Study on Numerical Simulation of Welding and Joint of 16MnR Steel Pipe

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Abstract. 16MnR steel pipe is a commonly used welding material, which has a great demand in steel structure, chemical industry, construction and so on. The research object of this paper is 16MnR steel pipe with 30*4*50mm. The numerical simulation of the welded joint is carried out by MSC. Marc software, and the temperature field and stress field distribution of the welded joint are analysed.

1 Preface

16MnR steel pipe is a kind of welding material with good weldability, which generally does not need preheating before welding. There is a great market demand in steel structure, chemical industry, construction and other industries. In this paper, 16MnR steel pipe is selected for numerical simulation analysis. The selected specimens' size is 30*4*50mm, and the selected welding method is tungsten argon arc welding. Aiming at the physical properties of 16MnR and choosing the corresponding parameters, the temperature field and stress field of the welded joint were analysed by numerical simulation software, and their distribution laws were studied.

2 Modelling

The three-dimensional model is built by MSC. Marc software. According to the welding process requirements, the length of cylinder is set to 50 mm, the residual height of weld is set to 2 mm, and the number of weld layers is set to 2 layers. Firstly, the basic two-dimensional frame model is established, and then it is meshed. Considering the great temperature gradient in the welding process, the non-uniform meshing is adopted. The closer the mesh is, the more dense the mesh is, and the farther the base metal is from the weld, the looser the mesh is. The three-dimensional model is shown in Figure 1.

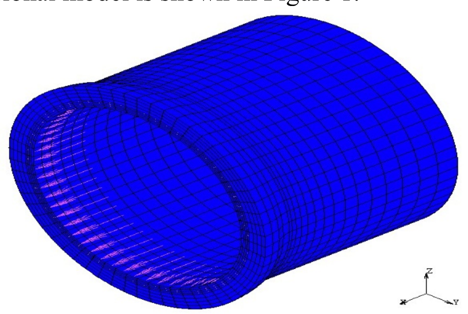

Figure 1 three-dimensional model

2.1 Setting weld layers and paths

According to the welding process, there are two layers, so there are two defined welding paths. The set welding path and the number of weld layers are shown in Figure 2.

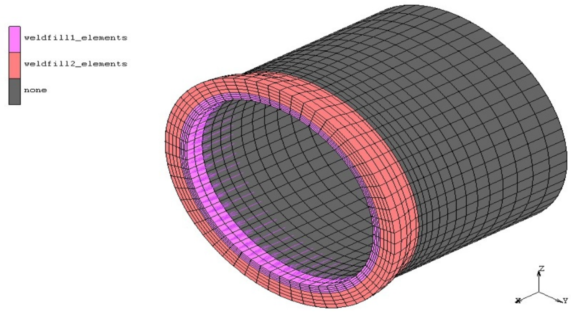

Figure 2 Seam Layer Setting

As can be seen from the figure above, the shape of the weld is circumferential weld, which is also consistent with the welding process. Different colours of the first and second seams are displayed.

In order to observe the weld path easily, you can close the display of nodes and units, and then you can see the welding path and direction, as shown in Figure 3. The arc welding path is composed of a small straight line welding path. The welding path is the tangent direction of these joints, that is, Z direction. The arc direction of welding is downward, that is, Y direction.

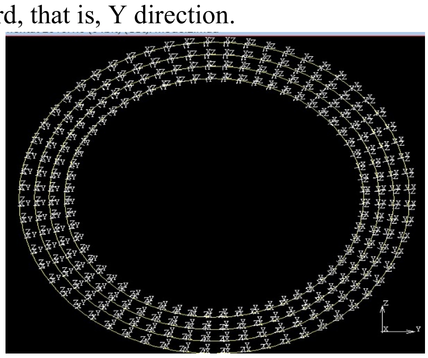

Figure 3 Display Welding Path

2.2 Applying material properties

Applying material properties means applying physical properties to the model. In the numerical simulation process, physical properties need to be applied to the model before the physical quantities such as temperature and stress can be calculated. In theory, the change of material properties with temperature is not considered in calculation. The physical properties of 16MnR steel pipe are obtained by consulting the data, as shown in Table 1.

Table 1 Physical properties of 16MnR steel pipe

Yield strength	Young modulus	Poisson ratio
345MPa	206GPa	0.33
Density	Conductivity	Specific heat capacity
7800	40	500

2.3 Applying boundary conditions

2.3.1 Selection of heat sources

The heat source model used in this paper is a plane Gauss heat source model. The planar Gauss heat source model is a more practical heat source distribution function than the centralized heat source model. The Gauss heat source model is shown in Figure 4.

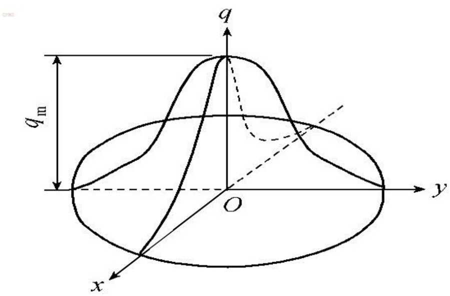

Figure 4 Gauss heat source model

Distribution of heat flux function at any point on heating spot,

$$q(r) = q_m \exp\left(-\frac{3r^2}{R^2}\right)$$

In the formula, q_m is the heat flux of the spot centre, unit is $J/m^2 \cdot s$.

R is the effective heating radius of arc, unit is mm.

r is the distance from the arc heating spot centre, unit is mm.

The analytic expression of the moving heat source is

$$q_m = \frac{3}{\pi R^2} Q$$

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2.3.2 Setting of mechanical boundary conditions

In the process of welding, the specimens need to be fixed by positioning welding, but the specimens themselves are not fixed, so the mechanical conditions on the symmetrical surface are constrained. According to the deformation of the workpiece, the displacement constraints in X and Z directions are defined respectively, so that the workpiece can be deformed freely. The setting of boundary conditions is shown in Figure 5 and 6.

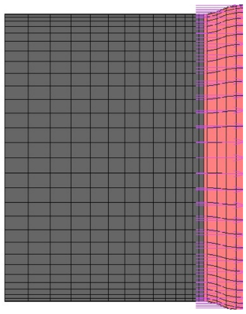

Figure 5 X-Direction Boundary Setting

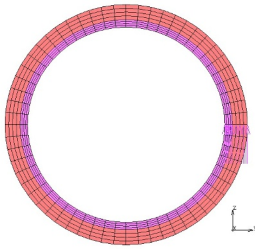

Figure 6 Z-Direction boundary setting

2.4 The setting of working conditions

In the simulation process, two layers of welds need to be set up separately, each layer needs to set the cooling time and time step, and the cooling time is consistent with the parameters of time step. When the cooling process is set, all the boundary conditions of the weld seam need to be cancelled, and the estimated cooling time and the detection increment time step are given. The set working diagram is shown in Figure 7.

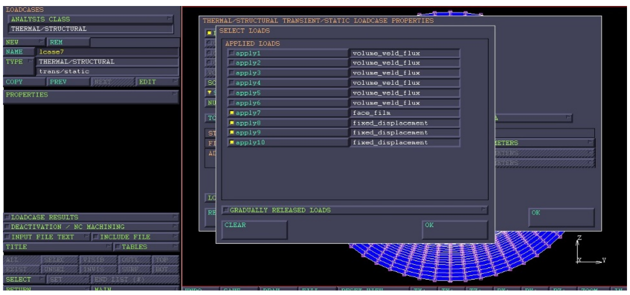

Figure 7 Working condition setting pattern of cooling process

3 Analysis of simulation results

The simulation process needs to analyse the results of temperature field and stress field respectively. The right and wrong of the analysis results can be judged by the serial number of the final output. The output serial number of this paper is shown correctly, which proves that the following results are correct.

3.1 Analysis of temperature field results

The calculation results can be viewed in the interface, and the temperature field of each second in the welding process can be viewed. The following is an example of temperature field distribution for each layer of weld, as shown in Figure 8.

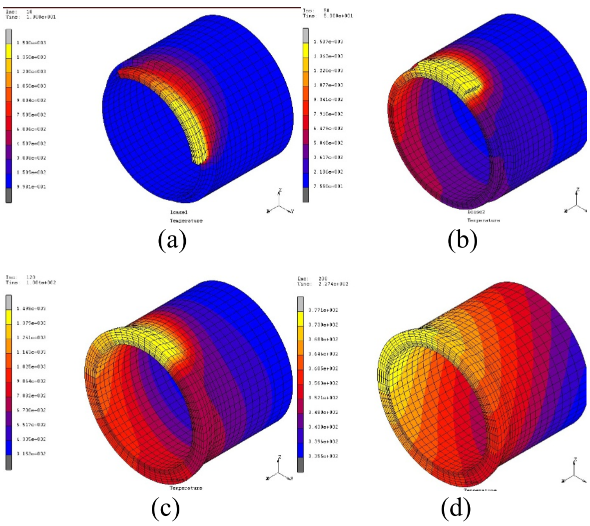

Figure 8 Temperature Field

As shown in the figure above, the temperature distribution maps of 10 steps, 50 steps, 120 steps and 200 steps are selected. Ten steps are the temperature field generated by the first layer of the weld, which is in accordance with the initial setting value; 50 steps are the temperature field of the second layer. Compared with the two steps, the maximum temperature is 1500 C, but the heating position is different, and the influence zone is also different. The 120 and 200 steps are also the temperature distribution maps of different positions on the second layer weld. The temperature display can be seen by the bar code on the left side. Through the overall observation, the temperature of the weld is the highest, and the closer to the base metal, the temperature gradually decreases. This is consistent with the actual theory.

In order to better observe the distribution of temperature field at different locations, firstly, three nodes with different distances from the weld zone are selected arbitrarily in the model, and their thermal cycle curves are analysed. The selected node location (3107, 2693, 215) is shown in Figure 9.

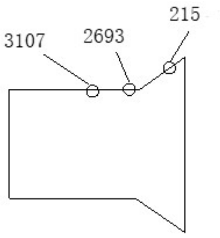

Figure 9 Node Selection Location Map

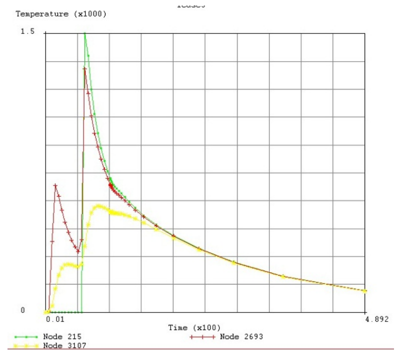

Figure 10 Cycle Curves of Three Joints

As can be seen from Fig. 10, node 215 is the nearest thermal cycle curve to the weld, and its highest temperature is the highest of the three curves. Node 2693 is nearer to the centre of the weld, and its highest temperature is close to 1500 C. Node 3107 is farthest from the centre of the weld, and its peak temperature is the lowest. In addition, it can be seen from the figure that the thermal cycle of the three nodes occurs simultaneously, which also shows that the thermal cycle is practical.

3.2 Analysis of stress field results

In this simulation process, the welding residual stress generated in the welding process is also analysed, and the analysis results are shown in Figure 11.

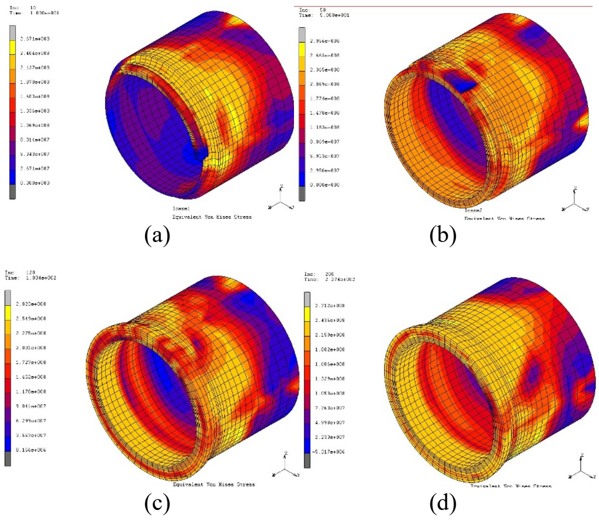

Figure 11 Equivalent stress field

It shows the equivalent force field model of steps 10, 50, 120 and 200 in Figure 11. It can be seen from the figure that the residual stress of the first layer of weld is the smallest after the welding process is completed. This is due to the thermal stress of the first weld caused by the weld of the back welding, which reduces the residual stress of the first layer of weld. At the same time, the stress on the weld is different from that on the base metal, one under tension and one under compression. This is precisely due to the uneven distribution of heat in the welding process, which is also consistent with the actual situation.

4 Conclusion

In this paper, numerical simulation of temperature field and stress field of 16MnR steel pipe weld is carried out. By selecting several nodes in different regions and locations, the corresponding distribution rules are obtained.

Firstly, for the temperature field, there is heat transmission in the welding process. The temperature in the centre of the weld is the highest, and the closer to the base metal on both sides, the lower the temperature. In the simulation, the melting point temperature of the metal is set to 1500 C and the ambient temperature is set to 20 C. During the welding process, the temperature of the centre of the weld is 1500 C. The closer to the base metal, the lower the temperature. This is because there is heat transfer to the base metal on both sides during welding, so the temperature of the base metal is higher than the ambient temperature. When cooled to room temperature, the overall temperature of the weldment is 20 C. The results are consistent with the experimental settings. The heat cycle curves of the selected nodes are in accordance with the actual law.

Secondly, for the stress field, the selection of stress field joints also proves the stress in the weld zone and base metal zone. Under the action of arc, the uneven distribution of temperature leads to uneven stress and less weld layers, the lower the residual stress after welding. Through observation, the residual stress in the weld zone after welding is 271 MPa.

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