Analysis of Numerical Simulation of 0Cr18Ni9 Stainless Steel Pipe Welded Joint

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Abstract: 0Cr18Ni9 stainless steel pipe is a commonly used welding material, which has great demand in shipbuilding, boiler pressure vessel and construction engineering. In this paper, for a given welding process condition, select reasonable parameters, carry out numerical simulation process on welded joints, analyze the temperature field distribution law and stress field value of welded joints, and judge whether it is consistent with the actual.

1. Introduction

Stainless steel is a kind of welding material with good weldability. It’s strength is relatively high, plastic toughness is better, especially it has good impact toughness. Under the low temperature condition of not exceeding -196°C, the test piece can be exempted from impact test. Stainless steel materials have a large market demand when using pipelines to transport chemicals such as oil and natural gas and certain corrosive media over long distances. In this paper, a welding process that has been qualified by non-destructive testing and mechanical property testing is selected. The material to be welded is 0Cr18Ni9 stainless steel pipe, the specification is Φ90×15mm, the length is 100mm, and the welding method is electrode arc welding. In view of the above welding process parameters, the author applied numerical simulation software “MSC.Marc2010” to analyze the temperature field and stress field of the welded joints, and studied their respective distribution laws.

2. Selected welding process

(1) Pipe position: horizontal fixed (5G)
(2) Preheating temperature: no preheating before welding
(3) Welding power supply equipment: Shandong Aotai ZX7-400 inverter DC arc welding power supply
(4) Welding rod selection: The welding rod grade is selected as A102, and the diameter of the welding rod is 3.2mm and 4.0mm respectively.
(5) Joint and groove form: According to the position of the pipe, the joint form is defined as a butt joint. The minimum stress concentration of the butt joint is the most ideal form of welded joint [1]. The groove form adopts a single-faceted V-shape, a blunt edge: 1.6±0.4mm, a groove angle of 40~45°, and a groove gap of 2.5~4.0 mm. No padding is required during the welding process, and the amount of misalignment after welding is less than 2.0 mm. The width of the cover weld requires that each side of the two sides be 0.5 to 2.0 mm wider than the outer surface groove. The weld height is 0 to 2.0 mm (the groove form and filling form are shown in Figure 1).
(6) Process requirements: welding arc welding is used, and the welding direction is downward. The temperature between the layers is controlled, the temperature between the fill beads and between the fill bead and the cover bead does not exceed 120°C \(^{[2]}\). The specific welding specification process parameters are shown in Table 1.

Tab.1 Welding process parameters

| Weld name    | Welding grade | Welding material diameter (mm) | Power polarity | Welding current (A) | Welding speed (cm/min) |
|--------------|---------------|--------------------------------|----------------|---------------------|------------------------|
| Bottom welding | A102         | 3.2                            | DC-            | 100~130             | 13~15                  |
| Fill layer   | A102         | 4.0                            | DC-            | 160~180             | 19~21                  |
| Cover layer  | A102         | 4.0                            | DC-            | 160~180             | 17~19                  |

(7) Welding rod drying: according to the manufacturer's requirements
(8) Appearance inspection: visual inspection, the test result is qualified
(9) Radiographic inspection: the test result is qualified

3. Establishment of 3D model in numerical simulation
When modeling, according to the welding process requirements, the length of the cylinder is set to 100 mm, the weld height is set to 2 mm, and the number of weld layers is set to 4 layers. Since the welded structure is a symmetrical form, it is only half a cylinder when modeling, but the final output will not be affected. The established 3D model diagram is shown in Figure 2:

![Fig. 2 3D model generation](image)

4. Establish welding path
According to the welding process, it is divided into 4 layers, so there are 4 welding paths defined. In order to make the 4-layer welds clear, the four shapes are used to describe the weld shape, as shown in Figure 3.
As can be seen from the above figure, the shape of the weld is a ring weld, which is also consistent with the welding process. By turning off the display of the nodes and cells, you can see the welding path and direction, as shown in Figure 4. The welding path of the arc is composed of a small linear welding path, and the welding path is the tangential direction of these nodes, that is, the Z direction. The direction of the arc of the weld is downward, Y-direction\cite{3}.

5. Applying boundary condition

5.1 Selection of welding heat source
In the numerical simulation, the model includes Volume weld flux, a concentrated heat source model, and a volume distribution model. The heat source model used in this paper is a double ellipsoidal sphere. The heat distribution function of the double ellipsoid consists of two quarters of ellipsoids, as shown in Figure 5. Assuming that the energy distribution in the first half of the heat source is $f_{r}$, the number of energy distributions in the second half $f_{r}$, and $f_{r}+f_{r}=2$\cite{4}, the distribution function of the first 1/4 ellipsoid of the heat source is:

$$q(r) = \frac{6\sqrt{3}fQ_{1}}{\pi^{3/2}abc} \exp\left(-3\left(\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2}\right)\right)$$ \hspace{1cm} (1)

The heat source distribution function in the latter half of the ellipsoid is:

$$q(r) = \frac{6\sqrt{3}fQ_{1}}{\pi^{3/2}abc} \exp\left(-3\left(\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2}\right)\right)$$ \hspace{1cm} (2)
The simulation process assumes that the welding material and the parent material have the same performance changes. During the simulation, some parameters of the heat source are given. The given heat source parameters are shown in Table 2:

| Number of weld layers | Flux Width (mm) | Flux Depth (mm) | Forward Length (mm) | Rear Length (mm) | Velocity (mm/s) |
|-----------------------|-----------------|-----------------|---------------------|------------------|-----------------|
| 1                     | 5               | 3               | 3                   | 15               | 2               |
| 2~4                   | 8               | 4               | 4                   | 16               | 3               |

5.2 Setting of thermal boundary conditions
When the thermal boundary condition is set, the convective heat transfer surface of the model is the contact surface between the workpiece and the air\cite{5}. The inner surface, the outer surface and the end surface of the workpiece are in contact with the air, and thermal boundary conditions are required. The symmetry plane does not participate in heat exchange, so when setting the thermal boundary condition, the symmetry plane is removed, as shown in Figure 6.

6. Simulation results analysis
The analysis process of the simulation results is very complicated, and the analysis time is proportional to the complexity of the model. After the simulation process is finished, the exit number is displayed as 3004, which indicates that the analysis process is correct.

6.1 Analysis of temperature field results
The calculation results can be viewed in the interface, and the temperature field of the welding process can be viewed every second\cite{6}. The following is an example of a temperature field distribution map selected for each weld seam, as shown in Figure 7.
As shown in the above figure, the excerpts are the temperature field distribution maps of 50 steps, 150 steps, 300 steps, and 605 steps (the last step). Step 92 is the temperature field generated by the first weld position of the weld. It can be seen from the temperature bar on the left side that the highest temperature is yellow, the temperature is 1500°C, the lowest temperature is blue, and the temperature is 49°C. When setting the parameters, the melting point of the weld metal is set to 1500°C, so it can be proved that the temperature field is reasonable, that is, when the first layer is welded, away from the weld zone, the temperature gradually decreases, which is also consistent with the facts. Step 150 is the temperature field at the second weld position. The maximum temperature is 1500°C and the lowest temperature is 75°C. This means that when the second layer is welded, the heat is superimposed, which is also in line with the actual situation. The 300 step is the temperature field of the third layer, and the lowest temperature is 112°C, which is also due to the gradual superposition of heat. Step 605 is the temperature field that is finally cooled to room temperature. It can be seen that the temperature is displayed as 20°C in both the yellow and blue regions, which is consistent with the initial setting.

In order to better observe the distribution law of temperature field at different locations, firstly, three nodes with different distances on the same axis are randomly selected on the model, and the thermal cycle curve is analyzed. Among them, node 4577 is located on the first layer of weld, node 2099 is located on the second weld, and node 1037 is on the third weld. The selected node location is shown in Figure 8:

![Figure 8 Node Selection Location Map](image.png)
It can be seen from Fig. 9 that the thermal cycle process of node 4577 is the first to occur. When the temperature is lowered, the thermal cycle of node 1037 begins to occur and gradually increases. The thermal cycle curve of node No. 2099 is the latest, and the thermal cycle of this point occurs when the fourth layer weld is welded, and coincides with the first two nodes, indicating that the heat is performed together. This has exactly one-to-one correspondence with the position when the node is selected, indicating that this thermal cycle is realistic.

6.2 Analysis of stress field results
In the simulation process, the welding residual stress generated during the welding process was also analyzed, and the analysis results are shown in Figure 9.

Figure 10 shows the transverse stress field model of steps 50 and 605. It can be seen from the figure that the 50 steps are the case of welding the first layer of welds. It can be seen that the value of the tensile stress in front of the arc is relatively large, that is, the yellow display area, which is due to the expansion of the arc before the heat is applied to the sides. Extrusion of the base metal. Step 605 is the value of the transverse residual stress after the weld is cooled. It can be seen that the first layer of weld is subjected to a certain tensile stress, and the base material close to both sides is subjected to a certain compressive stress, that is, blue display area.

7. Conclusions
In this paper, the numerical simulation process of temperature field and stress field is carried out for 0Cr18Ni9 steel pipe weld. Several nodes in different regional locations were selected, and the corresponding distribution rules were obtained, which are summarized as follows:

7.1 For the temperature field distribution, the temperature at the center of the weld is the highest, and the closer to the base material on both sides, the lower the temperature. This is because the heat is transferred to the base metal on both sides during the welding process, and therefore, the temperature of the base material is higher than the ambient temperature. The results of numerical simulations also prove this. The selected nodes are points on the same longitudinal weld, and their thermal cycle curves are in line with the actual law.

7.2 The distribution of the stress field is also consistent with the theory of welded structure. During the welding process, the weld zone is subjected to tensile stress and the base material receives
compressive stress. When cooled to room temperature after welding, the residual stress distribution is exactly opposite to that in the welding process, which proves the correctness of the numerical simulation process. At room temperature, the residual stress is 267MPa.

References
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