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Research Article

Arc characteristics and properties of a new rotating tungsten GTAW of 5A06 aluminum alloy

Rongmao Du[1], Yanlong Fan[1], Yu Sun[1,2], Hongtao Zhang[1,2*], Zecheng Wu[1]

[1] Shandong Provincial Key Laboratory of Special Welding Technology, Harbin Institute of Technology at Weihai, Weihai 264209, China

[2] State Key Laboratory of Precision Welding & Joining of Materials and Structures, Harbin Institute of Technology, Harbin 150001, China

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Abstract

In this study, the rotary movement of the tungsten needle in gas tungsten arc welding (GTAW) process was realized by direct current motor. The arc characteristics, the flow of molten pool and the microstructure and properties of the weld bead were studied. The results showed that the rotary motion of the tungsten needle transferred circumferential momentum to the arc as well as the molten pool, thereby conferring the latter with rotating fluid flow characteristics. Under the action of a relatively spiraling shielding gas, arc constriction occurred, and molten pool width dropped considerably. A finer and more uniform precipitated phase in the matrix, as well as a fewer large-medium pores, were achieved in the 5A06 aluminum alloy weld metal using this modified GTAW process, which noticeably increased the bending strength and tensile strength of weld metal and the microhardness of fusion zone.

Keywords Roating tungsten, Arc shape, Molten pool, Gas tungsten arc welding

1 Introduction

Gas tungsten arc welding, characterized as high welding quality and stable welding process, was a widely used technology [1–4]. To improve welding quality and efficiency, various novel GTAW methods were researched. Arc pressure was enhanced through a continual high-frequency oscillation from ultrasonic energy in the arc plasma, leading to a considerable increase in penetration depth [5]. The control of arc plasma by cusp-type permanent magnets could change the cross section of the arc plasma from a circular to an elliptical shape, causing deeper penetration [3]. Two electrodes were employed within a single torch could enhance the heat input into the weld. Two arcs pulled each other to form one coupled arc under the action of Lorentz force, consequently enabling a high-deposition rate [6–9].

Activating flux assisted was also a well-established method for the goal. This flux would change the temperature dependence of the surface tension grads from a negative value to a positive value, causing the fluid to flow along the surface of the weld pool toward the center and then downward. This fluid flow pattern efficiently transferred heat to the weld root and produced a relatively deep-narrow weld [10–12].

Rotary arc welding such as magnetically-control rotation has gradually emerged and diversified, which made the weld have excellent forming and performance. The essence of the arc was gas discharge, and the gas produced a plasma with high conductivity during the discharge process [13–15]. The method of magnetically-control rotary arc welding was to introduce a control magnetic field around the arc, which changed the shape and effect of the arc through the action of the magnetic field. It affected the transition form of the molten pool and the droplet and improved the welding quality though the rotation of the arc [16–18].

However, at present, the rotary arc welding methods generally controlled the arc rotation by applying ultrasonic vibration or magnetic field control. These meth-

* **Corresponding author:** Hongtao Zhang (1980–), Ph.D, Professor. Mainly engaged in multiple arc composite welding, ultrasonic additive manufacturing, laser welding. E-mail: zhanght@hitwh.edu.cn

ods were not stable and simple enough in the actual application process. This paper proposed a mechanical rotation of the tungsten electrode to arc rotation. It had higher stability and welding adaptability, while ensuring excellent welding results.

In this paper, a novel rotary tungsten needle GTAW (RT-GTAW) system was built. This novel RT-GTAW process offered a new approach to improve weld quality without using complicated equipment and additives. Butt welds in 5A06 aluminum were produced by this welding system. The effect of tungsten needle rotary motion on the arc shape and microstructure of welds were investigated. The mechanical property of the weld metal and the microhardness in the fusion zone were measured. The aim of research was to develop a new GTAW method and obtain excellent weld forming and performance.

2 Materials and methods

The schematic diagram of arc and molten pool rotation was shown in the Fig. 1. High-speed tungsten rotation drove high-speed arc rotation, arc rotation changed the arc shape of welding, affecting the melting of base metal and weld forming. At the same time, arc played the role of mechanical stirring in the process of rotation, which made the arc pressure and heat distribution uniform and changed the mass and heat transfer process during the crystallization of liquid metal in the molten pool. These

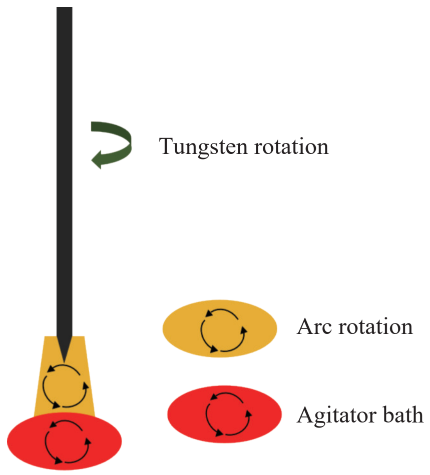

Fig. 1 Schematic diagram of RT-GTAW

behaviors refined the primary structure, reduced segregation and improved the performance of the weld. In addition, the Lorentz force generated during arc rotation made the charged particle flow in the arc column area shrink. It achieved the effect of arc compression, made the arc energy more concentrated, and finally improved the quality of weld. The principle has been confirmed in the experimental process, which can be seen in the following text.

A schematic diagram of the RT-GTAW equipment was shown in Fig. 2. Tungsten needle, linked to ordinary direct current (DC) motor by coupling, connecting rod and electrode holder, could rotate clockwise around the axial line of the electrode at different rotational speeds from 0 r/min to 10 000 r/min, and form the electric connect with the cathode by a brass spring plate.

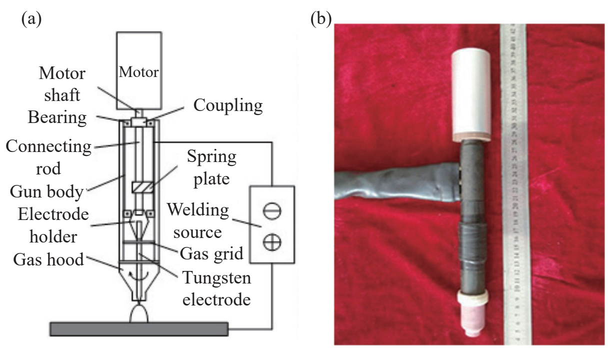

Fig. 2 schematic diagram of the RT-GTAW equipment: (a) Schematic of the experimental set-up, (b) Photograph of the RT-GTAW equipment

The RT-GTAW method was performed using the INVERTIG.PRO digital 240 DC TIG welding source. 5A06 aluminum alloy plate with dimension of 150 mm × 70 mm × 3 mm was used in the experiments. The procedure experiment was conducted with uniform welding parameters, except for the autorotation speed of the tungsten, which varied from 0 r/min to 10 000 r/min. The uniformly set processing parameters were shown in Table 1. During the welding process, the arc shape was photographed using Xiris Weld View Camera-1000.

The metallographic, microhardness and flat tensile specimens were sectioned transverse to the welding direction from the butt welds. The cross-sectional shape and microstructure of the fusion zone were examined

Table 1 Processing parameters

Current mode	DC frequency/Hz	Welding current/A	Travel speed /($mm·s^{-1}$)	Diameter of the tungsten needle/mm	Gas flow of shielding gas/($L·min^{-1}$)	Shielding gas
DC	180	150	4	2.4	12	99.99% Ar

using optical microscopy (SEM, SIGMA500, Zeiss, Germany). The mechanical property and the fracture surfaces were also observed.

Tensile tests were performed on a standard universal tensile testing machine with loading speed of 2 mm/min. In the case of no filler wire, three non-standard tensile specimens were cut from each sample transverse to the welding direction with a gauged size. The dimensions of the tensile specimens were 140 mm × 40 mm × 3 mm. The microhardness under different rotation speeds was obtained using Vickers microhardness at load of 1.961 N and dwell time 10 s. In the bending test, one positive bending specimen and one back bending specimen were cut from each welded specimen for bending test, where the diameter of the indenter was 26 mm and the maximum bending angle was 150°.

3 Results and Discussion

3.1 Arc characteristics

Improvement in the welding process was determined by the change in arc shape, which was in turn, influenced by the rotation of the tungsten needle. As shown in Fig. 3, the photographed arc shape from the weld view camera showed that arc constriction occurred when tungsten rotation was applied. The constriction was caused by the circumferential directional motion component which was applied by the rotation of tungsten to the arc. As a result, a low-pressure area was generated and the squeeze force from the shielding gas was enhanced. When the rotation speed raised from 0 r/min to 10 000 r/min, the arc contraction effect increased continuously, which was also confirmed by the drop of the molten pool width, it declined from 9.4 mm to 7.8 mm.

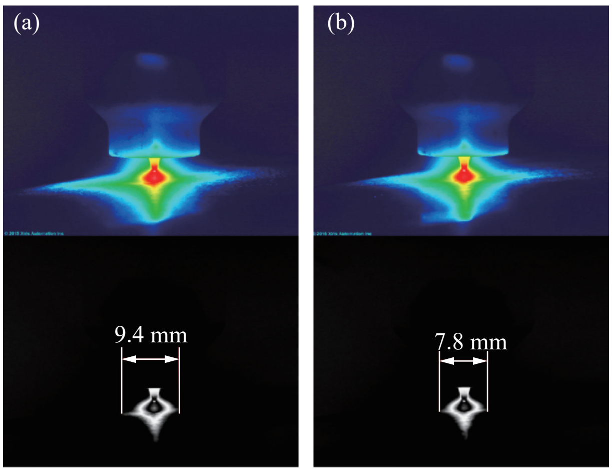

Fig. 3 Photographs of the arc shape and image processing at different rotation speeds: (a) 0 r/min, (b) 10 000 r/min

3.2 Microstructures and properties of weld

Fig. 4 shows the surface appearance, weld profile, optical microstructure of the weld at three different rotation speeds. Some uniform and fine ripples were observed on the surface of the weld at higher rotation speed. Such finding is a rare occurrence in the ordinary GTAW process. The phenomenon was attributed to the transfer of mechanical stirring at tungsten rotation by the arc to the molten pool. From the perspective of weld profile, when the tungsten electrode rotated, the melting width decreased, the collapse of the weld was improved, and the weld section shape was more reasonable. The reason for this finding was that the higher the rotation frequency, the more concentrated the arc energy. The metallographic photographs of the weld appearance revealed that the precipitated phase in the aluminum matrix became finer and more uniform as the rotation speed increased. This finding was achieved because the arc exerted a stirring effect on the molten pool, which prevented the growth and accumulation of the precipitated phase and made the microstructure more uniform.

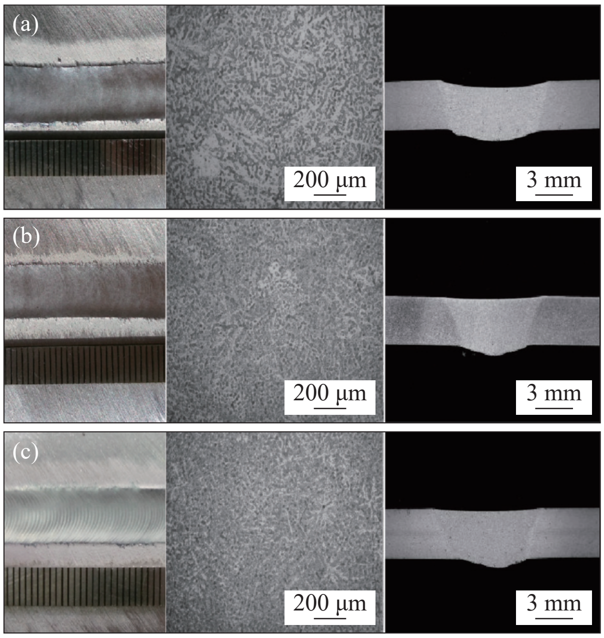

Fig. 4 Surface appearance, weld profile, optical microstructure of the weld appearance at three different rotation speeds: (a) 0 r/min, (b) 5 000 r/min, (c) 10 000 r/min

Compared with the welds obtained by ordinary GTAW, the welds obtained by RT-GTAW had higher strength. When the rotation speed was 5 000 r/min and 10 000 r/min, the tensile strength of the weld metal reached 320, 330 MPa, respectively, which was about 4.9% and 8.1% higher than that of the weld metal without the tungsten rotating GTAW process, respectively. The tensile strength of weld metal without tungsten rotating GTAW process was 305 MPa. The tensile strength of the weld metal regularly increased with the increase in tungsten rotation speed. Fig. 5 shows photographs of tensile specimen and fracture location at different rotation speeds.

The fracture surfaces of tensile specimens obtained at three different rotation speeds were examined using scanning electron microscopy (SEM). The existence of large-medium pores will affect the compactness of weld structure. The most important role for the pores and the fine microstructure is to reduce stress centralizing and hinder dislocation movement to improve the performance of the joint such as strength and hardness of the joint. As the SEM images shown in Fig. 6, the number of large-medium pores in the welds produced by RT-GTAW decreased significantly. As shown in Fig. 6a, miniature pores were mainly in the fracture at high rotation speeds. The reason for this result was that the molten pool flow was enhanced, resulting in gas escape. The reduction of large-medium pores was helpful to improve the performance of the joint such as strength and hardness of the joint.

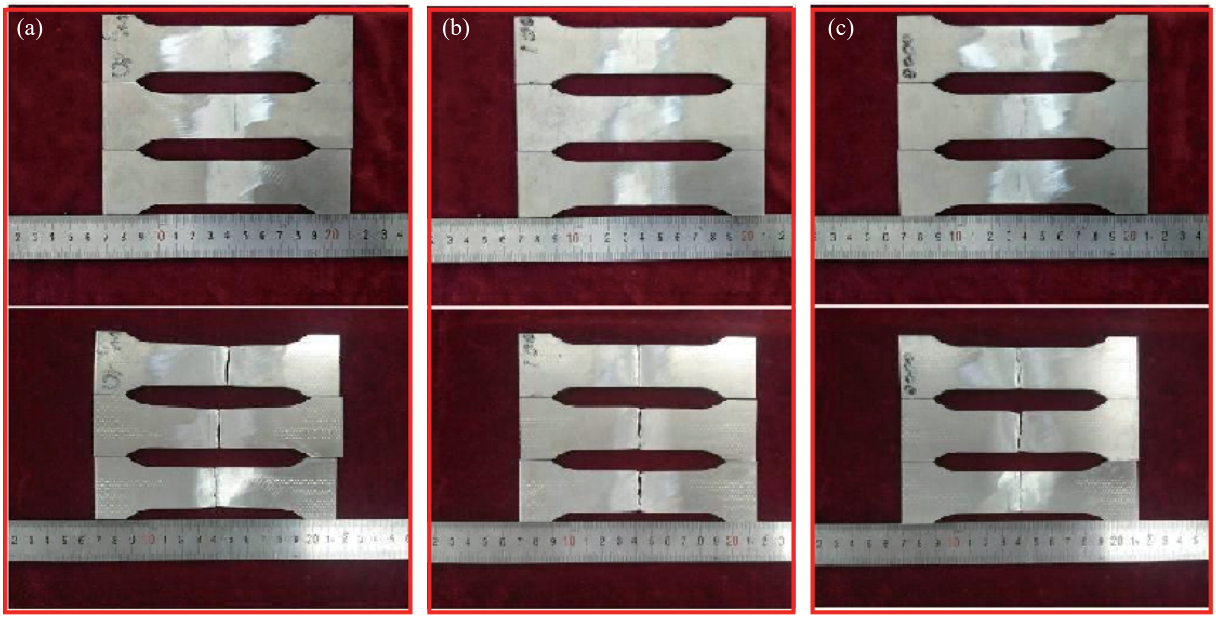

Fig. 5 Photographs of tensile specimen and fracture location at different rotation speeds: (a) 0 r/min, (b) 5 000 r/min, (c) 10 000 r/min

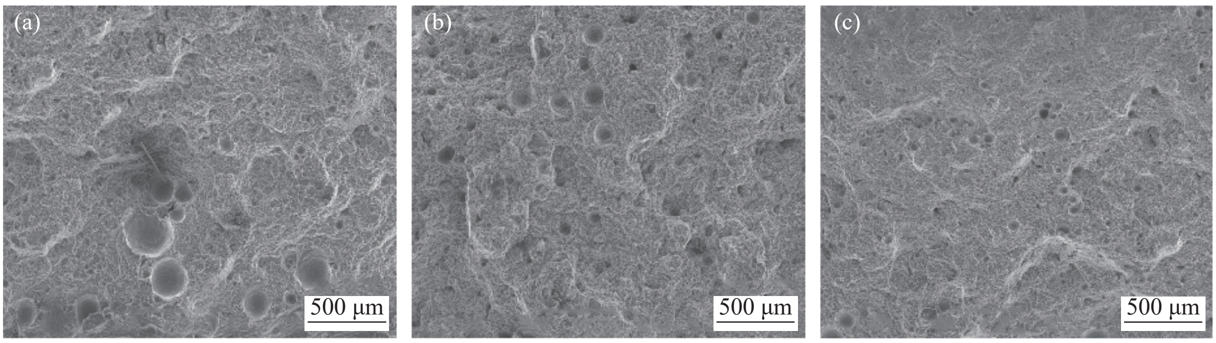

Fig. 6 SEM images of the fracture surface of tensile specimens at three different rotation speeds: (a) 0 r/min, (b) 5 000 r/min, (c) 10 000 r/min

Fig. 7 illustrated microhardness distribution of welded joints of 0, 5 000 r/min and 10 000 r/min rotation speeds, respectively. And the average microhardness of the fusion zone was 80.41, 82.7 HV and 86.03 HV, separately. When the tungsten electrode is rotated, the overall hardness of the weld will increase, and the grain refinement in some areas will be more obvious than the other, leading to its higher hardness and hardness variation.

In order to test the plasticity and toughness of welded joint, bending test was designed. When the sample was bent to the specified angle, only a small crack appeared in the positive bending sample with the rotation speed of 0 r/min. There was no crack appearing in other samples, as depicted in Fig. 8. The results show that the bending strength and plasticity of welded joints can be improved by increasing the rotation speed to a certain extent.

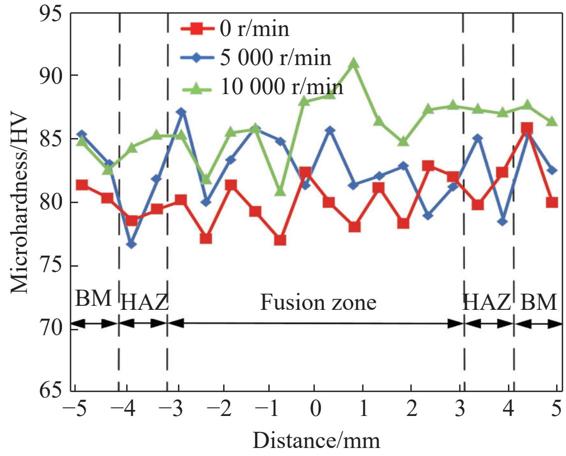

Fig. 7 Microhardness distribution profile of welded joint at three different rotation speeds

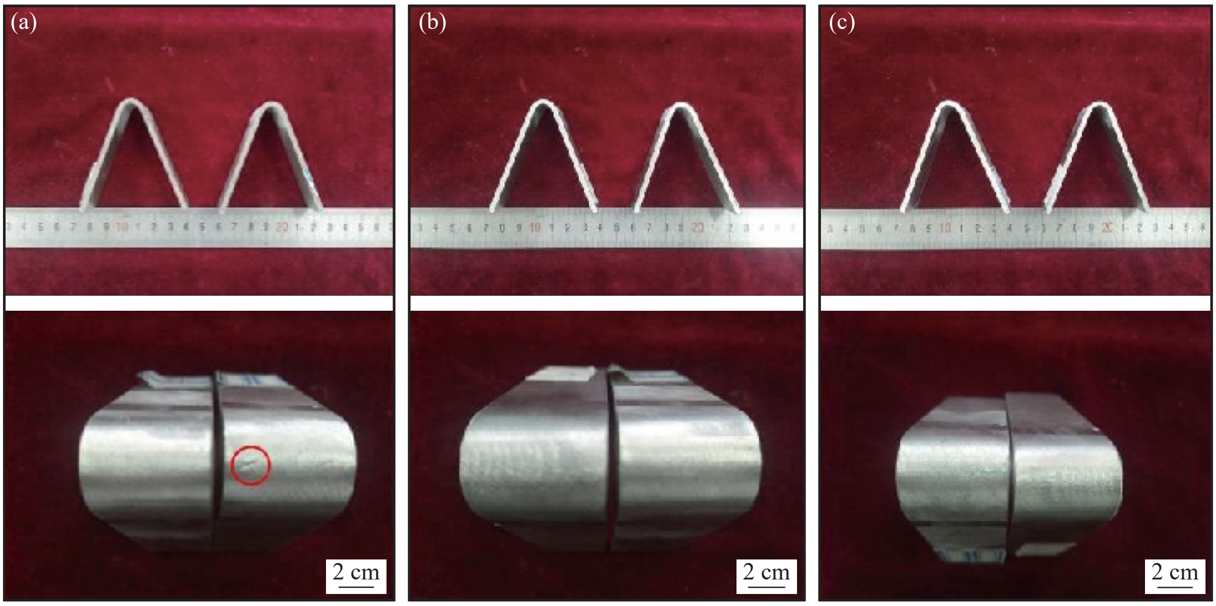

Fig. 8 Photographs of positive/back bending specimen at different rotation speeds: (a) 0 r/min, (b) 5 000 r/min, (c) 10 000 r/min

4 Conclusions

(1) Tungsten needle rotation in the GTAW process was realized by adding a brass spring plate into the current circuit and using a DC motor to drive the tungsten needle motion during the welding process.

(2) The rotation of the tungsten needle can transfer rotary momentum to the arc and cause the molten pool to flow rotationally. As a result, arc constriction occurred and fluid flow in the molten pool was enhanced.

(3) Tungsten autorotation can yield finer and more uniform precipitated phase and fewer large-medium pores in the weld metal. This effect increased the bending strength ang tensile strength of weld metal and raised the microhardness of fusion zone slightly.

Acknowledgments

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Author contributions

The original draft preparation, review and editing,methodology of the manuscript were written by Rongmao Du, Zecheng Wu, Yu Sun and Yanlong Fan. Funding acquisition and supervision of the manuscript were performed by Hongtao Zhang.

Conflict of interest

The authors declare that they have no conflict of interests.

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