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Fire performance of blind bolted composite beam to column joints

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ABSTRACT

Blind bolts can be used to connect steel beams to concrete filled steel tubular (CFST) columns, and the obtained composite joints have relatively high initial stiffness, flexural resistance, and ductility at ambient temperature. However, very limited research has been conducted on the fire performance of the blind bolted composite joints. In this paper, eight full-scale blind bolted joints were tested to study their fire performance. The test parameters include: (a) whether fire protection is applied to the steel beam or not; (b) beam load ratio (0.25 and 0.5); (c) type of steel used for the column (stainless or carbon steel); and (d) with or without binding bars in the connection region. The test results indicated that the joint failure was mainly dominated by flexural failure of the steel beam near the panel zone. In general, the blind bolted joints demonstrated very good performance in fire, and no bolt shank fracture or bolt pull-out failure was observed in any joint test. The beam protection or reduction of the beam load significantly increased the fire resistance of the joint, whereas the presence of the binding bars or the type of the steel tube had only moderate influence on the fire resistance.

1. Introduction

Framed structures consisting of concrete filled steel tubular (CFST) columns and steel beams have been widely used in modern construction. In framed structures, beam-column joints are critical elements for ensuring the load transfer among different components and maintaining the integrity of structural systems in fire [1]. Recently, joints with bolted connections are becoming more and more popular due to high reliability of service and ease of installation and inspection [2,3]. However, it is not practical to use standard bolts to connect steel beams to CFST columns due to the lack of accessibility to the interior of the steel tubes. In the last few decades, various blind bolts have been developed, which can be inserted and fastened from the outside of a steel tube [4]. Therefore, blind bolts have been used by a number of researchers to connect steel beams to CFST columns [5–15]. These studies indicate that well designed CFST joints with blind bolted connections are reliable in resisting bending moment, shear and tension forces transferred from adjacent components at ambient temperature.

Fire is a common hazard, and can have disastrous consequences for buildings. Therefore, fire safety must be considered in the design of any new buildings. Existing studies have mainly focused on the fire performance of CFST joints with fin plate, T-stub, reverse channel or external ring connections [16–19], whereas the fire performance of blind bolted CFST joints has received little attention. Recently, Pascual et al. [20] reported temperature field tests of twelve unloaded specimens consisting of a blind bolt that clamped an endplate and a tubular column. The test parameters included the section type of the column (hollow section, CFST section), section size of the column (150 × 150 × 8 mm, 220 × 220 × 10 mm, 250 × 150 × 10 mm, 350 × 150 × 10 mm), and blind bolt type (Hollo-Bolt, extended Hollo-Bolt). The test results indicated that the influence of section size on the temperature of blind bolts was minor. In contrast, the concrete filling significantly reduced the temperature of the embedded bolt shank. A numerical model was developed to conduct heat transfer analysis. Based on sensitivity analysis, a gap conductance of 200 $W/m^2 K$ was recommended for the sleeve to bolt hole surfaces and sleeve to shank interactions. Pascual et al. [21] further developed a finite element (FE) model to predict the fire behaviour of blind-bolts in the tension area of endplate connections between I-beams and CFST columns. In the analysis, two types of connections were analysed, including a single blind bolt connecting a plate to a CFST column and a double T-stub connection to a CFST column. The numerical analysis indicated that the connection failure was dominated by the failure of the bolt shank because of the tensile force, whereas the stress in the bolt sleeve was lower due to the presence of the concrete.

The above literature review indicates that no fire tests have been conducted on blind bolted joints. Since blind bolts are normally manufactured from quenched and tempered carbon steel, they have limited deformation capacity and their strength may dramatically decrease at elevated temperatures. Therefore, there is a need to conduct fire tests on blind bolted joints to provide test data. This paper reports test results of 8 full-scale blind bolted joint specimens subjected to ISO

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834 [22] standard fire. The influence of various parameters on the temperature distribution, failure mode and joint deformation is discussed.

2. Experimental program

2.1. Specimen preparation

A total of eight cruciform joints were designed according to Eurocode 4 [23] and Eurocode 3 [24]. Each joint consisted of a square or circular CFST column, two steel I-beam segments and a composite slab with profiled steel sheeting. A flush end plate with a thickness of 10 mm was welded to one end of the I-beam, and four blind bolts (Lindapter grade 8.8 M20 HB20-1 Hollo-Bolts) were used to connect the steel beam to the steel tube through the end plate, as shown in Fig. 1. According to the installation manual provided by Lindapter International, a recommended torque of 300 N·m was used to tighten all the blind bolts. It should be mentioned that commercially available Hollo-Bolts use rubber washers to increase the clamping force between the connected steelwork. Preliminary tests [25] conducted by the authors indicated that the rubber washers were burned completely after exposed to 800 °C, which greatly reduced the pretension force and clamping mechanism in the Hollo-Bolts. After cooled to room temperature, the loss of pretension force was 77% for the Hollo-Bolts with rubber washers. In contrast, the loss was reduced to 44% when conventional steel spring washer had been used to replace the rubber washer. Therefore, based on these test results, rubber washers were replaced with steel spring washers for the Hollo-Bolts used in the current specimens. The steel spring washer used is shown in Fig. 1. Its inside and outside diameters were 21 and 33.6 mm, respectively; whereas the section thickness was 4 mm. The steel spring washer was manufactured from AISI 4037 alloy steel.

The schematic of the joint specimens is shown in Fig. 2, and the detailed connection configuration is shown in Fig. 3. The geometric details are illustrated in Fig. 4 for the 120 mm thick composite slab. One row of shear studs with a diameter of 19 mm was welded on the top flange of the steel beam to provide full composite action between the steel beam and slab. The total height of the CFST column with two 20 mm thick endplates was 3800 mm, and the total length of the steel beam was 3900 mm.

A summary of the eight joint specimens is given in Table 1, where the first character “S” or “C” in the specimen label denotes a joint with square or circular column section, respectively. In Table 1, D is the width of a square column or diameter of a circular column; t_s is the steel tube thickness; h and b_f are the height and flange width of the I-beam, respectively; t_w and t_f are the web and flange thicknesses of the I-beam, respectively; k is the line stiffness ratio between the beam and column, which is defined as $k = [(EI)_b/L]/[(EI)_c/H]$, where $(EI)_b$ is the flexural stiffness of the composite beam with slab, which can be calculated according to Song et al. [18], and $(EI)_c$ is the flexural stiffness of the CFST column, which can be calculated according to Eurocode 4 [23], L is the length of the beam and H is the height of the column; n is the column load ratio, which is defined as $n = N_F/N_u$, where N_F is the axial load applied to the column, and N_u is the axial compressive capacity of the column at ambient temperature and can be determined by using the FE model developed by Hassan [26]; m is the beam load ratio, which is defined as $m = P_F/P_u$, where P_F is the vertical load applied at the beam tip, and P_u is the ultimate capacity of the composite beam at ambient temperature and can be determined by using the FE model developed by Hassan [26].

As indicated in Table 1, there are four major test parameters, including whether or not protecting the steel beam, beam load ratio, type of steel used for the column and presence of binding bars in the connection region or not. For specimen SB0-1, a layer of 30 mm thick ceramic fibre blanket was used to protect the upper column, and the top and side surfaces of the composite slab. Except for these components being protected, the I-beams in all other specimens were also protected using the same ceramic fibre blanket with a same thickness. The detailed arrangement of the ceramic fibre blankets is illustrated in Fig. 2. It is expected that the ceramic fibre would minimise the heat transfer from the environment to the protected parts during fire exposure. A total of six specimens adopted square columns, whereas circular columns were used for the remaining two specimens. For specimens with square columns, SB0-2 and SB1-1 were identical but had different beam load ratios, which were 0.5 and 0.25, respectively. Similarly, the beam load ratios for the two specimens with circular columns (CB2-1 and CB2-2) were chosen as 0.5 and 0.25, respectively. Since this research was part of a project to develop hybrid stainless-carbon steel composite beam-column joints, grade 1.4301 austenitic stainless steel tubes were used for all columns, except that traditional carbon steel was used to fabricate the steel tube for specimen SB1-3. All steel tubes were cold-formed from steel sheets with a thickness of 5 mm. To restrain the pull-out failure of blind bolts, different methods have been suggested by various researchers to reinforce the blind bolt system. Tizani and Pitrakkos [27] suggested a type of extended Hollo-Bolt system, which involves extending the shank of the blind bolt and adding a nut that will be anchored in the concrete. Li et al. [28] proposed a strengthening method using binding bars to tie the opposite surfaces of the steel tube together. Their test results indicated that the binding bars were effective in improving the stiffness and strength of blind bolted joints with square columns at ambient temperature [14,28]. In this paper, two binding bars were used in specimen SB1-2 to check their influence on the joint performance in fire. The diameter of the binding bars was 20 mm, and their positions are shown in Fig. 3(a) and (c). No binding bars were used in other specimens.

2.2. Material properties

In practice, the concrete strength of slabs is generally lower than that of columns. Therefore, two commercial concrete mixes were employed to fabricate the composite slabs and fill the tubes, respectively. At the time of testing, concrete cube compressive strengths for the composite slabs and columns were 49.4 and 58.2 MPa, respectively. For different

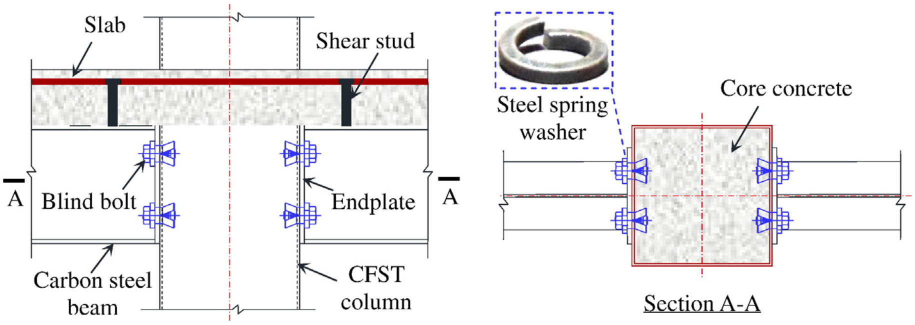

Fig. 1. Blind bolted connection.