CO_2 激光焊接不锈钢光致等离子体动态特性分析

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摘 要: 光致等离子体是 CO_2 激光焊接中一个重要的物理现象, 它与焊接的稳定性、焊接质量及能量利用率等都有密切的关系。利用高速摄像及光信号监测两种手段对等离子体的动态变化过程及其对焊接稳定性的影响进行了深入的研究。提出了等离子体的变化每个周期内分为四个阶段, 而影响焊接稳定性的根本原因是等离子体在穿透与未穿透之间的波动。

关键词: 激光焊接; 光致等离子体; 高速摄像; 光信号
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0 序 言

光致等离子体是 CO_2 激光深熔焊接过程中在高能量密度激光束作用下伴随小孔同时存在的不可避免的重要物理现象。特别在高功率焊接中, 由于其对入射激光束的屏蔽效应, 焊接熔深受到影响, 因而有很多研究注重于减弱其对焊接熔深的影响。另一类研究是利用光致等离子体这一特殊的现象来监测焊接过程的稳定性、缺陷的产生等。因为众多研究表明, 光致等离子体能改变激光与工件的能量耦合, 同时潜在地造成激光焊接缺陷, 如未熔透、气孔、成分变化等。而它的光及声、电等特性代表了某种焊接过程的特征, 可以通过对其深入研究而对焊接缺陷进行实时监测。利用光致等离子体监测焊接过程的缺陷等研究在 20世纪 90年代已进行很多。

但是 CO_2 激光焊接过程中, 光致等离子体具有什么特定的特征呢? 它的动态变化规律如何, 由于其不稳定且快速的变化特征, 以及其高强度的亮光等因素的制约, 因而研究比较少。Herziger Kreutz and Wissenbach等在 1986发表的文章中, 对高功率的 CO_2 激光焊接时的等离子体变化过程进行过研究, 认为等离子体以 $10^5 \sim 10^6$ cm/s的速度从工件分离[1~4]。

作者利用高速摄像及光声监测系统, 从图像动态形貌、光声特性等多方位分析了 CO_2 激光焊接时, 光致等离子体的动态特征和静态特征, 为充分利用这一特征过程奠定基础。

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1 试验设备与方法

试验所采用的设备为 CO_2 激光快速轴流设备, Q-Mode额定功率 4 kW, 连续。Phantom 高速摄像系统, 最高 38 000帧/s, 监测设备为自行研制的光声信号监测系统"高能束流加工过程监测系统"; 试件材料为 1Cr18Ni9Ti不锈钢, 厚度 2mm。焊接工艺参数为功率 $P=1\,700$ W, 焊接速度 $v=16.7$ mm/s, 同轴保护气体为氩气。

2 光致等离子体的动态特征分析

以 CO_2 激光焊接 2 mm厚不锈钢为例, 研究激光功率 $P=1\,700$ W 左右时, 熔透过程中光致等离子体变化情况。

2.1 过程特征

图 1是拍摄到的等离子体的一个周期内的动态变化过程, 而激光焊接过程是在不断重复这样的过程而完成的。图 2是一段时间内等离子体的兰紫光相对强度的变化图, 分析图 1和图 2的过程变化发现, 在熔透焊接时, 等离子的变化主要由四个不同的阶段组成, 各个阶段的特征如下。

2.1.1 材料蒸发阶段

激光作用在工件上, 当功率密度足够大时, 在材料表面起主要作用的是气化过程, 金属材料气化形

成只有少数电离存在的蒸气,入射激光穿过蒸气时,原子并不吸收光子,而是通过电离电子吸收能量,通过高能电子的碰撞,金属蒸气可以被加热到远超过气化温度。但由于此阶段电子密度低,因而等离子体相当弱,对激光的吸收也较弱(图 1a、b、c、d、e)。

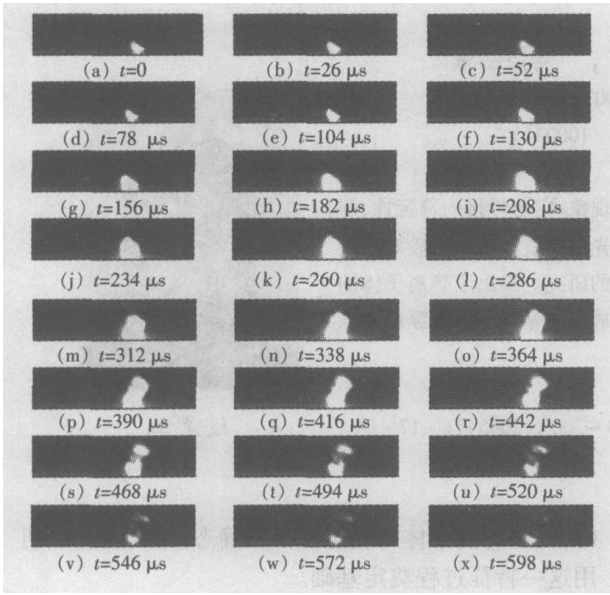

图 1 光致等离子体的动态变化(材料:不锈钢;焊接状态:熔透)

Fig. 1 Plasma images for full penetration welding of stainless penetrating weld

2.1.2 等离子体激增阶段

逆韧致辐射使入射激光光子转化为等离子体,其速度以指数级计,但是由于外部气流压力、熔池表面张力等,使得等离子体主要被抑制在小孔内及出口处。此时由于激光能量的被大量吸收,使得激光作用在被焊材料的能量减少,在等离子体强时,可能阻断激光焊接过程,小孔此时在低部处于闭合的情形(图 1f、g、h、i、j、k)。

2.1.3 等离子体爆炸分离阶段

当小孔内蒸气及等离子体的压力超过表面的约束力时,等离子体从小孔内爆炸,在强度大时,夹带熔化金属爆炸,快速膨胀到环境压力(图 1l、m)。

2.1.4 分离后等离子体团逐渐消散阶段

爆炸后的等离子体,一方面向周围扩散,同时等离子体渐渐复合,电子密度减少,对激光的影响变小,从而重新回到材料蒸发阶段(图 1n ~图 1x)

2.2 周期特征

从图 1中可以初步计算出等离子体的频率为 f_p =1 583 Hz。但是由于等离子体的过程是一个不稳定的过程,因而这个频率并非固定的,对高速摄像所获得的图像进行处理,测出了等离子体变化频率的部分结果(图 3)。结果表明,在此条件下等离子体的变化频率主要在 1 ~3 kHz之间变化,平均为 2 496Hz

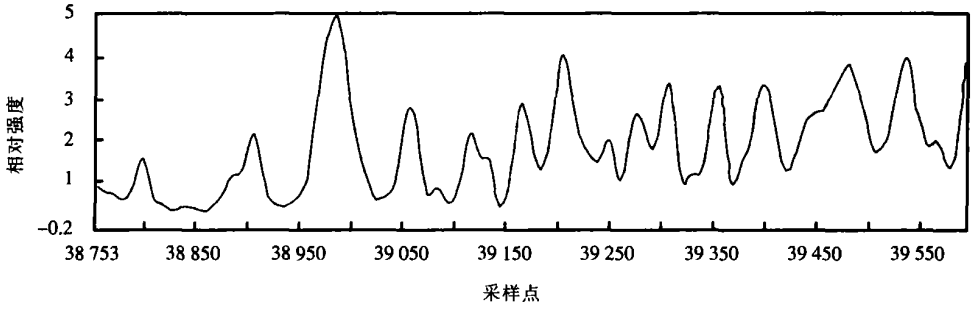

图 2 一段时间内等离子体的相对强度的变化过程

Fig. 2 Relative intense of plasma in some weld (0.3 ms/50 dot)

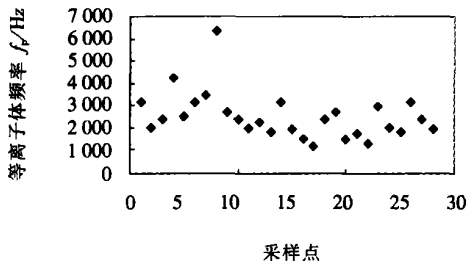

图 3 CO_2 激光焊接时所测得等离子体的变化周期

Fig. 3 Frequency of plasma in CO_2 laser welding

2.3 背部特征

激光熔透焊接时,背面是否有等离子体,这是一个有争论的问题,在研究中,同时在熔池的上方和背面获得了同样的等离子体图像(图 4),因而认为熔透焊接时,焊缝背面的等离子体变化周期与正面相同,特点如下。

(1) 在材料蒸发阶段,背面等离子体逐渐变小。

(2) 在等离子体激增阶段,背面等离子体消失。

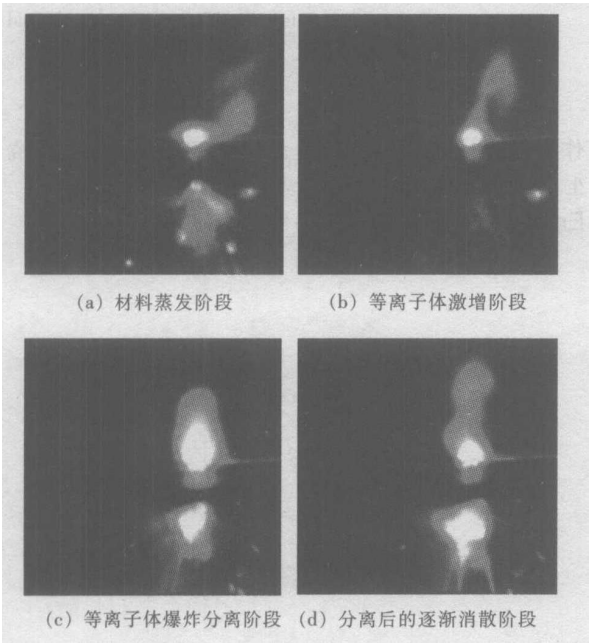

图 4　四个特征阶段熔池上方和背面等离子体

Fig. 4　Images of plasma on surface above molten pool and back of workpiece at different states

(3) 在等离子体爆炸分离阶段, 等离子体从背面小孔中爆炸分离。

(4) 在分离后的逐渐消散阶段, 等离子体从背部喷出。

3　光致等离子体对焊接稳定性的影响分析

光致等离子体的稳定, 表征着 "小孔 "的稳定, 同样代表了焊接过程的稳定。假设以等离子体的光信号的相对强度来描述等离子体的稳定性, 图 5给出了不等厚度焊接时, 焊缝的形貌所对应的相对强度。从图中可知, 稳定出现在两种状态时, 即焊缝背宽达到正面熔宽的一定比例时, 以及完全未熔透状态。此现象可以解释为当焊缝背面的熔宽达到一定比例时, 焊接过程几乎在每个等离子体周期内, 都是相一致的等离子体穿透背面的过程, 这时整个过程表现为稳定的过程; 而对于完全未熔透过程, 每个等离子体周期内, 都是未穿透的过程, 因而也是稳定的。但在二者中间, 等离子体表现为两种过程的交叉, 因而会产生不稳定的等离子体, 产生不稳定的焊

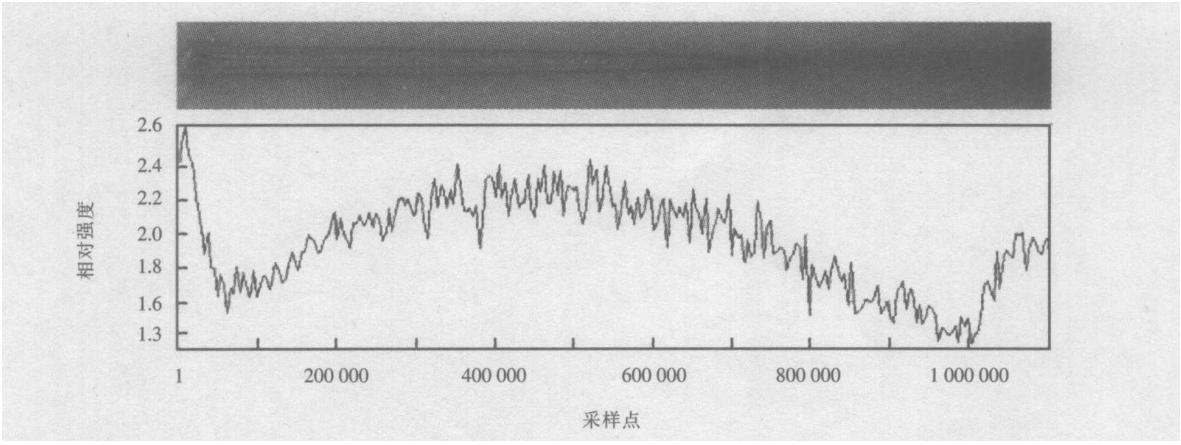

图 5　焊缝背面与所对应的等离子体光信号相对强度之间的关系

Fig. 5　Relation between back surface of weld and its optical signals of plasma

接过程。

4　结　　论

(1) 等离子体的变化每个周期内分为四个阶段: ① 材料蒸发阶段; ②等离子体激增阶段; ③ 等离子体爆炸分离阶段; ④ 分离后的等离子体团逐渐消散阶段。

(2) 在文中的焊接条件下, 等离子体主要是以1 ~3 Hz的频率在变化。

(3) 在熔透焊接时, 背部具有与熔池表面相同波动性的等离子体。

(4) 影响焊接稳定性的根本原因是等离子体在穿透与未穿透之间的波动。

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Key words: high temperature polymer matrix composite material; ceramic coating; erosion; thermal-resistance coating

Dynamic behavior of plasma in CO_2 laser welding of stainless steel

DUAN Ai-qin[1,2], CHEN Li[1,2], WANG Ya-jun[2], HU Lun-ji[1] (1. Huazhong University of Technology and Science, Wuhan 430074, China; 2. BAMTRI, Key laboratory for high energy density beam processing technology, Beijing 100024, China). p17 - 20

Abstract: Laser induced plasma is an important physical phenomenon in laser deep penetration welding. It has stronger relationsip to stability of process, quality of weld, and efficiency of laser energy. In this paper, two methods were used to study the dynamic behavior of plasma and the influences on stability of welding process. These methods were high-speed camera and optical signal monitoring. The results showed that the dynamic process of plasma can be divided into four steps, (1) material vaporing; (2) plasma increasing; (3) plasma bombing and separating; (4) plasma scattering. The main reason affected welding process stability is the fluctuation of plasma between non-penetration and penetration process.

Key words: Laser welding; laser induced-plasma; high-speed camera; optical signal

Weld residual stress distribution of GH536 superalloy with EBW measuned by Mathar method FU Peng-fei, LIU Fang-jun, FU Gang, MAO Zhi-yong (Key Laboratory of high energy density beam processing technology, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China). p21 - 23

Abstract: Electron beam welding is applied to manufacturing many superalloy components of aeroengine, but the researches of weld residual stress were very few for those components. In this paper, weld residual stress of GH536 superalloy components with EBW were measured by Mathar method. Test results showed that residual stress is low in the weld and its distribution accords with the traditional rules. This research can accumulate experiences and properties data for manufacturing aeroengine components with EBW.

Key words: GH536 superalloy; electron beam welding; hole drilling method; residual stress

Real-time monitor system based on virtual instrument technology for laser welding ZHANG Pu, PENG Qi-zhi, KONG Li (Huazhong University of Technology and Science, Wuhan 430074, China). p24 - 26

Abstract: The laser deep penetration welding monitoring system based on the virtual instrument technology was introduced. The component of hardware and the development of software were illuminated. Three signals of ultraviolet light, infrared light and acoustic signal acquired by three special sensors. The raw data were processed dy DSP, multi-sensors data fusion was done by neural network algorithm, and the reliable result of welding quality was oslained. The experimental data proved the system's validity and stability.

Key words: virtual instrument; laser welding; data fusion

Optimization selection of power source frequency in high frequency induction brazing HE Peng, LIU Duo, FENG Ji-cai (National Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p27 - 29

Abstract: Appropriate frequency of high frequency power source shoulded be selected to obtain perfect soldered joint during high frequency induction brazing according to the physical performance of joint materials. Numerical selection model for the frequency and its arrange of high frequency induction heating power source was set up by means of numerical analysis. It showed that numerical analysis can be used as an important artifice for design of high frequency power equipment. Compared the analytical results from the numerical model with that of the traditional formula, it showed that the former is more accurate. Because the latter was derived from the plane electromagnetic wave spreading characteristic in electro-conductive inter-media, it was more suitable for the frequency selection of board structure high frequency induction heating. But for frequency selection of pipe-structure or more complex structure high frequency induction heating, the numerical analytical method will be better.

Key words: high frequency induction brazing; power frequency; numerical analysis

Corrosion behavior of weld metal of low-alloy steel HUANG An-guo[1], LI Zhi-yuan[1], YU Sheng-fu[1], ZHOU Long-zao[1], ZHANG Guo-dong[2] (1. School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China; 2. School of Power and Mechanic, Wuhan Uniersity, Wuhan 430072, China). p30 - 34

Abstract: Two welding heat input were applied to 16Mn and X70 steel by SAW. The corrosion behavior of weld metal was investigated in two kinds of solution, NACE and 3.5% NaCl, respectively. The results show that corrosion tendency of acicular ferrite (AF) in weld is greater than other microstructures, but its corrosion velocity is slowly. The corrosion resistance of weld metal with AF increases with the increasing of ac-