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Experimental investigation of square concrete filled stainless steel tubular stub columns after exposure to elevated temperatures

Yu Chen[a,b,*], Kang He[a], Shaohua Han[b], Jiangang Wei[a]

[a] College of Civil Engineering, Fuzhou University, Fuzhou 350116, China
[b] School of Urban Construction, Yangtze University, Jingzhou 434023, China

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ABSTRACT

The behaviour of square concrete filled stainless steel tubular (CFSST) stub columns after exposure to elevated temperatures under axial compression is presented in this paper. A total of sixty-nine specimens were tested, including forty-eight square CFSST stub columns at elevated temperatures cooled in air, nine square CFSST stub columns at elevated temperatures cooled in water and twelve square CFSST stub columns left untreated at ambient temperature. A total of twelve square CFSST stub columns were carried out load-strain tests. The main parameters explored in the test include thickness (1.0 mm, 1.2 mm, 1.5 mm, 2.0 mm), concrete strength (C20, C30, C40), temperatures ranging from 400 °C to 1000 °C and cooling methods. This paper presents the failure modes, ultimate load-bearing capacity, load-strain curves, load versus displacement curves, initial compressive stiffness at the elastic stage and ductility of the specimens. It was found that high temperature had the greatest influence on the ultimate load-bearing capacity of the columns, and the cooling methods also had some effect on it. As the elevated temperature to which the specimens were subjected increased, the percentage of the ultimate load-bearing capacity decrease had an obvious increase and the ductility of the specimens was enhanced. The initial compressive stiffness decreased evidently as the temperature increased to 800 °C. A new failure mode was identified without visible corner crack in the specimens after exposure to elevated temperatures compared with the specimens at ambient temperature. The ultimate load-bearing capacity increased and the axial deformation versus load curves had a longer elastic stage as the concrete strength increased.

1. Introduction

Due to its strong corrosion resistance, easy maintenance and aesthetic characteristics, stainless steel is widely used in the field of civil engineering. The design methods and theories for stainless steel structures at room temperature have been thoroughly developed. However, there is little attention on the fire resistance of stainless steel. For aesthetic purposes, little fire prevention measure has been used in stainless steel structures. Therefore, it is of great significance to study the mechanical properties of stainless steel after exposure to elevated temperatures.

In the past decades, there have been some experimental researches on mechanical properties of stainless steel structures in fire and post-fire. Tondini [1] investigated the performance of EN 1.4003 ferritic stainless steel hollow section columns exposed to fire. Han et al. [2] carried out experimental tests to investigate the experimental behaviour of five full-scale circular and square concrete filled stainless steel tubular (CFSST) columns subjected to axial compression under standard fire test conditions. The differences of fire performance between the stainless steel and carbon steel composite columns were identified. Heidarpour et al. [3] carried out experimental tests to investigate the behaviour of square and triangular fabricated stub columns consisting of Grade 316 L stainless steel tubes and Grade 350 mild steel plates at ambient and elevated temperatures. And the results obtained from the experimental tests were compared with those given by finite element modeling, whereas the accurate prediction of the failure modes was demonstrated. New models for thermal conductivity of concrete and thermal contact conductance at the interface are proposed by Tao [4]. The results of numerical simulations tallied with extensive experimental results when the proposed models were used in the heat transfer analysis. A series of tests have been carried out by Tao [5] to investigate concrete-filled stainless steel tubular (CFSST) columns in fire and after fire exposure. The main variables explored in the test program include: cross-section type, axial load level and presence of reinforcement or

* Corresponding author at: College of Civil Engineering, Fuzhou University, Fuzhou 350116, China.
E-mail address: kinkingingin@163.com (Y. Chen).

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Nomenclature

Th	Thickness of square steel tube
C	Concrete strength
Te	Temperatures square steel tube subjected to
B	Overall width of square steel tube
H	Height of square steel tube
E_0	Elastic modulus of stainless steel
$\sigma_{0.2}$	0.2% proof strength of stainless steel
σ_u	Ultimate stress of stainless steel
δ	Elongation of the specimen
f_{cu}	Standard concrete cube compressive strength
N_u	Ultimate strength of square stainless steel tube
N_{eu}	Experimental ultimate load-bearing capacity
Per	Percentage of ultimate load-bearing capacity decrease
N_y	Yield load of the specimen
k_i	Initial stiffness at elastic stage of the specimen
Δ_y	Yield displacement
Δ_u	Ultimate displacement
Δ_u/Δ_y	Ductility coefficient
ε	Strain of the specimen
Δ	Deformation
P	Load
K_r	Reduction coefficient
N_{au}	Ultimate load-bearing capacity of specimens at ambient temperature
N_{cu}	Calculated load-bearing capacity of specimens after exposure to elevated temperatures
α	Breadth -thickness ratio
β	Parameter of concrete strength
γ	Parameter of high temperature

not. Fan [6] took 8 square sections of stainless steel columns tests to investigate the bearing capacity and failure mechanism of square stainless steel column in fire. The test results show that load ratio and eccentricity are the key factors for critical temperature and fire-resistance performance of the stainless steel column without axial constraints.

Some experiments have been done by researchers focusing on the mechanical properties of concrete filled steel tubular structures in fire and post-fire. Yao and Hu [7] took sixty-one CFST columns tests to investigate the residual strength of specimens subjected to uniform heating or ISO-834 standard fire to benchmark the proposed approach, which was developed to evaluate the residual strength of CFST after fire conditions. Ukanwa and Sharma [8] found that the axial capacity in fire of concrete filled steel tubular columns calculated in accordance with the codes wasn't safe in some design practice. The fire resistance performance of composite columns under different structural boundary conditions was studied by Rodrigues [9] through experimental research. Li et al. [10] took 12 recycled aggregate concrete-filled steel tube stub columns with different recycled coarse aggregate replacement ratios tests to investigate the compressive mechanical behaviors of RACFST stub columns exposed to different elevated temperatures. A study has been made by Wang et al. [11] on the axial compression capacity and buckling load of recycled concrete–filled steel tubular columns by a unified analytical formulation. Rodrigues [12] suggested a simplified procedure to determine the temperature registered in concrete-filled steel columns.

Some researches into mechanical properties of structures in fire have been made through numerical analyses. Lie [13] and Kodur [14] tried to predict fire resistance of CFST columns through numerical analyses. Nonlinear 3-D finite element models have been developed by Ellobody [15] to investigate the structural behaviour of unprotected simply supported composite carbon steel and composite stainless steel beam constructions under fire conditions. Cold-formed steel, stainless steel and composite columns under ambient and fire conditions have been investigated by Ellobody [16] using a consistent nonlinear 3-D finite element. A finite element (FE) study has been made by Patton [17] on concrete-filled lean duplex slender stainless steel tubular stub columns of different sections under pure axial compression.

There were some researches into mechanical properties of stainless steel structures at room temperature. Zhou et al. [18] tried to predict the flexural behaviour of circular concrete filled stainless steel tubular trusses under static load. Hassanein et al. [19] suggested a modified European design model to predict accurately axial compression capacity of the concrete-filled dual steel tubular slender columns. Tao et al. [20] took seven full-scale joints tests to investigate the performance of blind bolted connections to concrete-filled stainless steel tubular columns.

Although many researchers have investigated the fire-resistant performance of stainless steel and concrete filled steel, little research has been carried out on the behaviour of square concrete filled stainless steel tubular stub columns after exposure to elevated temperatures. This paper mainly investigates the performance of square concrete filled stainless steel tubular stub columns after exposure to elevated temperatures under axial compression. Frequent fire accidents have caused great threats to the safety of people's lives and property. In many cases, fire spreads locally before it is put out and doesn't cause building collapse, so recovering service performance of the structures after fire is a way to reduce the economic loss. Research into the residual mechanical performance of concrete filled stainless steel tubular stub columns after exposure to elevated temperatures is of great value to repair and reinforce this kind of structures after fire. The test parameters include temperature square CFSST stub columns suffered, thickness of square CFSST stub columns, and strength of core concrete and cooling methods. The influence of the four parameters on the ultimate load-bearing capacity, ductility and initial stiffness at the elastic stage is presented in this paper. Based on the experimental results, a formula is proposed to calculate the ultimate load-bearing capacity of square CFSST stub columns after exposure to elevated temperatures.

2. Experimental program

2.1. Specimen preparation

A total of 69 square CFSST stub columns were tested. Out of the total 69 specimens, 12 specimens were tested at room temperature and treated as control specimens. And the remaining 57 columns, including 48 air cooled columns and 9 water cooled columns, were subjected to different high temperatures for the same duration. The variables