Brief Discussion on Welding Process and Numerical Simulation of X70 Steel Tube

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Abstract: In this paper, X70 steel pipe with a diameter of 600mm and a thickness of 15mm was selected. In combination with the actual production situation, the welding process under the condition of electrode arc welding is established for the horizontal fixed (5G) position. After the welding is completed, the rationality of the process formulation is verified by the corresponding non-destructive testing methods and related mechanical properties tests. The temperature field of the joint was simulated by numerical simulation software, and the temperature field variation of the joint under different conditions was analyzed.

1. Introduction
At present, the long-distance transport of chemicals such as oil and natural gas is the tool used. This is also to achieve safety, environmental protection and convenience. When using steel for pipelines, there are special requirements for selecting steels due to the pressure, temperature and corrosiveness of the medium inside the pipeline. The quality requirements of pipeline steel are high [1], the performance is good, and the performance of large-diameter welded steel pipe can still meet the actual requirements. The performance requirements for pipeline steel are shown in the following aspects:

(1) The intensity is high. The strength of steel includes yield strength (σs) and tensile strength (σb) and pipeline steel is no exception. The strength of the steel varies greatly depending on the composition of the material; in the case of different treatment conditions, the strength of the steel varies equally. Generally speaking, while the yield strength of steel increases, the impact energy and plasticity indexes will decrease.

(2) Resilience is better. In the process of steel smelting, reducing the content of harmful elements in steel by means of denaturation treatment of inclusions is an effective method to improve the toughness of pipeline steel. When smelting, adding some chemical elements (such as Ca) to the steel can improve the toughness and have obvious effects on preventing the occurrence of cold cracks and lamellar tears.

(3) The weldability should be excellent. In the process of construction of pipeline steel, it is inevitable to carry out the welding process, and excellent weldability is essential.

2. The welding process
(1) Pipe position: horizontal fixed (5G)
(2) Preheating temperature: 120 °C. The preheating method is carried out using an oxy-acetylene flame.
(3) Welding power supply equipment: Shandong Aotai ZX7-400 inverter DC arc welding power supply.
(4) Welding rod selection: According to the different welding layers at the time of use, there are corresponding selection principles when selecting welding rods, as shown in Table 1. DC reverse connection should be used for welding. For the root welding, the Austrian Bole imported welding rod is used, the standard number is AWS A5.1 E6010, and its grade is BOHLER FOX CEL E6010. DC reverse connection [4] should be used for welding. The chemical composition and mechanical properties are shown in Tables 2 and 3. The welding rods used for the hot-welding layer, the filling layer and the cover layer are imported from Austria Bole, and the standard number is AWS A5.5 E8018-G, and the grade is BOHLER FOX BVD. The chemical composition and mechanical properties are shown in Tables 4 and 5.

| Tab. 1 electrode selection type | use        | Standard     | Brand               | Diameter |
|-------------------------------|------------|--------------|---------------------|----------|
| Root welding                  | AWS A5.1 E6010 | BOHLER FOX CEL |                     | 4        |
| Heat welding                  | AWS A5.5 E8010-P1 | BOHLER FOX CEL85 |                     | 4        |
| filling                       | AWS A5.5 E8018-G | BOHLER FOX BVD 85 |                     | 4        |
| Cover                         | AWS A5.5 E8018-G | BOHLER FOX BVD 85 |                     | 4        |

| Tab. 2 E6010 electrode chemical composition | C     | Mn     | Si     | S      | P      | Ni    |
|-------------------------------------------|-------|--------|--------|--------|--------|-------|
| guarantee value                           | ≤0.20%| 0.3%−0.6% | ≤0.20% | ≤0.0035% | ≤0.0040% | 1.35% |

| Tab. 3 E6010 welding rod mechanical properties | project  | Yield Strength (Mpa) | tensile strength (MPa) | Elongation (%) | Impact valu (J) |
|-----------------------------------------------|----------|----------------------|------------------------|----------------|-----------------|
| guarantee value                               |          | ≥570                 | ≥690                   | 22−28          | 130             |

| Tab. 4 E8018-G welding rod chemical formation | C     | Mn     | Si     | S      | P      | Ni    |
|----------------------------------------------|-------|--------|--------|--------|--------|-------|
| guarantee value                              | 0.05%| 1.1%   | 0.4%   | ≤0.0035% | ≤0.0040% | 1.4%  |

| Tab. 5 Mechanical properties of E8018-G electrode | project  | Yield Strength (Mpa) | tensile strength (MPa) | Elongation (%) | Impact valu (J) |
|--------------------------------------------------|----------|----------------------|------------------------|----------------|-----------------|
| guarantee value                                  |          | ≥580                 | ≥695                   | 27             | 120 (-20℃)     |

(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. 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. There is no need to add padding during the welding process, and the amount of misalignment after welding is less than 2.0mm. The width of the cover weld is required to be 0.5 to 2.0 mm wider on each side than the outer surface. The weld height is 0~2.0mm (the groove form and filling form are shown in Figure 1).

![Fig. 1 Groove form and filling form](image)

(6) Process requirements: welding arc welding is used, and the welding direction is downward. The temperature between the layers is controlled, between the fill bead and between the fill bead and the cover bead is greater than 60 °C [6], and the rest is greater than 80 °C. The specific welding specification process parameters are shown in Table 6.

| Tab. 6 Welding process parameters |
|----------------------------------|
| Weld bead name | Welding grade | Welding material | power supply | Welding current (A) | Welding speed (cm/min) |
| Root welding | BOHLER FOX CEL | 3.2 | DC– | 100~130 | 12~14 |
| Heat welding | BOHLER FOX BVD 85 | 3.2 | DC+ | 110~140 | 13~15 |
| filling | BOHLER FOX BVD 85 | 4.0 | DC+ | 190~220 | 19~21 |
| Cover | BOHLER FOX BVD 85 | 4.0 | DC+ | 190~210 | 17~19 |

(7) Welding rod drying: 250~350°C
(8) Appearance inspection: The implementation standard is Q/SY XQ 4-2003 “Code for Welding Construction and Acceptance of West-East Gas Pipeline Project”, and the test result is qualified.
(9) Radiographic inspection: The implementation standard is Q/SY XQ 6-2002 “Determination of weld seams of butt joints in pipelines of West-East Gas Pipeline Project”, and the test results are qualified.
(10) Post-weld heat treatment: none

3. Mechanical properties test and results analysis
(1) Tensile test results
The test pieces of the tensile test were made in four pieces, and the results are shown in Tab. 7.

| Tab. 7 tensile test results |
|-----------------------------|
| Sample number | 1 | 2 | 3 | 4 |
| Stretching | $\sigma_0$(MPa) | 671 | 672 | 674 | 672 |
It can be seen from Table 7 that the tensile test index is acceptable, and the tensile strength of each zone is higher than that of the parent metal, which proves that the welding process is correct.

(2) Bending test results
The bending test was also carried out in four sets of tests, and the recorded test results are shown in Tab. 8.

| Sample number | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| Side bend test | No obvious crack | No obvious crack | No obvious crack | No obvious crack |
|               | No obvious crack | No obvious crack | No obvious crack | No obvious crack |

It can be seen from the test results that the plasticity and toughness of the welded joint meet the requirements of the process, which proves that the formulation of the welding process is reasonable.

(3) Impact test results
The sampling positions of the impact test were respectively measured in the weld zone and the fusion line, and three were measured in the flat welding and vertical welding positions respectively. The specific results are shown in Tab. 9.

| Notch position | Flat welding position | Vertical welding position |
|----------------|-----------------------|--------------------------|
| Impact energy (J) | 127 125 126 100 110 | 90 125 146 143 104 156 136 |
| average value (J)  | 125 100 138 132 |

It can be seen from the data that the low temperature impact toughness of the joint is also up to standard, which proves that the welding process is correct.

4. Numerical simulation
In this simulation process, a numerical simulation was carried out for a long straight cylinder of size Φ79.4×14.7 mm to establish a model. Three welding process parameters were separately applied to the model. Since the weld form is a butt weld, when the model is built, only half of the cylinder is built for simplified modeling. The simplified model speeds up the entire calculation process and has no effect on the numerical simulation results.

The definition of material property parameters can be achieved using the "Material Properties" material property module. The welding method used in the actual welding process is electrode arc welding. When the welding material is selected, it matches the mechanical properties and chemical composition of the base material. Therefore, it is considered that the material properties of the weld bead are consistent with the material properties of the base material. After applying the parameters, assign the parameter settings to all the cells. The specific physical parameters are shown in Tab. 10:
Tab.10 X70 steel pipe physical performance parameters

| Property                  | Value |
|-------------------------|-------|
| Young's modulus (GPa)   | 205   |
| Poisson's ratio         | 0.3   |
| Density (Kg/m³)         | 7800  |
| Yield Strength (MPa)    | 465-580 |
| Conductivity (S/m)      | 40    |
| Specific heat capacity (J/kg °C) | 500 |

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. 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 [54]. When the model is modeled, it is half a test piece, so the symmetry plane does not participate in the heat exchange process. The model pattern after setting the thermal boundary conditions is shown in Fig. 2.

![Fig. 2 Thermal boundary condition setting](image)

The calculation results can be viewed in the interface, and the temperature field of the welding process can be viewed every second. The following is an example of a temperature field distribution map selected for each weld.

![Fig. 3 Temperature field distribution](image)

As shown in the figure above, the excerpts are the temperature field distributions of 1 step, 200 steps, 460, and 1100 steps (the last step). 1 step is the temperature field generated by the first welding position of the weld; 200 step is the temperature field generated by the welding position of the second
weld, it can be seen that the temperature field at the position and the finish of the first weld There is superposition; 460 steps is the temperature field of the second layer position, the heat has coverage like the surrounding base metal area; the 1100 step is the temperature field when the weld is cooled to room temperature, which can be seen by the bar code on the left side, the test piece has been Cooled to a temperature of around 20 °C, which also matches the initial setting.

5. Conclusion
Through the mechanical properties test, it is proved that the performance of the welded joint meets the requirements. Through the non-destructive testing of the test piece, no obvious defects were found, which proved that the quality of the welded joint meets the requirements under the welding process conditions. Therefore, the process methods used in this paper can contribute to the practical production. Through numerical simulation, it is proved that the temperature field is in accordance with the actual situation under the given welding process parameters.

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