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# Residual stress of 800 MPa high strength steel welded T section: Experimental study

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ABSTRACT

An experimental study is presented to investigate the residual stress in 800 MPa high strength steel welded T sections using the sectioning method. A total of four different sections with 7 mm thickness steel plates are tested to quantify the magnitude and distribution of both compressive and tensile residual stress. The effect of the width-thickness ratio of web and flange on the distribution of the residual stress is established. The results show the residual stress in all sections is in self-equilibrium. The maximum tensile residual stress locates in the central portion of flange, while the minimum tensile residual stress distributes on both ends of web and flame cutting edges of flange. The maximum tensile residual stress, ranging from $0.43f_y$ to $0.68f_y$, has no obvious relations with the width-thickness ratio of plate. The constant compressive residual stress distributes in the central portion of projecting flange and web. The maximum compressive residual stress, ranging from $0.09f_y$ to $0.46f_y$, decreases as the width-thickness ratio of plate increases, while the area of stress distribution zone increases as the width-thickness ratio of plate increases. A simplified model is suggested for analysis and design based on the magnitude and distribution of residual stress.



## 1. Introduction

As high strength steel can effectively reduce the size of members, weight of structures, and workload for constructing, it is widely used in civil engineering [1–5]. Welded connection, an important type of high strength steel connections, has the advantages of saving of work and materials and absence of drilling and overlap. However, the properties of weld, especially the sectional residual stress, have significant influence on the mechanical performance of steel structural members, such as the structural stiffness, fatigue failure, and stability of compressive members. Therefore, it is important to determine the magnitude and distribution of sectional residual stress for high strength steel structures.

In past years, several researchers have carried out experiments to investigate the residual stress. Kalakoutsky reported on a method of determining longitude stress in bars by slitting longitudinal strips from the bar and measuring their change in length [6]. Then, this method was known as the "sectioning method", and it was utilized by Luxion and Huber to measure residual stress in wide flange beam and compressive member [7,8]. After that, the sectioning method is widely used to measure residual stress and analyze the effect of weld on the strength of structures. Tebedge used two different hole-drilling methods to measure the residual stress in the welded wide-flange section 14H202 of A36 steel [9]. Grondin et al. analyzed the buckling capacity of steel plate stiffened with T shape stiffeners [10]. Faulker, Carlsen, and Smith considered the effect of residual stress on the strength of welded members and developed the related theory [11–13]. Nagaraja et al. investigated the stress distribution of welded box section, H section, and T section using the sectional method [14]. Beg et al. and Rasmussen et al. conducted experiments to study the distribution of compressive residual stress for 690 MPa steel welded I section and box section [15–17]. Wang et al. described the characteristics of residual stress distribution for several kinds of sections [18]. Ban et al. reported the results of residual stress distribution for 960 MPa steel welded I section using the sectioning method, and then they proposed the models of residual stress distribution [19].

As described above, there are some publications discussing the residual stress for high strength steel. However, few studies have concentrated on the residual stress distribution for high strength steel T section. In related codes, such as Chinese Code and Eurocode, the model of stress distribution for high strength steel welded T section is not given [20,21]. Hence, the development of the model of stress distribution for welded T section is necessary. The purpose of this paper is to

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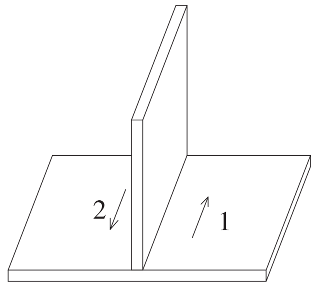


**Fig. 1.** Welding sequence of specimen.

experimentally study residual stress distribution of 800 MPa steel welded T section and establish its magnitude and distribution model.

## 2. Experimental program

### 2.1. Section specimen preparation

All component plates of 800 MPa high strength steel are flame cut with the thickness of 7 mm, and welded together using 6 mm fillet welds, which is according to the size and strength requirement of fillet welds for axial compression member in Chinese Code GB 50017-2003 [20]. The wire type is MK.GHS80, which satisfy the requirement of American code AWS ER120S-G and Chinese code ER80-G [22,23]. The yield stress of wire is 740 MPa, and its elongation after fracture is 17%. The distance between two plates is <2 mm. During the welding process, the gas shielded arc welding is utilized, and the shield gas is composed of 80% Ar and 20% $CO_2$. The welding speed is about 50 cm per minute. The welding current is about 230 A, and the voltage is 26 V. The temperature of welding environment is 25 degrees Celsius. Preheating is required before welding for ensuring the quality of welding, and the specific welding sequence is shown in Fig. 1. As the effect of the welding sequence on the distribution and magnitude of residual stress is not considered in this work, other welding sequence is not used. Fig. 2 shows T sections after welding. The quality of the weld is examined and qualified with Chinese Code for Welding of Steel Structures (GB50661-2011) and Chinese Code for Acceptance of Construction Quality of Steel Structure (GB50205-2012) [24,25]. According to the requirement for T section, four welded specimens are measured in this program, and their geometric parameters are shown in Table 1 and Fig. 3 [26]. From the results of tensile testing, the high strength steel of 800 MPa has no obvious yield point, and the strain hardening is not apparent, as shown in Fig. 4. It is similar with Rasmussen and Shi's

**Table 1**
Geometric parameters of specimens.

| Specimens | B (mm) | H (mm) | $b_f$ (mm) | $h_0$ (mm) | $t_f$ (mm) | $t_w$ (mm) | $b_f$ / $t_f$ | $h_0$ / $t_w$ |
|---|---|---|---|---|---|---|---|---|
| ST1 | 54.63 | 78.92 | 27.32 | 71.91 | 7.01 | 6.98 | 3.90 | 10.30 |
| ST2 | 83.38 | 96.97 | 41.69 | 89.94 | 7.03 | 6.97 | 5.93 | 12.90 |
| ST3 | 110.66 | 105.44 | 55.33 | 98.41 | 7.03 | 6.99 | 7.87 | 14.08 |
| ST4 | 138.91 | 120.23 | 69.46 | 113.21 | 7.02 | 7.04 | 9.89 | 16.08 |

Note: B is the width of specimen; H is the height of specimen; $b_f$ is the half width of flange; $h_0$ is the height of web; $t_f$ is the thickness of flange; $t_w$ is the thickness of web.

experimental results of high strength steel [16,27]. The yield stress, $f_y$, is defined by a stress of 0.2% residual strain, and the material properties are shown in Fig. 4 and Table 2. Fig. 5 shows the specimens after fracture. From four tensile coupon tests, the elastic modulus of 800 MPa high strength steel is 216.3 GPa, the yield stress is 809.0 MPa, and the ultimate stress, $R_m$, is 840.9 MPa.

### 2.2. Sectioning process

Fig. 6 represents a typical cutting arrangement for the welded T sections (taking ST2 for example), where the length of the adopted central portion is 300 mm (i.e. no <3.0 times of the sectional lateral size) and the distance from both ends is 200 mm (i.e. no <1.5–2.0 times of the sectional lateral size) so as to ensure a representative initial residual stress distribution over the entire steel profile [28]. The width of the strip specimens is taken as 10 mm, and its length is chosen as 270 mm. Two holes are prepared on each strip specimen with a distance of 254 mm for measuring the deformation, as shown in Fig. 6.

Fig. 7 shows the sectioning process, and the whole measurement process of residual stress includes four steps. In the first step, holes with 2 mm diameter on the strip specimens are marked and drilled. The chamfer drilling is utilized to eliminate the burr inside the hole. Then initial readings $l_1$ were taken for each couple of holes. In the second step, each specimen is cut into three parts, as shown in Fig. 7. In the third step, the middle part is cut into two parts along the welds between the flange and web, and then the readings $l_2$ for each couple of gage holes are measured to check the reading $l_1$. In the fourth step, the plates are separated into 10 mm strip specimens, as shown in Fig. 8, and the distance of gage holes, $l_3$, is measured again. As the oil or residue can block the hole during the process of the wire cutting, hole cleaning is performed before the measurement. Also the temperature correction is made before the measurement of each strip with a hole due to temperature variation.

**Fig. 2.** Specimen ST2 after welding.

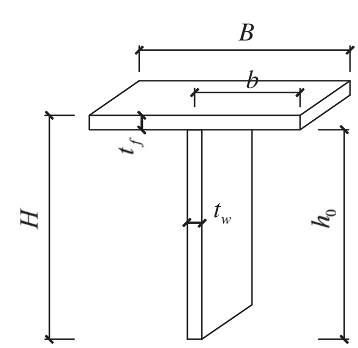


**Fig. 3.** Geometric parameters of T section.