Characterizations of TIG welded MB3/AZ80 joint using various filler wires

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Abstract
In this study, the MB3 and AZ80 Mg alloys were welded by tungsten inert gas welding process with different filler wires. The influences of Al content in filler metal on weld morphologies, microstructure and mechanical performances were studied. Experimental results reveal that the seam width of joint increased with the improvement of welding current and pores occurred in the weld seam with excessive heat input. In the weld seam zone, a great deal of Mg17Al12 precipitated phases occurred owing to the Al element in filler wire, which resulted in the enhanced metallurgical bonding and the increased micro hardness. The maximum tensile strength of 208 MPa was obtained with optimal current of 80 A and AZ61 filler wire, representing an 85% joining efficiency relative to MB3 Mg alloy parent plate. And fracture occurred at weld seam zone, revealing the potential point of joint strength improvement.

1. Introduction
In recent years, the issue of sustainable development has attracted increasing attention. To reduce greenhouse gas emissions and improve fuel efficiency, effective weight reduction of various vehicles is being energetically studied [1–4]. At present, there are some methods to realize the lightweight of transportation: (1) optimize the design and lower the thickness of structural parts, (2) increase the application of functional materials and reduce the number of components, (3) replace conventional steel with low-density materials. It is noteworthy that the third approach has the greatest potential during the three methods mentioned above.

The structural applications of Mg alloys are briskly rising in transportation vehicles owing to the pretty low density. What is particularly attractive is that Mg alloys are 78%, 61% and 36% lighter than steel, Ti alloy and Al alloy, which are also characterized by high specific strength, good damping property, excellent machinability and superior electromagnetic shielding property [5–8]. Nevertheless, the reliable welding of Mg alloys is decisive for the expansion of its application in various areas [9, 10]. A series of welding methods, such as electron beam welding [11, 12], brazing [13, 14], diffusion welding [15, 16], friction stir welding [17, 18] and tungsten inert gas welding [19, 20] have been developed to achieve the joining of Mg alloys. Gao et al [21] studied the microstructure features and mechanical performance of laser metal inert gas hybrid welded AZ31 Mg alloy joints. Experiment results revealed that arc zone had wider partial melted area and coarser grain size than that of laser area, and formation mechanism of porosity was studied on the basis of experimental observations. Singh et al [22] investigated the microstructure and mechanical properties of friction stir welded AZ61 Mg alloy joint. According to Singh, the micro hardness of thermo-mechanically affected area decreased while the micro hardness of stir area increased and exceeded that of base metal. The optimal tensile strength was about 82% of the base metal and fracture failure occurred in ductile mode, owing to the uniform deformation of material. Niknejad et al [23] reported the grain-boundary β-Mg17Al12 and fracture properties of resistance spot welded AZ80 Mg alloy. It can be found that continuous networks of β-Mg17Al12 phases were formed along grain boundaries in heat affected area and nugget area of spot welded joint. These continuous grain-boundary
\( \beta \)-Mg\(_{17}\)Al\(_{12}\) phases acted as effective crack growth ways and resulted in the decrease of weld strength. However, it is still difficult to obtain sound Mg alloy joint with superior mechanical properties owing to sorts of defects such as hot cracking, porosity and distortion.

Literatures reveal that some Mg-Al and Mg-Zn precipitated phases are usually formed in Mg alloy joints. And the amount, morphology and distribution of precipitated phases have obvious influence on the mechanical performance of weldment. Especially the continuous distribution of precipitated phase at grain boundaries, which would severely deteriorate the joining strength of joints. Therefore, reasonable controlling of the amount and distribution of intermetallic compounds is the key to obtain reliable Mg alloy joints. In the present study, MB3 and AZ80 Mg alloys were welded by tungsten inert gas welding technology and MB3, AZ61, AZ91 wires were selected as filler metal. On the basis of experimental results, this study revealed the influences of filler wire components and welding heat input on weld morphologies, microstructure features and mechanical performances of TIG welded MB3/AZ80 joints.

### 2. Experimental materials and methods

MB3 and AZ80 Mg alloy sheets both with 2 mm in thickness were used as base metals. The MB3, AZ61 and AZ91 wires with 1 mm in diameter were selected as filler materials. Table 1 shows the chemical compositions of base metals and filler materials. One-side welding with back formation was performed with a tungsten inert gas welding machine. Before welding, the base sheets and filler wires were polished by fine sand paper and cleaned by acetone. Then MB3 and AZ80 Mg alloy plates were fixed in the form of butt joint, as illustrated in figure 1. Argon was used as protective gas to prevent weld seam from oxidizing at high temperature. Table 2 lists the welding parameters adopted in the present study.

After completing the welding experiment, the weld samples for metallurgical observation were prepared by standard procedure and etched by a solution containing 2 ml acetic acid, 5 g picric acid, 16 ml ethyl alcohol and

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**Table 1.** The chemical compositions of base materials and filler wires.

| Elements (wt%) | Al | Zn | Mn | Si | Mg |
|---------------|----|----|----|----|----|
| MB3           | 4.2| 1.1| 0.2| —  | Bal.|
| AZ80          | 8.2| 0.8| 0.15| 0.01| Bal.|
| AZ61          | 5.8| 1.2| 0.2| —  | Bal.|
| AZ91          | 9.4| 1.2| 0.3| —  | Bal.|

**Figure 1.** The schematic diagram of tungsten inert gas welding of MB3 and AZ80 alloys.

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**Table 2.** The welding parameters adopted in this paper.

| Welding parameters          | Value |
|-----------------------------|-------|
| Welding current (A)         | 60–90 |
| Welding voltage (V)         | 15    |
| Welding speed (m min\(^{-1}\)) | 0.2   |
| Wire feed speed (m min\(^{-1}\)) | 0.5   |
| Flow rate of shielding gas Ar (l min\(^{-1}\)) | 10    |
| Welding arc length (mm)     | 2     |

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1 ml distilled water. The weld microstructure and typical fracture appearance were observed by optical microscope and scanning electron microscope (SEM) combined with energy dispersive spectroscopy (EDS). The backscattered images (BSE) were employed to reveal the amount, morphology and distribution of precipitated phases in weld seam. Vickers micro hardness tests of weld cross section with a load time of 10 s and loading force of 100 g were carried out by a digitalized micro hardness tester at room temperature. The mechanical properties of Mg alloy joints were measured by a universal tensile testing machine at a constant travel speed of 1.5 mm min$^{-1}$. Figure 2 present the dimensions of tensile testing specimens.

3. Results and discussions

3.1. Weld morphologies

Figure 3 presents the typical weld morphologies of MB3/AZ80 Mg alloy joints obtained with AZ61 filler and various welding current. It can be found that the welding heat input has obvious influence on weld morphologies. As the welding current is minimized (with current of 60 A), the weld seam is narrow and uneven, which is mainly due to the insufficient melting of base metal and filler material under deficient heat input, as depicted in figure 3(a). The heat input increases with the improvement of welding current and resulted in the enhancement of weld width. When the welding current increases from 60 A to 90 A, the width of weld seam increases from 3.8 mm to 7.1 mm. Of particular note is some pores occurred in the weld seam of joint obtained with current of 90 A, attributed to the severe evaporation of low-melting point Mg alloy under excessive heat input, as illustrated in figure 3(d).

Figure 4 presents the typical weld morphologies of MB3/AZ80 Mg alloy joints obtained with different filler metals (with current of 80 A). There is no obvious difference in weld morphology of Mg alloy joints obtained with MB3 and AZ61 filler wires, as illustrated in figures 4(a) and (b). However, severe pore defect occurred in the weld seam zone of joint welded with AZ91 filler, as shown in figure 4(c). The variation of weld appearance is mainly related to the composition of welding wire. Because the aluminum content of AZ91 filler metal is higher than that of MB3 and AZ61 filler metals. Literatures reveal that the Al-rich components would enlarge the solid liquid temperature range and resulted in more severe hydrogen evolution. Eventually, a number of welding pores were formed in the weld zone of MB3/AZ80 joint during the welding process with AZ91 filler material.
3.2. Microstructure features

Figure 5 presents the metallurgical structure of weld seam of MB3/AZ80 joint obtained with AZ61 filler metal and different welding current. As shown in figure 5(a), coarse α-Mg grains accompanied with dark precipitated phases occurred in the weld seam. Figures 5(b)–(d) indicate that grain coarsening increases with the improvement of welding current. According to intercept method, the average grain sizes of weld seam obtained under the current of 60 A, 70 A, 80 A and 90 A are about 26 mm, 32 mm, 37 mm and 41 mm respectively. The evolution of metallurgical structure of weld seam is mainly related to the solidification process of molten metal. As the welding heat input was inadequate (60 A), grains did not grow sufficiently owing to the low pool temperature and high cooling rate. On the contrary, adequate welding heat input (90 A) increased the pool temperature and prolonged the solidification process, resulting in sufficient time and energy for grain growth.

Figure 6 depicts the metallurgical structure of MB3/AZ80 joint welded under current of 80 A and MB3, AZ61, AZ91 filler wires. It can be found that apparent grain growth occurred in the weld zone of each joint, regardless of filler wire composition. However, with the increase of aluminum content in filler wire, the amount
of black precipitated phase in weld seam area increased obviously. Figure 7 presents the typical mapping EDS images of MB3/AZ80 joint welded with AZ91 filler and the current of 80 A. As shown in figure 7(b), a large amount of aluminum elements segregated in the weld seam area, revealed the formation of aluminum-rich intermetallic compounds. To further determine the phase structure of intermetallic compounds, point EDS testing was carried out and the results were presented in figure 8 and table 3. The EDS detection results of location 1 show that the precipitated phase contained 62.5 at% Mg and 37.5 at% Al, which were consistent with the element ratio of Mg_{17}Al_{12}. Besides, a spot of Zn element was detected in the partially precipitated phase. Literatures reveal that, during the cooling and solidification process of molten pool, some Al atoms of Mg_{17}Al_{12} phase would be replaced by Zn atoms to form Mg_{17}(Al, Zn)_{12} phase, attributed to the decrease of Gibbs free energy. As a result, the intermetallic compounds mainly have a form of Mg_{17}Al_{12} phase and accompanied with slight Mg_{17}(Al, Zn)_{12} phase.

Figure 6. The metallurgical structure of MB3/AZ80 joint welded under current of 80 A and different filler wires.

Figure 7. The typical concentration distributions of alloy elements of MB3/AZ80 joint welded with AZ91 filler and the current of 80 A.

Figure 8. The BSE images of MB3/AZ80 joint welded under current of 80 A and different filler wires: (a) MB3 filler, (b) AZ61 filler and (c) AZ91 filler.
3.3. Micro hardness distribution

Figure 9 shows the testing positions of micro hardness of MB3/AZ80 joint. The hardness values of each region were measured five times and averaged. The typical micro hardness distributions of weld seam are listed in table 4. The micro hardness of MB3 and AZ80 base sheet are 57 HV and 74 HV respectively. According to Hall-Petch formula, the growth of grain in the weld seam zone resulted in the decrease of micro hardness. Therefore, the weld seam zones with coarse α-Mg grain show lower micro hardness value than that of parent material. However, with the increase of aluminum content in filler wire, the micro hardness of weld seam gradually increased, as shown in table 4. The micro hardness evolution of weld seam area is mainly related to the distribution of precipitated phase. Orowan hardening mechanism indicates that the increase of precipitated phase is beneficial to improve the hardness value. Hence, the hardness value in weld zone is determined by grain size and precipitated distribution.

### Table 3. EDS analysis results of precipitated phases in weld seam marked in figure 8.

| Elements (at%) | Mg | Al | Zn |
|---------------|----|----|----|
| Point 1       | 62.5 | 37.5 | —  |
| Point 2       | 63.1 | 36.9 | —  |
| Point 3       | 60.3 | 39.3 | 0.4 |
| Point 4       | 55.8 | 44.2 | —  |

### Table 4. The micro hardness distributions of weld seam of MB3/AZ80 joint with various filler.

| Location     | Weld seam | AZ80 base metal | MB3 base metal |
|--------------|-----------|-----------------|----------------|
| With MB3 filler | 49 HV     | 74 HV           | 57 HV          |
| With AZ61 filler | 50 HV     | 74 HV           | 57 HV          |
| With AZ91 filler | 53 HV     | 74 HV           | 57 HV          |

3.4. Tensile strength and fracture characteristics

Figure 10 presents the mechanical properties of MB3/AZ80 joint obtained with different welding current and filler wires. Obviously, the welding heat input significantly influenced the mechanical performance of Mg alloy joint. As shown in figure 10(a), the joining strength presents an increasing tendency when the welding current increased from 60 A to 80 A, attributed to the formation of precipitated phases and the enhanced metallurgical bonding. The maximum tensile strength of 197 MPa was obtained with optimal current of 80 A, representing an 80% joining efficiency relative to MB3 Mg alloy parent plate. It is worth noting that, as the welding current furtherly increased to 90 A, the tensile strength of joint decreased to 163 MPa, owing to the severe grain growth of weld seam. Similar mechanical properties evolution tendencies were observed in the joint with AZ61 filler and AZ91 filler. However, when the welding current was all the optimal 80 A, the joint with AZ61 filler presented the optimized tensile strength of 208 MPa, representing an 85% joining efficiency relative to MB3 Mg alloy parent plate. And the tensile strength of joint with AZ91 filler decreased to 185 MPa, which was attributed to the formation of welding pores and a great deal of precipitated phases.
Figures 11 and 12 respectively present the typical fracture locations and corresponding fracture morphologies of MB3/AZ80 joint welded with various filler wires and optimal current of 80 A. It can be found that the fracture paths were all at the weld seam of joints, indicating that the weld zone was the weakest area of the whole joint. Besides, a number of welding pores were observed at the fracture surface of joint with AZ91 filler, which was consistent with the cross sectional micromorphology and limited tensile strength, as depicted in figure 12(c).
4. Conclusions

The tungsten inert gas welding of MB3 alloy and AZ80 alloy was carried out with various filler wires in the present study. The evolution of welding characteristics of heterogeneous Mg alloy joint was investigated and discussed. The following conclusions were obtained:

1. The dissimilar Mg alloys of MB3 and AZ80 were joined by tungsten inert gas welding process. The seam width of joint increased with the improvement of welding current and pores occurred in the cross section of joint welded with excessive heat input.

2. In the weld seam zone, a great deal of Mg17Al12 precipitated phases were generated owing to the Al element from filler wire, which resulted in the enhancement of metallurgical bonding and micro hardness.

3. The maximum tensile strength of 208 MPa was obtained with optimal current of 80 A and AZ61 filler wire, representing an 85% joining efficiency relative to MB3 Mg alloy parent plate. And fracture occurred at weld seam zone, revealing the potential point of joint strength improvement.

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Conflicts of interest

No potential conflict of interest was reported by the authors.

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References

[1] Yang J, Su J H, Yu Z S, Zhang G Z, Lin S B, Li Y I. and Zhou N Y 2020 Influence of Ni interlayer width on interfacial reactions and mechanical properties in laser welding/brazing of Al/Mg lap joint Sci. Technol. Weld. Join. 25 37–44
[2] Wang P, Zhang H Z, Hu S S, Yin F L and Ma S Q 2020 Microstructure and mechanical behaviour of CMT-welded Mg/Al dissimilar joint using Inconel 625 as filler metal Sci. Technol. Weld. Join. 23 10–9
[3] Chen R 2020 Effect of external magnetic field on the microstructure and strength of laser-welded aluminum to titanium J. Mater. Sci. 55 4054–64
[4] Xiong Y and Jiang Y Y 2020 Compressive deformation of rolled AZ80 magnesium alloy along different material orientations J. Mater. Sci. 55 4043–53
[5] Xu Z W, Li Z W, Xu L and Yan J C 2019 Reduction of intermetallic compounds in ultrasonic-assisted semi-solid brazing of Al/Mg alloys Sci. Technol. Weld. Join. 24 163–70

Figure 12. The typical fracture morphologies of MB3/AZ80 joint welded with various filler wires and optimal current of 80 A: (a) MB3 filler, (b) AZ61 filler and (c) AZ91 filler.
[6] Wang P, Zhang H Z, Hu S S, Yin F L and Ma S Q 2020 Microstructure and mechanical behavior of CMT-welded Mg/Al dissimilar joint using Inconel 625 as filler metal Sci. Technol. Weld. Join. 25 10–9
[7] Feng M N and Luo Z 2019 Interface morphology and microstructure of high power ultrasonic spot welded Mg/Al dissimilar joint Sci. Technol. Weld. Join. 24 63–78
[8] Liu Y, Wen J B, He J G and Li H 2020 Enhanced mechanical properties and corrosion resistance of biodegradable Mg–Zn–Zr–Gd alloy by Y microalloying J. Mater. Sci. 55 1813–25
[9] Xu Y Z, Li J Y, Qi M F, Gu J B and Zhang Y 2020 Effect of extrusion on the microstructure and corrosion behaviors of biodegradable Mg–Zn–Y–Gd–Zr alloy J. Mater. Sci. 55 1231–45
[10] Dai S, Wang F, Wang Z, Liu Z and Mao P L 2020 Microstructure, mechanical properties, and texture evolution of Mg–Zn–Y–Zr alloy fabricated by hot extrusion–shearing process J. Mater. Sci. 55 375–88
[11] Lei Z L, Bi J, Li P, Li Q, Chen Y B and Zhang D M 2018 Melt flow and grain refining in ultrasonic vibration assisted laser welding process of AZ31B magnesium alloy Opt. Laser Technol. 108 409–17
[12] Liu L M, Wang J F and Song G 2004 Hybrid laser–TIG welding, laser beam welding and gas tungsten arc welding of AZ31B magnesium alloy Mater. Sci. Eng. A 381 129–33
[13] Ma L, He D Y, Li X Y and Jiang J M 2010 Microstructure and mechanical properties of magnesium alloy AZ31B brazed joint using a Zn-Mg-Al filler metal J. Mater. Sci. Technol. 26 743–6
[14] Ma L, Qiao P X, Long W M, He D Y and Li X Y 2012 Interface characteristics and mechanical properties of the induction brazed joint of magnesium alloy AZ31B with an Al-based filler metal Mater. Des. 37 465–9
[15] Torun O, Karabulut A, Bakas B and Çelikyürek I 2008 Diffusion bonding of AZ91 using a silver interlayer Mater. Des. 29 2043–6
[16] Mahendran G, Balasubramanian V and Senthivelan T 2009 Developing diffusion bonding windows for joining AZ31B magnesium–AA2024 aluminium alloys Mater. Des. 30 1240–4
[17] Zang Q H, Chen H M, Lan F Y, Zhang J and Jin Y X 2017 Effect of friction stir processing on microstructure and damping capacity of AZ31 alloy J. Cent. South Univ. 24 1034–9
[18] Wang X H and Wang K S 2006 Microstructure and properties of friction stir butt-welded AZ31 magnesium alloy Mater. Sci. Eng. A 431 114–7
[19] Zhu T P, Chen Z W and Gao W 2008 Microstructure formation in partially melted zone during gas tungsten arc welding of AZ91 Mg cast alloy Mater. Charact. 59 1550–8
[20] Carlone P and Palazzo G S 2015 Characterization of TIG and FSW weldings in cast ZE41A magnesium alloy J. Mater. Process. Technol. 215 87–94
[21] Gao M, Zeng X Y, Tan B and Feng J C 2009 Study of laser MIG hybrid welded AZ31 magnesium alloy Sci. Technol. Weld. Join. 14 274–81
[22] Singh K, Singh G and Singh H 2018 Investigation of microstructure and mechanical properties of friction stir welded AZ61 magnesium alloy joint J. Magnes. Alloys 6 292–8
[23] Niknejad S T, Liu L, Nguyen T, Lee M Y, Esmaeil S and Zhou N Y 2013 Effects of heat treatment on grain-boundary β-Mg17Al12 and fracture properties of resistance spot-welded AZ80 Mg alloy Metall. Mater. Trans. A 44 3747–56.