

Numerical simulation on the shape of liquid surface of TIG full-penetrated weld pool

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Abstract: Based on the analysis of the three-dimensional liquid surface behavior of TIG penetrated weld pool, the three-dimensional shape models of weld pool with different values of the back fusion zone radius R_B were obtained. The effects of arc on the penetrated weld pool were studied by numerical simulation with finite elements analysis software Surface Evolver. The results show that the size and shape of the back weld pool are not affected obviously by the arc, and the top surface of the weld pool is lowered by arc. From pulse background to pulse peak, the increase of the arc voltage (or the arc light intensity) is due to two factors. One is the increase of the current, and the other is the lowering of the top weld pool surface.

Key words: TIG weld pool; full-penetrated weld; back fusion zone radius; arc; numerical simulation

1. Introduction

The weld quality is affected by the process of the weld pool melting and solidification. So the detection and control of the weld pool state is a main problem to control the welding quality. And the research of the weld pool state is a key for the welding quality control [1-2]. Analysis of the information of the top surface of the weld pool is a simple method to investigate the variation of the weld pool state [3]. But the electric arc welding is a complex process, so it is difficult to achieve the information of the top surface of the weld pool accurately through experiment. However, numerical simulation can simplify the complex research process [1-2] and can be used to predict the variation of the weld pool state.

For the full-penetrated TIG weld pool under the action of the arc, it is necessary to investigate the effects of the arc on the weld pool for the further studying of the three-dimensional shape of weld pool. So the influence of the arc on the liquid surface of the penetrated weld pool

was analyzed in this work, based on the numerical simulation of the three-dimensional shape of TIG weld pool.

2. Experimental procedure

Finite elements analysis software Surface Evolver developed by Brakke K.A. [5] was used to simulate the three-dimensional shape of penetrated weld pool under the action of the arc.

3. Three-dimensional shape model of full-penetrated weld pool

Fig.1 shows the shape model of full-penetrated weld pool. A sphere (radius R) intersects with a plate workpiece (thickness HH), and the sphere penetrates the work piece.

Then there are two parts. One is the intersection that stands for the fusion zone; the other is the cavity and residual area that stands for the solid metal. The full-penetrated weld pool can be described by the top fusion zone radius R_Z , the back fusion zone radius R_B and the

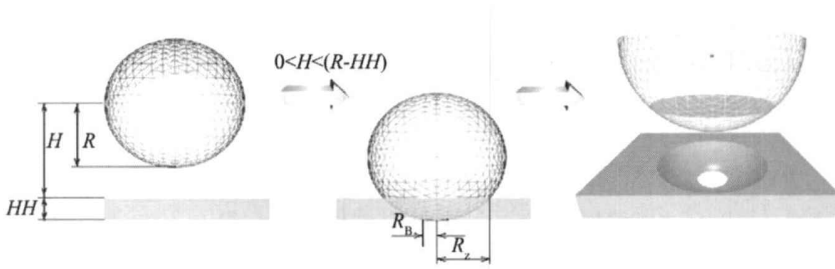


Fig.1. Schematic of three-dimensional shape model for full-penetrated weld pool .

thickness of work piece HH . Different values of R_B stand for weld pool with different penetrations in Fig.1 .

Fig. 2 demonstrates how to obtain the three-dimensional shape model of full-penetrated weld pools with different values of R_B , and the same values R_Z and HH .

4. Finite elements numerical simulation of the full-penetrated weld pool

4.1. Initial conditions

Fig.3 shows the division of initial grid for penetrated weld pool with arc acting .

The surface energy E_V , the gravitational potential energy E_G , the solid/ liquid interface energy E_{Cg} and the volume constraint condition were described as follows :

Constraint 1: equation: $x^2 + y^2 + z^2 = R^2$; energy: $E_W + E_G + E_{Cg}$; volume: $\int \omega_V \cdot ds + \int \omega_1 \cdot ds + \int \omega_2 \cdot ds$

Constraint 2: equation $x^2 + y^2 + z^2 = R^2$

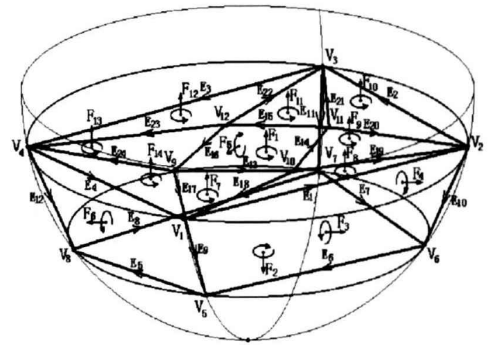


Fig.3. Division of initial grid for full-penetrated weld pool under arc acting .

Constraint 3: equation: $\frac{x^2}{R_f^2} + \frac{y^2}{R_f^2} + \frac{z^2}{C^2} =$

1 , where R_f stands for the virtual elliptic radius [6] , which describes the arc ; volume: $\int \omega_{Arc} \cdot ds$

Constraint 4: equation: $x^2 + y^2 = R_B^2$; energy: $E_W + E_G + E_{Cg}$; volume: $\int \omega_V \cdot ds + \int \omega_1 \cdot ds + \int \omega_2 \cdot ds$

In Fig .3 , codes $V_1 \sim V_4$ and lines $E_1 \sim E_4$ were restrained by constraint 1 ; lines $E_9 \sim E_{12}$ and faces $F_3 \sim F_6$ were restrained by constraint 2 ; codes $V_9 \sim V_{12}$, lines $E_{13} \sim E_{16}$ and face F_1 were restrained by constraint 3 ; codes $V_5 \sim V_9$ and lines $E_5 \sim E_9$ were restrained by constraint 4 ; faces F_1 , F_2 and $F_7 \sim F_{14}$ were dependent on the surface tension .

4.2. Results and discussion

In order to research the three-dimensional shapes of weld pools with different penetrations , the values of R_Z and HH are fixed ($R_Z = 4.0$ mm , $HH = 1.5$ mm) , and the value of R_B varies from 0.25 mm to 3.75 mm . The simula-

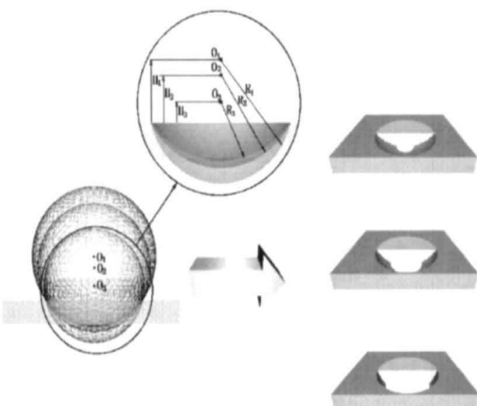


Fig.2 . Schematic of three-dimensional shape model for penetrated weld pool with different R_B .

tion results were exhibited in Fig.4. The left figures stand for the original states of weld pool without arc acting, the right figures show the different weld pool states under the action of arc .

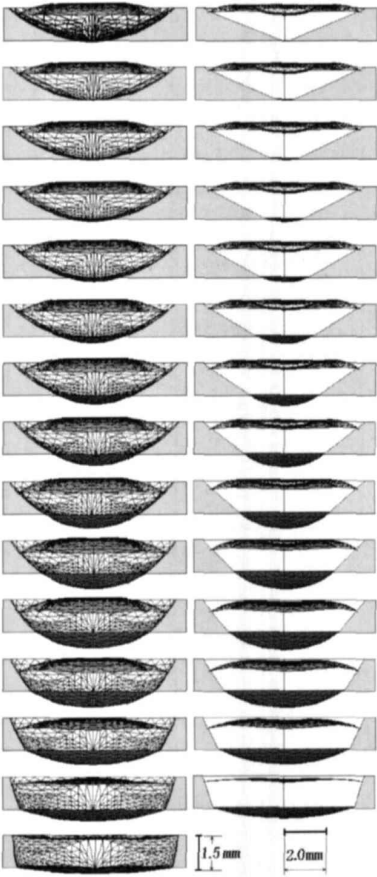


Fig.4. Three dimensional form of the penetrated weld pool liquid surfaces under arc acting .

The detailed description of the three-dimensional shape of the TIG weld pool was made by parameters $G_D(g \cdot cm)$ and $A_{S-L}(cm^2)$. G_D stands for the gravitational potential energy of the back weld pool surface . A_{S-L} stands for the area of solid/ liquid interface . The top weld pool surface was exactly described by characteristic parameters K_F and ΔR , where K_F stands for the covering ratio of the liquid metal and ΔR stands for the overburden width of the liquid metal[6] .

Fig.5 shows the results of the above parameters calculated by numerical simulation . Fig.6 shows the results of the top weld pool characteristic parameters . Through the above results, we can simulate the liquid surface equilibrium state during the time from impulse background to impulse peak .

Form Fig.5(b) , the following can be obtained : when R_z and H_H are constant , G_U is lower under the action of the arc . It shows that the top weld pool surface is lowered under the action of the arc . Combining the real welding process , this phenomenon stands for that , on the pulse peak time , the weld pool top surface is lowered , so the length of arc is longer ; on the pulse background time , the result is opposite . The fact that must be paid attention to is that the length of arc is indirectly detected by the arc voltage (or the arc light intensity) now . At the same arc length , the increasing current also increases the arc voltage (or the arc light intensity) . Therefore , during the time from pulse background to pulse peak , the increase

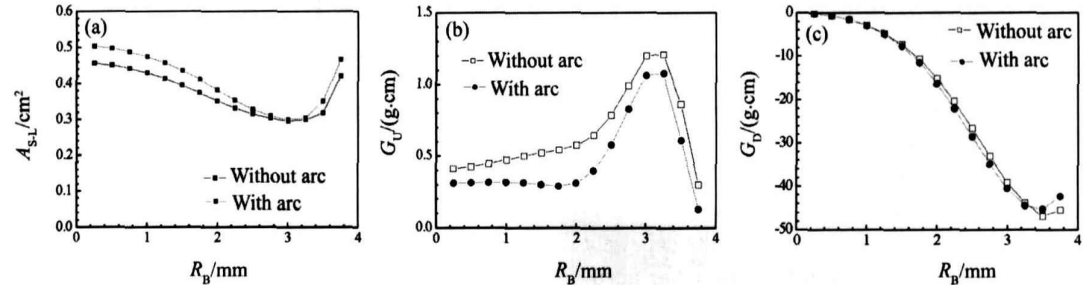


Fig.5. Simulating results of the full-penetrated weld pool liquid surfaces parameter under arc acting : (a) $A_{S-L} \sim R_B$; (b) $G_U \sim R_B$; (c) $G_D \sim R_B$.

of the arc voltage (or the arc light intensity) is due to two factors. One is the increase of the current; the other is the lowering of the top weld pool surface. In order to detect the latter accurately, it is necessary to exclude the effect of the former.

From Fig.5(c), the following can be seen that: with the arc acting, the curve of G_D is coincident with those without the arc acting. This phenomenon demonstrates that the arc doesn't affect the back weld pool size and shape obviously.

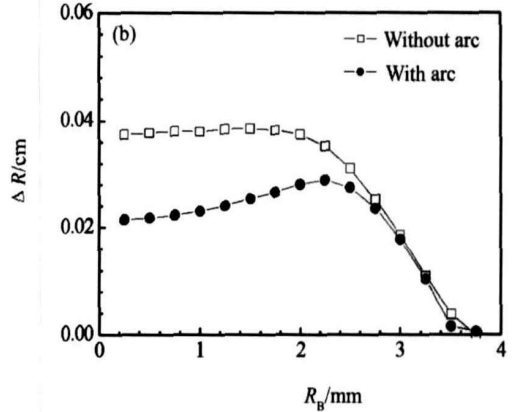
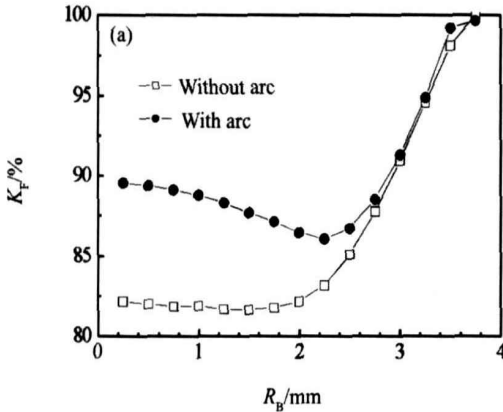


Fig.6. Feature regularity of the liquid surface of full-penetrated weld pool top under arc acting: (a) $K_F \sim R_B$; (b) $\Delta R \sim R_B$.

5. Conclusions

1. When R_Z and H_H are constant, if the back fusion zone is small ($R_B \leq 2.5$ mm in this article), the arc affects obviously the top weld pool surface characteristic parameters (K_F and ΔR); if the back fusion zone is too large, the arc doesn't affect these parameters obviously.

2. Whether the weld pool is affected by arc or not, the back weld pool size and shape don't vary obviously.

3. The action of arc is to lower the top weld pool surface. During the time from pulse background to pulse peak, the increase of the arc voltage (or the arc light intensity) was due to two factors. One is the increase of the current; the other is the lowering of the top weld pool surface. In order to detect the latter accurately, it is necessary to exclude the effect of the former.

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From the weld pool shape (Fig.4), numerical simulation results (Fig.5) and top weld pool surface characteristic parameters (Fig.6), the following results are obtained: when R_Z and H_H are constant, if the back fusion zone is small ($R_B \leq 2.5$ mm in this article), the arc obviously affects the top weld pool surface characteristic parameters (K_F and ΔR); if the back fusion zone is too large, the arc doesn't affect these parameters significantly.

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