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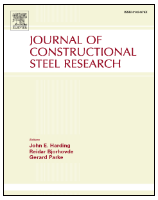

Structural behavior of extreme thick-walled cold-formed square steel columns

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ABSTRACT

This paper describes a study on the extreme thick-walled cold-formed square columns which are manufactured from circular to square shape, of which the width was 800 mm and the thickness was 22 mm. A systematic investigation of material behavior, residual stress distribution, and axial compression performance was performed numerically and experimentally. Results demonstrate thefollowing.1) The material properties of cold-formed columns manufactured by indirect method are clearly changed because of the cold-formed processes and are more uniform than those of cold-formed columns manufactured by direct method. 2)The extreme thick-walled cold-formed square columns work well under axial compression. 3) The residual stresses at the middle and corner parts of extreme thick-walled cold-formed square columnsareapproximately95 and 210 MPa, respectively.

1. Introduction

Cold-formed steel members are widely used in civil engineering because of their high strength-to-weight ratio; their thickness is generally limited to approximately3 mm because of the limitations of cold-forming technology in the early stage. This thickness is much thinner than that of hot-rolled steel section. Nowadays, cold-formed sections with a wall-thickness greater than 6 mm, which are referred to as "thick-walled", are more commonly manufactured and used in civil engineering [1]. They are commonly fabricated as closed shapes, such as circular or square hollow sections, and used increasingly in columns of high-rise buildings. The maximum size for the square hollow section is 800 mm wide by 22 mm thick; this type of section was used in the Tianjin Wanhui Square Project in China.

The cold-formed square hollow sections are divided into two kinds based on the forming processes [2–3]. A cold-formed square hollow section can be formed by rolling an annealed flat strip directly onto a square hollow section, which is then welded at the edges. A cold-formed hollow section can also be formed by first rolling an annealed flat strip onto a circular hollow section, which is then welded at the edges; the process is completed by further rolling onto a square hollow section. In this paper, the former forming process is called "direct square method," and the latter is called "indirect method from circular to square." The different forming processes for cold-formed steel members are known to result in their different mechanical properties, such as yield strength, residual stress distribution, axial compression behavior, and so on.

The material behavior is enhanced by cold-form processing, which make its structural behavior different from the hot-rolled steel members [4–7]. Although many studies have been performed to investigate the mechanical behavior of cold-formed steel members, they were mainly focused on thin-walled cold-formed steel members manufactured by the direct square method [8–13]. These studies provided important data for the design codes of thin-walled cold-formed steel members.

Few studies have analyzed the material properties and strengths of thick-walled cold-formed steel members. Li et al. [14], Li et al. [15], and Hu et al. [5] studied the strain hardening effect experimentally and theoretically for thick-walled cold-formed steel sections with thickness ranging from 8 mm to 12 mm. Guo et al. [1] studied the mechanical behavior of thick-walled cold-formed steel stub columns with thickness ranging from 8 mm to 12 mm under axial loading. Tong et al. [2] studied longitudinal residual stresses for cold-formed thick-walled square hollow sections.

The literature review above shows that past studies only focused on cold-formed thick-walled section, whose cross-section was smaller than 400 mm × 400 mm and whose thickness was thinner than 12 mm. The mechanical behavior of cold-formed thick-walled square

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hollow steel members change significantly with the increase of the cross-section and thickness. Therefore, the present work experimentally and theoretically studies the material properties, structural behavior, and strengths of cold-formed thick-walled steel sections with cross-sections of about 800mm × 800 mm and thickness greater than 22 mm.

2. Experimental scheme

2.1. Specimens design

Two thick-walled cold-formed steel stub columns with same geometric parameters were designed for this test, as shown in Fig. 1. The specimens were manufactured by indirect method from circular tosquare. The cross-section was 800 mm × 800 mm, the thickness was 22 mm, and the height was 2.4 m.

2.2. Material mechanical property

To understand the material mechanical property of the thick-walled cold-formed steel members with different cross-section, a total of 27 tensile coupon tests on three cross-section steel members were performed, as reported in Table 1; the tests included three corner coupons, three near -corner coupons, and three flat coupons from each specimen, as shown in Fig. 2. All these coupons were cut from the longitudinal direction. The geometric size of the coupons from the flat position is shown in Fig. 3(a). The geometric sizes of coupons from the flat corner position and near -corner position are shown in Fig. 3(b). The material properties of the cold-formed steel section for each group were determined as the average value of the three coupon tests from the same position. All the coupon dimensions complied with the Chinese metallic material-tensile testing code [16].

The tensile coupons were tested according to the with the Chinese metallic material-tensile testing code [16] using a 600 kN capacity Universal Testing Machine. The average stress-strain curve for each position is shown in Fig. 4. The average values of yield strength, ultimate strength, yield-strength ratio, and elongation for each position are listed in Table 1. Given that some coupons do not have evident yield platforms, the stress of 0.2% residual deformation was set as the yield strength.

Fig. 1. The geometric size of the tested specimen.

Table 1
The material test results of the cold-formed members.

Square tube	Position	Yield strength (MPa)	Ultimate strength (MPa)	Yield ratio	Elongation
600 × 16	Middle	396	475	0.834	18.50%
	Side	347	447	0.776	28.50%
	Corner	415	501	0.828	19.30%
700 × 20	Middle	375	450	0.833	23.50%
	Side	396	458	0.865	20.00%
	Corner	397	469	0.846	22.70%
800 × 22	Middle	328	434	0.756	30.00%
	Side	399	481	0.83	24.00%
	Corner	386	472	0.818	25.20%

Based on the test results shown in Fig. 4–5 and Table 1, the following conclusions were formed:

1) Almost all tensile coupons experience three stages: yielding, necking, and fracture; the fractures of all tensile coupons are always located at the parallel section as shown in Fig. 5. But several coupons had no yielding stages because the cold-formed process reduced the ductility of the steel materials to some extent.
2) Given that the cold-formed steel members formed by indirect method from circular to square experience the cold forming processes two times, its mechanical properties are more uniform than that of cold-formed steel members manufactured by direct method; this was proven by the test results. The yield strengths for the corner parts were 19.6, 5.9, and 17.68% higher than that of other locations, whereas the yield strengths for corner parts for the cold-formed steel members manufactured by direct method in previous studies were 30–50%. Therefore, the cold forming process has a significant effect on the material properties.
3) In addition to the individual tensile coupons, the mechanical properties of the cold-formed steel members studied in this research meet the following requirements: the elongation must be higher than 20%, and the yield ratio must be lower than 0.85.

The yield strengths of the studied cold-formed steel members were calculated by Formula (1) given in “Technical code of cold-formed thin-walled steel structures”(GB 50018-2002) [17]. f' is the calculated strength value of cold-formed steel. f is the design strength value of steel. η is the coefficent which depends on the shaping method, at this time, the square columns are manufactured from circular columns, so $\eta = 1.7$[17]. γ is the ratio of tensile strength to yield strength, regarding Q235 steel, $\gamma = 1.58$.n is the number of corners of cross section, for the columns here, $n = 4$.θ_i is the central angle of corner which is defined with rad. l is the length of cross section central axial line. t is the thickness of column section. The calculation results are listed in Table 2.

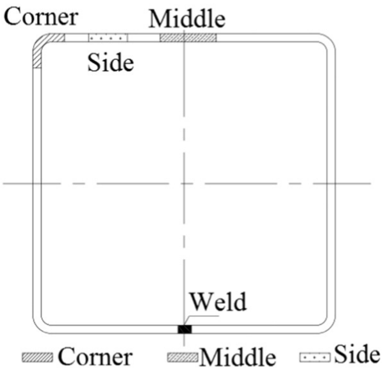

Fig. 2. Specimen sampling position.