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Bond-slip behaviour of concrete-filled stainless steel circular hollow section tubes

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ABSTRACT

This paper presents the repeated push-out tests on concrete-filled stainless steel circular hollow section (CHS) tubes with different values of height-to-diameter ratio, diameter-to-thickness ratio and concrete strengths. The bond-slip behaviour of all specimens and the strain distribution on the exterior of stainless steel tubes along the longitudinal height direction were carefully investigated. It was found that the shear failure loads of bonding slip decreased successively with more loading cycles of the repeated push-out test employed in the same direction. Hence, the mechanical interlock force and friction force of the interface elements gradually decreased. Furthermore, the bond-slip failure of the interface elements between the inner concrete and outer stainless steel tube of the specimens consists of the adhesive stage, the sliding stage and the friction resistant stage. It can be generally concluded that 70% of the shear resistance of the bonding strength is taken by the interface friction force, while the remaining 30% of the shear resistance of the bonding strength is sustained by the chemical adhesive force and the mechanical interlock force. On the other hand, it was demonstrated that the height-to-diameter ratio (H/D) and the diameter-to-thickness ratio (D/t) of the stainless steel tube as well as the concrete strength (C) have insignificant influence on the shear resistance of the bonding strength of the interface elements. It was also shown from the comparison that the current design rules of concrete-filled carbon steel CHS tubes are inapplicable to the shear resistance of the bonding strength of concrete-filled stainless steel CHS tubes.

1. Introduction

The applications of concrete-filled stainless steel tubes could be traced back to last century, which are nowadays increasingly used in high-rise buildings and arch bridges [1–2] owing to their esthetical appearance, excellent corrosion resistance, superior load carrying capacity and seismic behaviour, good durability and low cost of maintenance. It is worth noting that concrete-filled stainless steel tubes possess both good mechanical properties of concrete-filled steel tubes (CFST) and excellent durability of stainless steel, which promote the potential employment of concrete-filled stainless steel tubes in onshore buildings, offshore platform, bridges, and many other practical applications with requirement for higher durability. Many researches including experimental investigations and theoretical analyses were conducted on the mechanical behaviour of concrete-filled stainless steel columns under various loading conditions [3–12]. In addition, many studies were also performed to investigate the bond-slip behaviour of concrete-filled carbon steel tubular columns [13–16]. Up to the authors' knowledge, however, there is no research being carried out on the bond-slip behaviour of concrete-filled stainless steel tubes.

For the design of concrete-filled stainless steel tubes, the bond strength between inner surface of stainless steel tube and outer surface of concrete infill as well as the constitutive relation of the bond-slip behaviour are the most critical concerns to guarantee that the outer stainless steel tube and inner concrete could sustain the applied loads simultaneously and reinforce with each other. In this study, the effects of the concrete strength (C), the height-to-diameter ratio (H/D) of stainless steel tube, the diameter-to-thickness ratio (D/t) of stainless steel tube, and the repeated action on the bond strength for shear resistance between interfaces were all investigated by using testing method. Furthermore, the failure process of bond surfaces under shear action together with the strain development on the outer surface of stainless steel tube were both discussed.

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Nomenclature

A_c	cross-section area of inner concrete
A_s	cross-section area of outer steel tube
C	concrete strength
D	outer diameter of stainless steel CHS tube
d	outer diameter of steel CHS tube
D_0	inner diameter of stainless steel CHS tube
E_s	elastic modulus of stainless steel tube
f	friction resistance of bonding strength
f_c	concrete cube strength
f_t	tensile strength of concrete
f_u	ultimate tensile stress of stainless steel tube
f_y	0.2% tensile proof stress of stainless steel tube
H	overall height of stainless steel CHS tube
k	influential factor for exterior of steel tube
L_e	overall adhesive length
l_0	overall length of interface
N_u	shear failure load of bonding slip
n	loading cycle of repeated push-out test
P	axial load
P_{nu}	shear failure load or bond-slip load
S	bond slip between inner concrete and outer stainless steel tube
S_u	critical slippage at bond-slip failure
t	overall thickness of stainless steel CHS tube
α	steel ratio of concrete-filled steel CHS tube
γ	correction coefficient for uncertainty
θ	confinement factor for concrete-filled steel CHS tube
τ_{Kang}	shear resistance of bonding strength obtained from current design rules
τ_{Test}	shear resistance of bonding strength obtained from tests
τ_u	shear resistance of bonding strength

2. Experimental investigation

2.1. Test specimens

A total of 32 concrete-filled stainless steel circular hollow section (CHS) tubes with the identical outer diameter of 76 mm were designed and tested, as shown in Fig. 1, which included different values of height-to-diameter ratio (H/D) ranged from 4 to 10, diameter-to-thickness ratio (D/t) ranged from 69.1 to 152.0 and concrete strength (C) ranged from 20 MPa to 50 MPa. Dimensions of all specimens are detailed in Table 1, in which the label 'H304-t0.5-C20' defines a concrete-filled stainless steel CHS tube with height 'H' of 304 mm, thickness 't' of 0.5 mm and nominal concrete cube strength 'C' of 20 MPa. In the fabrication of test specimens, a gap of 50 mm was deliberately remained at the top end of each specimen between inner concrete and outer stainless steel tube for the repeated push-out test.

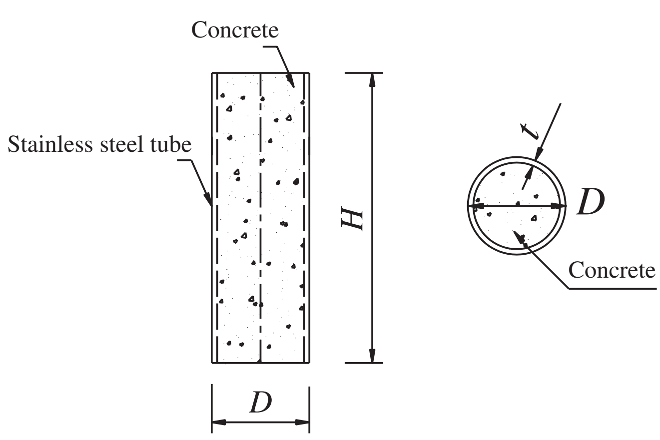

Fig. 1. Concrete-filled stainless steel CHS tube.

Table 1
Geometric parameters of concrete-filled stainless steel CHS tubes.

Specimen	D (mm)	t (mm)	H (mm)	D/t	H/D	C (MPa)
H304-t0.5-C20	76	0.5	304	152.0	4	32.3
H304-t0.7-C20		0.7	304	108.6	4	32.3
H304-t0.9-C20		0.9	304	84.4	4	32.3
H304-t1.1-C20		1.1	304	69.1	4	32.3
H456-t0.5-C20		0.5	456	152.0	6	32.3
H456-t0.7-C20		0.7	456	108.6	6	32.3
H456-t0.9-C20		0.9	456	84.4	6	32.3
H456-t1.1-C20		1.1	456	69.1	6	32.3
H608-t0.5-C20		0.5	608	152.0	8	32.3
H608-t0.7-C20		0.7	608	108.6	8	32.3
H608-t0.9-C20		0.9	608	84.4	8	32.3
H608-t1.1-C20		1.1	608	69.1	8	32.3
H760-t0.5-C20		0.5	760	152.0	10	32.3
H760-t0.7-C20		0.7	760	108.6	10	32.3
H760-t0.9-C20		0.9	760	84.4	10	32.3
H760-t1.1-C20		1.1	760	69.1	10	32.3
H304-t0.5-C50		0.5	304	152.0	4	51.7
H304-t0.7-C50		0.7	304	108.6	4	51.7
H304-t0.9-C50		0.9	304	84.4	4	51.7
H304-t1.1-C50		1.1	304	69.1	4	51.7
H456-t0.5-C50		0.5	456	152.0	6	51.7
H456-t0.7-C50		0.7	456	108.6	6	51.7
H456-t0.9-C50		0.9	456	84.4	6	51.7
H456-t1.1-C50		1.1	456	69.1	6	51.7
H608-t0.5-C50		0.5	608	152.0	8	51.7
H608-t0.7-C50		0.7	608	108.6	8	51.7
H608-t0.9-C50		0.9	608	84.4	8	51.7
H608-t1.1-C50		1.1	608	69.1	8	51.7
H760-t0.5-C50		0.5	760	152.0	10	51.7
H760-t0.7-C50		0.7	760	108.6	10	51.7
H760-t0.9-C50		0.9	760	84.4	10	51.7
H760-t1.1-C50		1.1	760	69.1	10	51.7

The material properties of stainless steel tubes were determined by uni-axial tensile coupon tests based on the recommendations of the Chinese Code of Metallic Materials (GB/T 228.1-2010) [17], which include the elastic modulus (E_s) of 206 GPa, 0.2% tensile proof stress (f_y) of 420 MPa and ultimate tensile stress (f_u) of 630 MPa. The material properties of concrete were determined from compressive concrete cube tests. The concrete cubes with nominal side length of 150 mm were produced using commercially available materials with normal mixing and curing techniques [18–19]. The material properties of the concrete are summarized in Table 2 that include the measured concrete cube strengths and the mean values for three batches of concrete cubes for nominal concrete cube strengths of 20 MPa and 50 MPa, respectively.

Table 2
Measured concrete cube strengths.

Nominal concrete strength (MPa)	Batch	Measured concrete cube strength (MPa)	Mean value (MPa)
20	1	31.4	32.3
	2	31.1	
	3	34.4	
50	4	48.7	51.7
	5	50.8	
	6	55.5	