Performance of Medium Strength of Steel Fibre Reinforced Self-Compacting Concrete (SFRSCC)

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Abstract. This paper presents the physical and mechanical performance of steel fibre reinforced self-compacting concrete (SFRSCC) using fly ash as cement replacement at 30% by weight of cement. It is understood that the weakness of concrete is the tensile resistance which is can be improve with the addition of steel fibre. This paper deals with the medium compressive strength class of SCC (30-40MPa) with the inclusion of hooked-end steel fibres. Four design mixes of SFRSCC with different steel fibres contents (0%, 0.5%, 0.75%, 1.0% and 1.25%) were designed. The fresh properties of SCC and SFRSCC were tested through slump flow, V-funnel L-box and sieve segregation to characterize the self-compactability characteristics of the mixes. Hardened properties of SCC and SFRSCC were determined through compressive test, flexural test and tensile test. Results shows that there is negative influence on the fresh state properties of SFRSCC with steel fibre content of 1% and more. The highest compressive strength, splitting tensile strength and flexural strength achieved by SFRSCC with optimum volume of 0.75% steel fibre.

1. Introduction

Self-compacting concrete (SCC) is high flowable concrete that has ability to fill the formwork and encapsulate the reinforcement without any help from vibrator for compaction purpose. SCC was first developed and prototyped in Japan in 1988 and completed the first usable version of SCC in the same year and was named as “High Performance Concrete”. The use of SCC has been widely accepted by industry due to its technical advantage [1]. SCC is similar to normal vibrated concrete composition, which consist of aggregate, cement, water, admixtures and mineral admixtures. The different is, SCC needs high powder content and less coarse aggregate contents. Therefore, it is recommended to replace partly of Portland cement content with industrial by products such as fly ash and granulated blast furnaces slag[2][3].

Generally, high powder contents in SCC is required to achieve rheological properties to be classified as SCC. High powder content will lead to high initial and final strength which is unnecessary for non-heavy duty structures. Thus, this inspires researchers to study medium strength class concrete. Early studies of medium strength class concrete with compressive strength between 28 MPa to 35MPa and compressive strength between 27.5 MPa to 48 MPa have been study by Su and Miao [4] and Su et.al [5] respectively with lower cement content.

Many researches have been done in order to understand the mechanical properties of concrete with the addition of steel fibre[6][7][8]. Conflicting results have been reported on the effect of steel fibre on compressive strength of concrete. It is reported compressive strength increase more than 12% with the increase of steel fibre content[9][10]. While, other researchers reported that the addition of steel fibre...
does not have significant impact on compressive strength on concrete[11][12]. However, the addition of steel fibre still change the mode of failure from brittle to ductile failure[11][13]. The effects of steel fibres on tensile strength and flexural strength of concrete have been reported by numerous researchers in their study. It is reported that the flexural strength and tensile strength of concrete are increase with the increase of steel fibre content. It is reported by previous researcher, the tensile strength of concrete is increase by addition of steel fibres due to the fibre bridging effect, bridging the gap between two sides of crack opening[6]. However, the increment of flexural strength is higher than tensile strength of concrete[14]. This is because steel fibre helps to increases the ductility of concrete, first crack strength and flexural strength[11]. Numerous researches have been carried out study of the effect steel fibre in concrete with compressive strength more than 40MPa[9][15][16]. SCC with medium compressive strength is proved to be technically and economically competitive in ready mixed industry[17] and general use. There is lack of study on the influence of steel fibre on medium strength SFRSCC. Therefore, this paper aims to study the influence of steel fibre on fresh properties and mechanical properties of medium strength of steel fibre self-compacting concrete (SFRSCC).

2. Methodology

This experimental research was conducted to study the change in performance of medium strength of SCC with addition of hooked-end steel fibres. Four design mixes of SFRSCC with different steel fibres contents, which are 0.5% (SFRSCC-0.5), 0.75% (SFRSCC-0.75), 1.0% (SFRSCC-1.0) and 1.25% (SFRSCC-1.25) corresponding to 39kg, 59kg, 79kg and 98 kg of steel fibres per cubic metre of concrete were designed, apart from normal SCC acting as a control mix. Fresh and hardened concrete properties were tested. Fresh concrete properties included workability, passing ability, segregation resistance were conducted to meet the requirement set by European Guidelines [18]. While hardened concrete properties included compressive strength (BS EN 12390-3:2009) [19], tensile splitting strength (BS EN 12390-6:2009) [20] and flexural strength of concrete (BS EN 12390-5:2009) [21]. British Standard procedures were followed for testing for all specimens at age 7, 14 and 28 days. Nine cubes dimensioning 100 x 100 x 100 mm, three cylinders’ specimens with diameter of 100mm and height of 200mm and three prisms dimensioning 100 x 100 x 500 mm were casted for each type of concrete for compressive strength, splitting tensile and flexural strength test respectively. After 24 hr of casting, all the specimens were removed from the moulds and kept in water tank for curing process as BS EN 12390-2:2009[22].

3. Materials and concrete mix design

All mixes for SCC and SFRSCC were designed to achieve the medium characteristic strength of 30-40 N/mm². SCC and SFRSCC mixes were designed based on modification of previous research in addition to the recommendation as stipulated by European Federation [18]. Normally, SCC needs high powder content range between 400kg/m³ to 600kg/m³ and low in coarse aggregate content[18]. Ordinary Portland cement was used in this study and fly ash was used to replace 30% of cement content as suggested by previous researchers[23] [24]. Polycarboxylate ether based superplasticizer (Sika ViscoCrete-2044) was used as high range water reducing agent. The maximum size of coarse and fine aggregate is limited to 5 mm and 10 mm respectively. The hooked-end steel fibres were used with length of 35mm, diameter of 0.58mm and the properties is shown in Table 1. The material composition for all SFRSCC mixes are given in Table 2.

| Diameter (mm) | 0.58 |
|--------------|------|
| Length (mm)  | 35   |
| Aspect ratio (L/D) | 60   |
| Density (kg/m³) | 7850 |
Table 2: Concrete mix compositions

| Concrete mix | Cement (kg/m³) | Fly ash (kg/m³) | Coarse aggregates (kg/m³) | Fine aggregates (kg/m³) | Water (kg/m³) | Steel fibres (kg/m³) |
|--------------|----------------|----------------|--------------------------|-------------------------|--------------|---------------------|
| SCC          | 342.4          | 146.7          | 675                      | 1090                    | 250          | 0                   |
| SFRSCC-0.5   | 342.4          | 146.7          | 675                      | 1090                    | 250          | 39                  |
| SFRSCC-0.75  | 342.4          | 146.7          | 675                      | 1090                    | 250          | 59                  |
| SFRSCC-1.0   | 342.4          | 146.7          | 675                      | 1090                    | 250          | 79                  |
| SFRSCC-1.25  | 342.4          | 146.7          | 675                      | 1090                    | 250          | 98                  |

4. Experimental works

Fresh state properties tested in this study are workability, filling ability, passing ability and segregation. The workability, filling ability, passing ability and segregation were conducted through slump flow test, V funnel, L-box and segregation test respectively. While, the hardened properties included compressive strength, splitting tensile strength and flexural strength.

Prior to hardened concrete properties tests, demolding was performed after 24 hours of casting and all the specimens were cured in water tank for 28 days. For compressive strength, 9 cubes were casted for each concrete mix and tested at the concrete age of 7, 14 and 28 days. The loading rate for compressive strength was kept constant at 6 kN/s for all tested specimens. For splitting tensile strength, 3 cylinders were casted for each concrete mix and tested at a constant loading rate of 1.25 kN/s. Lastly, for flexural strength three prisms were casted for each concrete mix and tested at a constant loading rate of 0.13 kN/s. Figure 1 shows the arrangement for compressive strength, splitting tensile strength and flexural strength.

![Figure 1](image1.png)

**Figure 1**: Hardened concrete tests: (a) Compressive strength test, (b) splitting tensile strength test and (c) flexural strength test.

5. Results and discussion

5.1. Fresh concrete properties

The increment of fibre volume contents in the mixture has inversely affected the fresh properties of concrete. As shown in Figure 2 the control mixture and SFSCC-1.25 shows the highest and lowest value of slump flow respectively. This is because the high content of steel fibre have increased the yield stress SCC[25]. Figure 3 shows the filling ability of the concrete in fresh state condition. According to the European Federation guideline for SCC, the control mixture, SFRSCC-0.5 and SFRSCC-0.75 were fell into VF1 categories(< 8 seconds) and the rest were fell into VF2 categories (9-25 seconds) [18]. All the mixes can be categorizing to have moderate to high viscosity. Figure 4 specifies the result of passing
ability of mixtures. The control mixtures obtain the highest L-box ratio compared to others mixture. While SFRSCC-1.25 shows result below the requirement by European Guidelines[18]. This mix not able to flow properly, and due to high volume content of fibre has resulted to the blockage at the corner of L-box. R. Hameed et.al recommended to use steel fibre with size 2 to 3 times bigger than maximum size of aggregates for better efficiency [13]. Therefore, larger bar spacing is required as the size of fibre is bigger than aggregates in order to prevent blockage. Lastly, Figure 5 shows the sieve segregation resistance of the concrete. Segregation resistance increase proportionally with the decrease of steel fibre content. This is because SFSCC needs more paste in order to bind fibres and aggregates as compared with SCC without fire content.

\[ y = -11.75x + 720.75 \]
\[ R^2 = 0.9329 \]

\[ y = 1.81x + 2.23 \]
\[ R^2 = 0.9984 \]

\[ y = -0.047x + 0.9891 \]
\[ R^2 = 0.9677 \]

\[ y = -0.47x + 18.75 \]
\[ R^2 = 0.9473 \]

\[ y = -0.47x + 18.75 \]
\[ R^2 = 0.9473 \]

5.2. Hardened concrete properties

The results of hardened concrete properties at 28 days are summarized in Table 3.

| Concrete mix     | Compressive strength (MPa) | Splitting tensile strength (MPa) | Flexural strength (MPa) |
|------------------|----------------------------|---------------------------------|------------------------|
| SCC              | 37.3                       | 3.05                            | 3.21                   |
| SFRSCC-0.5       | 37.0                       | 4.28                            | 4.50                   |
| SFRSCC-0.75      | 40.2                       | 5.01                            | 5.70                   |
| SFRSCC-1.0       | 36.6                       | 4.42                            | 4.80                   |
| SFRSCC-1.25      | 37.8                       | 4.31                            | 4.95                   |
5.2.1. Compressive strength

As shown in Figure 6, addition of steel fibre into plain SCC increases the compressive strength for SFRSCC up to 0.75% of fibre volume content. The pattern inversely changed when the fibres added up to 1% and more. However, it is still slightly higher than plain SCC. This is because the high concentration of steel fibres has disrupted homogeneity of concrete. As shown in Figure 2 and Figure 3, the flowability of SCC decrease proportionally with the increase of fibre content, thus cause inconsistent internal integrity. Moreover, the addition of fibres also caused the increase of entrapped air in concrete[26], which result to negative influence on compressive strength of concrete.

SFRSCC-0.75 shows slightly higher increment of compressive strength as compared with plain SCC which is about 8% only. This is in line with the study of previous researchers, the contribution of steel fibre in compressive strength of concrete is not remarkable[11][12]. Nevertheless, the failure mode observed showed that the addition of steel fibre still change the properties of concrete from brittle to ductile [11].

![Figure 6: Compressive strength of concrete](image)

5.2.2 Splitting tensile strength

Results of splitting tensile strength of concrete mixes are graphically presented in Figure 8. The addition of steel fibre increases splitting tensile strength about 40% to 64% as compared with the control mix. As shown in Figure 7, the sample of SCC was splitted into two parts after reached the ultimate load, while for sample of SFRSCC, only cracks were visible on the surface of the cylinders. This is due to the bridging effect of fibres in the concrete. This tensile stress that transferred to the fibres resist the propagating macro cracks from splitting up concrete. This helps in improve the splitting tensile strength of the concrete. The load applied overstress the plain concrete which leads to cracking and failure in the concrete. Previous study reported gradual increase in tensile and flexural strength of SFRSCC with the increase in steel fibre content[11].

The splitting tensile strength of concrete can be related to the density of concrete. In this study, SFRSCC-0.75 with the highest splitting tensile strength has highest density of concrete. It could be explained that the amount of 0.75% steel fibre volume content has just fit into concrete matrix thus producing highest density. This is line with the study by M.H.W. Ibrahim et.al, the splitting tensile strength influence by the density of concrete[27].

![Figure 7: Splitting tensile strength](image)
Figure 7: Failure mode of splitting tensile strength specimens: (a) Plain SCC specimens. (b) SFRSCC with 0.75% steel fibre content

(a)  
(b)

Figure 8: Splitting tensile strength of concrete

5.2.3 Flexural strength

Results of flexural strength of concrete presented in Table 2 and graphically shows in Figure 9. The flexural strength of SFRSCC-0.75 is higher by 90% compared to plain concrete, SCC. This is because the contribution of steel fibre in releasing fracture energy around crack tips requires crack growth by transferring it from one side to another side. Moreover, the flexural strength of SFRSCC is higher than splitting tensile of concrete. This can be explained that, the enhancement in flexural strength of concrete due to the improved fibre-matrix bond provided by using hooked-end steel fibres [28].

Figure 9: Flexural and splitting tensile strength of concrete
6. Conclusion

From this study, it can be concluded that:
1. Generally, fresh concrete properties (Slump flow, V-funnel, L-box and sieve segregation) decrease with the increase of steel fibre content. However, all mixes meet the requirement of SCC classification.
2. The fibre volume content has no significant effects on the compressive strength of concrete.
3. SFRSCC-0.75 is classified as the optimum mix concrete as it achieves the satisfying performance on the fresh and hardened concrete properties.

7. References

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