低碳钢高温相变对焊接角变形的影响

杨广臣[1,2]， 张彦华[1]
（1. 北京航空航天大学，北京 100083；
2. 承德石油高等专科学校，河北 承德 067000）

杨广臣

摘 要：低碳钢板具有良好的综合力学性能和焊接性能，被广泛地应用在各种焊接结构中，但是对接接头角变形一直是焊接过程中的突出问题. 文中通过测试低碳钢对接接头动态角变形，对其变化过程和特点进行了分析和总结. 结果表明，除温度变化引起的体积线性变化对角变形产生影响外，700 ℃以上温度发生的高温相变对自由状态下单层对接接头焊缝以及多层多道焊的首层焊缝角变形变化将产生影响；而多层焊接除首层以外的其它层焊缝，700 ℃以上温度的相变将对角变形变化不产生影响.

关键词：对接接头；低碳钢；多层多道焊；相变；角变形
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0 序 言

低碳钢具有非常好的综合力学性能以及良好的焊接性能，被广泛地应用在桥梁、船舶、矿山机械等国民经济各部门. 焊接过程中复杂的热过程导致了焊接结构出现焊接应力和焊接变形. 由于焊接应力和变形对结构的制造过程、使用性能以及结构安全性都存在非常大的影响，所以焊接工作者一直致力于对焊接应力和变形的影响因素进行研究总结.

单层焊和多层多道焊对接接头在各种大型结构中应用很多，焊接过程中角变形的产生和存在对结构承载以及外观等方面存在影响. 通过测量低碳钢对接接头角变形的动态过程，对低碳钢对接接头角变形的变化过程及特点进行分析，对影响对接接头角变形的因素进行总结.

1 角变形影响因素的分析

焊接工作者通过多年的实践和研究，对焊接过程中的应力应变关系基本上有了统一的认识，特别是近年来数值模拟技术的发展，使人们能够更加直观地表达焊接过程中热、力、变形的演变过程.

焊接应力和变形的出现过程非常复杂，但究其根本原因是焊接时的不均匀热输入使焊接结构经受复杂的热物理、热力学过程. 在这个过程中焊缝金属以及焊接热影响区金属由于各种原因可能发生比较复杂的体积变化，这种复杂的体积变化会在工件内部形成各种应力，进而对金属体积变化产生影响，最终形成焊接应力和变形. 同时，焊接时的各种机械力也可能使结构发生物理位移而导致焊接变形.

文献[1－4]指出，金属在加热及冷却时发生相变会引起比容及性能的变化，其中相变在加热冷却时容积变化如图1所示. 图1中Ⅰ为加热时的变化，Ⅱ为低碳钢冷却时的变化，一般情况下由于奥氏体转变为铁素体和珠光体的转变都在700 ℃以上发生，因此不影响焊接变形与应力. 当冷却速度很快或者合金及碳元素增加时，奥氏体转变温度降低，并可能发生马氏体转变，如图1中Ⅲ，在700 ℃以下的这种变化对焊接变形和应力将发生相当大的影响.

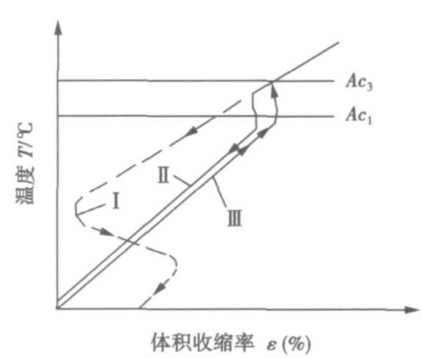

图1 钢材加热和冷却时的膨胀和收缩曲线
Fig. 1 Curves of expand and contract of metal

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2 低碳钢角变形动态变化过程测量

采用普通的机械方法,利用千分表分别对低碳钢 Q235对接接头多层多道焊接角变形的动态变化过程进行两组测量,绘制出角变形动态变化曲线.

两组试验焊接层数及测试点位置如图 2所示,焊接过程中,图 2中对接的两块板件中右侧试件二被刚性固定在工作台上,读取左侧试件一上测试点位置向上或者向下移动的量,换算出焊接过程中角变形量的大小(文中将测试点向上移动定义为角变形的正方向)

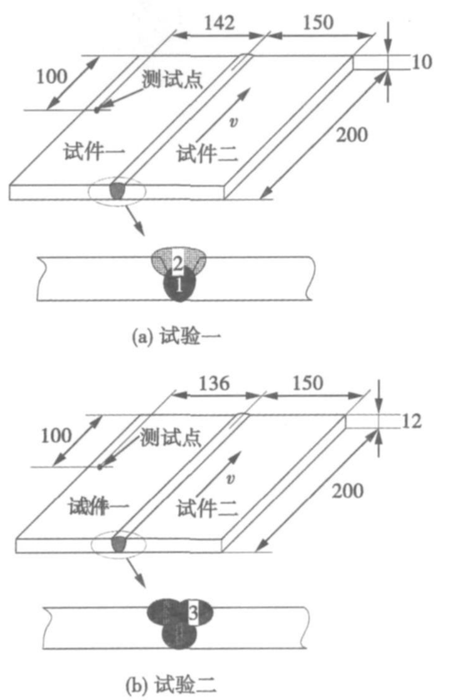

图 2 低碳钢 Q235测试试件尺寸(mm)
Fig. 2 Specimens of low carbon steel Q235

试验一第一层焊缝焊接速度为 5 mm/s; 第二层焊缝焊接速度为 2.8 mm/s. 试验二第一道焊缝焊接速度为 6.7 mm/s;第二道焊缝焊接速度为 4.4 mm/s;第三道焊缝焊接速度为 3.3 mm/s. 表 1列出两组试验使用的材料、焊接方法等.

表 1 试验原始数据
Table 1 Data of experiment

试验	长度 L/mm	宽度 B/mm	厚度 δ/mm	坡口角度 α/(°)	钝边 h/mm
一	200	150	10	60	2
二	200	150	12	60	2

试验	母材	焊材	焊丝直径 ϕ/mm	焊接方法
一	Q235	H08MnSi	1.0	CO_2 气体保护焊
二	Q235	H08MnSi	1.0	CO_2 气体保护焊

3 角变形动态过程测试结果分析

3.1 角变形变化过程特点

测试结果如图 3所示. 从上述两组试验结果可以看出低碳钢对接接头角变形的变化过程具有下面特点.

(1) 首层焊缝时,在焊接开始阶段,角变形都呈现快速增长趋势,如图 3a、b中的 AB段. 但是随着焊接过程的进行,角变形量达到一个峰值后会有一定程度的下降,如图中的 BCD段,之后角变形量又开始增加,最终达到稳定值.

(2) 第二层焊缝,焊接角变形变化过程比较简单,焊接阶段角变形量增长迅速,当电弧熄灭后角变形量增长缓慢,并最终达到稳定的值,即残余变形.

(3) 多层多道焊的总残余角变形量为每层焊缝残余角变形量的累加,如图 3a、b所示.

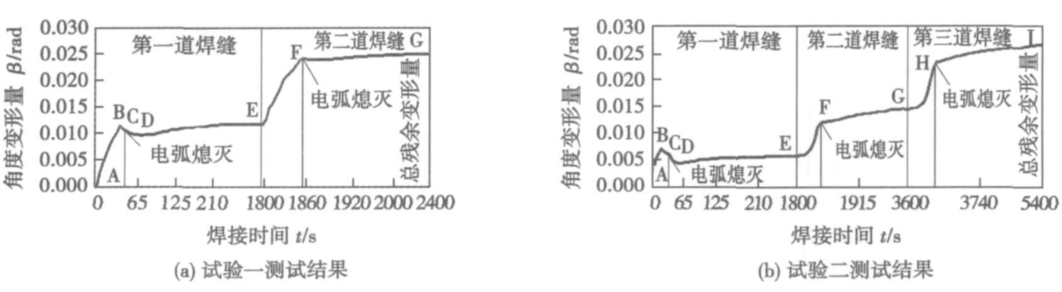

图 3 低碳钢 Q235角变形动态变化曲线
Fig. 3 Dynamic curves of angular distortion of low carbon steel Q235 during welding

3.2 角变形变化过程影响因素分析

对于首层焊缝,焊缝金属的热过程可以认为是填充金属直接从高温开始冷却的过程,不存在加热塑性变形阶段[5]. 焊缝及其热影响区金属从高温向

低温的冷却过程中，有两种因素将会对体积变化产生影响[6]：一是焊缝及其热影响区金属从高温向低温变化过程中体积随温度的线性变化，对于常见的金属材料，金属体积将随着温度的降低而线性减少，减少程度将由温度变化情况和金属本身的线膨胀系数 α 大小决定；二是从高温向低温变化过程中金相组织相变引起的体积变化．试验中母材金属 Q235 和填充金属 H08MnS都属于低碳钢材料，所以焊缝及其热影响区的高温金属从高温向低温的转变过程中，将发生由奥氏体向铁素体的转变．由于铁素体的比容大于奥氏体，所以金属体积将增大．

从上面分析可以看出，焊接过程中温度下降引起的体积线性变化和相变引起的体积变化对角变形的作用是相反的．图 3a，b中的 AB段，角变形迅速增长，可以认为是由于温度降低引起的体积线性减少导致的角变形增大；而图 3a，b中 BCD段相变引起的体积增大而导致的角变形减小．

对于两组试验的第二层焊缝，从测试结果中角变形变化过程可以看出，相变引起的体积变化对角变形变化过程的影响没有表现出来．说明低碳钢焊接过程中高温相变引起的金属比容变化只对单层焊对接接头或者多层多道焊对接接头首层焊缝的角变形产生影响，对首层焊缝之后或者平板堆焊角变形没有影响或者影响很小．

3.3　相变对对接接头不同层角变形的影响

低碳钢由奥氏体向铁素体的转变通常发生在 700 ℃以上[6]．对于第一层焊缝，如图 4所示．

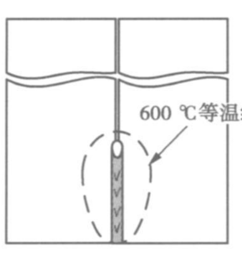

图 4　高温相变区域

Fig. 4　Area of high-temperature phase

当焊缝金属开始发生高温相变时，整个焊缝的温度都处于金属的塑性温度区内．由于焊缝金属处在高温状态时，本身抵抗变形的能力非常低，所以高温相变引起的金属体积变化对角变形会产生影响．随着焊接过程的进行，当部分冷却的焊缝金属温度降到 600 ℃以下时，发生在塑性温度区的高温相变对角变形的影响减弱并最终消失．对于第二层焊缝，由于被焊工件的焊缝及热影响区抗变形刚度很大，发生在材料塑性温度区内的高温相变对角变形将不产生影响．

4　结　　论

（1）低碳钢 700 ℃温度以上出现的高温相变对单层焊对接接头以及多层多道焊首层焊缝的角变形过程有影响；对多层多道焊接除首层以外其它层焊缝的角变形没有影响．试验中角变形动态变形曲线上的表现为：首层焊缝角变形过程较为复杂，角变形出现了增大、减小、再增大的变化过程．除首层焊缝外其它层焊缝角变形变化过程较为简单，角变形呈现单调增大的趋势．

（2）对接接头每道焊缝最终的残余角变形大小主要是焊接过程中产生，当电弧熄灭后角变形变化缓慢并最终形成残余角变形．所以，通过工艺方法控制焊接过程中角变形的产生和形成，对控制残余角变形的大小更为有力．

（3）多层多道焊对接接头总残余变形为每道焊缝残余角变形的叠加．因此，通过合理的安排焊层顺序，能够有效的控制残余角变形的总量．

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作者简介：杨广臣，男，1967年出生，博士研究生．主要从事焊接结构力学方面研究工作．发表论文 8篇．

Email：yanggc@gh—oa．com

tems Engineering, Xi'an Jiaotong University, Xi'an 710049, China). p57—60

Abstract: To improve the forming accuracy of thin-walled parts with smooth surface in laser metal direct manufacturing, the effect on the surface smoothness of samples is studied by different layer thicknesses. A model of layer thickness of thin-walled parts by single-trace laser cladding is proposed theoretically and studied by experimentally. The results indicate that the layer thickness can be defined as a function of the width and height of single-trace cladding layer under some conditions; when the layer thickness is equal to the value calculated, the sample can be fabricated with smooth surface. It is beneficial to choose process parameters for forming thin-walled parts in laser metal direct manufacturing.

Key words: laser metal direct manufacturing; thin-walled parts; layer thickness; surface smoothness

In-situ synthesized Al_3Ti-Al surface composites by friction stir processing

QIAN Jinwei[1,2], LI Jinglong, XIONG Jiangtao[1,2], ZHANG Fusheng, LIN Xin[1] (1. State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, China; 2. Shaanxi Key Laboratory of Friction Welding Technologies, Northwestern Polytechnical University, Xi'an 710072, China). p61—64

Abstract: After the surface of 1100-H14 Al alloy plate was machined into rectangular grooves which were then filled with Ti powder, the layer of Al_3Ti-Al composites was obtained by friction stir processing (FSP). The microstructures, phase compositions and hardness of the layer were analyzed by scanning electron microscopy, EDS and X-ray diffraction. The results show that Ti particles are severely broken under the thermal-mechanical coupling process of FSP, and the broken Ti particles rapidly react in situ with Al matrix and synthesize micron or submicron particles of Al_3Ti. Owing to the homogeneous distributions of Al_3Ti and residual Ti particles in the Al matrix, the microhardness of the layer reaches 71.39 HV, which is 2.1 times of the base metal.

Key words: friction stir processing; in-situ synthesized; surface composite layer; microhardness

Effect of high-temperature phase transition of low carbon steel on weld angular distortion

YANG Guangchen[1,2], ZHANG Yanhua (1. Beijing University of Aeronautics and Astronautics, Beijing 100083, China; 2. Chengde Petroleum College, Chengde 067000, China). p65—67

Abstract: For its good mechanical properties and weldability, low carbon structural steel is widely used in a variety of welded structure. The angular distortion is a serious problem to be resolved in the butt joint welding process. The angle distortion changes in multiplayer welding butt joint of Q235 low carbon steel plate are measured, and the angle changing process and characteristics of deformation of the joint are analyzed and summarized. The results show that linear variation in volume with temperature variation has an effect on angular distortion. In addition, high-temperature phase transformation above 700 ℃ will affect the angular distortion of single-layer weld and the root weld of multi-layer and multi-pass welding, but has less effect on that of the multi-layer welding except the root weld of multi-layer welding.

Key words: butt joint; low carbon steel; multi-layer welding; phase transformation; angular distortion

Laser welding of in-situ particulate reinforced aluminum matrix composites

CUI Haichao, LU Fenggui, TANG Xinhua, YAO Shun (Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China). p68—72

Abstract: The weldability of in-situ TiB_2 particulate reinforced ZL101 Al metal matrix composites by high power laser welding was studied. The studied results show that TiB_2 particles increase the viscosity and decrease the fluidity of molten pool, so the sensitivity of porosity is improved and at the same time weld appearance becomes bad. The hydrogen porosity as mainly pores distributes at the bottom of molten pool and around the fusion line. The grains of weld seam are much finer than that of base metal because of higher cooling rate. There is no segregation and TiB_2 particles distribute homogeneously in the weld seam because nanometer TiB_2 particles are not removed but trapped by the solid-liquid interface during the process of solidification. According to the results of X-ray diffraction and TEM, there are no interface reaction products such as brittle Al_3Ti or AlB_2 between the matrix and TiB_2 particles. The interface between TiB_2 and Al matrix is smooth and the reinforcing effect of TiB_2 is still unchanged.

Key words: composites; laser welding; pores; interface reaction; reinforcement distribution

Microstructures and wear resistance of hardfacing alloy containing internally produced carbide particulates

TANG Wenbo, GUO Yungang, ZHANG Yawei, WANG Hongrui (School of Material Science and Engineering, Zhengzhou University, Zhengzhou 450001, China). p73—76

Abstract: A new hardfacing alloy was fabricated and deposited on the low-carbon steel Q235 by shielded manual arc welding. The average degree of hardness, microstructure and chemical composition of the alloy were analyzed with the hardness gauge, optical microscopy, scanning electron microscopy and the EDAX pattern, and the abrasive wear resistance of the alloy was also tested. The results show that the microstructure of the alloy is the mixed martensite and little retained austenite with (NbCrTi)C particles which are dispersive distributed in the matrix. The amount of low-carbon and high-carbon martensite is identical, and the hard carbides which have strong metallurgic bonding with the matrix are hold in the matrix effectively. The hardness of the alloy is up to 57 HRC, which is 3.6 times more wearable than that of D707 tungsten carbide electrode.

Key words: hard-facing; in-situ reinforcement; wearing resistance; carbides

Approximate entropy GRNN forecast for aluminum alloy pulsed MIG welding stability

NIE Jing, SHI Yu,