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Impact of Metakaolin and Silica Fume on Strength Characteristics of Concrete

R. Suresh Reddy* and Dr. K. Ramakrishnan

School of Civil Engineering, SASTRA University, Thanjavur – 613401- INDIA

Abstract: In the present scenario the cost of binder (cement) used in the construction has increased alarmingly leading to the increase in construction cost. To minimize the cost of construction, concrete made with various mixturesof Ordinary Portland Cement (OPC)with diverse mineral admixtures as partial replacementof cement is the dire necessity of the day.This research wok focuses to observe the effect of Silica fume (SF) and Metakaolin (MK)mixture as a partial replacement of cement in concrete.Cubes cast with chemical admixture i.e., Superplasticizer (SP)gives better results than with the normal mix. This paper elaborates the influence of partial replacement of OPC by SF (6%, 7.5% and 10%) and MK (10%, 12.5% and 15%) by weight in M25 and M50 grade concrete with SP. Compressive strength at the end of 7 and 28 days is carried out on cubes of various mix proportions of SF and MKas partial substitution of cement for different Water-Binder (w/b) ratio as 0.3, 0.35 and 0.4. Optimum mix proportion is obtained from the compressive strength test results. Beams are cast for the optimum mix proportion to determine flexural behaviour. It is found that all the mixes with the inclusion of MK and SF have improvement in strength over that of the control mix.From the experiment it is found that the mix (MK+SF)-5 has remarkable increase in strength by 43.8% and 13.8% over the control mix for M25 and M50 grade respectively.

Keywords : OPC, Metakaolin, silica fume, chemical admixture, compressive strength, flexural behavior.

Introduction

Concrete is the significantly used and adaptable construction material which is usually used to resist compressive forces. Cement is the chief constituent of concrete as it acts as a binder to obtaina hardened matrix. The large scale production of cement lead to emission of carbon dioxide, which causes global warming there by imposing environmental problems. The solution to this global issue is the use of SCMs as partial cement replacement. Mineral admixtures like MK, Ground Granulated Blast furnace Slag (GGBS), Fly Ash (FA), Rice Husk Ash (RHA) and SFetc. are generally used SCMs.Most of the recent concrete mixes are improved in its property by adding admixtures, which increase the microstructure and drops calcium hydroxide concentration by utilizing it in pozzolanic reaction[1]. By this change in microstructure there will be an increase in durability and service-life properties and improvement in mechanical properties.

MK is a thermally stimulated alumina-silicate material achieved during calcination of kaolin clay with in the temperature range of 650°C –800°C[2]. SF is a derivative obtained during carbothermic reduction in electric arc furnaces in the production of ferrosilicon and silicon alloys[3].By addition of these mineral admixtures different properties of concrete like strength, workability and durability can be improved. Surface area and particle size are most significant for mineral admixtures. Higher surface area with smaller particle size favors concrete and makes it highly reactive with the alkaline environment[4].

MK is highly reactive pozzolana which reacts quickly with additional $Ca(OH)_2$ [calcium hydroxide] obtained during hydration of OPC[5].OPC when replaced with 10-15% MK compressive strength at 14 days increases by 30% than control mix[6].MK is helpful in attaining concrete quality, by improving strength and reducing setting time[7]. Integration of MK in the cement paste gives very compact microstructure having lesser total porosity and finer pore size distribution compared with the Portland and SF blended cement pastes[8]. The decrease in autogenous shrinkage at early age is more at greater replacement levels of MK and creep of concrete is significantly condensed due to MK addition predominantly at higher level of replacement[9]. Test results shows that replacement of cement by MK up to 15% has enriched performance of concrete[10].

SF is very effective pozzolanic material which is efficient in improving strength characteristics to higher range. For all the w/b ratios, tensile strength shows improvement with respect to control concrete at 5 – 10% replacements of SF[11]. High proportions of SF does not suggestively improve splitting tensile strength and improvement was trivial past 15%[11].SF enhance mechanical characteristics as well as durability of concrete. The amount of Super Plasticizer (SP) has an effect on concrete strength[12]. SP can affect the concrete strength even at constant water-cement ratio [13].If quantity of SP is altered with percentage replacement of SF, then the alterations in strength of concrete will take place because of change in SP. Henceforth the quantity of SP hasto be kept uniform and then variation in properties of concrete at every w/b ratio occurs mainly because of the integration of SF[14]. Initial cracking in silica fume blended cement concrete appeared earlier when compared with control concrete[15].

In the current work, the experimental investigation on the combined effect of MK and SF on strength characteristics and beam behavior are carried out. Control mixes prepared are of grade M25 and M50 with different w/b ratios of 0.3, 0.35 and 0.4 and other mixes are with different proportions of MK and SF(by weight) as partial replacement of cement.

Experimental Investigation

Materials

Ordinary Portland cement of 43 grade confirming to IS 8112[16]was used for this experimental study. Crushed granite of size ranging 20mm – 10mm was used and specific gravity was found to be2.74 confirming to IS 2386 (part III)[17]. Natural river sand passing through IS sieve 4.75mm of specific gravity 2.65 confirming to gradation Zone-IIIwas used. Potable tap water available in the laboratory was used for mixing of concrete and curing. Conplast SP430 which is a chemical admixture complies with IS: 9103 [18]and ASTM-C-494 [19] Type 'F' as a high range water reducing admixture was used to improve the workability and reduce the water content. MK and SF which are used as SCMs were obtained from ASTRRA chemicals, Chennai. The physical and chemical properties of OPC, MK and SF are given in Table1.

Table 1: Physical properties and Chemical composition of OPC, MK and SF

Description	OPC	MK	SF
Physical Properties			
Color	Grey	Off white	Light grey
Specific gravity	3.1	2.7	2.3
Specific Surface area (m^2/kg)	367	17000	23000
Chemical Composition			
CaO (%)	62.8	0.8	0.52
SiO_2 (%)	20.3	53.7	91.4
Al_2O_3 (%)	5.4	40.8	0.61
Fe_2O_3 (%)	3.9	1.6	1.4
MgO (%)	2.7	0.3	0.1
Na_2O (%)	0.14	0.18	0.3
K_2O (%)	0.53	0.11	1.1

Mix Proportions

In the current study, mix design for M25 and M50 grade of concrete were done by using the guidelines of IS:10262[20]and IS:456 [21]with the above mentioned fine aggregate, coarse aggregate, and the admixtures. The proportion of the materials (by weight)were 1:1.58:2.9and 1:1.04:2.13 for M25 and M50 respectively. The proportion of SP added is 1.5%, 1.2% and 1% by weight of the total cementitous material for the w/b ratio 0.3, 0.35 and 0.4 respectively for all the mixes. To study the effect of silica fume and metakaolin blend as partial substitution of cement, specimens were cast for reference (normal mix) and other mixes with different replacement levels of metakaolin and silica fume (by weight) as given in Table 2with different w/b ratios of 0.3, 0.35 and 0.4.

Table 2: Mix Proportions with various replacement levels of MK and SF

Mix	Replacement level (%)	
	MK	SF
Control (C)	0	0
(MK+SF)-1	10	6
(MK+SF)-2	10	7.5
(MK+SF)-3	10	10
(MK+SF)-4	12.5	6
(MK+SF)-5	12.5	7.5
(MK+SF)-6	12.5	10
(MK+SF)-7	15	6
(MK+SF)-8	15	7.5
(MK+SF)-9	15	10

Specimen casting and curing

To examine the consequence of addition of metakaolin and silica fume combination (as partial replacement of cement), 100mm cubes and 100mm dia., 200mm height cylinders were cast for reference and additional mixes comprising different mix combinations of MK and SF. Chemical admixture is added in all the mixes as it gives better results and good workability. Based on the test results of compressive and tensile strength,100mm × 150mm × 1200mm size beam specimens were cast for optimum mix proportion obtained for both M25 and M50 grade of concrete. Concrete were placed in the well lubricated mould and compacted and the specimens were left at room temperature for 24hrs and after that specimens were placed in curing tanktill their testing ages.

Specimen testing

The compressive strength of different mixes were found out at 7 and 28 days and Tensile Strength were found out at 28 days in a compression testing machine of capacity 3000KN confirming to IS: 516 [22].Three specimens were cast for every mix for calculating mean of each test and the ultimate results were presented and compared with the reference mix.

For finding flexural behavior, beams were tested under two point loading. Test setup was given in Figure 1. The control of load over the test was 10 kN/min. The parameters like first crack load, ultimate load, load-deflection characteristics, crack and failure pattern were to be calculated.

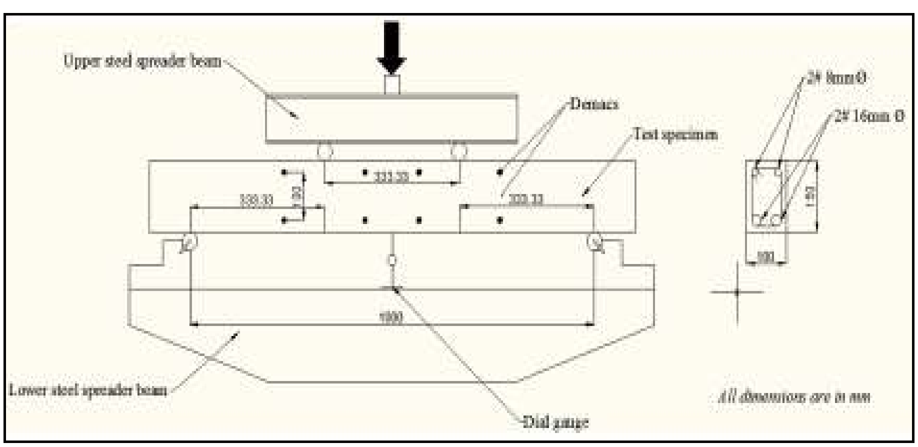


Fig.1 Test setup for Flexural behavior

Results and Discussions

Compressive strength

Compressive strength of these different mixes of M25 and M50 grade concrete with and without chemical admixture is given in Table 3.

Table 3: Compressive strength of normal mix with and without chemical admixture

Normal Mix	Strength for M25 (MPa)			Strength for M50 (MPa)		
	0.3	**0.35**	**0.4**	**0.3**	**0.35**	**0.4**
Without chemical admixture	28.7	27.1	25.6	60.4	57.9	55.4
With chemical admixture	31.9	30.7	29.8	62.9	61.2	60.4

28 days compressive strength results for mix with chemical admixture gives better results than normal mix without chemical admixture. So, chemical admixture is added for all the mix proportions of both grades.

Compressive strength results were found out for different mixes with chemical admixtures at 7 and 28 daysand the results are given in Figure2 and Figure 3.

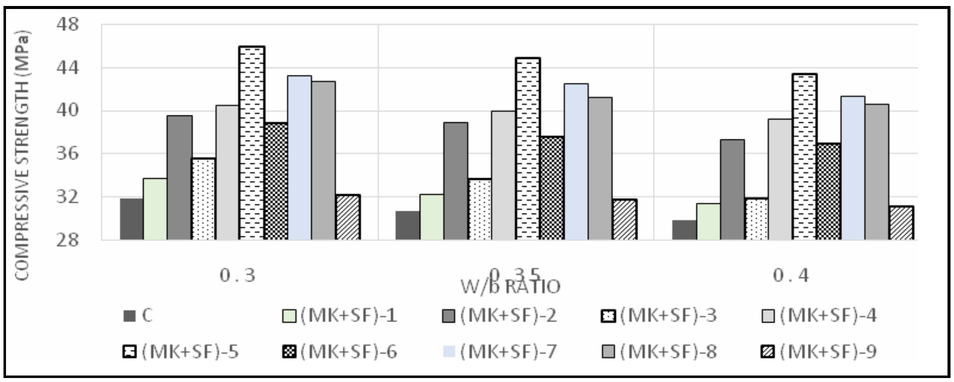


Fig.2 28days compressive strength results of M25 grade concrete mixes

From the results, it is clear that (MK+SF)-5 having 20 % replacement level with 7.5% SF and 12.5% MK gives higher compressive strength than control mix for all w/b ratios at all ages.

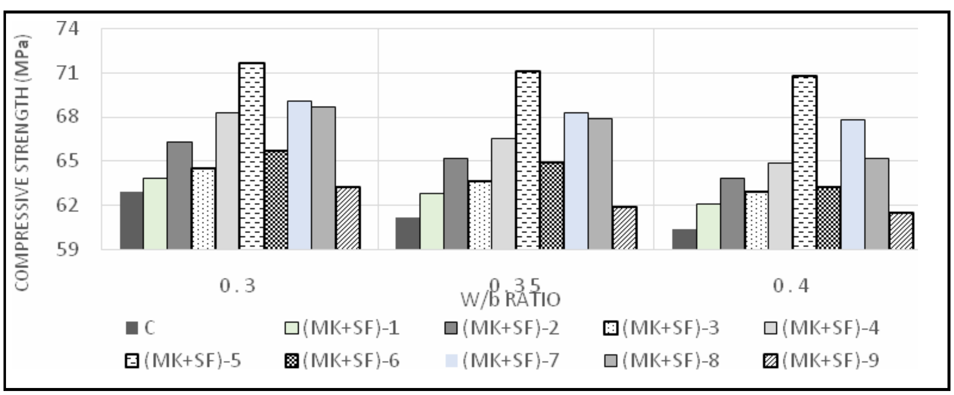


Fig.3 28days compressive strength results for M50 grade concrete mixes

For the mix (MK+SF)-5 there is an increase in strength by 43.8% and 13.8% than control mix for M25 and M50 grade respectively. Depending on the test results of compressive strength, beams were cast for the optimum mix proportion. The compressive strength improvement is due to the filler effects and pozzolanic reaction of SF, MK.

Split tensile strength

The findings in tensile strength gives the similar results as compressive strength.For all the w/b ratios, SF and MK replacements significantlyincrease the split tensile strength with reference to control for both M25 and M50 grade. Strength at 28 days for different w/b ratios are given in Figure 4 andFigure 5.

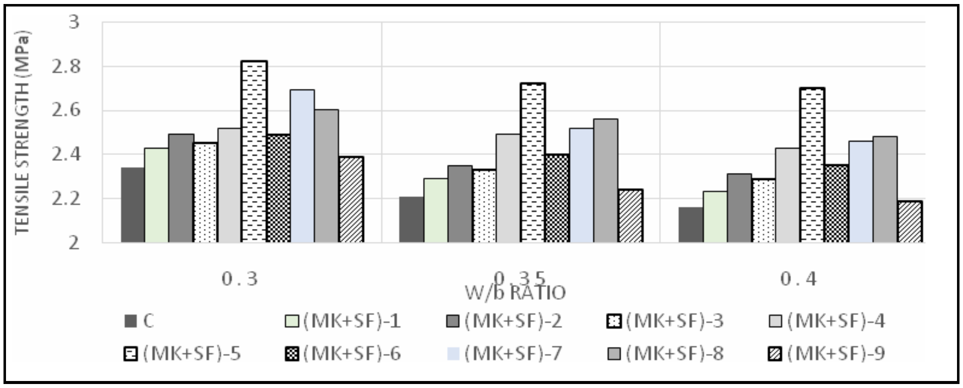


Fig.4 28days split tensile strength values for M25 grade concrete mixes

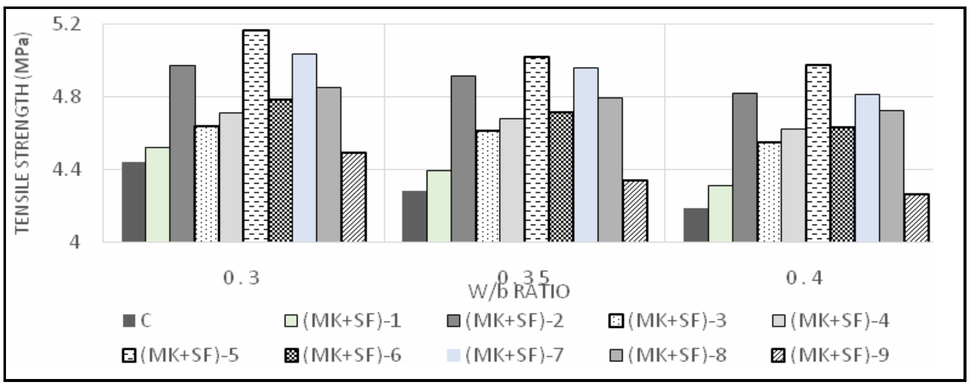


Fig.5 28days split tensile strength values for M50 grade concrete mixes

In M25 grade, it was observed that the rate of average increase of tensile strength i.e., 7.7% was found to be low when compared with that of compressive strength i.e., 43.8%. For M25 grade concrete the percentage increase of tensile strength increases with increase in w/b ratio. Tensile strength increases by 20.5%, 23.08% and 25% for w/b ratios 0.3, 0.35 and 0.4 respectively for M25 grade concrete mixes. There is an increase in tensile strength for mix (MK+SF)-5 by 20.5% and 16.2% than control mix for M25 and M50 grade respectively.

Flexural behavior

- First crack load:

  The first crack load for beams of M25 and M50 grade are given in Figure 6. It can be seen that optimum mix i.e. (MK+SF)-5 exhibits higher first crack load than the control mix for both the grades of concrete.From this, it is evident that the inclusion of SF and MKin concrete hasimproved the flexural strength of thebeams as it delays the development of first crack.

- Ultimate load:

  The ultimate load for beams of M25 and M50 grade are given in Figure 6. It can be seen that ultimate load of 90.5kN and 140.95kN has been achieved for mix (MK+SF)-5 which is 15.2% and 12.7% higher than M25 and M50 control beams respectively.

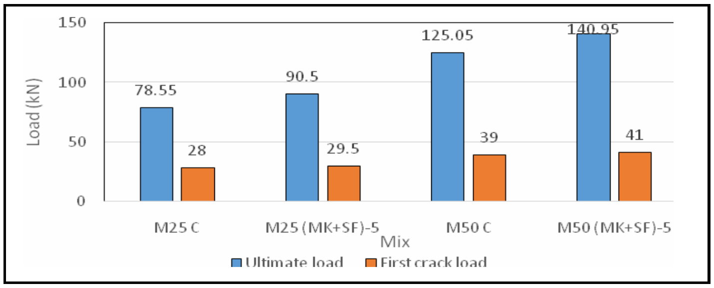


Fig.6 Ultimate load and First crack load for different mixes

- Load – deflection behaviour:

  At every load increment, it was noted that the beam with optimum mix has higher deflection values in comparison to that of control beam. This shows that the replacement of cement by SF and MK leads to ductile behaviour. The maximum deflection for M25 and M50 grade beams of different mixes are given in Figure 7.

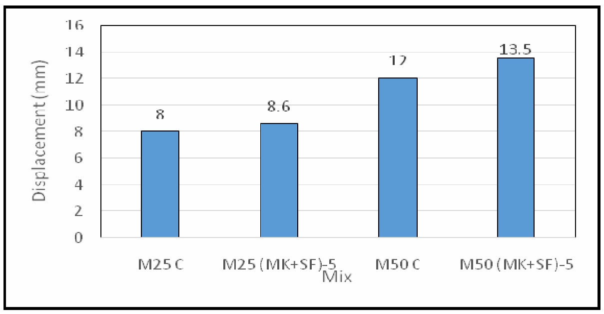


Fig.7 Maximum deflection for different mixes

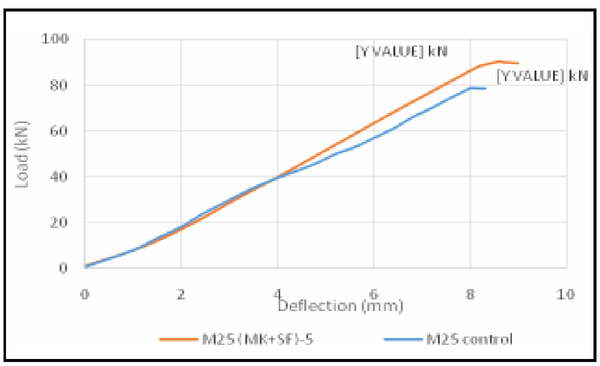


Fig.8 Load – deflection behavior of beams of M25grade mixes

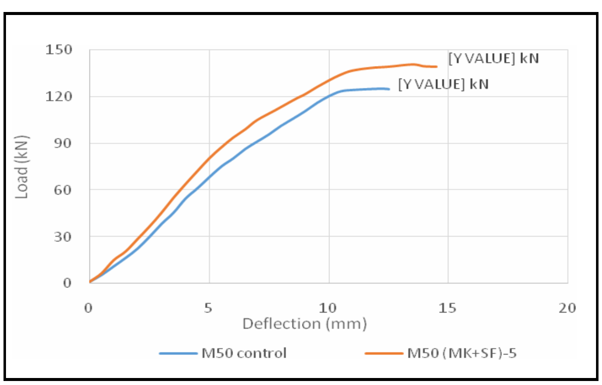
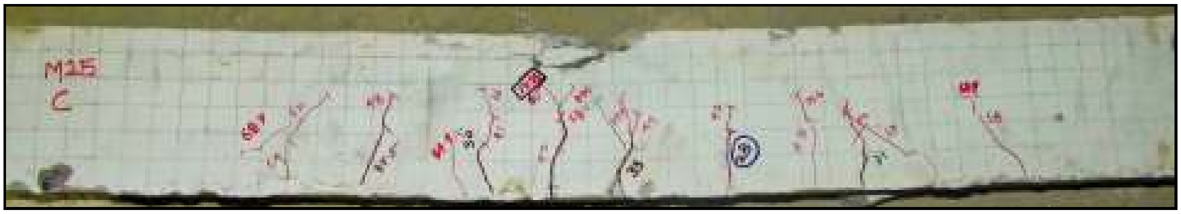


Fig.9 Load – deflection behavior of beams of M50 grade mixes

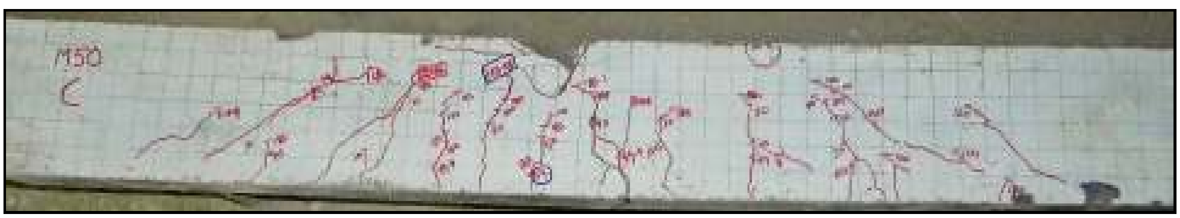
➢ Crack pattern and failure mode:

Cracks and failure pattern are shown in Figure 10.First flexural cracks were formed in the constant moment zone and these cracks are extended vertically upwards and developedgradually wide as the load is increased. Cracks are started in the shear spans of the beam also with increased loads. The final failure of the beam is described by large strains in the steel reinforcement &considerable deflection near collapse followed by extensive cracking.

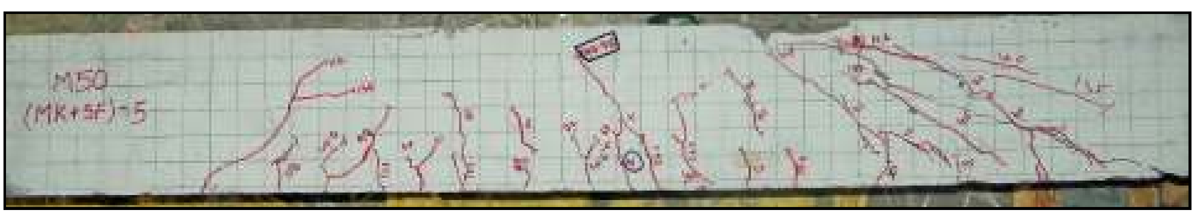


a. Crack pattern for M25 control beam

b. Crack pattern for M25 optimum mix (MK+SF)-5 beam



c. Crack pattern for M50 control beam



d. Crack pattern for M50 optimum mix (MK+SF)-5 beam

Fig.10Crack pattern and failure mode for tested beam specimens

Conclusions

Based on the results obtained in this experimental study the following conclusions were made:

➢ Addition of chemical admixture i.e., SP reduces water requirement by great extent and increases the workability.
➢ The optimum dose of MK and SF in combination is found to be 12.5% and 7.5% (by weight) respectively as a partial replacement of cementfor both M25 and M50 grade for all w/b ratios to achieve high compressive strength at the end of 7 and 28 days.
➢ The inclusion of MK and SF results in faster early age strength development of concrete. The average increase in strength at 7days is 12.82% and 28.17% for M25 and M50 grade respectively.
➢ There is an increase in 28 days strength for optimum mix (MK+SF)-5 by 43.8% and 13.8% over the control mix for M25 and M50 grade respectively.

- The split tensile strength of concrete for all mixes using MK and SF combination as partial replacement of cement is higher than control mix.
- The Ultimate load and first crack load for the beams with optimum mix is higher than the control beam for both grades due to the immediate filler effect, the acceleration ofcement hydration.
- Maximum deflection for the beam with mix (MK+SF)-5 is increased by 7.5% and 12.5% over the beam with control mix for M25 and M50 grade respectively.
- The results encourage the use of Metakaolin and silica fume, as pozzolanic material for partial cement replacement in producing high strength concrete and can compensate for environmental, technical and economic issues caused by cement production.

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