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Bond behavior of steel-fiber-reinforced self-stressing and self-compacting concrete-filled steel tube columns for a period of 2.5 years

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HIGHLIGHTS

- Effect of concrete age on bond behavior of FSSCFST is studied.
- Push-out tests under repeated load are carried out.
- Longer concrete age increases bond strength of FSSCFST.
- Steel fibers delay degradation of bond strength under repeated load.

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ABSTRACT

The aim of this study is to explore the influence of concrete age on the bond behavior of steel-fiber-reinforced self-stressing and self-compacting concrete-filled steel tube (FSSCFST) columns. The push-out tests of 36 FSSCFST columns are conducted at ages corresponding to 28 d or 2.5 y. All specimens with an age of 2.5 y are tested under four cycles of repeated loading. The variables considered in the test are as follows: (a) concrete age (28 d and 2.5 y); (b) thickness of the steel tube (2.5 mm, 3.5 mm, and 4.25 mm); (c) steel-fiber volume percentage (0% and 1.2%). The experimental results indicate that an increase in the concrete age increases the bond strength and corresponding slip (S_u) of FSSCFST columns. The addition of steel fibers improves the bond behavior at an early age and it generally loses its effect with increases in the concrete age. With increases in the loading cycle, the bond strength in the same direction exhibits a decreasing trend. However, steel fibers delay the degradation in bond strength.

1. Introduction

In modern structural constructions, concrete-filled steel tube (CFST) columns are increasingly used owing to their high stiffness, compression resistance, and ductility [1]. The aforementioned excellent structural properties of CFST columns are mainly due to the mutually beneficial interaction between the steel tube and concrete core. The steel tube provides a permanent formwork to the concrete core and also acts as a confining jacket to improve the compression strength of concrete. Concurrently, the concrete core delays local buckling and improves the stiffness of the steel tube [2–5].

However, the difficulty in concrete casting may result in surface defects of concrete that severely affect the mutual interaction. Self-compacting concrete (SCC) exhibits high fluidity to completely fill the steel tube and solve the casting problem [6–10]. However, the shrinkage of SCC is higher than that of traditional concrete owing to its higher dosage of cement [11,12]. Self-stressing concrete (SSC) exhibits self-expansion behavior to compensate for the shrinkage [13–16]. However, the self-stress induced by self-expansion behavior is unevenly distributed, and thereby reduces the favorable effect of self-stressing and self-compacting concrete. Given the above analysis, studies attempt to solve the aforementioned problems by adding steel fibers to self-stressing and self-compacting concrete. Steel fibers improve the ductility of concrete [17–20] by bridging cracks in the concrete and resisting their propagation [21,22]. Additionally, steel fibers are distributed in concrete in a disorderly manner, and thus result in well-distributed self-stress and a reduction in the self-stress loss. Therefore, studies use steel fibers with reinforced self-stressing and self-compacting concrete to improve the performance behavior of CFST columns.

The mechanical behavior of CFST columns under axial compression [23–26], eccentric loading [27–29], and reversed cyclic loading [30–32] was extensively studied and attention was also focused on the bond behavior of CFST columns. The earliest study on bond behavior of CFST columns can be traced back to 1975. Virdi and Dowling [33] conducted push-out tests of 88 circular

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CFST columns and concluded that concrete strength does not significantly affect bond strength. Studies focused on investigating the impact factors of the bond strength. Shakir-Khalil [34] reported the influences of interface type, shape, and size of cross-section on the bond strength. It was concluded that the influences were evident. Chang et al. [37] attempted to use expansive concrete to improve the bond behavior of CFST columns and obtained satisfactory results. Qu and Liu [39] performed push-out tests of 17 self-compacting lower expansion CFST columns. The influence of cross-sectional dimension, dosage of concrete expansive agent, concrete strength, steel tube fabrication method, and interface condition were evaluated. The test results indicated that the steel tube interface roughness, maximum flat width-to-thickness ratio (D/t), concrete strength and dosage of expansion agent were the main factors influencing bond strength. Petrus et al. [40] attempted to improve the bond strength of CFST columns by introducing internal stiffeners. Consequently, the results indicated that the bond strength increased with decrease in the tab spacing. Parsley et al. [41] presented a series of push-out tests of rectangular concrete-filled tubular columns to explore shear transfer mechanisms between concrete and steel tubes. The results indicated that the following three mechanisms were responsible for shear transfer: adhesion, friction, and wedging of the concrete core. Each mechanism played a role in transferring shear at various stages. Lu et al. [42] investigated the bond behavior of steel-fiber-reinforced self-stressing and self-compacting concrete-filled steel tube (FSSCFST) columns. The results showed that self-stress significantly improved the bond strength of CFST specimens, and the average improvement corresponded to 42.7%. The bond strength first decreased and then increased with the increase in the steel fiber volume percentage.

Additionally, concrete age plays an important role in the bond behavior of CFST columns. Roeder et al. [35] conducted push-out tests of 20 circular CFST columns at concrete ages varying from 23 d to 57 d. The study revealed that concrete shrinkage, which was affected by concrete age, was extremely detrimental to the bond strength. Tao et al. [36] described a series of push-out tests of circular and square CFST specimens to examine the impact of concrete age (31–1176 d). The experiment results showed that an increase in the concrete age decreases the bond strength. This is attributed to the influence of concrete shrinkage. Aly et al. [38] studied the bond strength of CFST columns subjected to cyclic loading. The specimens were tested at concrete ages ranging from 28 d to 106 d. The tests indicated that the bond strength of a normal-strength concrete-filled steel tube presented a small reduction with increases in concrete age. Nevertheless, it was not possible to obtain firm conclusions for the concrete age for specimens with high strength concrete. Previous studies mainly focused on the effect of ordinary concrete age. Hence, there is a paucity of information on the influence of steel-fiber-reinforced self-stressing with respect to the concrete age. This research gap should be addressed.

The present study investigates the influence of concrete age on the bond behavior of FSSCFST stub columns. The variables considered in the test include concrete age, thickness of the steel tube, and steel fiber volume percentage. All specimens with an age of 2.5 y are tested under four cycles of repeated loading to investigate

Table 1
Details of the specimens.

Series	Specimen ID	L (mm)	D (mm)	t (mm)	v (%)	Self-stress (MPa)	Age	f_{cu} (MPa)	f_y (MPa)
28d-t2.5	t2.5-0%-28d-1 t2.5-0%-28d-2 t2.5-0%-28d-3	500	165	2.5	0	4.43	28 days	53.9	305.3
	t2.5-1.2%-28d-1 t2.5-1.2%-28d-2 t2.5-1.2%-28d-3	500	165	2.5	1.2	3.74	28 days	54.4	305.3
28d-t3.5	t3.5-0%-28d-1 t3.5-0%-28d-2 t3.5-0%-28d-3	500	165	3.5	0	5.68	28 days	53.9	329.7
	t3.5-1.2%-28d-1 t3.5-1.2%-28d-2 t3.5-1.2%-28d-3	500	165	3.5	1.2	4.73	28 days	54.4	329.7
28d-t4.25	t4.25-0%-28d-1 t4.25-0%-28d-2 t4.25-0%-28d-3	500	165	4.25	0	6.09	28 days	53.9	327.5
	t4.25-1.2%-28d-1 t4.25-1.2%-28d-2 t4.25-1.2%-28d-3	500	165	4.25	1.2	5.09	28 days	54.4	327.5
2.5y-t2.5	t2.5-0%-2.5y-1 t2.5-0%-2.5y-2 t2.5-0%-2.5y-3	500	165	2.5	0	4.43	2.5 years	53.9	305.3
	t2.5-1.2%-2.5y-1 t2.5-1.2%-2.5y-2 t2.5-1.2%-2.5y-3	500	165	2.5	1.2	3.74	2.5 years	54.4	305.3
2.5y-t3.5	t3.5-0%-2.5y-1 t3.5-0%-2.5y-2 t3.5-0%-2.5y-3	500	165	3.5	0	5.68	2.5 years	53.9	329.7
	t3.5-1.2%-2.5y-1 t3.5-1.2%-2.5y-2 t3.5-1.2%-2.5y-3	500	165	3.5	1.2	4.73	2.5 years	54.4	329.7
2.5y-t4.25	t4.25-0%-2.5y-1 t4.25-0%-2.5y-2 t4.25-0%-2.5y-3	500	165	4.25	0	6.09	2.5 years	53.9	327.5
	t4.25-1.2%-2.5y-1 t4.25-1.2%-2.5y-2 t4.25-1.2%-2.5y-3	500	165	4.25	1.2	5.09	2.5 years	54.4	327.5