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变极性等离子电弧稳定性及其控制

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摘　要：以变极性等离子电弧稳定性机理及其控制方法为研究对象，自行研制了 80C196KC 单片机为控制核心，主电路为双逆变型电路拓扑结构的 VPPA－1 型变极性等离子焊接电源。重点分析小电流过零再引燃机理及其在大规范焊接条件下变极性等离子弧焊接系统及其电弧的稳定性。分别提出了在小电流焊接时通过程序设定方法将变极性等离子电弧由正极性变反极性之前提高过零电流，而大规范焊接条件下则控制过零电流的新观点，对科学认识变极性等离子电弧特性及其焊接过程控制有重要的指导意义。

关键词：变极性等离子弧焊接；电弧力；电弧形态
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0　序　　言

变极性等离子弧焊接(variable polarity plasma arc welding, VPPAW)方法与钨极氩弧或熔化极惰性气体保护焊相比，具有能量集中、电弧挺度大、一次穿透深度大以及焊后变形小等特点。VPPA 焊接常采用穿孔立焊工艺，更有利于消除气孔等焊接缺陷。因此，在火箭筒体、铝合金贮箱和宇宙飞船铝合金壳体的焊接中广泛应用[1－3]。近几年来国内也对变极性等离子焊接工艺进行研究，并取得了一定的成果，但到目前为止这种工艺还没有在实际生产中得到真正应用。变极性等离子电弧比直流等离子弧和其它焊接电弧有更多不同的特征，如文献[4]所研究的电弧过零时间越长或焊接电流越小时电弧空间保持的电离度越低，则所需的再引燃电压越高。相反，电离度越高，则再引燃电压越低，甚至无须附加稳弧脉冲。但未见在大规范焊接条件下变极性等离子电弧稳定性及其控制方法的研究报告。研究变极性等离子电弧稳定性机理及其控制方法，无论在理论方面还是在实际工程应用上都具有重要的意义。

1　试验设备

试验采用的变极性等离子弧焊接系统由图 1 所示。焊接电源为自行研制的，以 80C196KC 单片机为控制核心，主电路为双逆变型电路拓扑结构的 VPPA－1 型变极性等离子逆变电源。设计的焊接电源正、反极性的时间分别可调，反极性时间的调节范围为 1 ~ 99 ms。正极性时间的调节范围为 1 ~ 999 ms。输出正、反极性焊接电流的幅值最大为 400 A，并且具有电流缓升起弧、电流缓降收弧的功能，达到国外变极性焊接电源的调节功能和焊接工艺要求。

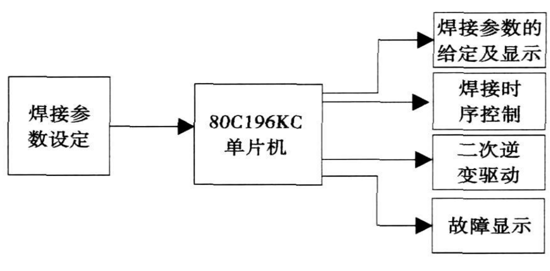

图 1　变极性等离子焊接电源单片机控制系统
Fig. 1　SCM control system of VPPA－1 welding power

试验采用 FASTCAM－Super10k 型高速摄像机对变极性等离子电弧进行拍摄和观测，高速摄像的帧频为 3 000 幅/s。

2　变极性等离子弧电弧稳定性分析

铝合金变极性等离子弧焊接时，输出变极性电

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弧存在焊接电流过零，电弧再引燃过程。伴随电弧熄灭再引燃，变极性电弧中气体收缩与膨胀，在弧柱径向产生附加热损失，并且，电弧温度达到最小值和最大值的时间都滞后于电流的变化。由于存在附加热损失，变极性电弧电压平均值比同样电流的直流等离子电弧电压高。变极性电弧这些特点对焊接过程稳定性有很大的影响。变极性电弧再引燃必须满足以下两个条件：（1）弧柱温度降低不多，并保持着足够高的电离度；（2）新成为阴极的电极表面尚未失去发射电子的能力。熄弧几微秒时间内绝缘耐力完全取决于电极附近区域所处的状态，与电极距离无关。电弧中电子流密度由下式[5]表示为

$$J = AT^2 \exp\left(-\frac{W_w - e\sqrt{eE}}{KT}\right) \quad (1)$$

式中：T 为热力学温度；W_w 为逸出功；J 为电子流密度；E 为电场强度；e 为电子电量。

等离子电弧与 TIG 焊接电弧比由于受机械压缩、热压缩和电磁压缩作用，电弧电压高。正常焊接条件下电极到工件距离大，因此变极性等离子弧再引燃较自由电弧困难。在铝合金变极性等离子弧焊接时电弧的正极性期间钨极作阴极，由于钨极强电子发射能力，电弧集中并稳定。变极性电弧反极性期间铝合金板为阴极，由于铝合金为冷阴极，热电子发射能力差，因此阴极斑点跳动使电弧较发散，电弧稳定性较差。图 2 为变极性等离子弧由正极性转为反极性时的高速摄像。

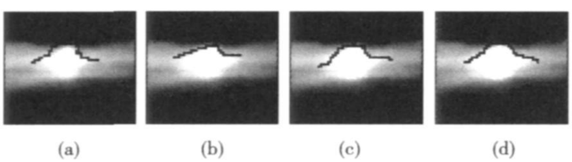

图 2　变极性等离子电弧高速摄像

Fig 2　High speed photogroph of VPPA

从电弧高速摄像图看出铝合金变极性电弧由正极性转为反极性时电弧由集中变发散，若此时焊接电流较小，则易引起断弧现象。

3　变极性等离子电弧稳定性控制

铝合金变极性等离子弧焊接工艺中，选择变极性电流的幅值和时间值时，除了考虑铝合金表面氧化膜清理和降低钨极烧损之外，变极性等离子电弧稳定性是必须考虑的问题。铝工件为负的半波，再引燃电弧是在冷阴极条件下实现的，为使铝阴极发射电子，首先应建立阴极电场。该电场的建立可以通过两种途径：一为外加电压脉冲；二为提高电弧电离度，有利于在阴极表面附近积聚正离子而形成阴极电场。由上述分析，在工件由正变负前电流波形的后沿叠加一个电流脉冲，可以瞬间提高电弧的电离度，有利于过零后的电弧再引燃。

图 3 为小电流焊接条件下的电流给定电压波形，给定电压1 V对应27 A。

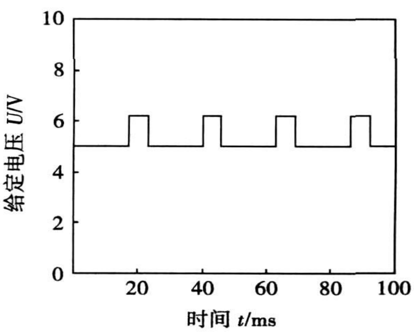

图 3　变极性电流给定电压波形

Fig. 3　Voltage waveform giving to current

图 4 为与图 3 电流给定波形所对应的变极性同步驱动波形。从两个波形图可看出，在变极性等离子弧由正极性变反极性前2 ms将焊接电流增大至一定值。叠加脉冲电流的目的在于，变极性等离子电弧变反极性之前提高电弧温度，从而提高了变极性等离子弧由正极性变反变极性时的电弧稳定性。

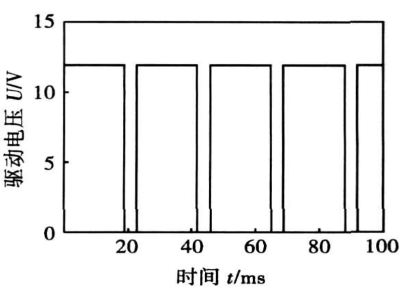

图 4　正极性驱动电压波形

Fig. 4　Voltage waveform of EN driving

图 5 为上述焊接电流给定和变极性同步驱动条件下获得的实际焊接电流波形。从焊接电流波形看出，转变极性时过渡正常，表明上述方法可保证小电流变极性等离子电弧稳定性。

在厚板铝合金变极性等离子弧焊接试验中发现，当平均焊接电流超过一定值（150 A）时，即便没有外加稳弧措施，也能保证交流电弧的稳定性。此时电弧温度较高，过零时的剩余电子数能够满足变极性电弧再引燃条件。研究中发现，在大厚度试板

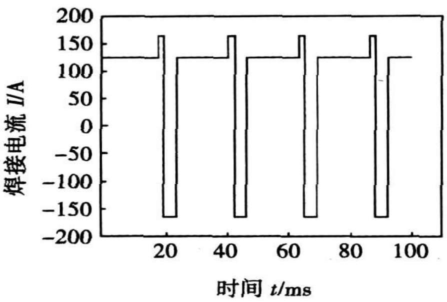

图 5 VPPA 焊接电流波形

Fig. 5 Welding current wave of VPPA

焊接时随着试板厚度和焊接规范的增大, 当变极性等离子弧焊接电流超过一定值后带来的问题是, 焊接电流转换极性时的 $\frac{\partial I}{\partial t}$ 过大, 回路电感上产生较大的电压尖峰, 这对开关管及其控制电路冲击较大, 有时出现过流和控制系统失控等现象。

图6 为采用工控机检测的大厚度试板变极性等离子弧焊接电流波形。图中显示, 因过大的过零电流产生的冲击波, 使单片机二次逆变驱动波形出现失步现象。电流波形中部出现几个周期无正极性电流现象, 说明在大电流焊接条件下, 控制系统中的驱动信号受到了干扰。

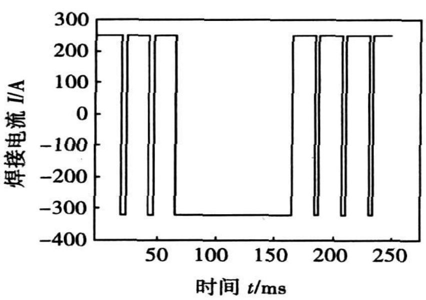

图 6 变极性等离子弧出现失步时的电流波形

Fig. 6 Current wave of VPPA when it losing steps

图7 为图6 变极性等离子电弧出现失步时所焊试件的焊缝形貌。从图中可看出, 当控制系统受到干扰时与之对应的焊缝处, 正反面都失去光滑和均匀性。

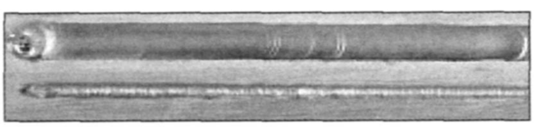

图 7 变极性等离子弧出现失步时的焊缝

Fig. 7 Weld of VPPA when it losing steps

由以上分析可知, 在大规范变极性等离子弧焊接条件下, 控制过零电流冲击是保证变极性等离子弧焊接系统及其电弧稳定性的关键所在。因此, 如何合理设定及控制过零电流是否可实现大电流变极性等离子弧焊接系统及其电弧稳定性的关键因素。

图 8 是为解决上述大电流变极性等离子弧焊接过程稳定性而设定的单片机给定焊接电流的电压波形。变极性等离子弧焊接电流给定波形上看, 正极性电流为250 A, 反极性电流为320 A, 1 V 给定电压对应27 A。而过零电流为定植。解决大规范焊接条件下的变极性等离子弧系统及其电弧稳定性, 对发挥变极性等离子弧焊接工艺优点, 推广该焊接方法有着重要作用。

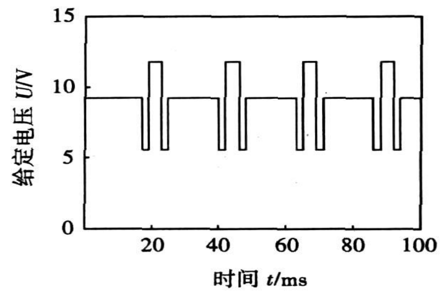

图 8 变极性电流给定电压波形

Fig. 8 Voltage waveform giving to current

4 结 论

(1) 小电流铝合金变极性等离子弧焊接时电弧稳定性主要取决于电流过零再引燃过程。通过程序设定方法在由正极性变反极性之前增大过零电流, 使变极性等离子电弧空间温度提高, 实现了小电流铝合金变极性等离子弧焊接电弧的稳定。

(2) 铝合金变极性等离子弧焊接电流超过一定值后使电弧过零电流冲击过大, 增大对电源硬件及软件系统的干扰。通过适当控制过零电流, 可降低大规范变极性等离子弧焊接电流换向时产生的冲击, 提高变极性等离子弧焊接系统稳定性。

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random variation of the drop shape and size. The study on the unstable phenomena of pulsed MIG welding process is helpful to the control of welding technical performance.

Key words: pulsed MIG welding; unstable transition; size of molten droplet; melting droplet barycenter; oscillation of weld pool

Arc stability and its control of VPPA HAN Yongquan[1], CHEN Shujun[2], YIN Shuyan[2], SONG Cheng[1] (1. College of Materials Science and Engineering, Inner Mongolia University of Technology, Hohhot 010051, China; 2. College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing 100022, China). p18—20

Abstract: The VPPA—1 welding power with 80C196KC MCU as the control center and double invert topological structure as the main circuit was prepared. Arc stability mechanism and control methods of VPPA were studied. The re-ignition principle after the zero passage at low current and the arc stability of VPPA in large-scale welding conditions were analyzed principally. It is proposed that zero passage should be enhanced before the positive electrode becomes negative electrode by program enactment at low current to control the stability. However, in the large-scale welding conditions, the arc stability is controlled by zero passage. It is helpful for the arc properties and welding process control in VPPA welding.

Key words: Variable Polarity Plasma Arc Welding; Arc force; Arc shape

Numerical simulation of welding stresses and distortions based on 3D dynamic substructure method LIU Chuan, ZHANG Jianxun (Welding Research Institute, Xi' an Jiaotong University, Xi' an 710049, China). p21—24

Abstract: Due to the strong nonlinear thermal-mechanical coupling procedure, the numerical simulation of welding stresses and distortion using 3D thermal-elastic-plastic finite element method takes very long computational time. In order to improve the speed of computation, a 3D dynamic substructure method, which takes the characteristics of welding problem, was developed. Noting that the region of fusion zone (FZ) and heat affected zone (HAZ) which exhibits strong nonlinearity by direct heating was limited in a very small zone compared to the size of the model to be analyzed and the remaining part far from the heat source is mostly linear, the 3D thermal-elastic-plastic computation for the whole size of the model can be remodeled to the combination of a large linear problem and a small but moving strong nonlinear problem. In the 3D dynamic substructure method, the FZ and the HAZ remain nonlinear, whereas the remaining part of the model is treated as substructures which are linear. Moreover, the sizes of the substructures are also changing with the moving heat source. The simulated residual stresses and distortions using the substructure model are compared with the results of the full model and the experiment. The result shows that the substructure method is an effective method in reducing computing time with precise results in the welding region.

Key words: dynamic substructure; welding; residual stress; distortion

Analysis on leak-before-break safety assessment of pressurized pipes DENG Caiyan[1], ZHANG Yufeng[1], HUO Lixing[1], WANG Dongpo[1], LUO Hong[2] (1. School of Materials Science and Engineering, Tianjing Unirersity, Tianjin 300072, China; 2. Offshore Oil Engineering Co. LTD, Tianjin 300452, China). p25—28

Abstract: According to British standard BS7910 and Europe standard SINTAP, a high-level safety analysis method of pressurized vessels and pipes, leak-before-break (LBB) analysis, is applied into the submarine pipeline in practice. In LBB analysis the determination of some parameters is given, which includes crack opening area, the leakage rate, and through-crack limit size and so on. The result shows that the flaw length at breakthrough, is less than the 110.62mm; limiting length of a through-wall flaw, 27.76mm, and the time to detect the leak is less than the 0.62year for the flaw to grow to a limiting length. So the pipeline meets the LBB condition. The application of LBB makes the safety assessment of pressurized component more scientific and more reasonable.

Key words: pressured pipe; LBB analysis; safety assessment

Microstructure and properties of electron beam welded joints of 18 Ni Co-free maraging steel MO Defeng[1], HE Guoqiu[1], HU Zhengfei[1], SHI Yanling[2], ZHANG Weihua[3] (1. School of Materials Science and Engineering, Tongji University, Shanghai 200092, China; 2. The 210 Research Institute of CASIC, Xi' an 710065, China; 3. State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China). p29—32

Abstract: Electron beam welding was used to weld 18 Ni Co-free maraging steels. The microstructure of welded joints was investigated by optical microscopy, and the microhardness of weld metal, heat-affected zone and base material was tested. The results show that the microstructure of the base materials is lath martensite, and the microstructure of weld metal exhibits a typical cystiform-dendritic morphology. The region adjoining the weld metal was heated to high temperatures in the austenite phase before rapid cooling. EB welding heat input was high enough to lead to grain recrystallization. The softest region is weld seam, while the hardest is fine-grained zone. the microhardness in the heat-affected zone increases with the distance being away from fusion line.

Key words: 18 Ni Co-free maraging steel; electron beam welding; microstructure; microhardness

Process of electroless copper plating on Al_2O_3 ceramics and its soldering at low temperature ZHANG Deku, WANG Kehong, YANG Zhimin, ZHOU Weiwei (Department of Materials Science and engineering, Nanjing University of Science and Technology, Nanjing, 210094, China). p33—36

Abstract: Al_2O_3 ceramics was treated by electroless copper plating, the surface of Al_2O_3 pretreatment process was studied. The influence of concentration of liquor of copper sulfate, liquor