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# A LABORATORIAL INVESTIGATION OF STRENGTH ANALYSIS USING COMPARATIVE APPROACH OF MINERAL ADMIXTURES BY PARTIAL SUBSTITUTION OF CEMENT IN HIGH STRENGTH CONCRETE

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*Abstract:* **In the modern era, most of the natural resources are exhausting expeditiously due to their excavation at a high rate. The necessity for pursuit of alternative construction materials especially cement, which is preeminent cause for emission of highly hazardous particles to the environment. Some of the alternative materials for cement are Fly ash, GGBS, silica fume, Metakaolin, etc. These are mineral admixtures used to produce High Strength concrete. The quest for the development of high strength concrete has increased considerably in recent times because of the demands from the construction industry. Mineral admixture is a prominent material component in High Strength Concrete. With the low water cement ratio, mineral admixture offers Increase later strength of concrete, reduction in hydration heat, enhance the compactness of concrete internal structure, improve the corrosion resistance and wear resistance, and decrease carbon dioxide emissions, so as to achieve rational utilization of resource and energy conservation and emission reduction under the new situation, and meet the economic and environmental requirement. The scope of the present investigation is to analyze the effect of mineral admixtures such as Silica Fume, Metakaolin, GGBS and Fly Ash towards the performance of HSC M60. The High strength Concrete M60 concrete designed by ACI 211 4R-93 Codal provisions by percentile substitutions of Metakaolin, Silica Fumes, GGBS and Fly Ash. The complete strength behaviour of concrete is analysed with Compressive and Split tensile strength with 5%, 7.5%, 10% of replacement of mineral admixtures with cement were studied at 28 days of curing. The strengths of maximum value for various percentile replacement of mineral admixtures were identified. This investigation is focused on utilization of mineral admixtures as partial replacement of cement.**

*IndexTerms* – **Mineral Admixtures, High Strength Concrete, Fly Ash, GGBS, Metakaolin, Silica fume, Percentile Substituion, Strength Analysis.**

## I. INTRODUCTION

The definition of high strength concrete is continually developing. In the 1950's 35Mpa was considered as high strength and in the 1960's compressive strengths up to 50Mpa were being used commercially. More recently, compressive strengths approaching 150Mpa have been used in cast-in-place buildings. High strength concrete columns can hold more weight and therefore be made slimmer than regular strength concrete columns, which allows for more useable space, especially in the lower floors of buildings.

Concrete is generally classified as normal strength concrete (NSC), High strength concrete (HSC) and ultra-high strength concrete (UHSC). There is no clear-cut boundary for the above classification. Indian Standard Recommended Methods of Mix Design denotes the boundary at 35Mpa between NSC and HSC. They did not talk about USHC. But elsewhere in the international forum, about 30 years ago, the high strength label was applied to concrete having strength above 40Mpa. More recently, the threshold rose to 50 to 60Mpa. In the world scenario, however, in the last 15years concrete of very high strength entered the field of construction, in particular construction of high-rise buildings and long span bridges. Concrete strengths of 90 to 120Mpa are occasionally used. In India there are cases of using high strength concrete for prestressed concrete bridges. But strength of concrete more than 35Mpa was not commonly used in general construction practices. Similarly high strength concrete was employed in bridges and flyovers.

## II. OBJECTIVES OF STUDY

The prime goal of this project is to study the Strength analysis of concrete using fly ash, GGBS, Metakaolin and Silica fumes with percentile replacement of cement in high strength concrete of M60 grade. The main objectives of the study with the incorporation of steel and bamboo fibres in the normal concrete were:

- The main objective of this investigation was to analyze the strength by studying the properties of mineral admixtures and their suitability in high strength concrete.
- With the help of this mineral admixtures, the overall strength in concrete can be improved.
- Investigating the behaviour as well as properties of high strength concrete in fresh and hardened state.
- Scrutinization of structural behaviour of high strength concretes with mineral admixtures
- Investigating the strength behaviour of concrete by the percentile inclusions of mineral admixtures in concrete and evaluating strength for 28days of curing.
- Identification of optimum combination of mineral admixtures to be used and their percentile replacement value.

## III. CONCRETE AND ITS CONSTITUENTS

### 3.1 CEMENT

Ordinary Portland cement available in the local market of standard brand of 53 grade confirming to IS 12269 - 1987 was used for the concrete mix. The physical properties obtained from various tests are listed in Table 3.1. All tests are carried out in accordance to procedure laid in IS 1489 (Part 1): 1991.

**Table 3.1:** Physical Properties of cement

| S. No | Property | Value Obtained Experimentally | Value as per IS: 1489-1991 |
|---|---|---|---|
| 1. | Normal Consistency | 29% | - |
| 2. | Soundness | 3.7 | Not >10 |
| 3. | Initial setting time | 45 min | Not<30 |
| 4. | Final setting time | 217 min | Not >600 |
| 5. | Specific gravity | 3.15 | - |

### 3.2 FINE AGGREGATE

Local sand was used as fine aggregate in concrete mix. The physical properties and sieve analysis results of sand are shown in Table 3.2

**Table 3.2:** Physical Properties of Fine Aggregate

| S. No | Property | Value Obtained |
|---|---|---|
| 1. | Specific gravity | 2.67 |
| 2. | Bulk density | 1721 Kg/M$^3$ |
| 3. | Fineness modulus | 2.16 |
| 4. | Water absorption | 1.8% |
| 5. | Grading Zone | Zone II |

### 3.3 COARSE AGGREGATE

Crushed stone aggregate of 20 mm size was used for concrete. The physical properties and sieve analysis results of coarse aggregate are shown in Table 3.3

**Table 3.3:** Physical properties of Coarse Aggregate

| S. No | Property | Value Obtained |
|---|---|---|
| 1. | Type | Crushed |
| 2. | Specific gravity | 2.81 |
| 3. | Fineness modulus | 2.64 |
| 4. | Water absorption | 1.58% |
| 5. | Bulk Density | 1674 Kg/M$^3$ |
| 6 | Size of Aggregate | 20 mm |

### 3.4 WATER

Water conforming to the requirements of BIS: 456-2000 is found to be suitable for making HSC. It is generally stated that water fit for drinking is fit for making concrete. The water used is potable water collected from laboratory taps and satisfies the code IS 3025:1984.

## IV. MINERAL ADMIXTURES

### 4.1 FLYASH

Fly Ash is a finely divided residue resulting from the combustion of pulverized coal and transported by the flue gases of boilers fired by pulverized coal as defined by IS:3812-1981. Fly ash particles can be spherical and rounded, sub-rounded, irregular and angular. Fineness is probably a single important physical characteristic which influences the activity of fly ash more than any other physical factor. The surface area is found to range between 3627 and 6091 Sqcm/gm showing India's fly ashes to be quite fine. Carbon Content fly ash influences the colour, fineness and temperature reactivity of fly ash.

### 4.2 SILICA FUME

Silica fume also referred to as micro silica or condensed silica fume. It is a product resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapor. It cools, condenses and is collected in cloth bags. It is further processed to remove impurities and to control particle size. Condensed Silica fume is essentially silicon dioxide in non-crystalline form. It is extremely fine with particle size less than 1micron and with an average diameter of about 0.1micron, about 100times smaller than average cement particles. Silica fume has specific surface area of about 20,000m$^2$/kg, as against 230 to 300m$^2$/kg. Its use simplifies the production of high-performance concrete and makes it easier to achieve compressive strengths in the range of 60 to about 90Mpa. For higher strengths the use of silica fume is essential.

### 4.3 METAKAOLIN

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Rocks that are rich in kaolinite are known as china clay or kaolin, used in the manufacture of porcelain. Between 100-200 degrees centigrade, clay minerals lose most of their adsorbed water. Between 500-800 degrees centigrade kaolinite becomes calcined by losing water through de-hydroxilization. The de-hydroxilization of kaolin to metakaolin is an endothermic process due to the large amount of energy required to remove the chemically bonded hydroxyl ions. Metakaolin is a valuable admixture for concrete/cement applications. Replacing Portland cement with 8%-20% (by weight) metakaolin produces a concrete mix which exhibits favourable engineering properties, including the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction.

### 4.4 GROUND GRANULATED BLAST FURNAC SLAG

Ground granulated blast furnace slag (GGBS or GBFS) is obtained by quenching molten iron slag (a byproduct of iron and steel making) from a blast furnace in water or stream, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. Use of GGBS significantly reduces the risk of damages caused by alkali-silica reaction (ASR), provides higher resistance to chloride ingress reducing.

## V. EXPERIMENTAL INVESTIGATIONS

The Experimental investigation composed of casting and testing of 13 sets. Each set consists of three cubes, two cylinders and two prisms. The admixtures such as Fly ash, Silica fume, Metakaolin, Ground Granulated Blast Furnace slag (GGBS), are used in combinations with different percentages.

Mix designs for each set having different combinations are carried out by using **ACI 211 4R-93** method. The mix proportion obtained for normal **M60 grade** is 1: 1.03: 2.05 with W/C ratio of 0.3

### 5.1 REPLACEMENT OF CEMENT ONLY WITH SILICA FUME

The concrete used in this study was proportioned to attain strength of 60 Mpa. The mixes M1, M2, M3, M4 were obtained by replacing 0, 5, 7.5, and 10 percent of the mass of cement by silica fume. ACI recommendation has been used for M60 design. The water binder (w/b) ratio is taken as 0.30.

**Table 5.1:** Replacement of Cement only with Silica fume

| Mix | Replacement of cement with silica fume (%) | Replacement of cement with fly ash (%) | Mix Proportion | Super Plasticizer |
|---|---|---|---|---|
| M1 | 0 | 0 | 1:1.07:2.05:0.3 | 1.5% |
| M2 | 5 | 0 | 1:1.05:2.05:0.3 | 1.9% |
| M3 | 7.5 | 0 | 1:1.04:2.05:0.3 | 2.0% |
| M4 | 10 | 0 | 1:1.03:2.05:0.3 | 2.1% |

### 5.2 REPLACEMENT OF CEMENT WITH SILICA FUME AND FLY ASH

The mixes M5, M6, M7 were obtained by replacing 0, 5, 7.5, and 10 percent of the mass of cement by silica fume along with 10 percent fly ash. ACI recommendation has been used for M60 design. The water binder (w/b) ratio is taken as 0.30.

**Table 5.2:** Replacement of Cement with Silica fume and Fly ash

| Mix | Replacement of cement with silica fume (%) | Replacement of cement with fly ash (%) | Mix Proportion | Super Plasticizer |
|---|---|---|---|---|
| M5 | 5 | 10 | 1:1.01:2.05:0.3 | 3.6% |
| M6 | 7.5 | 10 | 1:1.00:2.05:0.3 | 3.7% |
| M7 | 10 | 10 | 1:0.99:2.05:0.3 | 3.7% |

**5.3 REPLACEMENT OF CEMENT WITH SILICA FUME AND METAKAOLIN** The mixes M8, M9, M10 were obtained by replacing 0, 5, 7.5, and 10 percent of the mass of cement by silica fume along with 10 percent metakaolin. ACI recommendation has been used for M60 design. The water binder (w/b) ratio is taken as 0.30.

**Table 5.3:** Replacement of Cement with Silica fume and Metakaolin

| Mix | Replacement of cement with silica fume (%) | Replacement of cement with metakaolin (%) | Mix Proportion | Super Plasticizer |
|---|---|---|---|---|
| M8 | 5 | 10 | 1:1.03:2.05:0.3 | 1.5% |
| M9 | 7.5 | 10 | 1:1.03:2.05:0.3 | 1.5% |
| M10 | 10 | 10 | 1:1.01:2.05:0.3 | 1.5% |

### 5.4 REPLACEMENT OF CEMENT WITH SILICA FUME AND GGBS

The mixes M11, M12, M13 were obtained by replacing 0, 5, 7.5, and 10 percent of the mass of cement by silica fume along with 10 percent GGBS. ACI recommendation has been used for M60 design. The water binder (w/b) ratio is taken as 0.30.

**Table 5.4:** Replacement of Cement with Silica fume and GGBS

| Mix | Replacement of cement with silica fume (%) | Replacement of cement with GGBS (%) | Mix Proportion | Super Plasticizer |
|---|---|---|---|---|
| M11 | 5 | 10 | 1:1.05:2.05:0.3 | 1.5% |
| M12 | 7.5 | 10 | 1:1.04:2.05:0.3 | 1.5% |
| M13 | 10 | 10 | 1:1.03:2.05:0.3 | 1.5% |

## VI. TEST RESULTS AND DISCUSSIONS

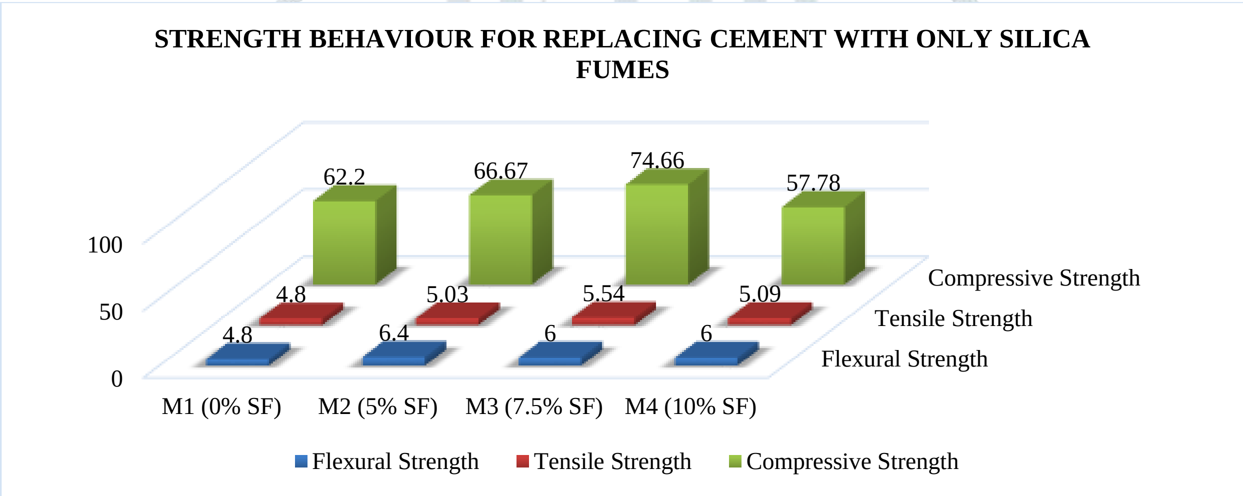
The entire investigation is divided into four parts:

### 6.1 REPLACEMENT OF CEMENT ONLY WITH SILICA FUME

The first part is designated as **'A'** Series. In this series cement is replaced with 0%, 5%, 7.5%, 10% silica fume as mineral admixture in each mix and designated as M1, M2, M3, M4 respectively. The mix proportions are different for each mix which are given in the before explained experimental program. The slump required for these different mixes is 50mm.

**Table 6.1: Test results of high strength concrete mix by replacing cement only with silica fume**

| Mix Name | Compressive strength, Mpa | Tensile strength, Mpa | Flexural strength, Mpa |
|---|---|---|---|
| M1 (Reference mix) | 62.20 | 4.80 | 4.80 |
| M2 (SF 5%) | 66.67 | 5.03 | 6.40 |
| M3 (SF 7.5%) | 74.66 | 5.54 | 6.00 |
| M4 (SF 10%) | 57.78 | 5.09 | 6.00 |



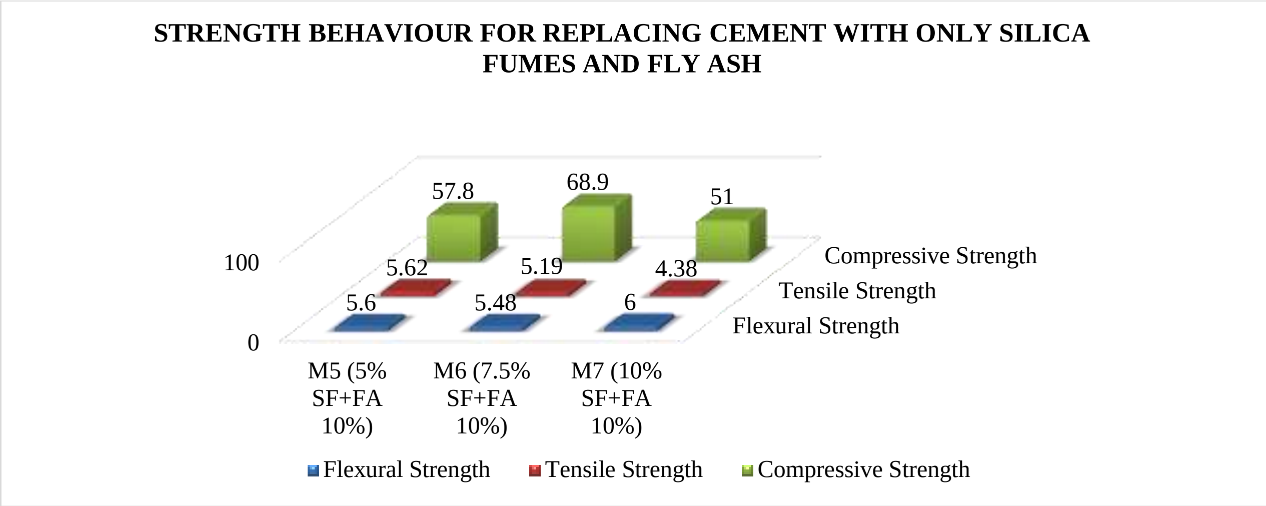

**Graph 6.1 Test results of high strength concrete mix by replacing cement only with silica fume**

### 6.2 REPLACEMENT OF CEMENT WITH SILICA FUME AND FLY ASH

In the experimental investigation the second part is designated as **'B'** Series. In this series cement is replaced with 5%, 7.5%,10% silica fume along with 10% fly ash as mineral admixtures in each mix and designated as M5, M6, M7 respectively. The mix proportions for different for each mix which are given in the before explained experimental program. The slump required for these different mixes is 50mm.

**Table 6.2: Test Results of High Strength Concrete Mix by Replacing Cement with Silica Fume and Fly Ash**

| Mix Name | Compressive strength, Mpa | Tensile strength, Mpa | Flexural strength, Mpa |
|---|---|---|---|
| M5 (SF 5% + FA 10%) | 57.80 | 5.62 | 5.60 |
| M6 (SF 7.5%+ FA 10%) | 68.90 | 5.19 | 5.48 |
| M7 (SF 10%+ FA 10%) | 51.00 | 4.38 | 6.00 |



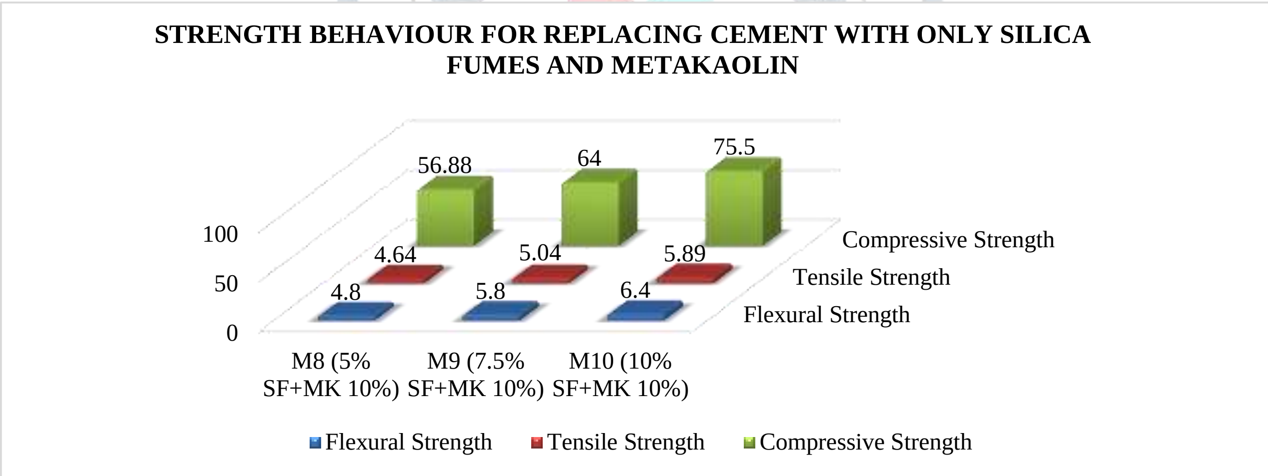

**Graph 6.2: Test Results of High Strength Concrete Mix by replacing Cement with Silica Fume and Fly Ash**

## 6. REPLACEMENT OF CEMENT WITH SILICA FUME AND METAKOLIN

In the experimental investigation the third part is designated as **'C'** Series. In this series cement is replaced with 5%, 7.5%,10% silica fume along with 10% metakaolin as mineral admixtures in each mix and designated as M8, M9, M10 respectively. The mix proportions for different for each mix which are given in the before explained experimental program. The slump required for these different mixes is 50mm.

**Table 6.3: Test Results of High Strength Concrete Mix by Replacing Cement with Silica Fume and Metakaolin**

| Mix Name | Compressive strength, Mpa | Tensile strength, Mpa | Flexural strength, Mpa |
|---|---|---|---|
| M8 (SF 5% + MK 10%) | 56.88 | 4.64 | 4.80 |
| M9 (SF 7.5%+ MK 10%) | 64.00 | 5.04 | 5.80 |
| M10 (SF 10%+ MK 10%) | 75.50 | 5.89 | 6.40 |



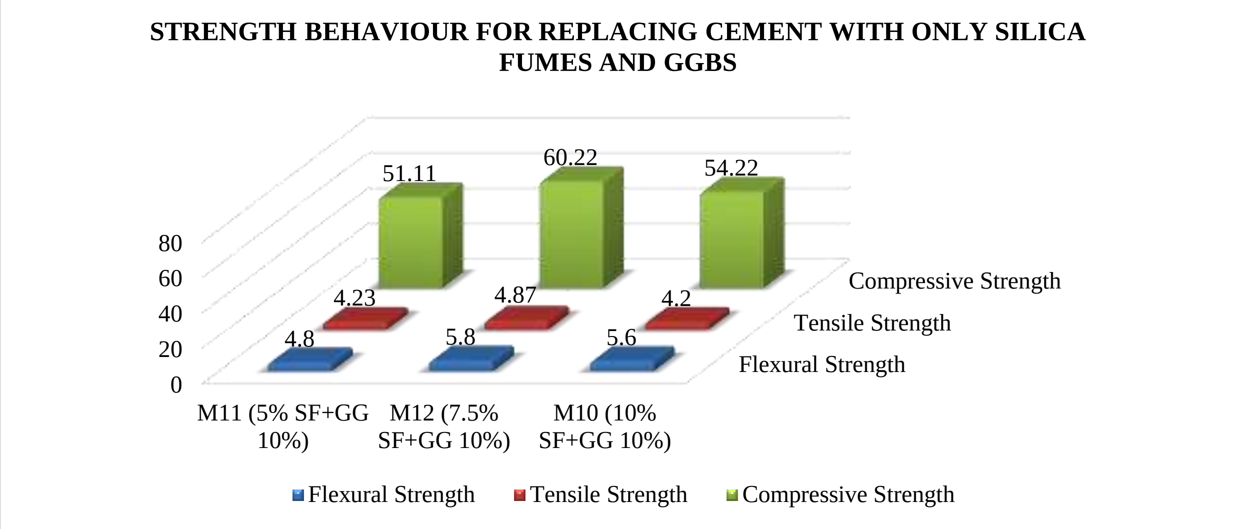

**Graph 6.3: Test Results of High Strength Concrete Mix by Replacing Cement with Silica Fume and Metakaolin**

## 6.4 REPLACEMENT OF CEMENT WITH SILICA FUME AND GGBS

In the experimental investigation the third part is designated as **'D'** Series. In this series cement is replaced with 5%, 7.5%,10% silica fume along with 10% GGBS as mineral admixtures in each mix and designated as M11, M12, M13 respectively. The mix proportions for different for each mix which are given in the before explained experimental program. The slump required for these different mixes is 50mm.

**Table 6.4: Test Results of High Strength Concrete Mix by Replacing Cement with Silica Fume and GGBS**

| Mix Name | Compressive strength, Mpa | Tensile strength, Mpa | Flexural strength, Mpa |
|---|---|---|---|
| M11 (SF 5% + GG 10%) | 51.11 | 4.23 | 4.80 |
| M12 (SF 7.5%+ GG 10%) | 60.22 | 4.87 | 5.80 |
| M13 (SF 10%+ GG 10%) | 54.22 | 4.20 | 5.60 |




**Graph 6.4: Test Results of High Strength Concrete Mix by Replacing Cement with Silica Fume and GGBS**

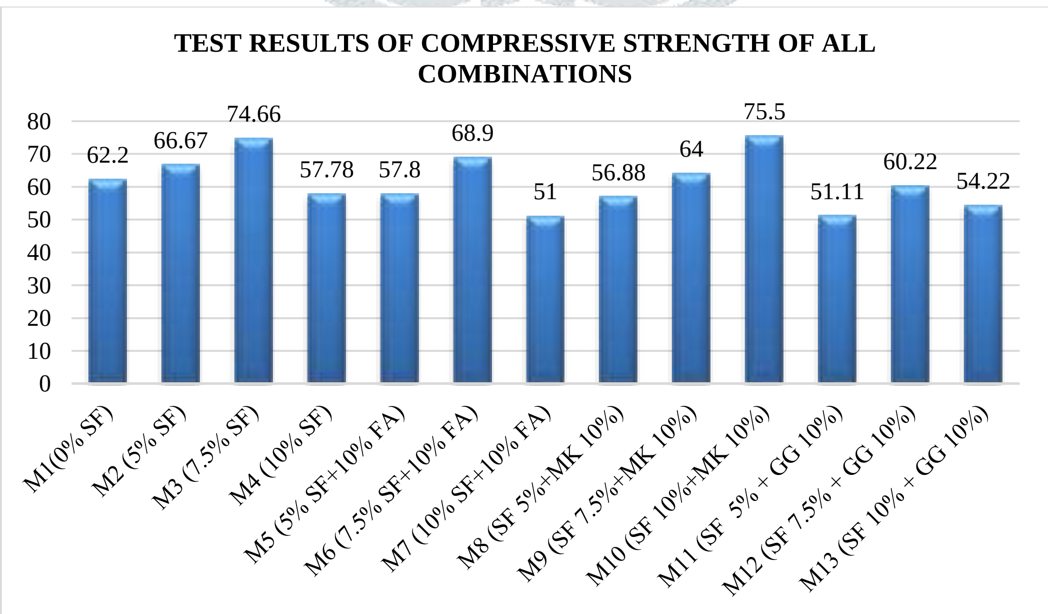
## 6.5 COMPRESHENSIVE RELATION OF DIFFERENT STRENGTHS OF ALL COMBINATIONS USED IN MIXES

### 6.5.1 COMPRESSIVE STRENGTH

The values of Compressive strengths of all combinations of mixes are tabulated below and their values are compared.

**Table 6.5: Test Results of Compressive Strength of all combinations**

| Type of combination of mix used | Compressive Strength, Mpa |
|---|---|
| M1(Reference Mix- 0% SF) | 62.20 |
| M2 (5% SF) | 66.67 |
| M3 (7.5% SF) | 74.66 |
| M4 (10% SF) | 57.78 |
| M5 (5% SF + 10% FA) | 57.80 |
| M6 (7.5% SF + 10% FA) | 68.90 |
| M7 (10% SF + 10% FA) | 51.00 |
| M8 (SF 5% + MK 10%) | 56.88 |
| M9 (SF 7.5% + MK 10%) | 64.00 |
| M10 (SF 10% + MK 10%) | 75.50 |
| M11 (SF 5% + GG 10%) | 51.11 |
| M12 (SF 7.5% + GG 10%) | 60.22 |
| M13 (SF 10% + GG 10%) | 54.22 |



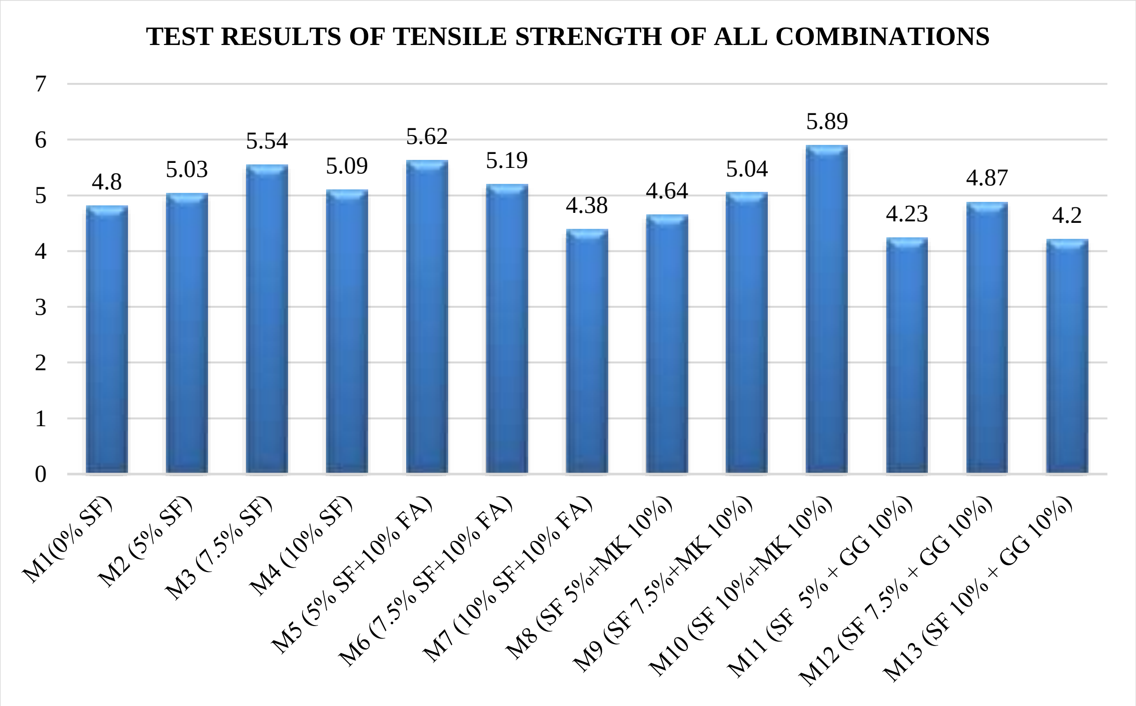

**Graph 6.5: Test Results of Compressive Strength of all combinations**

### 6.5.2 TENSILE STRENGTH

The values of Tensile strengths of all combinations of mixes are tabulated below and their values are compared.

**Table 6.6: Test Results of Tensile Strength of all combinations**

| Type of combination of mix used | Tensile Strength, Mpa |
|---|---|
| M1(Reference Mix- 0% SF) | 4.80 |
| M2 (5% SF) | 5.03 |
| M3 (7.5% SF) | 5.54 |
| M4 (10% SF) | 5.09 |
| M5 (5% SF + 10% FA) | 5.62 |
| M6 (7.5% SF + 10% FA) | 5.19 |
| M7 (10% SF + 10% FA) | 4.38 |
| M8 (SF 5% + MK 10%) | 4.64 |
| M9 (SF 7.5% + MK 10%) | 5.04 |
| M10 (SF 10% + MK 10%) | 5.89 |
| M11 (SF 5% + GG 10%) | 4.23 |
| M12 (SF 7.5% + GG 10%) | 4.87 |
| M13 (SF 10% + GG 10%) | 4.2 |




**Graph 6.6: Test Results of Tensile Strength of all combinations**

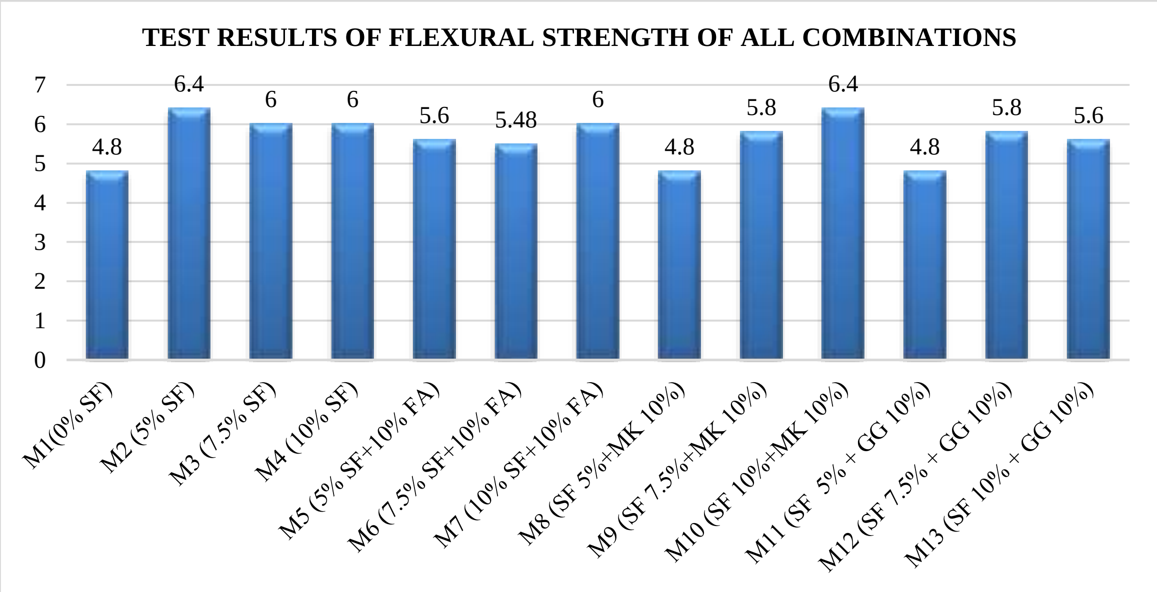
### 6.5.3 FLEXURAL STRENGTH

The values of Flexural strengths of all combinations of mixes are tabulated below and their values are compared.

**Table 6.7: Test Results of Flexural Strength of all combinations**

| Type of combination of mix used | Flexural Strength, Mpa |
|---|---|
| M1(Reference Mix- 0% SF) | 4.80 |
| M2 (5% SF) | 6.40 |
| M3 (7.5% SF) | 6.00 |
| M4 (10% SF) | 6.00 |
| M5 (5% SF + 10% FA) | 5.60 |
| M6 (7.5% SF + 10% FA) | 5.48 |
| M7 (10% SF + 10% FA) | 6.00 |
| M8 (SF 5% + MK 10%) | 4.80 |

| | |
|---|---|
| M9 (SF 7.5% + MK 10%) | 5.80 |
| M10 (SF 10% + MK 10%) | 6.40 |
| M11 (SF 5% + GG 10%) | 4.80 |
| M12 (SF 7.5% + GG 10%) | 5.80 |
| M13 (SF 10% + GG 10%) | 5.60 |




**Graph 6.7: Test Results of Flexural Strength of all combinations**

## VII. CONCLUSIONS

Based on the experimental investigation carried out, the following conclusions are made:

1. The super plasticizer demand of concrete containing fly ash and silica fume increases with increasing amount of fly ash and silica fume. The increase is primarily due to the high surface area of the fly ash and silica fume.
2. Fresh concrete containing fly ash and silica fume is more cohesive and less prone to segregation.
3. In the A series high strength concrete mix containing 7.5% Silica Fume shows highest Compressive Strength and Tensile Strength and mix containing 5% Silica Fume shows highest Flexural Strength.
4. In B series, the mix containing Silica Fume 7.5% and Fly Ash 10% shows highest Compressive Strength, the mix containing Silica Fume 5% and Fly Ash 10% shows highest Tensile Strength and the mix containing Silica Fume 10% and Fly Ash 10% shows highest Flexural Strength.
5. In C series, the mix containing Silica Fume 10% and Metakaolin 10% shows highest Compressive strength, Tensile and Flexural Strength.
6. In D series the mix containing silica fume 7.5% and GGBS 10% shows highest Compressive Strength, Tensile Strength and Flexural Strength.
7. The maximum compressive strength shown by mix M10 (10% SF + 10% MK) at 28 days of curing shows 75.5 Mpa which shows an increment of 17.61% of reference mix M1.
8. The maximum compressive strength shown by mix M7 (10% SF + 10% FA) at 28 days of curing shows 51 Mpa which shows a decrement of 18% of reference mix M1.
9. The maximum Tensile strength shown by mix M10 (10% SF + 10% MK) at 28 days of curing shows 5.89 Mpa which shows an increment of 18.5% of reference mix M1.
10. The minimum Tensile strength shown by mix M13 (SF 10% + GG 10%) at 28 days of curing shows 4.2 Mpa which shows a decrement of 12.5% of reference mix M1.
11. The maximum Flexural strength shown by mixes M2 (5%SF) & M10 (10% SF + 10% MK) at 28 days of curing shows 6.4 Mpa which shows an increment of 25% of reference mix M1.
12. The minimum Flexural strength shown by mixes M8 (SF 5% + MK 10%) & M11 (SF 5% + GG 10%) at 28 days of curing shows 4.8 Mpa which is equal to reference mix M1

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