

Ar-Ar 变动送气条件下 5A03 铝合金 TIG 焊 焊缝组织和性能

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摘要: 5A03 铝合金在传统 TIG 焊接过程中, 焊缝易存在强度低、晶粒粗大的问题. 为了改善 5A03 铝合金焊缝性能, 在传统 TIG 焊接方法的基础上, 改变保护气的送给方式, 针对板厚为 2.5 mm 的 5A03 铝合金板进行对接焊接试验. 焊后分别对焊缝进行拉伸试验、断口形貌分析、偏振光电子显微镜和扫描电镜的观察及电化学分析. 结果表明, 与传统焊获得的焊缝相比, 1 Hz 变动送气 TIG 焊所获得的焊缝抗拉强度提高了 18.5 MPa, 提升强度约为传统焊缝强度的 10%, 两种焊缝的断裂形式均为塑性断裂. 对比焊缝晶粒尺寸发现, 1 Hz 变动送气条件下获得的焊缝晶粒更加细小, 并且 β 相 Al_3Mg_2 在铝基体上呈现弥散形态分布; 电化学结果分析表明, 变动送气 TIG 焊焊缝自腐蚀电流密度增大, 容抗弧半径减小, 自腐蚀电位负移 0.04 V, 传统焊焊缝的耐蚀性较好.

创新点: 在原有 TIG 焊基础上, 将送气方式由连续送气改为变动送气.

关键词: 5A03 铝合金; Ar-Ar 交替; TIG 焊; β 相; 耐蚀性

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0 序言

铝及其合金具有密度小、比强度高、耐腐蚀性能好等一系列优点, 其中 5A03 铝合金被广泛应用于飞机和汽车零部件的制造^[1-3]. 目前最常用的焊接方法为 TIG 焊^[4-5] (非熔化极惰性气体保护焊). 对于铝合金, 传统 TIG 焊接方法所获得的焊缝强度低、气孔多、熔深浅、焊缝区晶粒粗大且耐蚀性较差^[6-9]. 因此寻找一种新的焊接方法以提高焊缝性能具有重大的意义. 通常改善以上焊接接头缺陷的方法有改变焊接电流、焊接速度和送气频率^[10-12], 相比较其它改善方法, 改变送气频率最为简便易行^[13-15].

针对 5A03 铝合金采用自制的变动送气装置进行送气, 利用计算机精确控制变动送气装置中的电磁阀, 通过两个送气通路在不同频率 Ar-Ar 交替送气下进行 TIG 焊接. 前期研究结果表明焊枪处气体流量的改变必然会导致由电弧推力引起高温气流运动, 将会以脉冲压力的形式直接作用到熔池表

面, 对焊缝成形产生影响^[16]. 焊缝表面呈现典型鱼鳞纹分布形式, 鱼鳞纹分布间隔和交替送气频率相对应. 文中将进一步研究变化送气条件下焊缝的性能与传统 TIG 焊焊缝性能的差异.

1 试验方法

试验板材为 5A03 铝合金, 合金力学性能及焊接参数见表 1.

表 1 5A03 铝合金力学性能
Table 1 Mechanical properties of 5A03 aluminum alloy

抗拉强度 R_m/MPa	条件屈服强度 R_{eL}/MPa	断后伸长率 $A(\%)$
≥ 220	≥ 80	≥ 15

选用 MasterTig MLS 3003ACDC 型焊机, 并配以焊接移动平台, 分别对板材进行 1 Hz 及传统送气 TIG 对焊焊接. 焊接原理图如图 1 所示.

为保证焊接接头质量, 焊接保护气体采用高纯度 99.99% 的氩气, 且保证保护气体充足, 防止保护气不足而影响试验结果. 焊接参数见表 2.

在对焊缝组织进行阳极覆膜处理后, 利用 GX-

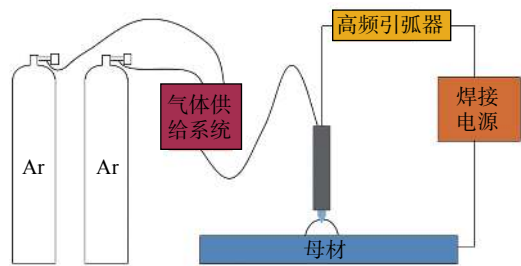


图 1 焊接原理图
Fig. 1 Diagram of welding principle

71 型偏振光电子显微镜和扫描电镜对焊缝进行显

微组织观察和 EBSD 分析;利用线切割机将所获得的焊缝切割出厚度为 2.5 mm 的标准拉伸试样,拉伸试样标距 10 为 40 mm,宽度 b 为 10 mm,总长度为 90 mm. 通过电子万能试验机测出焊缝区力-位移拉伸曲线,试验时拉伸速率 2 mm/min. 使用场发射扫描电镜对微观断口形貌进行分析;模拟海洋环境,利用 CS350 电化学工作站,对焊缝进行耐腐蚀性分析,试验时工作电极(腐蚀试样)的暴露面积为 4 mm²,辅助电极为铂片电极,参比电极为甘汞电极,扫描区间为-0.3 V ~ 0.3 V,扫描速率为 0.66 mV/s.

表 2 焊接工艺参数
Table 2 Welding parameters

序号	频率/Hz	电流类型	焊接电流/ I/A	保护气	交替类型	焊接速度 $v/(cm \cdot min^{-1})$
1	—	AC	90	Ar	Ar	21
2	1	AC	90	Ar	Ar- Ar	21

2 试验结果及分析

通过扫描电镜获得焊缝区 SEM 图像和 EBSD 图像如图 3、图 4 所示.

2.1 变动送气焊接方式对焊缝区晶粒的影响

通过偏振光电子显微镜获得传统送气焊缝和 1 Hz 下变动送气焊缝偏光形貌如图 2 所示.

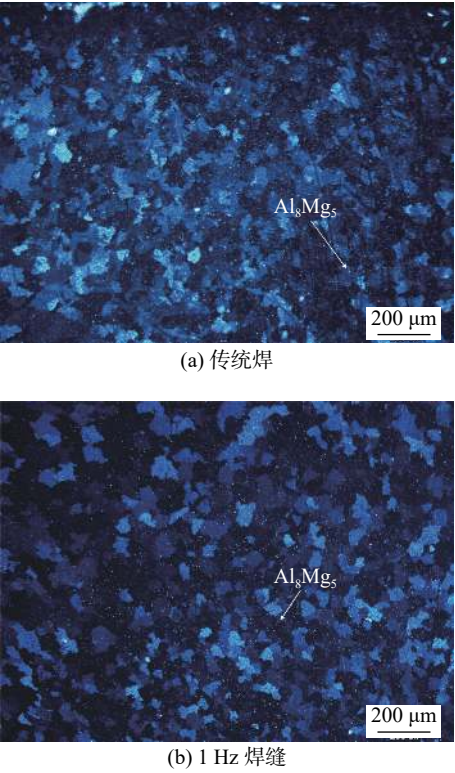


图 2 不同焊接方法焊缝组织形貌
Fig. 2 Weld organization chart of different welding methods. (a) traditional welding; (b) 1 Hz welding

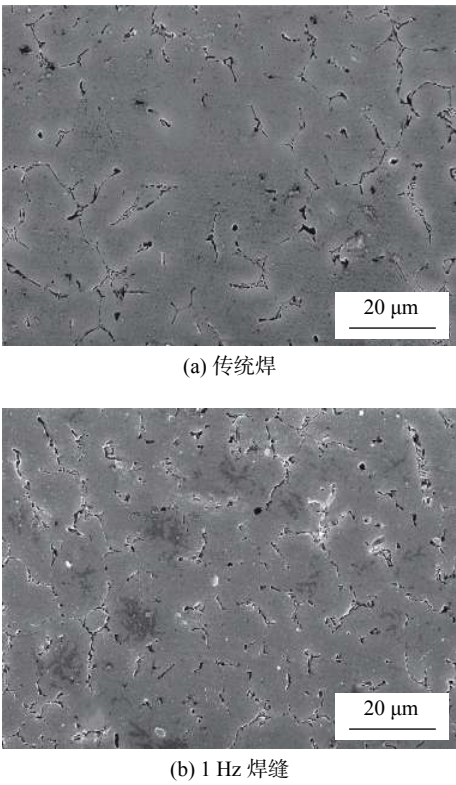


图 3 不同焊接方法焊缝 SEM 图像
Fig. 3 SEM images of different welding method. (a) traditional welding; (b) 1 Hz welding

从图 2、图 3 和图 4 中可以看出,随着送气频率的改变,焊缝区晶粒大小和均匀程度发生明显变化.与传统送气 TIG 焊所获得的焊缝相比,1 Hz 变

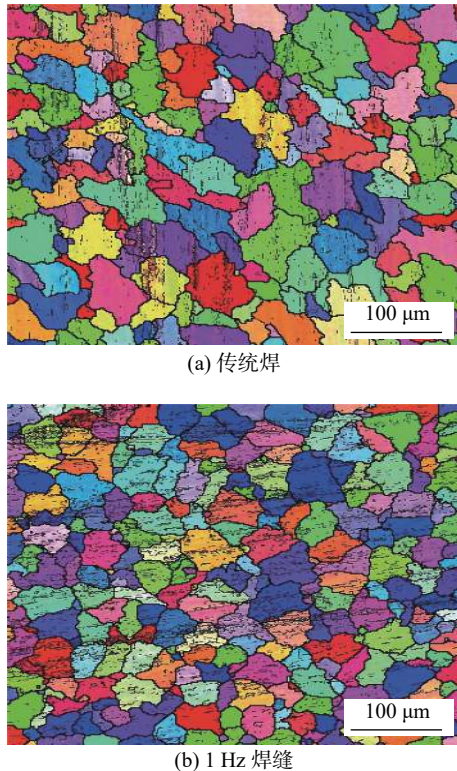


图 4 不同焊接方法的焊缝区 EBSD 图像
Fig. 4 EBSD images of different welding methods.
(a) traditional welding; (b) 1 Hz welding

动送气焊接方法所获得的焊缝晶粒尺寸明显减小, 分布更加均匀. 在 Al-Mg 合金中, β 相 (Al_3Mg_2) 是影响材料力学性能和耐蚀性的重要因素. Al_3Mg_2 在板材中呈鱼骨状分布, 但是在焊缝区呈质点状弥散分布, β 相的存在状态发生变化, 这说明在焊接过程中, 变动送气对熔池金属产生冲击和搅动的作用, 使熔池内形核质点增多, 晶粒发生细化; 与此同时鱼骨状的 Al_3Mg_2 在冲击下发生破碎, 以质点状弥散分布于焊缝中.

2.2 变动送气 TIG 焊对焊缝抗拉强度的影响

分别对两组焊缝拉伸试样的抗拉强度取平均值, 数据如表 3 所示.

表 3 拉伸试验参数
Table 3 Tensile experiment parameters.

送气频率	抗拉强度 R_m /MPa	屈服强度 R_{eL} /MPa	断后伸长率 A (%)
—	190.5	109	9.3
1 Hz	209	103	11.4

由拉伸试验结果可以得出, 5A03 铝合金在传统送气条件下的抗拉强度为 190.5 MPa, 约为母材的 86.4%; 1 Hz 变动送气 TIG 焊条件下, 焊缝的抗拉强度为 209 MPa, 约为母材的 95%, 均满足使用

要求. 传统送气焊缝和 1 Hz 变动送气焊缝的拉伸曲线如图 5 所示.

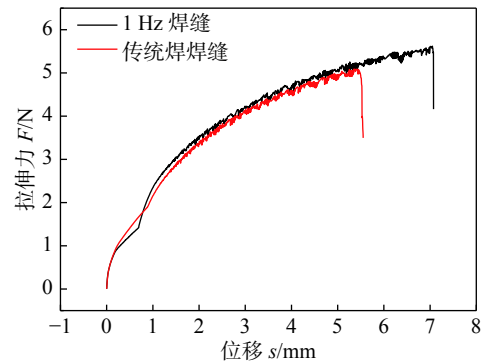


图 5 不同焊接方法焊缝拉伸曲线
Fig. 5 Tensile curves of welds in different welding methods

从拉伸曲线中可以看出, 两个试件均在经历短暂的屈服后直接进入了塑性变形阶段, 传统焊试样在力达到 1.908 kN 时, 达到屈服点, 试样开始发生塑性变形, 5.092 kN 时传统焊焊缝试样断裂, 1 Hz 试样在力达到 1.462 kN 时发生塑性变形, 力达到 5.616 kN 时 1 Hz 焊缝试样断裂. 1 Hz 焊缝抗拉强度略高于传统焊焊缝. 传统焊焊缝的屈强比为 0.37, 1 Hz 焊缝的屈强比为 0.26, 故变动送气焊缝的塑性略好.

两种送气频率焊缝的宏观断口形貌如图 6 所示, 从图中可以看出两种断口的表面粗糙不平, 颜色灰暗无金属光泽, 断面与拉伸轴线约成 60° 角, 初步判断为韧窝断裂.

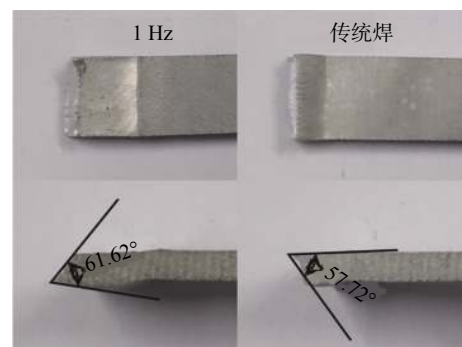


图 6 宏观断口照片
Fig. 6 Macro fracture photo

两种焊缝的微观断口形貌和 EDS 能谱如图 7 所示. 拉伸过程中, 在拉应力的作用下, 晶界、第二相质点以及焊缝缺陷处的位错会发生塞积现象, 产生位错塞积群. 随着拉应力的增大, 位错塞积群处会发生微孔的形核长大, 最终形成微裂纹引发断裂.

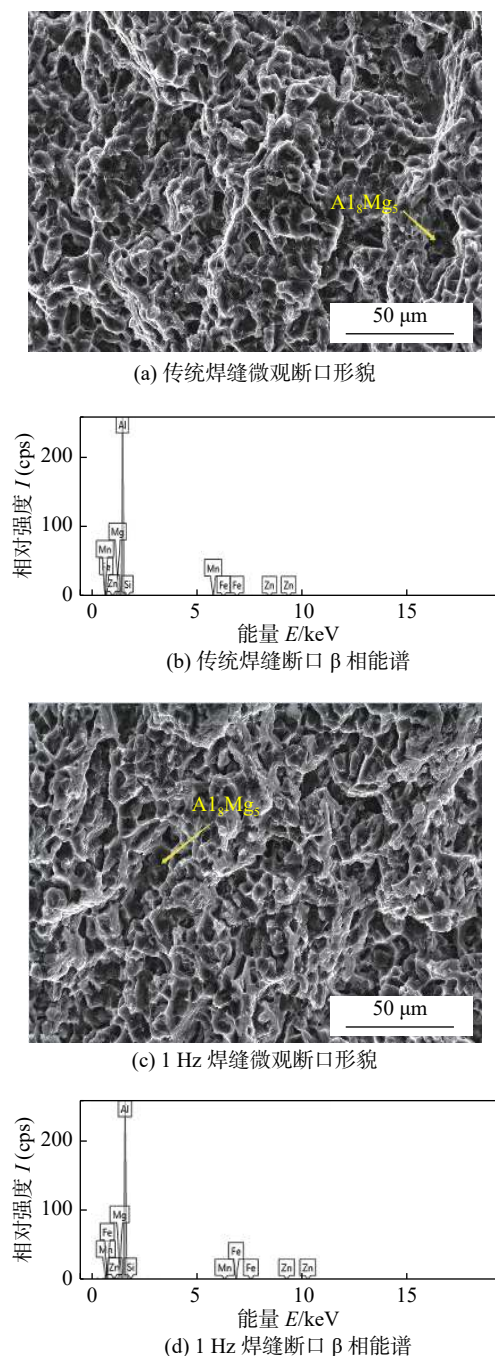


图 7 两种焊缝微观断口照片及 EDS 能谱

Fig. 7 Photographs of micro-fractures and EDS spectra of two types of welds. (a) micro-fracture morphology of traditional weld; (b) energy spectrum of β phase in traditional weld fracture; (c) microscopic fracture morphology of 1 Hz weld; (d) β -phase energy spectrum of 1 Hz weld fracture

从图 7 中可以看出两种焊缝断口表面呈纤维状, 整体灰暗, 且存在大量凹坑, 韧窝形状呈椭圆形, 两种焊缝断口形貌主要为剪切韧窝, 白色条带为剪切脊, 材料的断裂机理为微孔聚集型塑性断裂, 材料具有较好的力学性能. 传统焊缝断口的韧窝数量略少于 1 Hz 焊缝, 因此抗拉强度较低. 在断口韧窝处发

现 β 相质点, 对其进行 EDS 分析发现成分为 Al_8Mg_5 . 结合偏振光显微照片和 EBSD 图像可以发现: 在 1 Hz 变动送气条件下, Al_8Mg_5 均匀分布在晶粒中, 不沿晶界分布, 避免焊缝区晶界处产生应力集中, 故提高了焊缝的抗拉强度.

2.3 变动送气焊接方式对焊缝区耐蚀性影响

分别将两种焊接方法所获得的焊缝浸泡在浓度为 3.5% 的 NaCl 溶液中进行模拟海水腐蚀试验, 经电化学工作站测得塔菲尔曲线与尼奎斯特曲线 (Nyquist) 如图 8 所示.

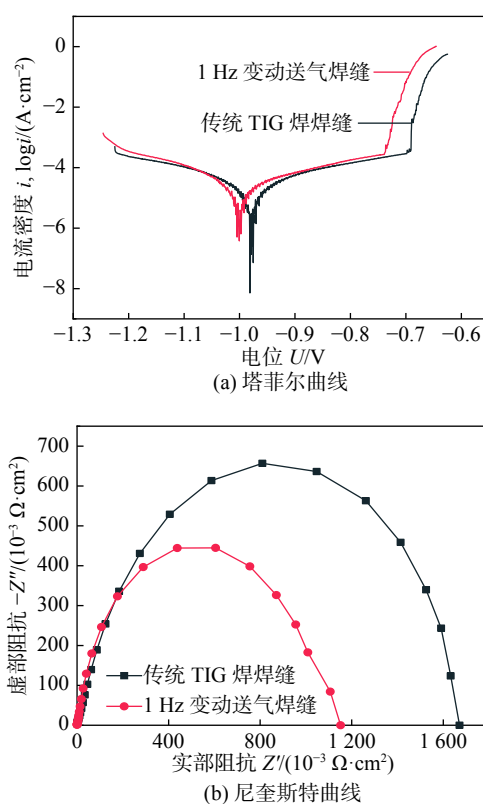


图 8 塔菲尔曲线与尼奎斯特曲线

Fig. 8 Tafel curve & Nyquist curve. (a) Tafel curve; (b) Nyquist curve

图 8a 为两种焊缝在 NaCl 溶液中腐蚀的塔菲尔曲线, 曲线中自腐蚀电位决定腐蚀倾向: 自腐蚀电位越高耐蚀性越强; 自腐蚀电流密度决定腐蚀速率: 自腐蚀电流密度越小耐蚀性越强. 从塔菲尔曲线中可以看出: 传统送气焊缝的自腐蚀电位为 -0.98 V , 1 Hz 变动送气焊缝的自腐蚀电位为 -1.02 V , 传统送气焊缝的耐蚀性较好.

从极化曲线中可以看到, 1 Hz 变动送气焊缝的自腐蚀电流密度大于传统送气焊缝的电流密度, 自两种焊缝的自腐蚀电位正移, 两种焊缝的电流密度上升速度均变缓, 说明此时腐蚀表面形成一层钝化

膜,在电位为 -0.738 V 时, 1 Hz 变动送气焊缝的电流密度开始陡升,说明此时发生点蚀现象. 传统送气焊缝在电位为 -0.69 V 时陡升,说明此时发生点蚀现象. 说明传统送气焊缝具有更好的耐腐蚀性. 结合偏光照片可以发现: 1 Hz 变动送气焊缝中 β 相的数量多于传统焊缝,所以在电化学腐蚀过程中会形成更多的微小的原电池,提高了电流密度,使腐蚀速率加快,故传统送气焊缝的耐腐蚀性略好.

图 8b 为两种焊缝在 $3.5\%\text{NaCl}$ 溶液中腐蚀的 Nyquist 曲线,阻抗的大小由曲线直径的大小决定. 从 Nyquist 曲线可以看出,两条曲线在高频区只有 1 个容抗弧,表明只有 1 个时间常数,是由于电荷转移电阻和双电层电容并联而成,说明腐蚀的进程由活化极化控制,腐蚀反应不存在浓差极化^[17]. 传统送气焊缝的阻抗弧明显大于 1 Hz 变动送气焊缝的阻抗弧,说明传统送气的焊缝生成更厚的氧化膜,耐蚀性更好.

3 结论

(1) 通过对比两种焊缝的偏振光照片和 EBSD 图像得出, 1 Hz 变动送气焊缝比传统焊缝晶粒更为细小,且焊缝中弥散分布的 β 相质点 (Al_8Mg_5) 更多,使得焊缝的抗拉强度有所提高.

(2) 对比两种焊缝的抗拉强度得出, 1 Hz 变动送气焊缝的抗拉强度更高且传统焊缝的屈服比小于 1 Hz 焊缝. 两种焊缝的抗拉强度均满足使用要求且传统焊缝的塑性较好.

(3) 通过对拉伸断口的 SEM 照片和断口处 β 相 EDS 能谱进行分析发现: 两种焊缝断口均为微孔聚集性塑性断裂; 韧窝处发现的 β 相为 Al_8Mg_5 , 裂纹形成于 β 相质点.

(4) 通过对两种焊缝进行电化学试验得出, 传统送气条件下获得的焊缝耐蚀性较强.

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joint strength shows a rising trend, up to 408 MPa, reaching 90% of the base material. The joint hardness shows a double "W"-shaped distribution. The fracture form is ductile fracture.

Highlights: (1) The robotic friction stir welding system is used to realize the welding of 0.5 mm thick ultra thin plate. (2) The characteristics of ultra-thin plate friction stir welding welding formation, microstructure and mechanical properties are analyzed.

Key words: robot friction stir welding; ultra thin aluminum alloy; microstructure; mechanical property

Effect of Cr on properties of TZM alloy joints brazed with Mo-45Ni brazing filler metal

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Abstract: In this paper, the application of TZM alloy and the development on brazing technology of TZM alloy is described. Combined with the practical engineering applications, the special brazing filler metal for TZM alloy which can serve at 1 300 °C is developed. The wettability of the brazing filler metal(BFM) over the surface of TZM alloy is tested, a reference wetting area is introduced to determine the vacuum wettability of the BFM and the effect of Cr on the properties of BFM is discussed. The results show that the corresponding relationship between shear strength and composition is that with the addition of Cr, the shear strength of the joint first becomes larger and then becomes smaller, which can provide an important reference for practical engineering applications. It is found that when the content of Cr in the BFM is 3 wt.%, the wettability of the BFM is the best and the shear strength of the joint is the highest at 135 MPa.

Highlights: (1) A special brazing filler metal Mo-45Ni-3Cr for brazing TZM alloy which can be used at 1 300 °C was developed. (2) The effect of Cr element in Mo-45Ni series brazing filler metals on the wettability of the brazing filler metals and shear strength of brazed joint was investigated. (3) The concept of "reference wetting area" was introduced to

determine the wettability of the brazing filler metal.

Key words: TZM alloy; Mo-Ni series brazing filler metal; arc smelting; vacuum brazing

Imprint characteristics extracted from images in resistance spot welding of high strength steels and relationship with welding quality

ZHANG Xuqiang, YU Zhihao (School of Mechanical Engineering, Petroleum University of China, Qingdao, 266580, China). pp 62-66,72

Abstract: High strength steel is widely used in industrial production because of its excellent properties. However, it is difficult to extract the welding characteristics of high strength steel and evaluate the quality of resistance spot welding. Electrode imprint is a direct reflection of the surface morphology of the spot welding and the end face of the electrode. Imprint image contains both spot welding information and electrode wear information. Through image processing and recognition, the contour edge of imprint image is detected and recognized, and the imprint characteristics parameters are extracted by ellipse fitting method. The imprint characteristic parameters and nugget diameter were analyzed, and the influence of each characteristic on spot welding quality was studied. The results show that the imprint contour fitted by ellipse can approximately replace the actual contour. There is a significant negative correlation between the average axial length and pitting area extracted from imprint characteristics and spot weld quality.

Highlights: (1) Image processing is used to process and extract features of high-strength steel imprint images; (2) The fitting ellipse of the imprint is used to replace its actual contour, and the relationship between the characteristics of the imprint image and the quality of the solder joint is analyzed.

Key words: weld quality; edge detection; image processing; electrode imprint

Research on the weld performance of 5A03 aluminum alloy with variable gas TIG welding

LI Jichao, DAI Hongbin (School of Materials Science and Engineering, Harbin University of Science and Technology, Harbin, 150040, China). pp 67-72

Abstract: In the traditional TIG welding process of 5A03 aluminum alloy, the weld is prone to have the problems of low strength and coarse grains. In order to improve the performance of the 5A03 aluminum alloy weld, on the basis of the traditional TIG welding method, by changing the shielding

gas supply Method of butt welding experiment on 5A03 aluminum alloy plate with plate thickness of 2.5 mm. After welding, the welds were subjected to tensile test, fracture morphology analysis, observation with polarized light electron microscope and scanning electron microscope, and electrochemical analysis. The results showed that: compared with the welds obtained by traditional welding, the results obtained by 1 Hz variable gas TIG welding The tensile strength of the weld is increased by 18.5 MPa, and the strength is about 10% of that of the traditional weld. The fracture modes of the two welds are plastic fracture. Comparing the weld grain size, it is found that the weld grains obtained under the 1 Hz variable air supply condition are smaller, and the β -phase Al_8Mg_5 presents a dispersed morphology distribution on the aluminum substrate; the electrochemical results analysis shows that the self-corrosion current density of the variable air TIG weld Increased, the capacitive arc radius decreases, and the self-corrosion potential moves to the negative half axis by 0.04 V. The corrosion resistance of the traditional welding seam is better.

Highlights: Based on the original TIG welding, the air supply method is changed from continuous air supply to variable air supply.

Key words: 5A03 aluminum alloy; Ar-Ar alternating; TIG welding; β phase; corrosion resistance

Laser joining of fiber reinforced thermoplastic composites and metal XU Jiejie, WANG Dong, XIAO Rongshi, HUANG Ting (High-Power and Ultrafast Laser Manufacturing Lab, Faculty of Materials and Manufacturing, Beijing University of Technology, Beijing, 100124, China). pp 73-86

Abstract: The structure composed with fiber reinforced thermoplastic composites and metal is effective to realize lightweight in the modern equipment manufacturing. Therefore, it is of great academic significance and practical value to achieve high quality, efficient and reliable joining in between. This paper reviews the recent research achievement of laser joining of fiber reinforced thermoplastic composites and metal at home and abroad. The laser joining principle, the bonding mechanism of interface as well as its strengthening methods, and the influence of laser joining parameters on shear strength were introduced in detail. The shear strength has satisfied the requirement of industrial application by using mechanical bonding and chemical bonding strengthening

methods as well as avoiding joining defects through controlling the heat input, providing the clamping pressure, and using additional resin. Finally the tendency of development in the near future is predicated.

Highlights: (1) The strengthening methods of interface were summarized on the roof of explanation the laser joining principle and the bonding mechanism of interface.

(2) The laser joining strengthening methods and the influence of laser joining parameters on shear strength were introduced in detail.

(3) The tendency of development to achieve high quality and efficient joining in the near future is predicated.

Key words: fiber reinforced thermoplastic composites; laser joining; ultrafast laser ablation; interface strengthening method; joint strength

Review on the research of the joining of tungsten based alloy and steel dissimilar materials XU Yuxin, QIU Xiaoming, RUAN Ye, WANG Suyu, ZHAO Xiaohui, XING Fei (Jilin University, Changchun, 130025, China). pp 87-96

Abstract: Tungsten-based alloy has excellent properties such as high melting point, high strength, and low thermal expansion coefficient. Steel is still the most widely used metal material at present. The structural parts formed by tungsten-based alloy and steel have broad application prospects in fusion reactors, die-casting molds and other fields. Due to the huge differences in the physical, chemical and mechanical properties of tungsten and steel, the high-performance joining of tungsten-based alloy and steel is a great challenge and a key issue in the field of joining. In this paper, we reviewed the development of the brazing and diffusion bonding of tungsten-based alloys and steels. Additionally, in order to provide reference for subsequent research, the possible future research directions of tungsten-based alloy/steel dissimilar materials joining were proposed combined with the application requirements.

Highlights: (1) The research development of joining between tungsten-based alloy and steel was reviewed from the prospects of joining process, interfacial bonding and mechanical properties.

(2) The future research direction of tungsten-based alloy/steel composite components was put forward, providing reference information and specific suggestions.

Key words: tungsten based alloy; brazing; diffusion bonding; interfacial microstructure; mechanical properties