Research on the Finite Element Model of Box Structure with Complex Spatial Weld Seams

Yuanbin Fang¹,², Minghu He³, Yong Wang⁴, Hu Feng³
¹ XCMG Jiangsu Xuzhou Engineering Machinery Research Institute, Xuzhou, J S 221004, China
² XCMG Xuzhou Mining Machinery Co. Ltd, Xuzhou, J S 221004, China
³ XCMG Road Machinery Corporation, Xuzhou, J S 221004, China
⁴ XCMG Xuzhou Mining Machinery Co. Ltd, Xuzhou, J S 221004, China
fybflying@163.com

Abstract. To establish box structure model with complex space weld seams, the grid partition method is studied. The finite element model is established, and the deformation distribution of the box structure is obtained. The simulation results are verified. The results show that the deformation trend of the box structure is towards warp at the free edge of the left and right vertical plates. The deformation of the plate centre is inner concave. The maximum deformation is 1.714mm at the centre position of the vertical plate. The bottom pad is produced the extruding tendency. The deformation of the bottom pad near the two sides is about 0.51mm, which is more than the deformation of 0.34mm far away from the two vertical plates. The deformation of the front and back Z plate is not consistent. The long strip occurs wavy deformation. The deformation curve of the measuring point is similar to the simulation curve of the bottom pad deformation. There are 5 peaks of the long strip ranged from 0.08mm to 0.53mm. The deviation between simulation results and measurement results is within 0.45mm. The error meets the requirements of engineering application and can effectively guide production.

1. Introduction

With the development of simulation technology, engineering application is more and more extensive. Welding with simple structure can be solved problems and meet the basic needs of production with the help of technicians. However, with the complex improvement of the structure, the size increase of the structure, the wave deformation, the deflection deformation, and so on, there is huge waste of resources in production. The research on welding simulation of large-scale and complex structures attracts more and more attention.

The efficiency and accuracy of simulation become the contradiction of large complex structure prediction. For it, experts have studied. The thermal physical and mechanical properties of materials directly affect the accuracy of simulation. Whether the material's high temperature property is correct or not is the key to improve the convergence of the model. Shi Qing Yu et al. [1] of Tsinghua University assumed four different high temperature yield strength of the same material, and analyzed the influence of the high temperature properties of the material on the accuracy of the calculation. The results showed that the assumption of high temperature yield strength had little effect on stress and strain. For heat source model, Rong Y. M. et al. [2] had studied the combination heat source model. Through the experiment and simulation, it was proved that the model of T-joint had high accuracy. In the estab-
lished grid, Dong Z. B. et al. [3] researched the influence of grid size on aluminum alloy with molten inert gas protection welding. It was determined that the grid size of 1~1.5mm can accurately predict the longitudinal stress distribution. To ensure that the accuracy of calculation is not reduced too much, the experts improve the efficiency of simulation calculation. Combined with experimental research and numerical simulation technology based on inherent strain theory, Wang J. C. et al. [4] successfully predicted the deformation of large offshore hull structures. Zhao H. Y. and Cai Z. P. [5] of Tsinghua University had researched on the prediction of deformation and the simplification of heat source in large-scale structures. For ensuring the calculation precision, a segmented heat source model was used. The influence of different calculation methods on the welding speed was analysed. Some of the results were used in T steel and web plate of the heavy machine. Therefore, how to establish an effective finite element model has an important influence on the accuracy and efficiency of computation.

As the research object of the ironing plate, the box structure with the space complex weld seams characteristics are modeled by finite element method. The deformation of the box structure is obtained, and the results are compared and verified with the test.

2. Methodology

2.1. Welding process parameters and detection methods.
The material is Q345 steel. The yield strength at room temperature is 345MPa, and tensile strength is 600MPa. Mechanical properties are excellent. The box structural ironing plate is made by carbon dioxide gas shielded arc welding, which is the welded by Fronius 5000 with the maximum welding current of 500A. The wire is ER50-6. The deformation of the key position is measured by a feeler gauge, as shown in Figure 1. The deformation of the key position affects the smoothness of the ironing plate.

![Figure 1. The position of deformation measurement](image)

2.2. Macroscopic metallographic analysis.
To simulate the deformation of the ironing plate, the welding heat input is first considered, and the macro metallographic analysis of the weld seam is used to determine the parameters of the welding heat source. The specimen is considered to be one side or two sides of the welded joint. The welded specimens have been cut through wire cutting, and they are lapped from 80 to 1500 mesh of the sand paper. The grinding method is used reticular in turn. The residue and moisture of the grinding surface are wiped with anhydrous industrial alcohol. Then the nitrate alcohol solution with a mass fraction of 4% is used for the research. The specimen of the mill is corroded. When the macroscopic phase of the weld seam is seen, it is rinsed with clean water immediately and wiped clean with anhydrous ethanol cotton ball. At the same time, the macroscopic metallography of the weld seam can be obtained by blowing the corrosion surface of the air blowing, which is used the vernier caliper to measure weld seam size.
3. The establishment of finite element model

3.1. The establishment of mesh model.

The grid transition is adopted at the ratio of 1:2 and 1:3, and the eight node hexahedron element is adopted. The size of the weld seam is 3mm, and the size far away from the weld seam is about 10mm. The grid is 389166. The minimum value of the Jacobi is 0.4, and the local complex weld seam is partially magnified, as shown in Figure 2. The finite element model of the ironing plate has multiple spatial and directional distributions.

![Mesh Model](image1)

(a) The mesh model

![Local Magnification Image](image2)

(b) The local magnification image

Figure 2. The finite element model

3.2. The establishment of related parameters.

With reference materials [6], the related parameters of Q345 steel for simulated materials are obtained that thermal and mechanical properties varied with temperature. The double ellipsoid heat source model is considered to be the most reasonable model of carbon dioxide gas shielded arc welding.

To avoid rigid body movement, the support plane is set up on the platform and the bottom of the ironing plate. A number of nodes are selected in the middle position of the front and back Z plates to limit the direction of Y and Z. A number of points are selected on the bottom of the left and right vertical plates to limit the X direction.
4. Result analysis and discussion

4.1. Simulation results analysis of the ironing plate.
As the finite element model of the ironing plate, the deformation distribution of the overall welding is calculated, as shown in Figure 3.

From Figure 3, the overall deformation is the maximum deformation at the center of the vertical plate that the peak value is 1.71mm. The deformation of the bottom pad is about 0.51mm near the two sides of the vertical plate, which is larger than that of 0.34mm at the middle of the bottom pad. At the same time, the maximum value of the front Z plate is 0.51mm, which is smaller than that of the back Z plate of 1.2mm. The left and right vertical plates are concave in the center of the plate, which is mainly due to the contraction of the internal weld seam and the external none balance of the force. The bottom deformation is mainly due to the contraction force of the lining plate and the left and right vertical plates, the lining plate and the front and back Z plate, leading to the outer convex trend of the bottom pad. The upper and concave deformation is caused by the contraction of the hinged hole. The deformation of the front and back Z plates is asymmetrical, which is due to the absence of symmetrical welding and the sequence difference of cooling. The upper and lower ends of the vibrator are different due to the different welding directions.

4.2. Analysis and verification of the key position welding deformation.
To further analyze the deformation trend of the key positions, it is extracted in the boundary of the long strip at the length direction, which is the welding deformation from the right vertical plate to the left plate. The deformation of the 1-3 measured point is corresponding to the bottom pad, and the Y direction deformation of the 1-3 measured point is shown in Figure 4(a). The bottom pad length of the measured point 1 is 95mm. The distance between the measured point 2 and the vertical right plate is 685mm, and the length of the bottom pad is 70mm. The distance between the measured point 2 and the vertical right plate is 905mm, and the length of the bottom pad is 95mm.

From Figure 4(a), the long plate has wavy deformation, and the curve of the bottom pad at the point 1-3 is consistent with the trend of the strip deformation. There are 5 peaks in the deformation of the long strip, and the deformation ranges from 0.08mm to 0.12mm. The wave deformation of the long strip is mainly related to the bottom pad, the long strip and the back Z plate.

Along the length of the long strip, the other boundary of the long strip is extracted, and the Y direction deformation of the 4-6 measured point is shown in Figure 4(b). The bottom pad length of the measured point 4 is 95mm. The distance between the measured point 5 and the vertical right plate is 245mm, and the length of the bottom pad is 70mm. The distance between the measured point 2 and the vertical right plate is 905mm, and the length of the bottom pad is 95mm.

From Figure 4(b), the long plate has wavy deformation, and the curve of the bottom pad at the point 4-6 is consistent with the trend of the strip deformation. The measured 4 and 5 points are in good agreement with the simulation results. The measured point 6 has 0.27mm deviation from the simulation results. At the same time, the peak position of the measured point and the simulation curve peak is similar. There are 5 peaks in the deformation of the long strip, and the deformation ranges
from 0.08mm to 0.36mm. The wave deformation of the long strip is mainly related to the weld seams, such as the bottom pad, the vibrator, the long strip and the front Z plate.

![Comparison welding deformation of the point 1-3](image1.png) ![Comparison welding deformation of the point 4-6](image2.png)

Figure 4. Comparison welding deformation of the bottom pad and the long strip

To sum up, the deviation between simulation results and measured results is within 0.45mm of the key position. This error meets the requirements of engineering application and can effectively guide production.

5. Conclusions
In this research, the finite element model of the box structure with the space complex weld seam is set up, and the welding deformation distribution is analyzed, and the deformation of the box structure is measured and compared. The following conclusions are drawn:

1. The overall deformation trend is up-warp at the free edge of the left and right vertical plates, and the deformation of the plate center is concave. The maximum deformation position occurs in the center of the vertical plate.

2. The bottom pad is produced the outward convex, and the deformation of the front and back Z plate is not consistent.

3. The long plate has wavy deformation. The peak position deformation of the measured point is similar to that of the bottom pad simulation.

The deviation error between simulation results and measured results can meet the requirements of engineering application, and can effectively guide production. From the view of engineering application, this research needs further optimization and improvement verification.

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