

# Effect of heat input on microstructure and properties of welded joint in magnesium alloy AZ31B<sup>①</sup>

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**Abstract:** Using the optical microscope, tensile test machine and micro-hardness meter, the effect of heat input on the microstructure and mechanical properties in fusion welding joints of AZ31B wrought alloys was investigated systematically, the mechanism on joint properties losing was analyzed, and a valid method to improve joint properties of the magnesium alloy fusion welding was explored. The results show that the heat input has an obvious effect on the microstructure and properties. Under the condition of penetration, with the heat input decreasing, the crystal grain in the weld and heat-affected zone (HAZ) becomes fine, the width of HAZ becomes obviously narrow, and the molding of the weld is improved, so the tensile strength and elongation are increased and the hardness of joints is improved. When the heat input reaches 60 J/mm, the high quality joints can be gained.

**Key words:** AZ31B; magnesium alloy; heat input; welded joint; mechanical properties

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## 1 INTRODUCTION

Because of the characteristics of low density, high ratio rigidity and specific strength, good damping and recycle<sup>[1-5]</sup>, magnesium alloys are praised of the green engineering material<sup>[6]</sup>, having a widely applied prospect in the fields of automotive industry, motor vehicle industry and aviation<sup>[7-9]</sup>. With the application of magnesium alloy structure components increasing, the welding of magnesium alloys need be resolved. Weld defects of oxidation and burning, crack and over-wide HAZ during welding easily occur<sup>[10-12]</sup> due to its low melting point, the high expansion coefficient and conductive coefficient, and it is hard to get high quality joints matching with base metals.

Heat input is one of the main factors that affect the molding of magnesium alloy weld bead<sup>[13]</sup>. The effect of heat input on the cooling rate of welds determines the microstructure and properties of the joint. In this paper, the effect of heat input on the microstructure and properties of TIG welding joints of AZ31B wrought alloys was investigated systematically, and an effective way was explored to improve the properties of fusion welding joints of magnesium alloy.

## 2 EXPERIMENTAL

### 2.1 Materials

In this experiment, AZ31B magnesium alloy sheets with 1.7 mm thickness were used as base metal, whose chemical compositions are shown in Table 1. The grease and oxidation film on the surface of the base metal were removed before welding.

**Table 1** Chemical composition of AZ31B magnesium alloy (mass fraction, %)

Al	Zn	Mn	Ca	
2.5 - 3.5	0.5 - 1.5	0.2 - 0.5	0.04	
Si	Cu	Ni	Fe	Mg
0.10	0.05	0.005	0.005	Bal.

### 2.2 Methods

AZ31B magnesium alloy sheets were welded by the automatic TIG butt-welding. The welding technique of one-side welding with both-sides molding was used. The heat input was adjusted by changing the welding speed, and the welding parameters are shown in Table 2. After the welding, the appearance observation and X-ray radiographic inspection on the weld joint were carried out, then the mechanical properties were tested and the microstructure was observed.

The standard slippery specimens were adopted for tensile tests. The tensile test was performed with a tensile machine, and the experimental results were taken by the average of three samples measurements.

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**Table 2** TIG parameters

Sample No.	I/A	U/V	Welding rate / (mm s <sup>-1</sup> )	Flow of argon / (L min <sup>-1</sup> )	Heat input / (J mm <sup>-1</sup> )
1	60	9	7	6	77.1
2	60	9	8	6	67.5
3	60	9	9	6	60
4	60	9	10	6	54

### 3 RESULTS AND DISCUSSION

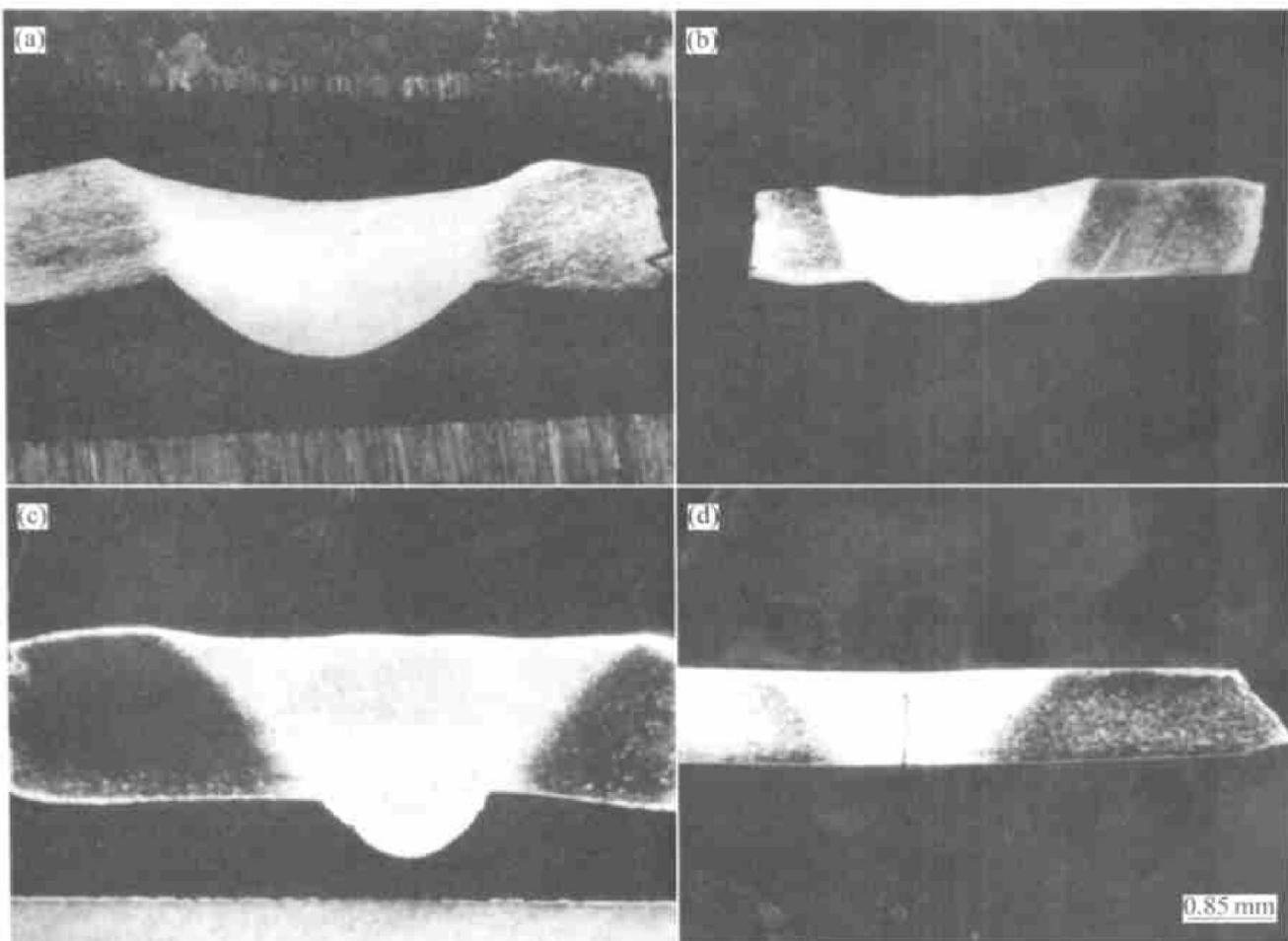
#### 3.1 Molding of welds

Due to the characteristics of the low melting point, high conductive coefficient, high linear expansion coefficient and heat expansion coefficient of Mg-based alloys, the effect of heat input on the molding of welds was obvious. The macrostructure photographs of joints under different heat input conditions were shown in Fig. 1. From Fig. 1, it can be seen that there exists certain effect of heat input on the joint geometry, which mainly reflects on the change of weld penetration (that is excessive penetration) and width. When the heat input is high (7 mm/s), obvious excessive penetration appears. The bigger the weld width, the more serious the deformation

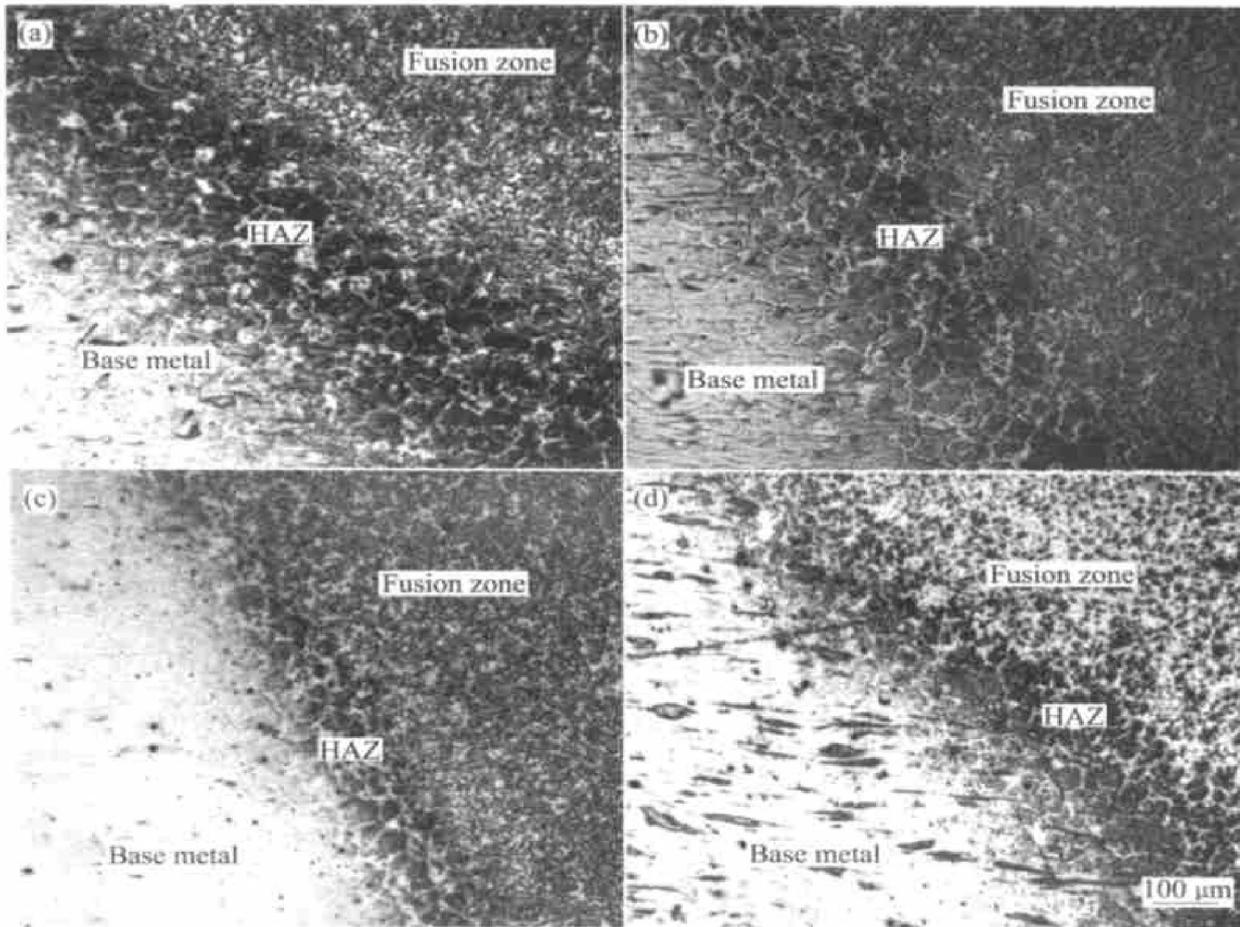
(Fig. 1(a)). And it also easily causes the defects of excessive burning, even burning through. With the increase of welding speed, the weld penetration and width become smaller (Fig. 1(b)), and the ripples start to appear on the face, then the appearance of weld is improved. When the welding speed is up to 9 mm/s, the even ripples appear, and there is no obvious excessive penetration and the appearance of the weld is perfect (Fig. 1(c)). With the welding speed further increasing, the irregular ripples appear and the appearance of the weld becomes poor, and the defects of incomplete fusion and undercut appear (Fig. 1(d)).

#### 3.2 Microstructure observation and analysis

To further investigate the effect of heat input on the quality of welding joint, microstructure observation on welded joint was carried out, and the results are shown in Fig. 2. The joint consists of fusion zone and HAZ. Due to the effect of the heat recycle process and the material of base metal<sup>[14,15]</sup>, the crystal grain in fusion zone is fine, while the crystal grain in HAZ is remarkably coarse. In Fig. 2, it is also found that heat input has some effect on the grain size of weld zone and the width of HAZ. With the decrease of heat input, the grain size of weld zone becomes bigger,



**Fig. 1** Macro photographs of welded joint under different welding speeds  
(a) —7 mm/s; (b) —8 mm/s; (c) —9 mm/s; (d) —10 mm/s



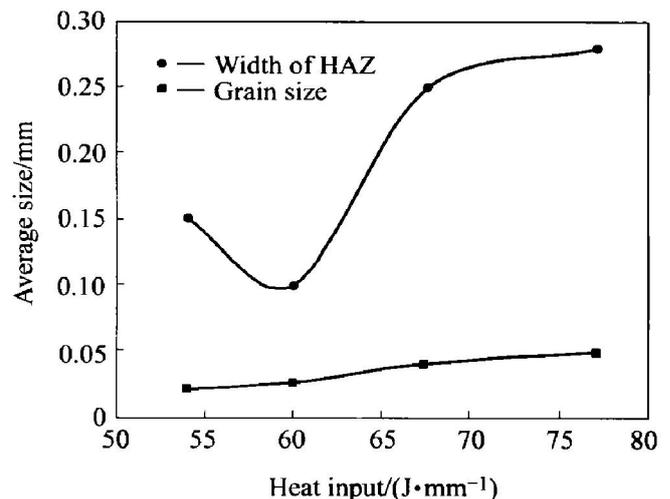
**Fig. 2** Microstructures of weld joint under different heat inputs  
 (a)  $-77.1 \text{ J/mm}$ ; (b)  $-67.5 \text{ J/mm}$ ; (c)  $-60 \text{ J/mm}$ ; (d)  $-54 \text{ J/mm}$

while the width of HAZ becomes smaller. When the heat input is  $77.1 \text{ J/mm}$ , the grain size in the weld bead and HAZ is large, and the area of HAZ is wide (Fig. 2(a)). With the increase of welding speed, the heat input decreases, the grain size in fusion zone and HAZ becomes fine, and the width of HAZ becomes narrow (Fig. 2(b)). When the heat input is  $60 \text{ J/mm}$ , the grain size in weld zone becomes fine obviously (Fig. 2(c)). As the heat input further decreases, due to the welding speed is over high, the wobble of arc is enhanced, and the effect area of the arc is enhanced, which causes the width of HAZ increase slightly (Fig. 2(d)). Based on the above analyses, it is found that the microstructure of magnesium alloy joints is sensitive to heat input. The relation between the heat input and the width of HAZ and grain size is shown in Fig. 3. It is considered that when the heat input is large, the liquid metal in the molten pool will keep long time at high temperature, the cooling rate is slow, and the overheat of joints is serious, causing the grain in weld zone grow up and the width of HAZ enlarge obviously. The fine crystal grains in fusion zone can enhance the joint properties, while the coarse grains in HAZ have the opposite effect on the mechanical properties of magnesium alloy joints. The HAZ is a dangerous zone of the joint fracture. Therefore, it is suggested that the large current, the high

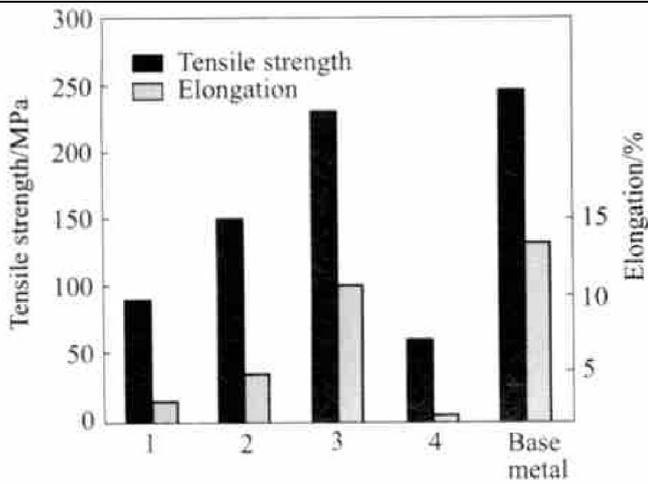
welding speed, and the lesser heat-input under the condition of penetration, are the keys to improving the quality of joints and inhibiting the inferior function of HAZ.

### 3.3 Mechanical properties of weld

The relation of heat input with tensile strength and elongation is presented in Fig. 4. The results show that the effect of heat input on tensile



**Fig. 3** Relation between heat input and width and grain size of HAZ



**Fig. 4** Relation of heat input with tensile strength and elongation

—77.1 J/mm; 2—67.5 J/mm; 3—60 J/mm; 4—54 J/mm

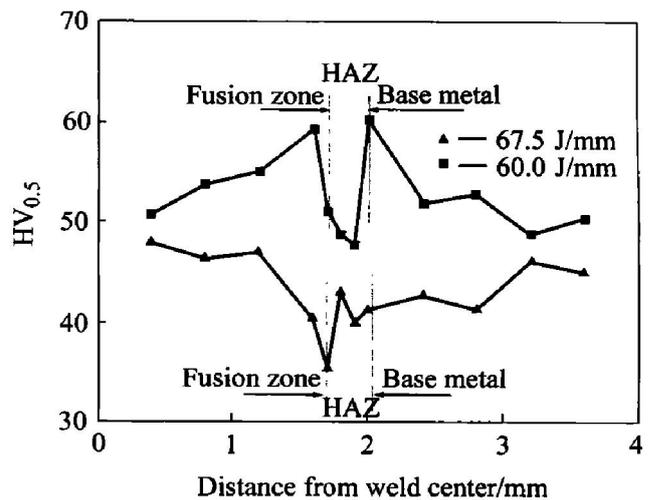
strength and elongation is obvious. With the decrease of heat input, the tensile strength and elongation of joints are enhanced obviously. For example, when the heat input is 77.1 J/mm, the joint efficiency  $\Phi$  is 0.36, and when the heat input is 67.5 J/mm,  $\Phi$  is 0.60. When the heat input is 60 J/mm, the tensile strength and elongation of joints are up to the maximum values ( $\Phi \approx 0.94$ ). Hereafter, with the further decrease of heat input, incomplete penetration occurs, and the mechanical properties of the weld decrease ( $\Phi \approx 0.24$ ).

The tensile test shows that the fracture of samples happens in the HAZ besides incomplete penetration and the fracture of base metals takes place in the middle of samples, which is related to the coarse grain in HAZ and the stress centralization of joints. The analysis shows there are some factors affecting the mechanical properties of joints. Firstly, the change of heat input affects the grain size in weld zone and the width of HAZ. When the heat input increases, the holding time at high temperature of the molten pool in liquid state is prolonged, and the growth of grains is very serious, which obstructs the increase of mechanical properties of joints; when the heat input decreases, the holding time at high temperature of the molten pool in liquid state is over short, the welding molten pool has not enough time to form, and easily cause defects of the incomplete penetration and undercut, which also decrease the mechanical properties of joints. Secondly, the change of heat input affects the appearances of joints. With increasing heat input, the excessive penetration and weld width enlarge remarkably, leading to serious stress convergence. Thirdly, due to the boiling point of Mg (1100 °C) is low, with increasing heat input, the time of molten pool in liquid state is prolonged, which made the oxidation and evaporation of Mg element serious<sup>[12, 15]</sup>.

The effect of heat input on hardness of the joint was investigated also. Table 3 lists the average hardness of joints under different heat inputs, and Fig. 5 shows the hardness of typical joints.

**Table 3** Hardness of welded joint (HV<sub>0.5</sub>)

Heat input/ (J·mm <sup>-1</sup> )	Hardness		
	Fusion zone	HAZ	Base metal
77.1	42.37	41.19	54.73
67.5	47.19	43.84	46.36
60.0	54.57	49.09	50.92
54.0	58.09	53.45	54.40



**Fig. 5** Hardness distributions of welded joint

It can be seen from Table 3 and Fig. 5 that, except for the sample with the highest heat input, the hardness of fusion zone is slightly higher than that of the base metal, but the difference is not obvious. Compared with the hardness of base metal, the hardness of HAZ has some decline. The less the heat input is, the higher the hardness is (Fig. 5). It is shown that the change caused by the joint rigidity has some relation to the grain size of weld joints. Nakata et al.<sup>[16]</sup> investigated the relation between grain size and hardness in magnesium alloy welds. The results showed that the hardness of joints is inversely proportional to the square root of grain sizes. Therefore, with the decrease of heat input, the grain size in weld zone decreases, and the hardness increases. The grain size in HAZ is coarse, thus the hardness is low. When the heat input is 77.1 J/mm, the hardness of fusion zone and HAZ increases, because the grain grows up seriously. In addition, the previous work<sup>[15]</sup> showed that the content of Mg and other element in fusion zone is different from that of the base metal due to the evaporation of Mg during the welding process. The content of Mg in fusion zone is lower than that in the base metal, while the contents of

Al and Zn are higher than those in base metal. The increases of contents of Al and Zn increase the hardness of fusion zone<sup>[12]</sup>, especially Al.

#### 4 CONCLUSIONS

1) The heat input has an obvious effect on the microstructure of magnesium alloy joints. With decreasing heat input, the grains size in the weld zone becomes fine, the width of HAZ becomes narrow, and the joint geometry is improved.

2) Under the condition of penetration, with the decrease of heat input, the tensile strength and elongation of the welds are increased. In this experiment, the tensile strength and elongation of the welds reach the maximum when the heat input is 60 J/mm.

3) The hardness of the weld joint increases with decreasing heat input. The hardness in fusion zone is higher than that in base metal due to its fine grain, while the hardness of HAZ is lower than that of base metal due to its coarse crystal grain.

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