The influence of node coupling on welding deformation and residual stress of T-joint welding root

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Abstract. High accuracy and high efficiency is the key to the application of structural welding simulation. To explore the influence of welding root node coupling on the precision of finite element establishing model, the finite element model of T-joint with coupling and uncoupling of nodes in welding root is established. The welding deformation and residual stress distribution of T joint are obtained, and the test results are verified. The results show that, from the trend, the welding deformation and residual stress results are all consistent with the distribution trend of measured results, which proves the correctness and validity of the finite element model. The maximum error of the node uncoupling calculation results and the experimental results is 5.4%, and the maximum error of the node coupling calculation results is 12.2%. The results of the welding root node uncoupling are more close to the actual measurement results. At the same time, the residual stress gradient near the weld seam and heat affected zone changes greatly, and the coupling of the welding root nodes has little influence on the residual stress distribution, and there are three wave peaks. The two treatments have the same trend of stress distribution curve, and the peak value is similar. The peak value of residual stress of node coupling is 303.9MPa, and the peak value of residual stress of node uncoupling is 304.5MPa. The error between welding root node uncoupling and the test result is 4.9%, and the error of node coupling is 7.7%. Therefore, it is suggested that the welding root of T-joint should be node coupling. The research results have important guiding significance for improving the prediction accuracy of welding simulation.

1. Introduction

With the development of welding numerical simulation technology, it is widely applied in engineering applications. The function of welding simulation software is constantly improving, and the popularization and application of the technology is directly related to the learning and application ability of technicians. The accuracy and efficiency of the calculation require higher requirements for welding mechanics. In engineering application, joint calculation has laid a foundation for large-scale structural analysis. The main factors affecting welding deformation and stress are mainly two aspects of design and manufacture. The design includes the welding structure design, the material design and the welding process design. The manufacturing mainly includes the welding method, the welding process parameter, the heat treatment mode, the welding sequence, the fixture and so on. The traditional welding process is generally designed, and then it is optimized. With the application of welding simulation,

welding prediction has gradually become a necessary part of the design stage. Considering the efficiency and accuracy, the calculation of joints becomes an important part of the research.

At present, the methods to improve the calculation precision are mainly from the following factors: the entity-shell element, the external constraint, the tack welding analysis, the phase transition, the mesh refinement, the considering residual deformation of the upper process, the flow of the molten pool and so on. To improve the accuracy and efficiency of the calculation, Peric M. et al. [1] used the shell-3D technology to establish the T-joint modeling. The temperature field, the welding deformation and the residual stress were analyzed. The temperature and displacement distribution were measured by the thermal imager and the optical measuring system. Deng D. et al. [2] studied the influence of the external constraint on the control of the welding deformation of the sheet joints, which reduced the deformation to a certain extent, but only the external constraint could not effectively eliminate the welding deformation. Abid M. et al. [3] studied the effect of tack welding position and root gap on the welding deformation and residual stress of pipe flange joint. The position of tack welding had great influence on the axial displacement and inclination angle of the flange, and the influence of the root gap was small. Improving the accuracy of joints is widely applied in the establishing models of large structural parts, so the computation efficiency should be taken into account to ensure practicality. For the efficiency, the welding root is using mode coupling. However, during the welding process, the position of the welding root is not connected, and the fusion position is only about 2mm after welding. The connection effect between steel plate and steel plate is smaller than that of node coupling treatment. Therefore, it is a problem to be solved how to accurately simulate the connection of welding root position and to clear the coupling relationship.

On the above research, the finite element model is established for welding root node coupling and uncoupling of T-joint on the thermal elastic plasticity theory. The results of welding deformation and residual stress are compared and verified by the experimental measurements.

2. Methodology

2.1. Welding process parameters.
The floor plate size of the T-joint is 200mm x 200mm x 20mm. The vertical plate size is 200mm x 100mm x 8mm. The material is Q345 steel. The welding method adopts the CO_2 gas protection welding, and the welding wire is ER50-6. The welding speed is 42mm/s. The two sides welding are used with no groove. The welding parameters are shown in Table 1.

Table 1. Welding process parameters for T-joint.

	Arc voltage (V)	Arc current (A)	Gas flow rate (L/min)
The left seam	24-26	260-280	20
The right seam	24-26	260-280	20

2.2. The detection method.
To verify the residual stress of the T joint, it is measured by HK21A residual stress tester. In the welding toe position, the residual stress is greater, so the research pays more attention to the larger position of the stress measurement that should be near the welding toe as far as possible. The distance between the measuring points and the welding toe 5mm is due to the interference between the drilling device and the T type joint vertical plate, so the sewing machine is used to cut the T-joint vertical plate.

The device can distinguish two holes in 30mm. The stress test of the joint is quite mature, so the two positions of T-joint are measured. In the selection of welding procedure qualification samples, the distance between the starting and the ending arc positions is usually 30mm or more, so they are 50mm from the starting and ending arc positions.

In the range of the left seam side, the polishing machine is used to polish the metal color and the test point is free from defects. It is used sandpaper and the absolute alcohol to wipe out the test points.

It is pasted the strain gauges to ensure no bubble state. The equipment is preheated 30min. After the display is stable, drill holes are the cross positions of the variable parts. The depth of hole is 2mm, and the stress value can be obtained, as shown in Figure 1.

Figure 1. The residual stress measurement of T-joint

3. The establishment of finite element model for T-joint

3.1. The establishment of material parameters.
With the literature [4], the relevant parameters of Q345 for simulated materials are obtained, as shown in Figure 2.
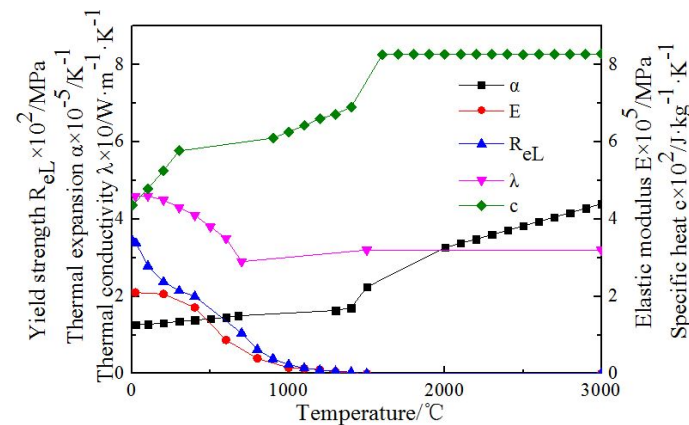

Figure 2. The relationship between thermal-mechanical parameters and temperature in Q345

3.2. The heat source model.
The double ellipsoid heat source appropriately reflects CO_2 gas shielded welding. To get the parameters, the macroscopic morphology of heat source is obtained by test. The welding height, weld width, depth and heat affected zone are measured, as shown in Figure 3.
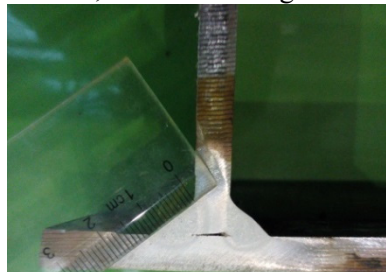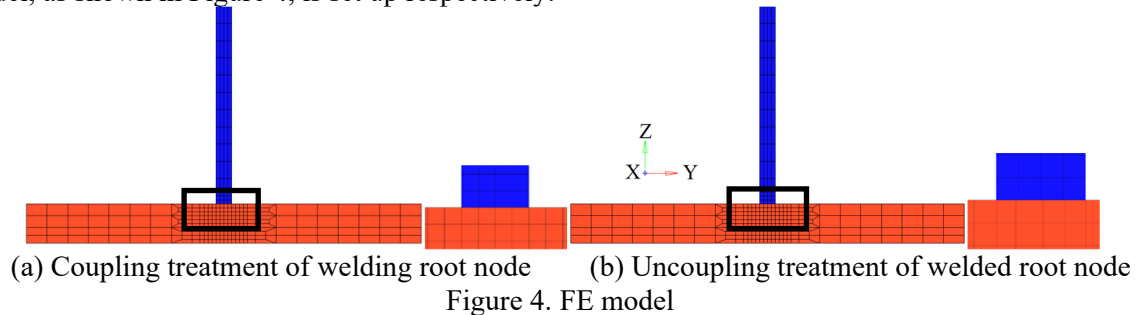

Figure 3. Heat resource

By measuring, the left double ellipsoid heat source is obtained that the penetration width is 11.84mm, and the penetration depth is 5.96mm. The right double ellipsoid heat source is obtained that the penetration width is 11.76mm, and the penetration depth is 5.80mm. They definite the heat source parameters of the double ellipsoid that the length of the ellipsoid in the front half is close to the penetration, and the length of the back ellipsoid is close to the two times of the front ellipsoid.

3.3. The establishment of grid model.

To compare the coupling or not of welding root nodes, the number of grid numbers is consistent, and the welding root nodes are treated differently. The joints are coupling and uncoupling in the welding root node. The weld seam unit size is 2mm, and the total number is all 22632 with the transition grid. The number of welding root node coupling and uncoupling is 25671 and 27388. The finite element model, as shown in Figure 4, is set up respectively.

(a) Coupling treatment of welding root node   (b) Uncoupling treatment of welded root node

Figure 4. FE model

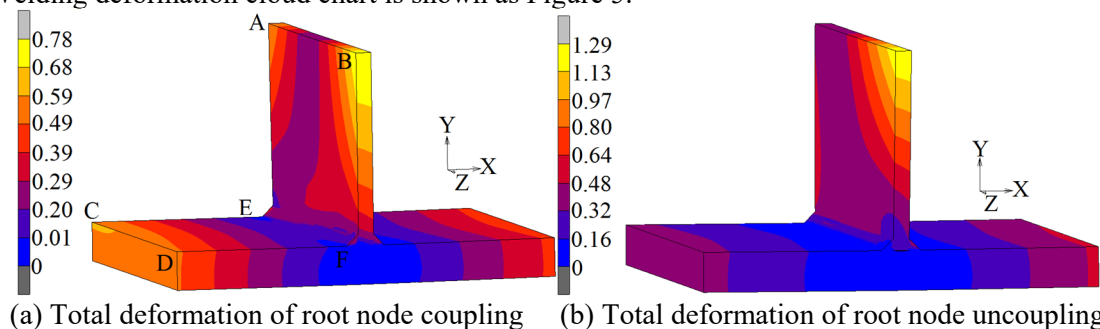### 3.4. The mechanical boundary conditions.

The mechanical boundary conditions the joint are general three-point displacement constraints, but it inevitably leads to excessive constraints, which causes the local distribution of the temperature field and the stress field to vary greatly with the actual gradient.

The mechanical boundary condition [5] selects two nodes along the width of weld seam and the lower surface of the middle section, which is used to limit the X direction. It does not affect the longitudinal shrinkage deformation. It sets some nodes behind weld seam to limit the Y direction and the Z direction, and does not affect the transverse contraction.

4. Result analysis and discussion

4.1. Influence of welding root node coupling and uncoupling on welding deformation.

Welding deformation of T-joint is obtained by simulation. The starting arc position is located on the side of point A, and the ending arc position of the other side weld seam is located on the side of point B. Welding deformation cloud chart is shown as Figure 5.

(a) Total deformation of root node coupling   (b) Total deformation of root node uncoupling

Figure 5. Welding deformation distribution

From figure 5, the maximum deformation of root node coupling is 0.78mm, and the maximum deformation of root node uncoupling is 1.29mm. The maximum deformation occurs at the free-end of the vertical plate, and the deformation is upwards at the free-end on the two sides of the floor plate. The deformation trend is the same in the two methods, which is the same as the deformation law of the classic T-joint. The prediction results of welding deformation are verified [6].

Using the tape, welding deformation is extracted along the X direction of the vertical plate and the BA point in the Y direction of the floor plate respectively. The results are compared with the test results, as shown in Figure 6.

As figure 6 (a), the maximum difference of root node uncoupling for vertical plate between the calculated results and the test results is 0.08mm, and the error is 5.4%. The maximum difference of root

node coupling for vertical plate between the calculated results and the test results is 0.16mm, and the error is 10.9%. From the deformation trend, welding deformation along the BA direction decreases gradually, and the results of the two methods are consistent with the experimental results. Because the point A is first welded and deformed, the deformation of the B point is influenced by the contraction, which makes the deformation of the starting arc increasing. The contractile effect of the other side weld seam on the first weld seam makes the welding deformation of the X direction of the vertical plate decrease. At the same time, because the starting arc position of the other side weld seam is located at the B point, the reverse shrinkage effect is weakened and it is not conducive to the decrease of the X direction of the vertical plate relative to the symmetric welding.

(a) X direction deformation of vertical plate   (b) Y direction deformation of floor pla4te
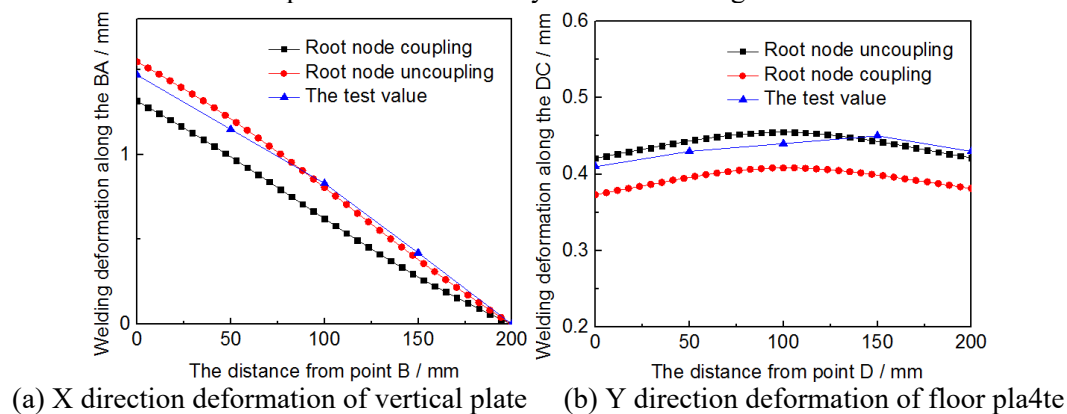
Figure 6. Comparison welding deformation of T-joint

As figure 6 (b), the maximum difference of root node uncoupling for floor plate between the calculated results and the test results is 0.01mm, and the error is 2.4%. The maximum difference of root node coupling for floor plate between the calculated results and the test results is 0.05mm, and the error is 12.2%. From the deformation trend, welding deformation along the DC direction first increases and then decreases gradually. The deformation results of the two methods are consistent with the experimental results. It can be seen that the difference between the results of root node coupling is large.

4.2. Influence of welding root node coupling and uncoupling on residual stress.

The residual stress distribution of T-joint is obtained through simulation, as shown in Figure 7 (a) and (b). At the same time, the simulation results are compared with the results of the blind-hole residual stress analyzer, as shown in Figure 7 (c).

From Figure 7 (a) and (b), residual stress near the weld seam and heat affected zone are larger. The peak value of welding root node coupling is 303.9MPa. The peak value of welding root node uncoupling is 304.5MPa, which is consistent with the theory of residual stress distribution [6].

As figure 7 (c), it has little influence on residual stress distribution whether is welding root node coupling, and there are three wave peaks. The stress distributions of the two methods are the same, and the peak values are similar. It is different from residual stress distribution of the classic T-joint that it is the tensile stress at the starting and ending arc, mainly because the other weld seam makes the tension stress. The peak value has a certain reverse force and the peak value decreases because of the tensile stress action of the second welds. Through comparison and calculation, the error of welding root node uncoupling is 4.9%, and the error of welding root node coupling is 7.7%.

To sum up, welding root node coupling or not has great influence on welding deformation of T – joint. The simulation result error of welding root node uncoupling is less than that of welding root node coupling, and the maximum error is 5.4%. Welding root node coupling or not has little influence on residual stress for the T-joint. The simulation result of welding root node uncoupling is less than that of welding root node coupling, and the error is 4.9%. Therefore, it is suggested that the T-joint should be used by welding root node uncoupling.

(a) Residual stress of root node coupling   (b) Residual stress of root node uncoupling

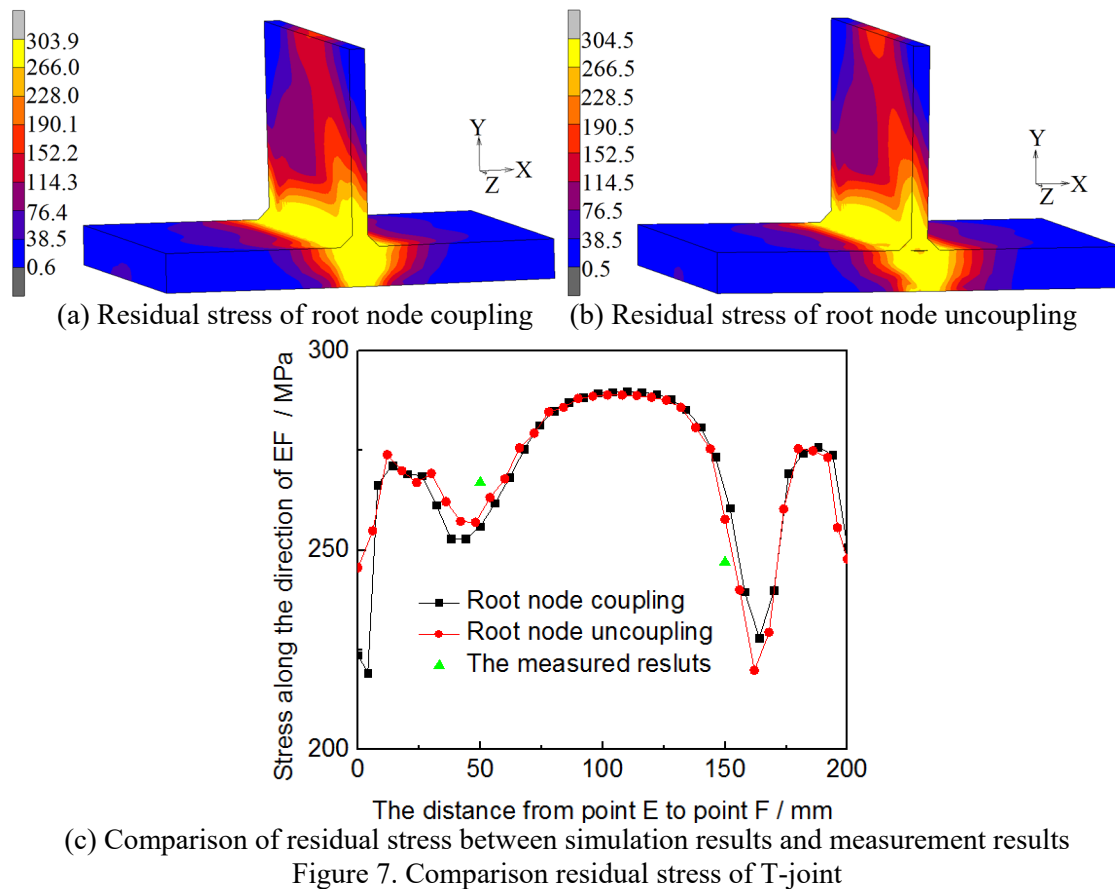(c) Comparison of residual stress between simulation results and measurement results

Figure 7. Comparison residual stress of T-joint

5. Conclusions

Through the analysis of welding root node coupling or not for T-joint, it influences on welding deformation and residual stress in the establishment of finite element mode, and the results are measured. The following conclusions are drawn. Welding deformation and residual stress distribution trend of welding root node coupling or not are consistent with the experimental trend. The results error of welding deformation and residual stress for T-joint are less than those of test results. Therefore, it is suggested that the T-joint should be used by welding root node uncoupling. In this research, the measurement point of residual stress distribution is less. It is controlled by the size of the model and the distance between the measuring points of the blind-hole method. Only two points are measured. Therefore, it is necessary to further analyze the method of X-ray nondestructive residual stress in the next step.

Acknowledgments

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