STUDY ON STRENGTH PROPERTIES OF FIBRE REINFORCED CONCRETE

A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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To

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN – 173 234

HIMACHAL PRADESH

INDIA

June, 2016

Dedicated to Our Families

CERTIFICATE

This is to certify that the work which is being presented in the project title **“Study On Strength Properties Of Fibre Reinforced Concrete”** in partial fulfillment of the requirements for the award of the degree of Bachelor of technology and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **Shubham Sharma (121692)** and **Barun Sanyasi (121706)** during a period from July 2015 to June 2016 under the supervision of **Dr. Ashish Kumar, Associate Professor**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of my knowledge.

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DECLARATION

We hereby declare that the project entitled "**Study on Strength Properties of Fibre Reinforced Concrete**" submitted by us to Jaypee University of Information Technology, Waknaghat in partial fulfillment of the Degree of Bachelor of Technology in Civil Engineering is a record of bona fide project work carried out by us under the guidance of **Dr. Ashish Kumar**. The information submitted herein is true and original.

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List of Symbols and Abbreviations

d – Diameter, depth (mm)

l – Length, mm

P – Load (kN)

R – Flexural Strength

T – Tensile Strength

V_f – Volume Fraction

W – Weight (gm)

Φ – Diameter (mm)

ASTM – American Society of Testing of Materials

BIS – Bureau of Indian Standards

CTM – Compression Testing Machine

FRC – Fibre Reinforced Concrete

RCC – Reinforced Cement Concrete, Roller Compacted Concrete

PPC – Portland Pozolana Cement

PPF – Polypropylene Fibres

PPFRC – Polypropylene Fibre Reinforced Concrete

SF – Steel Fibres

SFRC – Steel Fibre Reinforced Concrete

UTM – Universal Testing Machine

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Barun Sanyasi
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Abstract

This project involves discovering how the addition of fibres in plain concrete mix of M40 grade affects its strength properties. The Strength properties include compressive strength, split tensile strength and flexural strength. The goal of this project is to show that additions of fibres in plain concrete mix significantly improves its strength. This has been done by casting of numerous concrete cubes, cylinders and beams. The fibres used were Polypropylene fibres and Steel fibres. Upon experimenting on these, we have found out that strengths, i.e. compressive strength, split tensile strength and flexural strength has improved significantly.

We can thus conclude that fibres impart energy absorption, toughness and impact resistance properties to fibre reinforced concrete material and these characteristics in turn improve the fracture and fatigue properties of fibre reinforced concrete.

Chapter 1

Introduction to Fibre Reinforced Concrete

1.1 General

Concrete is a composite material containing cement, water, coarse aggregates and fine aggregates. The resulting material is a stone like structure which is formed by the chemical reaction of the cement and water. This stone like material is a brittle material which is strong in compression but very weak in tension. This weakness in the concrete makes it to crack under small loads, at the tensile end. These cracks gradually propagate to the compression end of the member and finally, the member breaks. The formation of cracks in the concrete may also occur due to the drying shrinkage. These cracks are basically micro cracks. These cracks increase in size and magnitude as the time elapses and the finally the concrete fails altogether.

The formation of cracks is the main reason for the failure of the concrete. To increase the tensile strength of concrete many attempts have been made. One of the successful and most commonly used methods is providing steel reinforcement. Steel bars, however, reinforce concrete against local tension only. Cracks in reinforced concrete members extend freely until encountering the bar. Thus need for multidirectional and closely spaced steel reinforcement arises. That cannot be practically possible. Fibre reinforcement gives the solution for this problem.

So, to increase the tensile strength of concrete, a technique of introduction of fibres in concrete is being used. These fibres act as crack arrestors and prevent the propagation of the cracks. These fibres are uniformly distributed and randomly arranged. This concrete is named as fibre reinforced concrete.

The main reasons for adding fibres to concrete matrix are to improve the post cracking response of the concrete, i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material. The initial researches combined with the large volume of follow up research have led to the development of a wide variety of material formulations that fit the definition of Fibre Reinforced Concrete.

There are many ways to minimize the failure of the concrete structures made of steel reinforce concrete. The custom approach is to adhesively bond fibre polymer composites onto the structure. This also helps to increase the toughness and tensile strength and improve the cracking and deformation characteristics of the resultant composite. But this method adds another layer, which is prone to degradation. These fibre polymer composites have been shown to suffer from degradation when exposed to marine environment due to surface blistering. As a result, the adhesive bond strength is reduced, which results in the de-lamination of the composite.

The principal reason for incorporating fibres into a cement matrix is to increase the toughness and tensile strength, and improve the cracking deformation characteristics of the resultant composite. In order for fibre reinforced concrete (FRC) to be a viable construction material, it must be able to compete economically with existing reinforcing systems. Only a few of the possible hundreds of fibre types have been found suitable for commercial applications.

1.2 Fibre reinforced concrete

Fibre reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. So we can define fibre reinforced concrete as a composite material of cement concrete or mortar and discontinuous, discrete and uniformly dispersed fibre.

Fibre is discrete material having some characteristic properties. The fibre material can be anything. But not all will be effective and economical. Some fibres that are most commonly used are:

a) Glass
b) Carbon
c) Natural
d) Steel
e) Synthetic

Steel fibre is one of the most commonly used fibre. Generally round fibres are used. The diameter may vary from 0.25 to 0.75mm.The steel fibre sometimes gets rusted and lose its strength. But investigations have proved that fibres get rusted only at surfaces. It has high modulus of elasticity. Use of steel fibres makes significant improvements in flexure, impact and fatigue strength of concrete. It has been used in various types of structures.

Glass fibre is a recently introduced fibre in making fibre concrete. It has very high tensile strength of 1020 to 4080Mpa. Glass fibre concretes are mainly used in exterior building façade panels and as architectural precast concrete. This material is very good in making shapes on the front of any building and it is less dense than steel. The glass fibres used are with modulus of elasticity 72 GPa, Filament diameter 14 microns, specific gravity 2.68, length 12 mm and having the aspect ratio of 85. The number of fibres per kg is 212 million fibres.

Use of carbon fibre is not a developed process. But it has considerable strength and young's modulus. Also investigations have shown that use of carbon makes the concrete very durable. The study on the carbon fibres is limited. Mainly used for cladding purpose.

Natural fibres are low cost and abundant. They are non-hazardous and renewable. Some of the natural fibres are bamboo, jute, coconut husk, elephant grass. They can be used in place of asbestos. It increases toughness and flexural strength. It also induces good durability in concrete.

Fibres are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibres produce greater impact, abrasion, and shatter resistance in concrete. Generally fibres do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement. Indeed, some fibres actually reduce the strength of concrete.

The amount of fibres added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibres), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). Fibres with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fibre's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibres that are too long tend to "ball" in the mix and create workability problems.

1.3 History

The use of fibres to increase the structural properties of construction material is not a new process. From ancient times fibres were being used in construction. In late BC, horse hair was used to reinforce mortar. Egyptians used straw in mud bricks to provide additional strength. Asbestos was used in the concrete in the early 19th century, to protect it from formation of cracks. But in the late 19th century, due to increased structural importance, introduction of steel reinforcement in concrete was made, by which the concept of fibre reinforced concrete was over looked for 5-6 decades. Later in 1939 the introduction steel replacing asbestos was made for the first time. But at that period it was not successful. From 1960, there was a tremendous development in the FRC, mainly by the introduction of steel fibres. Since then use of different types of fibres in concrete was made. In 1970's principles were developed on the working of the fibre reinforced concrete. Later in 1980's certified process was developed for the use of FRC. In the last decades, codes regarding the FRC are being developed.

1.4 Properties of fibre reinforced concrete

Properties of concrete is affected by many factors like properties of cement, fine aggregate, coarse aggregate. Other than this, the fibre reinforced concrete is affected by following factors:

a) Type of fibre
b) Aspect ratio
c) Quantity of fibre
d) Orientation of fibre

Type of fibre:

A good fibre is the one which possess the following qualities:

a) Good adhesion within the matrix
b) Adaptable elasticity modulus (sometimes higher than that of the matrix)
c) Compatibility with the binder, which should not be attacked or destroyed in the long term
d) An accessible price, taking into account the proportion within the mix
e) Being sufficiently short, fine and flexible to permit mixing, transporting and placing
f) Being sufficiently strong, yet adequately robust to withstand the mixing process

Aspect ratio:

Aspect ratio is defined as the ratio of length to width of the fibre. The value of aspect ratio varies from 30 to 150. Generally the increase in aspect ratio increases the strength and toughness till the aspect ratio of 100. Above that the strength of concrete decreases, in view of decreased workability and reduced compaction.

Fibre quantity:

Generally quantity of fibres is measured as percentage of cement content. As the volume of fibres increase, there should be increase in strength and toughness of concrete. But that doesn’t always happen. Usually at optimum fibre content, a maximum value of strength is obtained after which the values decline.

Orientation of fibre:

The orientations of fibres play a key role in determining the capacity of concrete. In RCC the reinforcements are placed in desired direction. But in FRC, the fibres will be oriented in random direction. The FRC will have maximum resistance when fibres are oriented parallel to the load applied.

1.5 Fibre mechanism

Fibre work with concrete utilizing two mechanisms:

a) The spacing mechanism and
b) The crack bridging mechanism.

The spacing mechanism requires a large number of fibres well distributed within the concrete matrix to arrest any existing micro crack that could potentially expand create a sound crack. For typical volume of fractions of fibres utilizing small diameter of fibres or micro fibres can ensure the required no of fibres for micro crack arrest.

The second mechanism termed crack bridging requires larger straight fibres with adequate bond to concrete. Steel fibres are considered a prime example of this fibre type that is commonly referred as large diameter fibres or micro fibres.

Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fibre-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete. Examination of fractured specimens of fibre-reinforced concrete shows that failure takes place primarily due to fibre pull-out or de-bonding. Thus unlike plain concrete, a fibre-reinforced concrete specimen does not break immediately after initiation of the first crack. This has the effect of increasing the work of fracture, which is referred to as toughness and is represented by the area under the load-deflection curve. In FRC crack density is increased, but the crack size is decreased.

1.6 Workability

A shortcoming of using fibres in concrete is reduction in workability. Workability of FRC is affected by fibre aspect ratio and volume fraction as well the workability of plain concrete. As fibre content increases, workability decreases. Most researchers limit volume of fibres to 4.0% and aspect ratio to 100 to avoid unworkable mixes. To overcome the workability problems associated with FRC, modification of concrete mix design is recommended. Such modifications can include the use of additives.

1.7 Strength and Durability

The most important contribution of fibre-reinforcement in concrete is not to strength but to the flexural toughness of the material. When flexural strength is the main consideration, fibre reinforcement of concrete is not a substitute for conventional reinforcement. The greatest advantage of fibre reinforcement of concrete is the improvement in flexural toughness (total energy absorbed in breaking a specimen in flexure).

Fibre-reinforced concrete is generally made with a high cement content and low water/cement ratio. When well compacted and cured concretes containing steel fibres seem to possess excellent durability as long as fibres remain protected by cement paste. Ordinary glass fibre cannot be used in Portland cement mortars and concretes because of chemical attack by the alkaline cement paste.

1.8 Objectives

Different types of fibres are available and used in concrete. Past studies have been conducted for the study in use of fibres in concrete. Fibres are used mainly to improve the strength properties of concrete. In the present study, following objectives are stipulated:

a) To check the suitability of polypropylene and steel fibres to be used as reinforcement in concrete.

b) To study the change in mechanical properties of M40 concrete reinforced with polypropylene and steel fibres.

c) To find the optimum fibre content for use in M40 concrete.

d) To study the changes in mechanical properties of M40 grade concrete when both the fibres are mixed in different proportions.

1.9 Limitations of the present study

This present study has the following limitations:

a) The study is limited to only M40 grade of concrete.

b) Only three strength properties, i.e. compressive, split tensile and flexural strengths are evaluated.

c) Two types of fibres, i.e. steel and polypropylene fibres are used.

Chapter 2

Literature Review

2.1 General

Fibre reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibres. Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributes discontinuous fibres is to bridge across the cracks that develop provides some post cracking "ductility". If the fibres are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post cracking stage.

There are, of course, other (and probably cheaper) ways of increasing the strength of concrete. When the fibre reinforcement is in the form of short discrete fibres, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fibre reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and pre-stressed structural members. However, because of the inherent material properties of fibre concrete, the presence of fibres in the body of the concrete or the provision of a tensile skin of fibre concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions.

The fibre reinforcement may be used in the form of three – dimensionally randomly distributed fibres throughout the structural member when the added advantages of the fibre to shear resistance and crack control can be further utilised. On the other hand, the fibre concrete may also be used as a tensile skin to cover the steel reinforcement when a more efficient two – dimensional orientation of the fibres could be obtained.

The conclusions about various properties of FRC from the various studies conducted can be summarised as follows:

2.2 Studies conducted on polypropylene fibre reinforced concrete

A. *Workability*

With addition of fibres, the entrapped air voids increase and hence the increased air content reduces the workability causing difficulty in compaction of mixes. The fibres may also interfere and cause finishing problems. Workability of concrete decreases with increase in polypropylene fibre volume fraction. The workability of concrete decreases with the addition of polypropylene fibres but it can be overcome by addition of High Range Water Reducing Admixtures.

Gencel et al. (2011) used monofilament polypropylene fibres in self compacting concrete with fly ash and studied the workability and Mechanical properties. The materials used in this study showed no workability or segregation problems. *Preti A Patel et al.* (2012) reported that the workability of concrete reduced with higher polypropylene fibre content. Vee Bee time indicated that at 0.5% of fibre content workability is high while at 1% it is medium.

Thirumurgan et al. (2013) reported that the workability of concrete decreased with the addition of polypropylene fibres but it can be overcome by addition of High Range Water Reducing Admixtures.

B. *Compressive strength*

Compressive strength of concrete is one of the most important properties of concrete. It is a qualitative measure of concrete. Failure of concrete under compression is a mixture of crushing and shear failure. The compressive strength varies as a function of both cement paste and fibres. Higher binder ratio gives higher compressive strength.

Anbuvelan et al. (2007) carried out tests for strength Prediction of Polypropylene Fibre Reinforced Concrete. Test results showed that the addition of polypropylene fibres to plain concrete increases its compressive strength from 4% to 17%.

Kumar et al. (2014) carried out experimental investigations on M15, M20 and M25 grade fly ash concrete reinforced with 0%, 0.5% and 1% polypropylene fibres. The compressive strength also increased with increase in fibre content up to 1% for all the three grades of concrete.

Priti A. Patel et al. (2012) found that the compressive, split tensile and flexural strength improved on addition of 1.5 % of polypropylene fibre in the concrete.

C. *Split Tensile Strength*

Split tensile strength can be determined by either direct methods, or indirect methods. The direct method has difficulties related to holding the specimen properly in the testing machine without introducing stress concentration, and in application of uniaxial tensile load which is free from eccentricity to the specimen. Since concrete is weak in tension even a small eccentricity of load will induce combined bending and axial force condition and the concrete fails at the apparent tensile stress rather than the tensile strength. Hence, indirect tests are generally adopted in which a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses developed in the specimen. This failure stress is termed the tensile strength of concrete. The splitting test is the well-known indirect test, in which compressive line load is applied along the opposite generators with the cylinder axis being horizontal between the compression platens. Due to compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter.

$$\text{Split tensile strength} = 2P/\pi\, DL$$

It is found that the split tensile strength increased with increasing fibre content fibres tend to bridge the micro cracks and hamper the propagation of cracks. When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete.

Gencel et al. (2011) conducted the split tensile strength using fibres up to 9 kg/m3. It is found that the split tensile strength increased with increasing fibre content Fibres tend to bridge the micro cracks and hamper the propagation of cracks. When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete.

Murahari et al. (2013) from their experimental investigations observed that there is not much significant interference of fibres on the split tensile strength. The split tensile strength gained more strength at early age of 28 days compared to 56 days.

D. Flexural Strength

There is marginal increase in flexural strength at first crack as fibre content increased from 0% to 1.0%.under three point loading in accordance with ASTM C78. It is observed that the flexural strength increased with content up to 0.3% and gained more strength at 28 days when compared to 56 days.

Gencel et al. (2011) reported that the flexural strength increases with addition of fibre content.

Kumar et al. (2014) studied the with M15, M20 and M25 grade concrete with 0%, 0.5 % and 1% fibres for flexure and shear behaviour of deep beams and it is reported that there is marginal increase in flexural strength at first crack as fibre content increased from 0% to 1.0%.

Murahari et al. (2013) tested 500 x 100 x 100 mm specimens under three point loading in accordance with ASTM C78. It is observed that the flexural strength increased with content up to 0.3% and gained more strength at 28 days when compared to 56 days.

2.3 Studies conducted on steel fibre reinforced concrete

A. Compressive strength

Compressive strength of concrete is one of the most important properties of concrete. The compressive strength varies as a function of both cement paste and fibres.

Ahsana et al. (2013) carried out tests for M30 grade concrete using hooked steel fibres and crimped steel fibres. Test results showed that the addition of hooked steel fibres to plain concrete increases its compressive strength by 30% while crimped steel fibres increased the strength by 38%.

Mohod et al. (2012) carried out experimental investigations on M30 grade concrete using hooked steel fibres. The compressive strength also increased with increase in fibre content up to 1%.

Nguyen et al. (2012) conducted study on the use of steel fibres in Reinforced concrete. They concluded that the compressive strength increased by 25% and the fibres also substantially increased the post cracking ductility of the material.

B. Split Tensile Strength

When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete.

Ahsana et al. (2013) carried out tests for M30 grade concrete using hooked steel fibres and crimped steel fibres. Test results showed that the addition of hooked steel fibres to plain concrete increases its compressive strength by 33% while crimped steel fibres increased the strength by 42%.

Nguyen et al. (2012) conducted study on the use of steel fibres in Reinforced concrete. They concluded Fibres aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% of smooth, straight steel fibres. However, for more or less randomly distributed fibres, the increase in strength is much smaller, ranging from as little as no increase in some instances to perhaps 60%.

C. Flexural Strength

There is marginal increase in flexural strength at first crack as fibre content increased from 0% to 1.0%.under three point loading in accordance with ASTM C78. It is observed that the flexural strength increased with content up to 1.0% and gained more strength at 28 days when compared to 56 days.

Ahsana et al. (2013) carried out tests for M30 grade concrete using hooked steel fibres and crimped steel fibres. Test results showed that the addition of hooked steel fibres to plain concrete increases its compressive strength by 39% while crimped steel fibres increased the strength by 45%.

Mohod et al. (2012) carried out experimental investigations on M30 grade concrete using hooked steel fibres. They concluded that the max. flexural strength was obtained at 0.75%.

Nguyen et al. (2012) conducted study on the use of steel fibres in Reinforced concrete. They concluded at 1% steel fibre composition, the flexural strength of the beam increased by 42%.

2.4 Studies conducted on composite fibre reinforced concrete

A. Compressive strength

Compressive strength of concrete is one of the most important properties of concrete. It is a qualitative measure of concrete. Failure of concrete under compression is a mixture of crushing and shear failure.

Varghese et al. (2013) carried out experiments for Hybrid concrete containing a mix of steel fibre and polypropylene fibres, compressive strength was increased by 3 per cent to 25 per cent for 7 to 28 days when compared to conventional concrete.

B. Split Tensile Strength

It is found that the split tensile strength increased with increasing fibre content fibres tend to bridge the micro cracks and hamper the propagation of cracks. When tensile stress is transferred to fibres, the micro cracks are arrested and thus improve the split tensile strength of concrete.

Varghese et al. (2013) concluded from their study that the split tensile strength of hybrid concrete increased by an amount of 40-80 per cent.

C. Flexural Strength

Varghese et al. (2013) concluded from their study that the flexural strength of hybrid concrete increased by an amount of 40 per cent.

2.5 Concluding remarks

1. The addition of polypropylene fibres at low values actually increases the 28 days compressive strength but when the volumes get higher, then the compressive strength decreases from original by 3 to 5%.
2. The tensile strength increases about 65%~70% % up to 0.40% after which it decreases.
3. There is about 80% increase in flexure strength by adding 0.20% fibres in concrete after which strength starts reducing with further increment in fibre ratios.
4. The shear capacity of concrete increases when fibres are added. There is a remarkable increase in load carrying capacity up to first crack appears.
5. The shrinkage cracking is reduced by 83 to 85% by addition of fibres up to 0.35% and 0.50 %.

6. It is observed that the workability of steel fibre reinforced concrete gets reduced as the percentage of steel fibres increases.
7. Compressive strength goes on increasing by increase in steel fibre percentage up to the optimum value. The optimum value of fibre content of steel fibre reinforced concrete was found to be 1%.
8. The flexural strength of concrete goes on increasing with the increase in fibre content up to the optimum value. The optimum value for flexural strength of steel fibre reinforced cement concrete was found to be 0.75%.

9. While testing the specimens, the plain cement concrete specimens have shown a typical crack propagation pattern which leaded into splitting of beam in two piece geometry. But due to addition of steel fibres in concrete cracks gets ceased which results into the ductile behaviour of SFRC.
10. The compressive strength of hybrid concrete is 3-25 per cent more than that of plain concrete.
11. There is an increase of 40-70 per cent in the split tensile strength when a mix of polypropylene and steel fibres is used as reinforcing admixtures.
12. It is observed that the flexural strength of hybrid concrete is 40 per cent higher than that of plain concrete.

Chapter 3

Experimental Programme

3.1 General

In order to study the suitability of polypropylene fibre and steel fibre in concrete, tests were conducted on M40 grade concrete. Mix design was done as per IS: 10262 - 2009. Following tests were conducted for this study.

Table 3.1: Tests on aggregates, cement and concrete

Sl. No.	Tests to be conducted
1	Specific gravity of PPC
2	Specific gravity and Water absorption of Coarse Aggregate
3	Specific gravity and Water absorption of Fine Aggregate
4	Fineness modulus of Fine Aggregate
5	Nominal size of Coarse aggregate
6	Compressive Strength Test
7	Split Tensile Test
8	Flexural Strength Test

The materials required were Portland Pozzolana cement, coarse aggregate, fine aggregates and polypropylene fibres and steel fibres. The concrete was tested in four batches consisting of the following:

1. Plain cement concrete of M40 grade having cement: fine aggregate: coarse aggregate ratio of 1: 1.4: 2.6.
2. Polypropylene fibre reinforced concrete of M40 grade for fibre content of 0.25%, 0.40% and 0.50% by weight of concrete.
3. Steel fibre reinforced concrete of M40 grade for fibre content of 0.25%. 0.50% and 0.75% by weight of concrete.
4. Composite fibre concrete mix of steel and polypropylene fibres for total fibre content of 0.5% by weight of concrete. Here, the fibre contents were divided into five categories i.e.
    i. 0% Polypropylene Fibre, 100% Steel Fibre
    ii. 25% Polypropylene Fibre, 75% Steel Fibre
    iii. 50% Polypropylene Fibre, 50% Steel Fibre
    iv. 75% Polypropylene Fibre, 25% Steel Fibre
    v. 100% Polypropylene Fibre, 0% Steel Fibre

3.2 Specification of Materials

Checking of materials is an essential part of civil engineering as the life of structure is dependent on the quality of material used. IS: 10262 – 2009 deals with Mixed Design of Concrete and thus it depend on different properties of cement and aggregates. The properties that the Concrete Mix Design requires are specific gravity, water absorption, fineness modulus and workability.

The main objective of this project is to compare the changes in strength properties in plain cement concrete and fibre reinforced concrete. The most important property of concrete is probably strength, although many other characteristics like durability may be equally important. On the other hand, concrete strength is an elusive property. Even if all the many factors that are known to affect the strength – the properties and inherent variability in the concrete making materials, proportions, air content, mixing, temperature and others – are absolutely constant, the may be a wide dispersion in the numerical values of the measured strength depending on how well the ingredients are mixed.

3.3 Materials

3.3.1 Portland Pozzolana Cement

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcined clay (IS: 1489 (Part II) - 1991) or fly ash (IS: 1489 (Part I) - 1991). Fly ash is a waste material, generated in the thermal power station, when powdered coal is used as a fuel.

Calcium silicates produce considerable quantities of calcium hydroxide, which is by and large a useless material from the point of view of strength or durability. If such useless mass could be converted into a useful cementitious product, it considerably improves quality of concrete. The use of fly ash performs such a role. The pozzolanic action is shown below:

$$\text{Calcium hydroxide} + \text{Pozzolana} + \text{water} \rightarrow C - S - H \text{ (gel)}$$

Portland pozzolana cement produces less heat of hydration and offers greater resistance to the attack of aggressive waters than ordinary Portland cement. Moreover, it reduces the leaching of calcium hydroxide when used in hydraulic structures. It is particularly useful in marine and hydraulic construction and other mass concrete constructions.

3.3.2 Fine Aggregates

Fine aggregate that will be used is *natural sand*. Natural sand is available abundantly in coastal areas and thus widely used all over India. Advantages of natural sand are that the particles are Cubical or rounded with smooth surface texture. Being cubical and rounded and smooth textured it gives good workability. Size less than 4.75 mm is considered as fine aggregates.

3.3.3 Coarse Aggregates

Coarse aggregates available are *crushed angular aggregates*. The shape of aggregates is an important characteristic since it affects the workability of concrete. Crushed angular aggregates possesses well defined edges. Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements. The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

3.3.4 Polypropylene fibre

For this study virgin polypropylene fibre were used. Its market name is Recron® 3s and it is manufactured and marketed by Reliance Industries Ltd.   Figure 4.1 shows the fibre.

Features and Benefits

- Provides residual strength
- Improves toughness and durability
- Reduces freeze/thaw damage
- Increases impact and shatter resistance
- Reduces plastic shrinkage and settlement cracking
- Reduces bleeding
- Increases cohesion and reduces segregation
- Controls cracking in concrete

Figure 3.1: Polypropylene Fibre

Figure 3.2: Recron® 3s

Physical and Chemical Properties of PPF

Fibre Length	6 mm
Type/Shape	Graded/Triangular
Water Absorption	Nil
Specific gravity	0.90
Electrical conductivity	Low
Melting point	162°C
Ignition point	593°C

3.3.5 Steel Fibre

Different kinds of steel fibres are available in the market today. Some of it includes crimped steel fibres, unglued hooked end steel fibres, glued hooked end steel fibres, stainless steel fibres, etc. Figure 3.3 shows these fibres. For this study, *crimped steel fibre,* as shown in Figure 3.3 (a), was used. It is commercially available in the market as Dramix Steel Fibre and it is marketed by Weldfab India in Delhi. It has higher tensile strength than unreinforced shotcrete and is quicker to apply than weld mesh reinforcement.

(a) Crimped Steel Fibres (b) Hooked-end steel fibres

(c) Glued Hooked-end steel fibres (d) Stainless steel fibres

Figure 3.3: Steel Fibres

Application of SFRC

The most common applications are pavements, tunnel linings, pavements and slabs, shotcrete and now shotcrete also containing silica fume, airport pavements, bridge deck slab repairs, and so on. There has also been some recent experimental work on roller-compacted concrete (RCC) reinforced with steel fibres. The list is endless, apparently limited only by the ingenuity of the engineers involved. The fibres themselves are, unfortunately, relatively expensive; a 1% steel fibre addition will approximately double the material costs of the concrete, and this has tended to limit the use of SFRC to special applications.

3.4 Tests on Cement and Aggregates for Mix Design

Following tests were conducted in order to check the feasibility of the materials required for mix design.

1. Specific gravity of PPC using Le Chatiliers' Flask
2. Specific gravity and water absorption of Coarse Aggregate
3. Specific gravity and water absorption of Fine Aggregate
4. Fineness modulus of fine aggregate
5. Nominal size of coarse aggregate

1. Specific gravity of PPC using Le Chatiliers' Flask

Specific gravity of cement is found out by using Le Chatelier's flask. The procedure for the test is done as given below as per IS: 4031 (Part XI).

Test Procedure

Weigh a clean and dry Le Chatelier Flask or Specific Gravity Bottle with its stopper (W_l). Place a sample of cement up to half of the flask (about 50 gm) and weight with its stopper (W_2). Add kerosene (polar liquid) to cement in flask till it is about half full. Mix thoroughly with glass rod to remove entrapped air. Continue stirring and add more kerosene till it is flush with the graduated mark. Dry the outside and weigh (W_3). Entrapped air may be removed by vacuum pump, if available. Empty the flask, clean it refills with clean kerosene flush with the graduated mark wipe dry the outside and weigh (W_4). Specific gravity of given kerosene is 0.79.

Result:

Specific gravity of PPC was found out to be 3.15 which conform to IS: 1489 (Part 1).

Detailed calculations and data are given in Annexure 1.

2. Specific Gravity and water absorption of Coarse Aggregate

This test is conducted by following the procedure mentioned in IS: 2386 (Part III).

Test procedure:

The sample shall be thoroughly washed to remove finer particles and dust, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22°C and 32°C with a cover of at least 5 cm of water above the top of the basket. Immediately after immersion the entrapped air shall be removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second. The basket and aggregate shall remain completely immersed during the operation and for a period of 24 ± l/2 hours afterwards. The basket and the sample shall then be jolted and weighed in water at a temperature of 22 to 32ºC. (Weight A). The basket and the aggregate shall then be removed from the water and allowed to drain for a few minutes, after which the, aggregate shall be gently emptied from the basket on to one of the dry clothes, and the empty basket shall be returned and weighed in water. The aggregate placed on the dry cloth shall be gently surface dried with the cloth. The aggregate shall then be weighed (weight B). The aggregate shall then be placed in the oven in the shallow tray, at a temperature of 100 to 110°C and maintained at this temperature for 24 ± l/2 hours. It shall then be removed from the oven, cooled in the airtight container and weighed (weight C).

Result:

Specific gravity of coarse aggregate was found out to be **2.8** while its water absorption was **0.8%.**

Detailed calculations and data are given in Annexure 1.

3. Specific Gravity and Water Absorption of Fine Aggregate

This test can be conducted using pycnometer or density bottle. We used density bottle.

Test Procedure:

Take the empty density bottle and weigh it (W_1). Add fine aggregate passing 4.75 mm sieve to the bottle and weigh it (W_2). Now add water till it is full. Remove any entrapped air and weigh it (W_3). Remove the contents and add only water and weigh (W_4). For water absorption test, take about 1 kg of fine aggregate and add water to the sample and keep it for 24 hours. After 24 hours, drain the excess water and surface dry the aggregate. Take 500 g of surface dried sample and oven dry it.

Result:

Specific gravity of fine aggregate was found to be **2.72** and water absorption was **1.2%.** According to IS 2386 (Part III), the range of specific gravity suitable for concrete mix is 2.5 to 3. Our result is within that limit so it can be used for mix design.

Detailed calculations and data are given in Annexure 1.

4. Fineness Modulus of Fine Aggregates

Fineness modulus is a ready index of coarseness or fineness of the material. Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material.

Test Procedure:

Sieve analysis is to be carried out in order to determine the fineness modulus of the fine aggregate. Sieves sizes of 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm and 150 μm. Take about 1.5 kg of sand and do sieve analysis. Calculate percentage passing for each sieve. Tally the result given in Table 4 of IS 383.

Result:

Fineness modulus of the sample was found out to be **2.74**. From Table 4 of IS: 383 (1970), the sample conforms to ***Zone II***.

Detailed calculations and data are given in Annexure 1.

5. Nominal size of coarse aggregate

According to size coarse aggregate is described as graded aggregate of its nominal size i.e. 40 mm, 20 mm, 16 mm and 12.5 mm etc. for example a graded aggregate of nominal size 20 mm means an aggregate most of which passes 20 mm IS sieve.

Nominal size is used to decide the water content in the concrete mix. Hence this test has to be carried out.

Test procedure:

Sieve analysis has to be done for this test as well. Sieve sizes of 80 mm, 63 mm, 40 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, 4.75 mm and 2.36 mm are used. Once the percentage passing has been calculated, the results are tallied with Table 2 of IS: 383.

Result:

The nominal size of the coarse aggregate sample is 20 mm.

Detailed calculations and data are given in Annexure 1.

3.5 Test Results

Following results were obtained based on above tests.

Table 3.2: Tests Results

Sl. No.	Tests	Results
1	Specific gravity of PPC	3.15
2	Specific gravity of coarse aggregates	2.8
3	Specific gravity of Fine aggregates	2.72
4	Fineness modulus of fine aggregate	2.74 (Zone II)
5	Nominal size of coarse aggregate	20 mm
6	Water absorption of coarse aggregate	0.8%
7	Water absorption of fine aggregate	1.2%

Above results are satisfactory and the materials are suitable for use in mix design. Specific gravity of PPC is 3.15 which conform to IS: 1489 (Part I). Specific gravity of coarse and fine aggregate is with the limit specified in IS: 2386 (Part III) which is 2.5 – 3. Similarly water absorption is below the required 5% limit. Hence the materials are suitable for use in mix design.

3.6 M40 Mix design

Design mix ratio of cement, sand and coarse aggregate: **1 : 1.4 : 2.6**

Water Cement Ratio: **0.4**

Detailed design procedure is given in Annexure 2.

3.7 Experimental Investigation

Details of specimens

For all tests, M40 grade concrete was used. M40 grade is of design mix of 1: 1.4: 2.6 and water cement ratio of 0.4 as mentioned in section 3.6.

The objective of our study is to find out the changes in strength properties of fibre reinforced concrete in comparison to plain cement concrete. Hence evaluations of compressive strength, split tensile strength and flexural strength is done as per standards.

Casting and curing of specimens

Concrete was mixed in a tilting type drum mixer and cast as per IS: 516 (1959). Standard moulds of cube 100 mm x 100 mm x 100mm, cylinder 100 mm diameter and 200 mm height and beams of 100 mm x 100 mm x 500 mm was used.

Concrete was poured and compacted using tamping rod in three layers. After 24 hours the mould was disassembled and the concrete was kept in normal curing tank for 7 days curing and for the 28 days curing, samples were placed in accelerated curing. In accelerated curing, a sample is kept in water at temperature of 90°C for 3 days i.e. 72 hours. After that tests were conducted upon surface drying.

3.8 Details of Testing

The constituent materials of concrete, viz. cement, fine aggregates, coarse aggregates, were tested for suitability of their use as per relevant Indian Standard codes. Concrete of M40 was designed. The three strength test to be carried out were compressive strength test, split tensile test and flexural strength test. The specimen details are tabulated below.

Table 3.3: Specimen details of PPFRC and SFRC

Sl. No.	Name of Test	Specimen dimensions (mm)	% PPF	No. of specimen	%SF	No. of specimen
1	Compressive strength	100 x 100 x100	0%	3	0%	3
			0.25%	3	0.25%	3
			0.40%	3	0.50%	3
			0.50%	3	0.75%	3
2	Split tensile strength	100*Φ* x 200	0%	3	0%	3
			0.25%	3	0.25%	3
			0.40%	3	0.50%	3
			0.50%	3	0.75%	3
3	Flexural strength	100 x 100 x 500	0%	3	0%	3
			0.25%	3	0.25%	3
			0.40%	3	0.50%	3
			0.50%	3	0.75%	3

Table 3.4 Specimen details of Composite Mix FRC

Sl. No.	Name of Test	Specimen dimensions (mm)	%SF: %PPF	No. of Specimen
1	Compressive strength	100 x 100 x100	0%: 100%	3
			25%: 75%	3
			50%: 50%	3
			75%: 25%	3
			100%: 0%	3
2	Split tensile strength	100*Φ* x 200	0%: 100%	3
			25%: 75%	3
			50%: 50%	3
			75%: 25%	3
			100%: 0%	3
3	Flexural strength	100 x 100 x 500	0%: 100%	3
			25%: 75%	3
			50%: 50%	3
			75%: 25%	3
			100%: 0%	3

3.8.1 Compressive Strength Test

Procedure

1. Placing the specimen
    a. Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherical seated (upper) bearing block.
    b. Carefully align the axis of the specimen with the centre of thrust of the spherically seated block.
    c. As the spherically seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.
2. Rate of Loading
    a. Apply the load at a constant rate of 4kN per second.
    b. Do not make any adjustment in the controls while the test is going on.
    c. Carry out the experiment until the specimen yields.

Figure 3.4: Compression Strength Test

3.8.2 Split Tensile Test

Procedure

i. Draw diametrical lines on two ends of the specimen so that they are in the same axial plane.
ii. Centre one of the plywood strips along the centre of the lower platen. Place the specimen on the plywood strip and align it so that the lines marked on the end of the specimen are vertical and centred over the plywood strip.

iii. Apply the load without shock at a constant rate to produce a split tensile stress, until no greater load can be sustained. Record the max. load applied to specimen.

Calculation

The splitting tensile strength of the specimen is calculated by:

$$T = \frac{2P}{\pi l d}$$

Where

P = Load at failure

l = Length of sample

d = diameter

Figure 3.5: Split Tensile Test

3.8.3 Flexural Strength Test (Single point load test)

Procedure

i. Turn the specimen on its side with respect to its position when moulded, and centre it on the supporting bearing blocks. The load-applying block shall be brought in contact with the upper surface at the centre line between the supports.

ii. Bring load applying block in full contact with the beam surface by applying a 3.1 N preload. Check to ensure that the beam is in uniform contact with the bearing blocks and the load applying block.

Calculation

The modulus of rupture is calculated as follows:

$$R = \frac{Pl}{bd^2}$$

Where:

R = Modulus of rupture in MPa

P = Load at failure

b = Average width of specimen

d = Average depth of specimen

l = Span length in inches

Figure 3.6 FRC beam in flexure test in UTM

Chapter 4

Analysis of Data & Discussion of Results

4.1 General

The main objectives of the present study was to study the mechanical properties of fibre reinforced concrete (Steel and polypropylene) for which a systematic series of experimentations were conducted. Particularly three tests were conducted i.e. cube compressive strength test, cylinder split tensile strength test and flexural strength test in the Concrete Laboratory of Civil Engineering Department of Jaypee University of Information Technology, Waknaghat. The results are analysed and discussed as under.

4.2 Properties of Plain Concrete

The mechanical properties M40 plain concrete such as compressive strength, split tensile strength and flexural strength were observed by cube compression test, cylinder split tensile strength and flexure test in concrete laboratory.

The results show that for M40 concrete the average 7 days and 28 days compressive strength was found to be 28.4 MPa and 44.76 MPa respectively. The average split tensile strength was found to be 4.62 MPa and the average flexural strength was found to be 4.30 MPa.

The detailed results are shown in Annexure 3.

Now in the following section we will discuss the results of plain and fibre reinforced concrete with varying percentage of fibre in detail.

4.3 Properties of Fibre Reinforced Concrete

A. Compressive Strength

Compressive strength is one of the most important properties of concrete and influences many other desirable properties of hardened concrete. Cubes were tested on Compression Testing Machine (CTM), for 7 days and 28 days strength. The results for 28 days strength are plotted in the figures below. Comparison has been done to find out the optimum fibre content.

The influence of the addition of polypropylene fibres of 0.25%, 0.40% and 0.50% weight of concrete on the mixes tested is compared with plain concrete mix and the results are tabulated in tables shown in Annexure 3.

It is seen that the maximum average increase in 7 days compressive strength of M40 concrete is 14.43% w.r.t plain concrete at 0.4% fibre content. Whereas with 0.25% and 0.50% the average increase in 7 days compressive strength of M40 concrete was found to be 13.73% and 11.26%. It was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 11.93% w.r.t. plain concrete at 0.4% fibre content. At 0.25% and 0.50% the average increase was found to be 11.26% and 8.80% respectively.

For Steel fibre reinforced concrete, three percentages of 0.25%, 0.50% and 0.75% were adopted. Tests results however did not give the optimum amount. Research by other persons indicate that the values of all three strengths can go on increasing up to 6% fibre content. However, once the fibre content gets more than 1%, the workability of the concrete mix gets seriously affected which in turn affects the compaction. Without the use of plasticizers, casting of such mixes becomes very difficult.

It was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 38.12% w.r.t. plain concrete at 0.75% fibre content. At 0.25% and 0.50% the average increase was found to be 10.89% and 31.44% respectively. Optimum value could not be found out but research indicates that the increase in compressive strength on addition of steel fibres is limited up to addition of 1% fibre content.

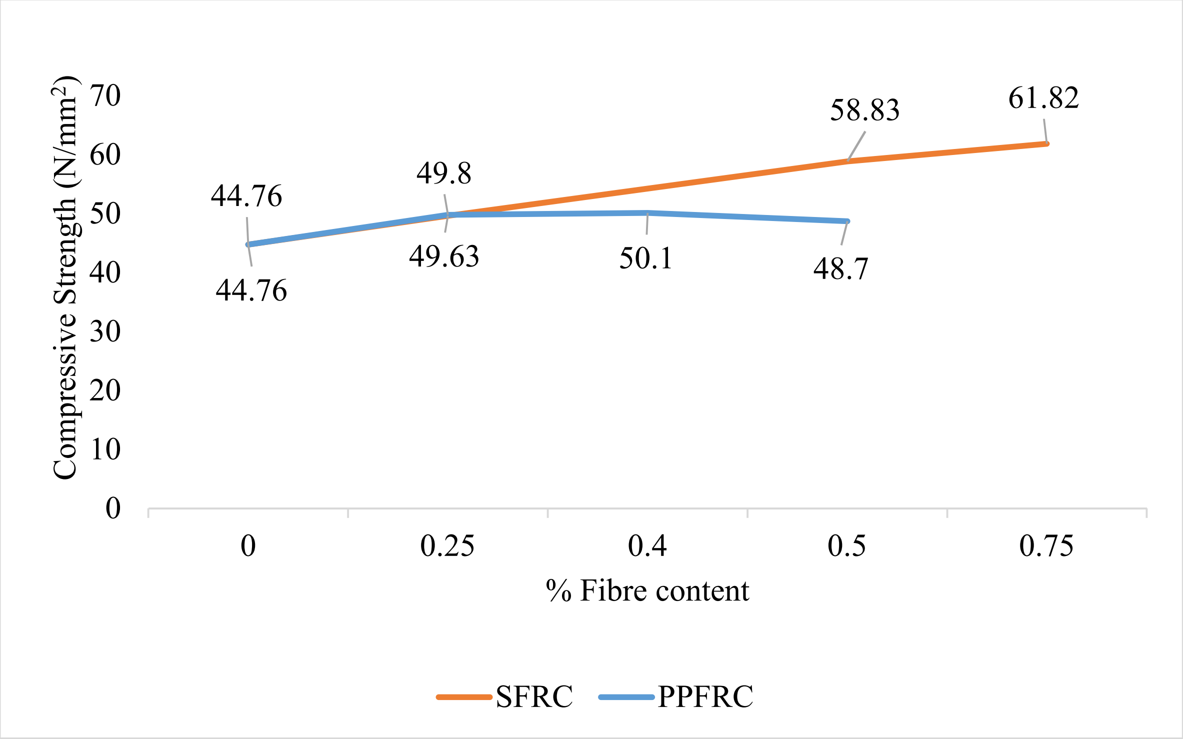

Figure 4.1: Compressive Strength of SFRC and PPFRC

B. Split Tensile Strength

Similarly for split tensile test, cylinders were cast and these were tested on CTM, for 28 days and the values are presented in the tables in annexure-3.

For polypropylene fibre reinforced concrete of M40 grade, the maximum average increase in 28 days split tensile strength was found to be 70.25% at a fibre content of 0.40%. At the fibre contents of 0.25% and 0.50% the percentage increase was found to be 69.61% and 68.10% respectively.

For steel fibre reinforced concrete of M40 grade concrete, the maximum average increase in 28 days split tensile strength was found to be 42.9% at a fibre content of 0.75%. At the fibre contents of 0.25% and 0.50% the percentage increase was found to be 18.15% and 37.64% respectively.

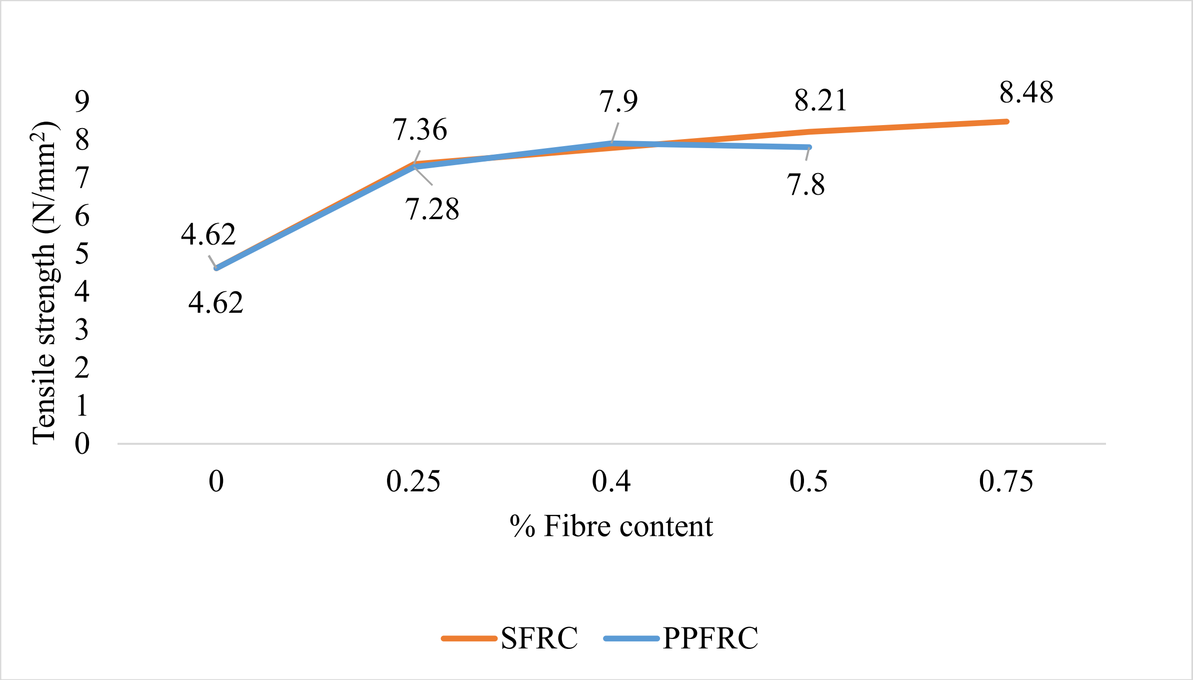

Figure 4.2: Split Tensile Strength of SFRC and PPFRC

C. Flexural Strength

For the flexural strength investigation, beams were casted and were tested in Universal Testing Machine (UTM), for 28 days and the values are presented in the tables in annexure-3.

For polypropylene fibre reinforced concrete of M40 grade, the maximum average increase in 28 days flexural strength was found to be 43.32% at a fibre content of 0.40%. At the fibre contents of 0.25% and 0.50% the percentage increase was found to be 42.32% and 41.86% respectively.

For steel fibre reinforced concrete of M40 grade, the maximum average increase in 28 days flexural strength was found to be 45.09% at a fibre content of 0.75%. At the fibre contents of 0.25% and 0.50% the percentage increase was found to be 18.15% and 37.64% respectively.

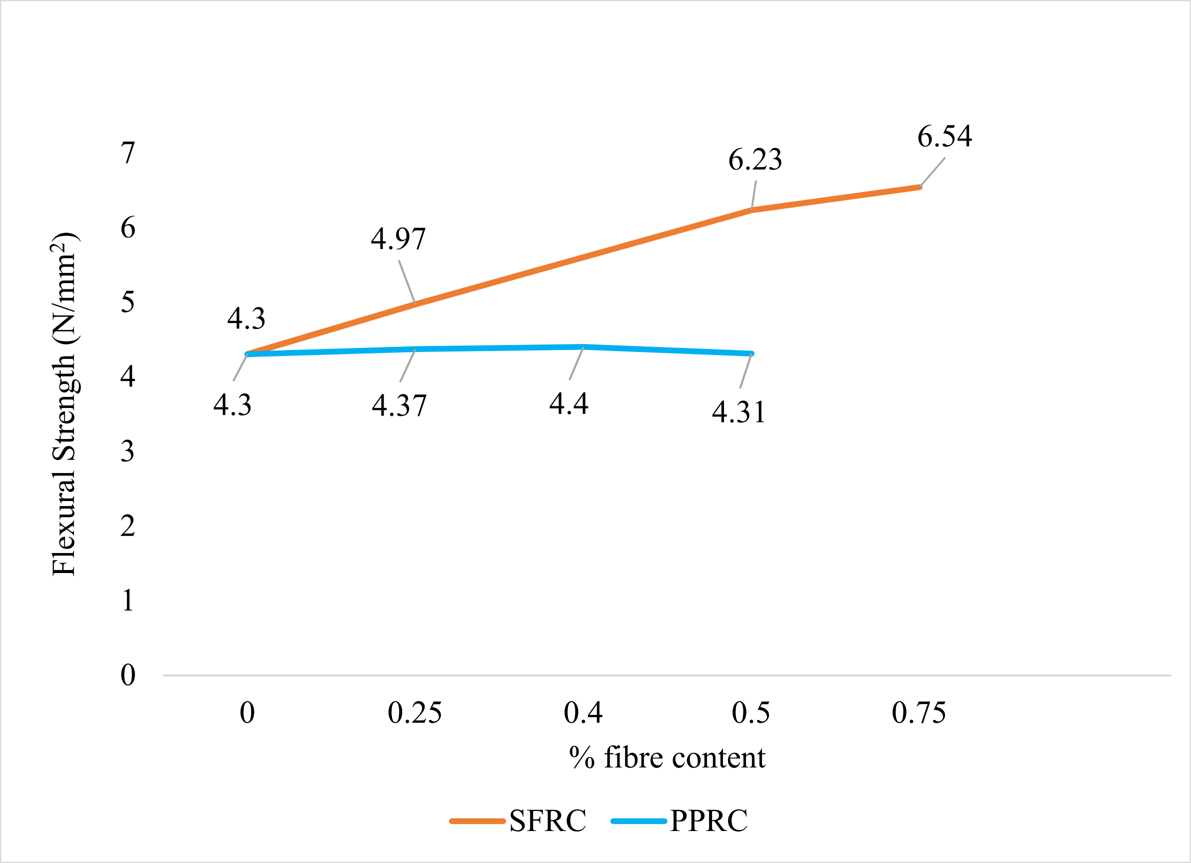

Figure 4.3: Flexural Strength of SFRC and PPFRC

4.4 Properties of Composite Mix

The composite mix was made for a total fibre content of *0.50%* by volume of concrete. The two fibres used were steel and polypropylene fibres. Here, the fibre contents have been divided into five categories i.e.

i. 0% Polypropylene Fibre, 100% Steel Fibre
ii. 25% Polypropylene Fibre, 75% Steel Fibre
iii. 50% Polypropylene Fibre, 50% Steel Fibre
iv. 75% Polypropylene Fibre, 25% Steel Fibre
v. 100% Polypropylene Fibre, 0% Steel Fibre

It was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 25.78% w.r.t. plain concrete at 75% SF and 25% PPF fibre content. However, compressive strength for 100% SF at 0.50% fibre content was still greater than the composite mix.

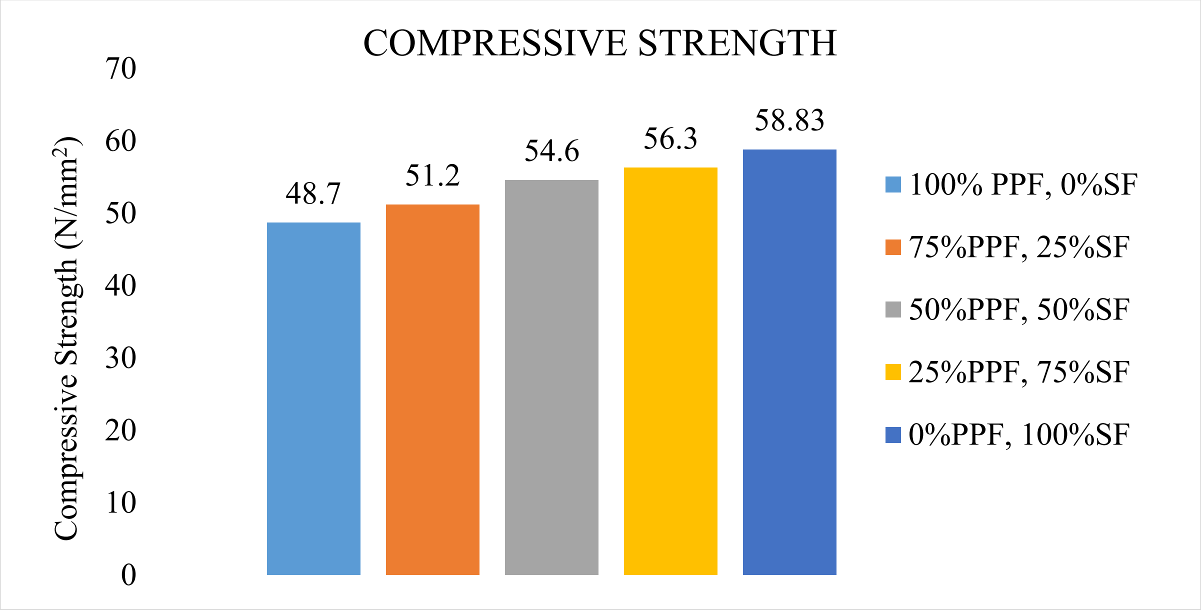

Figure 4.4: Compressive Strength of Composite Mix

The maximum average increase in 28 days split tensile strength was found to be 75.10% w.r.t plain concrete at 75% SF and 25% PPF fibre content. However, split tensile strength for 100% SF at 0.50% fibre content was still greater than the composite mix.

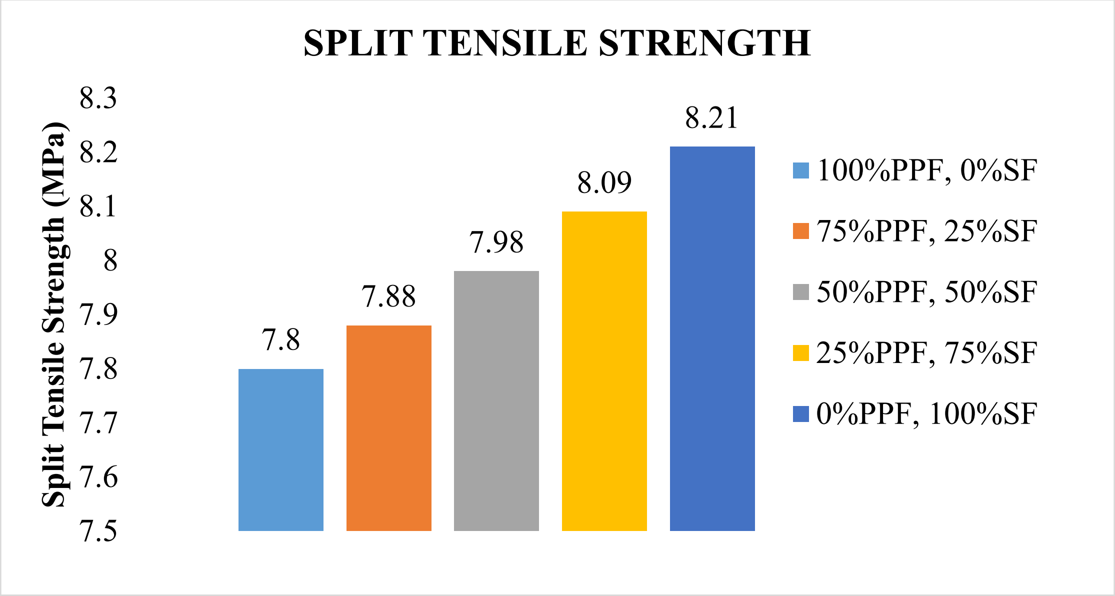

Figure 4.5: Split Tensile Strength of Composite Mix

The maximum average increase in 28 days flexural strength was found to be 44.18% w.r.t plain concrete at 75% SF and 25% PPF fibre content. However, flexural strength for 100% SF at 0.50% fibre content was still greater than the composite mix.

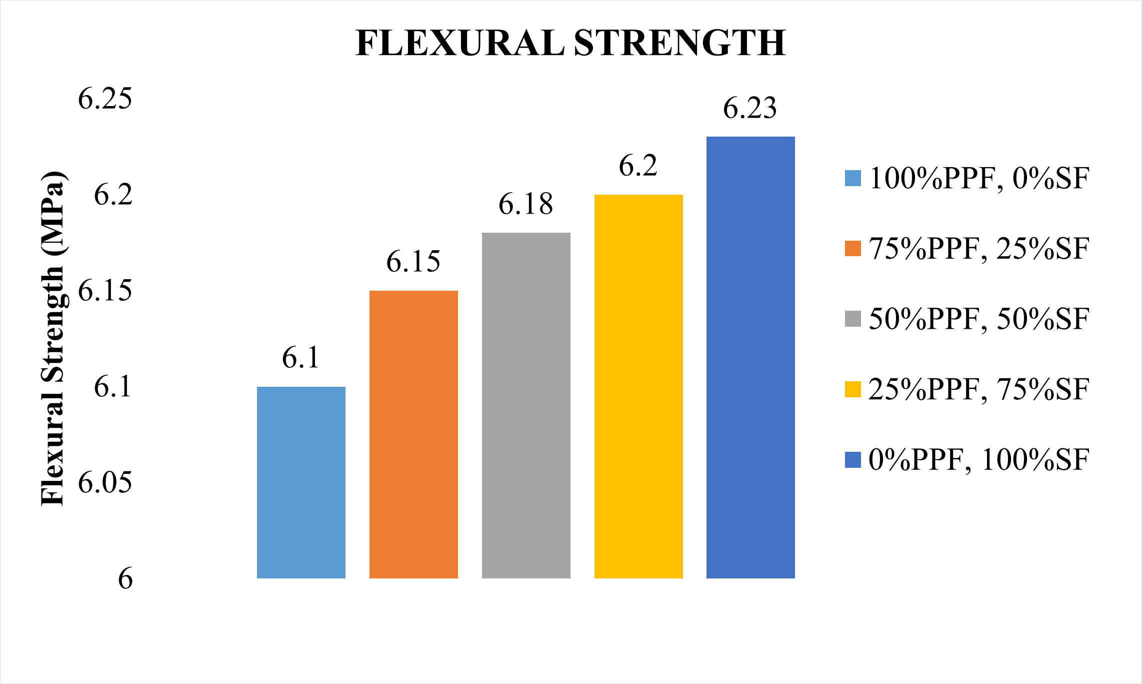

Figure 4.6: Flexural Strength of Composite Mix

4.5 Comparison with other studies

4.5.1 Polypropylene fibre reinforced concrete

In order to compare the effects of Polypropylene fibre on the mechanical properties of concrete, the results of *Saeed et al. (2012)* have been compiled below.

According to the study conducted by *Saeed et al.* the addition of polypropylene fibres at low values (0.20%-0.50%) actually increased the 28 days compressive strength but when the volumes get higher, the compressive strength decreased from original by 3 to 5%. The tensile strength increased about 65%~70% % up to 0.40% after which it decreased. There was about 80% increase in flexure strength by addition of 0.20% fibres in concrete after which strength started reducing with further increment in fibre ratios. The shear capacity of concrete increased when fibres were added. There was a remarkable increase in load carrying capacity up to first crack appeared. The shrinkage cracking was reduced by 83 to 85% by addition of fibres up to 0.35% and 0.50 %.

In our study on the effects of PP fibre on the mechanical properties of concrete it was observed that the maximum average increase in 7 days compressive strength of M20 concrete is 25.37% w.r.t. plain concrete at 0.4% fibre content. It was observed that the maximum average increase in 28 days compressive strength of M20 concrete is 16.20% w.r.t. plain concrete at 0.4% fibre content. A decrease of 2.40% in compressive strength was observed at the fibre content of 0.50%. It is seen that the maximum average increase in 7 days compressive strength of M40 concrete is 14.43% w.r.t plain concrete at 0.4% fibre content. It was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 11.93% w.r.t. plain concrete at 0.4% fibre content. It can be seen that the maximum average increase in 28 days split tensile strength of M20 concrete is 69.73% at 0.4% fibre content. For M40 concrete the maximum average increase in 28 days split tensile strength was found to be 70.25% at a fibre content of 0.40%. It can be seen that the maximum average increase in 28 days flexural strength of M20 concrete is 44.73% at 0.4% fibre content. For M40 concrete the maximum average increase in 28 days flexural strength was found to be 43.32% at a fibre content of 0.40%. Thus, it can be seen that the previous studies support our results and have almost same results for the tests that we conducted.

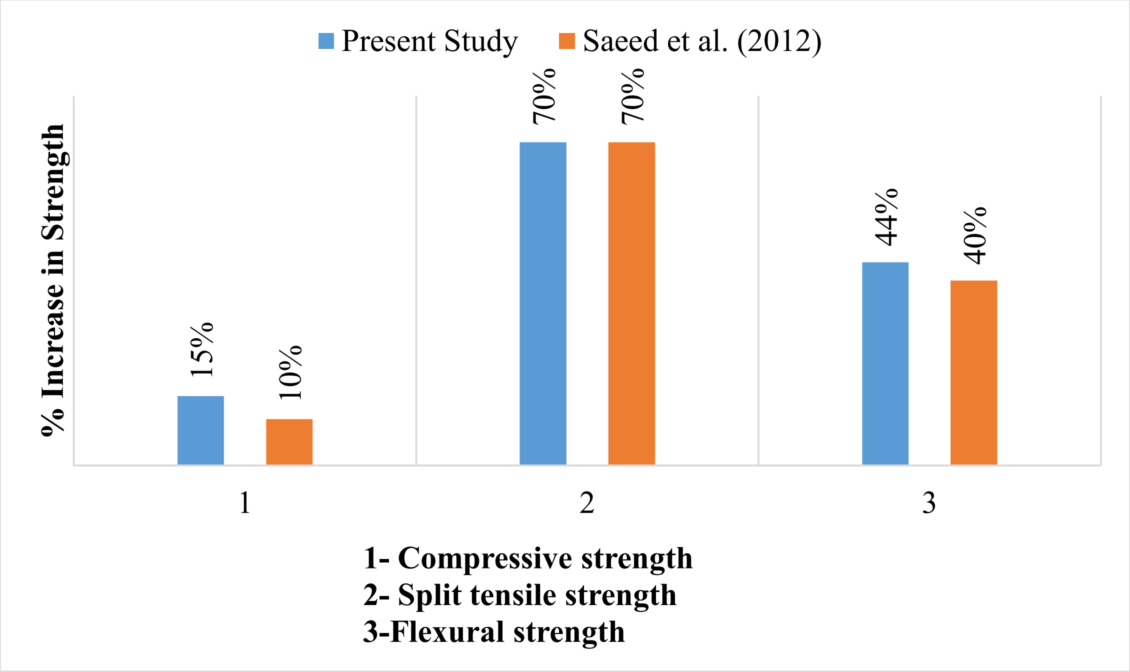

Figure 4.7: Comparison with other studies for PPFRC

4.5.2 Steel Fibre Reinforced Concrete

In order to compare the effects of steel fibre on the mechanical properties of concrete the results of *Ahsana et al.* (2014) and *Mohod et al. (2013)* have been compiled below.

According to the study conducted by *Ahsana et al.* and *Mohod et al.* the addition of steel fibres at low values (0.25%-1%) actually increased the 28 days compressive strength. The tensile strength increased up to 50% on the addition of steel fibres at 0.75% fibre content. There was about 50% increase in flexure strength by addition of 0.75% fibres in concrete. The shear capacity of concrete increased when fibres were added. There was a remarkable increase in load carrying capacity up to first crack appeared. The shrinkage cracking was reduced by 60% by addition of fibres up to 1 %.

In our study on the effects of steel fibre on the mechanical properties of concrete it was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 38.12% w.r.t. plain concrete at 0.75% fibre content. It can be seen that the maximum average increase in 28 days split tensile strength of M40 concrete is 42.9% at 0.75% fibre content. For M40 concrete the maximum average increase in 28 days flexural strength was found to be 45.09% at a fibre content of 0.75%. Thus, it can be seen that the previous studies support our results and have almost same results for the tests that we conducted.

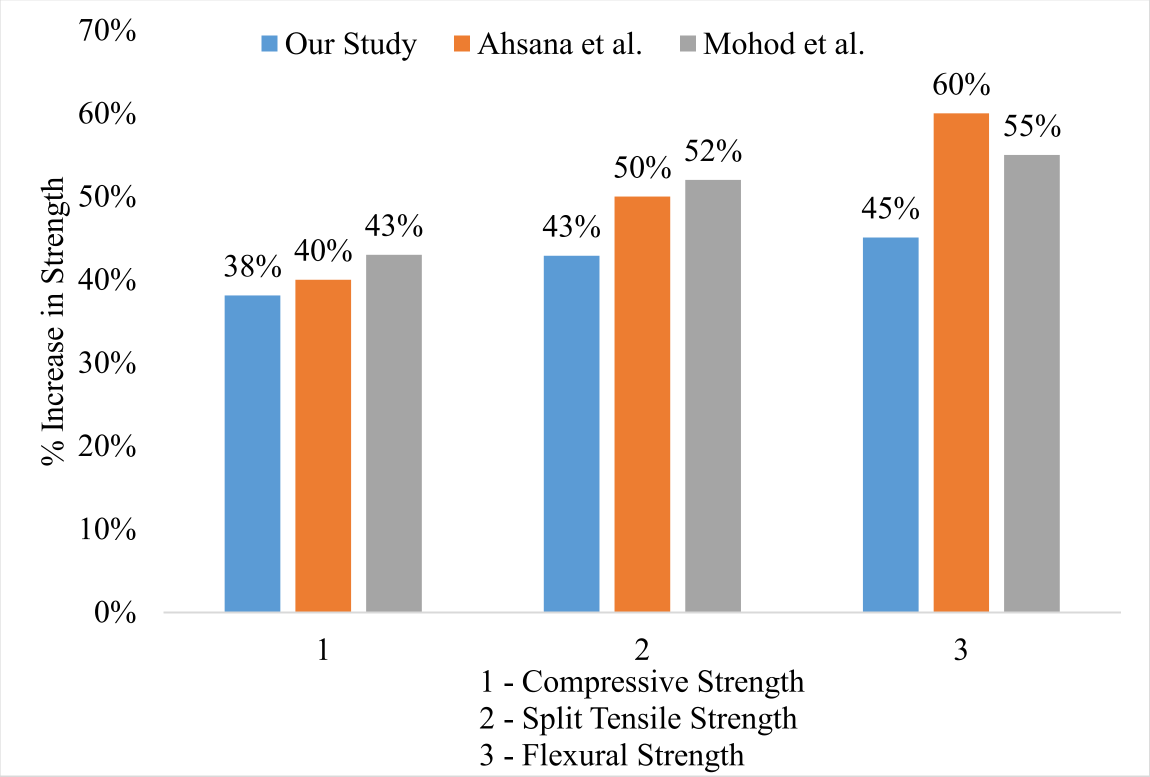

Figure 4.8 Comparison of Results with Previous Studies for SFRC

4.5.3 Composite Mix

According to Varghese et al. (2013), the compressive strength of the composite mix containing steel and polypropylene fibres increased by 25%. The tensile strength increased by 40 to 80% and the flexural strength increased by 40 %. Their concrete mix was of M30 grade.

In our study, on the effects of composite mix on the mechanical properties of concrete, it was observed that the maximum average increase in 28 days compressive strength of M40 concrete is 25.78% w.r.t. plain concrete. The tensile strength increased by 75.10% and the flexural strength increased by 44.18 %. It was observed that the maximum average increase in 28 days compressive strength, split tensile strength and flexural strength of M40 concrete was obtained at 75% SF and 25% PPF fibre content.

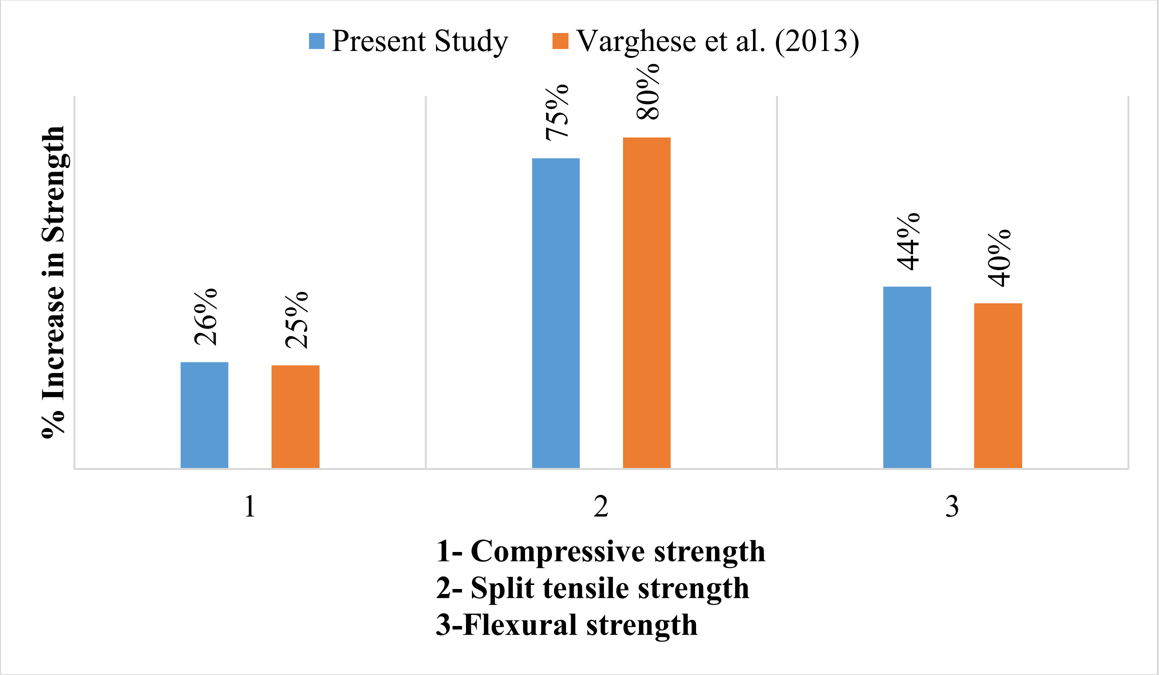

Figure 4.9: Comparison of Results with Past Study for composite mix

Chapter 5

Conclusions

Conclusion

Different types of fibres are available and are used in concrete. Many past studies have been conducted for the use of fibres in concrete. Fibres are used mainly to improve the strength properties of concrete.

In the present study polypropylene and steel fibres have been used. After conducting the experiments to calculate the compressive strength, split tensile strength and flexural strength, on concrete of M40 grade with fibres, following conclusions were drawn.

1. The addition of polypropylene fibres at low values actually increases the 28 days compressive strength but when the volumes get higher, then the compressive strength decreased from original by 3%.
2. The tensile strength increased by 65% - 70% for fibre content of 0.40% after which it decreases.
3. There is about 43% increase in flexure strength by adding 0.40% fibres in concrete after which strength starts reducing with further increment in fibre ratios.
4. It is observed that the workability of steel fibre reinforced concrete gets reduced as the percentage of fibres increases.
5. Compressive strength goes on increasing by increase in steel fibre percentage. The optimum value of fibre content of steel fibre reinforced concrete could not be found out as the workability of the concrete was severely affected as the fibre content was increased.
6. The flexural strength of concrete goes on increasing with the increase in fibre content. The maximum value for flexural strength of steel fibre reinforced cement concrete was found to be 0.75%. After this, the mix becomes uneconomical and unworkable.
7. Due to addition of steel fibres in concrete, cracks gets ceased which results into the ductile behavior of SFRC as well as PPFRC.
8. The compressive strength of hybrid concrete is 3-25 per cent more than that of plain concrete.
9. There is an increase of 40-70 per cent in the split tensile strength when a mix of polypropylene and steel fibres is used as reinforcing admixtures.
10. It is observed that the flexural strength of hybrid concrete is 40 per cent higher than that of plain concrete.

Annexures

Annexure 1

Preliminary Test Results and Calculations

A1.1 Specific Gravity of PPC

Table: A1.1 Data for Specific Gravity of PPC

Sl. No.	Details	Result
1.	Weight of empty density bottle, W_1	15.8 gm
2.	Weight of density bottle filled full with water, W_2	57.8 gm
3.	Weight of density bottle filled full with oil, W_3	55.5 gm
4.	Wight of density bottle with oil and cement, W_4	90.2 gm
5.	Weight of cement in density bottle, W_5	50.0 gm

Calculations:

$$G_{ppc} = \frac{W_5 \times (\mathrm{W}_3 - \mathrm{W}_1)}{(W_5 + W_3 - W_4)(W_2 - W_1)}$$

$$= \frac{50 \times (55.5 - 15.8)}{(50 + 55.5 - 90.2)(57.8 - 15.8)}$$

$$= 3.15$$

A1.2. Specific Gravity and water absorption of Coarse Aggregate

Table A1.2: Data for Specific gravity and water absorption of Coarse Aggregate

Sl. No.	Details	Results
1.	Weight of oven dried sample, A	1000 gm
2.	Weight of saturated surface dried sample in air, B	1008 gm
3.	Weight of saturated surface dried sample in water, C	650 gm

Calculations:

$$G_{CA} = \frac{A}{B-C}$$

$$= \frac{1000}{1008-650}$$

$$= 2.8$$

$$WaterAbsorption = \left(\frac{B-A}{A}\right) \times 100$$

$$= \left(\frac{1008-1000}{1000}\right) \times 100$$

$$= 0.8\%$$

A1.3 Specific Gravity and Water Absorption of Fine Aggregate

Table A1.3: Data for Specific gravity of fine aggregate

Sl. No.	Details	Results
1.	Weight of empty bottle, W_1	15.8 gm
2.	Weight of bottle + soil, W_2	57.8 gm
3.	Weight of bottle filled with FA and water, W_3	93.4 gm
4.	Weight of bottle filled with water, W_4	66.8 gm

Calculations:

$$G_{FA} = \frac{(W_2 - W_1)}{(\mathrm{W}_4 - W_1) - (\mathrm{W}_3 - W_2)}$$

$$= \frac{(57.8-15.8)}{(66.8-15.8)-(93.4-57.8)}$$

$$= 2.72$$

Water Absorption:

Table A1.4: Data for water absorption of fine aggregate

Sl. No.	Details	Results
1.	Weight of saturated surface dried aggregate, *A*	500 gm
2.	Weight of oven dried sample, *B*	494 gm

$$WaterAbsorption = \frac{A-B}{B} \times 100$$

$$= \frac{500-494}{494} \times 100$$

$$= 1.2\%$$

A1.4 Fineness Modulus of Fine Aggregates

Table A1.5: Results for Fineness modulus

IS Sieve	Weight Retained (gm)	Cumulative Weight Retained (gm)	Percentage Retained (%)	Percentage Passing (%)
4.75 mm	197.2	197.2	13.14	86.86
2.36 mm	169.5	366.7	24.44	75.86
1.18 mm	150.5	517.2	34.48	65.52
600 µm	165.2	682.4	45.49	54.51
300 µm	298.3	980.7	65.38	34.62
150 µm	383.8	1364.5	90.96	9.04
Pan	135.7	1500.2	100	-

From Table 4 of I.S. 383 (1970), the sample conforms to ***Zone II***.

$$\text{Fineness modulus } = \frac{\sum \text{(Percentage Passing)}}{100}$$

$$= \frac{273.88}{100}$$

$$= 2.74$$

A1.5 Nominal Size of Coarse Aggregates

Table A1.6: Results for Nominal size of Coarse Aggregates

IS Sieve	Weight Retained (gm)	Cumulative Weight Retained (gm)	Percentage Retained (%)	Percentage Passing (%)
20 mm	233.6	233.6	7.79	92.21
16 mm	1417.2	1650.8	55.02	77.65
6.3 mm	18.9	2996.4	99.87	0.13
4.75 mm	3.2	2999.6	99.88	0.12
Pan	0.5	3000.1	100	0

From Table 2 of IS 383 (1970), the sample conforms to **20 mm** nominal size.

Table A1.7 Nominal size of coarse aggregate (Table 2 of IS 383)

IS Sieve Designation	Percentage Passing for Single-sized Aggregate of Nominal Size						Percentage Passing for Graded Aggregate of Nominal Size			
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	-	-	-	-	-	100	-	-	-
63 mm	85 to 100	100	-	-	-	-	-	-	-	-
40 mm	0 to 30	85 to 100	100	-	-	-	95 to 100	100	-	-
20 mm	0 to 5	0 to 20	85 to 100	100	-	-	30 to 70	95 to 100	100	100
16 mm	-	-	-	85 to 100	100	-	-	-	90 to 100	-
12.5 mm	-	-	-	-	85 to 100	100	-	-	-	90 to 100
10 mm	0 to 5	0 to 5	0 to 20	0 to 30	0 to 45	85 to 100	10 to 35	25 to 55	30 to 70	40 to 85
4.75 mm	-	-	0 to 5	0 to 5	0 to 10	0 to 20	0 to 5	0 to 10	0 to 10	0 to 10
2.36 mm	-	-	-	-	-	0 to 5	-	-	-	-

Table A1.8 Zones of Fine Aggregate (Table 4 of IS: 383)

IS Sieve Designation	Percentage Passing For			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	20 – 70	55 – 90	75 – 100	90 – 100
600 µm	15 – 34	35 – 59	60 – 79	80 – 100
300 µm	5 – 20	8 – 30	12 – 40	15 – 50
150 µm	0 – 10	0 – 10	0 – 10	0 – 15

Annexure 2

Concrete Mix Design as per IS: 10262 - 2009

A2.1 M40 Mix design

Data:

a) Grade designation : M40

b) Type of cement : PPC

c) Max. nominal size of aggregate : 20mm

d) Min. cement content : 220 kg/m^3

e) Max. water cement ratio : 0.40

f) Workability : 100 mm (slump)

g) Exposure condition : Mild

h) Method of concrete placing : By hand

i) Type of aggregate : Crushed angular aggregate

j) Max. cement content : 450 kg/m3

k) Chemical admixture : Nil

Test data for Materials

a) Cement used : PPC conforming to IS 1489 (Part 1) : 1991

b) Specific gravity of cement : 3.15

c) Specific gravity of

  i. Coarse aggregate : 2.8

  ii. Fine aggregate : 2.72

d) Water absorption

  i. Coarse aggregate : 0.8%

  ii. Fine aggregate : 1.2%

e) Sieve analysis:

  i. Coarse aggregate : Conforms to 20 mm nominal size as per Table 2 of IS: 383

  ii. Fine aggregate : Conforming to grading Zone II of Table 4 of IS: 383

I. Target Strength for Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65\ s$$

$$= 40 + 1.65 \times 5$$

$$= 48.25\ \text{N/mm}^2$$

II. Selection of Water – Cement Ratio

Max. water-cement ratio = 0.40

Adopt water-cement ratio = 0.40

III. Selection of Water Content

Max. water content for 20 mm aggregate = 186 litre (25 to 50 mm slump range)

Estimated water content for 100 mm slump = $186 + \frac{6}{100} \times 186 = 197\,litre$

IV. Calculation of Cement Content

Water-cement ratio = 0.40

Cement content = $\frac{197}{0.40} = 492.5\ kg/m^3$

Clause 8.2.4.2 of IS 456 states that max. cement content should not exceed 450 kg/m^3

So reduce cement content to 450 kg/m^3

V. Proportion of Volume of Coarse Aggregate and Fine Aggregate Content

From Table A2.6, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone II) for water-cement ratio of 0.50 = 0.62

For water-cement ratio of 0.4, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10, the proportion of volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every± 0.05 change in water-cement ratio).

Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.40 = 0.64

Volume of fine aggregate = 1 – 0.64 = 0.36

VI. Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m^3

b) Volume of cement $= \frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{1}{1000}$

$$= \frac{450}{3.15} \times \frac{1}{1000}$$

$$= 0.143\ m^3$$

c) Volume of water $= \frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{1}{1000}$

$$= \frac{197}{1} \times \frac{1}{1000}$$

$$= 0.197\ m^3$$

d) Volume of all in aggregate = [a – (b + c)]

= 1 – (0.143 + 0.197)

= 0.660 m^3

e) Mass of coarse aggregate = d × Volume of Coarse Aggregate × Specific gravity of coarse aggregate × 1000

= 0.66 × 0.64 × 2.8 × 1000

= 1183 kg

f) Mass of fine aggregate = d × Volume of Fine Aggregate × Specific gravity of Fine aggregate × 1000

= 0.66 × 0.36 × 2.72 × 1000

= 647 kg

g) Ratio = cement: Fine Aggregate: Coarse Aggregate

= 450: 647: 1183

= 1: 1.4: 2.6

A2.2 Reference tables for Mix Design

Table A2.1: Assumed Standard Deviations for various concrete mixes (Table 8 in IS:456 - 2000)

Grade of Concrete	Assumed Standard Deviation
M10 to M15	3.5
M20 to M25	4.0
M30 to M55	6.0

Table A2.2: Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size (*Table 5 in IS: 456 - 2000*)

Environmental Exposure Condition	Plain Concrete			Reinforced Concrete		
	Min. cement content (kg/m^3)	Min. free water – cement ratio	Min. grade of concrete	Min. cement content (kg/m^3)	Min. free water – cement ratio	Min. grade of concrete
Mild	220	0.60	-	300	0.55	M20
Moderate	240	0.60	M15	300	0.50	M25
Severe	250	0.50	M20	320	0.45	M30
Very Severe	260	0.45	M20	340	0.45	M35
Extreme	280	0.40	M25	360	0.40	M40

Table A2.3: Environmental Exposure Condition (*Table 3 in IS: 456 - 2000*)

Sl. No.	Environment	Exposure Condition
1	Mild	▪ Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal areas
2	Moderate	▪ Concrete surfaces sheltered from severe rain or freezing whilst wet. ▪ Concrete exposed to condensation and rain. ▪ Concrete continuously under water. ▪ Concrete in contact or buried under non aggressive soil/ground water.
3	Severe	▪ Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation. ▪ Concrete completely immersed in sea water.
4	Very Severe	▪ Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing condition whilst wet
5	Extreme	▪ Surface members in tidal zone. ▪ Members in direct contact with liquid/solid aggressive chemicals.

Table A2.4: Maximum water content per cubic meter of concrete for nominal maximum size of aggregate (*Table 2 in IS: 10262 - 2009*)

Maximum water content per cubic meter of concrete for nominal maximum size of aggregate		
Sl. No	Nominal max. size of aggregate	Max Water content
1	10	208
2	20	186
3	40	165

The values given in the table shown above is applicable only for angular coarse aggregate and for a slump value in between 25 to 50mm.

Do the following adjustments if the material used differs from the specified condition.

Table A2.5: Adjustment rules

Type of Material/condition	Adjustment required
For sub angular aggregate	Reduce the selected value by 10 kg
For gravel with crushed stone	Reduce the selected value by 20 kg
For rounded gravel	Reduce the selected value by 25 kg
For every addition of 25 mm slump	Increase the selected value by 3%
If using plasticizer	Decrease the selected value by 5-10%
If using super plasticizer	Decrease the selected value by 20-30%

Note: Aggregates should be used in saturated surface dry condition. While computing the requirement of mixing water, allowance shall be made for the free surface moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregate are completely dry, the amount of mixing water should be increased by an amount equal to moisture likely to be absorbed by the aggregate.

Table A2.6: Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate (Table 3 in IS: 10262 - 2009)

Sl. No.	Nominal Max. Size of Aggregate (mm)	Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate			
		Zone IV	Zone III	Zone II	Zone I
1	10	0.50	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

Annexure 3

Strength Test Results

A3.1 M40 Grade mix (Plain Concrete)

Table A3.1: Compressive strength of Plain Cement Concrete

Sample	28 days (MPa)	Average
1	45	44.76 MPa
2	44.8	
3	45.5	

Table A3.2: Split Tensile Strength of Plain Cement Concrete

Sample	28 days (MPa)	Average
1	4.77	4.62 MPa
2	4.50	
3	4.62	

Table A3.3: Flexural Strength of Plain Cement Concrete

Sample	28 days (MPa)	Average
1	4.35	4.30 MPa
2	4.30	
3	4.27	

A3.2 M40 Grade mix (Polypropylene reinforced concrete)

Table A3.4: Compressive Strength of Polypropylene Fibre Reinforced Concrete

Fibre Content	7 days (MPa)	28 days (MPa)	% Change in 28 days strength
0.25%	32.3	49.8	11.26
0.40%	32.5	50.1	11.93
0.50%	31.6	48.7	8.80

Table A3.5: Split Tensile Strength of Polypropylene Fibre Reinforced Concrete

Fibre Content	28 days (MPa)	% Change in 28 days strength
0.25%	7.28	57.57%
0.40%	7.90	70.25%
0.50%	7.80	68.10%

Table A3.6: Flexural Strength of Polypropylene Fibre Reinforced Concrete

Fibre Content	28 days (MPa)	% Change in 28 days strength
0.25%	6.12	42.32%
0.40%	6.15	43.02%
0.50%	6.10	41.86%

A3.3 M40 Grade mix (Steel fibre reinforced concrete)

Table A3.7: Compressive Strength of Steel Fibre Reinforced Concrete

Fibre Content	28 days (MPa)	% Change in 28 days strength
0.25%	49.63	10.89
0.50%	58.83	31.12
0.75%	61.82	38.12

Table A3.8: Split Tensile Strength of Steel Fibre Reinforced Concrete

Fibre Content	28 days (MPa)	% Change in 28 days strength
0.25%	7.36	59.30
0.50%	8.21	77.70
0.75%	8.48	83.54

Table A3.9: Flexural Strength of Steel Fibre Reinforced Concrete

Fibre Content	28 days (MPa)	% Change in 28 days strength
0.25%	4.97	15.69
0.50%	6.23	45.09
0.75%	6.54	52.09

A3.4 M40 Grade mix (Hybrid/Composite concrete)

Table A3.10: Compressive Strength of Steel Fibre Reinforced Concrete

S. No.	% SF	% PPF	Compressive Strength	% Change in 28 days strength
1	0	100	48.7	8.80
2	25	75	51.2	14.38
3	50	50	54.6	21.98
4	75	25	56.3	25.78
5	100	0	58.83	31.43

Table A3.11: Split Tensile Strength of Steel Fibre Reinforced Concrete

S. No.	% SF	% PPF	Split Tensile Strength	% Change in 28 days strength
1	0	100	7.80	68.83
2	25	75	7.88	70.56
3	50	50	7.98	72.72
4	75	25	8.09	75.10
5	100	0	8.21	77.20

Table A3.12: Flexural Strength of Steel Fibre Reinforced Concrete

S. No.	% SF	% PPF	Flexural Strength	% Change in 28 days strength
1	0	100	6.1	41.86
2	25	75	6.15	43.02
3	50	50	6.18	43.72
4	75	25	6.20	44.18
5	100	0	6.23	44.88

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