A Study on Partial Replacement of Cement with Silica Fume in Steel Fibre Reinforced Concrete

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***Abstract:*-This research investigates and evaluates the results for M-40 grade of concrete having mix proportion 1:1.45:3.12 with water cement ratio 0.35 of steel fibre reinforced concrete (SFRC) by partial replacing of cement with Silica Fume of 4% 6% 8% 10% and containing steel fibres of 2% and 2.5% volume fraction, steel fibres of 50 aspect ratio were used to study the compressive strength, flexural strength, Split tensile strength. A result data obtained has been analyzed and compared with a control concrete specimens (0% fibre). A relationship between percentages of silica fume vs. Compressive strength, flexural strength, and Split tensile strength respectively are represented graphically. Result data will be clearly shown the percentage increase in 28 days of Compressive strength, Flexural strength and Split Tensile strength for M-40 Grade of Concrete, and to study of application of material in Structural elements like long beam for the deflection check. Two long beams are casted with the minimum reinforcement, one with conventional concrete and one with optimum percentages of silica fume and steel fibres. The long beams are subjected to two point loading and deflections readings are recorded, analyzed and compared with conventional concrete and theoretical values respectively. The strength and deflection of optimum concrete mix are appreciable when compare with conventional mix.**

Key Words: Silica fume; steel fibre; concrete; reinforcement; deflection; cracks.

I. INTRODUCTION

1.1 General

The attention of the engineers in charge and users of cement is drawn to the fact that quality of various pozzolana cements is to be determined on the basis of its conformity to the performance characteristics given in the respective

Indian standard specification for that cement concrete is most widely used construction material in the world due to its ability to get cast in any form and shape. It also replaces old construction materials such as brick and stone masonry. The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cementious material, aggregate and water and by adding some special ingredients. Hence concrete has some deficiencies, to overcome these deficiencies different types of materials are used

1.2 Importance of High Strength Concrete

High Strength Concrete (HSC) has been developed over the last two decades, and was primarily introduced through private sector architectural design and construction such as high rise buildings and parking garages. HSC is used for concrete mixtures, which possess high workability, high strength, high modulus of elasticity, high density, high dimensional stability, low permeability and resistance to chemical attack. According to ACI "High Strength Concrete is defined as concrete which meets special Strength and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing and curing practices".

1.3 Need for this study

Since structural concrete is used extensively in the construction ofvarious kinds of buildings, consumed at a rate of approximatelyone ton for every living human beingand aggregate contributessignificantly to the structural performance of concrete, the highdemand for concrete using raw materials such as cement, sand and gravel drastically reduces the natural resources and this damages the environment thereby causing ecological imbalance. Therefore, there is a need to explore and to find suitable additive material to obtain the high strength concrete productions are metallic fibres, non- metallic, pozzolanas, admixtures, etc.,.

Fibre reinforced concrete (FRC) is one of the special concrete under high strength concrete (HSC) which is recently developed in the concrete world. Though the basic properties of FRC, mechanical properties of FRC , bond properties of FRC and long term performance of FRC are in acceptable range, for structural applications, knowledge of the behavior of structures is essential for design so that an economical structures can be obtained consistent with safety and serviceability. Since, behaviors of reinforced lightweight FRC beam under flexure and shear had been already studied and published in the earlier publication, this study investigated and presented the experimental evaluation of partial replacement of cement with silica fume in Steel Fibre Reinforced concrete.

II. SILICA FUME (SF)

Silica fume is the most abundant mineral found in the crust of the earth. It forms an important constituent of practically all rock – forming minerals. Silica fume is a by product in the carbothermic reduction of high purity quartz with carbonaceous materials like coal, coke, wood – chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys. It is found in variety of forms, as quartz crystals, massive forming hills, quartz sand (silica fume), sand stone, quartzite, Tripoli, diatomic, flint, opal, chalcedonic forms like agate, onyx etc.., and in with numerous other forms depending upon colour such as purple quartz (amethyst), smoky quartz or false topaz (citrine), rose quartz and milky quartz. One of the major occurrences of silica is in sans stone.

Silica fume is an ultra fine material with spherical particles less than I um in diameter, the average being about 0.15 um. This makes it approximately 100 times smaller than the average cement particle. The bulk density of silica fume depends on the degree of deification in the silo and varies from 130(undensified) to 600 kg/m3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume typically ranges from 15,000 to 30,000 m2/kg.

III. FIBRE REINFORCED CONCRETE (FRC)

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC). Ordinary Portland cement, river sand, crushed granite stones, steel fibres and water are the constituents used for making FRC. Both for FRC and CC, minimum compressive strength of 40 N/mm^2 at 28-days was fixed as target strength with minimum workability considerations. If the steel fibres are used in FRC then the concrete is called as steel fibre reinforced concrete (SFRC). Steel fibres of aspect ratio (1/d ratio) 50 are collected from the local dealer and transported to SRM University premises. The Collected steel fibres and silica fume are shown in Fig. 1a and 1b respectively. From the previous studies, mix proportions were selected and the properties of mixes are shown in Table 1.

Fig.1 a) silica fume

Fig.1 b) Steel fibre

Table 1 Properties of concrete used

Parameters	Control concrete (CC)	SFRC with SF
Minimum target strength (N/mm^2)	40 - 45	40 - 45
Cement content (kg/m^3)	480	480
Sand (kg/m^3)	730	730
Crushed granite stone (CGS) (kg/m^3)	1510	1510
Silica fume %	--	0, 4, 6, 8 & 10
Steel fibre %	--	0, 2 & 2.5

Water Cement Ratio (W/C)	0.35	0.4
Mix ratios	1:1.52:3.16:0.35 (Cement: Sand: CGS: W/C)	1:1.52:3.16:0.35 (Cement: Sand: CGS: W/C)
Slump (mm)	5	5
Fresh state density (kg/m^3)	2486	2762
28 day hardened density (kg/m^3)	2413	2658

IV. EXPERIMENTAL INVESTIGATION

4.1Test program

High strength concrete has been produced using silica fume and steel fibre. Nine cubes, six cylinders and three beams were casted and tested. Two long beams, one with steel fibre – silica fume (optimum percentages) and one with normal control concrete. Study includes the general cracking behavior and analysis, crack width and deflection.

4.2 Specimen and reinforcement details

The cross sectional dimension of beam was taken as 100 × 100 mm and the length of the beam was taken as 500 mm, cylinder of 100mm dia with 200mm length, cubes of 100 mm for both CC and SFRC-SFmixes. In both the cases the grade of concrete has been considered as M40. The cross sectional dimension of long beams was taken as 150 × 200 and length was take as 1500 mm. The Fe 415 grade of steel was used for both longitudinal and transverse reinforcements. Table 2 show the details of minimum longitudinal reinforcements and spacing of transverse reinforcements required and actually provided respectively.

Table 2 Details of reinforcements for both CC and OM long beams

Beams Id	Area of longitudinal reinforcements (mm^2)		Spacing of transverse reinforcements (mm)	
	Minimum	Actually Provided	Minimum	Actually Provided
CC & OM	217	227	142	150

CC: Conventional Concrete OM: Optimum Mix

The diameter and the number of bars used for longitudinal reinforcements, diameter and the spacing of bars for transverse reinforcements are calculated and given in Table 3, respectively. Fig. 2shows the schematic diagram of the plan, elevation and section of the specimen with loading points. The beams has been designed and made strong to avoid the failure, especially at the middle portion.The cross sectional and the reinforcement details of the portion are shown in fig. 2 The beam size and length were chosen to ensure that the beams would fail in deflection and also to testthe specimen with the loading frame and the testing facilities available in the structural laboratory of SRM University

4.3 Specimen preparation

Formwork making use of plywood was prepared for the beam size. Reinforcements were made ready as per the details given in Table 2 .The inner surfaces of the mould were coated with a thin film of crude oil to prevent adhesion of concrete with the mould before placing the reinforcements. All the ingredients of the mix were weighed and machine mixed. The concrete was placed in three layers and internally compacted using a needle vibrator after placing the reinforcements. Care was taken to give uniform compaction for the specimens. Without delay after the beam cast, the beams were covered with plastic sheet to minimize the evaporation of water from the surface of the beam specimen. After 24 h, the sides of the formwork were removed and cured continuously with wet gunny bag for 28days, after which the beams were left alone until the time of test. Before testing, beamswere whitewashed to facilitate the observations of cracking patterns during the tests. Location of effective span, centre lines and the loading points were measured and marked.

Table 3 Diameter, number of bars used in long beams

Beam Id	Longitudinal reinforcements	Transverse reinforcements
CC & OM	2 # 10mm dia at top 2 # 12mm dia at bottom	8mm dia @ 150 mm c/c

4.4 Instrumentation for testing

The testing was done in a loading frame of capacity 40 tones. Load was applied by means of a hydraulic jack of capacity 25 tones. The load was measured using a proving ring of 20 tones capacity.Twists of the beam were measured by using dial gauges which are fixed at both the sides of twist meter, with a least count of 0.01 mm

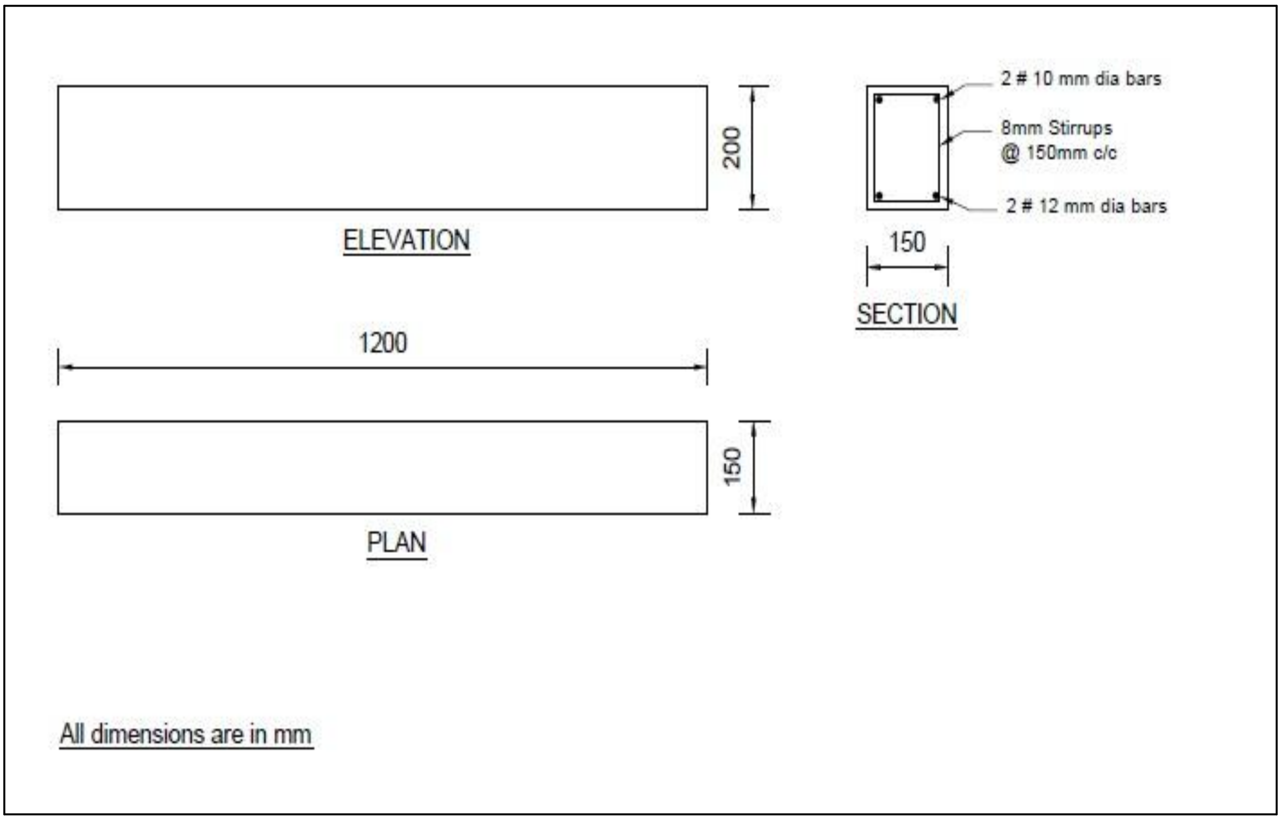

Fig. 2 Plan Elevation and Section of Beam Specimens

4.5 Conduct of experiments

The experiment conducted was explained here in a detailed manner and a side view of the complete experimental set up is shown in Fig. 3. The beam to be tested was lifted and kept inside the loading platform of the frame where the steel roller supports were made ready to carry the beams on both edges to act as simply supported beam. Indian standard medium beam (ISMB) 175 steel beam was placed parallel and seated on the top surfaces of the beam. Hydraulic jack of 25 T capacities was placed above the ISMB I75 for application of load. 20 T capacity proving ring was placed above the hydraulic jack at its centre. The beam was so adjusted that the centers of the proving ring and beams are in the same line by using plumb-bob. Dial gauge was fixed at the mid-point of the beam portion and supports are placed 5 cm away from either edges of the beam. The beam loading is done as of two point loading simply supported beam. Now the arrangement has been made ready for performing the experiment and the dial gauges were also set for zero before the start of tests. Load was constantly applied through the hydraulic jack. ISMB usedtransferred the load to its edges equally. Beams were allowed and subjected to a constant increase in rate of loading till the ultimate load was reached. Fig. 4shows the side view of specimen test arrangements respectively. Fig. 4 shows that the specimen under testing. Fig. 5 shows the tested specimens of both CC and OM beams respectively

Fig. 3 Test arrangement of specimen

Fig. 4 specimen under testing

Fig. 5 Tested CC and OM beams

V. RESULTS AND DISCUSSION

Before the discussion about this study, authors feel that it is necessary refresh the background of Silica fume concrete and Fibre reinforced concrete established elsewhere. These two concrete are belongs to high strength concrete, the High-strength concrete has a compressive strength greater than 40 MPa (5800 psi). High-strength concrete is made by lowering the water-cement (W/C) ratio to 0.35 or lower. Often silica fume is added to prevent the formation of free calcium hydroxide crystals in the cement matrix, which might reduce the strength at the cement-aggregate bond. Low W/C ratios and the use of silica fume make concrete mixes significantly less workable, which is particularly likely to be a problem in high-strength concrete applications where dense rebar cages are likely to be used. As we known the optimum percentage of silica replacement for cement is about 7% to 8% this percentage gives 20% to 25% higher strength with compare to conventional concrete. Where in fibre reinforced concrete the 2% to 2.5% is optimum percentage for addition of fibres in weight fraction.

In this study the M40 grade of concrete is used, and the cement is partially replaced by 0%, 4%, 6%, 8% and 10% with of silica fume, the fibre is of 0%, 2% and 2.5% to the weight of concrete. The results obtain in this study was appreciable, the combined optimum percentage is about 10% of silica fume replacement and 2.5% of fibre addition. This percentages give the more appreciable results when compared with other percentages and conventional concrete. The optimum percentages gives 28%, 70% and more than 75% higher results in compression test, split tensile test and flexure test respectively when compare to conventional concrete.

5.1 compression strength

Table 4 depicts that when cement is replaced by SF and 2.5 % of steel fibres are added, the maximum 7 days cube compression strength observed as 511.7 N/mm^2 and 28 days strength obtained as 56.4 N/mm^2 respectively when cement is replaced by SF. The 28 days compression strength curve is shown in Fig. 6 From the properties exhibited by concrete using silica fume replacing cement it is observed that there may be marginal loss of strength initially but the same improves effectively both with the age and incorporation of SF in place of cement. The increase in the strength development is due to the fact that silica fume dissolves in saturated solution of $Ca(OH)_2$ within few minutes. Calcium Silica Hydrate (C-S-H) gel is formed on the surface of silica fume particles. This gel produced by SF concrete has lower C:S ratio than that resulting from the normal cement concrete without silica fume.

Table. 4 compression strength of concrete 3,7 & 28 days in N/mm^2

Fibre 2%						**Fibre 2.5%**					**CC**
silica	**0**	**4**	**6**	**8**	**10**	**0**	**4**	**6**	**8**	**10**	**0**
3 days	28.4	28.7	29.3	31.8	32.2	29.2	28.8	31.4	34.2	33.5	28.5
7 days	37.7	39.7	42.2	48.1	46.7	38.9	37.4	47.9	50.2	51.7	36.3
28 days	47.2	46.4	48.6	53.1	52.2	48.7	50.2	51.7	55.8	**56.4***	43.9

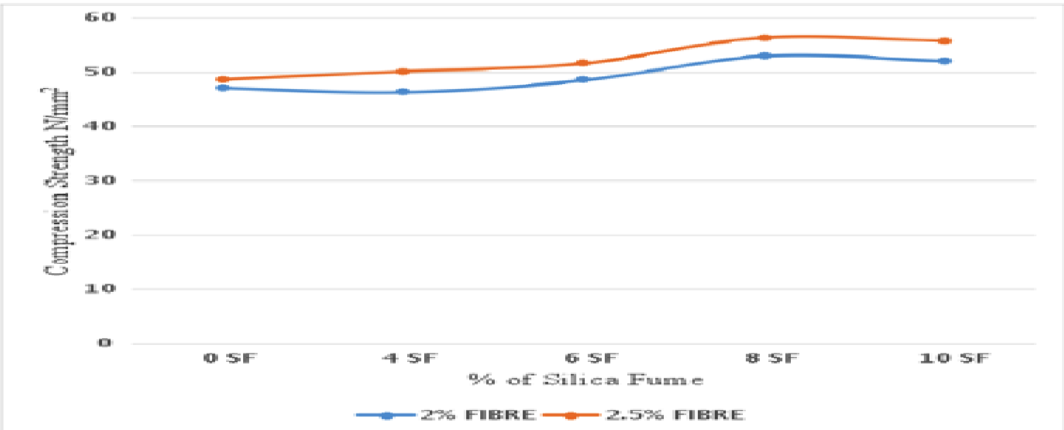

Fig.6. 28days compression strength cruve

5.2 Splilt Tensile Strength

From Table 5.2 and Fig. 5.2 it is clear that the maximum cylinder split tensile strength is found to 5.12 N/mm^2 at 10% cement replaced by SF and adding 2.5% of fibres (70% more than that of normal concrete).this tensile strength is mainly due to the presence of steel fibres which are strong in tension. Due to the presence of steel fibre the formation of micro cracks are reduced very much due to this the steel fibre bears the tensile load acting on the concrete, hence steel is good in tension the failure of the concrete will be arrested at higher loads. From the previous reasearch the silica fume also contribute 25% to 30% increase of tenile strengh.

Table 5 Split tensile Strength of concrete for 3, 7 & 28 days in N/mm^2

	Fibre 2%					Fibre 2.5%					CC
Silica	**0**	**4**	**6**	**8**	**10**	**0**	**4**	**6**	**8**	**10**	**0**
3 days	3.24	3.43	3.47	3.59	3.50	3.56	3.78	3.85	3.69	4.04	2.29
7 days	3.31	3.66	4.26	3.98	4.04	4.04	3.85	4.48	4.39	4.64	2.48
28 days	4.64	4.74	4.80	4.90	5.02	4.71	4.82	4.91	5.06	**5.12***	3.02

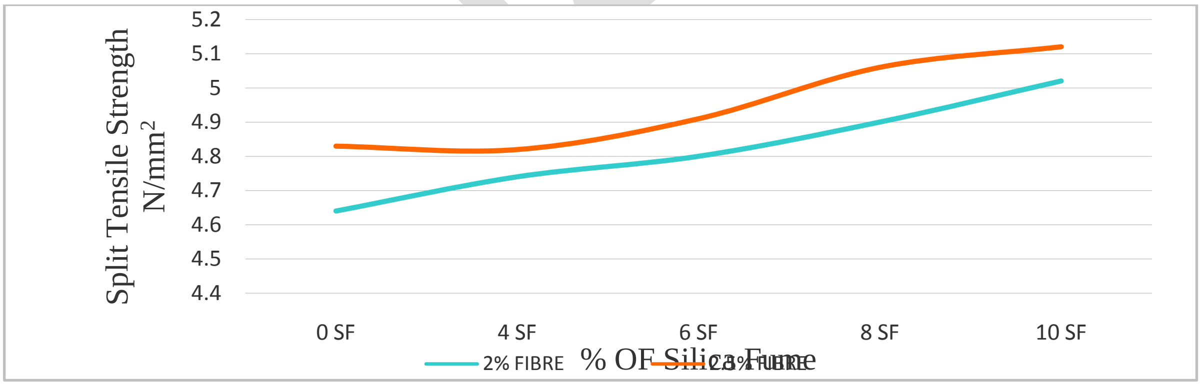

Fig.7 28days Split tensile strength cruve

5.3 Flexural Strength

From the Table 5.3 and Fig. 5.3 it is clear that the maximum flexural strength is 6.4 N/mm^2 at 10% cement replaced by SF and 2.5% of fibres (75% more than that of normal concrete)this value is far more than the value calculated from the expression $0.7(Fck)^{1/2}$ as specified by IS 456-2002 the Sf besides reacting with the free lime of cement and contributing to bind themselves tightly. The binding along the steel fibre results the aggressive flexure results.

Table 5 Flexural Strength of concrete for 3, 7 & 28 days in N/mm^2

Fibre 2%						Fibre 2.5%					CC
silica	0	4	6	8	10	0	4	6	8	10	0
3 days	2.4	1.6	2.4	2.8	3.2	1.2	2.4	2	2.4	3.6	1.2
7 days	2.4	2	2.8	3.2	3.6	2.8	2.4	3.2	4	4.8	2.8
28 days	3.6	4.4	4	5.6	5.6	4	3.6	3.6	5.6	**6.4***	2.8

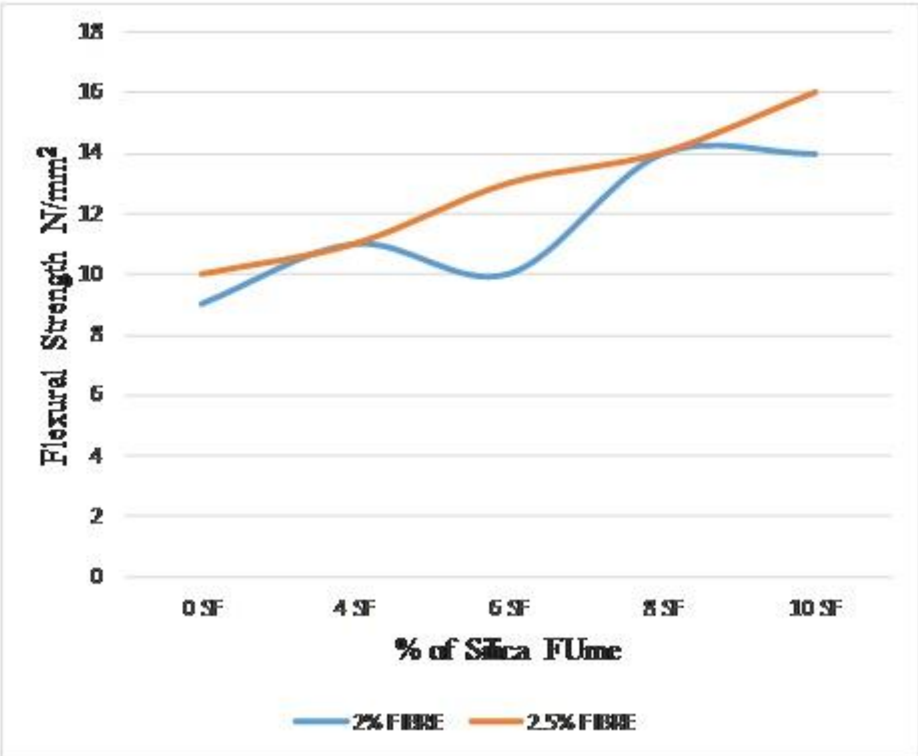

Fig. 8 28days Flexural strength cruve

5.5 Deflection characteristics

The deflection of the long beams are studied with the help of crack froming with respective the load applied and the deflection of the beam at the mid point of the beam. The table 5.4 represents the deflection and stiffeness reading for both conventional concrete and optimum mix concrete and Fig. 5.4 show the deflection cruve for bothe CC and OM beams.the maximum deflection of the conventional concrete is 7.86 mm at 8.4 tonnes of load and for optimum mix the maximum deflection is 5.72mm at 10.2 tonnes of load.

The initial crack in CC beam strats at 4.6 tonnes and for OM beam it starts at 2.4 tonnes itself. The CC beam cracks at the shear portion of the beam (at supports), this shear failure was arrested in the OM beam. The cracks formation is uniform (all over the beam) in the OM beam, comparitively the CC beams crack formation is not in uniform (more at supports) the specimens with the crack formation are show in Fig. 4.19 clearly.

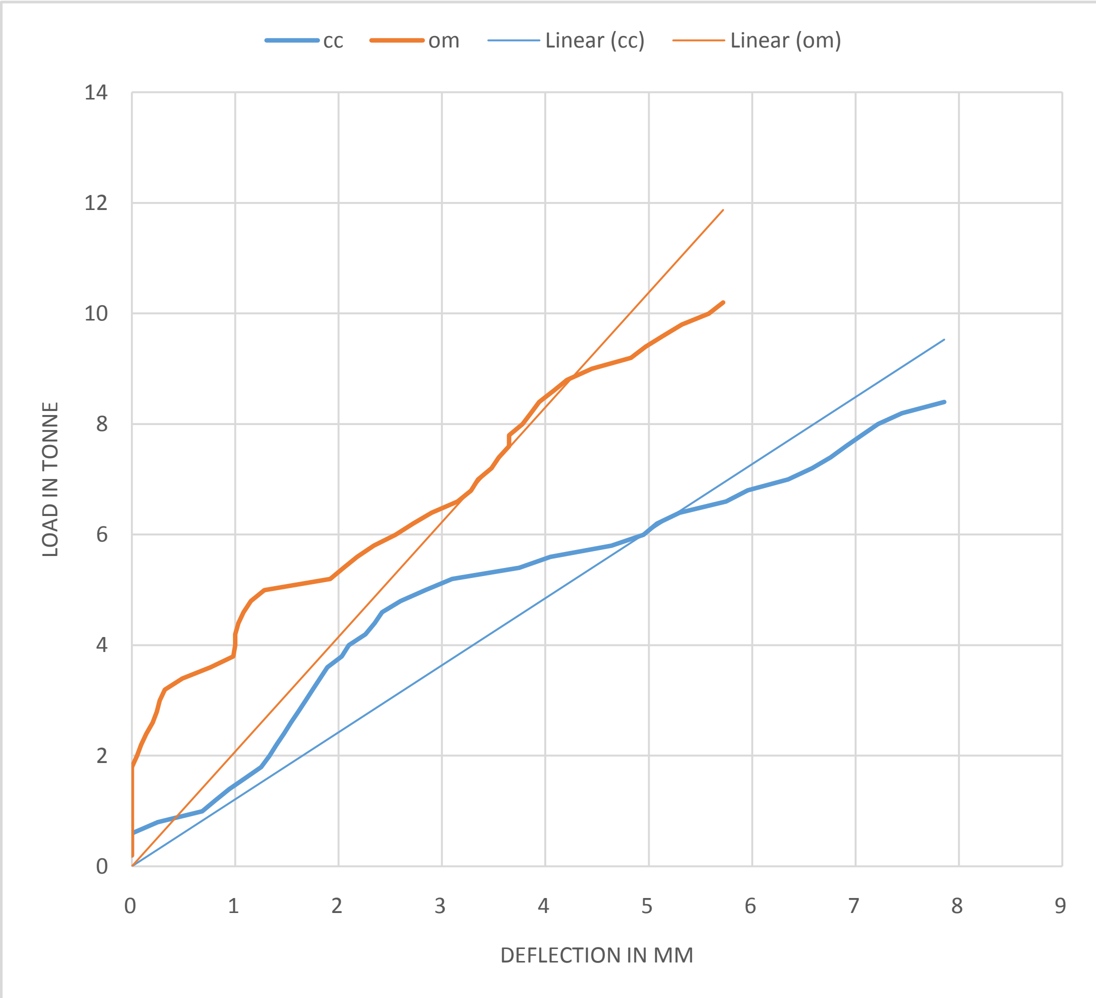

Fig. 9. Load Vs Deflection curve for CC and OM beams

CONCLUSIONS

The 10% replacement of silica fume in cement and 2.5% of fibre gives the optimum results. The quantity calculation of steel fibre gives apreciable results with weight fraction than volume fraction.The optimum mix gives 40%, 65%, and 75% increase in compression strength, split tensile strength and flexural strength respectively when compared with conventional concrete.The optimum mix concrete beam sustain 40% higher load compare to conventional concrete beamThe stifness increase about 60% with optimum mix compare to conventional concrete

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