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Ultrasonic vibration assisted tungsten inert gas welding of dissimilar magnesium alloys

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ABSTRACT

The effects of ultrasonic vibration assisted (UVA) treatment on the microstructures and mechanical properties of MB3/AZ31 dissimilar magnesium (Mg) alloy joints were studied by microstructural characterization, micro-hardness testing and tensile testing. Results indicate that the welding pores are eliminated and coarse α-Mg grains of fusion zone are refined to 26 μm, owing to the acoustic streaming effect and cavitation effect induced by the UVA treatment with an optimal ultrasonic power of 1.0 kW. In addition, $Mg_{17}Al_{12}$ precipitation phases are fine and uniformly distributed in the whole fusion zone of weldment. Micro-hardness of fusion zone of the Mg alloy joints increases to 53.5 HV after UVA process, and the maximum tensile strength with optimized UVA treatment increases to 263 MPa, which leads to fracture occurrence in the Mg alloy base plate. Eventually, it is experimentally demonstrated that robust MB3/AZ31 Mg alloy joints can be obtained by UVA process.

1. Introduction

Recently, under such a great pressure to reduce exhaust gas emissions from vehicles, railroad and air transportations, Mg alloys are currently receiving extensive attention owing to the excellent comprehensive performances, e.g., high specific strength, low density, outstanding castability and recycling ability [1–3]. In order to expand the application of Mg alloys with desired mechanical features, reliable joining methods were investigated in recent years [4,5].

At present, a series of joining techniques such as friction stir welding [6], diffusion bonding [7], laser welding [8] and transient liquid phase bonding [9] have been developed to achieve the reliable joining of dissimilar Mg alloys. However, weldments appearances are circumscribed by these welding technologies and the practical application is restricted owing to the high cost and low production capacity. Tungsten inert gas (TIG) welding, as an efficient bonding technique, is characterized of flexibility, high productivity and reliable welding quality [10,11]. In our previous studies, TIG welding process was investigated to join dissimilar Mg alloys [ref]. However, the success of joining dissimilar Mg alloys was limited because of the severe grain growth coarsening of welding seam of weldments.

In order to surmount above defects, grain refinement of Mg alloy joints is usually prepared by adding alloy elements, e.g., Sr, C, Sb and rare earth elements [12]. Though the addition of these elements can refine the microstructure, a series of problems are encountered at the same time. Hence a new way of grain refinement of Mg alloys joints without other elements addition is necessary.

Dynamic grain refinement means, e.g., ultrasonic vibration assisted (UVA) treatment, has been studied in the solidification of Mg alloys [12–15]. As ultrasonic vibration leads to a welding pool, cavitation phenomenon is motivated ultrasonically, which results in a great instantaneous pressure and temperature fluctuations in the welding pool [16]. Heterogeneous nucleation was induced accordingly for grain refinement. Furthermore, with the aid of ultrasonic vibration, spiral vortex occurs and leads to the acoustic streaming effect, which increases the cooling speed and decreases the temperature gradient of the welding pool, hence restrains the grain growth of Mg alloys.

The existing literature shows that UVA welding technology was developed to join Al alloys and stainless steel parts [17,18]. Results reveal that ultrasonic vibration encourages grain refinement of welding pool of the weldments and bonding strength of these weldments with UVA treatment increases significantly. Consequently, previous research reveals a promising effect of UVA treatment on

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Table 1
Chemical composition (wt%) of base metals and filler wire.

Alloys	Al	Zn	Mn	Fe	Si	Mg
AZ31	2.9	0.88	0.41	0.01	0.05	Bal.
MB3	4.8	0.92	0.49	0.05	0.10	Bal.
Wire	2.8	0.79	0.32	..	0.04	Bal.

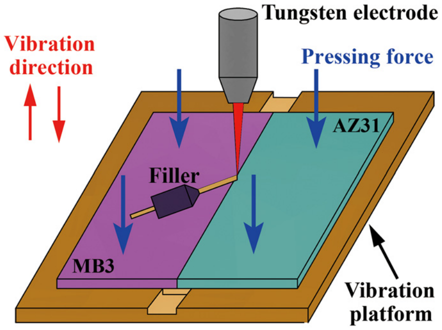

Fig. 1. Schematic illustration of UVA TIG welding.

the microstructure refinement and bonding strength improvement of the weldments [ref].

However, the applications of UVA treatment on Mg alloys weldments have been rarely investigated. Hence, the effects of UVA treatment on microstructure and bonding strength of Mg alloy weldments are studied by the experimental observations in this study.

2. Materials and methods

Mg alloys AZ31 and MB3 plates with dimensions of 50 mm × 70 mm × 2 mm were used as parent materials for welding experiments. Filler wire was Mg alloy AZ31with 1.2 mm in diameter. Table 1 shows the chemical composition of the parent metals and filler wire. Before welding, surface of the parent metals was cleaned with absolute ethanol to remove greasy contaminations and ground with emery paper to remove surface oxides.

A TIG welding machine (YC-300WP5HGN) was applied during the welding experiments of dissimilar Mg alloys. As shown in Fig. 1, ultrasonic vibration was produced by an ultrasonic generator with maximum 20 μm output amplitude and 20 kHz vibration frequency and subsequently imported into the molten bath by the variable amplitude bar. And the vibration direction was perpendicular to the parent metals. The main joining parameters are shown in Table 2.

After welding, microstructures of AZ31/MB3 weldments were analyzed by electron backscatter diffraction (EBSD, JSM-7800 F, and JEOL). The specimens for EBSD analysis were electrochemically polished with a voltage of 20 V in an AC_2 polishing solution at 20 °C. The tensile testing specimens with a width of 10 mm were cut from the Mg alloy weldments, as shown in Fig. 2. Tensile tests were carried out on a universal tensile testing machine (AG-X, SHIMADZU) and the tensile direction was perpendicular to the welding seams. Micro-hardness tests on cross-section of the weldments were performed on a Vickers hardness tester (MH-5 L, China) with a load of 500 g, a holding period of 10 s and a step size of 50 μm. Besides, the cross-sectional macrostructures and fracture characteristics of Mg alloy weldments were observed by scanning electron microscopy (SEM, VAGA 2 LMH, and TESCAN).

Table 2
Welding parameters applied in the present study.

Welding parameters	Values
Welding current, I (A)	70–110
Welding speed, v (m min^{-1})	0.2
Filler feed speed, v_w (m min^{-1})	0.5
Flow rate of protective gas (L min^{-1})	9
Diameter of tungsten electrode (mm)	2.5
Arc voltage (V)	17

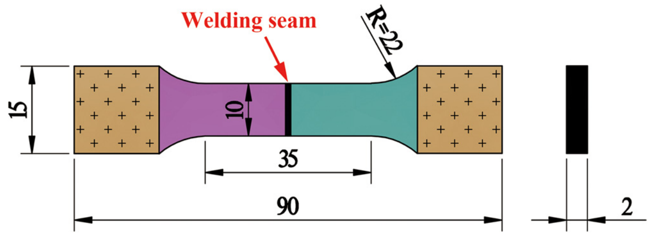

Fig. 2. Schematic illustration of a representative tensile testing specimen.

3. Results

3.1. Cross-sectional macrostructures

Fig. 3 shows the typical cross-sectional macrostructures of Mg alloy AZ31/MB3 joints welded with different currents. It can be found that a large number of pores occur at the welding seam with the increasing current. This phenomenon can be attributed to the extreme increment in temperature of welding pool and the evaporable character of Mg alloy under the currents of 100 A and 110 A.

Figs. 4 and 5 show the typical cross-sectional macrostructures of joints welded with the UVA treatment. As shown in Fig. 4, with an ultrasonic power of 1.0 kW, the number density of welding pores significantly decreases (compared with that in Fig. 3) indicating that reliable joining of Mg alloys was obtained with the above aided welding process. The improvement in cross-sectional macrostructures is mainly ascribed to the cavitation effect and acoustic streaming effect induced by the UVA process, which would be analyzed in the following discussion part. Fig. 5 shows the cross-sectional macrostructures of joints welded with different ultrasonic power. Note that the number of pores decreases with increasing ultrasonic power from 0.5 to 1.0 kW. However, when ultrasonic power further increases to 1.5 kW, irregular pores occur in the welding seam, attributed to the extremely unstable solidification process of joining. Similar results were reported by Xu et al. [10].

3.2. Microstructures

Fig. 6 shows the typical microstructures of Mg alloy joints welded with and without the UVA treatment. In the present work, the average grain sizes of joints were estimated by a line intercept technique on EBSD graphs. It can be found that, without any UVA treatment, the coarse Mg grains with an average grain size of 38 μm were formed in the welding seam of joints. Fig. 6(b–d) is the microstructures of Mg alloy joint welded with UVA treatment. As illustrated in Fig. 6(b), the coarse grain area of joint was slightly refined with an ultrasonic power of 0.5 kW. Furthermore, with the ultrasonic power increased to 1.0 kW, the coarse grains were refined to about 26 μm. The above results indicate that a fine uniform welding pool was obtained with UVA treatment. As shown in Fig. 6(d), the average grain size of welding pool varied slightly with the further increasing ultrasonic power to 1.5 kW.

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