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Influence of Bevel Angle on Welding Deformation of X80 Pipeline

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Abstract:

X80 steel, renowned for its excellent welding and corrosion resistance properties, is widely used in oil and gas pipeline transportation. During the welding process, the rapid heating at the weld joint and subsequent post-weld cooling generate significant residual stresses and deformations, which severely impact the load-bearing capacity and service life of the welded joint. This study primarily investigates the influence of groove angle on welding deformation by simulating the welding process using Ansys, providing a solid foundation for practical engineering applications.

Keywords: *X80; welding deformation; numerical simulation*

1 Introduction

The petrochemical industry is a pillar local industry in Yingkou City, currently forming two industrial clusters centered around the Yingkou Xianren Island Energy and Chemical Zone and the Yingkou Coastal Industrial Base Chemical Industry Zone. During the industry's development, extensive X80 pipelines have been laid to transport petrochemical products. These pipelines feature a wall thickness of 18.4 mm and a diameter of 1,219 mm, qualifying as large-diameter thick-walled steel pipes. During installation, each pipeline must be welded together. According to welding standards, beveling is required to ensure full penetration depth and complete fusion. This study focuses on analyzing the distribution patterns of welding stress fields under different bevel angles, providing a scientific theoretical basis for optimizing welding processes and reducing residual stresses.

2 Design Concept

In pipeline docking, generally speaking, the larger the bevel angle, the shallower the depth of non fusion, the greater the penetration depth, and the better the welding effect; The smaller the bevel angle, the deeper the depth of non fusion, the smaller the penetration depth, and the more the filling metal accumulates on the surface. However, the angle of the groove should not be too large, as it can cause the bottom of the V-shaped groove to be too thin, and during welding, it is prone to welding defects such as burning through and undercutting due to heat melting. Currently, butt welding of steel pipes requires single-sided welding and double-sided forming, that is, welding on the side of the workpiece with the groove, and the back can also be welded through and form a pattern. This process requirement determines that the current cannot be too small to ensure sufficient filling metal. At the same time, the different groove angles will directly affect the amount of filling metal melt, and the stress generated by the cooling of the molten metal solution will lead to post weld deformation. Therefore, the V-shaped groove welding opening should not be too large, not exceeding 60°. According to the welding manual, the V-groove angle is generally 40°~60° when the plate thickness is 7~26 mm. Similarly, for V-shaped welding, different groove angles can also lead to different deformations. Therefore, this article chooses three schemes of 40°, 45°, and 60° for design comparison.

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2.1 Main research methods

A pipe joint with wall thickness of 18.4mm, diameter of 1219 mm, and yield strength of 570 MPa (X80 pipe) is taken as the research object. Using ANSYS finite element software, the thermal-structural coupling method is employed with the birth-and-death unit technique, and considering the nonlinear characteristics of the material under high-temperature conditions, the temperature field, stress field, and deformation of multi-pass welding of the pipe are simulated and calculated. Based on the analysis of the results, an optimized welding scheme for the multi-pass welding of the pipe is obtained.

2.2 Design scheme

Write a program using APDL language of ANSYS software to achieve mobile loading of weld heat source. By using the birth death element method to achieve the movement of heat sources, the nonlinear problems of materials are considered in the finite element analysis of temperature and stress fields. Further simulate and calculate the temperature field, stress field, and deformation of the optimized welding process by changing the groove angle (40°, 45°, 60°, etc.), and compare the results with those before optimization. This provides a scientific theoretical basis for optimizing welding processes and reducing residual stresses.

3 Simulation Process

This study used SOLID 90 for temperature field analysis. This heat source model uses a volumetric heat source. Heat generation rate = $(K \times U \times I) / (A \times V \times DT)$. The welding process uses CO_2 gas protection, and the welding thermal efficiency is lower than that of argon arc welding, so the K value is taken as 0.55. A represents the cross-sectional area of the weld seam, while U, I, and V represent the welding voltage, welding current, and welding speed, respectively (see Table 1 below).

Table 1 Welding Parameters of V - Groove

bevel form	number of plies	current（A）	voltage（V）	Welding speed (mm/s)
V-shaped groove	1	150.00	21.20	3.95
	2	254.00	28.51	4.62
	3	250.00	28.40	5.26
	4	252.00	28.50	6

The formula for the cross-sectional area of the X80 pipeline bevel heat source is as follows:

$$A_1=3.14\times4\times4\div6$$

$$A_2=3.14\times(8\times8-4\times4)\div6$$

$$A_3=3.14\times(12\times12-8\times8)\div12$$

$$A_4=3.14\times(12\times12-8\times8)\div12$$

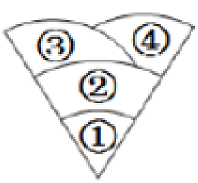

Figure 1 Schematic diagram of V-shaped groove shape

As shown in A1's formula, it represents one-sixth of the area of a circle with a radius of 4. Therefore, we selected two bevel angles of 40° . Both angles are divisible by 360° , making them suitable for heat source calculations. Comparing these three angles effectively demonstrates the deformation distribution patterns. The welding deformation of V-shaped bevels at 40° , and 60° is analyzed.

3.1 Grid division

(1) Select a surface or volume and divide it into tetrahedrons or hexahedrons. Common commands include: esize, amesh, vmesh.

(2) Set the subdivision level or equal divisions for all lines, then perform sweep or free division on the opposite face or volume. Common commands include: vsweep, vemsh.

(3) Create a surface and perform meshing on it. Common commands for stretching it into a meshed volume include: vext.

3.2 Define material properties

The physical properties of metals, including elastic modulus, yield stress, thermal conductivity, and specific heat capacity, vary with temperature. However, many metallic materials lack complete thermophysical parameters, particularly in high-temperature regions where specific heat capacity and thermal conductivity fluctuate with actual plastic deformation. Therefore, these thermophysical parameters must be incorporated into ANSYS analysis.

Table 2 Thermophysical Parameters of X80 Steel

order number	temperature （℃）	Density (kg/m^3)	specific heat capacity (J/(kg・K))	Thermal conductivity (W/(m・K))
1	20	7820-7850	460-470	50-54
2	100	7810	571	52
3	200	7790	660	50
4	400	7720	1084	47.7
5	600	7680	914	38
6	800	7610	1160	27.6

3.3 Loading of life-and-death units

During ANSYS operation, the system does not physically remove "killed" elements from the model. Instead, it applies a minimal factor (default: 1.0E-6) to their stiffness matrices, effectively nullifying load vectors. When elements are "born" (reactivated), they are not newly added but reactivated. The solver cannot generate new elements; to "add" one, it must first deactivate it and reactivate it during a valid load step. Upon reactivation, the element's stiffness, mass, and load values revert to original parameters, while the reactivated element retains no strain history or heat storage.

3.4 Analysis of V type bevel temperature field and stress field

First, we analyze the temperature field and stress field of the plate butt to find the distribution law of the residual stress of the V-shaped groove, and then apply this law to the pipe butt to find the influence of different groove.

The experimental results demonstrate that as the heat source is loaded and moved, the temperature distribution on the butt plate exhibits symmetrical characteristics. Temperature rises more rapidly near the heat source while remaining slower in distant areas, with the plate's outer sections gradually heating up. At step 31, the maximum temperature around the heat source reaches 1651℃, indicating a stable temperature field. As the heat source moves uniformly, the temperature in the weld-free regions of the plate increases from the initial room temperature of 25℃ to 25.05℃.

From Figure 4, it can be seen that the deformation increases as the free end moves farther from the weld zone. From the left side of Figure 5, the stress distribution cross-section of the butt joint, we can observe that the stress is mainly concentrated at the bottom of the weld, i.e., the bottom of the V-shaped opening, showing an increasing trend in the thickness direction.

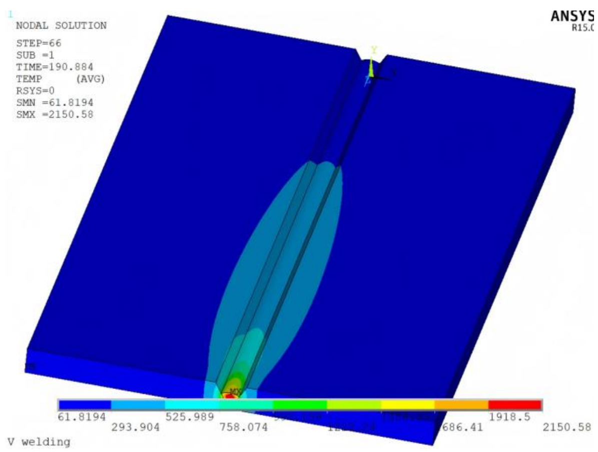

Figure 2 Temperature field at half loading

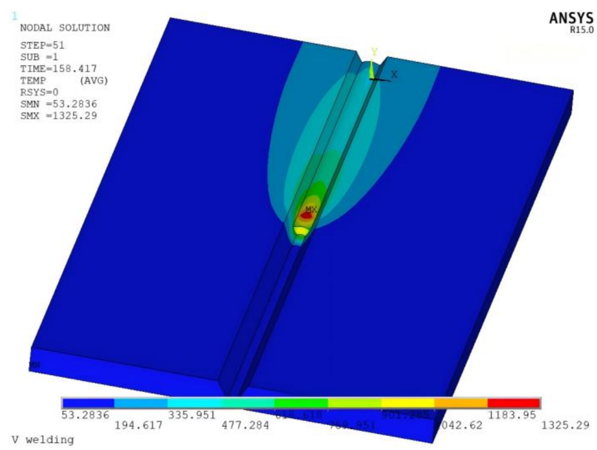

Figure 3 Temperature field after full loading

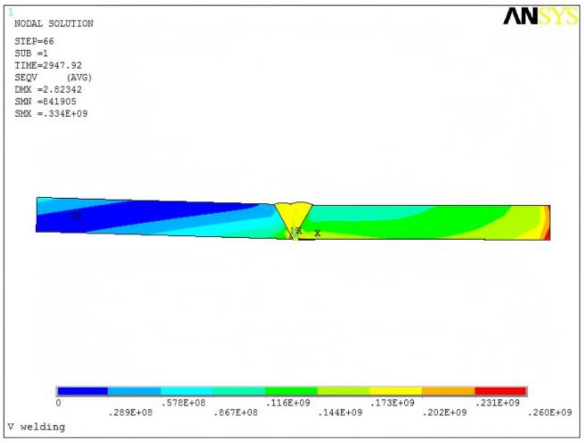

Figure 4 Overall von Mises stress map

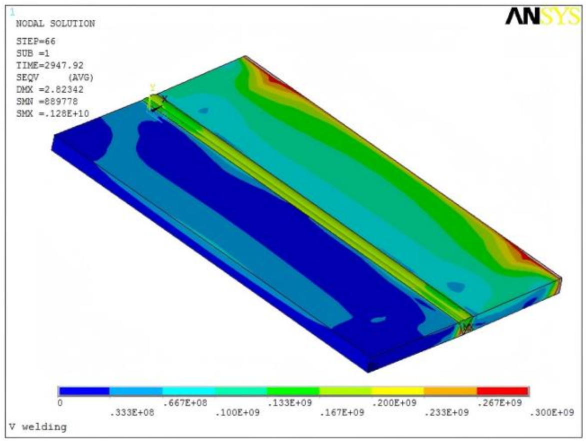

Figure 5 Cross-sectional von Mises stress map

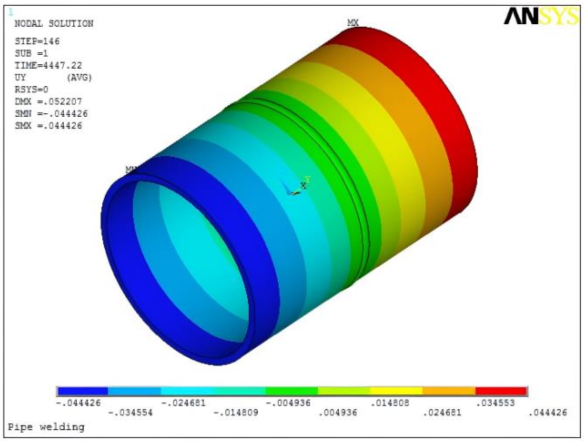

Figure 6 Deformation diagram of 40° bevel

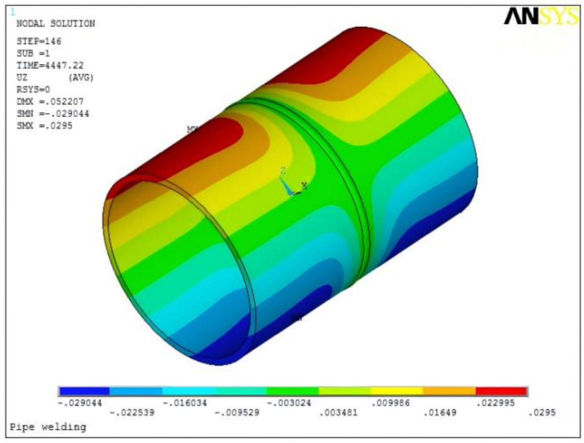

Figure 7 60° bevel deformation diagram

3.5 Simulation of pipe joint deformation for two types of bevel angles

Figure 7 shows that the greater the distance from the weld area to the free end, the more significant the deformation becomes. The overall stress on the upper surface of the welded part is higher than that on the middle and lower surfaces. Post-weld stress is primarily concentrated at the bottom of the weld seam, specifically at the base of the V-shaped opening, with a gradual increase in thickness direction.

The three images demonstrate that the V-groove deformation measures 4.66mm at 40° , and 2.82 mm at 60° , showing a gradual decrease with increasing angle until reaching its minimum at 60° . Therefore, for pipeline butt joints, a 60° V-groove is recommended.

4 Conclusion

This study primarily uses ANSYS software to simulate the temperature field and stress field of X80 pipelines during the welding process. Based on the simulation results, continuous optimization is carried out, providing directions and specific methods. It proves the feasibility of numerical simulation analysis in solving welding problems, which can accurately reflect the distribution patterns of residual stress and deformation. During welding, the temperature field is distributed in a quasi-steady state, with the heat source moving dynamically. The temperature increases more sharply at points on the weldment closer to the heat source. Post-weld stresses are mainly concentrated at the bottom of the weld, specifically at the bottom of the V-shaped opening, showing an increasing trend in the thickness direction. The welding deformation decreases gradually with increasing angle, reaching a minimum value at 60°. As the bevel angle increases, the number of welding layers required increases, the amount of filler metal needed increases, and the grinding becomes more difficult. Therefore, for pipeline butt welding, a 60° bevel should be preferred, which saves processing time and achieves good performance.

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