Engineering Structures 150 (2017) 318–333

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Investigation of grouted stainless steel SHS tubular X- and T-joints subjected to axial compression

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ARTICLE INFO

Article history:
Received 3 August 2016
Revised 12 February 2017
Accepted 17 July 2017

Keywords:
Axial compression
Experimental investigation
Finite element analysis
Grout
Parametric study
Square hollow section (SHS)
Stainless steel
Strain distribution
Tubular joint

ABSTRACT

An experimental investigation was conducted on empty and grouted stainless steel square hollow section (SHS) tubular X- and T-joints subjected to axial compression. A total of 24 specimens including empty tubular joints, tubular joints with grouted brace members only, tubular joints with grouted chord member only and tubular joints with both grouted brace and chord members were tested. The joint strengths, failure modes, axial load-vertical displacement curves, axial load-chord deformation curves and strain distribution curves of all specimens were reported. The corresponding finite element analysis (FEA) was also performed and calibrated against the test results. Therefore, an extensive parametric study was carried out to evaluate the effects of main influential factors (β, τ, grouting and grout strength) on the behaviour of grouted stainless steel SHS tubular X- and T-joints subjected to axial compression. It is shown from the comparison that the ultimate strengths of empty and grouted stainless steel SHS tubular X- and T-joints generally increased with the increase of the β and τ values. The enhancement of joint strengths obtained from grouting both brace and chord members is much greater than that obtained from grouting chord member only. In addition, the ultimate strengths of stainless steel SHS tubular X- and T-joints with both grouted brace and chord members generally increased with the increase of the grout strength. Whereas, the grout strength has little influence on the ultimate strengths of stainless steel SHS tubular X-joints with grouted chord member only. On the other hand, the joint strengths obtained from the tests and parametric study were compared with the design strengths calculated using the current design rules. It is shown from the comparison that the current design rules are generally conservative for the design of empty stainless steel SHS tubular X- and T-joints subjected to axial compression, but unconservative for the design of grouted stainless steel SHS tubular X- and T-joints subjected to axial compression. Therefore, the new design equations were proposed in this study, which were verified to be more accurate.

1. Introduction

Stainless steel is nowadays widely used in various fields owing to its aesthetic appearance, high corrosion resistance, notable ductility property, improved fire resistance and superior toughness at low temperature. On the other hand, square and rectangular hollow sections (SHS and RHS) are the typical structural members used in the long-span spatial structures, frame structures, awning, balcony and many other frameworks [1]. Hence, stainless steel SHS and RHS tubes have promising applications in the field of structural engineering by combining their unique characteristics, in particular grouted stainless steel SHS and RHS tubes which could greatly improve the structural performance in terms of both static and dynamic behaviour and facilitate the use of stainless steel to offset its higher material costs. The practical applications of grouted stainless steel tubes include the triangular frame of Hearst Building in New York and towers of Stonecutters Bridge in Hong Kong [2].

A test program was conducted by Zhen et al. [3] on the material properties of Chinese standard stainless steel SUS 304, which could be simulated by using the classic Ramberg-Osgood equation. It was found that cold working has great influence on the strengths of corner portion of SHS and RHS tubes. Experimental and numerical investigations were performed by Feng and Young [4] on stress concentration factors (SCFs) of cold-formed stainless steel SHS and RHS tubular X-joints. The current design code for SCFs of

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http://dx.doi.org/10.1016/j.engstruct.2017.07.052
0141-0296/

Nomenclature

A_{s1}	cross-section area of brace
A_{sc}	cross-section area of grouted brace
b_0	overall width of SHS chord
b_1	overall width of SHS brace
E	elastic modulus
f_u	ultimate tensile stress
f_y	0.2% tensile proof stress
f_{y0}	yield stress of chord
f_{y1}	yield stress of brace
L_0	overall length of chord
L_1	overall length of brace
N	axial load
N_{CC}	design strength obtained from Chinese Code
N_{eu}	ultimate strength of empty stainless steel tubular joint
N_{EC}	design strength obtained from Eurocode 3
N_{FEA}	ultimate strength obtained from finite element analysis
N_{gb}	ultimate strength of stainless steel tubular joint with grouted braces only
N_{gc}	ultimate strength of stainless steel tubular joint with grouted chord only
N_{gu}	ultimate strength of stainless steel tubular joint with both grouted braces and chord
N_p	design strength obtained from proposed design equations
N_{sc}	design strength obtained from design formulae of Han
N_{Test}	ultimate strength obtained from tests
N_u	ultimate strength
t_0	wall thickness of chord
t_1	wall thickness of brace
β	brace to chord width ratio (b_1/b_0)
δ	chord web deflection
ε_i	strain
ε_y	yield strain
ξ_0	confined coefficient of stainless steel tube
τ	brace to chord thickness ratio (t_1/t_0)
φ	structural stability coefficient
ψ_β, ψ_τ, $\psi_{\xi 0}$	correction factorchord flange indentation Vertical displacement

carbon steel tubular joints was found to be quite unconservative for SCFs of stainless steel tubular joints. A unified design equation was proposed for the SCFs of cold-formed stainless steel SHS and RHS tubular X-joints. A total of 120 characteristic models were developed by Voth and Packer [5] for branch plate-to-circular hollow section (CHS) tubular T-joints. The partial design strength functions were determined from the regression analysis of finite element analysis results and existing test results, which were considered to be the lower bound reduction factors. Concrete-filled carbon steel RHS X- and T-joints were experimentally and numerically investigated by Packer and Fear [6]. Tests were conducted by Rasmussen and Young [7] for stainless steel SHS tubular X- and K-joints. The design rules were proposed based on the current design recommendations for carbon steel tubular structures by replacing the yield stress with the relative proof stresses. Experimental investigations were also conducted by Feng and Young [8,9] on cold-formed stainless steel tubular T- and X-joints. The 0.2% proof stress was recommended to be more reasonable to predict the design strengths of stainless steel tubular T- and X-joints in both ultimate limit state and serviceability limit state. The deformation limit corresponding to the ultimate strength of cold-formed RHS tubular T-joints was proposed by Zhao [10], which mainly depends on the brace to chord width ratio (β). Tests were conducted by Feng and Young [11,12] on concrete-filled stainless steel SHS and RHS tubular T- and X-joints. The current design rules were found to be quite conservative for concrete-filled stainless steel tubular joints. The effects of stainless steel tubes on the bearing capacity of concrete-filled stainless steel SHS and RHS tubular T- and X-joints were recommended to be considered in the design rules.

The concrete was only filled in the chord member of stainless steel SHS and RHS tubular T- and X-joints specimens along the full chord length in Ref. [11,12]. The test results in Ref. [11,12] were just compared with the design strengths calculated using the CIDECT design rules for concrete-filled carbon steel tubular structures. The design formulae of stainless steel SHS and RHS tubular T- and X-joints under axial compression are not put forwarded in Ref. [11,12]. This study is a further investigation on grouted stainless steel tubular joints that mainly focuses on the strength and behaviour of stainless steel SHS tubular X- and T-joints with grouted brace members only, grouted chord member only, and both grouted brace and chord members subjected to axial compression. The empty stainless steel SHS tubular X- and T-joints were also tested under axial compression for comparison. The joint strengths, failure modes, joint deformations and strain distributions of empty and grouted stainless steel SHS tubular X- and T-joints subjected to axial compression are reported in this study. Furthermore, the corresponding finite element analysis was also performed to evaluate the effects of grouting the brace and chord members on the strength and behaviour of stainless steel tubular X- and T-joints. The design formulae are also proposed for grouted stainless steel SHS tubular X- and T-joints subjected to axial compression based on the current design rules.

2. Experimental investigation

2.1. Test specimens

A total of 24 stainless steel tubular joints including 12 tubular X-joints and 12 tubular T-joints were tested, in which 6 specimens were fabricated by welding empty brace members to empty chord member, 6 specimens were fabricated by welding grouted brace members to empty chord member, 6 specimens were fabricated by welding empty brace members to grouted chord member, and 6 specimens were fabricated by welding grouted brace members to grouted chord member. The brace members of all specimens were fully welded at right angles to the center of the continuous chord member. The brace and chord members of all specimens are designed as the SHS 50 × 1.1 and SHS 100 × 1.1, which have the nominal overall width (b_1 and b_0) of 50 mm and 100 mm, the nominal wall thickness (t_1 and t_0) of 1.1 mm, with the nominal overall length (L_1 and L_0) of 200 mm and 400 mm. Hence, the brace to chord width ratios ($\beta = b_1/b_0$) of SHS tubular X- and T-joints are 0.5 and 1.0, respectively. The specimen dimensions including brace members, chord members and critical geometric parameter $\beta = b_1/b_0$ are all summarized in Table 1, using the nomenclature defined in Fig. 1a and b for empty and grouted SHS tubular X- and T-joints, respectively.

The welds connecting stainless steel SHS brace and chord members were designed according to the American Welding Society (AWSD1.1/1.1 M) Specification [13] and laid using argon-arc weld-