

Numerical simulation of dynamic thermal process during double-sided asymmetrical TIG backing welding of large thick plates

Liu Dianbao, Zhao Huihui, Li Fuquan, Zhang Guangjun and Wu Lin

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Abstract The dynamic thermal process during double-sided asymmetrical TIG backing welding of large thick plates (1 000 mm × 700 mm × 50 mm) is numerically simulated using MSC. MARC. The effect of arc distance on the thermal cycle in weld zone during double-sided asymmetrical TIG backing welding is investigated. The results show that the workpiece experiences double-peak thermal cycle in double-sided asymmetrical TIG backing welding. On the one hand, the fore arc has the pre-heating effect on the rear pass, and the pre-heating temperature depends on the distance between the double arcs, the heat input of fore arc, and the initial temperature of workpiece. On the other hand, the rear arc has the post-heating effect on the fore pass. The mutual effects of two heat sources decrease with the increase of arc distance.

Key words numerical simulation, double-sided asymmetrical TIG backing welding, thermal process, double heat sources on double sides

0 Introduction

Structures of thick plates have been widely applied in shipbuilding and pressure vessel. And lots of attention has been paid to the improvement of welding production efficiency^[1-3]. Recently, a technology of double-sided asymmetrical double arc welding (DSADAW) has been proposed in our research^[4]. In the backing welding, the double TIG welding arcs on double sides with constant arc distance are employed, and the two TIG welding molten pools are both in the shielding gas. Whereas in the filling welding, the two synchronized MAG welding arcs on double sides are used.

In double-sided asymmetrical double arc welding, the welding production efficiency can be improved by several times due to the elimination of back chipping, which is required in the conventional welding. However, there still exist many unsolved theoretical problems in double-sided asymmetrical double arc welding, such as the complicated thermal cycles, the multi-layer multi-pass welding of thick plate structures, and the weldability of high-strength steel.

In the weld of thick plates, backing weld zone has the worst mechanical properties. And the microstructures and mechanical properties of backing weld are highly dependent on the undergoing thermal process. In this paper, the finite element model of double-sided asymmetrical TIG backing welding of large thick plates (1 000 mm × 700 mm × 50 mm) is presented. The thermal cycle characteristics of workpiece under the double-sided heat sources and effect of arc distance on thermal process are investigated in detail.

1 DSADAW experiment

In the double-sided asymmetrical TIG backing welding experiment, the high-strength steel with carbon content less than 0.1% is employed, and the dimensions of workpieces are 1 000 mm × 700 mm × 50 mm. The double TIG welding arcs move on double sides with constant arc distance, and the welding parameters adopted are shown in Table 1.

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Table 1 Welding parameters of double-sided asymmetrical TIG backing welding

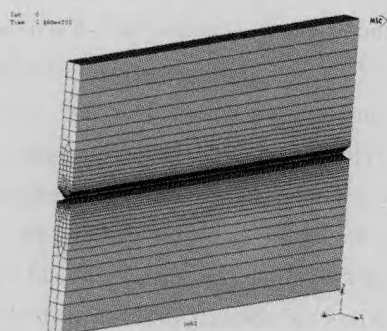
Peak current I_p / A	Ratio of background current and peak current $I_b / I_p (\%)$	Pulse current frequency f_H / Hz	Duty cycle $\delta (\%)$	Welding voltage U / V	Welding speed $v / mm \cdot s^{-1}$	Arc distance d / mm
200 – 300	50	1 – 2	50	10 – 15	1 – 3	20 – 50

2 Finite element model

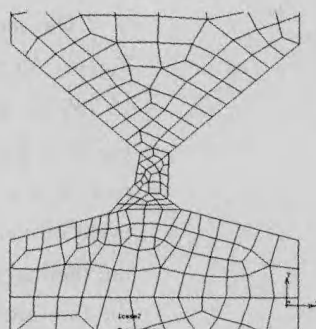
2.1 Three-dimensional model

The double-sided asymmetrical TIG backing welding process of large thick plates is a typical non-linear transient thermal process with non-uniform temperature field distribution and variational temperature gradient. In the

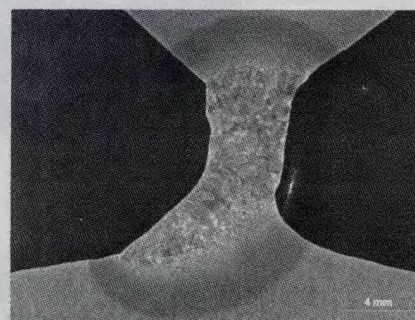
base metal area, the sparse meshes are adopted due to the small temperature gradient. Whereas the dense meshes are used in the weld zone because of the large temperature gradient. The three-dimensional finite element model is illustrated in Fig. 1. And the total numbers of nodes and elements are respectively 86 148 and 69 800.



(a) Three-dimensional model



(b) Meshes of welded joint



(c) Macrograph of welded joint

Fig. 1 Three-dimensional finite element model

2.2 Material properties

The melting point of welded material is 1 450 °C. The values of thermal conductivity and specific heat at different temperatures can be seen in reference [5]. The latent heat of liquid-solid phase transformation is taken into account in the numerical simulation, and latent heat of solid-solid phase transformation is not considered.

2.3 Heat source model and boundary conditions

The double ellipsoid heat source model^[6] is applied to simulate the TIG welding heat source, which considers the heat effect in depth direction. The heat efficiency of TIG backing welding is set to be 75%. The initial temperature of finite element model is 27 °C, which is the actual ambient temperature of welding process. Additionally, the combined heat transfer coefficient is employed as the thermal

boundary condition to consider the radiation and surface convection to the surrounding ambient^[7].

3 Results and discussion

3.1 Temperature field distributions

The temperature field distributions of the double-sided asymmetrical TIG backing welding are acquired. Fig. 2 shows the temperature field distribution on the cross section of fore pass. Fig. 3 illustrates the temperature field distribution on the cross section of rear pass. Fig. 4 shows the temperature field distribution of two molten pools on the side of rear arc. Fig. 5 shows the temperature field distribution of two molten pools on the side of fore arc. It can be seen that one-side welding with back shaping is accomplished during the welding of fore pass, and then the rear arc remelts the fore pass partially.

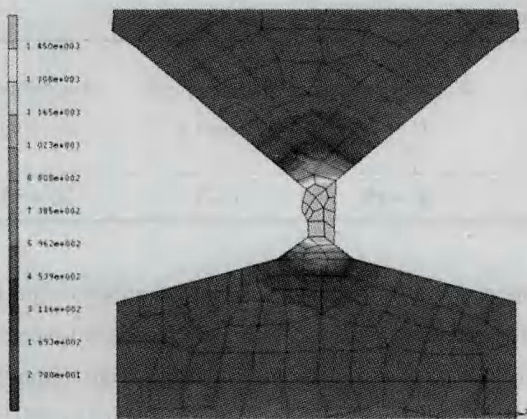


Fig. 2 Temperature field distribution on cross section of fore pass

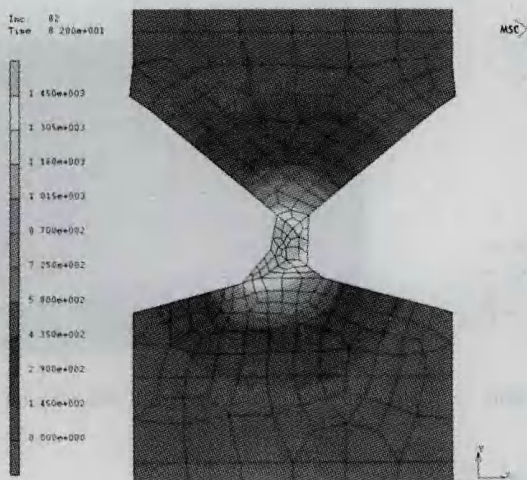


Fig. 3 Temperature field distribution on cross section of rear pass

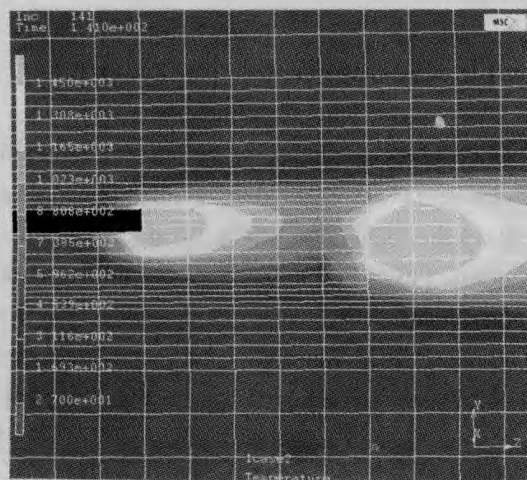


Fig. 4 Temperature field distribution of two molten pools on side of rear arc

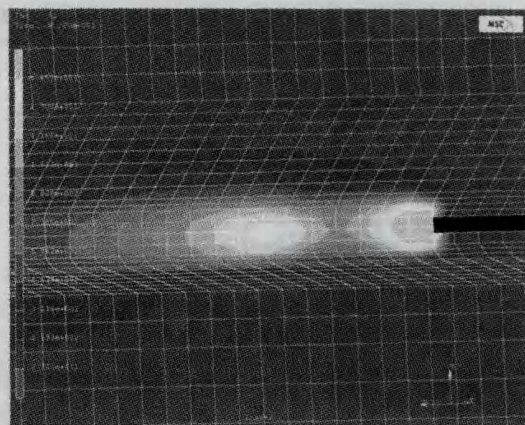


Fig. 5 Temperature field distribution of two molten pools on side of fore arc

3.2 Thermal cycles of welded joint

The locations of the concerned nodes are shown in Fig. 6. Moreover, Fig. 7 is the thermal cycle of node 15 739 at the bottom root location on the rear arc side. Fig. 8 is the thermal cycle of node 16 739 at the bottom root location on the fore arc side. Fig. 9 shows the thermal cycle of node 17 139 at the upper root location. Fig. 10 is the thermal cycle of node 59 739 on the surface of weld on the fore arc side. Fig. 11 is the thermal cycle of node 16 139 on the upper fusion line on the rear arc side. Fig. 12 shows the thermal cycle of node 57 339 in the upper heat-affected zone on the rear arc side. The cooling times $t_{8/5}$ and $t_{8/3}$ of concerned nodes are shown in Table 2 respectively.

According to the above thermal cycle curves of double-sided asymmetrical TIG backing welding, there exist two temperature peaks. The two peaks form respectively when the fore arc and rear arc pass by. The fore arc has the pre-heating effect on the rear pass, and the pre-heating temperature depends on the arc distance, the heat input of fore arc, and the initial temperature of workpiece. Moreover, the pre-heating effect can decrease the cooling speed of workpiece. Therefore, the cooling times $t_{8/5}$ and $t_{8/3}$ increase, and the cooling times of double TIG arc welding are much longer than that of single TIG arc welding. In the temperature scope (200 – 400 °C) of martensitic transformation, the cooling speed also decreases, and the martensite in the heat-affected zone experiences the self-tempering process. Furthermore, the rear heat source has the post-heating treatment on the fore pass.

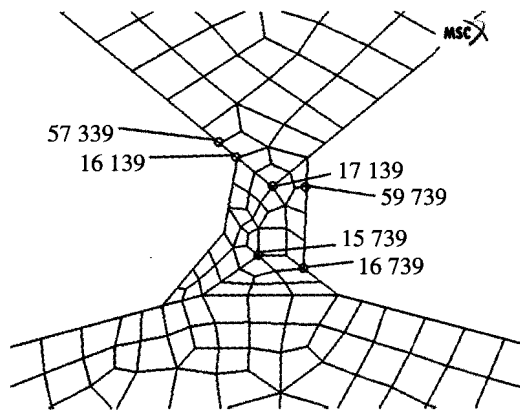


Fig. 6 Locations of concerned nodes

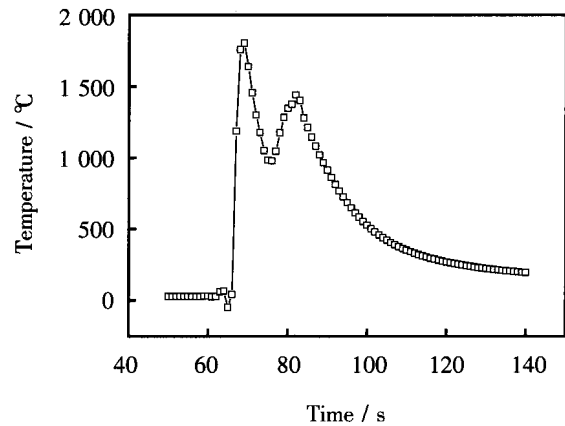


Fig. 9 Thermal cycle of node 17 139 at upper root location

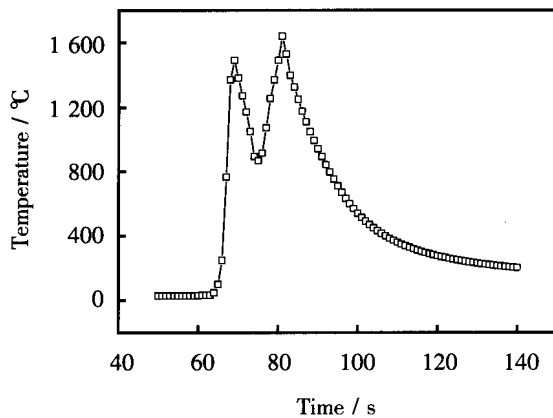


Fig. 7 Thermal cycle of node 15 739 at bottom root location on rear arc side

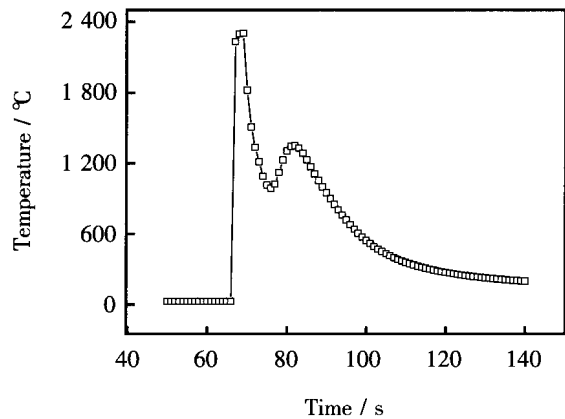


Fig. 10 Thermal cycle of node 59 739 on surface of weld on fore arc side

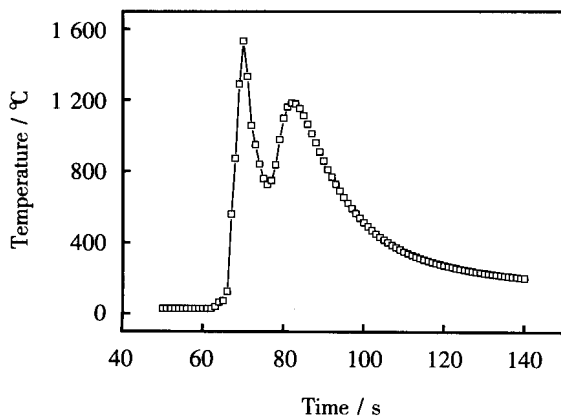


Fig. 8 Thermal cycle of node 16 739 at bottom root location on fore arc side

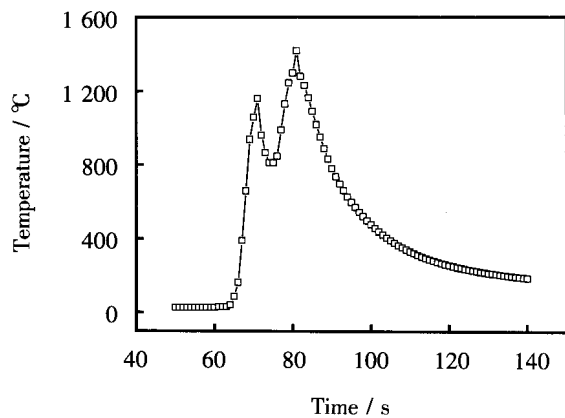


Fig. 11 Thermal cycle of node 16 139 on upper fusion line on rear arc side

3.3 Effects of arc distance

Arc distance is an important parameter in the double-sided asymmetrical TIG backing welding process, the

effect of arc distance on the thermal cycle is shown in

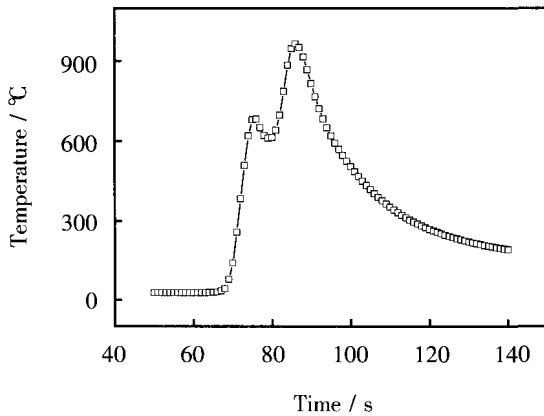


Fig. 12 Thermal cycle of node 57 339 in upper heat-affected zone on rear arc side

Table 2 Cooling times of concerned nodes

Nodes	$t_{8/5}$ / s	$t_{8/3}$ / s
15 739	9	23
16 739	10	25
17 139	9	23
59 739	9	23
16 139	10	24
57 339	10	26

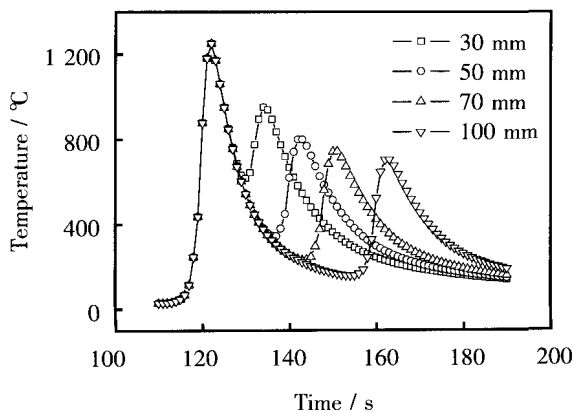


Fig. 13 Effect of arc distance on thermal cycle

Fig. 13. As seen, when the arc distance increases from 30 mm to 100 mm, the mutual thermal effects of two heat sources decrease gradually.

4 Conclusions

(1) There exist two peaks in the thermal cycle of double-sided asymmetrical TIG backing welding process. The fore arc has the pre-heating treatment on the rear pass, and the rear arc has the post-heating treatment on the fore pass.

(2) In double-sided asymmetrical TIG backing welding, the mutual thermal effects of two heat sources decrease as the arc distance increases.

References

- [1] Zhao B J, Cao L Y, Zheng H J, et al. Efficient welding technology and equipment of ship. Defense Manufacturing Technology, 2010(3): 5 – 11. (in Chinese)
- [2] Yin S Y. Research developments of efficient arc welding technology. Welding & Joining, 2006 (10): 7 – 14. (in Chinese)
- [3] Zhang F J, Ma D, Zhang G D, et al. Automatic MIG/MAG welding of steel BHW35 in ultra-narrow gap. Electric Welding Machine, 2006, 36(6): 59 – 62. (in Chinese)
- [4] Zhang H J, Zhang G J, Wu L. Effects of arc distance on angular distortion by asymmetrical double sided arc welding. Science and Technology of Welding and Joining, 2007, 12 (6): 564 – 571.
- [5] Hu J F, Yang J G, Fang H Y, et al. Numerical simulation on temperature and stress fields of welding with weaving. Science and Technology of Welding and Joining, 2006, 11(3): 358 – 365.
- [6] Goldak J, Chakravarti A P, Bibby M. A new finite element model for welding heat sources. Metallurgical and Materials Transactions B, 1984, 15B(2): 299 – 305.
- [7] Abid M, Siddique M. Numerical simulation to study the effect of tack welds and root gap on welding deformations and residual stresses of a pipe-flange joint. International Journal of Pressure Vessels and Piping, 2005, 82(11): 860 – 871.