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Study of effect of Silica Fume and Metakaolin combinations on strength properties of concrete

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Abstract

The use of supplementary cementitious materials is fundamental in developing low cost construction materials for use in developing countries. By virtue of adding pozzolanic materials to cement concrete the properties such as workability, durability, strength, etc. can get improved to a large extent. This project presents experimental investigation carried out to find the suitability of silica fume and metakaolin combination in production of concrete. It deals with M30 grade concrete by replacing cement with Silica Fume (0%,5%,10%,15%) and Metakaolin (0%,5%,10%,15%). Later combinations of Metakaolin and Silica Fume at highest strength of SF were carried. The current work focuses on studying mechanical properties of concrete in which silica fumes or metakaolin are replaced. The combinations will be compared with conventional concrete and results were be tabulated.

Keywords: Metakaolin, Silica Fume, Compressive strength, Split tensile strength, Flexural strength.

1. INTRODUCTION

Concrete is made from cement, fine aggregate, coarse aggregate and water. This hard and alkaline material along with steel is an excellent composite material used in the construction. The cement and water form glue or cream, which coats the sand and aggregate. When the cement is chemically reacted with the water, it is hardened and binds the whole mix. The setting of concrete takes place usually within a few hours. It takes some more weeks for concrete to get a full hardening and gain strength. So the time elapse the compression strength of concrete keep on increasing. With addition of pozzolanic materials such as metakoalin, GGBS etc. in certain proportions it is noticed that the compressive strength of concrete is improved.

Much research carried out for the betterment of concrete and its properties. In recent times concrete researchers are concentrating on secondary cementatious materials for the improvement of concrete and its strength etc. Hydraulic cement, a primary binder is produced on an average of two billion tons per year amounting to 2.5 tons of per capita consumption. Concrete structures got a perennial problem of contribution to CO_2 emission and as a result greenhouse effect. A method to reduce the cement content in concrete mixes is the use of some pozzolanic concrete materials. In this investigation some pozzolanic concrete materials were used that are metakaolin and silica fume are the partial cement replacement of concrete.

2. LITERATURE REVIEW

Varun Thampi et al (2016) Investigation studies on silica fume with recycled aggregates. Silica fume exhibited higher compressive strength when its percentage is 7.5 and for bending it is found to be 10%. Also at 7.5% replacement of silica fume showed higher flexural strength at both 7 and 28 days. Along with silica fume, recycled aggregates showed increase in strength up to 30% replacement.

Naresh Kumar (2014) From the investigation study concluded that when we replaced the metakaolin, the compressive strength got increased at all ages. It was also found that replacement 10% of metakoalin showed maximum 7 day and 28 day compressive strength. Silica also showed same behaviour at 10% replacement. Both silica fume and metakaolin when replaced independently showed improved flexural strength at all ages and maximum flexural strength at 10% replacement.

Vikas Srivastava et al (2012) have found that the optimum dosage of silica fume and metakaolin is 6% and 15% by weight correspondingly to get maximum compressive strength for 7 and 28 days. With increase in metakolin, the slump is decreased at all the silica fume contents.

Bhavanaben.K.Shah and Maitri Gajjar (2011) from the studies conducted, it was found that workability measured in terms of compaction factor decrease with the addition of silica fume/ metakaolin, whereas workability increased with activated fly ash. The optimum value of replacement of metakaolin is 9% for compressive strength and 10% for activated fly ash. Sorptivity & water absorption decreases with the increased silica fume or metakaolin, which leads in decreased permeability.

Abid Nadeem et al (2008) studied on effect of on the chloride permeability of high strength concrete and mortar specimens containing varying proportions of Metakaolin (MK) and Fly ash at elevated temperatures. Mixes with 5, 10 and 20 % of Metakaolin and 20, 40 and 60% of fly ash were prepared and tested by exposing 200, 400, 600 and 800^{o}C. In this study mortar mixes were also tested by exposing the above said temperatures. All concrete specimens had a minimum compressive strength of 85 N/mm^2. These studies showed that mortar is more chloride permeable than concrete even at higher temperatures such as 200°C and 400°C. Also it was noticed that the ratio of mortar to concrete chloride permeability was less at room temperature.

Poon et al (2001) studied compressive strength, porosity and pore size distribution along with hydration progress in high performance cement mortars made from Metakaolin. They established the fact that pozzolanic reactivity is proportionate to its strength.

Shannag (2000) investigated very high compressive strength of the range from 69 to 110 N/mm^2 concrete which is prepared by natural pozzolana and silica fume. From his investigation, concluded that 15% replacement of cement with silica fume along with 15% natural pozzolan gave relatively higher strength than without natural pozzolan.

3. MATERIALS AND METHODOLOGY

Cement: Ordinary Portland cement of 53 grade confirming IS 12269: 1987 was used in the study. Its Physical Properties are presented in Table 1

Table 1 Physical properties of cement

Parameters	**Result**
Specific Gravity	3.15
Standard Consistency	33%
Initial setting Time	90 min's
Final Setting Time	340 min's

Aggregates: Crushed angular granite metal obtained from local quarry was used as coarse aggregate having size ranging from 10mm to 20mm. The sand which was locally available and confirming Zone II of IS 383-1970is used as fine aggregate.

The properties of coarse aggregate and fine aggregate are presented in the Table 2.

Table 2 Properties of Aggregates

Properties	**Coarse aggregate**	**Fine aggregate**
Specific Gravity	2.78	2.67
Water Absorption	0.5%	1%
Fineness Modulus	7.52	3.05

Mineral admixtures: Commercially available Metakaolin was used for this study whereas silica fume from ASTRRA Chemicals, Moores Road, Moores Garden, Thousand Lights, Chennai, Tamil Nadu, India were used as admixtures.

The properties of mineral admixtures are presented in the Table 3 and 4

Table 3 Physical Properties of Admixtures

Physical Properties	**Test Results**	
	Silica fume	**Metakaolin**
Specific Gravity	2.6	2.5
Bulk density	0.76Gm/Cc	1.26

Table -4 Chemical Properties of Admixtures

Parameters	**Percentage by weight**	
	Silica fume%	**Metakaolin%**
Silicon Dioxide(SiO_2)	99.50	53.05
Alumina(Al_2O_3)	0.043	43.95
Iron oxide(Fe_2O_3)	0.040	0.5
Calcium oxide (CaO)	0.001	0.1
Magnesium oxide (MgO)	0.025	1.76
Sodium oxide(Na_2O)	0.003	0.05
Loss on ignition	0.015	0.30

Water: Close by available fresh bore well water confirming to the requirements of IS: 456 - 2000 was used for mixing concrete and curing the specimens as well.

Compressive strength:

Compression test is the most common test conducted on hardened concrete, because it is an easy test to perform, and most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. Compression test is carried out on specimen of cubical or cylindrical in shape. Compression test is done confirming to IS: 516-1959. Compression strength of concrete cubes are evaluated from hydraulically operated 2000 kN compression testing machines. Concrete cubes of size 150mm × 150mm × 150mm were tested for compressive strength. Compressive strength of concrete is determined by applying load at the rate of 140 kg/cm^2/minute till the specimens failed.

Based on the strength accessed by age, the cubes are taken out from the curing taken and placed under shade to dry, after sometime a clean dry cloth is taken to wipe off the cube surfaces. Cubes were tested at the age of 28 days using compression testing machine. The ultimate load before the cube fails is noted for three cube and an average value is expressed as cube strength.

Tensile strength:

This test is conducted in a 200 tones capacity of the compression-testing machine by placing the cylindrical specimen of the concrete, so that its axis is horizontal between the plates of the testing machine. Experimental setup for Split tension test is shown in Fig.5.2 .The load was applied uniformly at a constant rate until failure by splitting along the vertical diameter takes place. Based the equation suggested by IS: 5816 – 1970 the split tensile stress is calculated.

The following relation is used to find out the split tensile strength of the concrete

$$Ft = 2P/\pi DL$$

where P = Compressive load on the cylinder
L = Length of the cylinder
D = Diameter of the cylinder

FLEXURAL STRENGTH TEST

Flexural strength is one measure of the tensile strength of concrete. The flexural strength can be determined by Standard test method of third point loading or center-pint loading. In this study, three beams of size 100 mm × 100 mm × 500 mm were used to find flexural strength. The system of loading used for finding the flexural strength is shown in figure 5.3 and 5.4. In case of three point loading, the critical crack may appear at any section, of the pure bending zone.

Flexural strength is calculated using the following formula.

(a) When fracture initiates in the tension surface (i.e., the bottom surface) within the middle third of the beam, $MR = \frac{Pl}{bd^2}$

Where *P* is the failure load, *l* is the span length, *d* is the depth of the beam, and *b* is the width of the beam expressed in mm.

(b) If fracture initiates in the tension surface (i.e., the bottom surface) outside the middle third of the beam by not more than 5% of the span length.

$$MR = \frac{3Pa}{bd^2}$$

4. RESULTS AND DISCUSSION

4.1 Compressive Strength results

The variation of the cube compressive strength with the age of M30 grade concrete prepared using the various proportions of (5%, 10% & 15%) of Silica Fume (SF) and (5%, 10% & 15%) of Metakaolin (MK) are represented Graphically. For each category of concrete an average of compression strength of three cubes were considered. It can be observed that the compressive strength of concrete with 10% of Silica Fume and 10% of Metakaolin exhibits 29.39 % high Strength than the control concrete and then increase further in content of Metakaolin the strength will be decreases as shown in Fig. 4.1(a), 4.1(b) and4.1(c).

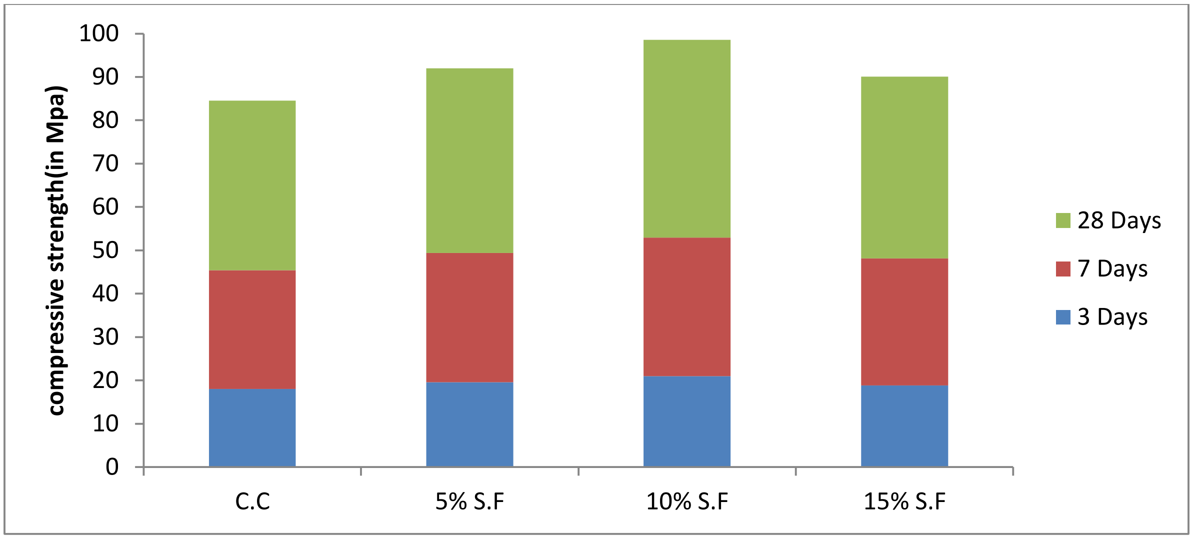


Fig. 4.1(a) Silica Fume

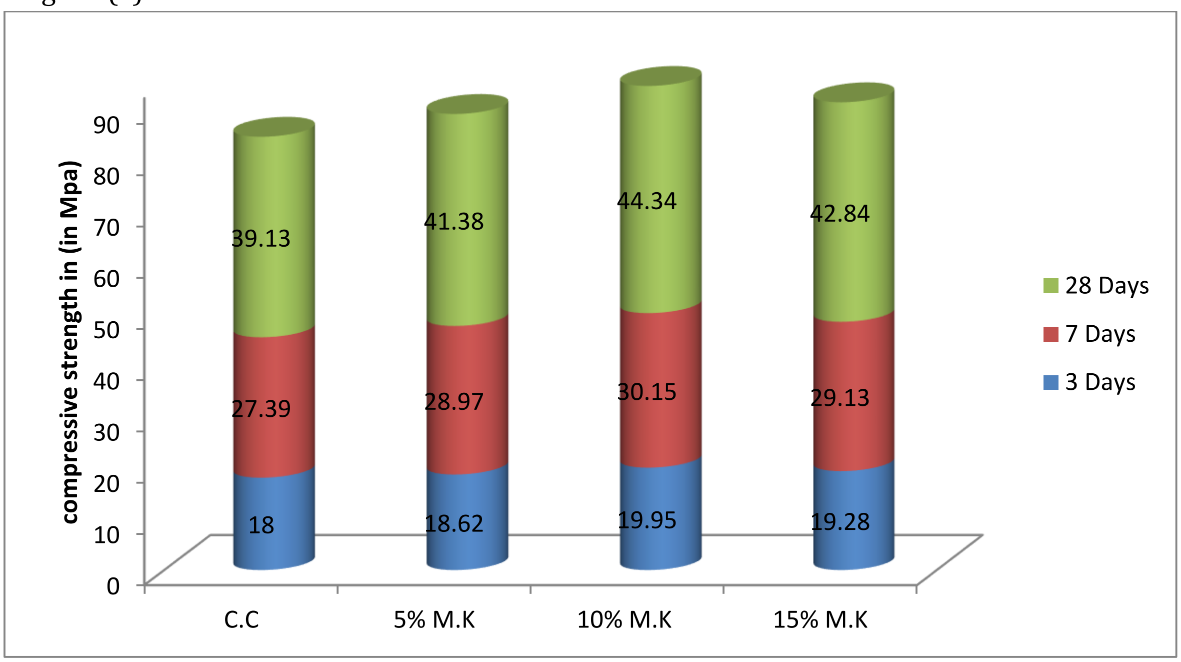


Fig. 4.1(b) Metakaolin

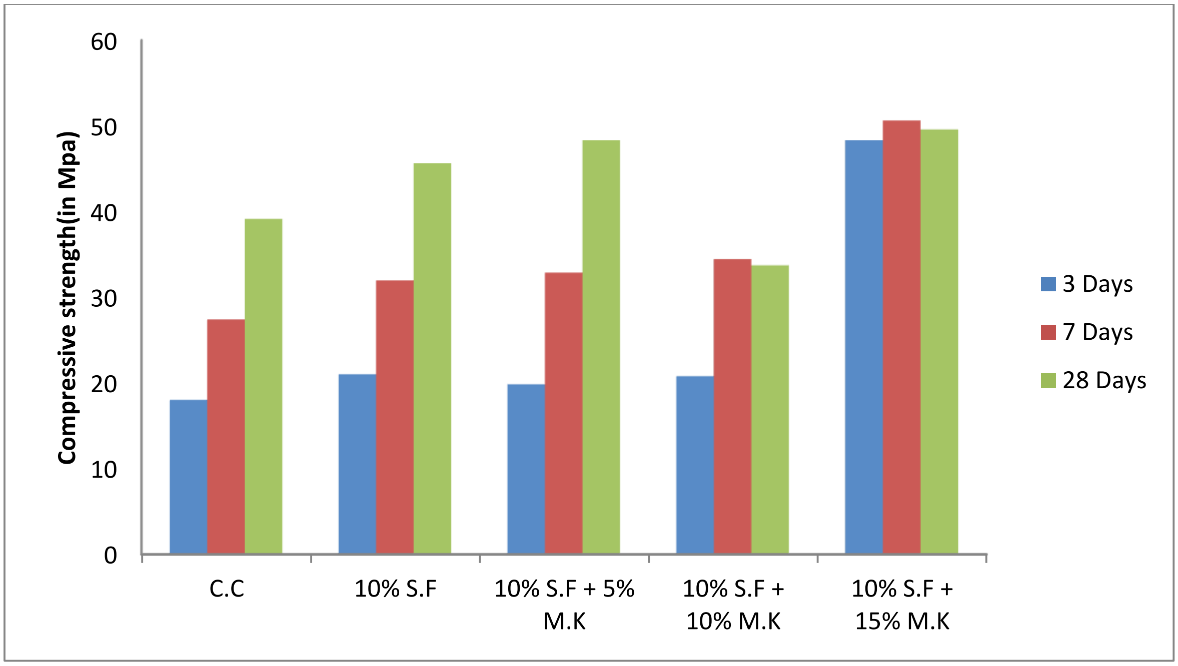
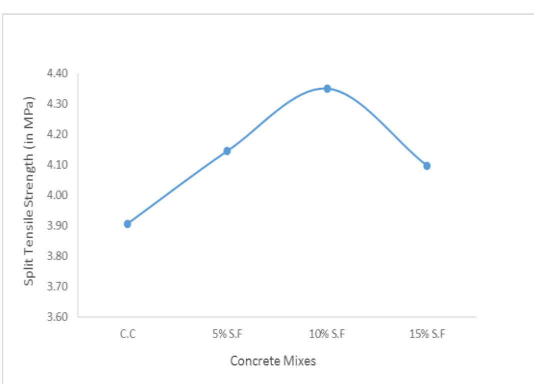


Fig. 4.1(c) Silica Fume and Metakaolin

4.2 Split Tensile Strength results

From the test of split tensile strength of M30 grade of control concrete is 3.91 MPa. The split tensile strength of concrete increases with all the proportions of Metakaolin (5%, 10% & 15%) and Silica Fume (5%, 10% & 15%), The Concrete with 10% of Silica Fume and 10% of Metakaolin possesses higher Split Tensile Strength when compared to all other proportions and with further increase in the content of Metakaolin, The split tensile strength decreases. The Ratio growth in the split tensile strength of M30 grade of concrete with 10% of Silica Fume and 10% of Metakaolin is 19.69 %. The Variation of Split Tensile Strength of M30 Grade of Concrete for Control Concrete and Metakaolin (5%, 10% & 15%), Silica Fume (5%, 10% & 15%) and Metakaolin (20%) & Silica Fume (5%, 10% & 15%) as shown in Fig. 4.2(a), 4.2(b) and4.2(c)



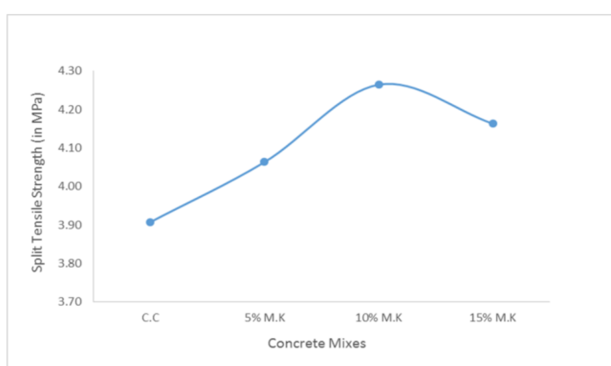


Fig. 4.2(a) Silica Fume

Fig. 4.2(b) Metakaolin

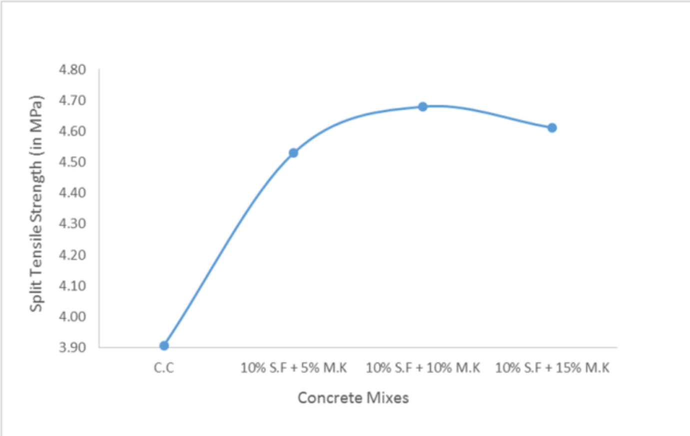


Fig. 4.2(c) Silica Fume and Metakaolin

4.3 Flexural Strength results

The Flexural strength of M30 grade of control concrete is 6.06 MPa. The Flexural strength of concrete increases with all the proportions of Metakaolin (5%, 10% & 15%) and Silica Fume (5%, 10% & 15%), The Concrete with 10% of Silica Fume and 10% of Metakaolin possesses higher Flexural Strength when compared to all other proportions and with further increase in the content of Metakaolin, The Flexural strength decreases as shown in Table No. 6.3. The Percentage increase in the Flexural strength of M30 grade of concrete with 10% of Silica Fume and 10% of Metakaolin is 22.44 %. The Variation of Flexural Strength of M30 Grade of Concrete for Control Concrete and Metakaolin (5%, 10% & 15%), Silica Fume (5%, 10% & 15%) and Metakaolin (20%) & Silica Fume (5%, 10% & 15%) as shown in Fig. 4.3(a), 4.3(b) and4.3(c).

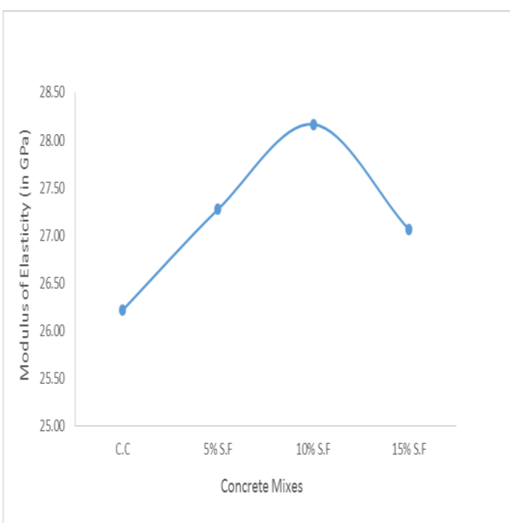


Fig. 4.3(a) Silica fume

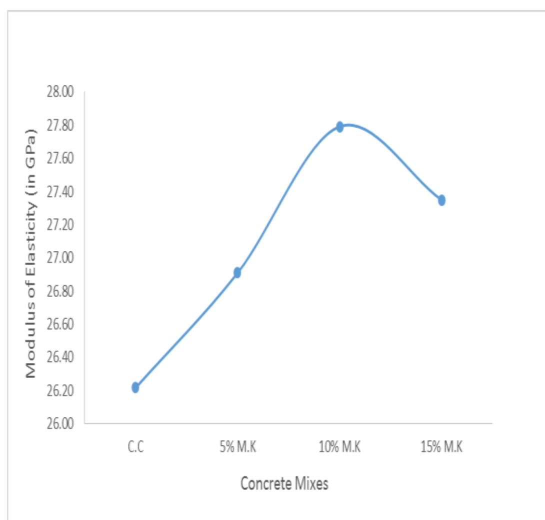


Fig. 4.3(b) metakaolin

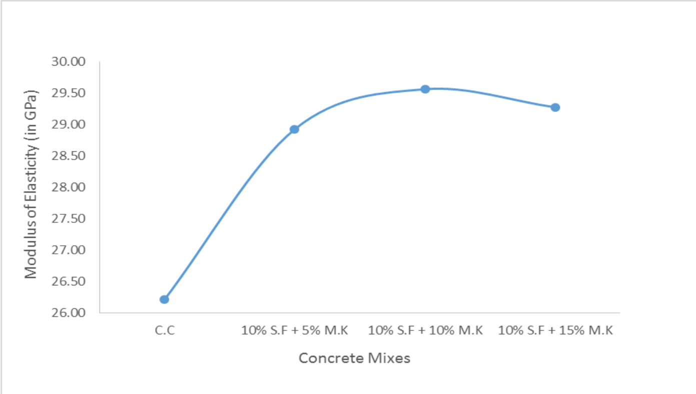


Fig.4.3(c) Silica fume and metakaolin

5. CONCLUSIONS

- At the initial ages, with the increase in the percentage replacement of Metakaolin and Silica Fume, the Compressive strength of Metakaolin and Silica Fume concrete is found to be increase gradually till 10% replacement of Metakaolin&10% Silica Fume and with further increase in dosage of Metakaolin it can be observed that the strength decreases.
- It is also observed that at individual replacements of Silica Fume and Metakaolin also shown improvement in Compressive Strength when compared to Control Concrete and the Percentage increase in replacement of Silica Fume and Metakaolin are 16.61 and 13.31 respectively.
- It can be observed that the compressive strength of concrete with 10% of Metakaolin&10% Silica Fume exhibits 29.69 % more Strength than the control concrete.
- Like development is observed in the case of Split Tensile Strength, There is 19.69 % increase in Split Tensile strength in Concrete (MK10% &SF10%) when compared to Control Concrete.
- Same trend followed in the case of Flexural Strength, There is 22.44 % increase in Flexural strength in Concrete (MK10% &SF10%) when compared to Control Concrete.

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