An Overview of Using Steel Fibers in Reinforced Concrete Structural Elements to Improve Shear Reinforcement

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Abstract— Recently, several studies have been conducted to investigate the shear behaviour of steel fiber reinforced concrete (SFRC). Over the last few decades, steel fibers have been shown to be applicable and effective in improving the shear reinforcement. This paper presents a summary of the main findings from the primary research contributors. Besides discussion on the research efforts, recommendations for the future research in using steel fibers to improve shear reinforcement are provided. This paper conclude that using steel fibers in reinforced concrete slab can possibly reduce the thickness of slab and fibers has substantial effect to serve as part of shear reinforcement in reinforced concrete slab

Keyword—Shear strength, Steel fiber, Steel fiber reinforced concrete, Shear behaviour, Shear failure.

1. INTRODUCTION

Concrete is very strong in compressive strength and weak in tensile strength that causes crack in the tension zone. Reinforced concrete is a combination of concrete and steel wherein the steel reinforcement improves the tensile strength lacking in the concrete [1]. Concrete deteriorates quickly and loses its capacity to carry loading and first cracks appear due to the brittleness and lack of post-peak resistance in the concrete. Shear failure is characterized by small deflections and a lack of ductility and is an undesirable mode of failure. The shear behaviour of reinforced concrete (RC) is a complex phenomenon which may lead to a variety of possible shear failure modes. In addition, the shear transfer mechanisms are difficult to quantify. In order to cater for the tensile stresses inside the concrete, steel bars which are strong in both compression and tension is added as reinforcement inside the concrete. Several studies were carried out in order to improve the performance, quality, behavior, and mechanical properties of reinforced concrete structures by using different materials. For example, adding admixtures, polymers and fibers in concrete [2]. Inclusion of fibers in concrete have been studied since early 1900 [3],[4] ,[5]. There are many advantages of adding fibers in concrete such as increasing the tensile strength by delaying the growth of cracks, and increasing toughness by transmitting stress across a cracked section. In addition, fibers in concrete also enhance the impact and fatigue strength and reduce shrinkage [4],[2]. Furthermore, some studies concluded that using fibers has substantial effect to serve as part of shear reinforcement in reinforced concrete structures[6],[7]. Many types of fibers that are usually added in concrete are available in the market such as, steel, glass, synthetic (e.g. carbon and polypropylene) and natural fibers (e.g. sisal, flax and kenaf). Amongst these types, several studies have been carried out on the behavior of steel fiber reinforced concrete structures. Early investigation carried out by Swamy and Lankard [8] and Hannant [9] show that fibers have a capability to control crack opening, thus improving the ductility, load carrying capacity and post cracking behavior of fiber reinforced concrete structures. In addition, studies carried out by Lewis and Premalal [10] and Mansur and Aziz [11] on natural fibers such as jute, kenaf, sisal and bamboo in reinforced concrete mixture also produce similar pattern of enhancement in the load carrying capacity, ductility, impact resistance and delays in crack propagation.

During the last few decades, many researchers [6, 7, 12-17] used fibers in reinforced concrete which focus on only a single type of fiber. However, few studies [18-21] have been also carried out to study the effect of using combination of two types of fibers in reinforced concrete structures which is later referred to as hybrid fibers reinforced concrete.

This paper focuses on the usage steel fibers as a part of shear reinforcement in structural elements. In addition, this paper addressed the advantages of using steel fibers to improve the shear reinforcement. The specific objectives of this work are (1) to identify the importance of using fibers to improve the shear reinforcement (2) to provide recommendations for future work to researches.

2. Fibers

Fibers are characterized by both material properties and geometrical parameters including the length, the equivalent diameter, the shape and the aspect ratio. The concept of using fibers in brittle matrix materials has a long history going about 3500 years ago, when sun-baked bricks reinforced with straw were used to build the 57 m high of "Agar Quf", which is located near Baghdad [4, 22]. Some types of fiber are available in the market which are manufactured produce such as steel, glass, synthetic (e.g. carbon and polypropylene) or made from natural plant and called as natural fibers such as sisal, flax and kenaf. Several studies used fibers as a part of shear reinforcement.

3. Steel Fibers Reinforced Concrete

Steel fibers are defined as short, discrete lengths of steel that having an aspect ratio (ratio of length to diameter) from about 20 to 100 %. The classification according to American Society for Testing and Materials (ASTM) A 820 divided this into four general types of steel fibers which known as cold-drawn wire, cut sheet, melt extracted and other fibers based on the product used in their manufacture [3]. The steel fibers have many types based on surface roughness and shape such as copped, hooked ends, crimpled and wavy. Typical equivalent diameter of steel fibers ranges from 0.15 mm to 2 mm and length from 6 mm to 76 mm. The tensile strength of steel fiber goes up to 2 Giga Pascal (GPa) and modulus of elasticity to 200 GPa [3],[9]. The performance of steel fibers is influenced by many factors such as shape, fiber content and aspect ratio. The fiber with deformed shape or hooked end usually behaves better than straight ones due to better bond with concrete [6].

Steel fiber reinforced concrete (SFRC) is concrete containing hydraulic cement with fine or fine and coarse aggregate and discontinuous discrete steel fibers. The shear behavior of structural concrete members has still not been fully explored and it is a topic of continuous debate among researchers looking for methods and models in order to determine the shear capacity of structural concrete elements. General shear models are also being extended to other materials such as Steel Fiber Reinforced Concrete [23]. Many researches have been conducted to investigate the various mechanical phenomena that steel fiber contributed with reinforced concrete. Juarez et al. [24] studied the behaviour of diagonal tension for reinforced concrete beams with addition of steel fibers. From the results, it was observed that the steel fibers increase the shear strength and the ductility of the beams. The efficiency of fibers to increase shear strength is dependent on many factors related to: matrix properties, fiber properties (materials properties, aspect ratio, and shape), fiber content, and bond stress versus slip response of fibers [17]. The volume fraction of steel fiber range between 0 and 2% can increase the ultimate shear capacity as fiber content increases [25]. Table.1 presents selected studies that used steel fibers to improve the shear reinforcement in structural elements.

Table 1: Selected Studies for Steel Fibers in Structural Elements

Author	Element	Type of test	Results
Swamy, et al. [12]	Slab	Subjected to punching shear	• Ultimate punching shear was increased.
Narayanan and Darwish [26]	Slab	Subjected to punching shear	• Shear strength was improved.
Tan and Paramasivam [27]	Slab	Subjected to punching shear	• Punching shear strength and the ductility were increased. • concrete strength were increased
Lim et al. [28]	Beam	Subjected to shear	• The amount of shear stirrups was reduced. • Shear strength was increased.
Cucchiara et al. [29]	Beam	Subjected to shear	• Modify the failure mode. • Improvement in the post-peak behaviour.
Khaloo and Afshari [15]	Slab	Subjected to flexural	• Does not significantly increase the ultimate flexural strength of slabs. • Increase in concrete strength enhanced the energy absorption capacity.
Dinh et al. [17]	Beam	Subjected to shear	• Shear strength was increased. • Fibers used as minimum shear reinforcement.
Ding et al. [30]	Beam	Subjected to shear	• Shear strength significantly increased. • Change the failure mode. • The stirrups can be partially replaced by steel fibers.
Minelli et al. [31]	Beam	Subjected to shear	• Loading capacity and ductility were increased. • Fibers was reduced the size effect of shear.
Abbas et al. [7]	Beam	Subjected to shear	• Load-carrying capacity and ductility were improved. • Changed the failure mode.

Research study by Lim et al. [28] investigated the influence of fiber reinforcement on the mechanical behaviour of reinforced concrete beams in shear. The findings showed that the first crack shear strength increases significantly as fiber content increases and enhance the ultimate shear strength. The test result also indicated that fiber reinforcement can reduce the amount of shear stirrups required and that the combination of fibers and stirrups may compensate the strength and ductility requirements.

In another study, Cucchiara et al. [29] indicated the improvement in the post- peak behaviour of the beam, due to the presence of fibers and in particular to the coupled effects of fibers and stirrups. The tests were carried out by considering two different values of shear span, different volume fraction of fiber and stirrups, for two series of beams. The load- deflection curves from the study recorded a post- peak branch, allowing the conclusion that adding fibers can modify the brittle shear mechanism into a ductile flexural mechanism.

Next, Dinh et al. [17] investigated the effectiveness of the fiber as shear reinforcement in a beam without stirrup reinforcement. They used 28 relatively large SFRC beams subjected to shear, simply supported. The findings showed that using hooked steel fibers in a volume fraction equal or greater than to 0.75 % led to multiple diagonal cracking and substantial increase in shear strength compared to reinforced concrete beams without stirrup reinforcement. The test result also indicated that the hooked steel fibers evaluated in this investigation can safely be used as minimum shear reinforcement in RC beams constructed with normal- strength concrete and within the range of member depths considered.

Another investigation conducted by Ding et al. [30] reported the experiments carried out on a series of simply supported beams, using steel fiber reinforcement with and without stirrups, and subjected to four-point symmetrically placed vertical loads. The major parameters are the volume fraction of steel fiber and stirrup ratios. The test result indicated that the shear strength significantly increased by increasing the fiber content. Furthermore, the addition of steel fibers in a suitable volume fraction can change the failure mode from a brittle shear failure into a ductile flexural failure. Moreover, the stirrups can be partially replaced by steel fibers. The combination of steel fibers and stirrups demonstrates a positive composite effect on the mechanical behaviour.

Minelli et al. [31] also reported some recent results of an experimental study of fiber reinforced concrete beams under shear loading tested on nine full scale beams, having a height up to 1,500 mm. The study investigated the effect of steel fibers on key parameters influencing the shear response of concrete members, with focus on size effect. The findings showed that a relatively low volume fraction of fibers can significantly increase loading capacity and ductility also the fibers substantially reduce the size effect of shear as well.

Subsequently, Abbas et al. [7] investigated the potential of using steel fibers to reduce the amount of conventional transverse steel reinforcement without compromising ductility and strength requirements set out in design codes. The investigation was carried out by increasing the spacing between shear links while steel fibers were added as a substitute. From the results, it was concluded that the addition of steel fibers improved the load-carrying capacity, changed the failure mode from a brittle shear mode to flexural ductile and improved ductility. The study confirmed the potential of fibers to compensate the reduction in conventional shear reinforcement.

In addition, previous work on behaviour of steel fibers in reinforced concrete slab focused more on the flexural and the punching shear of the slabs [12],[26],[27],[15]. For instance, early study carried out by Swamy, et al. [12]investigated the influence of steel fiber on the punching shear for reinforced concrete slab with various dosage of steel fiber. The findings showed that as the dosage of fibers increases, the ultimate punching shear loads also increased.

In another study, Narayanan and Darwish [26] studied the behaviour and strength of steel fiber inside reinforced concrete slab subjected to punching shear. This study was focused on three parameters such as the concrete strength, volume fraction of steel fiber and tensile reinforcement. From the results, it can be seen that the shear strength was improved by increasing the fiber content.

Next, Tan and Paramasivam [27] reported the experiments carried out to study the behaviour of punching shear for simply supported steel fibers reinforced concrete slabs and tested under a concentrated load at the center of slab. In this study, the parameters considered were slab thickness, concrete strength, volume fraction of fibers and size of load-bearing plate. The findings showed an increase in both the punching shear strength and the ductility of the slab when the values of slab thickness, volume fraction of fibers and concrete strength were increased.

Research by Khaloo and Afshari [15] investigated the influence of length and volume fraction of steel fibers on energy absorption of reinforced concrete slabs with different concrete strengths tested under flexure. From the results, it was observed that fibers with higher length and volume fraction provide higher energy absorption. On the other hand, the inclusion of fibers does not significantly increase the ultimate flexural strength of slabs. However, the increase in concrete strength enhanced the energy absorption capacity.

4. CONCLUSION

Many studies have been conducted to investigate the influence of steel fibers to improve the shear reinforcement in reinforced concrete elements. Based on the findings, it can be seen that several researchers have focused on adding fibers into reinforced concrete beams in order to enhance the tensile and shear capacities of the structures. In spite of that, there is still a gap in the literature that regarding the use of fibers in reinforced concrete slabs to serve as part of shear reinforcement to prevent shear failure.

Using the fibers in slabs with volume fractions from 0 – 2 % will increase the shear capacity and change the mode of failure from brittle to ductile. This result will reduce the thickness of slab that will lead to the decrease in the weight of concrete structure as well as the dead load which reflect on reducing the dimension of structural elements and the amount of reinforcement used as well.

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