

氮氧元素联合过渡对气体熔池耦合活性 TIG 焊电弧的影响

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摘 要: 针对外层引入氮氧混合气体的气体熔池耦合活性 TIG 焊电弧, 采用 Boltzmann 作图法分析在不同耦合度下电弧等离子体的温度分布和电弧电压的变化规律, 并与传统 TIG 焊及外层只引入氧气的气体熔池耦合活性 TIG 焊进行比较。结果表明, 氮氧联合过渡时气体熔池耦合活性 TIG 焊电弧的中心区域温度和电弧电压均高于传统 TIG 焊与外层只引入氧气时的气体熔池耦合活性 TIG 焊的数值; 当耦合度由 0 变为 +2 时, 电弧中心区域温度与电弧电压均略有升高。

关键词: 气体熔池耦合活性 TIG 焊; 光谱分析; 氮氧联合; 电弧

中图分类号: TG 403 文献标识码: A 文章编号: 0253-360X(2015)03-0031-04

0 序 言

20 世纪 60 年代乌克兰巴顿焊接研究所^[1]首先提出活性焊接方法, 引起了世界范围内的广泛关注。在以往的活性焊接法中, 活性元素通过在待焊焊道表面涂敷一层特制的活性剂(如 A-TIG)或者采用活性混合保护气体两种方式引入活性元素。陆善平等^[2]使用双层保护气体进行活性 TIG 焊, 防止了钨极烧损。兰州理工大学通过改变活性元素的引入种类和控制方式, 提出了一种新型活性焊接方法——气体熔池耦合活性 TIG 焊^[3] (gas pool coupled activating TIG, GPCA-TIG 焊), 该方法采用内外两层气体进行 TIG 焊, 内层惰性气体保护熔池金属和钨电极, 外层混合气体引入元素 N 和活性元素 O, 直接将活性元素 O 引入到熔池表面低温区域, 并通过调节外层活性气体与熔池金属耦合程度来微量调节元素 N 和 O 的引入区域和引入量, 可以方便地实现对焊缝成形和焊缝性能的控制。

与现有其它检测方法相比, 光谱分析法具有信息丰富、灵敏度高、响应速度快、抗干扰能力强等一系列独特的优点, 所以越来越多的学者用它来研究电弧等离子体。韩国明等人^[4]利用光谱分析对 Ar + H₂ 电弧温度及成分分布进行测量, 并开发了电弧中

有害氢的实时测控方法。刘凤尧等人^[5]逐点测试了活性化 TIG 焊 (A-TIG) 电弧光谱的空间分布及频域, 分析了 A-TIG 电弧光谱构成。目前尚无学者研究氮氧元素联合过渡对电弧的影响。

针对 GPCA-TIG 焊电弧, 采用 Boltzmann 作图法研究了外层气路引入氮氧混合气体时, 耦合度改变对电弧等离子体温度分布的影响, 并结合电弧电压的变化, 通过与传统 TIG 焊及外层气路加入氧气时的结果进行对比, 分析了氮氧元素联合过渡对 GPCA-TIG 焊电弧的影响。

1 试验方法

研究对象分别为传统 TIG 焊电弧和 GPCA-TIG 焊电弧, 其中 GPCA-TIG 焊如图 1 所示, 其内层气体为纯氩气, 外层气体为氮气 + 氧气混合气体。焊机为唐山松下公司的交直流两用脉冲氩弧焊机 WP300, 电弧光谱采集装置为荷兰 Avantes 公司的光纤式数字光谱仪 AvaSpec-2048-8-USB2。焊接电弧特性的分析和采集系统如图 2 所示, 其中 1 为采集电弧, 2 为准直镜头, 3 为通光小孔, 4 为光纤探头, 5 为光谱设备, 6 为微调平台, 7 为数据采集计算机。选用水冷紫铜块作为电弧阳极进行定点采集, 同时记录电弧电压。GPCA-TIG 焊工艺参数如表 1 所示。

由于外层气体与熔池表面的耦合程度不易直接测量, 用焊枪内外喷嘴的相对高度来表征。当外喷

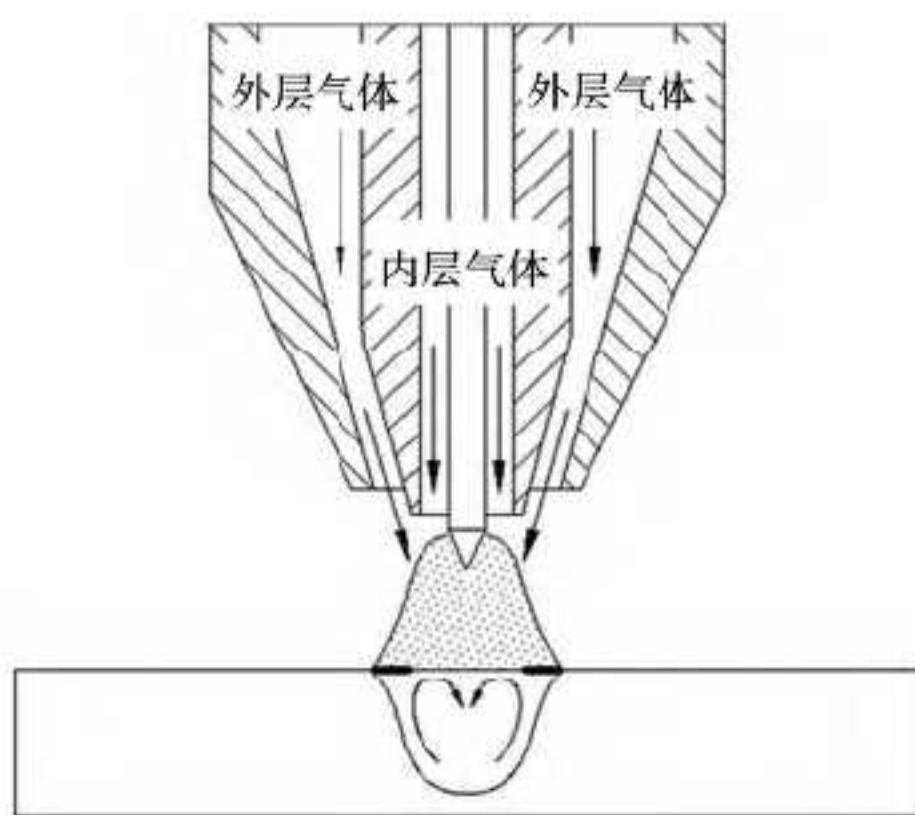


图1 GPCA-TIG 焊接方法示意图

Fig. 1 Schematic diagram of GPCA-TIG welding method

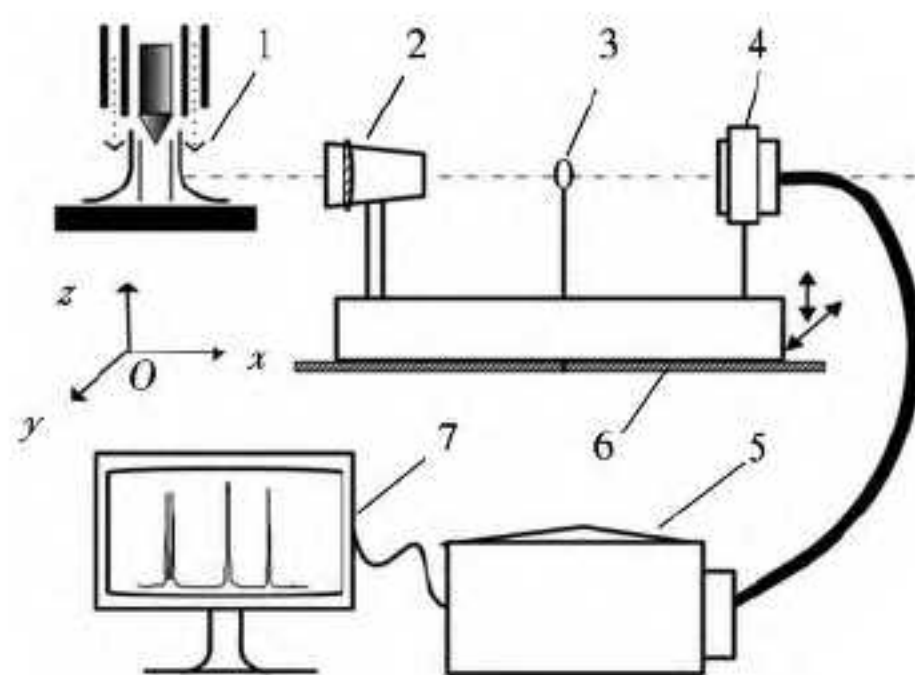


图2 采集系统

Fig. 2 Collection system

嘴相对于内喷嘴下降2 mm、平齐以及上升2 mm 时,

表1 不同耦合度 GPCA-TIG 焊试验参数

Table 1 Experimental parameters of GPCA-TIG welding under different coupling degrees

焊接电流	钨极直径	钨极伸出长度	钨极尖端角度	弧长	内层氩气流量	外层气体流量	耦合度
I/A	d/mm	L_1/mm	$\theta/(\circ)$	L_2/mm	$Q_1/(L \cdot \min^{-1})$	$Q_2/(L \cdot \min^{-1})$	h
180	2.4	3	45	4	10	2.5+2.5	0 或 +2

分别定义其耦合度分别为 $-2, 0, +2$ 。

2 试验结果

2.1 电弧光谱信息

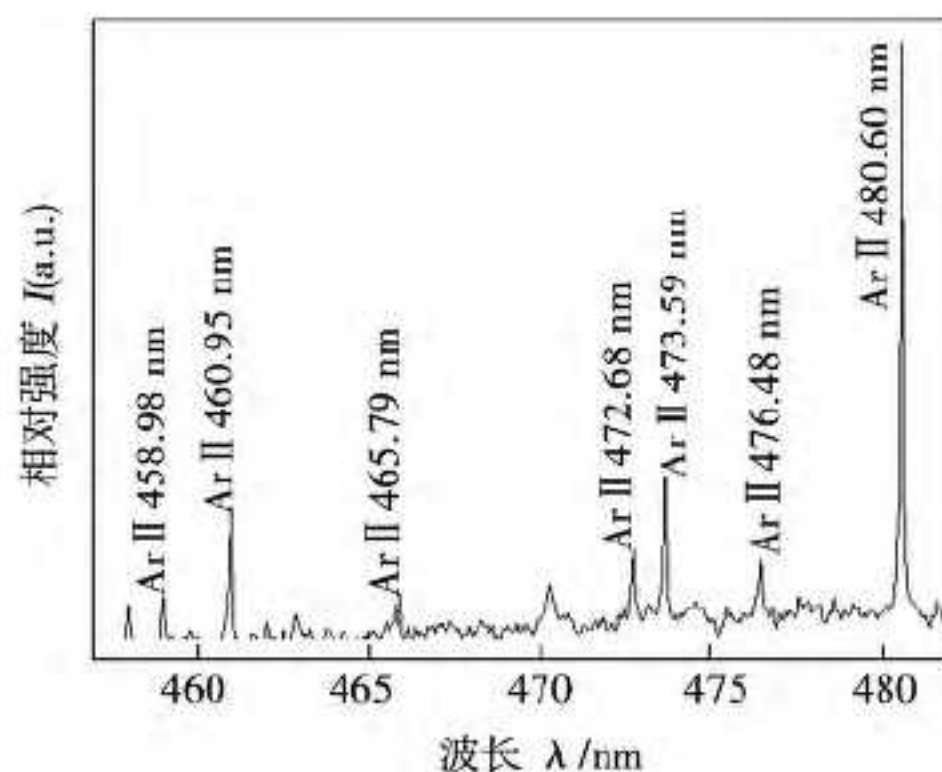
根据 Boltzmann 作图法的要求, 选取 Ar II 在 450 ~ 490 nm 谱线, 并查询 NIST 数据库内相关系数 (跃迁概率 A 、统计权重 g 和激发态能量 E), 对特征谱线进行标定, 如图 3a 所示。通过外层气路引入氮气与氧气的混合气体且耦合度为 +2 时, 采集得到电弧特征谱线如图 3b 所示, 其中出现了 NI、OI 谱线, 表明进行 GPCA-TIG 焊时, 电弧等离子体中引入了元素 N 与 O。

2.2 电弧温度测量计算

分别对传统 TIG 焊与 GPCA-TIG 焊钨极尖端正下方右侧 2 mm 层面位置上, 每隔 0.5 mm 对电弧信息进行扫描, 如图 4 所示。

将采集到的电弧信息, 运用 Boltzmann 作图法计算拟合出采集点的温度。数据计算处理过程以传统 TIG 焊为例, 计算的位置在钨极正下方距钨极端部 2 mm, 选取谱线的特征强度如表 2 所示。

对表 2 数据采用 Boltzmann 作图法进行分析, 得到 $\ln [\varepsilon_L / (v A g)]$ 与 E 的直线关系^[9], 如图 5 所示, 其中 ε_L 为辐射系数, v 为谱线频率。拟合计算结果为 $y = a + bx$, $a = -34.179 \pm 0.5536$, $b = -0.569 \pm 0.0276$, 其中方差为 0.9860。由斜率 ($-1/k_B T$) 可得到该位置的温度为 20 402.4755 K, 其中 k_B 为



(a) TIG焊

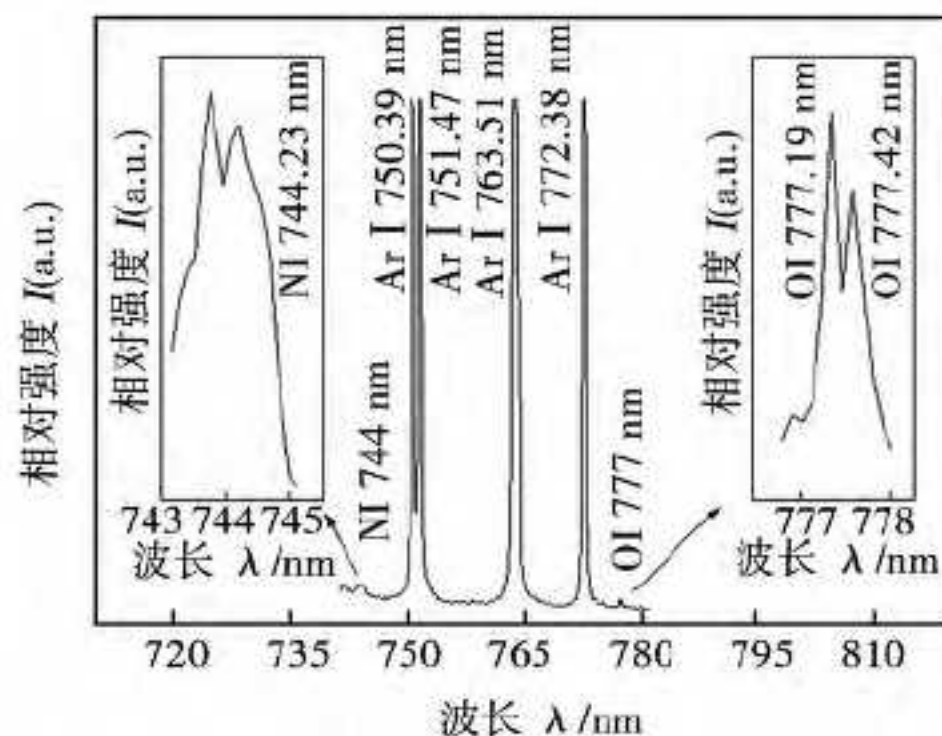
(b) GPCA-TIG焊 N_2+O_2

图3 光谱线

Fig. 3 Spectrum line

Boltzmann 常数, T 是等离子体温度。

对所采集到的电弧等离子体光谱信息, 拟合出距钨极尖端2 mm 层面上传统TIG焊与不同参数

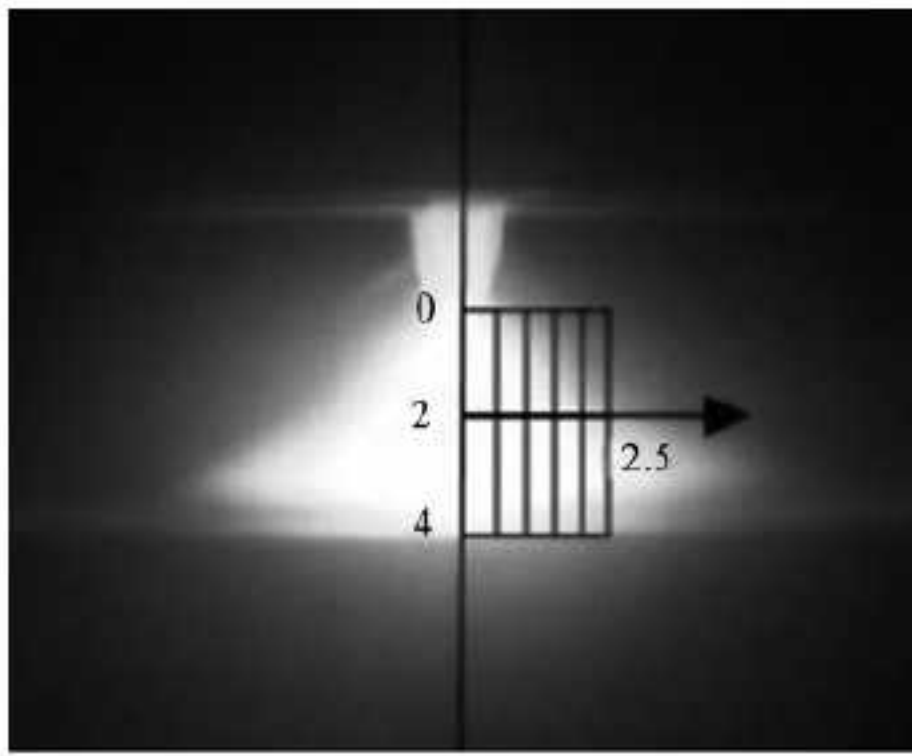


图4 扫描位置

Fig. 4 Scan place

表2 谱线强度

Table 2 Spectral intensity

编号	波长 λ/nm	特征强度 $I(\text{a. u.})$	编号	波长 λ/nm	特征强度 $I(\text{a. u.})$
1	458.98	2 426.120 1	5	473.59	3 560.409 9
2	460.95	3 257.600 2	6	476.48	2 758.030 0
3	465.79	2 139.297 9	7	480.60	7 629.460 4
4	472.68	2 855.159 9			

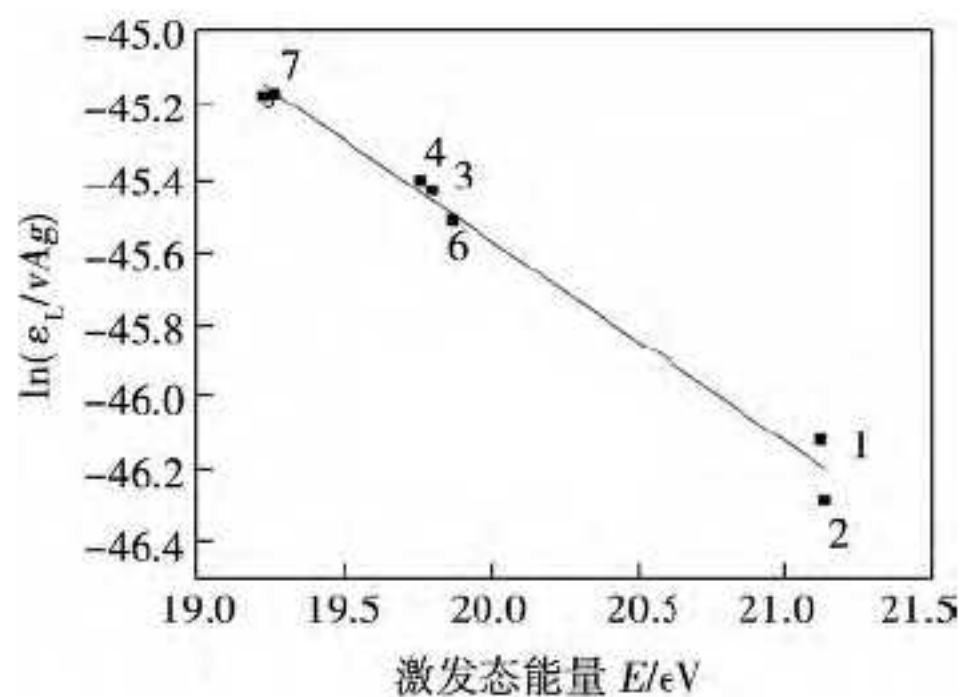


图5 玻耳兹曼作图方法

Fig. 5 Boltzmann plot method

GPCA-TIG 焊的温度分布如图 6 所示。可以看出: (1) 测量所得的传统 TIG 焊电弧温度分布与文献 [6] 的电弧温度分布基本吻合; (2) 与传统 TIG 焊相比, 外层气体引入氮气 + 氧气混合气体时的 GPCA-TIG 焊电弧中心温度增加约 2 000 K, 外围温度下降约 1 200 K; 耦合度为 +2 时的 GPCA-TIG 焊电弧中心区域温度略高于耦合度为 0 时的, 但不明显。

2.3 电弧电压测量

分别对传统 TIG 焊与外层引入氮气 + 氧气混合气体且耦合度为 0 和 +2 时的 GPCA-TIG 焊的电弧电压进行测量采集, 得到的电弧电压结果如表 3 所示。与传统 TIG 焊相比, 氮氧联合过渡时 GPCA-TIG

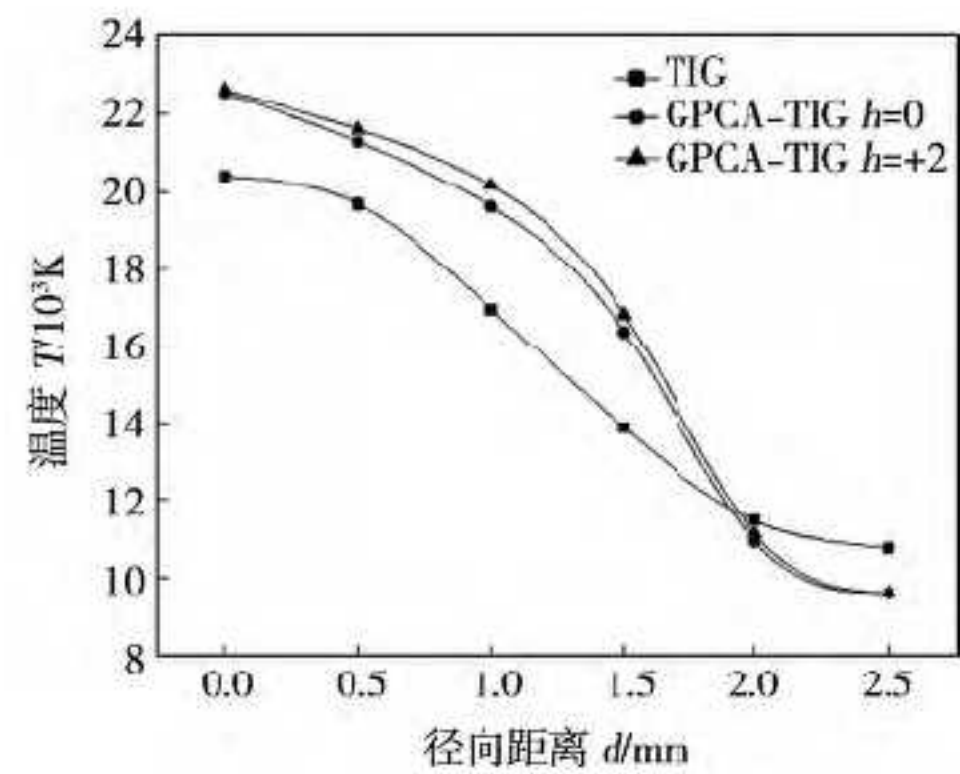


图6 温度分布

Fig. 6 Temperature distributions

焊电弧电压值有一定程度的升高, 且耦合度为 +2 时的电弧电压高于耦合度为 0 时的。

表3 GPCA-TIG 焊电弧电压

Table 3 Arc voltage of GPCA-TIG

焊接方法	耦合度 h	电弧电压 U/V	备注
TIG		19.2	
GPCA-TIG	0	20.8	外层引入氮气 + 氧气
GPCA-TIG	+2	21.5	外层引入氮气 + 氧气

3 分析与讨论

氮氧联合过渡时的 GPCA-TIG 焊电弧温度高于传统 TIG 焊, 且耦合度发生改变时电弧温度也有略变化; 与传统 TIG 焊相比, GPCA-TIG 焊电弧电压也较高。

探究其原因, 一方面是当外层气路引入气体时, 外层气体流动使得内层气体所产生的电弧等离子体的热量耗散加大, 根据最小电压原理, 电弧收缩, 电弧电压升高, 电弧中心等离子体电流密度增大, 导致电弧中心区域温度升高; 另一方面对于氮氧元素联合过渡情况, 焊接过程中氮气与氧气通过外层气路引入时, 不仅对内层气体起冷却作用, 氮气与氧气在高温电弧和高电场作用下还发生解离和电离过程, 进一步促使电弧等离子体的热量耗散加大, 导致电弧收缩, 电弧电压升高, 电弧中心区域温度升高。当耦合度为 +2 时, 外层气体的挺度大于耦合度为 0 时的, 更多外层较冷气体进入电弧等离子体中心区域, 对电弧等离子体的冷却作用加强, 故电弧收缩, 电弧电压升高, 电弧中心区域温度升高, 但变化量不大。电弧温度与电压变化趋势吻合。

将以上试验结果与外层气体为纯氧气时 GPCA-TIG 焊的电弧温度分布及电弧电压进行对比。图 7 为不同耦合度时, 外层气体分别为氮气 + 氧气混合

气体及纯氧气时的电弧温度分布。表 4 为外层气体为纯氧气时的电弧电压值。可以看出,氮氧联合过渡对 GPCA-TIG 焊电弧温度与电弧电压的作用强于外层气体为纯氧气时的。

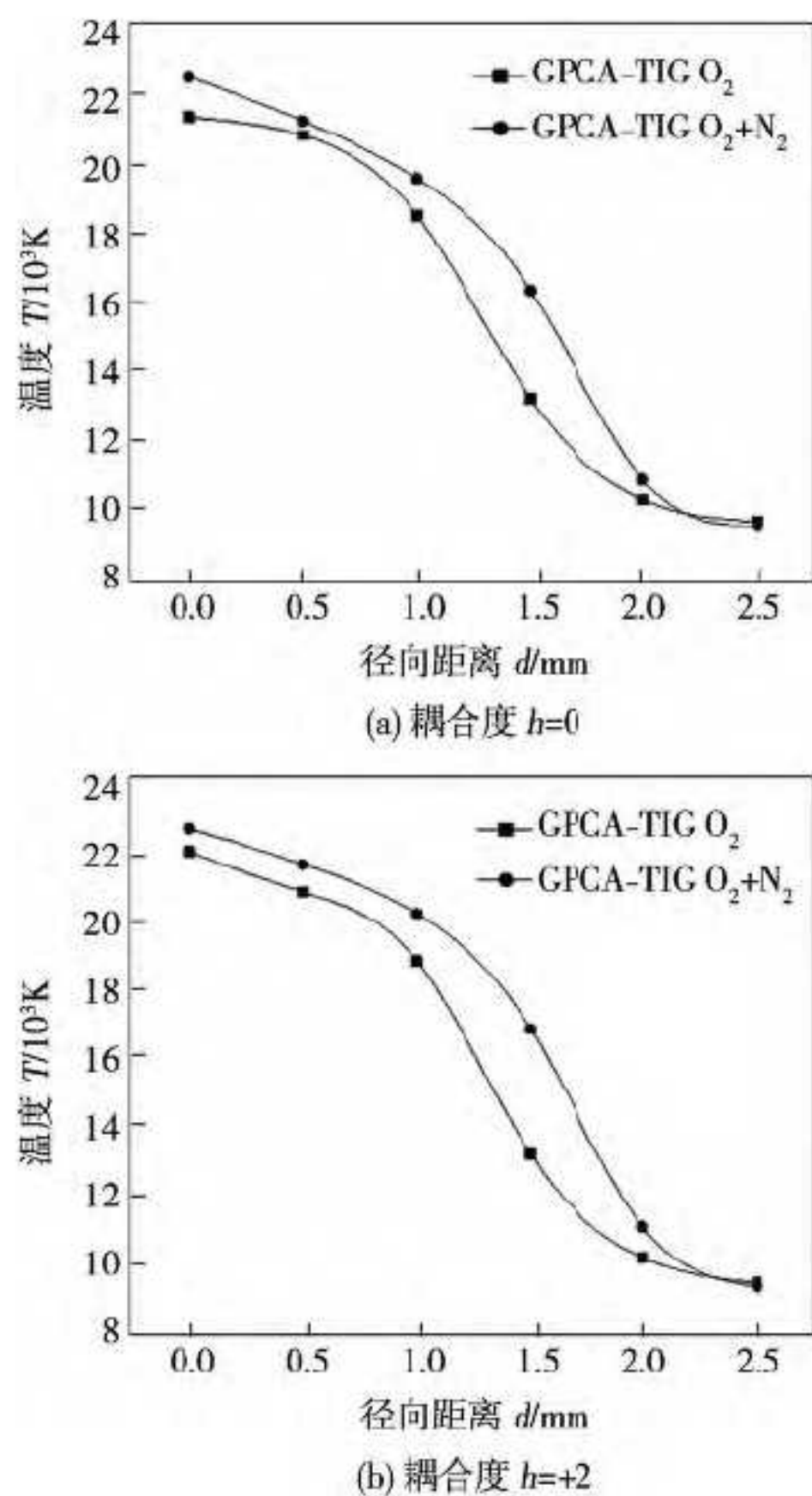


图 7 不同外层气体的电弧温度分布

Fig. 7 Arc temperature distributions of different outer gas layers

表 4 电弧电压值

Table 4 Arc voltage value

焊接方法	耦合度 h	电弧电压 U/V	备注
GPCA-TIG	0	20.6V	外层引入氧气
GPCA-TIG	+2	21.0V	外层引入氧气

造成这种现象的原因是由于在氮气分子中存在叁键 $N \equiv N$, 将它分解为原子需要吸收 941.69 kJ/mol 的能量, 而在氧气分子中存在 $O = O$ 双键, 将它分解为原子需要吸收 494 kJ/mol 的能量, 因此氮氧元素联合过渡对 GPCA-TIG 焊电弧的作用强于外层气体为纯氧气时的。

4 结 论

(1) 运用光谱分析法对 GPCA-TIG 焊电弧信息

进行分析, 与传统 TIG 焊相比, GPCA-TIG 焊外层气路引入氮气 + 氧气混合气体时, 电弧中心区域等离子体温度有一定程度升高, 耦合度为 +2 时电弧中心区域等离子体温度略高于耦合度为 0 时的。

(2) 气体熔池耦合活性 TIG 焊外层气路引入氮气 + 氧气混合气体时, 电弧电压升高。耦合度由 0 变为 +2 时, 电弧电压也略有升高。

(3) 气体熔池耦合活性 TIG 焊外层气路引入氮气 + 氧气混合气体时, 电弧温度与电弧电压均高于纯氧气时的。

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sensor· response surface method· seam-tracking signal

Effect of CO₂ content for droplet transfer in ultrasound-MAG hybrid welding

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Abstract: Since the presence of CO₂, the droplet control to MAG welding has always been a difficult problem. Based on preliminary studies, ultrasonic standing wave field, as a new method of droplet regulation, was introduced into MAG welding in this paper. In different conditions of shielding gas composition, the effect of ultrasound on droplet transfer was also studied. Under the conditions of low CO₂ content, ultrasonic effect was still very significant. But with the increase of CO₂ content, especially more than 20%, in short transition, the compression effect of ultrasound-arc tended to a constant and minimum. In droplet transition, this electromagnetic force gradually increased and eventually offset the downward ultrasound radiation force. Finally, the conclusions of the above analysis was verified by pure CO₂ ultrasonic-MAG welding experiment.

Key words: ultrasound-MAG hybrid welding; CO₂ content; arc compression ratio; conductive region angle

Characteristic of LB-VPPA hybrid heat source for welding process of aluminum alloy

HAN Yongquan, PANG Shigang, YAO Qinghu, SHI Zengjie (Key Laboratory of Material Forming, Inner Mongolia University of Technology, Hohhot 010051, China). pp 23 – 26

Abstract: Characteristic of laser beam-variable polarity plasma arc (LB-VPPA) hybrid heat source was studied for joining process of Al-Mn aluminum alloy. Arc shape was achieved by Y4-S2 high-speed camera, and welding current and arc voltage were obtained by Hannover welding quality analyzer. The results show that VPPA arc is attracted by laser and the mechanism which laser acts on arc is different for both positive polarity and negative polarity periods. Laser is concentrated on the roof of arc in positive polarity, while there is a protuberance-like plasma cylinder in negative polarity period. Roof plasma of VPPA arc absorbs laser by inverse bremsstrahlung, and cross sectional area of arc becomes large as temperature increase. Meanwhile, laser provides plenty of free electrons to VPPA arc, thus current density and conductivity increase. Arc voltage decreases about 3 – 4 volts as resistance decreases. With the increasing of laser power, it obviously enhances the effects on VPPA arc.

Key words: hybrid heat source; variable polarity plasma arc welding; aluminum alloy

Electron beam welding of SiC_p/2024 and 2219 aluminium alloy

CHEN Guoqing, ZHANG Binggang, YANG Yong, FENG Jicai (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 27 – 30

Abstract: SiC_p/2024 matrix composites reinforced with

SiC particles and 2219 aluminium alloy were joined by centered electron beam welding and deflection beam welding, respectively, and the microstructures and mechanical properties of these joints were studied. The results show that SiC particles were more likely to segregate by centered electron beam welding, meanwhile lots of Al₄C₃ brittle intermetallic compounds formed for serious interface reactions. Moreover, the tensile strength of the joints was about 104 MPa. The interface reaction was restrained by choosing deflection electron beam welding, and there was a little Al₄C₃ intermetallic compounds formed at the top of the joint and heat affected zone of SiC_p/Al. The quasi-cleavage fracture occurred at the interface reaction layer of the base metal. There was a hardness transition zone near the SiC_p/2024 fusion zone for both methods. The brittle intermetallic compounds Al₄C₃ formed in this zone results in the high hardness.

Key words: SiC_p/2024 matrix composite; 2219 aluminium alloy; electron beam welding; microstructure; mechanical properties

Effect of and oxygen on welding arc of gas pool coupled activating TIG

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Abstract: As to the gas pool coupled activating TIG arc with the outer gas being the mixture of nitrogen and oxygen, Boltzmann plot method was applied to analyze the temperature distributions of the arc plasma and the regularity for change of the arc voltage when they were under different coupling degrees, and then the results were compared with the traditional TIG arc and the gas pool coupled activating TIG arc only using oxygen as the outer gas, respectively. The results show that both the plasma temperature of central zone and the arc voltage of the gas pool coupled activating TIG arc with the outer gas being the mixture of nitrogen and oxygen are higher than those of the TIG arc and gas pool coupled activating TIG arc with oxygen being introduced only. When the coupling degree h is changed from 0 to +2, both the arc plasma temperature of central zone and arc voltage are increased slightly.

Key words: gas pool coupled activating TIG welding; spectra analysis; nitrogen in conjunction with oxygen; welding arc

Numerical simulation of temperature field of WC-12Co coating by monopoles electro spark deposition

WEI Hongmei, CHU Weishen, LIN Tiesong, HE Peng (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 35 – 38

Abstract: In order to determine the temperature field of WC-12Co coating, mathematical model of heat conduction was established by utilizing suitable heat source and the thermal boundary conditions. Numerical simulation was carried out by commercial finite element code ANSYS, and iso-surface, the temperature distribution curve and temperature variation curve