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微弧氧化处理改善 7N01-T5 铝合金搅拌摩擦焊接头的耐蚀性能

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摘　要： 利用微弧氧化技术在 7N01-T5 铝合金搅拌摩擦焊(FSW) 接头表面制备陶瓷涂层. 通过 SEM 和 XRD 技术测试微弧氧化涂层的微观形貌、物相组成等，并采用中性盐雾试验研究微弧氧化及封孔处理对焊接接头耐蚀性能的影响. 结果表明，微弧氧化可在 FSW 接头区域生成均匀的陶瓷涂层；陶瓷涂层表面残留许多火山口状放电微孔和熔融烧结痕迹，并且主要由 α-Al_2O_3 与 γ-Al_2O_3 两相构成；微弧氧化涂层具有较好耐腐蚀性，沸水封孔能生成水合氧化铝，使孔壁膨胀、孔径变小，进一步增强涂层的耐蚀能力，经 96 h 盐雾腐蚀后的单位面积失重量仅为 2.6 mg.

关键词： 微弧氧化；铝合金；搅拌摩擦焊；耐蚀性
中图分类号： TG174.4　**文献标识码：** A　**文章编号：** 0253-360X(2013)01-0029-04

0　序　言

7N01 铝合金为 Al-Zn-Mg 系铝合金，具有较高的强度，良好的成形性能和焊接性能，多用于制造高速轨道车辆的结构件[1]. 传统的熔焊方法很难对其进行高质量的焊接，而搅拌摩擦焊技术较好地解决了这一难题. 该技术是一种新型固相连接技术，通过高速旋转的搅拌头与被焊材料间的摩擦作用使其周围材料软化并发生塑性变形，在搅拌头的旋转作用下，软化层材料自动填充了搅拌针后方所形成的空腔，并在搅拌轴肩的挤压作用下实现了材料的连接. 焊接过程中低热输入和光滑的焊缝表面使得 FSW 接头拥有相对较好的力学性能和低变形等特点. 由于焊核区、热力影响区、热影响区等位置的显微组织均明显不同于母材，导致其耐蚀性、耐磨性等相关性能的差异[2,3]. 目前有关高速列车铝合金 FSW 接头表面防护方法的研究相对较少.

微弧氧化(microarc oxidation) 技术是通过电解液与电参数的匹配调节，利用微弧放电产生的瞬时高温高压作用，在阀金属及其合金表面原位生成陶瓷涂层为基体提供表面防护. 该技术突破了传统阳极氧化的诸多不足之处，具有对预处理要求低、工艺简单、处理效率高、环境污染小等优点. 通过对工艺过程的控制，可以显著提高材料的耐磨、耐蚀、绝缘等性能，对于铝、镁、钛等金属及其合金来说是一种较为理想的表面改性方法[4-6]. 文中采用微弧氧化技术在 7N01 铝合金搅拌摩擦焊接头表面生长一层氧化膜，并分析涂层的组成及处理前后性能的变化.

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1　试验方法

试验材料为 4 mm 厚的 7N01-T5 铝合金板材，其化学成分如表 1 所示.

表 1　7N01-T5 铝合金化学成分(质量分数，%)
Table 1　Chemical compositions of 7N01-T5 alloy

Zn	Mg	Mn	Cu	Si	Fe	Cr	Al
4.5~5.0	1.0~2.0	0.2~0.7	<0.20	<0.30	<0.35	<0.30	余量

试验所用焊接设备为 FSW-3LM-002 型龙门式数控搅拌摩擦焊机，采用平板对接，焊接速度为 200 mm/min，旋转频率为 500 r/min. 把焊接样件沿垂直于焊缝方向线切割成 25 mm × 15 mm × 4 mm 尺寸，表面磨光并抛光，超声波清洗，烘干后进行氧化处理. 微弧氧化装置包括脉冲电源(10 kW)、电解槽、搅拌系统及冷却系统. 电解液由 $NaAlO_2$，KOH 及一些复合添加剂组成，试样作为阳极，不锈钢槽体连接阴极，恒压控制模式，通过循环水冷控制溶液温度≤

40 ℃，正负占空比为20%.

采用Quanta200型扫描电镜(SEM)观察接头不同区域微弧氧化涂层的微观形貌，利用X射线衍射(XRD)技术分析涂层的相组成. 利用AC-60盐雾试验机，对微弧氧化前后沸水封孔处理(蒸馏水，90～95 ℃，20 min)的试样进行中性盐雾试验(参照国家标准GB/T10125—1997). 腐蚀介质为5% NaCl溶液，PH值为6.5～7.0，温度为35 ℃，试验时间分别为12，24，48，72，96 h，计算腐蚀率，绘制曲线. 通过扫描电镜观察接头及陶瓷层腐蚀后的表面形貌.

2 试验结果及讨论

2.1 涂层的微观组织结构

图1为所制备的7N01-T5铝合金FSW接头不同区域的微弧氧化涂层的SEM形貌.

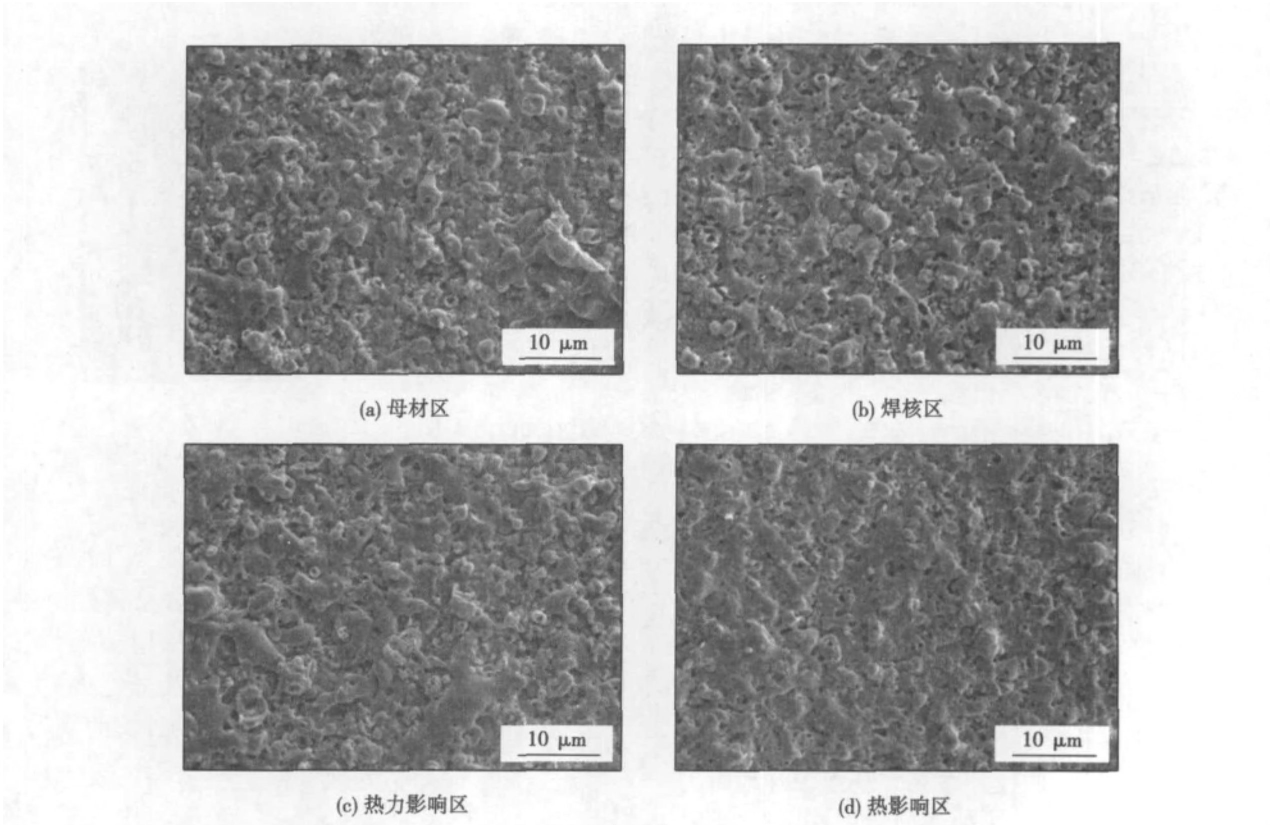

图1 FSW接头不同区域微弧氧化涂层的SEM形貌

Fig. 1 Surface morphology of micro-arc oxidation coatings of different regions in FSW joints

如图1所示，焊缝的不同区域与母材的微弧氧化涂层微观形貌相近，表明在FSW接头上获得的陶瓷膜是均匀的. 涂层表面均比较粗糙，残留许多微米级火山口状放电微孔，孔隙周围存在许多胞状堆积物，有明显的熔融烧结痕迹. 微弧氧化过程是放电—击穿—熔融—凝固反复进行的过程，这些胞状堆积物是熔融氧化物冷却凝固的产物，并会覆盖前期形成的放电残留孔隙.

2.2 涂层的物相组成

图2为7N01-T5铝合金FSW接头微弧氧化陶瓷膜XRD图谱. 如图2所示，氧化膜层主要由α-Al_2O_3和γ-Al_2O_3相组成，且衍射峰比较尖锐，说明结晶化程度较高；γ-Al_2O_3相含量较多. 这是由于其形核自由能比前者小，放电微孔喷出的熔融物遇到冷的电解液时急冷，首先会生成γ相，而且由于7系铝合金含有大量的Zn元素，也会抑制由γ-Al_2O_3相向α-Al_2O_3相的转变.

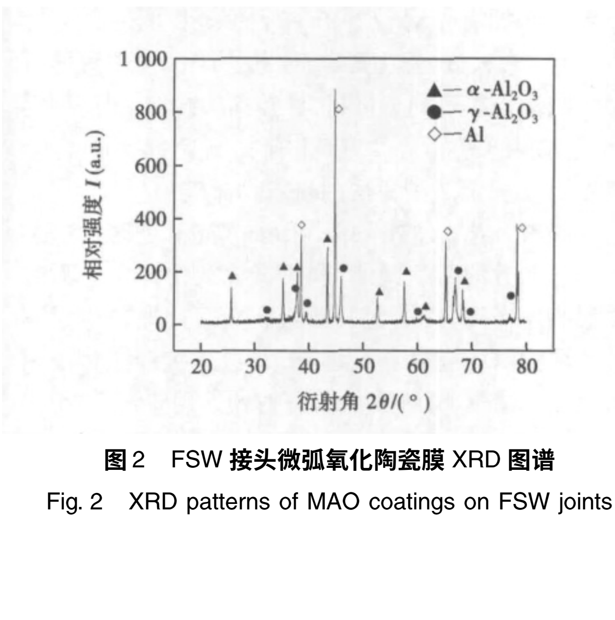

图2 FSW接头微弧氧化陶瓷膜XRD图谱

Fig. 2 XRD patterns of MAO coatings on FSW joints

2.3　耐蚀性测试

为研究微弧氧化陶瓷层和封孔处理对 FSW 接头耐蚀性能的影响，对试样进行中性盐雾试验. 图 3 为不同试样腐蚀率与腐蚀时间的曲线.

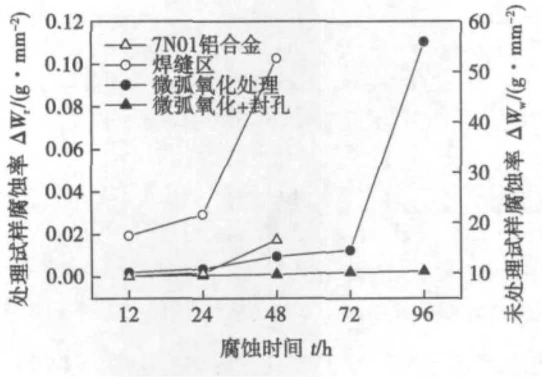

图 3　腐蚀速率曲线

Fig. 3　Corrosion rate curve

如图 3 所示，未经微弧氧化处理的 FSW 接头的耐腐蚀能力最差，由于 FSW 接头各区域的显微组织的不同，使其耐蚀性亦低于母材，接头经盐雾腐蚀 48 h 后的单位面积腐蚀失重约为 53 g. 微弧氧化处理后，在接头表面形成具有一定厚度的氧化物陶瓷层. 陶瓷层由具有封闭型孔洞的外部疏松层和连续致密的内层组成，能阻挡环境中的腐蚀物质的进入，提高接头的抗腐蚀能力. 封孔处理后的试样耐蚀性最好，96 h 盐雾腐蚀后，在精度为 10^{-4} g 的电子天平上测量的失重仅为 2.6 mg. 这是由于封孔处理的水合反应使氧化铝转变成勃姆体结构的水合氧化铝，使孔壁膨胀，孔径变小，有效地阻挡了腐蚀溶液的扩散，进一步增强了陶瓷层的耐腐蚀能力.

图 4 为 FSW 接头及其微弧氧化涂层经中性盐雾腐蚀后的微观组织形貌. 如图 4a 所示，未经微弧氧化处理的 FSW 接头的腐蚀较为严重，腐蚀 12 h 后即能观察到明显的腐蚀区域及裂纹扩展倾向. 这是由于盐雾中的 Cl^- 很容易穿透未处理试样在空气中形成的氧化薄膜，与内部材料发生电化学反应，造成接头材料的腐蚀. 对比观察沸水封孔与未封孔处理微弧氧化膜经受 96 h 盐雾腐蚀后的表面形貌，除前者孔径相对较小，表面稍光滑外，差别不大. 两者经历 96 h 腐蚀后，仍呈现微弧氧化膜的典型形貌，图 4b，c 中均没有明显的腐蚀痕迹，腐蚀产物及点蚀等现象不明显. 由于焊缝各区域形成微弧氧化膜是均匀一致的，说明微弧氧化处理和封孔处理可以有效的增强 FSW 接头的耐蚀能力.

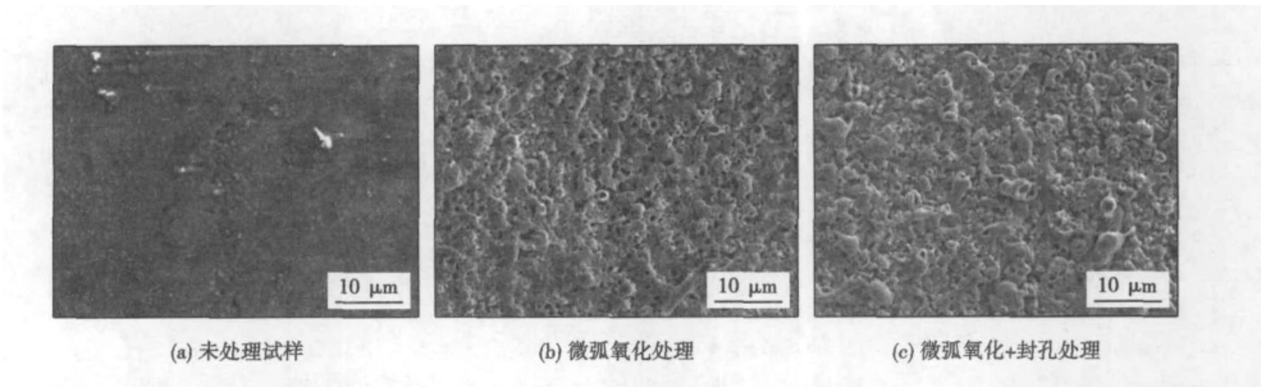

图 4　FSW 接头及其微弧氧化涂层盐雾腐蚀后的微观形貌

Fig. 4　Surface morphology of FSW joints and micro-arc oxidation coatings after salt fog corrosion

3　结　　论

(1) 采用微弧氧化技术在 7N01-T5 铝合金搅拌摩擦焊接接头原位生成均匀一致的陶瓷层.

(2) 7N01-T5 铝合金不同 FSW 接头区域的微弧氧化涂层，主要由 α-Al_2O_3 与 γ-Al_2O_3 构成，其中 γ-Al_2O_3 较多.

(3) 微弧氧化处理可显著提高 7N01-T5 铝合金搅拌摩擦焊接头的耐腐蚀能力，经封孔处理后微弧氧化陶瓷层的耐蚀性更好.

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Abstract: The distributions of the elements in CO_2 laser–metal active gas (MAG) hybrid welding were investigated with scanning electron microscope. The relation between the forming process of weld and the distribution of the element in CO_2 laser–MAG hybrid welding process was analysed with high-speed camera and scanning electron microscope. Both the melting metal flow and position of adding elements decide the element distributions. Metal flow varies due to changes of DLA (distance between laser and arc). The fluctuation of the keyhole can promote the uniform distribution of the element, but the impactness of the metal vapour enriches element in local zone of welding pool. The scanning and stiring of laser beam further make the uniform element distribution. The highest content and uniform distribution of elements can be obtained in the molten pool when the distance between laser and arc is 3 mm and elements are added from the location 1.0 mm away from the surface.

Key words: CO_2 laser-arc hybrid welding; melting metal flow; element distribution

Analysis of arc pressure and its weld quality in hybrid ultra–high frequency pulse VP-GTAW process

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Abstract: The variations of arc pressure and weld characteristics in the welding of 2219, 2A14 and 5A06 aluminum alloys were investigated based on the hybrid ultrahigh frequency pulse current variable polarity gas tungsten arc welding (HPVP-GTAW) process. The experimental results show that compared with the conventional VP-GTAW (variable polarity gas tungsten arc welding) process, arc pressure and weld penetration expressed by the ratio of weld depth to width are enhanced predominantly with the effect of high frequency pulse current. Mechanical properties of welded joints are improved obviously. At the given pulse current amplitude and pulse duty cycle, the welding process is influenced significantly by the pulse current frequency in the range of 10 kHz to 80 kHz. At the given pulse frequency of 40 kHz, arc pressure and weld penetration of welded joints increased by about 90% and 70%, respectively, compared with that of welded joints with no effect of pulse current.

Key words: ultrahigh frequency pulse current; variable polarity gas tungsten arc welding; arc pressure; weld quality

Nanoindentation properties of intermetallic compounds in lead-free solder joints

QIN Fei, AN Tong, ZHONG Weixu, LIU Chengyan (College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing 100124, China). pp 25 – 28, 32

Abstract: The growth of intermetallic compounds (IMC) at the Sn3.0Ag0.5Cu/Cu interface was investigated under isothermal aging temperature of 150 ℃ and aging time of 100, 300, 500 and 1 000 h, respectively. The relationship between the thickness of the IMCs layer and aging time was fitted out, and the growth law of the IMCs layer at Sn3.0Ag0.5Cu/Cu interface under isothermal aging condition was obtained. Mechanical properties of the Cu_6Sn_5 and Cu_3Sn were obtained by a nanoindentation tester. It indicates that with the Cu_6Sn_5 thickness increasing, its Young's modulus and hardness have no significant change. The Young's modulus of Cu_3Sn is greater than that of Cu_6Sn_5, but the hardness of Cu_3Sn is lower than that of Cu_6Sn_5. The nanoindentation experiments of the Sn3.0Ag0.5Cu/Cu interfacial zone show that the hardness of Cu, Cu_3Sn, Cu_6Sn_5 and Sn3.0Ag0.5Cu has an order of magnitude that is in sequence $Cu_6Sn_5 > Cu_3Sn > Cu > $ Sn3.0Ag0.5Cu.

Key words: electronic packaging; intermetallic compound; nanoindentation; mechanical property

Improvement of corrosion resistance of friction stir welded joint of 7N01-T5 aluminum alloy by micro-arc oxidation

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Abstract: The ceramic coatings were prepared on surface of friction stir welded joint of 7N01-T5 aluminum alloy by micro arc oxidation technology. The morphology and phase constituent of the micro arc oxidation coatings were studied by SEM, XRD. The corrosion resistance of the friction stir welded joint oxidized and sealed was tested through the neutral salt spray (NSS) test. The results show that micro arc oxidation coating formed on the FSW joint is uniform, and there are many discharge micro-porous like crater and melting, sintering traces on the surface, and which are mainly composed of α-Al_2O_3 and γ-Al_2O_3 phase. Micro arc oxidation ceramic coating has excellent corrosion resistance. Boiling water seal treatment can generate a hydrated alumina, which makes the hole wall inflated and the pore size decreaed, the corrosion resistance of the coatings can be greatly enhanced, and the weight loss is only 2.6 mg after enduring 96 h in NSS test.

Key words: micro arc oxidation; aluminum alloys; friction stir welding; corrosion resistance

Influence of ultrasonic time and pre-clearance on gap-filling behavior of filler metal during ultrasonic-assisted brazing of magnesium alloy

LI Hong[1], GENG Yuanyue[1], YAN Jiuchun[2], LI Zhuoxin[1] (1. College of Materials Science and Engineering, Beijing University of Technology, Beijing 100124, China; 2. State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 33 – 36

Abstract: In order to investigate the influence of ultrasonic on flow behavior of filler metal when the filler metal propagates on the solid/liquid surface in brazing process, the gap-filling behavior of the molten filler metal during ultrasonic-assisted brazing of magnesium alloy was in-situ observed by high-speed video camera. Besides, the gap-filling behavior in unparalleled gaps and brazed joint properties were investigated. When the filler metal fills the gap in the direction parallel to the ultrasonic energy propagation, the dynamic curve of filling-gap distance appears linear relation with the ultrasonic time. And it shows that at the same ultrasonic time, good pre-clearance results in low filling velocity. Along the filler flow direction, the thickness of brazed joint decreases gradually. The filling-gap distance decreases as ultrasonic time increases when filler metal is placed at large gap side. The compactness of the joint is general. The filling-gap distance increases firstly and then decreases with the ultrasonic time increasing when the filler metal is placed at small gap side. In this case, the defects appear in the whole joint. The analysis