IOP Conference Series: Materials Science and Engineering

Behaviour of reinforced concrete slabs with steel fibers

To cite this article: A O Baarimah and S M Syed Mohsin 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **271** 012099

IOP Conf. Series: Materials Science and Engineering **271** (2017) 012099 doi:10.1088/1757-899X/271/1/012099

Behaviour of reinforced concrete slabs with steel fibers

A O Baarimah[1] **and S M Syed Mohsin**[1]

[1] Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia
Corresponding author: eng.baarmh@gmail.com

Abstract. This paper investigates the potential effect of steel fiber added into reinforced concrete slabs. Four-point bending test is conducted on six slabs to investigate the structural behaviour of the slabs by considering two different parameters; (i) thickness of slab (ii) volume fraction of steel fiber. The experimental work consists of six slabs, in which three slabs are designed in accordance to Eurocode 2 to fulfil shear capacity characteristic, whereas, the other three slabs are designed with 17% less thickness, intended to fail in shear. Both series of slabs are added with steel fiber with a volume fraction of $V_f = 0\%$, $V_f = 1\%$ and $V_f = 2\%$ in order to study the effect and potential of fiber to compensate the loss in shear capacity. The slab with $V_f = 0\%$ steel fiber and no reduction in thickness is taken as the control slab. The experimental result suggests promising improvement of the load carrying capacity (up to 32%) and ductility (up to 87%) as well as delayed in crack propagation for the slabs with $V_f = 2\%$. In addition, it is observed that addition of fibers compensates the reduction in the slab thickness as well as changes the failure mode of the slab from brittle to a more ductile manner.

1. Introduction

Concrete has become one of the most important construction materials commonly used in many types of engineering structures. Concrete is a material which is strong in compression and weak in tension, thus causes cracking in the tension zone. Reinforced concrete is a combination of concrete and steel where the steel reinforcement improves the tensile strength lacking in the concrete. In the past decades, fiber reinforced concrete (FRC) has been gaining more attention in the development and are used in numerous types of civil engineering application such as shotcrete, pavement slabs, precast products, tunnel linings, seismic structures, bridge deck slab repairs, marine and refractory applications [1-5]. There are many advantages of adding fiber into reinforced concrete, such as improving the load carrying capacity and ductility of the structural members, controlling crack propagation, increasing energy absorption and altering the mode of failure [6-11].

Steel fiber reinforced concrete (SFRC) is a composite material containing Portland cement, water, aggregate and adding discrete discontinuous steel fiber. Steel fiber has been demonstrated its efficiency in enhancing the structural behaviour of reinforced concrete structural members [12-17].

Based on the literature, promising results were observed in the potential of steel fibers to serve as part of shear reinforcement in reinforced concrete beams, columns and beam-column joints. However, limited research is carried out to study this potential in reinforced concrete slab, especially for the case in which the thickness of the slab is controlled or reduced. Therefore, this study aims to investigate the effect of steel fiber added into reinforced concrete slabs as well as its potential to serve as part of shear reinforcement through the decrease in slab thickness.

2. Materials and methods

The concrete mixture was designed in accordance with British Standards (BS EN 206-1, 2000) for 20 MPa of concrete compressive strength. Three concrete mixtures were produced for SFRC using different volume fraction (V_f) as listed in table 1. The first mixture was a reference mixture (control) without adding any fiber, $V_f = 0\%$. Hooked-end steel fiber was added into the concrete mixtures. Table 2 presents the properties of the steel fiber. In addition, super plasticizer (SP) was used in the mixtures to improve workability and achieve the required slump.

Table 1. Concrete mix design.

Materials	Mix 1 ($V_f = 0\%$)	Mix 2 ($V_f = 1\%$)	Mix 3 ($V_f = 2\%$)
Cement (kg/m^3)	280	280	280
Coarse Aggregate (kg/m^3)	1292	1292	1292
Fine Aggregate (kg/m^3)	556	556	556
Water (Liter/m^3)	162	162	162
W/C ratio	0.58	0.58	0.58
SP (Liter/m^3)	5.6	5.6	5.6
Steel fiber (kg/m^3)	0	75	150

Table 2. Steel fiber properties.

Properties	Steel Fiber
Length, L (mm)	60
Diameter, D (mm)	0.75
Aspect Ratio, L/D	80
Tensile Strength (MPa)	1100
Unit Weight (kg/m3)	7500

In order to measure the compressive and flexural stress of the concrete mixtures, compression test and flexural test were conducted in this study using compression (cube) test and four-point bending test, respectively. Three cubes as well as three prisms were prepared for each mixture. A total number of nine cubes with a standard size of 150 x 150 x 150 mm as well as nine prisms with a dimension of 100 x 100 x 500 mm were tested on 28th day as recommended in British Standards BS EN 12390-3, 2009 and BS EN 12390-5, 2009, respectively.

In this study, two thicknesses of reinforced concrete slabs were prepared. The dimension of the first series of slab (slab size 1) was 1000 x 500 x 120 mm, while the dimension of the second series (slab size 2) was 1000 x 500 x 100 mm in length, width and depth, respectively. The difference in the slab thickness is to cater for the potential of the fibers to serve as part of shear reinforcement in the reinforced concrete slab. The second series of slab was designed with the thickness of slab less than the required so that the slab would be failed in shear. The reinforcement of slab was provided as mesh with the diameter of 10 mm, the main steel bar was H10 – 150 mm (4H10) and secondary steel bar was H10 – 320 mm (4H10).

The loading arrangement and details of the slab are shown in figure 1. Six samples of SFRC slabs were prepared for casting and were tested on the 28th day. For the first series, the slab S1-0, S1-1, S1-2 were added with fibers by a volume fraction of $V_f = 0\%$, $V_f = 1\%$ and $V_f = 2\%$, respectively, whereas the second series, slab S2-0, S2-1, S2-2 were added with fibers by a volume fraction of $V_f = 0\%$, $V_f = 1\%$ and $V_f = 2\%$, respectively. Slab S1-0 is considered as the control slab.

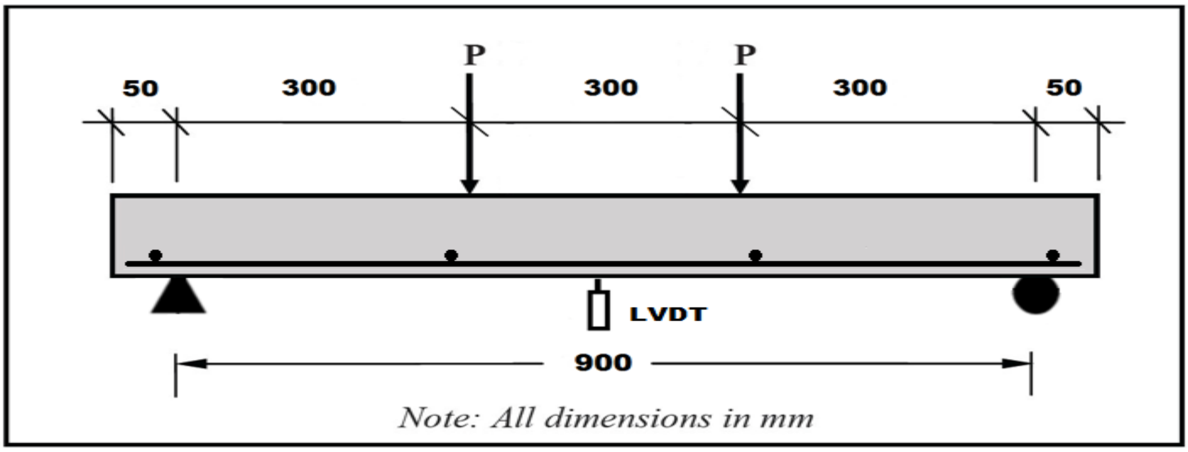

Figure 1. Load arrangement and details of the slab.

All specimens of the slab were tested under four-points bending test by using a hydraulic machine (Magnus Frame) with a capacity of 300 kN under static monotonic loading until failure over a clear span of 900 mm with a shear span of 300 mm as well as the distance between the two loading points of 300 mm. The mid-span deflection was measured by using linear variable differential transducer (LVDT) which was located at the center of the slab whereas the load cell indicated the applied load test set up for the slabs as shown in the figure above. During the loading, the crack propagation of the slabs sides was marked and identified their location.

3. Results and discussion

Table 3 shows the average compressive and flexural strength of the SFRC cubes and prisms. The observation shows that the compressive and flexural strength of the concrete with added fibers were higher than that of the concrete without fiber. The enhancement of compressive and flexural strength increase with increasing fiber volume fraction. The compressive strength of 1% and 2 % steel fiber specimens were compared to the control concrete increased by 6.3% and 24.7%, respectively. Furthermore, by adding fibers of 1% and 2 %, the flexural strength was increased by 114% and 197 %, respectively. These findings are in agreement with previous studies [18, 19].

Table 3. Compressive and flexural strength results.

V_f%	Compressive Strength (MPa)	Flexural Strength (MPa)
0	22.30	3.50
1	23.70	7.50
2	27.8	10.40

The relationship between load and deflection for first series and second series slabs are illustrated in figure 2 and figure 3, respectively. From figure 2, it can be seen that the inclusion of fibers has a moderate influence on the structural performance of the SFRC slabs. The strength of the SFRC slab with V_f = 1% and 2% are significantly higher in comparison to the control slab. There was a sudden drop in the load-deflection curve for S1-2 which could be due to the over reinforcement which in turn leads to the brittle behaviour as compared to the control slab. In addition, the slab becomes stiffer and less deflection (this is largely attributable to the fibers' role in bridging cracks and limiting their opening) [14].

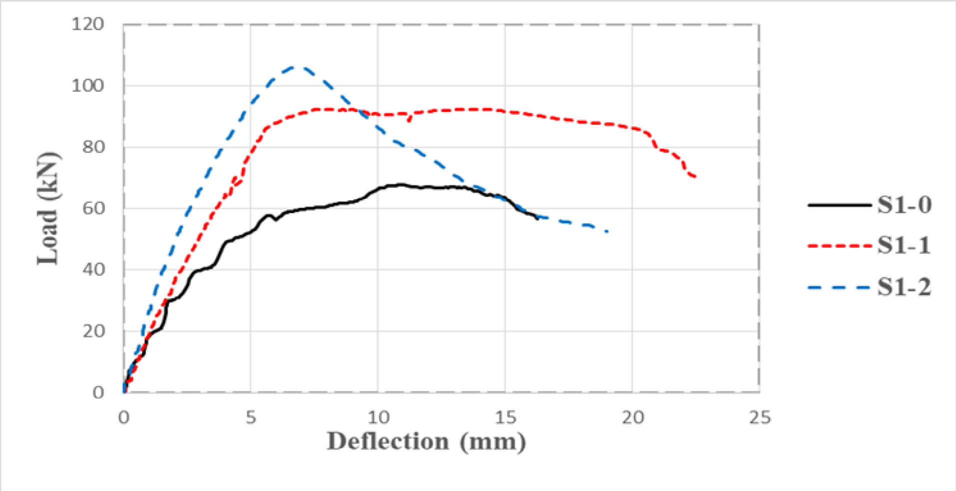

Figure 2. Load deflection curves for the first series of SFRC slabs.

For the second series slab, it can be seen that addition of fibers in the slab with reduced thickness resulted in better strength as compared to the slab without fiber (refer to figure 2 and 3). The results indicated that the steel fiber demonstrates its capability to compensate the loss of the shear capacity (from the slab thickness) and improves the slab structural behaviour while serving as part of shear reinforcement in the SFRC slabs. Furthermore, there was a proportional relationship between the ductility and the fiber volume fraction where the ductility of the SFRC slabs increases when fiber volume fraction was increased. This confirms the fact that adding fiber enhances the ductility of the brittle characteristics for concrete. It is apparent that the deflection of the S2-1 and S2-2 slabs was higher as compared to the slab S2-0. Moreover, the higher load was required to produce the deflection, suggesting that the slab is ductile and can sustain higher load carrying capacity.

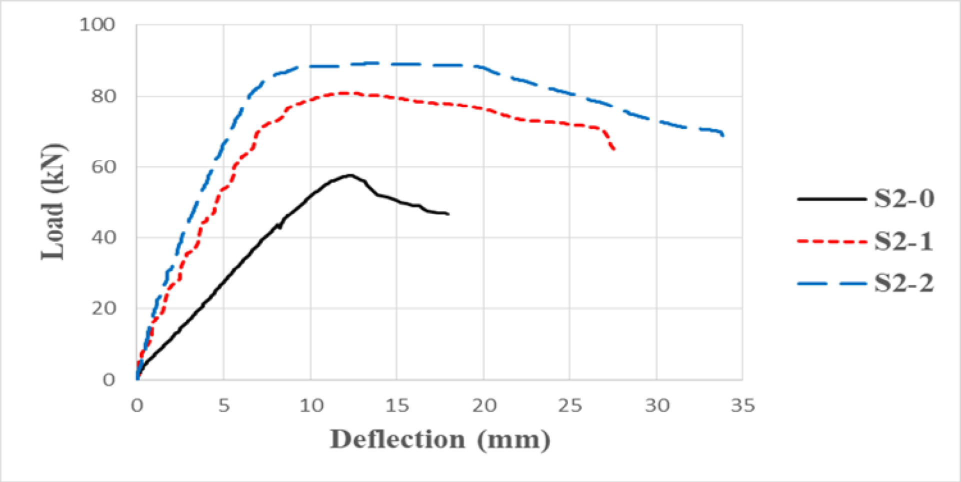

Figure 3. Load deflection curves for the second series of SFRC slabs.

The key parameters of strength and ductility from the load-deflection curves in Figure 2 and Figure 3 were summarized in table 4 and table 5, respectively. The key parameters involve the load at yield (*Py)* and its respective deflection (δy), the ultimate load (*Pu*) which represents the ultimate load at failure (taken as 85% of the maximum load) and its respective deflection (δu) and the maximum load (*Pmax)* and its respective deflection (δmax). Ductility ratio (μ) was computed by dividing the deflection at ultimate load to the deflection at yield ($\mu = \delta u / \delta y$).

It can be seen from the tables that the maximum strength (*Pmax*) and yield load (*Py*) for the second series of SFRC slabs are higher than that of slab without fiber. Added fibers are acting to keep the concrete matrix together. Subsequently, higher loading was needed to initiate the crack propagation. Moreover, fibers also serve as part of shear reinforcement to enhance the shear capacity of the slab as well as compensate the loss in concrete shear capacity of slab due to a reduction in the slab thickness.

Table 4. Result for the first series of SFRC slabs.

Specimen	*Py* (kN)	*δy* (mm)	*Pu* (kN)	*δu* (mm)	*Pmax* (kN)	*δmax* (mm)	*μ= δu / δy*
S1-0	57.75	5.83	57.53	16.15	67.68	10.87	2.77
S1-1	70.32	4.38	78.67	21.36	92.49	7.86	4.88
S1-2	80.81	3.94	90.23	9.40	106.16	6.86	2.40

Table 5. Result for the second series of SFRC slabs.

Specimen	*Py* (kN)	*δy* (mm)	*Pu* (kN)	*δu* (mm)	*Pmax* (kN)	*δmax* (mm)	*μ= δu / δy*
S2-0	43.53	8.12	49.21	15.93	57.50	12.46	1.96
S2-1	64.79	6.59	68.77	27.13	80.90	12.31	4.12
S2-2	70.47	5.43	75.93	28.10	89.33	13.80	5.17

In term of ductility, it can be seen that the ductility ratio (μ) of SFRC slabs continue to increase with the increase in the fiber volume fraction. However, there is an optimum amount of fibers depending on the amount of reinforcement or concrete shear capacity of the slab. For instance, in the first series of slab, the optimum amount of fibers can be taken as 1%, whereas for the second series of slab, the optimum amount of fibers increased to 2%. This because over reinforced of reinforced concrete structures tends to show a more brittle behaviour and should be avoided. Thus, it can be concluded that the inclusion of fibers introduces a ductile property into the concrete material, however, there is a certain limitation depending on the amount of the initial reinforcement presents in the structure.

Figure 4 to figure 7 illustrate the ratio of strength, ductility and energy absorption of the SFRC slabs normalized to control slab (thickness of 120 mm and $V_f = 0\%$) against fiber volume fraction. Figure 4 and Figure 5 show the ratio of the maximum load and the yield load to control slab (*Pmax*/*Pmax,0*) and (*Py*/*Py,0*), respectively.

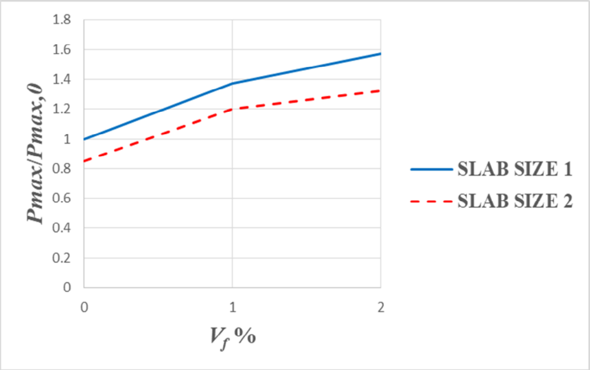

Figure 4. Graph *Pmax*/*Pmax,0* versus V_f.

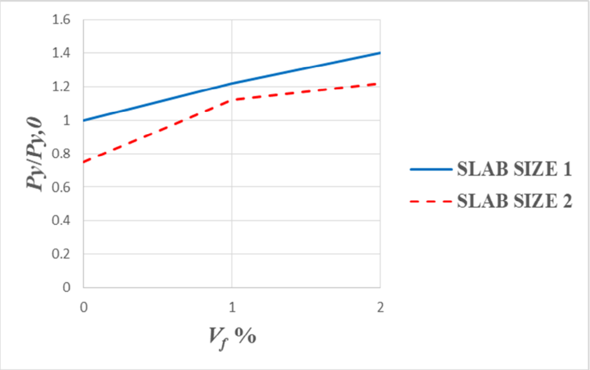

Figure 5. Graph *Py*/*Py,0* versus V_f.

A similar pattern was observed from the ratio of the maximum load (*Pmax*/*Pmax,0*) and load yield (*Py*/*Py,0*) as compared to the control slab. Slab S2-0 demonstrated a decrease in both maximum and yield ratios as compared to the control slab. On the other hand, the slabs with fibers show consistent enhancement the addition of fibers.

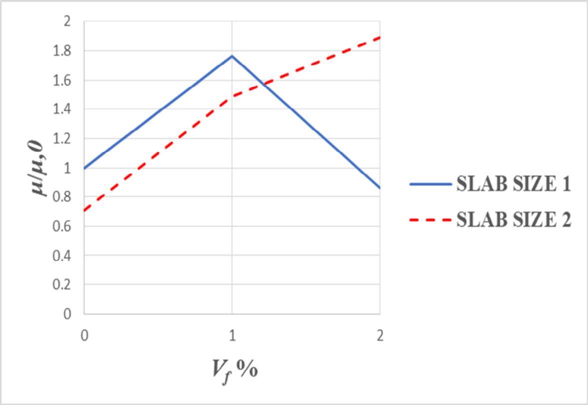

Figure 6. Graph $\mu/\mu,0$ versus V_f.

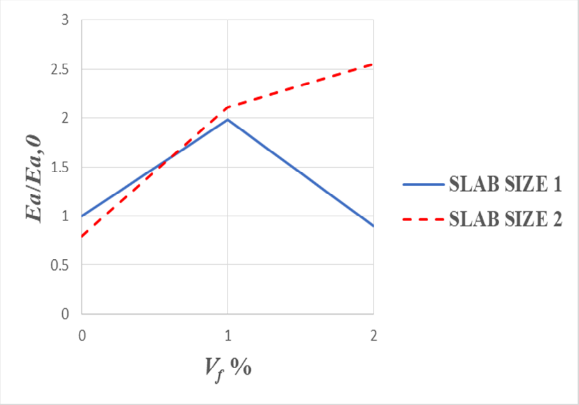

Figure 7. Graph $Ea/Ea,0$ versus V_f.

Figure 6 illustrates the results for the ratio between ductility ratio for each slab (μ) and that of the control slab specimen ($\mu,0$) plotted against volume fraction of steel fiber. The performance of ductility of the first series slab was an upward trend until V_f=1%, then followed by a sudden drop with V_f=2% due to over reinforcement which indicates to the early failure compared to the control slab. On the other hand, the ductility in second series slab was more promising with a continuous upward pattern. Moreover, at 1% of steel fiber volume fraction, the ductility ratio was higher than that obtained from the control slab. One of the key indicators of the structure's ability to absorb deformations which is energy absorption (*Ea*). Practically, energy absorption was calculated using the area under the load-deflection curve. The ratio between the energy absorption capacity of each slab (*Ea*) to the control slab (*Ea,0*) is given in figure 7. It is noticeable from the figures 6 and figures 7 that they have almost same pattern ratio graphs which confirmed that the actual trend and energy absorption ratio is similar to the ductility ratio which ensures its findings. These results are in agreement with previous studies reported by [3, 14]. It can be concluded that for significant improvement by inclusion steel fiber, the energy absorption was enhanced as compared with the control slab.

Figures 8, 9 and 10 represent the cracking pattern of the SFRC for the slabs S1-0, S1-1 and S1-2, respectively, whilst, the cracking pattern of the SFRC for the slabs S2-0, S2-1 and S2-2, are shown in figures 11, 12 and 13, respectively.

Figure 8. Cracking pattern at the failure of S1-0.

Figure 9. Cracking pattern at the failure of S1-1.

Figure 10. Cracking pattern at the failure of S1-2.

Figure 11. Cracking pattern at the failure of S2-0.

Figure 12. Cracking pattern at the failure of S2-1.

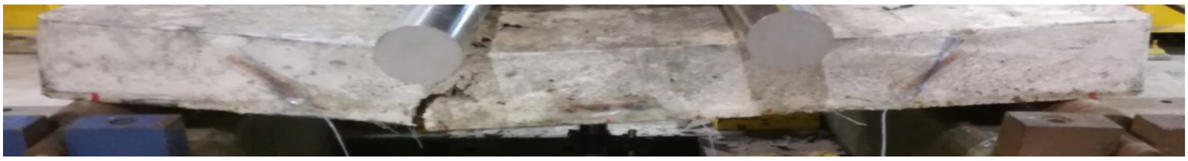

Figure 13. Cracking pattern at the failure of S2-2.

From the previous figures, most of the slabs showed cracking propagation along the mid-span and between support point and the loading. During testing, it was observed that S1-0 and S1-1 failed in bending, whilst, S1-2 failed in shear mode. As for the slabs with reduced in thickness, S2-0, without adding fibers was observed to fail in shear. Furthermore, as the fibers were added to the slabs, the mode of failure of the slabs change from shear to bending in S2-1 and S2-2.

4. Conclusion

Based on the results presented and discussed, it can be seen that the steel fibers have the potential to serve as part of shear reinforcement in reinforced concrete slabs as well as compensate the loss in concrete shear capacity of slab due to the reduction in the slab thickness.

The addition of steel fibers improves the load carrying capacity of the slabs consistently. In terms of ductility performance, the inclusion of fibers improved the ductility, delayed the crack propagation and managed to change the mode of failure of the slab from brittle to a more ductile manner. However, the optimum amount of fibers will reduce if the amount of initial steel reinforcement is higher. Reducing the shear capacity (through reducing the thickness) of the reinforced concrete slab causes higher optimum fiber volume fraction required to compensate the loss in the shear reinforcement.

5. References

[1] Swamy R N and Lankard D R 1974 Some practical applications of steel fibre reinforced Concrete *Proc. of the Institution of Civil Engineers* vol 56 (United Kingdom: ICE Publishing) pp 235-256

[2] Brandt A M 2008 Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering, *Compos. Struct.* **86** 3-9

[3] Syed Mohsin S M 2012 *Behaviour of Fibre-Reinforced Concrete Structures under Seismic Loading* Doctoral dissertation (London: Imperial College London) pp 46-50

[4] Mansur M A and Aziz M A 1982 A study of jute fibre reinforced cement composites, *Int. J. of Cement Compos. and Lightweight Concrete* **4** 75-82

[5] Abbas A A Syed Mohsin S M and Cotsovos D M 2016 A simplified finite element model for assessing steel fibre reinforced concrete structural performance, *Comput. and Struct.* **173** 31-49

[6] Hannant D J 2003 Fibre-reinforced concrete *Advanced Concrete Technology –processes* ed. J Newman and B S Choo (Oxford: Butterworth-Heinemann, Elsevier) chapter 6 pp 1 - 17

[7] Cucchiara C, La Mendola L and Papia M 2004 Effectiveness of stirrups and steel fibres as shear reinforcement, *Cement and Concrete Compos.* **26** 777-786.

[8] Khaloo A R and Afshari M 2005 Flexural behaviour of small steel fibre reinforced concrete slabs, *Cement and Concrete Compos.* **27** 141-149.

[9] Juárez C, Valdez P, Durán, A and Sobolev K 2007 The diagonal tension behavior of fiber reinforced concrete beams, *Cement and Concrete Compos*. **29** 402-408

[10] Ding Y, You Z and Jalali S 2011 The composite effect of steel fibres and stirrups on the shear behaviour of beams using self-consolidating concrete, *Eng. Struct.* **33** 107-117

[11] Minelli F, Conforti A, Cuenca E and Plizzari G 2014 Are steel fibres able to mitigate or eliminate size effect in shear?, *Mater. Struct.* **47** 459-473

[12] Kwak Y K, Eberhard M O, Kim W S and Kim J 2002 Shear strength of steel fiber-reinforced concrete beams without stirrups, *ACI Struct. J.* **99** 530-538

[13] Conforti A, Minelli F and Plizzari G A 2013 Wide-shallow beams with and without steel fibres: a peculiar behaviour in shear and flexure, *Compos. Part B: Eng.* **51** 282-290

[14] Abbas A A, Syed Mohsin S M, Cotsovos D M and Ruiz-Teran A M 2014 Shear behaviour of steel-fibre-reinforced concrete simply supported beams, *Struct. Build.* **167** 544-558.

[15] Gouveia N D, Fernandes N A, Faria D M, Ramos A M and Lúcio V J 2014 SFRC flat slabs punching behaviour–Experimental research, *Compos. Part B: Eng.* **63** 161-171

[16] Baarimah A O and Syed Mohsin S M 2016 An overview of using steel fibers in reinforced concrete structural elements to improve shear reinforcement *In: Proc. of the National Conf. for Postgraduate Research 2016 (Malaysia: Pahang)* (Malaysia: Universiti Malaysia Pahang) pp 260-265

[17] Marar K, Eren Ö and Roughani H 2017 The influence of amount and aspect ratio of fibers on shear behaviour of steel fiber reinforced concrete, *KSCE J. Civil Eng.* **21** 1393-1399

[18] Song P S and Hwang S 2004 Mechanical properties of high-strength steel fiber-reinforced concrete, *Constr. and Build. Mater* **18** 669-673

[19] Wang H T and Wang L C 2013 Experimental study on static and dynamic mechanical properties of steel fiber reinforced lightweight aggregate concrete, *Constr. and Build. Mater.* **38** 1146-1151