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LY12 铝合金摩擦塞焊接头组织分析

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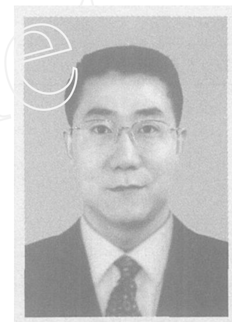

栾国红

摘　要：在介绍摩擦塞焊原理和优点的基础上，经过初步试验，分析了LY12铝合金摩擦塞焊接头的金相组织和硬度分布。结果表明，LY12铝合金摩擦塞焊接头明显分为五个区域，即母材、母材与塑化区Ⅰ过渡区、塑化区Ⅰ、塑化区Ⅰ和塑化区Ⅱ之间的过渡区、塑化区Ⅱ。其中塑化区Ⅰ和塑化区Ⅱ的材料发生了强烈的变形和流动，但流动方式和变形方式不同；硬度分布则是从母材区开始，硬度值逐渐下降，在塑化区Ⅰ达到最低值，随后硬度值逐渐增大，在塑化区Ⅱ趋于稳定且与母材硬度值相当。

关键词：LY12铝合金；摩擦塞焊；组织；硬度
中图分类号：TG453　　**文献标识码**：A　　**文章编号**：0253-360X(2006)10-001-03

0　序　言

摩擦塞焊(friction plug welding，FPW)最早由英国焊接研究所(The Welding Institute，简称TWI)发明，最初目的是用于海洋结构通孔的修补，后来该技术用于搅拌摩擦焊尾孔的消除以及焊接缺陷的修复[1,2]。

与常规熔焊方法相比，在加工成本及时间等方面，摩擦塞焊不具有优势。但是在某些情况下，如恶劣条件下的焊接作业或者材料焊接性差，摩擦塞焊这种技术方法就显现出明显的技术优势[1]。摩擦塞焊是在搅拌摩擦焊基础上发展起来的一种新兴的材料加工方法，在国际上引起了广泛关注，并很快形成了多项技术专利[3~6]，但是相关技术的基础工艺研究报道很少。文中针对铝合金LY12-CZ，这种对于传统熔焊方法而言焊接性不良的典型材料，开展了摩擦塞焊探索性研究，分析了接头的金相组织及硬度分布，同时分析了摩擦塞焊时材料的流动模式和特征。

1　摩擦塞焊原理

根据主轴压力施加的方向不同，可以将摩擦塞焊分为推式摩擦塞焊(friction push plug welding)[3]和拉式摩擦塞焊(friction pull plug welding)(塞棒承受拉力)[4~6]，这两种方法的主要区别在于塞棒的承力状态。推式摩擦塞焊中，塞棒承受压力；而拉式摩擦塞焊中塞棒承受拉力。

文中采用了推式摩擦塞焊方法。具体的加工过程为，首先将存在缺陷和尾孔部分的材料通过钻孔去除，塞棒边旋转边下降，塞棒端部与孔底及侧壁摩擦，使塞棒材料塑化，塑化材料的逐层堆积，填满待焊孔，此时塞棒停转，并施以一定的压力，完成整个塞焊过程，参见图1所示[7]。

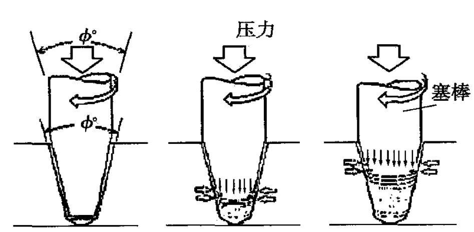

图1　推式摩擦塞焊原理图
Fig. 1　Basic principle of friction push plug welding

2　试验材料及方法

试验材料为LY12-CZ铝合金，其化学成分如表1所示[8]。这种铝合金材料用传统熔焊方法不易实现焊接，因此选用该材料为研究的试验材料，待焊试板尺寸为180 mm×40 mm×8 mm，在自制的摩擦塞焊设备UFSW-2005上进行焊接，先在待焊试板上加工直径为16 mm的待焊孔，称之为塞孔，然后用与该孔相匹配的塞棒进行焊接，焊接时塞棒的旋转

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速度为2 500 r/ min ,焊接后沿塞棒某一直径方向截取试样,经研磨抛光,后用混合酸溶液腐蚀,之后进行金相观察及硬度分布测试。

表 1 LY12 铝合金化学成分(质量分数, %)

Table 1 Chemical composition of LY12

Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	其它	Al
0.5	0.5	3.8～4.9	0.3～0.9	1.2～1.8	0.1	0.3	0.15	0.65	余量

3 摩擦塞焊接头组织分析

焊接后沿塞棒某一直径方向截取试样,进行铝合金搅拌摩擦塞焊接头组织观察,接头宏观形貌及微观组织分别见图 2 和图 3 所示。由图可见,摩擦塞焊接头形貌具有典型的铆钉状特征,上部较宽,随着深度的增加,焊缝区宽度变化很小,接头整体形貌与塞棒形状相似。从接头的宏观形貌来看,基本上可以分为五个区域,即 A 母材、C 塑化区 Ⅰ、E 塑化区 Ⅱ、B 母材与塑化区 Ⅰ之间的过渡区及 D 塑化区 Ⅰ与塑化区 Ⅱ之间的过渡区。

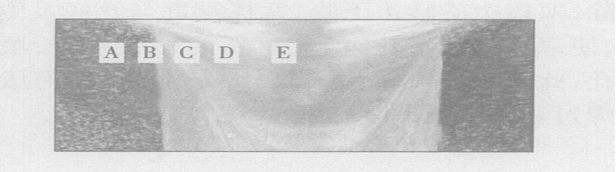
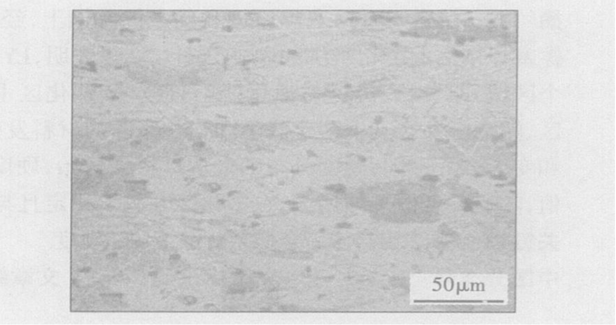


图 2 摩擦塞焊接头宏观形貌

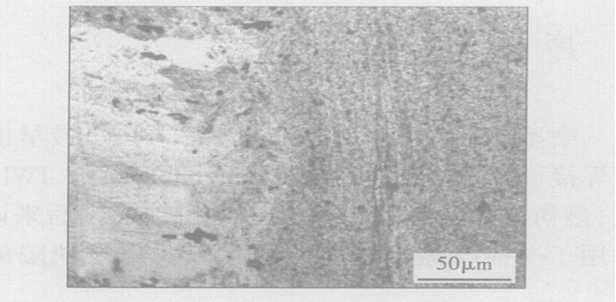
Fig. 2 Macrograph of friction plug welded joint

由图 3a 可见,塞焊接头的母材晶粒尺寸大概为 50～70 μm,可以看出明显的晶界;塑化区中晶粒发生回复和再结晶被细化,尺寸相对母材组织中的晶粒要小得多,母材与塑化区之间分界较为明显,塑化区 Ⅰ与塑化区 Ⅱ之间的过渡分界也较为清晰,这可能与塞焊过程材料的流动方式有关系。

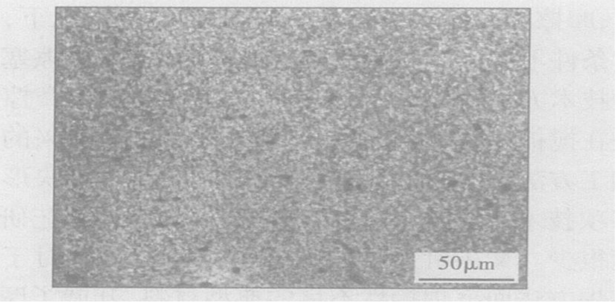
摩擦塞焊过程中,材料的流动方式参见图 4 所示。焊接时,塞棒边旋转边下降,图 4a 所示为塞棒与待焊塞孔刚接触状态;此后塞棒继续旋转并下降,塞棒与待焊孔壁发生强烈摩擦,产生摩擦热,由于散热条件不同,塑化层沿着塞棒向塞棒芯部转移,此时塞棒圆锥面上的金属及与该圆锥面接触的母材金属发生塑化,见图 4b 所示;随着摩擦和金属塑性变形产生的热量进一步增加,塑化金属继续向塞棒芯部转移及芯部金属完全塑化,塞棒的上下部分被塑化的金属分离,使塞棒断裂,此时,母材金属由于受热影响以及塞棒的挤压作用,材料具有向塞焊焊缝背面流动的趋势,见图 4c;随着塞棒的进一步下降,材料的流动方式又发生了变化,塞棒上发生塑化的金属由塞棒端部逐层向塞棒上部转移直至塑化层,从而堆积到焊件表面,形成了铆钉状接头形貌,完成整个塞焊过程,见图 4d。图 5 示意了塞焊接头最终的形貌及不同区域的材料的流动方式。



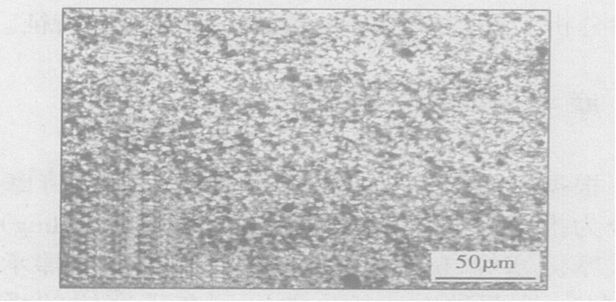
(a) A 区组织



(b) B - C - D 区组织



(c) C - D - E 区组织



(d) E 区组织

图 3 摩擦塞焊接头微观组织

Fig. 3 Microstructure of friction plug welded joint

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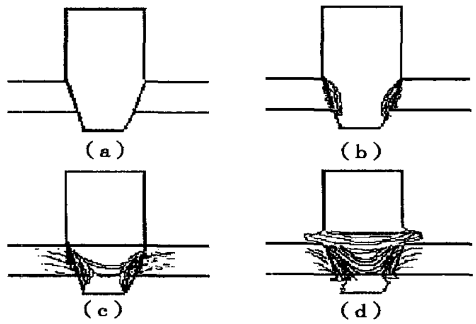

图 4　塞焊过程材料流动示意图

Fig. 4　Schematics of material flow pattern

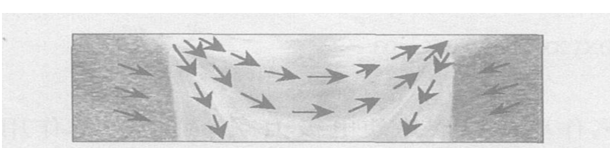

图 5　塞焊接头材料流动方式

Fig. 5　Material flow mode of friction plug welded joint

4　塞焊接头硬度分布研究

对 LY12 - CZ 铝合金摩擦塞焊接头的硬度分布进行了测试分析,测试位置是在材料厚度一半的位置,以焊缝中心成对称逐渐测试到母材。得到的硬度分布曲线见图 6,从图中可以看出,塞焊接头的硬度分布趋势是由母材区硬度(约为 111～118 HV)逐渐下降,至塑化区 I时达到硬度的最低值 100 HV,随后硬度值逐渐增加,在塑化区 II达到稳定值,约在 110～118HV 之间,此时的硬度值与母材相当。从硬度的分布规律可以看出,硬度的分布与接头的显微组织相对应。

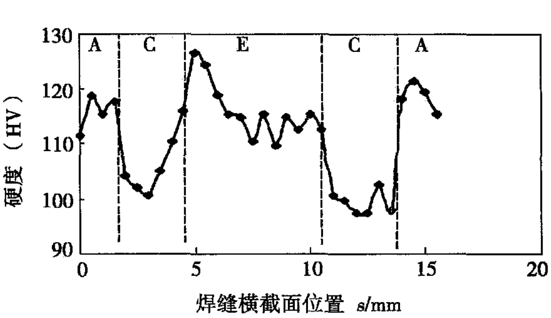

图 6　LY12 摩擦塞焊接头硬度分布曲线

Fig. 6　Hardness distribution of friction plug welded joint

5　结　　论

(1) 摩擦塞焊是一项固相连接技术,与常规熔焊方法相比,在加工成本及时间等方面,摩擦塞焊不具有优势。但是在某些情况下,如恶劣条件下的焊接作业或者材料焊接性差,摩擦塞焊这种技术方法就显现出明显的技术优势。

(2) LY12 铝合金摩擦塞焊接头明显分为五个区域,即母材区、母材与塑化区 I过渡区、塑化区 I、塑化区 I和塑化区 II之间的过渡区、塑化区 II。

(3) 与母材区的晶粒相比,塑化区 I和塑化区 II的晶粒明显细化,实现回复和再结晶过程。

(4) LY12 铝合金摩擦塞焊接头的硬度分布趋势是由母材区逐渐下降,至塑化区 I时达到最低值,随后硬度值逐渐增加在塑化区 II达到稳定值。

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MAIN TOPICS, ABSTRACTS & KEY WORDS

Microstructure of LY12 aluminium alloy welded joint of friction plug welding LUAN Guo-hong, JI Ya-juan, DONG Chun-lin, MA Xiang-sheng (China FSW Center, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China). p1 - 3

Abstract: Friction plug welding is a novel solid state joining and repairing process. Based on the introduction of basic principle of friction plug welding process, preliminary studies on microstructure and hardness distribution of friction plug welded joint were carried out. It is shown that five zones could be easily identified in LY12 joint, i.e. the base metal, plastic zone Ⅰ, the transition zone between base metal and plastic zone Ⅰ, plastic zone Ⅱ, the transition zone between plastic zone Ⅰand plastic zone Ⅱ. Drastic material deformation and metal flow occurr in plastic zone Ⅰand Ⅱ, but these two zones have different flow patterns. Hardness of the joint decreases from the base metal and reaches a minimum in the plastic zone Ⅰ, and then gradually increases to a stable level in plastic zone Ⅱ which equal to the base metal. The other side of the joint has the same trend of hardness distribution.

Key words: LY12 aluminum alloy; friction plug welding; microstructure; hardness

Analysis on electromagnetic force in resistance spot welding WU Pei, MA Yan-hua, HAN Bao-sheng, LI Fen-rong (Inner Mongolia Agricultural University, Huhhot 010018, China). p4 - 6

Abstract: In resistance spot welding, a strong magnetic field is generated due to a high current applied. A theoretical analysis on electromagnetic force caused in the process of resistance spot welding was carried out based on stationary machines by simplifying the electrode arms and electrodes as electric conductors, and the electromagnetic force was measured by means of a middle-frequency DC machine. The results indicate that the electromagnetic force has an effect on reduction of the electrode force, i.e. counteracting the electrode force. The electromagnetic force is mainly affected by the welding current and electrode-arm open depth. It is direct proportional to the square of the welding current and inverse proportional to the electrode-arm open depth. Therefore, the effect of electromagnetic force must be considered when the electrode force is set or measured in the real production.

Key words: resistance spot welding; electromagnetic force; electrode force

Ultrasonic TOFD technique and image enhancemetn based on synthetin aperture fousing techinque GANG Tie, CHI Da-zhao, YUAN Yuan (State Key Lab of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p7 - 10

Abstract: An ultrasonic TOFD (time of flight diffraction) B-scan image was processed in order to accurately locate crack tip in heavy aluminum butt weld. SAFT (synthetic aperture focusing technique) was introduced for improving lateral resolution of the image. According to the geometric relation between the probes and crack tip, an algorithmic model for SAFT processing was founded and SAFT reconstruted image was obtained. Linearization was proposed in order to enhance time resolution of the image before SAFT processing, and a novel technique named as L-SAFT (linearization-SAFT) was developed for ultrasonic TOFD B-scan image reconstruction. The results show that the technique can enhance resolution of the image effectively. Both lateral and vertical location of the crack tip in the specimen can be measured rapidly and accurately with this techinque, which contribute to precise locating and sizing of defect.

Key words: ultrasonic time of flight diffraction; crack; linearization; synthetic aperture focusing technique

Welding process parameter Web publish system based on internet WANG Ke-hong, YANG Yan, WANG Bo (Materials department, Nanjing University Science & Technology, Nanjing 210094, China). p11 - 14

Abstract: The welding process parameters system was built to solue the problem of the welding data acquisition and managing in far distance welding, and its software system and hardware system had also been designed. It can obtain lots of welding process information, such as welders, welding product, welds. The welding process information are acquired by several acquisition model and channel, then the software model was designed to acquire welding current and voltage and display their waveforms in the computer screen. At last the welding process parameter web publishing system is accomplished.

Key words: welding parameters; data acquisition; gas metal arc welding

Tandem GMAW procedure of 2519 high strength aluminum alloy FAN Cheng-lei[1,2], LIANG Ying-chun[2], YANG Chun-li[1], CHENG Shi-jun[1] (1. State Key Laboratory of Advanced Welding Production Technology 2. Mechanical Engineering Mobile Postdoctoral Center, Harbin Institute of Technology, Harbin 150001, China). p15 - 18, 22

Abstract: The relationship between mechanical properties and weld appearance of the joints by the two-pass welding with large current (DL) and the four-pass welding with small current (XS) were investigated in tandem GMAW of 20mm thick 2519 aluminum alloy plate. The results show the tensile strength of both joints are less than 60 % of that of the base metals, and the tensile strength and elongation percentage of the DL joints are larger than those of the XS joints, but the impact toughness of the DL joints is smaller. Based on the merits of the above two process, a new process named four-

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