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**Strength of Normal Concrete Using Metallic and Synthetic Fibers**

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**Abstract**

Based on the laboratory experiment, cube and cylindrical specimens have been designed with metallic and non-metallic groups of fibers. In metallic fibers, steel fibers of hook end with 50, 60 aspect ratio and crimped round (copper coated) of 52.85 aspect ratio containing 0% and 0.5% volume fraction were used without adding admixtures. In synthetic fibers category, fibrillated polypropylene fibers of 15 mm, 20 mm and 24 mm cut length at 0.4% by weight of cement were used without adding admixtures. Total 63 specimens were casted and tested for the work. Comparing the results of fiber reinforced concrete with plain concrete, this paper validated the positive effect of steel fibers with different aspect ratios and fibrillated polypropylene fibers with different cut length in compression and splitting strength improvement of specimen at 7 and 28 days, analyzed the sensitivity of different fibers to concrete with different strength.

**Keywords:** Steel fiber, Fibrillated Polypropylene fiber, Compressive strength, Split tensile strength, fiber reinforced concrete

**1. Introduction**

Concrete is most widely used construction material in the world. Because of its ability to get cast in any form and shape, it has almost replaced old construction materials such as brick and stone masonry [1-2]. The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cementitious material. Aggregate and water, and by adding some special ingredients. Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibers, which is largely dependent on the type of fiber, fiber geometry, fiber content, orientation and distribution of the fibers, mixing and compaction techniques of concrete, and size and shape of the aggregate\[8\]. The usefulness of fiber reinforced concrete (FRC) in various civil engineering applications is indisputable. Fiber reinforced concrete has so far been successfully used in slabs on grade, shotcrete, architectural panels, precast products, offshore structures, structures in seismic regions, thin and thick repairs, crash barriers, footings, hydraulic structures and many other applications. Fiber reinforced concretes (FRC) exhibit property improvement caused by the fibers\[4\].

The presence of micro cracks at the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mix. Different types of fibers, such as those used in traditional composite materials have been introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC). Thus the fibre-reinforced concrete is a composite material essentially consisting of conventional concrete or mortar reinforced by fine fibres \[7\]. Essentially, fibres act as crack arrester restricting the development of cracks and thus transforming an inherently brittle
matrix, i.e. cement concrete with its low tensile and impact resistances, into a strong composite with superior crack resistance, improved ductility and distinctive post-cracking behavior prior to failure[15].

Several different types of fibres have been used to reinforce the cement-based matrices. The choice of fibres varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos [10].

Currently the commercial products are reinforced with steel, glass, polyester and polypropylene fibres. The selection of the type of fibres is guided by the properties of the fibres such as diameter, specific gravity, Young’s modulus, tensile strength etc and the extent these fibres affect the properties of the cement matrix [11].

Research is being conducted for using fibre-reinforced concrete in structural applications such as beams, columns, connections, plates and prestressed concrete structures. High performance composites containing large volume fraction of steel fibres are also being developed for special applications. Some of the new approaches being investigated may alter the way we design and construct concrete structures [6, 7]. With the advent of the high-range water-reducing admixture, it is now possible to incorporate a fibre volume of 15 percent in cement matrices. Fibres in such large quantities seem to fundamentally alter the nature of cementitious matrices [13]. Thus, this paper deals with the study of effects of different type of steel fibers and fibrillated polypropylene fibers with low volume fraction on the compressive and tensile strength of plain concrete without any admixtures.

2. Materials and Methods

This paper deals with an investigation on behaviour of concrete produced from cement with various metallic and non-metallic fibers. Mix proportion was designed to produce workable concrete with target strength of 26 Mpa (M20) for the control mix. The effects of various metallic and non-metallic fibers on concrete properties were studied by means of the fresh properties of concrete and mechanical properties such as compressive strength and splitting tensile strength.

2.1. Cement

Ordinary Portland cement (OPC 43 Grade) having specific gravity of 3.15 with initial and final setting time of 20 min and 227 min respectively, was used as a binding material, conforming to I.S-8112-1989 [23].

2.2. Aggregates

Good quality river sand was used as a fine aggregate having specific gravity as 2.45, water absorption 2% and fineness modulus 3.18. Coarse aggregate passing through 22.5 mm and retained 20 mm sieve was used with specific gravity as 2.67 and fineness modulus as 7.10, conforming to I.S. 383-1970 [18].

2.3. Steel Fibers

Aspect ratio is the ratio of length of fiber to its diameter. This is also an important factor which influences the properties and behavior of the FRC. It has been reported that up to an aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced.

In this work, effect on strength of concrete with two hook end and one crimped round steel fibers were studied. Mild steel wire form Hook end and crimped round steel fibers of 30 mm, 35 mm, 50 mm (copper coated) and 50 mm length having density of 7.85 g/cm³ and minimum tensile strength as 345 Mpa, at 0.5% by volume of concrete collect from Stewols Pvt. Ltd. Nagpur, Maharashtra, India, were used. The different aspect ratios adopted were 50, 55 and 60 with diameter of fibers from 0.5 to 0.93 mm.

Properties of steel fibers used for investigation shown in table1.

| Fibre Designation | Length (mm) | Diameter (mm) | Material | Description               | Aspect Ratio (L/D) |
|------------------|-------------|---------------|----------|--------------------------|-------------------|
| S1               | 35          | 0.7           | Steel (wire) | Hook End            | 50.0              |
| S2               | 30          | 0.5           | Steel (wire) | Hook End            | 60                |
| S3               | 50          | 0.93          | Steel (wire) | Copper Coated Crimped Round | 53.85             |
2.4. Polypropylene Fibers

Fibrillated Polypropylene fibers of 15 mm, 20 mm and 24 mm cut length fibers having specific gravity 0.91 gm/cm$^3$, collected from Bajaj Plast Fiber, Nagpur, Maharashtra, India were used. Different cut lengths of polypropylene fibers with 0.4 % by weight of cement as shown below table

| Designation | Cut Length of Polypropylene Fibers (mm) | Polypropylene Fibers by Weight of Cement (%) |
|-------------|----------------------------------------|---------------------------------------------|
| P1          | 15                                     | 0%                                          | 0.4%                                       |
| P2          | 20                                     | 0%                                          | 0.4%                                       |
| P3          | 24                                     | 0%                                          | 0.4%                                       |

3. Mixture proportions

The mix proportion confirming to IS 10262- 2009[19] with target mean strength of 26 Mpa for the OPC control mixture was prepared for whole work. The total binder content was 383 Kg/m$^3$, fine aggregate was taken 672 Kg/ m$^3$ and coarse aggregate was taken 1100 Kg/ m$^3$. The water to binder ratio was kept constant as 0.5. The total mixing time was 5 minutes, the samples were then casted and left for 24 hrs before demoulding. They were then placed in the curing tank until the day of testing. Cement, sand and coarse aggregate were properly mixed together in the ratio 1:1.754:2.872 by weight before water was added and properly mixed together to achieve homogenous material. Water absorption capacity and moisture content were taken into consideration. Cube and Cylindrical moulds were used for casting. Compaction of concrete in three layers with 25 strokes of 16 mm rod was carried out for each layer. The concrete was left in the mould and allowed to set for 24 hours before the cubes were demoulded and placed in curing tank. The concrete cubes were cured in the tank for 7 and 28 days.

Mix proportion for M20 grade concrete as follows:

| Material                        | Quantity       | Proportion |
|---------------------------------|----------------|------------|
| Cement                          | 383 Kg/ m$^3$  | 1          |
| Sand                            | 672 Kg/ m$^3$  | 1.754      |
| Coarse Aggregates (20mm)        | 1100 Kg/ m$^3$ | 2.872      |
| Water                           | 192 Kg/ m$^3$  | 0.5        |
| Slump                           | 75-100 mm      | -          |
4. Experimental Methodology

4.1. Test on fresh concrete:

The workability of concrete mix is mainly determined to suit the type of construction, placing condition and the means of compaction available at the site. The properties of fresh concrete, amount and condition of reinforcement and the shape and size of mould are important factors which control workability. At every batch of mixing, the concrete slump was measured and recorded with slump cone apparatus as per IS 1199:1959 [21]. Workability was measured in terms of slump. The slump test results for each fresh concrete mix with different percentage of steel and polypropylene fibers as shown in figure below:

![Workability Chart](image)

Figure 3 Effects of fibers on workability of concrete

Figure 3 indicate the workability of fresh concrete by addition of fibers. It was observed that addition of S3 fibers at 0.5% by volume of concrete reduces maximum workability of concrete compared to other steel fibers. In synthetic fiber group, length of fibrillated polypropylene fibers plays an important role on workability of concrete. With same volume fraction, fiber having longer length reduces workability of concrete to higher percentage. It has been reported that addition of fibers can form a network structure in concrete, which restrain mixture from segregation and flow. Due to the high content and large surface area of fibers, fibers are sure to absorb more cement paste to wrap around and the increase of the viscosity of mixture makes the slump loss.

4.2. Test on hardened concrete

The tests were performed to determine the mechanical properties of control and fiber reinforced concrete using metallic and synthetic fibers under compression and split tension, for steel fibers 0%, 0.5% by volume of concrete and polypropylene fibers, 0.4% by weight of cement. The test for compressive strength on cubes and cylinders were measured at 7 and 28 days of curing as per IS : 516 – 1959[20] and test for split tensile strength on cylinder was measured at 7 and 28 days of curing as per IS : 5816 – 1999[22].

4.2.1 Compressive Strength (IS : 516 – 1959)

The strength of concrete is usually defined and determined by the crushing strength of 150mm x 150mm x 150mm, at an age of 7 and 28days. Steel mould made of cast iron dimension 150mm x 150mm x 150mm used for casting of concrete cubes filled with steel fibers 0%, 0.5% by volume of concrete and fibrillated polypropylene fibers, 0% and 0.4% by weight of cement fibers. The mould and its base rigidly damped together so as to reduce leakages during casting. The sides of the mould and base plates are oiled before casting to prevent bonding between the mould and concrete. The cube was then stored for 24 hours undisturbed at temperature of 18°C to 22°C and a relative humidity of not less than 90% (516-1959) [20]. It also stated in 516-1959 that the load was applied without shock and increased continuously at the rate of approximately
140 kg/sq cm/ min until the resistance of specimen to the increasing loads breaks down and no greater load can be sustained. The maximum load applied to the specimen was then recorded as per IS: 516-1959. The compressive strength was calculated as follows:

Compressive strength (MPa) = Failure load / cross sectional area.

4 2.2 Tensile strength Test (IS 5816:1999)

For tensile strength test, cylinder specimens of dimension 100 mm diameter and 200 mm length were cast. The specimens were tested at 7 and 28 days of curing on digital compression machine having 2000 kN capacity. In each category, three cylinders were tested and their average value was reported. Tensile strength was calculated as follows as split tensile strength: Tensile strength (MPa) = 2P / π DL
5. Experimental Results and Discussions

5.1. Compressive strength Test

The compressive strength test is consider the most suitable method of evaluating the behavior of fiber reinforced concrete for underground construction at an early age, because in many cases such as in tunnels, fiber reinforced concrete is mainly subjected to compression.

5.1.1 Compressive strength using cube specimen

Compressive strength of control concrete and FRC were calculated by above formula as per I.S. 516:1959. It is observed that when fibers in discrete form present in the concrete, propagation of crack is restrained which is due to the bonding of fibers in to the concrete and it changes its brittle mode of failure in to a more ductile one and improves the post cracking load and energy absorption capacity. Results of Compressive strength for M-20 grade of concrete on cube specimen with different fibres for different proportions as shown in table 4 and figure below.

Table 4: Test Results of Compressive strength using cube specimens

| Sr No | Fiber Notation | No of Days | Average compressive strength (N/mm²) |
|-------|----------------|------------|-------------------------------------|
| 1     | S0             | 7          | 24.26                               |
|       |                | 28         | 31.78                               |
| 2     | S1             | 7          | 25.72                               |
|       |                | 28         | 34.25                               |
| 3     | S2             | 7          | 26.80                               |
|       |                | 28         | 35.12                               |
| 4     | S3             | 7          | 27.01                               |
|       |                | 28         | 35.38                               |
| 5     | P1             | 7          | 25.61                               |
|       |                | 28         | 34.29                               |
| 6     | P2             | 7          | 25.95                               |
|       |                | 28         | 34.48                               |
| 7     | P3             | 7          | 26.56                               |
|       |                | 28         | 35.38                               |

Figure 6 Comparison of Percentage increase in compressive strength using cube at 7 and 28 days of curing
Fig. 6 indicates the results of compression test on cube for M20 grade of concrete using different fibers at different volume fractions. It was observed that addition of 0.5%, 50 mm copper coated crimped round steel fiber having aspect ratio 53.85 gives max compressive strength in comparison with other steel fibers at 7 and 28 days of curing. In non-metallic fibers group, addition of 24 mm cut length fibrillated polypropylene fibers at 0.4% by weight gives maximum compressive strength with compared to 15 mm and 20 mm cut length at 7 and 28 days of curing. Compressive strength is dependent on length of polypropylene fibers.

5.1.2 Compressive strength using cylindrical specimen

Results of Compressive strength for M-20 grade of concrete on cylinder specimen with different fibres for different proportions as shown in table 5 and fig below.

| Sr No | Fiber Notation | No of Days | Average compressive strength (N/mm²) |
|-------|----------------|------------|-------------------------------------|
| 1     | S0             | 7          | 14.12                               |
| 2     | S1             | 28         | 21.67                               |
| 3     | S2             | 7          | 15.54                               |
| 4     | S3             | 28         | 24.40                               |
| 5     | P1             | 7          | 24.02                               |
| 6     | P2             | 28         | 23.33                               |
| 7     | P3             | 7          | 26.40                               |

Table 5: Test Results of Compressive strength using cubes specimen

Fig7 indicates the results of compression test on cylindrical specimens for M20 grade of concrete using different fibers at different volume fractions. It is observed that addition of 0.5%, 50 mm copper coated crimped round steel fiber having aspect ratio 53.85 gives max compressive strength in comparison with other steel fibers at 7 and 28 days of curing. In non-metallic fibers group, addition of 24 mm cut length fibrillated polypropylene fibers at 0.4% by weight gives maximum compressive strength with compared to 15 mm and 20 mm cut length at 7 and 28 days of curing.
5.2. Tensile strength Test

Test Results of splitting tensile strength for M-20 grade of concrete with steel and fibrillated polypropylene fibers at different volume fractions as shown in table 6 and figure below:

Table 6: Results of splitting tensile strength using cylinder.

| Sr No | Fiber Notation | No of Days | Average Split Tensile strength (N/mm²) |
|-------|----------------|------------|---------------------------------------|
| 1     | S0             | 7          | 2.12                                  |
| 2     | S1             | 28         | 2.46                                  |
| 3     | S2             | 7          | 2.46                                  |
| 4     | S3             | 28         | 2.62                                  |
| 5     | P1             | 7          | 3.24                                  |
| 6     | P2             | 28         | 2.89                                  |
| 7     | P3             | 7          | 2.89                                  |
|       |                | 28         | 3.09                                  |

Fig. 8 Comparison of Percentage increase in split tensile strength at 7 and 28 days of curing

Fig.8 indicates the result of split tensile strength test on cylindrical specimens for M20 grade of concrete using different fibers at different volume fractions. It is observed that addition of 0.5%, 50 mm copper coated crimped round steel fiber having aspect ratio 53.85 gives max split tensile strength in comparison with other steel fibers at 7 and 28 days of curing. In non-metallic fibers group, addition of 24 mm cut length fibrillated polypropylene fibers at 0.4% by weight gives maximum compressive strength with compared to 15 mm and 20 mm cut length at 7 and 28 days of curing. Tensile strength is also dependent on length of polypropylene fibers. Addition of fibers in control concrete improves split tensile strength significantly. Under axial tension, control concrete specimen split into two parts, but FRC specimen shows development of cracks along its longitudinal axis. This may be attributed to the fact that fibers suppress the localization of microcracks and consequently the apparent tensile strength of the matrix increases.
6. Conclusions

The study on the effect of fibers with different sizes and materials can still be a promising work as there is always a need to overcome the problem of brittleness of concrete. The brittleness of concrete can be improved by addition fibrillated polypropylene and steel fibers.

The following conclusions could be drawn from the present investigation.
1. It was observed that max compressive strength for M20 grade of concrete was obtained by addition of 0.5%, 50 mm copper coated crimped round steel fibers having aspect ratio 53.85. Along with S3, fibrillated polypropylene fibers of 24mm cut length at higher doses, at 0.4 % also gives strength nearly equal to that of steel fiber S3. Addition of 0.4%, 24 mm polypropylene fibers increase 11.32% compressive strength using cube specimen and increase 18.16% using cylindrical specimen.
2. It was observed that max split tensile strength for M20 grade of concrete was obtained by addition of 0.5%, 50 mm copper coated crimped round steel fibers having aspect ratio 53.85. In synthetic fibers group, polypropylene fibers increase upto 45.61% split tensile strength by addition of 0.4%, 24 mm cut length fibrillated polypropylene fibers.
3. It was observed that the ratio of compressive strength of cylinders to the compressive strength of cube was found to be nearly 3:4 and ratio of compressive strength to split tensile strength was found to be nearly one tenth (1/10).
4. Workability of concrete affected by addition of fibers. Addition of S3 Fiber reduces workability of concrete in comparison to other fiber for different fraction of volume. The workability of concrete - decrease with increase in cut length of fibrillated polypropylene fibers up to 39.3%. Concrete was low workable at 50 mm, 0.5 % S3 Fiber compared to other. Length of fibrillated polypropylene fibers is an important factors effecting workability. Long polypropylene fibers reduce more workability compared to short length fibers at same volume fraction.
5. The paper concludes that fibrillated polypropylene fibers have little effect on workability of concrete. Since this fibers are non-absorbent, concrete is workable at addition higher percentage of fibers. Therefore we can achieve desired slump with this type of fibers.

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