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Study on plasma arc welding technology and properties of metal materials

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Abstract. Plasma arc welding (PAW) has developed rapidly in recent years due to its characteristic of high quality, high efficiency and low cost. It has become the main welding method of metal aluminium and steel in manufacturing industry. This paper introduces the principle of plasma arc welding and summarizes the application of plasma arc welding technology in metal aluminium and aluminium matrix composites and high strength steel. The programmed automatic plasma arc welding technology can improve the welding efficiency and quality at the same time. So the Programmed automatic plasma arc welding technology can be used as the development direction of plasma arc welding technology, and is more widely used in manufacturing industry.

1. The principle of plasma arc welding

Plasma arc is a kind of compressed tungsten argon arc. Its compression depends on the restraint effect of water-cooled copper nozzle. When plasma arc passes through water-cooled copper nozzle, it is compressed by mechanical compression, thermal compression and electromagnetic compression [1]. The plasma arc energy density can reach to 10^5 - 10^6 W/cm², and the temperature can reach to 24000-500000K. It has the characteristics of high welding quality, high welding efficiency and economy, and is often used in welding technology [2]. As shown in Figure 1, the plasma arc is approximately cylindrical, and the heating area of the base metal will not change significantly when the arc length fluctuates.

In plasma arc welding, inert gas argon is often used as working gas and protective gas. High temperature plasma arc is used as welding heat source. The melted welding material is deposited on the base metal by heating the melted welding material and the base metal. At the same time, the complex metallurgical effect between the melted welding material and the base metal forms the welding joint. The plasma arc is generally divided into three types: non-transfer arc, transfer arc and combined arc.



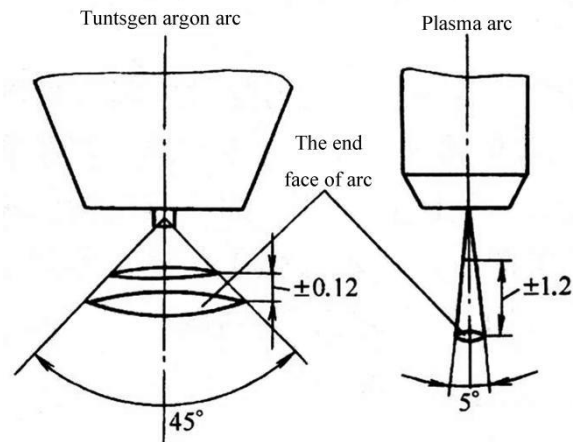


Figure 1. Plasma arc and tungsten argon arc

(1) Non-transfer arc

The non-transfer burns between tungsten pole and nozzle. When welding, the positive pole of power supply is connected with water-cooled copper nozzle, the negative pole is connected with tungsten pole, and the workpiece is not connected to the welding circuit. The arc is brought out by high-speed plasma gas, which is suitable for welding or cutting thin metals and non-metals, as shown in Figure 2.

(2) Transfer arc

Transfer burns directly between tungsten pole and workpiece. During the welding, the non-transfer arc between tungsten pole and nozzle is ignited first, and then the arc is transferred between tungsten pole and workpiece. Under working condition, the nozzle is not connected to the welding circuit. This arc is used to weld thicker metals, as shown in Figure 3.

(3) Combined arc

Transfer arc and non-transfer arc are combined arcs. Hybrid arc is stable at very low current, so it is especially suitable for welding thin and ultra-thin plates, as shown in Figure 4.

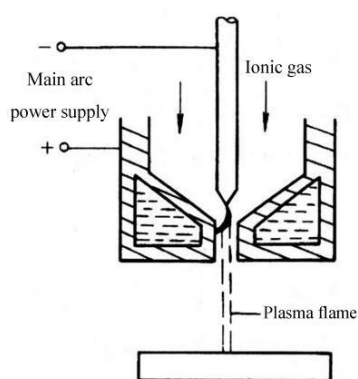


Figure 2. Non-transfer arc

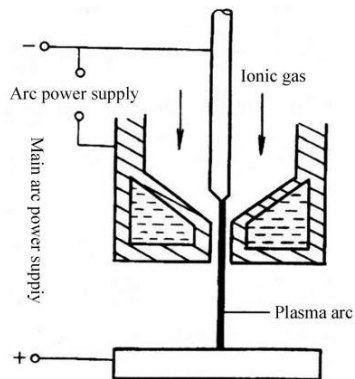


Figure 3. Transfer arc

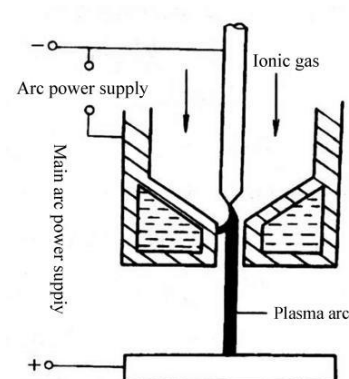


Figure 4. Combined arc

2. The characteristics of plasma arc welding

Because of the high energy density, temperature and rigidity of plasma arc, plasma arc has the following advantages which compared with general arc welding [3].

(1) Compared with tungsten argon arc welding, the plasma arc welding speed is much faster under the same weld penetration.

(2) The heat affected zone is narrow and the heat affected zone on the workpiece is small, so the deformation of thin plate is small during welding.

(3) The arc agitation is good and the temperature of the molten pool is high, which is conducive to

the release of gas in the molten pool.

(4) Because of the high compression effect and thermal ionization, the plasma arc is still stable when the current is small. It is especially suitable for welding micro precision parts.

(5) The plasma arc can produce stable small hole effect. Through small hole effect, good single-side welding and double-side forming can be achieved in front welding.

3. Application and performance study of plasma arc welding technology for metal material

With the development of modern science and technology and the upgrading of China's industry, the manufacturing industry is required to develop in the direction of high-end, lightweight and so on. Metal materials have become one of the research directions of today's manufacturing industry. Therefore, metal materials such as high strength steel, aluminium and aluminium and composite materials have come into people's vision. The use of these metals is increasing day by day, and higher requirements are put forward for welding technology with high efficiency and high quality. Processing method is a favorable guarantee for the rapid development of high-tech industry [6]. It can not only enhance China's core competitiveness, bring huge economic benefits, but also promote the development of related high-end industries.

The research direction of plasma arc welding based on aluminium alloy, aluminium matrix composites and metal steel mainly involves the microstructures and properties of base metal. For plasma arc welding, it has been used in many high precision welding occasions abroad, and has achieved some success [7].

3.1 Plasma welding technology and properties of aluminium and aluminium matrix composites

At present, variable polarity plasma arc welding (VPPAW) is widely used in plasma welding of aluminium alloy. VPPAW has strong penetrating force, low heat input, high welding efficiency, low stress and strain after welding. Its unique cathodic cleaning effect can remove oxide and impurities in molten pool, realize double-sided welding of aluminium alloy sheet and obtain better welding seam. Because of the difference of composition and welding parameters of aluminium alloy, the welding seam presents different microstructures and mechanical properties when variable polarity plasma arc welding aluminium alloy is used. After variable polarity plasma arc welding of 2024 aluminium alloy with Al 2319 as welding wire is in progress, Wang S C et al. [8] systematically inspected the change of welding structure. The results show that there are obvious differences in the structure of 2024 aluminium alloy after welding. The fusion zone is mainly composed of dendritic phase of eutectic $\theta(\text{Al}_2\text{CuMg})$, dendritic phase of $\text{S}(\text{Al}_2\text{CuMg})$ and quasicrystalline phase of $\Omega\text{Al}_7\text{Cu}_2(\text{Fe}, \text{Mn})$ and $\text{Al}_{12}(\text{Fe}, \text{Mn})_3\text{Si}$. In the partial melting zone, the microstructures contain high density eutectic $\theta(\text{Al}_2\text{CuMg})$ and $\text{S}(\text{Al}_2\text{CuMg})$ phase composite particles, and there is part of phase between the remelting zone and the aging zone, but the content is lower than that of $\text{S}(\text{Al}_2\text{CuMg})$. Because the distribution of different phases is different in these regions, two peaks of hardness distribution appear. Li G W et al. [9] successfully welded 7075 high strength aluminium alloy with 10 mm thickness by VPPAW. The range of force and heat balance in variable polarity plasma arc welding of 7075 aluminium alloy is narrow. Due to the high content of Mg and Zn in 7075 aluminium alloy, the fluidity of molten metal is poor, so the proper temperature gradient between molten pool and metal should be ensured during welding.

3.2 Plasma welding technology and properties of high strength steel

Advanced high-strength steel has the advantage of high specific strength, and the proportion of application in the body is increasing. Different parts of the body need to be placed with different strength materials. Therefore, the research of welding technology of high-strength steel for vehicles is particularly important. At present, the welding technology of advanced high strength steels for automobiles mainly includes resistance spot welding and laser welding. Resistance spot welding [10] has some defects such as burning through and spattering. Although laser welding [11] has beautiful shape and good mechanical properties of joints, it is expensive and requires high operating conditions.

Plasma arc welding has the advantages of strong adaptability, low assembly accuracy requirements and low cost. The pulse mode can effectively reduce the welding heat input, which has good applicability to the thinner size of high strength steel for automobiles. Aluminum alloys and aluminum matrix composites have light weight, high temperature resistance, high specific strength and modulus, good fracture toughness, wear resistance and corrosion resistance. With the rapid development, it will gradually replace some traditional metal materials and have a good prospect in many industries, such as ships, automobiles, electronics and electrical appliances, aerospace and so on.

The study on the microstructure and properties of high strength steel lays a foundation for the use of high strength steel. Geng W H et al. [12] mainly studied the microstructures and mechanical properties of plasma arc welded joints of DP1180 ultra-high strength steel/5A06 aluminum alloy, and the influence of welding process factors on the microstructures and mechanical properties of the joints. The results show that the plasma arc welding joint of ultra-high strength steel/aluminum alloy has typical characteristics of fusion-brazing joint. The joint mainly consists of fusion zone, weld zone and interface zone. The fusion zone is well bonded. There are no welding defects such as unfused and cracked. Maraging steel is widely used because of its high strength and toughness. Yang S et al. [13] welded solid solution C300 maraging steel by perforated plasma arc welding. The microstructure and hardness of welded joints were observed and analyzed by optical microscope, transmission electron microscope, scanning electron microscope and hardness tester. The results show that a well-formed welded joint can be obtained by perforated plasma welding; the welded joint is highly symmetrical, which can be divided into weld zone, solid solution zone (coarse and fine grain zone), aging zone and base metal zone; the weld metal has inverted horn shape; the peak hardness of the joint appears in aging zone, and the width of horizontal Zone on the hardness curve depends on the weld zone and solid solution. The width of the zone, the hardness of the weld seam and solution zone are basically the same as that of the base metal. There are differences in crack morphology and contents of nickel, molybdenum, titanium and cobalt in aging zone.

4. Conclusions

The development of plasma arc welding technology has lasted for about 60 years, from its initial application in aerospace industry to the popularization of various mechanical processing. The plasma arc welding technology will be more widely used.

With the rapid development and innovation of high-end equipment manufacturing industry, plasma arc welding technology will have greater development space and potential. Plasma arc welding will play a more full role in the future because of its characteristics, such as high arc energy density, strong penetration ability, strong arc directivity, fast welding speed and high efficiency. Especially at present, metal steel and aluminium and aluminium and composite materials are widely used in manufacturing industry. Programmed automatic plasma arc welding technology can not only further improve welding efficiency, but also greatly improve welding quality. Therefore, as the development direction of plasma arc welding technology, programmed automatic plasma arc welding technology will inevitably be more used in manufacturing industry.

Acknowledgments

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