Effect of Magnesium Alloy DE-GMAW Processing Parameters on Microhardness

Jian Li, Yinshui He, Donghua Liu and Guohong Ma

Abstract Since welding performance of the magnesium alloy sheet is relatively poor, the welding process parameters of magnesium alloy sheet are studied in DE-GMAW welding, and the influence of different welding process parameters on the microhardness of welds are discussed. Experiments show that different welding process parameters have different influences on the microhardness of the welding area, in a form of convex. In a certain range, with the variation of welding speed, the distance from tungsten tip to the workpiece and the dry elongation of the wire increased, the average microhardness decreases at the beginning and then increases.

Keywords AZ31B · DE-GMAW · Microhardness · Processing parameters

1 Introduction

Due to the excellent performance of magnesium alloy, various magnesium alloy processing technologies are emerging in an endless stream, magnesium and magnesium alloy resources have been regarded as the future strategic materials, and magnesium alloy is now widely used in communications, automotive and many other industries [1–3]. The reliable connection of magnesium alloy is one of the prerequisites for the widespread application of magnesium alloy, and welding as a connection method is an excellent choice for magnesium alloy connection.

J. Li · G. Ma (✉)
School of Mechanical Engineering, Key Laboratory of Lightweight and High Strength Structural Materials of Jiangxi Province, Nanchang University, Nanchang 330031, China
e-mail: my_126_my@126.com

Y. He
School of Environment and Chemical Engineering, Nanchang University, Nanchang 330031, China

D. Liu
Jiangxi Technician Collage, Nanchang 330200, China

S. Chen et al. (eds.), *Transactions on Intelligent Welding Manufacturing*, Transactions on Intelligent Welding Manufacturing,
https://doi.org/10.1007/978-981-10-8740-0_7

However, the welding performance of magnesium alloy is relatively poor, and is easy to collapse or burn through when welded, which easily leads to undercut, stomata, cracks and a series of welding defects, so it is difficult to achieve reliable connection. Therefore, this problem of magnesium alloy welding hindered its engineering applications [4, 5].

Non-consumable double-electrode gas metal welding is a high-speed welding method developed in recent years [6, 7]. The essence of this method is the improvement of conventional MIG, with a series of advantages of conventional MIG welding such as high quality, high productivity and wide application range, and can reduce the welding defects of magnesium alloy by reducing the heat input of the base metal to improve the welding quality. However, the study of magnesium alloy sheet welding before has not solved the above problems.

In this paper, the welding process parameters of magnesium alloy were studied in view of the above problems, and the influence of different welding parameters on the microhardness of welds was discussed.

2 Experiment

2.1 Experimental Materials

The deformed AZ31B sheet was used as the base material, and the dimensions were 165 mm × 50 mm × 2.3 mm. The main components and mechanical properties of AZ31B were shown in Tables 1 and 2. Select AZ31B plate with the same material AZ31B wire as a filler material, and the wire size is Φ 1.2 mm. The main components of the AZ31B wire are shown in Table 3. The protective gas is 99.99% pure argon.

Table 1 Chemical compositions of AZ31B magnesium alloys base metal (wt%)

Alloy type	Al	Zn	Mn	Fe	Cu	Ni	Si	Mg
AZ31B	2.85	0.75	0.62	0.0029	0.00045	0.00052	0.025	Bal.

Table 2 Mechanical properties of magnesium alloys base metal

Tensile strength σ_b (MPa)	Yield strength $\sigma_{0.2}$ (MPa)	Elongation δ (%)	Hardness HB
260	130	15.6	56

Table 3 Chemical compositions of AZ31B magnesium alloys wires (wt%)

Alloy type	Al	Zn	Mn	Fe	Cu	Ni	Si	Mg
AZ31B	3.07	0.95	0.432	0.00109	0.00230	0.00087	0.0155	Bal.

2.2 Experiment System

The main road power supply is a constant voltage power supply, the bypass power supply is constant current power supply, the torch structure is shown in Fig. 1. The geometrical parameters of the welding torch which affect the droplet transition and the arc shape are obtained by experiment. The distance from gas protection nozzle of the MIG welding gun to workpiece is d, the distance from the end of the welding wire to the workpiece is d_1, the distance from the end of the tungsten to the workpiece is d_2, the distance from the end of the welding wire to the end of the tungsten is d_3, two angle between the two welding gun is θ, The MIG current is I_{bm}, the bypass current is I_{bp}, the total current is I, as shown in Figs. 1 and 2, and they satisfy the following formula: (Table 4)

$$I = I_{bm} + I_{bp} \tag{1}$$

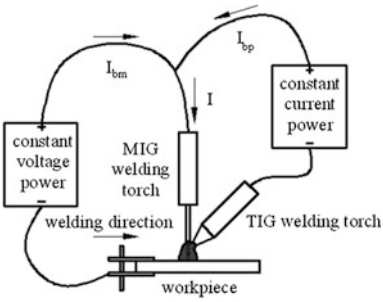

Fig. 1 Simple structure diagram of non-consumable DE-GMAW experimental system

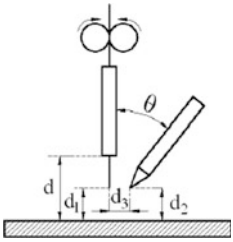

Fig. 2 Geometric position parameters of non-consumable DE-GMAW welding torch

Table 4 Welding parameters

Parameters	Value
MIG arc length (mm)	5
Torches distance (mm)	2.5
Torch angle (°)	35
I_{bm} (A)	70
I_{bp} (A)	140,155,170
Welding speed (mm/min)	200

2.3 Experimental Principle

Figure 1 demonstrates the schematic diagram of non-consumable DE-GMAW experimental system. Non-consumable DE-GMAW consists of a MIG welding torch and a TIG welding torch, which contains one more TIG welding torch than the ordinary MIG, making the whole system as MIG power source MIG arc—workpiece and TIG power–MIG arc—TIG arc current loops. As is showed in formula (1), while increasing the total current and bypass current at the same time, the bypass current increment is larger, which can reduce the main current and achieve the goal of improving the deposition rate of welding wire and reducing the base material heat input. The bypass current increases the electromagnetic shrinkage force of the droplet at the end of the wire, accelerates the necking and dropping frequency of the droplet, reduces the size of the droplet, increases the melting speed of the wire and thus reduces the critical value required for reaching the jet transition.

2.4 Experimental Equipment and Methods

The experiment uses non-consumable DE-GMAW to weld the AZ31B plate. NB-350IGBT inverter MIG welding machine is used as the main road constant voltage welding power supply. The welder is multi-featured and versatile, which is suitable for the welding of various welding methods and various materials. WS-250S DC TIG welding machine is used as the bypass constant current TIG power supply, which can easily ignite and concentrate energy. It is suitable for welding stainless steel, alloy steel, carbon steel, copper and other non-ferrous metals. MIG torch and TIG torch are fixed to the welding carriage bracket at a certain angle. The position relation between the welding gun can be adjusted freely. In the experiment, the welding speed can be changed by the welding car's movement speed adjusted by the driving voltage of the motor.

Because magnesium alloy has relatively low melting point, therefore, it is more likely to cause burn through and collapse phenomenon in the process of triggering arc with large current, which seriously reduces the arc stability and even leads to the arc interruption. Therefore, *An* is provided in front of the weldment in order to obtain a stable welding process to obtain a beautiful and high-quality weld. Because the ignition of MIG and TIG arc is artificial operation, it is found through experiments that when the length of the arc-striking plate is greater than 10 cm, the stable arc can act on the AZ31B sheet, which can avoid the collapse at the same time. The experiment uses the DC reverse connection way to connect, the MIG welding gun connects the positive pole, the welding piece and the TIG welding gun all connects the negative pole, the oxide layer on the surface of the welding piece can be cleaned by arc cathode atomization.

In order to prevent the influence of base metal surfaces' oil, water on the welding process and the quality of the weld, the wire brush is used to clean the oxide layer

of the front and the back until the weld metal exposes metallic luster, and finally acetone solution is used to clean up in order to improve the success rate of arcing.

3 Discussion

3.1 Influence of Bypass Current on Microhardness of Weld

Through several welding experiments, combined with microstructure, as shown in Fig. 3 magnesium alloy weld area which has serious oxidation has great differences on the base metal in material performance, especially in the heat affected area, corresponding to different macrophysics performance. Therefore, through the experimental analysis of micro-hardness, it can indirectly reflect the effect of the welding process parameters on the performance characteristics and can help us explore the relatively best parameters.

Several sets of different experiments' microhardness parameters are shown in Fig. 4 which is the microhardness of the weld at different bypass currents. From the figure, with the distance from the center of the weld increases, the average microhardness of the weld firstly decreases and then increases. That is, the microhardness of FZ and BM is higher than that of HAZ. This is because the fusion zone (FZ) is consisted of fine-equiaxed grain and has more β precipitation phase, so its microhardness is higher than the heat affected zone. And the heat affected zone is coarse grain and the precipitation of β-Mg17Al12 is relatively less, so the microhardness of the base material is higher than that of the heat affected zone.

In the experimental data table, when the I_{bp} value is equal to 140 A, the microhardness of the fusion zone is lower than that of the base metal region and when the I_{bp} value is equal to 155 and 170 A, the microhardness of the fusion zone

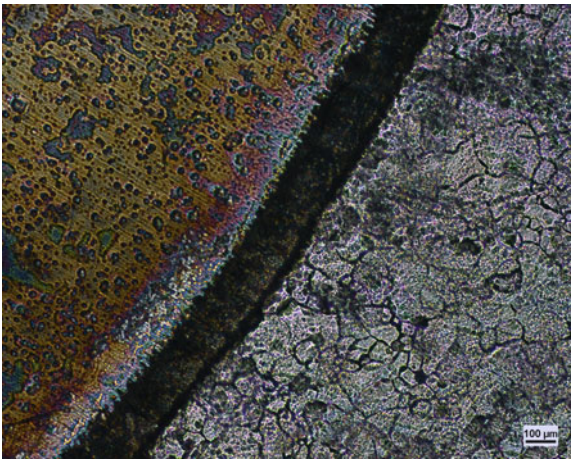

Fig. 3 Magnesium alloy welding area (the left part is the magnesium alloy weld, the right area is the base material, and the middle is the fusion area)

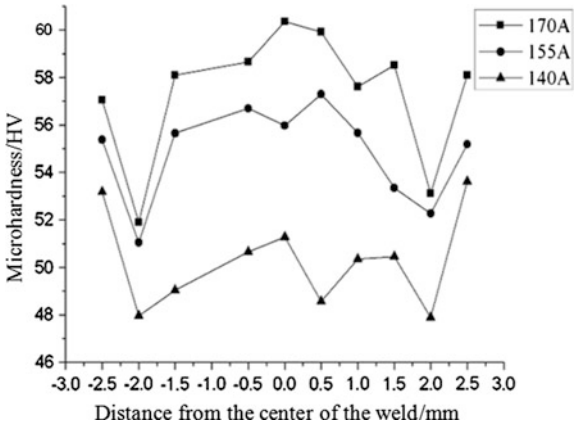

Fig. 4 Microhardness of welds at different bypass currents

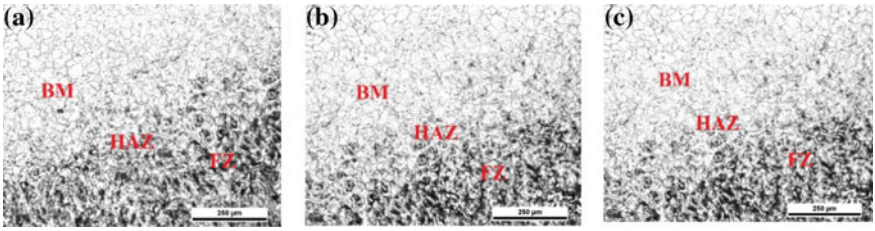

Fig. 5 Joint organizations at different bypass current: **a** 140 A; **b** 155 A; **c** 170 A

is higher than that of the base metal region. The increase of the bypass current directly leads to the decrease of the main current, which also leads to the decrease of the heat input in the weld pool. Therefore, the time for the molten metal in the weld pool to be kept at a high temperature is decreasing and the degree of supercooling becomes larger, which results in the grain refinement; At the same time the heat from the molten pool to the heat-affected zone becomes relatively less, so the heat-affected zone grain size is decreasing (as shown in Fig. 5). According to the Hall-Page relationship, it can be concluded that the microhardness of the heat-affected zone is the lowest among the welds, and the microhardness increases as the bypass current increases. The microhardness of the weld zone also increases as the bypass current increases in the same way as the HAZ.

3.2 Effect of Welding Speed on Microhardness of Weld

Figure 6 shows the microhardness of welds at different weld speeds. It can be seen from the figure, within a certain range, when *V* increases, the average

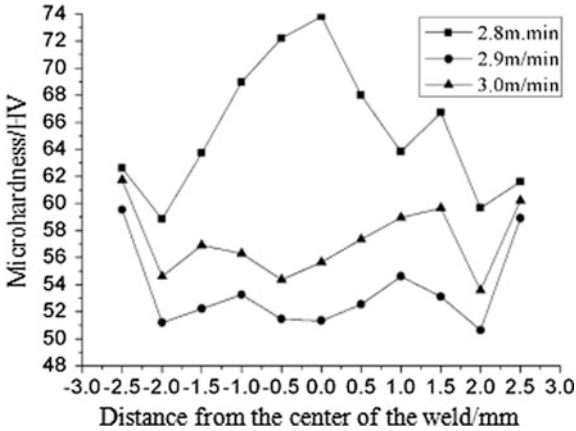

Fig. 6 Microhardness of weld at different welding speed

micro-hardness of the weld shows a trend from decline to rise. When the *V* is equal to 2.8 m/min, the heat input of the weld is relatively high, the grain is coarse and the precipitation is large, and when *V* is equal to 3.0 m/min, the heat input is relatively low and the grain size is small. When *V* is equal to 3.0 m/min, the average microhardness is higher than that of 2.8 m/min. While the welding speed is 2.9 m/min and the grain is larger than that of 3.0 m/min and the precipitation is less than that of 2.8 m/min, which may be caused by the lowest average microhardness.

3.3 *Effect of the Distance from Tungsten Terminal to Workpiece on Microhardness of Weld*

Figure 7 shows the microhardness of the weld at different distance from the tungsten ends to the workpiece. It can be seen from the figure, within a certain

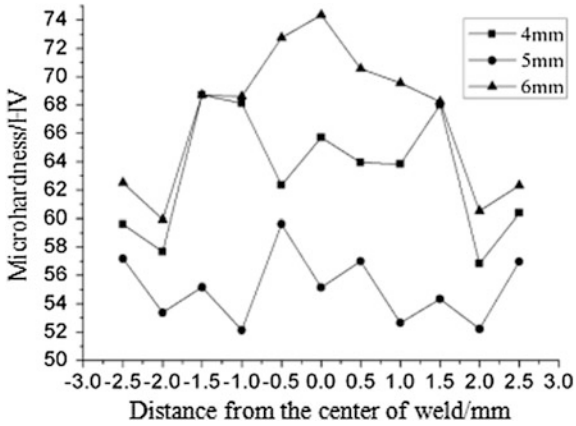

Fig. 7 Microhardness of weld at different d_2

range, with the distance from tungsten's ends to the workpiece increases, the average microhardness of the weld shows a trend from decline to rise. When d_2 is equal to 4 mm, the arc length is short, the current density is relatively high, the heat input is much bigger, and the weld precipitation phase becomes more; when d_2 is equal to 6 mm, the arc length is longer, the current density is relatively low, the heat input is less, the weld grain is smaller, which may lead to the reason that average microhardness of d_2 of 6 mm is higher than that of d_2 of 4 mm. And when d_2 is equal to 5 mm, the weld grain is bigger and the precipitation is relatively small, which may lead to the lowest average microhardness.

3.4 Effect of Elastic Extension of Wire on Microhardness of Weld

Figure 8 shows the microhardness of the weld at different elastic extension. It can be seen from the figure, within a certain range, the wire elastic extension *L*s increases, the average microhardness of the weld shows a trend from decline to rise. When the elastic extension *L*s is equal to 18 mm, the heat input of the weld is low, the grain size is small, and when the elastic extension *L*s is equal to 14 mm, the heat input of the weld increases, the weld grain becomes coarsening, and the amount of the β phase increases, Therefore, when the elastic extension *L*s is equal to 18 mm, the average microhardness is slightly greater than that of 14 mm. However, the weld microstructure with an elastic extension of 14 mm is larger when the distance from the center of the weld is 0.5 mm, which may be the reason that the β phase is measured. When the elastic extension *L*s is equal to 16 mm, the size of the weld grain is larger than *L*s = 18 mm and the amount of the β phase is less compared to *L*s = 14 mm, so the average microhardness is the lowest.

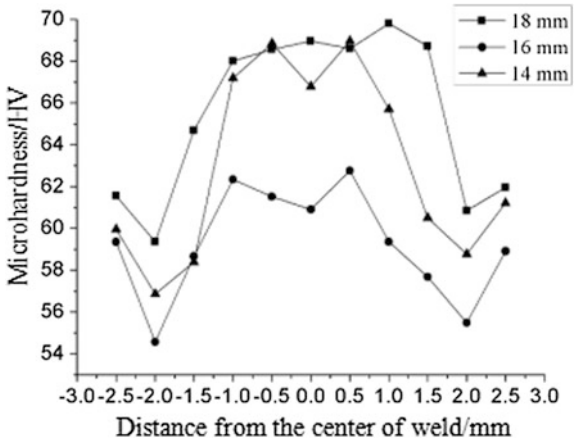

Fig. 8 Microhardness of weld at different elastic extension of wire

4 Conclusion

Different welding process parameters have significant influence on the microhardness of magnesium alloy showing a form of convex in the whole. The hardness of the weld area is relatively higher than that of base metal.

When the bypass current increases, the weld heat input decreases and the average microhardness of the weld increases. In a certain range, with the welding speed, and the distance from tungsten terminal to the workpiece and the dry elongation of the wire increases, the average microhardness firstly decreases and then increases.

Acknowledgements This project is supported by the National Natural Science Foundation of China (51665037, 61165008).

References

1. Sun BQ (1998) Great applied potentialities of magnesium alloy die-castings in automobile trade. Spec Cast Nonferrous Alloy 3:40–42
2. Cao X, Jahazi M, Immarigeon JP et al (2006) A review of laser welding techniques for magnesium alloys. J Mater Process Technol 171(2):188–204
3. Baghni IM, Wu YS, Li JP et al (2003) Mechanical properties and potential applications of magnesium alloys. Trans Nonferrous Met Soc China (English Edition) 13(6):1253–1259
4. Feng JC, Wang YR, Zhang ZD (2005) Status and expectation of research on welding of magnesium alloy. Chin J Nonferrous Met 15(2):165–178
5. Wang P (2009) Study on MIG welding process of magnesium alloy. Dissertation, Dalian University of Technology
6. Ma GH, Nie J, Zhang CY et al (2013) Double-electrode GMAW welding process research based on the DSC. Adv Mater Res 668:321–324
7. Zhang CY, Nie J, Ma GH (2014) Stability analysis on DE-GMAW welding arc of magnesium alloy. Hot Working Technol 43(19):155–157