the increase in percentage of steel fiber in HPC shows the increase in compressive strength 1.5% fiber content which was the optimum mix gave 4.22% increase from HPC, after that showed decrease in strength for 2% fiber but more than that of HPC.

6. The compressive strength of HPC increased 0.7% to 4.22% with addition of steel fibers compared to HPC with no fiber.

7. The split tensile strength of high performance concrete increased to 2.22% as compared to conventional concrete.

8. The split tensile is more for HPC with 1.5 % of steel fiber and it is 7.15 N/mm2 that is 3.92% more than HPC at 28 days.

9. Split tensile strength was decreased to 4.53% HPC with 2.0% fibers compared with HPC with 1.5% fibers.

10. The flexural strength of HPC with 1.5% steel fibers is 5.56% as compared to HPC.

11. The flexural strength is increasing as the fiber percentage increases and it is more for 1.5 % of fiber in HPC and decreases for HPC with 2% of fiber.

12. Water absorption is reduced, by effect of silica fume, GGBS and steel fiber.

13. Sorptivity decreases with increase in steel fiber content when compared to CC.

14. Percentage of weight loss reduces as the increase in steel fiber and it shows the concrete is resistant to acid.

15. Introduction of steel fiber in the high performance concrete will increase all its strength and durability properties.

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