Extended Abstract

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A keyhole plasma arc welding technology and its physical mechanism

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Abstract:

Arc welding technology is widely used in the manufacturing of pressure vessel, oil-pipeline connection, and petroleum chemical equipment. Generally it requires good groove preparation, suited filler wire and multi-layer and multi-passes welding. Plasma Arc Welding (PAW) is one of the most advanced welding technologies with a high power density. A keyhole PAW technology can fuse the work piece through its entire thickness with a single pass and without groove preparation. It has great potential in the advanced manufacturing industry. However, it requires strict welding conditions to maintain good weld joint quality at the keyhole welding state, since it involves very complex electric, magnetic, thermal and fluid dynamics phenomena, such as electro-thermal conversion, electromagnetic effects, heat transfer, gas-liquid two-phase impact and flow, interface deformation and solid-liquid phase change. Many researchers generally constructed equivalent heat source models to represent the actual thermal arc energy transfer for simplicity. Only a few researchers present the electro-magnetic-thermal-mechanical phenomena in the dynamic keyhole welding process by using the Volume of Fluid (VOF) method to track the keyhole interface. While their models cost too much computational resources and time. In the paper, a simplified and unified 2D axisymmetric mathematical model of plasma arc and weld pool was developed to reflect the electro-magnetic thermal - mechanical mechanism in PAW. The keyhole mode heat transfer was easily presented by using a simple arc pressure model calculated from the plasma arc region, which avoids the cumbersome keyhole tracking. Evolution processes of the electric field, magnetic field, temperature field and flow field in the whole PAW process were all obtained. Results show that there are the highest current density, electromagnetic force and temperature near the tungsten cathode tip, and they all fall dramatically away from the central line. The arc maintains a high energy density and high velocity due to the compression effect of the nozzle, shielding gas and electromagnetic force. With the unique electro-magnetic-thermal-mechanical effects in PAW, a “reversed bugle-like” shaped weld fusion line finally forms at the cross section of work piece. The calculated arc pressure coincides with previous research, and the predicted weld fusion line agrees well with experimental results, which validate the mathematical model. The paper provides easy access to the full understanding of the keyhole PAW technology. Lightweight manufacturing reduces energy consumption and protects the environment; therefore, it offers an important direction of development in engineering. Variable polarity plasma arc (VPPA) welding is a light gauge aluminum and magnesium alloy joining technology capable of the highly efficient welding of medium-thickness metals via the keyhole effect, and without the complex pre-processing required by traditional methods. However, the stability of the keyhole weld pool is easily lost, resulting in a much narrower parameter window than that of conventional methods. Here, through keyhole morphology analysis and x-ray *in situ* imaging experiments, we reveal the material flow behavior, the mechanism behind the stability of the keyhole weld pool, and the reason for the very narrow process parameter window in VPPA welding processes. We discovered that the polarity pressure difference of the plasma arc, which is induced by the keyhole boundary shape and plasma arc intensity, drives the flow pattern to the top side of the keyhole, which is beneficial for keyhole filling and the formation of a stable weld bead. The influence of the difference in plasma arc pressure and the keyhole boundary on the flow field revealed in this study may guide the optimization process of light metal joining to achieve the highly efficient and defect-free manufacturing of large and complex structures.

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