

# Research Progress in Plasma arc welding of Magnesium Alloys and Magnesium Matrix Composites

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**Abstract.** Magnesium alloys and magnesium matrix composites by means of its excellent performance have wide application prospect in electronics, automotive, biotechnology, aerospace field, and welding technology has become a key of restricting its application. This paper describes the welding characteristics of magnesium, the obvious advantages in the application and the domestic and foreign research advance technology of plasma arc welding of magnesium, and summarizes the existing problems and development trends of plasma arc welding technology of magnesium.

## 1. Introduction

Magnesium alloy and magnesium matrix composites in some performance and price are better than the aluminum alloy and aluminum matrix composites, and will be more competitive in 21th Century. The density of magnesium at 20°C is only 1.738g/cm<sup>3</sup>, which is 36% lower than the density of aluminum. Compared to the aluminum matrix composite, magnesium matrix composite has higher specific stiffness, specific strength, electromagnetic shielding properties, damping properties, and the lower cost of processing and recycling. In recent years, the price of magnesium alloy keep declining, and it is 10~20% cheaper than aluminum alloy in the same volume, considerably eliminating the restriction of the development of magnesium matrix composites [1, 2]. Magnesium alloys and magnesium matrix composites have a wide application prospect in the development of high-tech industry, biological technology and other fields, due to performance and lower price, but the development and application of magnesium alloy and magnesium matrix composites have been hindered by welding technology. Welding technology of magnesium mainly have resistance spot welding, MIG welding, TIG welding, electron beam welding, friction stir welding, plasma arc welding and laser welding. This paper elaborate the current development of plasma arc welding of magnesium.

## 2 Magnesium welding characteristics and plasma arc welding

### 2.1. The welding characteristics of magnesium alloy and magnesium matrix composites

Active chemical properties of magnesium and high melting point of oxide limit the range of the development and application of magnesium, but magnesium matrix composite not only has innate excellent properties of magnesium alloy, and improves the mechanical properties and oxidation resistance, but also has more competitive in development potential of high-tech field than other metal materials. These properties will produce a series of difficulties in the process of welding of magnesium alloys and magnesium matrix composites, and because of the reinforcement phase existing, the welding



puddle reaction is more complicated. The main problems are as follows [3]: oxidation and evaporation, coarse grain, thermal stress, weld joints collapse, porosity, heating cracking, reaction between the matrix and the reinforcement, burnthrough of thin workpiece. In addition, due to magnesium active chemical property, welding needs under the protection of inert gas or welding flux to prevent magnesium burning.

### *2.2. The plasma arc welding characteristics of magnesium alloy and magnesium matrix composites*

In 1954, in the American Union Carbide company Robert Gate found after arc compression the plasma arc more concentrated, the arc temperature and jet velocity also increased significantly and the density of arc free energy high, so the welding method known as plasma arc welding had good effect on performance and application in industry [4].

Plasma arc (or compression arc) is cylindrical shape with good straightness and small diffusion angle. Besides it has higher temperature and energy density, more stable properties, lower flame flow velocity, higher rigidity, faster welding speed, and stronger penetration compared to normal arc. According to the difference of the power connection and plasma arc, plasma arc welding includes transfer-plasma arc welding, non-transferred plasma arc welding, twin-body plasma arc welding. The plasma arc welding makes magnesium matrix composite melted through at one time without subplate and the weld joint surface smooth, showing good welding performance.

Compared with plasma arc welding, the resistance spot welding of magnesium has narrow range of application, tendency to adhere and welding deformation due to the small surface tension of molten magnesium when the welding current is too high; the place between electrode wire and the reinforcing phase in molten liquid matrix is bound during MIG welding and spatter in high temperature; Friction-stir welding of magnesium matrix composite with low temperature and small deformation, is a kind of environment-friendly welding method, but the fractional reinforcing phase and the changed organization structure lead to the softening and strength reduction of welding joint. As using laser welding, the laser welding power of magnesium must reach to a certain threshold, and because of the low ionization energy of magnesium alloy, high thermal conductivity and the small absorption rate of laser radiation, it will lead to poor welding stability.

According to the differences of physical properties of matrix and reinforced phase, the welding produce is complicated and not easy to control, therefore plasma arc welding has obvious advantages for magnesium matrix composite compared with other welding methods.

## **3. Research progress in plasma arc welding of magnesium alloys and magnesium matrix composites**

### *3.1. Research progress in plasma arc welding of magnesium alloys*

China's institute comprehensively studied plasma arc welding of magnesium alloys, and published papers in the domestic and foreign periodicals. Early Dalian University of Technology research team deeply studied the influence of variable polarity plasma arc welding (VPPAW) on welding seam and joint of AZ31 magnesium alloy, besides the method had the advantages of good welding structure, small deformation of the magnesium alloy, good performance of joint and simple operation process.

In the variable polarity plasma arc welding of thick plate, Liu Liming, Shen Yong [5] by optimizing the welding parameters such as welding speed, welding current, ion flow number and time ratio, make particle fine and uniform distribution, thus the joint strength was more than 90% of the parent material.

In terms of variable polarity plasma arc welding and keyhole behavior, Jiang Jianbo et al. [6] improved the method of forming protection and beveling, obtaining double sided forming joint with small heat affected zone by single layer welding. The mechanical properties were excellent and the hardness was higher than that of parent metal.

In terms of corrosion behavior, Zhao Hongkai et al [7] put salt spray corrosion test and electrochemical test on the welding joint. The result showed that the corrosion current density of the welding seam is similar to that of the parent metal and the microstructure of the joint was well formed

without obvious heat affected zone. Therefore, the corrosion resistance of the welding seam was stronger than that of the parent metal.

In terms of thermal cycle simulation, Yu Xike [8] drew a conclusion high welding temperature time long, fast cooling as well as experimental data optimization through the ANSYS finite element analysis of AZ31 magnesium alloy welding, establishing the double ellipsoid heat source model to realize the numerical calculation of the transient temperature field of the welding seam and better reflect the temperature distribution.

VPPAW was an efficient welding method for non-ferrous metals such as magnesium and aluminum. However, VVPPAW was sensitive to changes in welding process and experimental parameters due to its nature, leading to small reasonable parameter margin, narrow range and poor stability in the case of obtaining a good mechanical joint. Therefore, in the future, the research direction of VPPAW for magnesium alloys trended to comprehend the regularity of parameters, optimize the process, improve the quality of plasma arc welding and enlarge its application range.

W. G. Essers and A. C. Liefkent [9] (of PHILIPS company in Holland) first proposed the Plasma-MIG hybrid Welding method with strong arc, the metal filling capacity and the high energy density of plasma arc, realizing the high-efficiency production. According to the position of plasma arc at the position of the gun the method was divided into (a) bias-type plasma welding gun, the plasma arc burns at the tungsten pole, and (b) nozzle-type welding gun, the plasma arc burns under the nozzle.

According to the physical and chemical properties of magnesium and aluminum and the similarity of the welding difficulties of them, the research directions of welding of magnesium alloys can be determined.

Yang Tao [10] studied on the coupling mechanism of Plasma-MIG-Hybrid arc welding process, and research of welding procedure. The outer plasma arc of MIG was compressed, and the internal plasma arc flowed into the outer to reduce the internal arc temperature, contributing to changing the transform of droplet, weakening the thermal effect of MIG arc, and then improving the stability of welding process.

Kohei, Ono et al. [11] used this method to weld aluminum alloy. The result showed that MIG welding wire can be heated not only by resistance and MIG arc, but also by plasma arc. Therefore, it has higher deposition rate than plasma arc welding.

BAI Yan et al. [12] Studied on the influence of plasma-MIG arc welding parameters on welding porosity by orthogonal test, and the paper showed plasma gas flow had the greatest influence on the porosity. Research group of Southwest Jiao Tong University [13] welded AZ31B magnesium alloy by the DC plasma -MIG-Hybrid welding. The result showed the experimental parameters which mainly affects the reinforcement weld and weld width of the workpiece had little effect on the welding penetration, and melted droplet spattered obviously, thus the joint strength is as high as 98.77% of the parent metal.

The active agent is helpful to increase welding speed and improve penetration and welding seam. After adding active agent, plasma arc welding cross section was funnel shape with smaller back width. Research on welding activator types of magnesium alloy and magnesium matrix composites and direction of development are few. Marya (of Colorado mining school) [14] studied chloride activator for magnesium alloy effecting on the workpiece during direct current TIG welding was investigated. Harbin Institute of Technology had also studied three kinds of activator: Fluoride activator, Chloride activator and Oxide activator, and the influence of three kinds of activator used in welding. The study of Welding Research Institute found that the key of plasma arc welding activator of magnesium alloys is to find out the order and maximum multiple of increasing the melting depth.

Claus Emmelmann et al. [15] used common welding equipment by plasma-laser-hybrid welding method, optimizing the optimal parameters by orthogonal experiments and compensating the disadvantages of laser welding and plasma welding. Under the optimum parameters, the production had the lower rejection rate, the more stable welding process, and the easier welding process.

### 3.2. Research progress in plasma arc welding of magnesium matrix composites

Although the performance of magnesium matrix composite is superior to magnesium alloy, the reinforcement phase size, distribution and interface make magnesium matrix composites more difficult to weld than magnesium alloys. Therefore, there is some research on the welding of composites at home and abroad.

Lei Yucheng et al. [16] carried out plasma arc in-situ welding of aluminum matrix composites. The result showed that ion gas ( $N_2+Ar$ ) improving, filling material Ti increasing, in-situ welding or arc-ultrasonic method applying, contributing to reducing interface reaction, improving wettability, increasing fine particle. Thus, the defects of structure were reduced, and the joints had good mechanical properties. According to the similarity between magnesium matrix composites and aluminum composites, this method can still be applied to plasma arc welding of magnesium matrix composites and obviously resolve the problems of reinforcement phase in welding

Ruiying Zhang et al. [17] found that compared to the non-transferred plasma arc welding, twin-body plasma arc welding with an arc-end nozzle make the workpiece not connected to the loop and the energy loss small, thus this method provided a better method to control the plasma arc energy and expanded the application of plasma arc.

## 4. Outlook

(1) In terms of magnesium alloy and magnesium matrix composites, interface between reinforced phase and matrix will become the key of welding technology. The main research directions includes the formation of interface, the relationship between structure and performance, then further researching is consist of the reaction mechanism and synthesis methods between different reinforcement phase and the magnesium matrix. According to the 13th Five-Year national plan attached importance to environmental protection, how to resolve the problem of the environmental adaptability of magnesium alloys and magnesium matrix composites, to realize the recycling, and to achieve the sustainable development of the society, which will draw more attention.

(2) In terms of plasma arc welding technology, the main research direction aims at the relationship between process parameters with the welding joint performance, and the strength loss of weld joint attributed to various macroscopic welding defects in the joint. Thus the following research on molten-pool reaction not only needs to realize metallurgical bonding between the matrix, but also needs to get the good interface bonding of the welding joint, strengthening mechanical properties by reinforcement phase. The welding with ultrasonic and magnetic coupled field or friction stir will become the focus of the research on welding of magnesium.

(3) In terms of the existing welding technology, traditional welding is not good to resolve the existing welding problems, so it is necessary to develop an advanced welding method about magnesium alloy and magnesium matrix composites for solving the existing problems.

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