随焊旋转挤压对铝合金焊接接头组织和性能的影响

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摘　要：随焊旋转挤压是一种能够控制薄壁结构焊接应力和变形的新方法，这种方法同时能改善焊接接头的微观组织和力学性能。对 2A12T4 铝合金焊接接头的金相观察表明，随焊旋转挤压焊缝区晶粒明显细化，组织更加致密，气孔等缺陷大大减少。拉伸和三点弯曲试验结果表明，随焊旋转挤压之后焊接接头的抗拉强度、抗弯强度等力学性能得到不同程度的提高。由于薄弱的焊趾部位得到强化，部分试件的裂纹萌生部位由焊趾转移到焊缝。

关键词：随焊旋转挤压；铝合金；组织；力学性能
中图分类号：TG407　　文献标识码：A　　文章编号：0253－360X(2008)06－0101－04

0　序　　言

铝合金由于密度小、无磁性、热导率和强度高，以及良好的成形性、低温性能、耐腐蚀性能等被广泛应用于各种焊接结构中[1]，但其在焊接加工时存在残余变形大、热裂倾向性高、接头弱化严重等不足[2]。随焊旋转挤压方法(welding with trailing rotating extrusion, WTRE)[3] 是一种薄壁结构焊接应力与变形的焊中控制新工艺，不但能有效控制铝合金薄板的焊接应力和变形，还能明显改善其焊接接头的组织和力学性能。作者就该方法对铝合金薄板焊接接头组织和力学性能的影响进行研究。

1　随焊旋转挤压方法简介

焊接过程中的局部集中热源，在被焊工件中造成了热源附近温度很高而远离热源的区域温度较低的不均匀温度场[4]，在此温度场的驱使下，近缝区金属的热膨胀因受到两侧较冷部分的约束限制而产生弹塑性压缩变形。在焊缝冷却过程中，焊缝及近缝区金属的热收缩因受到两侧较冷部分的约束限制又要发生弹塑性拉伸变形。在冷却过程所产生的拉应力中，超过材料屈服极限的部分得到释放，但仍有接近于屈服强度的拉应力保留下来，并相应地在远离焊缝的区域产生与之平衡的压应力。对于薄板焊接构件，残留在焊缝及近缝区的弹性拉应力是焊后失稳变形的根源。随焊旋转挤压方法正是根据焊接应力和变形产生的机理提出的，它是通过特定形状的挤压头对冷却过程中的焊缝金属施加适度的旋转挤压作用，其所产生的纵向及横向延展能够减小或消除焊缝及近缝区的弹性拉应力，甚至将其转变为压应力，从而降低了残余应力和变形。挤压头对焊缝金属的挤压作用同时起到了改善焊缝组织和性能的作用。

随焊旋转挤压方法的工作原理如图 1 所示。挤压头工作时位于电弧后方，垂直作用于焊缝部位，对焊缝及近缝区金属进行旋转挤压。挤压头对焊缝金属的旋转挤压是一种热机联合作用，挤压头端面与焊缝上表面之间的摩擦生热会提高焊缝金属的塑性，实现以较低能量获得显著的控制效果。

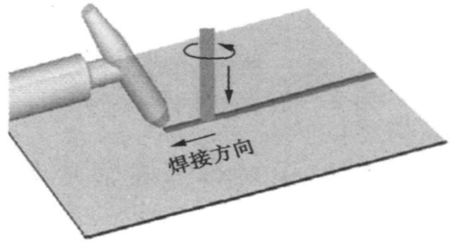


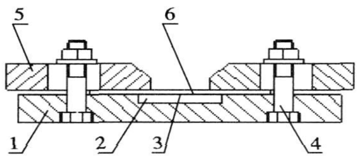
图 1　随焊旋转挤压方法的工作原理示意图
Fig. 1　Schematic map of WTRE

2　试验方法

试验材料采用 2A12T4 高强铝合金，尺寸为 270 mm× 130 mm×2 mm。焊接方法为交流钨极氩

收稿日期：2007－12－21

弧焊，采用不填丝的表面熔敷方式。为防止薄板在焊接过程中产生宏观变形而影响焊接过程的正常进行，焊接工件用刚性焊接夹具（图 2）夹紧。



1. 底板 2. 不锈钢垫板 3. 成形槽 4. 夹紧螺栓 5. 压板 6. 工件

图 2 刚性焊接夹具

Fig. 2 Schematic map of rigid welding clamp

试验中采用的具体焊接工艺参数如表 1 所示。

表 1 焊接工艺参数

Table 1 Welding parameters

焊接电流 I/A	氩气流量 q/(L·min^{-1})	焊接速度 v/(mm·s^{-1})	夹持距离 d/mm	夹紧扭矩 M/(N·m)
105	10	4.75	40	50

随焊旋转挤压采用直径为 ϕ14 mm 的挤压头，其形状如图 3 所示。试验中挤压头的旋转速度为 140 r/min，对工件施加的垂直作用力为 3 kN，与熔池的距离约为 50 mm。

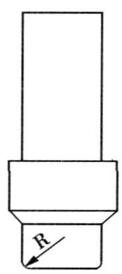
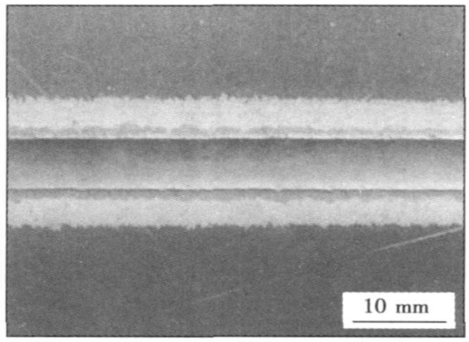


图 3 挤压头的外形

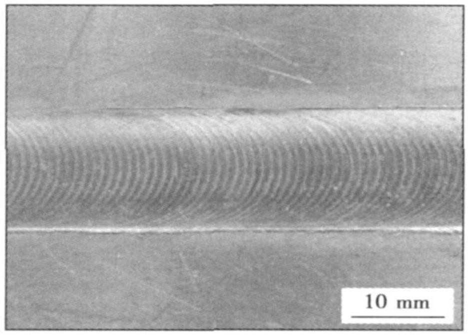
Fig. 3 Figure of extrusion head

3 随焊旋转挤压对焊缝表面质量的影响

图 4 和图 5 分别为 2A12T4 铝合金薄板常规焊缝与 WTRE 焊缝正面和横截面的形貌对比图。从图中可以看出，常规焊接接头表面粗糙，在熔合线处存在应力集中，而 WTRE 焊道由均匀细密排列的圆环纹组成，类似于搅拌摩擦焊焊缝的外观形貌，表面较为平整光滑，这将降低几何缺口效应的影响，缓解焊趾处的应力集中，有助于提高接头的拉伸、疲劳等力学性能。



(a) 常规焊试件



(b) WTRE 试件

图 4 常规焊缝与 WTRE 焊缝正面形貌对比

Fig. 4 Comparison of appearance between conventional weld and WTRE weld

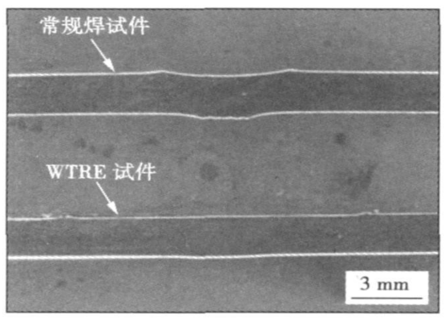


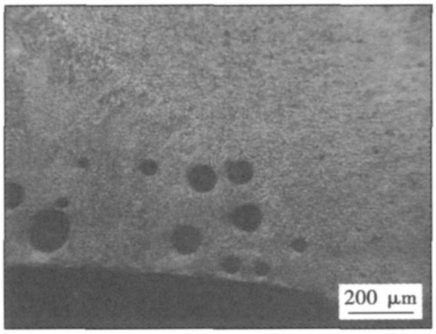
图 5 常规焊缝与 WTRE 焊缝横截面视图对比

Fig. 5 Comparison of cross section between conventional weld and WTRE weld

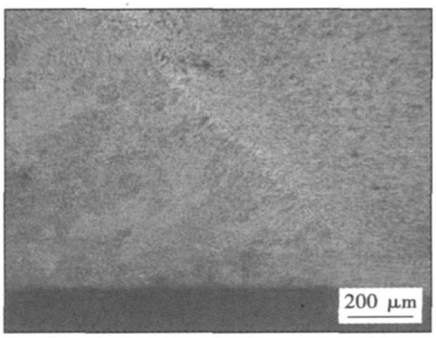
4 随焊旋转挤压对接头微观组织的影响

图 6a，b 分别为 2A12T4 常规焊缝和 WTRE 焊缝熔合线附近的低倍金相照片。从图中可以看出，常规焊试件焊缝中含有大量的气孔，而随焊旋转挤压焊缝中几乎看不到气孔，焊缝区组织更加致密。分析原因主要有两点，一是由于旋转挤压会使熔池产生振动，加速了气体的逸出，从而降低了气孔率；二是焊缝金属中的气孔和缩孔能被挤压头压实、焊合。在拉伸、弯曲等试验中，焊件中的大尺寸的气孔一直

是主要裂纹源, 常规焊试件的启裂位置常常为焊趾部位, 就是因为熔合区的气孔所致, 随焊旋转挤压方法能大大降低气孔率, 这为提高随焊旋转挤压试件的力学性能奠定了基础。



(a) 常规焊试件



(b) WTRE 试件

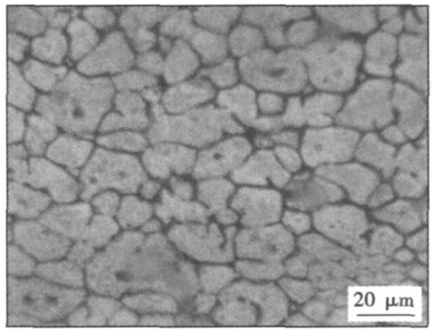
图 6　常规焊试件和 WTRE 试件熔合区金相组织

Fig. 6　Optical micrographs of bond zones of conventional weld and WTRE weld

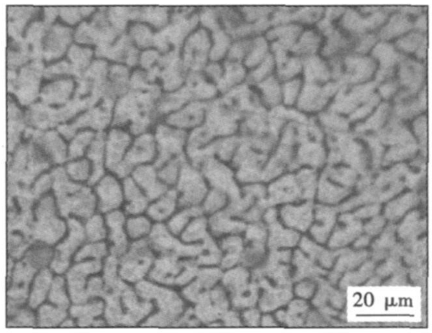
图 7a, b 分别为 2A12T4 薄板常规焊试件和 WTRE 试件焊缝区的金相照片。由图 7 可见, 常规焊试件焊缝区的晶粒粗大, 而 WTRE 试件焊缝区的晶粒明显细化。分析认为, 旋转挤压产生的微振, 一方面使正在长大的晶体碎裂成几个结晶核心, 另一方面使受振动的液态金属中的晶核提前形成[5], 因而提高了形核率。根据金属学知识, 晶粒大小对金属的力学性能有很大的影响, 在常温下, 金属的晶粒越细小, 强度则越高, 同时塑性、韧性也越好。

5　随焊旋转挤压对接头力学性能的影响

根据国家标准 GB/T13450—1992《对接焊接接头试样拉伸试验方法》, 对常规焊试件和 WTRE 试件进行了拉伸性能试验。试验在 INSTRON—5569 电子万能试验机上进行, 结果如表 2 所示。由表 2 可见, 随焊旋转挤压焊接头的平均抗拉强度比常规焊接头提高了 27.4 MPa; 常规焊试件有一半在焊趾部位萌生裂纹并最终断裂, 而 WTRE 试件都断裂在焊缝部位, 说明随焊旋转挤压之后焊接接头的薄弱部位——焊趾处被一定程度强化了。



(a) 常规焊试件



(b) WTRE 试件

图 7　2A12T4 常规焊试件和 WTRE 试件焊缝区金相组织

Fig. 7　Microstructures of conventional weld and WTRE weld

表 2　拉伸试验结果

Table 2　Results of tensile test

试件编号	常规焊试件		试件编号	WTRE 试件	
	抗拉强度 R_m/MPa	断裂位置		抗拉强度 R_m/MPa	断裂位置
1	303.4	焊缝	9	321.7	焊缝
2	292.6	焊趾	10	317.2	焊缝
3	295.3	焊趾	11	329.9	焊缝
4	302.3	焊缝	12	322.0	焊缝
5	304.3	焊缝	13	338.3	焊缝
6	294.1	焊趾	14	333.9	焊缝
7	295.3	焊缝	15	318.7	焊缝
8	297.7	焊趾	16	322.1	焊缝
平均值	298.1		平均值	325.5	

根据国家标准 GB 2653—1989《焊接接头弯曲及压扁试验方法》, 对常规焊试件和 WTRE 试件进行了三点弯曲试验。试件尺寸为 70 mm×10 mm×2 mm, 试验采用背弯方式, 跨距为 30 mm, 试验设备为 INSTRON—5569 电子万能试验机, 试验结果如表 3

所示。由表 3 可知,常规焊试件开始出现宏观裂纹的平均抗弯强度为 619.6 MPa,而 WTRE 试件的相应值与常规焊试件相比增加了近 100 MPa,再次说明 WTRE 方法可以强化焊接接头的力学性能。

表 3 弯曲试验结果

Table 3 Results of bending test

试件编号	常规焊试件抗弯强度 R_w/MPa	试件编号	WTRE 试件抗弯强度 R_w/MPa
1	577.2	6	698.6
2	623.5	7	613.5
3	605.8	8	756.2
4	631.8	9	779.6
5	659.7	10	749.3
平均值	619.6	平均值	719.4

6 结 论

(1) 2A12T4 铝合金薄板随焊旋转挤压焊缝表面由均匀细密排列的圆环纹组成,表面平整光滑,减小了应力集中。

(2) 随焊旋转挤压焊缝区晶粒明显细化,组织致密,气孔等缺陷大大减少。

(3) 与常规焊接头相比,随焊旋转挤压焊接头的平均抗拉强度提高了 27.4 MPa,三点弯曲的平均抗弯强度提高了约 100 MPa。

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gineering, Beijing University of Technology, Beijing 100124, China; 2. Shanghai Boiler Works Ltd., Shanghai 200245, China). p93—96

Abstract: New types of ferrite and austenite heat-resistant steels used in supercritical or ultra supercritical boilers have issued challenges to conventional welding techniques. As a reliable and advanced joining technique, laser welding may be one of the promising solutions for the welding of these steels due to the low heat input. A slab CO_2 laser with an output power of 3 500 W was applied and the narrow gap laser welding process was adopted with T—HR3C filler wire to weld HR3C tubes of the new type austenite steel with a thickness of 10 mm. The joint microstructure and high temperature lasting strength were investigated. It is found that a sound joint can be obtained by optimizing the process parameters. The microstructures in the weld bead are fine column austenite grains with a few fine equiaxed austenite grains, appear more or less symmetrically along the bead center. The grain size in the HAZ is not obviously coarsening. The micro-hardness in the weld is correspondence with that of the base metal, and no obvious softened zone is observed. The high temperature lasting strength of the laser welded joint in the as-welded condition is distinctly improved compared to that of TIG welding joint with post-weld heat treatment.

Key words: laser welding; power boiler; HR3C austenite heat-resistant steel; microstructure; high temperature lasting

Influence of welding parameters on laser-induced plasma temperature in CO_2 laser welding of aluminum alloys QI Junfeng, DING Peng, ZHANG Dongyun, ZUO Tiechuan (Institute of Laser Engineering, Beijing University of Technology, Beijing 100022, China). p97—100

Abstract: The spectrums of laser-induced plasma in CO_2 laser welding of 6061 aluminum alloy are measured through PI Pro2500i transient spectrometer. Boltzmann diagrams can be used to calculate the average temperature of laser-induced plasma, which are deduced from MgⅠ spectrums between 200—600 nm. The influence of welding parameters, such as laser power, welding speed, focus position and shielding gas, on laser-induced plasma temperature are investigated separately and the reasons are also discussed. Under the experimental conditions, laser power plays little role on laser-induced plasma temperature (6 000 K) when it exceeds the threshold power of laser penetration welding. The effect rule of welding speeds on laser induced plasma temperature likes inverted U curve. Laser-induced plasma temperature has been increased and then decreased when the flow rate of shielding gas is increased for a given diameter of nozzle. Laser-induced plasma temperature will increase 500—1 000 K when adding argon in to helium.

Key words: laser welding; aluminum alloys; laser induced plasma; spectrum

Effect of welding with trailing rotating extrusion on microstructure and mechanical properties of aluminum alloy welded joints

LI Jun, YANG Jianguo, WENG Lulu, FANG Hongyuan (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p101—104

Abstract: Welding with trailing rotating extrusion (WTRE) is a new technology to improve the microstructure and mechanical properties of welded joints as well as control welding residual stresses and distortion of thin-walled structures. The metallographs of 2A12T4 aluminum alloy welded joints show that the microstructure of the WTRE welds are more compact with refined crystal grains and less welding defects such as air cavities and shrinkage porosities than the ones of the conventional welds. The results of tensile and bending tests show that such mechanical properties as tensile strength and three-point bending strength of the welded joints are enhanced markedly. The cracks in some WTRE test pieces started from the weld center rather than the weld toes, which were strengthened by the rotating extrusion operation.

Key words: welding with trailing rotating extrusion; aluminum alloy; microstructure; mechanical properties

Effect of spherical radius of spot welding electrode on nugget size LI Rujuan, LI Mengsheng, WANG Yang, YAN Hongdan (Hefei University of Technology Academy of Material, Hefei 230009, China). p105—108

Abstract: Spherical radius is a very important factor which can affect the quality of spot welding. After solving the contact problem, an axial symmetry model to simulate the welding process was established. Effects of spherical radius of electrode on low-carbon steel resistance spot welding nugget size were investigated quantitatively through ANSYS software. Nugget sizes were simulated by adopting different eletrode radius, and accuracy of simulation was verified by welding experiment. Results indicate that electrode spherical radius has great effects on the nugget diameter and penatration rate, while has few effects on the size of heat-affersted zone. Results also show the error is less than 10% between simulated value and test value.

Key words: spot welding; temperature field; numerical simulation

Microstructure and properties of aluminum coatings on Al alloy surface by arc spraying XU Rongzheng, SONG Gang, LIU Liming (State Key Laboratory of Materials Modification, Dalian University of Technology, Dalian 116024, Liaoning, China). p109—112

Abstract: The pure aluminum coatings on 6061 Al alloy were prepared by arc spraying. The microstructure and porosity of the coating were observed by means of optical microscope. The evaluation of the corrosion properties of the coatings was carried out through the simulated immersing tests, salt spray test and electrochemical experiment in 5% NaCl solution. The results showed that the pure aluminum coating was homogeneous and dense, as well as lower porosity. The coatings can protect the Al alloy substrate from corrosion. The corrosion resistance of the coating with sealing was better than that of the coating without sealing.

Key words: Al alloy; aluminum coating; arc spraying; corrosion resistance