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Fire resistance of stainless steel beams with rectangular hollow section: Numerical investigation and design

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ABSTRACT

Mechanical properties of materials at elevated temperatures are the key factors of structural fire resistance design. Relative to the carbon structural steel, stainless steel has superior stiffness and strength at elevated temperatures. The fire resistant design method for stainless steel beams was investigated based on prior experimental studies on the 6 rectangular hollow section stainless steel beams in a fire. In this paper, the numerical simulation and analysis for the fire resistance performance of stainless steel beams were performed by the finite element software ABAQUS. The effects of parameters on the fire resistance performance of stainless steel beams were studied, which focused on the load patterns, load ratio, span and section sizes (height, width and thickness) of stainless steel columns. Referring to the design methods for fire resistance of stainless steel in the European Code (EN 1993-1-2) and the European Design Manual, the formulae for ultimate bearing capacity and critical temperature were fitted for rectangular hollow section stainless steel beams in a fire. Comparisons of fitting results with test results and code results indicate that the fitting formulae have a high level of accuracy and can predict the ultimate bearing capacity and critical temperature of the rectangular hollow section stainless steel beams in a fire.

1. Introduction

Compared to conventional structures such as concrete structures and wood structures, the metal members usually have the larger cross-section shape factor, and the thermal conductivity of metal materials is high. Thus, the temperatures inside the metal structure develop rapidly in a fire, and the reactions of the metal structure to the fire are more evident [1]. In recent years, the theoretical calculations and design methods for fire resistance in the steel structure in a fire have been well developed [2–5]. As a construction material, stainless steel has an attractive appearance, a strong resistance to corrosion, low life-cycle costs and easy maintenance [6]. In addition, booming growth in the production of stainless steel together with its great varieties and continuing improvements in processing methods has paved the way for its increased use in building structures in recent years, and under the strong impetus of the construction market, using stainless steel as an architectural material is the new trend in civil engineering and is welcomed by many architects and structural engineers. However, stainless steel structures always lack fire prevention measures for the aesthetic appearance, making the study of the mechanical properties of these structures particularly important.

Relative to carbon steel, stainless steel contains some beneficial alloying elements such as Ni, Cr and Mo, and the strength and reduction of stiffness for stainless steel are less than carbon steel at elevated temperatures. At the same time, the stainless steel is highly nonlinear with a low proportionality limit, which results in a small linear elastic range, are anisotropic and demonstrate obvious strain-hardening [7]. The two mechanical properties of carbon steel and stainless steel are quite different at elevated temperatures; thus, the fire resistant design methods for stainless steel columns are completely different from the fire resistant design methods for carbon steel columns

Some studies have been conducted on the design methods for fire resistance for stainless steel beams. The simplified calculation methods of bearing capacity of stainless steel beams at elevated temperatures are presented in the European Codes (EN1993-1-2/EN1993-1-4) [8,9], considering the influence of the nonuniform moment of beams and the nonuniform distribution of temperatures in the axial direction and cross-section of beams. Gardner and Baddoo [10] conducted full-scale fire tests and parametric

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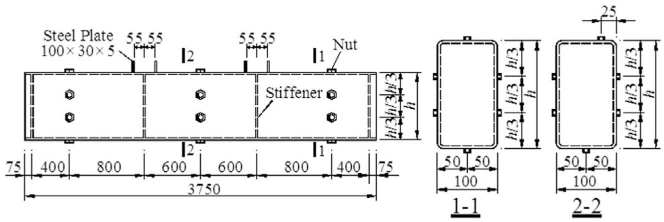

Fig. 1. Detailed dimensions of specimens.

Table 1
Section sizes and parameters of the specimens.

Specimen code	Section size $h\times b\times t$/ mm × mm × mm	Length L/ mm	Load ratio n	$M_{c,y,Rd}$ /kN·m	M_{max} /kN·m
B1	RHS 180 × 100 × 5	3750	0.15	45.88	6.88
B2	RHS 180 × 100 × 5	3750	0.27	45.88	12.39
B3	RHS 180 × 100 × 5	3750	0.39	45.88	17.89
B4	RHS 180 × 100 × 5	3750	0.51	45.88	23.40
B5	RHS 140 × 100 × 5	3750	0.39	30.41	11.86
B6	RHS 220 × 100 × 5	3750	0.39	63.05	24.59

Note: h is the section height of the specimen; b is the width of the specimen; t is the section thickness of the specimen; L is the length of the specimen; $n=M_{max}/M_{c,y,Rd}$ is the load ratio of the specimen; M_{max} is the maximum moment of the mid-span section of specimen in the test; $M_{c,y,Rd}$ is the moment of specimen at room temperature calculated by the software ABAQUS [16,17].

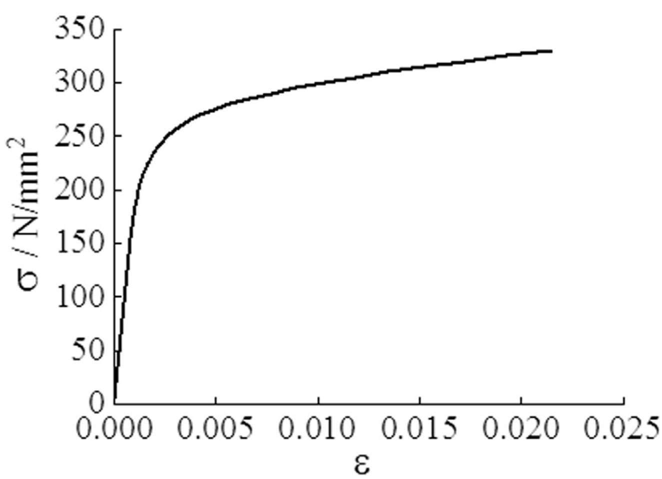

Fig. 2. Stress–strain curves of stainless steel at room temperature.

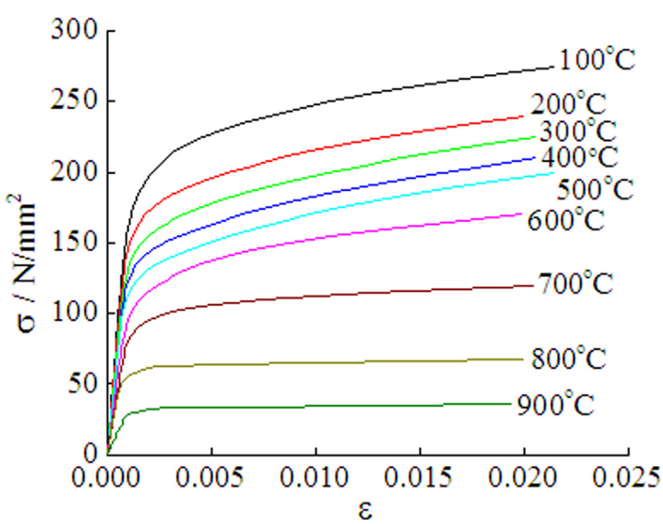

Fig. 3. Stress–strain curves of stainless steel at elevated temperature.

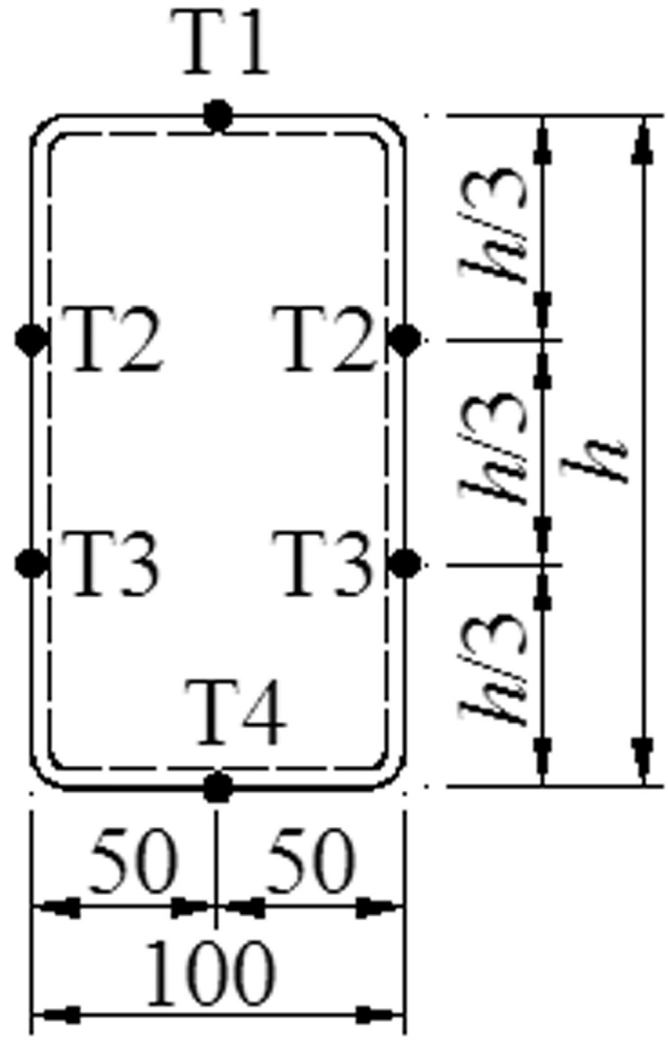

Fig. 4. Arrangement of the thermocouples.

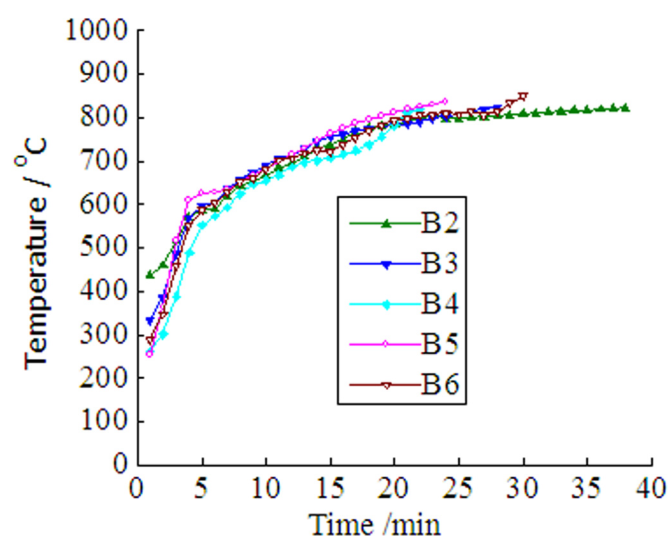

Fig. 5. Heating curves of the furnace chamber.

analysis on 4 stainless steel beams with concrete rib plates, and the design methods for fire resistance for stainless steel beams were recommended. Zhao and Blanguemon [11] conducted fire