Experimental study on mechanical properties of polypropylene fiber reinforced concrete with silica fume

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**Abstract.** In this research, the mechanical properties of polypropylene and silica fume are examined with the 0.40% water-cement ratio of M40 grade concrete. The synthetic polypropylene fibers of length 12mm short fibers. in this study, the polypropylene fibers are used up to 0.3% (0%, 0.1%, 0.2%, 0.3%). And the silica fume is being utilized as a substitute for cement with a 4% mass of cement in all the mix proportions. The addition of silica fume to the cementitious matrix strengthened fiber scattering, resulting in a substantial decrease in the absorbency of the polypropylene fiber reinforced concrete (PPFRC). Superplasticizer is also added to these concrete mixes to increase workability. The concrete samples are prepared and cured for 7, 28 days. After completing the curing duration, samples were tested. After That finally, the mechanical properties, as comp. strength, split tensile, bending strength and mode of failure and ultimate load are determined and all proportions of the mix are compared to traditional concrete.

**Keywords:** Polypropylene, Silica fume, PPFRC, M40, Mechanical properties.

1. **Introduction**

Concrete's flexibility, toughness, long-term sustainability, and low cost have made it the most-used building material on the earth. As man-made as existence. It is second only to water as the most-consumed resource on the planet. We know that concrete is good in compression but not in tension. The concrete takes the compressive forces, and it cannot bear the tensile forces [1]. Ordinary concrete has a little tensile strength, partial ductility, and no crack resistance [2]. Inner microcracks have spontaneously appeared in concrete, and their propagation induces the concrete's low tensile strength, ultimately leading to brittle fracture [3]. When prepared, micro-cracks propagate and open, and because of stress concentration, the micro-cracks propagate and open-up, to daze these effects and problems the fiber-reinforced concrete was used [4]. In the FRC, fibers are dispersed and make the concrete serves as a crack stopper and strengthens both static and dynamic properties [5].

The silica fume is of supplementary cementitious material. It is producing from silicon metal and ferrosilicon alloys [6]. The silica fume has good physical and chemical properties to give good strength and durability to the concrete. It is a reactive pozzolanic material. The supplement of silica fume enhanced fiberdistribution in the cementitious matrix, reducing the PPFRC's permeability significantly [7]. For example, as per Michael shydlowski, founder, master builder, inc, he wrote...
articles in the 1998 issue of ‘concrete international 25 years ago no individual in the concrete mixes would attain in-place compressive strengths as high as 120 Mpa.

The blend of silica fume and superplasticizer seems to be the basis of high-strength, high-performance concrete [8]. In addition to making high-strength and high-performance concrete, SF becomes a useful cementitious material while making high-performance concrete. SF is used very rarely in condition [9].

The silica fume or microsilica is a crucial modern material, which is available in the forms of undensified, densified, micro-pelletized, and slurry form. Micro silica is produced as an ultrafine unidentified powder with minimum 85 % of SiO₂ content, a mean particle size of 0.1 to 0.2 micron, a least specific surface area of 15,000 m²/Kg, and spherical particles [10].

Polypropylene is a synthetic man-made fiber, these are thermoplastic polymers used widely in construction applications[11]. The use of polypropylene fiber in concrete blends up to a specific ratio had such a definite impact on the mix’s dimensional constancy, mechanical properties, and durability. And in this research used pp fibers are the short synthetic fibers, and the fibers characteristics are in table 2.

The polypropylene fibers can effectively control the plastic shrinkage fractures in the concrete. As Well As decrease shrinkage strain while concrete drying and increasing the freeze-thaw resistance [12]. By adding synthetic fibers (polypropylene) to the concrete decreases water permeability, water absorption and improves chloride ion penetration [10].

The main objective of this study is to be finding the mechanical properties of the fiber induced concrete with a constant percentage of silica fume and constant water-binder ratio in all mixes and different ratios of pp fiber content were taken and strength properties and tensile and flexure experiments are started after 28 days of specimens. And considering the previous studies and calculations, analysis is considered.

2. Tentative procedures:

2.1. Materials

2.1.1. Cement. In this research, an ordinary Portland cement (OPC 53 grade) having a specific gravity of 3.14 was applied as a binding material. The biological composition of the OPC was given in table 1 [7].

| Oxides       | Content % |
|--------------|-----------|
| CaO          | 62.1      |
| SiO₂         | 22.1      |
| Al₂O₃        | 4.2       |
| Fe₂O₃        | 3.9       |
| MgO          | 3.3       |
| S₀₃          | 1.9       |
| Free lime    | 0.7       |
| L.O. I       | 3.1       |
| L.S. F       | 0.86      |
| Insoluble residue | 1.1     |
2.1.2. Fine aggregate. The locally available sand with a specific gravity of 2.36 and a fine and crystal texture is used as a filler material in concrete, and which passes through a sieve of 4.75mm Figure 1 depicts the fine aggregate fineness modulus.

![Figure 1. The fineness of sand.](image1)

2.1.3. Coarse aggregate. The coarse aggregate is 20mm and angular in shape, having a specific gravity of 2.64.

2.1.4. Superplasticizer. High-performance polycarboxylate-based superplasticizer ECMAS used as 1% of replacement of cement weight.

2.1.5. Polypropylene fiber. The polypropylene fiber (non-metallic), which is synthetic and has a length of 12mm (short fibers) with a specific gravity of 1 is used. These fiber gives good strength and acts as a secondary reinforcement in both tension and compression zone. The PP fiber having a modulus of elasticity >3500 Mpa. And the properties of the fibers are exhibited in table 2[4].

![Figure 2. Polypropylene fiber(12mm).](image2)

| Property            | Unit      | Value |
|---------------------|-----------|-------|
| Length              | mm        | 12    |
| Density             | KN/m³     | 9.1   |
| Diameter            | mm        | 0.034 |
| Sp. gravity         |           | 0.9   |
| Water absorption    | %         | 0.01  |
| Melting temperature | °C        | 169   |
2.1.6. **Silica fume.** The substance silica fume is a by-product of diminishing purity quartz with coal in an electric arc furnace to harvest silicon or ferrosilicon alloy. Because of its chemical and physical properties, it is beneficial to concrete. It is a pozzolanic substance with high reactivity. It would be considered that silica fume does not significantly add to the strength of the material. But, as an indistinguishable fine pozzolanic material, it provides strength to cement mortar by forming dense packing and void filler [8]. Because of the charisma of a lofty amount of superplasticizer and thick wrapping of cement paste, the high strengths of moderate concrete containing silica fume can be attributed to the presence of silica fume to a large extent. A decrease in water quantity is to be expected. Table 3 displays the physical properties of SF.

| Tests             | Values                        |
|-------------------|-------------------------------|
| Colour off        | Gray                          |
| Surface area      | 13000-30000 m²/kgm²/kg        |
| Bulk density      | 600 kg/m³                     |
| Specific gravity  | 2.2-2.3                       |

2.2. **Mixing procedure.**

The following process is initiating the mixing procedure of concrete as a requirement, firstly the coarse aggregate and the fine aggregate are mixed for 1min and then the cement (Opc) and silica fume (replacement of cement) of 4% as weight of cement is added and fibers are also added then mixed for 3mins and the water with superplasticizer was additional to the blend and mixing intended for 2mins. The fibers specifications and mix proportions are provided in table 4, 5.

| Mix ID   | Description                        |
|----------|------------------------------------|
| PC       | Plain concrete                     |
| PPFRC01  | PC+4%SF+0.1%PP                     |
| PPFRC02  | PC+4%SF+0.2%PP                     |
| PPFRC03  | PC+4%SF+0.3%PP                     |

**Note:** PPFRC - polypropylene fiber reinforced concrete, PC - plain concrete, SF - silica fume, PP – polypropylene, FRC- fiber reinforced concrete.

| Material | Cement (kg/m³) | Fine aggregate (kg/m³) | Coarse aggregate (kg/m³) | Water (kg/m³) | Superplasticizer (kg/m³) |
|----------|----------------|------------------------|--------------------------|---------------|--------------------------|

Table 3. Properties of silica fume[12].

Table 4. Mix proportion specifications.

Table 5. Mix proportion as ordinary concrete.
2.3. Preparing specimens and curing.
Specimens are prepared following the materials mixing, and the preparation of specimens is done in the laboratory having the room temperature of 23°C. The following materials are mixed with the drum mixer as step by step stirring of the materials. The coarse and fine aggregate are stirred for 60 sec, then the cement, fibers, and silica fume is added and stirred for 60 sec, and the water and superplasticizer adding to the previous mixed materials and stirred for 180 sec.

![Concrete Specimens](image)

**Figure 3.** Concrete Specimens.

With uniformly mixed concrete done the slump cone test and preparing the specimens and after 24 hrs demould it and curing for 7 and 28 days. After completing the curing, specimens are dried for 24 hrs and the test was performed.

3. Test procedures
3.1. Compressive strength test.
This test is done for the cube specimen having a dimension of 100x100 x 100 mm³. Tests are done at the time of 7, 28 days are performed. Each mix proportion of three specimens including plain concrete taking the average value and the test has performed in the compressive testing machine. The test was performed by using ASTM C39 shown in figure 4.

![Compressive strength test](image)

**Figure 4.** Compressive strength test.

3.2. Split tensile test.
The split tensile of concrete test performed at the time of 7 days & 28 days for the 100x300 mm² cylindrical specimens of three different mix proportion with plain concrete is tested. The test performed in ASTM C39 is shown in figure 5.
3.3. Bending strength test.
Bending strength of the concrete is done at the time of 7, 28 days for the 100x100x500mm³ prisms are tested. The average value of each three specimens of three different mix proportions with plain concrete. The test was shown in figure 6.

3.4. Mode of failure and ultimate load test.
This test is performed for the beam made of standard reinforced concrete and PPF02 with reinforcement of optimal fiber volume beams with dimensions of 150x150x700mm³. After 28 days of curing period beams are tested under single point load in UTM shown in figures 7, 8.

4. Discussion and conclusions

4.1. Workability of concrete.
In the process of finding the workability of concrete, slump measurement is also one of the methods. It is a widely used test for knowing workability. In this study, the slump is a measure for each mix proportion before the cast. The slump readings are representing in figure 8.
4.2. Compressive strength.
The concrete cubes of 100x100x100mm$^3$ in size are tested in ASTM C39. The cubes of plain concrete and fiber reinforced concrete up to 0.3% of fiber volume with silica fume specimens are performed the compressive strength test for 7 days, 14 days, and 28 days. The specimens tested results are represented in the graph (figure 10) as in order form of PC, PPF01, PPF02, PPF03. The maximum compressive strength is gain in both PPF02 and PPF03. But the maximum and good performance are shown in the PPF02.

4.3. Split tensile strength.
A concrete cylindrical specimen of size 150mmx300mm is performed testing in ASTM C496. The specimens are cured for 7, 28 days. The specimens of 0.1%, 0.2%, and 0.3% are compared with plain concrete (PC). The final values are taken from three readings of an average value of each mix proportion. The results are represented in figure 11.
Figure 11. Split tensile strength

4.4. Bending strength.
The flexure strength of concrete is performed test by using a prism of 100x100x500mm^3 in size. The test was done at the time of specimens 7, 28days. The fiber reinforced concrete with silica fume specimens is compared with the plain concrete. The calculated values are represented in below figure 12.

Figure 12. Bending strength

4.5. Mode of failure and ultimate load.
In this testing, the flexure failure and the ultimate load is calculated. And the beam of 150x150x700mm^3 in size is tested in the UTM. One plain concrete beam is compared with the PPF02 mix proportion beam. Both beams are having the reinforcement of 12mm dia main bars and 6mm dia bars as stirrups are placed in the beams. The first crack has appeared in a plain concrete reinforced beam at 58.86 KN, and the fiber-reinforced concrete beam is at 68.67 KN. The load vs deflection curves of both the RCC beam and PPF02 are shown in figure 13 and 14.
The ultimate load taken by the normal beam is 98.1KN and deflection is 7.28mm, and the fiber-reinforced concrete beam is taken 107.91 KN for deflection 4.36mm. Given that the central zone was subjected to pure bending, the mode failure occurred as predicted. When the load is applied continuously, cracks develop rapidly and broadly in the regular beam, but in the fiber-reinforced beam, cracks form steadily and narrowly. Since the fibers serve as secondary reinforcement in both the compression and stress areas, cracks form slowly and do not expand. Observations made during the serviceability load test for reinforced concrete beams indicated that the first crack occurred in the beam's mid-span.

Specimens revealed that the ultimate load capacity of beams and these are fulfilling the specification of the reinforcement bar after a contrast between the control specimen and the fiber-reinforced beam. The maximum load is determined by the maximum tensile stress of the reinforcement design, rather than a fully concrete beam.

5. Conclusions
The addition of silica fume can develop compressive strength, and PP fibers are active at resisting tensile forces and flexural moments. PPFRC with SF is contrasted to PC in terms of mechanical properties. The following are some of the outcomes of this research:

1. The usage of fibers in size 12mm are shown performance as expected range of absorbing the flexural load compared to PC.
2. The addition of 4% silica fume increased the compression performance, by its fineness material property.
3. Polypropylene dosage of 0.1% by concrete volume is shown less performance, and 0.2% shown the best performance when compared to the PC.
4. The PPF Concrete possesses very slow cracking while applying load on it.
5. PPF02 beam has a higher load-bearing capacity and having less deflection compared to the normal reinforced concrete beam.

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