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# Effect of Silica Fume and GGBFS on High Performance Concrete

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***Abstract: High Performance Concrete (HPC) is the concrete that attains special performance and uniformity requirements that can't always be achieved by conventional methods and practices. Special performance requirements using conventional materials are often achieved only by adopting low water binder ratio, which necessitate the utilization of high cement content. However the addition of chemical and mineral admixtures will scale back the cement content and this can achieve the economical HPC. The impact of a mineral admixture on the strength of concrete varies considerably with its replacement level sand its properties. Aitcin method was adopted for mix design, based on the combination of empirical method and absolute volume method. The use of mineral admixtures in concrete production improves the compressive strength, pore structure, and permeability of the concrete this is attributed to the pozzolanic reaction. This approach will have the potential to reduce costs, conserve energy, and waste minimization. Use of Ground Granulated Blast Furnace Slag (GGBFS) in producing mortar decreases the porosity and capillary. Thus, improves the durability against water and aggressive solutions. GGBFS replacement of cement in the proportion of 20%, 40%, and 50% and silica fume replacement of cement in the proportion of 5%, 10%, and 15% were done for making concrete of M85 grade. The effect of variation in strength parameters i.e., Compressive Strength and Split Tensile Strength were studied for different GGBFS and silica fume replacement proportions were done. The test results can be observed that higher strength than conventional concrete and almost same compressive strength as conventional concrete.***
***Keywords: HPC, GGBFS, Replacement of Cement, Strength Comparison.***

## I. INTRODUCTION

High performance concrete (HPC) is a new class of concrete that has been developed in recent decades. When compared with conventional cement concrete (CCC).HPC tends to have very low water content and can achieve sufficient rheological properties through a combination of optimized granular packing and the addition of high-range water reducing admixtures. High performance concrete (HPC) is not fundamentally different from the concrete that we have been using all along, as it neither contain any new ingredients nor involve new practices on site. But because of lower w/c ratio, presence of mineral and chemical admixtures etc., the HPCs usually have many features which distinguish them from conventional cement concrete (CCC). The development of HPC in this regard has been a great breakthrough in concrete technology. Important governing factors for HPCs are strength, long run durability, serviceability as determined by crack and deflection control, also as response to future environmental effects. One major notable quality in preparation of HPC is the virtual elimination of voids within the concrete matrix, which are mainly the reason behind most of the ills that generate deterioration.

Johann Plank et.al. Used plasticizers and superplasticizers to ensure good workability of concrete at low w/c ratios and found comb-type copolymers which consist of an anionic backbone and uncharged side chains as the most effective superplasticizers used among. And also found that Methacrylate-based Polycarboxylate Ether (PCE) s primarily disperse cement, whereas allyl ether-based PCEs are more effective with silica fume present in a UHPC. This concept may generally apply to blended cements containing fly ash, blast furnace slag, limestone powder or other secondary cementitious materials. The absolute value of their positive surface charge and their specific surface area will determine their impact on flow ability of the concrete and how much they compete with cement for superplasticizer adsorption [1].In [2] a combined investigation of Nano indentation, scanning electron microscope (SEM) and X-ray Diffraction (XRD) indicates that the fiber matrix transition zone is relatively defect free. A combination of Nano indentation, SEM and XRD provides strong evidence that there is no weak fiber–matrix interface zone in UHPC. It is suggested that this is due to the predominant presence of the High Density Calcium Silica Hydrates (HD C–S–H) in UHPC which ensures a uniform composite behavior.

O. Cakır and F. Akoz [3] investigated the effects of different curing condition on the mechanical and physical properties of mortars with and without ground granulated blast furnace slag. Compressive strength of mortars cured in elevated temperature affective condition is more than mortars cured in water, and control mortars compressive strength is more than slag replaced mortars.

They also found that the use of ground granulated blast furnace slag in producing mortar decreases the porosity and capillary, thus, improves the durability against water and aggressive solutions. Concretes containing silica fume (SF) or ternary blends of SF and ground granulated blast-furnace slag (GGBFS) exhibit improved chloride penetration resistance compared to those of plain Portland cement concretes [4]. M.F.M. Zain et.al. [5] Investigated the possibility of developing high performance concrete (HPC) using silica fume (SF) considering relatively high water binder ratios of 0.45 and 0.50. Test specimens were air and water cured and exposed to a medium temperature range of 20°C to 50°C and found that the highest level of compressive strength and modulus of elasticity and therefore the lowest level of ISA were produced by SF concrete under water curing and at temperature of 35°C. Data collected also revealed that, under controlled curing conditions, it's possible to develop HPC at relatively high water binder ratios.

## II. MATERIALS

Ingredients of HPC are almost same as those of Conventional Cement Concrete (CCC). But, because of lower water cement ratio, presence of mineral and chemical admixtures etc., the HPCs usually have many features which distinguish them from CCCs. HPC is prepared through a careful selection of each of its ingredients. Effective production of HPC that consistently meets requirements for workability and strength development places more stringent requirements on material selection than for CCC. From practical considerations, in concrete constructions, apart from the final strength, the rate of development of strength is also very important. The HPC usually contains both mineral and chemical admixtures. Hence, the rate of hydration of cement and the rate of strength development in HPC is quite different from that of CCC. For HPCs, however, all the components of the concrete mixture are pushed to their limits. Therefore, it's necessary to pay careful attention to every aspects of concrete production, i.e., selection of materials, mix design, handling and placing.

The material specifications for cement, fine aggregate, coarse aggregate and admixtures are discussed. Sieve analysis was done for sand, coarse aggregate to test their suitability for use in concrete and their specific gravity were found tabulated its average value, see table I.

Table I
Specific Gravity

| S.No | Materials | Specific Gravity |
|---|---|---|
| 1. | Cement | 3.01 |
| 2. | Fine Aggregate (sand) | 2.65 |
| 3. | Course Aggregate | 2.71 |

### *A. Mineral Admixtures*

Mineral admixtures, also called as Cement Replacement Materials (CRM), act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened cement matrix becomes denser and stronger. The effect of a CRM on the strength of concrete varies with their properties.

1) *Silica Fume:* Silica fume also referred to as micro silica or condensed silica fume is another material that is used as an artificial pozzolanic admixture. It is a product resulting from high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Since it is an air borne material like fly ash, it has spherical shape. It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. The use of silica fume in conjunction with super plasticizer has been the backbone for modern high performance concrete. The structure, Key Tower in Cleave land with design strength of 85Mpa is a testament to the benefits of silica fume technology in concrete construction. It should be realized that silica fume by itself, do not contribute to the strength dramatically ,although it does contribute to the strength property by being very fine pozzolanic material and also creating dense packing and pore filler of cement paste. The high strength of high performance concrete containing silica fume are attributable to a large degree ,to the reduction in water content which becomes possible in the presence of high dose of super plasticizer and dense packing of cement paste.

a) *Chemical Properties of Silica Fume:*

- Amorphous
- Silicon dioxide > 85%
- Trace elements depending upon type of fume

b) *Physical Properties of Silica Fume:*

Table II
Physical Properties of SILICA Fume

| | |
|---|---|
| Bulk density<br>1.(as-produced) | 130 to 430 kg/m3 |
| 2.(slurry) | 1320 to 1440 kg/m3 |
| 3.(densified) | 480 to 720 kg/m3 |
| Specific gravity | 2.2 |
| Surface area | 13,000 to 30000 m²/kg |
| Particle size (typical) | < 1 μ m |

c) *Using Silica Fume in Concrete*

- Enhancing Mechanical Properties
- Improving Durability
- Enhancing Constructability
- Producing High-Performance Concrete Structures

Silica fume are often used to replace cement in given concrete mixture while maintaining an equivalent compressive strength. The relative costs of the two materials do not make this a practical approach to saving cement. If cost saving is that the goal, fly ash or blast furnace slag could be a better.

2) *Ground Granulated Blast Furnace Slag:* The slag used in the concrete industry is mainly the slag from iron production. GGBFS (standard BS: 6699) is a fine powder that is used in concrete as a 'cement'. In the production of ready-mixed concrete, GGBS replaces a considerable portion of the traditional Portland cement content, generally about 50%, but sometimes up to 70%. The higher the proportion, the better is the durability. GGBS is also utilized in other sorts of concrete, including site-batched. The drawback of the higher replacement level of it is that early-age strength development is quite slower.

a) *Physical Properties of GGBFS*

Table III
Physical Properties of GGBFS

| Property | Slag Type and Value | | |
|---|---|---|---|
| | Air cooled | Expanded | Pelletized |
| Specific Gravity | 2.0-2.5 | - | - |
| Compacted Unit Weight, $Kg/m^3(lb/ft^3)$ | 1120-1360 (70-85) | (800-1040) (50-65) | 840 (52) |
| Absorption (%) | 1-6 | - | - |

b) *Chemical Properties of GGBFS:* The standard chemical composition of blast furnace slag shown in table IV. Are in general applicable to all type of slag. The data shown in the table recommend that the chemical composition of blast furnace slags produced has relatively consistent over the years.

Table IV
Chemical Properties Of GGBFS

| Constituent | Percentage | |
|---|---|---|
| | Mean | Range |
| Calcium Oxide (CaO) | 39 | 34-43 |
| Silicon Dioxide ($SiO_2$) | 36 | 27-38 |
| Aluminium Oxide ($Al_2O_3$) | 10 | 7-12 |
| Magnesium Oxide (MgO) | 12 | 7-15 |
| Iron (FeO or $Fe_2O_3$) | 0.5 | 0.2-1.6 |
| Manganese Oxide (MnO) | 0.44 | 0.15-0.76 |
| Sulphur (S) | 1.4 | 1.0-1.9 |

### *B. Chemical Admixtures*

Chemical admixtures, especially high range water reducing super plasticizer (SP), create conducive condition for the near complete hydration of cement by deflocculating the particles of fine materials, mainly cement. With the use of SP, it is possible to reduce the water content and yet produce same workability without affecting the strength of concrete if the water cement ratio is kept constant. But the effectiveness of the SP depends on the dosage used, ambient temperature, cement chemistry, fineness and other characteristics of the binder.

In this project, GLENIUM B233, a High Range Water Reducer (HRWR), is chosen as a super plasticizer. This complies with IS 9103:1999 and ASTM C494 Type F. In this project, GLENIUM B233, a High Range Water Reducer (HRWR), is chosen as a super plasticizer. This complies with IS 9103:1999 and ASTM C494 Type F.

1) *GLENIUM B233:* GLENIUM B233 is an admixture of a new generation that based on modified polycarboxylic ether. The product has been primarily developed for applications in HPC where the high level durability and performance is required. GLENIUM B233 is free of chloride and low alkali. GLENIUM B233 consists of a carboxylic ether polymer with long side chains. At the start of the blending process it initiates the same electrostatic dispersion mechanism as the traditional superplasticisers, but the side chains linked to the polymer backbone generates a steric hindrance which will greatly stabilises the cement particles ability to separate and disperse. Steric hindrance provides a physical barrier i.e. alongside the electrostatic barrier between the cement grains. With this process we can obtain flow able concrete with greatly reduced water content.

*a)* Type : Modified Poly carboxylic ether
*b)* Specific Gravity : 1.09
*c)* Total Solid contents : 34 % by weight

## III.MIX DESIGN

The object of any mix proportion method is to work out a cost-effective combination of concrete constituents which will be used for a primary trail batch to manufacture a concrete that is close to that which can achieve a good balance between the various desired properties of concrete at the lowest possible cost. In this study mix design was done as per Modified ACI Method (Aticin method).

Table V
Mix Proportions For M85 Grade Concrete

| W | C | FA | CA | SP |
|---|---|---|---|---|
| 140 | 560 | 710.2 | 1075 | 5.79 |

TABLE VI
Mix Ratio For M85 Grade Concrete

| Water | Cement | FA | CA |
|---|---|---|---|
| 0.25 | 1 | 1.26 | 1.92 |

Table VII
Mix Ratio For 20% Replacement Of Cement With GGBFS

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | GGBFS | | |
| 0.25 | 0.8 | 0.2 | 1.26 | 1.92 |

Table VIII
Mix Ratio For 40% Replacement Of Cement With GGBFS

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | GGBFS | | |
| 0.25 | 0.6 | 0.4 | 1.26 | 1.92 |

Table IX
Mix Ratio For 50% Replacement Of Cement With Ggbfs

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | GGBFS | | |
| 0.25 | 0.5 | 0.5 | 1.26 | 1.92 |

Table X
Mix Ratio For 5% Replacement Of Cement With SF

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | SF | | |
| 0.25 | 0.95 | 0.05 | 1.26 | 1.92 |

Table XI
Mix Ratio For 10% Replacement Of Cement With SF

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | SF | | |
| 0.25 | 0.9 | 0.1 | 1.26 | 1.92 |

Table XII
Mix Ratio FOR 15% Replacement of Cement with SF

| Water | Binder | | FA | CA |
|---|---|---|---|---|
| | Cement | SF | | |
| 0.25 | 0.85 | 0.15 | 1.26 | 1.92 |

## IV. EXPERIMENTAL METHODS

### *A. Test Procedures*

The specimens were cast for compression test and split tensile test. The tests were done as per specifications in IS 516 – 1959.

1) *Cube Compression Test:* Compression test is that the most typical test conducted on hardened concrete, partly because it's a simple test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compression strength. The cube specimen is of the size 150 x 150 x 150 mm. As an alternative, 100mm size cubes may also be used if the highest nominal size of the aggregate doesn't exceed 20mm. In this study 150 mm cubes were used. The test cube specimens were made as soon as practicable after mixing and in such a way as to produce full compaction of the concrete with no segregation or excessive laitance. The concrete is filled into mould in layers approx. 50mm deep. After the top layer of the concrete is compacted by table vibrator and the top surface is brought to the finished level with the top of the mould, using a trowel. For cured concrete, the test specimens were removed from the mould after 24 hours and immersed in water for curing. For self-cured concrete test specimens were removed from the mould after 24 hours and kept in open atmosphere. The cubes were tested for each trail mix combination after 7 days and 28 days in Compression Testing Machine (CTM).The tests were carried out at a uniform stress of 140 kg/cm2/minute, after the specimens were kept at centre in the testing machine. The loading was continued till the dial gauge needle just reversed its direction of motion. The maximum compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by cross sectional area.

   $Fc = P / A$

   Where,

   Fc – Compressive Strength in $N/mm^2$

   P – Maximum load in Newton

   A – Cross sectional area in $mm^2$

2) *Split Tensile Test:* This is an indirect test to determine the tensile strength of cylindrical specimens. Splitting tensile strength tests were carried out on cylinder specimens of size 150 mm diameter and 300 mm length at the age of 7 days and 28 days in compression testing machine as per IS 5816:1970.

This test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter.

The split tensile stress is given by

$$Ft = 2P / \Pi L D$$

Where,

P – Compressive Load in Newton

L – Length of cylinder in mm

D – Diameter of cylinder in mm

The loading condition produces high compressive strength immediately below the two generators to which the load is applied. But the larger portion corresponding to depth is subjected to a uniform tensile stress accordingly. It is estimated that the compressive stress is acting for about 1/6 depth and therefore the remaining 5/6 depth is subjected to tension.

## V. RESULTS AND DISCUSSION

Specimens were cast for M85 grade of concrete for various replacement of cement with GGBFS and SF. The specimens were tested at 7th day and 28th day from the date of casting and compared the results.

### *A. Compressive Strength*

The 150 mm cube specimens were used for compression test of concrete. Three specimens were cast for each test. For the 7th and 28th day compressive strength was found by testing. The average of 3 results for each test was taken. Results were given in Table XIII.

Table XIII

Compressive strength of hpc concrete at $7^{th}$ day and $28^{th}$ day for various dosages of ggbfs and silica fume.

| Type of specimen | $7^{th}$ Day Compressive Strength in $N/mm^2$ | $28^{th}$ Day Compressive Strength in $N/mm^2$ |
|---|---|---|
| 0% GGBFS | 55.24 | 87.3 |
| 20% GGBFS | 58.51 | 91.32 |
| 40% GGBFS | 61.26 | 93.71 |
| 50% GGBFS | 51.81 | 81.52 |
| 5% SF | 59.34 | 92.21 |
| 10% SF | 62.53 | 97.47 |
| 15% SF | 66.64 | 103.02 |

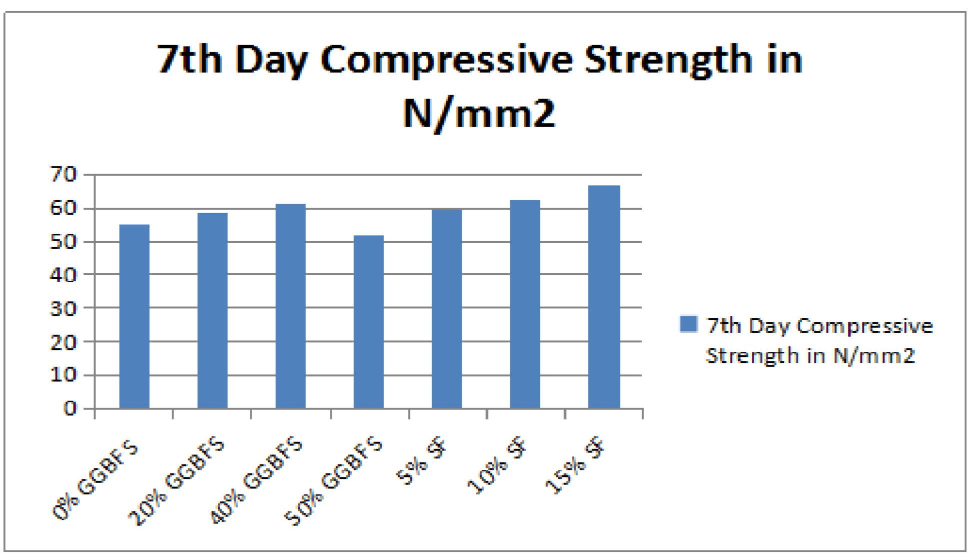


Fig. 1 Comparison of compressive strength of HPC concrete after 7 days water curing

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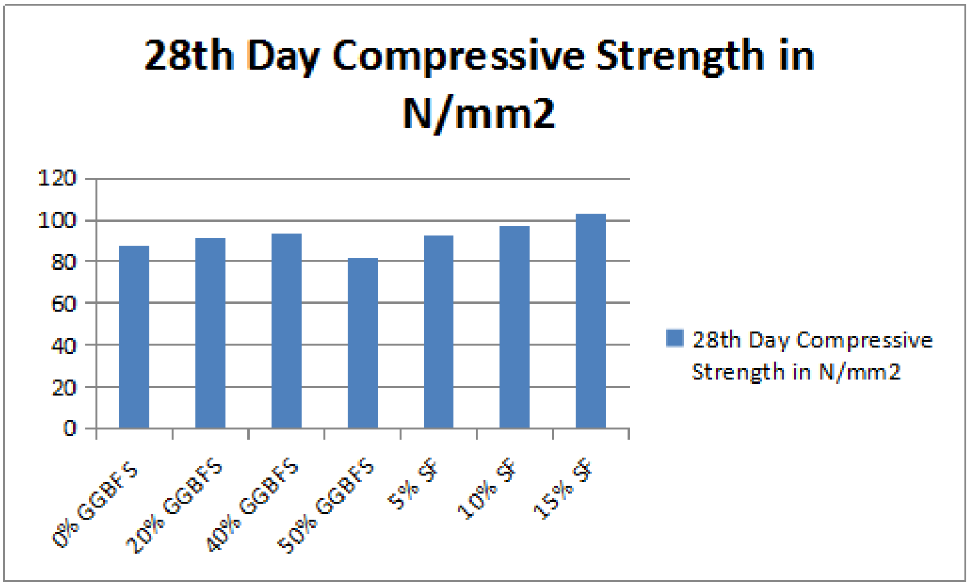


Fig. 2 Comparison of compressive strength of HPC concrete after 28 days water curing

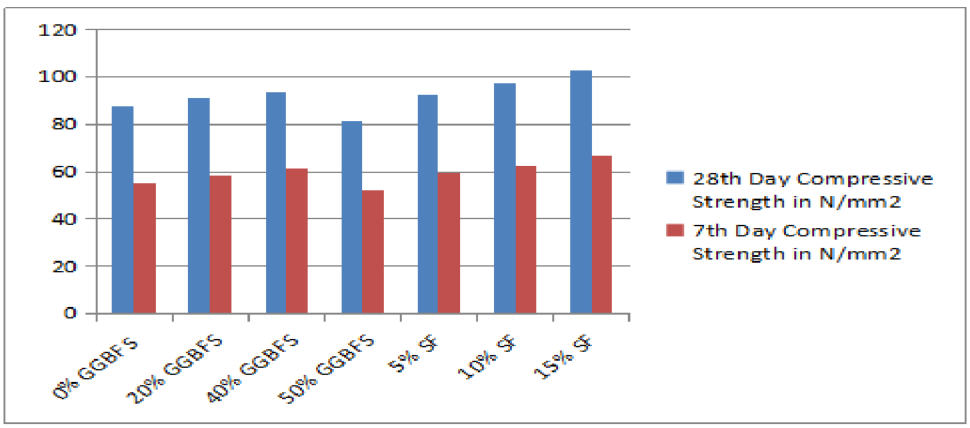


Fig. 3 Comparison of compressive strength of HPC concrete with 28 days and 7 days of water curing

### *B. Split Tensile Strength*

The 150 mm x 300 mm cylinder specimens were used for split tensile strength of concrete. Three specimens were cast for each test. For the 7th and 28th day split tensile strength was found by testing. The average of three results for each test was taken. Results were given in Table XIV.

Table XIV

Split Tensile Strength of HPC concrete at $7^{th}$ day and $28^{th}$ day for various dosages of GGBFS and SILICA fume.

| Type of specimen | $7^{th}$ Day Split Tensile Strength in $N/mm^2$ | $28^{th}$ Day Split Tensile Strength in $N/mm^2$ |
|---|---|---|
| 0% GGBFS | 4.05 | 5.52 |
| 20% GGBFS | 4.25 | 5.61 |
| 40% GGBFS | 4.39 | 5.74 |
| 50% GGBFS | 4.02 | 5.3 |
| 5% SF | 4.4 | 5.64 |
| 10% SF | 4.49 | 5.82 |
| 15% SF | 4.52 | 5.93 |

 

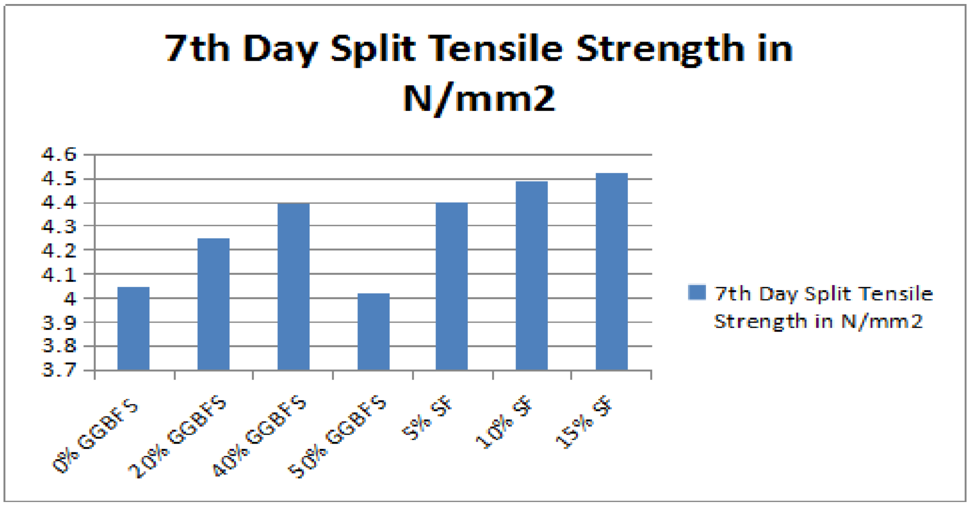


Fig. 4 Comparison of split tensile strength of HPC concrete after 7 days water curing

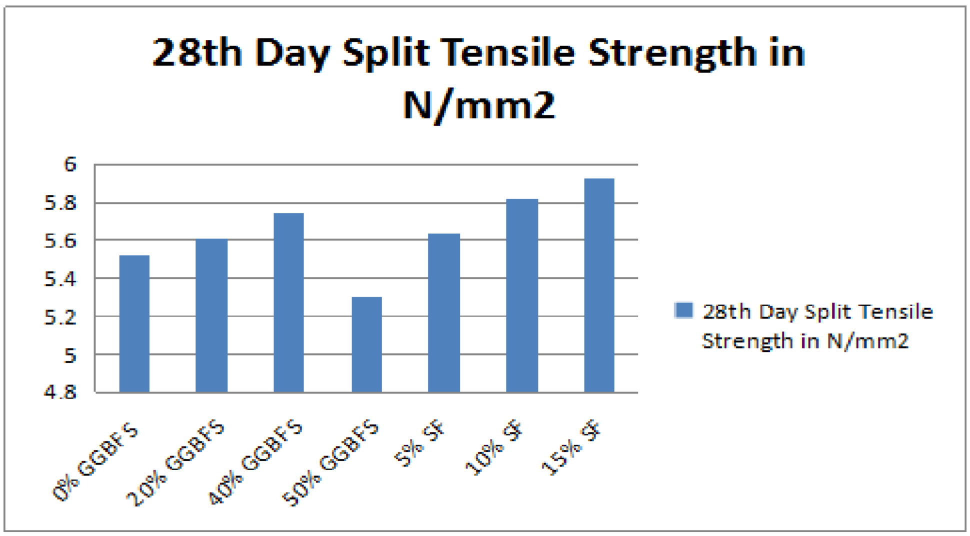


Fig. 5 Comparison of split tensile strength of HPC concrete after 28 days water curing

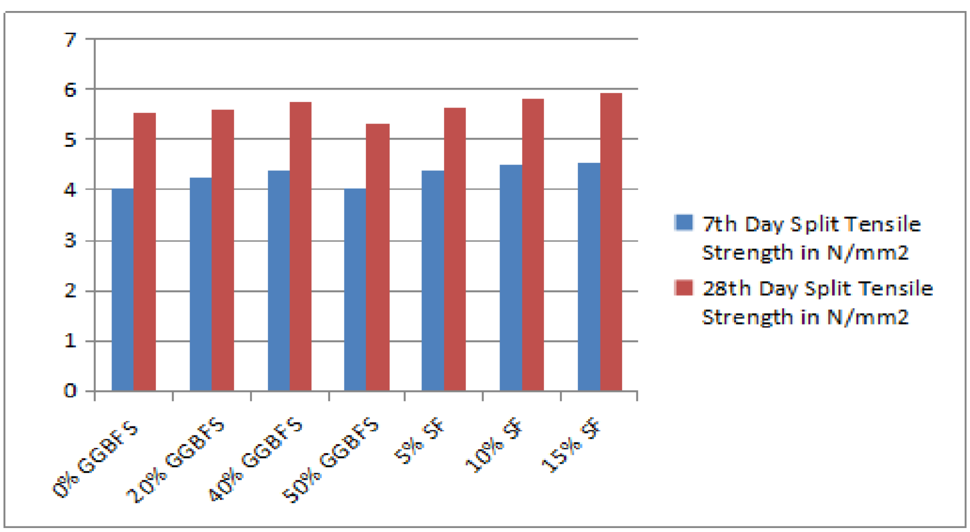


Fig. 6 Comparison of split tensile strength of HPC concrete with 7 days and 28 days of water curing

## VI. CONCLUSION

The strength parameters of HPC concrete for 0%, 20%, 40% and 50% GGBFS and 5%, 10% and 15% SF replacement of cement was studied for 7th and 28th days. The compressive strength and split tensile strength test were conducted to investigate hardened properties of HPC. Based upon the experimental investigation carried out, the following conclusions were made:

*A.* Compressive and split tensile strength of concrete specimens for 40% GGBFS replacement of cement gave the highest value.
*B.* Compressive and split tensile strength of concrete specimens for 15% SF replacement of cement gave the highest value.
*C.* Workability of concrete for 15% SF replacement of cement gave the lowest value.
*D.* The optimum dosage of GGBFS for replacing cement in HPC mix was observed to be 40% by weight of cement.
*E.* Replacement of cement with slag resulted in more economical mix compared to that with no replacement.

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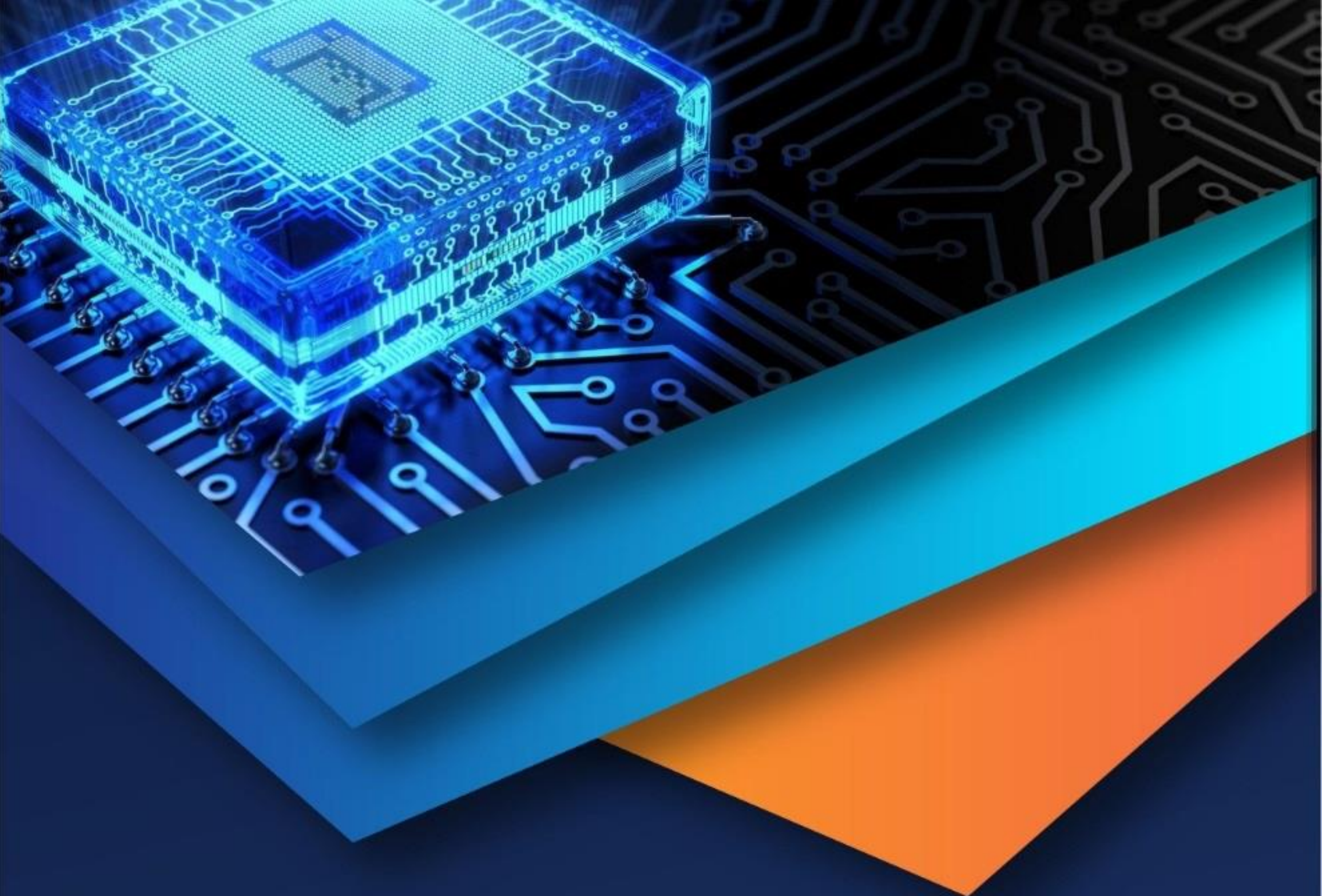

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