*

(730050)

:   –   –   VOF

      TIG   、Marangoni   、

                       .   ($I \geqslant 250$ A)   、

    Marangoni   、   、

Marangoni   .   TIG   TIG

. TIG   TIG

                    .   .

:   ;   ;   ;

0

                                                          TIG

         (TIG)   .

                                 .

                              .   TIG   TIG

TIG   (volume of fluid VOF)

     [1–3] .   、

           .   [4]

             、   、   .   GPCA–TIG   [9]

                                           .

1

. Tanaka   [5]   、   、

1.1

                         . Wany   、

[6]   (1)

                          Newton   ; (2)

                                                ;

                        (3)

                   . Choo   .

[7]   ### 1.2

                                      、

                  .   [8]   .

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0 \qquad (1)$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla \cdot (\rho V u) = \nabla(\mu \nabla u) - \frac{\partial p}{\partial x} + S_u \quad (2)$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla \cdot (\rho V v) = \nabla(\mu \nabla v) - \frac{\partial p}{\partial y} + S_v \quad (3)$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \cdot (\rho V w) = \nabla(\mu \nabla w) - \frac{\partial p}{\partial z} + S_w \quad (4)$$

$$\frac{\partial(\rho T)}{\partial t} + \nabla(\rho V T) = \nabla\left(\frac{k}{c} \nabla T\right) + S_T \quad (5)$$

: u v w x y z ; μ ; p
; T ; S_u S_v S_w x y z
        ; S_T ; V ; k
    ; c ; ρ .

1.3   −

        −   [10]

        f_l

$$f_l = \begin{cases} 0 & T < T_s \\ \dfrac{T - T_s}{T_l - T_s} & T_s \leqslant T \leqslant T_l \\ 1 & T > T_l \end{cases} \quad (6)$$

: T ; T_s ; T_l .

1.4

(VOF)   [11]

            $F(x\ y\ z)$

$$\frac{\partial F}{\partial t} + u \frac{\partial F}{\partial x} + v \frac{\partial F}{\partial y} + w \frac{\partial F}{\partial z} = 0 \quad (7)$$

: F

. $F = 0$; $F = 1$; $0 < F < 1$
.

1.5

        (1)

                        [11]

$$p = p_{arc} + \gamma \kappa \quad (8)$$

: p ; γ

        ; κ ; p_{arc}

.   [12]

$$p_{arc} = \frac{\mu_0 I^2}{8\pi^2 (\sigma_x + \sigma_y)^2} \exp\left(-\frac{(x + y)^2}{2(\sigma_x + \sigma_y)^2} \right) \quad (9)$$

: μ_0 ; I ; σ_x σ_y

.

$$\kappa = -\left[\nabla\left(\frac{n}{|n|} \right) \right] = \frac{1}{|n|}\left[\left(\frac{n}{|n|} \cdot \nabla \right) |n| - (\nabla \cdot n) \right]$$

$$(10)$$

: n

x y z .   :

$$n = \nabla F = \frac{\partial F}{\partial x} + \frac{\partial F}{\partial y} + \frac{\partial F}{\partial z} \quad (11)$$

(2)   Marangoni   :

$$\tau_{Mx} = \frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial x} \quad (12)$$

$$\tau_{My} = \frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial y} \quad (13)$$

Marangoni z

            S_u S_v .

$$\frac{\partial \tau_{Mx}}{\partial z} = \frac{\partial}{\partial z}\left(\frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial x} \right) \quad (14)$$

$$\frac{\partial \tau_{My}}{\partial z} = \frac{\partial}{\partial z}\left(\frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial y} \right) \quad (15)$$

(3) xz ($y = 0$) yz
($x = 0$).

$$\frac{\partial T}{\partial x} = 0 \quad \frac{\partial v}{\partial x} = 0 \quad \frac{\partial w}{\partial x} = 0 \quad u = 0 \quad (16)$$

$$\frac{\partial T}{\partial y} = 0 \quad \frac{\partial u}{\partial y} = 0 \quad \frac{\partial w}{\partial y} = 0 \quad v = 0 \quad (17)$$

1.6

                                            [13]

$$q(x\ y\ z) = \frac{6\sqrt{3} Q}{a_h b_h c_h \pi \sqrt{\pi}} \exp\left(-\frac{3x^2}{a_h^2} - \frac{3y^2}{b_h^2} - \frac{3z^2}{c_h^2} \right)$$

$$(18)$$

: Q ; a_h b_h c_h

            0.004 5   0.004 5
0.000 5 m.

1.7

                                                x y z

                [13]   .

$$(J \times B)_x = -\frac{\mu_0 I^2}{4\pi^2 \sigma_j^2 r} \exp\left(-\frac{r^2}{2\sigma_j^2} \right)\left[1 - \exp\left(-\frac{r^2}{2\sigma_j^2} \right) \right]\left(1 - \frac{z}{L_z} \right)^2 \frac{x}{r}$$

$$(19)$$

$$(J \times B)_y = -\frac{\mu_0 I^2}{4\pi^2 \sigma_j^2 r} \exp\left(-\frac{r^2}{2\sigma_j^2} \right)\left[1 - \exp\left(-\frac{r^2}{2\sigma_j^2} \right) \right]\left(1 - \frac{z}{L_z} \right)^2 \frac{y}{r}$$

$$(20)$$

$$(J \times B)_z = \frac{\mu_0 I^2}{4\pi^2 L_z r^2}\left[1 - \exp\left(-\frac{r^2}{2\sigma_j^2} \right) \right]^2 \left(1 - \frac{z}{L_z} \right)$$

$$(21)$$

: σ_j ; L_z .

2

PISO .

FLUENT6. 3. 2 .

.

. Courant number

10^{-5} s. .

3

.

SUS304

TIG 20 mm × 20 mm × 8 mm

13 250 A

14 V

.

3.1

1

0. 011 m/s

$\triangle x$ (VOF

14

4) +

0. 144 mm("+"

; "-"

) .

（a）温度场与速度场 （b）表面变形量

1

Fig. 1 Weld pool under buoyancy

3.2

2

- 0. 156 mm. .

（a）温度场与速度场 （b）表面变形量

2
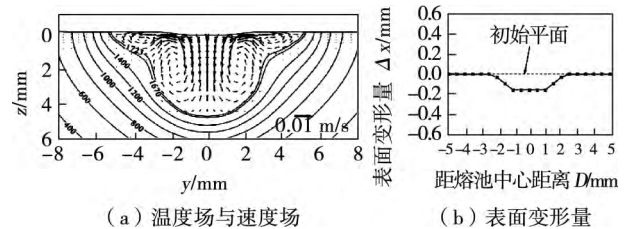
Fig. 2 Weld pool under arc pressure

3.3

3

+ 0. 053 mm. $z = 0$ mm

0. 12 m/s.

.

0. 22 m/s $z > 2$ mm .

.

$z = 2$ mm

（a）温度场与速度场 （b）表面变形量

3
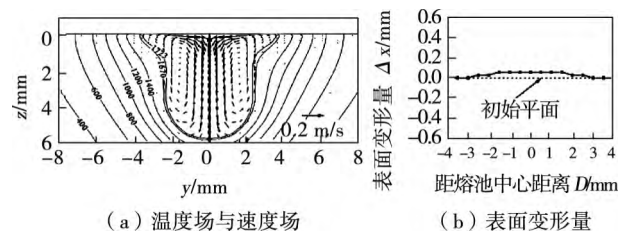
Fig. 3 Weld pool under electromagnetic force

3.4

4a $\partial\gamma/\partial T = -1. 2 \times 10^{-4}$ Marangoni

; .

.

4b   − 0. 208

mm.   Marangoni

.

4   ∂γ/∂T < 0   Marangoni

Fig. 4   Weld pool under Marangoni force(∂γ/∂T < 0)

3.5

5a   ∂γ/∂T = 1. 2 × 10⁻⁴   Marangoni

.

5b

0.071 mm.

Marangoni   0. 21

m/s   0. 1 m/s

0. 22 m/s   .

Marangoni

.

5   ∂γ/∂T > 0   Marangoni

Fig. 5   Weld pool under Marangoni force(∂γ/∂T > 0)

3.6

6a   250 A   TIG

.   6

.

.   6b

0. 140 mm   .

（a）温度场与速度场   （b）表面变形量

6   TIG

Fig. 6   Weld pool under TIG welding

7a   250 A   TIG

.

;

Marangoni   .

7b   TIG

0. 227 mm.

（a）温度场与速度场   （b）表面变形量

7   TIG
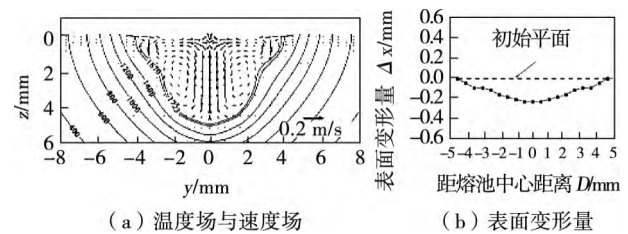
Fig. 7   Weld pool under activated TIG welding

250A   TIG

− 0. 140 mm   TIG

− 0. 227 mm.   TIG   TIG

、   、   Ma-

rangoni

+ 0. 144 mm、− 0. 156 mm、+ 0. 053 mm、

− 0. 208 mm(∂γ/∂T < 0)   + 0.071 mm(∂γ/∂T > 0)

− 0. 167 mm   − 0. 112 mm

TIG   TIG   .

.

4

（1）   、∂γ/∂T > 0   Marangoni   、

、$\partial\gamma/\partial T < 0$ 　　　Marangoni

．

（2）　　　TIG

；

TIG 　　　　Marangoni

．

（3）

．

（4）

．

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　　　　．　　　70　　　　．Email: hyorhot@ lut. cn

GAO Jian CHEN Hui（School of Materials Science and Engi-neering Southwest Jiaotong University Chengdu 610031 Chi-na）. pp 39-44

Abstract: High frequency pulses（HFPs）power source were parallelly connected with the power source of single-pulse mode MIG arc which are applied to laser-MIG hybrid welding. The cladding on A7N01 aluminum alloy was executed to investi-gate the dynamics of droplet transfer and arc with the effects of coupled HFPs through high speed camera observation. The sha-ping-characteristic and microstructure of cladding layer were also studied by metallographic analysis. The results show that the arc length and voltage increase after HFPs being coupled. The base current of single pulse MIG arc decreases while the peak current has little changes compared with that without HFPs coupling. In conventional laser-MIG hybrid welding the droplets are partly transferred as meso-spray mode. The finger-penetration weld can be obtained which probably causing defects in the weld root. After HFPs being coupled partly meso-spray transfer changes to completely spray transfer. The surface of cladding layer becomes smoother with the disappearance of fish-scale pattern and finger-penetration depth. Although the grain size has no significant changes the size of second phase particles becomes smaller and more uniformly distributed in grains as strengthened phase.

Key words: aluminum alloy; laser-MIG hybrid welding; high frequency pulses; droplet transfer; arc ultrasonic

Numerical simulation of effects of different driving force on surface deformation of weld pool

HUANG Yong LI Hui WANG Xinxin YAO Yuhang LU Suzhong（State Key Laborato-ry of Advanced Processing and Recycling of Non-ferrous Metals Lanzhou University of Technology Lanzhou 730050 China）. pp 45-49

Abstract: A three-dimensional transient mathematical model of weld pool for a stationary tungsten inert gas welding was established based on the fluid dynamic equations . In this mod-el enthalpy-porosity method was used to handle liquid-solid phase change VOF method was employed to track the free sur-face deformation of the weld pool. By solving these equations the deformation behavior of surface and the distributions of tem-perature and velocity were obtained under the independent action by buoyancy Marangoni force electromagnetic force and arc pressure respectively. The results indicate that at high welding current（$I \geqslant 250$ A） a surface projection forms in weld pool when buoyancy Marangoni force with positive temperature coef-ficient of surface tension and electromagnetic force were acted in-dependently while a surface depression formsunder the action of arc pressure Marangoni force with negative temperature coeffi-cient of surface tension. At high welding current weld pool de-pression phenomenon appears for both TIG welding and activated flux TIG welding. For TIG welding there exists an inward vortex in the central zone of the weld pool while a outward vortex ap-pears in the periphery. For activated flux TIG welding two in-ward vortexes are induced by different factors in the central zone and periphery of the weld pool respectively. The magnitude of surface deformation was not superimposed simply by each driving force.

Key words: VOF method; driving force; surface deform-ation; weld pool

Torque feature in bobbin tool FSW of 6061 aluminum alloy

CHEN Shujin CAO Fujun LIU Bin HU Xiaoqing LI Hao XUE Junrong（Jiangsu University of Science and Technolo-gy Zhenjiang 212003 China）. pp 50-54

Abstract: To investigate the torque characteristics in bob-bin tool friction stir welding（BTFSW）of 6061 aluminum alloy the torque in BTFSW was measured the frequency spectrum and the peak of torque were analyzed and then the relationship be-tween the torque oscillation and the surface shape of welded joint was also discussed. The research indicates that the torque in BTFSW is periodic. The major frequency of the torque is close to 2 times of the spindle frequency. The frequency difference illus-trates that the stacking behavior exists between the tool and the metal flow at different velocity. The experimental results indica-ted that the peak of torque increases with welding speed being in-creased and decreases with rotation speed being increased when interface temperature of tool and workpiece was lower than 500 ℃. Smaller torque oscillation will not affect the surface shape of welded joint but if the interface temperature was higher than 550 ℃ the torque will appear abnormal oscillation under adverse condition such as the too short distance between top and back shoulders slow travel speed high rotation speed. This research will be useful to indicate the mechanism of BTFSW 3-D force characteristics and the relationship between welding parameters and welding quality.

Key words: bobbin tool friction stir welding; welding torque; spectrum analysis; weld surface

Measuring residual stress of chain based on the method of digital image correlation

LIN Liexiong[1] LU Hao[1 2] XU Jijin[1] CHENG Zhewen[1]（1. School of Materials Science and En-gineering Shanghai Jiao Tong University Shanghai 200240 China; 2. Shanghai Key Laboratory of Materials Laser Processing and Modification Shanghai Jiao Tong University Shanghai 200240 China）. pp 55-58

Abstract: A stress measurement system was built based on digital image correlation method. The influence of speckle pattern quality on the measurement accuracy was analyzed and the accuracy of this measurement system was verified through in-plane translation and the test of plane stress state. The results show that the measurement accuracy can be improved with the in-crease of the quality of speckle pattern to a certain extent. All the relative errors in the test of in-plane translation were less than 3.5% which indicate that the system has high accuracy. When this measurement system was used to measure the welding residu-al stress of the chain the results are basically the same with that from strain gauges. It´s worth noting that this stress measure-ment system has advantages such as simple operation and high accuracy which can be used to measure the residual stress in-stead of strain gauge under certain conditions.

Key words: digital image correlation; welding residual stress; in-plane translation; plane stress; chain

Crystal orientation evolution of friction stir welding of 2024/7075 dissimilar aluminum alloys

ZHOU Jun[1 2] ZHANG Jin[1 2] JI Pengfei[1 2]（1. Institute for Advanced Materials Tech-nology University of Science and Technology Beijing Beijing 100083 China; 2. Beijing Key Lab for Corrosion Erosion and Surface Technology University of Science and Technology Bei-jing Beijing 100083 China）. pp 59-62

Abstract: The optical microscope and electron back scat-tering diffraction（EBSD）were used to comparative study the mi-crostructure features grain boundary characteristics and the evo-lution of the texture in friction stir weldedjoint and base metalof 2024/7075 dissimilar aluminum alloys. The results show that the content of low angle grain boundaryin thermal mechanical affect-ed zoneat retreating side grain is significantly higher than that of the base metal but there is no obvious change at advancing side. Dynamic recrystallization occurrs in stir zone and the con-tent of high angle grain boundary increases significantly. 2024 a-luminum alloy at retreating side has a weak orientation. 7075