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EFFECTIVENESS OF SteFib IN COMPOSITE STRUCTURAL MEMBER

NURHARNIZA ABDUL RAHMAN*, SITI HAWA HAMZAH, AHMED ABDULRAZZAQ

Institute of Infrastructure Engineering and Sustainable Management (IIESM),
Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia
*Author's correspondence: nurharnizaabdulrahman@gmail.com

Abstract

In advancement of concrete utilisation, one of the significant researches carried out is on utilisation of steel fibre in concrete mix to replace reinforcing bars. This paper attempts to further discuss the effectiveness of steel fibre (SteFib) as additional or replacement material concrete to be used as structural member. The improvement of strength and deformation properties are important aspects of structural design and are considered in this investigation to fully value the effectiveness of steel fibre reinforcement in the structural concrete member. Based on the compressive cube test with additional of 40 kg/m^3 SteFib dosage, it was found that the strength of concrete was improved. Thus the 40 kg/m^3 of fibre dosage used for the first stage of research works which is in SteFib wall panel (SteFib$_{WP}$) and SteFib slab panel (SteFib$_{SP}$). Due to the good performance of SteFib$_{WP}$, the fibre dosage was reduced to 30kg/m^3 for beam panels. Two walls panels measuring of 75×1000×1500 mm (thickness×width×height), two slabs panels measuring 75×1000×1300 mm (thickness×width×length), and three beams panels measuring 250×350×2700 mm (width×thickness×length), were prepared for this study. Load was applied up to failure by using the three points bending test for the beam and slab panels, while the wall panels was subjected to compressive axial load with pinned-fixed end conditions. The experimental test shows that SteFib increased the ultimate axial and bending capacity at about 43% for the wall panels compared to wire fabric wall panel. SteFib also helps to improve more than 50% of ultimate load for slab panels and beam panels compared to the theoretical load. Furthermore, SteFib improved the fracture toughness, reduced macro-cracks forming into micro-cracks, improved concrete ductility and its energy absorption capacity, as well as enhanced overall durability. This shows that steel fibre reinforced concrete (SFRC) is practical and economically attractive as it can be mixed, placed, and compacted using normal techniques. SteFib panels have better carrying capacity and advantages in terms of crack control than normal reinforced concrete panels.

Keywords: Axial and bending capacity, Steel fibres concrete panel,
Carrying capacity, Crack control.

1. Introduction

Steel fibre has been used in concrete pavement since the 1960s and as complementary reinforcement in the 1970s [1]. There are a variety of sizes, shapes and materials of steel fibre available in the market. Different manufacturing techniques and materials may affect the effectiveness of steel fibre reinforced concrete (SFRC). Steel fibre was designed with hooked ends, completely corrugated or with end cones, to improve anchorage and adhesion within the concrete matrix [2, 3]. Some deformed cross section for some of the steel fibre and milled fibres have completely irregular shapes. Normally steel fibre is supplied as single fibres but some are magnetically aligned or glued together in bundles in order to ensure better distribution after casting. The purpose of gluing steel fibres together is to reduce "*Fibre Balling"* or clamping during mixing.

Numerous researches have been conducted with respect to the use of steel fibre in beams [4-7] and slabs [5, 8]. From these previous research studies, hooked end steel fibre (SteFib) was found to be an additional material to improve mechanical resistance of concrete, ductility, reduce concrete plastic shrinkage or improve its resistance to abrasion, fire or impact [9]. SteFib was found to have improved the bond and anchorage of the steel fibres in concrete or shortcrete [3]. This condition may increase the reinforcing efficiency and ductility. Furthermore, the application of SFRC as slab topping was found to increase flexural capacity and is most suitable to use for roughen interface [10,11]. Roughen surface sustained higher flexural load with higher horizontal shear strength. On the other hand the application of steel fibres in ground concrete slabs was found to give a slight improvement to the ultimate load but greatly enhanced the slab ductility with only 0.38% of steel fibre in the volume. Small crack openings showed that higher energy was dissipated by using steel fibre in slabs [12]. The steel fibres had also made the slabs fail in more ductile mode [13]. Previous studies on the application of steel fibre in beams also showed more ductile failure with a higher stress level in the flexural reinforcement. However, the modification of the aspect ratio had little influence on the strength of the structural element [5].

The ability of SteFib to stitch cracks helps to reduce the permeability of the crack specimen [14]. Permeability is an important factor to take into consideration in structural design. It may affect the durability and integrity of structural performance. Permeability caused by cracks and porosity allows water and other corrosive agents to penetrate the structures and get through the reinforcing bars within the structures. High volumes of SteFib used in concrete will help to reduce the permeability of the concrete [14-17]. Apart from that the length of SteFib also affects the ability of SteFib to bridge/stitch the cracks in the structure. Longer SteFib gives higher bridging effect on cracks [18].

Based on the literature review of previous researches, none of them had studied the effectiveness of SteFib as reinforcement in structural components either partial or as total replacement especially in wall panels. Most of them had used steel fibres as additional reinforcement to the structural component. For that reason hooked end steel fibres were chosen as total reinforcement to be used in wall and slab panels and partially and totally used in beam panels. This study further probed the ability of SteFib to improve the structural component in terms of strength, ductility, energy absorption and reducing crack propagation.

2. Experimental Programme

A series of experimental studies were done to examine the effectiveness of SteFib in composite structural members. These experimental tests were carried out in the Heavy Structural Laboratory of Universiti Teknologi Mara Malaysia. Experimental works were carried out according to BS8110: Part 1. Hooked end steel fibres with tensile strength of 1200 Mpa; measuring 0.75 mm in diameter and 60 mm in length was used in this study. The aspect ratio is L/d=80. Figure 1 shows the hooked end steel fibre (SteFib) used in this present study.

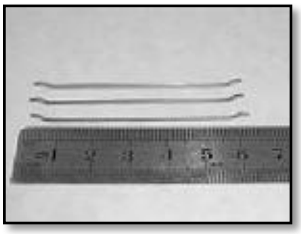

Fig. 1. Hooked End Steel Fibre (SteFib).

The first stage was focusing on the effectiveness of SteFib as total replacement of reinforcement in wall panel under axial compression line load. Two wall panels had been prepared for this stage with aspect ratio (h/L) and slenderness ratio (h/t) of 1.5 and 20 respectively. The size of the wall panel was 75×1000×1500 mm (thickness × width × height). A 40 MPa concrete strength with additional 40 kg/m^3 fibre dosage which is equal to 5 kg of SteFib was used in each wall panel. The SteFib were added after all the materials were mixed together at a rate of 20 kg/min while the drum mixer rotated at high speed for 5 minutes. The compressive cube test as discussed in a previous research by Nurharniza [19]. Steel fibre wall panel ($SteFib_{WP}$) was named as $SteFib_{WP1}$ and $SteFib_{WP2}$. Both panels were tested under axial compression test at the centre of the top of wall panels. $SteFib_{WP}$ was placed vertically with the upper end set as pinned and the lowest end as fixed.

Figure 2(a) shows the experimental setup for wall panels. Figures 2(b) and (c) show the position of LVDTs and the position of strain gauges respectively. The experimental results for $SteFib_{WP}$ were compared with steel fabric wall panel (WFC_{WP}) which were adopted from research by Siti Hawa et al. [20]. This comparison was done to study how much $SteFib_{WP}$ improved in strength compared to WFC_{WP}. WFC_{WP} used a similar size of wall sample and similar condition of experimental setup.

In the second stage, another two panels were prepared by using same procedure with $SteFib_{WP}$. These samples were considered as steel fibre slab panels ($SteFib_{SP}$) and were named as $SteFib_{SP1}$ and $SteFib_{SP2}$. The size of $SteFib_{SP}$ was 1300×1000×75 mm. The concrete strength and fibre dosage was similar as that used in $SteFib_{WP}$. The $SteFib_{SP}$ was tested under the three point bending test where the load was applied at the centre of slab length up to failure. SteFib was used as total replacement for reinforcement in $SteFib_{SP}$. Figure 3 shows the schematics diagrams for experimental set-up. Figure 4 shows the position of transducers and position of strain gauge for $SteFib_{SP}$.

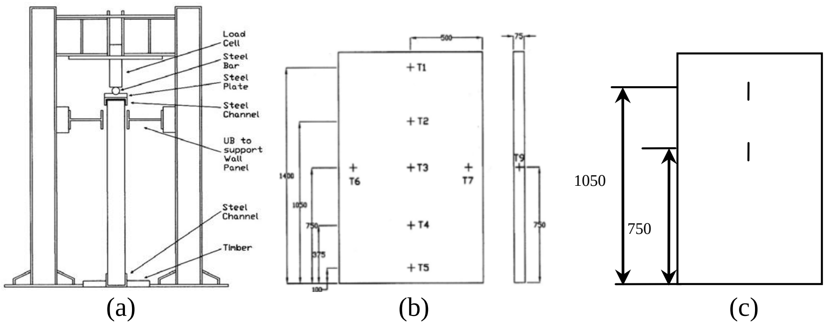

Fig. 2. Schematic Diagram for Wall Panel; (a) The Experimental Setup, (b) The Position of LVDTs, and (c) The Position of Strain Gauges.

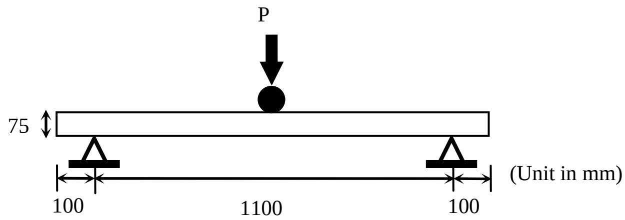

Fig. 3. The Schematic Diagram for the Experimental Set-up for SteFib Slab Panels.

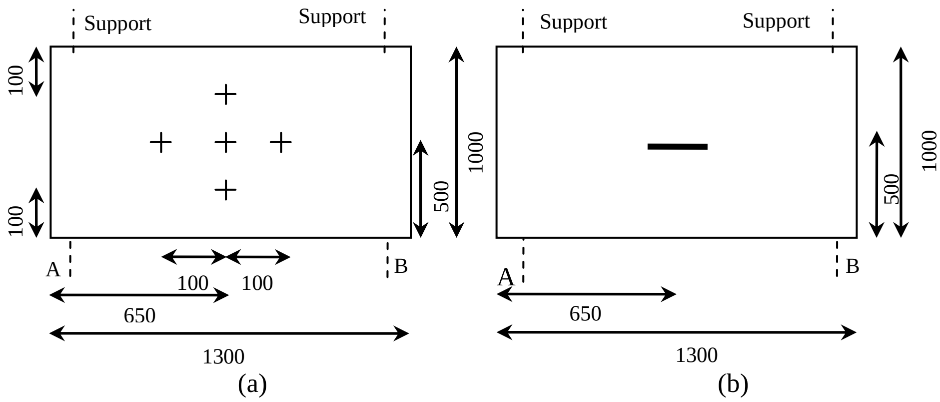

Fig. 4. Schematic Diagram for SteFib Slab Panel; (a) The Position of LVDTs and (b) The Position of Strain Gauge.

The last stage was the preparation of three different types of beams: normal reinforced concrete beam, steel fibre reinforced concrete beam, and steel fibre reinforced with normal reinforced concrete beam. These beams were named as Beam 1, Beam 2, and Beam 3. Concrete was designed for 30 MPa of concrete strength. At this stage fibre dosage was reduced to 30 kg/m^3. This dosage was reduced since the compressive cube test showed that this dosage also gives high compressive strength and for economic reasons. The compressive cube test on different series of concrete cube with different dosage of steel fibre was discussed in the previous paper [15]. Figure 5 shows the details of reinforcement used in the beam panels. Figure 6 shows the details position of transducers used and position of strain gauge used during experimental test.

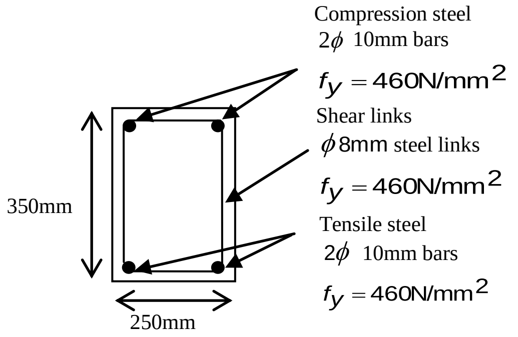

Fig. 5. Cross Section Details for the Reinforcement used in Beams Panels.

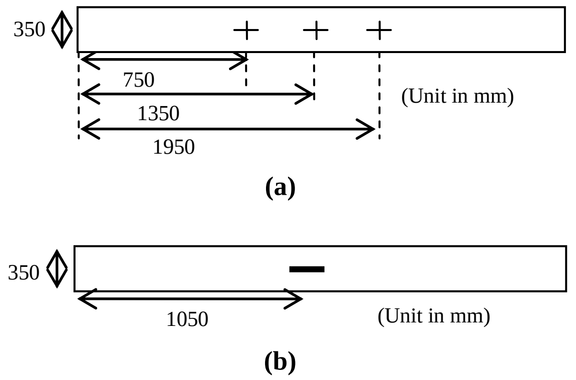

Fig. 6. (a) The Position of Transducers, and (b) The Position of Strain Gauge.

All beams were tested by using the four point bending test as shown in Fig. 7. The load was applied up to failure. The experimental results for these three different types of beams were compared to determine the effectiveness of SteFib for total or partial replacement for reinforcement in beam.

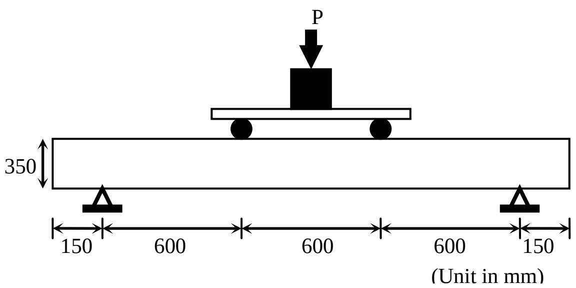

Fig. 7. The Experimental Setup for Beam Panels.

3. Results and Discussions

3.1. Wall Panel

The mode of failure of steel fibre wall panel (SteFib$_{WP}$) demonstrated that SteFib improved global structural response to the normal concrete wall panel. The comparison of SteFib$_{WP}$ with steel fabric wall panel (WFC$_{WP}$) showed that the ultimate load for SteFib$_{WP1}$ was 41% higher than WFC$_{WP1}$. Further the ultimate load for SteFib$_{WP2}$ was 45% higher than WFC$_{WP2}$. The distribution of SteFib through the concrete wall panel helped to receive high energy absorption over a high range of wall deformation. The detail of ultimate load with corresponding displacement for wall panels are shown in Table 1. Figure 8 shows the load-displacement relationship due to axial compression line load.

Table 1. Ultimate Load and Corresponding Displacement of Wall Panels.

Sample	SteFib$_{WP1}$	WFC$_{WP1}$	SteFib$_{WP2}$	WFC$_{WP2}$
P_{max} (kN)	1623.11	1150.00	1601.24	1108.00
δ_{max} (mm)	4.42	5.02	5.84	4.16
Location	T2	T2	T2	T2

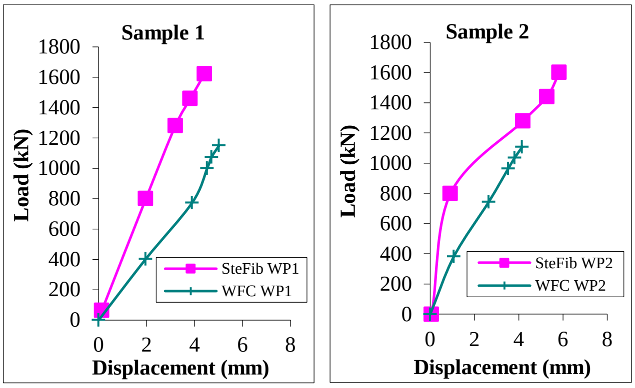

Fig. 8. Comparison of Load-Displacement Profile between SteFib$_{WP1}$ with WCF$_{WP1}$; and SteFib$_{WP2}$ with WCF$_{WP2}$.

The experimental results showed that SteFib$_{WP2}$ gave a high displacement value, but there was no crack observed on the sample. Visual observation on SteFib$_{WP}$ during the experimental test is shown in Fig. 9(a). On the other hand, sample WFC$_{WP}$ buckled at 0.75H (wall height) similar behaviour to the theory of buckling mode. Figure 9(b) shows the failure pattern on WFC$_{WP}$ due to axial compression load. SteFib$_{WP}$ displayed cracks near to the bottom support while WFC$_{WP}$ had cracks on the buckling surface area (refer to Fig. 9). This means that SteFib helps to improve the crack failure in wall panels under axial compression load. The distribution of SteFib in concrete in various directions helped to stop the cracks from further propagation. It is worth mentioning that the SteFib$_{WP}$ only reached the yield stage because the experiment was stopped due to apparatus capacity limitation before any apparent failure was exhibited by the specimen. In comparison, the WFC$_{WP}$ reached the yield point, cracked and collapsed at the same loading regime. The result reveals that steel fibre functions well in improving performance of members resisting axial compressive load [15].

(a) $SteFib_{WP}$ (b) WFC_{WP}

Fig. 9. Failure Visualisation of $SteFib_{WP}$ and WFC_{WP}.

3.2. Slab Panels

The ultimate load for sample $SteFib_{SP1}$ and $SteFib_{SP2}$ was doubled from the theoretical load due to the three point bending load test. Table 2 shows the details of load and displacement due to load increment during the experimental test. The analyses showed the enhancement provided by SteFib on the capacity of the concrete slab was about 28% to 68% compared to theoretical load calculation. Figure 10 shows the load versus displacement profile for $SteFib_{SP}$.

Table 2. Load and Displacement for Slab Panels.

Sample	$P_{ultimate}$ (kN)	P_{theory} (kN)	δ_{max} (mm)
$SteFib_{SP1}$	18.83	7	0.83
$SteFib_{SP2}$	20.89	7	0.94

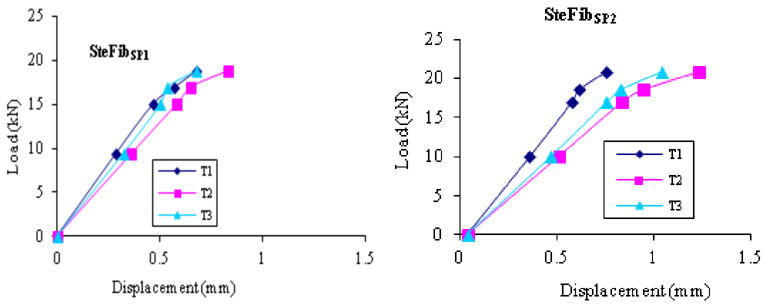

Fig. 10. Load vs. Displacement Profile for $SteFib_{SP}$.

The observation showed that the discrete SteFib demonstrated improved global structural response. Larger ultimate deformation was observed through the visual observation as shown in Fig. 11. This failure condition was due to high ductility of $SteFib_{SP}$ which brought about high fracture. This condition also indirectly gives high energy absorption of high strength concrete slabs. A crack occurred along the mid-span of the slab panel for $SteFib_{SP}$ and there was no hair crack observed on $SteFib_{SP}$. Research by Nurharniza et al. [14] showed that SFRC slab gave 13% increment of ultimate load with 3% reduction of displacement compared to normal concrete slabs. Thus this supports the evidence that SteFib helps to improve the strength and fracture in concrete slab.

Fig. 11. Crack Occurred at the Bottom of Slab when Subjected to Bending Test.

3.3. Beam Panels

SteFib was found to be very efficient to be used as shear reinforcement and gives high resistance in cracking development behaviour in the deep beam [15]. The deep beam was found to stand large deflection failure, high ductility and energy absorption property with the presence of SteFib as additional reinforcement. SteFib increased the strength of Beam 2 up to 57% and 74% of P_{ult}/P_{crack} and $P_{ult}/P_{elastic}$ compared to Beam 3. Table 3 shows the detailed results for three types of beams.

Table 3. Load Comparison of Three Different Type of Beam.

Dosage	P_{crack} (kN)	$P_{elastic}$ (kN)	$P_{ultimate}$ (kN)	P_{theory} (kN)	P_{ult}/P_{crack} (kN)	$P_{ult}/P_{elastic}$ (kN)
Beam 1	105.01	81.80	131.95	6.174	1.26	1.61
Beam 2	26.54	13.25	80.60	6.174	2.99	6.08
Beam 3	115.52	110.93	209.36	6.174	1.81	1.89

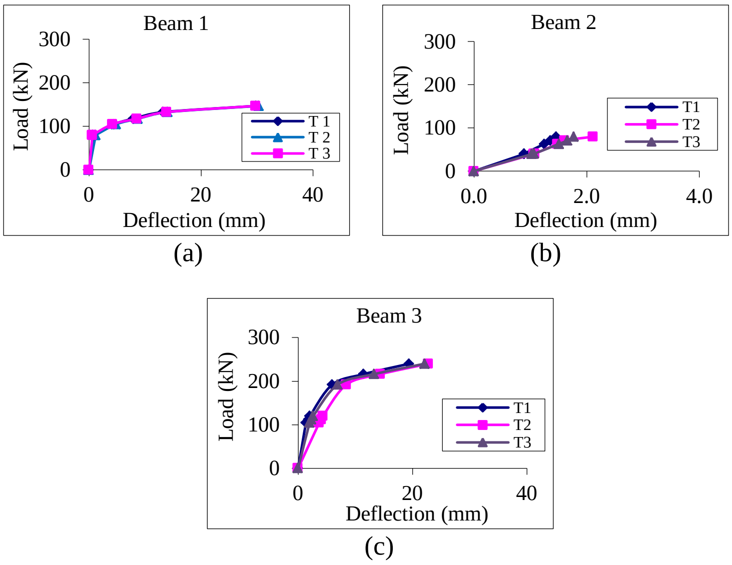

Fig. 12. Load vs. Displacement of Beam Panel; (a) Beam 1, (b) Beam 2, and Beam 3.

SteFib was found to be efficient at improving crack control and deformation characteristic at initial stage up to ultimate. The failure observation found in Beam 3 showed an increase in the stiffness of the concrete performance and improved the resistance of concrete spalling. It showed that SteFib was working together with the reinforcement bar in Beam 3 and exhibited large deflection failure, which is more than 50% compared to theoretical value. This theoretical value was calculated from theoretical calculation obtained in design standard. SteFib helped to reduce 20% of the displacement in Beam 3 compared to Beam 1. Table 4 shows the details displacement of beam panels. The addition of SteFib indicated high energy absorption from tensile stresses experienced within the matrix beside to control the crack initiation and propagation on the tension surface. Figure 13 shows the crack propagation on beam panels at ultimate load displacement. Based on the performance of SteFib in beam, the used of SteFib as additional reinforcement under flexure is less likely to be encouraged. It was based on the crack observation showed that the crack propagation were reduced with the present of SteFib. The shear cracks on Beam 3 were reduced compared to Beam 1 with the presence of SteFib. It was showed that SteFib was found efficient to be used as shear reinforcement in beams. A similar condition was found in a previous study where SteFib helped to increase 50% of the ultimate load compared to normal concrete beams with 27% increment of corresponding displacement [14].

(a) (b) (c)

Fig. 13. Crack at Ultimate Load Displacement; (a) Beam 1, (b) Beam 2, and (c) Beam 3.

Table 4. The Displacement of Beam Panels.

Beam	$d_{max, theo}$ (mm)	$d_{max, exp}$ (mm)
Beam 1	9.66	31.21
Beam 2	6.75	1.56
Beam 3	9.66	24.82

4. Conclusion

SteFib is practically and economically attractive as SteFib can be mixed, placed, and compacted with normal techniques. The strength, durability, and low cost of concrete structures can be achieved with SFRC. Moreover, it can be concluded that with minimal volume of SteFib as additional reinforcement, the improved strength, compression, bending and buckling in structural panels. Therefore it is practical to utilise SteFib in future studies on structural members. It has shown that SteFib have high potential in improving the structural member capacity to resist higher loads compared with plain concrete structural. The study of SteFib structural panels requires further investigation relating to other failure mechanism. Further studies on SteFib's ability to improve the strength of structural member especially in connection or joints needs to be investigated.

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