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Thermal behaviour of blind-bolted connections to hollow and concrete-filled steel tubular columns

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A B S T R A C T

This paper reports on the thermal analysis of blind-bolts connected to concrete filled steel tube (CFST) and hollow steel section (HSS) columns. The aim is therefore the investigation of the temperature distribution in the connected sections and the evaluation of the effects due to concrete filling and anchored bolt extension. For this purpose, experimental and numerical work was carried out. The test programme involved twelve small-scale unloaded specimens where the variables were: tube section dimensions, type of blind-bolt, and hollow or concrete filled steel tubes. Results from the experiments revealed the noteworthy effect of concrete on bolt temperature reduction, the insignificant influence of tube section dimensions, and the limited impact of embedded bolt extension. Finite element models (FEM) of connections were developed to simulate the behaviour of tested pieces. Comparison with tests allowed the calibration of thermal material properties and characteristics of heat flux in interactions. Furthermore, assessments of heat transfer problem on the simulation of small-scale pieces extended to the numerical model of the whole endplate connection between an I-beam and a tubular column. Finally, the suitability of simple methods from Eurocode 3 Part 1.2 and other references to obtain the temperature on the connection was evaluated.

1. Introduction

Besides the load bearing capacity, convenient aesthetical appearance and construction facilities, one of the most valuable advantages of CFST columns is its appropriate behaviour in fire. The concrete infill acts as a heat sink, which delays the rise of temperatures in the cross-section, at the same time that steel works as a shield and maintains the integrity of the element [1]. The thermal analysis of CFST columns has been covered in several researches, however, their connection with the beam is usually not studied. The lack of knowledge of the thermal behaviour of connection between the beam and column has made designers solve the problem by providing the same protection as in the elements joined. Nonetheless, catastrophic fires [2,3] have demonstrated the crucial role of connections in the building failure and the necessity of its further study.

Up to now, the studies of fire behaviour of endplate bolted connections are scarce. Initially they were limited to joints between I-section steel beams and open sections steel columns. For instance, Al-Jabri et al. [4,5] developed experimental and numerical work to produce relevant data and insight into flush endplate bolted steel connections at elevated temperatures. On the other hand, Wang et al. [6] and Dai et al. [7] carried out tests and simulations of 10 medium scale assemblies that included five different types of joints to open section steel columns. They studied the forces generated in connections during the fire due to restrained beam deformations.

In connections to CFST or HSS columns, the bolted solution has to use special fasteners able to be tightened from one side of the tube, called blind-bolts. Several types of blind-bolts exist, but Hollo-bolt system (Lindapter International, UK) was chosen for this study due to its easy assembly and its feasibility of resisting bending moments [8]. The Hollo-bolt is mainly made up of three parts (Fig. 1a): a standard bolt, a sleeve with four slots, and a cone with a threaded hole where the bolt is screwed. The Hollo-bolt works as follows [9]: firstly, the piece is inserted in the elements to join through clearance holes, then the bolt is tightened, so that the threaded cone moves against the inner face of the tube expanding the sleeve legs until the total clamping force is transmitted.

In recent years, the advantages of Hollo-bolt system have raised the interest of numerous researchers. Elghazouli et al. [10] studied, through experimental tests, angle connections between beam and tubular unfilled column by using Hollo-bolt under monotonic and cyclic loads. Their experimental programme also included tension tests on the blind-bolts that gave notice of the tension behaviour of the bolt system. Liu et al. [11,12] examined the same type of connections first subjected to shear loads and then to axial loads. Column and angle thickness together with the distance between Hollo-bolt and beam flange, were the principal parameters that influenced joint capacity and

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Notation

A/V	Section factor
CFST	Concrete filled steel tube
D	height of the beam
EC3	Eurocode 3. Part 1.2
EC4	Eurocode 4. Part 1.2
EXP	Experimental
EHB	Extended Hollo-bolt fastener system
FEA	Finite element analysis
FEM	Finite element model
f_c	Compressive cylinder strength of concrete at room temperature
f_y	Yield strength of structural steel at room temperature
f_u	Ultimate strength of structural steel at room temperature
HSS	Hollow steel section
HB	Hollo-bolt fastener system
h	depth in the connection
t	thickness of steel tube column
UHB	Hollo-bolt in an unfilled section
θ	temperature

deformation. Their studies comprised numerical analysis and component characterisation with a good adjustment to the experimental results. In addition, strength and stiffness of Hollo-bolt system in a T-stub connection was assessed by Wang et al. [13], who aimed to obtain a theoretical expression in the framework of component method. They noted the higher flexibility introduced by the sleeve ductile behaviour.

A modification of this type of blind-bolt (Fig. 1b), called the Extended Hollo-bolt, was developed at the University of Nottingham [8,14] in order to be used in CFST connections. The novelty was the use of a longer shank that ended in a screwed nut whose purpose was to take advantage of the concrete infill to improve the connection stiffness and be able to resist bending moments. Eight full-scale tests were carried out by Tizani et al. [8] on flush endplate connection to CFST columns with Extended Hollo-bolt, where results proved the enhancement provided by the bolt anchorage. It avoided stress concentration in the tube and the sleeve, distributing it within the concrete, at the same time that enabled the full development of tensile bolt strength. A more detailed study, focused on bolt behaviour was undertaken by Pitrakkos and Tizani [14], who distinguished four mechanisms involved in Extended Hollo-bolt behaviour: internal bolt elongation, expanding sleeves, shank bond and anchorage.

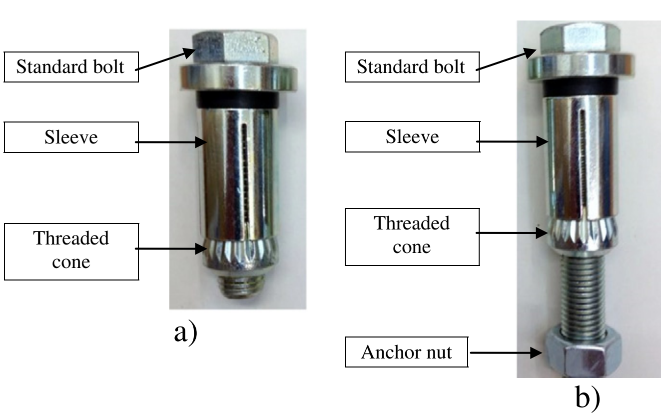

Fig. 1. Blind-bolts: a) Hollo-bolt type, b) Extended Hollo-bolt type.

Hence, the blind-bolt performance at room temperature has been studied by several researchers but there is still a gap in its understanding under fire conditions. In this respect, the European funded project COMPFIRE [15] has provided a helpful insight into the thermal behaviour of connections to partially encased composite columns and concrete filled tubular columns. This was preceded by the work of Ding and Wang [16,17], who tested four different types of joints to CFST column in fire and one of them used a blind-bolt (the Molabolt). However, none of the previous researches studied deeply the effect of the blind-bolt. On the other hand, it is noteworthy the discussion and contribution from Ding and Wang [17] to simplified temperature calculation methods of Eurocode 3 Part 1.2 (EC3) [18].

This paper deals with the thermal analysis of blind-bolts in endplate connections to HSS and CFST columns. Small-scale experiments and numerical models to obtain temperature distribution were conducted. The test programme involved twelve specimens with a single blind-bolt where variables were: section dimensions, Hollo-bolt or Extended Hollo-bolt, and HSS or CFST column. The aim of the work was to understand and evaluate the effect of these three variables.

Later on, the finite element models (FEM) of the tested specimens were carried out to simulate the heat transfer of the connections. An analysis of the thermal properties of materials and their interactions was accomplished by comparison with laboratory data. Numerical simulations were completed with models of the whole connection beam to column in order to verify the conclusions from the small-scale models.

Finally, the simplified methods of EC3 [18] and additional proposals developed by three researches were discussed. The suitability of these methods to calculate the temperature of blind-bolts in connection to HSS and CFST columns was evaluated by means of comparison with the experimental and numerical results.

Moreover, this work will provide valuable information for further thermo-mechanical calculations of these connections.

2. Experimental tests of the thermal response

Due to the lack of experimental data about the thermal behaviour of blind-bolts, a test programme of twelve unloaded specimens (Table 1 and Fig. 2) was undertaken. For the sake of simplicity, samples with only one fastener were used. As it is shown in Fig. 3, they consisted of a blind-bolt (Hollo-bolt fastener system) that clamped a steel plate (equivalent to endplate) and a tubular section (a piece of HSS or CFST column).

Table 1
Fire tests specimens.

Specimen index	*Type of bolt*	*Shank Length (mm)*	*Type of section*
Series 1-Section 150 × 150 t = 8 mm			
UHB16-8.8D-150 × 150 × 8	Hollo-bolt	75	HSS
HB16-8.8D-C30-150 × 150 × 8	Hollo-bolt	75	CFST
EHB16-8.8D-C30-150 × 150 × 8	Extended Hollo-bolt	120	CFST
Series 2-Section 220 × 220 t = 10 mm			
UHB16-8.8D-220 × 220 × 10	Hollo-bolt	75	HSS
HB16-8.8D-C30-220 × 220 × 10	Hollo-bolt	75	CFST
EHB16-8.8D-C30-220 × 220 × 10	Extended Hollo-bolt	120	CFST
Series 3-Section 250 × 150 t = 10 mm			
UHB16-8.8D-250 × 150 × 10	Hollo-bolt	75	HSS
HB16-8.8D-C30-250 × 150 × 10	Hollo-bolt	75	CFST
EHB16-8.8D-C30-250 × 150 × 10	Extended Hollo-bolt	120	CFST
Series 4-Section 350 × 150 t = 10 mm			
UHB16-8.8D-350 × 150 × 10	Hollo-bolt	75	HSS
HB16-8.8D-C30-350 × 150 × 10	Hollo-bolt	75	CFST
EHB16-8.8D-C30-350 × 150 × 10	Extended Hollo-bolt	120	CFST