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Behavior of steel fibers reinforced self-stressing and self-compacting concrete-filled steel tube subjected to bending

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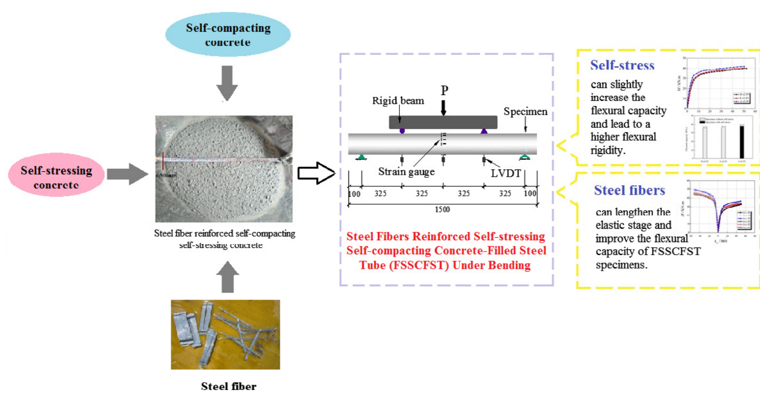
HIGHLIGHTS

- Study on steel fibers reinforced self-compacting self-stressing CFST under bending.
- Self-stress slightly increases flexural capacity and improves flexural rigidity.
- Steel fibers lengthen the elastic stage and improve flexural capacity.
- Design equations for the flexural capacity of FSSCFST specimens are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper described an experimental work for steel fibers reinforced self-stressing and self-compacting concrete-filled steel tube (FSSCFST) specimens subjected to bending. The study aimed to evaluate the effect of self-stress and steel fibers on the behavior of self-compacting concrete filled steel tube (SCCFST) specimens. Twenty-seven SCCFST specimens reinforced with steel fibers, self-stress or their couple were tested under bending. The variables considered in the test were self-stress, thickness of steel tube, concrete strength and steel fiber volume percentage. Experimental results showed that the FSSCFST specimens behaved in a relatively ductile manner, but steel fibers and self-stress failed to change the failure mode of CFST specimens. Self-stress can slightly increase the flexural capacity and lead to a higher flexural rigidity. Steel fibers can lengthen the elastic stage and improve the flexural capacity of FSSCFST specimens. This beneficial effect of steel fibers decreased with the increasing of steel tube thickness. A formula was proposed to predict the flexural capacity of FSSCFST specimens, and the comparison between predictions and experiment results proved the accuracy of the formula.

1. Introduction

With the development of modern buildings featuring with high-rise, long-span and heavy load, requirements for the bearing capacity and rigidity of columns become higher. In order to meet the requirements, concrete-filled steel tube (CFST) column is proposed and has been applied in actual engineering. 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. This combination results in fully utilization of the material strengths, high bearing capacity, rigidity and ductility of members and excellent earthquake-resistant property

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of structures. All the superior properties of CFST owe to the mutually beneficial interaction between steel tube and concrete.

Nevertheless, the difficulty in casting of concrete may result in the surface defects, which reduce the beneficial interaction between steel tube and concrete. To deal with this puzzle, self-compacting concrete (SCC) is adopted as a revolution in the field of concrete. SCC has the high fluidity to reach to parts of the formwork with gravity instead of vibration and completely fill the mold cavity to form a uniform dense concrete [1–5]. Due to its rheological properties, SCC has gained increasing usage in modern construction practice with the advantages of lower construction time and labour cost, the higher quality of the cast structures and the improved the structural durability. However, research [6] demonstrated that shrinkage of SCC was higher than traditional vibrated concrete due to the improved cement consumption. Shrinkage not only results in structural defects, weakening the confinement between filled concrete and steel tube, but also deteriorates durability of the structure. Researchers adopt a self-stressing concrete (SSC) with a self-expansion behavior to solve the problem of shrinkage. The self-expansion behavior is induced by chemical reaction inside SSC as a compensation for the shrinkage. The use of expansive additives could reduce the degree of shrinkage, fill up the gap between steel tube and concrete and improve the confinement effect provided by steel tube. In recent years, researches indicated that self-stress improved the ultimate capacity of CFST columns subjected to cyclic load [7], eccentric loading [8], shear load [9], sustained axial loads applied at early concrete ages [10] and axial load [11]. However, a significant decrease of deformation capacity also was found [11]. Besides, the maldistribution of self-stress also reduces the favourable effect of self-stress to the behaviour of CFST columns.

Adding steel fibers has been proved to be an effective method to eliminate the brittleness of concrete. The steel fibers can bridge the cracks of concrete and resist their propagation, just as straw in mud, thus a post-crack behavior of concrete is obtained. Meanwhile, the disordered fiber distribution can realize balance distribution of self-stress, reduce the self-stress loss and improve the behavior of CFST columns. This technology was no longer be considered as novel and dated back to the researches by Romualdi et al. [12] in 1960s. Researchers found that steel fibers not only can significantly increase the toughness or post-cracking energy absorption characteristics [13,14], but also lead to a greater compressive [15], flexural [16] and tensile strength [17] of concrete. There is a potential for using steel fiber reinforced concrete as filling to improve the behavior of CFST. A tremendous amount of effort was also made to study the behavior of steel fiber reinforced concrete filled steel tube (SFCFST) under axial compression [18–25], eccentric compression [26–30] and combined compression and bending [31–32]. Those researches indicated that the presence of steel fibers delayed the deformation of CFST, improved the ductility, and sometimes increased the ultimate capacity. In addition, Jin et al. [33] reported an experimental study on the ultra-high performance fiber reinforced concrete filled steel tube columns under blast loading. The SFCFST columns exhibited a favorable anti-blast performance and showed potential to be used in critical infrastructures. The fire resistance of SFCFST also has been investigated by Schaumann et al. [34], Kodur and Lie [35], Kodur [36] and Lie et al. [37]. The steel fibers were proved to enhance the fire resistance of CFST. 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 mechanical behavior of CFST column.

The performances of CFST column under various stress states are worth studying, including pure bending. Generally, CFST columns in buildings transfer vertical loads or moments induced by lateral loads or load eccentricity. Pure bending is the extreme case of beam-column in which there is no axial load present. Therefore, flexural capacity is an important reference point in the compression load-bending moment interaction diagram. Thus, it is crucial to thoroughly understand the behaviour of CFST members under pure bending. Experimental studies on the flexural behaviour of CFST members have been conducted by several researchers [39,44,46–47]. A few numerical modelings have also been introduced to simulate the flexural behaviour of CFST [48,49].

This paper aims to investigate the flexural behavior of steel fiber reinforced self-stressing and self-compacting concrete-filled steel tube (FSSCFST). A pure bending experiment of twenty-seven circular FSSCFST specimens is presented. The self-compacting concrete filled steel tube (SCCFST) specimens are reinforced with steel fiber, self-stress or their couple. The variables considered in the test are self-stress, thickness of steel tube, concrete strength and steel fibers volume percentage. Failure modes, flexural capacities, load-deflection curves and load-strain responds are studied to analysis the effect of self-stress and steel fibers on the behavior of SCCFST specimens. Moreover, predicted formulas are proposed to predict the flexural capacity of FSSCFST specimens.

2. Experimental program

2.1. Test specimens

A total of twenty-seven SCCFST specimens reinforced with steel fibers, self-stress or their couple were tested under pure bending. All the specimens have the same length of 1500 mm and external diameter of 165 mm. Effective length of all specimens, L_0, is defined as 1300 mm. The tested parameters include self-stress, thickness of steel tube, concrete strength and steel fiber volume percentage. For convenience, each specimen has an individual designation as: A-t1-P1, where "A" stands for the concrete mix, "t1" represents the thickness of steel tube in mm and "P1" is the volume percentage of steel fiber. The details of all specimens are summarized in Table 1.

2.2. Material properties

All specimens were fabricated by welded circular steel tubes. The thicknesses of steel tube (t) were designed as 2.50 mm, 3.50 mm and 4.25 mm to obtain different diameter-to-thickness ratios. Standard tensile coupon tests, according to Chinese codes GB/T 2975-1998 [38], were conducted to measure material properties of the steel tube. Three longitudinal arc-shaped coupons were taken from each of the steel sheets. The average yield strengths of steel tube with three kind 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 was 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 SCC as listed in Table 3. The mixes "A", "B" and "C" with sulphoaluminate-type expansive cement are used for specimens with self-stress, and the other mixes with common Portland cement are used for specimens without self-stress. The slump flow D and the time to expansion degree of 500 mm, T_{500}, are evaluation criterions of mixtures serviceability. Three concrete cubes with dimension of 150 mm × 150 mm × 150 mm were cast at the same time of each batch concrete pouring. The compressive cube strengths (f_{cu}) at 28 days age for different concrete mixes are also shown in Table 3.

A kind of hooked-end type steel fiber with a length of 30 mm and aspect ratio of 65 was added in the concrete mixtures. The