

Influence of Hooked-End Steel Fibers on Fresh and Hardened Properties of Steel Fiber Reinforcement Self-Compacting Concrete (SFRSCC)

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Submission date: 21-Oct-2019 11:28AM (UTC+0700)

Submission ID: 1196959890

File name: f_Physics_Conf._Series_1198_2019_032005_Faiz_Sulthan,_Saloma.pdf (835.09K)

Word count: 4181


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To cite this article: Faiz Sulthan and Saloma 2019 *J. Phys.: Conf. Ser.* **1198** 032005

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Influence of Hooked-End Steel Fibers on Fresh and Hardened Properties of Steel Fiber Reinforcement Self-Compacting Concrete (SFRSCC)

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Abstract. The use of steel fiber in SCC is known as steel fiber reinforcement self-compacting concrete (SFRSCC). Since its development, steel fiber consists of various shapes such as straight, crimped, and hooked-end. The purpose of this research is to analyze the influence of shape variation and volume fraction (V_f) of hooked-end steel fibers to fresh and hardened properties of SFRSCC. Fresh concrete testing is done based on EFNARC standard such as Slump flow test, V-funnel test, and L-box test. Hardened concrete testing is done in the form of compressive strength and splitting tensile strength. The steel fiber used is a hooked-end type which consists of three types namely, 3D, 4D, and 5D with value of volume fraction (V_f) are 0.50%, 0.75%, and 1.00%. The results of this study were indicated the effect of volume fraction (V_f) increasing can decrease the workability of SFRSCC. Mix design SFRSCC in this research meets SF1 and SF 2 filling ability classes, Viscosity VS2, VF1 and VF 2 class, and passing ability PA 2 class. For mechanical properties obtained maximum compressive strength of 55.85 MPa with percentage increase of concrete without steel fiber equal to 32.66%, and maximum splitting tensile strength of 6.38 MPa with percentage increase of 82.81%. The maximum mechanical properties are obtained by volume fraction (V_f) = 1.00% and 5D type steel fiber.

3 1. Introduction

Self-Compacting Concrete (SCC) is a concrete technology that has the ability to compact its own form in the casting process without the aid of a vibrator. SCC is used to save time and amount of labour in concrete work. The technology was first developed in Japan in 1986 by Professor Hajime Okamura and Kazumasa Ozawa of the University of Tokyo to overcome the problems of concrete durability and the increasing demand for skilled workers for concrete work [1-3].

The ability of SCC to perform its own compacting mechanisms makes the concrete denser so as to increase the compressive strength of concrete, but the denser concrete is more brittle. In order to increase the elasticity of concrete, it is necessary to add fiber in concrete, for example steel fiber. Steel fibers in concrete mixing can increase flexural strength, energy absorption capacity, ductile behaviour before ultimate collapse, inhibit widening of cracks and increase durability [4].

Negative side of using steel fiber is reduced workability in fresh concrete, so SCC technology can be used as a better alternative in field work [5]. The innovation of using steel fiber into SCC is known as steel fiber reinforced self-compacting concrete (SFRSCC). SFRSCC is a combination of two



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concrete innovations that have the workability advantages of SCC and improved mechanical properties of steel fiber [6].

The performance of steel fiber in concrete depends on many factors such as steel fiber type, shape, length, cross-sectional shape, tensile strength, fiber content, bond strength, matrix strength, mixed concrete composition and mixing in concrete [7].

The form of steel fiber develops continuously since the beginning of its discovery. Previous studies on the effects of various shapes of steel fibers consisting of a straight, crimped, and hooked-end showed that hooked-end steel fibers are the best shape to improve the mechanical properties of steel fiber reinforcement concrete [8].

In contrast, the impact of hooked-end steel fibers type on SCC workability when compared to straight and crimped type will reduce SCC workability, so it needs a good concrete mix to keep the SCC criteria [9].

This research was analyzed the influence of hooked-end steel fibers type on the fresh and hardened properties of steel fiber reinforced self-compacting concrete (SFRSCC).

2. Materials and Methods

2.1. Materials

The composition of the SFRSCC mixture used in this study was designed by collecting data from journals, EFNARC and ACI standards that can be seen in Table 1. The composition consists of Ordinary Portland Cement (OPC) type I cement, fine aggregate (FA) derived from natural sand of Tanjung Raja size of 0.125 - 4 mm, coarse aggregate (CA) maximum size 20 mm, water with water cement ratio (w/c) of 0.3, superplasticizer type F, and steel fiber.

The superplasticizer that used is Sika Viscocrete 8045P type with amount of 0.8% of the cement weight. The steel fibers that used in this mixture are steel fibers with a hooked-end shape that consists of three types: 3D, 4D and 5D with volume fraction (V_f) of 0.50% (39 kg/m³), 0.75% (59 kg/m³), and 1.00% (79 kg/m³). 3D steel fiber has single hooked-end, 4D type has double hooked-end, and 5D type has triple hooked-end. Properties and shapes of steel fibers can be seen in Table 2 and Figure 1.

Table 1. The compositions of 1m³ SFRSCC

| No. | Mix design | Steel fiber (kg/m ³) | Steel fiber Type | OPC (kg/m ³) | FA (kg/m ³) | CA (kg/m ³) | Water (kg/m ³) |
|-----|----------------|-------------------------------------|---------------------|-----------------------------|----------------------------|----------------------------|-------------------------------|
| 1 | SCC-N | - | - | 600 | 786 | 823 | 180 |
| 2 | SFRSCC-0.50-3D | 39(0.50%) | 3D | 600 | 777 | 820 | 180 |
| 3 | SFRSCC-0.75-3D | 59(0.75%) | 3D | 600 | 773 | 819 | 180 |
| 4 | SFRSCC-1.00-3D | 79(1.00%) | 3D | 600 | 768 | 817 | 180 |
| 5 | SFRSCC-0.50-4D | 39(0.50%) | 4D | 600 | 777 | 820 | 180 |
| 6 | SFRSCC-0.75-4D | 59(0.75%) | 4D | 600 | 773 | 819 | 180 |
| 7 | SFRSCC-1.50-4D | 79(1.00%) | 4D | 600 | 768 | 817 | 180 |
| 8 | SFRSCC-0.50-5D | 39(0.50%) | 5D | 600 | 777 | 820 | 180 |
| 9 | SFRSCC-0.75-5D | 59(0.75%) | 5D | 600 | 773 | 819 | 180 |
| 10 | SFRSCC-1.00-5D | 79(1.00%) | 5D | 600 | 768 | 817 | 180 |

Table 2. Properties of steel fibers

| SF Type | Length, l (mm) | Diameter, d (mm) | Aspect ratio (l/d) | Density (kg/m ³) |
|-------------|----------------|------------------|--------------------|------------------------------|
| 3D 65/60 BG | 60 | 0.9 | 65 | 7850 |
| 4D 65/60 BG | 60 | 0.9 | 65 | 7850 |
| 5D 65/60 BG | 60 | 0.9 | 65 | 7850 |

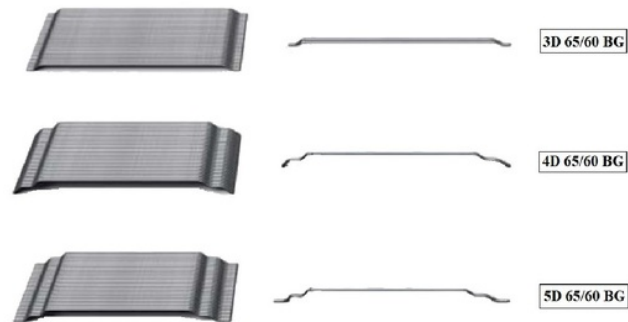


Figure 1. Various shapes of hooked-end steel fiber types

2.2. ³ Methods

The method that used in this research is an experimental method. The experimental method consists of fresh and hardening concrete test. Fresh concrete test was done to determine the workability of the concrete, it was done based on EFNARC standard [10] in the form of Slump flow test, V-funnel test, and L-box test. Hardened concrete test was done to determine the mechanical properties of the concrete, the compressive strength test refers to ASTM-C39 [11] (Figure 2a) on the cylindrical concrete of 150 x 300 mm of 28 daysage concrete and splitting tensile strength refers to ASTM-C496 [12] (Figure 2b) on cylindrical concrete of 150 x 300 mm of 28 daysage concrete.

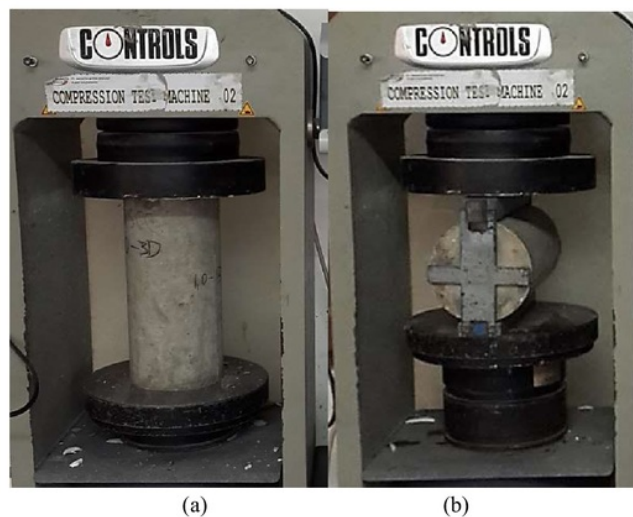


Figure 2. Hardening testing method, (a) compressive strength, (b) splitting tensile strength

3. Results and Discussions

3.1. The Result of Fresh Concrete Test SFRSCC

3.1.1. Slump flow test

The value based on slump flow test is obtained from four-way measurements and calculate the average. The results of slump flow test of 10 SFRSCC design mix obtained values range between 605 - 722 mm.

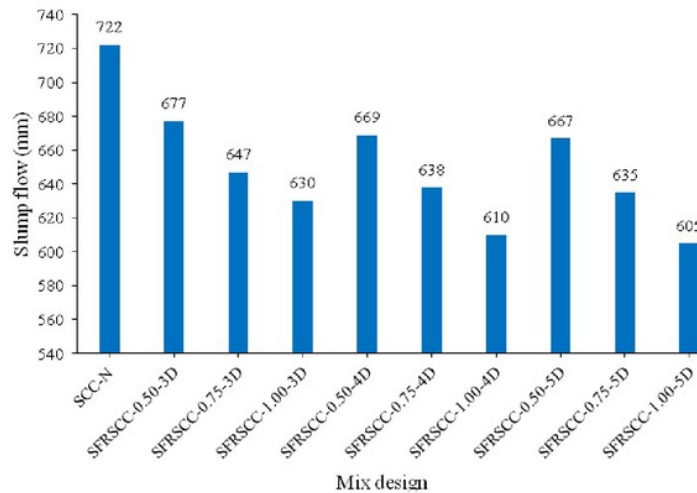


Figure 3. The influence of hooked-end steel fibers to SFRSCC slump flow testing

Table 3. Decrease percentage of SFRSCC slump flow value

| Mix design | Slump flow (mm) | Decrease percentage (%) | Class |
|----------------|-----------------|-------------------------|-------|
| SCC-N | 722 | 0.00 | SF 2 |
| SFRSCC-0.50-3D | 677 | -6.23 | SF 2 |
| SFRSCC-0.75-3D | 647 | -10.39 | SF 1 |
| SFRSCC-1.00-3D | 630 | -12.74 | SF 1 |
| SFRSCC-0.50-4D | 669 | -7.34 | SF 2 |
| SFRSCC-0.75-4D | 638 | -11.63 | SF 1 |
| SFRSCC-1.50-4D | 610 | -15.51 | SF 1 |
| SFRSCC-0.50-5D | 667 | -7.62 | SF 2 |
| SFRSCC-0.75-5D | 635 | -12.05 | SF 1 |
| SFRSCC-1.00-5D | 605 | -16.20 | SF 1 |

Based on Figure 3 and Table 3, it indicates that the mix design of SCC-N has the highest slump diameter of 722 mm at SFRSCC-1.00-5D has the lowest slump diameter of 605 mm. The results show an increase in steel fiber volume fraction can decrease the value of concrete slump flow. The shape of hooked-end steel fibers also has an effect, the 5D type shows the greatest slump flow decrease of 16.20%, while the results of 4D and 3D type consecutively are 15.51% and 12.74%.

Slump flow test is also done by measuring the time t_{500} . The t_{500} measurements were obtained based on the time calculation when the fresh concrete mixture passed the size of 500 mm in slump flow test. The result of t_{500} measurement of 10 design mix SFRSCC obtained values range from 3.80 to 6.00 s.

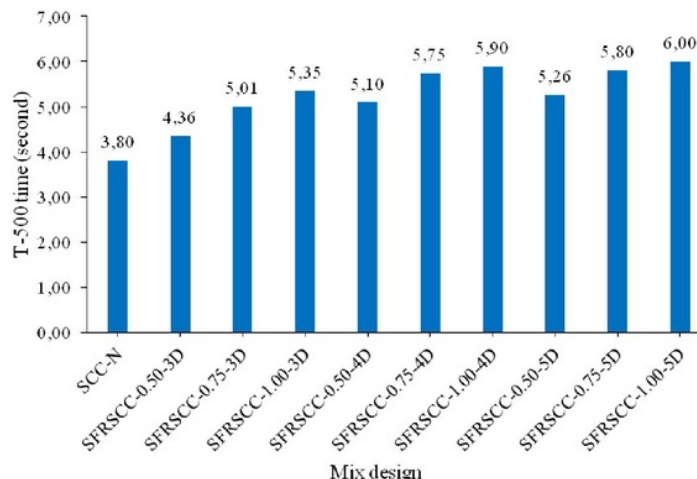


Figure 4. The influence of hooked-end steel fibers to SFRSCC t_{500} test

Table 4. Increase percentage of SFRSCC t_{500} time

| Mix design | t-500 (second) | Increase percentage (%) | Class |
|----------------|----------------|-------------------------|-------|
| SCC-N | 3.80 | 0.00 | VS 2 |
| SFRSCC-0.50-3D | 4.36 | 14.74 | VS 2 |
| SFRSCC-0.75-3D | 5.01 | 31.84 | VS 2 |
| SFRSCC-1.00-3D | 5.35 | 40.79 | VS 2 |
| SFRSCC-0.50-4D | 5.10 | 34.21 | VS 2 |
| SFRSCC-0.75-4D | 5.75 | 51.32 | VS 2 |
| SFRSCC-1.50-4D | 5.90 | 55.26 | VS 2 |
| SFRSCC-0.50-5D | 5.26 | 38.42 | VS 2 |
| SFRSCC-0.75-5D | 5.80 | 52.63 | VS 2 |
| SFRSCC-1.00-5D | 6.00 | 57.89 | VS 2 |

Based on Figure 4 and Table 4 it indicates that the SCC-N mix design has the fastest t_{500} that is 3.80 s and SFRSCC-1.00-5D has the longest t_{500} that is 6.00 s. The results show an increase of volume fraction and hooked-end steel fibers type can retard the time of t_{500} test. 5D type with $V_f = 1.00\%$ shows the largest increase of t_{500} time that is 57.89%, while for 4D type is 55.26%, and 3D type is 40.79%. This is because the cohesiveness of fresh concrete mixture increases with increasing volume of steel fiber fraction. The triple hooked-end (5D) steel fiber shape also influences the cohesiveness of fresh concrete mixtures, the hooked-end shape makes the steel fiber hold onto other materials in fresh concrete mixes increased. So, the cohesiveness of the concrete mixture increases linearly with the addition of hooked-end to the steel fiber. Characteristic of fresh concrete on

slump flow test fulfills EFNARC standard SF1 and SF2 filling ability class, and the t-500 test fulfills VS2 class.

3.1.2. ⁶V-funnel test

⁶The test was done by measuring the SFRSCC viscosity or fresh concrete velocity flowing inside the V-funnel test tool. The result of V-funnel test on 10 design mixture of SFRSCC obtained the time value range of 7.95 - 12.17 s.

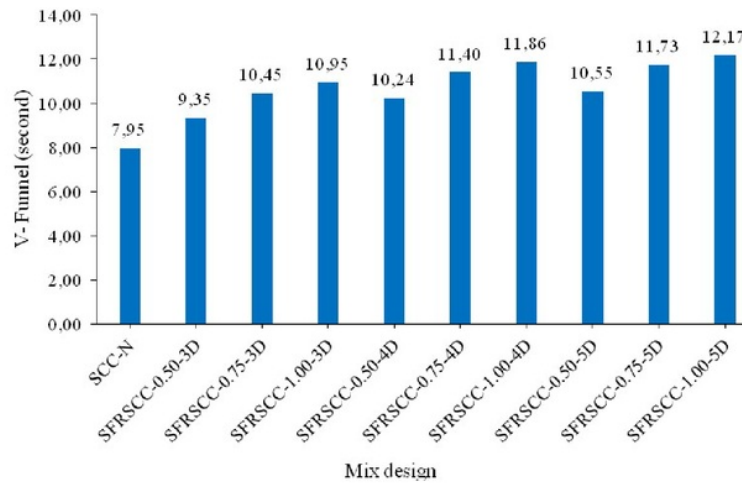


Figure 5. The influence of hooked-end steel fiber to SFRSCC V-funnel test

Table 5. Increase percentage of V-funnel SFRCC testing time

| Mix design | V-funnel (second) | Increase percentage (%) | Class |
|----------------|-------------------|-------------------------|-------|
| SCC-N | 7.95 | 0.00 | VF 1 |
| SFRSCC-0.50-3D | 9.35 | 17.61 | VF 2 |
| SFRSCC-0.75-3D | 10.45 | 31.45 | VF 2 |
| SFRSCC-1.00-3D | 10.95 | 37.74 | VF 2 |
| SFRSCC-0.50-4D | 10.24 | 28.81 | VF 2 |
| SFRSCC-0.75-4D | 11.40 | 43.40 | VF 2 |
| SFRSCC-1.50-4D | 11.86 | 49.18 | VF 2 |
| SFRSCC-0.50-5D | 10.55 | 32.70 | VF 2 |
| SFRSCC-0.75-5D | 11.73 | 47.55 | VF 2 |
| SFRSCC-1.00-5D | 12.17 | 53.08 | VF 2 |

Based on Figure 5 and Table 5 it indicates that the SCC-N mix design has the fastest V-funnel test time of 7.95 s and SFRSCC-1.00-5D has the longest time of 12.17 s. 5D type with $V_f = 1.00\%$ shows the greatest increase of V-funnel test time of 53.08%, while for 4D type is 43.40%, and 3D type is 37.74%. The results show an increase of volume fraction and hooked-end steel fiber type can retard the time of fresh concrete flow in V-funnel test. This is due to the increased volume of steel fiber fraction making the viscosity of concrete mixture increased, as well as the increasing number of hooked-end shape in steel fiber. The hooked-end shape creates a bigger friction between the fresh

concrete mix and the surface of V-funnel test, thus increasing the flow time. Characteristic of fresh concrete on V-funnel test fulfills EFNARC standard by fulfilling VF1 and VF2 viscosity class.

3.1.3. L-box test

The L-box test is performed to check the passing ability ratio of SFRSCC. This test is done by measuring the height of fresh concrete that flows through the reinforcement (H₂) and measuring the height of fresh concrete at the base of the L-box (H₁). The result of L-box testing on 10 design mixture of SFRSCC obtained the range of 0.78 - 0.92.

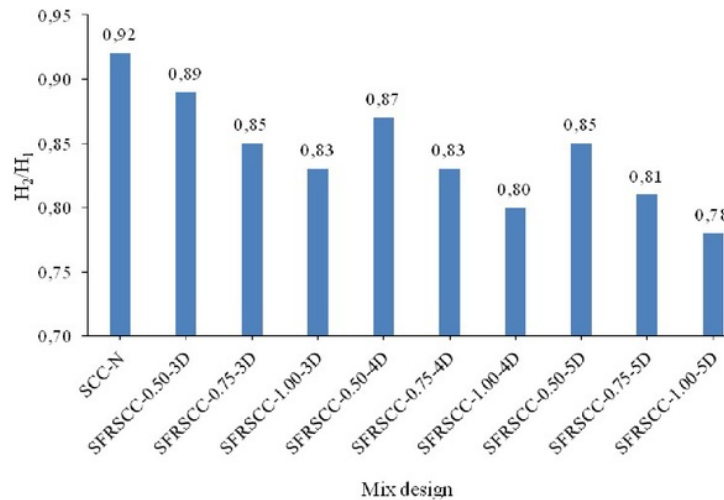


Figure 6. The influence of hooked-end steel fibers to SFRSCC L-box test

Table 6. Decrease percentage of H₂/H₁ value on SFRSCC L-box test

| Mix design | L-box | Decrease percentage (%) | Pass |
|----------------|-------|-------------------------|------|
| SCC-N | 0.92 | 0.00 | 5 |
| SFRSCC-0.50-3D | 0.89 | -3.26 | PA 2 |
| SFRSCC-0.75-3D | 0.85 | -7.61 | PA 2 |
| SFRSCC-1.00-3D | 0.83 | -9.78 | PA 2 |
| SFRSCC-0.50-4D | 0.87 | -5.43 | PA 2 |
| SFRSCC-0.75-4D | 0.83 | -9.78 | PA 2 |
| SFRSCC-1.00-4D | 0.80 | -13.04 | PA 2 |
| SFRSCC-0.50-5D | 0.85 | -7.61 | PA 2 |
| SFRSCC-0.75-5D | 0.81 | -11.96 | PA 2 |
| SFRSCC-1.00-5D | 0.78 | -15.22 | - |

Based on Figure 6 and Table 6 it shows that the SCC-N mix design has the highest H₂/H₁ value of 0.92 and SFRSCC-1.00-5D has the smallest H₂/H₁ value of 0.78. 5D type with $V_f = 1.00\%$ has the greatest decrease of H₂/H₁ value that is 15.22%, while for 4D type is 13.04%, and 3D type is 9.78%. Almost all mix design fulfills passing ability characteristic in L-box test that is class of PA 2 with category that passed 3 reinforcements, except on SFRSCC-1.00-5D which have H₂/H₁ value equal to 0.78. EFNARC requires the ability of SCC passing ability through 3 reinforcements having a minimum H₂/H₁ value of 0.83. This result shows that the increasement of volume fraction and hooked-end steel fibers can decrease the ability of fresh concrete to pass through the reinforcement, this is due

to volume fraction increasement and the more hooked-end shape make the fresh concrete mixture become more concentrated. The volume increment of steel fiber fractions can be interpreted by the increasing number of steel fiber units. Although the steel fibers are substituted from aggregate volumes, its non-graded shapes with aggregates make the homogeneity fresh concrete declining. The hooked-end shape also results in high fresh concrete cohesiveness. The higher the cohesive between the materials on the concrete mix will make it more difficult to pass through the obstacle as well as the reinforcement on the L-box test.

3.2 Hardened Properties of SFRSCC

Hardened properties testing performed on 28 days age of 10 SFRSCC mix designs consists of compressive strength and splitting tensile strength test. The test results can be seen Table 7.

3.2.1. Compressive strength

Table 7. The result of compressive strength and splitting tensile strength test

| Mix Design | Compressive strength | | Splitting tensile strength | |
|----------------|----------------------|-------------------------|----------------------------|-------------------------|
| | Value(MPa) | Increase percentage (%) | Value (MPa) | Increase percentage (%) |
| SCC-N | 42.10 | 0.00 | 3.49 | 0.00 |
| SFRSCC-0.50-3D | 44.77 | 6.34 | 3.92 | 12.32 |
| SFRSCC-0.75-3D | 46.01 | 9.29 | 4.40 | 26.07 |
| SFRSCC-1.00-3D | 48.49 | 15.18 | 4.78 | 37.02 |
| SFRSCC-0.50-4D | 47.87 | 13.71 | 4.59 | 31.46 |
| SFRSCC-0.75-4D | 52.48 | 24.66 | 5.12 | 46.70 |
| SFRSCC-1.50-4D | 54.36 | 29.12 | 5.67 | 62.46 |
| SFRSCC-0.50-5D | 48.63 | 15.51 | 5.20 | 49.00 |
| SFRSCC-0.75-5D | 52.78 | 25.37 | 5.93 | 69.91 |
| SFRSCC-1.00-5D | 55.85 | 32.66 | 6.38 | 82.81 |

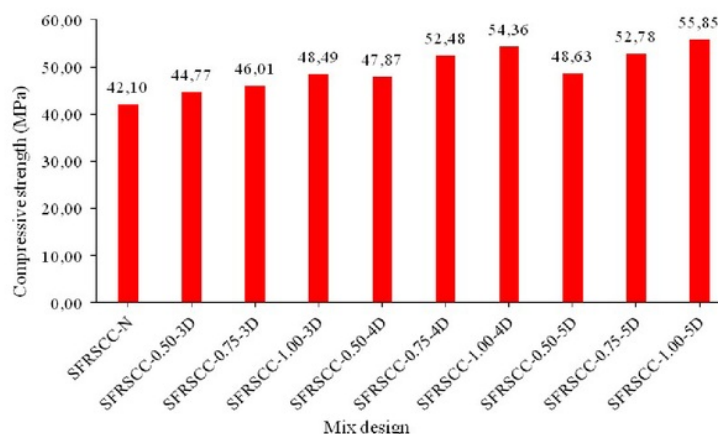


Figure 7. The influence of hooked-end steel fibers to compressive strength SFRSCC

Based on Table 7 and Figure 7 it shows that the increasement of steel fiber volume fraction is directly proportional to the increasement of concrete compressive strength, the optimum V_f value is

1.00%. The increase percentage due to volume fraction is quite significant, 3D steel fiber type has increased 6.34-15.18%, 4D type 13.71-29.12%, and 5D type 15.51-32.66%. This is because the steel fiber in the concrete gives the toughness properties of the strain due to the compressive load, so that the concrete tested by the compressive strength behaves like a concrete with confinement. The higher volume of steel fiber fraction causes the greater the compressive strain that can be achieved so the compressive strength of the concrete also increases.

For the influence of steel fiber type to increase compressive strength, it is known that the more hooked-end shape in steel fiber hence give more confinement on the concrete. 5D type has the biggest increasement, but when compared with 4D type there is not a big difference. The largest value of compressive strength is 5D type of 55.85 MPa, while the 4D type is 54.36 MPa. This is because the concrete is tested with a compressive load that when the load direction is parallel to the steel fiber form, the tensile strength of the steel fiber will hold it, while the bond and anchorage of the steel fiber to the concrete of its hooked-end shape only contributes slightly. Therefore, the difference in the number of hooked-end on steel fiber does not contribute greatly to increasing the compressive strength of concrete.

3.2.2. Splitting tensile strength

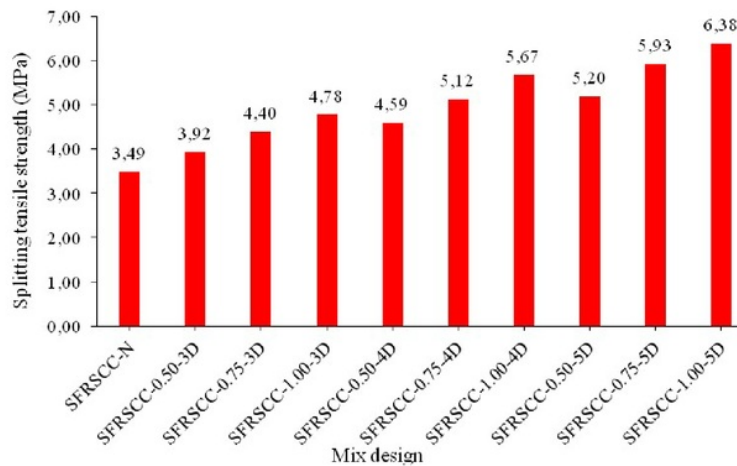


Figure 8. The influence of hooked-end steel fibers to splitting tensile strength SFRSCC

Based on Table 7 and Figure 8 it shows that the increasement of steel fiber volume fraction makes concrete splitting tensile strength also increases, the optimum V_f value is 1.00%. The increase percentage due to volume fraction is significant, 3D type steel fiber has increased 12.32-37.02%, 4D type 31.46-62.46%, and 5D type 49.00-82.81%. This is due to the addition of steel fiber cumulatively increases the tensile strength of concrete. Each steel fiber simultaneously provides lateral confinement, thus making the concrete having a ductile behavior before the ultimate collapse.

Unlike the compressive strength test, the bond-slip of steel fiber working against the tensile force, so the bond and anchorage of steel fiber contribute significantly to the splitting tensile strength test. This makes the hooked-end shape very influential to increase the tensile strength of the concrete. The more hooked-end shape in steel fiber, the tensile strength of concrete increased significantly. Using $V_f = 1.00\%$, 5D type produces the largest splitting tensile strength of 6.38 MPa (82.81%), then 4D type of 5.67 MPa (62.46%), and 3D type 4.78 MPa (37.02%).

4. Conclusion

Based on the results of research and discussion that has been described, obtained some conclusions as follows:

- Increased volume fraction and hooked-end steel fiber shapes decreases the workability of SFRSCC. Triple hooked-end steel fiber (5D) with $V_f = 1.00\%$ has the highest percentage of 16.20%. The higher volume and amount of hooked-end steel fiber on the SFRSCC mixture made a decrease on workability. Workability test results with slump flow EFNARC fulfill the standard of SF1 and SF 2 filling ability class.
- Increased volume fraction and hooked-end steel fiber shapes increases the time of fresh concrete flow. The result of t-500 test obtained by triple hooked-end steel fiber (5D) with $V_f = 1.00\%$ has the highest percentage of fresh concrete uptime increase of 57.89% and meets EFNARC standard in viscosity class t-500 VS2.
- V-funnel test results obtained that fresh concrete flow increased with increasing volume fraction and hooked-end steel fiber shape. Triple hooked-end steel fiber (5D) with $V_f = 1.00\%$ has the highest percentage increase is 53.08%. The results of workability testing with V-funnel meet the EFNARC standard in viscosity class VF1 and VF 2.
- Result of the test with L-Box meet the qualification of EFNARC for 9 SFRSCC mix design with H_2/H_1 values in the range 0.81-0.92. There is one mix design that does not meet, the mixture is SFRSCC-1.00-5D with the H_2/H_1 value of 0.79, this is because SFRSCC-1.00-5D has a very concentrated fresh concrete flow along with the increasing of volume fraction ($V_f = 1.00\%$) and the shape of hooked-end steel fiber (5D).
- Compressive strength of SFRSCC increases significantly as volume fraction increases. The optimum value of volume fraction used is 1.00%. Type of steel fiber is also influential, Triple hooked-end (5D) and double hooked-end (4D) significantly increase compressive strength when compared to single hooked-end (3D).
- Volume fraction of steel fiber significantly increases the splitting tensile strength of SFRSCC. From the three variations of volume fraction, obtained $V_f = 1.00\%$ being the optimum value. Splitting tensile strength is also increasing with the change of steel fiber type. The use of triple hooked-end (5D) resulted in the highest splitting tensile strength values, followed by double hooked-end (4D), and single hooked-end (3D).

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