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Bond behavior of steel fibers reinforced self-stressing and self-compacting concrete filled steel tube columns

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HIGHLIGHTS

- Push-out tests on steel fibers reinforced self-compacting self-stressing CFST.
- Self-stress significantly improves the bond strength of CFST specimens.
- Steel fibers firstly decrease and then increase the bond strength of CFST specimens.
- Predicted formulas for the bond strength of FSSCFST specimens are proposed.

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ABSTRACT

This paper investigates the bond behavior of steel fibers reinforced self-stressing and self-compacting concrete filled steel tube (FSSCFST) columns. A series of push-out tests on ninety CFST columns are conducted. The variables considered in the test are: (a) concrete type (self-compacting concrete and steel fibers reinforced self-stressing self-compacting concrete); (b) the thickness of steel tube (2.5–4.25 mm); (c) concrete strength (C40, C50 and C60); and (d) steel fibers volume percentage (0%, 0.6% and 1.2%). Experimental results show that the bond strength of FSSCFST specimens varies from 0.50 MPa to 2.51 MPa, which is generally higher than the self-compacting CFST specimens. Self-stress significantly improves the bond strength of CFST specimens, and the average improvement level is 42.7%. The bond strength firstly decreases and then increases with the increase of steel fiber volume percentage. Finally, formulas are proposed to predict the bond strength of FSSCFST columns, and the proposed formulas give a more accurate prediction than the existing design codes.

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1. Introduction

In recent decades, concrete-filled steel tube (CFST) columns have gradually become a central element in structural systems owing to their high bearing capacity, rigidity and ductility, desirable performance under seismic loading or fire conditions. All the superior structural properties of CFST columns are mainly due to the composite action of steel tube and concrete core [1–6]. The steel tube serves as longitudinal and transverse confinement to the concrete infill, and the concrete core can stabilize and stiffen the steel tube to delay the local buckling. Apparently, the composite action requires excellent bond behavior between steel tube and concrete core [7–10].

A tremendous amount of effort has been made to study the bond behavior of CFST columns. Shakir-Khalil [11] revealed that the bond strength was significantly influenced by the interface type, shape and size of the cross-section through the push-out tests of 40 CFST columns. Tao et al. [12] conducted a series of push-out tests to investigate the bond strength of circular and square CFST specimens. The filled concrete included normal, recycled aggregate and expansive concretes. Expansive concrete has a self-expansion behavior during hardening process to compensate the shrinkage of the concrete. In this research work, Tao et al. added the expansive additive in the concrete to obtain the self-expansion behavior. The steel type included carbon and stainless steels. The test results showed that stainless steel CFST columns had a lower bond strength compared with carbon steel counterparts, and the bond strength decreased remarkably with increasing cross-sectional dimension and concrete age. Using expansive concrete can improve the bond strength through reducing the shrinkage of concrete. Roeder et al. [13] described a push-out test of 20 circular CFST columns. They concluded that the bond strength decreased as the diameter-to-thickness ratio increased. The concrete

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shrinkage remarkably reduced the bond strength of CFST columns, especially the ones with large cross-sectional dimension. Hunaiti [14,15] presented the test results of 135 battened composite specimens and concluded that the bond behavior between steel and concrete was affected by concrete age, size of the specimen, curing condition and temperature. The concrete age was the most significant influence factor among them. Chang et al. [10] studied the bond behavior of pre-stressing circular CFST columns. The results indicated that the bond strength of pre-stressing CFST columns were 1.2–3.3 times as that of conventional CFST columns. An empirical equation was proposed for predicting the bond strengths of pre-stressing CFST columns with acceptable accuracy. Chen et al. [16] reported the repeated push-out tests on concrete-filled stainless steel circular hollow section (CHS) tubes. It was found that the bond-slip failure consisted of the adhesive stage, sliding stage and friction resistant stage. The shear failure loads of bonding slip decreased successively with more loading cycles. 70% of the shear resistance of the bonding strength was taken by the interface friction force, while the remaining 30% of the shear resistance of the bonding strength was sustained by the chemical adhesive force and the mechanical interlock force. Aly et al. [17] performed a series of pushout tests to study the bond strength of CFST columns subjected to cyclic loading. The tests showed that the interface bond strength of CFST columns under repeated loading was lower than that under static loading. Tao et al. [18] presented the push-out tests of 64 CFST columns, which had been exposed to ISO834 standard fire for 90 min or 180 min. The bond strength was found to decrease after 90 min fire exposure, while a strength recovery occurred when the fire exposure time was extended to 180 min. This is because the concrete is easier to dilate under axial compression after severely damaging. The radial expansion of concrete can increase the contact area and pressure of steel tube, therefore improving friction resistance.

Although, previous studies are rich and provide valuable information to understand the bond behavior of CFST columns. Some research gaps still need to be filled up. The difficulty in casting of concrete may result in the surface defect which is rather unfavorable to the bond behavior between steel tube and concrete core. To deal with this problem, self-compacting concrete (SCC) can be adopted because of its high fluidity [19–23]. Due to its rheological properties, SCC can flow under its own weight to completely fill the steel tube instead of vibration. Nevertheless, researches [24,25] demonstrated that shrinkage of SCC is higher than traditional vibrated concrete due to the increased cement consumption. According to previous studies [10,12,13], concrete shrinkage could be very adverse to the bond strength of CFST columns. Researchers adopt a self-stressing concrete (SSC) with a self-expansion behavior to solve the problem. Self-stressing concrete is one kind of expansive concrete. Expansive concrete can be divided into two basic classes: shrinkage compensating-concrete and self-stressing concrete [37,38], which are distinguished according to the magnitude of expansion. Generally, the expansion of shrinkage compensating-concrete is small and induced by adding expansive additive. The expansion of self-stressing concrete is substantial, which not only compensates for shrinkage of the concrete but also induces compressive stress on steel tube. Self-stressing concrete is usually obtained by using non-shrinkage cement [26–28]. However, the loss and the maldistribution of self-stress reduce the favourable effect of self-stressing concrete. Adding steel fibers has been proved to be an effective method to solve this problem. The three-dimensional distribution of steel fibers in concrete can realize balance distribution of self-stress, reduce the self-stress loss and improve the beneficial effect of self-stressing concrete. Based on the above analysis, some efforts have been made by the authors to use the steel fiber reinforced self-stressing and self-compacting concrete to improve the bond behavior of CFST columns.

Therefore, this study aims to investigate the bond behavior of steel fibers reinforced self-confinement and self-compacting concrete-filled steel tube (FSSCFST) stub columns. The push-out tests of ninety specimens, including twenty-seven self-compacting CFST specimens and sixty-three FSSCFST specimens, is presented. The main parameters in the test are self-stress, thickness of steel tube, concrete strength, and steel fibers volume percentage. Failure mode, bond strength, load-slip curve and load-strain respond are discussed in detail. Moreover, predicted formulas are proposed to calculate the bond strength of FSSCFST specimens.

2. Experimental program

2.1. Test specimens

Push-out tests are conducted on thirty groups specimens, including twenty-one groups steel tubes filled with steel fibers reinforced self-stressing and self-compacting concrete (FSSCFST), and nine groups steel tubes filled with self-compacting concrete (SCCFST). Every group includes three specimens with the same parameters to improve the test precision. All the specimens have the same length of 500 mm and external diameter of 165 mm. The tested parameters include concrete strength (C40, C50 and C60), thickness of steel tube (2.5, 3.5 and 4.25 mm), steel fiber volume percentage (0%, 0.6% and 1.2%) and self-stress (with and without). The details of all specimens are summarized in Table 1. For convenience, each specimen has an individual designation as: A-t2.5-0.6%-1, where "A" stands for the concrete mix, "2.5" represents the thickness of steel tube in mm, "0.6%" is the volume percentage of steel fiber and "1" refers to the specimen number. All the specimens are classified into nine series according to concrete strength grade and thickness of steel tube. Each series includes one group benchmark SCCFST specimens and two or three groups FSSCFST specimens.

2.2. Material properties

All specimens are fabricated by welded circular steel tubes. The thicknesses of steel tube are designed as 2.50, 3.50 and 4.25 mm to obtain different diameter-to-thickness ratios. Standard tensile coupon tests, according to Chinese code GB/T 2975-1998 [29], are conducted to measure material properties of steel tube. Three longitudinal arc-shaped coupons are taken from each of steel sheets. The average yield strengths of steel tube with three kinds of thicknesses are 305.3 MPa, 329.7 MPa and 327.5 MPa, and the ultimate tensile strengths are 430.4 MPa, 386.2 MPa and 417.9 MPa, respectively.

In order to obtain self-stress, sulphoaluminate-type expansive cement is mixed in concrete, and its chemical compositions are shown in Table 2. Six concrete mixes proportions are considered in this study, including three kinds of self-stressing self-compacting concrete and three kinds of self-compacting concrete (SCC) as listed in Table 3. The mixes "A", "B" and "C" with sulphoaluminate-type expansive cement are the self-stressing self-compacting concretes with strength grades of C40, C50 and C60, respectively. The mixes "D", "E" and "F" with common Portland cement are self-compacting concretes with strength grades of C40, C50 and C60, respectively. The slump flow D and the time needed for SCC to reach 500 mm, T_{500}, are evaluation criterions of mixtures serviceability [30]. Three concrete cubes with dimension of 150 mm × 150 mm × 150 mm are cast at the same time of each batch concrete pouring [31]. The compressive cube strengths at 28 day age for different concrete mixes are also shown in Table 3.

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