铝合金激光双光点焊接工艺特性

姚 伟[1]， 巩水利[1]， Steve Shi[2]
(1. 北京航空制造工程研究所 高能束流加工技术国防科技重点实验室, 北京 100024;
2. 英国焊接研究所, 英国 剑桥 CB1 6AL)

摘 要: 对铝合金薄板激光单光点和双光点焊接(包括不填丝和填丝)的焊缝成形、对接间隙和准直度容许裕度以及气孔状况进行了比较, 并分析了双光点能量分布的激光对铝合金焊接的影响。结果表明, 与激光单光点焊接相比, 激光双光点焊接铝合金所得焊缝表面质量更好, 焊缝熔宽更大, 对接间隙和准直度容许裕度明显放宽。激光双光点焊接铝合金可以显著减少焊缝中大气孔的数量, 但对焊缝中小气孔数量的影响不明显。此外, 填加焊丝可以进一步改善焊缝表面质量并放宽对接间隙和准直度容许裕度, 但将增大焊缝产生大气孔的倾向, 采用激光双光点焊接仍可使焊缝中大气孔的数量明显减少。

关键词: 激光焊接; 单光点; 双光点; 填加焊丝; 铝合金
中图分类号: TG46.7 文献标识码: A 文章编号: 0253-360X(2007)04-108-05

姚 伟

0 序 言

聚焦激光作为一种高能量密度热源用于焊接与传统弧焊方法相比具有明显优势, 因此近些年来激光焊接技术应用研究越来越得到世界各发达国家的高度重视。然而, 由于用于焊接的聚焦激光斑点非常小, 其直径一般在 0.6 mm 以下, 因此激光焊对工件装配精度要求极高, 这使其在实际工程中推广应用十分困难。另外, 在用激光焊接铝合金时, 即使采用波长较短的 YAG 激光, 焊缝往往也存在表面塌陷、咬边和气孔等缺陷[1,2]。这主要是因为入射激光与铝合金之间的交互作用比与钢等其它材料的交互作用强烈得多, 导致匙孔不稳定性增大造成的。资料[3]研究表明, 利用双光点能量分布的激光进行铝合金焊接不仅可以降低激光焊对工件装配精度的要求, 而且可以改善焊缝表面和内部质量。目前国内还未对该项技术开展系统研究。作者对铝合金薄板激光单光点和双光点焊接(包括不填丝和填丝)的焊缝成形、对接间隙和准直度容许裕度以及气孔状况进行了比较, 并分析了双光点能量分布的激光对铝合金焊接的影响。

1 试 验

试验采用的激光器为 Trumpf 灯泵浦 YAG 激光器, 其最大输出功率为 3 kW。焊接采用 HIGHYAG 双光点焊接头, 其聚焦透镜的焦距为 150 mm。激光通过光纤传输经双光点焊接头聚焦, 调整双光点焊接头楔形块的位置可以获得两个位向和距离均可调的、焦斑直径为 0.45 mm 的激光光斑, 即可实现激光单光点和双光点焊接。填丝焊时采用 PLANETICS 推拉式送丝机构填加焊丝。焊接过程中工作台静止, 由六轴机械手带动激光相对运动实现。

试验材料采用 5083 铝镁合金, 试板规格为 300 mm×150 mm×3mm。焊接边长 300 mm, 铣削加工平直, 焊前打磨并用丙酮清洗。焊丝采用 5183 铝合金焊丝, 直径 1.2 mm。5083 和 5183 铝合金化学成分如表 1 所示[4]。焊接过程中采用氩气作为熔池和焊缝保护气。

针对 YAG 激光单光点和双光点焊接(包括不填丝和填丝)工艺, 预定离焦量为 0, 激光功率为 3kW。根据板面堆焊焊缝的熔透性和表面质量确定最佳焊接速度, 并以此焊接工艺参数进行对接焊。对接焊方式包括 0 间隙对接焊、0~1 mm 变间隙对接焊以及 0 间隙光点偏移 0~1 mm 对接焊, 如图 1 所示(箭头所示方向为焊接方向)。激光双光点焊接时, 预定光点功率配比为 50/50, 光点距离为 0.27 mm, 光点位向与焊接方向的关系如图 2 所示。填丝焊时, 填丝方向与焊接方向相反, 且与激光方向间夹角为 30°, 填丝速度为 1.5 m/min。为减小反射光对激光器和外光路光学元件的损害, 焊接头中轴线逆着焊接方向偏转 10°。

收稿日期: 2006-04-07

表 1　5083 和 5183 铝合金化学成分(质量分数, %)

Table 1　Chemical composition of 5083 and 5183 aluminum alloys

铝合金	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
5083	0.40	0.40	0.10	0.40~1.0	4.0~4.9	0.05~0.25	0.25	0.15	余量
5183	0.40	0.40	0.10	0.50~1.0	4.3~5.2	0.05~0.25	0.25	0.15	余量

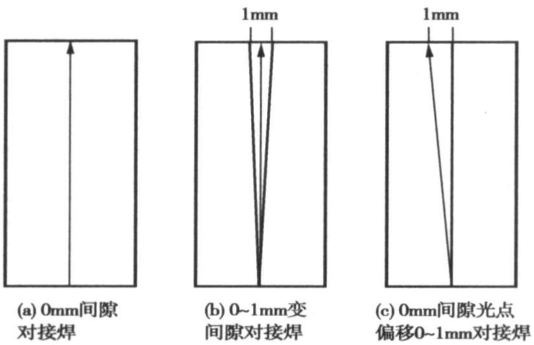


图 1　对接焊方式

Fig 1　Style of butt joint

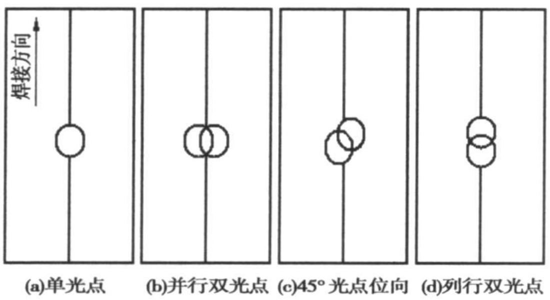


图 2　光点位向与焊接方向的关系

Fig. 2　Relationship between laser spot rotation and welding direction

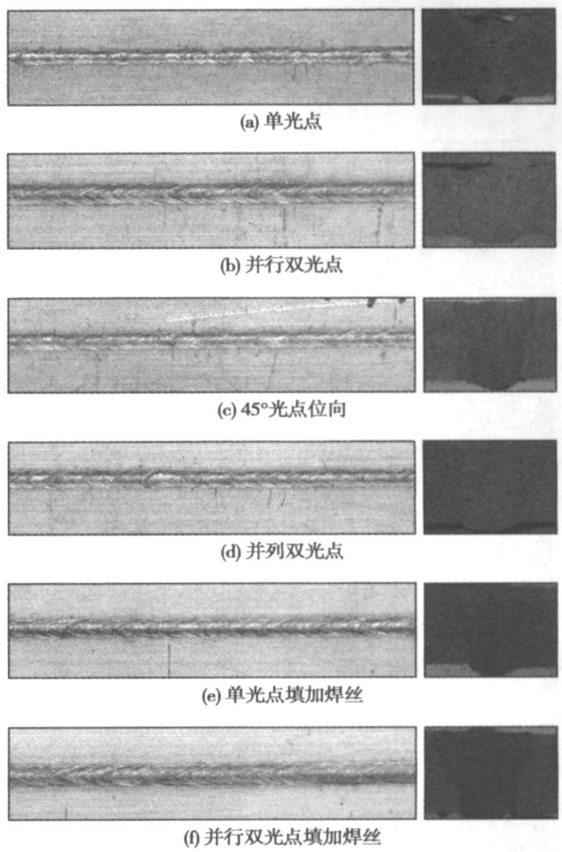


图 3　0 间隙对接焊焊缝的外观形貌和横截面形貌

Fig 3　Top surface appearance and cross-section of butt joint with 0 mm gap

2　试验结果与分析

2.1　焊缝成形

图3 为 0 间隙对接焊焊缝的外观形貌和横截面形貌。从图可以看出, 不填加焊丝条件下, 激光单光点焊接铝合金焊缝熔宽非常窄, 焊缝正面塌陷严重, 咬边尖锐。激光双光点焊接所得焊缝熔宽增大, 焊缝正面塌陷状况得到改善, 咬边变得平缓。填加焊丝条件下, 激光单光点和双光点焊接铝合金都可以获得较好的焊缝成形, 焊缝表面无塌陷和咬边缺陷, 但激光双光点焊接所得焊缝熔宽更大。

2.2　对接间隙和准直度容许裕度

图4为0 ~ 1mm 变间隙对接焊焊缝的外观形貌(箭头以左焊缝完全熔合, 箭头以右焊缝不完全熔合), 图 5 为 0 间隙光点偏移 0 ~ 1 mm 对接焊焊缝 X 射线检测照片(箭头以左焊缝完全熔合, 箭头以右焊缝不完全熔合)。表 2 为各种激光焊接工艺焊接铝合金薄板的对接间隙和准直度容许裕度测量结果。试验结果表明, 与激光单光点焊接相比, 不填加焊丝条件下, 激光双光点焊接的对接间隙容许裕度放宽 0.2 ~ 0.3 mm, 准直度容许裕度放宽 0.1 ~ 0.2 mm。并且, 激光双光点焊接时, 光点位向对对接间隙和准直度容许裕度有较大影响。其中, 并行双光点焊接的对接间隙和准直度容许裕度最大, 45°光点位向焊接次之, 列行双光点焊接再次之。填加焊丝条件下,

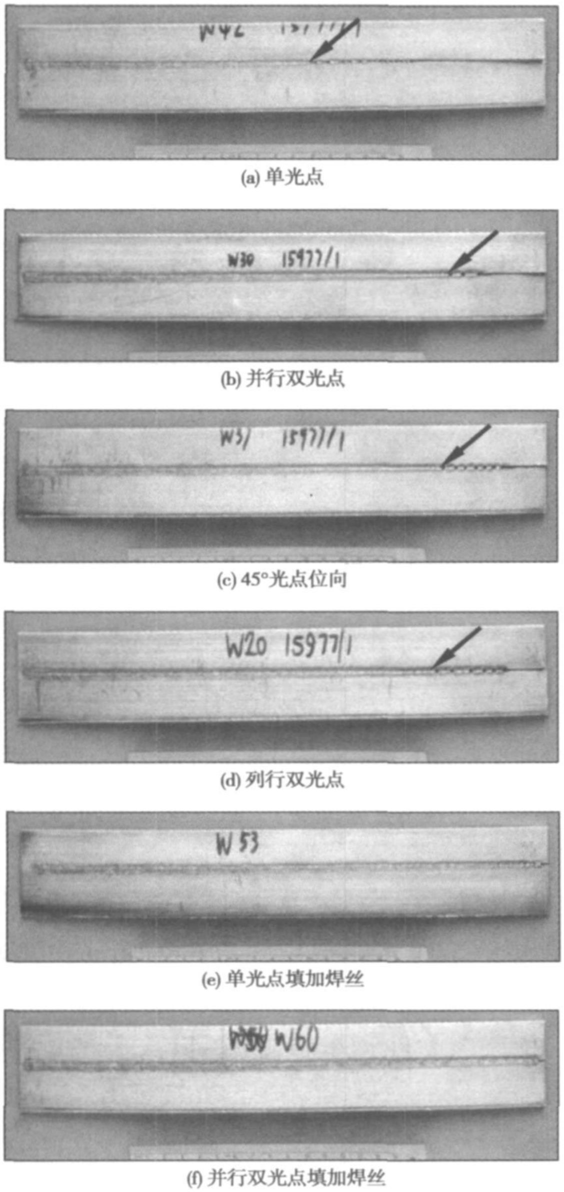


图 4 0~1 mm 变间隙对接焊焊缝的外观形貌

Fig. 4 Top surface appearance of butt joint with 0-1 mm variable gap width

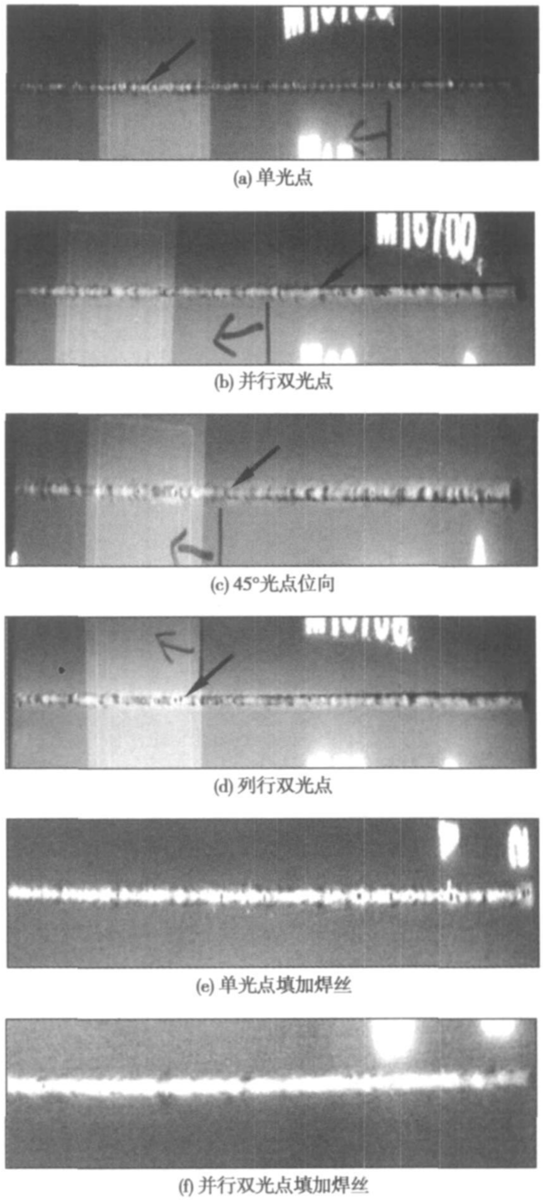


图 5 0 间隙光点偏移 0~1 mm 对接焊焊缝 X 射线检测

Fig 5 Radiograph of butt joint with 0mm gap width and 0-1 mm variable laser spot separation

表 2 各种激光焊接工艺的对接间隙和准直度容许裕度

Table 2 Thresholds of gap width and laser spot separation of various laser welding procedures

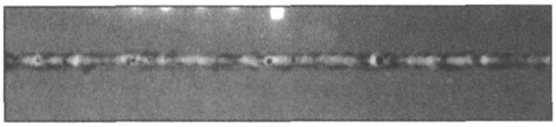
容许裕度 δ/mm	不填丝				填丝	
	单光点	并行双光点	45°光点位向	列行双光点	单光点	并行双光点
对接间隙	0.55	0.85	0.75	0.75	>1.00	>1.00
准直度	0.40	0.60	0.55	0.50	>1.00	>1.00

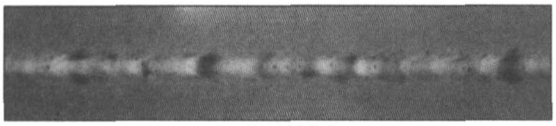
激光单光点和双光点焊接的对接间隙和准直度容许裕度都超过 1 mm。

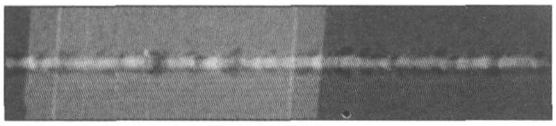
2.3 气孔状况

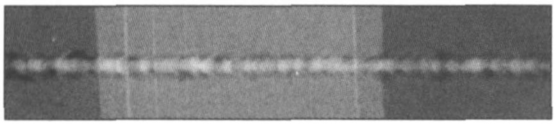
图6 为 0 mm 间隙对接焊焊缝 X 射线检测照片。从图可以看出，激光焊接铝合金焊缝中存在两种不同类型的气孔。其中一种气孔体积较小，数量较多，分布于焊缝及其两侧的熔合区内。这类气孔在传统铝合金熔焊焊缝中也比较常见。另一种气孔

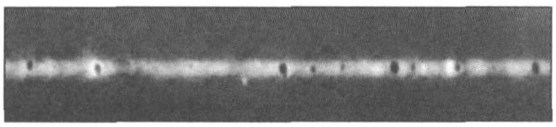
体积较大, 大多分布于焊缝中心, 也有个别气孔靠近于焊缝两侧。


(a) 单光点


(b) 并行双光点


(c) 45°光点位向


(d) 列行双光点


(e) 单光点填加焊丝

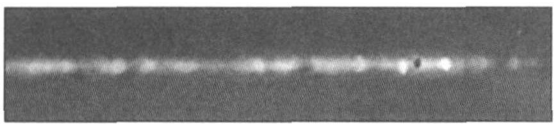

(f) 并行双光点填加焊丝

图 6　0 间隙对接焊焊缝 X 射线检测

Fig 6　Radiograph of butt joint with 0 mm gap

表 3 是对 300 mm 长度焊缝上不同直径气孔数量统计结果。从统计结果可以看出, 与激光单光点焊接相比, 激光双光点焊接铝合金可以显著减少焊缝中大气孔(直径≥0.6 mm)的数量, 但对焊缝中小气孔(直径≤0.4 mm)数量的影响不明显。并且, 激光双光点焊接时, 光点位向对焊缝中大气孔的数量有较大的影响。其中, 列行双光点焊接大气孔数量较少, 并行双光点焊接大气孔数量较多, 45°光点位向焊接大气孔数量介于前两者之间。填加焊丝将增大焊缝产生大气孔的倾向, 但采用激光双光点焊接仍可使焊缝中大气孔的数量明显减少。

2.4　激光双光点焊接的影响

激光双光点焊接时, 光点作用面积增大, 一方面使激光加热范围增大, 熔化金属量增多, 焊缝熔宽增大; 另一方面使激光功率密度降低, 激光穿透能力减弱。为了获得同样的焊接熔深, 需要降低焊接速度, 焊接热输入增大, 也使熔化金属量增多, 焊缝熔宽增大。激光功率密度降低也使材料汽化剧烈程度降低, 金属蒸气和等离子体对熔池的扰动减弱, 同时双光点能量分布的作用方式也使焊接匙孔更加具有柔性, 熔池流动性增强, 从而使焊缝正面塌陷状况得到改善, 咬边变得平缓。此外, 激光双光点焊接可以熔化更多的母材金属, 使焊缝熔宽增大, 这必然也增大其对接间隙和准直度容许裕度。

文献[5]中指出, 焊接过程中匙孔瞬间失稳是铝合金激光焊接大气孔产生的根本原因。为了减少大气孔的数量, 必须保证焊接过程中匙孔的稳定。试验结果表明, 采用双光点能量分布的激光焊接铝合金在稳定焊接匙孔和控制大气孔数量方面具有明

表 3　300 mm 长度焊缝上不同直径气孔数量统计结果

Table 3　Number of gas pore of different diameters in weld of 300 mm length

焊接工艺	气孔直径等级 D/mm								
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
单光点	20	9	10	5	3	3	0	1	0
并行双光点	20	5	5	3	0	0	0	0	0
45°光点位向	21	2	2	0	0	0	0	0	0
列行双光点	25	6	0	0	0	0	0	0	0
单光点, 填加焊丝	29	9	7	7	4	2	1	0	1
并行双光点, 填加焊丝	24	9	2	1	0	1	0	0	0

显效果。双光点激光各自产生的匙孔叠加在一起, 使匙孔张口和根部直径得到扩大, 匙孔壁的波动状态也得到改善, 一方面匙孔前壁材料汽化面积增大, 削弱了材料汽化对匙孔后壁的局部冲击, 金属蒸气和等离子体更容易从匙孔张口喷发出去, 另一方面金属蒸气和等离子体的周期性波动不易造成匙孔壁

的封闭,增强了匙孔的稳定性,从而减少了大气孔的产生。此外,双光点能量作用方式还可以降低熔池冷却速度,使液态熔池存在时间延长,有利于液态熔池中大气泡的逸出,从而减少焊缝中大气孔的数量。

3 结 论

(1) 与激光单光点焊接相比,激光双光点焊接铝合金所得焊缝表面质量更好,焊缝熔宽更大,对接间隙和准直度容许裕度明显放宽。

(2) 与激光单光点焊接相比,激光双光点焊接铝合金可以显著减少焊缝中大气孔的数量,但对焊缝中小气孔数量的影响不明显。

(3) 填加焊丝可以进一步改善焊缝表面质量并放宽对接间隙和准直度容许裕度,但将增大焊缝产生大气孔的倾向,采用激光双光点焊接仍可使焊缝中大气孔的数量明显减少。

参考文献:

[1] Mandal N R. Aluminum welding[M]. Pangbourne: Alpha Science International Ltd., 2002.
[2] Ion J C. Laser beam welding of wrought alumi-num alloys[J]. Science and Technology of Welding and Joining, 2000, 5(5): 265—275.
[3] Sárady I, Nilsson K, Magnusson C, *et al*. Investigations into the welding of superalloys with a CW Nd:YAG laser and dual-focusing optics[C]. Section F—ICALEO 1998, 87—93.
[4] Aluminum Association. Aluminum standards and data 1976[S]. USA: Aluminum Association, 1976, 92.
[5] Akira Matsunawa. Dynamics of keyhole and molten pool in high power laser welding[J]. Journal of laser Applications, 1998, 10(6): 247—254.

作者简介:姚 伟,男,1978 年生,工程师。主要从事轻质合金激光焊接新技术研究,已发表论文 6 篇。
Email: yaoweing@163.com

ficult manipulation. From the method, the arc current and voltage can be automatically controlled within the meso-spray zone by confirming the pulsed current in response to the arc voltage and also automatically meet the fluctuating of wire feed rate and arc length. For Aluminum wire of 1.6 mm diameter, the meso-spray zone based on the above control idea is confined within 14.5—22 V and 30—235 A, and the pulsed welding experiments companied with high speed photogragh are put into effect and show good control of meso-spray, the good weld appearance and better prevention from producing welding defects.

Key words: aluminium; pulsed metal inert-gas welding; meso-spray transfer; self-adapting control

Analysis on runner welding residual stress affected by local heating

JI Shude[1], ZHANG Liguo[1], FANG Hongyuan[2], LIU Xuesong[2] (1. Institute of Astronautical Technology, Shenyang Institute of Aeronautical Engineering, Shenyang 110034, China, 2. National Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p97—100

Abstract: According to the property of weld formation, local heating method was brought out to improve the distribution of welding residual stress in of runner blade. Moreover, on the basis of local heating' s reasonable position attained by plane experiment, regulating and controlling on some hydroelectric station' s runner welding residual stress field was researched by means of local heating. The result shows that for the plane whose dimension is 500 mm×500 mm ×16 mm, local heating can decrease residual stress and the best opsition is 60 mm or so away from the edge of heating area; transverse residual stress engenders in the dangerous area of blade of runner by means of local heating. Moreover, from the view of the effect on decreasing residual stress near blade outlet, the effect of local heating processing after heat treatment excels that of before heat treatment.

Key words: blade; local heating; dangerous area; welding residual stress

Microstructural formation of Al_2O_3 fiber reinforced Al-matrix composites joint by capacitor discharge welding

LEI Ming, ZHAI Qiuya, XU Jinfeng (School of Material Science and Engineering, Xi' an University of Technology, Xi' an 710048, China). p101—104

Abstract: The capacitor discharge spot welding of the Al_2O_3 fiber reinforced Al—matrix composites was conducted. In the welded joint, the microstructure has a well transition from matrix to nugget, and the small quantity of Al_2O_3 fiber are broken down due to the effect of electrode force, which distributes in periphery of the nugget. Due to very short time in welding, the cooling rate of the joint reaches to 10^6 K/s, and the microstructure of the nugget is obviously characterized by rapidly solidified microstructure. The segregation of alloy elements in the alloy phase decreases. The solid solubility of Si atoms in the α—Al is increased. The eutectic transformation is suppressed, and the microstructure of nugget refines remarkably. Under the heat cycle, because of the different coefficient of thermal expansion between Al_2O_3 fiber and α—Al matrix, the interface of Al_2O_{3F}/ADC12 becomes potential crack source.

Key words: Al-matrix composites; capacitor discharge welding; Al_2O_3 fiber; joint microstructure

Microstructure and properties of laser remelt YPSZ coatings

WANG Hongying[1], TANG Weijie[1,2], CHEN Hui[2], LI Zhijun[1], Mo Shouxing[1] (1. Shenzhen Polytechnic, Shenzhen 518055, Guangdong, China; 2. Southwest Jiaotong University, Chengdu, 610031, Sichuan, China). p105—107

Abstract: CO_2 laser system was used to remelt YPSZ (yttria partially stabilized zirconia, 8% Y_2O_3—ZrO_2) coatings. The microstructure, phases and microhardness of the coatings were studied. Results show that after rapid melting and solidification by laser beam, the porosity and the crack in the YPSZ coatings are decreased, meanwhile the strength and toughness of YPSZ coatings are increased. This change is due to the variation of phases. The YPSZ coatings treated by laser remelting is composed of lots tetragonal and few cubic phases. Tetragonal phase is the main reason to improve the mechanical properties of coating surface.

Key words: ZrO_2; plasma coating; laser remelting

Twin spot laser welding characteristics of aluminum alloy

YAO Wei[1], GONG Shuili[1], STEVE Shi[2] (1. National Key Laboratory For High Energy Density Beam Processing Technology, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China; 2. TWI Ltd, Cambridge CB1 6AL, United Kingdom). p108—112

Abstract: Single spot laser and twin spot laser welding of aluminum alloy, with or without wire feeding, were carried out. The weld appearauce, the thresholds of gap width and spot separation, as well as the states of porosity in weld with various laser welding procedures were compared, and the influences of twin spot laser on welding of aluminum alloy were analyzed. It showed that in contrast to single spot laser welding, twin spot laser welding can improve the weld surface quality, and increase the weld width, the thresholds of gap width and spot separation. Twin spot laser can decrease obviously the large gas pore, but can not decrease the small gas pore. In addition, wire feeding in process of welding can improve weld surface quality and increase thresholds of gap width and spot separation further, but increase large gas pore. Twin spot laser welding with wire feeding can decrease the large gas pore.

Key words: laser welding; single spot; twin spot; wire feeding; aluminum alloy