Journal of Constructional Steel Research 138 (2017) 65–71

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Post-fire residual slip resistance and shear capacity of high-strength bolted connection

Hongbo Liu [a,b,c], Dongyu Liu [c], Zhihua Chen [a,c], Yujie Yu [c,*]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] Institute for Infrastructure and Environment, University of Edinburgh, Scotland, UK
[c] Department of Civil Engineering, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Article history:
Received 25 June 2016
Received in revised form 20 April 2017
Accepted 24 June 2017
Available online xxxx

Keywords:
Post-fire
High-strength bolted connection
Slip resistance
Shear capacity
Prediction formula

ABSTRACT

High-strength bolted connection is one of the main connecting forms of steel structure and its post-fire residual mechanical properties are important basis for post-fire evaluation and recovery of steel structure performance. This paper made an experimental study on slip resistance and shear behaviors of common engineering 8.8 s and 10.9 s high-strength bolted connection after high temperature, getting the load-displacement curves of high-strength bolted connection under different firing temperatures and cooling modes. The post-fire slip resistance and shear capacity of high-strength bolted connection were analyzed. Based on analysis of test data, it is found that post-fire slip resistance and shear capacity of high-strength bolted connection generally declined with the increase of the firing temperature. When the firing temperature is lower than 600 °C, slip resistance and shear capacity of high-strength bolted connection were similar with those under room temperature. However, when the firing temperature exceeds 600 °C, they declined quickly. The reduction factors of slip resistance and shear capacity at 900 °C reduced to about 0.35 and 0.75, respectively. The cooling mode could influence post-fire slip resistance and shear behaviors of bolted connection to a certain extent, but no explicit law was discovered, which needs further deep researches. Finally, the prediction formula concerning the reduction factors of post-fire slip resistance and shear capacity of high-strength bolted connection was proposed based on test data fitting, providing certain references for evaluation of post-fire residual performance and recovery of steel structures.

1. Introduction

Recently, fire accidents of steel structure increased year by year. However, only few complete collapses of steel structure after fires have taken place. Post-fire mechanical properties of steel structural materials and connection can be recovered to a large extent and most structures could be put into use again after reasonable reinforcement, thus reducing fire damages. Influenced by high temperature in fire accidents, post-fire mechanical properties of steel structural materials and connection degrade to a certain extent, which reduces bearing capacity of the steel structure. Therefore, accurate evaluation of residual mechanical properties of steel structural materials and connection after fires is the basis of post-fire recovery and reinforcement.

Extensive studies have been conducted recently to investigate the post-fire mechanical properties of various structural steels, such as structural steels Q235, Q345 and Q460 [1–2], cold-formed steels G300, G500, and G550 [3], high-strength structural steels S460, S690 and S960 [4–6], stainless steels [7], high-strength steel tie rods [8], pre-stressed steel wires [9], and reinforced steels [10]. Extensive studies have been also conducted on the post-fire structural behavior of concrete-filled steel tubular columns [11–15].

High-strength bolted connection of steel structure possesses significant economic advantages in manufacturing and installation, which is widely used in China and other countries. But limited researches have been carried out on the post-fire mechanical behavior of steel connections. Existing researches on the high-strength bolted connection mainly focus on the mechanical properties under room temperature and high temperature [16–21]. Few current researches referred to the post-fire mechanical behavior of the high-strength bolted connections. Yu [22] and Lou et al. [23] have studied the post-fire mechanical behavior of the bolts A325 and A490 in United States and the bolts 8.8 and 10.9 in China respectively.

Although Lou et al. have studied the post-fire mechanical behavior of the bolts 8.8 and 10.9 used in China, most bolt connection specimens in their study occurred hole wall bearing damage because the hole wall bearing strength of connection steel plate was higher than shear capacity of bolts. Therefore, the test results in reference [23] cannot reflect the post-fire shear capacity of the bolts 8.8 and 10.9 used in China. This paper carried out an experimental study on slip resistance and shear behaviors of high-strength bolted connection after fires and cooling, getting the degradation law of post-fire slip resistance and shear capacity.

* Corresponding author.
E-mail address: yujietju@tju.edu.cn (Y. Yu).

http://dx.doi.org/10.1016/j.jcsr.2017.06.026

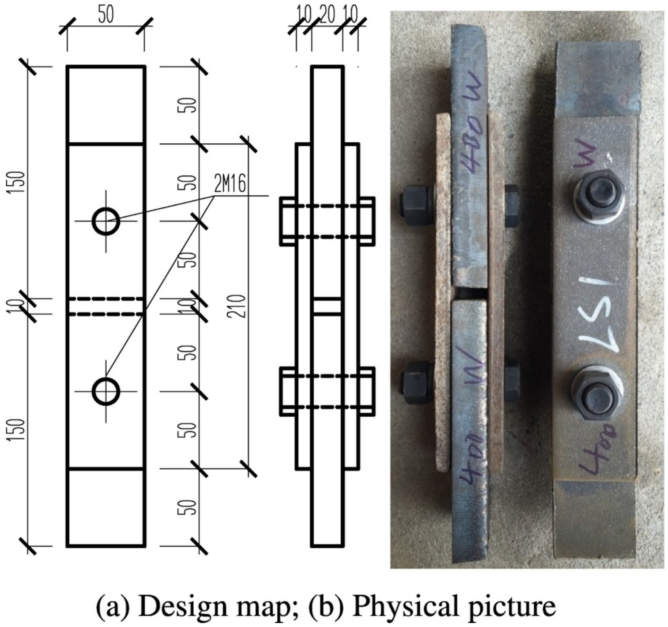

Fig. 1. Specimen structure. (a) Design map; (b) physical picture.

Fig. 2. High temperature furnace.

Research results provide important references for evaluation and recovery of overall post-fire performance of steel structures.

2. Experimental investigation

2.1. Specimen design

To study post-fire slip resistance and shear behaviors of high-strength bolted connection, two specimens were designed in this paper: 8.8 s high-strength bolted connection and 10.9 s high-strength bolted connection. Diameter of bolts was 16 mm. The diameter of bolt holes in the plates was designed to 18 mm and all steel plates used Q345B. Steel plate was cleaned and sand blasted. Processing and screwing of bolted connection specimens were accomplished by skilled workers to reflect real mechanical properties of high-strength bolted connection in engineering practice. Specimen structure and physical pictures are shown in Fig. 1.

This paper mainly studied post-fire slip resistance and shear behaviors of high-strength bolted connection. Therefore, the tensile strength of steel plate in the specimen was far higher than the shear strength of high-strength bolt. This can cause shear failure of the bolt, thus enabling to get post-fire slip resistance and shear behaviors of high-strength bolted connection. According to the formula in *Design Code for Steel Structures* (GB50017), designed shear capacity of testing bolts and designed shear capacity as well as designed local bearing capacity of steel plate are listed in Table 1. It can be seen from Table 1 that the designed bearing strength of the steel plate is over 1.5 times higher than the shear strength of bolt.

Based on test data about residual mechanical properties of different steel materials after high temperature in previous studies, it is found that when the temperature is lower than 300 °C, steel maintains basically the same mechanical properties as those under room temperature. To reduce experimental cost and improve test efficiency, this paper tested residual mechanical properties of bolted connections under 400 °C, 500 °C, 600 °C, 700 °C, 800 °C and 900 °C. Meanwhile, bolted connected in actual fire accidents may be cooled naturally or by high-pressure water gun. In this experiment, each group of specimens considered natural cooling and water cooling. Each type of specimens has one control group (room temperature). Hence, a total of 26 specimens were designed in this experiment.

2.2. Test equipments and steps

A high temperature furnace (Fig. 2) was used for heat treatment of specimens. The Universal tester (Fig. 3) was applied for static stretching test of specimens after high temperature, which got the displacement-load curve of high-strength bolted connection after high temperature. Specific steps are as follows:

1) Four specimens (8.8 s and 10.9 s high-strength bolted connection specimen; natural cooling water cooling) under every testing temperature were put into the high temperature furnace simultaneously. The heat treatment was implemented according to temperature rise route in Fig. 4. T is the designed temperature of every specimen.
2) After the heat treatment, four specimens were taken out and divided into two groups according to cooling mode: natural cooling and water cooling.
3) Specimens after heat treatment were stretched by the universal tester until tensile failures. The displacement-load curve of specimens was gained. During static tensile test, pre-loading was needed. 10% of designed loads (about 10kN) shall be applied firstly and kept for 1 min. Next, continue to load steadily until specimen failure. Loading adopted displacement control and loading rate was set 5 mm/min.

Table 1
Bearing capacities of high-strength bolted connection specimens (kN).

Specimens	Slip resistance of bolt	Shear capacity of bolt	Tension capacity of steel plate	Bearing capacity of steel plate
M16 bolt 8.8s	80	100	–	–
M16 bolt 10.9s	100	125	–	–
Q345B steel plate	–	–	214	189