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A review of the effect of steel fibers on the shear capacity of concrete beams without shear reinforcement

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Abstract

The shear strength of reinforced concrete beams is largely governed by the compressive strength of concrete, which represents a major component of the overall shear capacity. Incorporating steel fibers into the concrete matrix has been shown to enhance this capacity and significantly improve structural performance. A comprehensive review of previous experimental studies indicates that the shear strength is primarily influenced by the longitudinal reinforcement ratio and the shear span ratio (a/d), while the effect of compressive strength becomes more evident in high strength concrete. It was also observed that the inclusion of steel fibers at a volume fraction of approximately 0.75% can increase the shear strength of beams by 25-35% compared with plain concrete specimens. Moreover, steel fiber-reinforced beams demonstrated superior crack control and enhanced ductility, thereby reducing the risk of sudden brittle shear failure. Notably, the improvement in shear behavior was found to be relatively independent of the fiber type, while the overall workability of the concrete remained within acceptable limits. These findings highlight research gaps regarding the optimum fiber dosage under different loading conditions and long-term performance.

Keywords: *Steel fibers, Concrete Beams, Fiber-Reinforced Concrete (FRC), Shear Strength, Shear Failure, Shear Span Ratio(a/d), Compressive Strength.*

1. Introduction

Understanding the properties and structural behavior of concrete is crucial because it is the most widely used construction material in the worldwide and is employed in diverse structural applications. The behavior of reinforced concrete (RC) members depends primarily on two materials: concrete and steel. Although concrete is strong in compression, it is weak in tension [1]–[3], which makes shear failure one of the most brittle and dangerous modes in RC beams. Conventionally, stirrups are provided to resist shear stresses [4]. However, when high shear demand requires closely spaced stirrups, construction difficulties such as honeycombing and poor bonding may occur. For this reason, steel fibers have been introduced as a potential alternative or supplement to transverse reinforcement. Unlike flexural reinforcement, steel fibers are randomly distributed within the matrix and mainly enhance shear resistance by bridging cracks and improving ductility, without compromising compressive strength [1]-[2]

Although numerous studies have examined the shear behavior of concrete, the mechanism of shear failure remains complex and not fully understood. The shear capacity of beams is strongly influenced by compressive strength, yet due to the brittle nature of concrete, shear failure often occurs suddenly without warning [7]. For more than four decades, researchers have investigated the use of fibers to partially replace stirrups, with the goal of improving ductility and load capacity. This has led to the development of fiber-reinforced concrete (FRC), which can incorporate steel fibers (SF), natural fibers [8] [9], or synthetic fibers[10][11] each offering different mechanical benefits.

1.1 Steel fiber

It is non-continuous fibers distributed randomly within the concrete matrix. It is made from cold-drawn steel wire with a low percentage of carbon or stainless-steel wire. It is distinguished by its ability to improve the properties of concrete, such as resistance to tensile and shrinkage, controls the development of cracks, as well as increases the durability of the concrete matrix. It transforms the fracture mechanics of concrete from a brittle and sudden fracture to a ductile and gradual fracture, thus reducing the risk of failure. It transforms the mechanical properties of concrete from a brittle material to a ductile material capable of absorbing the applied stresses[12].

Steel fibers come in different shapes, including straight, hook-end, crimped, stranded, and twisted, as shown Fig.1. Steel fiber-reinforced concrete is less expensive than the hand-tied form of reinforcement bars[13]. Fiber geometry and volume fractions have an obvious effect on the strength and behavior of concrete [14]. Steel fibers usually have equivalent diameters (depending on cross-sectional area) ranging from 0.15 to 2 mm and lengths ranging from 7 to 75 mm. Aspect ratios typically range between 20 and 100 [15].

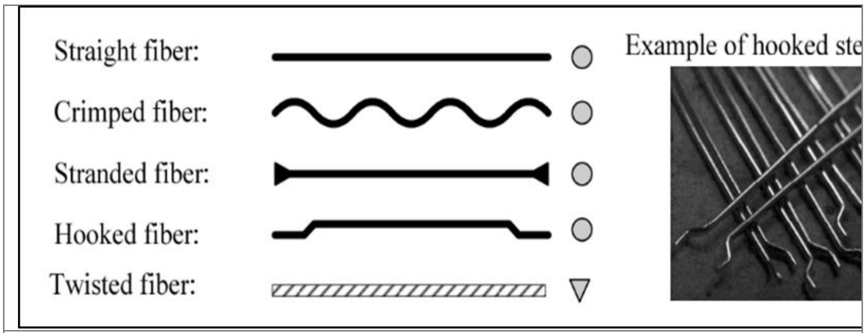

Fig. 1: Types of steel fiber [15]

In 1874, the concept of fibrous concrete began to emerge, which is ordinary concrete composed of cement and aggregate and containing short, non-continuous fibers randomly distributed within the concrete matrix[16]. Using superplasticizers can improve the workability of concrete mixture and reduce the phenomenon of steel fiber agglomeration. The agglomeration phenomenon depends on many factors, such as the shape, length, surface roughness, aspect ratio of steel fiber. The main purpose of adding steel fibers is to increase ductility and tensile strength and control cracks within the concrete matrix. Fibrous concrete must meet both economic and efficiency requirements to be able to be used in construction work.

There are four types of fiber-reinforced concrete (FRC), including steel fiber-reinforced concrete (SFRC) [17], glass fiber-reinforced concrete (GFRC) [18], natural fiber-reinforced concrete (NFRC) [19], and synthetic fiber-reinforced concrete (SNFRC) [20]. Many previous studies have proven that concrete with steel fibers has higher ductility and resistance compared to concrete with glass fibers and polypropylene fibers [16]. Subsequently, researchers examined how different types of steel fibers affect the behavior of concrete. These studies showed that hooked-end steel fibers are more effective in improving the flexural and compressive behavior of concrete compared to straight and crimped fibers [21]. The use of randomly distributed steel fibers within the concrete matrix represents a good alternative method to increase the shear strength of RC beams. However, the role of steel fibers in the shear behavior of beams is not fully understood, which limits the exploration of the advantages of using steel fibers to enhance shear resistance [15].

There are many areas of use of fibrous concrete, such as paving roads and airport runways, hydraulic structures, heat-resistant concrete, precast concrete, shell ceilings, and the bases of machines that generate vibration. It is preferable to use steel fibers in these buildings because it is considered a useful and effective option that improves the engineering performance of these important structures [22].

When a concentrated force is applied to the center of a simply supported beam with a rectangular cross-section, moment and shear forces cause flexure stress and shear stress, respectively, in every part of the beam. When taking a section at a distance (x) from the support, the internal stresses are distributed over the cross-section of the beam; the maximum normal stresses are at the top and bottom of the beam's surface.

The compressive stress represents the stress at the top of the beam surface, while the tensile stress represents the stress at the bottom of the beam. As the loads continue to apply and approach the ratio ($0.62\sqrt{f_c'}$) represented by the flexural stress of the

concrete[16] flexural cracks start to appear in the mid-span beam due to the brittleness of the concrete and its weakness in resisting tensile stress.
After the concrete fails to resist this type of stress, the role of longitudinal tension reinforcement comes in resisting the stress. It significantly increases the strength of the beam and is more resistant to the development of flexural cracks. Inadequate beam reinforcement and exposure to stresses above its capability can cause the reinforcement to yield. This results in the beam failing in flexural. However, if the beam is adequately reinforced with flexural reinforcement, it will increase the tensile strength of the concrete. Increasing applied stresses because multiple cracks to appear and develop along the beam span in the region confined between the support and the load. This results in an interaction between flexural stress and shear stress. These interactions between stresses produce shear flexural cracks. Increasing stresses generate a diagonal shear crack, which appears at the middle depth of the beam, as demonstrated in Fig.2.
The role of shear reinforcement becomes more pronounced, as it is considered the only effective part after the appearance of the diagonal crack [23].
It is responsible for resisting stresses and reducing the speed of development of the diagonal crack. It increases the shear resistance of the compression zone, confines the concrete, and prevents the failure of longitudinal reinforcement by slip. So the components of the concrete remain interfering with each other, including the aggregate, which has a role in resisting the shear. There is an interaction between the basic components of concrete that contribute to shear resistance according to their roles. This includes the compressive strength of concrete, the interlock of aggregate, longitudinal reinforcement, and transverse reinforcement (stirrups) [24].

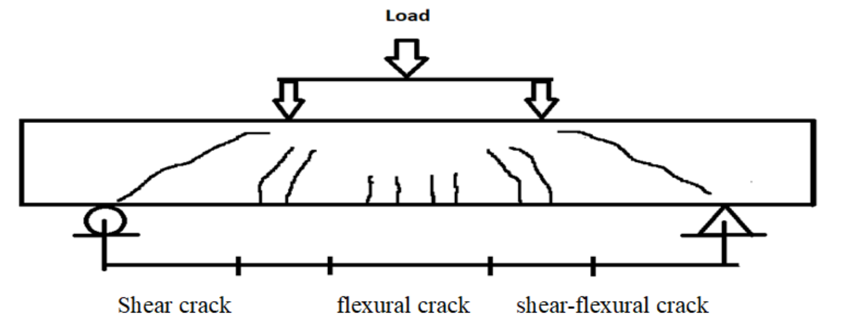

Fig. 2: Crack pattern of simply supported beam [24]

2. Theoretical Survey

The stress distribution mechanism for fibrous concrete follows the same method mentioned for reinforced concrete. The steel fibers replace the shear reinforcement (stirrups), as the steel fibers take on the role of transverse reinforcement in resisting the shear stresses of reinforced concrete. Steel fibers retard the growth and extending of cracks and delay the slip failure of longitudinal reinforcement [23]. Steel fibers are efficient in controlling the width of cracks, the speed of their development, and the formation of diagonal cracks because the fiber is distributed widely within the concrete matrix, unlike transverse reinforcement, which is in specific places [25].
Despite this, one of the most important problems in analyzing the shear strength of fibrous concrete is the distribution of steel fibers within the concrete matrix. It is expected that not all steel fibers will be in the direction that contributes to resisting the shear stresses of the concrete and which improves the mechanical properties of the concrete matrix [26]. In general, the factors that can affect the shear strength of fibrous concrete subjected to a concentrated and uniform force and supported are the cross-section shape of the beam, beam depth, the ratio of tensile reinforcement, the compressive strength, the maximum size of aggregate [1]. As well as the characteristics of the steel fibers, such as type and aspect ratio (ratio of length to diameter), and the volume fraction [14], [27].

2.1 Discussing Shear Strength Tests of Reinforced Concrete Beam (Rc) Without Shear Reinforcement

Many previous researchers have studied the shear strength of normal strength reinforced concrete (NSRC) and high-strength reinforced concrete (HSRC) without shear reinforcement because it is a brittle material and can fail suddenly without any initial indications. Their studies discussed the most important factors that affect shear strength and cause an increase or decrease in beam capacity. In this part, a summary was prepared by a group of researchers that studied the shear strength of concrete beams without shear reinforcement. Some of these studies are:
Taylor [28] presented an experimental study on the shear strength of reinforced concrete beams without stirrups, under the influence of both the amount of longitudinal reinforcement, the compressive strength of concrete, and the method and location of loading. The test was conducted on concrete beams of rectangular cross-section. The test results showed that the diagonal

crack load increases with increasing concrete strength and increases at a lower rate with increasing the amount of longitudinal reinforcement. As for the effect of the shear span, the diagonal crack load decreases as the shear span increases, but as the crack widens, the specimen loses its bearing capacity.
Salau & Balogun [29] studied the shear strength of reinforced concrete beams without shear reinforcement under the influence of load locations, the amount of longitudinal reinforcement, as well as the laterite content ratio. Lateritic concrete is defined as that which contains soil of lateritic origin as a complete or partial replacement for fine aggregate. Forty-six specimens with a rectangular cross-section with dimensions (150mm, 150mm) and a length of 750mm were prepared. Thirty-two specimens of the total number of specimens are lateralized concrete containing laterite at a rate of (25, 50, 75, and 100%) of the amount of fine aggregate, and six specimens have different percentages of longitudinal reinforcement (1.81, 2.28, and 2.75%), while the remaining eight specimens contain ordinary concrete with a longitudinal reinforcement ratio of 1.21% and used as a reference specimen. Shear span to the effective depth ratio ranges between (0.5–2) and an increase of 0.5. Also the maximum crushing load decreases with an increase in the percentage of laterite, while the failure mode does not depend on this percentage but depends on the shear span. Also, it recorded that, the ultimate shear stress of the lateralized concrete increases with an increase in the amount of longitudinal reinforcement. Their results also showed that the presence of laterite in the concrete improves its ability to resist cracking due to the high ductility, hardness, and high control over cracking of the laterite content compared to normal concrete.
Wafa [30] prepared an experimental study on the shear behavior of high-strength concrete beams without stirrups. Eighteen specimens with a rectangular cross-section with dimensions of (125 mm, and 250mm) (width, and height) were prepared. All specimens were reinforced with flexural reinforcement only, without shear reinforcement, and were tested under two-point load until failure. The effect of shear span to effective depth ratio as well as the longitudinal reinforcement ratio was studied. Their results of the tested specimens showed that shear capacity decreases as the ratio of shear span to effective depth increases. Their results also showed that beams reinforced with low ratios of flexural reinforcement fail in flexural, regardless of the value shear span (a/d). Two empirical models were proposed to predict the best shear capacity of high-strength concrete beams without stirrups.
Sneed [31] presented an experimental and analytical study to clarify the role of beam depth in the shear strength of concrete beams without shear reinforcement. Eight specimens were designed, cast, and tested until failure. The data for this test were collected with data adopted from previous literature to obtain a broad database showing the effect of effective depth on shear strength. Their results showed that the effective depth has an impact on the mechanisms of shear transfer and influences the relative behavior and shear strength. The geometry of the specimen affects, in particular, the mechanisms of the arch action, the dowel action, and interface shear transfer, as an increase in the effective depth leads to an increase in the beam's shear strength.
Saqan & Frosch [32] studied the shear capacity and behavior of reinforced concrete beams without shear reinforcement under the influence of flexural reinforcement (normal and prestressed) of concrete sections. Nine specimens with a large rectangular cross-section without transverse reinforcement were prepared. Flexural reinforcement was of two types: prestressed bars and regular reinforcement bars. For this reason, the specimens were divided into three groups, each group containing one specimen with prestressed bars and the other with different proportions of reinforcing bars. All specimens were supported and tested by simply applying a single concentrated force at the center of the specimen with a constant shear span to effective depth ratio of 3.33. Their results showed that flexural reinforcement (prestressed or normal) has an important role in the shear strength of prestressed concrete sections. Also it showed that there is a strong relationship between the depth of the neutral axis and the shear strength of the concrete section.
Hamrat et al. [33] studied the shear strength of reinforced concrete beams without stirrups for normal and high-strength concrete. Beam failure was studied under the influence of the shear span to effective depth ratio, the longitudinal reinforcement ratio, and the compressive strength of the concrete. Sixteen reinforced concrete specimens were tested without stirrups. During the test, the maximum load of the specimens was recorded, and digital video recording was also used to continuously monitor shear cracking in terms of crack development and propagation. After recording and analyzing the experimental test results, it was shown that shear strength is primarily influenced by the flexural steel ratio and the shear span ratio, as well as to a lesser extent by the compressive strength in the case of high-strength concrete (HSC).
Thamrin et al. [34] introduced an experimental study on the shear strength of reinforced concrete beams without shear reinforcement under the influence of both the cross-section shape of the beam as well as the ratio of longitudinal reinforcement. Six simple reinforced concrete beams were prepared without shear reinforcement, consisting of three beams with a rectangular section with dimensions (125 mm width, and 250mm height), three beams with T cross-sections with dimensions (250mm flange width, 70mm flange thickness, 125mm web width, and 250mm web height), and three different ratios of longitudinal reinforcement (1, 1.5, 2.5%). All specimens were tested under a two-point load until failure. During their test, both the values of the diagonal crack loads and the maximum load were recorded. Their results showed that the shear capacity is significantly affected by changes in both the cross-section shape and the ratio of longitudinal reinforcement, as the shear capacity increased by 5–20% for the T-section beam when compared to the rectangular cross-section beam. Also, from their results were recorded, the angle of the diagonal crack in the shear span zone is affected by the percentage of longitudinal reinforcement, so it decreases with the increase in the percentage of longitudinal reinforcement, regardless of the section shape.

Deng et al. [35] introduced study about the shear behavior of reinforced concrete beams without stirrups under the influence of coarse aggregate size. Eight specimens with a rectangular cross-section with dimensions (200mm width, 400mm height) were prepared and divided into two groups with two different ratios of shear span to effective depth (2.2, 3), and four different sizes of coarse aggregate (10, 20, 31.5, 40mm) were used in each group. After conducting their test and analyzing their results, it found that the effect of the maximum size of the aggregate on the tensile strength of the concrete was small, but it improved the shear strength of the concrete beams without stirrups. Their results also showed that beams with a high ratio (a/d) showed more brittle features.

2.2 Shear Strength Tests of Steel Fiber Reinforced Concrete Beams (SFRC) Without Shear Reinforcement

Kwak et al.[12] conducted a study on the shear strength of concrete beams reinforced with steel fibers. Twelve specimens with a rectangular cross-section with dimensions (125mm width and 225mm height) were prepared and tested until failure to evaluate the effect of the volume fraction of steel fibers, shear span to the effective depth ratio, and the compressive strength of concrete on the strength and ductility of the concrete beams. Their experimental results showed that normal stress at the shear crack and the maximum shear stress increase with an increase in both the percentage of steel fibers and the strength of the concrete but decrease with an increase in the shear span to effective depth ratio.

Kumar et al.[36] prepared an experimental study about the efficiency of steel fibers in shear strength to reinforced concrete deep beams with and without transverse reinforcement. The experimental program for their study consists of eighteen simply supported specimens with a rectangular cross-section (90mm, 260mm) width and depth, respectively, with different ratios of transverse reinforcement (0, 0.25, 0.5), steel fibers (0, 1, 1.25%), and shear span to effective depth (0.75, 1, 1.25). Their results showed a noticeable increase in the first crack strength and the maximum shear strength of beams reinforced with steel fibers. This increases as the percentage of steel fibers increases. These results confirm the possibility of replacing the minimum ratio of transverse reinforcement with steel fibers.

Dinh [23] studied the behavior of concrete beams reinforced with steel fibers. It was focused on study the maximum shear strength and the possibility of replacing the minimum shear reinforcement with steel fibers. Also the efficiency of steel fibers studied in reducing the shear-size effect of concrete beams. Twenty-eight relatively large, simply supported specimens were prepared under four-point loading to conduct the shear test. A set of parameters was adopted to be studied in this research, including type of fiber, volume fraction of steel fiber, the ratio of longitudinal reinforcement, and the depth of beam. This result showed that using hook-end steel fibers at a rate of 0.75% or more can achieve a noticeable improve in shear strength and reduce the effect of shear strength for beams with large depths. These results also showed that hook steel fibers can be used as a safe alternative for the minimum amount of shear reinforcement for reinforced concrete beams with normal strength.

Minelli & Plizzari [37] studied the shear strength of concrete beams reinforced with steel fibers without shear reinforcement. Nine full-size specimens with a rectangular section of width (250mm) and variable height (500, 1000, and 1500mm) were prepared. In addition to studying the shear strength of the specimens, it was focused on studying the hardness of fibrous concrete. Their results showed that reinforcing concrete with small percentages of steel fibers can significantly increase the bearing capacity and ductility so that it can give an initial indicator before failure and collapse.

Sahoo et al. [38] evaluated the effect of the type and size of steel fiber on the shear strength of reinforced concrete specimens without stirrups in the shear span. The experimental study was carried out on seven concrete specimens with dimensions (150mm width, 200mm height) and a clear span (1800mm) and use two types of fibers, including steel and polypropylene, with a volume fraction of 0.5–1% for each type. All specimens were simply supported and tested under three-point loading. After conducting the examination, their results showed that the specimen reinforced with steel fibers only at a rate of 0.5% recorded shear strength similar to the shear strength of the reference specimen without stirrups, while adding polypropylene fibers only at a rate of 1% led to a decrease in shear strength compared to the reference specimen without stirrups. However, their study proved that adding steel fibers at a rate of 1% and polypropylene at the same rate to the concrete mixture leads to an increase in shear strength and susceptibility to deformation by 20% and 40% respectively, compared to the reference specimen.

Merdas et al. [39] investigated the shear strength under the effect of replacing 50% of natural coarse aggregate (gravel) with recycled aggregate (crushed brick) as well as the effect of steel fibers. Five concrete beam specimens have dimensions (2, 0.3, 0.2 m) (length, depth, width), respectively. The founding determined that replacing 50% of natural aggregate with recycled aggregate decreased ultimate shear strength, while adding 1% steel fiber by volume resulted in an increase of 31.8%. The effect of steel fiber 0.5%, 1% for the ordinary concrete increases the shear strength by 18.3%, 30.8%, respectively.

Yoo et al. [40] studied the possibility of using deformed steel fibers as an alternative to minimum shear reinforcement in reinforced high-strength concrete (HSC). To verify this, five large-sized concrete beams were prepared with steel fibers, with and without stirrups. The test results showed that using steel fibers in 0.75% of the concrete volume without stirrups can increase beam strength, as the presence of steel fibers transforms the failure mode of the specimens from concrete crushing failure to flexural failure. Thus, the effectiveness of steel fibers can be confirmed by 0.75% of the concrete volume as an alternative to the minimum shear reinforcement.

Ulzurrun & Zanuy [41] determined the possibility of improving the impact resistance of concrete specimens without stirrups by using steel fibers. A group of specimens with a rectangular cross-section with dimensions (125mm width and 250mm height), and a length of 2000mm were prepared while maintaining a constant ratio of longitudinal reinforcement and shear span to effective depth. The effect of the steel fiber content (0, 0.5, and 1%) and the type of steel fiber (hooked, smooth, and prismatic) was considered. Their results showed that specimens not reinforced with steel fibers can fail by brittle impact, but the presence of steel fibers with a ratio of 0.5% can achieve shear failure of the specimens, but the effect of this ratio depends on the type of steel fibers, as it is achieved with steel fibers of the (hooked and prismatic) type, but it is not possible with smooth fibers, while the presence of steel fibers at a rate of 1% regardless of the fiber type can change the failure mode to flexural failure.

Yuan et al. [42] prepared an experimental study to determine the shear behavior high-strength concrete beams (HSC) under the influence of different reinforcements. Five large concrete beams were prepared and cast with dimensions of (300 mm, 500 mm, and 4400 mm) (width, height, and length). All beams were simply supported and tested under four-point loading until failure. Using two types of reinforcement: one specimen reinforced with steel fibers as an alternative to stirrups, and other specimens reinforced with stirrups at variable distances. Their test results showed that the shear strength of specimens reinforced with steel fibers (0.75%) by volume of concrete is higher and is more efficient in controlling shear cracks compared to specimens with a minimum amount of shear reinforcement.

Bui et al. [43] demonstrated the behavior of concrete beams without stirrups under the influence of steel fibers. Four specimens with dimensions (80mm, 150mm, and 1700 mm) (width, height, and length) respectively, were prepared and cast to study the possibility of completely replacing traditional transverse reinforcement (stirrups) with steel fibers, also verifying the possibility of steel fibers improving the mechanism of action of longitudinal reinforcement. Their experimental test results demonstrated the possibility of using steel fibers (1.27%) as a percentage of the concrete volume as an alternative to transverse reinforcement. It also demonstrated the efficiency of the reinforcement in recording better bending strength if steel fibers were mixed with it.

Shoukry et al. [44] presented an experimental study to test the effect of shear strength of fiber-reinforced concrete beams without stirrups. Twelve simply supported rectangular specimens were prepared and tested under a single concentrated load. The specimens were divided into two groups: six containing steel fibers as web reinforcement and the other containing traditional stirrups. The effect of the volume fraction of steel fibers (0, 0.5, 1, 1.5%) and the type of fibers (end hooked, corrugated), as well as the effect of the minimum stirrups were studied while keeping the dimensions of the cross-section of the specimen, the shear span ratio, the length of the specimen, as well as the ratio of longitudinal reinforcement constant. During the test, the crack propagation methods, failure mode of the specimens, deflection of the specimens, and strain of the longitudinal reinforcement were recorded and monitored. Their test results showed that the first shear crack and maximum shear stress increased significantly with increasing fiber volume content. In addition, it was shown that the addition of steel fibers by 1.5% with a minimum amount of stirrups could change the brittle shear failure mode to ductile flexural failure.

Merdas et al. [45] studied the shear strength of steel fiber-reinforced concrete beams without shear reinforcement, considering the effects of tensile reinforcement ratio, compressive strength, shear span ratio, and aggregate type. Thirteen beam specimens tested. The results showed that increasing the compressive strength enhanced the maximum shear strength by up to 60%, while increasing the flexural reinforcement ratio improved it by 53%. In contrast, an increase in the shear span ratio reduced the shear strength by about 30%. Replacing 50% of the natural coarse aggregate with recycled aggregate decreased the maximum shear strength by 10%. Steel fibers improved beam behavior by 18% with volume fraction 0.5%, and by 30-50% when the fiber content was increased to 1% of concrete volume.

2.3 Effect of steel fiber type

Soulioti et al. [14] examined how the volume percentage and shape of the steel fiber affected the SFRC's flexural performance. There were two steel fiber geometries utilized, as shown in Fig.3. The first form was waved steel fiber with a 33-aspect ratio; the other was a 41-aspect ratio steel fiber with hooked ends. Four steel fiber volume fractions, ranging from 0.0 to 1.5% with a 0.5% interval, were used in the investigation. Overall, their experimental results showed that fiber, particularly at high fiber volume fractions, is crucial in improving the mechanical characteristics of concrete. However, it reported that when the amount of fiber in the concrete mix increases, the workability considerably reduces. As a result, the consolidation process of FRC would be extremely challenging, leading to higher air content in the mixture. In addition, analysis of compressive strength results indicated that fiber had little effect on the compressive strength of concrete.

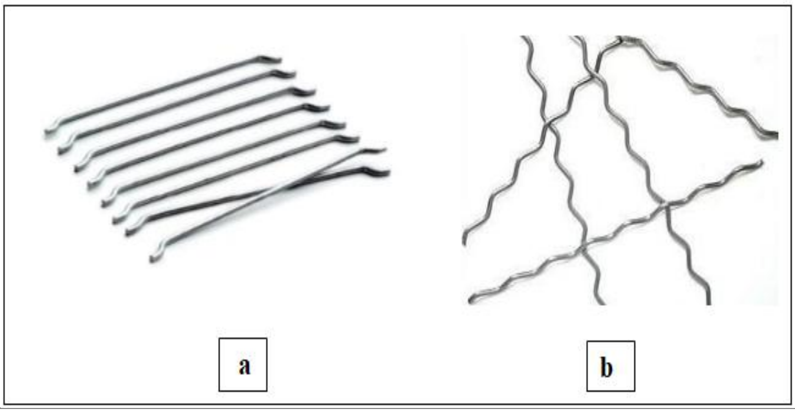

Fig. 3: Types of steel fiber used (a) Hook end (b)waved [14]

Sinha & Verma [27] studied the effect of crimped flat-shaped steel fibers on the strength properties and workability of high-strength concrete (60MPa), as shown in Fig.4. Fibers with an aspect ratio of (50) were incorporated at different volume fraction (0, 0.5, 0.75, 1, 1.25, 1.5, and 2%). Compressive strength was measured using standard cubes, tensile strength using standard cylinders, and flexural strength using prisms. The test results showed that the optimum fiber content was1% by volume, which increased compressive and tensile strength of 3.7% and 22%, respectively. Higher fibers contents produced adverse effects on compressive and tensile strength due to the fiber agglomeration and weak bonding with concrete matrix. Conversely, flexural strength continued to improve, showing an 18% increase at 2% fiber volume, attributed to bridging action of steel fibers across cracks during loading.

Fig. 4: Crimped flat-shaped steel fibers used by Sinha and Verma [27]

Yang et al. [46] conducted a comparative study on the flexural response of high-strength fibrous reinforced concrete (HSFRC) and conventional high-strength concrete (HSC. Straight steel fibers with an aspect ratio (L/D) 97.5 were used at a 1.0% volume fraction, as illustrated in Fig5. The test results showed that cracking stiffness of HSFRC's was nearly twice that of HSC, a difference attributed entirely to the inclusion of steel fiber.

Fig. 5: Straight steel fiber used by Yang et al. [46]

Soroushian & Bayasi [21] presented an experimental study to determine the influence of steel fiber type on the performance of fibrous concrete, Three types of steel fibers were investigated, hook-end, crimped, and straight-each added at 2% of the concrete volume. The study evaluated their effects on compressive strength, workability, and flexural strength. The results determined that hooked-end fibers were more effective in improving concrete properties compared with crimped and straight fibers. It was also shown that the workability of the mix concrete was not significantly affected by the type of fiber used.

3. Results and Conclusion

The results of previous literatures have demonstrated that the effect of steel fibers on improving the shear strength of unreinforced concrete beams is related to several interconnected factors, most notably the compressive strength of concrete, shear span ratio(a/d), and the longitudinal reinforcement ratio. Although most studies have confirmed the positive role of fibers in increasing strength and controlling cracks, the level of improvement and the details of the failure mechanism vary from one study to another, which necessitates a comparative analytical discussion.

1. Previous studies have shown that the effective shear span ratio plays an important role in determining the failure mode of concrete beams. For ($a/d<2.5$), it was observed that a significant improvement in shear strength, i.e., a change in failure mode from brittle shear failure to more ductile flexural failure, consistent with what was demonstrated by Hamrat et al.[36] and Dinh [23]. While at high ratios (a/d), beams fail more brittlely, and the effect of steel fibers remains limited.
2. The effect of normal compressive strength on the shear strength of concrete beams is less significant compared to that of high-strength concrete (HSC). Steel fibers also contribute to improving the brittle shear strength of high-strength concrete, improving the stress distribution mechanism after cracking and delaying sudden collapse.
3. The shear strength of concrete beams has been show to increase by (25-35%) when steel fibers are added by 0.75% compared to conventional concrete without shear reinforcement, as confirmed by a study of Kwak [47] and Yoo et al.[40] However, ratios lower than 0.5% are insufficient to achieve a significant improvement in the behavior of concrete beams. Adding a higher percentage of 1% of concrete volume leads to clear workability issues, including agglomeration and inhomogeneity in the concrete mixture, as explained in the study by Soulioti et al. [14] and Sinha & Verma[27]. This means that the role of steel fibers is limited and requires balance between mechanical benefits and operational requirements.
4. In terms of fiber type and geometric shape, it has been shown that hook-end fibers are more efficient than straight or corrugated fibers in improving shear strength and increasing ductility, as confirmed by the results of Soroushian & Bayasi[21] and Dinh[23]. However, no significant differences were found between fiber types regarding their effect on workability.
5. The stress distribution mechanism for fibrous concrete follows the same method mentioned for reinforced concrete. The steel fibers replace the shear reinforcement (stirrups), as the steel fibers take on the role of transverse reinforcement in resisting the shear stresses of reinforced concrete. Steel fibers retard the growth and extending of cracks and delay the slip failure of longitudinal reinforcement.

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