Narrow Gap MAG Welding and Joint Performance Analysis of 25Cr2NiMo1V Thick Plate

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Abstract. The narrow gap MAG welding system was used to successfully weld the 50mm thick butt joint of 25Cr2NiMo1V rotor steel. After 15-layer bead welding, heat treatment is performed on the welded joint. Compare the changes in the microstructure, tensile strength and impact energy of the welded joints and the heat-treated joints at 580°C (20h). The results show that after the heat treatment of the structure, the side lath ferrite in the coarse-grained region grows up, and the eutectoid ferrite grows up in the fine-grained region first. The strength of the welded joint is about 605MPa, and the fracture is characterized by ductile fracture. After heat treatment at 580°C (20h), the strength is about 543MPa, the fracture is characterized by ductile fracture, and there are also a large number of discontinuous small surface platforms, and the characteristic of brittle fracture appears slightly. The impact energy of the weld center of the welded joint is about 141J, the fusion line area is about 113J, and the toughness of the fusion line is slightly lower than that of the weld center. After heat treatment, the impact energy at the center of the weld is about 183J, the fusion line area is about 95J, the toughness of the weld center increases, and the toughness of the fusion line decreases.

1. Introduction
A steam turbine unit is usually composed of a high-pressure cylinder (HP), an intermediate-pressure cylinder (IP), and a low-pressure cylinder (LP). At present, the single-cylinder design has become a trend that combines HP and LP. The single-cylinder structure has the advantages of low cost, high thermal efficiency, small footprint, compact structure and good operation control performance, and has become one of the preferred structures of modern advanced steam turbine units. 25Cr2NiMo1V is one of the most Commonly Used Advanced Steam Turbine Steels[1,2,3]. It has sufficient high temperature strength and appropriate toughness on the high pressure side, and high strength, high toughness and low ductile brittle transition temperature on the low pressure side. Advanced welding technology has become a key tool in actual production[4]. Narrow gap MAG welding has higher welding productivity, higher welding joint bearing capacity, lower welding residual stress, lower welding production cost, and is a better choice for welding such thick and extra-thick plates[5].

In this paper, a narrow gap MAG welding system is used to weld a 50mm thick butt joint of 25Cr2NiMo1V rotor steel. After inspecting the structure, tensile strength, impact energy, etc. of the
welded joint, compare it with the heat-treated joint to explore the changes in the structure and mechanical properties of the narrow gap joint.

2. Experiment
The experiment uses 25Cr2NiMo1V rotor steel thick plate, the size of the butt joint test plate is 400×120×50mm, the assembly clearance is 19.9mm, the assembly clearance is 18.04mm, and the groove is 2.3°. Welding wire brand JM-56, diameter 1.2mm. The alloy composition of base metal and welding wire is shown in Table 1.

|            | C   | Si  | Mn  | Mo  | Cr  | V   | P   | S   | Cu  | Ni  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Metal      | 0.26| 0.31| 0.77| 0.95| 2.4 | 0.41| 0.031| 0.028| 0.23| 0.27|
| JM-56      | 0.077| 0.87| 1.45| 0.002| 0.031| 0.004| 0.012| 0.013| 0.125| 0.017|

The experiment uses a narrow gap welding swing arc welding gun, as shown in Figure 1, the shielding gas is a mixture of CO2 (20%) + Ar (80%), and the gas flow rate is 20 L/min. The welding voltage is about 30V, the welding speed is about 20cm/min, the wire feeding speed is about 10m/min, and the interlayer temperature is about 80°C. A total of 15 layers are welded, and the average thickness of each layer is about 3.3mm.

![Figure 1. MAG narrow-gap oscillating arc welding gun](image)

The test plate is rigidly fixed with welding fasteners before welding, and there is sufficient welding space in the welding gap, as shown in Figure 2.

![Figure 2. Test plate with narrow gap and rigid fixation of thick plate](image)

3. Results and Discussion

3.1. Microstructure of Welded Joint
The microstructure of the welded and heat-treated weld joint is shown in Figure 3. Compare the changes of the coarse-grained region and the fine-grained region of the weld structure under the heat treatment state. The grain boundaries of the coarse-grained regions in the heat-treated and welded state are mainly side lath ferrite, and the side lath ferrite in the coarse-grained regions grows up after heat
treatment. The fine-grained area in the as-welded state is mainly granular bainite. After heat treatment, the grains grow up slightly.

![Microstructure images](image)

**Figure 3.** Microstructure (a) Microstructure of the welded coarse-grained region; (b) Microstructure of the welded fine-crystalline region; (c) Microstructure of the heat-treated coarse-grained region; (d) Microstructure of the heat-treated fine-grained region

### 3.2. Tensile Strength

The tensile results of the welded and post-welded heat treatment are shown in Figure 4. The tensile strength of the welded state decreases from bottom to top, and the tensile strength is about 605MPa; the tensile strength after heat treatment is the largest in the upper part, and the middle and lower parts decrease. The tensile strength is about 543MPa. It can be seen that after heat treatment, the joint strength is slightly reduced.

![Tensile strength graph](image)

**Figure 4.** Comparison of tensile strength between welding state and post-welding heat treatment.

The tensile fracture of the welded joint can be seen in Figure 5(a). The fracture is rugged and forms a large number of dimples, showing ductile fracture characteristics. The tensile fracture of the joint after heat treatment can be seen in Figure 5(b). The fracture also formed a large number of dimples, showing ductile fracture characteristics as a whole, but at the same time there were a large number of discontinuous facet platforms, and the brittle fracture characteristics appeared slightly.
3.3. Impact Energy
The impact energy of the center of the joint weld and the fusion line area is shown in Figure 6. It can be seen that the impact energy of the weld center of the welded joint is about 141J, the fusion line area is about 113J, and the toughness of the fusion line is slightly lower than that of the weld center. After heat treatment, the impact energy at the center of the weld is about 183J, the fusion line area is about 95J, the toughness of the weld center increases, and the toughness of the fusion line decreases.

![Figure 6. Impact energy of weld center and fusion line area](image)

The fracture morphology of the welded joint is shown in Figure 7. The fiber area shows a large number of dimples, which is characterized by ductile fracture, and the radiation area shows a large number of platforms and dissociation surfaces, which are characterized by brittle fracture.
After heat treatment, the fracture morphology of the joint is shown in Figure 8. Similar to the welded joint, the fiber zone shows a large number of dimples, which is characterized by ductile fracture, and the radiation zone shows a large number of platforms and dissociation surfaces, which is characterized by brittle fracture. At the same time, it was found that the area of the dissociation platform in the center of the joint weld was relatively small after heat treatment, showing some ductile fracture characteristics.

Figure 7. Fracture morphology of weld center and fusion line area of welded joint (a) Central fiber area of the weld;(b) Central Radiation Zone of Weld;(c)Fiber area in the fusion line area;(d) Radiation area of fusion line area.

Figure 8. Fracture morphology of weld center and fusion line area of heat-treated joint (a) Central fiber area of the weld;(b) Central Radiation Zone of Weld;(c)Fiber area in the fusion line area;(d) Radiation area of fusion line area.
4. Conclusions

(1) MAG welding of 50mm thick butt joints was tested through a narrow gap welding system. After the structure is heat-treated, the side lath ferrite in the coarse-grained region grows up, and the eutectoid ferrite grows up in the fine-grained region first.

(2) The strength of the welded joint is about 605MPa, and the fracture is characterized by ductile fracture. After heat treatment at 580 (20h), the strength is about 543MPa, the fracture is characterized by ductile fracture, and there are also a large number of discontinuous small surface platforms, and the characteristic of brittle fracture appears slightly.

(3) The impact energy of the weld center of the welded joint is about 141J, the fusion line area is about 113J, and the toughness of the fusion line is slightly lower than that of the weld center.

(4) After heat treatment, the impact energy at the center of the weld is about 183J, the fusion line area is about 95J, the toughness of the weld center increases, and the toughness of the fusion line decreases.

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