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Introduction

1.1 Research Background

Currently, most steel structures are made of mild steel for its satisfactory mechanical properties and availability. However, there has been an increasing interest in the use of high-strength steel (HSS), which generally has yielding strengths larger than 460 MPa, due to recognition of the benefits from an increase in the strength-to-weight ratio and savings in the cost of materials. One major application of HSS is in jack-up structures. Obvious increases of its application have occurred in the topside areas of jacket structures where the weight saving not only produces overall saving in materials but also allows crane barge installation of more complete topside processing and accommodation units with significant savings. Some HSSs with yield strengths up to 700 MPa have been used in mobile jack-up drilling rigs to minimize weight during the transportation stage (Billingham et al. 2003). In some offshore structures, such as the BP Harding Jack-up and Siri field production Jack-up, HSS has been successfully used.

Another application of HSS is in building and bridge construction. Application of HT780 high-strength steel plate to structural member of super high-rise building can be found (Mochuzihi et al. 1995; Hagiwara et al. 1995).The roof truss of the Sony Center in Berlin sets an example for the use of high-strength steel S690 in buildings (Sedlacek and Muller 2005). This steel S690 is aimed to protect an old masonry building by suspending several stories of the building. The truss structure is made of steel S460 and S690 and it is formed in solid rectangular shapes to keep the dimensions of the cross section small (Figures 1.1 and 1.2). Some examples of the application of HSS can also be found in Asian countries. For example, in Japan Landmark Tower in central Yokohama is the first project using HSS in the construction of buildings. Another application of HSS with minimum tensile strength 600 MPa is the Shimizu super high-rise building, which is 550 m high and comprised of 127 levels, where HSS was used for reducing the column section size. HSS research in Australia was first launched by Rosier and Croll and it was used in the project of Grosvenor Place in Sydney in 1989.

It can be found that HSS is more widely used in construction engineering for its advantages in economy, architecture, sustainability, and safety when compared

Welded High Strength Steel Structures: Welding Effects and Fatigue Performance, First Edition. Jin Jiang.

Figure 1.1 Sony center in Berlin.

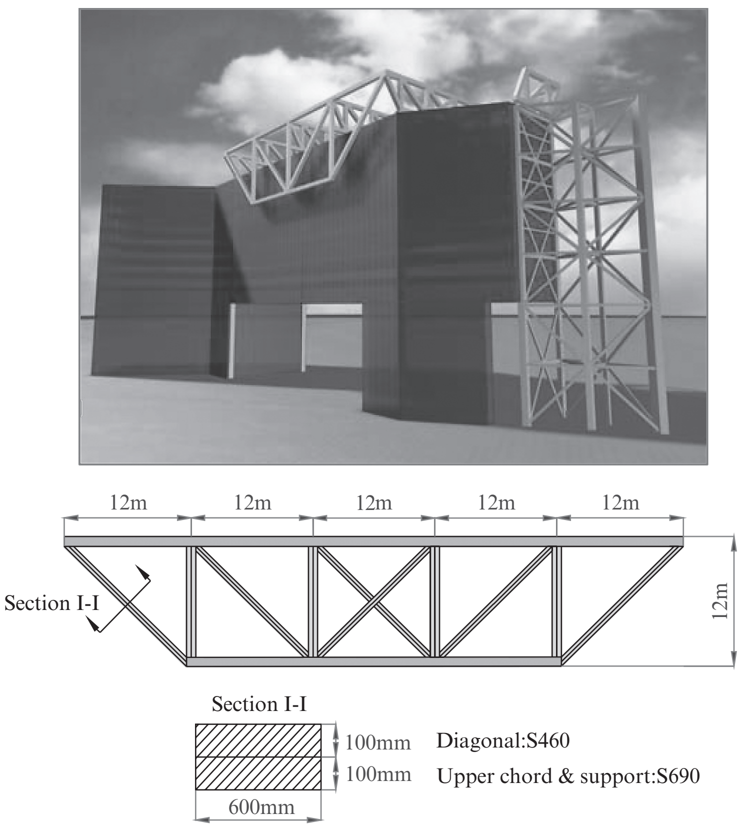

Figure 1.2 Application of HSS in Sony center in Berlin.

with mild steel. The weight and size of the structural sections can be reduced by using HSS and hence fabrication and erection costs can be reduced. Aesthetic and elegant structures can be achieved by using HSS to reduce the size of structural sections. In addition, the use of HSS means reduced consumption of raw materials and is beneficial in sustainability. Figure 1.3 shows the development of the production processes for rolled steel products. It is shown in Figure 1.4 that by increasing the strength of steel the structural section can be reduced, followed by a reduction of structure weight (Sedlacek and Muller 2005).

On the other hand, the stress-strain behavior of HSS is different from the stress-strain behavior of mild steel, since HSS shows reduced capacity for strain hardening after yielding as well as reduced elongation. Therefore, HSS generally has lower ductility than mild steel. Also, HSS is difficult to weld due to its much higher carbon and alloy contents than mild steel. The residual stress due to the welding may have

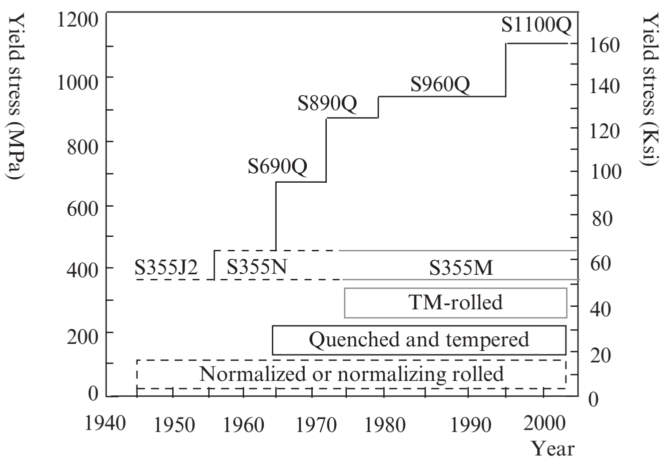

Figure 1.3 Historical development of production processes for rolled steel products (Sedlacek and Muller 2005).

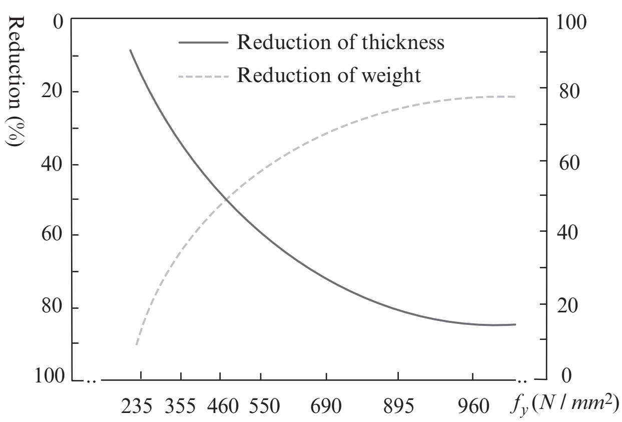

Figure 1.4 Reduction of wall thickness and weight with increasing strength of steel (Sedlacek and Muller 2005).

significant influence on the fatigue performance of HSS structures. In addition, fatigue is one of the major problems causing the HSS structures' degradation in long term integrity when cyclic load exists.

Unlike mild steel, which can be provided in rectangular hollow section (RHS) and circular hollow section (CHS), HSS, especially for the steels with yielding stress larger than 690 MPa, is mainly supplied in plate form. Therefore, when HSS is to be used in tubular structures, it is necessary to form the box sections firstly by welding. Box hollow section joints are then fabricated by welding the profiled ends of the braces onto the surface of the chord. When the HSS box joint is under cyclic loading, fatigue failure initiates at the intersection part due to the stress concentration effect, which is caused by the weld profile and residual stress. However, most fatigue design standards only cover the steels with the yielding stress less than 500 MPa. Fatigue performance data for the welded HSS box section joint is rare. In addition, many investigations of the fatigue analysis for RHS and CHS joints assume that the residual stress due to the welding in the intersection of brace and chord can be ignored. However, this assumption may not be suitable for HSS box section joints. The distribution of welding residual stress in HSS box joints and the influence of welding parameters on the residual stress files are still lacking data.

Welding method, welding position, and welding parameters such as welding speed, preheating temperature, and weld pass are of importance in view of residual stress. The welding residual stress field can be diverse when different welding processes are used. In practice, arc welding prevails in steel structure construction because of its simplicity and ease of handling in the field. Welding power is supplied to create and maintain an electric arc between the base material and an electrode to melt metals at the welding position. Due to highly localized heat input during the arc welding, microstructure and properties in the base material near the weld are altered. The cooling rate at different locations of the base material is different, causing thermal strain and stress in the welding process. In order to investigate the welding residual stress on the welded joints, many experimental works can be found (Teng et al. 2001). However, most of these works are based on simple butt welds with base material less than 460 MPa. In addition, numerical modeling of residual stress has advantages in understanding the impact of welding parameters. However, few works on the modeling of the residual stress in HSS box T/Y-joints can be found in the literature.

1.2 Objectives and Scope

Based on the discussion above, the main objectives of this book focus on the residual stress and its effect on stress concentration for plate-to-plate T/Y-joints and box T/Y-joints fabricated using HSS with yield stress up to 690 MPa. In particular, attentions are given in the following areas:

- To experimentally investigate the residual stress distribution of welded plate-to-plate T/Y-joints which are fabricated with HSS with yielding stress up to 690 MPa.
- To numerically model the residual stress fields of the HSS plate-to-plate T/Y-joints corresponding to the specimens used in experimental investigation and to validate the accuracy of the numerical models.

- To experimentally investigate the residual stress distribution of welded HSS box T-joints and to evaluate the effect of preheating on the residual stress magnitude near the intersection of the joints.
- To experimentally and numerically investigate the stress concentration factors in the intersection part of the HSS box joints under basic and combined load cases.
- To numerically model the residual stress fields of the HSS box T/Y-joints corresponding to the specimens used in experimental investigation and to organize parametric study to evaluate the impact of joint geometry and welding parameters on the residual stress field.

In order to achieve the proposed objectives, the scope of this book is outlined below. At the same time, Figure 1.5 shows the organization of the thesis.

- To explore the residual stresses distribution in welded HSS plate-to-plate joints. To find the distribution of residual stresses at different conditions, 18 plate-to-plate HSS joints, with different intersection angles, base plate thicknesses, preheating temperature, and cutting treatment, will be examined.

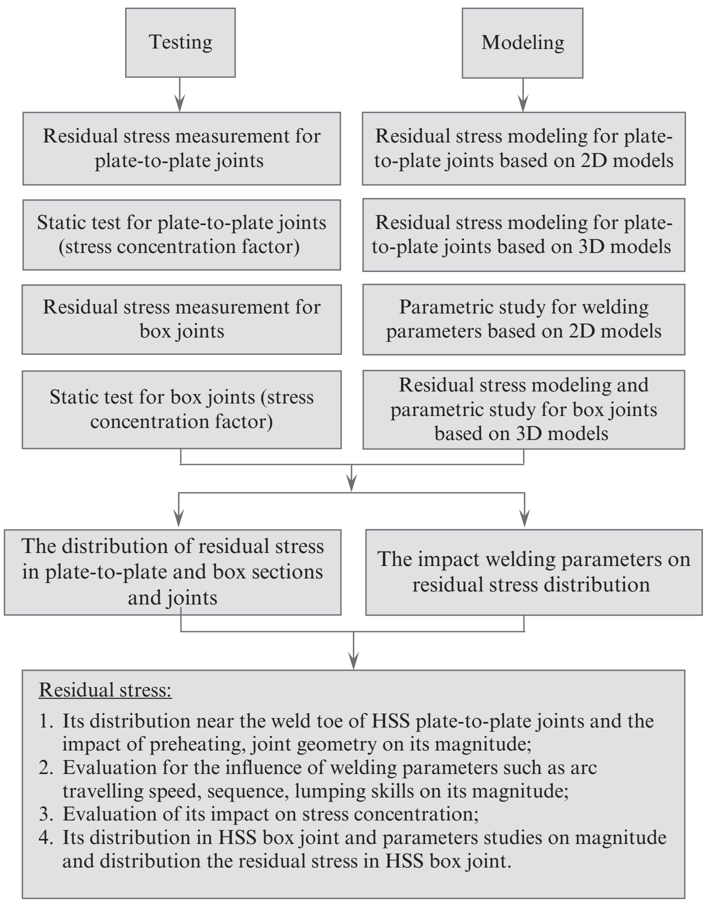

Figure 1.5 Technical flow of the book.

- To simulate the residual stress fields for the joints corresponding to the specimens used in experimental investigation based on 2D and 3D modeling. In addition, by conducting a small-scale parametrical study, the impacts of welding parameters such as arc travelling speed, welding sequence, and preheating temperature on the distribution of residual stress will be examined.
- To experimentally study the residual stress due to the weld in the chord and brace box and to investigate the residual stress distribution around the chord weld toe when the HSS box joint is formed. Two specimens, one welded at ambient temperature and the other preheated to 100 °C before welding, will be tested to evaluate the effect of preheating on the residual stress magnitude. To investigate the stress concentration factor (SCF) distributions of welded box T-joints under the basic and combined load cases experimentally and numerically. Three basic loads, axial load, in-plane bending, and out-of-plane bending, and their combinations will be applied to check the stress concentration effect due to the weld profile and fabrication procedure near the chord and brace intersection part of the welded box T-joints.
- To numerically model the residual stress fields of the HSS box chord and brace formed by welding and to show the final residual stress fields when the welded HSS box T-joints are formed. A parametric study is conducted to investigate the impact of geometry of joint and welding parameters based on 3D models.

1.3 Contributions and Originality

The main contributions of this book are to provide the residual stress fields for HSS plate-to-plate joints and box joints from experiments and numerical analyses. The main contributions and originalities of this study are outlined below:

- Experimental investigation of welding residual stress of HSS plate-to-plate joints with different geometries and welding treatments and evaluation of the influence of joint geometries and preheating temperature on the residual stress field. The originality of this part includes revision for the HS-200 drilling setup to fit the specimens used in the testing and finding of the preheating effect of the residual stress for HSS plate-to-plate joints.
- Numerical investigation of welding residual stress of HSS plate-to-plate joints based on 2D and 3D models and evaluation of the impact of welding parameters such as preheating temperature and welding speed on the residual stress magnitude. The originality of this part includes finding for the effect of welding parameters (preheating temperature, welding speed, welding sequence, welding direction), mechanical boundary condition, and modeling skill (lumping way) on the residual stress field.
- Experimental investigation of welding residual stress of HSS box chord, brace sections and T-joints and experimental study of the stress concentration factor of HSS box joints under basic and combined loads. The originality of this part

includes finding for the residual stress distribution in HSS box joints and effect of the welding residual stress on the stress concentration.
- Numerical investigation of welding residual stress of HSS box chord, brace sections, and T- and Y-joints based on 3D models. The originality of this part includes the application for fully coupled thermo-mechanical analysis in welding residual stress simulation. The evaluation for the influence of welding parameters, including welding speed, preheating temperature, and joint geometry on the residual stress is another main originality in this part.

1.4 Organization

The organization of this study is arranged as follows:

- Chapter 2 covers literature review. The relevant research and work will be reviewed and the background of related theories will be introduced.
- Chapter 3 introduces the experimental investigation of residual stress of HSS plate-to-plate joints. The test method, specimens, test procedure, and findings will be introduced. The residual stress near the weld toe of the HSS plate-to-plate joints will be shown. Eighteen joints with different joint angles, plate thicknesses, and preheating treatments will be included to study the residual stress.
- Chapter 4 investigates 2D and 3D numerical modeling for residual stress of HSS plate-to-plate joints. The modeling techniques used will be covered. The modeling results will be validated with the testing results from Chapter 3. A small-scale parametric study will be carried out after the modeling validation to investigate the impact of welding parameters on the residual stress field.
- Chapter 5 gives the experimental investigation of residual stress of HSS box T-joints. In this chapter, the residual stress field around the chord weld toe of the HSS box T-joints will be shown. Comparison of residual stress between two box T-joints, one welded at ambient temperature and the other welded with preheating, will be organized to evaluate the effect of preheating.
- Chapter 6 shows 3D numerical modeling for the residual stress of HSS box T-joints. The geometrical modeling for the joints will be introduced first in this chapter. The residual stress fields for both joints will be shown next. A parametric study will be carried out to investigate the influence of preheating temperature, welding start position, welding speed, and joint angle on the residual stress field.
- Chapter 7 covers the full-scale static test of two box T-joints for investigating the stress concentration factors around the chord weld toe under basic and combined loads. The test rig and test procedure will be introduced and the SCFs around the weld toe in different loads cases will be shown.
- Chapter 8 summarizes the results and observations in this thesis. Conclusions are drawn based on the experimental and numerical works and some recommendations will also be given in this chapter for future works.