Experimental Research on The Distribution Law and Formation Reasons of As-cast Magnesium Alloy Laser Welding Porosity

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Abstract. Characteristics and distribution of the weld porosity are observed by using OM and SEM after as-cast magnesium alloy AZ91D is welded by CO2 laser. And then the formation model of two types of porosity is established by use of organization composition and distribution of metal base. Besides, the mechanism of pores in welding is explained on three aspects including microscopic porosity, macroscopic porosity and escape of bubbles. Based on these models and mechanisms, the shape characteristics and distribution of a welding porosity in a welding seam is explained and the formula of bubbles escape is also given. In addition, the measures to prevent welding porosity are discussed preliminarily. And based on the preliminary research on this topic, when (0.2%Ca+0.4%Y) is added to AZ910D magnesium alloy and high strain rolling is used, the laser weld porosity ratio of magnesium alloy can be effectively reduced.

1. Research background

Magnesium has the advantages of low density, high specific strength, high specific stiffness, high damping, good shock resistance and good thermal conductivity, which lead to its increasingly extensive applications in industries such as aerospace, aviation, automotive, communication equipments and electronics [1-3]. At present, the use of magnesium alloys in engineering structure is dependent on a kind of high energy density welding method named laser welding, which can effectively alleviate issues such as molten pool collapsing seriously, large deformation and residual internal stress in magnesium alloy melting welding such as traditional Metal Inert Gas (MIG) Welding and Tungsten Inert Gas (MIG) Welding. However, there are many problems in as-cast magnesium alloy laser welding, in which the porosity problem is relatively serious. In fact, the porosity will produce, expand, gather, grow up, merge and escape so as to produce a large number of blowhole defects in the welded structure [4-7]. The presence of weld porosity reduces the bearing area and the strength of the joint as well as increase the local internal stress and the sensitivity of the gap, which then affects the application and promotion of magnesium alloy structure. Hence, there are important academic significance and engineering application value in studying the distribution law and mechanism of magnesium alloy weld porosity.

There are many scholars who have researched on the porosity problem of as-cast magnesium alloy at present. For example, H.Zhao etc. [8] studied the forming mechanism of porosity of laser welding die casting magnesium alloy AM60B and pointed out that different laser welding mode (heat conduction...
mode or hole mode) have different effects on weld porosity mechanism. Zhao etc. [9-10] researched on the blowhole problem of die casting magnesium alloy laser welding and concluded that the blowhole of die casting magnesium alloy laser welding comes from the expansion and consolidation of original pores during the melt of base metal. M. Wahba etc. studied the laser welding die casting magnesium alloys and then found out that the instability of porosity during laser welding contribute a lot to the formation of weld porosity, with an analysis of relative mechanism as well. Nakata etc. investigated the laser welding blowhole problem of AE42 and AS41 heat-resistant magnesium alloy and analysed the forming mechanism of porosity according to the gas composition analysis of the porosity. And then he concluded that the porosity in the weld mainly come from the pre-existing micro hole in the base metal during the fibre laser welding melt of AS41 and AE42. C. T. Chi etc. did research into the electron beam welding of the AZ series of magnesium alloy and analysed the relationship between process parameters and defects such as the blowhole in the fusion area. In short, the researches above only provide a general explanation of the mechanism of cast magnesium alloy porosity but lack of in-depth and systematic study. Therefore this paper is going to give out the distribution law of weld porosity according to studying the mechanism of porosity in laser welding of die casting magnesium alloy. Besides, this paper will do some exploring on the prevention and control measures of weld porosity.

2. Experimental Method

The experimental material is the as-cast magnesium alloy AZ91D (dimensions is 100mm×60mm×2mm), of which the chemical composition is as Table 1.

| Alloy | Al  | Zn  | Mn  | Si  | Mg   |
|-------|-----|-----|-----|-----|------|
| AZ91  | 9   | 0.6 | 0.3 | 0.1 | Bal. |

The laser used in the welding is a kind of high power crosscurrent CO2 laser named GS-TFL-3KW, together with 802D automatic welding system. The Laser beam is under the mode of TEM01, with the divergence angle less than 2 mrad and the focal plane at 0 mm. The welding is in the form of butt welding. The weldment is under double gas protection, which is made of 99.99% high purity argon. The welding sample is under metallographic observation with the help of Leitz MM-6 horizontal metallographic microscope, of which the joint is corroded by corrosion liquid consisting of 1.3 g of picric acid, 10ml of acetic acid, 5 ml of alcohol and 20 ml of water. Joint tissue morphology is observed by a Quanta200 scanning electron microscopy.

3. Experimental Result

Figure 2 is about the metallography of the as-cast AZ91 magnesium alloy while figure 3 shows the XRD of it. According to Figure 2(a) and Figure 3, the as-cast AZ91 magnesium alloy mainly consists of α-Mg and β-Mg17Al12, of which the matrix phase is the solid solution of α-Mg. The β-Mg17Al12
phase is distributed along α phase boundary since divorced eutectic β-Mg<sub>17</sub>Al<sub>12</sub> is caused by non-equilibrium crystallization. The small material points scattered in α phase are Mn-Al compounds. In addition, the phase of β-Mg<sub>17</sub>Al<sub>12</sub> distribute as a net with blocky shapes in local area, which makes its plasticity become worse. However, the β-Mg<sub>17</sub>Al<sub>12</sub> phase at the grain boundary will be easy to soften and hard to pin the grain boundary effectively when the temperature of the plate exceeds 120 °C, leading to the grain boundary sliding and its plasticity become better. Since the β-Mg<sub>17</sub>Al<sub>12</sub> phase in AZ91 magnesium alloy is much higher than in AZ61 magnesium alloy, a temperature higher than the homogenization treatment temperature of AZ61 is needed, which will in turn enhance the rolling properties and the uniformity of organization of plate. In this experiment, the process parameter for homogenization is 418°C/20h. Figure 2(b) shows the metallographic structure of AZ91 magnesium alloy that has received homogenization treatment. As shown in the figure, there are still some second phase particles on the intracrystalline and grain boundary of processed AZ91, but the grain boundary of alloy becomes narrow and clear.

Figure 2. Plate organization of AZ91 magnesium alloy (a) as-cast; (b) 418°C/20h homogenization treatment

Figure 3. XRD of as-cast AZ91 magnesium alloy

Figure 4 shows the SEM image of micro porosity in laser welding area of AZ91 magnesium alloy. It can be seen from figure 3 that the shape of cross section of micro porosity is suborbicular and that the wall is very smooth without any trace scoured by metal liquid, which has apparent characteristics of hydrogen porosity. There is a close relationship between the formation of porosity in magnesium alloy laser welding and hydrogen in welding process. The hydrogen in molten pool mainly comes from the hydrogen dissolved in from surrounding atmosphere during the welding process and original hydrogen contained in welding metal base (diffusion hydrogen, original small porosities and water adsorbed on the surface of metal base). Since there is no arc column with strong water absorption in laser welding of AZ91 magnesium alloy, the amount of hydrogen in weld mainly depends on original
content of hydrogen (diffusion hydrogen and original content of hydrogen in metal base) in metal base, of which the formation process is as followed:

\[
\begin{align*}
\text{H}_2\text{O} & \rightarrow \text{MgO} + 2\text{H}(\text{H}^+) \\
\text{H}(\text{H}^+) & \rightarrow \text{H}_2 \uparrow
\end{align*}
\]

(1)

(2)

4. Research On The Distribution Law of Welding Porosity In Weld

It seems that the distribution of welding porosity in molten pool is irregular. But the fact is that the size and distribution of welding porosity have some certain discipline. As shown in figure 5, the distribution law of welding porosity on the cross section of welding is as follows. (1) Welding porosities which have the same distance to the surface of welding distribute linearly and have few difference in size. (2) The diameter of porosity in the middle of the weld is larger than that on both sides of the weld. (3) Porosities near the upper surface distribute linearly while those near the lower surface distribute irregularly. (4) Two adjacent porosities have a tendency to get close to each other due to the pressure difference between gas and liquid in molten pool.
middle of the weld in experiments, as shown in figure 6. Besides, gas escapes mainly from the upper surface in welding process. During escape process, porosities on the upper surface of weld distribute linearly and have similar sizes because the pressure and the growing environment in places that have the same distance to the upper surface. While for porosities on the lower surface of weld, distribution and combination of their bubbles are irregular because the pressure of bubble is far less than that of liquid and the pressure difference between adjacent bubbles is also far less than the pressure of liquid metal.

Figure 6. Diagrammatic sketch of weld fracture

5. Research On The Measures to Prevent Welding Porosity

At present, prevention and control measures in allusion to laser welding porosity of casting magnesium alloy mainly include rinse before welding, heating before welding, optimizing welding process and remelting after welding, of which the role is very limited. Shan Jiguo etc. significantly reduce the porosity in weld of laser welding of casting magnesium alloy by adding zirconium into casting magnesium alloy. In the preliminary research of this research group on the large strain rolling process of AZ91D magnesium alloy, it is found that the porosity in weld of laser welding of casting magnesium alloy can be efficiently reduced by adding (0.2% Ca + 0.4% Y) to AZ91dD magnesium alloy as shown in table 2 and using large strain rolling.

Table 2. Chemical compositions of AZ91 magnesium alloys

| NO. | Al | Zn | Mn | Si  | Ca  | Y    | Mg   |
|-----|----|----|----|-----|-----|------|------|
| 1#  | 9  | 0.6| 0.3| 0.1 | 0.2 | 0.4  | Bal. |

After adding (0.2% Ca + 0.4% Y) to AZ91dD magnesium alloy, homogenize the ingot casting and put it into the chamber electric furnace. Then heat it for 20 hours at 418 ℃. The ingot casting needs to be covered with sand in order to prevent severe oxidation. After homogenization treatment, roll the ingot casting from 10 mm to 2 mm at one time with single channel and second-highest rate on the rolling mill. Heat it for 10 minutes at 420 ℃ in chamber electric furnace. The specification of roller is Φ360X600. The roll speed of roller is 430 mm·s⁻¹.

Figure 7 shows the weld cross section of as-cast AZ91D laser welding and high strain rolling state AZ91D-0.2%Ca-0.4%Y laser welding. According to the figure, high strain rolling state AZ91D-0.2%Ca-0.4%Y can efficiently reduce the porosity in weld of laser welding. After adding (Ca + Y) and high strain rolling, there will be no new phase generated in welding base metal. Besides, its organization will be finer and uniform in distribution. In addition, transgranular granular dispersed phase will increase and there will be no more net structure in the whole organization. Therefore, the mechanism of high strain rolling state AZ91D-0.2%Ca-0.4%Y suppressing welding porosity is different form that of as-cast AZ91D, which needs further in-depth study.
6. Conclusions

(1) The distribution law of welding porosity on the cross section of weld is as follows. (i) Welding porosities which have the same distance to the surface of welding distribute linearly and have few difference in size. (ii) The diameter of porosity in the middle of the weld is larger than that on both sides of the weld. (iii) Porosities near the upper surface distribute linearly while those near the lower surface distribute irregularly. (iv) Two adjacent porosities have a tendency to get close to each other due to the pressure difference between gas and liquid in molten pool.

(2) Adding (0.2\% Ca + 0.4\% Y) to AZ91D magnesium alloy and using high strain rolling can efficiently reduce the porosity in the laser weld of magnesium alloy.

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