Article ID: 1003－6326(2004)03－0550－06

Microstructure and mechanical properties of wrought magnesium alloy AZ31B welded by laser-TIG hybrid①

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Abstract: The laser-TIG hybrid welding was mainly used to weld the wrought magnesium alloy AZ31B. The technical characteristics of laser-TIG hybrid welding process was investigated and the interactional mechanism between laser and arc was discussed, at the same time the microstructure and mechanical properties of the wrought magnesium alloy AZ31B using laser-TIG hybrid welding were analyzed by optical microscope, EPMA, SEM, tensile machine, hardness machine. The experimental results show that the presence of laser beam boosts up the stability of the arc during high speed welding and augments the penetration of weld; the crystal grains of magnesium alloy weld are fine without porosity and cracks in the best welding criterion and the microstructure of HAZ does not become coarse obviously. The elements profile analysis reveals that Mg content in the weld is lower than that of the base metal, but Al content is higher slightly. Under this experimental condition, the wrought magnesium alloy AZ31B joint can be achieved using laser-TIG hybrid process and the tensile strength of the joint is equivalent to that of the base metal.

Key words: wrought magnesium alloy AZ31B; laser-TIG hybrid welding; weld
CLC number: TG 401 **Document code:** A

1 INTRODUCTION

With the development of industrial technology, the demand for properties of automobile, motor, airplane comes higher and higher. Reducing the structure mass becomes one important solution to improve these properties. Magnesium and magnesium alloys have many advantages, such as low density, high specific strength and recovery, and are praised as the most potential materials in the 21st century[1]. The joining method for materials' development is of paramount importance, and excellent joining is an effective solution for simplifying product design and decreasing the cost. The development degree will have a direct effect on the application of magnesium alloys. At present, friction welding[2], argon arc welding[3], laser welding[4] and electron beam welding[5] are mainly used in the magnesium alloy welding. But due to the worse weldability of magnesium and magnesium alloys and the increasing demand for high function, high precision, high security, high efficiency with new products, the traditional weld technology, such as TIG etc, can not satisfy the above demands. Laser welding has experienced considerable development in the last 20 years and becomes an established process in practice[6]. In spite of wide application opportunities for lasers in joining, there are certain limitations, such as high cost of equipment and maintenance, the demands imposed on joint preparation, welding positions, and workpiece thickness etc, which encourages people to develop a new technology.

Arc augmented laser welding was first reported by Eboo et al[7] in 1978. They found that with the laser and arc on opposite sides of the workpiece, 300% increase in speed was obtained for an arc current of 25 A on 0.2 mm thickness mild steel, and with the laser and arc on the same side of the workpiece, 100% increase in speed at the same arc current was achieved on 0.8 mm thickness titanium. William[8] found that an electric arc could be added to the interaction between a laser beam and a material surface in such a way that in welding and cutting it produced an effect similar to that from a more powerful laser in 1980. In this paper the laser-TIG hybrid welding was mainly used to weld the wrought magnesium alloy AZ31B and the microstructure and mechanical properties of the wrought magnesium alloy AZ31B of laser-TIG hybrid welding were analyzed, aiming to promote the application of magnesium and

① **Foundation item:** Project(2002AA331160) supported by Hi-tech Research and Development Program of China
Received date: 2003－11－04; **Accepted date:** 2004－02－19
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its alloys in our country and to make our magnesium welding technology catch up the international level.

2 EXPERIMENTAL

2.1 Equipment

Trials were performed using an LWS-500YAG pulsed laser with a TIG and the experimental sketch map is shown in Fig. 1.

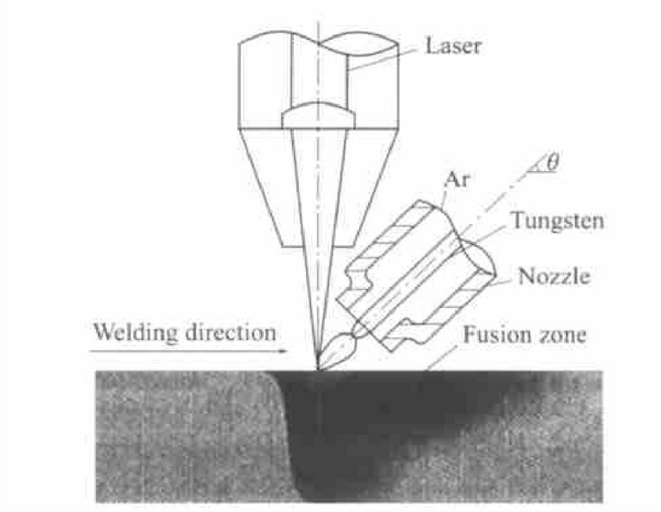

Fig. 1 Principle of laser-TIG hybrid welding

2.2 Materials

The wrought magnesium alloy AZ31B plates with size of 300 mm × 120 mm × 2.5 mm were used as base materials. The tensile strength of base metal was 241 MPa and its chemical compositions are shown in Table 1. The top surface of each specimen was brushed with stainless steel wire and cleaned with acetone to remove oxides and residue before welding.

Table 1 Chemical compositions of base metal (mass fraction, %)

Al	Zn	Mn	Cu	
2.5-3.5	0.5-1.5	0.2-0.5	0.04	
Ca	Si	Fe	Ni	Mg
0.10	0.10	0.005	0.005	Bal.

2.3 Method

The weld test was carried out on bead-on-plate without appending filler and argon was used as a shield gas. After welding, the microstructure and mechanical properties of joint were analyzed by MEF-3 optical microscope, EPMA-1600, CSS-2205 tensile machine, JSM-5600LV SEM and NMT-3 hardness machine.

3 RESULTS AND DISCUSSION

3.1 Interaction between laser and arc

The typical weld morphology of the magnesium alloy AZ31B using YAG-laser, AC-TIG and laser-TIG hybrid welding is shown in Fig. 2(a). From Fig. 2(a), it is found that using the hybrid welding can get excellent bead quality without the defects of porosity, fracture and inclusion etc. Its penetration is double to TIG weld alone and four times to laser weld alone. To increase the penetration, one factor proposed at the simplest level was the heating of the surface and the increase of its temperature and absorptivity to laser radiation. The other factor was the dynamic effect of the laser and its role in changing the arc heat source characteristics during combined welding. By the combined action of the welding arc and the laser beam, the arc was rooted to the laser's impingement point and the temperature increased greatly up to 2 000 K. It is well known that the greater the temperature difference between the arc center and the environment is, the stronger the welding arc contraction is[9]. In this way the arc energy was centralized and the penetration increased. Gureev[10] also considered that a part of arc

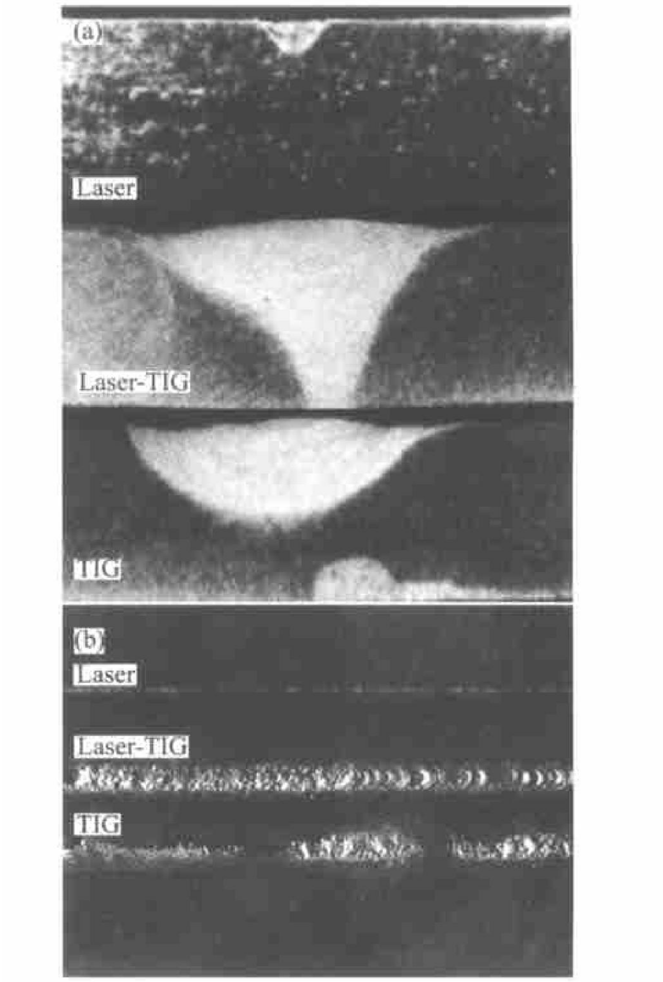

Fig. 2 Welded images in different process
(a) —TIG, current 100A, laser power 400 W, welding speed 1 100 mm/min
(b) —TIG, current 60A, laser power 400 W, welding speed 1 100 mm/min

entered into the keyhole formed with metal plasma during welding and became a deep source. Fig. 2(b) is the image of top bead appearance of different process in the same condition. It is found that under this condition the arc is severely unstable and the spot moves to and fro, which brings about the incontinuity of weld. When the laser enters into the molten pool, the spot of arc is rooted to the impingement made by laser to materials and the stability of arc is improved obviously, leading to the continuity of weld. William[11] investigated the effect of laser added on current and voltage, as shown in Fig. 3. It is found that adding laser can decrease the resistance of arc column and make the arc more stable than that without laser, whichreveals that a strong mutual interaction existed between laser and arc.

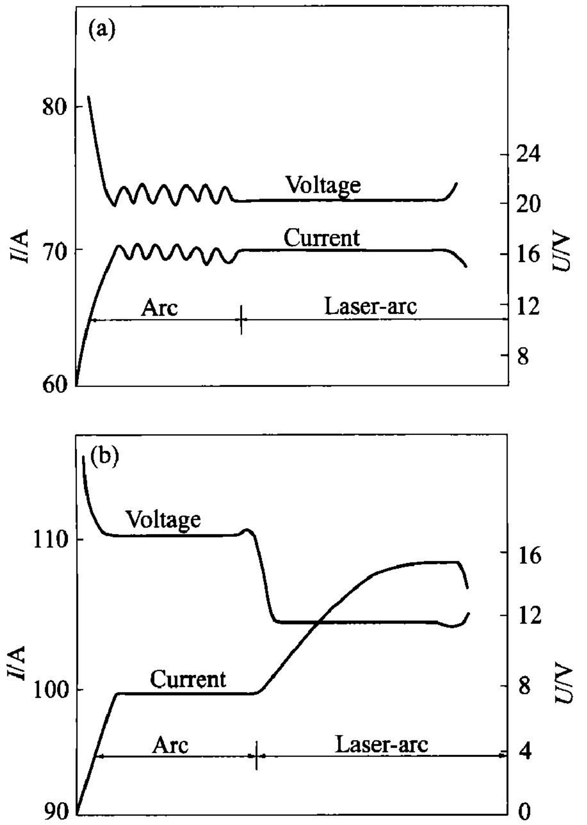

Fig. 3 Effect of laser on arc current/voltage for stable or unstable arcs
(a) —Stabilization of unstable arc by laser;
(b) —Decrease in arc column resistance because of laser

3.2 Microstructure analysis of joint

3.2.1 Phase analysis

The metallographic specimens were prepared along vertical welding direction. After metallographic corrosion the microstructure characteristics of cross-sections were observed by the optical microscope, as shown in Fig. 4. Base metal presented equal-axis crystals whose size is not uniform, which is because the base metal is a wrought magnesium alloy by heat treatment after rolling, and the fine crystals distribute around the strip large crystals. The transition zone between the HAZ and bead is shown in Fig. 4 (b), and the arrow head points to the molten line. Observed from Fig. 4(b), the transition zone is jointed excellently, and the microstructure is uniform. Affected by the heat recycling, the crystals become uniform in HAZ, and the crystals don't grown obviously. On the contrary, the crystal size presents evident coarse using the TIG, which affects obviously the joint properties[12]. Because the welding speed of hybrid heat sources is fast and the conductivity of magnesium alloy is high, the microstructure in bond area presents the typical foundry microstructure of rapid cooling, shown in Fig. 4(c), which is made up of fine equal-axis crystals[13].

3.2.2 Element analysis of joint

To observe the element distribution of the bead zone, the main elements of joint, such as Mg, Al, and Zn, were analyzed and tested using EPMA including element distribution and line content distribution, shown in Figs. 5 and 6, respectively. The face analysis of the transition zone of joint is shown in Fig. 5, and the appearance map is shown in Fig. 5 (a). The bottom of map is the top surface of bead and the arrow head pointed to the fusion line. Observed from Fig. 5(b) and Fig. 6(a), the Mg content decreases evidently from HAZ to fusion zone, and presents the element segregation, and the Al and Zn are also shown in segregation, respectively, which however is not obvious because the content of base

Fig. 4 Microstructures of welded joint
(a) —Base metal; (b) —Transition zone; (c) —Bond area
(v = 850 mm/min, I = 100 A, Z = −1 mm, D_{LA} = 3 mm, B = 3 ms; f = 40 Hz)

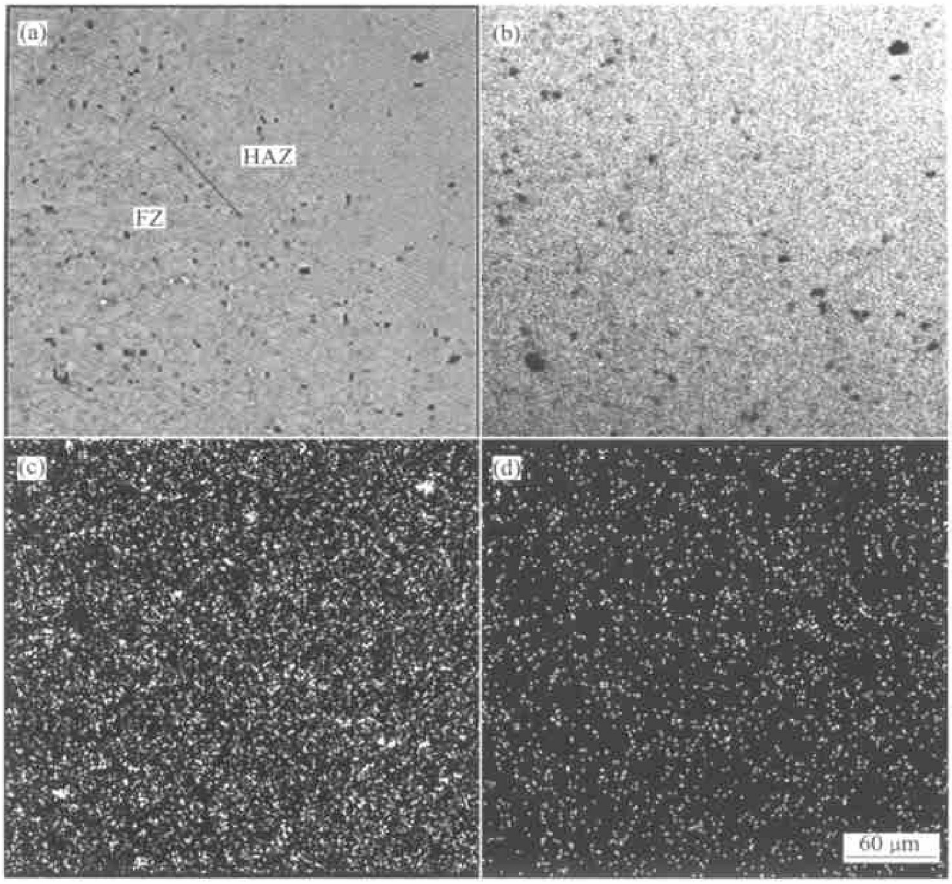

Fig. 5 Distribution of alloy element
(a) —Analysis location; (b) —Mg element; (c) —Al element; (d) —Zn element
(v = 850 mm/min, I = 100 A; Z = − 1 mm; D_{LA} = 3 mm, B = 3 ms; f = 40 Hz)

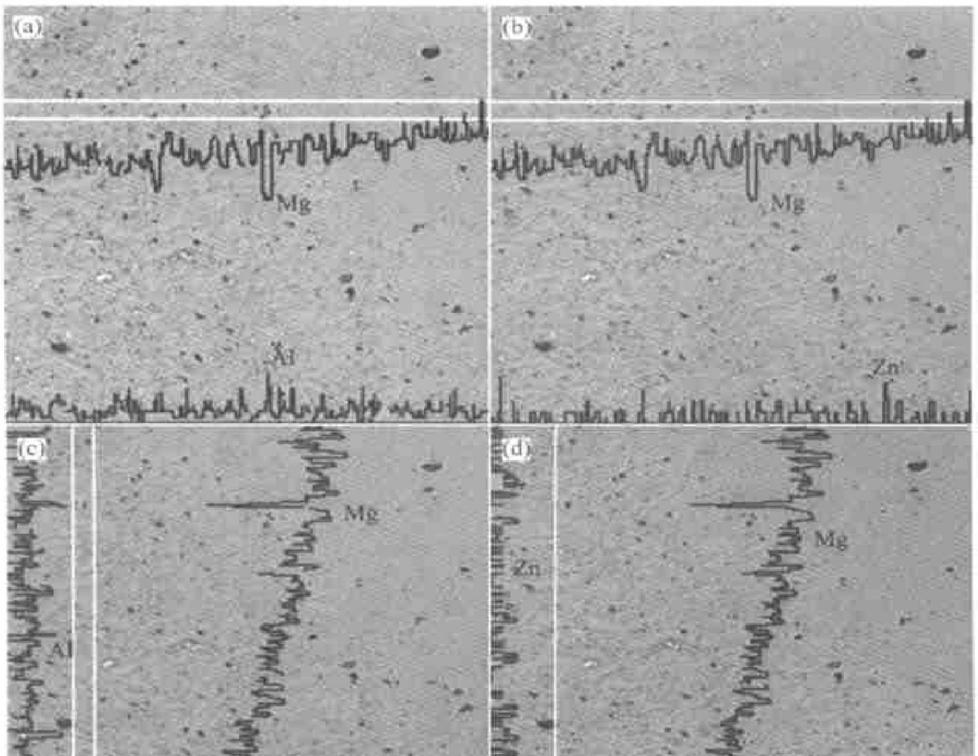

Fig. 6 Alloy elements profile data
(a) —Mg-Al profile data in cross direction; (b) —Mg-Zn profile data in cross direction;
(c) —Mg-Al profile data in depth direction; (d) —Mg-Zn profile data in depth direction
(v = 850 mm/min, I = 100 A; Z = − 1 mm; D_{LA} = 3 mm, B = 3 ms; f = 40 Hz)

metal is low and mainly enriches at the crystal boundary, shown in Figs. 5(c) and (d). Observed from Fig. 6(c) and (d), it is found that the Mg content of bead top face is obviously lower than that of the bead bottom face, however, the contents of Al and Zn have a little increase. The main reason resulting in the change of Mg distribution and content is the low melting point of magnesium, and Mg is easily vaporized during the welding and forms the metal steam which caused the content of Mg decreasing. On the other hand, the bead surface of the hybrid heat source is wide, but the bottom is narrow (shown in Fig. 2), so there exists the temperature grades during the molten pool concreting, which results in the difference of Mg vaporized degree between the top and the bottom part of the bead zone and the content and distribution of Mg element. The loss of Al and Zn is not great, which results in the content of Al and Zn increasing in the bead zone[14]. The Mg loss in the welding process has a great effect on the microstructure and properties of bead, which can be dissolved by the following ways: 1) control the heat input, increase the welding speed and decrease the vaporization of Mg; 2) control the vaporized pressure of molten pool surface by adjusting the flux and pressure of shield gases to make the magnesium stream not overflow; 3) adjust the elements in the bead zone by filler metal.

3.3 Mechanical property analysis

3.3.1 Tensile experiment

A series of specimens of magnesium alloys by hybrid welding were prepared, and the properties were tested by a tensile machine. It is found that the highest tensile strength is 240.7 MPa when the welding speed(v) is 850 mm/min, the welding current(I) is 100 A, the defocus distance(Z) is taken as -1 mm, the distance between molten pool center and impingement point(D_{LA}) is 3 mm, the pulse width(B) is 3 ms and the frequency(f) is 40 Hz. This is equivalent to the base metal. Observed the fractography, it is found that the fracture was the shear fracture by 45°. From the photography by SEM, shown in Fig. 7, it is found the fractography of base metal is similar to that of joint, both of which have the high brittleness, and a little of honeycomb is found there, which belongs to the mixture fracture.

3.3.2 Hardness experiment

The hardness distribution is shown in Fig. 8. From Fig. 8, it is found that the hardness of fusion zone is the highest in joint, the hardness of HAZ takes the second place, and that of base metal is the lowest. By above element analysis, it is found that the content of Al in fusion zone is increased, and Al element plays the function of rigidification in the magnesium alloys[15], at the same time Al can also refine the crystal, increase the magnesium alloy strength, which results in the high hardness of bead zone.

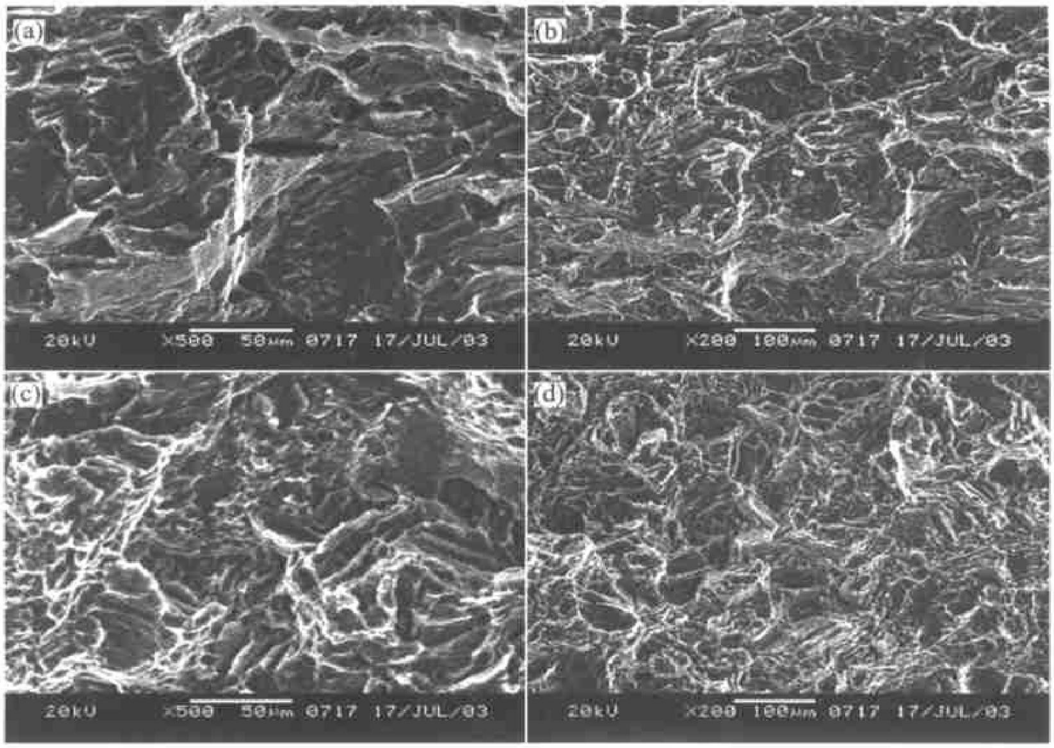

Fig. 7 Fractographs of base metal and welded joint
(a) —Base metal; (b) —Base metal; (c) —Weld; (d) —Weld
(v = 850 mm/min, I = 100 A; Z = -1 mm; D_{LA} = 3 mm; B = 3 ms; f = 40 Hz)

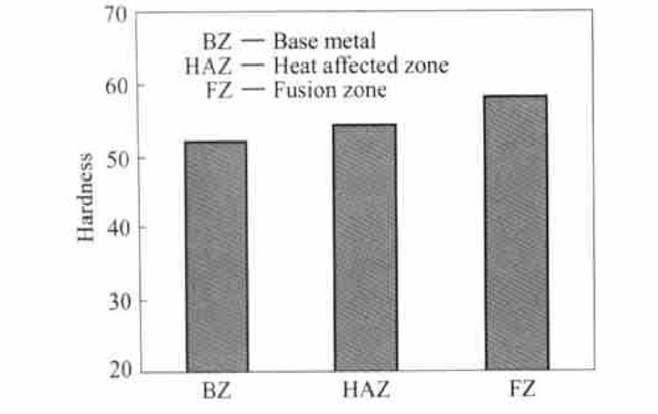

Fig. 8 Hardness distribution across welded joint (v = 850 mm/min; I = 100 A; Z = − 1 mm; D_{LA} = 3 mm; B = 3 ms; f = 40 Hz)

4 CONCLUSIONS

1) Using the laser-TIG hybrid process to weld wrought magnesium alloys can get excellent appearance of bead and compact microstructure without the porosity and fracture defects. The crystals of HAZ don't have obviously growth, and the bead is made up of fine equal-axis crystals. The tensile strength of joint is equivalent to that of the base metal, which indicates laser-TIG hybrid welding is a perfect welding technology.

2) There exists the element segregation of Mg, Al and Zn in bead zone, and the Mg content in bead zone is lower than that of HAZ. Furthermore, the Mg content of top face is lower than that of bottom face, but the contents of Al and Zn have a little increase.

3) There is a high proportional brittle fractography, and a little of honeycomb is found there, which belongs to the mixture fracture.

4) The hardness of fusion zone is the highest, that of HAZ takes the second place, and that of base metal is the lowest. This is because the Al content increases in bead zone and results in the hardness decrease of magnesium alloys.

REFERENCES

[1] Sun Z, Pan D, Wei J. Comparative evaluation of tungsten inert gas and laser welding of AZ31 magnesium alloy [J]. Science and Technology of Welding and Joining, 2002, 7(6): 343 - 351.

[2] Nakata K, Inoki S, Nagano Y, et al. Weldability of friction stir welding of AZ91D magnesium alloy thixomolded sheet[J]. Journal of Japan Institute of Light Metals, 2001, 51(10): 528 - 533.

[3] Asahina T, Tokisue H. Some characteristics of TIG welded joints of AZ31 magnesium alloy[J]. Journal of Japan Institute of Light Metals, 1995, 45(2): 70 - 75.

[4] Zhao H, Debroy T. Pore formation during laser beam welding of die-cast magnesium alloy AM60B —mechanism and remedy[J]. Welding Research Supplement, 2001 (8): 204 - 210.

[5] Su S F, Huang J C, Lin H K, et al. Electron-beam welding behavior in Mg-Al-based alloys[J]. Metall Mater Trans, 2002, 33A(5): 1461 - 1473.

[6] Xie J. Weld morphology and thermal modeling in dual-beam laser welding[J]. Welding Journal, 2002, 21(12): 283 - 290.

[7] Eboo M, Steen W, Clarke J. Arc augmented laser welding[A]. Proc 4th Int Conf on Advances in Welding Processes[C]. Abington: Welding Institute, 1978. 257 - 265.

[8] William M. Arc augmented laser processing of materials [J]. J Appl Phys, 1980, 51(11): 5636 - 5641.

[9] Tusek J, Suban M. Hybrid welding with arc and laser beam[J]. Science and Technology of Welding and Joining, 1999, 4(5): 308 - 311.

[10] Gureev D M, Zolotarevskii A V. Structure formation in laser and laser-arc alloying aluminium alloys[J]. Physics and Chemistry of Materials Treatment, 1991, 25(3): 294 - 298.

[11] Steen W M, Eboo M. Arc augmented laser welding[J]. Metal Construction, 1979, 2(7): 332 - 335.

[12] Miao Y G. Microstructure characteristic analysis of wrought magnesium alloy joint[J]. Journal welding, 2003, 24(2): 63 - 66.

[13] ZHANG Chun-lei, WU Min-sheng, HONG Ye-ping, et al. Effects of arc-excited ultrasonic on microstructures and properties of weld[J]. Trans Nonferrous Met Soc China, 2000, 10 (6): 712 - 716.

[14] LIU Gui-zhong, SU Yan-qing, GUO Jing-jie, et al. Change law of real vapor pressure of Al element in Ti-xAl (x = 25 - 50) melt during ISM process[J]. Trans Nonferrous Met Soc China, 2002, 12(2): 222 - 226.

[15] Gu Y X. Especial Engineering Material Welding[M]. Liaoning: Liaoning Science Technology Press, 1998. 249.

(Edited by LI Xiang-qun)