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Design of Pavement Surface for Sustainable Development Using Silica Fume

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Abstract
This study evaluates the use of silica fume as a supplementary cementitious material in high-performance concrete intended for durable infrastructure applications. Ordinary Portland cement was partially replaced with silica fume at 0, 2.5, 5.0, 7.5, 10.0 and 12.5% by mass. The concrete was proportioned for an M60 target strength at a water-to-binder ratio of 0.30, with a polycarboxylate-based or other high-range water-reducing admixture, the exact product requiring verification. Cubes, cylinders and beams were tested at 7, 14, 28 and 56 days for compressive, splitting-tensile and flexural strength. Within the reported 28-day dataset, the 7.5% silica-fume mixture produced the highest compressive strength (74.07 MPa), flexural strength (4.12 MPa) and splitting-tensile strength (5.17 MPa). Relative to the control values reported in the manuscript, these correspond to increases of approximately 29.3%, 26.4% and 52.1%, respectively; the stated 25%, 23% and 22% increases should therefore be recalculated and reconciled. The results indicate that silica fume can improve strength when dispersion, workability and curing are adequately controlled. However, the optimum dosage is mixture-specific and should not be generalized without reporting variability, fresh-concrete properties and durability data.

KEYWORDS: Silica Fume (SF), Marsh cone test, Compressive strength (CS), Split tensile strength (ST), and Flexural strength (FS).

Introduction

Concrete production has a substantial environmental footprint because clinker manufacture requires energy and releases process and combustion-related carbon dioxide. Partial replacement of cement with industrial by-products can reduce clinker demand, provided that the alternative material is consistently characterized and the resulting concrete satisfies strength, durability and constructability requirements. Silica fume is a very fine, silica-rich pozzolanic material generated during the production of silicon and ferrosilicon alloys. Its particles can refine the pore structure through filler action, while its amorphous silica reacts with calcium hydroxide to form additional calcium–silicate–hydrate gel. These mechanisms can improve strength and reduce permeability, although the very high specific surface area commonly increases water demand and may require a high-range water reducer [1–4].
The present investigation examines the effect of silica-fume replacement on the mechanical performance of M60 concrete. The study is relevant to pavement and infrastructure applications, but the current experimental programme evaluates material-level strength only. Pavement-specific conclusions should therefore be limited unless slab, fatigue, abrasion, permeability, shrinkage, or field-performance data are added.

2.0 Materials Used And Their Properties

Cement, fine aggregate, coarse aggregate, silica fume and chemical admixture were used. The reported silica fume complied with ASTM C1240 and IS 15388:2003; the certificate of compliance, loss on ignition, moisture content, particle-size distribution and activity index should be appended. Mix proportions were based on the applicable edition of IS 10262 and project durability requirements. Because the manuscript uses a water-to-binder ratio of 0.30, all replacement percentages must be stated explicitly as a percentage of total cementitious material, and the binder mass must be recalculated consistently for every mixture.

2.1 Cement:

JK cement of ordinary Portland cement (OPC) of 43 Grade was used which satisfies the requirements of IS: 12269-1987. The properties of cement are shown in Table 1. Table 1 establishes the baseline physical characteristics of the cement. The reported specific gravity is used in absolute-volume calculations, while setting time and consistency indicate handling and placing requirements. The 28-day cement strength confirms the supplied cement's general strength class; it should not be interpreted as the strength of the concrete mixture.

Table 1: Physical Properties of Cement

Sl.no	Property of cement	Results
1	Normal Consistency	32.5%
2	Initial setting time	60 min
3	Final setting time	160min
4	Specific gravity	3.148
5	Compressive strength of cement at 28 days	44.5Mpa

2.2 Aggregate: Fine Aggregate:

locally available sand collected from Tungabhadra River bed was used. The sand was conforming to zone II as per IS: 383-1987. The properties of fine aggregate are shown in Table 2. Table 2 indicates that the sand was classified as Zone II and had a fineness modulus of 2.1. These parameters influence paste demand, grading, workability and packing. The reported 2% free moisture must be incorporated into batch-water corrections; otherwise, the effective water-to-binder ratio will differ from the design value.

Table 2: Physical Properties of Fine aggregate

Sl.no	Properties	Results
1	Bulk density, kg/m3	1650
2	Specific gravity	2.58
3	Fineness modulus	2.1
4	Free surface moisture (%)	2.0

2.3 Coarse Aggregate:

The crushed aggregate was used from the local quarry. In this experiment the aggregate was used of 20mm down and tested as per IS: 2386-1963(I, II, III) specification. The properties of coarse aggregate are shown in Table 3. Table 3 summarizes aggregate size, density and resistance indicators. The 20 mm nominal size is compatible with conventional reinforced-concrete placement, subject to reinforcement spacing. Impact and abrasion values provide an initial indication of toughness, but pavement suitability also requires verification of soundness, polishing resistance and relevant project specifications.

Table 3: Physical Properties of Coarse aggregate

Sl.no	Properties	Results
1	Maximum nominal size	20mm
2	Bulk density (kg/m3)	1800
3	Specific gravity	2.75
4	Fineness modulus	4.6
5	Impact value	24.09%
6	Abrasion value	36.28%

2.4 Silica Fume:

The Silica Fume was used in these experiments conforms to ASTM C 1240 and IS 15388:2003. The Micro silica is extremely fine particle, which exists in Grey color powder form. Micro silica has been procured from Goregaon(west) Industrial Area, Mumbai, Maharashtra. The properties of silica fume is shown in Table 4 and chemical properties shown in Table 5. These tables identify silica fume as a grey, low-specific-gravity and silica-rich material. The high SiO2 content supports its classification as a reactive pozzolan, while the fine particle size explains its filler effect and increased demand for dispersing admixture. The surface-area unit should be corrected: “20,000 kg/m3” is not a surface-area unit; report the actual Blaine or BET value with units.

Table 4: Physical Properties of Silica Fume

Sl.no	Properties	Results
1	Specific gravity	2.21
2	color	Grey

Table 5: Chemical Properties of Micro silica

Sl.no	Properties	Results
1	Silicon Dioxide, SiO_2 (%)	90-98
2	Calcium Oxide, CaO (%)	0.2-0.7
3	Alumina Oxide, Al_2O_3 (%)	0.4-0.9
4	Ferric Oxide, Fe_2O_3(%)	1-2

5	Other (%)	2-3
6	Bulk density(Kg/m^3)	550-650
7	Surface area(Kg/m^3)	20,000

2.5 Super Plasticizers:
Fosroc Aura mix 400 was used for M40 and M50 Grade of concrete. The properties of super plasticizer is shown in table6

Table 6 Properties of Aura mix 400 Super Plasticizer

Properties	
Appearance	Light yellow coloured liquid
Ph	Minimum 6.0
Volumetric mass @ 20°C	1.09 kg/ liter
Chloride content	Nil
Alkali content	Typically less than 1.5 g Na2o equivalent liter of admixture

3.0 EXPERIMENTAL PROGRAMME
The experimental program was designed to compare the mechanical properties i.e. compressive strength, split tensile strength, and flexural strength of high strength concrete with M60 grade of concrete and with different replacement levels of ordinary Portland cement (JK cement 43 grade) with Micro silica (2.5%, 5.0%, 7.5%, 10% and 12.5%). Strength properties of M60 grade concretes were also studied for combination of optimum replacement levels of SF (7.5%).

3.1 Mix Proportions:
Concrete mixes were designed to a compressive strength of M60 grade with water cement ratio of 0.30. As per IS code 10262-2009, MORT&H and IRC44-2008. The cement was replaced with MS by (2.5%, 5%, 7.5%, 10% and 12.5%) the proportions of constituent materials for Mixes are presented in table 7

Table 7 Mix proportion of concrete

SL. No	**Materials**	**Quantities in Kg/m^3 M$_{60}$ Grade**
1	Cement	496
2	Water	148.8
3	Fine aggregate	605.27
4	Coarse aggregate	1206.81
5	Water cement ratio	0.3
6	Super plasticizer	1.8%

The specimens of standard cubes (150mmx150mmx150mm), standard cylinders of (150mm Dia x300mm height) and standard beams of (100mmx100mmx700mm) were cast with various percentage replacements of MS. Compression testing machine (CTM) was used to test compressive strength and split tensile strength of specimens. Universal Testing Machine (UTM) was used to test flexural strength of specimens. Test for 7, 14, 28 and 56 days. Table 7 gives the nominal control mixture. It should be expanded to show the cement, silica fume, total binder, water, aggregates, admixture dosage and fresh properties for every replacement level. A consistent mass-balance check is necessary because replacing cement while retaining the same cement mass changes total binder content unless the mix is redesigned.

4. Results And Discussions

4.1 Mechanical Properties:

4.1.1 Compressive Strength:
The compressive strength M60 grade concrete, MS concrete at the age of 28 and 56 days is presented in table 8. There is a significance improvement in the strength of concrete because of high pozzolanic nature of Micro silica and their filling ability. Compressive strength of M60 at 28- and 56-days age, with replacement of MS was increased gradually up to an optimum replacement level of 7.5% and then

decreased. The maximum 28 days cube strength of M60 grade with 7.5% of Micro silica was 74.07Mpa, and for 56 days 75.26Mpa.

4.1.2 Flexural Strength:

The flexural strength of M60, MS concrete at the age of 28 and 56 days is presented in table 9. Flexural strength of M_{60} at 28- and 56-days age, with replacement of MS was increased gradually up to an optimum replacement level of 7.5% and then decreased. The maximum 28 days beam strength of M60 grade with 7.5% of Micro silica was 4.12Mpa, and for 56 days 4.21Mpa.

4.1.3 Split Tensile Strength:

The Split tensile strength M60 grade concrete, MS concrete at the age of 28 and 56 days is presented in table 10. There is a significance improvement in the strength of concrete because of high pozzolanic nature of Micro silica and their filling ability. Split tensile strength of M60 at 28- and 56-days age, with replacement of MS was increased gradually up to an optimum replacement level of 7.5% and then decreased. The maximum 28 days cube strength of M60 grade with 7.5% of Micro silica was 5.17Mpa, and for 56 days 5.38Mpa. Tables 8–10 show a rise in the reported 28-day strengths up to 7.5% silica fume, followed by a reduction at higher replacement levels. This pattern is consistent with an optimum between beneficial pore refinement/pozzolanic reaction and adverse effects from agglomeration, poor dispersion or reduced workability. The missing 56-day data must be restored before claiming age-dependent trends.

Table: 8 shows the compressive strength of concrete at 28 and 56 days

SL.NO	**% of Micro silica**	**Compressive strength in Mpa**	
		28 days	**56 days**
1	0	57.26	57.26
2	2.5	66.52	69.04
3	5.0	70.81	72.15
4	**7.5**	**74.07**	**75.26**
5	10.0	67.70	69.19
6	12.5	66.52	67.85

Table: 9 shows the Flexural strength of concrete at 28 and 56 days

SL.NO	**% of Micro silica**	**Flexural strength in Mpa**	
		28 days	**56 days**
1	0	3.26	3.26
2	2.5	3.53	3.59
3	5.0	3.70	3.79
4	**7.5**	**4.12**	**4.21**
5	10.0	3.94	3.97
6	12.5	3.82	3.88

Table: 10 shows the Split tensile strength of concrete at 28 and 56 days

SL.NO	**% of** Silica Fume	**Split tensile strength in Mpa**	
		28 days	**56 days**
1	0	3.40	3.40
2	2.5	4.03	4.25
3	5.0	4.46	4.81
4	**7.5**	**5.17**	**5.38**
5	10.0	4.95	5.02
6	12.5	4.53	4.67

Plot silica-fume content on the horizontal axis and compressive strength on the vertical axis, using separate series for 28 and 56 days. The expected interpretation from the reported data is an increase to 7.5% followed by a decline. Avoid duplicating the same graph under different captions; retain one figure with clear units, error bars and a legend.

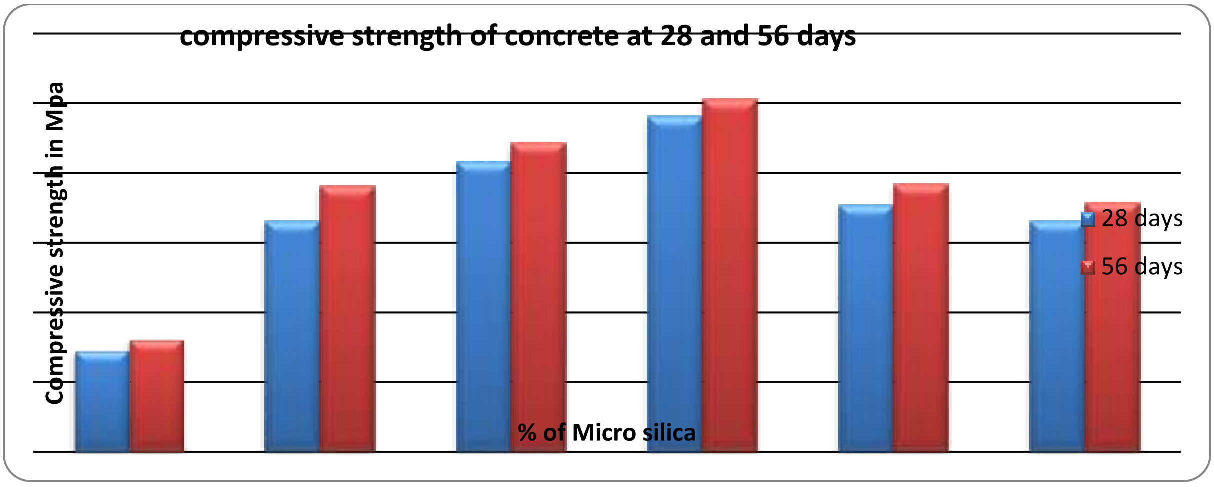

Fig: 1 Variation of compressive strength with Silica Fume

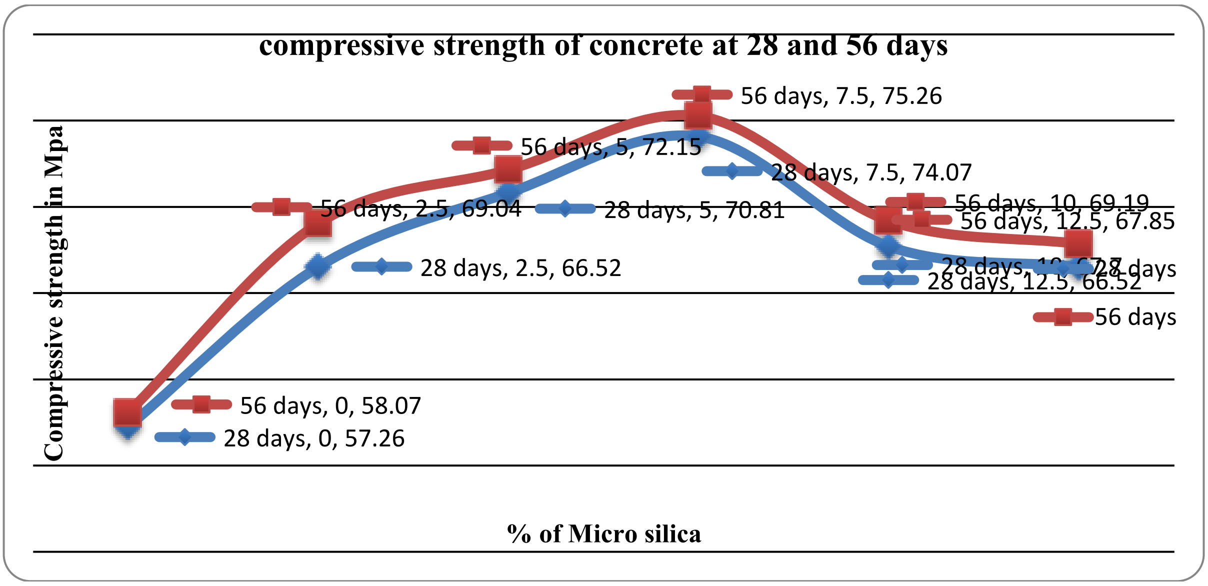

Fig: 2 Variation of compressive strength with silica

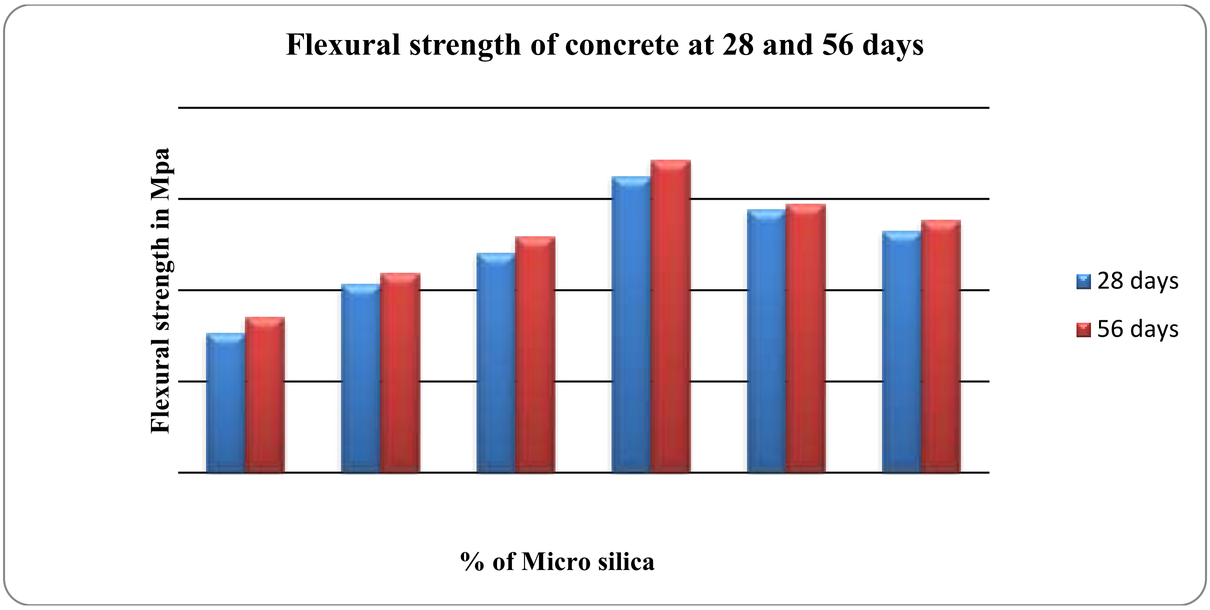

Fig: 3 Variation of Flexural strength with Silica Fume

These figures should show the same dosage–response pattern for flexural strength. Explain that flexural performance is influenced by matrix densification, aggregate–paste bond and specimen variability. State the loading configuration and test standard in the caption.

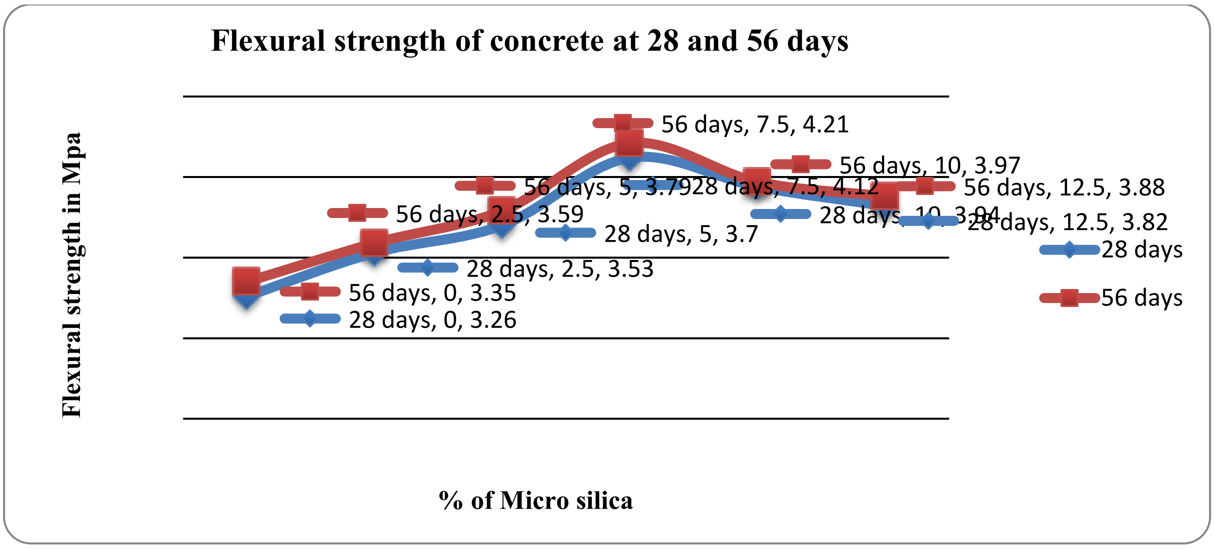

Fig: 4 Variation of Flexural strength with Silica Fume

Use one clearly labelled figure unless the two figures represent different curing ages or datasets. Explain that the 7.5% mixture has the highest reported 28-day value, but the result should be interpreted with replicate variability and failure-mode observations.

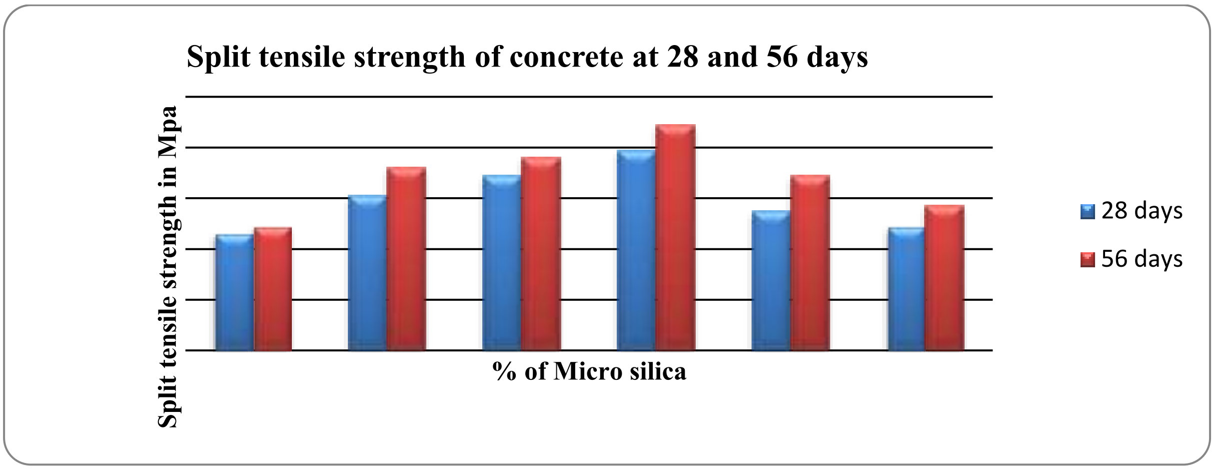

Fig: 5 Variation of Split tensile strength with Silica Fume

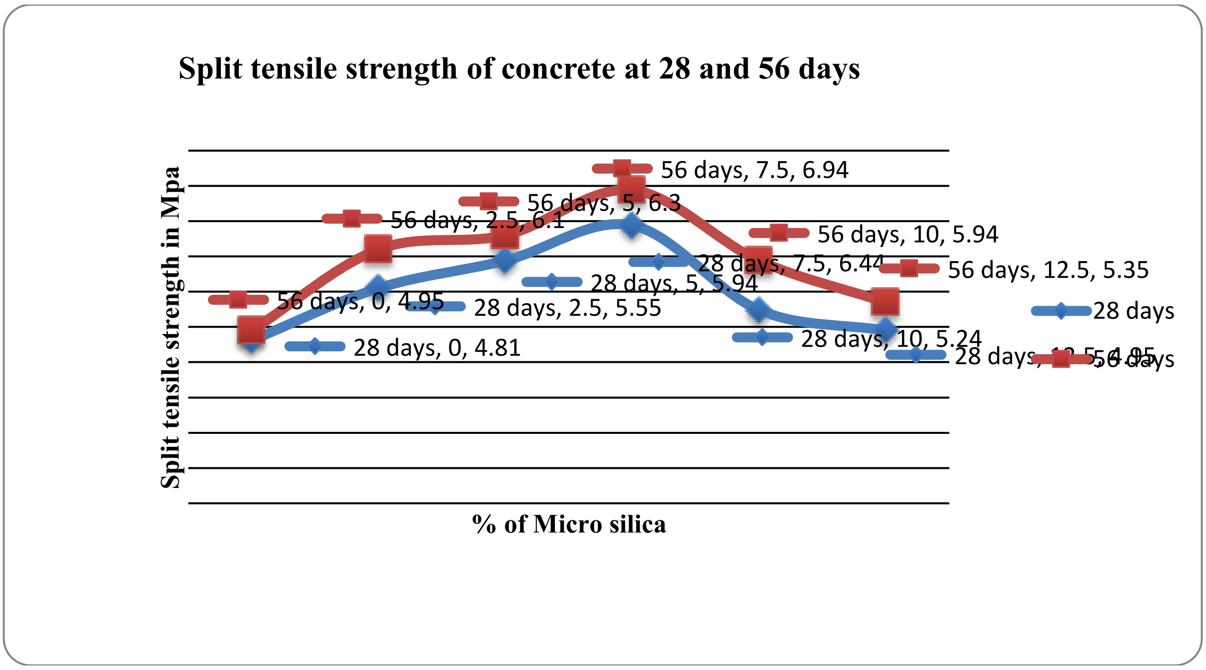

Fig: 6 Variation of Split tensile strength with Silica Fume

5.0 COMPARISON OF NORMAL CONCRETE WITH SILICA FUME (7.5%):

The compressive, flexural and split tensile strength of M_{60} grade concrete at the age of 28 days strength is present in Table 11,12 and 13. This shows the comparison of Normal concrete and Replacement of Micro silica concrete i.e peak value 7.5% of MS. These tables should compare the control mixture and the 7.5% mixture at each curing age. In their present form they contain only control values, so they cannot substantiate the claimed percentage improvements. Add mean, standard deviation, coefficient of variation and the number of specimens.

Table: 11 shows the compressive strength of normal and replacement of 7.5% of MS of concrete at 28 days

SL.NO	Test age in days	Compressive strength in Mpa	
		Normal concrete	7.5% of MS
1	7	41.48	52.74
2	14	51.26	67.70
3	28	57.26	74.07
4	56	57.26	75.26

Table: 12 shows the Flexural strength of normal and replacement of 7.5% of MS of concrete at 28 days

SL.NO	Test age in days	Flexural strength in Mpa	
		Normal concrete	7.5% of MS
1	7	-	-
2	14	2.07	3.08
3	28	3.26	4.12
4	56	3.26	4.21

Table: 13 shows the Split tensile strength of normal and replacement of 7.5% of SF of concrete at 28 days

SL.NO	Test age in days	Split tensile strength in Mpa	
		Normal concrete	7.5% of MS
1	7	-	-
2	14	2.69	4.10
3	28	3.40	5.17
4	56	3.40	5.38

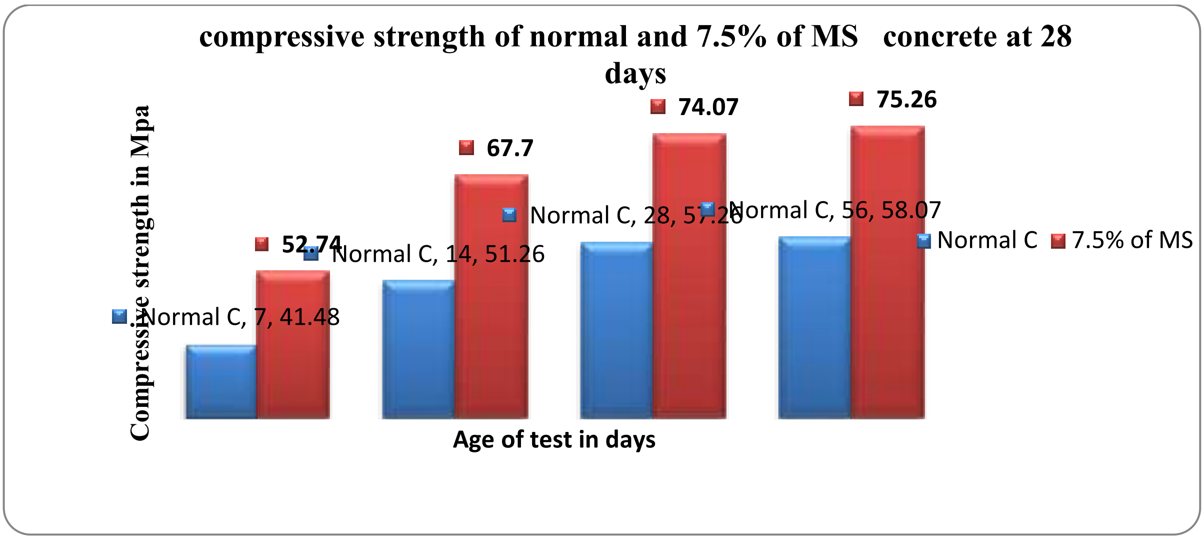

Fig: 7 Comparison of compressive strength with Normal and silica fume concrete

Use grouped bars or lines showing control and 7.5% mixtures at 7, 14, 28 and 56 days. The current manuscript labels two figures as Figure 8 and does not show the silica-fume comparison values; correct numbering and add the complete dataset. The reported 28-day results show that silica fume improved all three measured strength properties up to a replacement level of 7.5%. Compressive strength increased from 57.26 MPa for the control to 74.07 MPa, an increase of 16.81 MPa or approximately 29.3%. Flexural strength increased from 3.26 to 4.12 MPa, approximately 26.4%, while splitting-tensile strength increased from 3.40 to 5.17 MPa, approximately 52.1%. These percentages differ from those stated in the conclusion and should be corrected after the raw data and specimen averages are checked.

The reduction at 10 and 12.5% may reflect the combined effects of silica-fume agglomeration, increased surface area, inadequate dispersion and loss of workability. The explanation should be supported by slump or flow, admixture dosage, density and air-content measurements. Strength alone is insufficient to establish sustainability: a complete assessment should also report cement reduction per cubic metre, silica-fume sourcing, transport, curing energy, service-life indicators and, preferably, a life-cycle or embodied-carbon comparison.

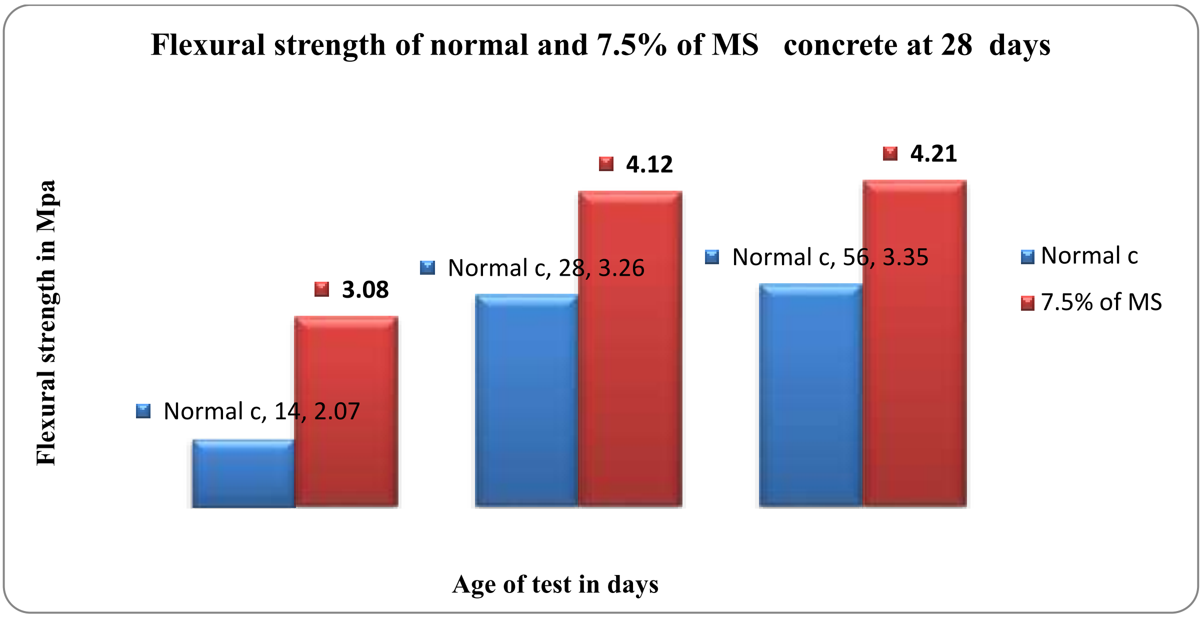

Fig: 8 Comparison of Flexural strength with Normal and silica fume concrete

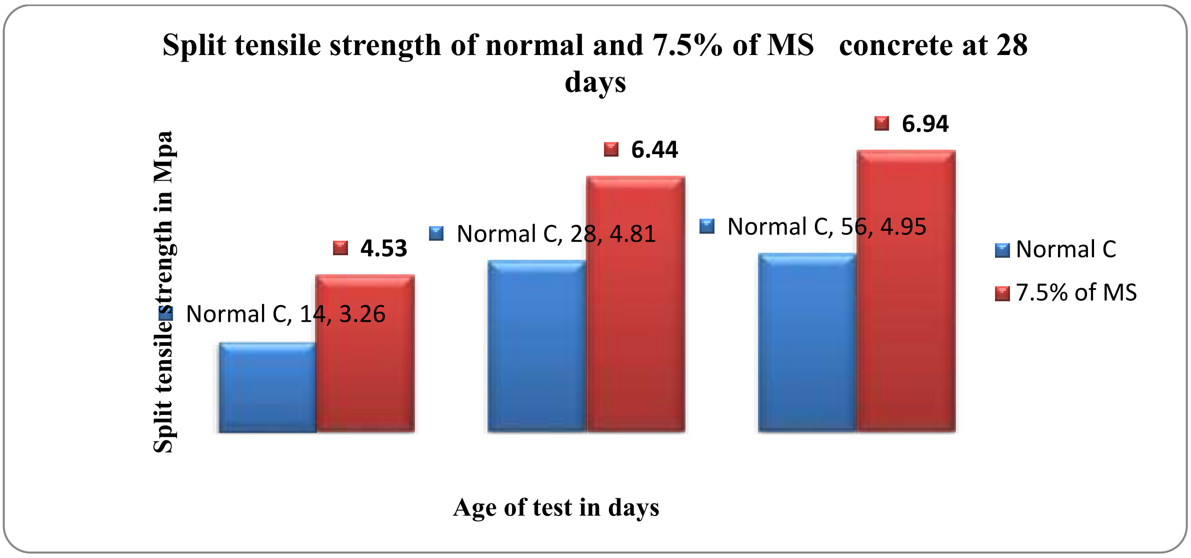

Fig: 8 Comparison of Split tensile strength with Normal and silica fume concrete

6. Conclusions

As per the above investigations, following conclusion were drawn.

- Within the reported experimental range, 7.5% silica fume gave the highest 28-day compressive, flexural and splitting-tensile strengths.
- The reported 28-day values at 7.5% were 74.07 MPa, 4.12 MPa and 5.17 MPa, respectively; the percentage improvements should be reported as recalculated after verification of raw data.
- Replacement levels above 7.5% reduced the reported strengths, demonstrating that the optimum dosage depends on mixture proportions, dispersion, admixture compatibility and curing.
- The study supports the potential use of silica fume in high-performance concrete, but pavement-

performance and sustainability claims require additional durability, workability, environmental and field evidence.

- Future work should include chloride migration, water absorption/sorptivity, shrinkage, abrasion, permeability, fatigue and statistical analysis.

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