International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Mathematical Modelling of Engineering Problems
Vol. 12, No. 3, March, 2025, pp. 884-892
Journal homepage: http://iieta.org/journals/mmep

Experimental Investigation on Structural Shear Behaviour and Mechanical Characteristics of Steel Fiber Reinforced Concrete Beams Without Stirrups

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https://doi.org/10.18280/mmep.120314

Received: 4 October 2024
Revised: 13 January 2025
Accepted: 20 January 2025
Available online: 31 March 2025

Keywords:
hooked-end steel fiber, mechanical characteristics, reinforced concrete beam, shear behaviour, flexural behaviour, steel fiber volume fraction

ABSTRACT

Reinforced concrete beam (RCB) is used in a wide range of construction systems as one of the primary elements to bear various loads. This paper utilised an RCB to study and evaluate the hooked-end steel fiber structural behaviour; in addition, the mechanical characteristics of mixtures were also evaluated. In total, four concrete mixtures were utilised; three mixtures were prepared by different volume fractions (v_f) of hooked-end steel fiber 0.5% S.F., 1.0% S.F., and 1.50% S.F., in addition to the mixture without the presence of steel fibers (0% S.F.) as a control mixture. The mixture was referred to as a group; each group included one RCB with a cross-section area of 120×120 mm and a length of 1000 mm, as well as four standard cubes, cylinders, and three prisms. The experimental results indicate that the increase in the hooked-end steel fiber v_f ratio in RCB significantly improves load-carrying capacities and structural behaviour when compared with non-fibrous RCB. The mechanical results approach that the higher v_f of 1.50% hooked-end steel fiber produced a higher tensile strength of 6.36 MPa and a higher flexural strength of 10.35 MPa, resulting in an increase of 71.89% and 116.5% in the splitting tensile strength and modulus of rupture, respectively. Also, in terms of structural shear performance, the load capacity of the RCB with 1.50% v_f reinforced has increased by 70.13%, with a reduction in mid-span deflection of 39.64% as compared to the RCB without steel fiber. On the other hand, the presence of fibers in 0.5 and 1.0% v_f had a negative impact on compressive strength, while 1.50% of steel fiber showed a slight improvement and increased by 6.70% on it. These findings have practical implications for the construction of RCBs, as they demonstrate the potential for improving shear and flexural strength through steel fiber reinforcements.

1. INTRODUCTION

Reinforced concrete (RC) is the most common construction material from which most structures are built, such as viaducts, buildings, retaining walls, tanks, conduits, tunnels, high-rise buildings, etc. The RC structures have different elements, such as slabs, columns, and beams [1-5]. The reinforced concrete beam (RCB) is a structural element used in constructing bridges and buildings, and it transfers the load from the load-carrying member to the supporting structure, such as walls or columns. Traditional steel bar reinforcement grids are used in RCBs at different locations to overcome the fragility nature of concrete and significantly improve flexural and shear forces. For instance, the increases in shear reinforcements improve, the shear resistance capacity of the RC sections, however, contributes to increased dead weight as well as material and construction costs. So many previous studies tested and analysed specimens of simply supported RCBs to obtain the characteristics of RCB with different test parameters, Liu et al. [6] examined the flexural capacity of simply supported steel-concrete composite beam and box beams under positive bending moment through combined experimental and finite element modelling. The results of this study suggest that flexural capacity increased with the increased of transverse reinforcement ratio, and the box-shaped composite beams have a high capacity than I-shaped composite beam. Sadati et al. [7], investigated the shear capacity of full-scale RCBs fabricated with high-volume fly ash and coarse recycled concrete aggregate. The performance of the RCB improved by reducing the dead load of the structure, and it is possible to improve the overall performance of the construction system. This may include increasing the load capacity of the structure, improving the flexibility of the system, or enhancing the durability of the materials.

The steel fibres are especially appealing for high-strength concrete mixtures, which can be somewhat fragile without them, when the traditional steel stirrups can be removed or reduced in RCBs, which lessens the congestion caused by reinforcements and conservatism of shear performance when utilized steel fibres. Steel fiber reinforcement is a construction technique that involves adding tiny, uniformly metallic fibers in concrete mixtures that have acquired popularity as reinforcement in concrete structures. Concrete reinforced with steel fiber is widely used in applications that require durability, high strength, and resistance to deformation and cracking [8]. Steel fibers can enhance the shear capacity of concrete elements, particularly under dead load conditions. It also provides additional reinforcement to the beam, enabling it to resist deformations and sagging under its weight [9, 10]. Kwak et al. [11] experimented with 12 steel fibers RCB specimens and demonstrated the impact of steel–fibers volume fractions V_f, a/d, as well as concrete compressive strength on the incipience of shear strength, shear cracking, ultimate deflection, and failure modes; they found that beams with a/d equal 2 were a failure in a combination of flexural and shear, and strength increased from 68% to 80%, while the beams with a large a/d were a failure in flexural with strength increased from 22% to 38%. Fiber-RCB increased shear strength and ductility stem from the post-cracking tensile strength of fiber-reinforced concrete. Also, these residual strengths tend to reduce crack widths and spacings. Altun and Aktaş [12] investigated whether adding steel fiber increased prismatic RCBs toughness capacity and flexibility. Through this experimental study, the addition of steel fibers increased the bearing strength and ductility of the RCBs and enhanced their shear strength performance. Steel fibers are available in different types depending on their physical properties and intended application. The most common steel fibers include hooked-end, straight steel, crimped, micro steel, and deformed steel fibers, which can be of different shapes, lengths, and aspect ratios and are typically added in small amounts to the concrete mixture. Bui et al. [13] presented the shear performance of steel fiber RCBs without traditional steel stirrups, by experimental investigation of the steel fibbers' effect on the bending behaviour of RCB; the key purposes were first to realize whether the usage of steel fibers allows the total substitution of traditional transverse reinforcements (stirrups) and second to inspect the impact of a mixture of steel fibers and longitudinal bars. The reinforced concrete with steel fiber enhances concrete's flexibility, allowing it to deform without fracturing; this is important for structures that may experience significant deformation, such as earthquake-resistant structures or structures subject to thermal expansion and contraction. Furthermore, it increases the concrete tensile strength and enhances cracking resistance and deformations under loading, particularly for structures subject to dynamic loads, such as pavements, bridge decks, and industrial floors. Therefore, the durability of concrete will be improved with steel fibers due to increased resistance to environmental factors such as abrasion, freeze-thaw cycles, and chemical attacks. The previous research recorded that adding steel fibers to concrete can significantly increase tensile strength and improve resistance to bending and shear forces [14-16]. The study conducted by Yazıcı and Arel [17] carried out the effect of using steel fibers on the bond between deformed steel bars and concrete. It showed that when the number of steel fibers and aspect ratio increased, the loads increased by 7-16% compared to concretes without steel fiber. Wang et al. [18] added volumes of 1%, 2%, and 3% of steel fiber for every cement mortar mixture with four levels of superplasticizer dosage of about 0.180, 0.200, 0.240 and 0.220, respectively. the conclusion is that the addition of steel fibers to concrete may cause fiber interlock, which can lead to issues such as balling or clustering of steel fibers, causing poor mixing and reduced workability of the concrete. The increase in superplasticizer dosage improved the workability of the concrete mixtures and reduced the water content. Improved flowability can contribute to more homogenous distribution of steel fibers throughout the concrete matrix by reducing the chance of steel fiber interlock in the concrete mix and optimizing the particle dispersion of steel fibers in the mixture [19, 20]. Aoude et al. [21] studied the effects of steel fibers on shear capacity, failure mechanisms, and crack control, and the test results demonstrate that adding fibers improves shear resistance in shear-deficient beams. Furthermore, their findings demonstrated improvements in ductility and crack control. Reinforced concrete parts, especially those in the support zones, are vulnerable to shear failure when bent. This failure mode, which is particularly risky in components lacking shear reinforcement, can reduce the load-bearing capacity to less than the full bending capacity due to the longitudinal reinforcements. Krassowska and Kosior-Kazberuk [22] looked into the fact that members made of fiber-reinforced concrete did not deform easily and maintained their shape when subjected to a load. The fiber-RCB exhibited a higher density of narrow diagonal cracks. Quick and easily broken, brittle cracking was the hallmark of RCBs devoid of fibers. Contrary to plain concrete, they found the steel fibers could transfer a substantial amount of shear stress following cracking. Numerous studies have documented the failure behaviours of steel fiber and fiber-RCBs with and without steel stirrups in shear [23-25]. However, there is a necessity for increased comprehensive knowledge about the effect of hooked-end steel fibers on the mechanical characteristics and structural performance of concrete, especially in shear strength behaviour. Zhao et al. [26] explain that by supplementing steel fibers to the concrete mixtures, the shear capacity in concrete elements can be improved, tensile cracks substantially inhibited, and so on, portion or all the steel shear reinforcements can be superseded to minimize the cost of hand fixing; their results revealed that counting steel fibers with a volume fraction of 0.75% increment the shear capacity by 154.8%, under the same concrete strength and stirrups reinforcement ratio, which means steel-fibers addition can effectively enhance the shear capacity of the RCBs.

In the current study, the specific issue of this work is to replace stirrup reinforcement in the concrete beam with steel fibre to lessen cost and time work. Hooked-end steel fibers were utilized in various volume fractions 0% (non-fiber reinforced), 0.50%, 1.00%, and 1.50% in concrete mixtures. The study's objective is to investigate a new approach to improving the shear and flexural strength of RCBs, specifically through hooked-end steel fibers reinforcement, as well as provide data on structural performance and mechanical characteristics. Experimental investigations are conducted on small-scale RCBs with square cross-sections of 120×120 mm and lengths of 1000 mm to investigate structural performance, besides standard samples (cubes, cylinders, and prisms) to determine the mechanical characteristics. The RC beam samples are tested under a four-point monotonic load. The aim of the investigation, carried out by considering the effect of several parameters, such as ultimate load capacity, fiber volume fraction (v_f), modulus of rupture (f_r), splitting tensile strength (f_t), and concrete compressive strength (f_c), consists of the evaluation of the improvement in the peak load behaviour due to the presence of hooked-end steel fibers and eliminate stirrups.

2. EXPERIMENTAL PROGRAM

Experiments were conducted on four groups of concrete specimens to evaluate the effectiveness of concrete reinforced by hooked-end steel fibre in carrying shear and flexural capacities. Each group includes an RCB (without stirrups), cubes, cylinders, and prisms; their numbers and types are described in Table 1. The RCBs are utilized to evaluate the structural performance and standard samples of cubes, cylinders, and prisms for mechanical characteristics such as compressive strength, splitting tensile strength, and flexural strength as a modulus of rupture. The first group without V_f steel fiber (0% S.F.) was a reference, and the others included gradually increased steel fiber V_f ratios of 0.5% S.F., 1% S.F., and 1.5% S.F.

The conventional reinforcement steel bars with an 8 mm diameter and a yield strength of f_y=380 MPa were used in the main reinforcement. The RCBs with a square cross-section have an internal dimension of 120×120×1000 mm with a two-steel bar Ø8 mm (2Ø8 mm) in the tension and compression zone, which represents a flexural reinforcement; the concrete cover was 20 mm from the top and bottom of the beam. In contrast, non-shear reinforcement (stirrups) was used, as shown in Figure 1.

Table 1. Details of the typical group

Specimens Type	RCB	Prisms	Cubes	Cylinders
Number	1	3	4	4

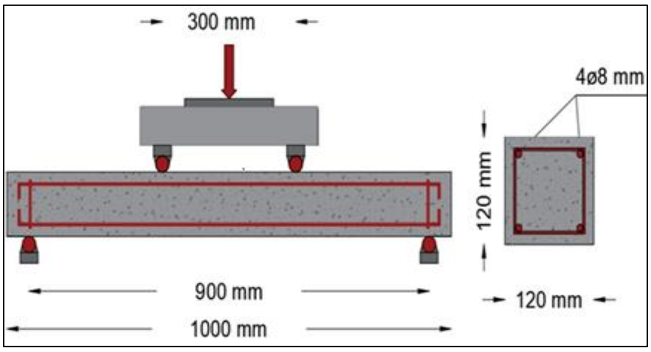


Figure 1. Details of RCB cross-section

2.1 Materials and mixtures

The normal strength concrete (NSC) mixture design was dependent on ACI 211.1-93 [27, 28] and included Portland cement, sand, aggregate with a maximum size of 12.50 mm, and water cement ratio (W/C=0.38). The steel fibres type was hooked-end with a standard length of 35.00 mm and 0.70 mm diameter (aspect ratio L/D=50), as illustrated in Figure 2.

Figure 2. Physical characteristics of Hooked–end steel fibres

Table 2. Mixtures proportions (kg/m^3)

Code	Cement	Sand	Agg.	Super.	W/C	S.F V_f*
SF0	535	910	829	3.10	0.38	0
SF0.5	535	910	829	3.90	0.38	39.25
SF1	535	910	829	4.70	0.38	78.50
SF1.5	535	910	829	5.88	0.38	117.75

*: Hooked end steel fibre volume fraction V_f.

The new generation of high-range water reducer superplasticizer produced by Sika®, named ViscoCrete®-180 G, was used in all mixtures. The concrete mixture proportions of all groups are tabulated in Table 2.

2.2 Preparation and casting

The moulds of the RCB were prepared from hardwood plywood to obtain a smooth surface for drawing cracks during the test, while the standard metal moulds were used for cubes, prisms, and cylinders. The dray mixture components of cement, sand, and aggregate were put in a concrete mixer machine for 5 minutes; hooked-end steel fiber was added up progressively while the machine worked, adding 70% of water in three parts gradually, while 30% of residual water was mixed with the superplasticizer and added to the concrete mix until completed. The mixture was cast in the moulds by three layers, which were vibrated from each side to extrude air voids and prepared for finishing and curing. The curing for all specimens occurred in water and continued for 28 days.

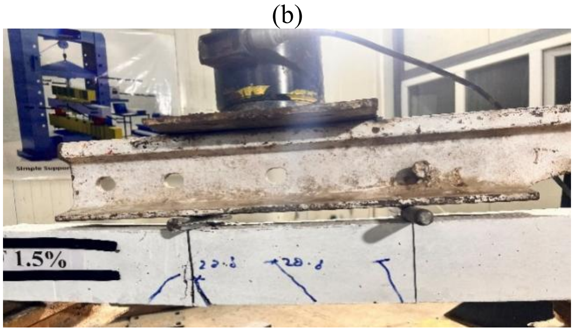
2.3 Testing procedure

The flexural and shear performance of the hooked-end steel fibre RCB is evaluated by testing under four-point loading, as shown in Figure 3. The RCB has a clear span of 900 mm between supports, and the distance between two-point loads is 300 mm. The dial gauges are mounted under the beam to obtain mid-span deflections. A load cell was positioned in the centre of the RCB to record the load vs. time; the load was applied with a constant load increment of 5.00 kN per minute until failure. The applied load was arrested a few seconds after the first crack appeared in order to mark the cracks and take photographs.

Figure 4 illustrates the test devices for cylinders, cubes, and prisms. The shear performance of mixtures is evaluated by splitting tensile stress according to ASTM C496-17 [29-32] while the compressive strength of concrete is evaluated by applying a load vertically upon the cubes ASTM C39-18 [33] and BS EN 12390-1 [34]. The flexural strength as a modulus of rupture was tested according to ASTM C78-22 [35]. The mechanical characteristics presented are the average of three sample test results.

(a)

(b)



(c)

Figure 3. Standard test method for simply supported beam

Figure 4. Test devices of cube, prism, and cylinder

3. RESULTS AND DISCUSSION

Steel fibers at small volumes fractions 0.50–1.00% delay crack initiation and growth through mechanical interlocking and frictional resistance, while larger fibers enhance energy dissipation in macrocrack zones, providing enhanced post-yield behavior. Kakooei et al. [36] indicated fibers at 0.7% V_f enhanced toughness without significant loss of mixture workability, outperforming higher V_f mixes. Mohammadi et al. [37] explained longer fibers 50.00-60.00 mm provided superior flexural toughness but were less effective for microcrack control compared to shorter fibers 25.00 mm.

3.1 Machinal characteristics

3.1.1 Shear and flexural strengths

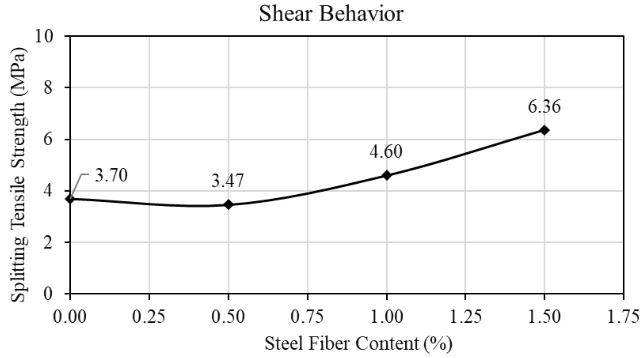
The shear strength represented by splitting tensile strength and flexural strength as modules of rapture behaviours of steel fiber-reinforced concrete mixtures is indicated in Figure 5. The indirect shear tests are used to investigate splitting tensile strength. The splitting tensile strength was obtained by subjecting the cylindrical samples to a compressive load, and the average of three sample results are used, shown in Table 3, and calculated by Eq. (1) [32]. It is considered essential for structural applications as it can control or defer the outset of brittle failure modes, such as shear compression, cracking, and splitting.

$$f_t = \frac{2P}{\pi DL} \quad (1)$$

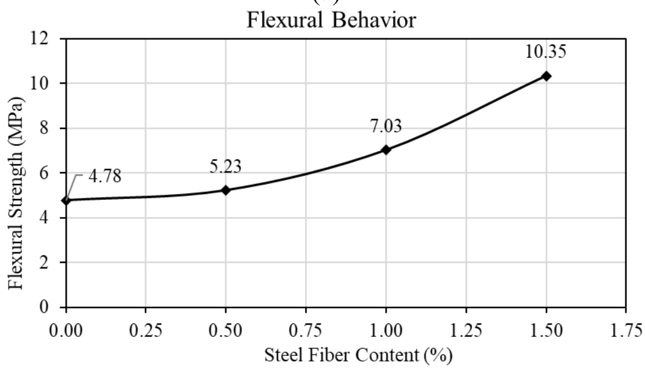
where, P is applied load, D is diameter of sample, L is length, π is constant.

Table 3. Load capacity of cylinders and prisms

S.F V_f (%)	Load Capacity of (kN) Prisms	Cylinders
0	8.28	117.06
0.50	9.05	109
1.00	12.14	145.6
1.50	17.9	207.15



(a)



(b)

Figure 5. Shear and flexural strength behaviour

The cylindrical specimen without steel fiber achieved 3.70 MPa in splitting tensile strength; this result was decreased when adding 0.5% (39.25 kg) steel fiber to the concrete mix and having an increase in the 1.0% (78.50 kg) steel fiber, and getting maximum capacity when 1.50% (117.75 kg) of steel fiber V_f used, this explains that the addition of steel fiber can improve the shear behaviour of the concrete mixtures. This advancement in shear strength was due to the improved mixtures tensile capacity, which occurs owed to the reinforcing action of the steel fibbers. Moreover, the steel fiber increased the energy absorption capacity and improved ductility characteristics. The 1.50% (117.75 kg) fiber content recorded the maximum shear strength of about 6.36 MPa, and it can contribute to shear in RCB by replacing the amount of the required stirrups for the RCB; furthermore, the fibers delayed the onset of cracks and promoted multiple cracks, leading to a more ductile failure mode than traditional concrete beams [38]. The flexural strength (modulus of rupture) was evaluated by testing steel fiber-reinforced concrete prism specimens and calculated from Eq. (2) [35].

$$fr = \frac{PL}{bd^2} \quad (2)$$

where, P is applied load, L is span length, b and d are width and depth.

The modulus of rapture obtained from loads shown in Table 3 declared that flexure strength gradually improved with increased steel fibre V_f content and reached a maximum at prism with a 1.50% steel fibre V_f of about 116.53% compared with prism without steel fibres.

3.1.2 Compressive strength

The effect of steel fibre content on compressive strength appeared in Figure 6, showing 40.50 MPa for cubes without steel fibre. It can be noticed in this work that the addition of steel fibres to normal-strength concrete mixtures has little outcome on compressive strength; 0.50% and 1.00% of steel fibre V_f decreased the compressive strength of concrete mixtures, while 1.50% of V_f caused an increase, which achieved about 43.20 MPa. A similar behaviour was also observed in Miao et al. [39] and Ou et al. [40]. These results declared that the normal concrete mixture design with f_c 35 MPa required a percentage of 1.50% of steel fibre V_f to improve the compressive strength, also, it was compatible with Behbahani et al. [38] and Tanoli et al. [41] test results. The addition of steel fibres V_f to the concrete mixture may cause fibres to interlock, which can lead to issues such as balling or clustering of steel fibers, causing poor mixing and reduced workability of the concrete; for this issue, the superplasticizer content increased when the steel fiber V_f ratio increased [42].

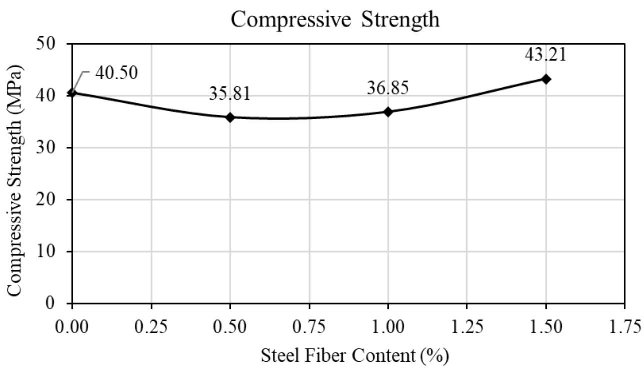
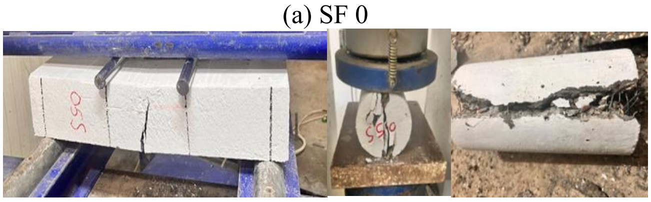
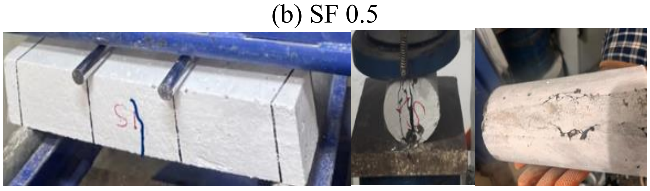


Figure 6. Steel fibre content influences on compressive strength

(a) SF 0



(b) SF 0.5



(c) SF 1.0

(d) SF 1.5

Figure 7. Failure mode of prisms and cylinders samples

Table 4. Mechanical characteristics and strength effectiveness

Strengths (MPa)	Compressive		Splitting Tensile		Flexural (Modules of Rapture)	
V_f (%)	Meas.	Effect	Meas.	Effect.	Meas.	Effect.
0.00	40.50	–	3.70	–	4.78	–
0.50	35.81	-11.58	3.47	-6.21	5.23	9.41
1.00	36.85	-9.01	4.60	24.32	7.03	47.07
1.50	43.21	6.70	6.36	71.90	10.35	116.53

Table 4 demonstrates the effectiveness of splitting tensile strength, modulus of rupture, and compressive strength results from steel fibre concrete mixtures included.

The failure modes in mechanical characteristics samples (prism and cylinder samples) are indicated in Figure 7. Prism specimen failure explains that a prism without steel fibre distributed and splits into two pieces because it is under reinforcement; the second with V_f 0.5% steel fibre has a wide crack failure, and the diameter of this crack decreased by using V_f 1.0% steel fibre in the third specimen. Meanwhile, the fourth one, which contains V_f 1.50% steel fibre, shows higher resistance against cracks and failure in the diagonal shear mode because the effective bond between concrete and hooked-end steel fibre assists against defects and cracks and absorbs energy from applied loads, which leads to improving toughness and making the RCB more resistant to failure [43].

The test specimen cylinder without steel fibres split the specimens into two parts through the testing process and the addition of steel fibres enhances the toughness of the concrete cylinder by increasing its resistance to cracking, particularly under shear loading conditions. The hooked-end steel fibres help to bridge the cracks formed in the concrete, thereby inhibiting their propagation and increasing the cylinder's shear strength and redistribution stresses in microstructure [44].

3.2 Structural performance

3.2.1 Load deflection response

The group SF0 the RCB-0 first crack appeared at 15.00 kN of load, with a mid-span deflection of 1.80 mm. The loading continued until the RCB-0 failed at a peak load of 22.10 kN and a deflection of 9.36 mm. The beam's tensile reinforcement was less than the reinforcement of the balanced section. As a result, the tensile reinforcement reached its yield strength (f_y) before the concrete reached its compressive strength 0.85 f_c, causing the strain in the tension reinforcement to reach the yield strain (ε_y). In contrast, the strain in concrete at its maximum (ε_c) reaches the value 0.003. This type of failure is preferable to other types because it gives warning indicators before collapse through the appearance of cracks and gradually increasing delamination, providing the opportunity or space to avoid sudden collapse. In this type of failure, the reinforcement steel yields before cracking occurs in the concrete. The RCB-0 section contains a small amount of flexural reinforcing steel. The reinforcement of the RCB-0 was improved by adding hooked-end steel fibre reinforcement to investigate the influences of the steel fibre on the shear and flexural performance of the RCB without stirrups, The ratio 0.5% V_f of (39.25 kg) in group SF 0.5; the RCB-0.5 testing appears delayed in the first crack load, which is equal to 20.00 kN with 1.96 mm in mid-span deflection and increasing in the peak load of 32.50% (29.30 kN) with increasing of 5.10% (9.84 mm) in deflection. The second ratio of steel fibre (group SF1) was 1.0% of the V_f (78.50 kg); the testing result of RCB-1 declared significant improvement in the first crack load, which reached 23.80 kN with 2.05 mm deflection, and the beam failure load happened at 36.00 kN with deflection of 7.30 mm, the load caring capacity of the RCB-1 in this ratio enhanced by 62.40% from the load in reference beam (RCB-0) and the deflection decrease by 22.0%. In comparison, the third ratio of V_f steel fibre is 1.50% (117.75 kg) in group SF 1.5; the RCB-1.5, resulting in 28.00 kN for first crack loading corresponding to 2.61 mm deflection. The RCB-1.5 still caring load until failure at 37.60 kN, which represents the maximum peak load increasing by 70.13% from the load in RCB-0 as well as controlled the mid-span deflection to reach 5.65 mm, causing a reduction by 39.64%, as shown in load-deflection curves in Figure 8, which exhibited a comparison between the RCB-0 (without steel fibre) with the other specimens (RCB-0.5, RCB-1 and RCB-1.5) that contain a different ratio of steel fibres v_f. Also, the influences on the first crack loading are shown in Figure 9, These curves explain the optimum ratio of hooked-end steel fibre v_f that can control mid-span deflection of about 1.50% in this study, which exhibited the maximum ultimate load. This is due to getting solid bond interactions between steel fibre and concrete matrix decreases the number of cracks, and as a result, toughness improves. Also, the increasing steel fibre v_f increased ductility and improved shear strength in concrete were previously reported [45].

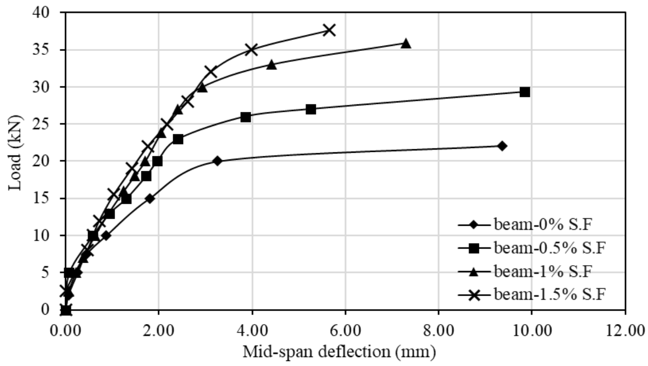
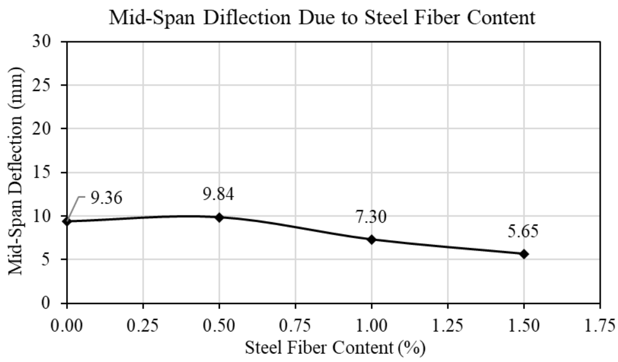
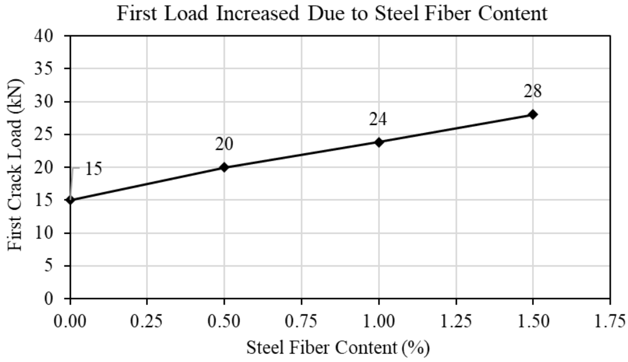


Figure 8. Load-deflection (beam with and without steel fibres)



(a)



(b)

Figure 9. Steel fibre content influences on first crack load and mid-span deflection

3.2.2 Failure mode

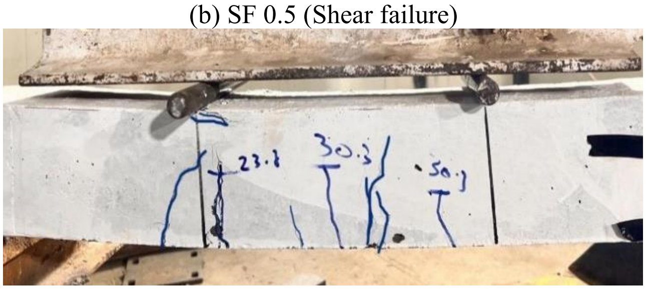
The failure mechanisms of SFRC beams are complex, involving the interaction between the concrete matrix and the steel fibers, particularly the hooked-end fibers. These mechanisms can be categorized based on the type of loading (e.g., flexural, shear, or combined) and the behaviour of fibers under stress. Hooked-end fibers improve the shear capacity of beams by bridging shear cracks and providing a mechanism for stress redistribution. In flexural loading, cracking initiates in the tension zone, and hooked-end fibers help resist crack opening. With higher fiber content V_f, the beam exhibits more ductile behaviour, characterized by multiple cracks before the ultimate failure. At ultimate load, failure may occur due to crushing of the concrete in the compression zone, particularly if the fiber content primarily enhances tensile resistance without significantly altering compressive behaviour. The hooked ends significantly enhance the bond strength, reducing the likelihood of slip and improving the overall load transfer efficiency [46, 47].

The failure modes of the RCB-0 to RCB-1.5 are shown in Figures 10(a) to 10(d), respectively. The crack pattern of the RCB-0 forms with the growth of vertical cracks (flexural cracks) at the base of the beam due to flexural tensile stress. Then, as the load on the RCB-0 rises, this crack extends both in width and length and curves in a diagonal direction as it transfers to the upper part of the beam toward the loading point; this failure mode is a shear failure as shown in Figure 10 (a), this is attributed to the lack of shear reinforcements, no stirrups reinforcement set to control the shear failure which causes shear force exceeds the shear capacity of different materials of the RCB resulting from shear resistance lower than flexural strength of the RCB [48, 49]. This failure shear classified as diagonal tension failure, occurred because it was under-reinforced; the reinforcement ratio in the RCB-0 is lower than the balanced reinforced ratio and its agreement with Abbass et al. [50].

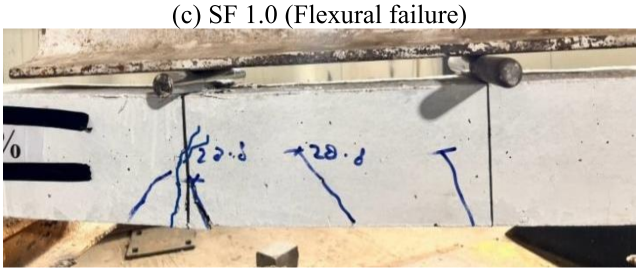
The RCB-0.5 with V_f 0.5% steel fibre in a concrete mixture resulted in a composite material that enhanced shear resistance effects and improved the behaviour of the RCB-0.5; the concrete tensile failure mode happened due to shear forces. As a result, the crack width is decreased, and the stress distribution becomes more uniform compared to RCB-0. It also increased ultimate load and shear strength, lessening dependence on stirrups, as shown in Figure 10(b). The increase of steel fibre V_f from 0.5% to 1.0% and 1.5% in the RCB1, and RCB1.5 appeared to gradually improve in post-cracking behaviour and fewer cracks' distributions in mid-span; it occurred because hooked-end steel fibres enhanced shear resistance properties and depended on shear resistance on the main reinforcements of the RCB. This behaviour allowed for higher loads to be carried before shear failure occurred, and then its failure was flexural as appeared in Figure 10(c), and Figure 10(d) agreement with Kwak et al. [11], Yuan et al. [51], and Biolzi and Cattaneo [52].

(a) SF 0 (Shear failure)

(b) SF 0.5 (Shear failure)



(c) SF 1.0 (Flexural failure)



(d) SF 1.5 (Flexural failure)

Figure 10. Failure mode of RCB

4. CONCLUSIONS AND RECOMMENDATIONS

The conclusions can be deduced from the findings of this experimental study:

1) Hooked-end steel fibre-reinforced concrete is especially effective in resisting the creation of shear cracks under lower loads than non-fibre-reinforced concrete and reducing cracking by preventing the propagation of small cracks in the concrete by bridging and restricting them and reducing crack width procedures.
2) To protect the beam against sudden brittle failure, minimum shear reinforcement can be demanded by utilizing the steel fiber volume fraction ratio of the of the upper 1.0% in the concrete mixture, which occurs when the RCB is subjected to bending. Also, the shear mechanism can transform from brittle into a ductile flexural mechanism by including steel fiber in concrete RCB.
3) The increase of steel fibre V_f from 0% to 1.5% can enhance shear and flexural effectively in reinforced concrete elements. The ratio of 1.50% steel fibre V_f can improve the load carried by the RCB by 70.13% with a reduction in mid-span deflection of 39.64% as compared to the RCB without steel fibre and showed more resistance to deformation and cracking.
4) Superplasticizers can improve the workability of concrete mixtures containing steel fibres. It gradually increases with steel fibre volume fraction increases, reducing the water demand, as well as improving the flowability of the mixtures, which can contribute to a more homogenous distribution of steel fibres throughout the concrete and minimise steel fibre interlock in the concrete mix by optimising particle dispersion of steel fibre among the mixtures.
5) Hooked-end steel fibres in NSC have a limited effect on concrete's compressive strength, depending on the steel fibre v_f proportion and proper mix design. A 1.5% SF V_f improves compressive strength by 6.69% compared with concrete without steel fibre.
6) The authors are recommended for future studies to examine the long-term durability properties and the reinforced concrete beam behaviour under dynamic loads. Likewise, try different sizes of steel fiber and compare the beam behaviour under each volume.
7) The authors recommend that finding additional results, such as crack propagation, ductility index, toughness, etc., would provide more insights into the effects of steel fiber.

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