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Experimental study on the residual stresses of 800 MPa high strength steel welded box sections

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ABSTRACT

This study presents the residual stresses magnitude and distribution of 800 MPa high strength steel welded box sections. The value of residual stresses is investigated using a method of sectioning, and the effect of width to thickness ratio on the magnitude of stresses is considered in the analysis. From the results of experiment, the influence of width to thickness ratio on the tensile residual stresses in welded zone is small, while the effect of width to thickness ratio on the compressive residual stresses located in the center of plates is large. The maximum tensile residual stresses values change from 0.30 f_y to 0.56 f_y, and the constant compressive stresses ranges from 0.06 f_y to 0.26 f_y. The residual stresses distributed in all cross-section satisfies the self-balancing requirement. Comparison of distribution and magnitude of residual stresses between test data and existing models are made. A simplified model is suggested to estimate the residual stresses distribution of steel welded box section made of 800 MPa high strength steel.

1. Introduction

High strength steel (HSS), which can reduce the weight of structures and cost of buildings, has been widely utilized in civil engineering. 800 MPa plate, a new kind of HSS material, has been developed in Japan and Korea [1–3] and it has been applied successfully in a few super high-rise buildings, such as Midland Square and Tokyo Skytree in Japan [4]. However, the investigation on the performance of 800 MPa compressive members is limited. The residual stresses caused by flame cutting, welding and uneven cooling has a significant influence on the stability of compressive members, and it affects the bearing capacity of steel structure. For the safe design of steel structure, the value and distributing region of residual stresses should be considered in the structural analysis. Hence, it is crucial to develop a model for estimating the distribution and magnitude of steel welded box section made of 800 MPa HSS.

The first study on residual stresses dates back to Nishino, who carried out an experiment to investigate the magnitude of residual stresses for box section [5]. Then, Usami and Rasmussen presented tests to investigate the residual stresses of welded box section fabricated from 460 MPa and 690 MPa steel using the sectioning method [6–8]. Jiang et al. measured the residual stresses for box columns fabricated from HSS plates by the method of hole-drilling [9]. However, these researches just show the experimental data of residual stresses, and models for estimating the residual stresses are not given.

Ban et al. [10] and Li et al. [11] conducted experiments of residual stresses for welding HSS box made of 460 MPa and 690 MPa, and they proposed different simplified distribution models of residual stresses for box section made by 460 MPa and 690 MPa. Ban et al. [12] performed test of Q960 HSS welded box section to investigate the residual stresses distribution. Khan et al. [13] carried out tests to investigate the residual stresses distribution for box section made of HSS plate using single or multiple weld passes. The results of tests showed that the differences of compressive residual stresses between single weld passes and multiple weld passes were not obvious while the tensile residual stresses in sections using multiple weld passes was higher than that of sections using single weld passes [13].

Although previous studies have made great progress, there are no models for estimating residual stresses of box section welded by HSS plate with the strength of 800 MPa. Therefore, the purpose of this paper is to propose a distribution model of residual stresses for welded box columns made of 800 MPa HSS plates using experimental analysis.

2. Experimental study

2.1. Details of specimens

The components, fabricated from the 7-mm-thickness plate made of 800 MPa HSS, are connected by welding using 6 mm fillet welds, which meets the requirement of Chinese Code GB50017-2003 [14]. The gas

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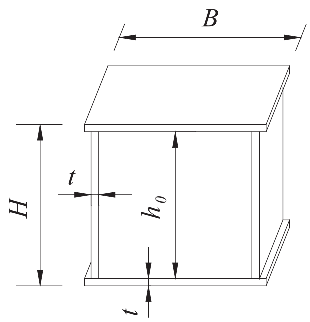

Fig. 1. Geometric parameters of box section.

shielded arc welding (Ar80% and $CO_2$20%) is used during the welding process. The wire type was MK·GHS80, which were made to Chinese norm ER80-G and American norm AWS ER120S-G [15, 16]. The elongation of wire is 17%, and the yield stresses established from the test is 740 MPa. The voltage and current of welding are 26 V, 230 A, respectively. The welding speed is 50 cm per minute. For insuring the requirement of welding, preheating is utilized before welding. Only the fillet welding with single-pass welds is considered in this study. After welding, the quality of weld is inspected according to Chinese Codes GB50661-2011 and GB50205-2012 [17, 18].

As discussed by Ban et al. [10], the value of width to thickness ratio (b/t) is an important parameter affecting the distribution and magnitude of residual stresses. As a result, several types of width to thickness ratio (b/t), ranging from 12.28 to 29.10, are chosen to investigate their effects on the distribution and magnitude of residual stresses. The geometric parameters of four different specimens are shown in Fig. 1 and Table 1. The tensile testing results show that the yield point of 800 MPa HSS is not obvious, and the process of strain harden is not apparent, which are similar with tensile testing results of HSS in Rasmussen's and Shi's [19, 20]. Hence, a stress with 0.2% strain is used to define the yield stress, and the material properties of 800 MPa HSS are shown in Fig. 2. In this figure, f_y is the yield stress, f_u is the ultimate stress, and E is elastic modulus. The specimens of tensile testing after failure are shown in Fig. 3. From the tensile coupon tests, the yield strength of the steel is 791.0 MPa, the elastic modulus is 214.0 GPa, as summarized in Table 2.

2.2. Measurement contents

In this experiment, the residual stresses of weld-up box section fabricated from 800 MPa HSS were tested by the sectioning method [21]. The deformation before and after the segmentation was measured using the Whittemore strain gauge. A representative arrangement of the sectioning method for the welded box section is shown in Fig. 4.

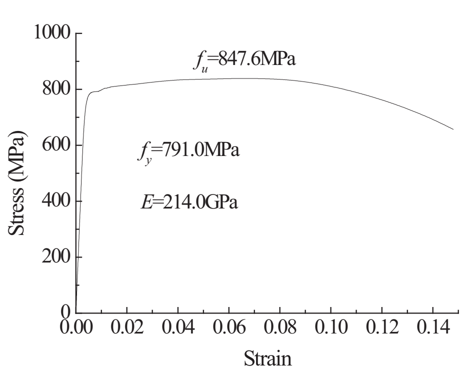

Fig. 2. Stress-strain curve of 800 MPa high strength steel.

Table 1
Geometric parameters of specimens.

Specimens	*H* (mm)	*B* (mm)	*t* (mm)	h_0/t
B1	99.65	99.06	6.98	12.28
B2	138.91	138.64	7.05	17.70
B3	179.68	179.33	7.03	23.56
B4	218.33	218.99	7.02	29.10

Fig. 3. Specimens of tensile testing after failure.

Take specimen B2 as an example, where the length of cut middle zone is 450 mm (i.e. ≥3.0*a*, *a* is the length of cross section) and the length of two ends is 300 mm (i.e. ≥1.5–2.0*a*), so as to ensure that the measured stress distributed over the entire section of steel component can represent the reality [10, 22]. The plates are cut into strips with 10 mm width and 270 mm length. Two holes with a central distance of 254 mm are prepared on each strip to test the deformation of sectioning strip, and the holes are drilled in a cold working condition for reducing the input of the heating energy, as shown in Fig. 4.

The testing progress is divided into four steps: hole-drilling, part-cutting, plate-separating, and strip-cutting, as shown in Fig. 5. More details of this process has already been shown in previous study [21]. The cutting parts and final strips are shown in Figs. 6 and 7. As the inside part has narrow operating space, only the readings outside the plate are considered in this experiment. And each hole of strip must be cleaned before the meterage as the oil pollutes or the residues block the hole.

The temperature correction is utilized to consider the effect of the temperature variation, as shown in Eq. (1) [21].

$$\varepsilon_t = \frac{(l_0 + l_{t3}) - (l_0 + l_{t1})}{(l_0 + l_{t1})} \tag{1}$$

where ε_t is the strain of temperature compensation, l_{t1} and l_{t3} are the distances between two holes of the temperature compensation strip; l_0 is the measuring length of instrument, which is equal to 254 mm.

Table 2
Material properties of specimens.

Specimens	Young's modulus E (GPa)	Yield stress f_y (MPa)	Ultimate stress f_u (MPa)
B1	213.8	792.9	849.6
B2	215.0	803.5	863.8
B3	214.3	782.3	837.8
B4	212.9	785.1	838.9
Average	214.0	791.0	847.6