



A COMPARATIVE STUDY OF POLYPROPYLENE FIBER REINFORCED SILICA FUME CONCRETE OF GRADE M40

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ABSTRACT

This research paper presents an experimental framework for evaluating M40 grade concrete modified with silica fume and polypropylene (PP) fibers. The study is designed to compare conventional M40 concrete with concrete containing silica fume and different polypropylene-fiber dosages, with emphasis on workability, compressive strength, split tensile strength, flexural strength, density and durability-related indicators. Silica fume is a highly reactive supplementary cementitious material that can refine the pore structure and improve the paste–aggregate interface, while polypropylene fibers provide distributed reinforcement and can control microcracking and improve post-cracking behaviour. The combined use of the two materials is therefore expected to produce a concrete matrix with improved mechanical and service-performance characteristics, although excessive fiber dosage may reduce workability and cause fiber balling or inadequate compaction.

The proposed investigation uses M40 concrete as the reference grade and compares a control mix with mixes containing a selected silica-fume replacement level and several polypropylene-fiber volume fractions. Mix proportioning should be performed using IS 10262:2019, aggregate requirements should follow IS 383:2016, and concrete strength testing should follow the applicable Indian Standards. Published experimental literature has reported beneficial long-term strength and water-absorption behaviour from combined silica fume and polypropylene fiber systems, but the optimum dosage depends on constituent materials, water-to-binder ratio, fiber geometry, curing and mixing procedure. Consequently, this paper does not treat illustrative numerical values as actual laboratory results. A complete test matrix, calculation procedure, result-sheet templates, statistical analysis method and discussion framework are provided so that measured laboratory data can be inserted without changing the scientific structure of the paper.

Keywords: M40 concrete, polypropylene fiber, silica fume, supplementary cementitious material, compressive strength, split tensile strength, flexural strength, workability, durability.



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1. INTRODUCTION

Concrete is the most widely used construction material because of its availability, versatility, mouldability and relatively high compressive strength. Conventional concrete, however, has limited tensile capacity and is susceptible to cracking caused by plastic shrinkage, drying shrinkage, thermal effects, restrained deformation and service loading. Conventional M40 concrete can achieve the required compressive strength, but improving crack resistance and tensile behaviour remains an important engineering objective. Silica fume is an extremely fine, silica-rich supplementary cementitious material. Its very small particle size contributes to filler action, while its pozzolanic reaction consumes calcium hydroxide and generates additional calcium-silicate-hydrate phases. These mechanisms can densify the interfacial transition zone and reduce connected pore space. The fine particle size and high surface area, however, can increase water demand and reduce slump if the mix is not properly proportioned.

Polypropylene fibers are synthetic, non-corroding fibers that are distributed throughout the concrete matrix. They do not act as conventional longitudinal reinforcement; instead, they bridge microcracks and distribute localized tensile strains. Their effect is commonly more pronounced in crack control, toughness and tensile/flexural behaviour than in compressive strength. Fiber dosage and dispersion are critical: insufficient dosage may provide only a limited effect, whereas excessive dosage can reduce workability and compromise compaction.

The combined incorporation of silica fume and polypropylene fiber is technically attractive because the two modifications address different aspects of concrete performance. Silica fume primarily modifies the cementitious matrix and interface, while polypropylene fibers provide discrete crack-bridging reinforcement. A published study investigating silica-fume fiber-reinforced concrete used 8% silica fume and polypropylene fiber volume fractions of 0%, 0.2%, 0.3% and 0.5%, reporting increased long-term compressive strength and reduced water absorption in the modified systems. Such findings support a systematic M40 investigation, while also showing why dosage optimization is necessary.

2. RESEARCH GAP

Many studies investigate silica fume or polypropylene fibers independently, while fewer experimental programmes examine their combined effect under a single M40 mix-design and testing protocol. Reported optimum dosages vary because of differences in cement type, aggregate grading, water-binder ratio, admixture, fiber dimensions, curing regime and testing age. A controlled comparative study using the same base materials can therefore provide useful evidence on the interaction between matrix densification and fiber bridging.

The present work addresses the following gap: establishing a repeatable experimental methodology for comparing M40 control concrete with silica-fume concrete and polypropylene-fiber reinforced silica-fume concrete while measuring both fresh and hardened properties. The study also emphasizes workability and practical dosage optimization rather than considering strength alone.



3. AIM AND OBJECTIVES

- To design and produce a reference M40 concrete mix using a standard mix-proportioning procedure.
- To investigate the effect of silica fume on the fresh and hardened properties of M40 concrete.
- To study the effect of polypropylene fiber dosage on silica-fume modified M40 concrete.
- To compare compressive, split tensile and flexural strength of the different mixes.
- To evaluate the influence of fiber and silica fume on density and selected durability indicators.
- To identify a practical dosage range that balances strength, crack-control potential and workability.
- To develop a statistical basis for determining whether observed differences between mixes are significant.

4. MATERIALS

4.1 Cement

Ordinary Portland cement or another cement permitted by the adopted mix-design specification may be used. The cement should be from a single batch as far as practicable. Record specific gravity, standard consistency, initial and final setting time and compressive strength as required by the applicable standards.

4.2 Silica Fume

Commercial-grade silica fume conforming to the relevant Indian specification should be used. Record supplier, grade, specific gravity, fineness/particle characteristics, moisture content and chemical composition where available. For the proposed experimental programme, 8% of the cementitious binder by mass may be adopted as the primary silica-fume level, with the exact percentage finalized through preliminary trials.

The selected level is consistent with published combined silica-fume/PP-fiber research, but it should not be assumed to be universally optimum.

4.3 Fine Aggregate

Natural river sand or manufactured sand conforming to IS 383:2016 may be used. Record grading zone, specific gravity, water absorption, moisture content, fineness modulus and bulk density. Fine aggregate grading is important because silica fume and fibers can change the paste demand of the mix.

4.4 Coarse Aggregate

Crushed coarse aggregate of nominal maximum size 20 mm is recommended for the M40 experimental mix. The aggregate should satisfy IS 383:2016. Determine specific gravity, water absorption, impact/crushing/abrasion characteristics as applicable, flakiness and elongation indices, and grading.



4.5 Polypropylene Fiber

Use commercially available monofilament or fibrillated polypropylene fiber. The manufacturer should provide fiber length, equivalent diameter, density, tensile strength and recommended dosage.

For a comparative study, a practical series can be 0%, 0.10%, 0.20%, 0.30% and 0.40% fiber by volume of concrete. If the selected fiber manufacturer recommends a different range, the experimental levels should be adjusted accordingly. Fiber volume fraction must be calculated consistently and reported explicitly.

4.6 Chemical Admixture

A polycarboxylate-ether or other compatible high-range water-reducing admixture may be used to maintain target workability without unnecessarily increasing water. The dosage should be established through trials and kept consistent unless the experimental design specifically studies admixture dosage.

5. REVIEW OF LITERATURE

5.1 Silica Fume in Concrete

Silica fume has a dual physical and chemical effect. Its fine particles fill voids between cement grains and its pozzolanic reaction contributes additional calcium-silicate-hydrate. The resulting microstructure can be denser, with improved paste–aggregate bonding and lower permeability. These benefits generally become more useful when water-binder ratio and curing are properly controlled. However, the high surface area of silica fume increases paste demand and can reduce slump.

5.2 Polypropylene Fiber Concrete

Polypropylene fibers are particularly useful for controlling the propagation and width of small cracks. Because the fibers are short and randomly distributed, their contribution to peak compressive strength is generally smaller and less consistent than their contribution to tensile/flexural response and crack control. Fiber dispersion, aspect ratio, dosage and mixing sequence are important variables.

5.3 Combined Silica Fume and Polypropylene Fiber

The combined system can be viewed as a matrix-and-bridge mechanism. Silica fume improves matrix compactness and the interfacial transition zone, while polypropylene fibers provide crack-bridging across developing microcracks.

Published work on silica-fume fiber-reinforced concrete has reported long-term compressive-strength improvement and reduced water absorption, although fiber addition may slightly reduce some electrical-resistance benefits. A recent 2026 study also specifically investigated M40 concrete containing silica fume and polypropylene fibers for tensile strength, demonstrating continued research interest in this combined system.



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5.4 Summary of Literature

Study / source	Main variables	Reported implication	Relevance
Long-term SF–PPF study (2012)	8% SF; PPF 0, 0.2, 0.3, 0.5%; w/b 0.46 and 0.36	Improved long-term compressive strength; lower water absorption in SF–fiber systems	Supports combined-material experimental design
Sharma et al. (2026)	M40; SF, waste foundry sand and PPF	Investigated tensile strength optimization	Shows current M40 research direction
IS 10262:2019	Concrete mix proportioning	Provides proportioning framework including supplementary materials	Basis for M40 mix design
IS 383:2016	Fine and coarse aggregates	Specifies aggregate requirements	Basis for material qualification

6. EXPERIMENTAL PROGRAMME

6.1 Mix Identification

Mix ID	Silica fume	PP fiber	Purpose
M0	0%	0%	Control M40 concrete
M1	8%	0%	Effect of silica fume alone
M2	8%	0.10%	Low fiber dosage
M3	8%	0.20%	Medium-low fiber dosage
M4	8%	0.30%	Medium fiber dosage
M5	8%	0.40%	Higher fiber dosage

The proposed percentages are a research design, not a claim that these are universally optimum. The final levels should be confirmed by preliminary workability and trial-mix observations.



6.2 Specimen Schedule

Test	Specimen	Recommended ages / measurements	Minimum comparison
Slump/workability	Fresh concrete	Immediately after mixing	All mixes
Density	Fresh/hardened	Fresh and 28 days	All mixes
Compressive strength	150 mm cubes	7 and 28 days; 56/90 days if available	At least 3 specimens/age/mix
Split tensile strength	150×300 mm cylinders	28 days; optional 56/90 days	At least 3 specimens/mix
Flexural strength	Prisms, e.g. 100×100×500 mm	28 days	At least 3 specimens/mix
Water absorption	Cubes/discs	28 days	At least 3 specimens/mix
Optional permeability	Specified specimens	28/56 days	Selected mixes

7. MIX DESIGN OF M40 CONCRETE

Mix proportioning should be performed using IS 10262:2019 and checked against durability and exposure requirements of the applicable design code. The standard explicitly covers proportioning using supplementary cementitious materials and includes an illustrative M40 example. The final quantities must be calculated from the actual specific gravities, absorption, moisture conditions, selected water-binder ratio and required workability of the laboratory materials.

For an academic project, the following calculation sequence is recommended:

1. Establish characteristic compressive strength = 40 MPa.
2. Determine target mean strength from the adopted standard and assumed standard deviation.
3. Select water-binder ratio based on strength and durability requirements.
4. Select water content for the target slump and aggregate size.
5. Calculate cementitious-material content.
6. Allocate silica fume as a percentage of total binder.
7. Determine coarse and fine aggregate quantities using absolute-volume calculations.
8. Select superplasticizer dosage by trials.
9. Apply moisture and absorption corrections.
10. Produce trial mixes and adjust proportions for workability and strength.

A laboratory mix should never be fabricated from a generic published proportion when the actual aggregate and cement properties are different.



8. PROPOSED MIX-DESIGN WORKSHEET

Parameter	Value to be entered from laboratory design
Concrete grade	M40
Target mean strength	_____ MPa
Nominal aggregate size	20 mm
Desired slump	_____ mm
Water-binder ratio	_____
Total binder	_____ kg/m ³
Cement	_____ kg/m ³
Silica fume	_____ kg/m ³
Water	_____ kg/m ³
Fine aggregate	_____ kg/m ³
Coarse aggregate	_____ kg/m ³
Superplasticizer	_____ kg/m ³
PP fiber	_____ kg/m ³

For the 8% silica-fume series, silica fume should be calculated from the selected total cementitious binder basis and the adopted replacement convention. Clearly state whether the percentage is based on replacement of cement mass or addition to cement; these two conventions are not equivalent.

9. MIXING AND CASTING PROCEDURE

- Condition all materials and determine aggregate moisture before batching.
- Dry-mix coarse aggregate, fine aggregate and cementitious materials until reasonably uniform.
- Disperse polypropylene fibers gradually rather than dumping the entire quantity at once; this reduces the risk of fiber balls.
- Add part of the mixing water and chemical admixture in accordance with the selected mixing sequence.
- Continue mixing until uniform dispersion and the required workability are achieved.
- Measure slump and fresh density before casting.
- Fill moulds in layers and compact consistently using the same method for every mix.
- Mark specimens clearly with mix ID, casting date and intended test age.
- Cure specimens under controlled conditions and record temperature and curing medium.
- Test specimens at the prescribed age and record individual results rather than only the average.

10. TEST METHODS

10.1 Slump

Slump should be measured immediately after mixing using the standard slump-cone procedure. Because fibers can reduce apparent workability, slump loss with time should also be observed where possible.



10.2 Compressive Strength

Compressive strength should be determined using standard cube specimens and the applicable Indian Standard test procedure. For each mix and age, use at least three specimens where laboratory resources permit. Report individual strengths, mean strength, standard deviation and coefficient of variation.

10.3 Split Tensile Strength

Cylindrical specimens may be tested at 28 days. The result should be reported as the mean of individual specimens with the failure mode recorded. Fiber-reinforced specimens should be examined for crack pattern and post-peak behaviour if the test setup allows it.

10.4 Flexural Strength

Prism specimens should be tested using the selected third-point or centre-point loading arrangement in accordance with the applicable standard. Record first-crack behaviour where the apparatus permits and document whether fibers remain bridging the crack after matrix cracking.

10.5 Water Absorption

Water absorption can be used as an indicator of connected porosity. Specimen conditioning must be identical for all mixes. Report dry mass, saturated mass and percentage absorption. It should be treated as a comparative indicator rather than a direct substitute for full permeability testing.

11. DATA REDUCTION AND STATISTICAL ANALYSIS

For each property, calculate the mean, standard deviation and coefficient of variation. Percentage change relative to control is calculated as:

Percentage change = $[(\text{Property of modified mix} - \text{Property of control}) / \text{Property of control}] \times 100$.

For a stronger M.Tech. dissertation, one-way ANOVA should be performed separately for each response at a selected significance level (commonly $\alpha = 0.05$). If the ANOVA indicates significant differences, a suitable post-hoc comparison can identify which mixes differ. Report the number of specimens and assumptions used. Statistical significance should not be confused with engineering significance.

12. RESULTS TABLES — TO BE COMPLETED WITH ACTUAL LABORATORY DATA

Mix	Slump (mm)	7-d fck (MPa)	28-d fck (MPa)	28-d split tensile (MPa)	28-d flexural (MPa)
M0	—	—	—	—	—
M1	—	—	—	—	—
M2	—	—	—	—	—
M3	—	—	—	—	—
M4	—	—	—	—	—



M5	_____	_____	_____	_____	_____
Mix	Density (kg/m ³)	Water absorption (%)	SD of 28-d compressive strength	CV (%)	
M0	_____	_____	_____	_____	
M1	_____	_____	_____	_____	
M2	_____	_____	_____	_____	
M3	_____	_____	_____	_____	
M4	_____	_____	_____	_____	
M5	_____	_____	_____	_____	

13. EXPECTED TREND AND INTERPRETATION FRAMEWORK

The expected trends should be verified experimentally rather than assumed. Silica fume is likely to reduce slump at a fixed water content because of its high fineness and surface area. Polypropylene fibers are also likely to reduce slump and increase cohesiveness. A properly dosed high-range water reducer can compensate for some of this loss.

For compressive strength, silica fume may increase later-age strength because of matrix densification and pozzolanic reaction. The addition of polypropylene fibers may produce a smaller or variable change in peak compressive strength. Therefore, a higher compressive strength should not be the only criterion for selecting the preferred mix.

For split tensile and flexural strength, a moderate fiber dosage may provide a more visible improvement because fibers bridge cracks and redistribute tensile stresses. If fiber content becomes excessive, poor workability and inadequate compaction can offset the benefits. The actual optimum must therefore be established from the combined strength, workability and quality observations.

For water absorption, silica fume is expected to reduce absorption when the matrix is properly cured. Fibers may have a neutral, beneficial or adverse effect depending on dispersion and the quality of compaction. A poorly dispersed fiber system can introduce defects and should not be interpreted as an intrinsic failure of polypropylene fiber technology.

14. DISCUSSION

The central comparison should be between M0 and M1 to quantify the effect of silica fume, followed by comparison of M1 with M2–M5 to isolate the additional effect of polypropylene fiber. This arrangement avoids attributing the entire change in strength to fibers when silica fume itself has already changed the concrete matrix.

The workability-strength relationship is particularly important. If a fiber mix shows lower strength than the silica-fume control but also shows a substantial reduction in slump, the result may reflect poor consolidation rather than an intrinsic reduction in material capacity. Conversely, a moderate-strength improvement accompanied by better crack resistance may be valuable even if the increase in compressive strength is small.



The failure surfaces should be photographed. Control concrete typically exhibits a more abrupt brittle failure, while properly fiber-reinforced concrete may show greater crack bridging and residual integrity. Such qualitative observations should support, rather than replace, numerical measurements.

Durability-related observations should also be interpreted cautiously. Lower water absorption generally indicates a less connected pore system, but a full durability assessment requires appropriate permeability, chloride ingress, carbonation, sulfate or other tests depending on the intended exposure environment.

15. COMPARATIVE PERFORMANCE INDEX

For an M.Tech. project, a multi-criteria comparison can be useful. A normalized performance index may be calculated from compressive strength, split tensile strength, flexural strength and water absorption, with weights justified before seeing the results. Workability can be included as a constraint rather than simply maximizing strength. The study should avoid selecting a mix solely on the basis of a single test. A suitable decision rule is: the selected experimental mix should satisfy the required M40 strength, demonstrate acceptable workability and compaction, and provide measurable improvement in one or more tensile/crack-control or durability-related indicators without an unacceptable increase in material cost or processing difficulty.

16. COST AND PRACTICAL CONSIDERATIONS

Silica fume and polypropylene fibers generally increase material cost compared with ordinary concrete. The economic benefit therefore depends on the magnitude of performance improvement and the application. A cost analysis should include cement, silica fume, fiber, chemical admixture and any additional mixing/handling cost. If improved durability extends service life, life-cycle cost may be more informative than initial cost. Fiber handling also affects production. Fibers should be introduced in a controlled manner to avoid clumping. Silica fume may increase dust exposure during handling, so appropriate industrial hygiene and personal protective equipment should be used.

17. ENVIRONMENTAL SIGNIFICANCE

Partial replacement of cement with silica fume can reduce the quantity of Portland cement required for a given binder content, while also utilizing an industrial by-product/material. The environmental benefit should nevertheless be quantified using actual material quantities and transport distances rather than assumed. Polypropylene fiber is a synthetic polymer, so its environmental contribution should be included in a life-cycle assessment if sustainability is a major research objective.

18. LIMITATIONS

- The optimum silica-fume and fiber contents are material-specific and cannot be generalized from one laboratory programme.
- Short-term laboratory tests do not fully represent long-term field durability.
- Fiber dispersion and compaction can introduce operator-dependent variability.



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- Water absorption is an indirect durability indicator and should not replace specialized permeability tests.
- Illustrative mix levels in this paper are a proposed experimental design; they are not reported laboratory findings.
- Actual conclusions must be based on measured specimens and statistical analysis.

19. CONCLUSIONS

The proposed study provides a systematic basis for evaluating polypropylene-fiber reinforced silica-fume M40 concrete. The principal conclusions to be tested experimentally are:

1. Silica fume is expected to modify the concrete matrix through filler and pozzolanic mechanisms and may improve later-age strength and reduce water absorption.
2. Polypropylene fibers are expected to contribute more strongly to crack control, split tensile behaviour and flexural/post-cracking response than to peak compressive strength.
3. Increasing fiber content is expected to reduce workability unless compensated by appropriate mix proportioning and water-reducing admixture.
4. The combined system may provide complementary matrix and crack-bridging benefits, but excessive fiber dosage can produce poor dispersion and compaction.
5. The optimum mix should be selected from the combined evidence of strength, workability, durability indicators, crack behaviour and cost.
6. Actual laboratory data, rather than the expected trends in this paper, must be used for the final M.Tech. project conclusions.

20. RECOMMENDATIONS FOR FURTHER WORK

- Study 56- and 90-day compressive and tensile strengths.
- Measure rapid chloride permeability or another suitable permeability indicator.
- Study drying shrinkage and plastic shrinkage cracking.
- Use scanning electron microscopy to examine the silica-fume-modified matrix and fiber interface.
- Investigate different fiber lengths or fiber geometries.
- Perform life-cycle cost and environmental assessment.
- Use response-surface methodology to optimize silica-fume and fiber dosage simultaneously.

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