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高速列车用耐候钢活性 MAG 焊接技术

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摘　要： 提出了活性熔化极气体保护焊焊接新方法，获得了高质量的活性熔化极气体保护焊焊接接头. 结果表明，活性熔化极气体保护焊焊缝表面成形好、活性焊接接头内部质量高、活性焊接操作性好、活性熔化极气体保护焊相对传统熔化极气体保护焊同等焊接热输入下熔深增加，焊接接头拉伸及弯曲力学性能不降低，同时焊接接头的冲击韧性得到提高，特别是活性焊接接头热影响区的冲击吸收功得到提升，焊接接头的断口韧窝尺寸更细小. 活性熔化极气体保护焊可以提高耐候钢焊接质量，改善难熔结构焊接熔深，具有工程应用价值.

关键词： A-MAG 焊接；　耐候钢；　高速列车

中图分类号： TG404　　**文献标识码：** A　　**文章编号：** 0253-360X(2013)11-0105-04

路　浩

0　序　言

在机车车辆制造过程中，焊接是重要的加工制造工艺. 车体结构、底架结构、转向架结构等重要的承载焊接结构主要使用 MIG，MAG 焊接. 机车车辆制造中一些复杂结构焊接的熔透不足问题成为制约产品质量的瓶颈问题，采用活性剂 MAG 焊方法可以改善焊接过程熔透不足的问题，降低加工制造成本，提高焊接效率与产品质量.

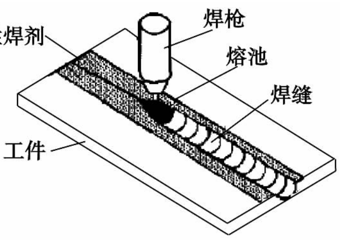
活性 TIG 焊接方法(activating flux TIG welding)发明以来已应用于焊接碳钢、C-Mn 钢、不锈钢、镍基合金及钛合金等多种材料. 活性 TIG 焊可使焊接熔深显著增加，可达传统 TIG 焊的 2~3 倍，提高焊接生产效率，但仅局限应用于非熔化极气体保护焊[1-9].

文中提出了活性熔化极气体保护焊(A-MAG)接方法，将活性焊接方法引入熔化极气体保护焊，发展出 A-MAG 焊接技术，即通过在传统 MAG 焊前将表面活性剂涂敷在施焊工件表面、坡口或焊缝层间，然后进行焊接，在保证焊缝质量的基础上，可增加焊接熔深，提高焊接效率. 文中将 A-MAG 焊接方法引入机车车辆制造行业中，通过对其焊缝成形、焊接工艺、焊接接头组织及力学性能等进行研究分析，展示了活性 MAG 焊接方法是一种可提高焊接效率、提高焊接质量、降低焊接成本的高效优质焊接技术.

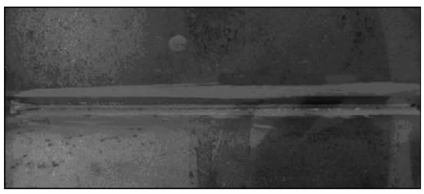
1　A-MAG 焊接工艺及试验

1.1　A-MAG 焊接工艺

通过大量试验开发了一种适用于熔化极气体保护焊的多组份活性剂. 通过在传统 MAG 焊前将很薄的一层表面活性剂涂敷在施焊板材表面，然后进行正常焊接，在保证焊缝质量的基础上，可以增加熔深，提高效率，实施方式及实例如图 1 所示.



(a) A-MAG焊接实施方式



(b) 活性剂涂覆实例

图 1　A-MAG 焊接实施方式及涂覆实例

Fig. 1　Diagram of A-MAG

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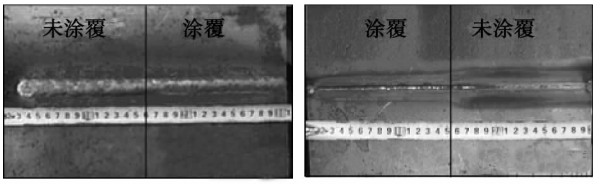
1.2 焊缝表面形态及质量检验

进行了大量的 A-MAG 焊接试验，对试验结果进行举例说明，如图2所示，焊接工艺参数见表1. 母材选用 15 mm 厚高速列车转向架架构用钢 SMA490 板材，保护气体选用 80% Ar + 20% CO_2 的混合气体，使用松下 YD-500GL3 型气体保护焊焊机，焊丝直径为 1.2 mm，保护气体流量范围为 18 ~ 24 L/min.



(a) 试件正面 (b) 试件背面

图2 焊缝宏观形貌

Fig. 2 Macrograph of weld seam

表1 试件焊接参数

Table 1 Welding parameters of specimen

接头形式	间隙尺寸 L/mm	焊接层数 n	焊接速度 v/(mm·s^{-1})	焊接电流 I/A
对接	1.5	1(打底)	4.3	186 ~ 192
对接	1.5	2(填充)	5.0	242 ~ 252
对接	1.5	3(盖面)	5.0	248 ~ 260

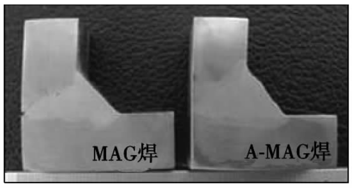
从图2中可以看到，涂覆活性剂后试件背面熔透明显改善，母材变色范围明显收缩，说明施加活性剂后电弧集中收缩，引起热影响区变窄. 热影响区是焊接接头的薄弱环节，热影响区宽度的减小完全可以提高焊接接头的整体性能. 这主要是因为 A-MAG 焊活性剂的添加收缩了焊接电弧，提高了电弧的能量密度，减小了电弧的加热区域，从而改善了热影响区的性能.

根据 EN970《焊缝外观检测》标准对试验件进行外观检验，焊缝饱满、宽度均匀一致、表面规则、波痕均匀致密，焊缝余高验收合格; 根部熔透均匀且在验收标准之内; 放大镜下热影响区无任何裂纹及多孔结构. 外观检测结果说明活性剂的使用不会显著影响焊缝的表面质量，使用活性剂之后焊缝外观合格. 对试验件按照 EN 1290《焊缝的无损检验——磁粉检验》标准对焊缝进行表面裂纹检测，未发现任何可疑磁痕，说明活性剂的使用不会在焊件表面产生裂纹. 对试验件按照 EN1435《无损检测——焊缝射线探伤》标准对焊缝进行内部缺陷射线检测. 结果显示，对接试件内部熔合良好，未发现熔合不良、夹渣等缺陷.

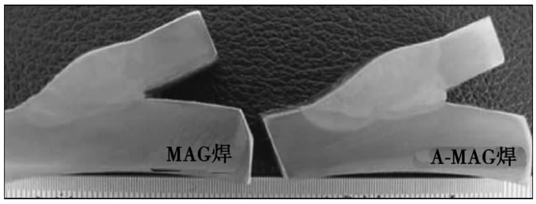
1.3 焊接接头宏观观察

选取具有代表性的 T 形接头和板管搭接接头进行焊接，在相同焊接参数、间隙、焊接层数等工艺参数下进行.

试验发现 A-MAG 焊缝完全熔透，与两侧母材熔合良好，未发现裂纹、夹渣等缺陷，且相对 MAG 焊熔深增加明显，如图3所示.



(a) T形接头



(b) 管板搭接接头

图3 接头宏观对比

Fig. 3 Comparsion of macro metallographic

2 焊接接头力学性能

2.1 拉伸试验

对相同焊接工艺参数下 MAG 焊、A-MAG 焊及母材试件按照 EN 10002《金属材料. 拉伸试验——第1部分: 常温试验方法》标准进行拉伸试验，部分数据见表2.

表2 平对接拉伸试验结果

Table 2 Results of tension test

试样编号	宽度 L/mm	厚度 H/mm	抗拉强度 R_m/MPa	断后伸长率 A(%)	断裂位置	活性剂
1	25.01	11.28	552.5	22.32	母材	无
2	25.06	11.48	579.3	22.47	母材	有
3	24.68	15.00	520.6	28.13	母材	无
4	24.66	15.00	537.2	27.90	母材	有
母材	25.10	11.70	549.9	25.78		

无论添加活性剂与否，拉伸试样都无一例外的断在距离焊缝中心 30 ~ 50 mm 的母材处，断裂前均表现出明显的塑性变形，断裂方式均为韧性断裂，断后伸长率均在 20% 以上，其中 15 mm 板材断后伸长率比 12 mm 板材断后伸长率略高，达到了 25% 以上.

所以活性剂的添加不影响接头断裂方式及强度.

2.2　弯曲试验

根据 EN 910《金属材料焊缝破坏试验——弯曲试验》标准，选定 12 mm 板材 A-MAG 焊焊接接头进行面弯和背弯；15 mm A-MAG 焊板材焊接接头进行侧弯. 弯曲在 WQ-1000 型弯曲试验机上进行.

拉伸试验测得母材的断后伸长率大于 25%，根据《金属材料焊接工艺规程及评定——焊接工艺评定试验——第 1 部分：钢的弧焊和气焊、镍及镍合金的弧焊》标准 15614-1，弯曲试验选取弯头直径 $D = 4T$（T 为母材厚度），弯曲角度为 180°. 弯曲后试样均完好无损，没出现裂纹，满足标准要求，说明活性剂的添加至少不会降低接头的弯曲性能.

3　冲击试验及断口分析

冲击试样按照标准《金属材料焊缝的破坏试验——冲击试验——取样位置、缺口定位和检验》EN 875 选定取样位置和切口方向，按照 EN 10045——1 确定试样尺寸. 冲击试验在 JB-30B 型冲击试验机上进行，试验温度为 −40 ℃，冲击断口形貌如图 4 所示.

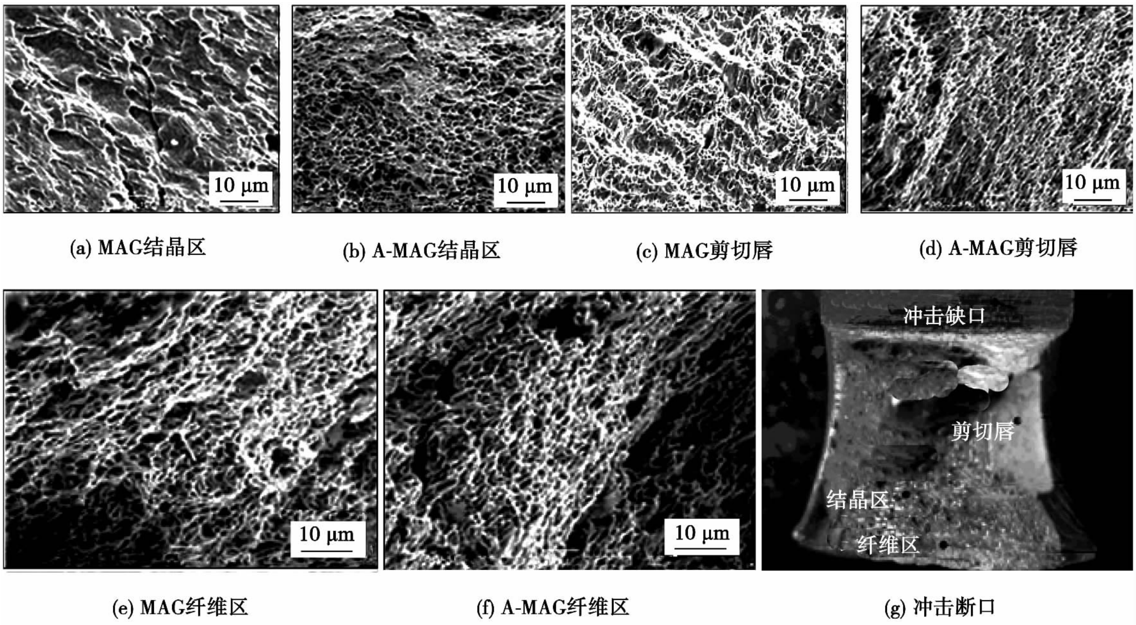


图 4　冲击断口形貌

Fig. 4　Impact fracture morphology

对 MAG 焊和 A-MAG 焊的热影响区冲击断口进行了对比分析，冲击试验数据表明 15 mm 厚 A-MAG 焊的热影响区冲击吸收功由普通 MAG 焊的 136 J 提升为 155 J.

从涂覆活性剂与未涂覆活性剂焊接接头热影响区冲击韧性断口的对比可以看到，剪切区和纤维区的韧窝尺寸细小、较深且被剧烈拉长，结晶区断裂模式为准解理断裂，断口上具有被拉长的深度较浅的韧窝及解理小刻面. 有活性剂条件下接头是热影响区的韧窝尺寸更小，明显优于无活性剂焊接接头热影响区组织.

4　结　　论

（1）A-MAG 焊接方法焊缝成形及内部质量高，不低于普通 MAG 焊.

（2）A-MAG 焊接方法相对 MAG 焊接接头力学性能不下降，且冲击韧性提高. 在温度为 −40 ℃ 条件下，A-MAG 焊焊接接头具有良好的韧性储备. A-MAG 焊焊接接头热影响区的冲击性能优于普通 MAG 焊.

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welded by double beam laser welding was developed based on birth-death control by the temperature of each element. In the method, an element was killed or activated according to its temperature during welding. The welding deformation obtained by two different computational methods were compared, one using the birth-death control method, and the other not. Except the above difference, material, geometry, boundary and initial conditions were identical for the two computational methods. The results showed that, whether using the birth-death control or not, which had an important influence on the computational results of deformation of T joint welded by double beam laser welding, and the reason was analyzed.

Key words: T joint; double beam laser welding; welding deformation

Numerical simulation of temperature and flow field of CO_2 gas shielded arc XIA Shengquan, OU Zhiming, SUN Xiaoming (Key Laboratory for Advanced Materials Processing Technology, Tsinghua University, Beijing 100084, China). pp 97 – 100

Abstract: A transient three-dimensional model of welding arc in CO_2 gas shielded arc welding was founded. With the experimental data of transient welding current, the basic theory of magneto hydrodynamics (MHD) and the coupling of multi-physics function of ANSYS, the distribution of the current density in electric field, the electromagnetic force in magnetic field, the temperature and velocity in the flow field were simulated. The simulation result for arc temperature filed is basically identical with the experimental data in the reference. In addition, the laminar hypothesis and incompressible assumption in the model were verified by computing the Reynolds number and Mach number. The numerical model can provide theoretical guidance with the controlling of welding arc in the CO_2 gas shielded arc welding, and it also lays a foundation for the further study on the analysis of transient CO_2 arc.

Key words: welding arc; numerical modeling; multi-field coupling

Interfacial IMC evolution in micron Sn-Ag-Cu soldered joint during thermal aging TIAN Ye[1,2], WU Yiping[2], AN Bing[2], LONG Danfeng[3] (1. School of Mechanical and Electrical Engineering, Henan University of Technology, Zhengzhou 450001, China; 2. School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China; 3. Department of Precision Instruments and Mechanology, Tsinghua University, Beijing 100084, China). pp 101 – 104

Abstract: The interfacial intermetallic compound (IMC) evolution in micro-soldered joints in thermal aging process of flip-chip assemblies was investigated. The results show that all $(Ni, Cu)_3Sn_4$ on the Ni pad interface are transformed into $(Cu, Ni)_6Sn_5$ after 300 h for thermal aging due to the effect of Cu atoms diffused from the Cu pad interface on the $(Ni, Cu)_3Sn_4$. On the Cu pad interface, a thin layer of Cu_3Sn forms on the interface between the Cu pad and $(Cu, Ni)_6Sn_5$ after 100 h for aging, however in the subsequent thermal aging, Cu_3Sn experiences little growth because of the limitation effect of Ni on its growth. The growth rate of $(Cu, Ni)_6Sn_5$ on the both pad interfaces are fast before 100 h, and after 100 h, it become slower and slower. Furthermore, as the aging time increases, the interface of $(Cu, Ni)_6Sn_5$ grain inclines to be flat.

Key words: lead-free solder; intermetallic compound; flip chip assembly; interfacial reaction; thermal aging

Research on A-MAG welding of weathering resistant steel LU Hao[1], XING Liwei[2], CHEN Dajun[3] (1. Technical Engineering Department, CSR Qingdao Sifang Co., Ltd., Qingdao 266111, China; 2. Technology Center, CSR Qingdao Sifang Co., Ltd., Qingdao 266111, China; 3. Harbin Welding Training Institute, Harbin 150046, China). pp 105 – 108

Abstract: A-MAG welding was proposed to obtain the welded joints with high quality. The experiment results show that A-MAG weld appearance, internal quality of welded joint and the welding operation performance are very well. Experiments also show that the A-MAG welding can improve weld penetration, which is compared with MAG welding under the same heat input. The tensile strength and bending strength of A-MAG welded joint are not reduced, while impact strength is improved, especially in the HAZ. Dimples size in fracture appearance of A-MAG welded joint is finer. It is showed that the active MAG welding can improve the welding quality and weld penetration of weathering resistant steel, which is applicable in engineering application.

Key words: A-MAG welding; weathering resistant steel; high speed train

Grain types and composition distribution of agglomerated flux with high slag detachability XU Guoliang[1], ZHENG Zhentai[1], LIU Pengfei[2], ZHANG Lisheng[1], WANG Tao[1] (1. School of Materials Science and Engineering, Hebei University of Technology, Tianjin 300132, China; 2. Luo Yang Institute of Ship Materials, Luoyang 471023, China). pp 109 – 112

Abstract: In order to enhance slag detachability of agglomerated flux for low-alloy steel in root bead, uniform design method was used to optimize slag systems for MgO-Al_2O_3-CaO with high basicity and slag detachability test. Then scanning electron microscopy (SEM), energy dispersive x-ray analysis (EDAX) and X-ray diffraction (XRD) were used to analyze the microstructure, compositions and phase of slag. The results show that the No. 10 slag with higher detachability is mainly made of compound rock phases, whose main elements are Zr, Mg, Ca, Al and Si. Since the element content is different in slag microzone, it can form snowflake grain with Zr, cross grain with Mg, and dentrite with Ca. Dentrite with Ca and snowflake grain with Zr can hinder the growth of cross grain with Mg. In addition, Zr has a role in refining cross grain with Mg. So the increase of the contents of marble and zircon sand in flux can change the continuity and direction of cross grain with Mg in slag. It will be a valid way to improve slag detachability.

Key words: agglomerated flux; microstructure; composition distribution; slag detachability