Journal of Constructional Steel Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Structural behaviour of cold-formed stainless steel bolted connections at post-fire condition

Yancheng Cai, Ben Young *

Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

ARTICLE INFO

Article history:
Received 20 December 2017
Received in revised form 24 February 2018
Accepted 26 March 2018
Available online xxxx

Keywords:
Bolted connection
Cold-formed stainless steel
Experimental investigation
Post-fire test
Ultimate strength

ABSTRACT

This paper presents an experimental investigation on cold-formed stainless steel single shear and double shear bolted connections at post-fire condition. The connection specimens were fabricated by three different grades of stainless steel. The three different grades of stainless steel are austenitic stainless steels EN 1.4301 (AISI 304) and EN 1.4571 (AISI 316Ti) as well as lean duplex stainless steel EN 1.4162 (AISI S32101). The post-fire connection specimens were heated to different nominal temperatures of 350, 650 and 950 °C, respectively, and then cooled down to room (ambient) temperature condition. A total of 82 new connection tests was conducted. The test results of post-fire specimens were compared with those tested without post-fire condition for the same specimen series. Generally, it is found that the single shear and double shear bolted connection specimens cooled down from the nominal temperatures of 350 and 650 °C had higher ultimate strengths than those specimens without expose to high temperatures for all three different grades of stainless steel. The specimens cooled down from 950 °C generally had lower ultimate strengths than the aforementioned specimens. It is also found that the failure modes of cold-formed stainless steel bolted connection specimens at post-fire condition are similar to those tested without post-fire condition. Finally, design rules are proposed for cold-formed stainless steel bolted connections at post-fire condition for temperature up to 950 °C.

1. Introduction

The desirable characteristics of stainless steel as compared to carbon steel including attractive appearance, corrosion resistance, ductility excellence, better fire resistance and life-cycle cost savings, can be exploited in a wide range of construction applications [1,2]. The usages of stainless steel are found in high-rise buildings (i.e. The Cheung Kong Center, Hong Kong), bridges (i.e. Helix Bridge in Singapore) and other structural applications. New opportunities for stainless steel are arising from the pursuit of sustainable development, such as nuclear power generation, solar power generation, biofuel power generation, sustainable building envelopes and renovation [2]. Investigations on the performances of stainless steels at room (ambient) temperature have been carried out in recent years, such as material properties [3,4], beams [5,6], columns [7,8] and bolted connections [9–11]. The structural behaviour of stainless steels at high temperatures was also investigated, including structural members [12–14] and bolted connections [15–17].

Fire safety is one of the critical scenarios in the design of steel structures due to the strength and stiffness deterioration at elevated temperatures. The full process of fire development can be assumed as four stages: incipient, growth, burning after flashover, and decay [18]. Structural members will cool down along with the decreasing atmosphere temperature in the last stage. It is cost-consuming and time-consuming if all the structures exposed to fire are dismantled and replaced by new alternates, i.e. steel members; while safety is concerned if structures are directly reused or reinforced after exposed to fire. Therefore, the performance of structures after exposed to fire need to be assessed. The post-fire behaviour of concrete-filled steel tubular columns [19] and steel beam to concrete-filled steel tubular column connections have been investigated [20]. Tests on the post-fire mechanical properties of high strength structural steels S460, S690 and S960 showed that mechanical properties are not affected until they are exposed to fire temperatures above 600 °C [21,22]. A recent study on the post-fire behaviour of ferritic stainless steel material showed that the soak time and cooling rates have negligible effect on the strength of the material [23]. Bolted connections are commonly used in carbon steel and stainless steel structures. However, it should be noted that there is presently no research work on the post-fire behaviour of stainless steel bolted connections. Therefore, an experimental investigation on the structural behaviour of cold-formed stainless steel bolted connections at post-fire condition was carried out.

A series of cold-formed stainless steel bolted connections have been tested at elevated temperatures by steady state test method and transient state test method [15–17]. The connection specimens in this study were fabricated from the same batch of cold-formed stainless steel as those tested in [11,15–17]. The three different grades of stainless

* Corresponding author.
E-mail address: young@hku.hk (B. Young).

https://doi.org/10.1016/j.jcsr.2018.03.024

steel are austenitic stainless steel EN1.4301 (AISI 304) and EN1.4571 (AISI 316Ti having small amount of titanium) as well as lean duplex stainless steel EN1.4162 (AISI S32101). The cold-formed stainless steel bolted connection specimens were designed by varying the size of bolt, the number of bolt and the arrangement of bolt. The connection specimens were heated to different nominal temperatures of 350, 650 and 950 °C, respectively, and then cooled down to room (ambient) temperature. A total of 82 new connection tests was conducted in this study. The test results were compared with those obtained from room temperature tests without exposing to high temperatures for the same specimen series, including connection strengths and failure modes. In addition, the micro structures of the stainless steel at post-fire condition and without post-fire condition were also investigated. Finally, design rules are proposed for cold-formed stainless steel bolted connection specimens at post-fire condition for temperature up to 950 °C.

2. Experimental investigation

2.1. Test specimens

The bolted connection specimens were fabricated from three different grades of cold-formed stainless steel, including austenitic stainless steels EN1.4301 (AISI 304) and EN1.4571 (AISI 316Ti having small amount of titanium) as well as lean duplex stainless steel EN1.4162 (AISI S32101). The austenitic stainless steels have lower strengths than the lean duplex material. The lean duplex stainless steel is considered as high strength material and the austenitic stainless steels as normal strength materials in this study. For simplicity, these three types of stainless steels, EN1.4301 (AISI 304), EN1.4571 (AISI 316Ti) and EN1.4162 (AISI S32101) are labelled as types A, T and L, respectively, in the context of this paper.

The bolted connection specimens were cut from the stainless steel rectangular hollow sections. The stainless steel hollow sections were supplied from STALA Tube Finland in uncut lengths of 3000 mm and nominal section size of 20 × 50 × 1.5 mm (width × depth × thickness). The single shear and double shear bolted connections were tested with stainless steel washers in both sides of the bolt. The single shear connection specimen is bolted with two plates having one shear plane, while the double shear connection specimen is bolted with three plates having two shear planes. The nominal width and thickness of each connection specimen were 50 mm and 1.5 mm, respectively. They were cut from the stainless steel tubes with a specified length. The length of the specimen plates were ranged from 381 to 404 mm such that the total length of each assembled connection specimen was maintained at approximately 690 mm. The length of the gripping part at each end of the connection specimen was 65 mm.

Three types of connection plates with different bolt numbers and bolt configurations were designed for the single shear and double shear bolted connection specimens, as shown in Fig. 1. Lips were designed for the connection plates except for the middle plate of the double shear bolted connections. The nominal dimensions of the plates for single shear and double shear (middle plates) bolted connection specimens are presented in Table 1. The dimensions of the specimens were the same as those tested by Cai and Young [11]. Two different sizes of A4 stainless steel bolts [24] of grade 8.8 were used, namely M8 bolt and M12 bolt. Standard size of bolt holes (do) were adopted in accordance with the ASCE [25] and AS/NZS standards [26], and the size of bolt hole is 1 mm larger than the nominal bolt diameter (d) if d is smaller than 12 mm, otherwise the do is 2 mm larger than d. Generally, the spacing in the connected parts satisfies the minimum requirements of the specifications, except for the case when there are three bolt holes in the plate, as shown in Fig. 1(c). In this case, the perpendicular spacing between the centers of two bolt holes is 22 mm for M8 bolts, which could still follow the requirements of EC3-1.8 [27], but 2 mm less than the minimum requirements of 24 mm in the ASCE Specification [25] and AS/NZS Standard [26].

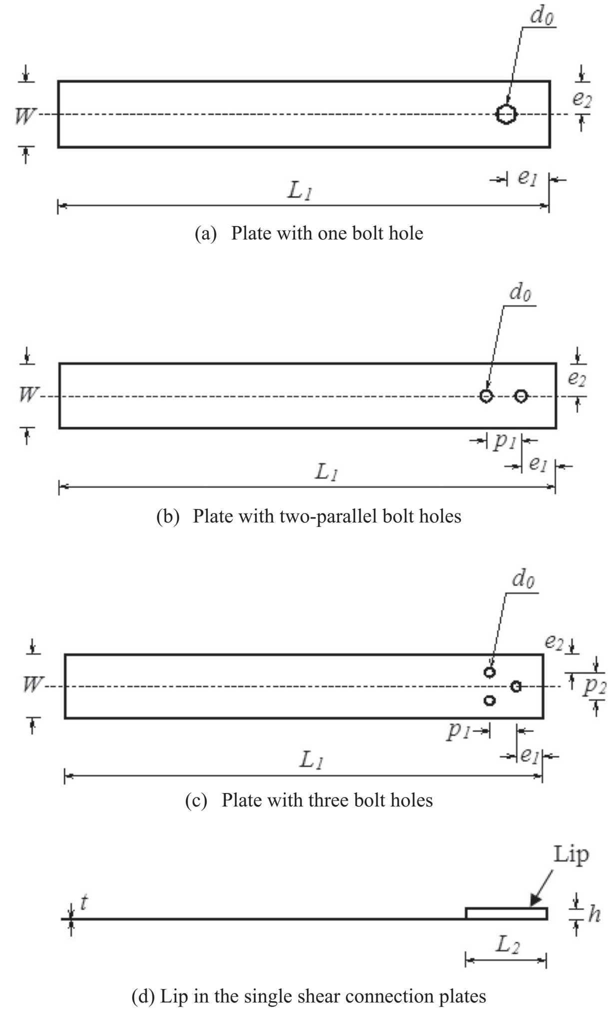

Fig. 1. Configuration of connection specimens.

2.2. Specimen labeling

The specimens are mainly separated into two groups according to the connection types, namely the single shear and double shear bolted

Table 1
Nominal dimensions of the plates for cold-formed stainless steel bolted connection specimens [11].

Specimen	Nominal (mm)						
	h	L_2	e_1	e_2	p_1	p_2	L_1
A-S-1-12	10	72	36	25	–	–	381
T-S-1-12	10	72	36	25	–	–	381
L-S-1-12	10	72	36	25	–	–	381
A-S-2Pa-8	10	81	27	25	27	–	386
T-S-2Pa-8	10	81	27	25	27	–	386
L-S-2Pa-8	10	81	27	25	27	–	386
A-S-3-8	10	81	27	14	27	22	386
T-S-3-8	10	81	27	14	27	22	386
L-S-3-8	10	81	27	14	27	22	386
A-D-1-12	–	–	55	25	–	–	405
T-D-1-12	–	–	55	25	–	–	405
L-D-1-12	–	–	55	25	–	–	405
A-D-2Pa-8	–	–	45	25	27	–	404
T-D-2Pa-8	–	–	45	25	27	–	404
L-D-2Pa-8	–	–	45	25	27	–	404
A-D-3-8	–	–	45	14	27	22	404
T-D-3-8	–	–	45	14	27	22	404
L-D-3-8	–	–	45	14	27	22	404

Please cite this article as: Y. Cai, B. Young, Structural behaviour of cold-formed stainless steel bolted connections at post-fire condition, J Constr Steel Res (2017), https://doi.org/10.1016/j.jcsr.2018.03.024