Civil Engineering and Architecture 9(5A): 128-137, 2021 http://www.hrpub.org
DOI: 10.13189/cea.2021.091315

Reinforced Concrete Slab with Added Steel Fibers for Engineering Application: Preliminary Experimental Investigations

Siti Junnaidah Baserah*, Nur Azwa Muhamad Bashar, Yee Hooi Min

School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, 13500, Permatang Pauh, Pulau Pinang, Malaysia

Received January 29, 2021; Revised July 27, 2021; Accepted August 15, 2021

Cite This Paper in the following Citation Styles

(a): *[1] Siti Junnaidah Baserah, Nur Azwa Muhamad Bashar, Yee Hooi Min , "Reinforced Concrete Slab with Added Steel Fibers for Engineering Application: Preliminary Experimental Investigations," Civil Engineering and Architecture, Vol. 9, No. 5A, pp. 128 - 137, 2021. DOI: 10.13189/cea.2021.091315.*

(b): *Siti Junnaidah Baserah, Nur Azwa Muhamad Bashar, Yee Hooi Min (2021). Reinforced Concrete Slab with Added Steel Fibers for Engineering Application: Preliminary Experimental Investigations. Civil Engineering and Architecture, 9(5A), 128 - 137. DOI: 10.13189/cea.2021.091315.*

Abstract The application of steel fiber as added materials in a plain concrete-shows many potential benefits in improving structural properties namely tensile and flexural strength. The plain concrete with steel fibers added is said to be effective for both short and long terms duration based on its characteristics mainly size, shape, volume, and distribution. Such potentials have made it a material worthy to be further studied. This research was conducted to assess the strength of a plain concrete with the addition of steel fibers in the conventional concrete slab. Several testings were conducted to determine the strength characteristic (compressive and flexural) of the control sample; conventional reinforced concrete (RC) and reinforced concrete with steel fibers added (RCSF). In this study, the commercial steel fibers taken from Dramix which is categorised under 5D-Type was added during the concrete mixing processes according to the three different percentages of 0.5%, 0.75% and 1.0%. Obtained result shows that the concrete with steel fibers added (0.5%) had the highest compressive strength while both reinforced concrete and concrete with 0.75% addition of steel fibers showed almost similar flexural strength value. Deflection testing was conducted on both RC slab and RCSF slab via Three-point bending test. It is found that the RC slab showed a higher mid-span deflection rate. Furthermore, result from the physical observation and measurement for crack propagation evaluation shows that RC slab had a wider cracking gap compared to RCSF. In a nutshell, steel fibers in plain concrete gives several advantages and provide an alternative for the construction practitioner in minimizing the construction cost while maintaining the quality and reducing the cracking problem mainly due to the structural properties of concrete.

Keywords Steel Fibers (5D-Type), Reinforced Concrete Slab, Concrete Workability, Compressive Strength, Deflection, Cracking Pattern

1. Introduction

A reinforced type of flat slab with a smaller thickness compared to its span has been widely used across the world in the construction of flooring systems for the residential buildings [1]. The addition of steel reinforcement may reduce the deformation and bending problem occurred due to the larger and wider physical appearance of the concrete slab. On the other hand, by considering adequate amount of steel fibers in the concrete bring a lot of benefits including tensile strength improvement and controlling of the cracking which causes structural elements failure. Research on the concrete slab with steel fibers added shows that about 23% of the punching capacity is improved. Furthermore, 6% punching shear capacity increment is reflected by the 23% of the flexural reinforcement ratio [2].

Over the years, rising amount of construction cost is contributed by the expensive cost of steel reinforcement and skilled worker requirement for site installation [3]. In addition, the usage of the steel reinforcement in shear-reinforced concrete slabs can be one of the main challenges to the construction practitioner [4]. The steel reinforcement experiences corrosion problems that minimises its functionality [5]. Marí et al. [6], investigates the value of compressive strength affected by the bending moments force around the column. This compressive strength sets a limitation to the concrete compression chord of the slab. About 300-mm diameter of creator is generated on the surface due to the damage. This may give huge impacts on longitudinal direction instead of transverse direction [7]. Largest slip occurred in a plain reinforced concrete slab without any addition of steel reinforcement [8].

An innovation has been done focusing on the technical improvement including structural improvement of reinforced concrete by the addition of steels fibers. Oad et al., [3] in his research suggested that the shrinkage cracking resistance, tensile strength and deformation characteristics can be improved by adding a certain dosage of steel fibers. Besides, steel reinforcement on-site installation period and construction time can be minimized [8, 9]. In addition to this, it offers ease to the concrete work where it can be added directly during the concrete mixing process after the required weight has been determined. Additionally, the increment of load carrying capacity may improve the structural performance, cracking properties, interface slip in plastic loading stage together with a good fire resistance performance which eventually contribute to cost saving [8, 9]. Zhang et. al. [10] stated that the improvement of bonding performance between steel rebars and concrete can be done by adding the steel fibers. This can be achieved by proposing a required dosage of steel fibers for a great performance of steel-concrete bonding and fluidity of concrete. It is recommended that the amount of steel fibers dosage should be between 0.25% and 0.75%.

Other researchers [11] recommended the steel fibers as an alternative to shear reinforcement in a one-way thick type bridge slab, where it is found that the addition of the steel fiber provides easiness to thick slab construction as well as shear strength improvement similar to the conventional steel reinforcement. Research done by Mansour et al., [8] confirmed that the steel fibers added in a composite slab increase energy absorption and ductility resulting in the toughness and ductility improvement.

Research conducted by Salehian and Barros, [12] on the elevated steel fibre reinforced concrete, found that the increment of ultimate load may be influenced by the increment of compressive strength (up to 80 MPa) while the increment of steel fibers dosage (in between 0.6% to 1.2%) has huge impacts on the loading carrying capacity (up to 80%). [13]. Research on the steels fibers reinforced concrete with respect to service stresses shows improved service performance when the concrete slab contains small reinforcement ratios but provide larger deflection rate which is 7.6 mm (concrete slab strip combined with steel located at the centre of the slab).

This research proposes the study on steel fibers reinforced concrete in comparison with the reinforced concrete in terms of strength characteristics measurement. Then, the determination on the deflection rate both for the reinforced concrete slab and steel fibers reinforced concrete slab at a several dosages (0.5%, 0.75% and 1.0%) and evaluation on the cracking propagation based on the physical observation and measurement were also conducted.

2. Materials and Methods

This section mainly focus on summarising the research activity comprises of the flow chart, experimental design (concrete mixed design), formwork preparation for concrete casting and methods involved for testing of the fresh concrete (slump test), concrete cube (prior to 28 days of curing procedure) and casted reinforced concrete slab (conventional and steel fibers added).

2.1. Flow Chart of Research Activity

In this research, several activities were conducted for the concrete cast-in (reinforced concrete slab and reinforced concrete with steel fibers slab). **Figure 1** shows the flow chart of the research activities.

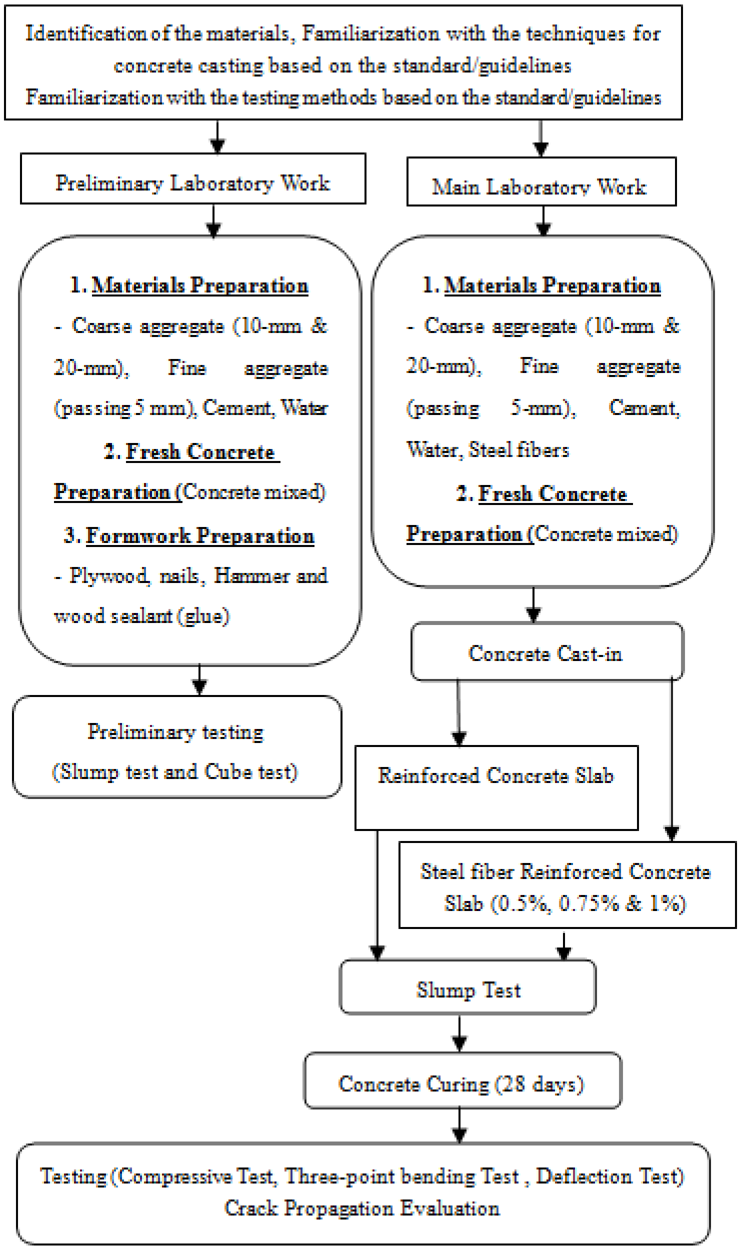
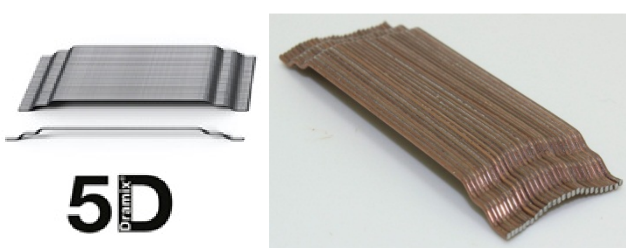


Figure 1. Flow chart of the research activities

2.2. Materials Properties

2.2.1. Concrete mix

The objective of the mix was to provide a regular concrete with a specified strength of 30 MPa. The mix proportion of the concrete was conducted prior to the standard MS523:1993/BS5328 [14]. The steel fibers concrete mix was designed based on the guideline to obtain the same strength as the available reinforced concrete. Thus, the steel fiber concrete mix considered the same raw materials with the addition of slightly more water and cement while the quantities of sand and aggregates were reduced. The fine aggregate sieved passed through a 5-mm sieves tray in sieve equipment. This process is vital to separate between the coarse and fine aggregate or any other unnecessary materials. The steel fibers used in concrete were 60 mm long and 0.9 mm in diameter with long double end-hooked fibres (Dramix 5D) as shown in **Figure 2.**



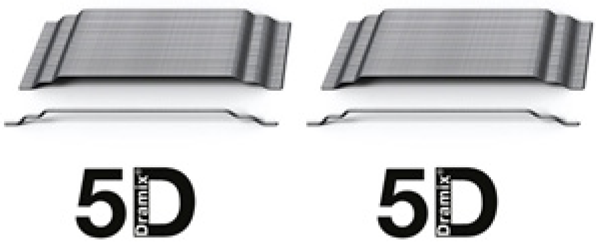


Figure 2. The shape of the steel fiber [9]

The tensile strength of this steel fiber was 2300 MPa [9]. This special 5D grade series are provided with the great performance in terms of ultimate anchorage, ductility wire (high) and tensile strength (ultra-high) tensile strength. The amount of added steel fibers dosage in this research was determined by referring to the minimum dosage of steel fiber which is 15 kg/m^3 (3.0 km per m^3). The young's modulus, wire ductility, and aspect ratio were 210000 N/mm^2, 6%, and 65, respectively. **Table 1** shows the estimated amount of steel fiber for concrete slab and cube according to the percentage amount of steel fibers.

Table 1. Estimated amount of steel fiber for concrete slab and cube

Volume of Steel Fibre	Amount of Steel Fibers (kg)	
	Concrete Slab	Concrete Cube
0.5%	0.9	0.24
0.75%	1.35	0.37
1.0%	1.80	0.49

Table 2 shows the estimated amount of materials used to produce one cubic meter of reinforced concrete and reinforced concrete with steel fibers (according to percentage).

Table 2. Mix proportion of concrete

Component	Concrete Slab (kg)	Concrete Cube (kg)
Water	17	4.6
Cement	34	9.3
Fine aggregate	54	14.7
Coarse aggregate	96	26.2

2.2.2. Formwork

The plywood type-formwork was prepared into a specific designed size for concrete slab (1000 mm x 500 mm x 150 mm). The moisture and water absorption rate for plywood material were 13.77% and 27.1%, respectively [15]. The selection of the formwork material gives good impacts on the water absorption and concrete compressive strength characteristics where the good concrete density and compressive strength can be achieved by the higher water adsorption rate.

2.3. Methods

The methods used in these studies are slump test, compression test, three-point bending test and deflection test. Detail explanations are provided in the following section.

2.3.1. Slump Test

The slump test was conducted prior to the workability or strength of the concrete as written in British Standard (BS EN 12350-2:2019) [16]. Casting procedure and slumps height determination using slump test were conducted directly on site (to avoid hardened concrete). The height of the slump should be in the range of 120 mm and 150 mm. **Figure 3** shows the testing of slump height during slump test.

Figure 3. Slump height testing procedure

2.3.2. Compressive Test

To evaluate the compressive strength of concrete, both the conventional and steel fiber reinforced concrete were tested in the laboratory. In this research, the cube test tested were six number of samples for both types of the concrete samples (reinforced concrete and steel fiber reinforced concrete) using the standard size cube (150 mm x 150 mm x 150 mm).

The casted concrete cubes were tested for compressive strength prior to 7, 14 and 28 days of curing procedure. The curing procedure was conducted based on the British Standard; BS EN 12390 - 2: 2019 [17] where it clearly mentioned the prevention of moisture losses in concrete. The compressive strength test was conducted according to the British Standard; BS EN 12390 Part 3: Compressive Strength of Test Specimens [18].

Compression cube test for compressive strength estimation on the reinforced concrete during the preliminary laboratory works is essential prior to the listed strength as in the concrete mixed design manual. Then, the proportion of the concrete mixture is used for the preparation of the sample.

2.3.3. Three-Point Bending Machine and Testing

Determination of the concrete slab strength was conducted using the reaction frame machine (Three-point bending testing apparatus) as shown in **Figure 4.** For this testing, the point load was applied at the middle of the simply supported concrete slab. The loading rate for the applied loading was 0.02 mm/sec and it was continuously applied on the concrete slab until the maximum rate was achievable. The size of the concrete slab used in this study was 1000 mm x 500 mm x 150 mm. **Figure 5** shows the setup of the instruments and its loading.

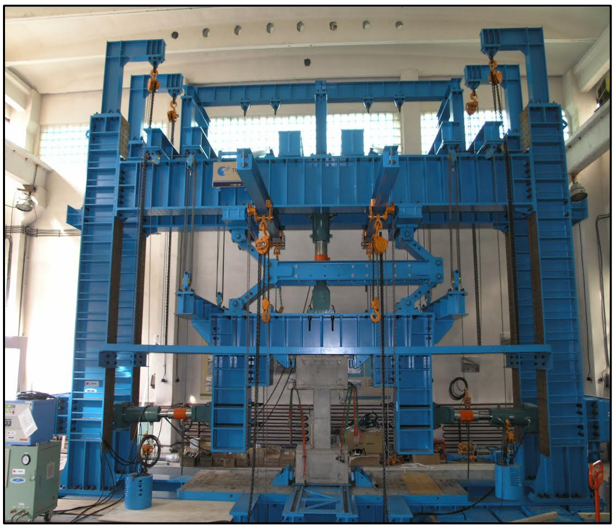


Figure 4. Reaction frame machine arrangement

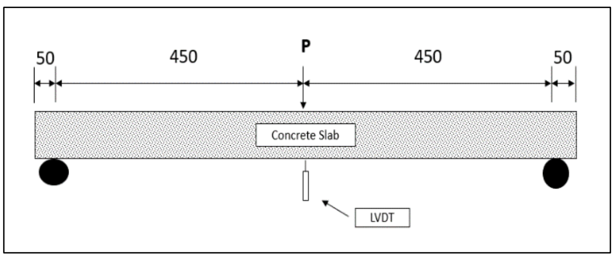


Figure 5. Loading arrangement of the three-point bending test

2.3.4. Deflection Test

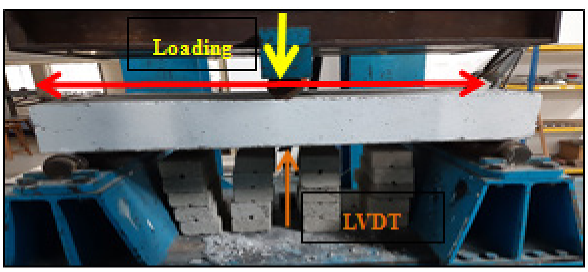


Figure 6. Arrangement of the sample on the machine

The vertical deflection of the slab samples was monitored by using Three Linear Variable Differential Transformers (LVDT). The maximum deflection was measured at the mid-span point of the slab samples via LVDT. As support, several towers of bricks were placed about 100 mm from the bottom of the slab sample. **Figure 6** shows sample arrangement on the required machine.

3. Result and Discussion

The obtained results were arranged to achieve the objective on the workability of the fresh concrete sample. Then, the comparison on the strength (compressive and flexural), deflection assessment and crack evaluation both for conventional and steel fibers reinforced concrete sample were conducted.

3.1. The Workability of Fresh Concrete

The fresh samples are compulsory to be tested for its workability through physical observation and measurement of the slump height and classified according to the type of slump characteristic. British Standard (BS EN 12350-2:2019) [16] classified the type of slumps into true slump, zero slump, collapsed slump and shear slump. It should be highlighted; the mix proportion including the addition of the steel fibers may influence the workability of fresh concrete either good, average, or lower. **Figure 7** shows the measurement height of slump for conventional (C) fresh concrete and steel fibers fresh concrete (SF). The addition of steel fibers into fresh concrete were of three different percentages namely SF1, SF2 and SF3, for 0.5%, 0.75% and 1.0 %, respectively.

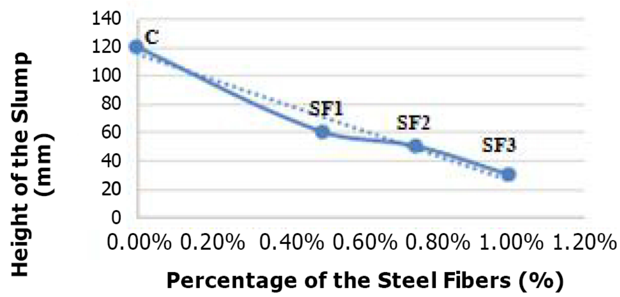


Figure 7. Measurement height of the slump

Based on **Figure 7,** the control specimen or fresh reinforced concrete gives remarks of 120 mm and it is within the range of 120 mm to 150 mm as listed in the standard procedure. However, the added 0.5%, 0.75%, and 1.0% steel fibers in the fresh concrete are 60 mm, 50 mm and 30 mm, respectively. The percentage or dosage of the steel fibers has largely influenced the workability of the concrete. The workability may be affected by the changes of water cement ratio where the ratio was slightly changed according to the added amount of steel fibers in the concrete mix.

The tendency of the slump height to decrease is higher if there is an increment in the dosage of the steel fibers. Furthermore, the workability of the steel fiber added to the fresh concrete may slightly reduce due to the type and shape of the steel fiber in fresh concrete. The research administered by Zeyad [19] supported this finding where the diameter of the slumps was reduced with respect to the different amount of steel fibers, type and shape. In addition, wide fibers surface area indicates a large slump diameter. This effect due to the weight of the steel fibers and disperse location of the steel fibers in concrete. Other researchers [20] found that lower slump values were observed for Mix-SF sample associated with higher fiber concentrations.

3.1. Concrete Strength

The strength of the conventional and steel fibers reinforced concrete were assessed in terms of compressive and flexural strength and discussed in the following section.

3.1.1. Compressive Strength of the Conventional and Steel Fibers Reinforced Concrete

Compressive strength experiment was determined for 7, 14, and 28 days, as presented in **Figure 8.** This strength type was determined according to the BS EN 12390 Part 3 [18].

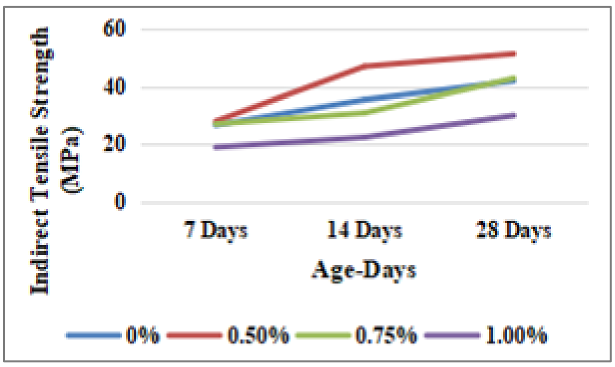


Figure 8. Compressive strength of the casted samples

Based on **Figure 8,** the finding indicated that the added steel fibers gained higher strength compared to the conventional reinforced concrete. The cube sample with addition of 0.5% steel fiber measured a rate of 28.03 MPa compared to the addition of 1.00% steel fiber that indicated about 18.97 MPa of compressive strength at day 7. The compressive strength for conventional concrete were 26.67 MPa (day 7), 35.45 MPa (day 14) and 41.91 MPa (day 28), respectively. From the plotted graph, the higher compressive strength values for 0.5% added steel fibers at 14 days and 28 days are 46.96 MPa and 51.33 MPa, respectively while the lowest strength is 1.0% added steel fibers (30.02 MPa) on day 28.

The 1.00% of steel fibre concrete cube presented the lowest result in compressive strength among the added percentage of steel fibers as well as the conventional concrete. In contrast, 0.5% added steel fibre concrete cube shown a higher compressive strength results for day 7, 14 and 28. The addition of steel fibers gradually increased the strength of the mix. This depends on the dosage, type, shape and arrangement or distribution of the steel fibers in the mix. This finding is consistent with Zayed [19]. However, it is inconsistent with the result of the previous research by Alabduljabbar et. al. [20], where steel fibers addition slightly increased the compressive strength of the concrete mix. Other researchers [21], conduct an analysis on the several dosages (1%, 2%, 3% and 4%) of steel fibers added into plain concrete and found that the highest compressive strength was obtained at 2% dosage of steel fiber, Furthermore, the steel fibers added greater than 2% showed a reduction in strength.

The variation of the compressive strength values was also affected by the workability result of the sample where the addition of steel fibers reduces the efficiency of the fresh concrete properties compared with conventional concrete sample based on the slump height. Furthermore, the reduction of the compressive strength is due to the age and the presence of air trapped around the steel fibers [22]. The compressive strength was also affected by the type of steel fibers where the 60-mm length was remarked as the lowest compressive strength [19].

3.1.2. Flexural Strength of the Conventional and Steel Fibers Reinforced Concrete

The flexural strength results were presented as in **Figure 9.** Based on the obtained results, the higher flexural strength is 5.67 MPa, from the reinforced concrete without steel fibers added. The value of flexural strength from this study is higher compared to the study conducted by Baarimah and Syed-Mohsin [23] where the measured strength is 3.50 MPa.

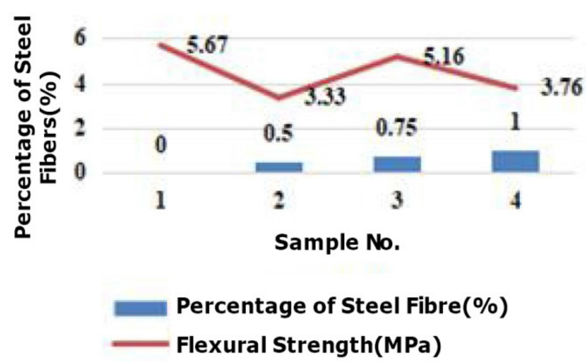


Figure 9. Flexural strength of the casted samples

Based on **Figure 9**, graph shows higher flexural strength, 0.75% of the steel fibre at 5.16 MPa while 0.5% of the steel fibre reinforced concrete gives a value of 3.33 MPa. This flexural strength results show the contrast relationship with the workability of the concrete, where with the 0.75% addition of steel fibers remarked the higher slump flow compared to others steel fibers added. The fibers addition and fibers type directly affect the flexural strength of the steel fibers reinforced concrete. Research done by Zeyad [19] and Pradeep et. al. [24]

concrete slab sample with 0.75% of steel fibre. For this sample, the first cracking started to appear from the bottom (red marking) while the second cracking was remarked by the blue marker. The presence of the first cracking was followed by the second cracking (on the same cracking line). Based on the observation, it is found that the cracking also affects the tension zone. However, the detected cracking is smaller compared to the early cracking.

Figure 14 shows the cracking pattern of the 1.00% steel fibre reinforced concrete slab sample. The red marking shows the appearance of the early sample cracking slowly occurred during the testing and this was followed by the second cracking after a few seconds when the loadings were continuously applied. The appearance of the cracking patter was coloured in blue marking as shown in the figure. **Table 3** shows the cracking evaluation based on the different types of applied loadings.

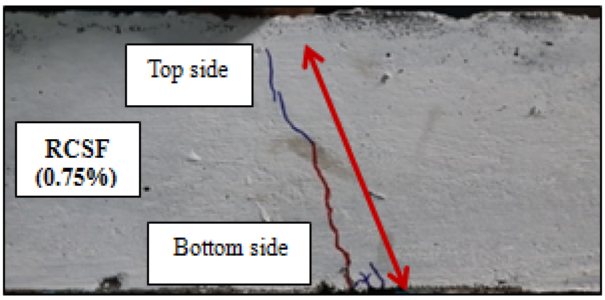


Figure 13. Cracking pattern for steel fibers reinforced concrete slab (0.75%)

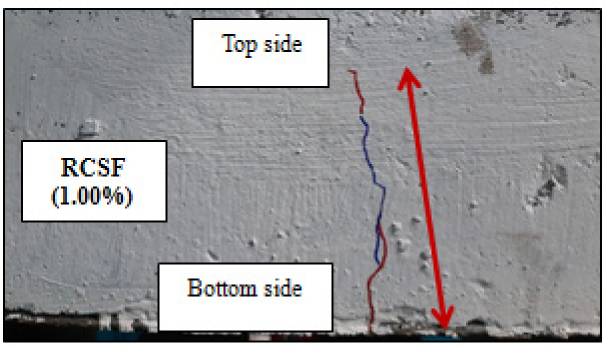


Figure 14. Cracking pattern for steel fibers reinforced concrete slab (1.00%)

Table 3. Cracking evaluation by several applied loadings

Percentage of Steel Fibers (%)	Loadings (KN)	Length (mm)	Width (mm)
0%	34	194	4
0.5%	26.89	127	< 1
0.75%	36	137	< 1
1.0%	24.68	119	< 1

Based on **Table 3.**, the addition of 0.75% steel fibers dosage was able to withstand the largest loading among the added steel fibers reinforced concrete slabs at 36 kN while the length of the cracking appears on the concrete surface is about 137 mm. The cracking length both for 0.5% and 1.00% added steel fibers reinforced slab are 127 mm and 119 mm, respectively. Based on Table 3, 1.00% steel fiber reinforced concrete slab showed a lowest cracking length. The cracking width of the 1.00% steel fiber reinforced concrete shows similar values as 0.5% and 0.75% of steel fiber reinforced concrete slab which is less than 1-mm. Nguyen et al. [25] investigated that the effect of steels fibers amount with respect to the flexural cracking where the higher amounts of fibers added into the concrete matrix, the lower the number of flexural cracks created and the higher the punching shear resistance of the concrete slab with steel fibers addition. Furthermore, cracking patterns of the slabs showed that adding fibers to the concrete mixture may impede the appearance of the first crack. Furthermore, the presence of cracking failure depended on the volume fraction of the steels fibers and its position.

The conventional reinforced concrete slabs were able to withstand maximum loading at 34 kN when the cracking started to occur and appeared on the concrete surface with the length and width of the cracking of 194 mm and 4 mm, respectively. This value indicates the maximum cracking length and width appeared on the concrete surface compared to other samples (steel fibers added). This result was supported by McMahon and Birely [13], where the location of the steel reinforcement causes huge impacts to the cracking pattern of the reinforced concrete slab (in this case conventional reinforced concrete contains 8-mm wire mesh at the bottom). The average crack width is expected to be larger for the steel reinforcement located at the centre of the slab rather than at the bottom side. The addition of steel fibers into concrete slabs mainly hybrid (steel reinforcement and steel fibers) is effective in managing the width of the cracks prior to large deformations [13]. In terms of failure patterns, sample without steel fiber exhibit a distinct brittle failure mode while the samples with steel fibers addition exhibit slow ductile failure characteristics [27].

4. Conclusions

This experimental research intended to investigate the performance of the steel fibers reinforced concrete in comparison to the conventional reinforced concrete slab in terms of their workability, strength (compressive and flexural), deflection and cracking evaluation on the concrete slab surface. Based on the obtained results, the following observations can be highlighted:

i. Addition of steel fibers in the concrete mix changes the fresh and hardened properties both positively (increment) or negatively (decrement) depending on the dosage of the steel fibers in comparison with the conventional reinforced concrete.

ii. The highest slump height was reinforced concrete sample. This may be due to the reduction of certain components in the concrete mix and the arrangements of the steels fibers in the concrete. Thus, a proper calculation of required dosages based on the types and shape should be conducted prior to the improvement in the future work.

iii. Compressive strength was affected by different extents of the fiber dosages. The steel fibers with 0.5% content have higher compressive strength compared to other percentage of steel fibers added.

iv. The higher flexural strength value belonged to the reinforced concrete slab with strength value of 5.67 MPa while the steel fibers with 0.75% added are 5.16 MPa. Based on these two values, it shows a small difference. Thus, it can be concluded that the proposed 0.75% steel fibers slab is at par in terms of flexural strength behaviour with the reinforced concrete slab.

v. The reinforced concrete slab shows larger cracking compared to the reinforced concrete slab with different dosage (0.5%, 0.75%, 1.00%).

vi. Reinforced concrete slab with 0.75% steel fibers, remarks the maximum loading, 36 KN with the length of cracking and width of 137-mm and 1-mm, respectively. However, the lowest cracking length was measured on the surface of the reinforced concrete with 1.00% added steel fibers at 119 mm.

vii. Further investigations and details assessment should be conducted on the effect of different types of steel fibers dosage, arrangement, or dispersion of the steel fibers in concrete, some of the issues remain to be addressed in the future investigations to improve the current preliminary work.

Acknowledgments

We would like to thank Beakert (M) Sdn. Bhd. for funding this research under Private Research Grants Scheme and Universiti Teknologi MARA, Cawangan Pulau Pinang for the facilities and support.

REFERENCES

[1] L. Facconi, F. Minelli, & G. Plizzari, Steel Fiber Reinforced Self-Compacting Concrete Thin Slabs – Experimental Study and Verification Against Model Code 2010 Provisions. Engineering Structures, 122, 226–237, 2016.

[2] R. T. S. Mabrouk, & A. A. Hegab. Analysis of the Punching Behavior of RC Flat Slabs with Horizontal and Vertical Shear Reinforcement. MATEC Web of Conferences, 120, 01006, 2017.

[3] R. Oad, A. A. Jhatial, S. Sohu, M. T. Lakhiar, & N.-K. Bhatti, Effect of Steel Fibres on the Compressive and Flexural Strength of Concrete. International Journal of Advanced and Applied Sciences, Vol. 5, No. 10, 16–21, 2018.

[4] D. Kueresa, M. A. Polaka, and J. Hegger, Two-parameter kinematic theory for punching shear in steel fiber reinforced concrete slabs. Engineering Structures, 205, 110086, 2020.

[5] N. Zhuang, H. Dong, Y. Zhou, & D. Chen, Cracking Behavior of Reinforced Concrete Piles Externally Bonded with Carbon Fiber Reinforced Polymer in a Marine Environment Construction and Building Materials, 190, 1154–1162, 2018.

[6] A. Marí, A. Cladera, E. Oller, & J. M. Bairán, A Punching Shear Mechanical Model for Reinforced Concrete Flat Slabs with and without Shear Reinforcement, Engineering Structures, 166, 413–426, 2018.

[7] N. Bonora, G. Curiale, A. Ruggiero, E. Sacco, P. Brandão, V. Infante, & A. M. Deus, Analysis of Reinforced Concrete Slabs Under Blast Loading. Procedia Structural Integrity, 9, 272-278, 2018.

[8] F. R. Mansour, S. A. Bakar, I. S. Ibrahim, & A. K. Marsono, Flexural Performance of a Precast Concrete Slab with Steel Fiber Concrete Topping, Construction and Building Materials, 75, 112–120, 2015.

[9] Dramix@5D – Technical Documents, Online available from https://www.bekaert.com/en/products/construction/concrete-reinforcement/dramix-steel-fiber-concrete-reinforcement-solutions, 2019.

[10] X. Zhang, W. Zhang, C. Cao, X. Fu, Y. Caiqian, Positive Effects of Aligned Steel Fber on Bond Behavior between Steel Rebar and Concrete, Cement and Concrete Composites, 114, 1 – 11, 2020.

[11] E. Ahmed, F. Legeron, M. Ouahla, Steel Fiber as Replacement of Minimum Shear Reinforcement for One-Way Thick Bridge Slab, Construction and Building Materials, 78, 303–314, 2015.

[12] H. Salehian, & J. A. O. Barros, Prediction of The Load Carrying Capacity of Elevated Steel Fibre Reinforced Concrete Slabs, Composite Structures, 170, 169–191, 2017.

[13] J. A. McMahon, & A. C. Birely, Service Performance of Steel Fiber Reinforced Concrete (SFRC) Slabs, Engineering Structures, 168(April), 58–68, 2018.

[14] MS523:1993/BS5328: JKR 20800 – 132 – 23 (Sec D:2005) (Concrete Mix Design)

[15] I. A. Rubaratuka, Influence of Formwork Materials on the Surface Quality of Reinforced Concrete Structures, International Journal of Engineering and Applied Sciences, Vol. 4, No. 5, 2013.

[16] BS (2019). EN 12350-2: Tesing Fresh Concrete: Slump Test. British Standard, UK.

[17] BS (2019). EN 12390-2: Testing Hardened Conrete: Making and Curing Specimens for Strength Test. British Standard, UK.

[18] BS (2019). EN 12390-3: Testing Hardened Concrete: Compressive Strength of Test Specimens. British Standard, UK.

[19] A. M. Zeyad, Effect of Fibers Types on Fresh Properties and Flexural Toughness of Self-Compacting Concrete, Journal of Material Research and Technology, Vol. 9, No. 3, 4147–4158, 2020.

[20] H. Alabduljabbar, R. Alyousef, F. Alrshoudi, A. Alaskar, A. Fathi and A. M. Mohamed, Mechanical Effect of Steel Fiber on the Cement Replacement Materials of Self-Compacting Concrete, Fibers, Vol. 7, No. 36; 1-11, 2019.

[21] Jawad Ahmad, Aneel Manan, Asif Ali, M. Waleed Khan, M. Asim, Osama Zaid, "A Study on Mechanical and Durability Aspects of Concrete Modified with Steel Fibers (SFs)," Civil Engineering and Architecture, Vol. 8, No. 5, pp. 814-823, 2020. DOI: 10.13189/cea.2020.080508.

[22] K. Pilakoutas, K. Neocleous and H. Tlemat, Reuse of tyre steel fibres as concrete reinforcement, In: Proceedings of the Institution of Civil Engineers-Engineering Sustainability, Vol. 157, 131–8, 2004.

[23] A. O. Baarimah, & S. M. Syed-Mohsin, Behaviour of Reinforced Concrete Slabs with Steel Fibers. IOP Conference Series: Materials Science and Engineering, 271(1), 2017.

[24] S. Pradeep, V. U. Eezha Vengai, D. F. More, Experimental Investigation on the Usage of Steel Fibres and Carbon Fibre Mesh at Plastic Hinge Length of Slab, Materials Today: Proceedings, 14, 248–256, 2019.

[25] T. N. Nguyen, T. T. Nguyen, and W.t Pansuk, Experimental study of the punching shear behavior of high performance steel fiber reinforced concrete slabs considering casting directions, Engineering Structures, 131, 564–573, 2017.

[26] M. Ju, J. W. Ju and J. Sim, A new formula of punching shear strength for fiber reinforced polymer (FRP) or steel reinforced two-way concrete slabs, Composite Structures 259, 113471, 2021.

[27] X. Li, Y. Zhang, C. Shi, and X. Chen, Experimental and numerical study on tensile strength and failure pattern of high performance steel fiber reinforced concrete under dynamic splitting tension, Construction and Building Materials, 259, 119796, 2020.