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A keyhole plasma arc welding technology and its physical mechanism

Arc welding technology is widely used in the manufacturing of pressure vessel, oil-pipeline connection, and petroleum chemical equipments. 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 workpiece 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 workpiece. The calculated arc pressure coincides with previous research, and the predicted weld fusion line agrees well with experimental result, which validate the mathematical model. The paper provides easy access to the full understanding of the keyhole PAW technology.

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