A COMPARITIVE STUDY ON COMPRESSIVE AND FLEXURAL STRENGTH OF FIBER REINFORCED CONCRETE (STEEL AND POLYPROPYLENE) AND ORDINARY CONCRETE

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Abstract: Ordinary concrete is a composite material containing cement, water, coarse aggregate and fine aggregate. 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 finally makes the concrete to fail.

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 a rebar. Thus, need for multidirectional and closely spaced steel reinforcement arises. That cannot be practically possible. Fiber reinforcement gives the solution for this problem. So, to increase the tensile strength of ordinary concrete a technique of introduction of fibers in concrete is being used. These fibers act as crack arrestors and prevent the propagation of the cracks. These fibers are uniformly distributed and randomly arranged. This concrete is named as fiber reinforced concrete.

The main reasons for adding fibers to ordinary concrete matrix is 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. Their main purpose is to increase the energy absorption capacity and toughness of the material, but also increase tensile and flexural strength of concrete.

In the Present study, Steel Fiber Reinforcement and Polypropylene Fiber Reinforcement of 1% and 3% by weight are considered and compared with respect to compressive strength and flexural strength.

The present study can be concluded that 3% Steel fibers can be added as a reinforcement to ordinary concrete to enhance both compressive strength by 55% at 28 days curing duration and flexural strength by 60% at 28 days curing duration. Further study may be carried out to find the optimal percentage replacement.

1. HISTORY AND DEVELOPMENT

The use of fibers to increase the structural properties of construction material is not a new process. From ancient times fibers were being used in construction. In olden days, 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 fiber reinforced concrete was over looked for 5-6 decades. Later in 1939 the introduction of 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 fibers. Since then use of different types of fibers in concrete was made. In 1970's principles were developed on the working of the fiber 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. According to terminology adopted by American Concrete Institute (ACI) Committee 544, there are four categories of Fiber Reinforced Concrete namely 1) SFRC (Steel Fiber Reinforced Concrete), 2) GFRC (Glass Fiber Reinforced concrete), 3) SNFRC (Synthetic Fiber Reinforced Concrete) and 4) NFRC (Natural Fiber Reinforced Concrete). It also provides the information about various mechanical properties.

2. ADVANTAGES OF FIBER REINFORCED CONCRETE

- **Temperature resistance**

  Concrete elements exposed to fire undergo temperature gradients and as a result, undergo physical changes or spalling which leads to expose steel reinforcement. This causes distress in concrete structures. The performance of concrete can be improved with the addition of steel fibers to concrete especially when it is exposed to heat.

- **Toughness**
  Steel fibers reinforce concrete against impact forces, thereby improving the toughness characteristics of hardened concrete.
- **Plastic shrinkage cracking**
  Shrinkage cracks are short, irregular cracks that can develop in concrete within the first 24 hours after concrete placement. In fiber reinforced concrete, fibers dispersed evenly throughout the concrete matrix. This multidimensional reinforcement reportedly gives fresh concrete more tensile capacity to resist typical volume changes. It also helps to distribute tensile stresses more evenly. If shrinkage cracks do form, fibers bridge these cracks, helping reduce their length and width.
- **Ductility**
  By adding steel fibers while mixing the concrete, a so-called homogeneous reinforcement is created. Thus, ordinary concrete, which is a brittle material, is turned to the pseudo ductile steel fiber reinforced concrete. After matrix crack initiation, the stresses are absorbed by bridging fibers, and the bending moments are redistributed. The concrete element does not fail spontaneously when the matrix is cracked, the deformation energy is absorbed and the material becomes pseudo-ductile.
- **Tensile and flexural strength**
  One of the important properties of steel fiber reinforced concrete (SFRC) is its superior resistance to cracking and crack propagation. As a result of this ability to arrest cracks, fiber composites possess increased extensibility and tensile and flexural strength, both at first crack and at ultimate, particular under flexural loading and the fibers are able to hold the matrix together even after extensive cracking.

3. DISADVANTAGES OF FIBER REINFORCED CONCRETE

- Fibers, which are randomly distributed throughout the concrete, can overcome cracks and control shrinkage more effectively. These materials have outstanding combinations of strength and energy absorption capacity. In general, the fiber reinforcement is not a substitution to conventional steel reinforcement. The fibers and steel reinforcement have their own role in concrete technology. Therefore, many applications in which both fibers and continuous reinforcing steel bars can be used together.
- However, fibers are not efficient in withstanding the tensile stresses compared to conventional steel reinforcements. But fibers are more closely spaced than steel reinforcements, which are better in controlling crack and shrinkage. Consequently, conventional steel reinforcements are used to increase the load bearing capacity of concrete member; fibers are more effective in crack control. The lack of corrosion resistance of normal steel fibers could be a disadvantage in exposed concrete situations. The synthetic fibers are uneconomical to medium level people.

4. PROPERTIES OF FIBER REINFORCED CONCRETE

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

- Transfer of stress between matrix and fiber
- Aspect ratio
- Quantity of fiber
- Orientation and distribution of fibers

Transfer of stress between matrix and fiber:

- ➢ Modulus of elasticity of matrix must be lower than that of fiber for efficient stress transfer.
- ➢ Interfacial bonds also determine the degree of stress transfer.
- ➢ Bonds can be improved by larger area of contact, improving frictional properties and degree of gripping.

Aspect ratio:

Aspect ratio is defined as the ratio of length to width of the fiber. 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 75. Above that the strength of concrete decreases, in view of decreased workability and reduced compaction. From investigations it can be found out that good results are obtained at an aspect ratio around 80 for steel fiber

Fiber quantity:

Generally, quantity of fibers is measured as percentage of cement content. As the volume of fibers increase, there should be increase in strength and toughness of concrete. Regarding our fiber, we hope that there will be an increase in strength, with increase in fiber content. In the present study, it is finalized to test for percentages of 1.0% and 3.0%.

Orientation and distribution of fibers:

For randomly dispersed fibers the placement depends on the method of adding fibers, the casting equipment used and the fresh concrete properties among others. A problem when casting fiber reinforced concrete is that the fibers may clot together and prevent a good flow of the concrete. This can cause a less fortunate dispersing of the fibers. Another problem that may occur is separation, which can cause the steel fibers to sink to the bottom of the formwork. Figure1 shows different distribution of discontinuous fibers.

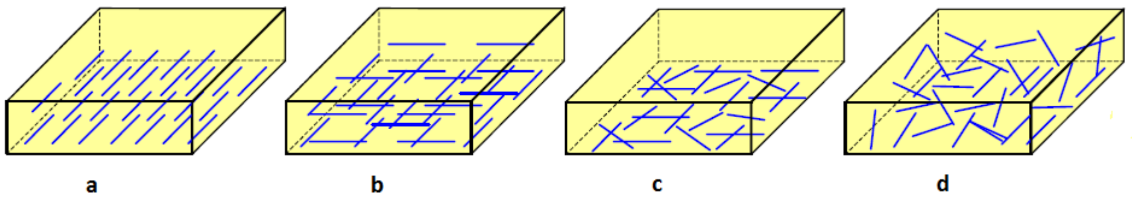


Figure 1: Different distributions of discontinuous fibers

a) Biased 1-D fiber orientation
b) Biased 2-D fiber orientation
c) Plane random fiber orientation
d) Random fiber orientation

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

- Good adhesion within the matrix.
- Compatibility with the binder, which should not be attacked or destroyed the concrete.
- An accessible price, taking into account the proportion within the mix.
- Being sufficiently short, fine and flexible to permit mixing, transporting and placing
- Being sufficiently strong, yet adequately robust to withstand the mixing process.

5. OBJECTIVES

The aim of the project is to study the strength variations of concrete by addition of different fibers (Steel and Polypropylene) and compare the strengths of fiber reinforced concrete and ordinary concrete at different ages.

To fulfill the study carried out, following are the objectives of the present study:

- To calculate the amount of cement, fine aggregate, coarse aggregate, water and fiber.
- Casting and curing of fiber reinforced concrete specimens and ordinary concrete specimens.
- To conduct compressive strength test and flexural strength test on the specimens at different ages.
- To analyze the obtained results and compare the strengths of ordinary concrete and fiber reinforced concrete (Steel and Polypropylene).

6. PREVIOUS RESEARCH ON FIBRE REINFORCED CONCRETE

Durability:
A.L. Ardeshana et al (2012) (1) expresses that addition of polypropylene fibers improved durability of concrete. The polypropylene fibers bridge the cracks and minimize interconnecting voids, this resulted in dense concrete. Therefore, this can be used for water retaining structures like water tanks, swimming pools, which ought to be designed as impermeable.
Strength:
L.N. Vairagade et al (2015) (2) states that the inclusion of steel fiber in the concrete mix leads to an improvement in mechanical properties and a better resistance to heating effects. It also increases crack resistance to a high extent. The properties (flexural strength, tensile strength & compressive strength) of steel fiber reinforced concrete are superior to that of ordinary concrete. From his experimental work it was observed that the flexural strength increases for 0.75% and 1.5% of steel fibers in ordinary concrete whereas it decreases in case of 2%.
Compressive behavior of SFRC:
Yu-Chen Ou et al (2012) (3) conducted compression tests on SFRC cylindrical specimens and states that adding steel fibers had little effect on the modulus of elasticity or the compressive strength of SFRC.
Economical consideration:
M.A. Mansur et al (2015) (4) expresses that the use of jute fiber reinforced concrete help to a great extent in providing low cost housing where jute fiber is abundant. Jute fiber reinforcement has more energy absorption capacity used in shatter and earth quake resistant construction.
Load carrying capacity:
Amit Rai et al (2010) (5) states that plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded, on the other hand, fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete. Steel fibers reinforce concrete against impact forces, thereby improving the toughness characteristics of hardened concrete.
Effect of Polypropylene Fiber on Properties of Concrete:
Vinay Kumar Singh (2014) (6) studied the effect of addition of polypropylene fiber in ordinary concrete. Addition of fibers in different percentages (0% to 0.7%) has been studied for their effect on strength properties of concrete. Results showed that the addition of polypropylene fiber (upto certain limit) to concrete exhibit better performance and has shown improvement in compressive strength and flexural strength to that of plain concrete. It is observed that the compressive

strength of concrete and flexural strength of concrete increases with addition of fibers upto certain limit. Addition of 0.35% fibers into the concrete showed better results in compressive strength and addition of 0.25% fibers into the concrete showed better result in flexural strength. Also, it can be observed that 28 days compressive strength is increased by 2.44% with addition of 0.35% of fiber compared to Plain M-25 concrete. It can be observed that 28 days flexural strength is increased by 51.05% with addition of 0.25% of fiber compared to normal concrete.

6.1. TYPES OF REINFORCING FIBERS USED IN PRESENT STUDY:

- Steel fibers
- Polypropylene fibers

Steel fiber:

The steel fibers may have different shapes. An important issue is that the bond between the fibers and the concrete needs to be ductile. Therefore, it's better if the structure fractures when the fibers get pulled out of the concrete, rather than by fracturing of the fibers themselves. Steel fibers reduce the permeability and water migration in concrete, which ensures protection of concrete due to the ill effects of moisture. Steel fibers reinforced concrete against impact forces, thereby improving the toughness characteristics of hardened concrete. The steel fibers have a disadvantage when it comes to the aesthetic prospect. Since fibers get spread out in the matrix some of them will be at the surface of the structure. These might rust so that the surface gets discolored by rust stains.

Polypropylene fiber:

The synthetic fibers have the advantage compared to steel fibers that they have a very high resistance to acidic and alkaline environment and thus do not require concrete cover to protect against corrosion. This also gives FRC with synthetic fibers a better aesthetical surface than FRC with steel fibers as the steel fibers at the surface will corrode and discolor the concrete when exposed to outdoor weather. An important negative aspect to the synthetic fibers is that they will soften at elevated temperatures and melt at about 150- 160°C, thus losing all their mechanical properties. This limits their use in structures where there is a risk of fire.

6.2. MECHANICAL PROPERTIES:

Concrete is a quite brittle material with very little tensile strength, so to use concrete in structures it is necessary to improve its tensile qualities. The traditional way of doing this is adding steel bars with high yield strength to take the tensile forces in the structure element. Another way to improve the tensile strength of concrete is to add reinforcement fibers. This might enhance the concrete's toughness, ductility and energy absorption under impact and increase the post crack capacity when added in sufficient quantity. The fibers can act in different ways, but mainly in two mechanisms: They can stop micro cracks from developing into larger cracks either from external loads or from drying shrinkage. Secondly, after cracking the fibers that span the cracks that have formed will give the concrete a residual load bearing capacity. With enough fibers this capacity may be considerable, but the fibers may influence the casting qualities of the fresh concrete.

Compressive strength

In the stress-strain relation for concrete in compression the concrete has got an almost linear response up to about 30% of the compressive strength. After this a gradual softening happens up to the concrete compressive strength, where the stress-strains relation exhibits a strain softening until failure by crushing. The main explanation of the concrete's macroscopic behaviour during compressive failure is proposed by Neville (1997). This explanation states that there are interfaces between the aggregate and the hardened cement paste, and that in these interfaces micro cracks develop even at smaller load levels. These cracks develop through the weakest part of the concrete (the cement is less strong and stiff than the aggregate for normal-strength concrete, but in high-strength concrete these are more equal), and eventually result in crushing.

When fibers are added to the ordinary concrete it becomes more ductile and increase the resistance against longitudinal crack growth. The effect of fibers on concrete compressive strength is highly dependent of the fiber type, their size and properties, the amount of fibers added and the properties of the matrix.

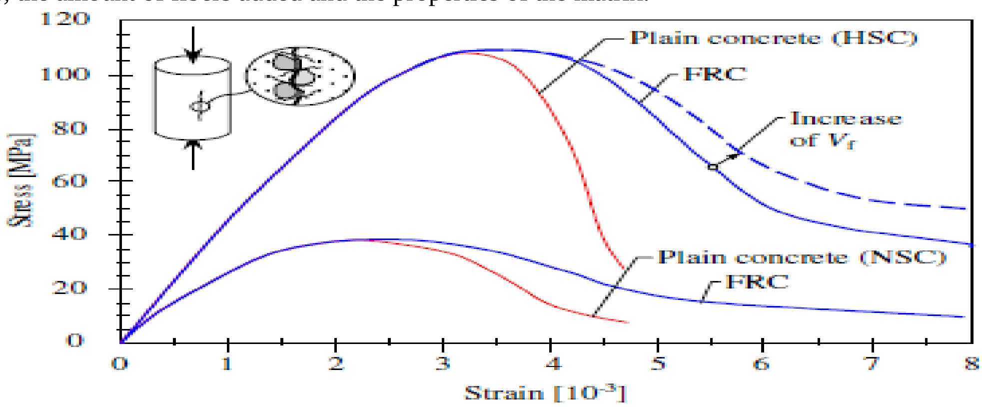


Figure 2: Behaviour of Standard concrete and FRC in compression

Tensile strength

The important effect of fibers on concrete tensile strength is on the tensile fracture behaviour. In normal concrete the tensile load carrying abilities of the concrete will decrease a lot after crack widths of about 0.3 mm. The FRC will be able to carry considerable loading after cracking.

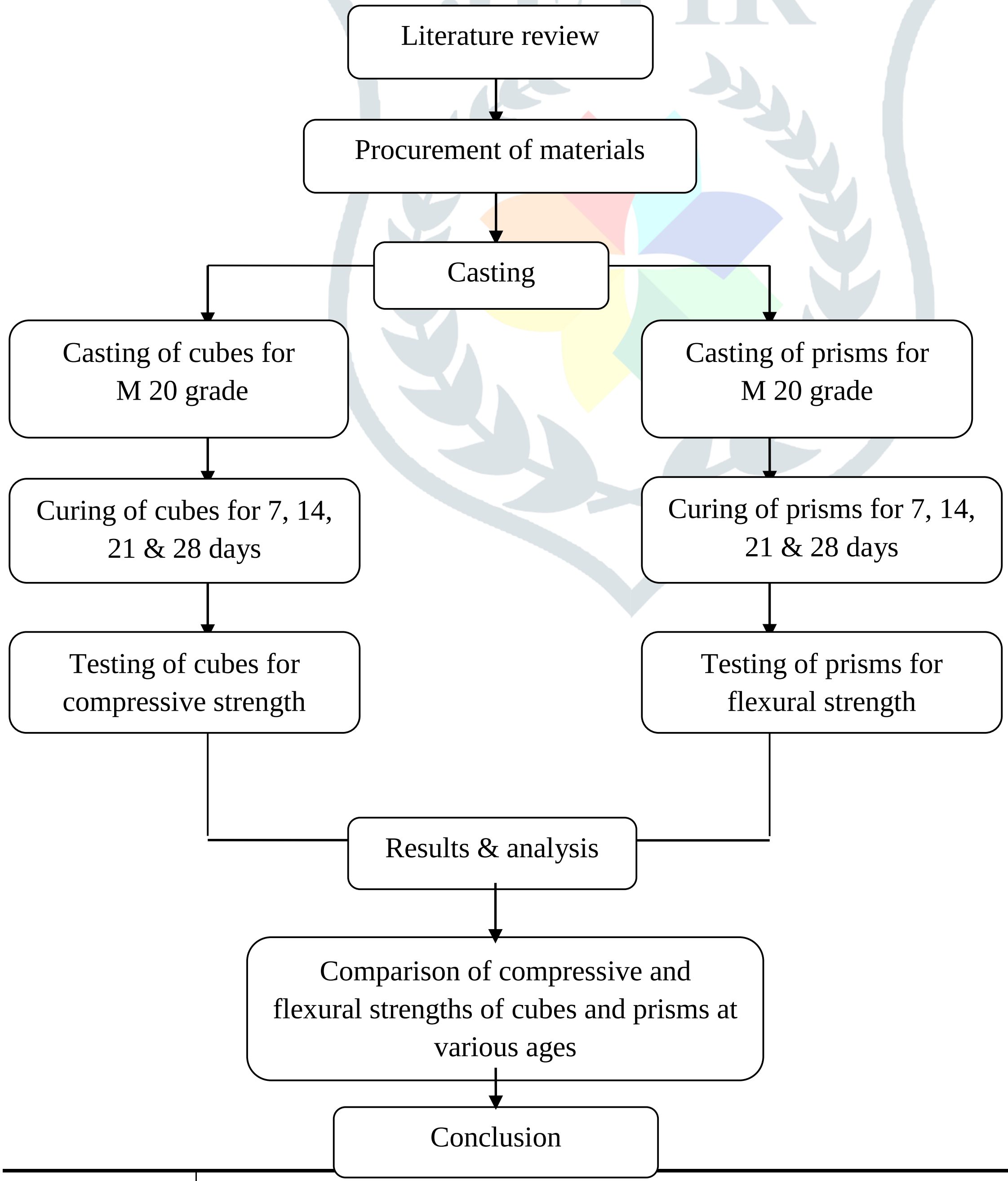
After the initial cracking has started, the fibers across the cracks will often be able to carry more load than other weak zones in the matrix. Therefore, new cracks will continue to form in the brittle matrix. When many cracks have formed the fibers will have plastic deformations by being drawn out of the concrete matrix. The ultimate failure will happen when the fibers get completely drawn out of the concrete. This way the FRC will have a much more ductile behaviour than regular concrete and will have some residual capacity after the stress-strain diagram has reached its peak.

Shear properties

In ordinary concrete the shear forces are transferred across a crack by interlocking of the aggregate and friction. For FRC the fibers are activated when the cracks occur and the shear force is transferred by the fibers across the cracks. After cracking, the fibers start being pulled out and provide a ductile behaviour of the concrete and significant toughening behaviour. Earlier experiments have indicated that the fibers have a great effect on the shear capacity and can increase the capacity up to 60% of the compressive capacity for regular concrete with low or moderate dosages of fibers. For high-strength concrete with 40 kg/m^3 steel fibers the increase has been measured up to 100% of the compressive capacity. This is because the fibers act as dowels between the crack surfaces and therefore increase the capacity quite significantly. The effect increases with higher fiber volume fractions.

7. WORK PLAN

The following work plan was formulated keeping in view of the project objectives:



8. MATERIALS USED IN OUR PRESENT STUDY

In the present study, grade of concrete considered is M 20 (1:1.5:3) with a water cement ratio of 0.5.

- **Cement:**
  Ordinary Portland cement (OPC) is by far the most important type of cement. The OPC was classified into three grades namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. Ordinary Portland cement of 53grade is used in this project work.
- **Fine aggregates:**
  It should be passed through IS Sieve 4.75 mm.

- **Coarse aggregates:**
  It should be hard, strong, dense, durable and clean. It must be free from adherent coatings and injurious amount of disintegrated pieces, alkalis, vegetable matters and other deleterious substances. It should be roughly cubical in shape. Flaky pieces should be avoided.
- **Water:**
  Water should be free from acids, oils, alkalis, vegetables or other organic impurities. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form the cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a lubricant in the mixture of fine aggregates and cement.
- **Steel fibers:**
  Plain steel fibers of typical diameter approximately 0.8 mm are being used in the present study. Length of these fibers considered is 76 mm and the aspect ratio is nearly equal to 95.

Fig 3: Steel fibers used in the present study

- **Polypropylene fibers:**

Fig 4: Polypropylene fibers used in the present study

Table 1: Properties of polypropylene fibers

S.NO	PROPERTIES	
1	Cut length	12mm
2	Effective diameter	25-40 microns
3	Specific gravity	0.90-0.91
4	Melting point	160-165 °C
5	Young's modulus	>4000 MPa
6	Alkaline stability	Very good

9. CALCULATION OF QUANTITIES OF MATERIALS USED IN THE PRESENT STUDY

Table 2: List of cubes and prisms

S. No	Type of Concrete	Cubes	Prisms
1	FRC with 1% Steel fibers (by weight)	12 (3 for 7 day ,3 for 14 day, 3 for 21 day and 3 for 28days strength)	12
2	FRC with 3% steel fibers	12	12
3	FRC with 1% polypropylene fibers	12	12
4	FRC with 3% polypropylene fibers	12	12
5	Plain cement concrete	12	12

For cubes:
Volume of cubes = 0.15 x 0.15 x 0.15
V = 3.375×10^{-3} m^3
Increase volume by 50% because cement and sand fills the gaps between aggregate
V = $1.5 \times 3.375 \times 10^{-3}$
= 5.0625×10^{-3} m^3
Total number of cubes = 60
Therefore, total volume of concrete for cubes = $60 \times 5.0625 \times 10^{-3}$ m^3
= **0.30375 m^3**

For prisms:
Volume of prisms = 0.50 x 0.10 x 0.10
V = 5×10^{-3} m^3
Increase volume by 50% because cement and sand fills the gaps between aggregate
V = $1.5 \times 5 \times 10^{-3}$
= 7.5×10^{-3} m^3
Total number of prisms = 60
Therefore, total volume of concrete for prisms = $60 \times 7.5 \times 10^{-3}$ m^3
= **0.45 m^3**

In the present study, grade of concrete considered is M 20 (1:1.5:3)
Total volume of concrete = 0.30375 + 0.45 = **0.75375 m^3**

Volume of cement = (0.75375 x 1) / (1 + 1.5 + 3) = 0.1370 m^3
Volume of fine aggregate = (0.75375 x 1.5) / (1 + 1.5 + 3) = 0.2055 m^3
Volume of coarse aggregate = (0.75375 x 3) / (1 + 1.5 + 3) = 0.4111 m^3
Weight of cement = volume x density
= 0.1370 x 1440 = 197.28 kg ≈ **200 kg**

From Table 9 of IS 456-2000
For M 20 grade concrete, total quantity of dry aggregates by mass per 50 kg of cement, to be taken as the 250 kg (sum of individual masses of fine and coarse aggregates)
Total weight of aggregates = (250/50) x 200 = 1000 kg
Ratio of fine aggregate to coarse aggregate is 1: 2
Weight of fine aggregate = (1000 x 1) / (1 + 2) = 333.33 kg ≈ **334 kg**
Weight of coarse aggregate = (1000 x 2) / (1 + 2) = 666.67 kg ≈ **666 kg**

Steel fibers (1%) are added in 12 cubes and 12 prisms

Volume of cubes = 0.15 x 0.15 x 0.15
V = 3.375×10^{-3} m^3
Increase volume by 50% because cement and sand fills the gaps between aggregate
V = 1.5 x 3.375 x 10^{-3}
= 5.0625 x 10^{-3} m^3
Total number of cubes = 12
Therefore, total volume of concrete for cubes = 12 x 5.0625 x 10^{-3} m^3
= 0.06075 m^3
Volume of cement = (0.06 x 1) / (1+1.5+3) = 0.01 m^3
Weight of cement = 1440 x 0.01 = 15.71 kg
Weight of steel fibers (1%) added in cubes = (15.71 x 1)/100 = **0.157 kg**
Weight of steel fibers (3%) added in cubes = (15.71 x 3)/100 =**0.471 kg**
Volume of prisms = 0.50 x 0.10 x 0.10
V = 5 x 10^{-3} m^3
Increase volume by 50% because cement and sand fills the gaps between aggregate
V = 1.5 x 5 x 10^{-3}
=7.5 x 10^{-3} m^3
Total number of prisms = 12
Therefore, total volume of concrete for prisms = 12 x 7.5 x 10^{-3} m^3
= 0.09 m^3
Volume of cement = (0.09 x 1) / (1 + 1.5 + 3) = 0.016 m^3
Weight of cement = volume x density
= 0.016 x 1440 = 23.56kg
Weight of steel fibers (1%) added in cubes = (23.56 x 1)/100 = **0.235 kg**
Weight of steel fibers (3%) added in prisms = (23.56 x 3) / 100 = **0.707 kg**
Total quantity of steel fibers required = 0.157 + 0.471 + 0.235 + 0.707 = **1.57 kg**
Similarly, weight of polypropylene fibers = **1.57 kg**

Water cement ratio = 0.5
Amount of water required = 0.5 x 200 Kgs = **100 liters**

Table 3: Total quantities of materials used in the present study

S. No	Ingredient	Quantity
1	Cement	200kg
2	Fine aggregate	334kg
3	Coarse aggregate	666kg
4	Steel fibers	1.57 kg
5	Polypropylene fibers	1.57 kg
6	Water	100 liters

10. CASTING OF SPECIMENS

Mixing:

About 25 percent of water required for mixing is first introduced into the mixer drum to prevent any sticking of cement on the blades and bottom of the drum. Then the ingredients are discharged in to the mixer. The sequence of loading should be added such that, first half the coarse aggregate and then half the fine aggregate and over this total cement and then the balance aggregates. The ingredients are mixed dry in electric concrete miller for two minutes. Now the balance water is added to the mix and the mixer is rotated for two more minutes. While mixing fiber reinforced concrete, the fibers are added while mixing the ingredients in dry state.

Fig 5: Concrete mixer

Preparation of specimens:
Cubes:

To study the compressive strength of concrete, 12 cubes of 150 mm size for each type of concrete were cast. 150 mm cube moulds were filled with concrete and placed on table vibrator and vibrated for 1 minute, after the compaction was completed, the surfaces of the cubes are levelled with a trowel and were marked for identification. These specimens were demoulded after 24 hours of casting and cured in water for required age.

Fig 6: Cube mould

Prisms:

To study the flexural strength of concrete, 12 prisms of 500 mm X 100 mm X 100 mm size for each type of concrete were cast and compacted. These specimens were demoulded after 24 hours of casting and cured in water for required age.

Fig 7: prism mould

Curing of specimens

After the specimens were demoulded, these were stored under water at room temperature until tested at an age of 7, 14, 21 & 28 days.

Fig 8: Specimens in curing tank

11. TESTING OF SPECIMENS

After curing period, specimens were taken out of curing tank and tested for compressive and flexural strength of concrete.

Compression test

The bearing surfaces of the compression testing machine were wiped clean. The cubes to be tested were placed concentrically and in such a manner that the load was applied to the opposite sides of the cube as cast, that is, not on the top and bottom. Then the load is applied without shock and increased continuously at a rate of 140 kg/ cm^2/minute until the specimen fails. The maximum load applied to the cube was then noted down. The average of the three values is taken as compressive strength of the concrete.

Then compressive strength of the concrete = (maximum load) / (Cross-sectional area)

Fig 9: Compression test set up

Flexure test

The flexural strength test is performed to estimate the tensile load at which concrete may crack. This is an indirect test for assessing the tensile strength of concrete. The prism to be tested is placed in the testing machine on two 38 mm diameter rollers with a c/c distance of 400 mm. the load is applied through two similar rollers mounted at the third points, i.e., spaced at 135 mm c/c. The load is applied without shock and increasing continuously at a rate of 7 kg/cm^2/minute until the specimen fails.

Flexural strength is calculated as follows

Case 1 where fracture occurs within the middle third of the span

Then flexural strength of concrete = $(Pl) / (bd^2)$

Case 2 where fracture occurs outside the middle third of the span

Then flexural strength of concrete = $(3Pa) / (bd^2)$

where, a is the distance between the line of fracture and the nearest support,

b and d are width and depth of specimen,

l is the length of the span on which the specimen is supported,

P is the maximum load applied to the specimen

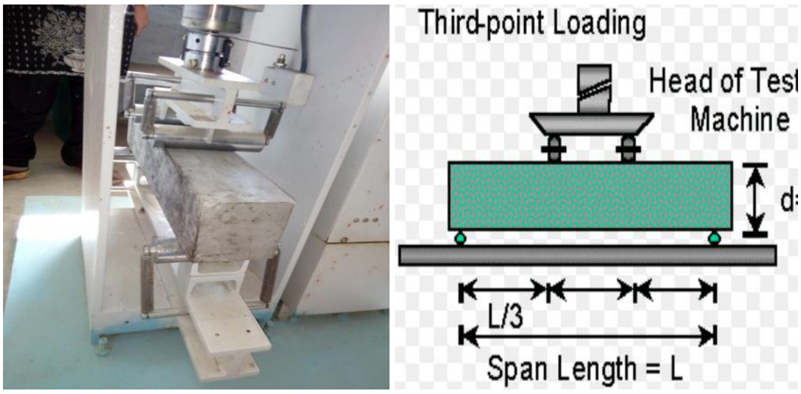


Fig 10: Flexural strength test set up

12. RESULTS AND DISCUSSIONS

1.0 Comparison between Compressive strength of 1% SFRC and 3% SFRC

Table 4: Compressive strength of cubes with 1% Steel fiber

Cube number	Curing duration (days)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
1 2 3	7	32.22 33.56 35.33	33.70
4 5 6	14	38.22 37.77 40.88	38.95
7 8 9	21	42.25 41.11 42.88	42.08
10 11 12	28	44.44 44.44 45.33	44.74

Table 5: Compressive strength of cubes with 3% Steel fiber

Cube number	Curing duration (days)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
13 14 15	7	32.28 33.26 31.23	32.26
16 17 18	14	38.88 35.56 35.56	36.67
19 20 21	21	39.20 38.77 38.56	38.84
22 23 24	28	41.77 41.33 40.88	41.33

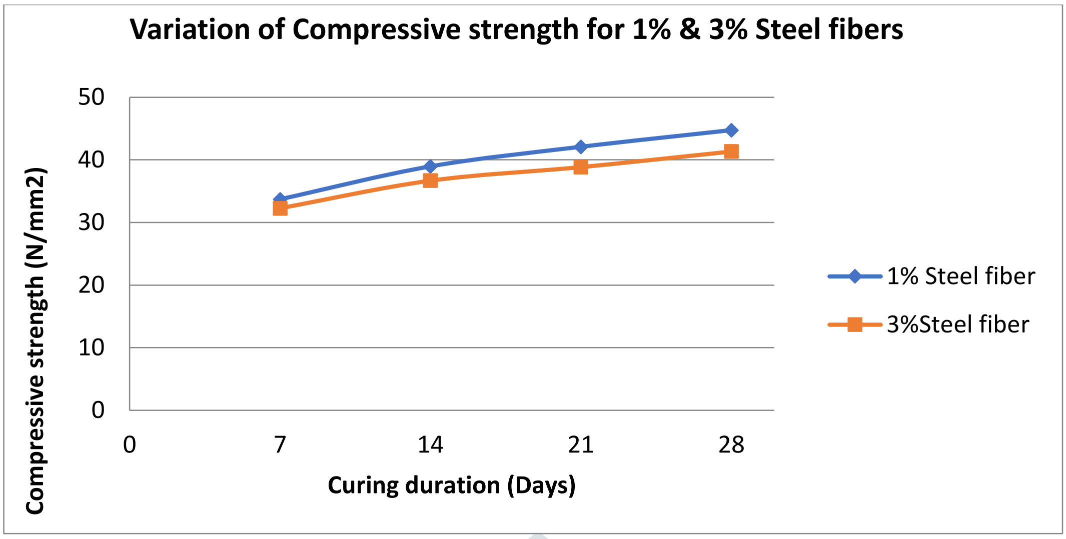


Table 6: Percentage variation in compressive strength for 1% and 3% steel fiber reinforced concrete

Curing duration (Days)	Compressive strength of 1% SFRC (N/mm^2)	Compressive strength of 3% SFRC (N/mm^2)	Percentage variation of Compressive Strength
7	33.70	32.26	-4.27
14	38.95	36.67	-5.85
21	42.08	38.84	-7.69
28	44.74	41.33	-7.62

From the graph:

- At 7 days of curing period the compressive strength of fiber reinforced concrete with 1% steel fibers is higher by 4.27% than that of fiber reinforced concrete with 3% steel fibers.
- At 14 days compressive strength of concrete with 1% steel fibers is 5.85% more than the concrete with 3% steel fibers.
- At 21 days compressive strength of concrete with 1% steel fibers is 7.69% more than the concrete with 3% steel fibers.
- At 28 days compressive strength of concrete with 1% steel fibers is 7.62% more than the concrete with 3% steel fibers.

2.0 Comparison between Flexural strength of 1% SFRC and 3% SFRC

Table 7: Flexural strength of prisms with 1% Steel fiber

Prism number	Curing duration (days)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
1 2 3	7	3.40 4.00 4.00	3.80
4 5 6	14	4.00 3.80 4.00	3.93
7 8 9	21	4.00 4.20 4.20	4.13
10 11 12	28	4.60 4.60 4.20	4.47

Table 8: Flexural strength of prisms with 3% Steel fiber

Prism number	Curing duration (days)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
13		3.80	

14 15	7	4.00 4.00	3.93
16 17 18	14	4.40 4.40 4.00	4.27
19 20 21	21	4.40 4.60 4.60	4.53
22 23 24	28	4.60 5.00 5.00	4.87

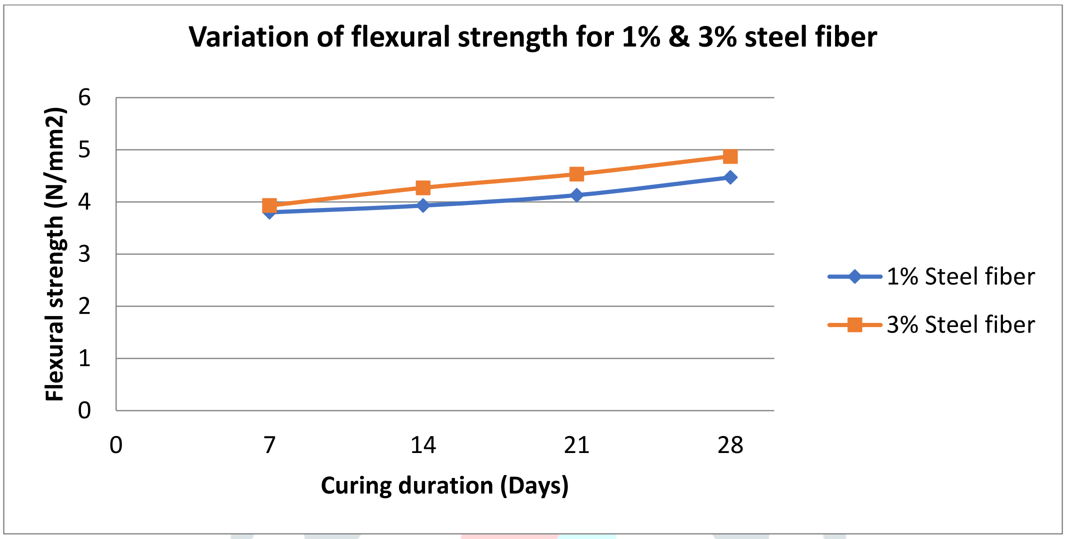


Table 9: Percentage variation in flexural strength for 1% and 3% steel fiber reinforced concrete

Curing duration (Days)	Flexural strength of 1% SFRC (N/mm^2)	Flexural strength of 3% SFRC (N/mm^2)	Percentage variation of Flexural strength
7	3.80	3.93	+3.42
14	3.93	4.27	+8.65
21	4.13	4.53	+9.68
28	4.47	4.87	+8.94

From the graph:

- At 7 days of curing period the flexural strength of fiber reinforced concrete with 3% steel fibers is higher by 3.42% than that of fiber reinforced concrete with 1% steel fibers.
- At 14 days flexural strength of concrete with 3% steel fibers is 8.65% more than the concrete with 1% steel fibers.
- At 21 days flexural strength of concrete with 3% steel fibers is 9.68% more than the concrete with 1% steel fibers.
- At 28 days flexural strength of concrete with 3% steel fibers is 8.94% more than the concrete with 1% steel fibers.

3.0 Comparison between Compressive strength of 1% PFRC and 3% PFRC

Table 10: Compressive strength of cubes with 1% Polypropylene fiber

Cube number	Curing duration (days)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
49 50 51	7	31.56 32.89 32.00	32.15
52 53 54	14	35.56 37.33 36.44	36.44

55 56 57	21	40.88 40.88 41.33	41.03
58 59 60	28	43.11 42.67 43.11	42.96

Table 11: Compressive strength of cubes with 3% Polypropylene fiber

Cube number	**Curing duration (days)**	**Compressive strength (N/mm^2)**	**Average compressive strength (N/mm^2)**
61 62 63	7	15.56 14.67 15.56	15.26
64 65 66	14	17.78 17.78 17.78	17.78
67 68 69	21	18.67 19.11 18.22	18.67
70 71 72	28	19.56 18.67 19.56	19.26

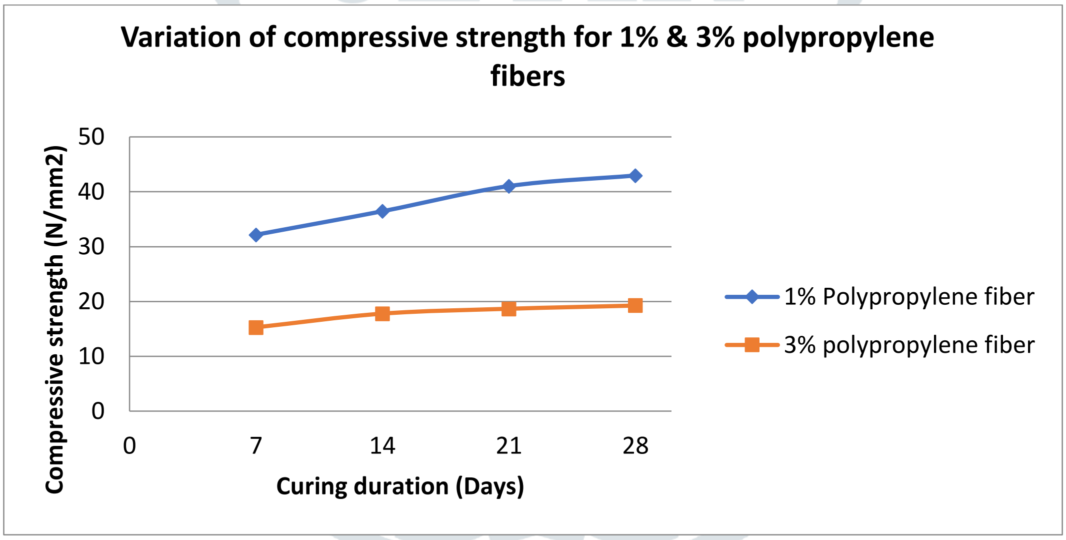


Table 12: Percentage variation in compressive strength for 1% and 3% Polypropylene fiber reinforced concrete

Curing duration (Days)	**Compressive strength of 1% PFRC (N/mm^2)**	**Compressive strength of 3% PFRC (N/mm^2)**	**Percentage variation of compressive strength**
7	32.15	15.26	-52.53
14	36.44	17.78	-51.20
21	41.03	18.67	-54.50
28	42.96	19.26	-55.17

From the graph:

- At 7 days, compressive strength of PFRC with 1% polypropylene fibers is higher by 52.53% than that of PFRC with 3% polypropylene fibers.
- At 14 days compressive strength of PFRC with 1% polypropylene fibers is 51.20% more than PFRC with 3% polypropylene fibers.
- At 21 days compressive strength of PFRC with 1% polypropylene fibers is 54.50% more than PFRC with 3% polypropylene fibers.

- At 28 days compressive strength of PFRC with 1% polypropylene fibers is 55.17% more than PFRC with 3% polypropylene fibers.

4.0 Comparison between Flexural strength of 1% PFRC and 3% PFRC

Table 13: Flexural strength of prisms with 1% Polypropylene fiber

Prism number	Curing duration (days)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
49 50 51	7	3.00 3.20 3.40	3.20
52 53 54	14	3.80 3.60 3.80	3.73
55 56 57	21	4.00 4.20 4.20	4.13
58 59 60	28	4.60 4.20 4.40	4.40

Table 14: Flexural strength of prisms with 3% Polypropylene fiber

Prism number	Curing duration (days)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
61 62 63	7	2.40 2.60 2.80	2.60
64 65 66	14	3.40 3.40 3.40	3.40
67 68 69	21	4.00 3.80 4.00	3.93
70 71 72	28	4.20 4.20 4.20	4.20

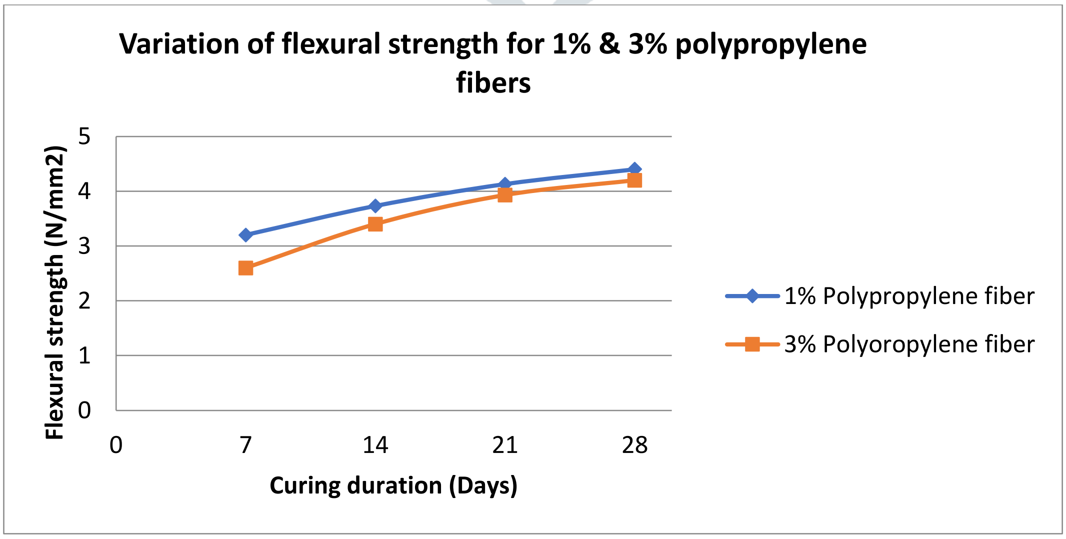


Table 15: Percentage variation in flexural strength for 1% and 3% polypropylene fiber reinforced concrete

Curing duration (Days)	Flexural strength of 1% PFRC (N/mm^2)	Flexural strength of 3% PFRC (N/mm^2)	Percentage variation of Flexural strength
7	3.20	2.60	-18.75
14	3.73	3.40	-8.85
21	4.13	3.93	-4.84
28	4.40	4.20	-4.54

From the graph:

- At 7 days, flexural strength of PFRC with 1% polypropylene fibers is higher by 18.75% than that of PFRC with 3% polypropylene fibers.
- At 14 days flexural strength of PFRC with 1% polypropylene fibers is 8.85% more than PFRC with 3% polypropylene fibers.
- At 21 days flexural strength of PFRC with 1% polypropylene fibers is 4.84% more than PFRC with 3% polypropylene fibers.
- At 28 days flexural strength of PFRC with 1% polypropylene fibers is 4.54% more than PFRC with 3% polypropylene fibers.

5.0 Comparison between Compressive Strength of Ordinary Cement Concrete and Fiber Reinforced Concrete (Steel and Polypropylene)

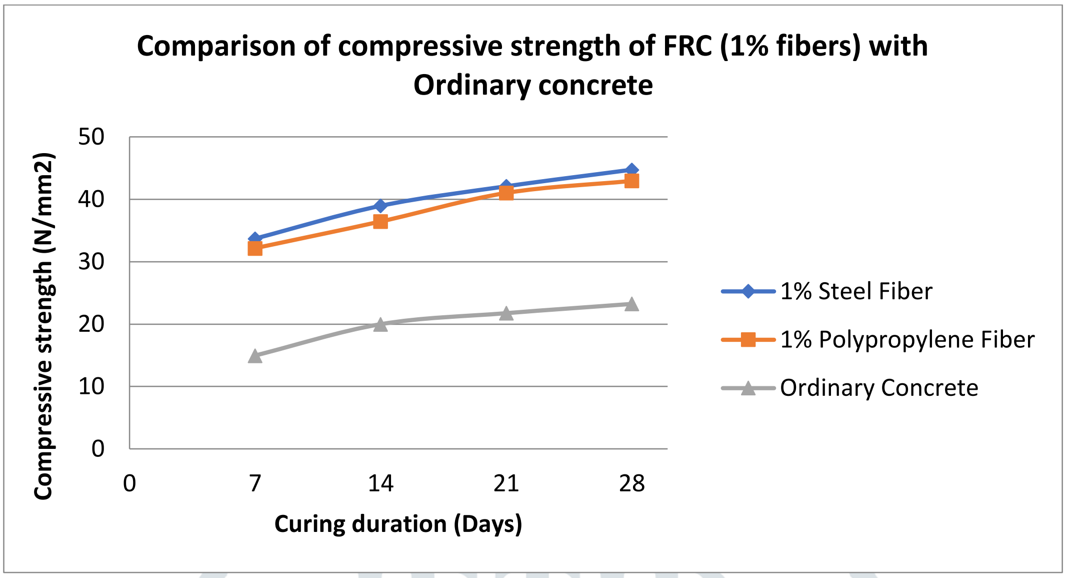
5.1 1% Fiber Reinforced Concrete and Ordinary Concrete

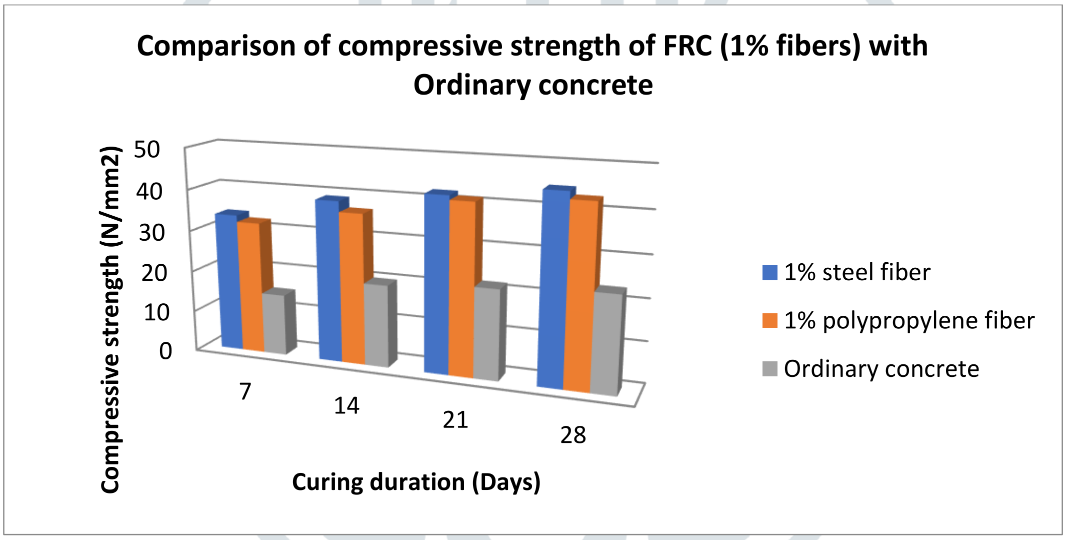
Table 16: Compressive strength of Ordinary Cement Concrete cubes

Cube number	Curing duration (days)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
73 74 75	7	14.67 15.11 15.11	14.96
76 77 78	14	19.55 20.44 20.00	20.00
79 80 81	21	21.78 21.33 22.22	21.77
82 83 84	28	23.11 23.56 23.11	23.26

Table 17: Percentage variation in Compressive strength for Ordinary concrete and 1% SFRC and 1% PFRC

Curing duration (Days)	Compressive strength of Ordinary concrete (N/mm^2)	Compressive strength of 1% SFRC (N/mm^2)	Percentage variation of compressive strength (SFRC)	Compressive strength of 1% PFRC (N/mm^2)	Percentage variation of compressive strength (PFRC)
7	14.96	33.70	+125.26	32.15	+114.91
14	20.00	38.95	+94.75	36.44	+82.20
21	23.26	42.08	+80.91	41.03	+76.40
28	26.63	44.74	+68.00	42.96	+61.32





From the graph:

- Fiber addition in ordinary concrete is expected to enhance the compressive strength than that of the ordinary concrete.
- For 1% Steel fiber reinforced concrete, it can be observed that there is a significant increase in the compressive strength than that of ordinary concrete by approximately 70%
- For 1% Polypropylene fiber reinforced concrete, it has enhanced the compressive strength significantly by 60% compared to ordinary concrete.
- Also, for 1% Polypropylene fiber reinforced concrete, it has enhanced the compressive strength but lower compared to the 1% steel fiber reinforced concrete.

5.2 3% Fiber Reinforced Concrete and Ordinary Concrete

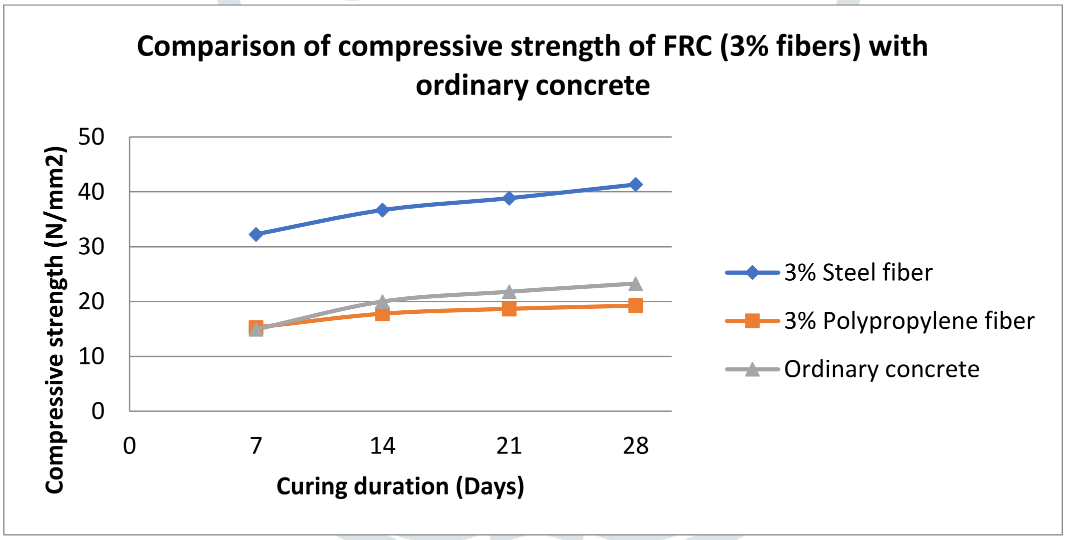
Table 18: Compressive strength of Ordinary Cement Concrete cubes

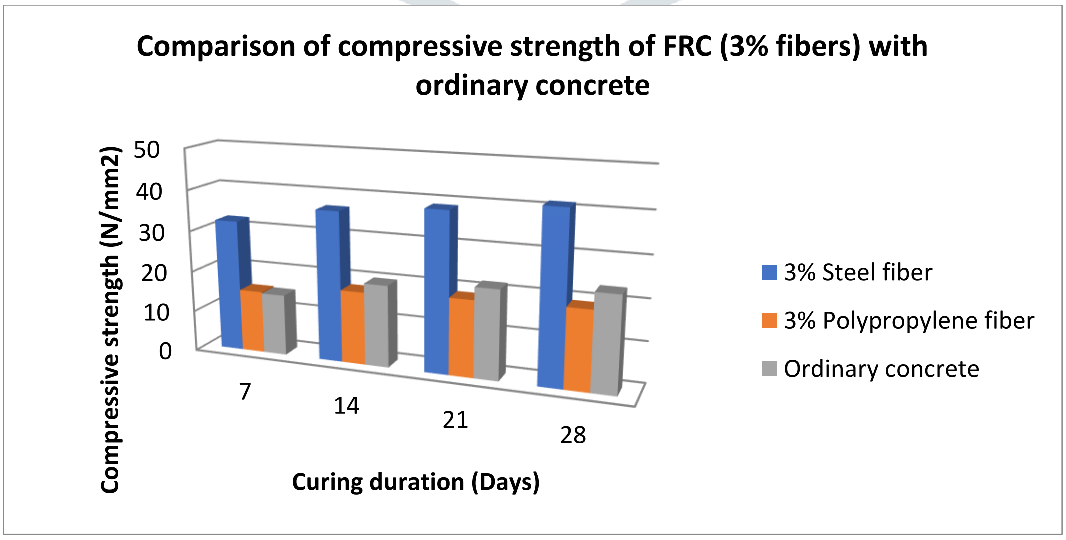
Cube number	Curing duration (days)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
73		14.67	
74	7	15.11	14.96
75		15.11	
76		19.55	
77	14	20.44	20.00
78		20.00	
79		21.78	
80	21	21.33	21.77

81		22.22	
82 83 84	28	23.11 23.56 23.11	23.26

Table 19: Percentage variation in Compressive strength for Ordinary concrete and 3% SFRC and 3% PFRC

Curing duration (Days)	Compressive strength of Ordinary concrete (N/mm^2)	Compressive strength of 3% SFRC (N/mm^2)	Percentage variation of compressive strength (SFRC)	Compressive strength of 3% PFRC (N/mm^2)	Percentage variation of compressive strength (PFRC)
7	14.96	32.26	+115.60	15.26	+2.00
14	20.00	36.67	+83.35	17.78	-11.10
21	23.26	38.84	+73.38	18.67	-19.73
28	26.63	41.33	+55.20	19.26	-27.67





From the graph:

- Increased (3%) percentage of fiber replacement resulted in decrease of compressive strength when compared to that of 1% fiber replacement.
- For 3% Steel Fiber reinforced concrete, though it has significantly contributed for the increase in compressive strength but low compared to 1% steel fiber reinforced concrete.
- For 3% Polypropylene Fiber reinforced concrete, it could not contribute for the increase in compressive strength with increase in percentage fibers. This decrease might be a cause of the discrete action of mixing of polypropylene fibers.

6.0 Comparison between Flexural Strength of Ordinary Cement Concrete and Fiber Reinforced Concrete (Steel and Polypropylene)

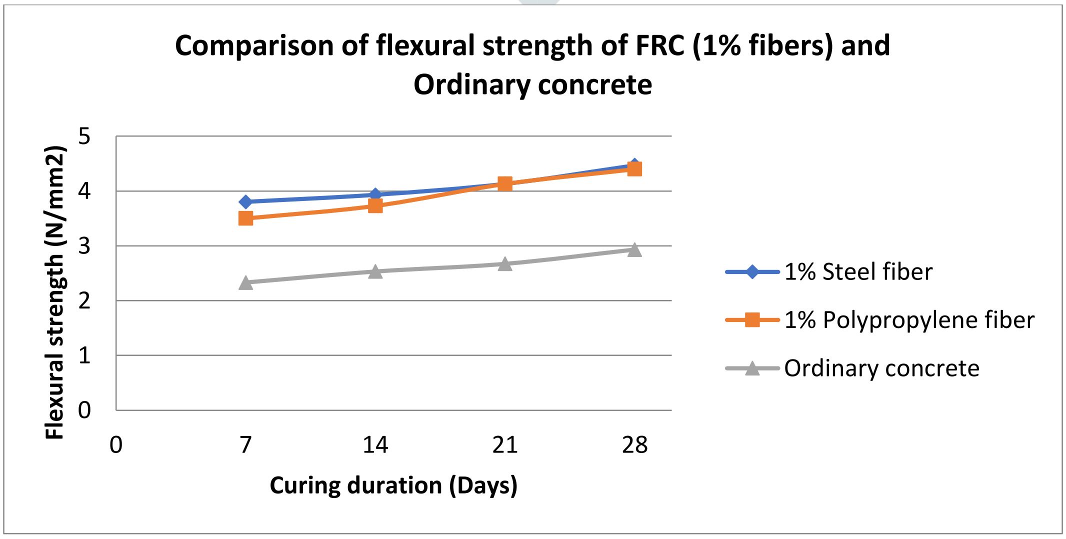
6.1 1% Fiber Reinforced Concrete and Ordinary Concrete

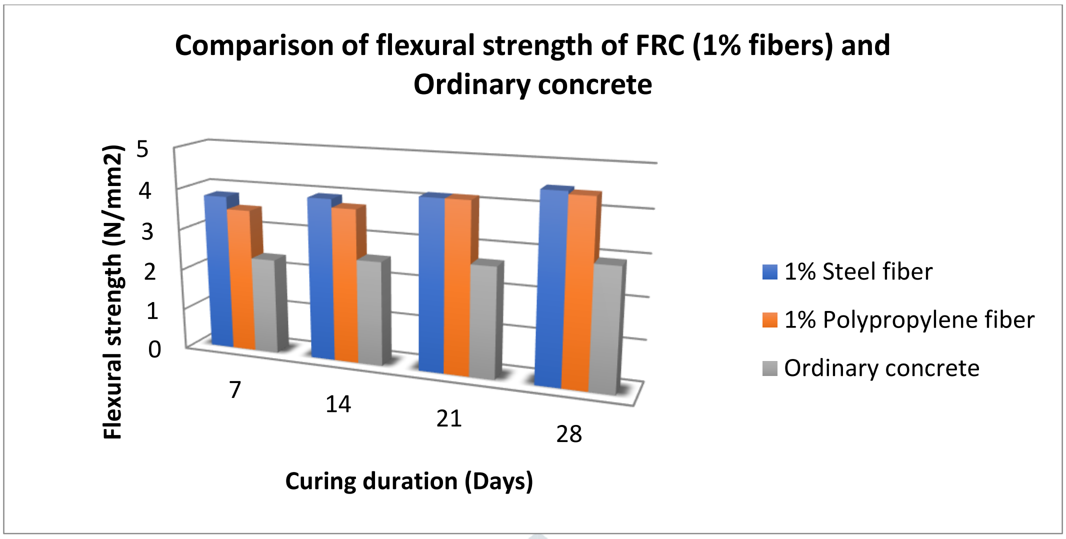
Table 20: Flexural strength of Ordinary Cement Concrete prisms

Prism number	Number of curing days	Flexural strength in N/mm^2	Average Flexural strength in N/mm^2
73 74 75	7	2.40 2.40 2.20	2.33
76 77 78	14	2.40 2.60 2.60	2.53
79 80 81	21	2.80 2.60 2.60	2.67
82 83 84	28	3.00 3.00 2.80	2.93

Table 21: Percentage variation in Flexural strength for Ordinary concrete and 1% SFRC and 1% PFRC

Curing duration (Days)	Flexural strength of Ordinary concrete (N/mm^2)	Flexural strength of 1% SFRC (N/mm^2)	Percentage variation of Flexural strength (SFRC)	Flexural strength of 1% PFRC (N/mm^2)	Percentage variation of Flexural strength (PFRC)
7	2.33	3.60	+63.09	3.20	+37.33
14	2.53	3.87	+55.33	3.73	+47.43
21	2.67	4.07	+54.68	4.13	+54.68
28	2.93	4.20	+52.56	4.40	+50.17





From the graph:

- Fiber addition in ordinary concrete is expected to enhance the flexural strength than that of the ordinary concrete.
- For 1% Steel fiber reinforced concrete, it can be observed that there is a significant increase in the flexural strength than that of ordinary concrete by approximately 55%
- For 1% Polypropylene fiber reinforced concrete, it has enhanced the flexural strength slighter higher but, lower compared to the 1% steel fiber reinforced concrete.

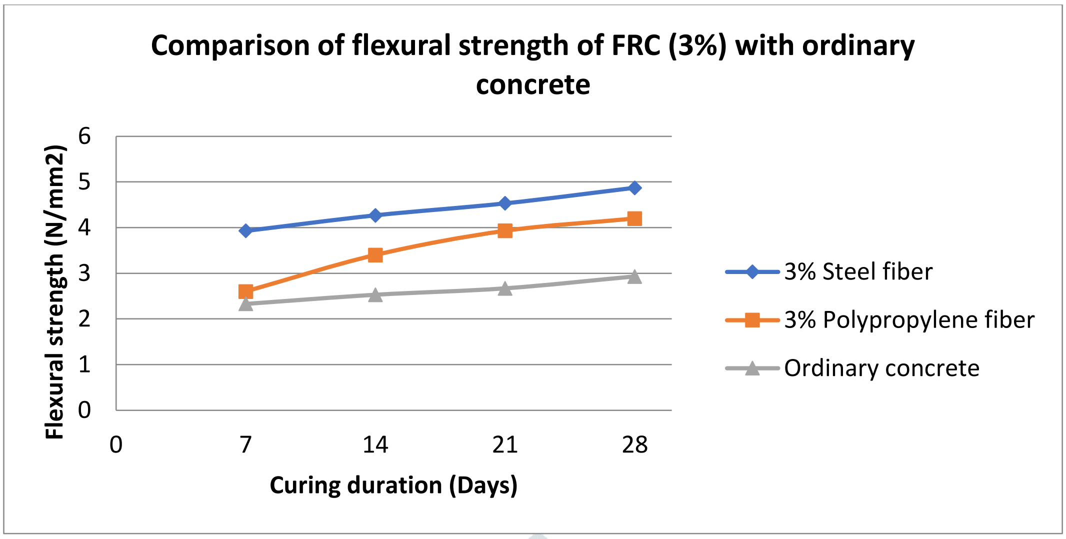
6.2 3% Fiber Reinforced Concrete and Ordinary Concrete

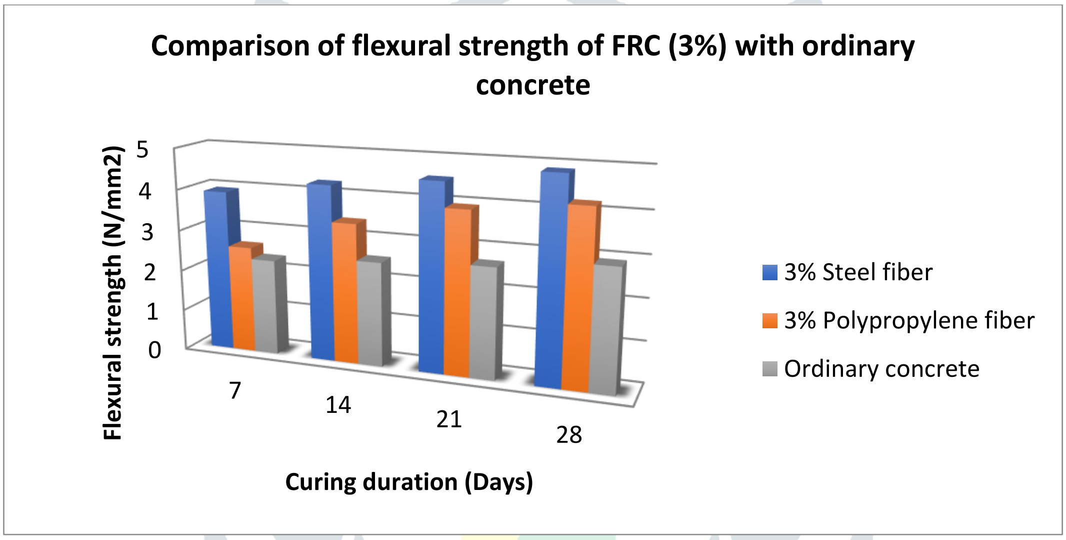
Table 22: Flexural strength of Ordinary Cement Concrete prisms

Prism number	Number of curing days	Flexural strength in N/mm^2	Average Flexural strength in N/mm^2
73 74 75	7	2.40 2.40 2.20	2.33
76 77 78	14	2.40 2.60 2.60	2.53
79 80 81	21	2.80 2.60 2.60	2.67
82 83 84	28	3.00 3.00 2.80	2.93

Table 23: Percentage variation in Flexural strength for Ordinary concrete and 3% SFRC and 3% PFRC

Curing duration (Days)	Flexural strength of Ordinary concrete (N/mm^2)	Flexural strength of 3% SFRC (N/mm^2)	Percentage variation of Flexural strength (SFRC)	Flexural strength of 3% PFRC (N/mm^2)	Percentage variation of Flexural strength (PFRC)
7	**2.33**	**3.93**	**+68.67**	**2.47**	**+11.58**
14	**2.53**	**4.27**	**+68.77**	**3.40**	**+34.38**
21	**2.67**	**4.53**	**+69.66**	**3.93**	**+47.19**
28	**2.93**	**4.87**	**+66.21**	**4.20**	**+43.34**





From the graph:

- Increased (3%) percentage of fiber addition resulted in increase of flexural strength when compared to that of 1% fiber replacement, particular in steel fiber.
- For 3% polypropylene fiber reinforced concrete, though it contributes significantly for the increase in flexural strength but it is less than that compared to 1% polypropylene reinforced concrete respectively.
- Further increase in percentage of fiber added may result for even low flexural strength values.

13. CONCLUSIONS

Based on the experimental work and analytical work carried out in the present study, the following conclusions are made:

1. Addition of fibers (by weight percentage 1% and 3% in the present study) in ordinary concrete significantly contributes for the increase in the compressive strength and flexural strength.
2. 1% Steel Fiber reinforced concrete yielded for higher compressive strength values (+70%) than that of Polypropylene fibers and 3% steel fibers but, 1% steel fibers comparatively yielded lower flexural strength values (-10%) compared to 3% steel fibers.
3. 1% Polypropylene fiber reinforced concrete yielded for higher compressive strength compared to ordinary concrete but, it was observed that further increase is resulting in decrease of the compressive strength whereas, Flexural strength for both 1% and 3% polypropylene fiber reinforced concrete has increased significantly. In due consideration of compressive strength decrease further study can be carried out to identify the optimal percentage.
4. As a comparison between the types of fibers i.e. Steel and Polypropylene, Polypropylene fibers are comparatively better in mixing and casting but the load carrying capacity of the percentage of fibers being added is much low therefore, it has led to a decrease in the compressive strength with increase in percentage of fibers added.
5. The present study can be concluded that 3% Steel fibers can be added as a reinforcement to ordinary concrete to enhance both compressive strength by 55% at 28 days curing duration and flexural strength by 60% at 28 days curing duration. Further study may be carried out to find the optimal percentage replacement.

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