DETERMINATION OF WELDING RESIDUAL STRESSES IN TUBULAR JOINTS WITH MULTI-PASS WELDS

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Abstract
Tensile residual stresses caused by welding potentially lend to detrimental consequences on the structural integrity and durability of tubular joints in the engineering field. This paper presents the experimental and numerical investigations to determine the welding residual stresses in X-tubular joints. This paper describes a new modeling approach to establish the finite element model of the tubular joint with a multi-pass weld to simulate the welding process with multiple welding passes and analyses the welding residual stresses. Assisted by the non-destructive residual stress measurement by the X-ray diffraction approach, the numerical results realized by the proposed modeling approach and the thermal-mechanical simulation method agree well with the X-ray diffraction measurement.

1. Introduction
Tubular joints have wide applications in large-scale infrastructures, such as steel tubular trusses, bridges, and offshore platforms. The tubular joint combines several tubular brace members with a chord member through the welding process, which results in complicated geometry and complex residual stress distributions around the weld position. Residual stresses caused by welding are the self-equilibrating stresses in a structure resulting from the resistance to shrinkage caused by the inhomogeneous distribution of temperature in the welding process. For welded tubular structures, tensile residual stresses potentially lead to detrimental consequences on the structural integrity and durability, because they can cause crack initiation and reduce the material fracture toughness. Early determination of the residual stresses allows for proactive measures to reduce the repair and maintenance cost of welded structures. Therefore, accurate determination of welding residual stresses in the tubular joint is essential for the evaluation of fracture and fatigue performance of tubular structures. Due to the complicated geometry of the tubular joint, previous studies have not considered the multiple welding passes and the gradual addition of the filler material at the weld. To fill the research gaps and determine residual stresses in tubular joints, this paper proposes an entire numerical simulation framework that includes a simplified modeling approach to build the finite element model with multi-pass welds, and a thermal-mechanical approach to analyze the welding residual stresses by simulating the heat input during the welding process. This paper presents the experimental results of X-ray diffraction measurements of the residual stresses in the tubular joint to validate the numerical simulation framework.

2. Results
The numerical simulation method includes two parts, that is the modeling approach and the thermal-mechanical simulation approach. The procedure of the modeling approach of the tubular joint with a multi-pass weld as described below:

a. Building a T-plate with a multi-pass groove weld. Figure 1(a) takes a T-plate with a three-pass weld as an example. After the extrusion, Fig. 1(b) shows the 3D geometry of the T-plate. To obtain a convergent solution of the FE model, the mesh size near the weld zone is finer than the area far away from the weld, as shown in Fig. 1(c).
b. Based on the nodal coordinate modification code, the horizontal and vertical slabs in the T-plate model become curved into the chord member and the brace member, respectively, as shown in Fig. 1(d). The self-written code can record the nodes and elements in each welding pass for subsequent utilization in the thermal-mechanical simulation.
c. After building the rest mesh of the chord member, Fig. 1(e) demonstrates the one-quarter FE model of the tubular joint, and Fig.1 (f) depicts the side view to show the details of the multi-pass weld.

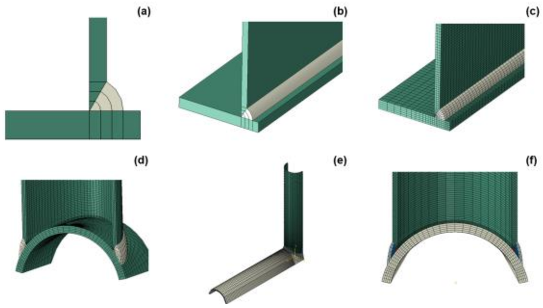

Fig.1 – Procedure to generate a tubular joint: (a) 2D T-plate geometry; (b) 3D T-plate geometry; (c) 3D T-plate FE model; (d) generating brace and chord members; (e) one-quarter model; (f) side view of the model.

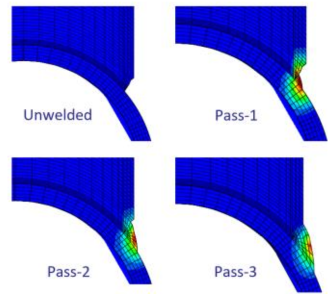

Fig.2 – The welding heat input during the three passes welding process.

The thermal-mechanical simulation utilizes the finite element code ABAQUS combined with the user subroutine DFLUX to determine residual stresses. As shown in Fig.2, this study simulates the welding process by moving the electrode combined with the element birth and death technique both in the welding direction and the thickness direction, which allows gradual filling of solder as the welding takes place. The addition of weld filler material is equivalent to activating new elements through the element birth technique and introducing the deformed geometry from the previous step to the next step. The heat source input modeling adopts a double ellipsoidal volumetric heat source model implemented through a user subroutine. In calculating the residual stress field, the numerical procedure imposes minimum constraints on the welded plate model to eliminate the rigid body motions. The temperature-dependent material properties are essential for thermal-mechanical analysis which integrates the combined hardening model.

This study presents the experimental measurements for tubular joints through the X-ray diffraction approach. For the X-tubular joint shown in Fig. 3, there are 9 paths (S0~S40) of measuring points arranged on both the left side and right side with different distances from 0 mm to 40 mm from the saddle point. The distance between the measuring points is 10 mm. The peak residual stresses are mostly within this range from 110 MPa to 160 MPa with some scatters. The position with a distance of 30 mm has a larger tensile residual stress of 200 MPa. There are good symmetric on the left side and right side near the saddle point (shown as -L, -R). Figure 3 plots the difference in residual stresses between the chord member (denotes as -c) and the brace member (denotes as -b). The peak residual stress in the chord is larger than the brace near the saddle point.

Fig.3 – The test setup for X-ray diffraction measurements of the X-tubular joint.

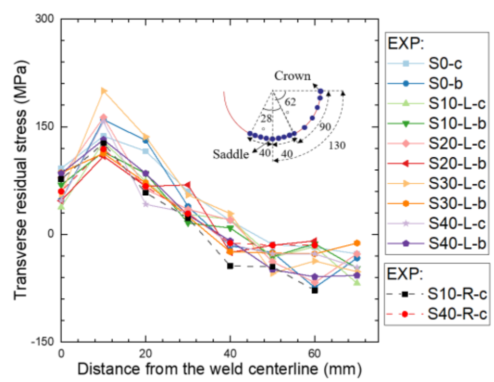

Fig.4 – Measured as-welded residual stresses near the saddle point of the X-tubular joint.

3. Conclusions

The experimental results of X-ray diffraction measurements of the residual stresses in tubular joints validate the numerical simulation framework that includes a simplified modeling approach to build the finite element model with multi-pass welds, and a thermal-mechanical approach to analyze the welding residual stresses by simulating the heat input during the welding process.