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Review

Plasma arc welding: Process variants and its recent developments of sensing, controlling and modeling

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ABSTRACT

Plasma arc welding process uses a highly constricted arc to produce a keyhole inside the weld pool, process efficiency is much increased compared to the traditional gas tungsten arc welding process. Keyhole stability is one of the critical factors to determine the process stability and the resultant weld quality. Deeper understanding of the keyhole, and appropriate process control methods are required to improve the welding process stability. This survey paper provides variants of the plasma arc welding process, recent advances in plasma arc keyhole process sensing, controlling and numerical modeling. It shows that recent research works, especially the employment of camera-based vision system to observe the keyhole behavior, deepen the understanding of the keyhole process, sound quality welds have been made in mid-thick stainless steels (9.5–12.5 mm) by new designed control systems; more accurate numerical models have established to explore the keyhole behavior evolution process.

Contents

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1. Introduction

Plasma arc welding (PAW) process is a novel welding process developed based on the traditional gas tungsten arc welding (GTAW) process [1]. In PAW, the welding torch is specially designed. As shown in Fig. 1, the welding arc is constrained by a water cooled copper orifice, the arc jet diameter is reduced compared to the orifice size. As the out layer is cooling down by the low-temperature orifice wall, the constrict degree of the arc column is enhanced. The current density is hence highly increased after the arc column size is reduced, Lorentz force induced by the current flow is heavily increased to further strengthen the constrict degree of the arc column [2]. Because of the constriction, the arc property is improved, ionizing degree, heat source energy and temperature are notably increased, flow speed of the plasma articles in the arc jet is highly increased to level of 340 m/s, arc force is hence strengthened [2,3]. This kind of highly constricted arc is called as plasma arc [4].

The plasma arc welding process is schematic in Fig. 2. As the plasma arc deposits onto the workpiece surface, the metal is melted and the liquid metal is pressed away to the side, keyhole forms inside the weld pool. If the penetration ability of the arc is high enough, keyhole will fully penetrate the workpiece, this welding process is called as keyhole mode PAW. While if the arc is not so powerful to penetrate the workpiece, the welding process works in melt-in mode or conduction mode. As the PAW torch moves along the welding direction, most of the liquid metal is displaced to the weld pool tracking the arc jet, cools down and solidifies into the weld bead [5].

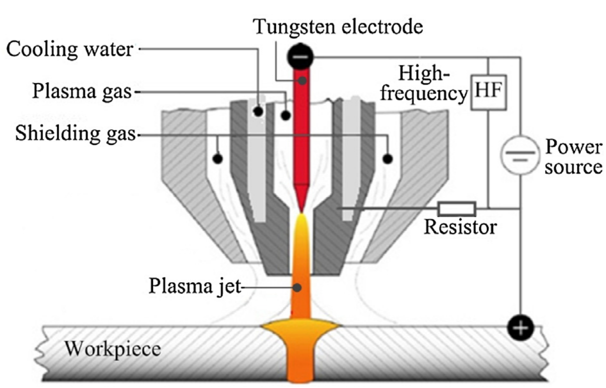

Fig. 1. Schematic of plasma arc welding torch.

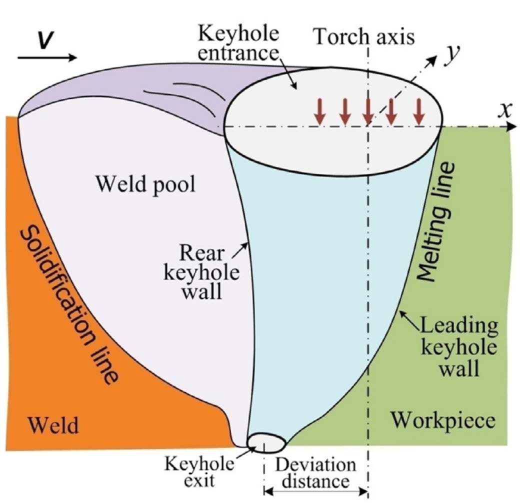

Fig. 2. Schematic of PAW keyholing process.

The employed arc source is a constricted arc, the heat and force quality is much improved compared to the GTAW arc. PAW has better advances over GTAW [6]: (1) mid-thick plate can be welded by one pass process, manufacturing efficiency is highly improved; (2) high-quality weld can be produced, grain over-growth is avoided for less heat input is inputted, distortion is reduced as the high depth-to-width ratio weld is made in PAW. And, PAW also has advantages over laser beam welding (LBW) and electron beam welding (EBW) in equipment cost, joint tolerant, and operation convenience [7,8]. Hence, PAW easily finds application in welding of airplanes [9], automobiles [10], rockets [11], shuttles [12], and structural steel [13].

However, the weld quality is highly determined by the keyhole behavior during the welding process [13], while the keyhole behavior is directly controlled by coupling behaviors between the plasma arc, weld pool and workpiece [14]. So the keyhole behavior is in turn sensitive to many factors, especially the physical properties of the metal to be welded and the welding process parameters to be used [13,14]. In order to stabilize the keyhole behavior, works have been done from several aspects: (1) PAW welding equipment should be modified to improve the arc property; (2) keyhole process is sensed and controlled in real time to avoid defects formation; (3) understanding of the keyhole behavior should be focused by experimental methods or computer simulation.

This survey article provides introduction to the development of the PAW welding equipment machine/system and their applications in recent years; summarizes the recent research results in keyhole state sensing, especially in the vision observation; reviews keyholing behavior control system developments; and describes the advances in modeling simulation of the keyhole behavior in PAW process.

2. Variant processes of PAW

Plasma arc has increased penetration ability among the arc welding processes, can be used to weld most metal materials [15–17]. Researchers and engineers did much to improve the penetration ability of the plasma arc or make the PAW process more suitable to be employed in special industrial applications. Many variation processes have been developed.

2.1. Variable polarity plasma arc welding (VPPAW)

To weld aluminum alloys, surface oxide film should be cleaned up by cathode atomization effect without damage the tungsten tip. Boeing Company improved the PAW power in 1970s to meet the requirement, the variation is called as variable polarity plasma arc welding (VPPAW) [12,18,19]. In VPPAW, AC square wave current is used, the amplitude and duty cycle of the current waveform can be freely adjusted [1]. During the electrode positive duration, workpiece acts as the cathode, oxide film on the surface can be cleaned up. The current waveform is optimized to avoid the tungsten consume. In the electrode negative duration, workpiece acts as the anode and more heat is deposited into the weld pool to melt the workpiece. Under appropriate parameter combinations, the aluminum alloy of thickness up to 12.5 mm can be well welded in a single pass [20], it is widely employed in space industries [21,22]. Compared with traditional VP-TIG welding, VPPAW is of higher process efficiency, the aluminum welds obtained by VPPAW have less distortion, less welding defects.

2.2. Double sided arc welding

In the PAW process, the current flow loop is usually “welding power–welding torch–workpiece–welding power.” However,