

Microstructure and porosity analysis in ultrasonic assisted TIG welding of 2014 aluminum alloy

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Abstract The ultrasonic assisted tungsten inert gas (U-TIG) welding is a newly developed arc welding method, which is aimed at improving the weld quality and efficiency. TIG welding and U-TIG welding of 2014 aluminum alloy with 5 mm thickness were experimentally carried out in this paper. The microstructure and porosity of welded joints were analyzed. Compared with conventional TIG welding, the columnar crystals are changed into equiaxed crystals at the centre of weld zone and the grain of fusion zone in U-TIG welding is refined and equiaxed. The porosities of joint decrease after the ultrasonic was applied on the arc. The mechanism of crystal grain refinement is discussed in this paper and the reasons of porosity decrease in U-TIG welded joint may be due to the effect of acoustic streaming and cavitation, which need further research.

Key words aluminum alloy, ultrasonic assisted TIG welding, grain refinement, porosity

0 Introduction

2014 aluminum alloy shows improved specific stiffness and strength, better wear resistance and greater thermal stability in respect to the corresponding unreinforced matrix alloys, thus finding application mainly in the aerospace, automotive and motorsport fields^[1-3]. Tungsten inert gas (TIG) welding is the most common industrial welding process for aluminum alloy^[4]. Due to the dispersing of arc heat and low arc force, the conventional TIG welding is poor in penetration, low in efficiency and coarsening in grains, which limit its application^[5]. Researches have been focused on achieving a more efficient welding process and better weld quality in recent years. Although, great efforts have been made to improve the efficiency, such as activating flux TIG welding^[6], double-sided arc welding^[7], low frequency arc oscillation^[8] and so on, each one has its limitation.

Ultrasonic is considered as a good way to refine the grain size of metal. The dendrite is broken away from the primary crystal and the nucleation process is accelerated to refine grain by the effect of acoustic streaming and ultrasonic cavitations in molten alloys. When the ultrasonic vibration is applied in the welding arc in TIG welding

process of 304 stainless steel, the welding arc is constricted effectively and the weld penetration is increased under the same welding parameters^[9]. Therefore, it is inferred that the ultrasonic wave should also have same effects in the TIG welding process of aluminum alloy.

In this paper, U-TIG welding of 2014 aluminum alloy was experimentally carried out. The differences of microstructure and quality of the welded joints between U-TIG welding and conventional TIG welding of 2014 aluminum alloy were analyzed.

1 Experimental procedures

1.1 Experimental setup

The main components of U-TIG welding system include three parts, the hybrid welding torch, the ultrasonic power and the TIG welding power. The schematic diagram of the experimental apparatus is shown in Fig. 1. The ultrasonic power outputs 20 kHz high frequency ultrasonic wave. The design of U-TIG welding torch is based on the ultrasonic vibration system consisting of ultrasonic converter and the ultrasonic horn. The ultrasonic converter utilizes the reversed piezoelectric effect to transform high frequency voltage into mechanical oscillation with same fre-

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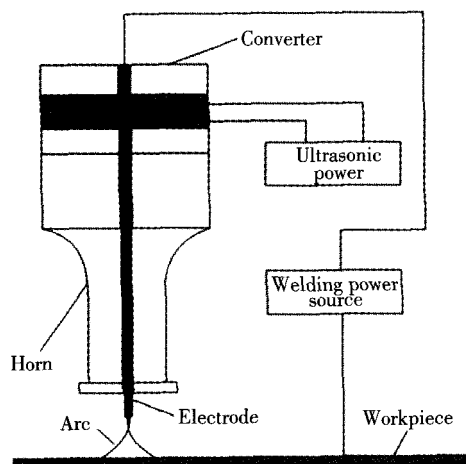


Fig. 1 Schematic sketch of the experimental system

quency. The ultrasonic horn amplifies the ultrasonic vibration amplitude. The ultrasonic wave is finally radiated

from the end of the ultrasonic horn into the arc environment. Tungsten electrode is installed at the center of horn and is connected with TIG power source. Arc is ignited between tungsten electrode and workpiece.

1.2 Experimental materials and parameters

The material chosen was 2014 aluminum alloy, which chemical composition is shown in Table 1. Bead-on-plate welding experiments were carried out to study the differences of microstructure between the U-TIG welding process and the TIG welding process. The size of workpiece was 200 mm × 120 mm × 5 mm. DCEP TIG welding was used with helium as shielding gas. The welding parameters were given in Table 2. The welded joint was then polished and etched using Keller's reagent, i. e., a solution mixture of hydrofluoric acid (HF), hydrochloric acid (HCl), nitric acid (HNO₃) and distilled water.

Table 1 Chemical composition of 2014 aluminum alloy (wt.%)

Si	Fe	Cu	Mn	Mg	Zn	Ni	Ti	Other elements	Al
0.6 - 1.2	0.7	3.9 - 4.8	0.4 - 1.0	0.4 - 0.8	0.3	0.1	0.15	0.15	the rest

Table 2 Welding parameters

Welding current / A	Welding speed / mm · min ⁻¹	Gas flow rate / L · min ⁻¹	Arc length / mm	Electrode diameter / mm	Tungsten electrode angle (°)	Ultrasonic frequency / kHz	Ultrasonic power / W
90	150	15	3	3	30	20	100

AC-TIG welding was also used with argon as shielding gas. Both of U-TIG welding and the conventional TIG welding were carried out under the same welding param-

eters, shown in Table 3. The size of workpiece was 200 mm × 120 mm × 4.5 mm.

Table 3 Welding parameters

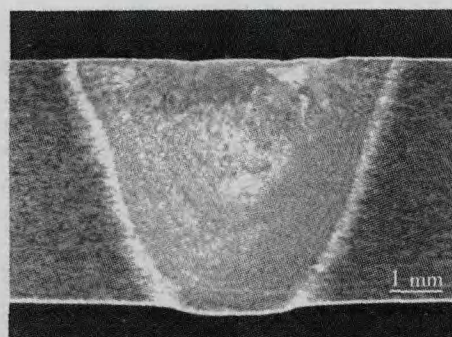
Welding current / A	Welding speed / mm · min ⁻¹	Gas flow rate / L · min ⁻¹	Arc length / mm	Electrode diameter / mm	Tungsten electrode angle (°)	Ultrasonic frequency / kHz	Ultrasonic power / W
120	100	25	3	3	30	20	100

2 Results

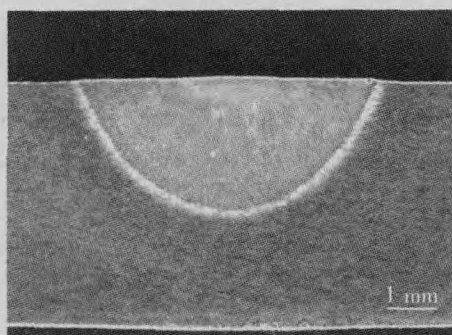
Fig. 2 shows the cross section photos of welded joint by both U-TIG welding and TIG welding of 2014 aluminum alloy under the same welding parameters in Table 2. The

key dimensions of weld are shown in Table 4. The results indicate that with the ultrasonic vibration applied, aluminum alloy welded joint with a thickness 5 mm can be fully penetrated, while the maximum penetration depth of weld

is only 2.81 mm in TIG welding. The weld depth-to-width ratio is increased up to 167% of conventional TIG welding. It can be concluded that ultrasonic wave can improve the penetration depth and depth-to-width ratio of weld bead.



(a) U-TIG welding



(b) TIG welding

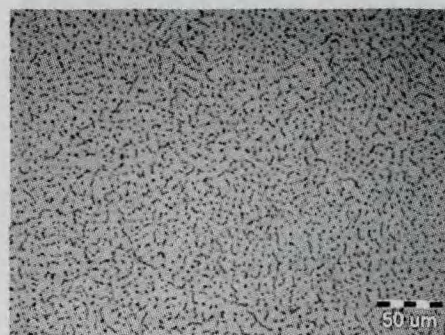
Fig. 2 Weld cross section of 2014 aluminum alloy by DC TIG welding

Table 4 Weld bead geometry

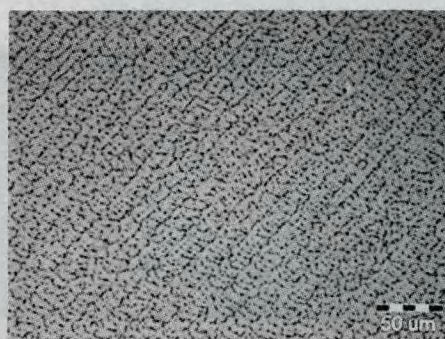
	Penetration H / mm	Weld width B / mm	Depth-to-width ratio H / B
Conventional TIG welding	2.81	6.80	0.41
U-TIG welding	5.00	7.10	0.70

The mechanical properties are determined by microstructure such as the shape and size of grain. Equiaxed crystal is better than columnar crystal with clear growth direction. Smaller size of crystals is good for mechanical properties of welded joint. Fig. 3 gives the microstructure at the top surface of weld zone, which were obtained by U-

TIG welding and TIG welding. The microstructure by TIG welding presents columnar crystals, with clear growth direction. After the ultrasonic wave was applied, the microstructure changes from columnar crystals to equiaxed crystals. However, the transformation can only be found in the 2.5 mm width area locating 0.8 mm under the surface. Fig. 4 shows the grain structure of fusion zone closing to the weld top surface in two welds obtained by U-TIG and TIG welding. Compared with the weld made by TIG welding, a much finer structure is observed. The results indicate that ultrasonic wave can significantly refine grain structure and even change crystal mode from columnar crystals to equiaxed crystals.



(a) U-TIG welding

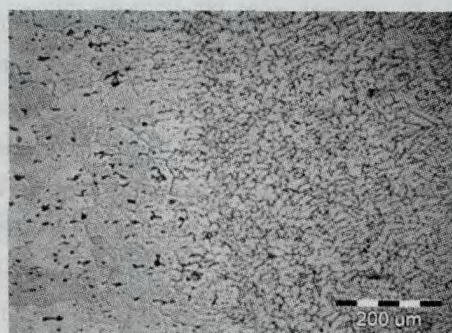


(b) TIG welding

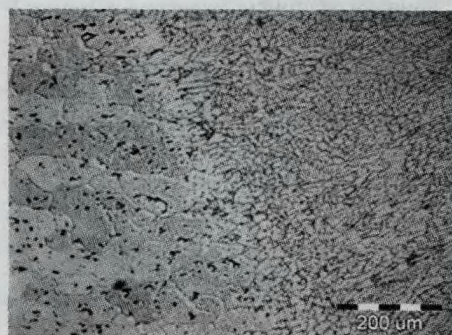
Fig. 3 Microstructure of the top surface of weld

Fig. 5 shows the cross section photos of welded joint of U-TIG welding and TIG welding of 2014 aluminum alloy under the welding parameters in Table 3. It can be shown that there is much porosity in welded joint of TIG welding. But the number of porosities decreases in the welded joint with the application of ultrasonic wave. The results show that ultrasonic wave can decrease the trend of weld porosi-

ty of 2014 aluminum alloy under these parameters mentioned above.

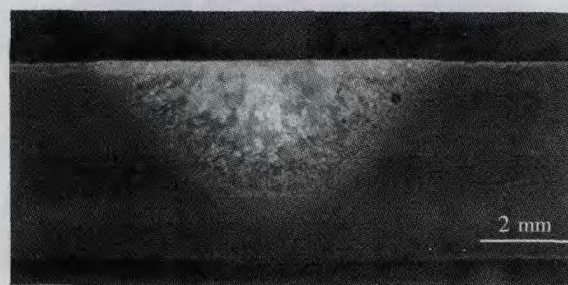


(a) U-TIG welding

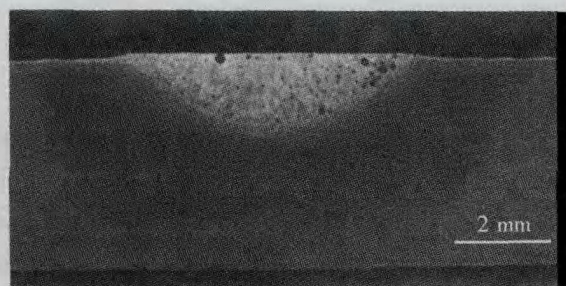


(b) TIG welding

Fig. 4 Microstructure of the fusion zone



(a) U-TIG welding



(b) TIG welding

Fig. 5 Weld cross section of 2014 aluminum alloy

3 Discussion

In the U-TIG welding process, the ultrasonic energy is introduced into the weld pool. It is known that ultrasonic vibration has the effect of cavitation because of its non-linear behavior. Stable cavitation and transient cavitation are two main types of cavitation depending on the ultrasonic energy. During transient collapse process, energy is focused within the bubble to generate a range of potential local effects, including a gaseous hot spot and gas shocks. Firstly, these effects can promote the weld pool convection and cause the grains detaching themselves from the primary crystal immediately adjacent to the weld pool. If they survive in the weld pool, they can act as nuclei for the formation of new grains in the weld metals. Secondly, non-linear pulsation, compression and transient collapse can result in the increase of super-cooling degree which stimulates generation of new nuclei. Both of two actions can refine the grain and even can change the crystal mode from columnar crystals to equiaxed crystals. In addition, when ultrasonic propagates in the arc and liquid environment, ultrasonic vibration accelerates heat transfer by convection and changes thermal cycle. The cooling rate during solidification increases, which is beneficial for refining grain by preventing the growth of grain.

However, because of the viscosity of liquid metals, part of the ultrasonic energy may be absorbed by the liquid and transformed into heat during the propagation in the weld pool. The ultrasonic energy decreases with the increase of distance from the top surface of weld. Without transient collapse, no effect can obviously refine the grain. Therefore, the refinement of grain and the changing of crystal mode can only be found in quite low depth.

Ultrasonic wave can decrease the trend of weld porosity of 2014 aluminum alloy. The reasons may be due to acoustic streaming and cavitation, which can push porosity to get out of weld pool before solidification. However, the real reasons of porosities decrease by ultrasonic wave need further research.

4 Conclusions

Ultrasonic assisted TIG welding is a more efficient welding process than conventional TIG welding. The penetration depth and depth-to-width ratio of weld bead are im-

proved with the application of ultrasonic. The experimental results of bead-on-plate U-TIG welding of 2014 aluminum alloy show that ultrasonic can refine grain structure and change the crystal mode from columnar crystals to equiaxed crystals.

References

- [1] Clyne T W, Withers P J. An introduction to metal matrix composites. Cambridge: Cambridge University Press, 1993.
- [2] Taya M, Arsenault R J. Further comments on "the strength differential and baushinger effects in SiC-Al composites". *Materials Science and Engineering*, 1989, 35 (3): 285 – 288.
- [3] Loyd D J. Particle reinforced aluminium and magnesium metal matrix composites. *International Materials Reviews*. 1994, 39(1): 1 – 45.
- [4] Cary H B. Modern welding technology. New Jersey: Prentice Hall, 1989.
- [5] Yang C L, Ushio M, Tanaka M. Effect of surface active flux on welding pool depth and arc phenomenon in TIG welding. *Chinese Journal of Mechanical Engineering*, 2000, 36(12): 43 – 46. (in Chinese)
- [6] Paskell T, Lundin C. GTAW flux increases weld joint penetration. *Welding Journal*, 1997, 76 (4): 57 – 62.
- [7] Zhang Y M, Zhang S B. Double-sided arc welding increases weld joint penetration. *Welding Journal*, 1998, 77 (6): 57 – 61.
- [8] Kou S, Le Y. Improving weld quality by low frequency arc oscillation. *Welding Journal*, 1985, 64 (3): 51 – 55.
- [9] Sun Q J, Lin S B, Yang C L, et al. Arc characteristic of ultrasonic assisted TIG welding. *China Welding*, 2008, 17 (4): 52 – 57.