

变极性 TIG 焊电弧压力分析

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摘 要: 采用压力传感器获取不同条件下的变极性钨极氩弧焊(VPTIG)横焊时的电弧压力, 研究分析了电弧压力在径向上的分布规律, 对比研究了直流 TIG 焊、反极性期间占 5%、15% 的变极性 TIG 中心电弧压力。结果表明, 变极性 TIG 焊电弧压力的径向分布属于双面指数分布。焊接电流在 100 ~ 140 A 范围内, 在电流均值相等的情况下, 由于反极性期间电子发射机制和电弧发散等原因, 随着一个周期内钨极为正半波的时间比例增加, 电弧压力逐渐减小, 且焊接电弧积分力与电流的平方近似成正比例关系。

关键词: 双面指数分布; 电弧压力; 横焊; 变极性钨极氩弧焊

中图分类号: TG 442 **文献标识码:** A **文章编号:** 0253-360X(2014)11-0101-04

0 序 言

铝合金工程结构越来越复杂, 性能要求越来越高, 同时对铝合金焊接质量提出了更高要求。变极性 TIG 焊通过减小钨极为正的时间, 增大钨极为正的电流幅值, 使得在保证阴极清理的情况下, 最大限度地减小钨极烧损^[1]。在运载火箭和立式储罐的大型化中, 在横焊位置施焊, (相对于平焊位置) 工装简易且焊件同轴性高, 焊后变形及应力集中较小, 具有生产周期短、安全可靠等优点, 具有较大工程价值。

在变极性 TIG 焊接过程中等离子流力作用于液态熔池表面使之产生液面差, 其沿着电弧径向分布形态直接影响着熔池中液体金属的流动、焊缝截面形貌和成形状况, 是焊接电弧的主要机械作用力^[2,3]。焊接电弧压力依靠电流密度分布改变熔池以及固液结合面的形貌, 其与 TIG 焊中的驼峰、咬边等缺陷形成机制之间存在着密切关系^[4-6]。在变极性 TIG 横焊中, 液态铝合金在重力作用下容易下淌形成咬边和焊瘤, 焊枪倾斜向上, 以电弧力向上的分力平衡部分重力对成形有利。熔池中的电弧力、重力和表面张力决定着金属熔池的流动和焊缝的成形质量, 从熔池受力方面研究变极性 TIG 横焊是必要的。

国内外对变极性 TIG 电弧压力研究较少, 文中对变极性 TIG 横焊电弧压力进行试验研究, 分析了不同电流条件下电弧压力在径向上的分布趋势, 并分析了直流 TIG、不同反极性时间比例的变极性 TIG

焊电弧力的区别以及其与电流之间的关系, 研究结果为金属熔池受力分析、工艺优化和模拟奠定理论基础。

1 试验方法

变极性 TIG 焊电弧压力测试系统如图 1 所示, 试验中采用 Miller Dynasty700 焊机, CK Worldwide 公司的 CWM350 型焊枪, 压力传感器为 GB-3000G 型, 其压力范围为 0 ~ 1 000 Pa, 将采集到的压力信号线性的转换为 0 ~ 5 V 的电压信号输出。

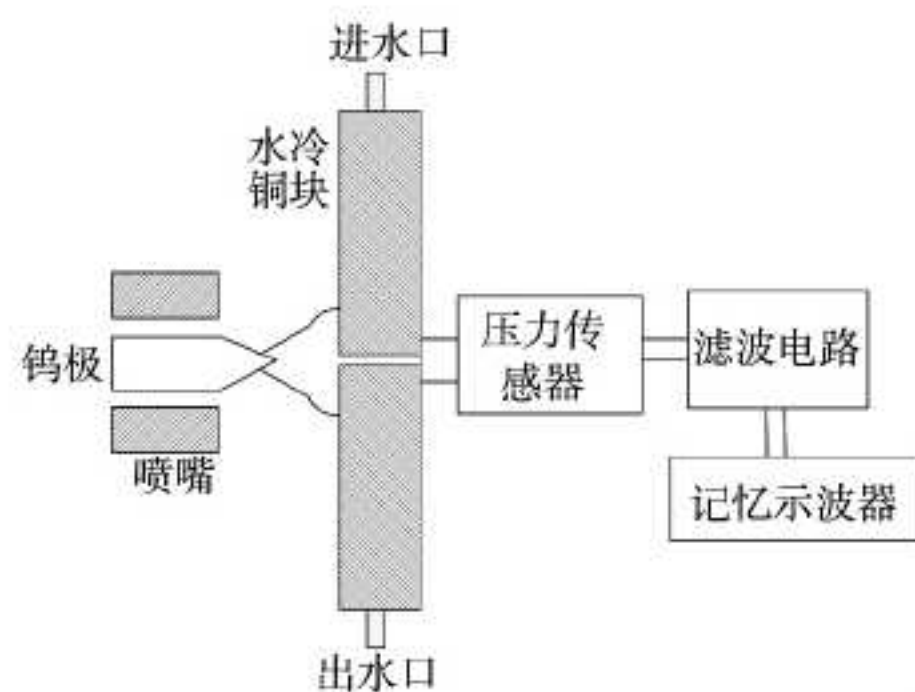


图1 电弧压力测试原理图

Fig. 1 Schematic diagram of arc pressure measurement

电弧压力通过水冷铜块上直径为 0.8 mm 的小孔传输到压力传感器上, 信号经滤波后传输到记忆示波器上。每次试验前将水冷铜块用 2000 号砂纸打磨并机械抛光, 以去除表面的污点和凹凸不平, 以保证试验测量时各点的导电性质一样。试验时先将

钨极中心与测试小孔对中,测量后每次移动 0.5 mm 的距离,待电弧稳定后再测量下一点的电弧压力,电弧压力径向分布试验示意如图 2 所示。

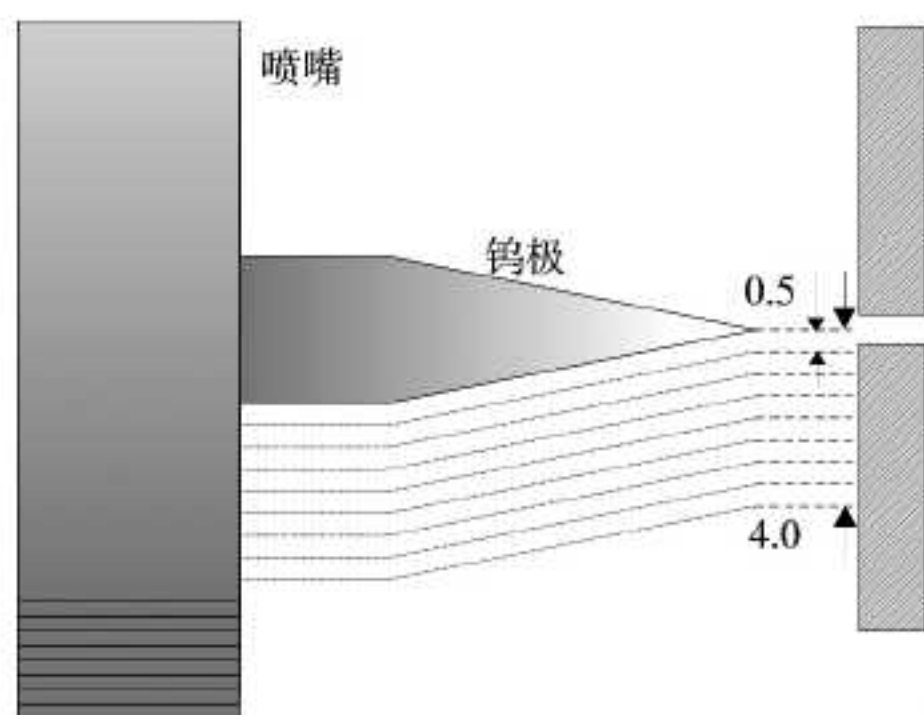


图 2 电弧压力沿径向上的测量 (mm)

Fig. 2 Schematic diagram of pressure measurement with radial distance from arc axis

电弧压力测试试验中钨极直径为 3.0 mm,钨极到工件之间的距离为 2.0 mm,保护气体流量为 10 L/min. 试验在横焊位置施焊,为了降低测量误差,在相同参数下每组试验测量三次,取平均值作为测量结果. 试验过程中为了保持钨极尖端形貌、弧长均采用高频引弧. 电弧压力沿径向分布试验参数如表 1 所示,试验由组 1、组 2、组 3、组 4 组成。

表 1 变极性钨极氩弧焊电弧压力试验参数

Table 1 Welding parameters for pressure measurement of VPTIG

	正极性电流 I_{EN}/A	反极性电流 I_{EP}/A	变极性频率 f/Hz	反极性期间所占比例 $S(\%)$
组 1	80	120	100	20
组 2	100	140	100	20
组 3	120	160	100	20
组 4	140	180	100	20

2 试验结果与分析

2.1 变极性 TIG 焊电弧压力径向分布

目前关于 TIG 焊电弧压力沿径向分布存在两种基本理论,一些研究者认为电弧压力沿径向分布服从电流密度和等离子体流动的分布规律,属于高斯分布^[7];另外一些研究者认为电弧压力沿径向分布属于双面指数分布^[2,8]. 若变极性 TIG 焊电弧压力沿径向上为高斯分布,则电弧压力表达式为

$$p(r) = p_{\max} \exp(-a\delta^2) \quad (1)$$

式中: $p(r)$ 为径向距离 r 处测量的电弧压力值; $p_{\max}$ 表示电弧中心处的电弧压力值; a 为电弧压力分布

曲线集中系数; δ 为极半径。

若按照变极性 TIG 焊电弧压力沿径向为双面指数分布,则电弧压力表达式为

$$p(r) = p_{\text{peak}} \exp(-a|r|) \quad (2)$$

式中: p_{peak} 为电弧轴线上的压力峰值,表达形式为

$$p_{\text{peak}} = p_{\max} \frac{a^2 r_0^2}{2 [1 - e^{-ar_0} (ar_0 + 1)]} \quad (3)$$

式中: $p_{\max}$ 为实际测量的电弧中心的压力值; r_0 为测量小孔的直径;系数 a_n 的表达式为

$$a_n = \frac{1}{r_{n+1} - r_n} \ln \frac{p_n}{p_{n+1}} \quad (4)$$

式中: r_n, r_{n+1} 为压力 p_n, p_{n+1} 处的径向极坐标。

在弧长为 2 mm 情况下按照表 1 的试验参数进行变极性 TIG 焊电弧压力径向分布试验,得到试验结果如表 2 所示。

表 2 VPTIG 电弧压力沿径向分布测量值

Table 2 Radial arc pressure distribution measurement of VPTIG

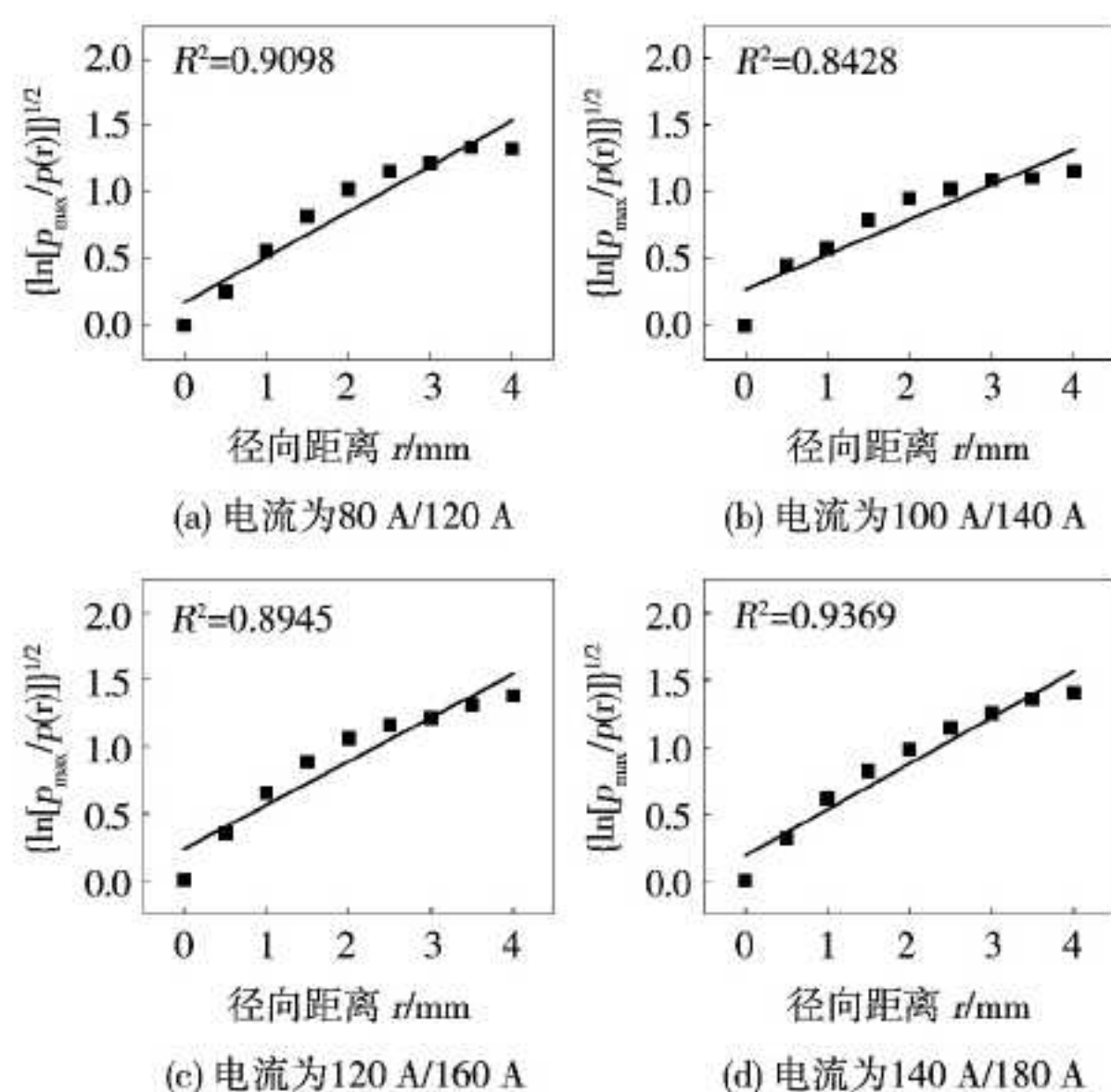
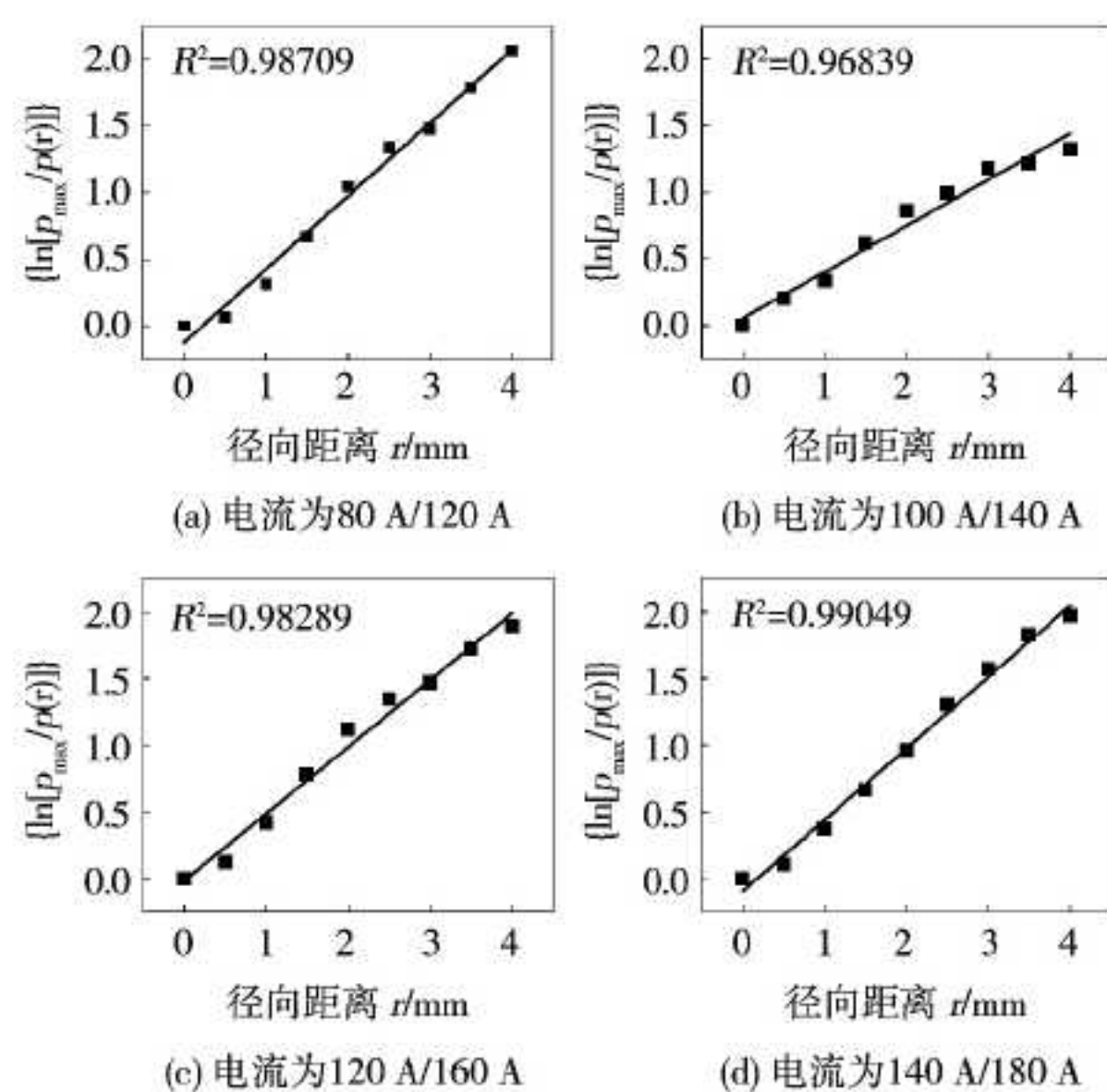
径向距离 r/mm	组 1 电弧压力 p_1/Pa	组 2 电弧压力 p_2/Pa	组 3 电弧压力 p_3/Pa	组 4 电弧压力 p_4/Pa
0	1 969	2 101	3 262	4 220
0.5	1 708	1 802	2 286	3 821
1.0	1 442	1 505	2 138	2 910
1.5	1 008	1 133	1 492	2 166
2.0	692	891	1 067	1 613
2.5	516	778	849	1 147
3.0	447	643	751	881
3.5	329	622	583	675
4.0	249	514	548	589

2.1.1 径向分布按照高斯分布拟合

根据测量结果,如果 $\{\ln [p_{\max}/p(r)]\}^{1/2}$ 与径向距离 r 呈线性关系,则说明电弧压力在径向分布属于高斯分布. 根据表 2 的试验结果按照高斯分布拟合 $\{\ln [p_{\max}/p(r)]\}^{1/2}$ 和 r , 得到的二者之间的关系如图 3 所示. 其中 R^2 为根据数据拟合得到直线的相关系数, R^2 越接近于 1, 数据的线性度就越高, 则说明数据之间的关系越接近于线性分布. 由图 3 可以看出在变极性 TIG 焊正半波电流 I_{EN} /负半波电流 I_{EP} 分别为 80/120 A、100/140 A、120/160 A、140/180 A 下测量的数据和拟合的直线之间线性度不大,说明变极性 TIG 焊电弧压力沿径向分布与高斯分布的符合程度不高。

2.1.2 径向分布按照双面指数分布拟合

根据表 2 的测量数据按照双面指数分布规律拟合 $\ln [p_{\max}/p(r)]$ 和 r , 得到的二者之间的关系如图 4 所示。

图 3 实测的 $\{\ln [p_{\max}/p(r)]\}^{1/2}$ 与径向距离 r 的关系Fig. 3 Relationship between measured $\{\ln [p_{\max}/p(r)]\}^{1/2}$ and radius r 图 4 实测的 $\ln [p_{\max}/p(r)]$ 与径向距离 r 的关系Fig. 4 Relationship between measured $\ln [p_{\max}/p(r)]$ and r

由图 4 可以看出按照双面指数分布来拟合变极性 TIG 焊电弧压力的径向分布, 拟合的直线与试验数据之间耦合性比较高, 拟合的相关系数 R^2 均大于 0.95, 接近于 1. 对比按高斯分布拟合的图 3 和按双面指数分布拟合的图 4 可以看出, 变极性 TIG 电弧压力在径向分布上更接近于双面指数分布. 双面指数分布与高斯分布相比, 电弧中心压力大, 且中心部位的电弧压力梯度大, 这样熔池中心部位受力大, 熔深较大, 熔融金属更易从熔池中心向四周流动. 在横焊过程中, 电弧压力分布影响熔池截面形状, 同时

影响电弧向上承托熔池的力大小及分布, 进而影响焊缝成形. 另外, 也为熔池表面和内部流动乃至焊缝成形等数值模拟提供更精确的边界受力条件.

2.2 焊接电流对变极性 TIG 焊电弧压力的影响

根据变极性 TIG 焊电弧压力在径向上为双面指数分布, 在一定条件下, 把实测的电弧压力 $p_1, p_2, \dots, p_n$ 和相应的径向距离 $r_1, r_2, \dots, r_n$ 带入到系数 a_n 的表达式(4)之中, 得到的 $a_1, a_2, \dots, a_n$ 大小基本相近, 此处将 $a_1, a_2, \dots, a_n$ 的平均值作为双面指数曲线分布集中系数. 由焊接参数组 1、组 2、组 3、组 4 分别计算的 a 值和 p_{peak} 值带入到双面指数分布表达式(2)中得到不同电流条件下的双面指数分布的表达式, 根据计算的双面指数表达式绘制的曲线与实测的数据之间的关系如图 5 所示.

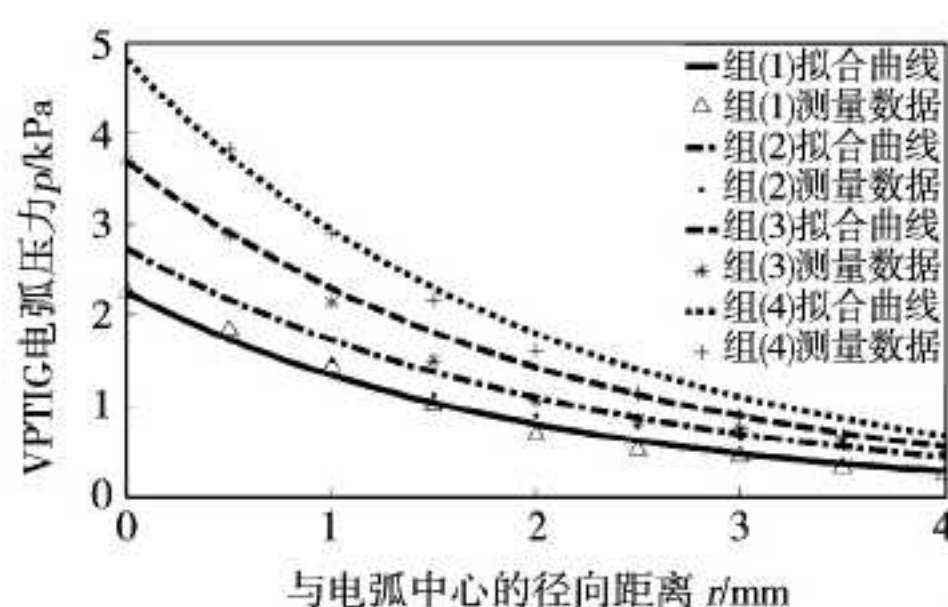


图 5 电弧径向压力测定值与拟合的双面指数分布关系曲线

Fig. 5 Radial arc pressure distribution measurements and hyperbolic distribution fitting curve

在径向距离 r 为 0 时, 当焊接电流均值相等的情况下研究直流 TIG 焊、变极性 TIG 焊反极性 DCEP 所占比例为 5% 和 15% 条件下电弧中心电弧压力变化趋势, 焊接电流对电弧中心电弧压力的影响规律试验结果如图 6 所示.

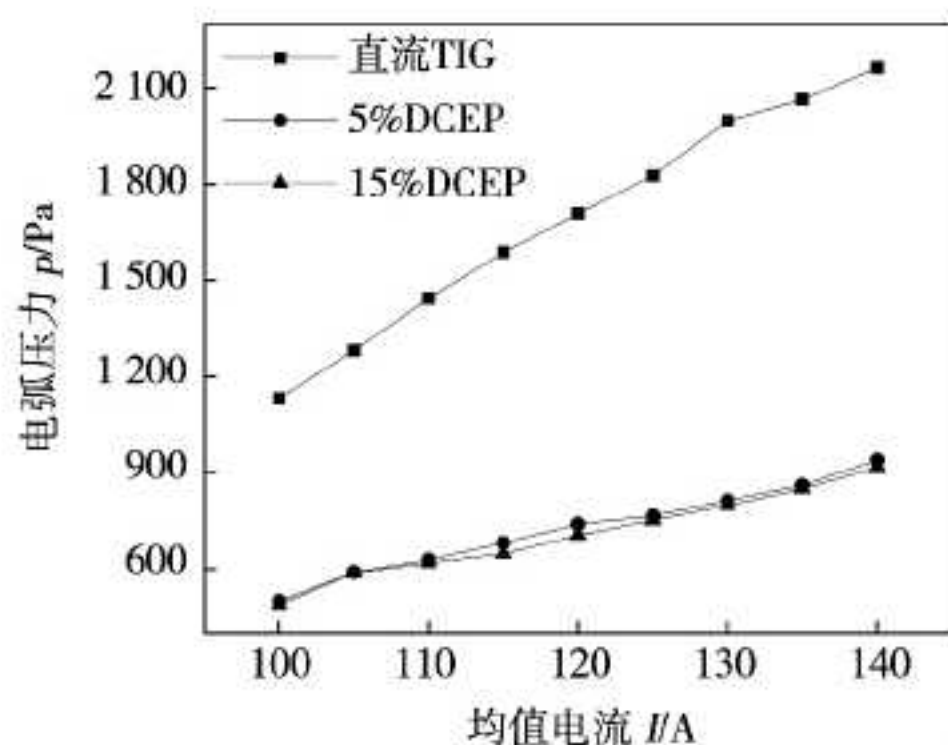


图 6 不同 TIG 条件下电弧中心压力随电流变化趋势

Fig. 6 Central pressure with different welding currents in TIG

由图 6 可以看出, 电流在 100 ~ 140 A 范围内,

直流 TIG 焊电弧压力明显大于变极性 TIG 中 DCEP 占 5% 的电弧压力, 大于变极性 TIG 中 DCEP 占 15% 的电弧压力. 分析其原因, 由电弧压力的表达式^[4]知:

$$p_{\text{arc}} = \frac{\mu_0 I^2}{4\pi^2 R_1^2} \quad (5)$$

式中: I 为焊接电流; R_1 为电弧半径; μ_0 为真空磁导率. 由式(5)知电弧压力不仅与电流平方, 而且和电弧半径的平方也有关系. 在变极性 TIG 焊正极性期间钨极为热阴极, 电子发射方式主要以热发射为主, 钨极发射电子能力强, 电弧形态稳定且集中, 电弧中心处电子密度以及动量较大, 所以电弧压力较大. 而在反极性期间铜板作为冷阴极, 热电子发射能力差, 电子发射主要以场致发射为主, 电弧中心电子密度及动量较小. 阴极斑点跳动, 电弧发散, 电弧半径变大, 从而导致钨极为正半波(DCEP)阶段的电弧压力小于钨极为负半波(DCEN)阶段的电弧压力. 由直流 TIG 焊、DCEP 占 5% 变极性 TIG 焊到 15% 的变极性 TIG 焊, 随着钨极为正半波(DCEP)的时间比例逐渐增加, 则一个周期内的电弧中心处电弧压力逐渐减小.

随着焊接电流的增加, 电弧产生更多的能量, 激发更多的带电离子且加大了离子的喷射速度, 导致电弧压力也显著增大. 假定 TIG 焊电弧在 100 ~ 140 A 内, 电弧分布集中系数保持不变, 则可以得到不同电流条件的电弧积分力 F . 以焊接电流的平方为横轴, 电弧积分力 F 为纵轴, 得到的焊接电弧积分力与焊接电流平方之间的关系如图 7 所示.

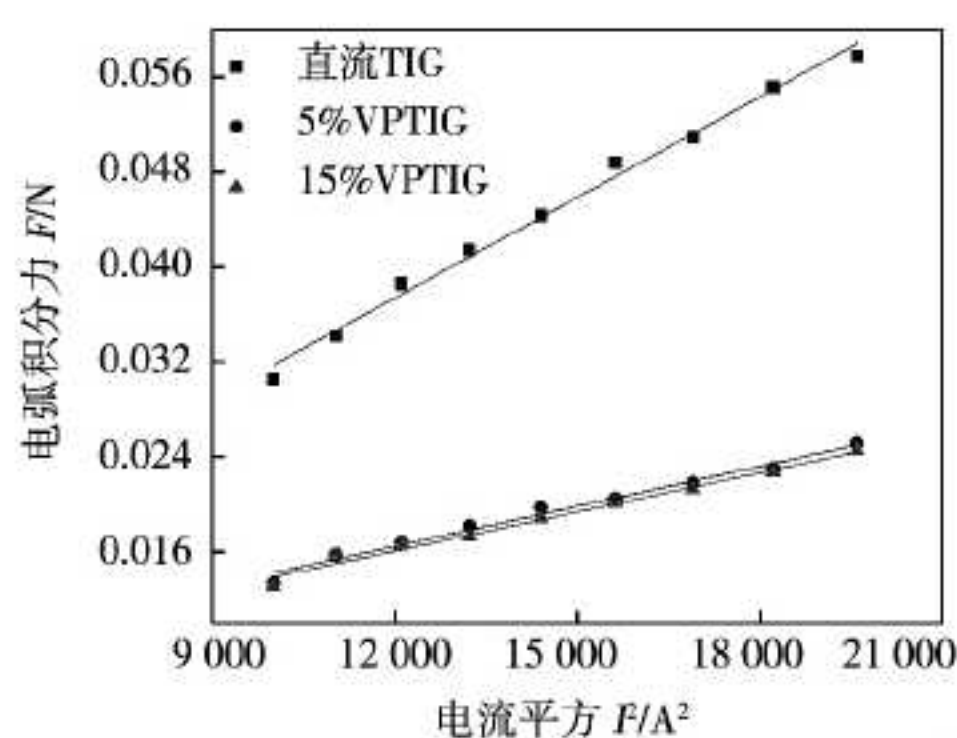


图 7 电流平方与电弧积分力之间的关系

Fig. 7 Relationship between I^2 and integrated arc force

由图 7 可以看出在测量误差一定的范围内, 焊接电弧积分力与焊接电流的平方成正比例关系, 同时可以看出不同 TIG 焊接方法, 电弧力与电流平方比值是不同的, 以直流 TIG 焊的斜率最高, 而占 5% 的 DCEP 的变极性 TIG 焊与占 15% 的变极性 TIG 焊

的斜率基本一致, 可以说明变极性 TIG 焊接方法中 DCEP 所占的时间比例对电弧力与电流平方之间的斜率影响不大.

3 结 论

(1) 变极性 TIG 焊电弧压力沿径向属双面指数分布.

(2) 在电流均值相等的情况下, 直流 TIG 电弧压力大于变极性 TIG 焊电弧压力.

(3) 在变极性 TIG 焊反极性期间, 电弧的产生机制和电弧的发散使电弧压力小于正极性期间电弧压力, 从而导致 DCEP 占 15% 的变极性 TIG 焊电弧压力小于 DCEP 占 5% 的变极性 TIG 焊电弧压力.

(4) 按照双面指数分布得到的电弧力的积分力近似与电流的平方呈正比.

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Abstract: In order to understand the corrosion resistance of different materials surfaces machined by micro wire electrical discharge machining (MWEDM), the specimens of three kinds of materials, including W18Cr4V, 60Si2Mn and M42, were separately processed. The micro electrolytic cell equipment and electrochemical workstation were applied to test the corrosion resistance of specimen surfaces, and the electrochemical impedance spectroscopy and potentiodynamic polarization curves were measured and analyzed. Besides, the surfaces after corrosion were observed with inverted metallurgic microscope, and were compared to flat grinding surfaces. The results showed that corrosion resistance of MWEDM surfaces was superior to that of flat grinding surfaces. For different materials, corrosion resistance of MWEDM surfaces was significantly different from each other. For the same material, the surface with better corrosion resistance could be obtained by using appropriate processing parameters.

Key words: micro wire electrical discharge machining; corrosion resistance; electrochemical impedance spectroscopy; potentiodynamic polarization curve

Using dynamic induction heating to inhibit martensite structure formed in heat-affected zone of U71Mn steel rail after surface welding YAN Wentao, LI Xiaoyan, LI Hui, SUN Jiantong (School of Material Science and Engineering, Beijing University of Technology, Beijing 100124, China). pp 97 - 100, 108

Abstract: A dynamic induction heating method was used to inhibit the formation of martensite in heat-affected zone (HAZ) of U71Mn steel rail after surface welding. The inhibition of martensite structure was characterized by optical microstructure analysis and microhardness testing. The experimental results showed that when the U71Mn steel rail was welded in cold welding condition, cracks would form directly in the heat-affected zone, and the microstructure was martensite. With the increase of preheating and post-heating temperature, the amount of martensite reduced significantly. When the preheating temperature was 320 °C and post-heating temperature was 550 °C, the martensite structure could be inhibited completely, and the heat-affected zone consisted of sorbite structure whose size was smaller than pearlite structure in the base metal. The microhardness of the heat-affected zone also distributed uniformly.

Key words: dynamic induction heating; U71Mn steel rail; surface welding; martensite

Arc pressure analysis in variable polarity TIG welding CHENG Lin, HU Shengsun, WANG Zhijiang (Tianjin Key Laboratory of Advanced Joining Technology, Tianjin University, Tianjin 300072, China). pp 101 - 104

Abstract: The arc pressure during horizontal variable polarity gas tungsten arc welding (VPTIG) was measured by pressure transducer under different welding conditions. The radial distribution of arc pressure was investigated, and the central arc pressures for DC TIG welding and VPTIG welding with a period of 5% and 15% for direct current electrode positive (DCEP) were compared. The experimental results showed that the radial

distribution of VPTIG pressure was hyperbolic. When the welding current was in the range of 100 A to 140 A and with the same root mean square value, the arc pressure decreased gradually with the increase of time ratio of DCEP at one cycle during DC TIG welding and VPTIG welding with a period of 5% and of 15% for DCEP, due to the difficulties of electron emission and arc divergence in the period of DCEP. And the integrated arc force was directly proportional to the square of welding current.

Key words: hyperbolic distribution; arc pressure; horizontal welding; variable polarity gas tungsten arc welding

Effect of hot-cutting defect on reliability of brazing process in ceramic package manufacturing—II. Brazing structure design ZENG Chao, WANG Chunqing, TIAN Yanhong, ZHANG Wei (State Key Lab of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 105 - 108

Abstract: Reliability of brazing process in ceramic package manufacturing depends on the interaction between thermal stress induced by mismatch of CTE (coefficient of thermal expansion) and defect in ceramic generated in the process before brazing. This paper based on the feature that defects with different degrees of danger spatially locate differently, and employed ANSYS software to analyze the distribution of the thermal stress in brazing process. A novel idea of avoiding the stress locating at defect region was applied to improve the reliability of assembly process. This idea is different from the traditional optimizing method to lowering the stress over the whole component, and is more flexible for the package design, and it is also more effective for improving the reliability of ceramic package manufacturing.

Key words: thermal mismatch; package structure; process reliability

Finite element numerical simulation of electron beam welding of TC4 titanium alloy ZENG Qingji¹, XU Lianying^{1,2}, HAN Yongdian^{1,2}, JING Hongyang^{1,2}, ZHOU Chunliang³ (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin 300072, China; 3. The 18th Research Institute of CETC, Tianjin 300381, China). pp 109 - 112

Abstract: The optimized welding parameters for electron beam welding of 9 mm thick TC4 titanium alloy plate were obtained. A finite element model was established based on ABAQUS software, and the simulated results of the weld appearance and residual stress on the weld surface agreed well with the experimental results. This proved that the combined heat source with highly penetrating cone heat source and highly irradiative dual-ellipsoid heat source could characterize the electron beam welding. Further simulated results showed that high residual stress occurred around the weld, especially, dangerous three-dimensional tensile stress existed within the weldment.

Key words: electron beam welding; TC4 titanium; finite element numerical simulation; residual stress; composite heat source