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INFLUENCE OF HOOKED-END STEEL FIBERS ON FLEXURAL BEHAVIOR OF STEEL FIBER REINFORCED SELF-COMPACTING CONCRETE (SFRSCC)

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ABSTRACT: The weaknesses of the concrete material are weak to the tensile strength and brittle. The solution to overcome this weakness is by adding fibers like steel fiber. The use of steel fibers has constraints in workability. It was developed to become self-compacting concrete (SCC) to facilitate work in the field. SCC, which uses additional steel fibers, is known as steel fibers reinforced self-compacting concrete (SFRSCC). In this study, the use of steel fibers in the SFRSCC was examined where the steel fiber used was a hooked-end type. Hooked-end steel fibers have been developed into several forms, namely 3D, 4D, and 5D. This study aimed to analyze the effect of hooked-end steel fibers consisting of 3D, 4D, and 5D types on the workability, modulus of elasticity, and flexural behavior of SFRSCC. The experimental method in this study refers to the EFNARC standard for the workability test, ASTM C-469 for the modulus of elasticity test, and ASTM C-1609 for the flexural strength test. Workability tests such as slump flow, T-500, V-funnel, and L-box decreased with the addition of steel fiber. The best workability is found in 3D type steel fiber with a fraction of 0.5, with details of slump flow = 677 mm, T-500 = 4.36 seconds, V-funnel = 9.35 seconds, and L-box = 0.92. In the various shapes of hooked-end 3D, 4D, and 5D, the type that provides increased flexural strength and maximum energy absorption capacity of SFRSCC is type 5D. Energy absorption in steel fiber type 3D = 147.23 Joules, type 4D = 166.16 Joules, and type 5D = 178.03 Joules. The hooked-end shape greatly absorbs energy when the beam is subjected to bending forces. Type 5D steel fiber is the most common form of hooked-end. The more hooked-end forms, the tensile strength of steel fiber increases. The increase in the tensile strength of steel fibers resulted in the SFRSCC's flexural strength increasing.

Keywords: Steel fiber, Self-compacting concrete (SCC), Hooked-end steel fibers, Flexural behavior, workability

1. INTRODUCTION

Steel fibers reinforced self-compacting concrete (SFRSCC) is a concrete innovation that combines steel fibers reinforced concrete (SFRC) and self-compacting concrete (SCC) technology. SFRC is concrete that uses fibers with steel material to increase the ability of concrete to the tensile strength and reduce the brittle properties of the concrete. The SFRC has good capabilities in durability, energy absorption capacity, and ductile behavior before the ultimate collapse. One disadvantage of SFRC was the workability [1].

One of the efforts to overcome the workability problems in the SFRC is the use of SCC technology to form the SFRSCC. SCC is a concrete technology developed by Professor Hajime Okamura and Kazumasa Ozawa from the University of Tokyo, Japan, in 1986. SCC has the advantage of being able to compact its shape without the help of labor or vibrators [2].

Previous research on SFRSCC has been carried out. The use of the various shape of steel fibers, such as straight, crimped, and hooked-end, shows different results on SFRSCC workability. The hooked-end shape is known to give a decrease in workability when compared to other shapes. The aspect ratio of steel fibers is also the same. The higher aspect ratio in fiber steel also decreases the workability [3]. The volume fraction affects SFRSCC workability due to steel fibers apart from their shape and aspect ratio. The use of steel fibers in the concrete mixture is measured by the parameter of volume fraction. The higher the volume of a fraction of steel fibers will make SFRSCC workability decrease [4, 5].

As is generally known, steel fibers can improve concrete's mechanical properties, especially the flexural strength of concrete. Steel fibers with a straight shape can increase the flexural strength of concrete up to 12%, then the crimped shape can also increase the flexural strength of concrete up to 30%, and the hooked-end shape is 38.95%. Of the several forms of these steel fibers, the hooked-end shape provides the greatest flexural strength enhancement [6]. The effect of hooked-end steel fibers compared to straight shapes on SFRSCC flexural behavior shows that the hooked-end shape has eater flexural strength and greater fracture energy than straight shapes. Flexural tensile strength and fracture energy increase as volume fraction increases [7].

Currently, the hooked-end shape is developed into several forms with the Dramix trademark, namely 3D, 4D, and 5D. These three types have different shapes, which is seen from the number of hooked-end [8-10].

Based on the description above, the purpose of this study was to analyze the effect of hooked-end type steel fiber consisting of 3D, 4D, and 5D types on the workability and flexural behavior of SFRSCC. The effect of hooked-end type steel fiber geometry and volume fraction on the flexural behavior of the beam was examined. To achieve this, various types of hook-end steel fibers with different hook-end geometries, i.e., 3D, 4D, and 5D, and three different volume fractions of 0.50, 0.75, and 1.0%, were considered.

2. RESEARCH SIGNIFICANCE

Steel fiber reinforced concrete (SFRC) is one of the material developments to overcome the weaknesses of conventional concrete. With the addition of steel fibers, the failure mode changes from brittleness to ductility failure when subjected to compression and bending. SFRC has the disadvantage of reducing workability and setting time combined with self-compacting concrete (SCC). SCC is weak against tensile forces, so steel fiber can increase ductility and performance against seismic loads. The use of the right fiber in terms of type, length, cross-section, final shape, and composition can result in improved concrete properties as expected.

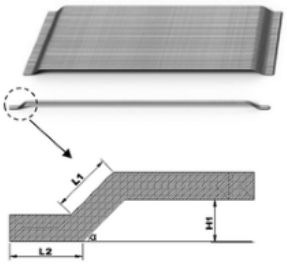
3. MATERIALS

The material used in this study is steel fibers reinforced self-compacting concrete (SFRSCC). SFRSCC consists of constituent material in the form of Ordinary Portland Cement (OPC) type 1 with ASTM C 150-07 standard [11]. Fine aggregate (FA) used is sand with a size of 0.125 - 4 mm. Coarse aggregate (CA) used has a maximum size of 20 mm. This study's superplasticizer (Sp) is a type F superplasticizer Sika Viscocrete 8045P product.

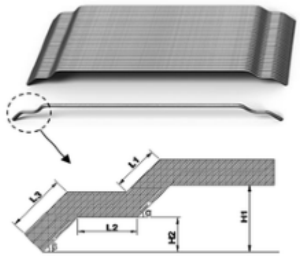
Steel fibers used in this mixture are the hooked-end shape that consists of three types, namely 3D, 4D, and 5D as shown in Figure 1. Each steel fiber has the same length (l) and diameter (d), which are 60 mm and 0.9 mm, so the aspect ratio (l/d) is 65. For volume fraction (V_f) it is used 0.50%, 0.75%, and 1.00% as in Table 1.

Table 1 Properties of steel fibers

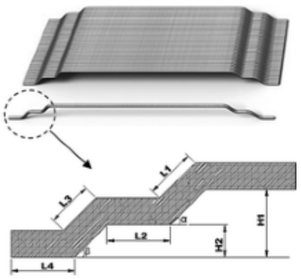
Mix code	Steel fiber	l/d	V_f (%)	E (MPa)	F_L (MPa)
3D-0.50	3D	65	0.50	7,850	1,160
3D-0.75	4D	65	0.75	7,850	1,600
3D-1.00	5D	65	1.00	7,850	2,300
4D-0.50	3D	65	0.50	7,850	1,160
4D-0.75	4D	65	0.75	7,850	1,600
4D-1.00	5D	65	1.00	7,850	2,300
5D-0.50	3D	65	0.50	7,850	1,160
5D-0.75	4D	65	0.75	7,850	1,600
5D-1.00	5D	65	1.00	7,850	2,300



(a) 3D 65/60 BG



(b) 4D 65/60 BG



(c) 5D 65/60 BG

Fig.1 Shape of hooked-end steel fibers types

The composition of the mixture of SFRSCC was designed to refer to the EFNARC [12] and ACI [1] standards which were then conducted through trial and error to obtain the desired mixture of concrete with steel fibers that were in the SCC category. The composition of the SFRSCC mixture in 1m^3 in this study can be seen in Table 2.

Table 2 The compositions of 1m^3 SFRSCC

Mix code	Steel fiber	OPC	FA	CA	Water	Sp
N	-	600	786	823	180	4.8
3D-0.50	39	600	777	820	180	4.8
3D-0.75	59	600	772	819	180	4.8
3D-1.00	79	600	768	817	180	4.8
4D-0.50	39	600	777	820	180	4.8
4D-0.75	59	600	772	819	180	4.8
4D-1.00	79	600	768	817	180	4.8
5D-0.50	39	600	777	820	180	4.8
5D-0.75	59	600	772	819	180	4.8
5D-1.00	79	600	768	817	180	4.8

4. METHODS

The experimental method in this study consisted of a workability test and flexural strength test SFRSCC. Workability test refers to EFNARC [12], which consists of slump flow test, T-500, V-funnel, and L-box. Modulus of Elasticity tests refers to the ASTM-C469 [13] (Fig.2) and flexural strength tests refer to the ASTM-C1609 standard [14].

Fig.2 Elasticity modulus test

The load used in the elastic modulus test is only 40% of the load in the compressive strength test, so it is necessary to calculate the ultimate load on each mixture based on the compressive strength test. The modulus testing procedure begins by adjusting the compressor according to the marks that have been made on the cylindrical test object, then installing a device for measuring deformation (dial gauge). Make sure all tools attached to the cylindrical test object are symmetrical and centric. Next, place the cylindrical test object that has been fitted with a compressor and dial gauge on the compression testing machine, as shown in Fig.2. Compressive loading is carried out at a rate of 20 kN/sec. Record the change in length that occurs (Δl) at a 20 kN load increase; loading is stopped when the load has reached 40% of the ultimate load.

The specimen used in the flexural strength test is a concrete beam with a size of 150 x 150 x 600 mm and a curing age of 28 days. ASTM C-1609 [14] requires a beam depth size of 150 mm for the use of steel fiber with a length of 50-75 mm and the distance from the placement to the edge of the beam at least 25 mm, as can be seen in Fig.3 and Fig.4. LVDT is used in the middle of the span installed on the rigid frame to measure beam deflection. LVDT devices and universal testing machines are connected to the computer so that the load and deflection data are integrated into the load-deflection curve.

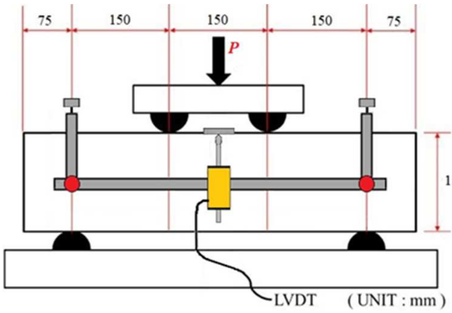


Fig.3 Setup of the flexural strength test

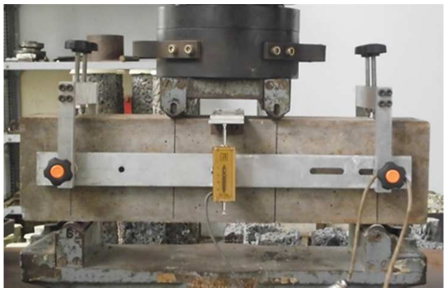


Fig.4 Flexural strength test

5. RESULTS AND DISCUSSION

5.1 Workability of SFRSCC

Based on the EFNARC standard [12], SCC workability can be seen from the results of the fresh concrete test in the form of slump flow, T-500, L-box, and V-funnel tests. The slump flow test produces a diameter value of fresh concrete flow. The larger the flow diameter, the better the workability of fresh concrete. T-500 and V-funnel are tests that produce fresh concrete flow times. The faster the fresh concrete flow time indicated by the small flow time, the better the concrete workability.

The L-box test is a test to see the passing ability of fresh concrete. The L-box measurement results in the H_2/H_1 ratio. The higher the H_2/H_1 ratio, the better the fresh concrete's workability. The workability of SFRSCC in this study can be seen in Fig.5 to Fig.8.

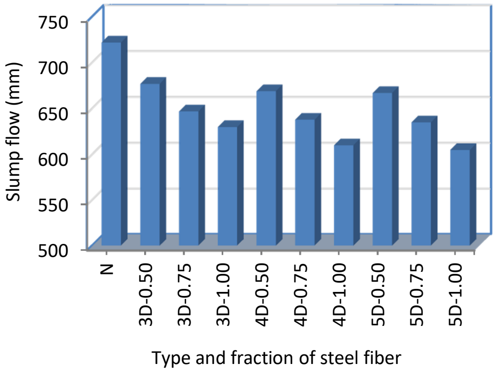


Fig.5 Slump flow

Fig.5 shows that the largest slump flow diameter is found in 3D-type steel fiber with a volume fraction of 0.50, which is 677 mm. The smallest slump flow diameter is found in 5D type steel fiber with a volume fraction of 1.00, which is 605 mm. The slump flow diameter meets the filling ability requirements contained in the EFNARC [12] standard, which is between 550 to 850 mm. SCC-N concrete with the highest slump diameter of 722 mm and SFRSCC-1.00-5D had the lowest slump diameter of 605 mm (Fig.5). Increasing the volume of the steel fiber fraction can reduce the slump flow value of the concrete. The shape of the hooked-end steel fiber also has an effect, the 5D type shows the greatest decrease in slump flow value, namely 16.20%, while the 4D type is 15.51%, and 3D is 12.74%.

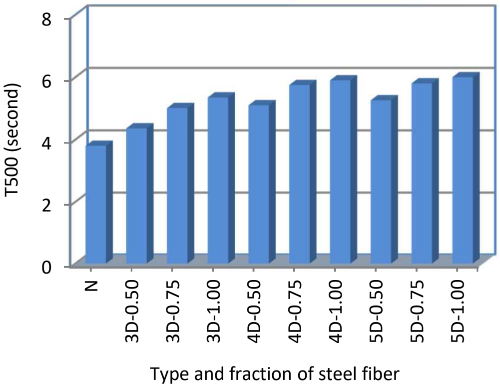


Fig.6 T-500

The results of the T-500 measurement of 10 mixed designs of SFRSCC obtained a range of values from 3.80 to 6.00 seconds (Fig.6). SCC-N has the fastest T-500 time of 3.80 seconds and SFRSCC-1.00-5D has the longest T-500 time of 6.00 seconds.

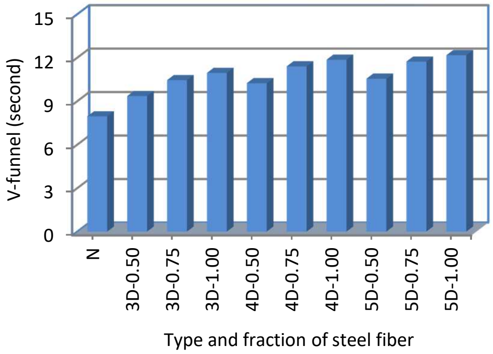


Fig.7 V-funnel

Figures 6 and 7 present the SFRSCC viscosity. The viscosity class for SCC is divided into two classes according to the testing time of T_{500} and V-funnel [12]. The SFRSCC V-funnel value ranges from 9.35 to 12.17 seconds. The maximum V-funnel value is found in 5D steel fiber, while the minimum V-funnel value is in 3D steel fiber. Classification of flow time based on the EFNARC standard [12], including class VF 2 with a flow time range of 9 to 25 seconds.

The increase in the volume fraction and the shape of the hooked-end steel fiber can slow down the T-500 time. The 5D type with a volume fraction of 1.00% resulted in the largest increase in T-500 time, namely 57.89%, while for the 4D type, it was 55.26% and 3D was 40.79%. This is because the cohesiveness of the fresh concrete mix increases as the volume of the steel fiber fraction increases. The shape of the three hooked-end (5D) also affects the cohesiveness of the fresh concrete mix, the more hooked ends on the steel fiber make the grip of the steel fiber on other materials in the fresh concrete mix increase so that the cohesiveness of the concrete mix increases. However, the concrete mix still meets EFNARC standards [12] for filling ability classes, namely SF1 and SF2, and the T-500 test meets VS2 class.

SCC-N has the fastest V-funnel testing time of 7.95 seconds and SFRSCC-1.00-5D has the longest time of 12.17 seconds. The 5D type with Vf = 1.00% has the largest increase in V-funnel testing time, namely 53.08%, while for the 4D type, it is 43.40%, and 3D is 37.74% (Fig.7). These results indicate that the increase in the volume fraction and the shape of the hooked-end steel fiber can slow the flow time of fresh concrete in the V-funnel test.

The increase in the volume of the steel fiber fraction makes the viscosity of the concrete mix increase, as well as the increase in the number of hooked ends on the steel fiber, the more hooked ends, the friction between the fresh concrete mix and the walls of the V-funnel is greater so that the flow time decreases. The characteristics of fresh concrete in the V-funnel test meet the EFNARC standards [12] by meeting the viscosity classes VF1 and VF2.

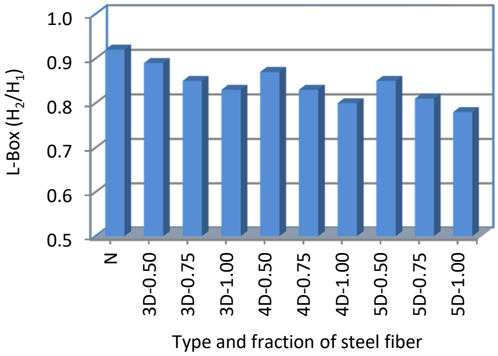


Fig.8 L-Box

The highest H_2/H_1 value is SCC-N, which is 0.92, while the smallest H_2/H_1 value is SFRSCC-1.00-5D, which is 0.78. For type 5D with Vf = 1.00%, the largest decrease in the value of H_2/H_1 was 15.22%, while for type 4D, it was 13.04%, and 3D was 9.78% (Fig.8). Almost all of the mixtures met the characteristics of passing ability in the L-box test, namely PA class 2 with the category of passing through 3 reinforcement, except for SFRSCC-1.00-5D with an H_2/H_1 value of 0.78. EFNARC [12] requires the passing ability of SCC through 3 bars to have a minimum H_2/H_1 value of 0.80.

Table 3 Workability of SFRSCC

Mix code	Workability parameters			
	Slump flow (mm)	T-500 (second)	V-funnel (second)	L-Box (H_2/H_1)
N	722	3.80	7.95	0.92
3D-0.50	677	4.36	9.35	0.89
3D-0.75	647	5.01	10.45	0.85
3D-1.00	630	5.35	10.95	0.83
4D-0.50	669	5.10	10.24	0.87
4D-0.75	638	5.75	11.40	0.83
4D-1.00	610	5.90	11.86	0.80
5D-0.50	667	5.26	10.55	0.85
5D-0.75	635	5.80	11.73	0.81
5D-1.00	605	6.00	12.17	0.78

Table 3 shows the results for all workability tests, hooked-end steel fiber 5D type and 1.00% volume fraction produced the smallest workability. When sorted, the hooked-end type that provides a decrease in workability from the smallest to the largest is 3D, 4D, and then 5D. For the effect of volume fraction, the increase in volume fraction makes the workability decrease. Based on this, it is known that the more hooked-end shapes on the steel fibers type and the increase in volume fraction make the density of the fresh concrete mixture increase, thereby reducing the diameter and time of the fresh concrete flow [4, 14].

The increase in the volume fraction and the shape of the hooked-end steel fiber can make the ability of fresh concrete to pass through the reinforcement decrease. This is because the increase in the volume fraction and the shape of the hooked-end make the fresh concrete mix more concentrated. The increase in the volume of the steel fiber fraction can be interpreted as an increase in the number of steel fiber units. Even though steel fiber is substituted from the aggregate volume, the shape is not graded with the aggregate making the homogeneity of fresh concrete decrease. The hooked-end shape also causes the cohesiveness of fresh concrete to be high. The higher the adhesion between materials in the concrete mixture, the more difficult it is to pass through obstacles such as reinforcement in the L-box test equipment.

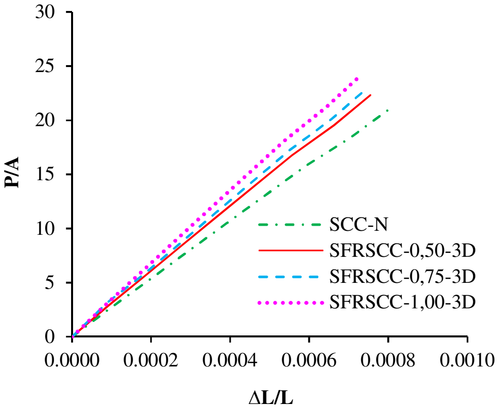
5.2 Modulus Elasticity

The slope of the stress-strain curve with the proportional limit of the material describes the modulus of elasticity. The usual approach to measuring the modulus of elasticity of concrete is to determine the modulus of the tangent as the slope of the tangent to the stress-strain curve at some percentage of the ultimate strength of the concrete, determined by a compression test. The modulus of elasticity is an important mechanical parameter that expresses the ability of a material to deform elastically.

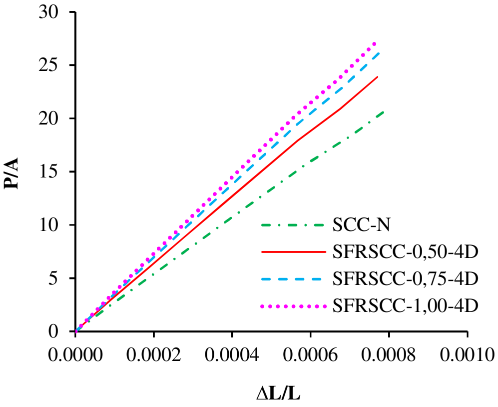
Testing the modulus of elasticity of SFRSCC on 150 mm x 300 mm cylindrical concrete at the age of 28 days. The results of the SFRSCC modulus of elasticity test are shown in Fig.9. As the volume of steel fiber fraction increases, the modulus of elasticity of SFRSCC increases [6-7]. The percentage increase due to volume fraction is quite significant; 3D type steel fiber gives an increase of 26.14%, 4D type 34.98%, and 5D type 36.04%.

The increase in the modulus of elasticity due to the addition of the volume of the steel fiber fraction is due to the steel fiber providing restraint to the cylindrical test object. The more steel fiber fraction, the greater the restraint, so that the longitudinal strain that occurs is getting smaller [7].

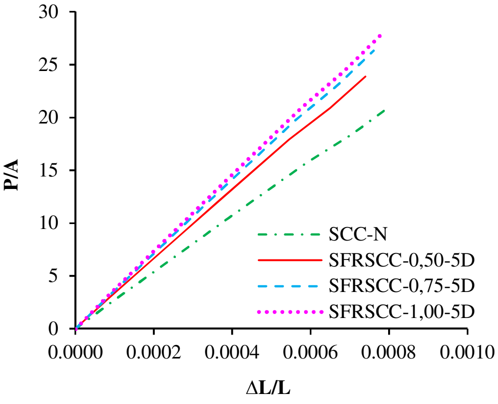
Steel fiber type 5D provides the most optimum increase in modulus of elasticity, followed by type 4D and then type 3D. This is because the hooked-end shape increases the bond and anchorage of steel fibers in the concrete. Thus, the type of steel fiber that has more hooked-end shapes can reduce the longitudinal strain and has an impact on the greater modulus of elasticity of the concrete.



(a) 3D 65/60 BG



(b) 4D 65/60 BG



(c) 5D 65/60 BG

Fig.9 Modulus of elasticity of SFRSCC

5.3 Flexural Strength of SFRSCC

The main parameters of the mechanical properties of SFRSCC are flexural strength concrete. This is because one of the purposes of using steel fibers in concrete is to increase its flexural strength. Flexural strength is the ability of concrete to resist indirect tensile forces in the flexural area of the concrete beam due to the load in the middle of the span. In this study, flexural strength was calculated by Eq. (1) [14].

$$f = \frac{PL}{bd^2} \tag{1}$$

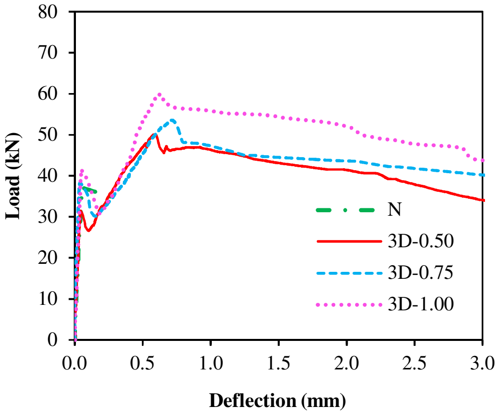
f = the flexural strength (MPa)
P = the load (N)
L = the span length (mm)
B = the average width of the specimen (mm)
D = the average depth of the specimen (mm)

ASTM C 1609 [14] requires the calculation of flexural strength through a load-deflection curve. The load-deflection curve of the effect of volume fraction on flexural strength can be seen in Figure 10 and the effect of hooked-end steel fibers type in Figure 11. Based on the load-deflection curve, each mixture was analyzed for peak load, peak flexural strength, and energy absorption capacity. Energy absorption capacity is calculated based on the area of the load-deflection curve with a zero-deflection limit to a deflection of L/150, as shown in Table 4.

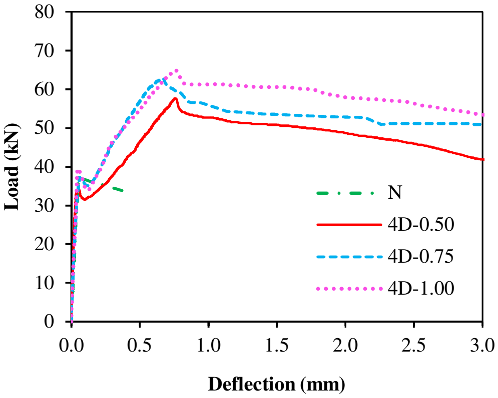
Based on Figure 10, it is known that the increase in volume fraction has a significant effect on the flexural strength of the concrete. The load-deflection curve on steel fibers with Vf = 1.00% shows a larger shape than the volume fraction of 0.50% and 0.75%. This shows that the flexural strength received by the concrete is greater [15].

The increase in fraction volume also shows an increase in the properties of concrete ductile, in contrast to non-steel fibers concrete which has collapsed after receiving peak load [3, 15].

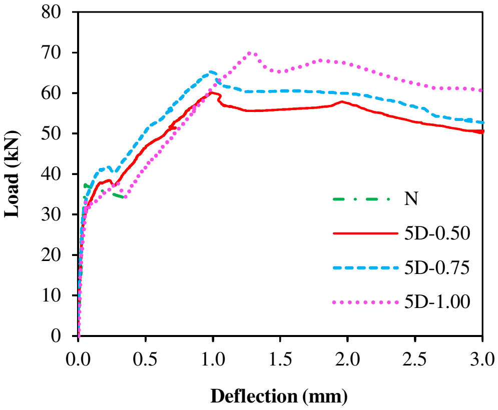
Fig.10 also shows that beams using steel fibers can still receive loads after the first crack. The first crack occurs by marking the first load peak and then the load decreases. Table 4 shows the value of P1 or the first peak load. This first peak load shows that the concrete material has collapsed. This is analyzed based on the load-deflection curve on the mixture without steel fibers. After experiencing the first peak load, the mixture that does not use steel fibers is no longer able to withstand the load received.



(a) 3D 65/60 BG



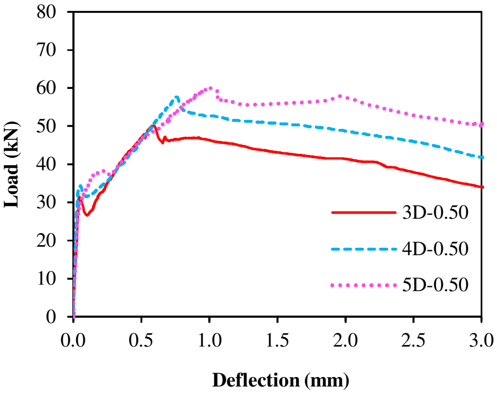
(b) 4D 65/60 BG



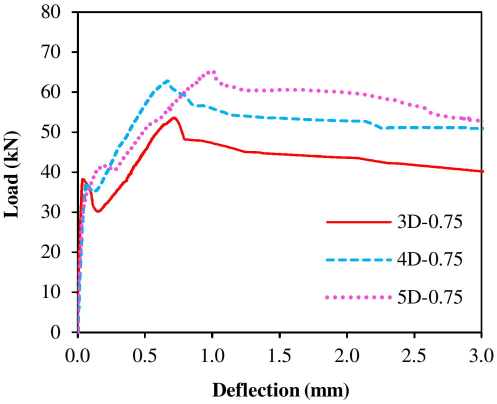
(c) 5D 65/60 BG

Fig.10 Effect of steel fibers volume fraction on SFRSCC flexural strength

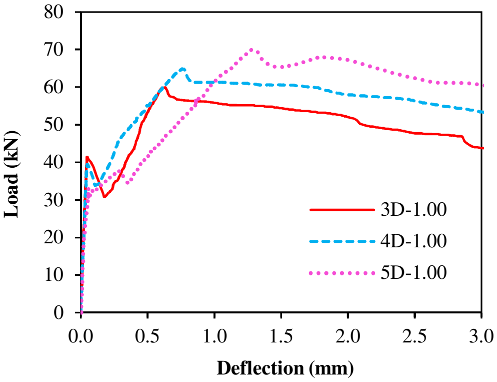
Fig.11 shows that the 5D type steel fiber provides the greatest flexural strength. Although seen at the beginning of loading, the load capacity received by type 5D shows a smaller value compared to type 4D and 3D. However, when reaching peak load, type 5D produces the highest peak load of 70031.87 N, so flexural strength is obtained at 9.34 MPa. The residual load capacity also shows that the 5D type has higher toughness properties compared to 4D and 3D types, as can be seen in Table 4. Results of energy absorption capacity (T100, 3.00) show hooked type fibers steel with more hooked-end produce greater energy capacity [2, 17]. Using a volume fraction of 1.00%, the 3D type produces T = 147.23 Joules, type 4D T = 166.16 Joule, and type 5D T = 178.03 Joule. This is due to the hooked-end shape that greatly contributes to absorbing energy when the beam experiences bending force. Type 5D is a hooked-end steel fiber, the most hooked-end shape. The more hooked-end shapes produce greater tensile strength of steel fibers, and the increase in tensile strength of steel fibers makes the flexural strength of SFRSCC also increase [16-17]. The specimen failure of the SFRSCC flexural strength test can be seen in Fig.12.



(a) Steel fiber 0.50%



(b) Steel fiber 0.75%



(c) Steel fiber 1.00%

Fig.11 Effect of steel fibers type on SFRSCC flexural strength

Fig. 12 shows cracks occurring in the bending moment of the beam. The addition of steel fibers makes the beam still able to accept the load even though the first crack has occurred. The load continues to increase until the crack reaches the upper surface of the beam. Even though the crack reaches the upper surface, the beam does not split because the steel fiber on the two sides of the concrete is still bonded to one another.

Fig.12 The specimen failure of the SFRSCC

Table 4 Flexural strength test of SFRSCC (1)

Mix code	P_1 (N)	f_1 (MPa)	P_P (N)	*PHP* (MPa)
N	37359.99	4.98	37359.99	4.98
3D-0.50	32305.57	4.31	50064.84	6.68
3D-0.75	38146.29	5.09	53542.91	7.14
3D-1.00	41183.35	5.49	59924.45	7.99
4D-0.50	34334.92	4.58	57654.96	7.69
4D-0.75	37268.60	4.97	62822.12	8.38
4D-1.00	50587.72	6.75	64888.28	8.65
5D-0.50	38428.78	5.12	60113.50	8.02
5D-0.75	41770.41	5.57	65340.76	8.71
5D-1.00	37746.48	5.03	70031.87	9.34

Table 5 Flexural strength test of SFRSCC (2)

Mix code	$P_{100,0.75}$ (N)	$f_{100,0.75}$ (MPa)	$P_{100,3.00}$ (N)	$f_{100,3.00}$ (MPa)	$T_{100,3.00}$ (J)
N	-	-	-	-	-
3D-0.50	46541	6.21	34125	4.55	120.42
3D-0.75	52549	7.01	40197	5.36	128.03
3D-1.00	56582	7.54	43802	5.84	147.23
4D-0.50	57438	7.66	41895	5.59	140.35
4D-0.75	59909	7.99	50977	6.80	158.48
4D-1.00	64654	8.62	53429	7.12	166.16
5D-0.50	53603	7.15	50065	6.68	155.26
5D-0.75	58469	7.80	52782	7.04	162.28
5D-1.00	51427	6.86	60620	8.08	178.03

Tables 4 and Table 5 show that by adding steel fiber, the peak load that can be received by the concrete beam increases. The load on the first crack of each mix shows a trend that results are not the same, some are increasing, but some are decreasing. This is caused by the interaction between different concrete and steel fiber matrices in each mixture [16]. Type 5D steel fiber provides the greatest flexural strength capacity. At the beginning of loading, the load capacity received by the 5D type shows a smaller value than the 4D and 3D types. But when it reaches peak load, the 5D type produces the highest peak load. The remaining load capacity also shows that the 5D type has higher toughness compared to the 4D and 3D types. The energy absorption capacity (T100.3.00) shows that the hooked type steel fiber with the hooked-end produces more energy capacity. This is because the hooked-end shape greatly contributes to absorbing energy when the beam is subjected to bending forces. The hooked-end shape also increases the tensile strength of the steel fiber material so that when the concrete beam structure works in a composite manner, the steel fiber contributes greatly to the tensile of the concrete.

6. CONCLUSION

Workability testing based on EFNARC standards results in decreased SFRSCC workability. In the various hooked-end shape, the more number of hooked-end in steel fibers, the SFRSCC workability decreases. The same thing also produces the volume fraction, increasing the volume fraction of steel fibers which causes the working power to decrease.

The use of 0-1.00% volume fraction in all steel fibers type obtained optimum value Vf = 1.00%. The flexural strength and energy absorption capacity of the SFRSCC increases significantly as the volume fraction increases.

In the various shapes of hooked-end 3D, 4D, and 5D, the type that provides increased flexural strength and maximum energy absorption capacity of SFRSCC is type 5D.

Increased flexural strength and energy absorption capacity of SFRSCC shows the use of hooked-end steel fibers type significantly increased ductility of the SFRSCC.

The greater the tensile strength of steel fibers, the greater the flexural strength of the SFRSCC. This is due to the steel fibers working in a composite with concrete material when given a load, so the steel fibers contribute tensile strength to the SFRSCC.

This research shows that SFRSCC with 3D, 4D, and 5D steel fiber types have several advantages in terms of compaction, better filling ability, flowability, passing ability, pumping ability, and good flexural capacity.

This research does not use mineral additives. Further research can be done by adding mineral additives such as fly ash, husk ash, palm ash, and other waste materials.

In future research, it is necessary to conduct a durability test on the effect of hooked-end steel fiber on the durability of SFRSCC. The use of volume fractions below 1.00% shows a linear effect. For volume fractions above 1.00%, further research needs to be done.

Further research on the behavior of structural elements using SFRSCC is very much needed, such as in beam and column structural elements with full scale.

7. ACKNOWLEDGMENTS

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8. NOMENCLATURE

SFRSCC = Steel Fiber Reinforced Self-Compacting Concrete
SCC = Self-Compacting Concrete
EFNARC = European Federation of National Associations Representing for Concrete
SFRC = Steel Fiber Reinforced Concrete
OPC = Ordinary Portland Cement
FA = Fine Aggregates
CA = Coarse Aggregates
Sp = Superplasticizer
ACI = American Concrete Institute
LVDT = Linear Variable Differential Transformer

9. REFERENCES

[1] ACI 544.1R-02, 2002. State of the Art Report on Fiber Reinforced Concrete. USA: American Concrete Institute.

[2] Aocheng Z., Massoud S., Elisa L., Zhiyuan Z., and Priyan M., Flexural Capacity Prediction Model for Steel Fibre-Reinforced Concrete Beams. International Journal of Concrete Structures and Materials, Vol. 15, Issue 28, 2021, pp.1-12.

[3] Jeffri R., James C., James M., Brabha N., Keerthan P., and Wai M. C., Crack Detection and Localisation in Steel-Fibre-Reinforced Self-Compacting Concrete Using Triaxial Accelerometers. Sensors (Basel), Vol. 21, Issue 6, 2021, pp.1-20.

[4] Khaloo A., Raisi E. M., Hosseini P., Tahsiri H., Mechanical performance of self-compacting concrete reinforced with steel fibers. Construction and Building Materials, vol. 51, pp. 179–186, 2014.

[5] Wael Z. and Tu N., Mixture Design Study of Fiber-Reinforced Self-Compacting Concrete for Prefabricated Street Light Post Structures. Advances in Civil Engineering, pp.1-7, 2020.

[6] Xinxin D., Changyong L., Minglei Z., Jie L., Haibin G., and Lei L., Tensile Behavior of Self-Compacting Steel Fiber Reinforced Concrete Evaluated by Different Test Methods. Crystals, Vol. 11, Issue 251, 2021, pp.1-12.

[7] Sumith V., Siva R. K., Venu M., Tarunkumar K., Jagadish B., Strength and Durability Properties of Steel Fiber Reinforced Self Compacting Concrete. Turkish Journal of Computer and Mathematics Education, Vol. 12, Issue 5, 2021, pp. 818-826.

[8] Soulioti D. V., Barkoula N. M., Paipetis A., Matikas T. E., Effects of Fibre Geometry and Volume Fraction on the Flexural Behaviour of Steel-Fibre Reinforced Concrete. Strain, Vol 47, 2011, pp. 535–e541.

[9] Leila S., Sudharshan N. R., Mohd Z. J., Johnson A., Influences of the volume fraction and shape of steel fibers on fiber- reinforced concrete subjected to dynamic loading – A review. Engineering Structures, Vol. 124, 2016, pp. 405–417.

[10] Seung J. L., Doo Y. Y. and Do Y. M., Effects of Hooked-End Steel Fiber Geometry and Volume Fraction on the Flexural Behavior of Concrete Pedestrian Decks. Appl. Sci. Vol. 9, Issue 6, 2019; pp.1-21.

[11] ASTM C 150-07, 2007. Standard Specification for Portland Cement, Annual Books of ASTM Standards, USA: Association of Standard Testing Materials.

[12] EFNARC Association, 2015. The European Guidelines for Self-Compacting Concrete.

[13] ASTM C469, 2010. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, USA: Association of Standard Testing Materials

[14] ASTM C1609, 2010. Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading), USA: Association of Standard Testing Materials

[15] Sathya T. and Padmanaban I., Effect of Steel Fibres as Reinforcement in Self Compacting Concrete. International Journal of Advanced Research Methodology in Engineering & Technology, Vol. 1, Issue 2, 2017, pp.170-173.

[16] Jawad A., Fahid A., Rebeca M. G., Mohamed H. El O., and Khalid M. K., Performance of sustainable self-compacting fiber reinforced concrete with substitution of marble waste (MW) and coconut fibers (CFs). Scientific Reports, Vol. 11, 2021.

[17] Matheus G. C., Rodrigo de M. L., and Valdirene M. S. C., Influence of concrete strength, fiber content and aspect ratio in the residual flexural strength of steel fiber reinforced self-compacting concrete. IBRACON Estrut. Mater. Vol. 14, Issue 5, 2021, pp.1-14.