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Study on Removal Mechanism of blowholes in Straight Polarity Direct Current Tungsten Arc Welding of Aluminum Alloy

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Keywords： DCSP TIG Welding; A-TIG welding; weld porosity; Activating Flux

ABSTRACT

2219 aluminum alloy has a series of advantages, such as good mechanical properties, stress corrosion resistance, welding performance, low hot crack tendency, and is widely used in the aerospace field. In the process of evaluating the welding process performance of 2219 aluminum alloy, it was found that the high porosity was proved to be the main weakness of the joint quality of AC TIG welding. The Straight Polarity Direct Current（DCSP）TIG welding process of 2219 aluminum alloy is realized by removing the oxide film on the surface of aluminum alloy with activating flux. The outstanding feature is that the internal porosity of TIG weld is effectively reduced, and the welding quality is improved. Therefore, the mechanism of activating flux to remove the internal porosity of 2219 aluminum alloy DCSP TIG welding was studied. The results show that DCSP TIG welding arc is stable, and the activating flux covers the weld pool surface, which can protect the weld pool and reduce the hydrogen solubility in the weld pool. The infrared thermal imager is used to measure the temperature of the welding joint. The coating of activating flux can increase the heat input of the DCSP TIG welding joint. The increase of the welding heat input reduces the solidification speed of the molten pool, increases the existence time of the molten pool, and hydrogen bubbles have enough time to escape from the molten pool. Through the analysis of the force on the surface of the molten pool, it can be seen that the coating of activating flux increases the heat input of the TIG welding joint. The greater the heat input, the stronger the effect of Lorentz force and plasma force on the molten pool, thus changing the movement direction of the metal in the molten pool, which is conducive to the bubble floating, and effectively inhibits the generation of weld porosity.

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INTRODUCTION

2219 aluminum alloy belonged to Al-Cu-Mn series aluminum alloy, which was developed by the United States in 1950s. Cu was an important alloy element, which played the role of solid solution strengthening, while other micronutrient such as Mn, Ti and V can improve recrystallization temperature, refine grain size, and improve the shape and solderability of the alloy, thus, 2219 aluminum alloy had the advantages of high strength, better corrosion resistance and weldability.[Sun Y 2015, E.V. Vorobyov, 2022]

In the field of aeronautics and Astronautics, the storage box of the aircraft carrier was a kind of complicated welded structural component, which required high strength, plastic toughness, corrosion resistance and weldability of the structural material, and 2219 aluminum alloy had these advantages, to make it an indispensable structural material in the aerospace field, especially in the field of carrying tanks [Immarigeon J P,1995, Dongrui Li 2022] . In the 1960s and 1970s, 2219 aluminum alloy was used by the United States on the storage tanks of Saturn v rockets and space shuttles. The comprehensive properties of 1201 aluminum alloy developed in the former Soviet Union and 2B16 aluminum alloy developed in China are close to those of 2219 aluminum alloy, which was also a reflection of its importance[Yao J S 2006, Jian-wu Huang 2021].

Variable polarity TIG welding (VPTIG), variable polarity plasma piercing vertical welding (VPPAW), and friction stir welding (FSW) were the three main welding methods for tank structure, VPPAW was only used to weld the circumferential seams of the tank segment, while VPTIG including manual and automatic welding was used to weld all the structural seams of the tank. There were still some quality problems in VPTIG joint such as high porosity and dense porosity near fusion line, especially in manual VPTIG joint[Di-Yao Su 2022, X. Lu 2022].

The necessity of AC TIG welding[J. C. Ion 2001, Drits A M,2012] including conventional AC TIG, square wave AC TIG and variable polarity TIG for aluminum alloy was mainly due to the fact that aluminum alloy was more active than Ferrous, there was a dense oxide film on the surface which was easy to oxidize, and the EP welding arc had the function of cathode crushing and cleaning to the welding position during the AC TIG welding. However, during EP welding, the tungsten electrode was easily exploded by electron bombardment, which resulted in Tungsten inclusion in the weld. In addition, when using AC TIG welding, the stability of AC arc was worse than that of DCSP TIG welding because of the zero-crossing point of current commutation and the constant zero-crossing of arc, weld blowhole of the weld was higher than that of DCSP TIG welding.
Active TIG welding (A-TIG) was originally developed to eliminate porosity in titanium alloy welds, and was later further applied to improve penetration and weld performance of titanium alloys[Wu Feihu 2011, Tomohiko 1997]. A-TIG welding has been widely used in the welding and manufacturing of thin-walled structures of titanium alloy, stainless steel, nickel base alloy, aluminum alloy, copper alloy, carbon steel and low alloy steel. The main purpose is to increase the weld penetration and improve the welding efficiency[J. Matsuda 1988, K.Nanda.Naik,2014]. In recent years, domestic and foreign researchers have increased their research on A-TIG welding combination activating flux ratio, microstructure and properties, corrosion properties, residual stress[E.Ahmadi, R.Rajasekaran, A. R. Pavan 2022, J.Sivakumar,2021], and behavior simulation of molten pool liquid in the welding process[Anoop.K.Unni 2021, Sara Pourmand 2020]. Research shows that compared with ordinary TIG welding metal, the weld obtained by using the best combination of flux can better withstand sudden load and obtain better mechanical properties, However, the corrosion resistance of the metals welded with A-TIG is slightly reduced, and the research results provide a comprehensive guidance for further research on TIG welding[Pratishtha Sharma,2020]. At present, there is little research and application on A-TIG welding process concerning aluminum alloy porosity, especially in DCSP A-TIG of 2219 high-strength aluminum alloy. H. Li [H. Li 2017] has studied A-TIG welding process of aluminum alloy porosity. DCSP A-TIG welding of 2219 aluminum alloy is mainly carried out to solve the problem of high porosity of 2219 high-strength aluminum alloy welds in conventional AC TIG welding, and make full use of the characteristics of DC TIG welding arc combustion stability to meet the requirements of dynamic and consistent metallurgical reaction of the molten pool, so as to effectively reduce the occurrence of weld porosity and improve weld quality. In this paper, the DCSP A-TIG welding process of 2219 aluminum alloy was studied systematically.

TEST MATERIALS AND METHODS

2219-T6 High Strength Aluminum Alloy Plate was selected as the research object in this experiment. The chemical composition was shown in Table 1. The size of the test plate was 300mm×100mm×4 mm. The activating flux can not only increase the weld penetration depth and heat efficiency, but also remove the oxide film on the base metal surface, remove weld blowhole and ensure the quality of the weld surface and internal formation. The formulation of activating flux was shown in Table 2. The DCSP A-TIG welding adopted the WAVE 2600 AC-DC pulsed TIG welding machine made by Fronius company and the self-developed welding trolley walking device. The welding process parameters were shown in Table 3. During the welding process, the test plate was clamped on the self-designed welding fixture, the TIG welding gun was fixed and the welding cart moved in a straight line. In this experiment, the temperature field of 2219 aluminum alloy DCSP positive TIG welding joint was measured by FLIR infrared thermal imager, which was used to reflect the temperature change of the joint coated with activating flux. The porosity in TIG welded joints of 2219 aluminum alloy were observed and analyzed by JEM-2100F transmission electron microscope.

TEST RESULTS AND ANALYSIS

1、Analysis of internal blowhole defects in TIG weld

The blowhole problem in TIG weld of 2219 aluminum alloy was outstanding. The formation mechanism of different types of porosity in TIG weld of 2219 aluminum alloy was discussed by studying morphology and distribution character -ristics of porosity in different areas of the joint, which provided a basis for reducing/eliminating porosity.

Table 1 Chemical composition of 2219 Aluminum alloy

material	Cu	Mn	Fe	V	Zn	Si	Zr	Al
2219	6.48	0.32	0.23	0.08	0.04	0.09	0.02	remain

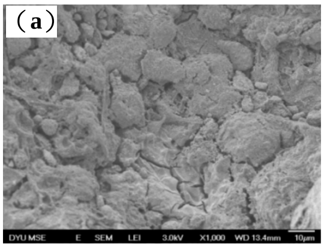
Table 2 The formulation of activating flux (wt.%)

component	ZnF_2	LiF	Nocolok	AlF_3
mass percentage	40	5	10	45

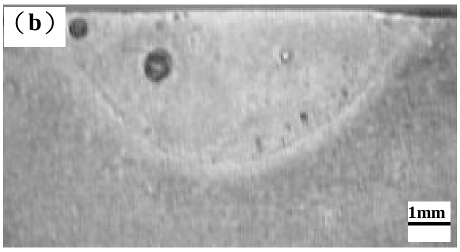
Table 3 Processing parameters of experiment

welding current I/A	welding speed υ /mm·min^{-1}	arc length L/mm	shield gas flow rate Q/L·min^{-1}	Tungsten electrode diameter Φ /mm	Wire feed rate υ /mm·min^{-1}
140	140	3	11	3.2	1200

According to the morphology distribution characteristics of porosity in TIG welding of 2219 aluminum alloy, the types of porosity in welded joints were divided into four types: large porosity in weld zone, porosity near weld surface, porosity near fusion zone and chain porosity in butt joint. Fig.1(a) showed the appearance of large porosity in the weld, which were spherical in shape and relatively few in number. Fig.1(b) showed the morphology of the inner wall of the air hole, which was uneven and had cracks, and the existence of the air hole reduced the mechanical properties of the joint. During TIG welding, the fluidity of molten pool metal directly affected the bubble growth and floating behavior. The formation of this kind of porosity was mainly due to the interaction between metal stress in molten pool and bubble stress. Under the action of high temperature arc in TIG welding, the weld pool temperature was very high, the base metal changed from solid to liquid, and the internal hydrogen was easy to be released. The air hole in the middle and upper part of the weld pool was hindered by liquid metal in the process of floating, and was stirred by high temperature arc, which was beneficial to bubble floating, so the number of bubbles formed in the weld was relatively small. The bubbles in the lower part were far away from the weld surface, which was greatly hindered by liquid metal, and underwent a process of merging and grew up. Because the floating speed was less than the crystallization speed of metal, they eventually stayed in the weld to form larger porosity.



(a) distribution of large porosity in weld area



(b) morphology of inner wall of porosity

Fig.1 Large porosity in weld zone

Fig.2 showed the morphology of porosity near the surface of weld zone. As shown in Figure 2, these porosity were small in size and spherical in shape, and they mainly came from the base metal and a small amount from the external environment, such as air and moisture in the arc column atmosphere. To prevent such porosity, it was necessary to strictly control the hydrogen source and slow down the cooling rate of the molten pool during welding.

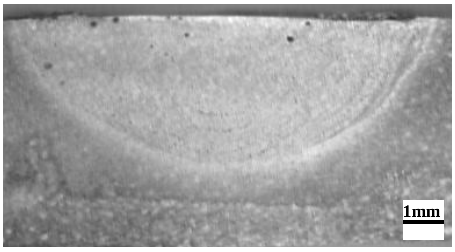


Fig. 2 Near surface porosity of weld zone

Fig.3 showed the morphology of porosity in the fusion zone. For TIG welding of 2219 aluminum alloy, whether it was surfacing welding or butt welding, the fusion zone was the hardest hit area that produced porosity. The fusion zone was located between the weld zone and the base metal zone. Although the range was very narrow, the microscopic behavior was very complex and chemical composition and microstructure and properties were quite uneven, which had a great influence on the strength and toughness of the joint.

The fusion zone was also an area where solid base metal and liquid molten pool metal coexist. Because of the difference of solubility of hydrogen in solid and liquid, hydrogen released from base metal formed bubbles in the fusion zone, and the bubbles expanded constantly. With the decrease of temperature, the molten metal solidified from the grain surface of the base metal near the fusion zone, forming a large number of dendrites. The floating and growing of bubbles were inevitably hindered by a large number of dendrites, so bubbles can only grow to a very small size, which need to be observed with the aid of a microscope. At the same time, with the decrease of temperature, the viscosity of liquid metal increased sharply, the crystallization speed of molten pool increased, and bubbles can't escape, thus forming porosity in fusion zone. In order to prevent this kind of porosity, it was necessary to control the hydrogen content of the base metal, and the hydrogen content of high-quality aluminum should not exceed 0.4mL per 100g aluminum.

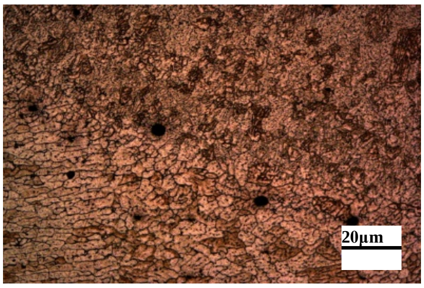


Fig.3 porosity in fusion zone

Fig.4 showed the morphology of chain porosity in butt joint，chain porosity is shown in the yellow circle. The chain porosity were distributed along the center line of weld, which coincided with the intermittent position of butt joint, sometimes located at the root of weld. The welding experiment proved that this kind of air hole was related to moisture, water containing oxide film and hydrocarbon pollutants on the aluminum butt joint surface. In order to prevent this kind of air hole, the butt joint surface and groove must be thoroughly cleaned before welding.

Fig.4 Chain porosity in butt joint

2、Mechanism of inhibiting porosity in TIG Weld

It is a complex problem to prevent weld porosity, which had a great influence on the mechanical properties of aluminum alloy, and correspoding measures should be taken to control them. Through the analysis of internal porosity in TIG weld of 2219 aluminum alloy, it can be seen that different types of porosity were easy to appear in weld area and fusion line, and DCSP A-TIG welding can effectively reduced the generation of porosity, which was obvious in eliminating internal porosity in 2219 aluminum alloy weld.

2.1 Influence of welding method on weld porosity

In industrial production, the arc welding methods of aluminum and aluminum alloy were mainly AC TIG and MIG. The two welding methods had high requirements on the cleaning of welding materials, welding conditions and welding process parameters, otherwise it was easy to produce porosity and deformation of weldments. The control of related conditions of MIG welding was more stringent, and the tendency of air holes produced was larger than that of TIG welding. However, TIG welding was slow in welding speed and relatively large in heat input, so the crystallization speed of weld was slow, which was convenient for hydrogen to escape. Moreover, the electrodes of TIG welding were not melted and there was no transition problem of deposited metal. At the same time, the electric arc had a strong stirring effect on the molten pool, which was also beneficial to bubble escape. In production practice, AC TIG welding was generally used to weld Mg-Al alloy and its alloy. The polarity of AC current changed periodically during welding. Due to the great difference in performance between tungsten electrode and weldments, when the positive and negative half-waves alternated, the zero crossing reversed. When the current changed negatively from tungsten electrode to aluminum plate, it was difficult to re-ignite the arc because of the poor ability of weldments to emit electrons. The voltage required to re-ignite the arc was very high, and the no-load voltage of the power supply was not enough to maintain the continuous burning of the arc, resulting in unstable arc. In severe cases, even the arc was extinguished in the negative half cycle. Unstable arc affected the welding quality. The welding seam was prone to porosity and tungsten inclusions, so the arc of AC TIG welding was less stable than that of DCSP A-TIG welding, which led to poor protection of the molten pool, and the moisture in the surrounding environment easily entered into the molten pool, making it easier to generate air holes in the welding seam.

In addition, the process of metal crystallization in the molten pool, the supersaturated liquid metal precipitated hydrogen, and the solid grains, solid dendrites and solid particles around the molten pool provided conditions for hydrogen bubble nucleation. The energy required to form bubble nuclei was shown in the expression.

$$E_p = -(P_h - P_L)V + \sigma A\left[1 - \frac{A_a}{A}(1 - \cos\theta)\right] \tag{1}$$

E_P——the energy required to form bubble nucleus;
P_h —— the gas pressure in the bubble;
P_L —— liquid pressure;
V —— the volume of bubble nucleus;
σ —— interphase tension;
A ——surface area of bubble nucleus;
A_a —— action area of adsorption force;
A_θ —— the wetting angle between bubble core and ready-made surface.

It can be seen from formula(1) that when bubbles cling to the ready-made surface, the interphase tension (σ) was reduced and the Aa/A ratio was increased, which led to the decrease of energy (E_p) and made it easier to produce bubbles. During AC TIG welding of 2219 aluminum alloy, the oxide film on the surface of the molten pool was decomposed into a large number of oxide film fragments under the action of cathode atomization, which provided a large number of ready-made surfaces for bubble nucleation, which was one of the reasons why air holes were easy to occur in AC TIG welding. There were many and complex factors for the formation of bubbles in aluminum alloy welds. The direct reason was that the moisture carried by welding wire, base metal and surface oxide film decomposed at high temperature during welding, and the moisture absorbed by arc during welding provided supersaturated hydrogen for pore nucleation. Fluoride activators such as LiF, ZnF_2, Nocolok and mixed components can remove the oxide film on the surface of 2219 aluminum alloy, and prevent the hydrogen source formed by the oxide film on the surface of base metal from causing bubbles in the weld.

2.2Effect of activating flux on hydrogen dissolution in weld pool

The solubility of hydrogen in weld metal is shown in Sievert's Law expression:

$$[H] = K\sqrt{P_{H_2}} \tag{2}$$

[H]-the solubility of atomic hydrogen;
$\sqrt{P_{H_2}}$ -hydrogen partial pressure above the molten pool;
K- equilibrium constant.

It can be seen from Equation (2) that the solubility of hydrogen in the molten pool ([H]) was proportional to the partial pressure of hydrogen above the molten pool, that was, the concentration of hydrogen in the hydrogen source during welding. The greater the concentration of hydrogen in the hydrogen source, the greater the amount of hydrogen dissolved into the molten pool. Fluoride decomposed under the action of high temperature arc to form free fluorine ions. Fluorine ions and hydrogen ions combined at high temperature to form HF gases insoluble in aluminum alloy and low diffusion coefficient, which reduced the partial pressure of hydrogen in the arc and reduced the solubility of hydrogen in the molten pool, Therefore, fluoride activating flux can reduce the porosity of hydrogen in weld, and the schematic diagram of fluoride removal of hydrogen porosity was shown in Fig.5. According to the theory of aluminum alloy smelting, Fluoride activators had adsorption effect on oxidation inclusions, and it can remove hydrogen in metal liquid while removing inclusions. The degassing effect caused by the thermal decomposition of the activating flux was also beneficial to reduce the tendency of the weld to form bubbles.

In addition, the slag formed by the activating flux covered the surface of the liquid metal bath, forming a layer of protective film, which can isolate the moisture in the welding atmosphere from entering the bath, thus reducing the generation of weld bubbles. When hydrogen was transitioning through the slag to the metal, its solubility depended on such factors as the partial pressure of hydrogen, water vapor in the gas phase, the basicity of the slag, the content of fluoride, and the oxygen content in the metal. Basicity was an important chemical property of slag. Because the fluorine base slag system contained more alkaline oxides, the basicity of slag was large, the cleaner the weld was, the lower the hydrogen content was, so the solubility of water in slag decreases, and the porosity can be eliminated.

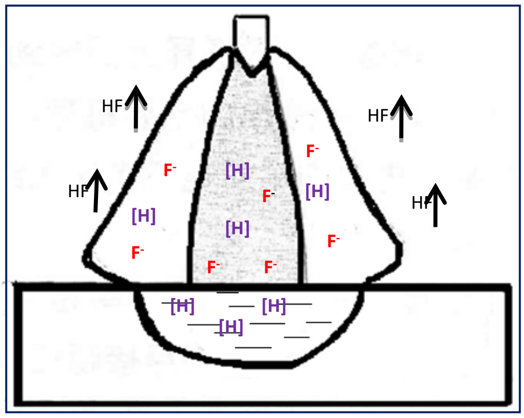


Fig.5 Hydrogen fluoride reaction diagram

2.3Effect of activating flux on cooling rate of weld pool

The key to whether bubbles can escape from the weld pool was its floating speed, which can be expressed by Stocks formula:

$$v=\frac{2}{9}\frac{(\rho_l-\rho_g)\,gr^2}{\eta} \tag{3}$$

v——bubble floating speed
P_l—— density of liquid metal
P_g—— density of gas
G —— acceleration of gravity
r —— radius of the bubble
η ——viscosity of liquid metal

From the above formula (3), it can be seen that the bubble floating speed (v) was proportional to the square of the bubble radius which grew to different degrees. The larger the bubble radius, the faster the floating speed, and it was easier to escape from the surface of the molten pool without forming porosity. The viscosity (η) of liquid metal also had an important influence on the formation of porosity. The higher the viscosity, the lower the bubble floating speed and it was easier to form porosity. Welding parameters had influence on bubble floating speed and viscosity of liquid metal. Fig.6 showed the infrared thermal image of the front temperature of the joint taken by the infrared thermal imager. In the temperature measurement test of infrared imager, butt welding with flat filler wire was adopted.

It can be seen from Fig.6 that the joint temperature coated with AlF_3 and ZnF_2 were obviously higher than that without activating flux, especially the joint temperature coated with AlF_3 and ZnF_2 is about 450℃ higher than that without activating flux. This means that the welding zone absorbed more heat after coating with activating flux. Because the welding speed and welding current remained unchanged, more heat must come from welding arc, that was, the increase of welding heat input.

The analytical solution of three-dimensional heat conduction in welding process can adopt the formula derived by Rosenthal(Rosenthal D,1946) as shown in Formula (4). Along the x axis direction of the workpiece, there were y=z=0,R=x, formula(4) becomes(5),Then the temperature gradient was (6), According to the formula(7), The result cooling rate was formula(8).

$$\frac{2\pi(T-T_0)kR}{Q}=exp\frac{-V(R-x)}{2\alpha} \tag{4}$$

T —— temperature
T_0 —— temperature of the workpiece before welding
K —— thermal conductivity of the workpiece
Q——Heat transferred from the heat source to the workpiece
V —— welding speed
α —— thermal diffusivity of workpiece
R——the radial distance to the origin, for a given material and a given welding condition, the radius of isotherm T is R on a plane at a given x.

$$T-T_0=\frac{Q}{2\pi kx} \tag{5}$$

$$\left(\frac{\partial T}{\partial x}\right)_t=\frac{Q}{2\pi x}\frac{-1}{x^2}=-2\pi k\frac{(T-T_0)^2}{Q} \tag{6}$$

$$\left(\frac{\partial x}{\partial t}\right)_T=V \tag{7}$$

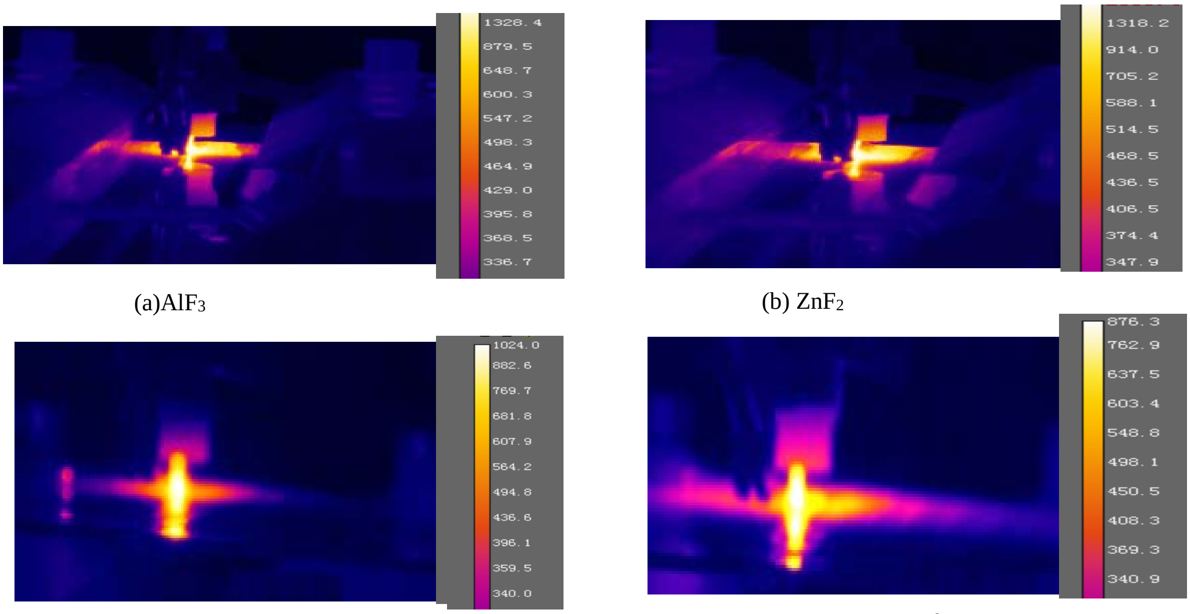
$$\left(\frac{\partial T}{\partial t}\right)_x=\left(\frac{\partial T}{\partial x}\right)_t\left(\frac{\partial x}{\partial t}\right)_T=-2\pi kV\frac{(T-T_0)^2}{Q} \tag{8}$$

The welding conditions in this test were 150A, 13V and 2.2mm/s; The arc efficiency was 80%, and the thermal conductivity of aluminum was 237 W/(m). Not coated with activating flux, The cooling rate of TIG welding joint without activating flux at temperature T was(9),The cooling rate of TIG welding joint coated with activating flux at temperature T was(10).

Obviously, the temperature of welded joint rose due to the application of activating flux, that was, $T_{with} > T_{without}$, the cooling speed of welded joint was reduced, the crystallization speed of weld pool was reduced, the existence time of molten pool was increased, and there was enough time for hydrogen to escape from the molten pool. In addition, the activating flux covered the surface of molten pool, which prevented hydrogen from entering the molten pool, thus effectively reducing the generation of air holes. On the other hand, the increase of temperature reduced the viscosity of liquid metal, improved the fluidity of metal, and had little resistance in the process of bubble floating, which can promote bubble escape and help to reduce the generation of porosity.

$$\left(\frac{\partial T}{\partial t}\right)_x=[-2\pi\times237\ \text{W/(m}^\circ\text{C)}\times2.2\times10^{-3}\ \text{m/s}]\frac{(T-T_{without})^2}{0.8\times150\text{A}\times13\text{V}}=-2.1\times10^{-3}(T-T_{without})^2 \tag{9}$$

$$\left(\frac{\partial T}{\partial t}\right)_x=[-2\pi\times237\ \text{W/(m}^\circ\text{C)}\times2.2\times10^{-3}\ \text{m/s}]\frac{(\text{T}-\text{T}_{with})^2}{0.8\times150\text{A}\times13\text{V}}=-2.1\times10^{-3}(T-T_{with})^2 \tag{10}$$



(a)AlF_3 (b) ZnF_2

(c) with activating flux (d) without activating flux

Fig.6 Infrared thermography of the temperature field of welded joints

2.4Effect of activating flux on fluid flow

Driving forces of fluid flow in molten pool included buoyancy, Lorentz force, shear stress caused by surface tension gradient of molten pool and shear stress caused by arc plasma, as shown in Figure 7. As the result of the combined action of these forces, the liquid metal in the molten pool was in a moving state, and the flow of the liquid metal had an important influence on the formation of weld and the emergence of bubbles. Fig. 7(a) showed the flow pattern of liquid metal in the molten pool caused by buoyancy. The temperature gradient in weld pool caused the density of liquid metal to change. The temperature at the boundary of the pool was the lowest and the density was the highest, so the liquid metal dropped along the boundary of the pool and rose along the axis of the pool.

Compared with Lorentz force and surface tension of weld pool, buoyancy has less influence on weld pool flow. Fig. 7(b) showed the flow pattern of liquid metal in the molten pool caused by Lorentz force. When welding current entered the molten pool, it caused the divergence of current field in the molten pool. The current density just below the arc was large, while the current density away from the arc was small. The change of current density caused electromagnetic contraction and pressure difference in the fluid, so that the liquid metal was pushed down along the axis of the molten pool and flowed up along boundary of the molten pool.

Fig. 7(c) showed the flow pattern of liquid metal in the molten pool caused by surface tension. Convection driven by surface tension was also called Marangoni convection, and the magnitude of surface tension depends on the composition and temperature of liquid metal. Within a certain temperature range, there was a linear relationship between temperature T and surface tension, and the mathematical expression was (11).

$$\gamma_T = \gamma_m + \frac{\partial \gamma}{\partial T}\left(T - T_m\right) \tag{11}$$

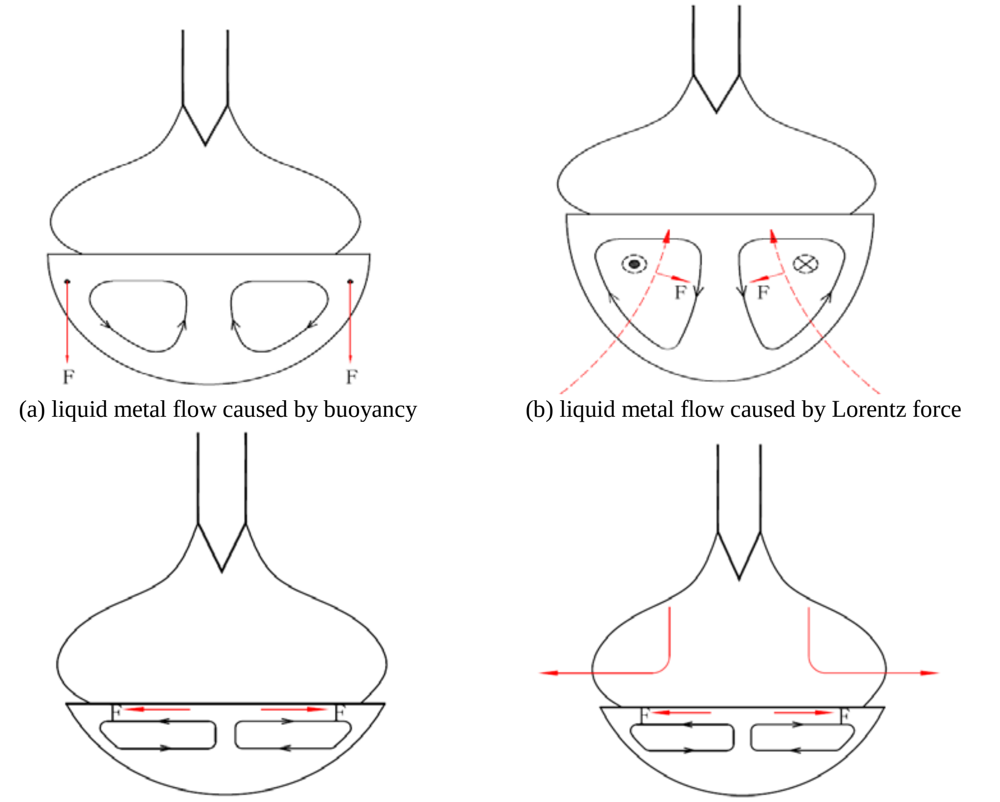
γ_T ——surface tension;

γ_m —— surface tension;

T_{m} ——melting point temperature of metal;

$\frac{\partial \gamma}{\partial T}$ —— Temperature coefficient of surface tension

When there is no activating flux on TIG weld surface, the surface tension of liquid metal decreases with the increase of temperature, that was, negative surface tension temperature coefficient. The liquid velocity driven by surface tension was very high. The liquid at the center of molten pool had lower surface tension, while the liquid at the boundary of molten pool had higher surface tension. The metal at the boundary pulled the metal at the center outward, causing the liquid metal to flow from the center of molten pool surface to the edge and return under the surface of molten pool. The weld was shallow and wide.



(a) liquid metal flow caused by buoyancy (b) liquid metal flow caused by Lorentz force

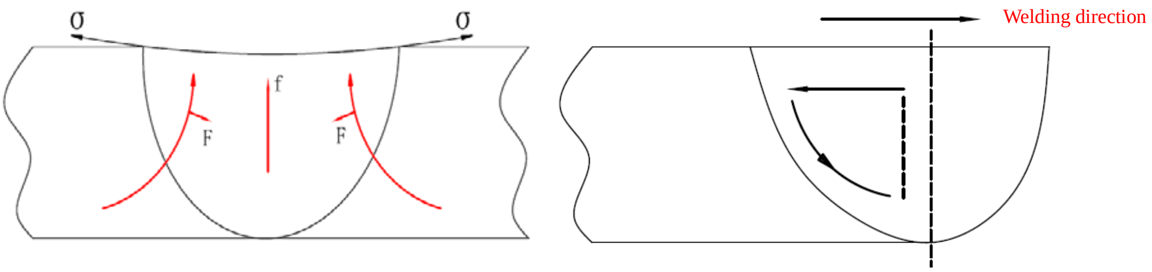
(c) liquid metal flow caused by surface tension (d) liquid metal flow caused by arc plasma force

Fig.7 Infrared thermography of the temperature field of welded joints

When there was a small amount of active surfactant on the surface of the molten pool, it changed from negative value to positive value, which was beneficial for liquid metal to bring more heat to the bottom of the molten pool and increase weld penetration. Fluoride activator was used in this test, which had a low melting point, and a large number of activators was decomposed and ionized in the arc. the influence of fluoride activator on the weld pool of aluminum alloy only acted on the surface of weld pool, and it was difficult to enter the weld pool with the flow of liquid metal, Therefore, it was difficult for fluoride activating flux to change the surface tension temperature gradient from negative value to positive value.

Fig. 7(d) showed the flow pattern of liquid metal in the molten pool caused by arc plasma. The high-speed low of plasma created an outward shear stress along the molten pool surface, which m the liquid metal flow from the center to the edge of the molten pool surface and return below the molten pool surface. When low current welding was used in tungsten gas shielded welding, the arc pressure had little influence on the fluid flow.

The flow model of conventional TIG weld pool was shown in Fig.8. it can be seen from Fig. 8(a) that the conventional TIG weld pool was affected by surface tension, Lorentz force, buoyancy, etc. because the pool was less affected by Lorentz force and buoyancy, the metal flow in the pool was mainly affected by surface tension, and the movement form is along the highest central temperature zone to the edge of the pool, as shown in Fig. 8(b), contrary to the bubble floating direct. Under the condition of DCSP connection, the welding heat input can be increased by coating activating flux such as AlF_3 and ZnF_2. the increase of heat input was caused by the increase of welding voltage or welding current density. the greater the heat input, the stronger the Lorentz force and plasma force act on the weld pool, and the weld pool surface sagged under the action of arc pressure, as shown in Fig. 9. Just like increasing welding current and welding heat input, it also made the surface of molten pool concave. The flow model of A-TIG welding pool in DCSP was shown in Fig.10. the Lorentz force and arc plasma force enhance the excavation of the pool due to the increase of heat input. when the heat input increases to a certain extent, the pool moves along the edge of the pool to the area with high central temperature as shown in Fig. 10(a), which was in the same direction as the bubble movement



(a) stress analysis of molten pool (b) flow pattern of metal in molten pool

Fig. 8 Flow model of conventional TIG weld pool

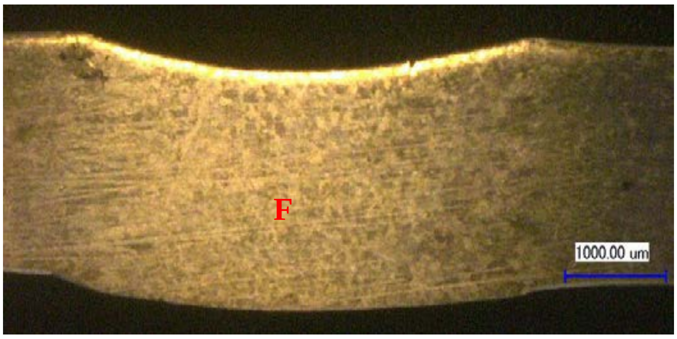
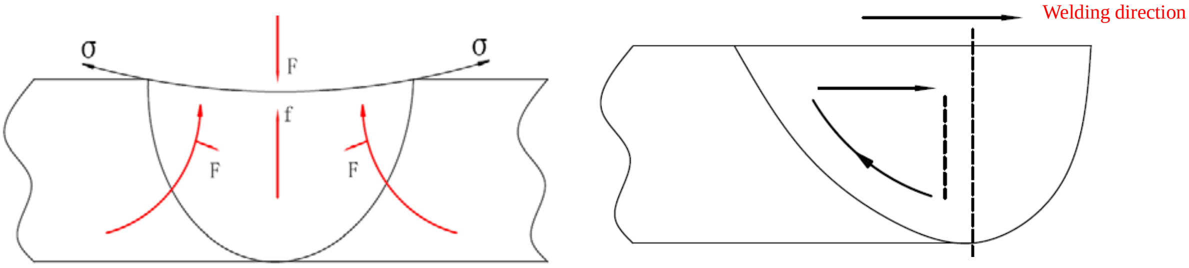


Fig. 9 Weld forming of DCSP A-TIG welding



(a) analysis of molten pool stress (b) flow mode of molten pool metal

Fig.10 Flow model of DCSP A-TIG weld pool

as shown in Fig. 10(b), which was beneficial to inhibit the generation of air holes. At the same time, the increase of heat input increased the radial component of arc, made the liquid metal in molten pool flow from center to both sides, made a part of melting heat transfer to the periphery of molten pool continuously, increased the size of molten pool, and helped bubble float out.

CONCLUSION

(1) 2219 aluminum alloy TIG weld porosity were divided into four types: large porosity in the weld zone, near the weld surface porosity, near the fusion zone porosity and butt joint chain porosity, and DCSP A-TIG welding can effectively reduce the generation of porosity.

(2) The AC TIG welding arc was not stable, which led to the poor protection of the weld pool, and the moisture in the surrounding environment was easy to enter the weld pool, and it was easier to generate porosity in the weld. Fluoride activating flux used in the project can remove the oxide film on the surface of 2219 aluminum alloy and prevent the hydrogen source formed by the oxide film on the surface of the base metal from leading to the formation of porosity in the weld.

(3) The molten pool by lorentz force and buoyancy effected on the conventional TIG welding pool is small, so the molten pool of metal flow was mainly

affected by the surface tension, the movement form was highest temperature along the center area to the molten pool edge flow, and bubbles floating in the opposite direction, thus unfavorable to bubble to.

(4) With the increase of heat input, the excavation effect of Lorentz force and arc plasma force on the molten pool is enhanced. When the heat input increases to a certain extent, under the joint action of Lorentz force and arc plasma force, the molten pool moves along the edge of the molten pool to the area with high central temperature, and bubbles move in the same direction, which is beneficial to inhibit the generation of air holes.

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鋁合金直流正接鎢極氬弧焊氣孔去除機理研究

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摘 要

2219 鋁合金具有良好的力學性能、抗應力腐蝕性能、焊接性能，熱裂紋傾向低等一系列的優點，被廣泛應用在航空航太領域。開展 2219 鋁合金的焊接工藝性能評估過程中發現,氣孔發生率高被證實是交流鎢極氬弧焊（TIG）接頭品質的主要薄弱點。利用活性劑去除鋁合金表面氧化膜實現 2219 鋁合金的直流正接 TIG 焊工藝，其突出的特點是有效降低了 TIG 焊縫內部氣孔,改善了焊接品質。本文研究了活性劑去除 2219 鋁合金直流正接 TIG 焊縫內部氣孔的機理。研究結果表明：直流正接 TIG 焊接電弧穩定，活性劑覆蓋在焊縫熔池表面，可保護熔池，減小氫在熔池中的溶解度。採用紅外熱像儀測量焊接接頭的溫度,塗覆活性劑能增加直流正接 TIG 焊接頭熱輸入,焊接熱輸入的增大降低了熔池的凝固速度，增加了熔池存在時間，氫氣泡有足夠時間從熔池中逸出。通過對熔池表面受力情況進行分析可知,塗覆活性劑增加了 TIG 焊接頭熱輸入，熱輸入越大，使洛倫茲力和等離子體力對熔池的作用效果增強,從而改變熔池金屬的運動方向，有利於氣泡浮出，有效抑制了焊縫氣孔的產生。