# 控制焊接残余应力方法的超声波监控

张世平<sup>1</sup>, 路 浩<sup>2</sup>, 刘夕林<sup>1</sup>, 方洪渊<sup>3</sup>
(1.哈尔滨工业大学 电气工程及自动化学院,哈尔滨 15000 !;
2 南车青岛四方机车车辆股份有限公司 焊接实验室,山东 青岛 26611 !;
3 哈尔滨工业大学 现代焊接生产技术国家重点实验室,哈尔滨 150001)

摘 要:为了减少焊接件的残余应力测量时间,基于声弹性效应,采用对应力最为敏感 的临界折射纵波,建立了焊接残余应力超声波测量系统,可以准确的检测出焊接结构的 内部应力.用该测量系统对随焊旋转挤压法、随焊冲击碾压法、电磁冲击法、预置应力 法等一系列降低焊接残余应力的控制方法进行了监控,试验结果给出了各控制方法的 残余应力降低程度,确认了工艺参数的合理性.该试验过程无损快速克服了传统切割 释放测量方法的耗时费力,加快了控制方法的研制进程.

关键词: 超声波法; 应力控制方法; 焊接残余应力

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张世平

## 0序言

为了降低焊接残余应力,需要研发新的残余应 力和变形控制方法,但这些方法在研究过程中摸索 合理的工艺参数工作量非常巨大,占用了新方法研 制过程的一半时间以上.新方法工艺参数是否合理 的重要评价标准之一是残余应力水平降低程度的大 小,根据残余应力的降低结果来选取最优的工艺参 数.这些新方法主要是对壁厚在 3 mm左右的薄壁 铝合金焊接件进行残余应力和变形控制.而传统残 余应力测量方法中小孔法无法对壁厚 5 mm以下的 薄壁结构进行测量,一般只能使用切割释放法对焊 接件进行残余应力测量,其测量过程耗时费力,大大 延迟了新方法工艺参数的探寻,延缓了新方法的研 究进度.

基于声弹性效应并采用对应力最为敏感的临界 折射纵波,开发了焊接残余应力超声波法测量系统<sup>[1]</sup>.文中使用该系统对随焊旋转挤压法、随焊冲 击碾压法、电磁冲击法、预置应力法等一系列降低残 余应力新方法的效果进行了评定,不仅看出残余应 力得到显著的降低说明新方法的有效性,另外也说 明了焊接残余应力超声波法测量的可靠性,试验过 程无损、实时快速,为焊接新方法的研制提供了便捷 的验证手段,从而加快了研制的进程.

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1 超声波法应力测量系统

建立的焊接残余应力超声波测量装置结构如 图 1所示.



图 1 测量装置组成

Fg 1 Schematic diagram of measurement device

测量装置本体大小类似于一个普通台式计算机 的主机,如图 2 所示.超声波探头是特殊加工的用 来产生临界折射纵波,在测量铝合金应力时的入射 角度为 27.6<sup>°</sup>;超声波的收、发探头加工为一体,发、 收探头的引出线分别接到测量装置留出的激励和测 量的接口,数字键盘用于测量时的功能输入.

测量时首先对零应力板进行校准,可以克服温 度等外界条件的改变对测量结果的影响.每一个应 力点连续测量 10次后取平均,同时可以输入测量点 距焊缝中心的距离,系统将自动绘制出残余应力的 分布曲线;最后将测试数据存储在优盘供计算机读 取分析用.



图 2 测量装置照片 FE 2 Photo ofm easurement device

使用此测量系统对铝合金和钢材两种结构的焊 接残余应力进行了测量<sup>[23]</sup>,并与有限元模拟、应变 片法和激光全息小孔法进行了对比测量,验证了该 测量系统的准确可靠<sup>[4]</sup>,而且还在高速列车车体上 进行了测量应用和验证<sup>[5]</sup>.此外该系统克服了薄壁 结构件测量中特殊波形的影响,实现了 2 mm薄壁 焊接结构件的应力测量<sup>[6]</sup>.

2 控制方法降低残余应力的评定

2.1 随焊旋转挤压法

随焊旋转挤压是一种高效的随焊控制焊接变形 的新方法,其原理是通过置于焊枪后方一定距离的 柱状挤压杆对焊后尚处高温的焊缝金属进行旋转挤 压作用来延展焊缝,从而达到减小焊接残余应力,控 制焊后变形的目的<sup>[7]</sup>.

试验材料为 LY12 铝合金,试样规格为 300 mm× 140 mm× 2 mm,焊接方法为交流钨极氩 弧焊,采用不填丝的表面熔敷方式,旋转挤压杆直径 10 mm,试件 A为常规焊,试件 B的旋转挤压位置 在焊缝中心,试件 C的旋转挤压位置在焊缝两侧, 试件外观见图 3.

由于铝合金平板厚度为 2 mm,不适合用小孔法 验证,因此用超声波测量铝合金薄板焊接残余应力



图 3 随焊旋转挤压试件 Fg 3 Samples welled by trailing rotating extrusion method

的同时,选取试件 A和试件 B通过切割释放用应变 片测量来进行验证.测量结果如图 4<sup>-6</sup>和图 4<sup>b</sup>所 示,试件 C和试件 A的残余应力对比如图 4<sup>-6</sup>所示.



图 4 随焊旋转挤压旋法的评定 F 8 4 Assessment of trailing rotating extrusion method

从图 4 和图 4 b中可以看出,超声波法和应变 片法测得的残余应力分布吻合良好.试件 B焊缝中 心残余应力相对试件 A从 190 MP 降到 - 40 MP 说明旋转挤压法能够降低焊接残余应力,而且旋转 碾压部位都出现了压应力.此外对比图 4 b和图 4 <sup>c</sup> 可知,旋转挤压法旋转挤压焊缝中心降低残余应力 的效果最为明显.

### 22 随焊冲击碾压法

随焊冲击碾压控制焊接应力变形防止热裂纹新 方法是以空气锤作为冲击动力源,通过前后冲击碾 压轮对焊接接头的不同部位实施一定频率的同步冲 击碾压作用,控制、调整焊缝区的应变场和塑性流变 场的分布,将接头的残余变形控制在较低的水平. 强化接头,改善了残余应力的分布状态,实现了高强 铝合金薄壁结构低应力小变形无热裂焊接,实现了 平面封闭焊缝残余应力变形的随焊控制<sup>[8]</sup>.

试验材料采用 LY12 铝合金,两个试样由两个 圆环镶嵌焊接而成 (图 5).大环外径 340 mm,内径 162 mm,小环外径 162 mm,内径 75 mm,厚度为 2 mm,图中左侧的工件为常规焊试件,右侧的工件 采用了随焊碾压处理,随焊冲击力 35 N



图 5 随焊冲击碾压试件 FE 5 Sampeswelled by trailing in pactive rolling method

用超声波法测量了两个试件直径方向上的径向 和切向残余应力,结果如图 6所示.常规焊圆环件 的应力分布与理论值相符,随焊碾压法有效地降低 了残余应力.常规焊焊址部位应力达 200 MP;4 经随 焊碾压处理后其应力值降低了一半,同时径向和切 向残余应力梯度明显变缓,切向残余应力梯度几乎 呈水平线分布,拉应力区宽度减小了三分之一,压应 力绝对值明显减小.



图 6 随焊冲击碾压法的评定



#### 2.3 电磁冲击法

电磁冲击控制焊接应力变形法是根据电磁感应 原理,利用电磁力冲击焊缝附近区域,对焊缝施加额 外的拉伸应变,使焊缝得到延展,从而控制焊接应力 与变形.该方法可实现非接触控制焊接应力和变 形,对焊缝不产生损伤,冲击能量易于控制,操作方 便灵活.该方法不改变焊缝成分,能量易于控制,可 实现无机械接触控制热裂纹,焊件表面无损伤,不影 响接头疲劳性能<sup>19</sup>.

试验材料采用 1060 <sup>12</sup>4 工业纯铝, 工件如图 7 所示.此种方法目前是焊后处理, 图中可以看到处 理后的工件变形明显减小.



图 7 电磁冲击试件 F g 7 Samples by electrom agnetic in pactmethod

试验测量了电磁冲击前后同一测量线的残余应 力值,图 8为常规焊和电磁冲击试件纵向残余应力 分布的对比图,经过电磁冲击后纵向残余应力峰值 明显降低,拉应力峰值比常规焊降低了 66%,拉应 力的范围变大,应力分布更加平缓.分析认为这是 由于在电磁冲击的过程中焊缝金属的纵向压缩塑性 变形受到了充分的延展,使得焊缝金属有所伸长. 压缩塑性变形得到延展,残余应力水平降低.



图 8 电磁冲击法的评定 Fg 8 Assessment of epetromagnetic in pactmethod

#### 24 预置应力法

双向预置应力控制焊接变形和残余应力新工艺,解决了焊接变形和热裂纹问题.预置纵向拉应 力控制焊接变形和降低焊接残余应力,与此同时预 置横向压应力抵消焊缝金属固有的凝固收缩时受到 的拉应变以及预置纵向拉应力对焊缝金属造成的额 外拉应变,从而起到防止热裂纹的作用<sup>[10]</sup>. 试验材料为 <sup>LY</sup>12铝合金,尺寸为 200 <sup>mm</sup>×310 <sup>mm</sup>×2 <sup>mm</sup>外观形貌见图 9所示.



**图 9 铝合金预置应力试件** Fg **9** Samples by pre\_stressm ethod

预置应力法试验结果见图 10所示.预置应力 为 0.3倍屈服强度.从结果看,预置应力明显降低 了残余应力值.



图 10 应力法的评定 F g 10 Assessment of pre\_stress method

3 结 论

(1)使用超声波法对一系列降低残余应力控制 方法的效果进行了评定,并进行了对比验证,表明该 方法的测量结果可靠.试验过程无损、实时快速,说 明该测量系统为焊接控制方法的研制提供了便捷的 验证手段.

(2)随焊旋转挤压法、随焊冲击碾压法、电磁冲 击法、预置应力法等一系列控制方法有效地降低了 焊接残余应力,具有实用价值.

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作者简介: 张世平,男, 1974年出生,博士,副教授. 主要研究方向为焊接残余应力的无损测量. 已发表论文 10余篇.

Em a il tempspzhang@163 com

perment results demonstrate that the appearance of the part is good and the inner in the part is detect free under optimum pain ing conditions. When the rotating speed is 960 r/m in and the welding speed is 70 mm/m in the tensile strength of the part reaches 186 6 MPa and the conductivity of the part is approximately equal to that of the base metal

K ey w ords friction stirwelding T2 copper thick plate mechanical properties

U trason c m on tor ing of residual stress reduction methods

ZHANG ShiPing, LUHaë, LUX ilin, FANG Hongyuan (1. School of Electrical Engineering and Automatic Harbin Institute of Technology Harbin 15001, China, 2. CSR Sifang Lo. comotive and Rolling Stock Company Limited Qingdao 266000 China, 3. State Key Laboratory of Advanced Welding Production Technology Harbin Institute of Technology Harbin 15001, China), P 77-80

Abstract The ultrasonic system of accurately measuring internal stress of welding structure is established based on acous toelasticity effect and critically refracted longitudinal wave that is most sensitive to stress in order to shorten the time of the welding residual stress measurement A new series decreasing residual stress methods such as trailing rotating extrusion, trailing impactive rolling electromagnetic impact and pre-stress are verfied by this measurement system. The experiment results show that the decreasing degree of residual stress can validate the effectiveness of technical parameters by those methods. The measurement speed of the nondestructive system is quicker than that of traditional section release methods which accelerates the research process.

 $\label{eq:Keywords} \begin{array}{ll} K \mbox{ ey words} & u \mbox{ trassnic measurement} & control \mbox{ residual} \\ s \mbox{ tress methods} & w \mbox{ elding residual} \mbox{ stress} \end{array}$ 

Effects of service conditions on properties of in situ particle reinforced composite solder joint TAIFeng GUO Fu MA Lin in HAN Mengting (College of Materials Science and Engineering Beijing University of Technology Beijing 100124 China). P81-84

Abstract In situ particle rein forced composite solder was considered as an effective method to enhance the properties of lead free solders In situ Cu Sn particles were added into the eutectic Sn3 5Ag solder to fom in situmetal particles enhanced SnAg based composite soller Them crostructure and mechanical properties of the composite solder pint during reflow and iso. thermal aging were investigated and the fracture mode of composite solder joint and the role of in situ Cu Sn particles were analyzed Experimental results show that the microstructure and dimensions of in situ Cu Sn particles in composite soldermatrix have changed during reflow and isothermal aging So the shear strengths of composite solder pints have influenced by the sizes of in situ Cu Sn particles Besides the deformation of compos. ite solder joint is dominated by shear bonding mode and the in situ Cu Sn reinforced particles can retard the fracture path of shear bonds

Keywords in situ Cu  $S_5$  particle composite solder

#### $\operatorname{ref} p_{v_i}$ aging $s_h$ ear strength

M icrostructure and mechanical properties of ultrafast convert VPT G arc welding of **2219** high strength alum inum alloy CONG Baoqiang QI Bojin ZHOU Xingguo ILUO Jun (School of Mechanical Engineering and Automation, Beijing University of Aeronautics and Astronautics, Beijing 100191, China), P85-88

A novel ultrafast convert intermediate and Abstract h gh-frequency variable polarity arcwelding technology for alum i num alloys was developed The effect of variable polarity current frequency on the microstructure and mechanical properties of 2219-T87 weld joints was researched based on the variable polar it'TG welding process The experimental results show that the structure in the weld zone is predominantly columnar in the case of lower variable polarity current frequency The grain structures in the weld zone become finer and more equiaxed with the in crease of current frequency. Tensile strength and percentage elongation of the weld pints also improve predominantly The type of weld fracture is changed from brittle to them ixture of dimple and brittle. Under the current frequency of 1 kHz the rates of weld tensile strength and percentage elongation of the pints are 69% and 58% than those of the base metal respectively

 $\label{eq:Keywords} Keywords = hgh strength alum num alloy ultrafast convert variable polarity grain refinement$ 

Nonlinearmultiple regression model of resistance spot welding for galvanized steel sheet LUO YI, PI Fengxian, XIDNG Chengahi, LIU Link (1. School of Material Science and Engineering Chongqing University of Technology Chongqing 400050 China, 2. Chongqing South Jinkang Auto Parts Ltd, Chongqing 401120 China). P 89-92

A bstract A method of nonlinear multiple orthogonal regression assembling design was applied in the investigation of the resistance spot welling process on galvanized steel sheet. The indexes studied in experiments were nugget geometry and tensile, shear strength of spot welds. Furthermore, four process parameters namely welding current electrode force welding current duration and preheat current, and interactions among them were considered as the factors in pacting indexes. The experimental results showed that there was a more accurate prediction on nugget size and mechanical properties of spot welds by the models optimized. Based on these prediction results to the effect of parameters and interactions on the welding quality

Keywords galvanized steel sheet spotwelding regres. sion model nugget diameter tensile shear strength

Condenser discharge percussion welding of iron wire to copper sheet KANG Jing, ZHAO Malaun, IÜ Juan, ZHAO Xueqin, Suzuki JIPPEF (1. College of Material Science and Engineering Xi an University of Technology Xi an 710048 China, 2. Faculty of Mechanical Engineering Mie University Tsu 514-8507, Japan). P93-96

Abstract In order to study new pinting technique about