

**EFFECT OF MOULD TYPE ON FLEXURAL STRENGTH OF SELF-COMPACTING STEEL FIBRE-REINFORCED CONCRETE****Nguyễn Việt Đức<sup>1</sup>**

**Abstract:** *Fresh self-compacting steel fibre-reinforced concrete (SCSFRC) of strength class 30 MPa was casted into the small (100x100x400 mm<sup>3</sup>) and large (100x300x400 mm<sup>3</sup>) moulds. The large specimen was splitted into three small identical ones (100x100x400 mm<sup>3</sup>). All of the specimens were subjected to third-point bending in as-cast direction. Flexural strength of SCSFRC obtained from small specimens (100x100x400 mm<sup>3</sup>) yielded 10% higher than that from large specimens of the same size. While flexural strength defined by the small specimens (100x100x400 mm<sup>3</sup>) that were cut from the large specimens was almost the same. When pouring fresh SCSFRC into the small mould, steel fibres were orientated along with the flow of the fresh concrete due to the wall-effect and the velocity profile. Likely, this phenomenon did not occur in the case of large mould. This was the main reason why flexural strength was influenced by mould type.*

**Keywords:** Self-compacting steel fibre-reinforced concrete, fibre orientation, mould type, wall effect, flexural strength.

**1. INTRODUCTION**

The concept of Self-Compacting Concrete (SCC) was proposed in 1986 by Professor Hajime Okaruma, but the prototype was first developed in 1988 in Japan by Professor Ozawa at the University of Tokyo. SCC was developed at the time to improve the durability of concrete structures (Okamura & Ouchi, 2003). Since then various investigations have been carried out and SCC has been used in practical structures not only in Japan, but also in many other countries, mainly by large construction companies. Investigations for establishing a rational-mix design method and testing methods have been carried out from the viewpoint of making it a standard concrete (Domone, 2007).

Nowadays, SCC is considered as a material that can flow under its own weight and fill formwork without the need for any type of internal or external vibration. SCC is used to facilitate and ensure proper filling, and good structural performance of restricted areas and

heavily reinforced structural members. It has gained significant importance in recent years because of its advantages. Besides, this concrete has also gained wider use in many countries for different applications and structural configurations (Sahmaran et al., 2015).

Self-compacting steel fibre reinforced concrete (SCSFRC) combines the benefits of SCC in the fresh state and shows an improved performance in the hardened state due to the addition of steel fibres. This kind of concrete mix can mitigate two current concrete weaknesses: low workability in fibre reinforced concretes and reduced cracking resistance in plain concrete (Ferrara et al., 2011). Steel fibres bridge cracks and retard their propagation. The enhanced properties of SFRSCC enable to step up both the constructive process and the material mechanical properties. By the utilization of SCSFRC, bleeding and segregation, which may exist due to improper vibration and may reduce the fibre/matrix bond strength, can be avoided (Hossain & Lachemi, 2008).

The addition of steel fibres to a cementitious matrix may contribute to improve the energy absorption and ductility, load transfer capacity,

---

<sup>1</sup> Bộ môn Vật liệu xây dựng, Khoa Công trình, Trường Đại học Thủy lợi

residual load bearing capacity, durability, fire and impact resistance, e.g. (Torrijos et al., 2010). However, the contribution of fibres to bridge stresses across a crack depends not only on the uniformity of the fibre dispersion but also on their orientation (Ferrara et al., 2011). These issues are a consequence of a multiplicity of factors, namely fresh-state properties, casting conditions into the formwork, flowability characteristics, vibration and wall-effect introduced by the formwork (Grunewald, 2004, Nguyen, 2015).

In this paper, the effect of mould type on flexural strength of SCSFRC is studied. To perform this evaluation, two types of SCSFRC specimens, which have a size of 100x100x400 mm<sup>3</sup> and 100x300x400 mm<sup>3</sup>, were casted using the same base mix proportions. The large specimens (size 100x300x400 mm<sup>3</sup>) were cut and splitted into three small specimens similar to the others. All of the specimens were then subjected to third-point bending test in as-cast direction to evaluate flexural strength.

## 2. MATERIALS AND METHODS

The material used for this study are presented as follows:

### 2.1. Cement and silica fume

Portland blended cement PCB40 with commercial brand But Son, which is conforming to the Vietnamese standard TCVN 2682:2009, is used in this study. Physical and mechanical characteristic of cement are given in Table 1. In addition, silica fume is used as powder content in combination with cement in SCSFRC mix, its specific density is 2.2 g/cm<sup>3</sup>.

**Table 1. Physical and mechanical characteristic of cement**

Parameters	Units	Test results
Specific density	g/cm <sup>3</sup>	3.12
Bulk density	g/cm <sup>3</sup>	1.31
Blaine fineness	cm <sup>2</sup> /g	3150
Consistency	%	28.2
Initial setting time	min.	102
Final setting time	min.	285
Soundness of cement	mm	2.1

Parameters	Units	Test results
3 days compressive strength	N/mm <sup>2</sup>	30.1
28 days compressive strength	N/mm <sup>2</sup>	41.5

### 2.2. Fine and coarse aggregates

Natural sand and crushed stone from the area close by Hanoi city are used as fine and coarse aggregates respectively for SCSFRC mix. Their characteristics are given in Table 2. Besides, in order to obtain grading of aggregates, sieve analysis is also carried out, hence the results are shown in Table 3.

**Table 2. Characteristic of coarse and fine aggregates**

Parameters	Units	Crushed stone	Sand
Specific density	g/cm <sup>3</sup>	2.65	2.61
Bulk density	g/cm <sup>3</sup>	1.47	1.53
Water absorption	%	1.1	1.5
Clay, silt and dust content	%	1.4	0.9
Fineness modulus	-	-	2.34

**Table 3. Gradation of aggregates by sieve analysis**

Sieve size	Crushed stone	Sand
70	0.0	
40	2.5	
20	47.5	
10	81.3	
5	98.0	0.0
2.5		9.2
1.25		20.8
0.63		37.6
0.315		70.2
0.14		95.3
Pan	100	100

### 2.3. Steel fibre

Steel fibre used in this study is made of high strength steel. Yet, it is copper-coated to enhance tensile performance, as it can be observed in Figure 1. The characteristic of steel fibre is provided in Table 4.

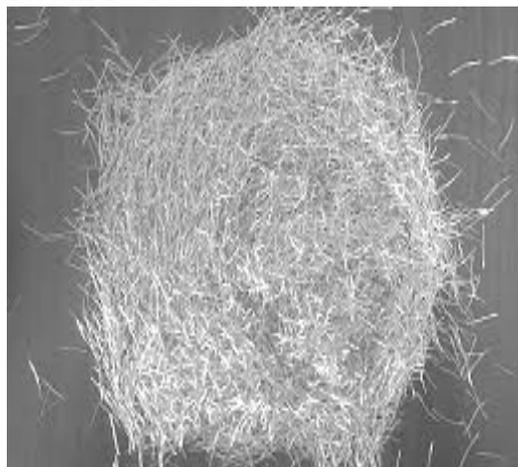


Figure 1. Steel fibres used in this study

### 2.4. Superplasticizer, viscosity modifying agent and water

Superplasticizer (SP) is a high-range water reducer admixture, which is a third generation polycarboxylate superplasticizer. Besides, in order to improve segregation resistance and cohesiveness of fresh concrete, viscosity modifying agent (VMA) was also used to produce SCSFRC mix. Water used in this study is tap water at Hanoi area. Characteristic of SP, VMA, and water is shown in Table 5.

Table 4. Characteristic of steel fibre

Steel fibre conforming EN14889-1	Units	Value
Diameter	mm	0.2
Length	mm	13
Aspect ratio	-	65
Tensile strength	MPa	2850

Table 5. Characteristic of superplasticizer (SP), viscosity modifying agent (VMA) and water

Parameter	Units	SP	VMA	Water
Specific density	g/cm <sup>3</sup>	1.075 ÷ 1.095	1.05	1
pH value	-	4 ÷ 6	7 ÷ 8	7

### 2.5. Mix proportion, fresh properties and compressive strength of SCSFRC at different ages

In this study, SCSFRC mix corresponding to strength class of 30MPa at the age of 28 days is designed. The “VMA-type SCC” mix design method is considered, apart from the increase of powder content and reduction of coarse aggregate content (EFNARC, 2006). The silica fume dosage is 10% of cement content. The water to powder

ratio is 0.5, besides the coarse to fine aggregate volume ratio was 1.85. Meanwhile, the content of fibres is specified as a percentage over the bulk volume of concrete, yet the fibre contribution is included into the grading of the solid fraction (Ferrara, 2007). Steel fibre content is 30 kg per cubic meter. Some “trial-and-error” were involved, the final mix proportion of SCSFRC is given in Table 6.

Table 6. Mix proportion of SCSFRC

Mix	Cement PCB40	Silica fume	Sand	Crushed stone	Steel fibre	SP	VMA	Water
	kg	kg	kg	kg	kg	l	l	l
	410	41	985	556	30	6.5	5.0	225

After a relevant mixing procedure, SCSFRC was tested at fresh state in order to define slump-flow value and T<sub>500</sub>, as it is illustrated in Figure 2. Afterward, nine standard cube specimens (150x150x150 mm<sup>3</sup>) were prepared in order to determine compressive strength at different ages

such as 3, 7, 28 days.

The fresh properties and compressive strength at different ages of SCSFRC are provided in Table 7. It can be observed that the slump-flow value and T<sub>500</sub> of SCSFRC mix in this study are in agreement with the guideline

for SCC mix (EFNARC, 2002). This implies that SCSFRC mix is properly proportioned. Compressive strength evolution of SCSFRC at hardened state coincides with the previous study of the corresponding concrete strength class (Neville, 2002).

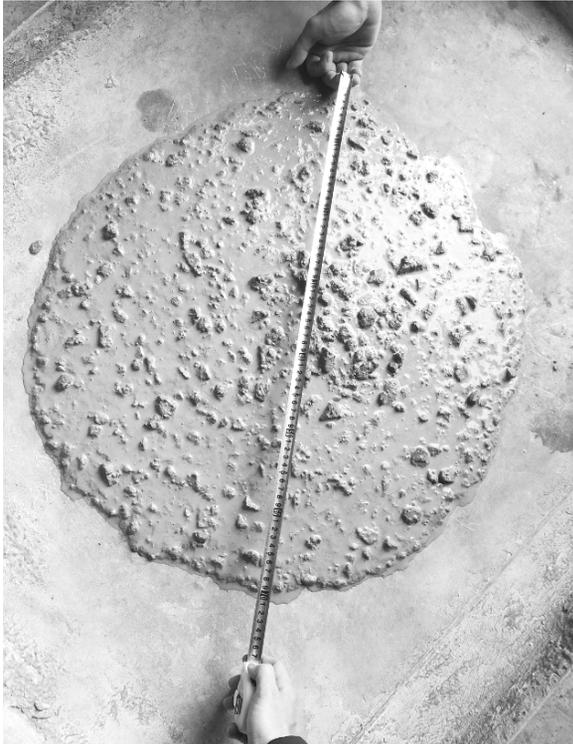


Figure 2. Slump-flow test on SCSFRC at fresh state

**Table 7. Fresh properties and compressive strength at different ages of SCSFRC**

Fresh properties		Compressive strength, MPa		
Slump value, mm	T <sub>500</sub> , s	3 days	7 days	28 days
700±20	4	18.5	25.2	35.4

### 2.6. Specimen preparation for experimental program

At the same time when the cube specimens were prepared, the fresh SCSFRC mix was poured into a small mould size of 100x100x400 mm<sup>3</sup> and another large one size of 100x300x400 mm<sup>3</sup>, as shown in Figure 3 and Figure 4 respectively.

After casting SCSFRC into the moulds, the

specimens were kept in the laboratory for 24 hours, then they were removed from the moulds and cured under the standard condition (T=20±2°C; W>95%) up to the testing date. In total, there were 3 large specimens (100x300x400 mm<sup>3</sup>) and 3 small (100x100x400 mm<sup>3</sup>), which have been produced for experimental study.

At the age of 27 days, the large specimen was cut and splitted into three identical specimens with dimension of 100x100x400 mm<sup>3</sup>. In the next day or at the age of 28 days, all of specimens were subjected to third-point bending test in as-cast direction with the span-length of 300 mm.



Figure 3. Casting of SCSFRC mix into the small mould

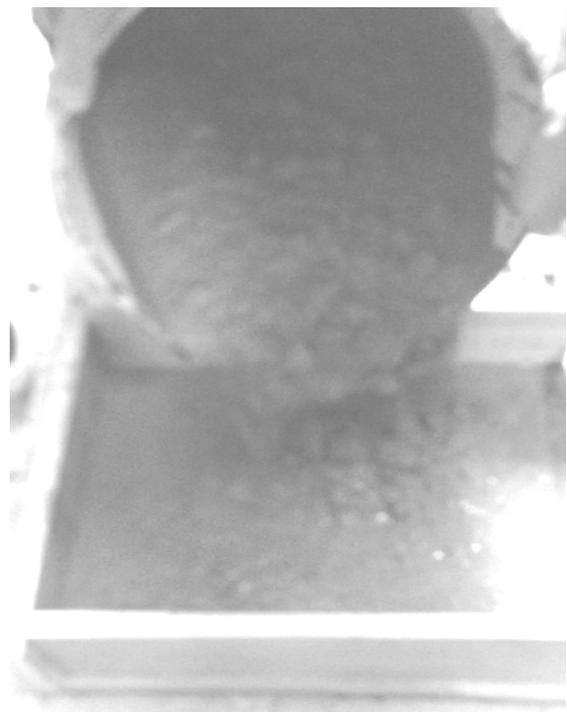


Figure 4. Casting of SCSFRC mix into the large mould

### 3. RESULTS AND DISCUSSION

#### 3.1. Flexural strength obtained from the small and large specimens

As stated before, the large specimens were splitted into three small ones, there are two exteriors (LS-ex1 and LS-ex2) and one interior (LS-in), and they are also denominated, as shown in Figure 5. The average of flexural strength obtained from small (SS) and large specimens ((LS-ex1, LS-ex2, and LS-in) is shown in Figure 6.

Regarding flexural strength obtained from large specimens (LS-ex1, LS-ex2, and LS-in), it can be observed that the result is almost the same value of about 3.9 MPa with a deviation of 0.1 MPa. It is noteworthy that flexural strength obtained small specimens (SS) is about 10% greater than that from large ones.

#### 3.2. Influence of mould type on flexural strength

Although all of the specimens were casted from the same SCSFRC mix, flexural strength obtained from different mould type yielded different results. The outcome pointed out that while casting SCSFRC into the moulds (100x100x400 mm<sup>3</sup> and 100x300x400 mm<sup>3</sup>), taking into account the same depth and length, the wider breadth (Figure 3 and Figure 4), the smaller flexural strength was obtained, as shown in Figure 6.

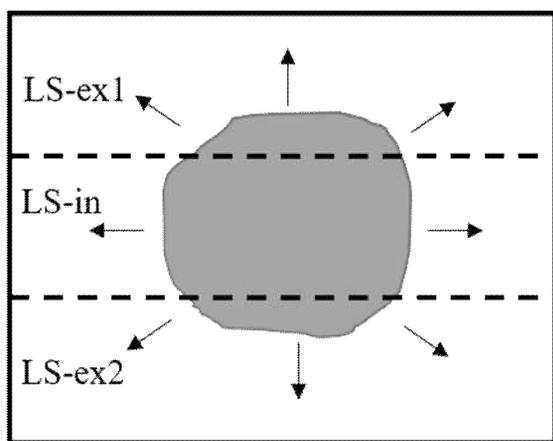


Figure 5. Illustration of SCSFRC flowability in the large mould

It can be observed in Figure 5 that SCSFRC mix flowability in large mould seems to cause fibre dispersion in all directions. On the other

hand, since breadth of the small mould is much narrower, i.e. the flow channel of SCC is restricted, therefore steel fibres can be aligned along the flow of the fresh SCSFRC due to the wall-effect and the velocity profile (Grunewald, 2004, Ferrara et al., 2011). Since the flow direction is parallel to the tensile stresses, as it can be seen in Figure 3, thus under third-point bending test in as-cast direction, the SCSFRC specimens obtained from small moulds produce higher flexural strength than that from the large moulds.

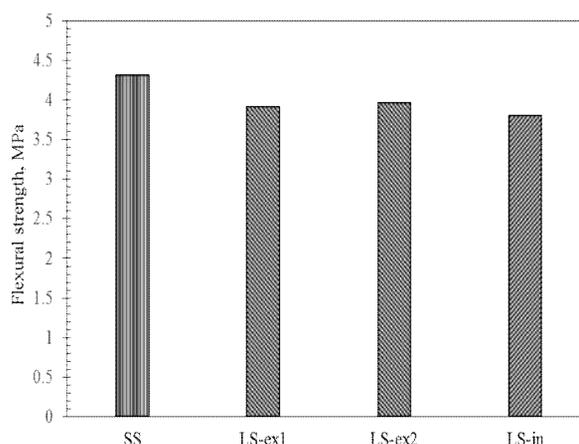


Figure 6. Flexural strength of SCSFRC obtained from small and large specimens

### 4. CONCLUSION

The effect of mould type on flexural strength of self-compacting steel fibre reinforced concrete (SCSFRC) was studied in this paper. Indeed, flexural strength of SCSFRC obtained from small specimens (100x100x400 mm<sup>3</sup>) yielded 10% higher than that from large specimens of the same size. While flexural strength defined by the small specimens (100x100x400 mm<sup>3</sup>) that were cut from the large specimens was almost the same.

In comparison with the large mould for the case of the small mould, while casting into the mould, the flow channel of SCSFRC mix was restricted, thus the steel fibres were orientated along the flow of the fresh concrete due to the wall-effect and the velocity profile. Likely, this phenomenon did not occur in the case of large mould. This is the main reason why flexural strength is influenced by mould type.

## REFERENCES

- Domone P.I. (2007). *A review of the hardened mechanical properties of self-compacting concrete*. Cement & Concrete Composites, Vol 29, p. 1-12.
- EFNARC. 2002. *Specification & guidelines for self-compacting concrete*. English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.
- EFNARC. 2006. *Guidelines for Viscosity Modifying Admixtures for Concrete*. English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.
- Ferrara, L., Ozyurt, N., di Prisco, M. (2011) *High mechanical performance of fibre reinforced cementitious composites: the role of “casting-flow induced” fibre orientation*. Materials and Structures, Vol. 44, p. 109-128.
- Ferrara, L., Park, Y.D., Shah, S.P. (2007) *A method for mix-design of fiber-reinforced self-compacting concrete*. Cement and Concrete Research, Vol. 37, p. 957-971.
- Grunewald, S. (2004). *Performance based design of self-compacting steel fiber reinforced concrete*. Doctoral thesis document, Delft University of Technology.
- Hossain, K.M.A. & Lachemi, M. (2008). *Bond behavior of self-consolidating concrete with mineral and chemical admixtures*. International Journal of Materials in Civil Engineering, Vol. 20, No. 9, p. 608-616.
- Neville A.M. (2002). *Concrete Properties 4th edition*. Person Education Limited, Edinburgh.
- Nguyen, V.D. (2015). *Mechanical behavior of laminated functionally graded fibre-reinforced self-compacting cementitious composites*. Doctoral thesis document, Technical University of Madrid.
- Okamura, H. & Ouchi M. (2003). *Self-Compacting Concrete*. Journal of Advanced Concrete Technology, Vol. 1, No.1, p. 5-15
- Sahmaran, M., Yurtseven, A., Yaman, O. (2015). *Workability of hybrid fiber reinforced self-compacting concrete*. Building and Environment 40, p. 1672-1677.
- Torrijos, M.C., Barragan, B.E., Zerbino, R.L. (2010). *Placing conditions, mesostructural characteristics and post-cracking response of fibre reinforced self-compacting concretes*. Construction and Building Materials, Vol. 24, p. 1078-1085.

### Tóm tắt:

### ẢNH HƯỞNG CỦA KÍCH THƯỚC KHUÔN ĐÚC MẪU ĐẾN CƯỜNG ĐỘ KÉO KHI UỐN CỦA BÊ TÔNG TỰ LÈN CỐT SỢI THÉP

Hỗn hợp bê tông tự lên cốt sợi thép (BTTLCSST) với mác cường độ 30 MPa được đổ vào các khuôn  $100 \times 100 \times 400 \text{mm}^3$  và  $100 \times 300 \times 400 \text{mm}^3$ . Mẫu lớn sau đó được cắt ra làm 3 mẫu nhỏ như nhau  $100 \times 100 \times 400 \text{mm}^3$ . Các mẫu được tiến hành thí nghiệm đánh giá cường độ kéo khi uốn. Thí nghiệm đã chỉ ra rằng các mẫu từ khuôn  $100 \times 100 \times 400 \text{mm}^3$  cho ra kết quả lớn hơn mẫu từ khuôn  $100 \times 300 \times 400 \text{mm}^3$  là 10%, mặc dù các mẫu thí nghiệm có kích thước như nhau. Trong khi đó, cường độ xác định trên các mẫu cắt ra từ khuôn  $100 \times 300 \times 400 \text{mm}^3$  cho kết quả gần giống nhau. Khi đổ hỗn hợp BTTLCSST vào khuôn kích thước nhỏ, các sợi thép đã được định hướng theo dòng chảy của hỗn hợp bê tông tươi tự lên do hiệu ứng thành ván khuôn và các đặc tính về tốc độ chảy gây ra. Hiện tượng này có thể đã không xảy ra đối với khuôn  $100 \times 300 \times 400 \text{mm}^3$ . Đây chính là nguyên nhân chính dẫn đến sự ảnh hưởng của kích thước khuôn đúc mẫu đến cường độ kéo khi uốn của bê tông tự lên cốt sợi thép.

**Từ khóa:** Bê tông tự lên cốt sợi thép, sự định hướng của sợi, kích thước khuôn, hiệu ứng thành ván khuôn, cường độ kéo khi uốn.

---

Ngày nhận bài: 29/11/2019

Ngày chấp nhận đăng: 02/01/2020