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MECHANICAL PROPERTIES OF DRAMIX HOOKED END STEEL FIBER REINFORCED CONCRETE

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Abstract

Concrete and other cementitious materials are renowned for their poor tensile strength and brittle failure. One of the best ways to combat the brittleness of cementitious materials is by using steel fibres. This research aims to provide knowledge on the properties of steel fibre-reinforced concrete. The research will focus mainly on the mechanical properties of concrete reinforced with Dramix hooked-end steel fibre with different proportions of 0%, 0.5%, 1%, 1.5%, and 2%. The evaluation of concrete properties will include the workability of concrete using a slump test, compressive strength test, splitting tensile test, and flexural strength test at the age of 7 and 28 days of curing. The slump values of steel fibre reinforced concrete (SFRC) are lower to the tune of 1.74 – 6.97 %. There is an increase in compressive strength of SFRC from 4.37% - 15.11%. The maximum increase in splitting tensile strength of 15% was obtained at a steel fibre volume fraction of 2.0%. The addition of steel fibres significantly improves the mechanical properties of concrete. A 2% volume of steel fibre is recommended as the optimum steel fibre context in concrete for practical applications.

Keywords: Concrete, Steel Fiber, Compressive strength, Tensile Strength, Flexural Strength

Introduction

One of the most frequently utilized building materials worldwide is concrete. The number of infrastructures, such as buildings, structures, highways, and railroads, has increased recently, and so the needs for concrete. Concrete is in higher demand, which has led to increased performance criteria. Additional requirements for concrete are also put forth by environmental protection and energy conservation laws. Furthermore, concrete exhibits poor tensile and strain endurance, crimp failure, and is a semi-brittle material. Typically, the tensile strength of a material is 8–15% of its compressive strength (Mahmud, 2022). To increase tensile strength and ductility, reinforcement, such as steel bars or fibres, is used to enhance ductility and tensile strength (Banthia and Sappakittipakorn, 2007). Concrete reinforced with steel fibres has improved energy absorption, deformation before failure, and ductile behaviour as a result of the incorporation of steel fibres (Islam et al., 2021).

Before cement was invented, the Egyptian and Babylonian civilizations employed steel fibres to reinforce brittle materials (A. A. Shah and Ribakov, 2011). It is generally known that steel fibres' primary function is to reinforce concrete by bridging cracks as they form and enhancing its ductility. Steel fibre-reinforced concrete has more energy absorption capacity due to the inclusion of fibres, which also increase strain at peak load. It has been shown that steel fibres also significantly increase the concrete's impact resistance, tensile resistance, ductility, and static flexibility (Mohammadi et al., 2008). Furthermore, steel fibre improves concrete's tensile strength and flexural properties, which are regarded as the material's major structural weaknesses (Lee, 2017; Mahmud, 2022). There are several uses for fibre-reinforced concrete, including buildings, tunnels, and bridges. The influence of steel fibres on concrete has been the subject of numerous studies over the past few decades. Steel fibres' mechanical properties can be improved by using deformed fibres like hooked fibres. Theoretically, compared to other forms of fibre, fibres with hooked ends offer higher mechanical coupling (Boulekbache et al., 2016).

In general, increasing fibre volume can improve mechanical qualities. This is due to the rise in fibre usage to support loads (Z. Wu et al., 2019). Despite a decrease in flowability, Wu et al. (2019) showed that adding around 3% more fibre to SFRC enhanced its compressive and flexural properties when mixed with a consistent superplasticizer (SP) dosage. According to Shi et al., (2016), concrete with 2% steel fibre is much more dependable than concrete with 1% or 3% steel fibre, and 2% is the optimal fibre level for SFRC. The impact of steel fibres on the rheological characteristics, flexural toughness, flexural strength, splitting tensile and compressive strength of self-compacting concrete (SCC) was examined by Khaloo et al., (2014). The findings showed that employing large percentages of fibres resulted in a loss in various rheological properties that have been stipulated by EFNARC and ACI 237R, which in turn influenced the workability of medium and high-strength SCC classes. Similar findings were reported by Li et al., (2017) which showed that adding steel fibres greatly reduced the workability of freshly produced concrete. The following reasons might be given for the decline in slump value: (i) The networks of randomly positioned fibres reduced the workability of freshly mixed concrete; (ii) Since the fibres had a big surface area, they required a lot of cement paste to wrap it, thus, increasing the viscosity of the freshly mixed concrete mixes. According to Mohammadi et al., (2008), the compressive strength increases as the proportion of short fibres in the concrete mix as well as the gross fibre content of the mixture rises.

In the study by Chen and Carson (1971), the concrete mixes with shorter fibres showed better compressive strengths than those with longer fibres for a given volume fraction of fibres. In the research of Shah and Rangan (1971), the addition of fibres to concrete increased compressive strength by up to 23%. According to a study by Khaloo et al., (2014), fibre volume fractions have an impact on the splitting tensile strength, with higher fibre fractions increasing splitting tensile strength. The SCC specimens' splitting tensile strength was improved by the inclusion of steel fibres. By spanning the space between the two sides of the crack opening, steel fibres increase the splitting tensile strength. For the medium and high-strength plain specimens, the inclusion of a 2% fibre volume fraction increased splitting tensile strength by 28.5% and 17.1%, respectively. A key indicator that can indicate the toughening effects of fibres and the interior structural performance of matrices is flexural toughness. Furthermore, Lin et al., (2014) examined the impact of fibre types on the flexural properties of self-compacting fibre-reinforced cementitious composites and found that these factors had a minimal bearing on specimens' initial crack strength and pre-cracking behaviour. However, fibre properties had a big impact on post-cracking behaviour and deflection types (deflection-hardening or deflection-softening). Additionally, Wu et al., (2016) investigated how the amount and shape of steel fibres (SF) influenced the flexural properties of ultra-high performance concrete (UHPC). The scientists found that whereas SF concentration had a significant impact on peak load, it had minimal impact on first crack strength and the corresponding deflection of UHPC. The findings from Deng et al., (2016) showed that increasing fibre length, fibre content, and concrete strength considerably improved the post-cracking behaviour of fibre-reinforced concrete (FRC). Comparable to this, Khaloo et al., (2014) find that the use of steel fibres increased the flexural strength.

Further research has shown that adding steel fibres to concrete enhances its flexure and impact strength. Song, and Hwang (2004) assessed the effect of fibre on the compressive resistance of concrete in terms of the fibre-reinforcing factor. They have discovered that while high-strength concrete has weak tensile resistance and strain capacities, adding steel fibres to it can make it less brittle. Rai and Joshi (2014) did a study on the properties and usage of SFRC. Their study revealed that the use of fibre boosts concrete's ductility and ability to withstand loads after cracking. Concrete that has fibres added to it is more resistant to bending and can absorb energy after the initial break (Abaza, 2014). Vega (2016) noted that the use of fibres aids in reducing the thickness of the structural elements because it avoids the use of minimal coatings to ensure the integrity of the reinforcement and the different fibres better sew the concrete matrix, which results in better control of cracks and increases the durability of the material. Researchers discovered that steel fibres may greatly improve post-cracking energy absorption properties as well as toughness (Fantilli et al., 2011; Marar et al., 2011) but also lead to a greater compressive (Lu and Hsu, 2006), flexural (Ding and Liu, 2010) and tensile strength (Grimaldi and Luciano, 2000) of concrete. Concrete's brittleness has been effectively reduced by the use of steel fibres. Similar to straw in mud, steel fibres may span concrete fissures and prevent them from spreading, giving the concrete a post-crack behaviour.

This study examines the mechanical characteristics of Dramix hooked-end steel fibre reinforced concrete with various steel fibre contents of 0%, 0.5%, 1%, 1.5%, and 2% to enhance concrete performance. The characteristics of steel fibre-reinforced concrete will be experimentally investigated in both the fresh and hardened states. The workability of concrete will be assessed using a slump test as part of the assessment of fresh properties. Whereas the hardened properties of the concrete comprise the compressive strength test, splitting tensile test, and flexural strength test. Based on the findings of the study's results, the optimal steel fibre content to be employed will be chosen.

Materials and Methods

Cement

The concrete mixes were made using ordinary Portland Cement of CEM 1 with a strength of 42.5 MPa and a specific gravity of 3.15. The chemical composition of the cement utilized is presented in Table 1.

Fine and Coarse aggregates

Natural river sand with relative densities of 2.65 kg/m^3, 1.15% water absorption, and 3.17 in terms of fineness modulus were employed for the mixes. A well-graded 10 mm aggregate with a relative density (SSD) and water absorption value of 2.66 kg/m^3 and 1.0%, respectively, was utilized as coarse aggregate, according to BS 882 (1992).

Table 1. Chemical Composition of Portland Cement

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Ignition Loss
Weight (%)	20.60	4.80	2.90	63.60	2.50	3.20	1.10	0.40	0.07

Steel Fibers

Four different volume fractions of Dramix Hooked-end section circular steel fibre were used: 0.5%, 1%, 1.5%, and 2%. The steel fibres utilized were Dramix hooked-end steel fibres, BN type RC 65/35, with dimensions of 35 mm in length, 65 in aspect ratio, 7850 kg/m3 in density, and 1250 MPa in tensile strength. The physical appearance of the Hooked-end steel fibre is shown in Figure 1. It has been proven that steel fibre with hooks at one end will help the fibre and concrete matrix bind appropriately. Additionally, the binding is dependent on the mechanical interlocks created by the hooks of the fibres in addition to chemical adhesion and static friction (Abdallah et al., 2018).

Mixture Proportions and Specimen Preparation

Table 2 displays the mixture proportion for the steel fibre-reinforced concrete (SFRC) employed in this experiment. The water-to-cement ratio in the concrete is 0.48. No water-reducing additives were used. Hooked-end steel fibres having a density of 7850 kg/m3 were employed in five different ratios: 0%, 0.5%, 1%, 1.5%, and 2% by volume fraction. The laboratory investigation consisted of tests for both fresh and hardened concrete properties.

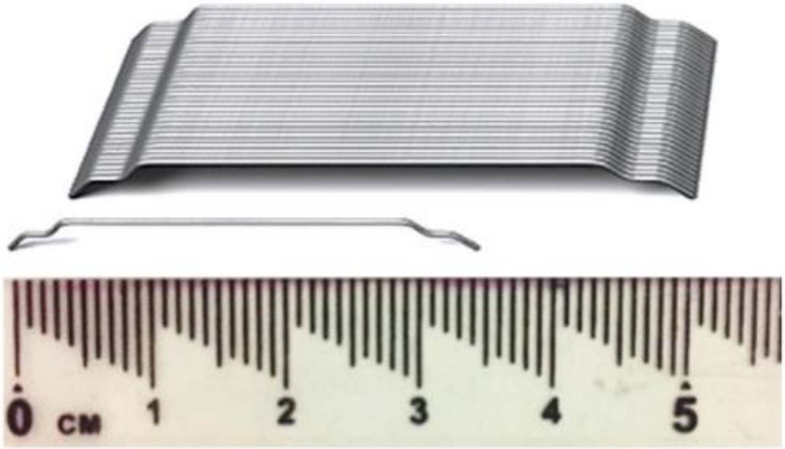

Figure 1. Dramix hooked end section of circular steel fibre

Table 2. Mixture Proportion of SFRC

Volume Fraction	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Hooked-end Steel Fiber (kg/m^3)
0%	400	651	1087	192	0
0.5%	400	651	1087	192	39
1.0%	400	651	1087	192	78
1.5%	400	651	1087	192	118
2.0%	400	651	1087	192	157

A consistent SFRC blend was made by three different rounds of fibre mixing. The top of the mould was cleaned of excess material, and the surface was trowelled smoothly. After 24 hours, the samples were demolded, and they were left to cure at room temperature until testing age.

Slump Test

The workability of concrete will be assessed using a slump test as part of the assessment of the fresh properties. For the workability of SFRC, ACI Committee 544 suggested using an inverted slump cone test (ACI544.2R-89, 2009). According to the ACI manual of concrete practice, the workability of the fresh concrete mix is its capacity to adequately fill the form or mould with the necessary work (vibration) while maintaining the quality of the concrete. The broad end of the cone should be facing down on a flat, nonabsorptive surface. Then, it is filled in three equal levels, each of which is tamped with a steel rod to compact the layer (ASTMC143/C143M-10a, 2010). The encased material will slump somewhat owing to gravity when the cone is carefully taken off, as illustrated in Figure 2.

Figure 2. Slump Test

Hardened Properties Test

The hardened properties test on the concrete comprises:

Compressive Strength Test

According to BS EN12390-3 (2009), a 3000 kN capacity universal testing equipment was used to perform the compressive strength test on 100 × 100 mm cubes, as depicted in Figure 3. The test was conducted at the ages of 7 and 28 days. For each batch, three (3) samples were tested, and the average value was computed to determine the compressive strength by applying Equation 1.

$$F_C = {}^{F}/_{A_C} \qquad \text{Eqn. (1)}$$

Where; F_C is the compressive strength (N/mm^2 or MPa), F is the compressive force at failure (N) and A_C is the specimen cross-sectional area (mm^2).

Splitting Tensile Test

According to ASTM C496/C496M-11 (2002) specifications, a splitting tensile test on 100 x 200 mm cylinders was performed using an NL Compression machine with a 3000 kN capacity. Equation 2 below was used to calculate the maximum fracture load, which was recorded directly from the machine;

$$F_{ct} = {}^{2F}/_{\pi LD} \qquad \text{Eqn. (2)}$$

Where; F_{ct} is the splitting tensile strength in MPa, F is the maximum load in Newton, L is the height of the sample in mm, and D is the diameter of the specimen in mm.

Flexural Strength Test

According to BS EN 12390-5 (2009), a flexural strength test on a 100 x 100 x 500 mm prism was conducted at 7 and 28 days after curing. By applying force through the top and lower rollers, the sample is subjected to a four-point bending test. Up to 20% of the failure load was applied as the initial load during testing. After the initial load was applied, the load was maintained at a constant rate of 0.04 N/mm^2 until sample failure.

Figure 3. Compressive strength test on Concrete cube samples

Figure 4. Flexural Strength Test

The flexural strength was then calculated by using Equation 3.

$$f_{ct} = \frac{P \times I}{d_1 \times d_2^2} \quad \text{Eqn. (3)}$$

Where 'P' is the maximum applied load (N), 'I' is the distance between the supporting rollers (mm), d_1 is the width of specimen (mm) and d_2 is the depth of specimen (mm).

Results and Discussions

Fresh Concrete

Following the addition of 2% steel fibre to the concrete, workability decreased. The findings of the slump test shown in Figure 5 indicate that concrete reinforced with steel fibres has lower slump values than reference concrete. In comparison to the reference concrete, the findings reveal a slump value reduction of 1.74 to 6.97%. As the steel-fibre ratio rises, the slump value decreases as well. Parallel to this, Köroğlu (2018) also noted that when the amount of steel fibre in concrete increases, the slump value decreases.

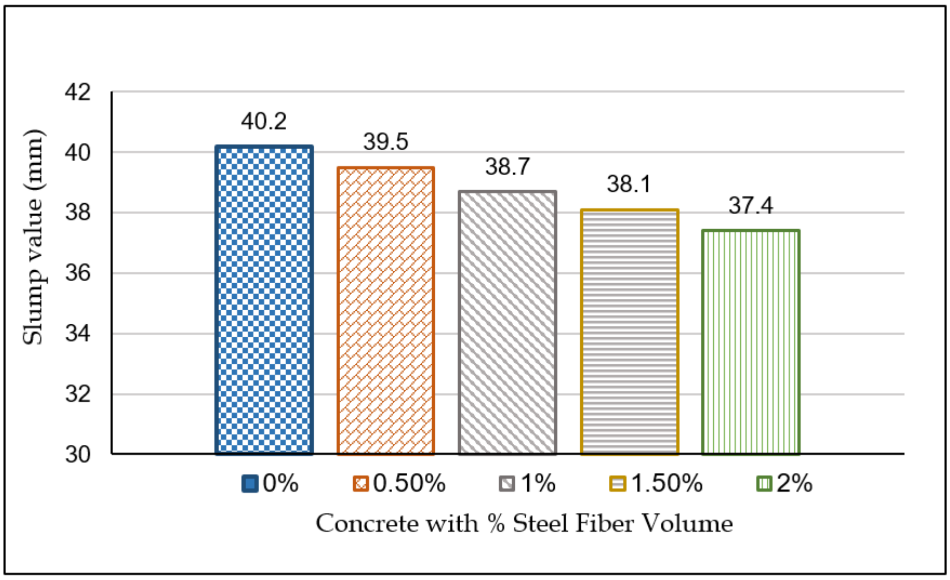

Figure 5. Slump Value of Steel Fiber Reinforced Concrete

The workability of concrete may be affected by steel fibre. The coarse aggregate movement is prevented by the fibres, which lessens the material's flexibility. An increase in the mortar composition and/or the initial slump might lessen such impact and create ideal working conditions (Figueiredo et al., 2015). Superplasticizers and other high-range water-reducing admixtures should always be used in SFRC. Low-level fibre addition minimizes fibre balling and creates concrete with homogenous material consistency and excellent workability (Song and Hwang, 2004). Thus, considering the experimental test results, a 2% volume of fibre is recommended as the optimum fibre context for practical applications. A recommendation of 2% was used in many studies (Aksoylu et al., 2022; Zeybek et al., 2022).

Hardened Properties of SFRC

The properties considered in this section are compressive strength, splitting tensile strength, and flexural strength.

Compressive strength of SFRC

Figure 6 displays the results of compressive strength tests on reference concrete and SFRC with various fibre volume fractions for a curing age of 7 and 28 days. It is clear that when the fraction of fibres rises, the compressive strength increases as well. According to the findings, adding fibres to concrete at a curing age of seven days often increases compressive strength ranging from 3.96% to 19.75%, as shown in Figure 6. Additionally, it can be seen that at a curing age of 28 days, concrete with 0.5%, 1.0%, 1.5%, and 2.0% volume fractions of fibres increases its compressive strength by 4.37%, 6.63%, 12.57%, and 15.11%, respectively. This can be due to the presence of steel fibre, which primarily works to prevent fractures from forming. Therefore, the steel fibres' major role is mostly as a crack preventer rather than in actual compression (Majain et al., 2019). Furthermore, there is an optimal volume proportion of fibres for a given mix that provides the highest strength, and this is 2.0%.

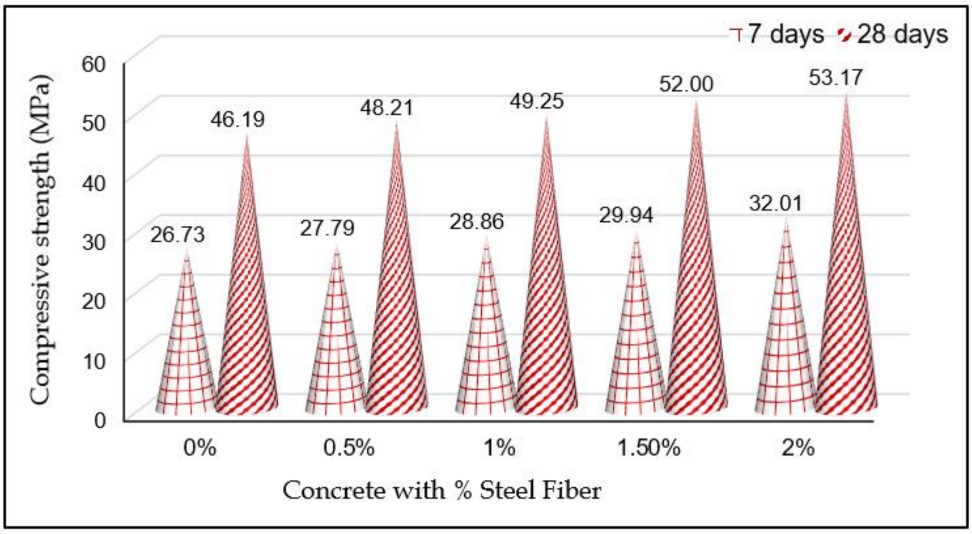

Figure 6. Compressive Strength of SFRC

In general, it can be deduced that the compressive strength increases as the amount of steel fibre in the mixture raises. According to Mohammadi et al., (2008), the compressive strength improves with an increase in the proportion of short fibres in concrete mix and an increase in the gross fibre content in the mix. Likewise, Shah and Rangan (1971) stated that the addition of steel fibres to concrete increased compressive strength by up to 23%.

Splitting Tensile Strength of SFRC

The splitting tensile strength test was performed to find the capacity of SFRC in tension, which is an important mechanical parameter for concrete performance. Figure 7 depicts the impact of steel fibre on the concrete's splitting tensile strength at 7 and 28 days after curing. Figure 7 makes it clear that the inclusion of steel fibre increases the splitting tensile strength of the concrete in comparison to the reference concrete.

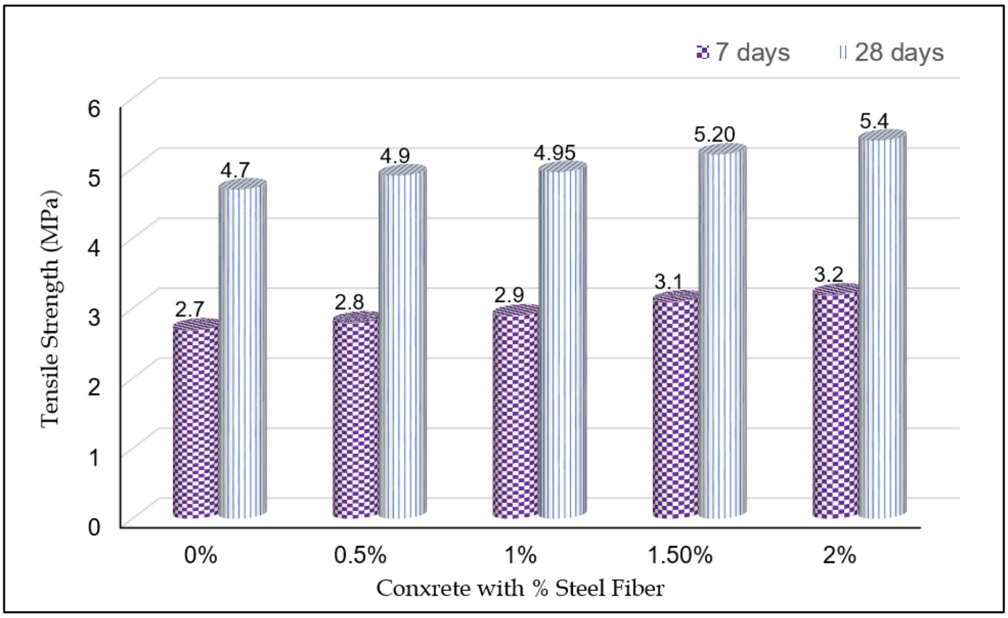

Figure 7. Tensile Strength of SFRC

The 28-day findings revealed an increase in tensile strength of 4.26%, 5.32%, 10.64%, and 14.89% for concrete mixes containing volume fractions of steel fibre of 0.5%, 1.0%, 1.5%, and 2.0%, respectively. At a steel fibre volume percentage of 2.0%, a maximum improvement in splitting tensile strength of 15% over reference concrete was noted. The SF's bridging effect across the fracture is what causes the increase in tensile strength, which in turn prevents the crack from spreading and enlarging (Grimaldi and Luciano, 2000).

Flexural Strength of SFRC

The flexural strength of the SFRC beam is improved by the inclusion of steel fibre as depicted in figure 8. In comparison to the reference concrete, which had a flexural strength of 4.63 MPa, the SFRC beam's flexural strength was 8.98 MPa for 2% steel fibre volume. The engineering properties of concrete are considerably improved by the inclusion of steel fibres.

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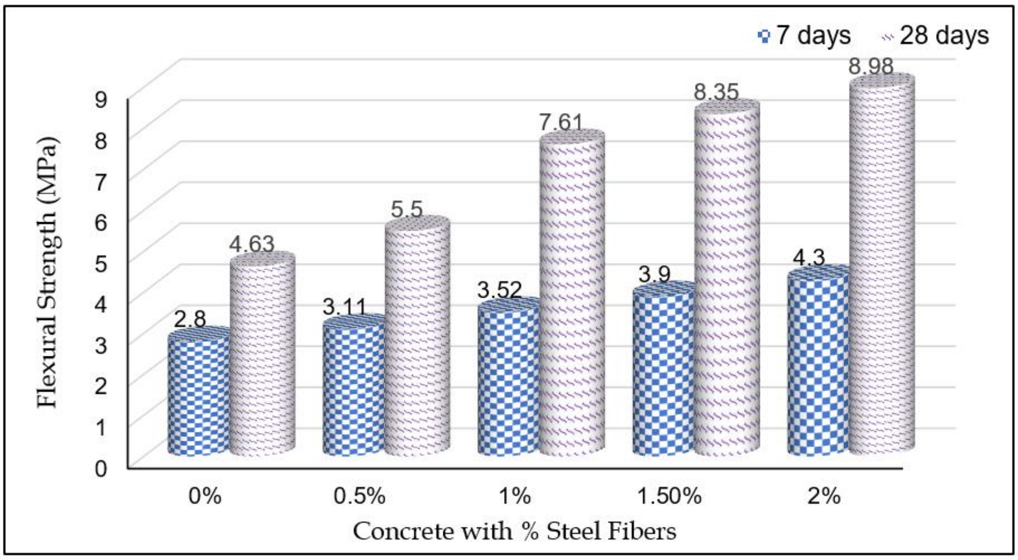

Figure 8. Mean Flexural Strength of SFRC

The 7-day flexural strength of the SFRC is accompanied by a 54% increase in strength compared to the reference concrete at 2% steel Fiber, demonstrating that the SFRC has increased flexural strength and can withstand higher loads. Additionally, the results at 28 days show that the SFRC's flexural strength was increased by 94% when compared to reference concrete containing 2% steel fibre. Salihu and Mallum, (2020) have provided documentation of a comparable finding. According to the findings, adding steel fibre to concrete caused a positive growth in the flexural strength of the concrete.

Conclusion

This paper highlights the mechanical properties of Dramix hooked-end steel fibre reinforced concrete with different proportions of steel fibre of 0%, 0.5%, 1%, 1.5%, and 2%. Based on the findings from the experiments, the following conclusions were outlined:

- The slump values of concrete with steel fibres are lower to the tune of 1.74 – 6.97 % compared to the reference concrete. Steel fibres act as a barrier to coarse aggregate movement reducing the flexibility of the material.
- There is an increase in compressive strength of SFRC from 4.37% - 15.11%. It may be concluded that with an increase in the volume fraction of steel fibre in the mix, the compressive strength improves.

- The maximum increase in splitting tensile strength of 15% with respect to reference concrete was obtained at a steel fibre volume fraction of 2.0%. The increase in tensile strength is due to the bridging action of SF across the crack, which controls the crack widening and propagation.
- The flexural strength of SFRC improves by 94% compared to reference concrete at 2% steel fibre content.
- The addition of steel fibres significantly improves the mechanical properties of concrete.
- Thus, based on the experimental test results, a 2% volume of steel fibre is recommended as the optimum steel fibre context in concrete for practical applications.

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