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Transient state tests of cold-formed stainless steel single shear bolted connections

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ABSTRACT

A total of 87 cold-formed stainless steel single shear bolted connections was conducted. The specimens were tested using transient state test method. The single shear bolted connection specimens were fabricated by three different grades of stainless steel. 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). Three different load levels of 0.25, 0.50 and 0.75 of the failure load at room temperature were investigated. The tendency of the test strength reduction of the stainless steel single shear bolted connections conducted using the transient state test method is similar to those results obtained by the steady state test method. However, the critical temperatures determined by the transient state test results are usually slightly higher compared with those deduced from the steady state test results at the load levels of 0.25 and 0.50 of the failure load at room temperature. The austenitic stainless steel grade EN 1.4571 (AISI 316Ti) generally has better resistance than the other two stainless steel grades in transient state tests as higher values of critical temperatures were obtained. Two main failure modes, namely the bearing and net section tension failures, were observed in the transient state tests. The failure modes of the specimens in transient state tests at the load level of 0.25 are generally consistent with those specimens in the steady state tests.

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, can be exploited in a wide range of construction applications [1,2]. Bolted connection is widely used in steel structures. The design rules of stainless steel bolted connections are available in current specifications, such as the American Specification (ASCE) [3], Australian/New Zealand Standard (AS/NZS) [4] and Eurocode 3 Part 1-4 (EC3-1.4) [5]. Tests of stainless steel bolted connections were conducted at room (ambient) temperature by Bouchaïr et al. [6] and Cai and Young [7]. The effects of elevated temperatures on bolted connections of cold-formed steel [8], screw connections of thin sheet steel [9,10] and welded tubular joints in the brace member [11] have been investigated. However, investigation on the behavior of bolted connections of cold-formed stainless steels at elevated temperatures is limited up-to-date. It should be noted that the current stainless steel bolted connection design rules in the specifications [3–5] are only applicable at room temperature condition.

The material properties of stainless steels at elevated temperatures have been investigated [12–15]. A test program on cold-formed stainless steel single shear bolted connection specimens using steady state test method is reported by Cai and Young [16]. It is shown that the current design predictions by the ASCE Specification [3], AS/NZS Standard [4] and EC3-1.4 [5] are generally conservative for cold-formed stainless steel single shear bolted connections, where in calculating the design connection strengths, the design equations in these specifications for room temperature are used directly for specimens at elevated temperatures by substituting the deterioration of the material properties.

The tests on structural fire resistance are mainly carried out by two methods, namely steady state test method and transient state test method. For the transient state test method, the test specimen is loaded and maintained at a given load level and then the temperature increased until the failure of specimen [17]. However, experimental investigation of cold-formed stainless steel single shear bolted connections using transient state test method is limited.

In this study, the structural behavior of 87 stainless steel single shear bolted connections were conducted. The connection

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Nomenclature

E_N	elastic modulus at room (ambient) temperature
E_T	elastic modulus at elevated temperatures
$f_{0.2,N}$	longitudinal 0.2% tensile proof stress at normal room temperature
$f_{0.2,T}$	longitudinal 0.2% tensile proof stress at elevated temperatures
$f_{u,N}$	longitudinal tensile strength at normal room temperature
$f_{u,T}$	longitudinal tensile strength at elevated temperatures
$\varepsilon_{u,N}$	ultimate strain at room temperature
$\varepsilon_{u,T}$	ultimate strain at elevated temperatures
$P_{pre,load}$	pre-load for transient state test
$P_{u,N}$	ultimate load of bolted connection tests at room temperature
$P_{u,T}$	ultimate load of bolted connection tests at elevated temperatures
θ	gas temperature in fire compartment
t	time in minute

specimens were fabricated from three different grades of cold-formed stainless steel. The stainless steel grade, bolt size, number of bolt and arrangement of the bolt were varied in 15 test series. The configurations of the test specimens are detailed in Cai and Young [16] for steady state tests. The transient state test method was adopted. The tests considered three different load levels for 0.25, 0.50 and 0.75 of the failure load at room temperature. The test results obtained from the transient state tests were compared with those obtained from the steady state tests. In this study, the critical temperature is defined as the temperature that caused the failure of the specimen.

2. Coupon tests

The cold-formed stainless steel single shear bolted connections were fabricated from the same batch of cold-formed stainless steel as those specimens tested using the steady state test method in Cai and Young [16]. The stainless steel grades are the 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). For simplicity, the three types of stainless steels, EN 1.4301 (AISI 304), EN 1.4571 (AISI 316Ti) and EN 1.4162 (AISI S32101) are labeled as types A, T and L, respectively, in the context of this paper. The tensile coupon specimens were conducted in MTS 810 Universal testing machine using steady state test method. The material properties of these three grades of cold-formed stainless steel including the elastic moduli (E_N and E_T), 0.2% proof stresses ($f_{0.2,N}$ and $f_{0.2,T}$), tensile strengths ($f_{u,N}$ and $f_{u,T}$) and ultimate strains ($\varepsilon_{u,N}$ and $\varepsilon_{u,T}$) from normal room temperature of 22 °C to high temperature of 950 °C were obtained. The coupon test results are reported by Cai and Young [16].

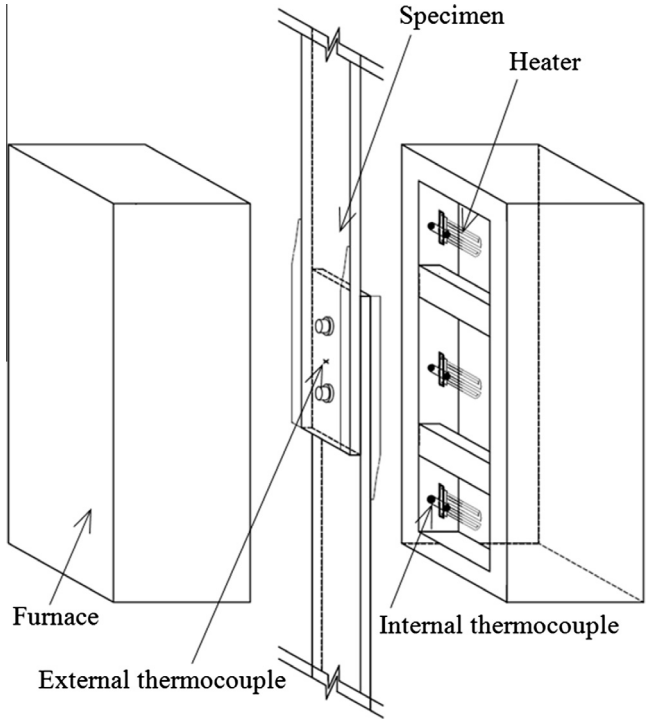

Fig. 2. Schematic view of transient state tests and location of external thermocouple.

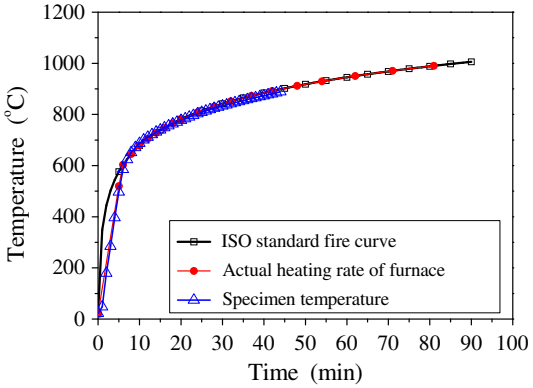

Fig. 1. Comparison of specimen temperature (T-S-3-8 at $0.25P_{u,N}$) and ISO fire curve.

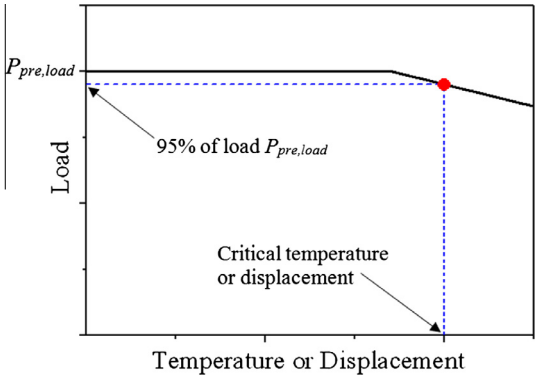

Fig. 3. Definition of the critical temperature or the critical displacement for single shear bolted connection.