Research of Shear Experiment of Interface between New Steel Fiber Self-compacting Concrete and Old Ordinary Concrete

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Abstract. In prefabricated concrete structure, the shear performance of interfaces between prefabricated parts and cast-in-place parts needs improvement. Steel fiber self-compacting concrete is a desirable kind of concrete to solve this problem. This paper introduced Z-shape specimens with interfaces between new steel fiber self-compacting concrete part and old ordinary concrete part as direct shear experiment objects. Factors including steel fibers volume ratio and inserting rebars were also studied. The results show that the shear strengths of interfaces increase with the increases of steel fibers volume ratio, and inserting rebars can improve shear strengths and change failure form from brittle failure to ductile failure.

Keywords: Steel fiber self-compacting concrete; Shear strength of interface; Direct shear experiment; New and old concrete.

1. Introduction

Prefabricated concrete structure (PCS) features energy saving, environmental protection and short construction period. The development of PCS is an inevitable trend for the sustainable development of construction industry. However, some problems that inhibit the development of PCS still exist, such as poor seismic performance and weak connection between prefabricated parts and cast-in-place parts. Because the concrete of prefabricated parts sets earlier than that of cast-in-place parts, the interface between them becomes a vulnerable part of structures. So, it is of great significance to study the shear strength of the interfaces between cast-in-place and prefabricated concrete. Nowadays, researches on the shear strength of interfaces between cast-in-place and prefabricated concrete have matured, but there are still some shortcomings. Steel fiber self-compacting concrete (SFSCC) is a suitable kind of concrete with prominent mechanical properties to cope with such problem. However, most of the previous researches focused on study of the shear strength of interfaces between ordinary cast-in-place concrete and old ordinary concrete (OOC), there are few researches on the shear strength of interfaces between cast-in-place SFSCC and OOC. Therefore, this paper presents the research results of shear experiment on specimens with interface between SFSCC and OOC. Introducing 2 kinds of interface process methods including rebars-inserting and rough interface and grooves-setting interface and through the change steel fibers volume, its effect on shear strength is studied. Meanwhile, the effect of rebars-inserting on failure form is also studied.
2. Experimental Study

2.1. Specimen Design
According to existing reference [1] and considering the shear transmission and distribution on the interface, adopting Z-shape specimen to study the shear strength of interface between SFSCC and OOC.

The geometric dimensions and appearance of Z-shape specimen are shown in Figure 1.

![Figure 1. The geometric dimensions and appearance of Z-shape specimen.](image)

2.2. Materials and Mix Proportion
The cement used for this experiment is grade 42.5 P·O. The coarse aggregate is crushed stone. Fine aggregate is river sand with good gradation. Superplasticizer is chosen as concrete admixture. Mineral admixture is grade II fly ash. The length of steel fiber is 30mm and its nominal diameter is 0.5mm.

Mix proportion of ordinary concrete is designed according to Code for Design of Mix Proportion of Ordinary Concrete [2]. Mix proportion design of SFSCC refers to Technical Specification for Application of Self-Compacting Concrete [3]. Details of mix proportion is demonstrated in Table 1.

| Strength grade | Amount of ingredients in concrete (kg/m³) |
|----------------|-----------------------------------------|
|                | Water | Cement | Sand | Stone | Fly ash | Superplasticizer | Steel fiber |
| C30            | 185   | 350    | 650  | 1190  | —       | —                | —           |
|                | 192   | 350    | 815  | 816   | 200     | 4.15             | 39          |
| C45            | 192   | 350    | 815  | 816   | 200     | 4.15             | 78          |

2.3. Process of Interface.
Ordinary concrete parts of Z-shape specimens were cast on January 12, 2017. After 3 around months, interfaces of ordinary concrete parts of Z-shape specimens were processed. Process methods contain 2 different types, including roughness with rebars-inserting and grooves-setting. Ordinary concrete parts of Z-shape specimens with rebars-inserting and rough interface (RIRI) are shown in Figure 2. Ordinary concrete parts of Z-shape specimen with grooves-setting interface (GSI) is shown in Figure 3.

![Figure 2. Rebars-inserting and rough interface.](image)  
![Figure 3. Grooves-setting interface.](image)
2.4. Finish Specimens
SFSCC part of Z-shape specimens was poured in May 2017, 100 days after the ordinary concrete part was poured. As shown in Figure 4, ordinary concrete part whose interface was already processed was put in wood template. Simultaneously, put pearl cottons to make entire specimen form Z-shape after SFSCC set. Then 2 days later, Z-shape specimens were removed from templates and cured by water for 2 months. One of finished Z-shape specimen is shown in Figure 5.

![Figure 4. Ordinary concrete part.](image1)

![Figure 5. Finished Z-shape specimen.](image2)

Totally 6 different types of Z-shape specimens with different interfaces were made, and the number of each of them is 3, including 3 ordinary concrete specimens that were integrally cast and used for comparison. List of Z-shape specimens is shown as Table 2.

| Types                   | Codes  | Groove depth (mm) | Groove width (mm) | Steel fibers volume ratio (%) | rebars inserting ratio (%) |
|-------------------------|--------|-------------------|-------------------|------------------------------|---------------------------|
| Groove-setting interface| S1-G2  | 12                | 30                | 0.5                          | /                         |
|                         | S2-G2  | 12                | 30                | 1.0                          | /                         |
|                         | S3-G2  | 12                | 30                | 1.5                          | /                         |
| Rough and rebars-inserting interface | S1-CP2 | /                 | /                 | 0.5                          | 0.32                       |
|                         | S2-CP2 | /                 | /                 | 1.0                          | 0.32                       |
| Comparison specimens    | ZT     | /                 | /                 | /                            | /                         |

2.5. Load Methods and Experimental Machines
According to Specification for Seismic Test of Buildings [4], Procedure of experimental load can be divided into two steps, which are pre-load and formal load. Pre-load is important [5]. Because it can help to ensure that all parts of the specimens are in good contact with machines, the relationship between load and deformation is stable, the reliability of experiment machines and whether all devices work normally or not [6]. Generally, the value of pre-load should not be greater than the crack load, so the value of pre-load is 15KN. Formal load contains force load and displacement load. Force load was divided into 3 stages. In first stage, load rate is 60N/s and maximum value is 5KN. In second stage, load rate is 100N/s and maximum value is 60KN. In last stage, load rate is 40N/s and maximum value is 80KN. Finally, displacement loaded uniformly at the speed of 0.005mm/min until the specimen fail.

As shown in Figure 6, the shear load machine is 100 tons SANS computer controlled electro-hydraulic servo pressing machine. The SFSCC part of Z-shape specimens was set at the load side, OSC part was set at the fastened side. Strain gauges is set at the SFSCC part. Baffles were used to fasten specimens. Displacement can be measured by dial indicator.
3. Experimental Result and Analysis

3.1. Failure Phenomena

3.1.1. Failure phenomena of specimens with GSI. At the beginning of load, small cracks began to appear from the load side. As the force load process went on, the cracks that appeared from load side gradually extended to the fastened side along the interface. Then, as displacement load went on, tiny vertical cracks began to appear at the bottom of bond surface. Finally, these cracks became wider. Meanwhile, the shear stress reached the peak value, the shear strength of specimens with GSI reduced sharply. Therefore, shear failure had happened. It also had the characteristics of brittle failure. The typical initial and failure states are shown in Figure 7.

3.1.2. Failure phenomena of specimens with RIRI. At the beginning of force load, small cracks began to appear from the load side. When the displacement load continued after the force load, cracks began to extend along the interface to the fastened side. As the displacement load process went on, the crack at the load side continued to widen to 0.5 mm. Meanwhile, the shear stress firstly reached the peak value, and cracks began to appear at the fasten side. When shear stress decreases sharply to about 85% of the first peak value, it increased again, which indicated rebars worked. Meanwhile, the surface along interface began to peel off, cracks became wider, and maximum width is up to 5mm. However, because of the effect rebars, the specimen remained as a whole, which represented ductile failure. The typical initial and failure states are shown in Figure 8.
3.2. Shear Strength

Shear stress is calculated by equation (1). Its values are shown in Table 3.

$$\tau = \frac{V}{A}$$  \hspace{1cm} (1)

where $\tau$ is shear stress, $V$ is shear force and $A$ is area of interface.

**Table 3.** List of shear stress.

| Specimens | Number | Interface type       | Steel fibers volume ratio (%) | Shear force (KN) | Shear stress (MPa) | Mean values (MPa) | Ratios to comparison specimens (%) |
|-----------|--------|----------------------|-------------------------------|------------------|--------------------|--------------------|-------------------------------------|
| S1-G2     | 1      | Grooves-setting      | 0.5                           | 179              | 5.85               | 5.56               | 62.2                               |
|           | 2      | Grooves-setting      | 1.0                           | 242              | 7.57               | 7.88               | 88.1                               |
|           | 3      | Grooves-setting      | 1.5                           | 343              | 10.73              | 9.33               | 104                                |
| S2-G2     | 1      | Grooves-setting      | 0.5                           | 170              | 5.32               | 5.56               | 62.2                               |
|           | 2      | Grooves-setting      | 1.0                           | 262              | 8.18               | 7.88               | 88.1                               |
|           | 3      | Grooves-setting      | 1.5                           | 326              | 9.60               | 9.33               | 104                                |
| S3-G2     | 1      | Grooves-setting      | 0.5                           | 185              | 5.78               | 5.56               | 62.2                               |
|           | 2      | Grooves-setting      | 1.0                           | 260              | 8.12               | 7.88               | 88.1                               |
|           | 3      | Grooves-setting      | 1.5                           | 233              | 7.29               | 9.33               | 104                                |
| S1-CP2    | 1      | Rebars-inserting and rough | 0.5                       | 250              | 7.82               | 7.74               | 86.6                               |
|           | 2      | Rebars-inserting and rough | 1.0                       | 307              | 9.60               | 9.33               | 104                                |
|           | 3      | Rebars-inserting and rough | 1.5                       | 326              | 9.73               | 9.33               | 104                                |
| S2-CP2    | 2      | Rebars-inserting and rough | 0.5                       | 233              | 7.29               | 7.74               | 86.6                               |
|           | 3      | Rebars-inserting and rough | 1.0                       | 260              | 8.11               | 8.04               | 89.9                               |
|           | 2      | Rebars-inserting and rough | 0.5                       | 252              | 7.86               | 8.94               | 100                                |
| ZT        | 2      | Comparison specimens | 0                            | 239              | 9.17               | 8.94               | 100                                |

Note: Cracks appeared at the bottom of S2-G2-3 before load, which resulted in low shear strength, so it was not included in the list.

3.3. The Effect of Steel Fibers Volume Ratio of SFSCC on Shear Strength.

Shear strengths of specimens with RIRI are shown in Figure 9 (a), when specimens’ interfaces are rough and inserted two rebars, as steel fibers volume ratio increases from 0.5% to 1.0%, shear strength increases 3.88% correspondingly. Shear strengths of specimens with GSI are Figure 9 (b), when grooves width and depth of interface are 30mm×2 and 12mm respectively, as steel fibers volume ratio increases from 0.5% to 1.0% to 1.5%, shear strength increases from 5.56MPa to 7.88MPa to 9.33MPa, the increase rate are 41.8% and 18.4% respectively.

It is obvious that steel fibers can effectively improve the shear strength of Z-shape specimens. As the
Steel fibers volume ratio increases, shear strength increases. Moreover, it reaches its peak value when steel fiber ratio is 1.5%, and there is still room for improvement [7]. Because, steel fiber can prevent extension of cracks by reducing the stress concentration at crack tips, remarkably reduce the shrinkage of SFSCC. Furthermore, part of steel fibers slowly extends into interface of OOC during water curing period. The bridge effect of steel fibers [8] across the interface improves specimens shear strength.

**Figure 9.** Comparison of shear strength between specimens with different steel fibers volumes ratio. Note: 1, 2 and 3 denote the number of three identical specimens in the same group

### 4. Conclusion
Generally, cracks of different specimens appeared along the bond surface, then they extended from load side to fastened side. Finally, specimens failed because those cracks widened. The failure of specimens without inserting rebars at interface is typical brittle failure, nonetheless the failure of specimens with inserting rebars at interface is typical ductile failure. Steel fibers can effectively improve the shear strength of interface of SFSCC and OOC. The shear strengths of interfaces of Z-shape specimens increase with the increase of steel fibers volume ratio. Shear strengths of specimens (S3-G2) with GSI and 1.5% steel fibers volume ratio exceed that of comparison specimens by 4%.

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