The weldability of Magnesium Alloy

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Abstract: The AZ31 magnesium alloy sheet of a 10mm thickness was welded by a CO₂ laser welding. The OM, SEM and XRD were used to analyze macroscopic morphology, microstructure, element distribution and phases of the seam. It was found that the topside of the weld sunk, but a good appearance was obtained on the opposite. The fine equiaxed grain is found in the weld which is composed of Mg but no Al-Mg low melting phase. The mean tensile strengths can reach 212MPa values, but a lot of pores existed in the fracture.

1. Introduction
Magnesium alloy has been widely applied in various fields because of its own advantages[1], such as low density, high specific strength, good recyclability, non-polluting, resource-rich. With the large number of applications of magnesium alloys, it has remarkable industrial significance that the various processing technologies of magnesium alloy were investigated and developed. As is known to all, welding is an important mean of forming structure, thus research on weldability of magnesium alloy material has important theoretical and practical significance.

Because magnesium alloy is easily oxidized, it’s prone to burn during welding. Besides, welding crack and coarse grains are likely to appear in the weld due to the higher coefficient of linear expansion and thermal conductivity. These problems will be more serious with the increase of thickness of sheet, so it is difficult to obtain a desirable welded joint.

In recent years, research on magnesium alloy welding is mainly involved in TIG welding, electron beam welding, laser welding, friction welding, laser-TIG welding[2-5], etc. Laser welding of the thin plates use the heat transfer characteristics of laser, then the base materials are melted and joined. However, laser welding of the thick plates are use of the deep penetration characteristics of laser, and the high depth-to-width ratio weld in which a lot of pores existed due to evaporation of the metal will be obtained. So far, there are fewer studies on laser welding of the thick plates. In this article, the CO₂ laser penetration welding of the AZ31 magnesium alloy sheet with a thickness of 10mm was investigated.

2. Material and experimental procedure
The material used for this investigation was the AZ31 magnesium alloy sheet under solution treatment condition. The dimension of the plate was 200 mm×100 mm×10 mm, and the compositions were listed in table 1. The equipment was a axial flow CO₂ laser and the light spot with a diameter of 0.6mm was focused by a 280mm focal lens after four flat reflecting mirrors. The maximum power of the laser was 5kW. The base plates were clamped in the butt way with no gap and groove. The back of the weld was braced by the steel plate with a semicircular groove to use Helium as shielding gas. Butt welding tests were carried out with a 3.5kW laser and a 0.0167m/s scanning speed. The location of the beam focal plane was 0mm, and gas flow rate was 25L/min.
Table 1. Chemical composition of AZ31 magnesium alloy (mass fraction/%)

|   | Al   | Zn   | Mn   | Ca  | Si  | Cu  | Ni  | Fe  | Mg  |
|---|------|------|------|-----|-----|-----|-----|-----|-----|
|   | 2.5~3.5 | 0.5~1.5 | 0.2~0.5 | 0.04 | 0.10 | 0.05 | 0.005 | 0.005 | rest |

3. The result and discussion

3.1. Bead aspect

The Morphologies of cross section of Joints of AZ31 magnesium alloy were shown in the Fig.1. The topside and backside weld bead shape were shown in the Fig.2 (a) and (b) respectively. The topside of the weld with poor uniformity of the surface texture sunk and there was a small amount of circular pits. These morphologies formed because (a) weld metal flowed to the gap between the roots of the parent metals; (b) Welding process would produce splash due to a small surface tension and the pulse impact the high power density; (c) a small portion of weld metal evaporated because of the low melting point of the magnesium alloy. It was found that the above welding parameters could ensure the 10mm plate penetrated fully, and the backside of weld formed uniformly.

![The morphology of cross section of weld](image1)

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![The macroscopic view of the weld](image2)

3.2. Microstructure of the weld

The microstructure of the parent metal is shown in the Fig.3. The microstructure of the parent metal is shown in the Fig.4. The microstructure of the weld center is shown in the Fig.5. The weld microstructure of the upper area is shown in the Fig. 6. It is observed that the grain in the upper area is bigger than in the bottom area, but smaller than the grain of base metal. The weld grain size was lower than the base metal when the weld cooled rapidly because energy density of laser and heat conductivity of magnesium alloy was high. The laser and plasma heat interacted on the surface, so the temperature of the upper molten pool was the highest, and the cooling speed was the slowest, which leaded that the grain size of the area was biggest than the other region of weld, it was different from laser welding of the thin plate, the size of the grains in the weld was consistent[9]. The interfacial microstructure was shown in the figure 2, the left was fusion zone and the middle was heat affected.
zone (HAZ) which was 0.6~0.7mm in width. the grains in the HAZ grew slightly, and it was more and more obvious from base metal to the HAZ.

3.3. Analysis of elements and phases in the weld

3.3.1 Analysis of elements
The result of EDX analysis for the weld showed interface area around each 0.5 mm, the left was the region of weld and the right was the base metal. It was measured that the mass faction of Mg decreased, and the mass faction of Zn had no substantial changes, but the content of Al increased. Due to the boiling point of magnesium was only about 1,107 °C, far below the boiling point of Al (2,056 °C), pores forming during laser welding mainly resulted from the evaporation of magnesium. At the same time, the Al content increased with the reduction of magnesium. And zinc, while with low boiling point, because of its fewer content and the evaporation of magnesium, would be inhibited to evaporate from the molten pool. So it was not obvious for the change of zinc content in the welding process.

3.3.2 Analysis of phases
It showed the analytical result of phases in the weld. α-Mg was the main phase in the weld according to the peak position, and there was no Al-Mg low melting point phase, which was consistent with the metallographic analysis results. Because of the faster welding speed and small heat input, aluminum had no enough time to diffuse toward grain boundary, so it was difficult to form enrichment of aluminum, which could react with Mg and Al element.
3.4. Hardness of the joint
The Vickers hardness distribution curve in the welding joint was presented in the fig.6. Weld was on the left of the vertical dashed line, and the base metal was on the right. Result showed that weld center hardness was the highest, 52.7 HV, but the hardness of HAZ was lowest, 47.2 HV. For one thing the faster welding speed and high thermal conductivity of magnesium alloy would lead to refining the weld grains, which was beneficial to improve the hardness of weld. For another thing, the loss of Mg element and the corresponding increase of aluminum would be helpful to enhance the hardness of the seam. The HAZ was prone to soften due to the heat from weld, but it was not serious in the study because of the higher welding speed and heat conduction speed.

3.5. Strength of joint and fracture analysis
The result of joint strength is shown in the table 2. The mean strength and the elongation after fracture was less than the base metal. The SEM was used to observe fracture morphology. Nonporous parts of the fracture belonged to ductile fracture, and there were more micro-pores in the middle of the fracture. In penetration welding process of magnesium alloy, the hole would form, but the formation of holes would cause magnesium evaporation, and it was easy to produce pores in the weld. The strength of the joint was less than the parent metal because of the presence of pores.

4. Conclusions
(1) The topside of the weld sunk because of the gap between the parent metals and the evaporation of magnesium alloy under high temperature. Base on the deep penetration characteristics of laser, the high depth-to-width ratio of weld would reach 5:1.
(2) Due to grain refinement and the loss of Mg element, weld center hardness was the highest. But the hardness of HAZ was the lowest because of thermal effect and coarse grains.
(3) The evaporation of magnesium was caused by the formation of the hole during penetration welding process, and it was easy to produce pores which could deteriorate the strength of the joint.

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