Influence of steel fiber shapes on fresh and hardened properties of steel fiber reinforcement self-compacting concrete (SFRSCC)

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Abstract. Concrete material has low tensile strength and brittle characteristics. The solution to overcome this weakness is using ductile materials such as steel fibers. The use of steel fibers has constraints in workability. To facilitate work in the field, it was developed to become self-compacting concrete (SCC). SCC which uses additional steel fibers is known as steel fibers reinforced self-compacting concrete (SFRSCC). The development of steel fiber shapes from beginning to the present has produced many types of shapes, including straight, crimped, and hooked. Based on the various shapes of steel fiber, further development of SFRSCC technology needs to be carried out. This paper analyzed the influence of steel fiber types consisting of the three types of shapes on the physical and mechanical properties of SFRSCC. The methodology in this paper is to use a literature review and experimental methods. The results of the analysis show that all types of steel fibers result in a decrease of workability. The most decreased workability contains steel fibers of hooked type, and while the least decreased one used steel fibers of straight type. The results of the mechanical properties analysis showed the opposite, the largest increase in mechanical properties was obtained using hooked type, and straight type. For optimum physical and mechanical properties, crimped type is recommended as a type of steel fiber in the SFRSCC.

1. Introduction

Indonesia's infrastructure development is in very significant development of which are roads and bridges. Road and bridge infrastructure development is inseparable from the technology of materials making up the infrastructure. The most dominant material used mainly for the infrastructure of the bridge is a concrete material.

Concrete technological developments made progress with the development of construction technology and construction material needs. Concrete technology that began many developed ones of which is compacted concrete technology itself, or better known as Self-Compacting Concrete (SCC).

SCC is a concrete technology with the ability to condense his form in the casting process without the aid of a concrete vibrator as in general. SCC used to save time and labour in concrete construction. SCC technology was first developed in Japan in 1986 by Professor Hajime Okamura and Kazumasa Ozawa from the University of Tokyo to overcome the problems durability concrete and the increasing demand for skilled workers to work on concrete [1].

Concrete is a material that has an advantage in compressive strength but weak in tensile strength, it makes concrete including a brittle material. SCC characteristics that can perform compaction mechanism itself makes very dense concrete thereby increasing the compressive strength of the concrete,
but the concrete denser than the concrete will be more brittle. To increase the elasticity of concrete it is necessary to increase the fiber in concrete.

Concrete fiber into innovation to overcome the weaknesses of the concrete material. Fiber concrete consists mainly of artificial and natural fibers. Artificial fibers commonly used are steel fibers. The use of steel fibers can reduce the workability of fresh concrete, to ease the work in the field is used SCC. Innovative use of steel fibers into the SCC can be called with steel fiber reinforced self-compacting concrete (SFRSCC). SFRSCC is a combination of two concrete innovation which has the advantage of workability of SCC and increased mechanical properties of the addition of steel fiber.

The development of steel fiber shapes the beginning until now has produced many types of shapes, of which consists of a straight, crimped, and hooked. Based on the diversity of the steel fiber shapes, for technological development SFRSCC need to do further research. Based on the explanation above, this study aimed to analyze the influence of the type of steel fiber shape on the physical properties of fresh concrete and mechanical properties SFRSCC.

2. Literature Review

2.1. Steel Fiber Reinforced Self-Compacting Concrete (SFRSCC)

Steel fiber reinforced self-compacting concrete (SFRSCC) is a technology innovation that combines steel fiber reinforced concrete (SFRC) and self-compacting concrete (SCC). SFRC is concrete with the fiber using steel material to increase the ability of concrete. SFRC also has a good ability in durability. Steel fibers in concrete works to increase the density of concrete, reduced cracking, and reduced permeability, so as to make the concrete more resistant to the environment [2]. The use of steel fibers in the SFRC making workability of fresh concrete decreases, so its use should be combined with a concrete mix that has good workability is SCC.

Advantages of using steel fibers in concrete are as follows [3]:

a. Increase flexural strength,
b. Improving the energy absorption capacity,
c. Increase ductile behavior before the ultimate collapse.
d. Inhibit the growth and widening cracks.
e. Improved durability.

The only drawback is the use of steel fibers degrade workability and a setting time of fresh concrete. This drawback can be overcome with the use of SCC superplasticizer to form a mixture. Performance of steel fibers in concrete depends on many factors such as the type of steel fiber, shape, length, cross-sectional shape, tensile strength, fiber content, bonding strength, the strength of the matrix, the composition of the concrete mix, and mixing distribution in concrete [2]. Steel fibers have various types of shapes, from the beginning to the present use of steel fiber shapes are still in use consists of a straight, crimped, and hooked as in Figure 1.

2.3. Mixture composition SFRSCC

SFRSCC composition consists of a mixture SFRC and SCC. Mix SFRC and SCC have regulations respective compositions. SFRC is set in the standard 544.IR ACI-02 [4], and SCC is set in the standard ACI 237 R-07 [5] and EFNARC [6]. ACI-02 544.IR give proportions for SFRC mix. The mixture proportions shown in Table 1.
### Table 1. SFRC mix proportions [4]

| Parameter                              | 3/8 in. The maximum size of aggregate | 3/4 in. The maximum size of aggregate | 1.5 in. The maximum size of aggregate |
|----------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Cement, lb / yd³                        | 600-1000                              | 500-900                               | 470-700                               |
| The ratio w / c                         | 0.35 to 0.45                          | 0.35 to 0.50                          | 0.35 to 0.55                          |
| Levels of fine to coarse aggregate, %  | 45-60                                 | 45-55                                 | 40-55                                 |
| The air content, %                     | 4-8                                   | 4-6                                   | 4-5                                   |
| Fiber volume fraction, %               | 0.4 to 1.0                            | 0.3-0.8                               | 0.2 to 0.7                            |
| Deformed fiber                         |                                       |                                       |                                       |
| Smooth fiber                           | 0.8 to 2.0                            | 0.6 to 1.6                            | 0.4 to 1.4                            |

Based on ACI 544.1R-02 standard [4], it is known that the maximum size of the aggregate affect other constituents of the composition. The smaller the aggregate size requires more fillers. The maximum size of coarse aggregate 3/8in (10 mm) require more filler than the maximum size of the aggregate 3/4in (19 mm) and 1.5in (3.81 mm). As for SCC mix proportions, ACI 237 R-07 [5] gives the mix proportions shown in Table 2.

### Table 2. Proportion of SCC mix [5]

| Parameter                              | Value                                                                 |
|----------------------------------------|-----------------------------------------------------------------------|
| The volume of coarse aggregate         | 28-32% (the maximum size > 12 mm)                                     |
|                                        | 50% (maximum size 10 mm)                                              |
| Fraction pasta (by volume)             | 34-40% (the total volume of the mixture)                              |
| Fraction mortar (by volume)            | 68-72% (the total volume of the mixture)                              |
| w / c                                  | 0.32 to 0.45                                                          |
| Cement                                 | 386-475 kg / m³ (lower by VMA)                                        |

### 3. Methodology

This research was conducted using the method of literature review and experimental. The study of literature in this study conducted by collecting and studying data of scientific papers, journals, textbook, and books SFRSCC discussion. Data obtained connect and explain the problem of the influence from the type of steel fibers to the physical and mechanical properties of compacted fibrous concrete itself.

The object of discussion in this study is SFRSCC with the independent variable is the type of form that consists of straight, crimped, and hooked as in Figure 1.

![Figure 1. The type of steel fiber shapes](image-url)
Primary data in this study was obtained by the method of experimental studies based on direct testing in the laboratory. Primary data were obtained from the type of steel fiber influence hooked. Secondary data is research data obtained from scientific papers and journals. Secondary data were obtained from the type of steel fiber influence of straight and crimped.

Experimental methods that do consist of testing the physical properties of fresh concrete and testing of mechanical properties of concrete. Physical properties of fresh concrete testing conducted to determine the workability of the concrete, the testing was done by the slump flow test, T-500, V-funnel and L-box based on The European Federation of Specialist Construction Chemicals and Concrete Systems standard (EFNARC). Testing of mechanical properties of hard concrete was conducted to determine the mechanical properties of concrete. Tests carried out at the age of 28 days in the form of concrete compressive strength test, splitting tensile strength test, modulus of elasticity test, and flexural strength test. Testing of mechanical properties of concrete based on ASTM standards.

3.1. Physical Properties of Fresh Concrete Testing

Based EFNARC standards [6], the concrete can be categorized as SCC if it meets the characteristics of filling ability, viscosity or flowability, passing ability and segregation resistance. These characteristics are obtained by testing the fresh concrete on a particular tool in accordance with the type of characteristics.

a. Filling Ability

One of the characteristics of SCC are filling abilities which can be determined by testing the slump flow. Results of testing the slump flow diameter of the spread in the form of fresh concrete with a diameter of between 550-850 mm. Slump flow testing was performed using plates and Abrams Cone. Plates were used have a minimum size of 900 x 900 mm made of a rigid material, does not absorb water (impermeable), has a smooth surface and have a clear mark on the diameter of 200 mm and 500 mm. While Abrams Cone used has a diameter of 100 mm at the top and a diameter of 200 mm at the bottom with a height of 300 mm as shown in Figure 2. Categorization of filling ability to SCC class is divided into three classes according to the slump flow value as shown in Table 3.

![Figure 2. The dimensions of the slump flow testing tools [7]]
Table 3. Class of filling abilities [6]

| No. | Class | Slump flow (mm) |
|-----|-------|-----------------|
| 1.  | SF 1  | 550-650         |
| 2.  | SF 2  | 660-750         |
| 3.  | SF 3  | 760-850         |

Tests carried out to check the slump flow filling ability SCC based on the diameter of its spread. The greater flow diameter spreading the better class SCC filling ability. Two parameters were measured in this test, the diameter distribution and a T-500. Time T-500 is the time when the diameter of the spread reached a diameter of 500 mm. Parameter diameter distribution showed the maximum limit that can be achieved by the flow of fresh concrete, while the time parameter T-500 shows the time indicated in the flow of fresh concrete.

b. Viscosity (Flowability)

Tests were conducted to measure the viscosity value SCC include the T-500 test, V-funnel test, O-funnel test, and Orimet. The fourth test provides results in the form of time measurement of fresh concrete flow (flow time). Grouping for SCC viscosity grade are divided into two classes according to the time of testing the T-500 and V-funnel are like in Table 4.

![Figure 3. Dimensions of testing the V-funnel [7]](image)

V-funnel testing conducted to measure the time required volume of fresh concrete to flow through the V-shaped funnel with a hole-like opening doors narrow neck. The shape and dimensions of the test tool V-funnel can be seen in Figure 3.

Table 4. Class of viscosity [6]

| No. | Class     | T-500 (seconds) | V-funnel (Seconds) |
|-----|-----------|-----------------|--------------------|
| 1.  | VS 1 / VF 1 | ≤ 2             | ≤ 8                |
| 2.  | VS 2 / VF 2 | > 2             | 9-25               |
c. Passing Ability

Passing ability SCC is the ability to pass through obstacles such as reinforcement in a mold. Tests were conducted to measure the value of the passing ability of SCC in this study is the L-box. Tests using L-box passing ratio produces a value that is used to classify the class passing ability as shown in Table 5.

| No. | Class | passing ratio            |
|-----|-------|--------------------------|
| 1.  | PA 1  | ≥ 0.80 with 2 rebar       |
| 2.  | PA 2  | ≥ 0.80 with 3 rebar       |

L-box testing is done by measuring the height of the fresh concrete after flowing through the reinforcement denoted by $H_2$ and measure the height of the fresh concrete at the base of the L-box area denoted by $H_1$. With this test, obtained after the height of the fresh concrete with reinforcement, the height of the base of the L-box, and the expected behavior of fresh concrete as it passes through reinforcement. The principle of measurement in the L-box testing can be seen in Figure 4.

![Figure 4. The principle of measurement of L-box test](image)

3.2. Testing of Mechanical Properties of Concrete

SFRSCC Tests carried out after curing of the concrete. SFRSCC testing was conducted to determine the mechanical properties of the concrete.

a. Compressive Strength

The main parameters of the quality of a concrete that is the result of the calculation load is shared widely referred to by the compressive strength of concrete. Compressive strength testing in this study refers to the standard ASTM C 39 [8] with the calculation of the compressive strength of concrete is given in Equation (1).

$$ f'c = \frac{P}{A} $$

Where:

- $f'c$ = Compressive strength (N/mm$^2$)
- $P$ = Force (N)
- $A$ = Surface area (mm$^2$)
b. Splitting Tensile Strength

One of the parameters of mechanical properties of concrete is splitting tensile strength. Splitting tensile strength obtained from tensile stress of concrete that weighed load \( P \) on the side of the blanket cylinder as shown in Figure 5. The mechanism of splitting tensile strength test is to provide a load \( P \) on both sides of the blanket cylinder to the concrete collapse. Expenses are recorded until the concrete collapse later be calculated based on the vast blanket of concrete cylinders.

\[
\text{Figure 5. Principle of concrete splitting tensile strength test [9]}
\]

Splitting tensile strength testing in this study conducted by ASTM C 496 [9] with the calculation as in equation (2).

\[
f_{sp} = \frac{2P}{\pi L_s D}
\]  

Where:
\( f_{sp} \) = Splitting tensile strength (N/mm²)
\( P \) = Maximum load (N)
\( D \) = Cylinder diameter (mm)
\( L_s \) = Height of the cylinder (mm)


c. Modulus of Elasticity

Concrete tested with the compressive load will be strained. The amount of compressive strain of concrete is influenced by the modulus of elasticity of concrete. Numerically the modulus of elasticity is a measure of mechanical properties of concrete are calculated from the compressive stress divided by concrete compressive strain. Testing the modulus of elasticity in this study using a standard ASTM C 469 [10] as shown in Figure 6 and its calculation as in Equation (3).

\[
E_c = \frac{S_2 - S_1}{\varepsilon_2 - 0.00005}
\]  

Where:
\( E_c \) = Modulus of elasticity (N/mm²)
\( S_2 \) = 0.4 \( f_c' \)
\( S_1 \) = The stress corresponding to the strain in the longitudinal direction of 0.0000531 MPa
\( \varepsilon_2 \) = Longitudinal strain due to stress \( S_2 \)
Compressive strain ($\varepsilon$) concrete due to compressive load on SFRSCC calculated with Equation (4).

$$\varepsilon = \frac{\Delta L}{L}$$  \hspace{1cm} (4)

Where:
$\Delta L$ = Decrease in the longitudinal direction (mm)
$L$ = High relative concrete (the distance between the two-strain gauge)

d. Flexural Strength
The main parameters of the mechanical properties of SFRSCC are flexural strength, it is because one of the purposes of use of fiber in concrete is to improve the bending ability. The flexural strength of concrete is a concrete ability to withstand tensile force is not directly on the concrete beam flexural areas due to load at midspan. The amount of force applied to the concrete beam to collapse generates bending moments and when divided by the moment of inertia of the beam resulting in bending stress. Flexural strength testing mechanism in this study conducted in accordance with standard ASTM C 1609 [11] as can be seen in Figure 6 and is calculated by Equation (5).

$$f_r = \frac{P \times L}{(b \times d^2)}$$  \hspace{1cm} (5)

Where:
$f_r$ = Flexural strength (N/mm2)
$P$ = Compressive force (N)
$L$ = Beam span length (mm)
$b$ = Beam height (mm)
$d$ = Thick beam (mm)

**Figure 6. Principle concrete flexural strength test** [11]

4. Results and Discussions
4.1. Physical Properties of Fresh Concrete Results
According [3] the addition of steel fibers in concrete will result in decreased workability, analysis of influence of steel fiber shapes on the physical properties of fresh concrete workability is presented
that the reduction in the percentage based on comparison of the influence of SCC with steel fibers and without steel fibers.

Pai and Kumar [12] investigating the influence of the type of steel fiber straight to the workability SFRSCC with a mixed composition used consisted of cement ratio of 1, silica fume, 7.5% volume fraction, 1.29 fine aggregate, coarse aggregate 1.43, and water 0:34. Additional materials used superplasticizer (SP) 0.6%, and viscosity-modifying admixture (VMA) 0.2%. Steel fiber type straight used has an aspect ratio (l / d) 50 and the volume fraction of 1.0%. The results of physical properties are shown in Table 6.

Sable and Rathi [13] examined the effect of the type of steel fiber to the workability SFRSCC crimped form shown in Table 7. The composition of the mixture used consists of cement ratio of 1, fly ash 0.3, 1.814 fine aggregate, coarse aggregate 1.48, and 0.408 water. To give a mixture flow used superplasticizer (SP) 1%, and viscosity-modifying admixture (VMA) 0.5%. Steel fiber type crimped used has an aspect ratio (l / d) of 50 and a large percentage of the cement 2.5%.

The results of the experimental method were performed using SFRSCC cement composition 1, 1.31 fine aggregate, coarse aggregate 1.37, 0.3 water, and superplasticizer (SP) of 0.8% by weight of cement. Hooked steel fiber with an aspect ratio (l / d) 65 and the volume fraction of 1.0%. The results of physical properties are shown in Table 8.

| Table 6. Effect of the straight shape on the physical properties SFRSCC [12] |
|-----------------------------------------------|
| Slump flow (mm) | T-500 (Seconds) | V-funnel (Seconds) | L-box (H2 / H1) |
|------------------|-----------------|-------------------|-----------------|
| without fiber    | 755             | 1.5               | 14              | 0.85            |
| Straight         | 750             | 1.7               | 16              | 0.75            |
| Percentage       | -0.66           | 13.33             | 14.28           | -11.76          |

| Table 7. Effect of the crimped shape on the physical properties SFRSCC [13] |
|-----------------------------------------------|
| Slump flow (mm) | T-500 (Seconds) | V-funnel (Seconds) | L-box (H2 / H1) |
|------------------|-----------------|-------------------|-----------------|
| without fiber    | 715             | 2.9               | 7.2             | 0.94            |
| crimped          | 705             | 4.1               | 8.1             | 0.89            |
| Percentage change (%) | -1.4          | 29.26             | 11.11           | -5.56           |

| Table 8. Effect of the hooked shape on the physical properties SFRSCC |
|-----------------------------------------------|
| Slump flow (mm) | T-500 (Seconds) | V-funnel (Seconds) | L-box (H2 / H1) |
|------------------|-----------------|-------------------|-----------------|
| without fiber    | 722             | 3.8               | 7.95            | 0.92            |
| Hooked           | 630             | 5.3               | 10.95           | 0.83            |
| Percentage change (%) | -12.7         | 40.79             | 37.74           | -9.78           |

Based on the results of the physical properties of fresh concrete, it is known that all types of steel fiber shapes show the results of a decrease in workability. In sequence from the largest decrease in workability hooked type provides the highest decrease, then the type of crimped and straight type. This result is caused by the contact area of the steel fibers to the fresh concrete matrix. Steel fibers with a
straight type only straight so that the contact area with fresh concrete bonding matrix is not as much as the type of crimped, and hooked. Hooked mode has the form linkages that create coherence in the concrete matrix is quite high.

4.2. **Results of Mechanical Properties of Concrete**

Advantages of the use of steel fibers in concrete are improving its mechanical properties [3]. Based on the experimental method that examines the influence of the type of shape hooked, and literature studies result SFRSCC mechanical properties due to the influence of the type of steel fibers are shown in Table 9.

| Type of steel fiber shape | Compressive strength | Splitting tensile strength | Modulus of elasticity | Flexural strength |
|--------------------------|----------------------|----------------------------|-----------------------|------------------|
| **Straight** [12]        | 11.16                | 4.97                       | -                     | 10.41            |
| **Crimped** [13]         | 29.84                | 29.05                      | -                     | 13.05            |
| **Hooked**               | 15.18                | 37.02                      | 26.14                 | 60.40            |

On the results of the mechanical properties SFRSCC, it is known that the type of steel fiber hooked shape gives the percentage increase in the mechanical properties of the largest, followed by the type of crimped, or straight. These results contrast with the results of the physical properties of fresh concrete. It showed that the mechanical properties SFRSCC influenced by the type of steel fibers that have the most contact area on the concrete matrix. Type of steel fibers that only a straight slightly improving mechanical properties when compared with the other two shapes. Bond and anchorage steel fiber increase with the number of the contact area. For the type of shape that has crimped and hooked contact area that much, it turns out more effective hooked type provides improved mechanical properties.

Steel fibers have a significant influence on the mechanical properties of concrete, especially in flexural strength. This is due to the flexural strength of concrete experience tensile stress so that the contribution of steel fibers are very influential. In the compressive strength, steel fibers also contribute to providing the power, but not very significant, because the concrete itself already has a high compressive strength property.

5. **Conclusion**

The conclusion of the study "Influence of Steel Fiber Shapes on Fresh and Hardened Properties of Steel Fiber Reinforcement Self-Compacting Concrete" is as follows:

- Based on literature and experimental studies, the use of hooked steel fiber type, crimped, or straight on SFRSCC cause the physical properties of fresh concrete (workability) decreases.
- Type of steel fiber shape which gives the percentage decrease in sequence workability of the biggest is the type of hooked, crimped, or straight.
- All types of steel fiber shape can improve the mechanical properties of concrete. The percentage increase is by using a hooked steel fiber type.
- Mechanical properties increased significantly due to the addition of steel fiber is the flexural strength of concrete, this is due to the contribution of steel fibers which increase the capacity of the concrete tensile stress.
- For the use of steel fibers to provide performance SFRSCC fresh concrete physical and mechanical properties are optimum, it is recommended to use the type of steel fibers crimped shape.
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