

Effect of steel fibres on the compressive and flexural strength of concrete



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ABSTRACT

Concrete, which is made of cement, fine and coarse aggregates and water, is the most used building material in the world. It's durable, strength and ease of availability have been its main advantages. Concrete is strong in compression while it is known to be weak in tensile. Over the years different methods and materials have been utilized to reinforce concrete to overcome such weakness. Fibre reinforcement has shown considerable improvement in the properties of concrete. Therefore, in this study, M20 grade concrete was reinforced with steel fibres which were added at a volume fraction of 1%, 2%, 3%, 4% and 5% and compared with a control sample with no steel fibres. The effect on the workability of concrete with the steel fibre reinforcement was determined as well as the effect on flexural and compressive strengths concrete. Based on the results, the reinforcement of steel fibres had a significant adverse impact on the workability, with the increase in fibre content, the workability decreased. On the other hand, a significant enhancement was observed in the mechanical properties of concrete with the addition of steel fibres, achieving higher strength than the control sample. The highest compressive and flexural strength was gained with the addition of 3%, a further increase in fibre content decreased the strength. Therefore, the optimum dosage of steel fibres was determined to be 3%. Although the compressive and flexural strengths are still higher at 5% reinforcement compared to controlled sample.

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1. Introduction

The construction industry plays a pivotal role in the economic growth, social development (Sohu et al., 2017) and is considered as a backbone of any country. Nowadays, concrete is one of the major construction building material used in the construction industry (Lakhiair et al., 2018) and due to this, the demand of concrete has risen to such a level that at present it is one of the most consumed material in the world. The popularity of concrete has increased due to durability and availability. A wide range of constructions utilize concrete ranging from residential houses, skyscrapers, bridges, pavements and dams. But it was known by early 1800's that concrete was very strong in compression while weak in tension (Agarwal et al., 2014; Behbahani et al.,

2011), due to which, it lacks tensile strength, ductility and ability to resist the cracking that may occur. Almost complete loss of loading capacity can occur once failure is originated, which ultimately limits its use and application. To overcome this weakness, steel bars have been used to reinforce concrete and thus improve its tensile strength. It is true that the steel reinforcement bars can enhance the tensile strength and ability to resist the cracking, but this is not without cost.

Concrete being a mixture of cement, sand, coarse aggregates and water, impart self-weight on the structure due to the presence of coarse aggregates. But with the reinforcement of steel bars, this already significant self-weight increases enormously thus putting more dead-load stress on the structures. Apart from this the steel bars also increase the cost of construction and non-renewability of steel (Agarwal et al., 2014). Thus, researchers have tried to find alternatives to improve the brittleness of concrete. This limitation of concrete can be resolved by addition of short randomly dispersed fibres.

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The utilization of fibres can remedy weaknesses of concrete in terms of enhancing its resistance to shrinkage cracking, achieving higher tensile strength and deformation characteristics of concrete. Fibre reinforced concrete (FRC) has become famous in recent years. FRC, a cement-concrete reinforced with thousands of small fibres which are dispersed and distributed randomly in the concrete during mixing, improves concrete properties in all directions (Rana, 2013). A wide range of natural and artificial fibres have been utilized in FRC, but the use of steel fibres has significantly increased in the construction of industrial pavements, roads, parking areas and airports over the past two decades due to it is diffused fibre it may help in improving the structural behaviour (Sorelli et al., 2006).

Therefore, this experimental work was carried out to study the effect on concrete when it is reinforced with steel fibres at various volume fractions and to determine the optimum percentage of steel fibres.

2. Literature review

The recent influx of migration from rural areas to urban areas in search for economic benefits (Jhatial et al., 2017), has sparked the construction of infrastructures using concrete has increased at an unprecedented rate ever since the development of concrete, basically due to its high compressive strength (Ranyal and Kamboj, 2016). But the brittleness nature of concrete has always been its main undesirable characteristic due to which it achieves low tensile strength (Behbahani et al., 2011). Steel, in the shape of steel bars, is known to be strong in tension, has been used to reinforce the concrete, such that reinforced concrete withstands the tension loads. But with the steel bar reinforcement, the weight of structural element increases thus exerting more self-weight or dead load on the structure (Jhatial et al., 2018). To reduce the dead load, Fibre Reinforced Concrete (FRC) was introduced. FRC is a type of concrete that is reinforced with fibres. Crack propagation in the matrix can be controlled as well as improve the brittle failure of concrete with the addition fibres (Manoharan and Anandan, 2014).

The past two decades has seen considerable improvement in compressive strength and enhanced for concrete but for tensile strength very little gains have been achieved. Nowadays, 50 – 60 N/mm² compressive strength can be achieved easily for concrete but the flexural tensile strength remains less than 7 N/mm² for the same concrete and due to this, it becomes very difficult for such concrete to meet the serviceability requirements of deflection or cracking (Shweta and Kavilkar, 2014).

Concrete develops micro-cracks even before any loading is applied, it can be caused due to drying shrinkage, curing, volume change and age of concrete. Though the width of such cracks is generally not more than few microns, they open up and propagate further once concrete comes in

contact with stress and additional micro-cracks also develop. Elastic deformation of concrete is caused due to the development of micro-cracks in concrete. To overcome such problems, concrete was reinforced using fibres.

Although addition of fibres to reinforce materials which have been weaker in tension than compression has been done since ancient times (Mindess, 2007), the modern use of FRC, has been gradually increasing in civil engineering constructions (Meda et al., 2012) worldwide. Utilization of fibres can be traced back to 10,000 years ago, when straws were used to reinforce mud clays in Middle East and sun-dried adobe bricks in Americas (Mindess, 2007). Various fibres have been used during the last century, starting with asbestos fibres in early 1900's, but in 1960's, research into the utilization of fibres and fibre-reinforced concrete started to gain focus. Fibres ranging from synthetically processed to natural occurring have been used, such as jute, polypropylene, steel and glass etc. The use of steel fibres has become probably more common among fibre materials due to its high stiffness. Quasi-brittle concrete is transformed into ductile material when steel fibres are added (Michels et al., 2012). Steel fibre reinforced concrete (SFRC) has the ability to achieve not only higher tensile strength but also flexural strength, while improving its fatigue shock resistance, ductility and crack arrest (Kawde and Warudkar, 2017).

Roads, airport runways, machine foundations and other elements where dynamic loads are applied, fibre reinforced concrete has been used with inclusion of steel fibres (Błaszczyska and Przybylska-Fałęka, 2015). Underground elements and structures have seen the potential use of steel fibre reinforced concrete. Surface slab of a dam constructed at Longshua, China using the SFRC, this area is in seismic impact area (Vitt, 2005), even in the recent event of earthquake no clear cracks are seen (Błaszczyska and Przybylska-Fałęka, 2015).

The effect of steel fibre was studied on the strength of reinforced concrete, in which the plain concrete cracked into two pieces upon being subjected to maximum tensile load, while the addition of steel fibre showed improvement in strength and ductility (Ganesan et al., 2010). A research (Mohod, 2012) was conducted in which the performance of SFRC was studied. M30 grade concrete was reinforced using 0.25%, 0.50%, 0.75%, 1%, 1.5% and 2% steel fibres by volume of cement. The reinforcement resulted in decrease in workability upon increase in fibre content while higher compressive and flexural strength was achieved.

Effect of steel fibres on M35 grade concrete was studied in which fibre content ranged from 0% to 5% with an increment of 0.5% (Ghaffar et al., 2014). Gain in compressive strength was observed with the addition of steel fibres, reaching the highest when concrete was reinforced with 3% steel fibres. Flexural strength also saw a similar trend in strength gain upon addition of steel fibres. 4% steel fibres

were found to be optimum for flexural strength. Ductility improved with the increase in fibre content while the width of cracks was found to be less in SFRC compared to plain concrete beams. Experimental work conducted by (Shweta and Kavilkar, 2014) to study the flexural and compressive strength of SFRC using varies aspect ratio (40, 50, 60 and 70) and fibre content (0%, 0.5%, 1%, 1.5%, 2% and 2.5%). The experimental results indicated that by increasing the aspect ratio from 40 to 70, significant increase in flexural strength can be achieved. Due to such properties and gain in strength, SFRC can be used for the design of curvilinear forms.

High strength concrete has also seen the addition of steel fibres, which resulted in achieving more brittleness under compression loads and improvement in deformability, durability and confinement of concrete (Gopalaratnam and Gettu, 1995; ACI, 1995). The addition of high brittleness fibres in high strength concrete was beneficial in terms of increased flexural strength, elastic modulus and durability (Manoharan and Anandan, 2014).

3. Research methodology

3.1. Materials

Cement is the most important ingredient in the production of concrete, as it causes all other ingredients to stick together when water is added creating a solid structural component. A 43-grade cement was used in this study.

Aggregates make up to 60% to 70% of volume of concrete. In this study, coarse aggregates which were used were crushed passing through 20 mm sieve and retaining on 4.75 mm, while the fine aggregates were uncrushed sand. M20 grade concrete was designed using the DoE mix design method was used for this study, with 1:1.5:3 ratio (one-part cement, 1.5 parts fine aggregates and 3 parts coarse aggregates). The water-cement ratio used was 0.50. Steel fibres were used to reinforce the concrete.

3.2. Steel fibres

The steel fibres can be specified in terms of its length, diameter, configuration, tensile strength and aspect ratio (Parashar and Parashar, 2012). The steel fibres length ranges from 5 mm to 50 mm, though 25 mm fibres provide resistance to macro-micro cracks as well as enhances properties of hardened concrete. Initially straight steel fibres were available and used to reinforce concrete, but it was quickly realised that their bonding potential was limited thus restricting their ability to improve the concrete properties (Parashar and Parashar 2012). To utilize the full potential of steel fibres in concrete, new products were developed to increase the bond between the fibre and concrete. Nowadays, steel fibres are available in different configurations such as, straight,

continuous-deformed, end-deformed, hooked-end and slit-sheet steel fibre.

The steel fibres used to reinforce concrete were used in volume fractions of 1%, 2%, 3%, 4% and 5%. For this study the steel fibres were having hooked-end configuration, length of 25 mm, and diameter of 0.5 mm while the aspect ratio was 50.

3.3. Experimental procedure

Cement, fine aggregates, coarse aggregates, steel fibres and water were uniformly mixed together in the concrete mixer. The slump test of the wet mix was determined according to BSI (2009a). Once the workability was determined, the wet mix was then poured into cylinder and beam moulds and kept for 24 hours. The samples were demoulded the next day (after 24 hours) and put into water tank for 28 days water curing. Once the samples achieved specified curing of 28 days, the cylinders of dimension 300 mm x 150 mm were tested in universal testing machine for compressive strength test according to the guidelines of BSI (2009b), while the beams of 500 mm x 100 mm x 100 mm were tested for flexural strength in accordance to BSI (2009c).

4. Results and discussion

4.1. Workability

The slump test was conducted to determine the effect of workability of concrete when reinforced with steel fibres. The average slump values are shown in Fig. 1. It can be seen that 58.42 mm slump was recorded when no fibres were added into the concrete, but when steel fibres were added into concrete the slump value started to decrease. With the inclusion of 1% of steel fibres in the concrete, the slump value decreased from 58.42 to 53.34 mm which is 8.7% reduction in workability. The slump value gradually decreases upon increase in % of steel fibres in concrete, such that at 5% addition of steel fibres, the workability is reduced to 20.32 inch, which is 34.78% reduction. Thus, it can be said that the addition of steel fibres has an adverse effect on the workability of concrete. This may be due to the number of fibres increases with the increase in % thus causing difficulty in movement for other ingredients of concrete, thus the workability is reduced.

4.2. Compressive strength

The compressive strength of concrete with and without being reinforced with steel fibres is shown in Table 1 and the average compressive vs. fibre content is shown in Fig. 2. For each steel fibres %, 5 cylindrical samples were prepared.

From the Table 1, it can be observed that with the increase in fibre content, the compressive strength also increases. The strength is gained continuously till 3% where the maximum strength is gained,

which is 9.77% higher than the strength achieved by controlled sample. The control sample achieved 26.6 MPa, with addition of 1% steel fibres the concrete achieved 29.34 MPa, further increase in steel fibre content to 2% gained higher strength of 30.44 MPa. The maximum compressive strength of 31.46 MPa was achieved with the addition of 3% steel fibres. Further increase in steel fibre content resulted in decrease in strength, though 4% steel fibre reinforced concrete achieved 30.7 MPa while 5% steel fibre reinforced concrete achieved 29.2 MPa, which were 15.41% and 9.77% higher than the control sample respectively.

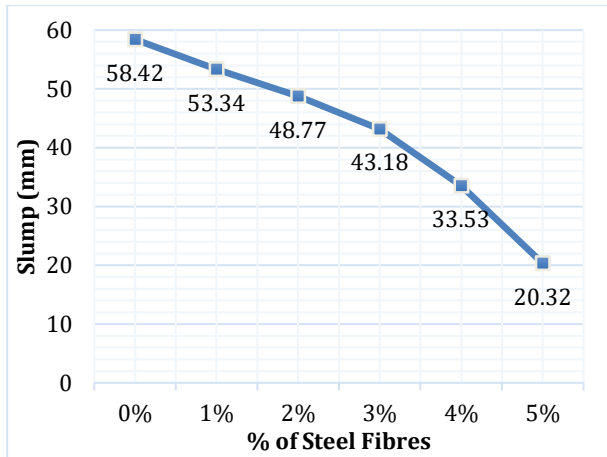


Fig. 1: Effect of steel fibres on the average slump of concrete

Table 1: Results of average compressive strength

Steel Fibres	Average Compressive Strength (MPa)	Variation in Strength w.r.t Control sample
0 %	26.6	----
1 %	29.34	+ 10.30 %
2 %	30.44	+14.44 %
3 %	31.46	+ 18.27 %
4 %	30.70	+ 15.41 %
5 %	29.2	+ 9.77 %

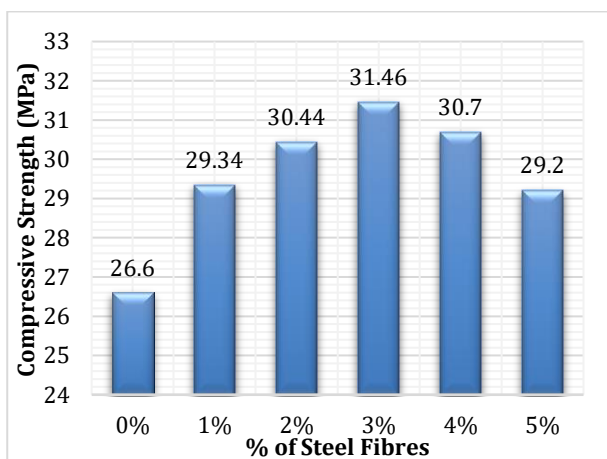


Fig. 2: Effect of steel fibres on the average compressive strength of concrete

From Fig. 2, it can be seen that further increase in fibre content beyond 3% substantially decreases the compressive strength. This decrease may be due to the fact that higher fibre content may cause

congestion of fibres, thus resulting in balling effect and improper bonding with concrete.

4.3. Flexural strength

The results of flexural strength test on beams is shown in Table 2. Three beams were cast for each % of steel fibres, the average flexural strength is shown in Fig. 3. Table 2 Effect of Various % Percentages of Steel Fibres on Flexural Strength of Concrete.

Table 2: Results of flexural strength

Steel Fibres	Average Flexural Strength (MPa)	Variation in Strength w.r.t Control sample
0%	4.06	----
1%	4.75	+ 17 %
2%	5.69	+ 40.15 %
3%	6.16	+ 51.72 %
4%	5.96	+ 46.79 %
5%	5.65	+ 39.16 %

From Table 2, it can be observed that the 1% steel fibre reinforced concrete achieved 4.75 MPa flexural strength compared to control sample which achieved 4.06 MPa. The increase in flexural strength of concrete with the increase in steel fibre reinforcement can be seen similar to that of compressive strength. The SFRC with 2% steel fibre reinforcement achieved 5.69 MPa, 3% achieved the highest flexural strength of 6.16 MPa. Further increase in steel fibre reinforcement dropped flexural strength to 5.96 MPa and 5.65 MPa for 4% and 5% steel fibres respectively, though the flexural strength achieved by 4% and 5% steel fibre reinforcement in concrete was higher than the control sample.

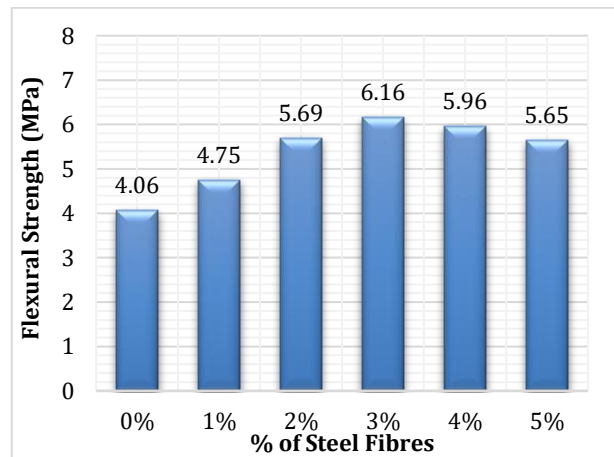


Fig. 3: Effect of steel fibres on the average flexural strength of concrete

The increase in flexural strength of concrete when reinforced with steel fibres is due to the fact that as the fibre content in the concrete gradually increases, it greatly helps in restricting the formation, propagation and widening of cracks more effectively. This results in increase in flexural strength. The ductile behaviour of concrete beam was observed due to the effective bridging action of fibres across the cracks. However, there is an upper limit of steel fibres which can be used to reinforce

concrete and improve the ductility of concrete. Beyond this limit, further increase in fibre content causes the balling effect and improper bonding with concrete, and due to this, loss in flexural strength occurs.

Normal concrete is known to be brittle material which fails without warning. Due to this brittleness it achieves relatively low flexural strength. With the steel fibre reinforcement of concrete, this brittle nature of concrete is converted into ductile as shown in Fig. 4.

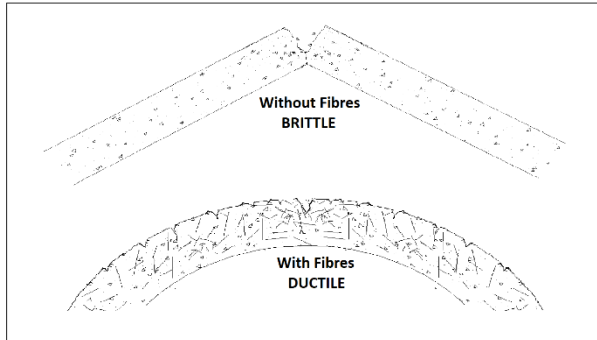


Fig. 4: The change from brittle to ductile behaviour of concrete with the reinforcement of steel fibres

The increase in ductility, with the steel fibre reinforcement, allows the concrete to resist cracking and crack propagation. Thus, the increase in flexural strength is achieved with the steel fibre reinforcement.

5. Conclusion

The reinforcement of concrete using steel fibres changes the property of concrete from brittle to ductile, which allows the concrete to resist the cracking thus increase the mechanical properties of concrete. Based upon the results, the following conclusions are drawn:

1. The steel fibres when used as reinforcement in concrete significantly reduces its workability. The increase in steel fibre volume fraction, the decrease in workability was seen.
2. The incorporation of steel fibres as reinforcement increased the compressive strength of concrete. The 3% steel fibre volume fraction reinforcement achieved the highest compressive strength of 31.46 MPa, which was 18.27% higher than the control sample.
3. With the improvement of ductility property of concrete with the steel fibre reinforcement, the concrete was able to increase the flexural strength, such that concrete reinforced with 3% steel fibre by volume fraction achieved highest flexural strength of 6.16 MPa which was 51.72% higher than control sample.
4. The optimum volume fraction of steel fibres was determined to be 3%, at which the maximum compressive and flexural strength were achieved at minimum reduction of workability.

5. The inclusion of steel fibres in concrete enhances the compressive strength of concrete but the increase is relatively little. The increase ranged from 9.77% to 18.27%. The addition of Steel fibre in concrete however, had significant impact on the flexural strength due to the improvement in ductility behaviour of concrete. The increase in flexural strength ranged from 17% to 51.72%.

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