

Experimental Investigation on the Mechanical and Durability Properties of Fiber-Reinforced Concrete with Varying Fiber Content

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Abstract: Steel fiber-reinforced concrete (SFRC) appears as one of the promising construction material, as it exhibits better mechanical properties, crack resistance and durability to conventional concrete. The current study aims to explore how the fresh and hardened characteristics of M30 grade of concrete change with different steel fiber contents. A series of six concrete mixtures - one control mixture (CM) and five mixtures with 0.25%, 0.50%, 0.75%, 1.00% and 1.25% steel fibers - were prepared. The water/cement ratio was kept constant (0.45) for all the mixes. Slump tests were conducted to assess the workability, and compressive strength tests, split tensile strength tests and flexural strength tests were also performed to assess the strength of the material, after 7 and 28 days. It was found that adding the steel fibers greatly affected the characteristics of concrete. As the fiber content increased, the workability of the mix started to drop and the slump dropped from 85 mm (control mix) to 45 mm (when 1.25% steel fiber was used in the mix). Significant gains were, however, noticed in the mechanical properties. At 28-days, the optimum compressive, flexural and split tensile strengths were respectively 50.3, 8.10 and 5.05MPa, which was produced from the mix with the proportion of steel fibers of 1.00%. A slight loss of strength was noted above this amount because of the decrease in workability and clustering of fibres. The study results revealed that the incorporation of steel fiber can effectively improve the strength properties of concrete, with

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an optimum value of about 1.00% vol of steel fiber as the best trade-off between workability and mechanical properties. The results show that SFRC can be used in the fields of structural applications that demand better crack resisting, ductile and load carrying capacity.

Keywords: *Steel fiber-reinforced concrete, Workability, Compressive strength, Split tensile strength, Flexural strength, M30 concrete, Mechanical properties.*

Introduction

Concrete is extensively used in construction in modern infrastructure due to its versatility, durability and economic viability. But the conventional concrete has comparatively low tensile strength, brittle property and weak resistance property for crack propagation which restricts the use of conventional concrete under tensile and flexural loading conditions. To save these disadvantages, the use of fibres in concrete has drawn the attention of the researchers and resulted in the formation of fiber-reinforced concrete (FRC) which has better mechanical and durability properties compared to the normal plain concrete [1-3]. Since then, fiber reinforcement has been shown to be effective to control crack formation and propagation, increase concrete ductility and toughness. Amin et al. [4] and Diab et al. [5] studied the contribution of fibers to structural properties and its anti-cracking characteristics under different loading conditions and concluded that fibers play a significant role in enhancing these properties. Likewise, Mehrab and Esfahani [6] reported fracture properties and energy absorption capacity of fiber-reinforced concrete which were better than those of conventional concrete. Many studies have concerned the effect of fibres on the properties of fresh concrete. The incorporation of fibers is known to be a change in the rheological properties of the concrete mix, and some studies, such as those of Dollaiah et al. [7] indicate a decrease in workability. The strength enhancing effect of fiber reinforcement in concrete has been proved by Qin et al. [8] in a study indicating that fibers redistribute stress within the concrete matrix and help the concrete to carry more loads. Hosseinzadeh et al. [9] also demonstrated that the natural and synthetic fibers/steel rates have positive effects on strength and durability properties, which can be slightly problematic when the amount of fibers is too high due to its negative influence on workability and dispersion. More recent research has shown that properties of mechanical and durability can be improved significantly, provided that the dose of fibers is appropriate. Latifi et al. [10] have achieved that crack-resistance and long term duration performance are enhanced due

to fiber incorporation. Libre et al. [11] reported significant improvements in compressive, split tensile and flexural strength because of the fibres bridging the cracks. Similarly, Wei et al. [12] found an enhancement on microstructural integrity and mechanical properties of fiber-reinforced concrete systems. Fiber Modification has also been used to provide improved impact resistance and postcracking performance for fiber cementitious composites, as reported by Kareem and Ahmed [13]. In numerous studies fibers are found to be effective for improving properties and performance of cementitious materials. Elkatatny et al. [14] reported that the fibers have beneficial effect on the enhancement of structural integrity and mechanical performance. Higher fibre addition was seen to significantly improve the permeability's and properties for Durability by Wang et al [15] by minimising crack development. Similar results were found in the case of strength and durability performance of fiber-reinforced self-compaction concrete (SCC) by Bhagwat et al. [16]. Workability is important for practice applications in relation with fiber content. The results of the following study proved that fiber's volume positively affects flowability because it increases with the rising amount. Altalabani et al. [17] proved that as fiber content increases its internal friction decreases resulting in a reduction of flowability. However, when optimum dosages of fibres are used, there are often advantages to be gained in terms of improved flexural resistance and/or structuring performance that offset any such loss in workability. Inclusion of fibres resulted in improved flexural performance and crack resistance for FRC composite material as reported by Qin et al. [18] and excellent improvement in bending ability for FRC composites was reported by Lakhia et al. [19]. Over the last few years, sustainability issues related to fiber-reinforced concrete have been gaining the spotlight. Yin et al. [20,21] developed life-cycle studies that showed that recycled fibers could help to minimize environmental damage without compromising the performance of the structure. Besides, Abd and Ahmed [22] mentioned that there are benefits of fiber reinforcement such as the improvement of impact resistance and energy absorption properties of concrete members. Based on a detailed review, Manso-Morato et al. [23] reported that FRC has very good advantages in terms of durability, service life and sustainability, thus becoming a new material for future construction development. While the behaviour of fiber reinforced concrete has been investigated by many studies, the determination of optimal fiber dosages to achieve maximum strength increment and acceptable concrete workability is still a challenge to research. Thus, the present study is to examine the workability, Compressive strength, Split tensile strength, flexural strength of M30 grade concrete with varying No of steel fibers content in the concrete i.e., 0%, 0.25%, 0.50%, 0.75%, 1.00%, 1.25% (by volume). The results of this research are anticipated to be helpful in

designing high performance SFRC having better mechanical and durability properties.

Literature Review

The use of FRC has gained a tremendous attention through the years because it has the capacity to improve the mechanical and durability properties of conventional concrete. Incorporation of fibres has been reported to enhance the crack resistance, energy absorption capacity and post-cracking behaviour to moderate brittle nature of concrete. Ghanim et al. [1] conducted an experiment that showed that mechanical strength as well as resistance to deterioration of Concrete could be improved by the addition of Fiber, under high temperature conditions. In a parallel study, Amin et al. [2] reported significant enhancements in the microstructural features and mechanical properties by the introduction of fibers. Among the most important parameters that are affected by the addition of fibers, workability stands out. Hosseinzadeh et al [3] studied the impact of steel and polypropylene fibres on high strength concrete; they found introducing steel fibres and polypropylene fibres both resulted in a reduction of workability, the former being more significant than the latter, associated with an increase in internal friction and fiber interlocking. The same conclusions were concluded by Altalabani et al. [4] who recorded that slump values decreased as the fiber dose increased in self-compacting lightweight concrete mixtures. There have been several studies on the effect of fibers on compressive strength. Latifi et al. [5] noted that incorporation of fibre improved the durability performance and compressive strength of concrete, through its role of providing better crack control and stress redistribution in the concrete matrix. Wei et al. [6] also noted that the compressive strength and microstructural integrity increased with the addition of fiber. These investigations indicate that there is an optimum amount of fiber present to yield a significant additional increase in strength but no further addition after that would raise the strength increment appreciably because of problems with dispersion and compaction of fiber. A significant amount of research has been done on evaluating the effect of fiber on the tensile and flexural properties. Libre et al., [7] showed that the split tensile strength and flexural strength of FRC were generally high compared to conventional concrete because of the ability of fibers to bridge cracks. In like fashion, Lakhia et al. [8] found that the flexural characteristics of fibre modified concrete specimens improved significantly, and the resistance to propagation of cracks was found to be very high. Qin et al. [9] also pointed out that the flexural load-carrying capacity and post-cracking characteristics are significantly enhanced by the fiber reinforcement. The issue of enhancing its durability by means

of fiber reinforcement is among those mentioned in recent studies. A better durability related performance was noted by Wang et al. [10] due to the ability of fibres to decrease permeability and crack widths. Manso-Morato et al. [11] performed a comprehensive review and found that FRC plays a significant role in extending the service-life and in sustainable construction as it provides superior structural performance and durability in the long-term. The effectiveness of the addition of fibres has been previously confirmed, but the amount of steel fibres needed to achieve the best mechanical properties without compromising the workability is still significant research challenge. Hence, the present study aims to examine the effect of different content of steel fibers on the workability, compressive strength, split tensile strength and flexural strength for M30 grade of concrete.

Methodology

3.1 Materials

In this experimental study, M30 grade of concrete was chosen. Ordinary Portland Cement (OPC) was used as a binding material and natural river sand and crushed coarse aggregate were used as fine and coarse aggregate, respectively. Only potable water that was suitable for concrete production and curing was used throughout the study. The concrete mixtures were made by incorporating hooked-end steel fibres at various volume fractions and the effect of steel fibres on workability and mechanical properties were investigated. Workability of concrete mixtures has been enhanced by the use of a dosage of superplasticizer at the rate of 1% by weight of cement. The ratio used for the control concrete in the present design is given in Table 1. Cement, fine aggregate, coarse aggregate and water used in the mix were 400, 650, 1200 and 180 kg/m³ respectively, with a water-cement ratio of 0.45.

3.2 Mix Proportioning

Experimental program included the preparation of six concrete mixes. These comprised a control mix (CM) with no fibers, and five steel fiber-reinforced concrete (SFRC) mixes with 0.25%, 0.50%, 0.75%, 1.00% and 1.25% of steel fibers, respectively. The amount of cement, aggregates, water, and superplasticizer (SP) was kept constant for all the mixtures and only the amount of steel fiber (SF) was changed. The compositions used in this study are listed in detail in Table 2.

3.3 Preparation of Concrete Specimens

The cement, fine aggregate and coarse aggregate required quantities were dry mixed first to ensure a good spread distribution. In order to avoid the fibers balling and to

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obtain a homogeneous mixture, steel fibers were gradually added into the mixture. Water was then added to the superplasticizer and the concrete was well mixed until proper and workable mix had been reached. The fresh concrete was poured into to form the moulds and vibrated to remove trapped air. After casting, the specimens were kept at room temperature for 24 hours. After demoulding, the specimens were cured in clean water for the age of test (7 and 28 days).

3.4 Experimental Program

An experimental research was conducted to examine the influence of different steel fiber contents for fresh and hardened characteristics. The workability was also evaluated in all concrete mixtures and the mechanical strength was investigated.

The overall experimental procedure involved:

1. Selection of constituent materials.
2. Preparation of control and fiber-reinforced concrete mixes.
3. Casting and curing of concrete specimens.
4. Workability evaluation using slump tests.
5. Compressive strength testing at 7 and 28 days.
6. Split tensile strength testing at 7 and 28 days.
7. Flexural strength testing at 7 and 28 days.
8. Comparative analysis of the obtained results.

3.5 Workability Test

The slump cone test was used to measure the workability of fresh concrete. Immediately after mixing, the concrete was placed in layers in the slump cone and compacted as specified in the standard concrete testing procedures. The change in height of the concrete after the cone was removed was measured and the result recorded as the slump value. All mixes were tested to determine the effect of adding steel fiber to the fresh concrete mix. The results obtained are listed in Table 3.

3.6 Compressive Strength Test

Concrete cubes were tested in compression after 7 and 28 days curing. Compression tests were carried out on the specimens, until failure. The highest load bearing capacity of each specimen was determined and the compression strength was calculated. The results indicate average compressive strengths of all the mixes reported in Table 4.

3.7 Split Tensile Strength Test

Cured cylindrical specimens were tested for split tensile strength on day 7 and 28 testing. The specimens were tested in horizontal position in the test machine with progressive load up to the crack and failure. The average values of split tensile strength obtained from the tests are given in Table 5 and used for the analysis of the effects of steel fibres on the tensile properties of concrete.

3.8 Flexural Strength Test

Seven and twenty-eight-day flexural strength tests were carried out on the concrete prism specimens. All specimens were loaded for third-point until failure. This test has been carried out to evaluate the contribution of steel fibers to enhance the bending resistance of concrete and to control cracks. The mean flexural strength results of all the mixtures are presented in Table 6.

3.9 Data Analysis

The workability, compressive strength, split tensile strength and flexural strength test results of the experiments were comparatively analysed for the effects of Steel Fiber on the performance of Concrete. The obtained results were analysed to find the best dosage of steel fiber for the maximum improvement of the mechanical properties with acceptable workability. This analysis allowed the optimal amount of fiber content to be used to make an excellent SFC for a structural application combination.

Results and Discussion

Table 1 has given the control mix proportion used for M30 grade concrete. The proportions used for the mix were: 400 kg/m³ of cement, 650 kg/m³ of fine aggregate, 1200 kg/m³ of coarse aggregate and 180 kg/m³ of water, giving a W/C ratio of 0.45. Furthermore, to get the required water-cement ratio, a superplasticizer dosage of 1% of the cement which is 4.0 kg/m³ was added, and the results were compared as illustrated in Table 1. All of the steel fiber concrete (SFRC) mixes were compared to the control mix. By keeping the same proportions of cement, aggregates, water, and admixture, any changes in the fresh and mechanical and/or durability properties that might be noticed could be mostly attributed to added steel fibers and not to changes in the base cement composition.

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Table 1. Control Mix Proportion (M30 Concrete)

Material	Quantity (kg/m ³)
Cement	400
Fine Aggregate	650
Coarse Aggregate	1200
Water	180
Water-Cement Ratio	0.45
Superplasticizer	4.0 (1% of cement)

The proportions of the mixes for the steel fiber Reinforced concrete (SFRC) specimens are given in Table 2. A total of six different mixes were developed, which includes one control mix (CM) and five mixes containing steel fibers ranging in percentage from 0.25% to 1.25% vol. Steel fiber can be incorporated into the mix during the concrete batching operation. Six different mixes were developed, one of which is a control mix (CM) and five concrete mixes with steel fiber volume fractions of 0.25%, 0.75%, 1.00%, 1.12% and 1.25% vol., respectively. All cement, fine aggregate, coarse aggregate and water quantities used for the mixes were kept constant and only quantity of fibbers varied. The various steel fiber dosage options enabled an examination of the effects of inclusion of Steel fibre on the fresh and hardened characteristics of concrete. The experimental program involved a constant set of all other constituents to allow the optimal content of fibres for improving the strength characteristics to be investigated while avoiding undue reduction of the workability and constructability.

Table 2. SFRC Mix Proportion Matrix

Mix ID	Steel Fiber Content (% Volume Fraction)	Cement (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Water (kg/m ³)
CM	0.00	400	650	1200	180
SFRC-1	0.25	400	650	1200	180
SFRC-2	0.50	400	650	1200	180
SFRC-3	0.75	400	650	1200	180
SFRC-4	1.00	400	650	1200	180
SFRC-5	1.25	400	650	1200	180

4.1 Workability Test

All the results of the slump test are given in Table 3. The slump value of the control mix was highest at 85 mm giving it satisfactory workability. But as the amount of steel fiber increased, however, there was a shift toward decreasing slump. The slump was lowered from 78 mm for SFRC-1 to 45 mm for SFRC-5, showing how detrimental the inclusion of the fibers was towards the flowability of fresh concrete. The decrease in workability can be explained by the more interlocking behavior and internal friction from the steel fibers in the concrete matrix. If there is a higher amount of fiber dosage, more cement paste will be needed to coat the fibers and to move aggregates. These results show that, the higher the amount of fiber present beyond 1.0%, the less the workability which would therefore require more super plasticizer for the practical use of high fiber content.

Table 3. Workability (Slump Test) Results

Mix ID	Steel Fiber Content (% by Volume)	Water-Cement Ratio	Slump (mm)
CM	0.00	0.45	85
SFRC-1	0.25	0.45	78
SFRC-2	0.50	0.45	70
SFRC-3	0.75	0.45	62
SFRC-4	1.00	0.45	54
SFRC-5	1.25	0.45	45

4.2 Compressive Strength Results

The summary of compressive strength into the 7 days and 28 days are shown in Table 4. At 7 and 28 days, the compressive strength of the control mix was 28.5MPa and 40.2MPa, respectively. When added, the compressive strengths of SFRCs gradually increased with the increase of fiber content up to 1.0% at which the maximum strengths of 34.5 MPa at 7 days and 50.3 MPa at 28 days were recorded for SFRC-4. This improvement in compressive strength can be explained by the crack arresting property of the steel fibers, which prevents cracking in concrete, thus distributing the stresses in the matrix. The strengths of SFRC-5 were slightly lower

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than those of SFRC-4, but still showed improvement over the control mix. This decrease in marginal reduction at 1.25% fiber might correlate with loss of workability, and may lead to some clustering of the fibers which could lead to poorer compaction quality and homogeneity of the matrix.

Table 4. Compressive Strength Results of Fiber-Reinforced Concrete

Mix ID	Steel Fiber Content (% by Volume)	Compressive Strength at 7 Days (MPa)	Compressive Strength at 28 Days (MPa)
CM	0.00	28.5	40.2
SFRC-1	0.25	30.1	42.8
SFRC-2	0.50	31.8	45.6
SFRC-3	0.75	33.2	48.1
SFRC-4	1.00	34.5	50.3
SFRC-5	1.25	33.8	49.2

4.3 Split Tensile Strength Results

The split tensile strength data shown in Table 5 indicates that the retention period increases as the amount of steel fibers increases. The tensile strength for control mix obtained were 2.60 MPa and 3.45 MPa at 7 days and 28 days respectively. The highest values of 3.60 MPa (7 days) and 5.05 MPa (28 days) were obtained with the SFRC-4. The main reason for this dramatic rise in tensile strength is thought to be the "bridging action" of the steel fibres between forming cracks. Under tensile loading, fibers can effectively transfer tensile stresses and work to retard crack opening, increasing the tensile strength of concrete. In the same order of compressive strength, a slight reduction was seen for SFRC-5 where addition of too many fibers does not always translate into proportional gains in strength and could therefor have a negative impact on the dispersion of the fibers within the matrix.

Table 5. Split Tensile Strength Results of Fiber-Reinforced Concrete

Mix ID	Steel Fiber Content (% by Volume)	Split Tensile Strength at 7 Days (MPa)	Split Tensile Strength at 28 Days (MPa)
CM	0.00	2.60	3.45
SFRC-1	0.25	2.85	3.85
SFRC-2	0.50	3.10	4.20
SFRC-3	0.75	3.35	4.65

SFRC-4	1.00	3.60	5.05
SFRC-5	1.25	3.50	4.90

4.4 Flexural Strength Results

The flexural strength results of the concrete mixes are shown in Table 6. The flexural strength of control mix was found as 3.80MPa and 5.20MPa at 7 and 28 days, respectively. The adding of steel fibres resulted in remarkable improvement of flexural performance and the flexural property of SFRC-4 was the highest flexural strength with flexural value of 5.80 MPa after 7 day and 8.10 MPa after 28 day. The flexural strength is enhanced because of steel fibers' bridging of microcracks and their resistance to tensile stresses in the tension zone of concrete beams. Fibers were observed to have positive effects on post crack behavior as well as energy absorbing capacity. The flexural strength value of SFRC-5 showed marginal decrease from SFRC-4 but still, the value was quite high, thus proving the effectiveness in increasing resistance to bending and crack of steel fibers in the concrete.

Table 6. Flexural Strength Results of Fiber-Reinforced Concrete

Mix ID	Steel Fiber Content (% by Volume)	Flexural Strength at 7 Days (MPa)	Flexural Strength at 28 Days (MPa)
CM	0.00	3.80	5.20
SFRC-1	0.25	4.25	5.85
SFRC-2	0.50	4.75	6.55
SFRC-3	0.75	5.20	7.25
SFRC-4	1.00	5.80	8.10
SFRC-5	1.25	5.65	7.95

Conclusion

Based on the experimental investigation carried out in various percentages ranging from 0% to 1.25% with the addition of steel fibers in M30 grade concrete, the following findings can be regarded:

- The steel fibres got into the fresh concrete, negatively impacting its workability. The slump value reduced from 85 mm of control mix to 45 mm of the mix with 1.25 % do-sized steel fibers showing the prominent decrease in workability with the increase in fiber dosage.

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- It can be concluded that this parameter (compressive strength) improved steadily with steel fiber content up to 1.00%. The SFRC-4 showed maximum compressive strength of 50.3 MPa after 28 days of compressive strength, which is about 25.1% higher than compared to the control mix.
- The steel fibres certainly played a major role in strengthening the tensile properties. Consequently, the maximum 28-day split tensile strength of 5.05 MPa obtained was for SFRC-4, which increased nearly 46.4% over conventional concrete.
- Among all mechanical properties investigated, flexural strength showed the most amount of improvement. The 28-day flexural strength for control mix was measured as 5.20 MPa while it was 8.10 MPa for SFRC-4, which means there was an increase of about 55.8% to enhance flexural strength of SFRC-4 in comparison with the control mix.
- This improvement in compressive strength, tensile strength and flexural strength can be explained, as steel fibers act as stress transfer and crack arrest mechanisms, which delayed the propagation of cracks in the concrete matrix, thus improving overall resistance to the cracks.
- The mix with 1.25% of steel fibres showed the highest strengths compared to the control mix, however, if compared to 1.00% fibre mix, a slight decrease was found. This can be attributed to lowered workability, lack of compaction, and potential fiber agglomeration at elevations in excess of 11.5% fiber.
- The concrete with 1.00% of steel fibers volume (SFRC-4) yielded the most favorable overall performance characteristics, having the highest mix of compressive, split tensile and flexural strength and possessing an adequate workability.

So, it can be concluded that 1.00% of steel fiber must be used in the volume of the concrete to get the excellent mechanical property and crack-resistance of the produced concrete have the excellent property will be applicable for technical structures.

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