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# Effect of steel fibers on self-compacting concrete slump flow and compressive strength

N Majain<sup>1\*</sup>, A B A Rahman<sup>1</sup>, R N Mohamed<sup>1</sup> and A Adnan<sup>1</sup>

<sup>1</sup>Department of Structures and Materials, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia

\*Corresponding author: nelly.majain1979@graduate.utm.my

**Abstract.** Ever since Self-Compacting Concrete (SCC) was introduced, various attempts have been made to further enhance its quality and robustness. The addition of steel fibers into the SCC mix is found to have increased the hardened properties of concrete. However, it is also acknowledged that the addition of steel fibers into the fresh SCC mix poses a negative effect on the workability which may cause segregation and bleeding. Thus, some modifications are required on the mix proportions to obtain a good flowability without bleeding mixes. In this study, four types of mixes were prepared which comprising of normal concrete (NC), SCC and Self-Compacting Concrete with Steel Fibers (SCCSF) with two volume fractions of still fibers 0.5% and 1.0%. The results revealed that an increased amount of steel fibers in the SCC mix improve the compressive strength of concrete but reduced the slump flow of the fresh SCC.

## 1. Introduction

The application of Self-Compacting Concrete (SCC) in the construction industry has gained wider attention ever since it was introduced in 1988 by Okamura [1]. Since then, it has been used for various types of structural elements such as bridges, slabs, precast beams, and tunnel segment. Undisputedly, SCC has many advantages over conventional concrete because it can flow and compact in a mould or formwork under its own weight without the need for vibration. Because of this superior quality, adequate compaction can be achieved even in a congested reinforcement and restricted areas. Basically, as stated in “The European Guidelines for Self-Compacting Concrete”[2], there are several testing methods that need to be performed in order to assess the SCC mixes. The result of the testing provides information on the flowability, viscosity, passing ability and segregation resistance of SCC at fresh state. Consequently, some desired mechanical properties are expected on the hardened state of SCC.

Various attempts have been made to further enhance the quality of SCC because just like normal concrete, it is also susceptible to tensile crack and flexural failure. The study of Self-Compacting Concrete with Steel Fibers (SCCSF) for reinforced concrete structure has gained wider attention due to the benefits of having more ductile and higher residual tensile strength as compared to conventional concrete [3]. Besides, depending on the structures, the use of steel fibers can reduce the required amount of conventional steel reinforcement while maintaining the satisfactory performance of the structure [4].



However, the addition of steel fibers into SCC may affect the fluidity of the materials. For instance, the increased in fibers volume fraction and aspect ratio will decrease the slump flow and passing ability, while increasing the flow time of SCCSF [5]. Often, a high content of steel fibers is difficult to be evenly distributed in a mix. Nevertheless, a good distribution is necessary in order to achieve optimum benefits of the fibers. Meanwhile, the effect of aspect ratio is different whether it is small or large values. Prior research has proven that the use of fibers with small aspect ratio can increase the workability of SCCSF [5]. In relation to strength, when the larger aspect ratio is being utilized, the strength performance will be increased. Hence, caution must be exercised when selecting the aspect ratio of steel fibers because this parameter has a major effect on both workability and strength properties of concrete. Accordingly, the development of optimum mix proportions for SCCSF is imperative since consideration needs to be given for both fresh and hardened properties. For that reason, this study attempts to investigate the effect of selected steel fibers on the workability of SCC and how it can enhance the hardened properties of concrete especially in mitigating crack propagation.

## 2. Experimental program

The experimental program was organized into two main parts. The first part is the mixing of NC, plain SCC, and SCC using a different volume fractions of steel fibers; SCCSF-0.5% and SCCSF-1.0%. The second part is the testing of fresh and hardened states for all concrete mixes.

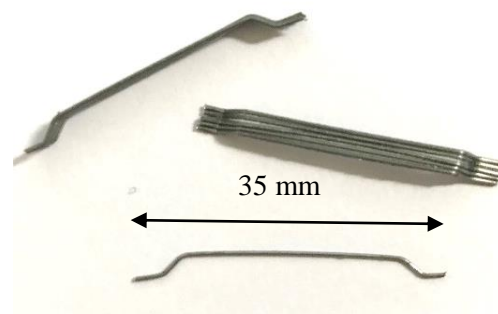
### 2.1. Materials

#### 2.1.1. Normal concrete and self-compacting concrete

In these mixtures, the cement used was the Ordinary Portland Cement (OPC) CEM I 42.5N according to European standard EN 197-1 [6]. The type of aggregates used were natural aggregates and consist of sand (0.15 – 4.75 mm) as fine aggregates and gravel (5 – 10 mm) as coarse aggregate, with relative densities of 2700 kg/m<sup>3</sup> for each type. For SCC mixes, in order to have an increased paste volume and a good cohesion, fly ash class F produced by coal-burning electric utilities obtained from Tanjung Bin Power Plant, Johor was added. The density of the fly ash is 2100 kg/m<sup>3</sup> and it replaces 30% of the total cement content. To achieve high flowability in SCC, superplasticizers or high range water reducing admixture is needed and vital. In this study, Sika Viscocrete-2044 was used and it is the third generation of polycarboxylate ether-based superplasticizer.

#### 2.1.2. Steel fibers

In this research, the STAHLCON Steel Fibers HE 0.55/35 (hooked end steel fibers) as shown in figure 1 were used with two different percentages of fibers volume fractions,  $V_f = 0.5\%$  and  $1.0\%$ . The properties and dimensions of the hooked end steel fibers are as given in table 1.



**Figure 1.** STAHLCON steel fibers HE 0.55/35.

**Table 1.** Properties of hooked end steel fibers.

Component	Value
Diameter (mm)	0.55
Length (mm)	35
Aspect ratio (L/D)	63.6
Density (kg/m <sup>3</sup> )	7850
Tensile Strength (MPa)	1200
Elastic Modulus (GPa)	205

## 2.2. Mix design

### 2.2.1. Mix design proportions

The mix design proportions for both NC and SCC were adopted from a previous researcher with some modification made [7]. The NC design was based on the Department of Environment (DOE) method while the SCC mix design was based on the recommendation by “The European Guidelines for Self-Compacting Concrete” issued by the European Federation. The mixes were designed to develop a 28-days characteristics strength of 40 MPa. The materials mix proportions are summarized in table 2. As for the superplasticizer, the supplier’s recommended dosage for SCC is within 1-2 % by weight of powder. The w/c ratio is kept as 34% in order to have the good flowability without bleeding.

**Table 2.** NC and SCC materials compositions (1 m<sup>3</sup> Volume).

Component	Content (kg/m <sup>3</sup> )	
	NC	SCC
Cement	444.44	416.82
Fly Ash	-	178.64
Fine Aggregate	812.93	783.14
Coarse Aggregate	954.30	729.00
Water	213.33	200.00

### 2.2.2. Mixing procedure

The mixing procedure for SCC and SCCSF follows the method suggested by previous researchers [8] and [9]. For SCC, the first step is to mix the coarse aggregate and fine aggregate together for 30 seconds. In the second step, half of the total volume of water was added and the mixing continues for a further 1 minute. Next, the powder (cement and fly ash) and half of the remaining water were added into the mixture for another 2 minutes. After that, the remaining water and superplasticizer were added progressively. Finally, the mixing process continued for another 2 minutes until the mixture became homogeneous. As for the SCCSF, the same steps were applied with the addition of steel fibers during the first step of the mixing.

## 2.3. Specimen details

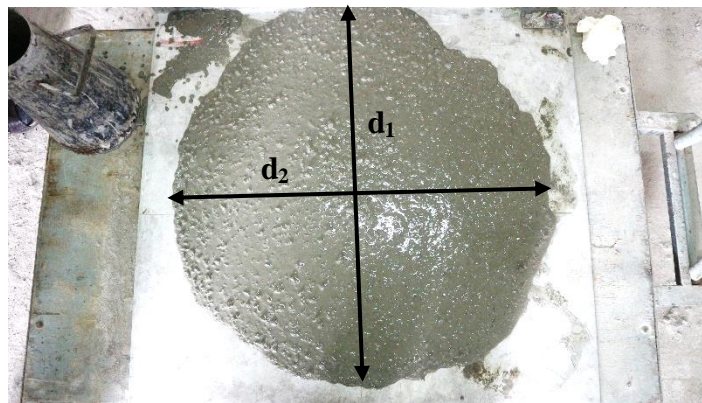
Four mixes were prepared in this study consisting of one mixture for normal concrete, one mixture for plain SCC and two mixtures for SCCSF with fibers volume fractions of  $V_f = 0.5\%$  and  $1.0\%$ . For each concrete mixes, six numbers of concrete cube specimens with dimensions of 100 x 100 x 100 mm were prepared for compressive strength tests.

## 2.4. Testing

In this study, the slump flow tests were conducted which is a primary testing used in the field because of the convenience and the ability to show the initial condition of the concrete mixture. This test gives some information on the flowability and segregation of fresh SCC and SCCSF through measurement and visual assessments. As for the hardened state, the cubic specimens were demoulded 24 hours after casting and then cured for 7 days and 28 days in water. Subsequently, the compressive tests were conducted to evaluate the strength of the concrete.

### 2.4.1. Slump flow test

The slump flow test for fresh SCC and SCCSF ( $V_f = 0.5\%$  and  $1.0\%$ ) were conducted in accordance with BS EN 12350-8-2010 [10]. Basically, the procedure begins with filling the slump mould in a single layer without compaction and then the mould is raised from the concrete immediately and slowly in a vertical direction. Often, this test is performed with the slump cone upside down to make it easier to fill. The value of the slump flow is the average of the largest slump flow diameter,  $d_1$  and the second diameter  $d_2$  that is perpendicular to the first measured diameter,  $d_1$ . Figure 2 presents the slump flow diameter measurement. The acceptance criteria as stated in “The European Guidelines for Self-Compacting Concrete” is between 550 mm and 850 mm.



**Figure 2.** Slump flow measurement.

### 2.4.2. Compressive strength test

The compressive tests were conducted using the NL Compression Machine with a capacity of 3000 kN as shown in figure 3. The test was performed based on the requirements by BS EN 12390-3:2009 [11]. In this test, the strength properties of all cubes specimens at hardened state for all concrete mixes, NC, SCC and SCCSF ( $V_f = 0.5\%$  and  $1.0\%$ ) were determined at the age of 7 and 28 days. The test begins with applying load on the cube not exceeding 30% of the design failure load and then followed by a constant and continuous loading until failure at a rate of  $0.6 \pm 0.2 \text{ N/mm}^2\cdot\text{s}$ . The compressive strength was derived by dividing the maximum compression force to the specimen cross-sectional area.



**Figure 3.** Compressive strength test machine.

### 3. Results and discussion

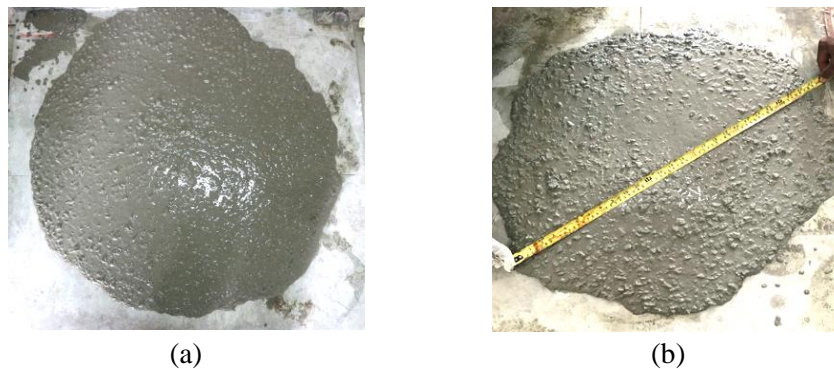
#### 3.1. Slump flow

The composition of materials are similar for all SCC mixes and the difference between all mixes lies on the fibers volume fractions. Table 3 presents the results of the slump flow for plain SCC and SCCSF with a fibers volume fraction of 0.5% and 1.0%. As shown, the average slump flow for plain SCC is 775 mm diameter which is higher than SCCSF-0.5% and SCCSF-1.0% with average slump flow of 675 mm and 640 mm, respectively. The reason is that concrete without steel fibers can flow easily without any obstruction from the fibers. Figures 4(a) and (b) present the slump flows for both SCC and SCCSF-0.5% which show good flowability without bleeding. However, the slump flow for SCCSF-1.0% shows some segregation and bleeding in the mix as depicted in figure 5(a), though in the previous study conducted [7], with the same mix composition there was no segregation and bleeding for this mix. This could be due to the different type of superplasticizer used in this study. As observed, the slump flow diameter for SCCSF-1.0% is only slightly smaller than the SCCSF-0.5% although it was expected that the diameter is significantly reduced due to the double amount of steel fibers used. Therefore, for SCCSF-1.0%, casting work was repeated with some slight adjustment on the amount of fine aggregate. The volume of fine aggregate was increased by 2% to allow for a higher volume of mortar and hence the dosage of the superplasticizer was also increased from 1.7% to 2%. Figure 5(b) shows the slump flow of SCCSF-1.0% after the adjustment was made. The concrete slump flow is much better compared to the previous mix design and there is no segregation observed. This proves that the content and particle size of aggregates play a vital role and can significantly affect the concrete flow.

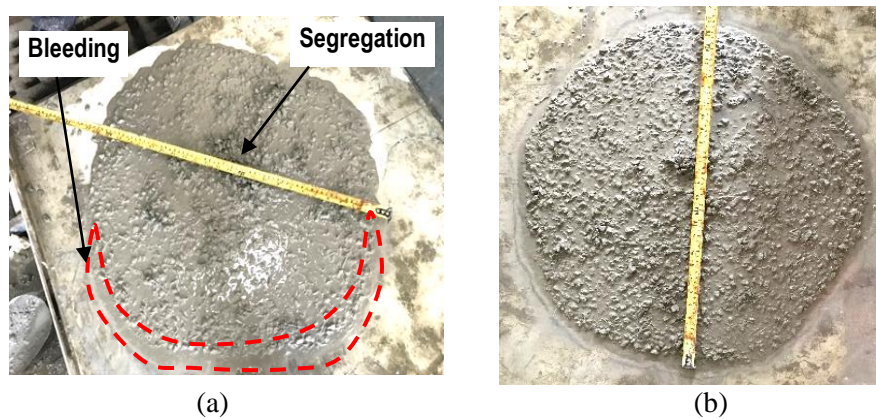
**Table 3.** Slump flow test results.

Mixture	$d_1$ (mm)	$d_2$ (mm)	Slump flow average (mm)	Superplasticizer dosage (%)	Remark
SCC	800	750	775	1.5	Satisfactory
SCCSF-0.5%	700	650	675	1.6	Satisfactory
SCCSF-1.0%	650	630	640	1.7	Bleeding & Segregation

\*  $d_1$  = Largest slump flow diameter \*  $d_2$  = diameter perpendicular to  $d_1$



**Figure 4.** Slump flow for SCC & SCCSF Mixes (a) SCC. (b) SCCSF-0.5%.



**Figure 5.** Slump flow (a) SCCSF-1.0%. (b) SCCSF-1.0% after adjustment of mix.

### 3.2. Compressive strength

Table 4 presents the results of the compressive strength test for NC, plain SCC, SCCSF-0.5% and SCCSF-1.0% at the age of 7 and 28 days. Generally, the characteristic strength of the concrete achieved the intended strength of 40 MPa at 28 days. In fact, the strength has already been achieved even on the seventh day and evidently, the strength of SCC is much higher than NC by 39% at 28 days. This is due to the low water/cement ratio in SCC which contributes to a higher strength of concrete. The outcome of the test also shows that the strength of SCCSF-1.0% was the highest although at fresh state there were some bleeding and segregation issues. This could be because the presence of steel fibers helped to improve the compressive strength in concrete as mentioned by other previous researchers [12]. However, the influence of steel fibers on the compressive strength is not very substantial as the increment of strength at 28 days between SCC and SCCSF-0.5% is only around 6.6% while between SCCSF-0.5% and SCCSF-1.0% is only 1.4%. The reason is that steel fibers primary contribution are not really in compression but mainly as a crack arrester which restricts the development of cracks. Consequently, the assessment was often made based on the failure mode of the specimens. Figure 6 shows the comparison of the failure mode between SCC, SCCSF-0.5% and SCCSF-1.0%. As can be seen, the plain SCC cube crushed along the perimeters of the cube whereas the SCCSF-0.5% cube showed some crack opening on the surface while for the SCCSF-1.0%, just a hairline crack was observed. This is owing to the fact that steel fibers were able to control the propagation of micro-cracks [13] and bridge the cracks formed during the compressive loading and thus prevent the cubes from crushing.

**Table 4.** Compressive strength test results.

Mixture	Average Compressive Strength (MPa)	
	7 Days	28 Days
NC	43.71	50.30
SCC	52.94	69.99
SCCSF- 0.5%	53.98	74.61
SCCSF- 1.0%	54.08	75.67

**Figure 6.** Comparison of Cube Test Failure Mode for SCC, SCCSF-0.5% and SCCSF-1.0%.

#### 4. Conclusion

In conclusion, the addition of steel fibers into the SCC mix may affect the workability and fluidity of the fresh SCC and causes segregation and bleeding in the mixtures. Thus, some modifications on the mix proportion of SCC may be required. Additionally, the inclusion of steel fibers in SCC have slightly increased the compressive strength of concrete and changes the failure modes.

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