International Journal of Minerals, Metallurgy and Materials
Volume 19, Number 4, Apr 2012, Page 360
DOI: 10.1007/s12613-012-0564-8

Effect of preheat on TIG welding of AZ61 magnesium alloy

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(Received: 18 April 2011; revised: 23 June 2011; accepted: 28 June 2011)

Abstract: The effects of preheat treatments on the microstructures and mechanical properties of tungsten inert gas (TIG)-welded AZ61 magnesium alloy joints were studied by microstructural observations, microhardness tests and tensile tests. The results showed that the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ intermetallic compound of in fusion zone (FZ) increased from 15% to 66% with an increase in preheat temperature. Moreover, the microhardness of the FZ and the ultimate tensile strength of the welded joints reached their maximum values when the preheat temperature was 300°C because more lamellar β-$Mg_{17}(Al,Zn)_{12}$ intermetallic compounds were distributed at the α-Mg grain boundaries and no cracks and pores formed in the FZ of the welded joint.

Keywords: magnesium alloys; TIG welding; preheating; microstructure; mechanical properties

[*This work was financially supported by the Key Scientific and Technological Project of Chongqing (No. CSTC, 2009AC4046), the Natural Science Foundation Project of CQ CSTC (No. CSTC, 2010BB4039), and the Fundamental Research Funds for the Central Universities of China (Nos. CDJZR10130010 and CDJXS10131155).*]

1. Introduction

Magnesium alloys have many attractive properties such as low density and high specific strength. It is predicted that the application of magnesium alloys will grow rapidly in the near future, especially in the transport industry [1]. Presently, magnesium alloy parts are mainly produced by casting. The use of other manufacturing technologies, such as plastic forming and welding, is still limited [2]. Production of complicated pieces of magnesium alloys is usually difficult and expensive because of their poor ductility and cold processibility at room temperature. Because of its advantages of utility and economy, tungsten inert gas (TIG) welding has been used extensively [3]. However, it exhibits some disadvantages such as a tendency toward crack formation, the appearance of porosity during solidification and the formation of a wide heat-affected zone. The pores and cracks often occur in the fusion zone during TIG welding of magnesium alloys, which reduces the mechanical properties of the welded joints. Liu *et al.* [4] found that the mechanical properties of a hybrid laser TIG-welded AZ31B magnesium alloy joint were enhanced because of the decrease in width of the heat-affected zone. Min *et al.* [5] reported that the ultimate tensile strength (UTS) of the TIG-welded AZ61 magnesium alloy joint increased with an increase in heat input. However, few researches have reported the effect of preheat treatments for magnesium alloys before the TIG welding process on the improvement of the microstructures and the mechanical properties of TIG-welded magnesium alloy joints.

Although TIG-welded magnesium alloy joints (especially Mg-Al alloys of the AZ series) have reasonable strength, their mechanical properties are still inferior to those of the base metal. Therefore, a deeper understanding of preheat treatment before TIG welding is of crucial importance. In this study, preheat treatment was applied to AZ61 magnesium alloy plates before the TIG welding process in order to improve their microstructures and mechanical properties.

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The microstructural evolution in the fusion zone (FZ) of the welded joints was investigated and the relationship between the microstructures and the improved mechanical properties of the TIG-welded AZ61 magnesium alloy joints was discussed.

2. Experimental

Hot-extruded AZ61 magnesium alloy plates with dimensions of 120 mm×30 mm×2 mm and AZ91D welding wires with a diameter of 2 mm were used for the TIG welding tests. Preheat treatments were performed (in a heat treatment furnace, SX2-4-10) at 100, 150, 200, 250 and 300°C. Before welding, the top surface of each specimen was cleaned to remove grease and residue then brushed with a stainless steel wire to remove oxides. After that the specimens were butt-welded on the top of a copper-backing strip containing a semi-circular groove with a dimension of 6 mm in width and 1.5 mm in depth. The welding parameters were as follows: the welding current (*I*) was 90 A, the welding speed (*v*) was 15 mm/s, the flow rate of argon gas was 5 L/min and the welding voltage (*U*) was 10 V. TIG welding tests were performed using NSA-500-1. The distance of the electrode to the work piece remained at 2 mm throughout the whole TIG welding process and the electrode angle was 45° (Fig. 1).

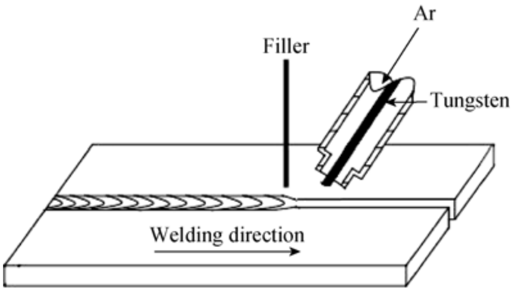

Fig. 1. Sketch of the TIG welding process.

After welding, the specimens were cross-sectioned, grounded and polished. The mounted samples were etched in a solution comprised of 5 mL acetic acid, 5 g picric acid, 10 mL water and 100 mL ethyl alcohol for 20-60 s until the microstructures were revealed. The microstructures were observed by field emission scanning electron microscopy (Nova400 Nano SEM). An energy dispersive spectrometer (OXFORD, Inc. ISIS3000 EDS) was used to help determine the precipitated phases in the welded seams. Microhardness tests were performed by a Vickers hardness tester (V-1000) with a load of 9.8 N and a load period of 20 s. Tensile test specimens with a gauge length of 15 mm and a width of 4 mm were sectioned from the welded seam parts by a numerically controlled linear cutting machine. The tensile tests were carried out with an electronic testing machine (WDW-S200) at room temperature. The tensile direction was perpendicular to the welded seams.

3. Results and discussion

Fig. 2(a) shows the microstructure in the FZ of the TIG-welded AZ61 magnesium alloy joint without preheat treatment. A bright white phase, a black phase and a gray phase formed in the FZ. EDS analysis results showed that the bright white phase contained Al (21.33wt%), Zn (3.51wt%) and Mg (74.28wt%), while the black and gray areas contained large amounts of Mg (96.27wt% and 97.75wt%, respectively). According to the Mg-Al binary phase diagram and other literatures [6], the bright white phase is the β-$Mg_{17}(Al,Zn)_{12}$ intermetallic compound (IMC), the black phase is a eutectic colony and the gray phase is primary α-Mg grains. In the sample without preheat treatment, the cooling rate of the welding pool was relatively high such that α-Mg nucleated and grew dendritically following the principle of primary phase solidification. Hence, the solute elements (Al and Zn) were ejected into the interdendritic liquid. Then the eutectic colony, containing α-Mg and β-$Mg_{17}(Al,Zn)_{12}$ IMC, formed by a Mg-Al eutectic reaction at 437°C. Figs. 2(b)-2(f) show the microstructures in the FZ of the preheated TIG-welded AZ61 magnesium alloy joints. Obviously, lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC formed in the FZ, and their volume fraction increased (15vol%-66vol%) with an increase in preheat temperature. This is because the increase in preheat temperature decreased the cooling rate of the welding pool. Hence, the growth of primary α-Mg grains was suppressed and more Mg atoms reacted with Al and Zn atoms to form more β-$Mg_{17}(Al,Zn)_{12}$ IMC with lamellar structures (see Figs. 2(b)-2(f)).

Fig. 3 shows the relationship between the microstructures and the mechanical properties of the FZ of the AZ61 magnesium alloy welded joints with or without preheat treatment. The microhardness of the FZ and the UTS value of the welded joints with preheat treatment are higher than those of the welded joint without preheat treatment. With an increase in preheat temperature, the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC, the microhardness of the FZ, and the UTS value of the welded joints increased. This is because the β-$Mg_{17}(Al,Zn)_{12}$ IMC distributed at the α-Mg grain boundaries impeded the movement of dislocations. Hence, increasing the preheat temperature led to more lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC forming at the α-Mg grain

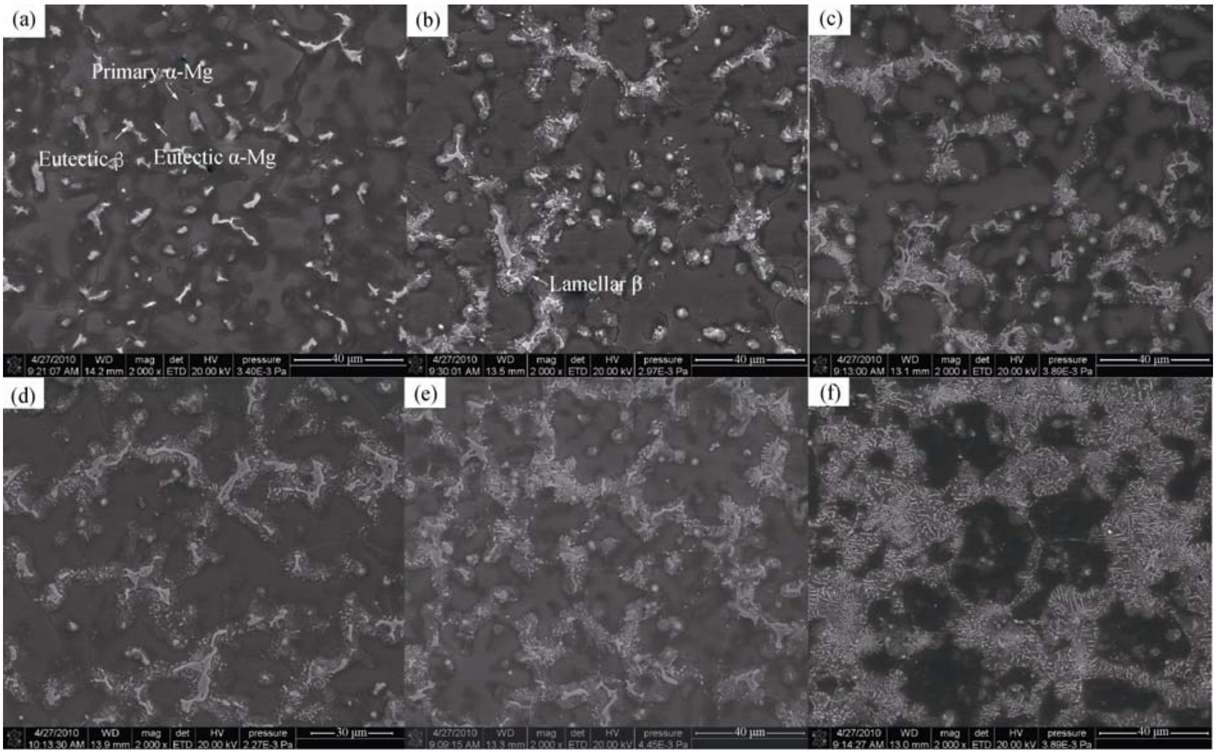

Fig. 2. Microstructures of the FZ in the TIG-welded AZ61 magnesium alloy joints without preheat treatment or with different preheat temperatures: (a) without preheat treatment; (b) after the 100°C preheat treatment; (c) after the 150°C preheat treatement; (d) after the 200°C preheat treatment; (e) after the 250°C preheat treatment; (f) after the 300°C preheat treatment.

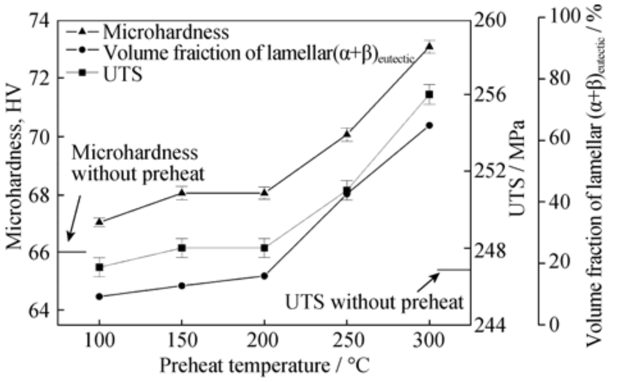

Fig. 3. Relationships between the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC and the mechanical properties of the AZ61 magnesium alloy welded joints with different preheat temperatures.

boundaries and strongly enhanced the microhardness and the UTS value of the FZ of the TIG-welded AZ61 magnesium alloy joints. With the increase in preheat temperature, the elongation of the welded joints decreased (7.8%-3.4%) gradually because of the increase in the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC. This phenomenon is similar to the research results of Liu *et al.* [7].

In addition, microstructural observations (see Fig. 4(a)) revealed that few cracks and pores formed in the FZ of the sample with the relatively low temperature preheat treatment (150°C). Hence, the UTS value of the welded joints with the low temperature preheat treatment was relatively low. However, when the preheat temperature reached 300°C, more lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC dispersed at the α-Mg grain boundaries and no cracks and pores formed in the FZ of the welded joint (see Fig. 4(b)). Therefore, the UTS value of the TIG-welded AZ61 magnesium alloy joints increased significantly.

4. Conclusions

The effects of preheat temperatures ranging from 100 to 300°C on the 2 mm butt joints of TIG-welded AZ61 magnesium alloys were investigated. It was found that the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC in the FZ , the microhardness of the FZ and the UTS value of the welded joints increased with the increase in preheat temperature. However, the elongation of the welded joints decreased gradually because of the increase in the volume fraction of the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC. Moreover, a high preheat temperature suppressed the formation of cracks

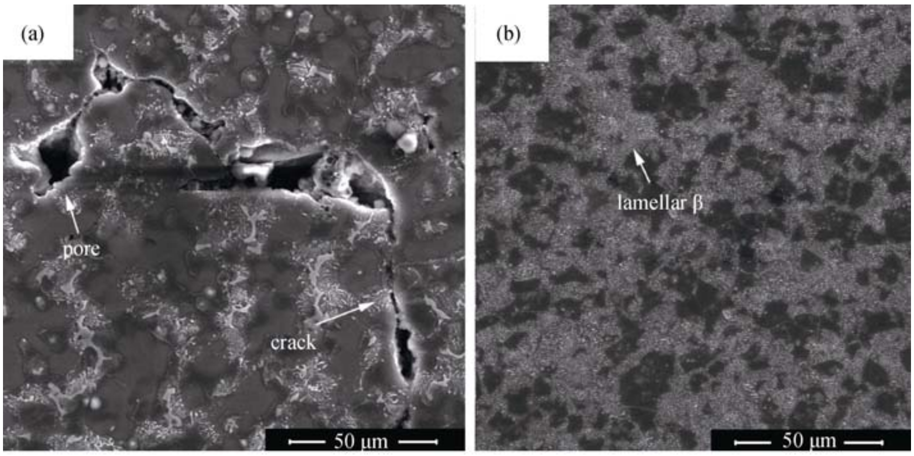

Fig. 4. Micrographs of defects and lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC in the FZ: (a) defects in the FZ after the 150°C preheat treatment; (b) the lamellar β-$Mg_{17}(Al,Zn)_{12}$ IMC in the FZ after the 300°C preheat treatment.

and pores in the FZ of the welded joint and greatly enhanced the UTS of the welded joints.

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