Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 4 Issue 2 (September 2025), 1-16
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v4i2.JSCET_S_000027

The Influence of Steel Fiber Type on the Flexural Performance of Steel Fibre Reinforced Concrete Beam

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Received: 18 November 2024 / Accepted: 30 July 2025 / Published online: 30 September 2025

Abstract

Concrete is the most widely used structural material due to its excellent workability and high strength. However, ordinary concrete has several drawbacks, including low tensile strength, low ductility and low crack resistance which leads to brittle failure. In this study, hooked end steel fiber of different type and content is used as reinforcements to evaluate the flexural performance of steel fiber reinforced concrete (SFRC) beam. The flexural performance encompasses parameters such as crack pattern, crack width, and deformation behavior under three-point bending. The research methodology involves the preparation and testing of SFRC beams with controlled fiber content of 0.25% and 0.5% and different steel fiber shapes of 3D steel fiber and 4D steel fiber. Fifteen (15) numbers of cube samples with dimension 150 x 150 x 150 mm were tested for its compressive strength and ten (10) beam samples with dimension 100 x 100 x 500 mm were tested for its flexural strength, and their performance were assessed through load-displacement curves, crack pattern observations, and measurement of crack width. The experimental data analyzed to determine the flexural strength, failure modes, and the influence of steel fiber type and content on the overall performance of the SFRC beams shows that the addition of hooked-end 4D steel fiber with 0.5% fiber content improved the flexural performance of SFRC beams when compared to other type of steel fibre reinforced concrete beams. Hooked-end 4D steel fiber with 0.5% fiber content thus approved for use in the fabrication of beams for structural and infrastructural use. Steel fiber in concrete beams proven to improve flexural performance as it offers better control over the crack propagation in a concrete structure.

Keywords: Steel fiber reinforced concrete; flexural performance; hooked-end fibres

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1. Introduction

Steel Fiber Reinforced Concrete (SFRC) has garnered significant attention in recent years due to its enhanced mechanical performance and durability under various loading conditions. The integration of steel fibers into the concrete matrix has been shown to improve not only the compressive and flexural strength but also the post-cracking behavior and crack control characteristics of concrete elements (Jang et al., 2016; Yoo & Moon, 2018; Zhao et al., 2023). Among the various parameters influencing the performance of SFRC, the type and volume fraction of steel fibers play a pivotal role in determining the structural behavior of SFRC beams.

Previous studies have indicated that different geometries and types of steel fiber, such as straight, crimped, twisted, and hooked-end results in varying levels of influence on mechanical performance. In particular, hooked-end fibers (often referred to as 4D fibers) have been reported to exhibit superior performance in terms of load-carrying capacity, energy absorption, and toughness compared to other fiber types, such as 3D crimped fibers (Anandan et al., 2019; Jang et al., 2016; Tang et al., 2010). These benefits are more pronounced at higher volume fractions, where the fiber content contributes significantly to the composite action between the fibers and the cementitious matrix (Menna et al., 2022).

The flexural strength of SFRC beams tends to increase with higher fiber volume fractions, indicating that fiber dosage directly influences the load-bearing capacity and ductility of the element (Jang et al., 2016; Yoo & Moon, 2018; Zhao et al., 2023). Beams incorporating 4D fibers at a 0.5% volume fraction demonstrate notable improvements in flexural strength and toughness when compared to lower dosages or other fiber geometries (Menna et al., 2022). The enhancement in flexural behavior is also evident in the load-displacement response, where beams with higher fiber content exhibit more ductile behavior and better energy dissipation under flexural loading (Menna et al., 2022; Yoo & Moon, 2018). These beams show a gradual reduction in load after peak strength, rather than an abrupt failure, indicating improved post-cracking resistance (Jang et al., 2016; Menna et al., 2022). In terms of crack propagation and control, the inclusion of steel fibers leads to more refined and distributed crack patterns. Higher fiber content contributes to a noticeable reduction in crack width and a more uniform crack distribution, which is particularly beneficial in serviceability considerations (Krassowska & Kosior-Kazberuk, 2018; Ren et al., 2023). Comparative evaluations reveal that SFRC beams reinforced with 4D fibers exhibit better crack control than those reinforced with 3D fibers, especially when the volume fraction is increased to 0.5% (Menna et al., 2022). Despite these advancements, the current understanding is constrained by certain limitations. Most experimental investigations are focused on the percentage of fiber contents. Consequently, the generalization of findings across different fiber geometries, dosages, and practical field applications may be limited (Jang et al., 2016; Menna et al., 2022; Yoo & Moon, 2018). Furthermore, the outcomes of such studies are also influenced by variables such as specimen size, concrete mix design, and testing protocols including loading rates, which can affect the reproducibility and applicability of results (Jang et al., 2016; Menna et al., 2022).

The aspect ratio of steel fibers significantly influences the flexural performance of steel fiber reinforced concrete (SFRC), particularly in terms of strength and toughness. Higher aspect ratios improve the ability of fibers to bridge cracks, enhancing load transfer across crack faces and delaying failure. Experimental findings indicate that hooked-end steel fibers with greater aspect ratios (e.g., 65) produce higher flexural strength and better post-cracking toughness compared to those with lower aspect ratios (e.g., 45) (Jeong et al., 2018; Sun et al., 2016; Wang et al., 2025; Zhao et al., 2023). Moreover, longer fibers provide increased residual flexural strength due to enhanced crack-bridging effects, which is essential for improving the energy dissipation capacity and serviceability of SFRC elements (Garcia-Taengua et al., 2022; Li et al., 2018; S. Yazici et al., 2007). The load-deflection behavior of SFRC is also strongly affected by fiber aspect ratio. Higher aspect ratios contribute to more ductile responses under flexural loading, reflected in smoother load-deflection curves and greater deflection capacity after peak load. This improved performance is particularly evident in beams reinforced with hooked fibers, where increased energy absorption and delayed crack propagation are observed (Li et al., 2018; Sun et al., 2016; Zhao et al., 2023). These enhancements make SFRC a suitable material for structural components subjected to dynamic or repeated loading.

Additionally, the synergy between fiber volume fraction and aspect ratio further amplifies SFRC performance. Higher volume fractions combined with higher aspect ratios result in superior mechanical behavior, particularly in terms of flexural strength, toughness, and crack control (Jeong et al., 2018; S. Yazici et al., 2007; Zhao et al., 2023). Among different fiber geometries, hooked-end fibers consistently outperform straight or crimped types due to their superior anchorage and pull-out resistance, which enhances the mechanical interlock within the concrete matrix (Li et al., 2018).

Understanding the role of fiber aspect ratio is thus crucial for optimizing SFRC mix designs, especially in applications requiring high performance with cost-effective material use. Proper selection of fiber geometry can reduce the need for higher dosages while maintaining structural integrity, which is vital in large-scale applications such as precast segments, high-strength elements, and tunnel linings (Biswas et al., 2021; Garcia-Taengua et al., 2022; Wang et al., 2025). This makes the aspect ratio a key parameter in the design and practical implementation of SFRC in advanced civil engineering structures.

Therefore, this study aims to investigate the influence of steel fiber type, specifically 3D and 4D fibers that varies in aspect ratios on the flexural performance of SFRC beams at volume fractions of 0.25% and 0.5%. By examining key performance metrics such as compressive and flexural strength, load-displacement behavior, and crack characteristics, this study seeks to provide a clearer understanding the contribution of fiber geometry

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varying in the aspect ratio and dosage to the mechanical behavior of SFRC under flexural loading.

2. Research Method

This section will be focusing on the materials, samples and the experimental setup applied in this study.

2.1 Materials and samples

A total of fifteen (15) cubes and ten (10) beams of C30 concrete mix were fabricated for this study. The size of the cubes was 150 x 150 x 150 mm while the beams were 100 x 100 x 500 mm length. The samples were tested for compressive test and flexural test. Two types of hooked end steel fibres i.e., Dramix 3D and Dramix 4D were included in the mix with two percentages of 0.25% and 0.5%. Figure 1 shows the flow of the research process together with the numbers of samples used in this study. All samples were designed using the C30 garde of concrete with water/cement ratio of 0.46 as tabulated in Table 1.

Table 1. Concrete Mix Design

Material	Water (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Per 1 m^3	180	395	515	1315

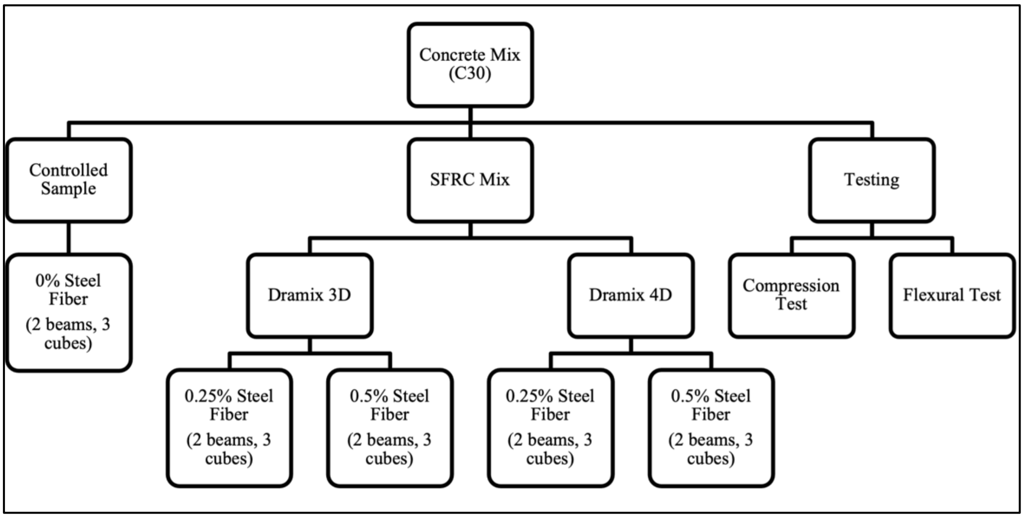

Figure 1. Research flow

The steel fibers used in this study are the Dramix 3D 80/60BG and Dramix 4D 65/60BG hooked-end type. The Dramix 3D fiber has an aspect ratio of 80, a length of 60 mm, and an approximate diameter of 0.75 mm, while the Dramix 4D fiber has an aspect ratio of 65 with the same length but a larger diameter of approximately 0.92 mm. Dramix steel fiber is a type of cold drawn hooked-end steel fiber that is glued in bundles with water-soluble glue. The purpose of the glue assures the fibers are well distributed in the concrete mix and helps prevent the fiber balling during concrete mixing process. The steel fibres used in this study have different hooked end details as shown in Figure 2. Dramix 3D with single hook has been used widely in steel fibre application in the construction industry. Dramix 4D on the other hand has a double curve hook which is designed to provide optimal crack control. The hook end's anchorage has been specially created to restrain concrete cracks between 0.1 and 0.3 mm width. Both fibers conform to international standards ASTM A820 and EN 14889-1, ensuring

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their suitability for structural applications. These fibers were selected for their potential to significantly improve the flexural behaviour, toughness, and residual strength of steel fiber reinforced concrete (SFRC), aligning with the objectives of this study.

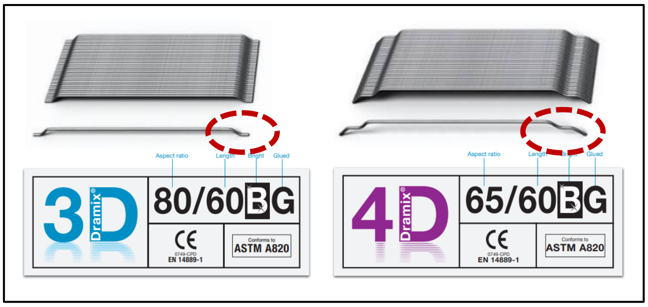


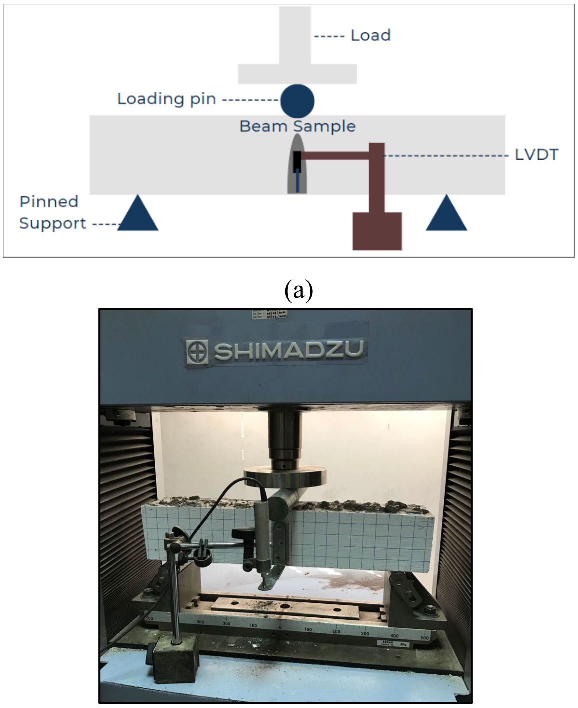
Figure 2. Steel fibre shape details (BOSFA, n.d.)

These steel fibers were used as an alternative to the conventional reinforcement bars in the reinforced concrete. Its durability and high-performance properties made it to be beneficial in use in terms of time efficient and cost effective. Two percentages of steel fibres were used in this study, which are 0.25% and 0.5%, respectively for both types of steel fibres. The selection of 0.25% and 0.5% steel fiber volume fractions in this study was based on balancing the mechanical performance of the mix with sufficient level of workability. These levels are commonly used in SFRC applications, where 0.25% allows assessment of minimum fiber effectiveness and 0.5% offers enhanced flexural strength and crack control. When using 60 mm long steel fibers, such as the Dramix 3D and 4D types, higher dosages increase the risk of fiber balling and reduce workability. Therefore, limiting the fiber content to 0.5% helps ensure proper fiber dispersion while maintaining the mix quality.

2.2 Experimental setup

The experimental program involved both compression and flexural tests to evaluate the mechanical performance of the steel fiber reinforced concrete (SFRC) specimens. Compression tests were conducted on cube samples in accordance with BS EN 12390-3:2019, using a 100 kN Universal Testing Machine (UTM) in the Heavy Concrete Laboratory, UiTM Cawangan Pulau Pinang (Figure 3). For flexural testing, SFRC beam specimens were tested under three-point bending following the procedure outlined in BS EN 12390-5:2019 (Figure 4). A Linear Variable Displacement Transducer (LVDT) was installed at the mid-span of each beam to accurately record the vertical deflection under loading. The beams were subjected to a controlled loading rate of 0.04 MPa/s during the flexural test.

Figure 3. Compression test setup (BS EN 12390-3:2019, 2019)



(a)

(b)

Figure 4. Flexural Test setup (a) Schematic diagram, (b) Arrangement for the flexural test (BS EN 12390-5:2019, 2019).

3. Results and Discussion

This section will be discussing on the results of the experimental work, i.e. the compressive strength of the cubes, the flexural performance and the failure mode of the tested samples.

3.1 Compressive strength of steel fibre reinforced concrete cubes

The effect of the steel fibre variation on the compressive strength of the steel fibre reinforced concrete cubes is presented in the section. Table 2 and Table 3 show the compressive strength results for SFRC cubes with variation of steel fiber types and percentages of 0.25% and 0.5% obtained at 28 days. The data show that the addition of steel fibers, regardless of type, increased the compressive strength of SFRC cubes significantly. Steel fibers served as reinforcement within the concrete matrix, improving its resistance to compressive stresses. The bridging effect of the steel fibers helps spread the applied load and inhibits crack development, which accounts for the higher compressive strength.

Table 2 shows that the addition of steel fibers in SFRC cubes at a dosage of 0.25% resulted in higher ultimate compressive strengths than the control cubes without steel fibers. The Dramix 3D steel fiber reinforced SFRC cubes had an average ultimate compressive strength of 58.63 N/mm^2, whereas the 4D steel fiber reinforced cubes had an average ultimate compressive strength of 59.15 N/mm^2. In contrast, the controlled cubes had an average ultimate compressive strength of 54.71 N/mm^2.

Table 2. Compressive Strengh of Cubes with 0.25% Steel Fibres.

Sample	Ultimate Compressive Strength (N/mm^2)		
	Controlled	SFRC 3D	SFRC 4D
Cube 1	50.22	61.21	57.31
Cube 2	51.68	56.47	61.14
Cube 3	51.90	58.21	59.00
Average	51.27	58.63	59.15

Error! Reference source not found. show the results of the compressive strength testing on 0.5% SFRC cubes. When compared to the control cubes, the addition of steel fibers resulted in higher ultimate compressive strengths. The ultimate compressive strength of the cubes reinforced with 3D steel fibers was 51.77 N/mm^2, while the cubes reinforced with 4D steel fibers was 61.16 N/mm^2. The final compressive strength of the controlled cubes averaged 51.27 N/mm^2.

Table 3. Compressive Strengh of Cubes with 0.5% Steel Fibres.

Sample	Ultimate Compressive Strength (N/mm^2)		
	Controlled	SFRC 3D	SFRC 4D
Cube 1	50.22	51.61	60.46
Cube 2	51.68	51.70	61.53
Cube 3	51.90	52.00	61.48
Average	51.27	51.77	61.16

According to the results, an increase in the amount of steel fibers from 0.25% to 0.5% enhanced the compressive strength of 4D SFRC cubes. The greater amount of steel fiber contributed to the increased crack resistance and load-carrying capacity, resulting in the ability of the cubes to sustain compressive stresses. The results clearly show that steel fibers have an effective effect on the compressive strength of the SFRC cubes. In comparison to the controlled cubes, both 3D and 4D steel fibers produced higher compressive strengths at various dosages. Steel fibers reinforced the concrete matrix, increasing its resistance to compressive forces and delivering greater compressive strength values.

The compressive strength results indicate that steel fibers have a favorable impact on the compressive strength of the SFRC cubes. The concrete grade used for this study is of concrete grade 30, which indicates the minimum compressive strength the concrete should achieve is 30 N/mm^2. Referring to results of compressive strength achieved from all samples, varying from controlled, SFRC with 3D steel fiber and SFRC with 4D steel fiber of different content, it can be concluded that the concrete is adequate for further usage in construction as it fulfills the required minimum compressive strength. When compared to the controlled cubes, both 3D and 4D steel fibers considerably improved compressive strength at different steel fiber content.

The SFRC of 0.25% steel fiber content shows that the average compressive strength achieved had an increment of 14.35% for SFRC of 3D steel fiber compared to the controlled samples, meanwhile for SFRC of 4D steel fiber increases 15.37% compared to the controlled samples. The SFRC of 0.5% steel fiber content shows that the average compressive strength achieved had an increment of 0.98% for SFRC of 3D steel fiber compared to the controlled samples, meanwhile for SFRC of 4D steel fiber increases 19.29% compared to the controlled samples.

Overall, these findings indicate that the efficiency of steel fiber content varies depending on percentage and type of steel fiber employed. In this scenario, the 4D steel fiber is particularly successful at increasing the compressive strength of the SFRC, especially at 0.5% fiber content. These findings add to a more thorough understanding of the behavior of SFRC under compressive loading settings and provide beneficial perspectives for SFRC structure design and construction.

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3.2 Flexural strength

This section discusses the results of the three-point bending test performed on the steel fiber reinforced concrete (SFRC) beams. The incorporation of steel fibers within the concrete matrix facilitates crack bridging, which enables a more efficient distribution of applied stresses. This leads to enhanced flexural capacity and improved crack control. The flexural strength of SFRC beams is a critical parameter that determines the beam's ability to resist bending and sustain applied loads. The inclusion of steel fibers enhances the flexural performance of concrete by providing additional reinforcement and improving its resistance to crack propagation. The flexural strength of the SFRC beams was calculated using Equation (1).

$$F = \frac{PL}{bd^2} \tag{1}$$

With F = Flexural strength (N/mm^2)
P = Maximum load (N)
L = Span length (mm)
b = Width of sample (mm)
d = Height of sample (mm)

Table 4 presents the flexural strength data of the SFRC beams reinforced with 0.25% steel fibres. The data showed that the inclusion of the Dramix 3D steel fibres increases the flexural strength of concrete significantly by 89%. However, significant decrement was observed for the inclusion of Dramix 4D fibres. This might be due to the improper distribution of the fibres inside the mix resulting in weak regions within the matrix.

Table 4. Flexural strength of SFRC beams with 0.25% of steel fiber.

Sample	CONT 1	CONT 2	SF0.25-3D1	SF0.25-3D2	SF0.25-4D1	SF0.25-4D2
Maximum Load (kN)	4.7	4.2	9.54	7.47	5.22	5.26
Average load (kN)	4.5		8.51		5.24	
Flexural strength (N/mm^2)	2.25		4.26		2.62	

The load versus displacement analysis provides significant insight on the behaviour and performance of steel fibre reinforced concrete beams. These tests allow us to assess the load-carrying capacity and bending resistance of the beams. The objective of this research is to assess the flexural strength of concrete beams influenced by different shapes and content of steel fibres. The vertical displacement of the beam in this research was measured using the LVDT that is connected to the three-point flexural testing setup. The load-displacement results on the SFRC beam samples is presented in flexural load versus displacement graph in Figure 5.

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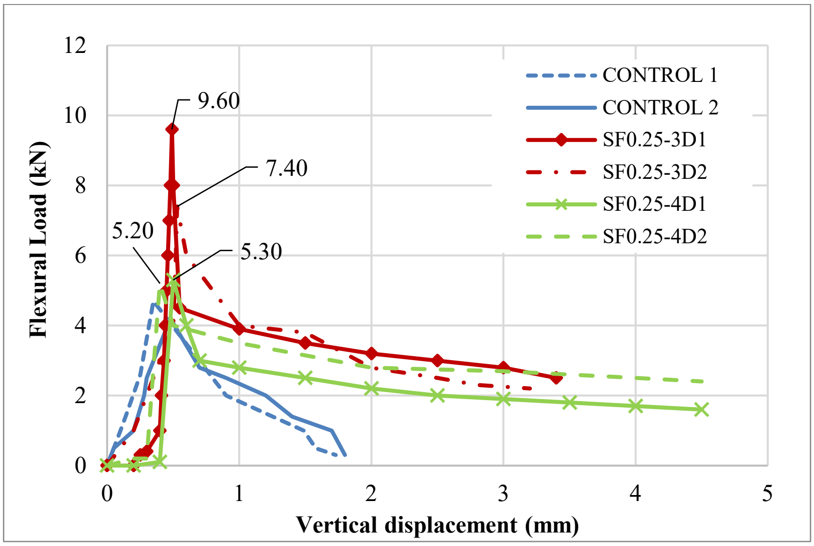

Figure 5. Flexural strength of beams with of 0.25% steel fiber.

Figure 5 presents the flexural load versus vertical displacement curves for SFRC beams containing 0.25% steel fiber, compared with control samples without fiber reinforcement. Among all specimens, sample SF0.25-3D1 recorded the highest peak flexural load of 9.60 kN, demonstrating a substantial enhancement in load-carrying capacity due to the inclusion of 3D steel fibers. In contrast, the lowest peak load was observed in control sample CONTROL 2, which failed at approximately 5.20 kN, indicating the limited flexural resistance of plain concrete without fiber reinforcement. Both 3D fiber-reinforced samples (SF0.25-3D1 and SF0.25-3D2) exhibited a steep initial loading phase followed by a more gradual decline post-peak, reflecting improved post-cracking behaviour and energy absorption. On the other hand, the 4D fiber-reinforced samples (SF0.25-4D1 and SF0.25-4D2), though exhibiting moderate peak loads of around 5.30 kN, displayed more prolonged deformation beyond peak load, suggesting better ductility but lower peak strength. The control samples experienced sudden and brittle failure immediately after reaching their maximum load, with very limited displacement. In contrast, all fiber-reinforced beams showed a more ductile response characterized by extended load resistance and delayed crack propagation. This trend underscores the beneficial role of steel fibers in enhancing not only the flexural capacity but also the deformability and toughness of concrete beams. Notably, the better performance of 3D over 4D fibers at this dosage may be attributed to more effective fiber dispersion and a higher number of fibers per volume due to the smaller diameter of 3D fibers.

In comparison of all SFRC beam samples tested, the percentage decrement of flexural force for SFRC 3D is roughly 21.73%, showing a decrease in force, whereas the percentage decrement of flexural force for SFRC 4D is around 0.76%, showing a modest drop in force. It should be noted that negative percentages indicate a decrease in force when compared to the initial value. Even so, the graph trend of all samples tested are similar, which shows a linear increase of force, and falls drastically as it reached the maximum load capacity to sustain the applied load. The ability of 4D SFRC beams to sustain larger loads before fracture is limited due to the results obtained are among the lowest compared to other samples. This implies that the addition of steel fibers, particularly in a 3D system, improves the load-carrying capacity and bending resistance of the beams. Even though the 4D beam sample reached the maximum load value earlier than the 3D beam sample, the displacement value for the 4D beam sample to survive fracture is the longest among the 3D beam sample.

According to previous study, the steel fiber provided the ductility of the beam structure under axial load (Kavya Sameera & Keshav, 2022). Beam with 4D steel fibers offers the best crack control for concrete structures as the hooked end holds the concrete matrix, decelerating the fracture process. The fibers acts as a medium to allow the load applied on beam to transfer the stress, holding the cracks well as maximizing the bonding of steel fibers

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and other next fiber to carry over the stress, postponing the crack's expansion.

Error! Reference source not found. shows the flexural strength results for the samples reinforced with 0.5% Dramix 3D and Dramix 4D steel fibres. The beam samples reinforced with Dramix 4D has shown more than double increment of the beam's flexural strength in comparison to the control sample. The results achieved by the Dramix 4D samples are significantly higher than the Dramix 3D beam samples with 89% increment.

Table 5. Flexural strength of SFRC beams with 0.5% of steel fiber.

Sample	CONT 1	CONT 2	SF0.5-3D1	SF0.5-3D2	SF0.5-4D1	SF0.5-4D2
Maximum Load (kN)	4.7	4.2	7.47	4.58	14.07	8.70
Average load (kN)	4.5		6.03		11.39	
Flexural strength (N/mm^2)	2.25		3.01		5.70	

Referring to Figure 6, the results of flexural load versus vertical displacement with the addition of 0.5% steel fiber. SFRC beams with Dramix 4D steel fibers had greater ultimate flexural forces than controlled beams, whereas Dramix 3D SFRC beams have a significant lower ultimate flexural force. These findings imply that adding 0.5% steel fibers increases the load- carrying capability of SFRC beams, and the type of steel fibers can influence the flexural response.

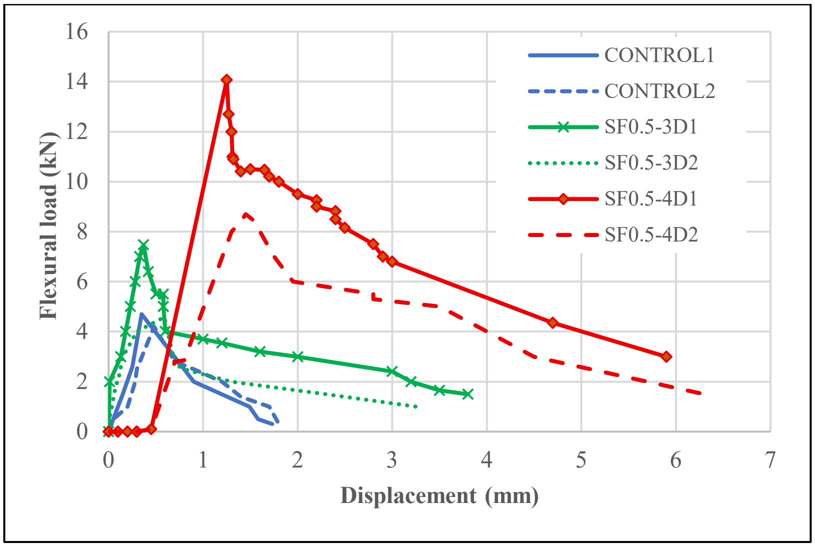

Figure 6. Flexural strength of beams with 0.5% steel fiber.

Figure 6 illustrates the flexural load versus displacement behaviour of SFRC beams containing 0.5% steel fibers, alongside control samples. The beam reinforced with Dramix 4D fibers (SF0.5-4D1) recorded the highest peak load of 14.07 kN**,** indicating superior flexural performance and load-carrying capacity at this fiber dosage. In contrast, the lowest peak load was observed in the control sample CONTROL 2, which failed at approximately 4.2 kN, reflecting the limited strength and brittle nature of plain concrete. Both SFRC beams with 4D fibers i.e. SF0.5-4D1 and SF0.5-4D2 exhibited enhanced ductility and energy absorption, as evidenced by the extended load-sustaining capacity beyond peak load and larger displacement values up to nearly 6 mm. The 3D fiber-reinforced beams, SF0.5-3D1 and SF0.5-3D2, while showing increased peak loads relative to control samples, reached lower maximum loads of 7.47 kN and 4.58 kN, respectively and underwent earlier load drops, indicating reduced toughness compared to the 4D samples. The control beams experienced abrupt failure post-

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peak, highlighting their brittle behaviour. In contrast, the 4D SFRC beams demonstrated a gradual decline in load after reaching peak capacity, indicating superior post-cracking behaviour and toughness, likely due to the enhanced mechanical anchorage of 4D fibers. These trends suggest that at 0.5% dosage, 4D fibers are more effective than 3D fibers in enhancing both the flexural strength and ductility of concrete beams, affirming the role of fiber geometry and content in influencing flexural performance.

A comparison of Figures 7 and 8 reveals that the flexural performance of SFRC beams is influenced not only by the fiber content but also by the aspect ratio and end-hook design of the fibers. Although both Dramix 3D and 4D fibers have the same length of 60 mm, the 3D fibers have a higher aspect ratio of 80 and a single hook, while the 4D fibers have a lower aspect ratio of 65 but feature a double-hooked end. At 0.25% fiber content, the higher aspect ratio of 3D fibers contributed to better crack bridging, toughness and stress transfer due to the greater number of thinner fibers per volume, resulting in higher peak loads compared to 4D. This is consistent with previous research showing that higher aspect ratios improve flexural strength (Garcia-Taengua et al., 2022; Zhao et al., 2023). However, at 0.5% dosage, the 4D fibers outperformed the 3D fibers, indicating that the enhanced mechanical anchorage provided by the double-hooked ends became more effective at higher volumes. The double hooks improve pull-out resistance and energy absorption, which is reflected in the improved post-cracking behaviour and higher flexural strength as supported by Jeong et al., (2018) and Li et al., (2018). This suggests that while a higher aspect ratio benefits performance at lower dosages, fiber geometry and anchorage mechanisms play a more dominant role as the fiber content increases emphasizing the need to optimize both parameters for improved structural performance (Biswas et al., 2021; Yazici et al., 2007)..

3.3 Mode of failure

Understanding beam flexural performance is crucial in structural design to make sure that they are capable of supporting the desired loads while maintaining structural integrity over time. Various design aspects, including as material selection, reinforcement initiatives, and beam dimensions, are considered to optimize flexural performance and assure the structure's safety and behaviour. Beams are tested for flexural performance by evaluations such as flexural strength, deflection, and crack development. Flexural strength is defined as the maximum bending moment that a beam can withstand before failing, demonstrating its ability to carry loads without excessive deflection or failure. Cracks on the surface of the beam can also indicate the onset of failure and have an impact on its load-carrying capacity and durability.

The overall result of the flexural strength of the SFRC beams is presented in Figure 7. All SFRC beams showed higher flexural strength in comparison to the control sample. Highest flexural strength was achieved by the SFRC beam reinforced with Dramix 4D at 0.5% steel fibres. The results presented suggest that the steel fibre content and type of steel fibres employed have a substantial impact on the flexural strength of SFRC beams. A higher fibre content generally leads to greater flexural strength, with 4D steel fibres displaying greater efficacy in improving beam flexural performance.

The bonding and steel fibers bridging that assist in resisting the crack's expansion for SFRC beams are presented in Figure 8. It shows that the bridging of steel fiber in concrete mix is effective due to the fiber that holds the bonding of other fibers and the surrounding concrete. Meanwhile the controlled beam failed in withstand load without any fiber bridging to support the load. The effectiveness of additional steel fibers of different content can be seen in Figure 9, as it exhibited the distribution of steel fiber content in concrete matrix. It shows that the higher amount of steel fiber content resulting in an increased and more dispersion of steel fibers, resulting to a higher effectiveness towards crack propagation and increases the flexural strength of SFRC beam.

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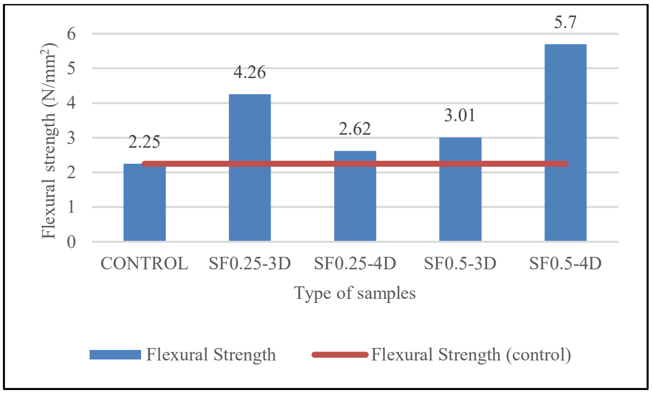

Figure 7. Flexural Strength of SFRC Beams.

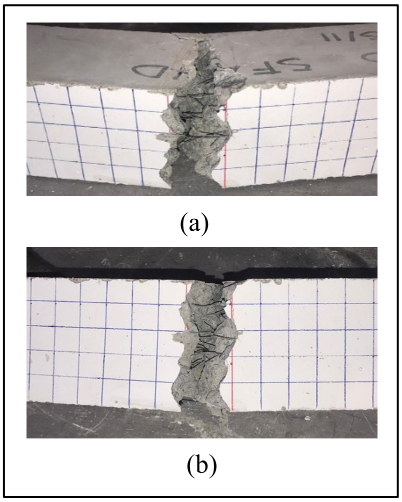

Figure 8. Fiber bridging in the SFRC beams (a) with 0.25% steel fibre content (b) with 0.5% steel fibre content.

e-ISSN: 2948-4294 | Volume 4 Issue 2 (September 2025), 1-16
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(a)

(b)

Figure 9. Distribution of steel fibres in the 3D SFRC beam (a) with 0.25% steel fibre content (b) with 0.5% steel fibre content.

The pattern and width of cracks define the failure mode of beams. The crack pattern depicts how cracks originated and spread in beams under varying pressures, revealing insights into their behavior. Crack width refers to the size of cracks on the surface of the beam and influences its durability and strength. Monitoring crack width assists in identifying potential problems and determining appropriate measures. Analyzing the failure mode of beams in terms of fracture pattern and width allows for informed decisions on reinforcing, repairs, and structural safety maintenance.

The observed crack pattern and crack width in the SFRC beams provide crucial information on the beams' behavior and effectiveness under flexural stress. These results can be used to evaluate the effectiveness of steel fibers in controlling cracking formation and propagation. The crack resistance depended on the reinforcement of steel fibers and its volume fraction (Kavya Sameera & Keshav, 2022).

The crack pattern and crack width of the SFRC beams were visually evaluated and measured during testing. The cracking pattern represents the overall distribution and direction of cracks on the surface of the beams, whereas the crack width represents the gap or separation between the crack surfaces. A study on the shear strength of steel fiber reinforced concrete beam by Ahmed and Siva (Ahmed & Siva Chidambaram, 2022) indicates that higher volume steel of fibers controls the shear cracks and its growth. The study also discovers that the improvement of shear strength and facilitates plenty of cracks to form resulting in better flexural behavior. Figure 10 and Figure 11 shows the crack pattern and crack width observed from the test results of SFRC with steel fiber content of 0.25% and 0.5%, respectively.

Sample SF0.25-3D1 shows a crack length measuring 87.5 mm with a crack width of approximately 5 mm. Several crack patterns are observed in sample SF0.25-3D2 with the crack width of 2 mm and the crack length measuring 98 mm in length. Crack width of 3 mm in exhibits in SF0.25-4D1 with crack length of 78 mm and

Journal of Sustainable Civil Engineering and Technology
e-ISSN: 2948-4294 | Volume 4 Issue 2 (September 2025), 1-16
https://joscetech.uitm.edu.my
https://doi.org/10.24191/jscet.v4i2.JSCET_S_000027

finally sample SF0.25-4D2 indicates a wider crack width of 10 mm, measuring the crack length about 98 mm.

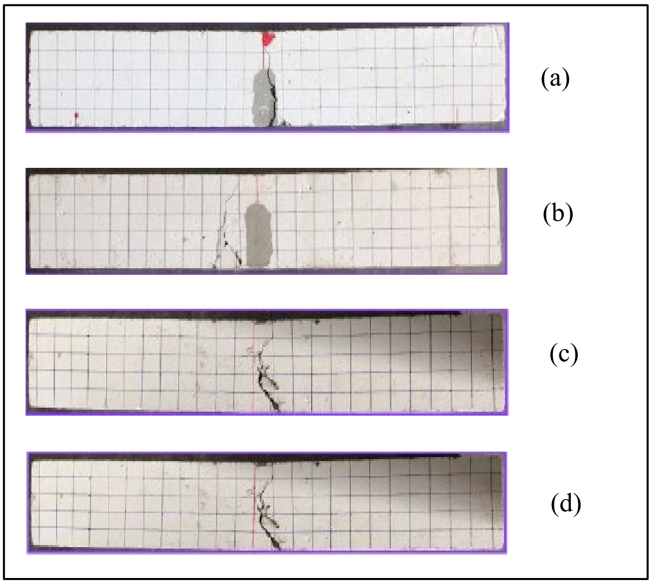

Figure 10. Crack pattern and crack width of samples with 0.25% steel fiber content after flexural testing (a) SF0.25-3D1 (b) SF0.25-3D2 (c) SF0.25-4D1 (d) SF0.25-4D2.

Figure 11 shows the crack pattern of the SFRC beam samples reinforced with 0.5% steel fibres. Sample SF0.5-3D1 beam shows a crack length measured 78 mm with a crack width of approximately 2.4 mm. Moreover, several crack patterns of sample SF0.5-3D2 appear the presence of crack width of 2 mm, with the crack length of 73.5 mm. Samples SF0.5-4D1 and SF0.5-4D2 show a nearly similar crack length propagation approximately 80 mm with crack width ranges 2 mm to 4.5 mm, respectively.

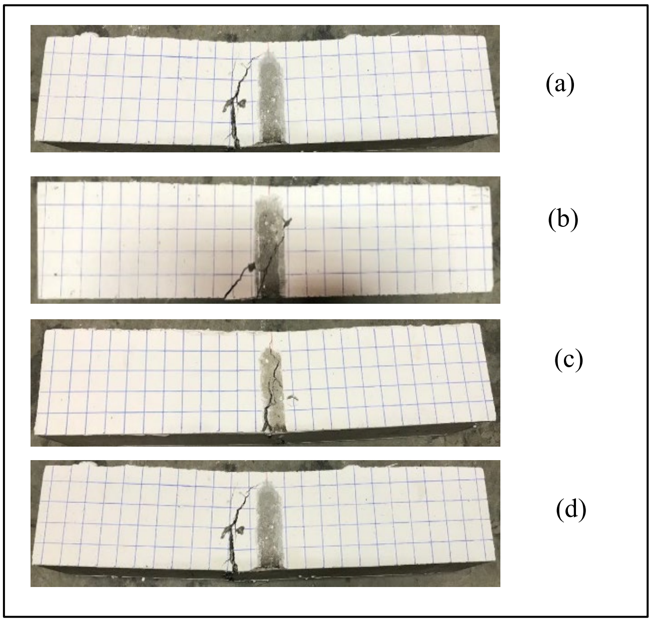

Figure 11. Crack pattern and crack width of samples with 0.5% steel fiber content after flexural testing (a) SF0.5-3D1 (b) SF0.5-3D2 (c) SF0.5-4D1 (d) SF0.5-4D2.

Because of the unique features of the Dramix 4D steel fibers, the beam reinforced with this type of fibres has better crack resistance. The Dramix 4D steel fiber's design which features a double hooked end, improves the bond between the fibers and the surrounding concrete matrix. This enhanced bond helps to transfer stress more effectively and prevents crack growth. The hooked ends of the fibers operate as anchor points within the concrete, preventing crack initiation and reducing crack propagation. As a result, the Dramix 4D SFRC can sustain higher flexural forces, reducing the likelihood and extent of cracking compared to plain concrete and Dramix 3D steel fiber. The greater resistance to cracks in Dramix 4D SFRC comprises to improved ductility, structural integrity, and overall performance of the concrete elements.

The Dramix 4D SFRC beams with 0.5% steel fiber content is more resistant to cracks compared to 0.25% because of the higher concentration of steel fiber in concrete mix. The increased steel fiber content improves concrete matrix reinforcing and crack resistance. The additional steel fibers operate as minor reinforcements, assisting in the more effective distribution of stress, lowering the likelihood and spread of cracks. The increased fiber content increases the SFRC's overall toughness and ductility, allowing it to sustain larger loads and strains without cracking. As a result, the Dramix 4D SFRC with 0.5% steel fiber content has better crack resistance, making it a better alternative for applications needing increased durability and structural integrity. Overall, Dramix 4D SFRC beam with 0.5% shows a better flexural performance than other SFRC beam of Dramix 3D and Dramix 4D SFRC with 0.25% steel fiber content.

The influence of steel fibers shape and fiber content on the flexural performance and failure mode of steel fiber reinforced concrete can be seen from the fracture pattern analysis where the addition of steel fibers successfully controls and limits crack widths in SFRC beams. When compared to the controlled samples, both types of steel fibers showed a considerable reduction in crack width. The hooked end shape of the fibers is critical in limiting crack propagation and maintaining beam integrity. This adds to the SFRC beams' enhanced strength and long-term performance. Also, failure mode observations reveal that the addition of steel fibers, particularly hooked end 3D and 4D steel fibers, promotes a more ductile failure mode in SFRC beams. The fibers effectively inhibit crack propagation and increase the beams' energy absorption capacity. As a result, the failure mechanism is more controlled and progressive, minimizing the possibilities of rapid and severe damage under bending loads.

4. Conclusion

This study investigated the flexural performance of SFRC beams reinforced with Dramix 3D and 4D steel fibers at volume fractions of 0.25% and 0.5%, focusing on the effects of fiber type, geometry, and dosage. The results showed that the Dramix 4D fiber at 0.5% content provided the highest flexural strength and best post-cracking behaviour. In contrast, at 0.25% steel fibre dosage, the 3D fiber with a higher aspect ratio performed better, indicating that aspect ratio and fiber count are more influential at lower volumes. The 0.5% Dramix 4D SFRC beams also exhibited improved crack resistance, ductility, and toughness due to the greater number of fibers acting as micro-reinforcements, enabling better stress distribution and control of crack propagation. These findings confirm that both fiber type and volume fraction significantly affect flexural behaviour, and the use of 0.5% hooked-end Dramix 4D fibers is recommended for structural applications requiring enhanced durability and structural integrity.

Nevertheless, this study was limited to the investigation of only two fiber volume fractions, 0.25% and 0.5%, and only two specific types of hooked-end steel fibers, which are Dramix 3D and 4D. with the length of 60 mm. Thus, this study does not address the potential effects of varying fiber lengths, diameters, or alternative geometries, which could influence fiber dispersion, crack-bridging efficiency, and overall mechanical performance. Furthermore, workability challenges such as fiber balling and reduced slump were observed also need to be properly assessed in consideration of practical application. Therefore, future studies should investigate a broader range of fiber dosages, explore different fiber geometries and dimensions, and include sufficient evaluation of workability and mixing behaviour to ensure optimal performance in both fresh and hardened states.

Acknowledgments

The authors of this study would like to acknowledge Universiti Teknologi MARA, Pulau Pinang Branch, Permatang Pauh Campus, Pulau Pinang, Malaysia for providing all necessary supports and facilities in accomplishing the objectives of this research.

Author Contributions

Conceptualisation, Hazrina Ahmad; Methodology, Nurul Amira Jazlan; Validation, Hazrina Ahmad; Analysis, Nurul Amira Jazlan; Investigation, Nurul Amira Jazlan; Resources, Goh Lyn Dee; Data Curation, Name; Writing-Draft Preparation, Ruqayyah Ismail; Writing-Review & Editing, Norlizan Wahid; Visualisation, Fariz Aswan Ahmad Zakwan; Supervision, Hazrina Ahmad.

All authors have reviewed and approved the final version of the manuscript for publication.

Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

References

Ahmed, T., & Siva Chidambaram, R. (2022). Shear strength of steel fiber reinforced concrete beam– A review. *Materials Today: Proceedings*, *64*, 1087–1093. https://doi.org/10.1016/j.matpr.2022.05.368

Anandan, S., Islam, S., & Khan, R. A. (2019). Effect of steel fibre profile on the fracture characteristics of steel fibre reinforced concrete beams. *Journal of Engineering Research (Kuwait)*, *7*(2), 105–124. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85072349001&partnerID=40&md5=94da60a789539917e94f16f5e3d476d9

Biswas, R. K., Bin Ahmed, F., Haque, M. E., Provasha, A. A., Hasan, Z., Hayat, F., & Sen, D. (2021). Effects of Steel Fiber Percentage and Aspect Ratios on Fresh and Harden Properties of Ultra-High Performance Fiber Reinforced Concrete. *Applied Mechanics*, *2*(3), 501–515. https://doi.org/10.3390/applmech2030028

BOSFA. (n.d.). *Value Engineering using Fibre Reinforced Concrete*. Retrieved August 30, 2023, from https://bosfa.com/products/dramix-5d-4d-3d/

BS EN 12390-3:2019. (2019). BS EN 12390-3:2019 - Testing hardened concrete Compressive strength of test specimens. In *British Standard Institution*.

BS EN 12390-5:2019. (2019). BS EN 12390-5:2019 - TC Testing hardened concrete - Flexural strength of test specimens. In *BSI Standards Publication*.

Garcia-Taengua, E., Martí-Vargas, J. R., & Serna, P. (2022). Residual Flexural Strength of SFRC: A Multivariate Perspective. In *RILEM Bookseries* (Vol. 36, pp. 232–243). https://doi.org/10.1007/978-3-030-83719-8_21

Jang, S.-J., Jeong, G.-Y., Lee, M.-H., Rokugo, K., & Yun, H.-D. (2016). Compressive strength effects on flexural behavior of steel fiber reinforced concrete. *Key Engineering Materials*, *709*, 101–104. https://doi.org/10.4028/www.scientific.net/KEM.709.101

Jeong, G. Y., Jang, S. J., Kim, Y. C., & Yun, H. D. (2018). Effects of steel fiber strength and aspect ratio on mechanical properties of high-strength concrete. *Journal of the Korea Concrete Institute*, *30*(2), 197–205. https://doi.org/10.4334/JKCI.2018.30.2.197

Kavya Sameera, V., & Keshav, L. (2022). Properties and performance of steel fiber reinforced concrete beam structure – Review. *Materials Today: Proceedings*, *66*, 916–919. https://doi.org/10.1016/j.matpr.2022.04.643

Krassowska, J., & Kosior-Kazberuk, M. (2018). Failure mode in shear of steel fiber reinforced concrete beams. *MATEC Web of Conferences*, *163*. https://doi.org/10.1051/matecconf/201816302003

Li, B., Xu, L., Shi, Y., Chi, Y., Liu, Q., & Li, C. (2018). Effects of fiber type, volume fraction and aspect ratio on the flexural and acoustic emission behaviors of steel fiber reinforced concrete. *Construction and Building Materials*, *181*, 474–486. https://doi.org/10.1016/j.conbuildmat.2018.06.065

Menna, D. W., Genikomsou, A. S., & Green, M. F. (2022). Compressive and cyclic flexural response of double-hooked-end steel fiber reinforced concrete. *Frontiers of Structural and Civil Engineering*, *16*(9), 1104–1126. https://doi.org/10.1007/s11709-022-0845-x

Ren, H., Li, T., Ning, J., & Song, S. (2023). Bending damage and fractal characteristics of steel fiber-reinforced concrete under three-point bending test. *Construction and Building Materials*, *409*. https://doi.org/10.1016/j.conbuildmat.2023.134053

Sun, L.-Z., Lu, P.-F., Yang, F., Zhao, J.-L., & Yu, X.-N. (2016). Investigation on the Flexural Behavior of Extra-short Extra-fine Steel Fiber Reinforced Concrete. *Wuhan Ligong Daxue Xuebao/Journal of Wuhan University of Technology*, *38*(7), 63–68. https://doi.org/10.3963/j.issn.1671-4431.2016.07.011

Tang, J.-Y., Gao, D.-Y., Zhu, H.-T., & Zhao, J. (2010). Influence of steel fiber on flexural property of high strength concrete. *Jianzhu Cailiao Xuebao/Journal of Building Materials*, *13*(1), 85–89. https://doi.org/10.3969/j.issn.1007-9629.2010.01.018

Wang, J., Xia, Z., Chen, C., Sun, H., Wang, S., Tian, Y., Hu, Y., & Chen, J. (2025). Experimental Study on Flexural Performance of Steel Fiber Reinforced Concrete and Application of Large-Diameter Shield Segments. *Yingyong Jichu Yu Gongcheng Kexue Xuebao/Journal of Basic Science and Engineering*, *33*(1), 244–255. https://doi.org/10.16058/j.issn.1005-0930.2025.01.022

Yazici, S., Inan, G., & Tabak, V. (2007). Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. *Construction and Building Materials*, *21*(6), 1250–1253. https://doi.org/10.1016/j.conbuildmat.2006.05.025

Yazici, Ş., Inan, G., & Tabak, V. (2007). Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. *Construction and Building Materials*, *21*(6), 1250–1253. https://doi.org/10.1016/j.conbuildmat.2006.05.025

Yoo, D.-Y., & Moon, D.-Y. (2018). Effect of steel fibers on the flexural behavior of RC beams with very low reinforcement ratios. *Construction and Building Materials*, *188*, 237–254. https://doi.org/10.1016/j.conbuildmat.2018.08.099

Zhao, L., Chen, G., & Huang, C. (2023). Experimental investigation on the flexural behavior of concrete reinforced by various types of steel fibers. *Frontiers in Materials*, *10*. https://doi.org/10.3389/fmats.2023.1301647