Numerical Simulation of Droplet Transfer of AZ31B Magnesium Alloy Based on FLUENT

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Abstract. According to electromagnetic theory and fluid dynamics theory, the AZ31B magnesium alloy GMAW droplet transfer was simulated in the paper, by VOF model of FLUENT software to track the free interface of gas-liquid, use UDF order to add source term of momentum and energy equation. The simulation results show that when welding current is 100 A, the type of transfer belongs to globular transfer, and the type of droplet transfer of 280 A belongs to projected transfer; the critical transition current from globular transfer to projected transfer is about 220 A. With the increase of welding current, the diameter and length of droplet become small, the ratio of long axis length to the short axis length become more and more small, and the shape of droplet changes from long-oval to round. The neck part produces the maximum pressure, maximum pressure coefficient, maximum droplet velocity; the temperature gradient increases along with the axial direction; those factors will accelerate formation of the pencil tip and promote the droplet transfer.

Keywords: AZ31B · GMAW · VOF · UDF · Droplet transfer

1 Introduction

With the development of the society, every industry has put forward increasingly requirement to products about reducing mass, magnesium and magnesium alloy are used widely as a result of the smaller density of metal, magnesium alloy not only has light density, high specific strength and stiffness, can also reduce shock and unnecessary noise; owing to the high heat conduction rate and high expansion coefficient and lower melting and boiling points of the magnesium alloy, those physical property bring more difficult for magnesium alloy welding [1]. In order to improve the magnesium alloy welding quality and efficiency, this paper utilizes the electromagnetic theory and the fluid dynamics theory, and based on the computational fluid dynamics (CFD) software FLUENT14.5 to simulate the droplet transfer procedure of AZ31B magnesium alloy Gas Metal Arc Welding (GMAW), by simulating different welding currents to gain the characteristic and regulation of droplet transfer, welding parameter of simulation has a certain reference value for magnesium alloy welding test.

According to literature [2–7], the theory of droplet transfer simulation included static force balance theory (SFBT), pinch instability theory (PIT), mass-spring theory, the

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minimum energy theory, volume of fluid (VOF) theory; comprehensively compared with five kinds of theories, this paper choose the VOF theory to simulate the droplet transfer procedure, through user defined function (UDF) order to add the source term of the Navier-Stokes equation. In order to track the morphology of droplet, the droplet falling speed, the distribution of pressure and pressure coefficient distribution and temperature distribution in different moments, we need to establish a transient GMAW droplet transfer model under the condition of using VOF theory, the biggest advantage of VOF theory is that you can use VOF model track the free surface of the gas-liquid. The formation and stability of metal transfer depends on the comprehensive effect of various forces which act on the end of liquid metal; according to the appearance and characteristics of the transition, metal transfer mode is usually divided into two basic types: contact transfer and free-flight transfer, the former included short-circuiting, the latter included globular transfer and projected transfer and spay transfer, this paper simulated globular and projected transfer.

2 Numerical Simulation

Figure 1 is a two-dimensional axial symmetry model that imported into FLUENT software to calculate, the level is *Y* direction, the distance is 8 mm which is equal to nozzle diameter, the vertical is *X* direction, the distance is from nozzle to the workpiece surface which is 7.5 mm. Calculation region included the gas phase and liquid phase, the grid region means the first phase which is shied gas (Ar), the purity of Ar is 99.99%, the liquid magnesium alloy was regarded as the second phase that added by initialization, the rectangular area of BCDE is the series of AZ31B magnesium alloy welding wire which diameter is 1.2 mm, all of the above data are in accord with the test process.

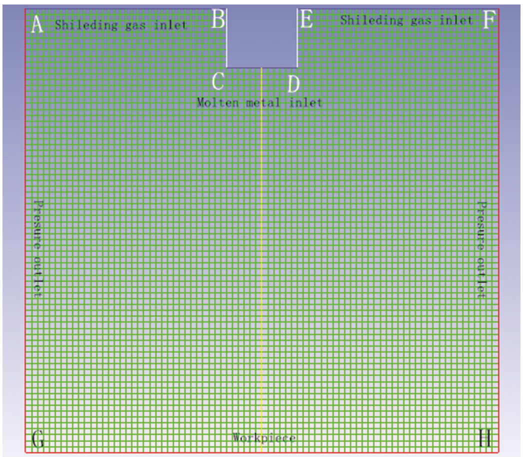

Fig. 1. Mathematical model of droplet transfer

2.1 Assumptions

In order to facilitate the simulation of the complex process of droplet transfer, put forward the following hypothesis [8]:

1. The droplet transition simplify into a two-dimensional axial symmetry problem (mathematical model as shown in Fig. 1).
2. The liquid metal is incompressible Newton fluid.
3. The liquid metal physical parameters are assumed as constant.
4. The welding protective gas (Ar) at atmospheric pressure, and ignore the influence of the pressure change of surrounding.

2.2 Mathematical Equation

During the simulation process of droplet transfer based on FLUENT, the liquid droplet is acted as incompressible Newton fluid, the fluid was manipulated mainly by the equation of mass conservation, momentum conservation and energy conservation [9], those are given below:

Mass conservation equation:

$$\frac{\partial \mathrm{u}}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum conservation equation:

$$\frac{\partial \mathrm{u}}{\partial t} = X - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}) \tag{2}$$

$$\frac{\partial \mathrm{v}}{\partial t} = Y - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}) \tag{3}$$

In the above equations: u and v are the velocity of the fluid in the direction X and Y, respectively; ρ is the liquid metal density; p is the pressure on the fluid; μ is the Kinematic viscosity of liquid metal; X and Y is the body force, which conducted in the indirection of vertical and level, respectively.

In the process of simulation of droplet transfer, because it involved gas-liquid two phase fluid, we need use VOF model in the module to track the change of free interface. VOF model is equal to the cell fluid volume function $F(x, y, t)$, which satisfied the following conservation equation:

$$\frac{\partial F}{\partial t} + (\overrightarrow{\nabla}\cdot\nabla)F = 0 \tag{4}$$

If =0, means no liquid metal fluid in the cell; if =1, means liquid metal fluid filled with cell completely; if 0 << 1, indicate the cell contain two phase fluid.

2.3 Droplet Force Analysis

The metal transfer process is mainly controlled by the gravity, electromagnetic force, surface tension, and the plasma flow, owing to the mass density of AZ31B magnesium alloy is light (1780 kg/m^3), so the effect of promoting droplet transfer of gravity is trivial, the surface tension was controlled by the surface tension coefficient of the first phase and the second phase, in order to simplify calculation, the surface tension coefficient is set as 1.0. Therefore, we can infer that the decisive force for metal transfer process of GMAW is the electromagnetic force, before we imported the physical model into FLUENT, we need add the source term of the momentum equation by UDF order, which was compiled by C program, the main contest of UDF order is about electromagnetic force, calculation formula of the electromagnetic force was given below:

$$F_{em} = \frac{\mu_0 I^2}{4\pi}[\ln\frac{\mathrm{R}\sin\theta}{\mathrm{r}} + \frac{2}{(1-\cos\theta)}\ln\frac{2}{1+con\theta} - \frac{1}{1-con\theta} - \frac{1}{4}] \tag{5}$$

where μ_0 is the Magnetic permeability; R is the radius of wire; I is the welding current; θ is the arc root angle; r is the radius of droplet at any time.

2.4 Boundary Condition

This paper simulated 11 groups data, every simulation group executed under different voltage and current; what's more, the boundary condition of each group are shown in Table 1, is equal to the Wire Feed Speed (WFS), is the velocity of shield gas, T is the temperature, is the volume of second phase; Table 2 is the physical parameters about AZ31B magnesium alloy [1]; Table 3 is the value of voltage and WFS under different currents.

Table 1. Boundary condition of the model

Boundary	u (m/s)	v (m/s)	T (K)	F
AB/EF	vg	0	300	0
CD	vf	0	1380	1
AG/FH	0	0	300	0
GH	0	0	1680	0

Table 2. Material properties of AZ31B Magnesium alloy

Property	Value
Mass density ρ	$1780\ \mathrm{kg} \cdot \mathrm{m}^{-3}$
Kinematic viscosity μ	$0.006\ \mathrm{m}^2 \cdot \mathrm{s}^{-1}$
Magnetic permeability μ_0	$4\pi \times 10^{-7}\ \mathrm{H} \cdot \mathrm{m}^{-1}$
Electrical conductivity σ	$7.7 \times 105\ \Omega^{-1} \cdot \mathrm{m}^{-1}$
Gravitational acceleration g	$9.81\ \mathrm{m} \cdot \mathrm{s}^{-2}$

Table 3. The voltage and wire feed speed

Current (A)	Voltage (V)	WFS (m/s)	Current (A)	Voltage (V)	WFS (m/s)
100	19	0.05	220	25	0.093
120	20	0.0566	240	26	0.103
140	21	0.0632	260	27	0.123
160	22	0.0698	280	28	0.133
180	23	0.0764	300	29	0.144
200	24	0.083			

3 Results and Discussion

Figure 2 is the droplet transfer process when the welding current is 100 A, voltage is 19 V, the type of droplet transfer belongs to typical globular transfer, as it's depicted in Fig. 2, when the welding current is 100 A, the period of droplet transfer is about 144 ms. Through the initialization to add a semi-circle at the end of wire, the radius of the circle is 0.6 mm, in addition, we regarded this moment as the initial time, namely the time is 0 ms; from 0 to 136 ms, the liquid droplet was elongated slowly and grew up under the action of gravity.

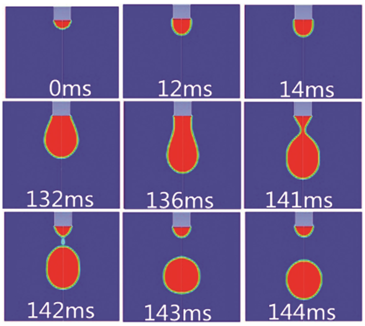

Fig. 2. Process of droplet transfer under 100 A

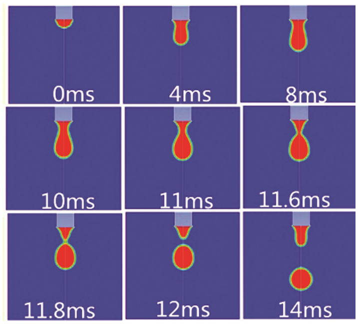

Fig. 3. Process of droplet transfer under 280 A

During this period, owing to the arc root angle is smaller, the upward axial electromagnetic force prevented droplet transfer; at the moment of 141 ms, the neck formed as a result of the radial electromagnetic shrinkage force, due to the neck formed fully, the arc root angle became larger, with the increase of arc root angle, the direction of the electromagnetic force change from upward to downward, so the downward axial electromagnetic force and gravity promote the droplet transfer collectively.

On the other hand, the surface tension hamper the droplet transfer, and the radial shrinkage stress increased, those factors lead to the formation of wire tip; because the resultant of vertical downward electromagnetic force and the gravity is greater than the surface tension, so the droplet detached from the end of the wire rapidly.

From 142 ms to 144 ms, owing to the detached metal conducted only by gravity and surface tension, therefore the droplet deforms from approximate long oval to circular;

what's more, the residue liquid metal at the wire tip will rebound and oscillate as a result of surface tension, which can be seen from the last three small picture in the Fig. 2.

Figure 3 is the droplet transfer process when the welding current is 280 A, voltage is 28 V, the type of droplet transfer belongs to projected transfer, the tip of a pencil fully formed, the period of droplet transfer is approximately 14 ms, the cycle became shorter obviously when compared with 100 A, as we can see from Fig. 3, the neck formed fast, the direction of electromagnetic force change from vertical upward into downward, this change will promote metal transfer. According to the calculation formula of the electromagnetic force, due to the current increased, the axial electromagnetic force and the radial electromagnetic force will increase, those will lead to the formation of neck and the tip of pencil rapidly, the period of droplet transfer became shorter. So, we can infer that the type of droplet transfer related to the speed of formation of the neck, when the neck formed rapidly, the type of droplet transfer will vary.

Figure 4 is the cycle of droplet transfer under different welding currents, as it's displayed, with the increase of welding current, the period of droplet transfer becomes shorten, droplet transfer cycle shortened greatly from 100 A to 220 A, droplet transfer cycle shortened slightly from 220 A to 300 A, we regarded the moment of transformation of metal transfer type as the critical transition, so the critical transition current is about 220 A; what's more, we can speculated that the formation of droplet transfer belong to spray transfer when the current is more than 300 A.

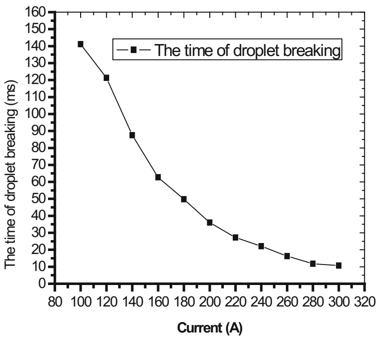

Fig. 4. The time of droplet breaking under different currents

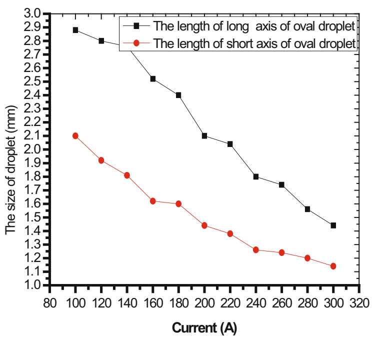

Fig. 5. The size of droplet under different currents

Owing to the shape of detached droplet is similar to a long-oval, Fig. 5 shows the length of long axis and short axis of oval droplet at the detaching time under different currents, the length of short axis is equal to the diameter of droplet, we can see from the graph that the length of long axis and short axis of oval droplet became smaller with the increase of welding current. The length of long axis is greater than the droplet diameter, which may be related to the density of magnesium alloy and the surface tension coefficient, the metal can be elongated easily under the comprehensive action of all kinds of force. According to the distance between long axis and short axis under the condition of the same current in Fig. 5, the ratio of the long axis to short axis is more and more small with the increase of current, then the droplet shape change from a long-oval to round slowly. During the region of 100 A to 220 A, the droplet diameter is greater than the wire diameter, so the droplet transfer mode belongs to globular transfer, from 220 A to 300 A, the diameter of droplet is smaller than the wire diameter, so the transition from attributed to projected transfer. Figure 6 displayed the maximum length of liquid metal at the end of wire (namely the distance from the bottom of the droplet to wire at the moment of droplet falling soon, such as the moment of 140 ms in Fig. 2 and 11.6 ms in Fig. 3) under different current conditions, as can be seen from the graph, with the increase of welding current, the maximum length became small, which maybe relate to the type of droplet transfer, when globular transfer, droplet is long and large, when projected transfer, droplet is small and thin.

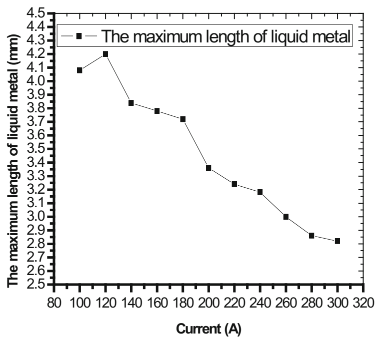

Fig. 6. The maximum length of droplet under different currents

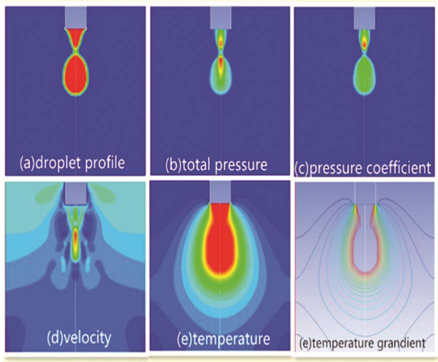

Fig. 7. Distribution of physical property in the droplet ($I = 280$ A, $t = 11.8$ ms)

In order to analyze the droplet transfer process in more detail, we need to monitor the droplet shape, the pressure distribution on the droplet, velocity and testing pressure coefficient and temperature distribution at arbitrary moment. Figure 7 shows the droplet physical parameters distribution at 11.8 ms when the welding current is 280 A, the Fig. 7(a) is the function of volume distribution for the liquid droplet, namely the droplet shape profile, at this moment the liquid bridge formed fully and the curvature of the neck part is larger than other place; what's more, we can see that the maximum total pressure located in the neck part from the Fig. 7(b), it's necessary to pointed out that the red part represent the greater value from Fig. 7(b) to (f); on the contrary, the maximum pressure coefficient not located in the neck part, but behind the neck part; the maximum velocity of liquid metal located in the neck part as show in the Fig. 7(d), the maximum value was approximately 2.9 m/s; Fig. 7(e) is the temperature distribution on the droplet and Fig. 7(f) s the gradient distribution of temperature, the temperature gradient is smaller when it closed to the bottom of the droplet, approaching to the workpiece has a larger temperature gradient, so temperature gradient increased along the axial direction of welding wire; those factors will accelerate the formation of the tip of pencil and promote the droplet transfer.

Given some physical property parameters of AZ31B magnesium alloy in high temperature state are uncertain, this paper ignored the effect of metal vapor pressure to the droplet transfer, so in the future work we need fully consider the influence of high temperature properties of the liquid metal and the shied gas to make the simulation results more accurate.

4 Conclusions

In this study, it based on the FLUENT software to simulate AZ31B magnesium alloy GMAW droplet transfer process under different welding currents, when the welding current is 100 A, the type of droplet transfer belongs to globular transfer, the type of droplet transfer of 280 A belongs to projected transfer; the critical transition current from globular transfer to projected transfer is about 220 A.

With the increase of welding current, the diameter and length of droplet become small, the ratio of the long axis length to the short axis length is also more and more small, so the droplet shape change from long-oval to round.

The neck part produces the maximum pressure, maximum pressure coefficient, maximum droplet velocity; the temperature gradient increases along the axial direction; those factors will accelerate the formation of the tip of pencil and promote the droplet transfer.

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References

1. Mordike BL, Ebert T (2001) Magnesium properties-application-potential. Mater Sci Eng A 302(1):37–45
2. Schnick M, Fuessel U, Hertel M et al (2010) Modelling of gas–metal arc welding taking into account metal vapour. J Phys D Appl Phys 43(43):434008
3. Fan HG, Kovacevic R (2004) A unified model of transport phenomena in gas metal arc welding including electrode, arc plasma and molten pool. J Phys D Appl Phys 37(18):2531
4. Boselli M, Colombo V, Ghedini E et al (2011) Time dependent modeling of droplet detachment in GMAW including metal vapor diffusion. IEEE Trans Plasma Sci 39(11):2896–2897
5. Wu CS, Chen MA, Lu YF (2005) Effect of current waveforms on metal transfer in pulsed gas metal arc welding. Meas Sci Technol 16(12):2459
6. Nemchinsky VA (1997) Heat transfer in a liquid droplet hanging at the tip of an electrode during arc welding. J Phys D Appl Phys 30(7):1120
7. Guo H, Hu J, Tsai HL (2010) Three-dimensional modeling of gas metal arc welding of aluminum alloys. J Manuf Sci Eng 132(2):237–247
8. Wu CS, Zhang MX, Li KH et al (2007) Numerical analysis of double-electrode gas metal arc welding process. Comput Mater Sci 39(2):416–423
9. Ding X, Li H, Yang L et al (2013) Numerical simulation of metal transfer process in tandem GMAW. Int J Adv Manuf Technol 69(1):107–112