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Comparison of residual stress in equal matching and undermatching weld joints of the high strength steel thick plate

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***Abstract*：** - In this paper, numerical simulation by finite element software MARC was used to study the residual stress in equal matching and undermatching weld joints of the high strength steel thick plate. Equal matching weld selected ferritic welding consumables and the undermatching weld consisted of austenitic welding consumables. 3D finite element model of thermal-force coupling was developed and the distribution of residual stress in equal matching and undermatching weld was acquired. The simulation results were analyzed and compared. The results showed that the equivalent stress and longitudinal stress in undermatching weld joint are significantly smaller than those in equal matching weld joint, two transverse stresses are not very different. The stress maximum in equal matching case occurs in the weld and heat affected zone, and stress maximum in undermatching case appears only in the heat affected zone.

Keywords: *- equal matching weld, undermatching weld, residual stress, numerical simulation*

I. INTRODUCTION

Due to its high strength, good ductility, toughness and good weldability, low alloy high strength steel thick plate is widely used in pressure vessels, ships, construction machinery, bridges, buildings, etc. [1]. Cold cracking is one of the main problems in welding [2]. Residual stress due to local heating and strong binding of thick plate, hardened microstructure and hydrogen content in weld are the three factors to cause cold cracking [3].

An effective measure to avoid cold cracking for the welding of high strength steel thick plate is the use of undermatching welding joint [4]. That is the strength of filler metal is lower than the base metal of high strength steel. For undermatching welding joint, plastic deformation of the weld of good plasticity and toughness can lower its three-restraint stress, reduce cold cracking tendency [5].

In this paper, finite element software Marc was used to simulate welding and later cooling process of high strength steel thick plate with equal matching and undermatching filler metal. Calculation and analysis of the distribution of residual stress in two cases were the research focus.

II. THREE-DIMENSIONAL FINITE ELEMENT MODEL

The model of high strength steel thick plate in the simulation is 50 mm thick, 120mm in width and 300mm in length.

The mesh model is shown in Figure1. The model is established by using the simulation software MARC.MSC. In order to balance computing accuracy and efficiency, fine mesh is used around weld, but coarse mesh has to be used far from the weld. There are 30400 elements and 34542 nodes in the model.

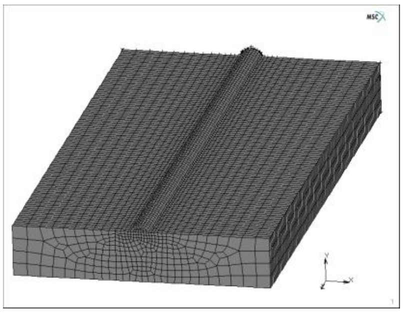
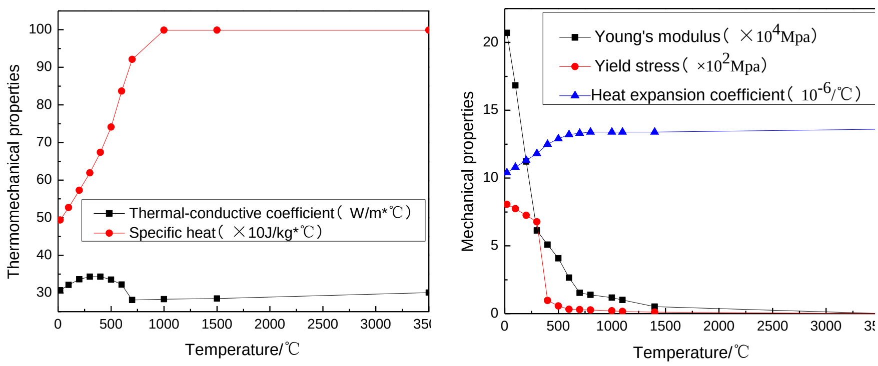


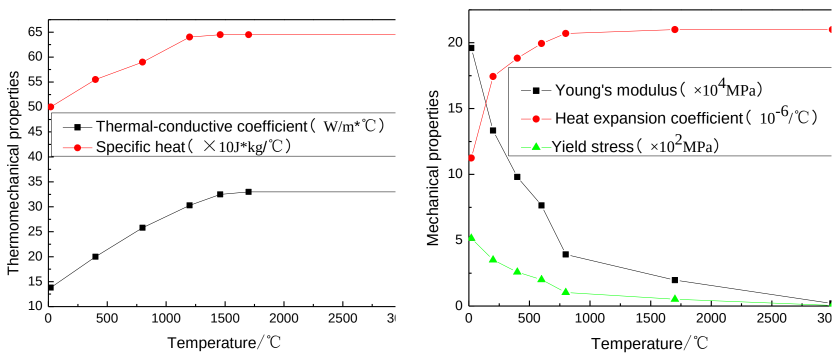
Fig.1 Three-dimensional finite element model

2.1 The thermal physical and mechanical properties of used materials

Carbon content of high strength steel thick plate adopted in this paper is 0.1%. At the situation of ambient temperature, the melting point is 1450℃,the Poisson's ratio is 0.285, the density is 7.8kg/m^3. The specific heat is 434J·kg^{-1}·℃$^{-1}$, yield strength 850MPa, heat conductivity 30.7k·℃·W·m^{-1}, thermal expansion coefficient 1.06×10^{-5}℃$^{-1}$, and Young's modulus 2.08×10^{5}MPa.



(a) Base matal



(b) Austenitic welding consumables

Fig.2 Thermomechanical properties

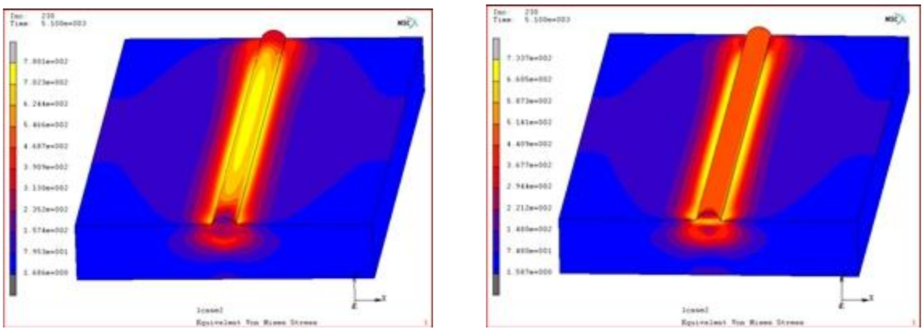
At room temperature, the used austenitic welding consumables have 0.3 Poisson's ratio, and its density is 7.93kg/m^3.

Figure 2 shows the thermodynamic properties of used materials.

III. RESULTS AND DISCUSSIONS

3.1 Stress nephogram

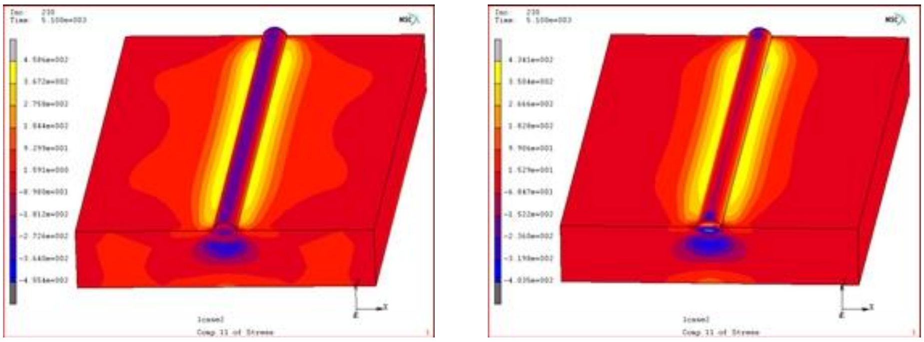
It can be seen from stress nephogram in Figure 3 that the maximal equivalent stress in equal matching case occurs in weld and heat affected zone, which value is 780Mpa. The maximal equivalent stress in undermatching case exists only in heat affected zone, which value is 734Mpa, 6% less than that in equal matching joint.



(a) Equal matching (b) Undermatching

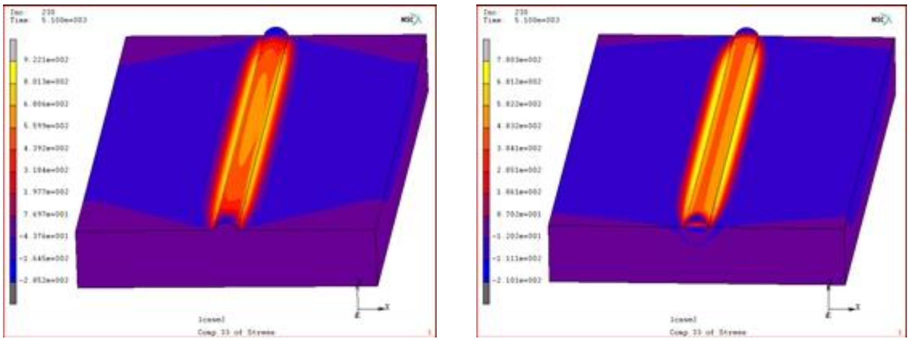
Fig.3 Equivalent Von Mises Stress

The transverse stress and longitudinal stress distributions are shown in Figure 4 and Figure 5 respectively. The maximal transverse stress in equal matching joint is 458Mpa，434Mpa in undermatching case. The two values are roughly same.



(a) Equal matching (b) Undermatching

Fig.4 Transverse stress nephogram

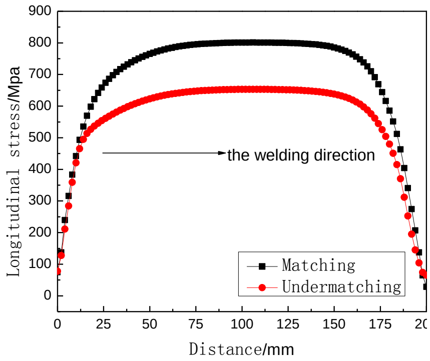


(b) Equal matching (b) Undermatching

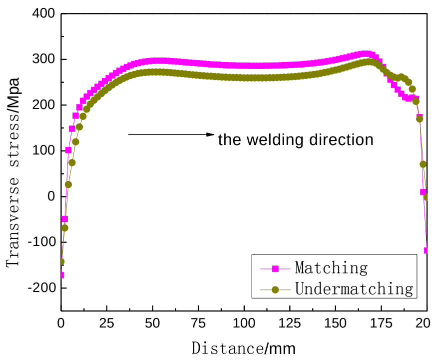
Fig.5 Longitudinal stress nephogram

For equal matching joint, maximal longitudinal stress is 922Mpa, which occurs in weld and heat-affected zone; For undermatching joint, maximal longitudinal stress is 780Mpa, which exists only in heat-affected zone. It also can be seen that stress distribution in undermatching case is more uniform than that in equal matching joint.

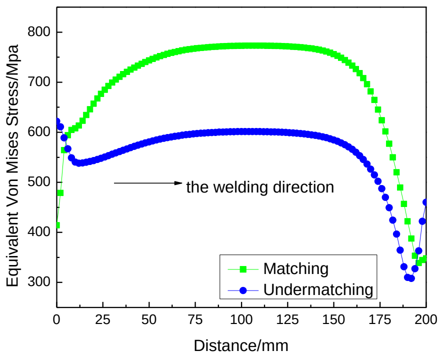
3.2 Stress distribution curves



(a) Longitudinal stress



(b) Transverse stress

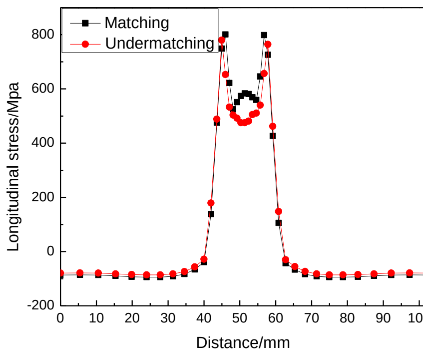


(c) Equivalent stress

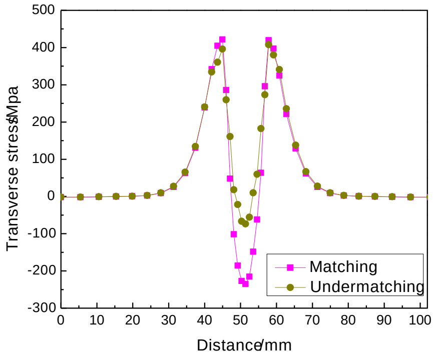
Fig.6 Distribution of residual stress on weld toe along weld direction in two cases

Residual stress distribution on weld toe along welding direction is shown in Figure 6. There exists a stable zone in the middle part of weld for the transverse stress, longitudinal stress and equivalent stress. Stresses on two ends of weld vary quickly. The equivalent stress and longitudinal stress on weld toe of undermatching weld joint are significantly smaller than those in equal matching weld joint. The maximal equivalent stress on weld toe in equal matching joint is 773Mpa, the maximal longitudinal stress is 801Mpa. For undermatching joint, maximal equivalent stress on weld toe is 601Mpa, 22% smaller than equal matching joint, and the maximal longitudinal stress is 653Mpa, 18% smaller than equal matching joint. The transverse stresses in tow cases are roughly same.

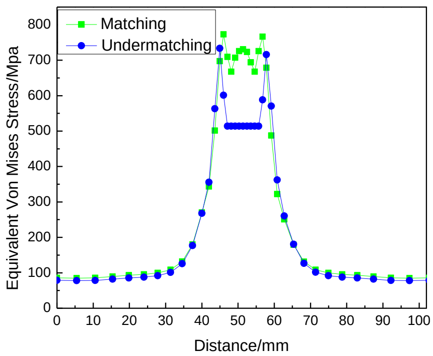
Figure 7 shows stress distribution on top surface of the middle section with different filling materials. It can be seen that the trend of stress distribution is roughly same in equal matching and undermatching joint. The difference is that the stress in undermatching weld is significantly less than stress in equal matching joint.



(a) Longitudinal stress



(b) Transverse stress



(c) Equivalent stress

Fig.7 Distribution of residual stress perpendicular to weld direction in two cases

IV. CONCLUSIONS

(1) Temperature field and stress field of high strength low alloy steel weldment with different filling materials were successfully simulated by Marc finite element simulation software.

(2)The equivalent stress and longitudinal stress in undermatching weld joint are significantly smaller than those in equal matching weld joint, two transverse stresses are not very different.

(3) The stress maximum in equal matching case occurs in the weld and heat affected zone, and stress maximum in undermatching case appears only in the heat affected zone.

V. ACKNOWLEDGMENTS

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