



## The Study of Mechanical Properties of High Strength Concrete Containing Steel and Polypropylene Fibers

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### Abstract

From industrial point of view, recently a great attention has been paid to the use of additives such as steel and polypropylene fibers in concrete and cement products. Investigations have revealed that the addition of steel and polypropylene fibers into normal concrete impart significant improvement in controlling its surface cracking, increase their tensile and flexural strength and durability. Considering the advantages of these additives, high strength concrete samples were produced with different mix design as well as using cement replacement materials such as silica fume according to a well-established experimental set up. The tests show that mixed use of steel and polypropylene fibers give good results in terms of improving structural characteristics of the concrete material developed. In all samples, the surface cracking was decreased significantly by adding suitable fibers in terms of sort, diameter, and length. However, the use of 1 kg polypropylene and 78 kg steel fibers in 1 cubic meter concrete was proposed as optimum mix design, regarding the improvement of compressive, tensile and flexural strength of concrete as well as scientific and practical points of view. So that, these newly developed structural concrete reveals promising potentials for further research and development as well as an structurally important building block material.

*Keywords:* High-Strength Concrete; Polypropylene Fibers; Steel Fibers; Silica Fume; Super Plasticizer.

### 1. Introduction

Nowadays, concrete is by far the most widely used construction material. It is versatile, has desirable engineering properties, and also can be molded into any desired shapes and more importantly is produced with very cost-effective raw starting materials. To make good concrete with desired properties, now variety of innovative materials such as fibers, admixtures and construction chemicals, pozzolans and different concrete making techniques are well scientifically adopted in present day modern construction. In recent years, intensive research has resulted in significant advances and innovation in the technology of reinforcement fibers such as glass, polypropylene, carbon, steel etc., and more basic knowledge has been gained on the behavior of cement concrete containing these fibers. Concrete containing hydraulic cement, water, aggregate, and discontinuous discrete fibers is called fiber-reinforced concrete (FRC). The incorporation of short discrete fibers (steel, polypropylene, glass, carbon) can lead to practically useful improvements in the mechanical behavior of a given concrete mixture. In recent years, many studies have been conducted in the mechanical characteristics of FRC. Such FRC is also used in retrofitting and repairing the covering of concrete structure, tunnels, etc. Polypropylene fibers (at relatively low volume fractions of about <0.3%) are used for: secondary temperature shrinkage reinforcement, overlays and pavements, slabs, flooring systems, crash barriers, precast pile shells and shot-crete for tunnel linings, canals and reservoirs [1]. According to the researches, the increase of formability and bending strength are the extra advantages of adding the fibers to the concrete. Two kinds of fiber that very often used in the concrete are: steel fiber and polypropylene fiber [2]. The evaporation of concrete surface

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water is a factor in creating the contract paste fracture in concrete which leads to the formation of tension compression since the concrete starts to strengthen [3]. It was mentioned that using polypropylene fibers can improve spalling behavior of concrete [4]. The paste fractures are formed when the acceleration of water evaporation is more than the movement of concrete emulsion to the surface. Here, the negative pressure is generated in the capillaries through which the concrete paste flows and proportionately the tension compression is formed. Such compression is developed during the concrete strengthening and the concrete is cracked where the compression is more than the concrete strength. The cracks caused by paste contracting in the concrete are formed in the first hours after pouring the concrete in the frames and before the concrete reaches its initial strength. Such cracks create critical points in the concrete sensitivity for attaching harmful materials to internal parts of concrete that finally can lead to corrosion and damaging the material in the concrete. Consequently, the performance, servicing or profiting capability, duration, aestheticism and strength of the concrete structures are reduced. Controlling the paste contract tracks in the concrete is of great importance in more duration and resistibility of concrete in the shortest time of structural utilization [4]. In ordinary concrete, where vibration is necessary, the best and most acceptable method for preventing cracks formations caused by paste contract is by using fibers, particularly thin artificial ones with the volume of less than 0.5% [5, 6]. Polypropylene fibers have hydrophobic levels, which protect them against wetting with cement paste. The hydrophobic nature of polypropylene has no effect on the amount of water needed for concrete. The characteristics of different fibers are listed in the Table 1 [7]. Some techniques that are widely used for high strength concrete development include utilization of natural lightweight aggregates such as pumice, diatomite, and volcanic cinders, or artificial byproducts such as perlite, expanded shale, clay, slate, and sintered pulverized fuel ash (PFA). In spite of its benefits, lightweight concrete exhibits its brittle characteristics and lower tensile strength compared with normal concrete. On the other hand, fiber addition into concrete mixes becomes more widely used to improve concrete tensile behavior. The geometrical size and modulus of elasticity of fibers are the main factors which will affect the performances of fiber reinforced concrete. In order to optimize the benefits of fiber addition in concrete construction, the application of different fiber types into fresh concrete mixtures was introduced and commonly known as hybrid fiber reinforced concrete (HyFRC). It becomes more popular in these recent years and expected to provide better physical and mechanical properties in concrete for structural purposes. The use of different types of fiber in a suitable combination may potentially improve the mechanical properties of concrete and result in synergic performance [8-12]. Addition of steel fiber generally provides contribution to the energy absorbing mechanism (bridging action), while nonmetallic fibers offer its ability to delay the formation of microcracks and avoid catastrophic breaking, and also has much lower density [11, 13]. In this study the influence of different amount of polypropylene and steel fibers content on concrete properties were investigated by measuring compressive, bending, and splitting tensile strength.

## 2. Experimental

### 2.1. Martials

Cement used for preparation of concrete samples in this study was Portland (type II) cement supplied by Soufian Cement Co. (East Azerbaijan, Iran). Cement used in all studies was of 425-2 type with special density of 3.15 g.cm<sup>-3</sup> and Blin area of 3345 cm<sup>2</sup>.g<sup>-1</sup>. Chemical composition and physical as well as mechanical characteristics of this cement as reported by the manufacturer were in accordance with Iran National Standard No.398 and Chapter 5 of National Building and Construction Standard.

**Table 1. Chemical Analysis of type II Cement**

Oxides	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Alkaline
Percent	17-25	3-8	0.5-6	60-67	1-4	1-3	0.2-1.3

In this study, due to the fact that three different assays of cement were used, and also for characterization of concrete resistance conditions for assays higher than 600 kg/m<sup>3</sup>, cement assays from 480 to 600 kg/m<sup>3</sup> were adopted. Water used in concrete samples mix design was Tabriz City potable water which is accordance with National Construction Requirements [14]. Sand used was of river sand type supplied by Misho Sand Company (Marand, East Azerbaijan). Trial and error approach was adopted in order to obtain an optimum mixing ratio of gravels to achieve a rather ideal composition. A typical example of the mentioned approach is as follows; 21% with 50% sand having 70% of its particles in 0-3 mm range and 30% in 3-6 mm range. Special density of mixed sand was measured to be 2.51 g.cm<sup>-3</sup> and its water uptake was 0.92%. In order to minimize the experimental errors and obtaining consistent as well as logical results, water uptake, moisture and special weight of the sand in SSD state before sampling were measured and the results were indicated in Table 2.

**Table 2. Characteristics of Sand used for concrete samples preparation**

No.	Property/Details of Test	Unit	Standard	Standard Limit	Test Result
1	Grain Distribution	-	ASTM C136	-	Appendix
2	Sand Softness Index	-	ASTM C136	2.3-3.2	3.14
3	Transferred from 200 sieve	%	ASTM D 2419	≤ 3	1.3
4	Water uptake	%	ASTM C128	≤ 2	0.92
5	Special weight	gr/cm <sup>3</sup>	ASTM C128	-	2.684
6	Real Special Weight	gr/cm <sup>3</sup>	ASTM C128	-	2.624
7	Saturated Special Weight with dry surface	gr/cm <sup>3</sup>	ASTM C128	-	2.648

Grain size distribution of sand was determined using standard sieves. Distribution curve was in the range recommended in ASTM C33 Standard [15]. Bulk special density of small sized gravels was 2.69 g.cm<sup>-3</sup> and its water uptake was 2.57%. Maximum diameter of its grain was about 12.5 mm.

Microsilica is added to concrete in its formation state in order to improve mechanical resistance, increase in compression and durability in freezing cycles and decreasing concrete permeability. Microsilica particles which are about 100 times softer than cement, act as effective filler, filling the residual space between cement in concrete so enhancing concrete durability and lowering its permeability. The technical characteristics of the microsilica powder are pH (9-10), particle size (0.05-0.15 micron), Particle Shape (spherical), Special weight (200-300 Kg/m<sup>3</sup>), and special surface area (20.4 m<sup>2</sup>/g). Table 3. indicate the chemical analysis of the microsilica power, respectively.

**Table 3. Chemical analysis of the microsilica power**

Material	AL <sub>2</sub> O <sub>3</sub>	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	L.o.I	Density
Percentage %	17-23	8-15	>0.9	>0.9	10-12	1.3	2-3	1.8-2.1

Microsilica is usually added at about 5 to 15% of cement weight at concrete preparation step to the truck mixture followed by same minutes mixing to obtain a homogenous mixture. Also it would enhance total performance efficiency [16]. Noting similar properties of microsilica and microsilica gel and due to lack of microsilica treatment equipment in the laboratory, in this research use was made of only microsilica gel. Microsilica gel was supplied by Forsroc Co. (UK); and its chemical composition (0.4-2 % Fe<sub>2</sub>O<sub>3</sub>, 2-2.3 % CaO, 0.1-0.9 % MgO, 1.7 % AL<sub>2</sub>O<sub>3</sub>, 85-95 % SiO<sub>2</sub>) and physical properties were (amorphous structure, spherical shape, 0.2-0.3 Micron grain size distribution, high reaction surface area for hydration reaction, 200 Kg/m<sup>3</sup> bulk density) respectively.

In this research, superplasticizing agent Conplast Sp 430 supplied by Iran Fars Co (Ltd.), manufacturing branch of Forsroc, International was used. This compound is a water soluble polycarboxylic acid. According to the instruction provided by the manufacture, 50% to 2% of the cement weight can be compromised of this super plasticizing agent, optimum concentration of the agent being 50 to 25% water solutions. The technical properties of this agent were shown in Table 4.

**Table 4. Conplast Sp 430 Technical properties**

State	Concentrated Liquid
Color	Brown
pH	5.6
Cl Content	No Cl
Density	1.8 g/cm <sup>3</sup>
Package	1 Barrels and 20 Kg Packs210
Transport	Non-Dangerous

Fibers used for the preparations of samples were steel hooked end and sinusoidal hooked-end provided by Zanjan Wire Co. (Iran). These fibers met the requirements of ASTM 820 Standard. The Characteristics of these fibers were (0.8 mm fiber diameter, 51 mm fiber length, 63.75 length/diameter ratio, 7850 Kg/m<sup>3</sup> density, and 1220 MPa tensile strength) [17].

In order to prevent problems such as cracking and crack propagation, polypropylene fibers are usually added to the concrete mixture. Also propylene fibers decrease the brittleness of the concrete samples and enhance their fire

resistance properties. These fibers melt at 160 °C forming a network of channels through the concrete through which liquids and water vapor can easily escape thus reducing the internal pressure (Yao 2000). In this work, polypropylene fibers provided by Forsoc Co. (UK) were used. Table 5. indicates the properties of these fibers.

**Table 5. Properties of polypropylene fibers**

Material	Polypropylene
Kind	staple
Water Uptake	0
Length	6, 12 mm
Diameter	22 Micron
Shape	Fiber
Density	0.91 g/cm <sup>3</sup>
Alkaline	0
Sulfate Content	0
Chloride Content	0
Fiber Thickness	18-30 Micron
Young Modulus	5500-7000 MPa
Tensile Strength	350 N/mm <sup>2</sup>
Melting Point	160 °C

In this work, total amount of microsilica gel and 1/3 of the total water to be used in Mix Design and whole of super-plasticizing agent were thoroughly mixed with each other to form a gel with the hope of achieving more enhancing effect of this pozzolan on the concrete properties.

## 2.2. Mixing Order

In Mix Designs of A1, B1, and C1, cement was always added at the final stage because of its different water uptake properties compared with gravels; so if cement was added at the first stage, conglomeration of the mixture is possible. But in Mix Designs of A2-A6 and B2-B6 and C2-C3; cement was added to the mixture one step before final addition. Mixing time after addition of cement for all Mix Designs was about 3-8 min and finally, steel fibers or polypropylene fibers were simultaneously added to the mixture followed by another 3-6 min mixing time.

## 2.3. Molding

In this step, prepared concrete mixtures were molded in cubic 10×10×10 cm molds that were formerly cleaned and lubricated. After molding, the weight of the samples measured and recorded. Samples were exposed to laboratory environment for 24h. Then samples were taken out from molds and 3 of the samples were submerged in water for 7 days and another 3 of were submerged for 28 days to be quite treated. After then, samples were taken out form water followed by weighing and measuring their compression resistance. Figure 1. shows the samples after molding step.



**Figure 1. Samples after molding step**

## 2.4. Mix Design

The purpose of Mix Design is to develop a formula according to given properties of the concrete. In this work, a total number of 24 Mix Designs was developed in which ratio of water to sticky materials is 0.3, microsilica amount was in three assays of 0, 11 and 25 percent of cement weight while super fluiding agent was 3% sum of weights of cement and microsilica, which this sum is fixed in all Mix Designs. Cement assay was in the range of 480 kg/cm<sup>3</sup> to 600 kg/cm<sup>3</sup>. The details of volumetric percentage of rock materials in Mix Design are (1 design code, 21% nut shaped gravel, 29% pea shaped gravel, and 50% sand)

It should be noted that all parameters in Mix Designs were chosen so that the requirements of ASTM C330 is met as close as possible from grain size distribution point of view. Details of weight percentage of materials for Mix Designs of A, B, and C were given in Tables 6 to 8, respectively.

**Table 6. Weight percentage of materials for Mix Design of A**

Mix Design	A1	A2	A3	A4	A5	A6	A7	A8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

\* Conditions: cement weight (600 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (0 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>), and water (180 L/m<sup>3</sup>).

**Table 7. Weight percentage of materials for Mix Design of B**

Mix Design	B1	B2	B3	B4	B5	B6	B7	B8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

\* Conditions: cement weight (540 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (60 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>), and water (180 L/m<sup>3</sup>).

**Table 8. Weight percentage of materials for Mix Design of C**

Mix Design	C1	C2	C3	C4	C5	C6	C7	C8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

\* Conditions: cement weight (480 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (120 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>), and water (180 L/m<sup>3</sup>).

## 2.5. Adjustment (Correction) of Weight Percentage of Materials for Mix Design

Due to the fact that calculated Mix Design was based on microsilica gel used throughout this work, so some correction is necessary to be performed. The corrected weights for Mix Designs of A-C were shown in Tables 9-11, respectively. It should be noted that since no microsilica was used in Mix Design A, so there is no change in weight for Mix Designs A.

**Table 9. Corrections made in weight of materials for A Mix Design**

Mix Design	A1	A2	A3	A4	A5	A6	A7	A8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

\* Conditions: cement weight (600 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (0 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>), and water (180 L/m<sup>3</sup>).

**Table 10. Corrections made in weight of materials for B Mix Design**

Mix Design	B1	B2	B3	B4	B5	B6	B7	B8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

\* Conditions: cement weight (540 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (100 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>), and water (140 L/m<sup>3</sup>).

**Table 11. Corrections made in weight of materials for C Mix Design**

Mix Design	C1	C2	C3	C4	C5	C6	C7	C8
Steel Fibers kg/m <sup>3</sup>	0.0	39	78	117	156	78	0.0	0.0
Polypropylene kg/m <sup>3</sup>	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0

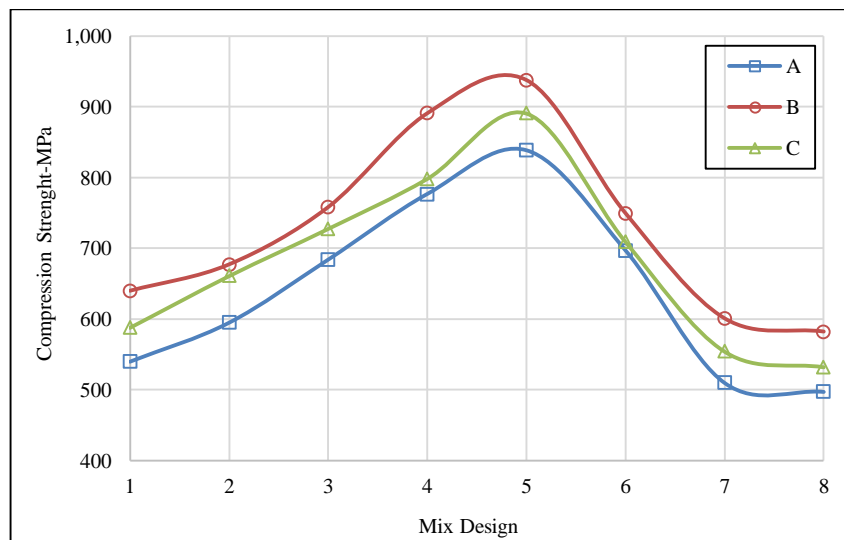
\* Conditions: cement weight (480 kg/m<sup>3</sup>), water/bulk ratio (0.3 W/b), micro silica (200 kg/m<sup>3</sup>), super plasticizer 3.0% (18.00 L/m<sup>3</sup>), nut gravel (335 kg/m<sup>3</sup>), pea gravel (470 kg/m<sup>3</sup>), sand (800 kg/m<sup>3</sup>, and water (100 L/m<sup>3</sup>).

### 3. Results and Discussion

After preparation and treatment of samples in laboratory temperature and environmental conditions, tensile strength, compression strength, bending strength and slump measurements were performed on the samples along with measuring their weight at different conditions.

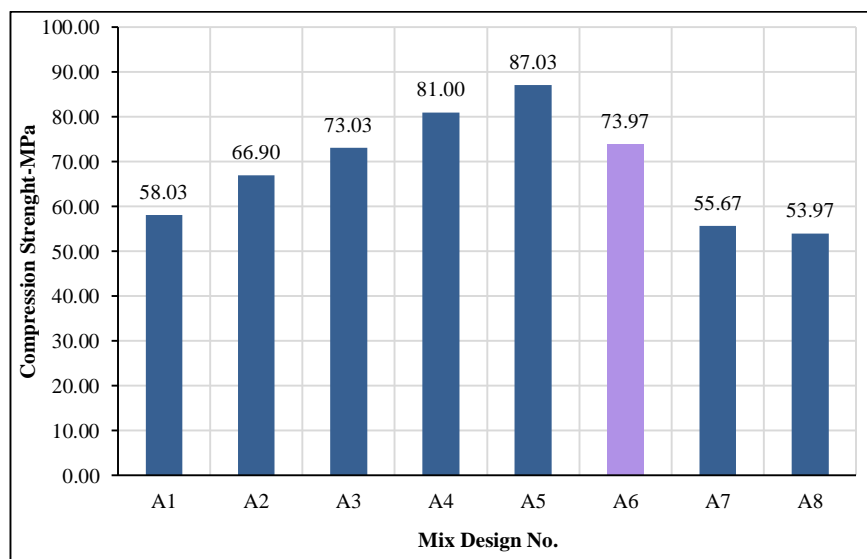
#### 3.1. Mean Compression Strength of the Mix Design Samples

Compression strength of the samples at 27 and 28 days age was measured according to ASTM C39 on cubic 10×10×10 cm<sup>3</sup> samples and the results were compared with each other and samples without any steel and/or polypropylene fibers. Measurements were performed with electrohydraulic loading machine with capacity of 2000 KN and a loading rate of 0.3 MPa/sec<sup>1</sup>. Figure 2. shows the results for samples with different percent of polypropylene for 7 days age.



**Figure 2. The results for samples with different percent of polypropylene for 7 days age**

The similar results for 28 days age samples were given in Figures 3 to 5.



**Figure 3. The results for a mix design samples with different percent of polypropylene for 7 days age**

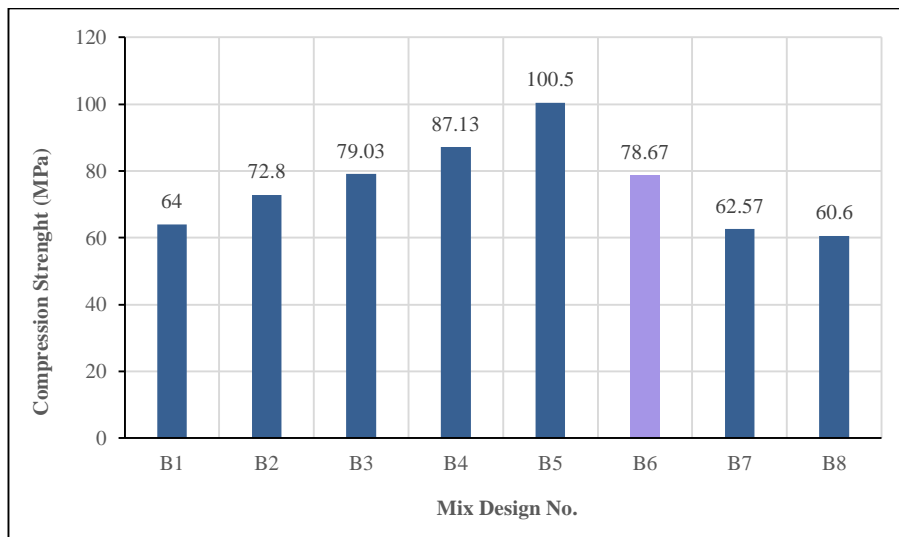


Figure 4. The results for B mix design samples with different percent of polypropylene for 7 days age

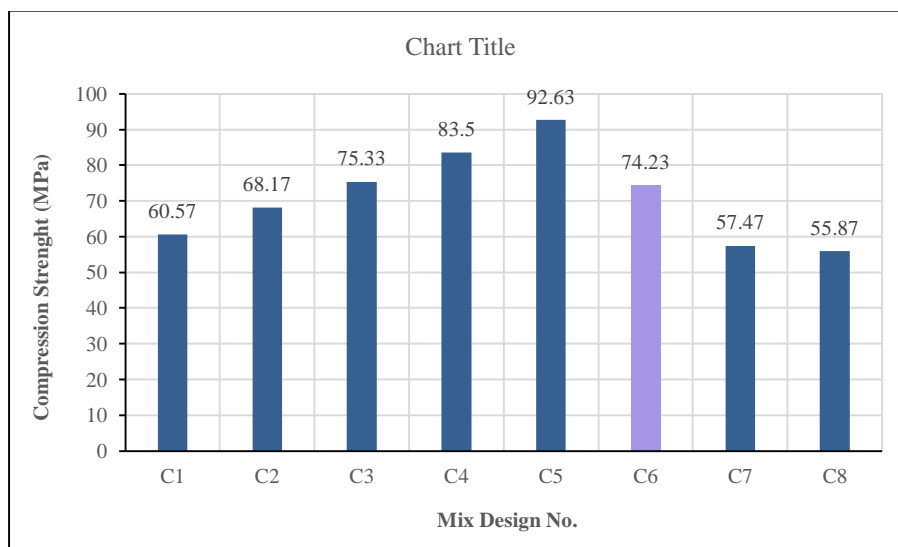


Figure 5. The results for C mix design samples with different percent of polypropylene for 7 days age

According to the results of Figures 3-5, addition of polypropylene fibers has a negative effect on the compression strength of the concrete samples. This may be attributed to the pores or channels filled with fibers. In other words, addition of polypropylene fibers decreases the compression strength of concrete. Tables 12-14. indicate the same results for samples containing steel fibers after 7 days treatment in water.

Table 12. As above for 7 days age samples containing steel fibers

Mix Design	Fiber Content kg/m <sup>3</sup>	Fiber Content (%)	7 days strength of 3 samples (Mpa)			Mean of 7 days Compression Strength	Percentage of change in strength compared with sample without fiber (%)
A1	0	0	56.1	53.5	52.4	54.00	0
A2	39	0.50	57.3	59.8	61.4	59.50	10
A3	78	1.00	68.7	68.5	68.0	68.40	27
A4	117	1.50	76.5	78.5	78.0	77.67	44
A5	156	2.00	83.5	83.8	84.2	83.83	55
A6	78	1.00	68.4	70.0	70.7	69.70	29

Table 13. As above for 7 days age samples containing steel fibers

Mix Design	Fiber Content kg/m <sup>3</sup>	Fiber Content (%)	7 days strength of 3 samples (Mpa)			Mean of 7 days Compression Strength	Percentage of change in strength compared with sample without fiber (%)
B1	0	0	64.1	63.8	64.0	63.97	0
B2	39	0.50	66.5	68.0	68.6	67.70	6
B3	78	1	74.1	76.0	74.7	74.93	17

B4	117	1.50	90.8	90.4	86.0	89.07	39
B5	156	2	94.1	93.2	94.0	93.77	47
B6	78	1	76.1	75.9	75.4	75.80	18

Table 14. As above for 7 days age samples containing steel fibers

Mix Design	Fiber Content kg/m <sup>3</sup>	Fiber Content (%)	Mean of 7 days Compression Strength	7 days strength of 3 samples (Mpa)			Percentage of change in strength compared with sample without fiber (%)
C1	0	0	58.80	60.3	57.1	59.0	0
C2	39	0.50	66.10	65.8	66.4	66.1	12
C3	78	1	72.77	73.2	73.0	72.1	24
C4	117	1.50	79.83	80.0	80.1	79.4	36
C5	156	2	89.07	89.2	87.9	90.1	51
C6	78	1	70.93	70.1	70.6	72.1	21

### 3.2. Tensile Strength of Samples

Samples of reinforced concrete (with steel fibers and polypropylene fibers) were tested by samples cleavage (Brazilian) test. Tensile strength measurements were performed on 28 days age samples according to ASTM C 496 Standard. In this test, cylindrical samples with 100×200 mm<sup>2</sup> dimensions were used. Tensile strength was calculated according to the following equation:

$$T = \frac{2P}{\pi L} \times d^2 \quad (1)$$

Where T is the tensile strength (kg/cm<sup>2</sup>), P indicated the maximum load applied (kg), L is the length of sample (cm) and finally d shows the diameter of the sample (cm).

### 3.3. Bending Strength of Samples

For this test, pyramid shaped samples with dimensions of 10×10×50 cm<sup>3</sup> were used according to AREM Part 4 Guidelines (ASTM C1609/C 2005). Bending strength (Fracture resistance) was calculated by the following equation:

$$Fr = \frac{MC}{I} = \frac{PL}{bh^2} \quad (2)$$

Where Fr is the Fracture resistance of concrete (N/mm<sup>2</sup>), P is the maximum load applied (N), d is the width of sample (mm) and h indicates the height of the sample (mm).

Generally, increase in bending strength (fracture resistance) is in close relation with an increase in tensile resistance because practically tension developed from bonding is the controlling factor of the Fracture load. Results of this work show that at single point loading additions, steel as well as polypropylene fibers significantly enhances bending strength through improvements in transition zone and micro crack control.

### 3.4. Analysis of Compression Strength Results

In all cases, with increasing polypropylene content in the concrete samples, compression strength decreases due to some voids formed in the concrete matrix by fibers. But with increasing steel fibers, in all cases, compression strength increases up to 1.5% steel fibers content but beyond this percentage, no significantly enhancing effect was observed.

### 3.5. Analysis of Tensile Strength Results

In all cases, addition of fibers (both of polypropylene and steel fibers) increases the tensile strength but this is not the case with high fibers content more than 2 kg/m<sup>3</sup> at which a sudden decrease in tensile strength is observed. This finding may be attributed to the fact that at low contents, fibers act as proper reinforcing materials but at high content they lower density and increase porosity so, as a result, tensile strength decreases beyond 2 kg/m<sup>3</sup> of fibers content (Figure 6).



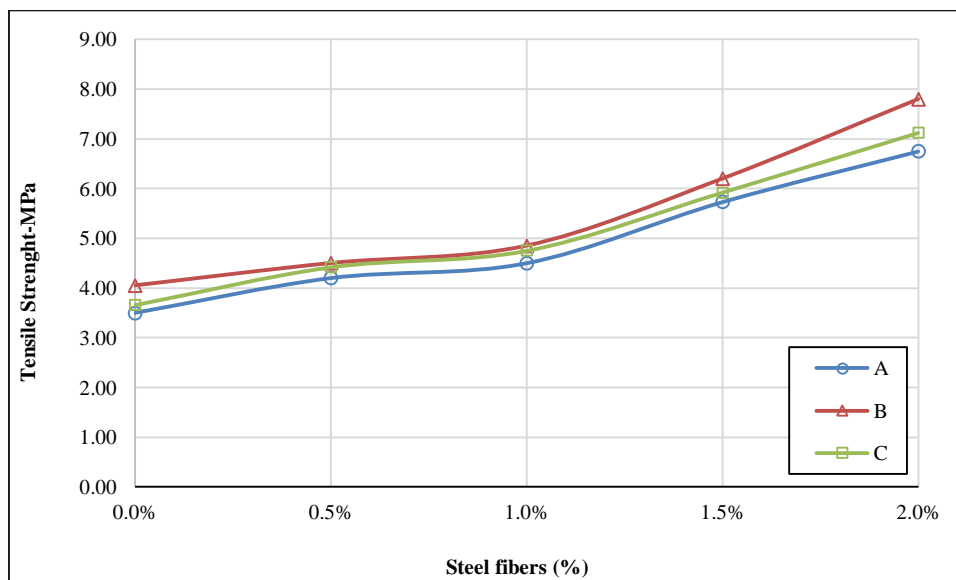


Figure 6. The effect of steel fibers on the compressive tensile test

### 3.6. Analysis of Fracture Resistance (Bonding Strength)

Addition of steel fibers significantly enhances bending strength of concrete. Low fiber content inserts more profound results. Due to rather higher cost of steel fibers, it is suggested by the results obtained in this study that steel fibers are to be used at a content of about 78 kg/m<sup>3</sup> or about 1% of concrete content. Tables 12-14. and Figure 7. gives the summery of the results obtained for compression, tensile, and bending strength of samples with different Mix Designs (A, B, and C).

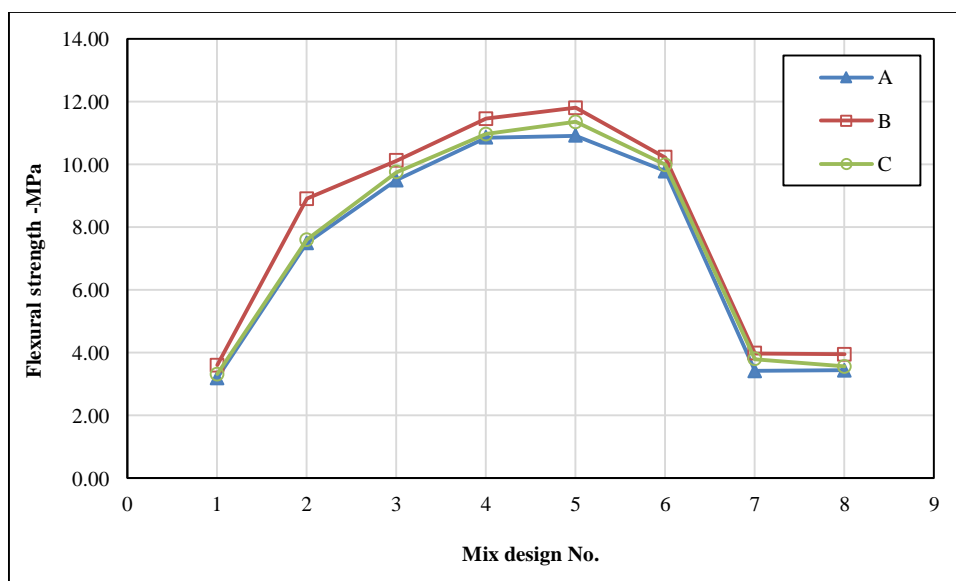


Figure 7. Flexural strength test results

## 4. Conclusion

According to the experimental results detained and further analysis performed, the following conclusions may be asserted from this study:

- Addition of microsilica up to 25% enhances the compression strength with on optimum content to be about 11%. The same finding is true in the case of both tensile strength and fracture resistance. Additions beyond 25% has no more significant enhancing effect and further additions may lower concrete strength characteristics due to micro filler effect of microsilica and its incapability to participate in hydration reactions.
- Addition of steel fibers significantly enhances all of three types of strengths i.e. compression, tensile, and bending resistance. This enhancing effect is rather slow up to 1% of fibers content but beyond this a sharp increase in concrete resistance was observed.

- Addition of polypropylene to high strength concrete, decrease the compression strength but on the other hand has positive effect on tensile strength up to 2 kg/m<sup>3</sup> fibers content at which increase in tensile strength as doped from 7% down to 4%. The same is true for bending resistance and at a fiber content of 1 kg/m<sup>3</sup>, bending strength increases about 11% and at fiber content of 2 kg/m<sup>3</sup>, enhancing effect was rather less and was about 8%.
- Combining 1% steel fibers and 1 kg/m<sup>3</sup> polypropylene, has a net enhancing effect on compression strength and also on tensile strength as well as to some to some extent on bending strength.

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