Structures 4 (2015) 105–113

Contents lists available at ScienceDirect

Structures

journal homepage: http://www.elsevier.com/locate/structures

Advanced materials for concrete-filled tubular columns and connections

Ana Espinos, Manuel L. Romero *, Antonio Hospitaler, Ana M. Pascual, Vicente Albero

Instituto de Ciencia y Tecnología del Hormigón (ICITECH), Universitat Politècnica de València, Valencia, Spain

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form 27 August 2015
Accepted 28 August 2015
Available online 6 September 2015

Keywords:
Concrete-filled steel tube
Fire resistance
Advanced materials
High strength steel
Fire-resistant steel
Blind-bolts
Shape memory alloys
Superelastic

ABSTRACT

The advantages of concrete-filled steel tubular (CFST) columns are well known at room and elevated temperatures, however, beyond a certain slenderness their load-bearing capacity starts to decrease. Besides, blind-bolts represent a proper system to allow endplate bolted connections to hollow steel tubular columns and CFST, although the resistance of the bolt shank conditions affects the performance of the connection. In this paper, the use of innovative materials is proposed as a method of enhancing of the load-bearing capacity for both CFST columns and connections. In this line, a first approach of the benefits using high strength steel, fire-resistant steel and geopolymer concrete applied for CFST columns in the fire situation is developed, obtaining better fire results although depending on the columns cross-sections configuration and the part where the advanced material is applied. Related to blind-bolts connections under fire conditions, the use of fire-resistant bolts is assessed. Their higher strength retention in fire could avoid the use of protection, but only in limited cases. Furthermore, a preliminary study on shape memory alloys in the blind-bolts is performed at room temperature and supporting cyclic pull-out loading.

1. Introduction

This paper deals with innovative materials in Concrete-Filled Steel Tubular (CFST) columns and blind-bolted connections to hollow steel section columns and CFST columns. CFST columns are being increasingly used in modern buildings due to their high load-bearing capacity, elevated ductility and, in particular, their higher fire resistance as compared to traditional steel solutions. Besides, the connection between beam and tubular columns represented initially a handicap for designers due to the scarce knowledge and data, but nowadays several commercial fastener systems (including blind-bolts, able to be tightened form one side of the columns) have proved their ability to provide the required capacity.

The purpose using advanced materials is the resistance enhancement at room temperature and under fire conditions of both CFST columns and connections.

In the case of CFST columns with high slenderness, the fire performance limits their use, as already proved in previous experimental (Romero et al. [1], Moliner et al. [2]) and numerical (Espinos et al. [3, 4]) investigations. Two strategies can be considered to increase the fire resistance of CFST columns: On one hand the usage of innovative cross-sections like double-skin and double-tube columns (Zhao et al. [5,6], Han et al. [7] or Romero et al. [8]), and on the other hand the improvement of the fire resistance by using advanced materials in columns and connections. Nonetheles, in this paper the emphasis is on the materials.

Regarding blind-bolted connections between beam and tubular column, the capacity of the blind-bolt is usually determining the connection resistance. The use of new bolt materials represents a method of enhancement at room and elevated temperatures [9,10].

High strength steels (HSS) with a yield strength (fy) over 420 MPa are acquiring an increasing popularity in the construction market, having been used in recent construction, such as the “Freedom Tower” in New York (USA), the Olympic Stadium “Bird's Nest” in Beijing (China) or the Millau viaduct (France) [11].

In structural steelwork, high strength steels allow using less material amount, which in turn reduces the costs associated to construction, transport and assembly. Regarding their behavior at elevated temperature, limited information exists in the literature and the building codes do not include design recommendations for this type of steels in the fire situation. Only results from Lange and Wohlfeil [12], Schneider and Lange [13] and Outinen [14] on HSS S460, or Chen et al. [15] and Chiew et al. [16] for HSS S690 can be found. Recently, Qiang [11,17, 18], investigated the properties at elevated temperatures of HSS S460, S690 and S960, proposing reduction coefficients of the mechanical properties of these steels at elevated temperature based on experimental results, see Fig. 1. Tondini et al. [19] conducted three fire tests on circular hollow sections (CHS) and an additional fire test on a CFST column using HSS, where the superior performance of these steels was proved. Besides, other report from Zhao et al. [20] based on recent research works in HSS tubular members and connections can be pointed out.

* Corresponding author.
E-mail address: mromero@mes.upv.es (M.L. Romero).

http://dx.doi.org/10.1016/j.istruc.2015.08.006

Notation

CFST	Concrete-filled steel tube
CHS	Circular hollow section
HSS	High strength steel
FE	Finite element
FR	Fire resistant
FRR	Fire resistance rating
f_y	Yield strength of steel
f_u	Ultimate strength of steel
HB	Hollo-Bolt
SMA	Shape memory alloy
UHB	Unfilled Hollo-Bolt

Concerning Fire Resistant (FR) steels, their recent development is motivated by the higher fire resistance requirements on the building codes. One of the ways for meeting these requirements is to use external protection (mineral wool, intumescent coating, etc.) to limit the temperature of the steel members. However, these options increase the construction costs and require a periodic maintenance. In turn, through the use of FR steels, external protection is only needed for temperatures over 600 °C [21], which allows for a significant reduction of the use of passive protection, being most of the times unnecessary. Thus, the use of FR steels reduces the construction costs and times, while it allows for a more efficient use of space.

The improvement in the mechanical properties at elevated temperatures of FR steels is due to their different chemical composition and the hot rolling process itself. According to the studies by Sakumoto et al. [22,23,24], while the yield strength of conventional steels starts to decrease around 350 °C (2/3 of its value at room temperature), the yield strength of FR steels remains over 2/3 of its room temperature value above 600 °C (Fig. 2), which means a significant increase of strength as compared to conventional steels.

Kelly and Sha [25] confirmed that the mechanical properties of FR steels at elevated temperatures are higher than those of conventional steels, retaining a 50% of their room temperature capacity up to 650 °C.

These steels have been tested by authors as Chung et al. [26] in beams forming steel connections, proving their better fire performance. Their utility in steel columns was verified through a fire test carried out in Japan [21], where it was found that the fire resistance time of a column using FR steel was higher than that of a column of the same dimensions fabricated with a conventional steel.

Fire resistant steel bolts were tested by Sakumoto et al. [27] under tensile and shear loads. Specific reduction factors were obtained which evidenced the higher strength retention capacity of this type of bolts in comparison with conventional steel (Fig. 3).

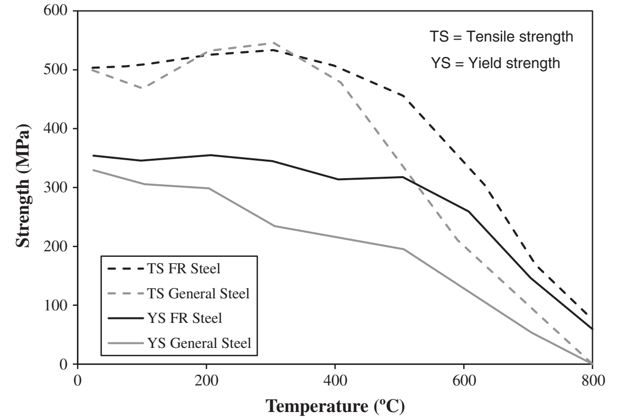

Fig. 2. Comparison of the loss of strength with temperature of FR steels against general steels. Adapted from [22,23].

Other innovative materials are Shape Memory Alloys (SMAs) whose ability to recover their shape after suffering large deformations has found application in many fields, e. g. for medical applications, in the aerospace industry or for seismic structural design. SMAs present two unique properties: shape memory effect, that involves a recovery while through heating when the SMAs are deformed in its martensitic form; and superelastic effect, when deformation under their austenitic form is recovered removing the load. The last SMAs property makes them highly appropriate for seismic resistant design. Their recentering and energy dissipation capability have attracted the attention of researches and engineers. During the last decade the effort to increase the knowledge and application of these materials has been reflected in several investigations. For instance, DesRoches et al. [28] tested SMA wires and bars, comparing their characteristics under different sizes, loading histories and loading rates. The superelastic effect on the cyclic behaviour of beam to column connections has been also undertaken by Fang et al. [29] and Yam et al. [30] in end-plate connections, Wang et al. [31] in connections to CHS columns or Hu et al. [32] in partial restraint connections to CFST columns.

Apart from steel, the enhancement in the case of CFST columns can be achieved by a better performance of the concrete. In that respect, the use of geopolymer concrete has been considered. This type of concrete is an aluminosilicate binder, an alternative to Portland cement, which can promote the sustainability in the cement and concrete industry in terms of CO_2 emissions and production energy requirement [33].

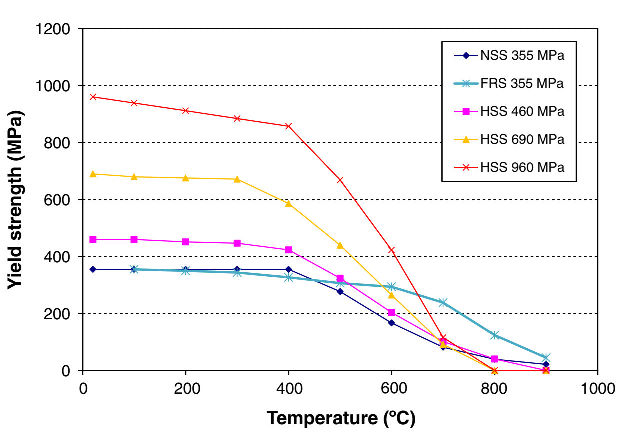

Fig. 1. Reduction of yield strength with temperature, for different steel grades.

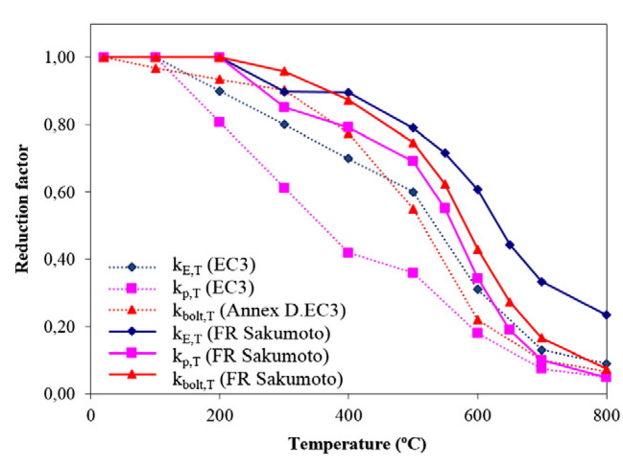

Fig. 3. Reduction factors from Eurocode 3 Part 1.2 Annex D [41] and for FR steel bolts from Sakumoto et al. [27].