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High temperature tests of cold-formed stainless steel double shear bolted connections

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ABSTRACT

There is currently no design rule on bolted connections of cold-formed stainless steel structures at elevated temperatures. In this study, a total of 194 double shear bolted connection specimens with three different grades of stainless steel were tested, where 106 specimens were tested by steady state test method and 88 specimens were tested by transient state test method. The three different grades of stainless steel are austenitic stainless steel EN 1.4301 (AISI 304) and EN 1.4571 (AISI 316Ti having small amount of titanium) as well as lean duplex stainless steel EN 1.4162 (AISI S32101). The connections were designed with different bolt diameters, number of bolts and arrangement of the bolts. Bearing failure and net section tension failure modes were observed in the double shear bolted connection tests. The test results were compared with the nominal strengths calculated from the design rules in the American Specification, Australian/New Zealand Standard and European Codes for stainless steel structures. In calculating the nominal strengths of the connections, the material properties at elevated temperatures were used in the design equations for room temperature. It is shown that the strengths of the cold-formed stainless steel double shear bolted connections obtained from the specifications are generally conservative at elevated temperatures. The connection strengths decrease as the temperature increases in the similar manner for the steady state tests and the transient state tests as well as the material coupon tests. It is also found that the austenitic stainless steel type EN 1.4571 generally has better resistance than the stainless steel types EN 1.4301 and EN 1.4162 for double shear bolted connections at elevated temperatures.

1. Introduction

The desirable characteristics of stainless steel, such as attractive appearance, corrosion resistance, better fire resistance as compared to carbon steel and low maintenance cost, are able to provide attractive usage in certain applications, where the achievable benefits may compensate for the extra material cost compared to carbon steel [1,2]. Significant progress has been made in developing design rules for stainless steel structures at room (ambient) temperature in recent years, while the performance of fire resistance of stainless steel structures has received little attention [3]. Previous research has shown that the strength and stiffness retention of austenitic stainless steel (EN 1.4301) at elevated temperatures is superior to those of carbon steel [4]. Bolted connections are commonly used in construction for both carbon steel and stainless steel structures. Currently, the design rules of stainless steel bolted connections are available in different specifications, including the American Society of Civil Engineers Specification (ASCE) [5], Australian/New Zealand Standard (AS/NZS) [6] and Eurocode 3 Part 1-4 (EC3-1.4) [7]. Zadanfarrokh [8] and Rogers and Hancock [9–11] conducted a series of tests on carbon steel bolted connections at room temperature, whereas tests of stainless steel bolted connections conducted by Bouchaïr et al. [12] and Cai and Young [13] were also at room temperature. However, there are presently few investigations on the behavior of stainless steel bolted connections at elevated temperatures.

The material properties of stainless steel at elevated temperatures have been investigated by Gardner and Baddoo [3], Sakumoto et al. [14], Makelainen and Outinen [15], Chen and Young [16] and Brnic et al. [17,18]. The behavior of stainless steel columns and laterally restrained beams at elevated temperatures has been investigated by Ng and Gardner [19]. To and Young [20] numerically studied the performance of cold-formed stainless steel tubular columns at elevated temperatures. Yan and Young [21,22] studied the structural behavior of single shear bolted connections of thin sheet carbon steels at elevated temperatures by steady state and transient state test methods. Furthermore, Yan and Young [23] also conducted a series of tests on double shear bolted connections of carbon steel at elevated temperatures. It should be noted that investigation of stainless steel bolted connections at elevated temperatures is limited up-to-date. Cai and Young [24] recently conducted 100 tests of cold-formed stainless steel single shear bolted connections at high temperatures using steady state test method. It should be noted that the current design rules [5–7] on stainless steel bolted connections are only applicable at room temperature, and these design rules do not cover elevated temperatures.

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Table 1
Coupon test results at elevated temperatures [24].

Nominal temperature (°C)	Stainless steel series	22	200	350	450	500	550	650	800	950
Coupon specimen temperature (°C)	A	22	205	351	–	496	544	648	800	950
	T	22	206	356	449	498	548	645	800	950
	L	22	206	356	–	501	553	652	795	948
$f_{0.2,T}/f_{0.2,N}$	A	1.00 (474[a])	0.81	0.71	–	0.67	0.65	0.54	0.33	0.13
	T	1.00 (463[a])	0.84	0.80	0.79	0.75	0.72	0.67	0.53	0.20
	L	1.00 (724[a])	0.78	0.70	–	0.62	0.54	0.42	0.16	0.02
$f_{u,T}/f_{u,N}$	A	1.00 (759[a])	0.69	0.66	–	0.62	0.58	0.46	0.21	0.09
	T	1.00 (677[a])	0.77	0.77	0.78	0.75	0.71	0.62	0.38	0.14
	L	1.00 (862[a])	0.82	0.81	–	0.73	0.60	0.42	0.16	0.03

[a] Test results obtained at room temperature in the unit of MPa shown in Ref. [13].

In this study, a total of 194 double shear bolted connection specimens with three different grades of cold-formed stainless steel were tested, where 106 specimens were tested by steady state test method and 88 specimens were tested by transient state test method. In the steady state tests, the stainless steel bolted connections were investigated in the temperature ranged from 200 to 950 °C, while in the transient state tests, the connections were tested under 3 different load levels, namely 0.25, 0.50 and 0.75 of the failure load at room temperature. The three different types of stainless steels are austenitic stainless steel EN 1.4301 (AISI 304) and EN 1.4571 (AISI 316Ti having small amount of titanium) as well as lean duplex stainless steel EN 1.4162 (AISI S32101). The investigation of the double shear bolted connections involved different bolt diameters, number of bolts and arrangement of the bolts. A total of 15 series of specimens were considered. The observed failure modes involved bearing failure and net section tension failure. The ultimate strengths of stainless steel double shear bolted connection tests at elevated temperatures were compared. It is found that the stainless steel type EN 1.4571 generally has better resistance than the stainless steel types EN 1.4301 and EN 1.4162 at elevated temperatures. It is also shown that the strengths of the cold-formed stainless steel double shear bolted connections predicted by the specifications are generally conservative at elevated temperatures. The connection strengths decrease as the temperature increases in the similar manner for the steady state tests and the transient state tests as well as the material coupon tests.

2. Current design rules of cold-formed stainless steel bolted connections

The current stainless steel design specifications for bolted connections are applicable at room temperature only [5–7]. In the current design specifications, different failure modes for bolted connections

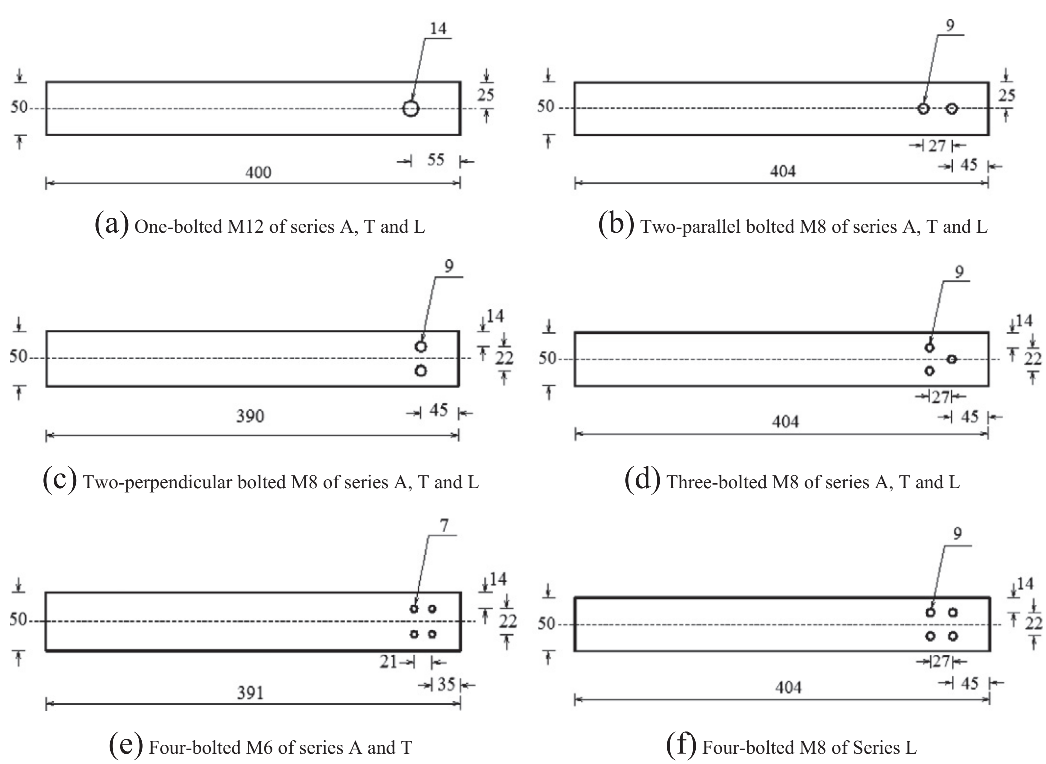

Fig. 1. Nominal dimension of double shear (internal plate) bolted connection specimens: (a) One-bolted M12 of series A, T and L; (b) Two-parallel bolted M8 of series A, T and L; (c) Two-perpendicular bolted M8 of series A, T and L; (d) Three-bolted M8 of series A, T and L; (e) Four-bolted M6 of series A and T; (f) Four-bolted M8 of series L.