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Joining of aluminum and magnesium via pre-roll-assisted A-TIG welding with Zn interlayer

H.T. Zhang*, X.Y. Dai, J.C. Feng

School of Materials Science and Engineering, Harbin Institute of Technology at Weihai, Weihai 264209, Shandong Province, People's Republic of China

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ABSTRACT

AZ31B Mg and 6061 Al alloys were successfully welded via a novel pre-roll-assisted A-TIG welding technique with Zn interlayer at an overlap configuration. The rolling operation increased the contact area and control tightly between Zn interlayer and plates at an interlayer-assisted overlap configuration to avoid the adverse effect of gaps. B_2O_3 activating flux was coated on the upper Al plates to provide contraction of the arc column to increase the arc energy density; welding penetration was increased without improving heat input, which reduced the formation and grain coarsening of Al–Mg IMCs. Therefore, the tensile–shear strength of the joints was improved obviously. The average of tensile–shear strength joined was 71.2 MPa with a maximum of 74 MPa compared to 41.1 MPa with a maximum of 45.2 MPa by conventional TIG with Zn interlayer.

1. Introduction

Mg and Al alloys are used as structural materials in aerospace and electronic industries as well as in automotive industry because of their extremely high strength/weight ratio, good castability, workability, and damping capacity [1,2]. In order to extend the application, the joining of Mg–Al dissimilar metal has attracted huge interests recently. However, the hard and brittle Al–Mg intermetallic compounds preferentially act as the source of micro-cracks during mechanical property testing, which deteriorate the mechanical property of the joint [3]. Therefore, special joining processes such as laser welding [4], laser–TIG hybrid welding [5], friction-stir welding [6], and diffusion bonding [7] have been employed to join Mg and Al alloys. But the conventional fusion welding process is still a promising method owing to its low cost and convenient manipulation.

In order to reduce the intermetallic compounds during fusion welding process, a third metal was essential to be introduced into the weld. In our previous research, Zn interlayer was used to restrain the reactions between Al and Mg atoms; therefore the Al–Mg intermetallic compounds were reduced [8]. However, two main thorny issues were encountered, which deteriorated the mechanical property of the joint. One restraint was that the gap between the lapped Mg and Al alloy plates should be controlled tightly in interlayer-assisted overlap welding. If not, the gap could act as the source of cracks during lap shear strength testing, which resulted in brittleness of the joint [9]. In addition, the higher welding heat input resulted in extreme reactions between Al and Mg atoms to form a large amount of Al–Mg IMCs [10]. Besides, the lower heat input led to incomplete fusion defects. Thus B_2O_3 activating flux was coated on the upper plates to increase the welding penetration without improving heat input. Based on the above analysis, a novel pre-roll-assisted A-TIG process with Zn interlayer was employed in this work. And the mechanical property of the joint was improved obviously.

2. Experimental

AZ31B Mg alloy and 6061 Al alloy were used in this study. The dimension of the alloy plates was 150 mm × 50 mm × 1 mm and the oxide film on the welding location was chemically removed prior to welding. The schematic representation of the assembled pre-roll-assisted A-TIG device is shown in Fig. 1. The Al alloy plate was placed on top of the Mg alloy with an overlapping width of 10 mm and 0.2 mm thickness Zn interlayer was used as the interlayer between the Al alloy plate and the Mg alloy plate. A spring-loaded roller was used to make the Zn interlayer and plates contact closely to reduce the adverse effect of the gap. The parameter of pressure was determined by spring deformation. The Al alloy plate on the welding location was coated with a layer of B_2O_3 activating flux, which could improve the welding penetration by the mechanism of arc constriction [11]. Therefore, the Zn interlayer could melt completely at lower heat input, which prevented not only a large amount of brittle Al–Mg IMCs formation

* Corresponding author. Tel.: +86 631 5677156; fax: +86 631 5687305.
E-mail address: zhanght@hitwh.edu.cn (H.T. Zhang).

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but also the appearance of unmelted Zn at interfacial of the joint. The optimized welding parameters were listed as follows: welding current of 120 Å, welding voltage of 20 V and welding speed of 0.4 m/min.

The cross-section of the weld bead was examined via a scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS). Phase identification was analyzed via X-ray diffraction (XRD). Five 10 mm wide specimens perpendicular to the welding direction were prepared and subjected to tensile testing machine with a speed of 0.5 mm/min at room temperature.

3. Results and discussion

Fig. 2 shows the appearance of the back weld by pre-roll-assisted A-TIG and conventional TIG process. Continuous and uniform back weld can be obtained in Fig. 2(b), while welding defects of incomplete fusion are observed obviously in Fig. 2(a) at the same welding parameters for comparison. This is because the B_2O_3 activating flux could provide contraction of the arc column, and therefore welding penetration was increased significantly without improving heat input compared to that in Fig. 2(a). The tensile–shear strength was used to assess the joining quality of the joints. The average of tensile–shear strength joined by pre-roll assisted A-TIG with Zn interlayer was 71.2 MPa with a maximum of 74 MPa compared to 41.1 MPa with a maximum of 45.2 MPa by conventional TIG with Zn interlayer. The tensile–shear strength of the joints was improved obviously.

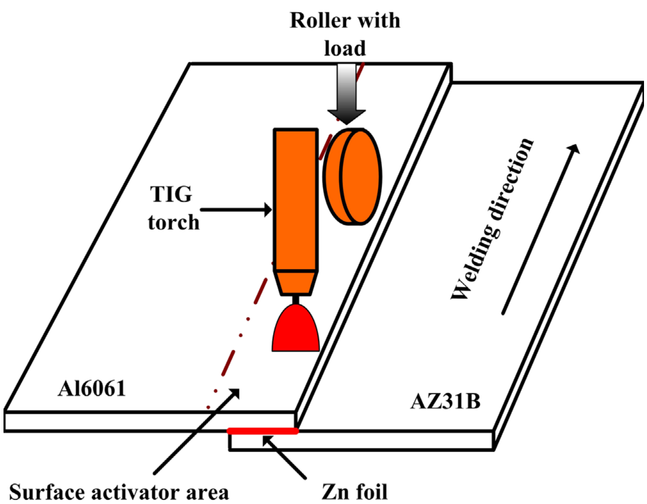

Fig. 1. Schematic representation of the pre-roll-assisted A-TIG device.

Fig. 2. Back weld appearance: (a) conventional TIG with Zn interlayer and (b) pre-roll assisted A-TIG with Zn interlayer.

Fig. 3 shows the backscattered SEM images of the fusion zone near Mg alloy side and weld seam. It could be seen that the discrete gaps produced at the lapped Mg and Al alloy plates were not observed. The interaction characteristic between the fusion zone and the Mg substrate was obvious. As shown in Fig. 3(a), the microstructure of the fusion zone near Mg side is mainly composed of cellular fine grains instead of columnar coarse grains and the microstructure is uniform and homogeneous because of the grain refinement effect. Some strip-like phases are randomly distributed in a typical eutectic structure as shown in Fig. 3(b). The high-magnification image shown in the inset of Fig. 3(b) illustrates that the matrix phase shows a characteristic with lamellar morphology. According to EDS results (Table 1) and XRD analysis (Fig. 4), the cellular grains are mainly composed of Mg-based solution and $MgZn_2$ (PDF#65-2226) phases. The strip-like phases and eutectic structure were Zn-based solution and Mg–Zn eutectic phases respectively. However, the diffraction peak of $Al_{12}Mg_{17}$ phase was not obvious, which illustrated that small amounts of $Al_{12}Mg_{17}$ phase were formed near Mg side. In other words, the formation of Al–Mg IMCs was restricted during this welding process.

In our previous study, the key difficulty was to control the growth of Al–Mg IMCs in Al–Mg dissimilar fusion welding process. Reducing the heat input was undoubtedly right. This is because the higher heat input resulted in extreme reactions between Al and Mg atoms to form not only a large amount of Al–Mg IMCs but also coarsen the grain of IMCs. The moderate reactions of Al and Mg atoms were the results that we needed the most. However, the lower heat input resulted in incomplete fusion defects, which deteriorated the mechanical property of the joint. Therefore, B_2O_3 activating flux was coated on the upper plates to increase the welding penetration without improving heat input. The evaporation of B_2O_3 activating flux could provide contraction of the arc column to increase the arc energy density. Therefore, the fusion joining of dissimilar Al–Mg at lower heat input could be obtained. Another problem was that the gap between the lapped Mg and Al alloy plates controlled tightly or not. This is because the gap served as the source of cracks during tensile–shear strength at the overlapped configuration. A spring-loaded roller was applied to increase the contact area or even resulted in plastic deformation to

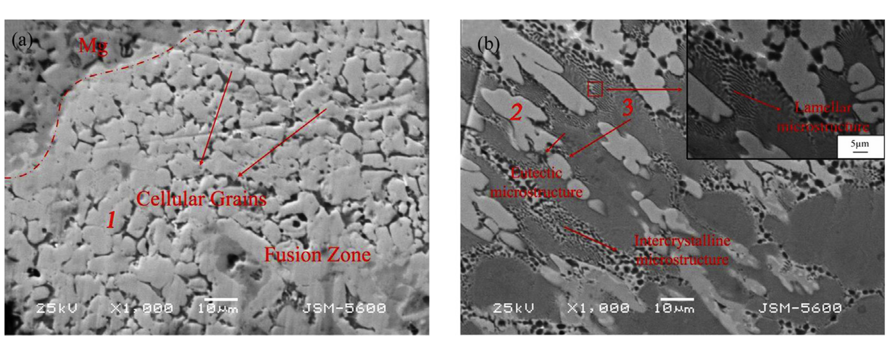

Fig. 3. SEM micrographs of pre-roll assisted A-TIG: (a) the fusion zone near Mg side and (b) weld seam.

Table 1
Chemical compositions (at%) based on the EDS results.

Points	Al	Mg	Zn
1	17.5	52.3	30.2
2	12.1	13.4	74.5
3	9.6	32.3	58.1

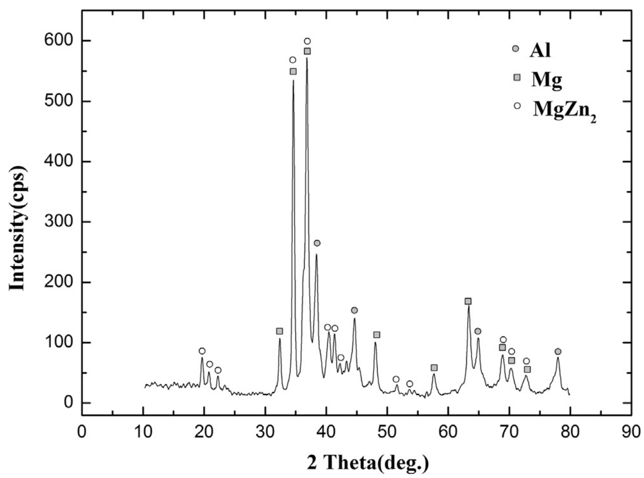

Fig. 4. XRD analysis of the fusion zone near Mg substrate.

reduce the adverse effect of gaps. According to crystallization kinetics, deformation could affect the crystallization behavior, which results in grain refinement. Based on the results of tensile–shear strength, it was clear that the quality of joint by pre-roll assisted A-TIG with Zn interlayer was better than the joint by conventional TIG with Zn interlayer, which corresponded with above analysis.

4. Conclusions

(1) AZ31B Mg and 6061 Al alloys were successfully welded using a novel pre-roll-assisted A-TIG process with a Zn foil interlayer. The tensile–shear strength of the joints was improved obviously. The average of tensile–shear strength joined was 71.2 MPa with a maximum of 74 MPa compared to 41.1 MPa with a maximum of 45.2 MPa by conventional TIG with Zn interlayer.

(2) A spring-loaded roller was applied to increase the contact area and control tightly between Zn interlayer and plates at the interlayer-assisted overlap configuration to avoid the adverse effect of gaps. Besides, B_2O_3 activating flux was coated on the upper Al plates to provide contraction of the arc column to increase the arc energy density. Therefore, the welding penetration was increased without improving heat input, which reduced the Al–Mg IMCs formation and grain growth coarsening. Thus, the mechanical property of the joint was improved obviously.

References

[1] Schubert E, Klassen M, Zerner I, Walz C, Sepold G. J Mater Process Technol 2001;115:2–8.
[2] Mordike BL, Ebsert T. Mater Sci Eng A 2001;302:37–45.
[3] Jing S, Wang KH, Zhou Q, Zhang DK, Huang J, Li GL. Mater Design 2012;34:559–65.
[4] Liu LM, Wang H, Song G, Ye JN. J Mater Sci 2007;42:565–72.
[5] Liu LM, Liu XJ, Liu SH. Scr Mater 2006;55:383–6.
[6] Venkateswaran P, Reynolds AP. Mater Sci Eng A 2012;545:26–37.
[7] Wang YY, Luo GQ, Zhang J, Shen Q, Zhang LM. J Alloys Compd 2012;541:458–61.
[8] Zhang HT, Song JQ. Mater Lett 2011;65:3292–4.
[9] Liu LM, Qi XD, Wu ZH. Mater Lett 2010;64:89–92.
[10] Wang J, Feng JC, Wang YX. Mater Sci Technol-Lond 2008;24:827–31.
[11] Howse DS, Lucas W. Sci Technol Weld Join 2000;5:189–93.