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Numerical simulation of the temperaturbe filed in fixed-TIG welding pool

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Abstract: Based on the mechanism that temperature gradient distribution and the dynamic depth-to-width ratio in the welding pool have great effect on the generation of undercut, a three-dimensional finite-element model is developed in the Gaussian manner to simulate the temperature field of fixed-point TIG welding pool by the software ANSYS. This paper simulates the temperature field of weld pool on the condition of the same energy input, and analyzes the analog result. Finally, a key principle about the temperature gradient distribution and the depth-to-width ratio is drawn. From the simulation results, it can be gotten that the distribution of temperature gradient and the change of depth-to-width ratio in the welding pool have corresponding relationship with the generation of undercut.

Keywords: TIG welding; ANSYS; temperature field; undercut

0. Introduction

With the development of science and the acceleration of production process，the efficiency of the welding process is required higher and higher. In order to improve the efficiency of the welding process, they always be adopted that increasing the welding current and enhancing the welding speed. However, if only using these methods to improve the efficiency of the welding process, the welding qualities are worse, and even bring some welding defects. If the welding engineer test is introduced to solve these problems, it will not only take too much times and manpower, but also the results have no commonality and only fit the specific welding conditions. Consequently, many scholars have studied the heat and mass transfer in welding pool by numerical simulation in recent years. Since the conditions of the welding in high speed are complicated, the study of the heat and mass transfer in the pool is very difficult. According to the research about thermodynamics, the conditions of the fixed-point welding pool and the moving welding pool have corresponding relationships, that is, the heat and mass transfer in moving welding pool can be reflected by which in the fixed-point welding pool. Thus, this paper analyzed the temperature field of the fixed-point pool, which was simulated by the finite element software ANSYS, to reflect the temperature field in the moving pool [1] .The paper also made a lot of welding technology experiments, and got the result of the experiments, which coincided with the results of the numerical simulation. Finally, the article generalized the law of undercut in the welding bead.

1. Mathematic model

The assumptions made in the model are as follows:

(1) The weld pool surface is flat.

(2) Arc power is distributed in the Gaussian manner at the top surface.

(3) Arc force and buoyancy are not considered in the model.

The three-dimensional finite element model is showed in Fig.1, and it's material is Q235 steel. The model size is 100mm×50mm×3mm, and it is divided by map grid. The total number of nodes is 27000, and the number of nodes in the center region, which is multiplied, is 9000.

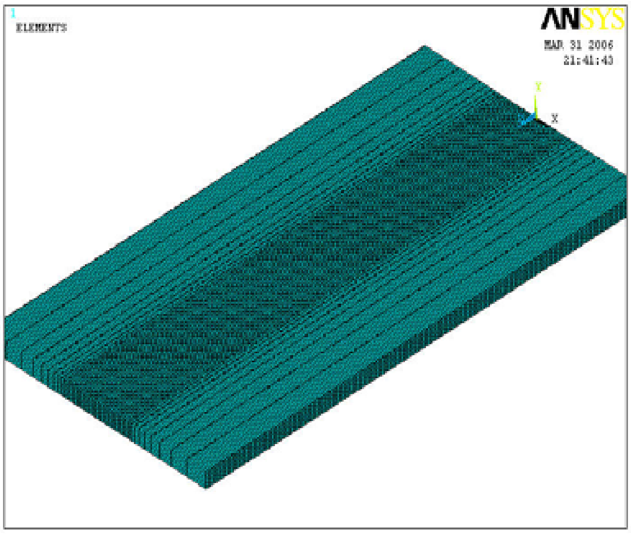

Fig.1 Three dimension model and its meshed grids

1.1. Governing equation in rectangular coordinate system

In a general three-dimensional model, the differential equation, with which the transient thermal field variable T (x, y, z, t) should be satisfied in the rectangular coordinates, is the governing equation in which all physical quantities obey the conservation of energy principle in the welding process. The governing equation is showed by (1), and it is also the thermal balance equation in the model,

$$\rho c\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}(k\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})+Q \quad (1)$$

In the equation, $\boldsymbol{\rho}$ is mass density, $\boldsymbol{c}$ is specific heat, $\boldsymbol{T}$ is temperature, and $\boldsymbol{k}$ is heat conductivity, $\boldsymbol{Q}$（$\boldsymbol{x,y,z,t}$）is intensity of inner heat source in the solving region, $\boldsymbol{k}$、$\boldsymbol{c}$ and $\boldsymbol{\rho}$ vary with temperature.

The first item is the energy used to heat up the microbody, and the following three items are the quantities of heat transferred to microbody in x, y, z directions respectively, the last item is the quantity of heat generated by the thermal source in the microbody.

1.2. Boundary conditions and heat source manner

In the process of heat exchange between weldment and surrounding medium, heat is dissipated mainly by radiation and convection. Radiation is the main style for heat dissipation when temperature is high, otherwise, convection dominates in heat dissipation.

For heat dissipation, radiation is the main style when temperature is high, otherwise, convection is the dominant style. In the model, there is no heat transfer in the symmetry plane, and the heat source is added on the top wall, the styles of heat transfer in other walls are radiation and convection.

In this paper, heat source distributes in Gaussian manner, and the position of the heat source center is （0，0，0.05）in the model coordinate.

The function of Gaussian manner is

$$q(r)=\frac{\eta \mathrm{UI}}{\pi r_H{}^2}\exp(-\frac{r^2}{r_H{}^2})$$

$$=\frac{\eta \mathrm{UI}}{\pi r_H{}^2}\exp(-\frac{(x^2+(z-0.05)^2)}{r_H{}^2}) \quad (2)$$

Where $\boldsymbol{U}$ is welding voltage, $\boldsymbol{I}$ is welding current, $\boldsymbol{r_H}$ is the radius of welding heat spot, and $\boldsymbol{r}$ is the distance from a point in the heat source to the center. η is the welding heat efficiency, in this paper, it's 0.65 .

1.3. Fluid flow in the welding pool

The fluid flow in the welding pool increases the heat transfer speed of material, which has an important effect to the temperature filed in the welding process. In this article, the effect of fluid flow in the welding pool upon the whole temperature field is considered by increasing the coefficient of effective heat transfer.

1.4. Physical properties of Material

The material of Q235 steel is chosen, and its physical properties are shown in Table.1

Table1. Physical properties of Q235 steel

temperature（K）	20	200	500	800	1100	1500	1700	2000
Density（kg/m^3）	7880	7880	7710	7588	7320	7278	7105	7009
Thermal conductivity（W/m-K）	52.56	47.54	39.19	26.18	28.51	31.38	140	142
specific heat（J/Kg-K）	474.77	509.5	666.64	919.82	644	726.67	768.67	831.67
enthalpy（J/m^3）	7.17e8	14.35e 8	28.7e8	43.7e8	52.95e8	82.15e8	90e8	95e8

2. Results and discussion

In the simulation, Q235 steel sheet is selected as the weldment, and three groups of parameters are selected, as shown in table 2.

Table2. Welding current and heating time

Welding current（A）	190	150	110
Heating time（S）	2.4	3.4	5.04

The three groups of parameters used in the fixed-point weld, correspond to the assemblages of different welding current with different welding speed when the energy input is uniform in the moving weld. That means big welding current combines with high welding speed [2]. So, the distribution of the temperature field in moving welding pool can be deduced from the simulation with the fixed-point welding pool. It is shown in Fig.2 that temperature distribution in the maximum width section under the same heat input.

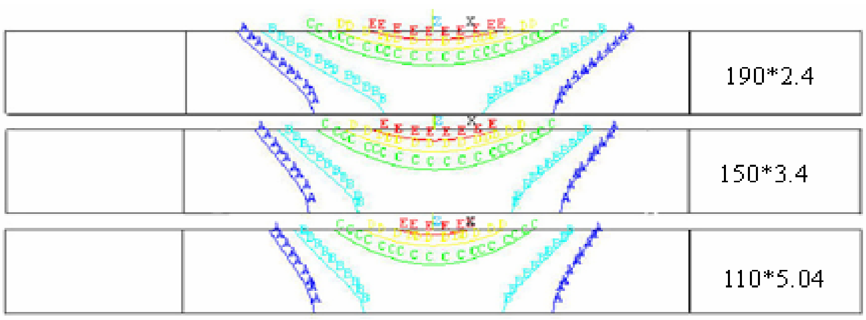

Fig.2 Temperature distribution on the maximum width section under the same heat input

As can be seen from Fig.2, the distribution of temperature field is different, although the heat input is uniform. The temperature distribution is concentrated in the diametric direction of welding pool, when a low current is used to heat for a long time [3]. Thereby, the conclusion can be drawn that a bigger depth-to-width ratio can be obtained by using a low current to weld a long time under the same heat input.

Taking account of the relationships between the fixed-point weld and the moving weld, it also can be deduced that using a low current in a low speed to weld can get a big depth-to-width ratio of welding pool in the moving weld with the same heat input.

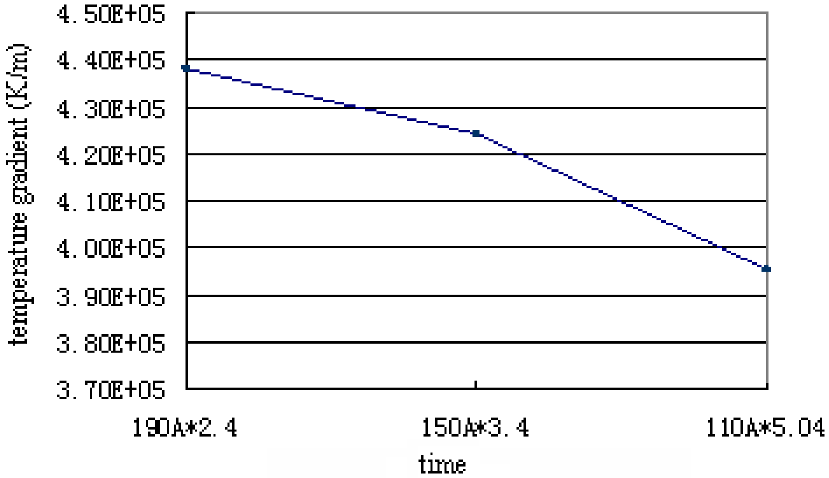

Fig.3 Comparison of temperature gradient in same input energy

It can be seen from Fig.3, in the situation of same heat input, a bigger temperature gradient appears when using a high current to weld a short time, and however, the temperature gradient is smaller when using low current to weld a long time. Based on the mechanics that the temperature gradient and the depth-to-width ratio have a great effect to undercut, some conclusions are obtained from the analog result, that is, when using a high current to heat a short time, undercut appears easily[4]. From conclusions above, it can be conclude that using high current in a high speed is easy to bring undercut in the moving weld.

3. Experimental verification

They are conditions of welding experiment, that weldment is Q235steel sheet, flux of Ar gas is 10L/min, the distance from tungsten electrode to weldment is 5mm, stickout of tungsten electrode is 5mm, and the rake angle of tungsten electrode is 60° .

In the condition that the heat input is uniform, but the current and the welding speed are different. That the depth of undercut grows along with the increase of current and the decrease of heating time, in other words, it means high current and short heating time in the welding brings larger depth of undercut [5]. The experimental results match up to the results of numerical simulation commendably.

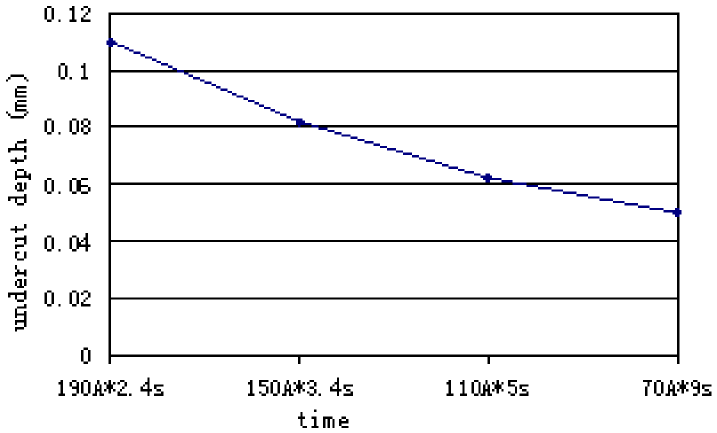

Fig.4 Undercut depth of different welding current as the same input energy

4. Conclusion

A three-dimensional computational model is built in this article by the software ANSYS to simulate the transient process of heat transfer in the fix-point welding pool with the same heat input. From the simulation results, it can be gotten that the distribution of temperature gradient and the change of depth-to-width ratio in the welding pool have corresponding relationship with the generation of undercut. According to the relationship and the analysis of simulation results, the conclusion is finally drawn that undercut occurs easily when using high current to weld a short time with the same heat input in the fixed-point weld process, and taking account of the corresponding relationship between the fixed-point welding pool and the moving welding pool, it is equal to using a high current in a high speed in the moving weld process. Meanwhile, a lot of fixed-point welding experiments are carried out in the paper, and their results reveal that deep undercut can be gotten by using high current and short heating time under the condition of same heat input. The experiment results are consistent with the numerical simulation results and ensure the correctness of numerical simulation.

5. References

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