Microstructure and mechanical properties of Mg/Al joints by pulse MIG assisted induction pre-heating with composite interlayers

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Abstract. Butt Joints of AZ31 magnesium alloys and Al1060 aluminium plates were produced by conventional MIG welding process with composite interlayers composed of zinc, copper and aluminium foil and induction pre-heating method was used to promote the melting degree of the high melting interlayers, which achieved the connection of dissimilar materials effectively by comparison via SEM and tensile test. The results indicated that crack-free Al/Mg butt joints were obtained. The analysis of the microstructure of the joints showed that the phase composition at the interface between base metal and fusion zone related to the sequence of the different foils. The tensile strength of the joints could reach 21 MPa and the fracture located at the interfacial zone which was mainly composed of brittle Al-Mg compounds.

1. Introduction
Aluminum alloys is widely used in aerospace, ship industries and automotive industries because of have its high strength and combination mass reduction [1,2]. Magnesium has a greater potential for weight reduction than other lightweight alloys due to its lower density [3,4]. Therefore, the joining of magnesium to aluminum become a key technology for industrial application of these dissimilar metals joint in the future [5,6].

The main problem of joining Mg and Al is that the very brittle Mg-Al intermetallic compounds(IMCS) formed at the interface between fusion zone and magnesium base metal, which can deteriorate the mechanical properties of the joints [7,8]. So many researchers have attempted to use brazing [9], friction stir welding [10,11], laser-TIG hybrid welding processes to joining the two different metals [12]. It is difficult to use conventional fusion welding process to join the two metals directly for the macroscopic crack usually appear after completion of the welding. However, using fusion welding process to join the two metal also is attractive for its low cost and convenient manipulation. According to Mg-Zn, Al-Cu binary phase diagrams and a series of previous researches [13-16], Al/Cu/Zn composite interlayers was selected to reduce the brittle Al-Mg IMCS. In this paper, pulse MIG assisted induction pre-heating with Al/Cu/Zn composite interlayers was used to joint dissimilar aluminum and
magnesium alloy and the microstructure and prosperities of the joints were researched.

2. Experiment
In order to exclude the influence of other alloying elements, the materials used for welding are AZ31 and Al1060 sheets with the thickness of 3 mm. And the chemical composition of of the experimental materials was shown in table 1. The dimensions of the plates were 50 mm×200 mm×3 mm and I-groove was selected as shown in figure 1.

**Table 1. The chemical composition of Mg and Al alloy.**

| Element(wt.%) | Al | Zn | Mn | Si | Cu | Mg |
|--------------|----|----|----|----|----|----|
| Al 1060      | 99.6 | 0.05 | 0.05 | 0.2 | 0.05 | 0.05 |
| AZ31         | 3 | 1 | 0.5 | 0.08 | 0.01 | 94.6 |

**Figure 1. The schematic illustration of the MIG welding process**

Welding process were finished with conventional pulse MIG welding power source (ADP 350) and a medium frequency induction coil was placed upon the assembled sheets up to about 150°C to preheat the base metal and interlayer, which could promote the fusion of the high melting point interlayer metal. ER4043 Al-Si wire was selected as filler metal and the welding speed was 6.6 mm/s, the welding basic current was 20 A, the voltage of induction pre-heating was 200 V. In the experiments, the sequence of zinc, copper and aluminum foil was changed to investigate its effect on the joint properties. Label “ZCA” represented joint made with the interlayer which the zinc foil contact with magnesium base metal and aluminum foil contact with aluminium base metal and copper foil was placed at the center. On the contrary, label “ACZ” represent the aluminum foil contacted with magnesium alloy during welding.

Scanning electron microscopy (SEM, TESCAN VEGA II) with energy dispersive spectrometer (EDS) were used to observe the cross-section microstructure and fracture surface of the tensile specimens. The tensile specimens were cut from weld to undergo tensile strength tests on an electronic tension machine (Instron 5967) so as to estimate the mechanical property of the different types joint.

3. Results and discussion

3.1. Weld appearances
Figure 2 shows the surface appearances of Mg/Al joints made by this novel process. The surface appearance of the weld “ZCA” was shown in figure 2(a) and the surface appearance of the weld “ACZ” with the same processing parameters was shown in figure 2(b). The weld formation was good and obvious burning loss of magnesium element could be seen from the surface of magnesium alloy near the weld.
3.2. Microstructure of dissimilar metals joints

Figure 3 shows the scanning electron microscope image (SEM) photos of the different types’ joints in different areas. As to weld “ZCA”, the SEM microstructure of joint cross sections and XRD results of it were illustrated in figures 3(a)-3(c) and figure 4, respectively. And the obvious interfacial compound layer between magnesium and the fusion zone as shown in figure 3(a); there are no obvious micro-cracks between the compound layer and the magnesium side. The chemical constitution of compound layer marked in figure 3(a) was analyzed by XRD. This intermetallic compound layer was composed of Al₁₂Mg₁₇ phase near magnesium base metal. Some MgO crystals with irregular shape could also be found at the center of fusion zone with white Mg₂Si phase distributing in its interior as shown in figure 3(b). The main phase in the center and the zone near aluminum side was Al–Cu eutectic structure zone in figures 3(b) and 3(c).
Figure 4. X-ray diffraction patterns of joints of ZCA

Figure 5. X-ray diffraction patterns of joints of ACZ

“ACZ” Joint was made when aluminum foil contacted with magnesium base metal during welding. And the SEM microstructure and XRD results of joints were sketched in figures 3(d)-3(f) and figure 5, respectively. The microstructure of fusion zone near magnesium base metal was very different with that of “ZCA” joint. Some disperse Mg base solid solution with aluminum atoms dissolved in it could be seen near magnesium side and mass of Al$_{12}$Mg$_{17}$ phase were distributed around the Mg base solid solution as shown in figure 3(d). In the fusion zone there was mass of Al–Cu eutectic structure and some regular shape of MgO crystals in it as shown in figure 3(e). The main phase near aluminum side was Al-Cu eutectic structure in figure 3(f).

3.3. Tensile property and fracture behaviour
The fracture surface of the two different joints presents brittle fracture as shown in figure 6. In tensile tests, fracture occurred at the edge of the fusion zone which was composed of Mg–Al intermetallic and
the average tensile strength of the joints could reach 21 MPa in figure 7 when the zinc foil was put near magnesium. However, the average tensile strength of the joints without interlayer reached 13 MPa.

**Figure 6.** The SEM images of fracture surface

![SEM images](image)

**Figure 7.** Tensile strength of welded joints with different interlayer

It was a novel technology using composite interlayers to join aluminum and magnesium with oinduction pre-heating by conventional MIG welding process. However, the brittle Mg-Al intermetallic could not be restrained effectively by the Al-Cu-Zn composite interlayer. There was no Mg-Zn intermetallic compound generated in the joint for the evaporation of zinc foil during welding by XRD and a better interlayer should be found to improve the mechanical property of the Mg-Al joints by comparison and this give a reference to join aluminum to magnesium by conventional fusion welding process.

**4. Conclusions**

Dissimilar metals joints between Al1060 and AZ31B magnesium alloy were made by conventional MIG welding process with composite interlayers assisted in inductionpre-heating method. Major conclusions of this study could be summarized as follows: butt joints between AZ31 and Al1060 can be successfully jointed by conventional MIG welding process with composite interlayers. The quantity of Al–Mg
intermetallic compounds phase can be decreased obviously for the Al-Cu eutectic structure generated in the fusion zone and the tensile strength of the joint could reach 21 MPa. The existence of the brittle Mg-Al intermetallic compounds determined the tensile strength of the dissimilar metals joint and the joints all fractured at the brittle zone which was composed of Al-Mg intermetallic compound phase.

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