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Microstructure of TIG welded with selected magnesium alloys

Mikrostruktura wybranych stopów magnezu spawanych metodą TIG

Abstract
An evaluation of the macro- and microstructure of magnesium alloy tungsten arc-welded butt joints is presented in this paper. Al-Zn-Mn magnesium alloys are taken into consideration in the research. Their main alloying elements are zinc and aluminum, respectively. The dendritic microstructure of the base metal is obtained. The analysis shows that achieving good-quality butt joints of magnesium alloys is possible.
Key words: microstructure, TIG welding, magnesium alloys

Streszczenie
W pracy przedstawiono ocenę makro- i mikrostruktury wybranych złączy stopów magnezu, spawanych elektrodą nietopliwą w osłonie gazów osłonowych (TIG). Do badań użyto stopów z grupy Al-Zn-Mn, w których głównymi dodatkami stopowymi są aluminium i cynk. Zaobserwowano dendrytyczną mikrostrukturę stopów w materiale rodzimym. Wykonane próby wykazały możliwość uzyskania złączy spawanych wysokiej jakości.
Słowa kluczowe: mikrostruktura, spawanie TIG, stopy magnezu

1. Introduction

Among metallic materials used in construction, magnesium alloys are the lightest, with a density of 1.8 g/cm^3. These alloys are about 30% lighter than aluminum and four times lighter than steel, and the coefficient of strength to specific gravity is much higher for magnesium than for steel. The key features that determine the physical metallurgy of the alloys are the hexagonal lattice structure of magnesium and an atomic diameter of only

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0.32 nm. Alloying elements such as aluminum, zinc, or manganese have a significant impact on the functional properties of magnesium alloys. Aluminum and zinc mostly improves the mechanical properties, and small additions of manganese provide increased corrosion resistance in wet and moist conditions.

Further development and application of magnesium alloys depends on the possibility of using a welding method where joints meet the quality requirements for the appropriate mechanical properties and a lack of porosity and hot or cold cracks. For example, adding zinc to the alloys causes some strengthening, but its amount is limited due to the increase in susceptibility to hot cracking during solidification.

The process of joining must ensure quality repeatability of obtained welds and be susceptible to mechanization and/or automation (which is particularly important in mass production) [1–3]. These requirements are met by creating joints via the laser welding method [4–6]. At the same time, it seems that conventional methods such as TIG or MIG are suitable for small batch production or in connection with regeneration and repair of machinery and equipment due to the low cost of equipment and proclivity towards automation [7–10].

This paper presents a study of macrostructure examination by light microscopy of butt joints of AZ91, AM-Lite, and AM-50 alloys. The welding is carried out by the TIG method (142) without the use of filler material.

2. Experimental method

The tested materials are the following cast magnesium alloys: AZ91, AM50, and AM-Lite (with their chemical compositions shown in Table 1). Plates 100 mm long and 3 mm thick cut from cast ingots were used. Joints were made along the longest edge without the use of filler material. The welding edges were cleaned mechanically by acetone for removing oxides and residues before welding.

Table 1. Chemical composition of welded magnesium alloys

Alloy	**Content of elements [wt %]**			
	Aluminum (Al)	**Zinc (Zn)**	**Manganese (Mn)**	**Magnesium (Mg)**
AZ91	9.0	0.7	0.17	balance
AM50	5.0	< 0.2	0.17	balance
AM-Lite	2.7	13.8	0.16	balance

Automatic gas tungsten arc welding (TIG) carried out with an AC power source coupled with a linear welding manipulator for carrying the torch was used. Helium (16 l/min), fed to the face side of the weld, was used as a shielding gas. The variable process parameters were: welding current (70–100 A) and welding speed (0.2–0.3 m/min). Before welding, the plates were preheated to a temperature of 100–170°C (in order to prevent hot cracking observed in previous tests) [8].

Macro- and microstructure evaluation was carried out on a metallographic cross-section made in a plane perpendicular to the direction of welding, using light microscopy. Preparation of the metallographic specimens included grinding, polishing, and etching the surface.

3. Results and discussion

3.1. Quality assessment

The quality assessment allows us to find the optimum parameters of welding. In the quality assessment, the width of the joints as well as the presence of cracks and porosity in the face of the welds (or the lack of a joint at the root of weld side) were taken into consideration.

Obtained width of the joints are 9–12 mm for welding current 80 A. Using a higher welding current (90 or 100 A) for AZ91 and AM50 alloys allows us to make high-quality joints; but, for AM-Lite, a crack in the base material near the weld was observed. Also, zinc evaporation was observed. It was noticed that, for the used welding current and welding speed values, a correct weld shape was obtained. A preheating temperature that is too low is the reason of cracks for all welds. The results of TIG welding of cold (without preheating) AZ91 and AM-Lite are presented in work [8].

An angle deformation less than 5° during bending tests is noticed for all materials.

3.2. Macrostructure

Figure 1 presents the macrostructure of cross-sections of the joints of welded alloys. The joints are regular and symmetrically shaped. Moreover, the shape of the face and the root of the weld are correct; but, for the AM-Lite alloy, a concavity of the face of the weld is noticed in some samples. The width of the face of the weld is greater than on the root side. The fusion line is irregular. About a 3-mm width of the heat-affected zone (HAZ) is obtained. It is noticed that the width of the HAZ increases with an increase of heat input (increase of power or lower welding speed). With a welding current of 70 A and welding speed 0.27 m/min, the HAZ width is 1.8 mm, and with a welding current of 100 A, is about 3 mm.

The optimum parameters of the process that guarantees good quality joints of all examined materials has been found. As the criteria of qualifying the parameter as optimum, being considered are low porosity, lack of hot and cold cracking, and good shape of weld. Process efficiency has not been considered.

Fig. 1. Macrostructure of TIG welded joints: a) AZ91, 70 A, 0,27 m/min, 130°C; b) AM-Lite, 80 A, 0,27 m/min, 170°C; c) AM50, 80 A, 0,27 m/min, 100°C

3.3. Microstructure

Figures 2–4 present the microstructure of the base material (BM), the heat-affected zone (HAZ), and the weld. For a clearer presentation, the microstructure examination started in the base material, followed by the HAZ, and then step-by-step through the fusion line to the weld.

The structure of as-cast magnesium alloys is a typical casting structure without dendrite orientation arising from the direction of heat dissipation in the casting process. The change of structure is also not observed during and after heating materials up to 170°C before TIG welding. The BM is characterized by fine and uniform equiaxed grain structure. In agreement with the literature [11] and the chemical composition of tested alloys, it is suspected that the BM consist of large grains – α-Mg phase and in the boundaries – β-$Mg_{17}Al_{12}$ phase for AZ91 and AM50 alloys and for AM-Lite in the boundaries – β-$Mg_{17}Al_{12}$ phase and – α-MgZn.

In the TIG welding process, the temperature of the base material next to the weld increased to 527 K, which is higher than the recrystallization temperature of AZ series magnesium alloys. This might be the reason for the grain refinement in the HAZ compared to the base material. When the heat input was relative, the grain size in the HAZ was close to that of the BM; however, etching gave different results. Moving to the fusion line (FL), the grain refinement was increased as a result of an increase in heat input. The grain size of α-Mg in the HAZ decreased with the increase of heat input. A coarse-grained and close-grained structure is obtained next to FL.

In the fusion line area, the fine grain structure is observed (an effect of a relatively high cooling rate). Moreover, a more-continuous β-$Mg_{17}Al_{12}$ phase formed in the FZ as compared to the HAZ is observed (Figs 2b, 3b, 4b). For the grains of α-Mg, a refinement of structure is obtained.

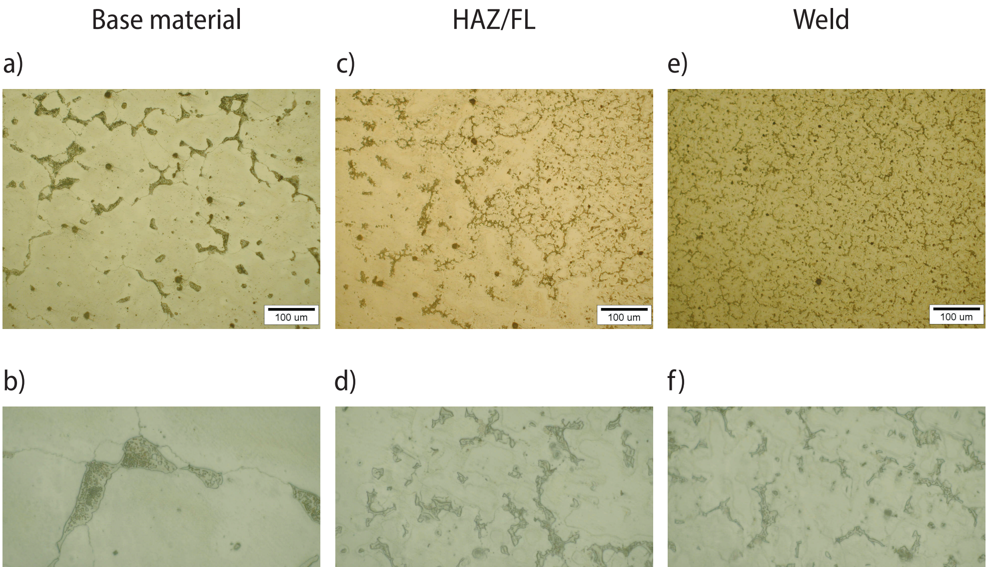

Fig. 2. Microstructure of TIG welded joints of AZ91 alloy: a–b) base metal; c–d) heat affected zone near fusion zone; e–f) weld metal

The weld structure is similar to the FL structure. Compared to the BM, a fine-grained structure of α-MgZn surrounded by continuous eutectic β-$Mg_{17}Al_{12}$ phase (AZ91, AM50, and AM-Lite) and α-MgZn (AM-Lite) phase is obtained. The average size of α-MgZn phase grain in the weld is 2–10 µm. In the weld metal, some porosity for AZ91 and AM50 is observed.

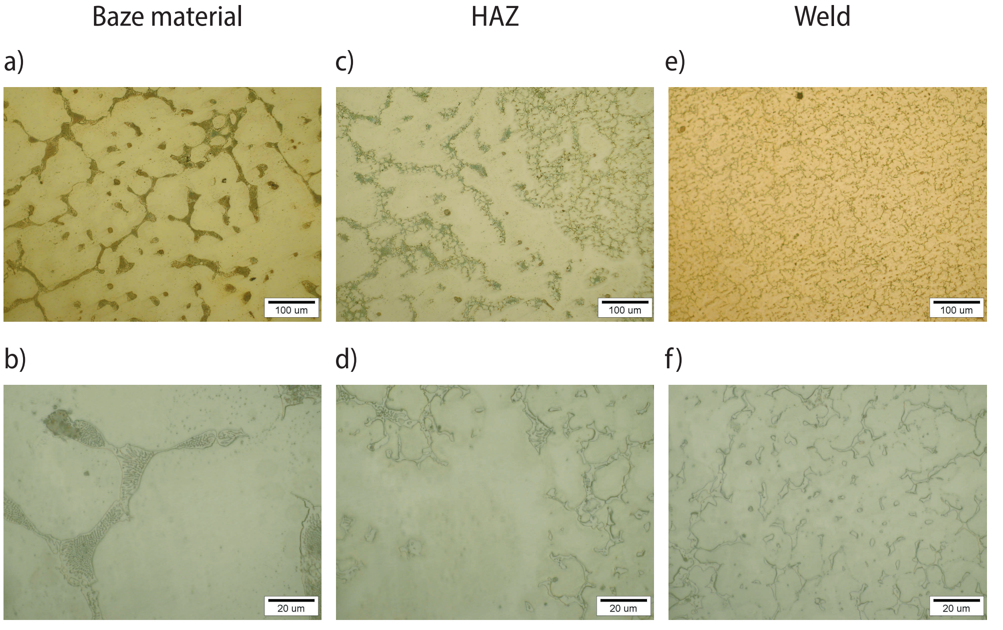

Fig. 3. Microstructure of TIG welded joints of AM-Lite alloy: a–b) base metal; c–d) heat affected zone near fusion zone; e–f) weld metal

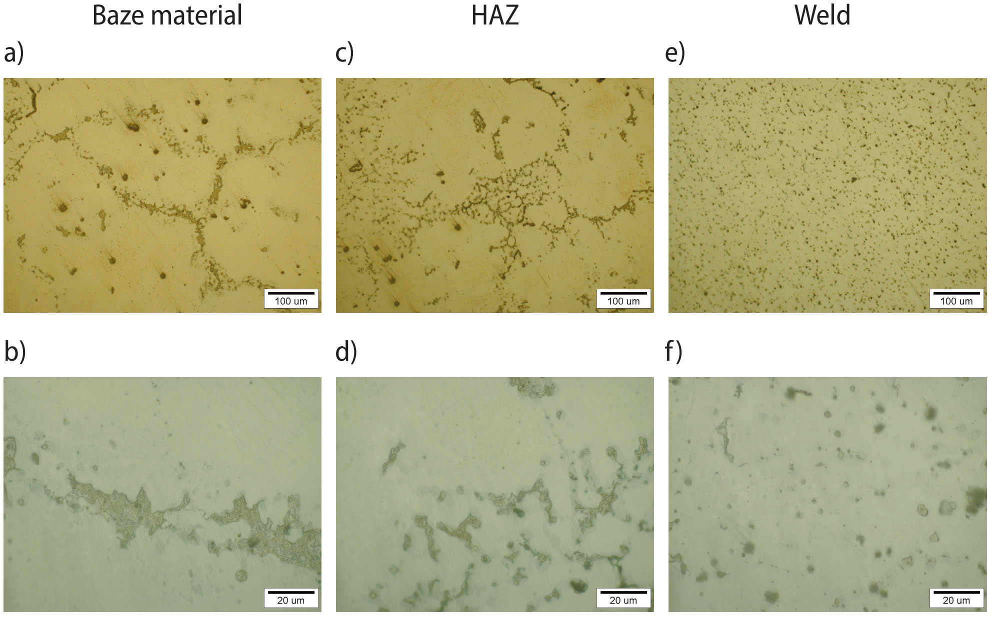

Fig. 4. Microstructure of TIG welded joints of AM50 alloy: a–b) base metal; c–d) heat affected zone near fusion zone; e–f) weld metal

4. Conclusions

In this study, the microstructure of TIG welded joints of magnesium alloys AZ91, AM-Lite, and AM50 with plates of 3-mm thickness were examined. Based on the results of the experimental procedure carried out, the following conclusions can be formulated:

- Good-quality joints are possible by using the TIG method with helium as a shielding gas and preheating plates up to 170°C for welding magnesium alloys.
- Grain refinement in the weld metal strictly depends on the heat input.
- Grain size of α-Mg as well as the width of HAZ depends on the heat input.

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References

[1] Kulekci M.K.: Magnesium and its alloys in applications in automotive industry. Journal of Advanced Manufacturing Technology, 39 (2008), 851–865
[2] Friedrich F., Schuman S.: Research for a "new age of magnesium" in the automotive industry. Journal of Materials Processing Technology, 117 (2001), 276–281
[3] Vesling F., Ryspaev T.: Effect of heat treatment on the superplasticity of magnesium alloys. Russian Journal of Non-Forrous Metals, 48 (2007), 57–62
[4] Cao X., Jahazi M., Immarigeon J.P., Wallace W.: A review of laser welding techniques for magnesium alloys. Journal of Materials Processing Technology, 171 (2006), 188–204
[5] Lehner C., Reinhart G., Schaller L.: Welding of die-casted magnesium alloys for production. Journal of Laser Applications, 11, 5 (1999), 206–210
[6] Kołodziejczak P., Kalita W., Kolasa A.: Spawanie stopów magnezu wiązką lasera CO_2. Prace Naukowe, Mechanika, z. 215 (2009), 97–109
[7] Peng L., Yajiang L., Haoran G., Juan W.: Microstructure characteristics in TIG welded joint of Mg/Al dissimilar materials. Materials Letters, 61 (2007), 1288–1291
[8] Tuz L., Kołodziejczak P., Kolasa A.: Struktura złączy stopów AZ91 i AM-Lite wykonanych metodą TIG. Przegląd Spawalnictwa, 12 (2010), 41–43
[9] Tuz L., Kołodziejczak P., Kolasa A.: Struktura złączy ze stopów magnezu wykonanych metodą FSW. Prace Naukowe, Mechanika, z. 230 (2010), 135–146
[10] Tuz L., Kołodziejczak P., Kolasa A.: Zgrzewanie tarciowe metodą FSW stopów magnezu AZ91 i AM-Lite. Przegląd Spawalnictwa, 11 (2009), 41–43
[11] Sękowski K. Piaskowski J., Wojtowicz Z.: Atlas struktur znormalizowanych stopów odlewniczych, WNT, Warszawa, 1972