激光全息小孔法验证超声波法残余应力无损测量

路浩,刘雪松,杨建国,方洪渊^{*} (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:基于声弹性效应,超声波可以无损检测出结构内部应力。利用建立的基于临 界折射纵波的超声波法焊接残余应力测量系统,对低碳钢双丝焊纵向焊接残余应力进 行了实时快速无损测量。使用激光全息小孔法对超声波法测量系统的测量结果进行了 验证。对两种方法的测量过程和测量结果进行了对比。结果表明,超声波法测量结果 可靠,声波法克服了传统应力测量方法费时、耗力、破坏、体积庞大等缺点,整个设备轻 便,可单人手提。系统支持程序使测量操作简便,过程实时快速。

关键词: 超声波法; 激光全息小孔法; 焊接残余应力

中图分类号: TG404 文献标识码: A 文章编号: 0253-360X(2008)08-0077-03



路 浩

0 序 言

焊接残余应力对结构可靠性有很大影响,特别 是影响结构的疲劳寿命、尺寸稳定性和抗腐蚀能力。 焊接残余应力是焊接结构质量评定的重要参数之 一。对于在服役状态下的焊接结构,如石油管道、航 天器、核电站设备,无损或者精确测量出结构重要部 位残余应力分布,就可以对服役状态下的焊接结构 进行安全评估和疲劳寿命预测,工程价值巨大。

超声波可以无损检测出结构内部应力。超声波 法测量应力基于声弹性效应。Hughes D S, Kelly J L^[1]最早提出了声弹性方程的表达形式,描述了材料 中声波传播速度与应力关系的声弹性效应,奠定了 声弹性理论基础。此后多人不断对理论进行完善, 例如 Toupin R A, Bernstein B (1961), Thurston R N, Brugger K (1964), Thurston (1964), Tatsuo Tokuoka 和 Yukio Iwashimizu (1968), Man 和 Lu (1987)^[2-9]。现代 焊接生产技术国家重点实验室在国内首次开发出了 超声波法应力无损实时测量系统,使用此测量系统 对低碳钢平板双丝焊纵向残余应力进行了无损测 量,测量过程无损实时快速^[7]。目前正在进行复杂 焊接结构残余应力无损测量研究工作。

在传统破坏测量方法中,乌克兰巴顿焊接研究 所研制的激光全息小孔法设备具有很高测量精度, 操作也极为方便。使用此设备对超声波法测量系统 的测量结果进行了验证。验证了超声波法测量系统 的可靠性。

1 超声波法残余应力测量系统

声弹性效应是非常微小的,应力应变关系非线 性决定了应力对声速的影响非常微小。应力改变引 起声速的变化很微小,100 MPa 大约只引起声速 0.1%的变化。用超声波法测量应力,必须实现对声 速的准确测量。拉应力引起声波传播时间变长,声 速变慢,压应力引起声波传播时间变短,声速变快。

自主开发的超声波法焊接残余应力测量系统框 图见图 1。硬件主要组成部分:汕头超声所 CTS-22 型超声波发生器,自制特殊探头组,带有特殊数据采 集卡的 RIGOL 示波器、进行数据存储和处理的笔记 本计算机。超声波发生器产生脉冲激发特殊探头产 生临界折射纵波,示波器与脉冲信号同步,系统支持 程序控制计算机及数据采集卡。试验系统实现了纳 秒精度信号采集,满足超声波法应力测量需要的精 度。使用虚拟仪器软件 Labview 编写了系统支持软 件,测量操作简便,过程实时快速。系统支持软件控 制测量系统各组成部分工作时序,存储测量数据,进 行数据处理和结果显示。

开发的焊接残余应力测量系统设备轻便、体积 小、单人可轻易携带,可以对多种材料焊接结构件单 向和两向残余应力进行测量,也可以对加载应力进 行测量。此系统还可以对各种材料的声弹性常数进 行精确标定,主要技术参数如下。

收稿日期: 2007-09-29

基金项目:中俄政府间科技合作项目资助(2007DFR70070)

^{*}参加科研工作的还有周广涛,闫德俊

测量最小厚度 2 mm,加载应力测量精度 ±5 MPa,残余应力测量精度< 0.1 倍屈服强度,重 量7 kg,体积< 0.02 m³,电源 220 V,频率 50 Hz。



图 1 超声波法应力测量系统 Fig. 1 Schematic diagram of experimental setup

2 激光全息法残余应力测试设备

乌克兰巴顿焊接研究所研制的激光全息小孔法 残余应力测试设备,以激光全息技术为基础,可以测 量出测量点互相垂直的两个主应力和一个剪切应 力,可以计算出此点纵向和横向残余应力、最大主应 力与纵向应力的夹角。

设备的重要组成部分——全息激光头见图 2, 应力释放后得到的应变云图见图 3,图4为应变计 算显示界面,主要技术参数如下。



图 2 全息激光头 Fig. 2 Photograph of holographic laser head assembly



图 3 应力释放后应变云图 Fig. 3 Strain nephogram after stress relaxation

测量材料范围是一切具有近似恒定弹性模量的 材料。测量最小厚度4 mm,残余应力测量精度约 0.05 倍屈服强度,重量 10 kg,体积<0.04 m³,电源 180~240 V,频率 50 Hz。



图 4 应变计算界面 Fig. 4 Interface of strain calculation

3 测量方法及结果比较

3.1 测量方法比较

两种测量方法的比较见表 1。超声波法测量迅 速、快捷、无损、实时、连续,最显著特点是快速,在支 持软件的配合下,对一点的应力测量从操作到计算 出应力值只需要数秒钟;可以对一点的应力状态反 复进行测量,但是测量结果包含的信息量不大,只能 进行纵向或横向应力的单独测量。激光全息小孔法 测量精度高,测量结果信息量丰富,操作较传统小孔 法更为方便,不需要粘贴应变片,测量时间主要耗费 在打孔时间上。

表	1 两种测	则量方剂	去比	较
Table 1	Comparis	son of	two	methods

		-			
方法	一点测量 时间 <i>t</i> /s	破坏 与否	测量 过程	精度	测量结果 信息量
激光全息 小孔法	30	破坏	不连续	$5\% R_{eL}$	丰富
超声波法	3	无损	连续可 重复	$< 10^{\circ}/_{\circ} R_{eL}$	不丰富

3.2 测量结果比较

使用自主开发的超声波法焊接残余应力测量设备和引进的激光全息小孔设备对低碳钢双丝焊对接平板纵向残余应力进行了测量。测量工件由两块420 mm×200 mm×12 mm的低碳钢平板开 V 形坡口对焊而成。使用的焊接方法为双丝 MIG 焊。

使用超声波法焊接残余应力测量设备测量纵向 残余应力时,探头组排列与焊缝平行,沿垂直焊缝方 向移动。移动探头的同时,测量系统实时计算出测量点的残余应力值,存储和显示到计算机屏幕上。 工件中心线上纵向残余应力分布多次测量结果如图 5 所示。探头有一定尺寸,宽度26 mm,双丝焊接工 艺焊缝熔宽也很大,约25 mm,所以近缝区高应力区 测量不到。实际焊接状态下,平板对焊两侧的散热 情况不完全相同,所以纵向残余应力值分布不完全 对称。在残余应力场的弹性区,声波法数据波动范 围在 ±15 MPa以内;在残余应力场的塑性区,声波法 数据波动范围在 ±2.5 MPa以内,称这种现象为"弹 性区声弹性不稳定现象",详细解释见文献[7]。



图 5 纵向残余应力测量结果比较

Fig. 5 Comparison of longitudinal residual stress measurements

超声波法测量完毕后,使用激光全息小孔设备 对左测的纵向残余应力进行了验证,对 30 个点的残 余应力进行了测量,结果与超声波法测量结果吻合 良好。图 5 实线连接的五角星表示的数据点为其测 量结果。其中一点的结果显示界面如图 6 所示,可 以同时计算出纵向和横向残余应力、主应力与纵向 应力夹角等6 个数据量。



图 6 应力计算显示界面 Fig. 6 Interface of stress calculation results

4 结 论

(1)开发的超声波法焊接残余应力测量系统实现了二维焊接残余应力场的无损测量,测量结果可靠,重复性好。克服了传统应力测量方法费时、耗力、破坏、体积庞大等缺点。整个设备轻便,可单人手提。系统支持程序使测量操作简便,过程实时快速。但是声波法装置的探头尺寸需要进一步减小。

(2)试验结果表明,超声波法焊接残余应力测 量装置可在多种不同材料构件的平面、角焊缝、直角 边等处进行灵活地测量。可以在结构制造过程中监 控应力状态,可对服役状态下的焊接结构残余应力 分布进行测量,在不破坏的情况下进行焊接结构的 安全评估和疲劳寿命预测,可广泛应用于建筑钢结 构、船舶、桥梁、核电站设备、锅炉、航天器、油气管道 等制造过程应力监视调控,服役状态安全检查,服役 结构疲劳寿命预测,结构维修指导。

(3)激光全息法测量结果准确,测量信息丰富, 一个测量点上可以得到纵向残余应力和横向残余应力。

参考文献:

- Hughes D S. Ultrasonic velocity in an elastic solid J. Journal of Applied Physics, 1950, 21(3): 294-301.
- [2] Tokuoka T, Iwashimizu Y. A coustical birefringence of ultrasonic waves in deformed isotropic elastic materials[J]. International Journal of Solids Structures, 1968 4:383-389.
- [3] Fukuoka H, Toda H, Yamane T. A coustoe lastic stress analysis of residual stress in a patch-welded disk[J]. Experimental Mechanics, 1978, 7: 277-280.
- [4] Yabdallahoui H, Walaszek, Peyrac C, et al. The use of ultrasonic in the optimization of welding processes [J]. Welding International, 2001, 15(4): 1-12.
- [5] Egle D M, Bray D E. Measurement of acoustoelastic and third-order elastic constants for rail steel[J]. The Journal of the Acoustical Society of America, 1976, 60(3): 741-744.
- [6] Man C, Lu W Y. Towards an acoustoelastic theory for measurement of residual stress[J]. Journal of Elasticity, 1987, 17: 159–182.
- [7] Lu H, Liu X S, Yang J G, et al. Ultrasonic stress evaluation on welded plates with Lcr wave [J]. Science & Technology of Welding and Joining, 2008, 13(1): 70–75.

作者简介:路 浩,男,1981 年出生,博士研究生。主要研究方向 为焊接结构力学及可靠性评价。发表论文 10余篇。

Email: 1hhit9@163.com

V

p73-76

Abstract: Finite element method is used to analysis the soldered joint reliability of FCBGA, the unified viscoplastic Anand constitutive equation is employed to represent the viscoplastic deformation behavior of Sn63Pb37 alloy. The results shows that the stress concentrated on the top surface of the chip-edge FCBGA corner soldered joint and present cyclical changes with time, stress relaxation and accumulated enhancement trend of stress can be obvious acquired from the curve. Select three different ball size device for the study, it indicates that the ball size of 0.4 mm \times 0.28mm has the maximal soldered joint stress, 0.46 mm imes 0.34mm ball second, and 0.52 mm imes 0.4mm ball minimum. Based on the analysis of plastic work accumulation can acquire the same trend. The trends is obtained by the consistent results with practical application of the device. At the same time provide a basis for the theoretical research of flip-chip devices.

Key words: FCBGA; finite element method; viscoplastic; stress concentration

Verification of ultrasonic residual stress evaluation method by laser hologram method LU Hao, LIU Xuesong, YANG Janguo, FANG Hongyuan, ZHOU Guangtao, YAN Dejun (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001). p77-79

Abstract: Based on the acoustoelasticity, the residual stress can be measured by ultrasonic method. Experimental system to measure the residual stress by ultrasonic is established with Lcr waves. The longitudinal stress of twin wire welded plate is measured by the system. The result of the ultrasonic method is verified by laser hologram interference hole-drilling method. The measurement processes of two methods are compared. The measurement process is not only nondestructive, but also real-time and quick. The system is portable and overcomes the shortcomings of the tradition methods.

Key words: ultrasonic; laser hologram; welding residual stress

Microstructures and mechanical properties of CGHAZ in 440 MPa ship hull steel YANG Yinhui^{1,2}, YANG Caifu², SU Hang², ZHANG Yongquan², CHAI Feng², DAI Jian qing¹ (1. Kum ming University of Science and Technology, Kunming 650093, China; 2. Central Iron and Steel Research Institute, Beijing 100081, China). p80–84

Abstract: The results showed that the austenite grain size in low carbon high niobium (LCHN) alloy steel was smaller than that in high carbon low niobium steel (HCLN) by adopting welding heat physical simulation, and the low temperature impact toughness of LCHN steel was higher than that in the HCLN steel when $t_{8/5} \leq 40$ s. The microstructure of coarse grain heat affected zone (CGHAZ) in experimental steels were predominantly granular bainite, the shape of M-A island exhibited long lath morphology when $t_{8/5} \leq 40$ s and it shows massive morphology when $t_{8/5} > 40$ s. The size and the amount of granular bainite in LCHN steel were much lower than that in

HCLN steel. The precipitation equilibrium diagrams of two experimental steels were calculated by using Thermo-Calc software. The second phase particles mainly precipitated in the temperature higher than 1 200 $^{\circ}$ C and the mean size of particles larger than 120 nm in HCLN steel but the second phase particles only precipitated in the temperature lower than 1 200 $^{\circ}$ C and the mean size of particles lower than 50 nm in LCHN. The fine second phase precipitation dispersed in LCHN steel inhibited the growth of prior austenite grain boundary and improved the low temperature impact toughness significantly.

Key words: coarse grain heat affected zone; grain size; granular bainite; the second phase particles

Content of Fe in TIG cladding copper alloy layer on surface of steel LÜShixiong SONG Jianling YANG Shiqin (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p85-88

Abstract TIG cladding was carried out on the surface of 35 CrMnSiA steel using HS201 welding wire. The content of Fe in the cladding layer and the microstructure of the interface between copper layer and base metal were analyzed. The evolvement and development of the distribution and the shape of the Fe in the cladding layer was investigated systemically. The results show that with the increased welding current, the content of Fe is increased and the shape is transformed qreatly. The shape of Fe is granular and treeing-like in the cladding layer with the welding current below 270A; the shape of Fe is changed strongly and the large spherical Fe particle appears in the cladding layer with the welding current surpassing 300 A. Under the effect of the arc force, the liquid Cu and Fe is mechanically mixed and the configuration of the solidified microstructure is the inclusion of Cu and Fe.

Key words: TIG cladding; 35CrMrSiA steel; copper welding wire; content of Fe

High temperature oxidation behavior of Sn-8Zn-3Bi-P and itseffect on propertiesFANG Yili, ZHOU Jian, XUE Feng, SUNYangshan (Jiangsu Key Laboratory for Advanced Metallic MaterialsSoutheast University, Nanjing 211189, China). p89-92, 96

Abstract The effect of alloying P on oxidation behavior of the liquid Sn-8Zn-3Bi lead-free solder at 250 $^{\circ}$ C was investigated by themogravimetry experiment. The effect mechanism of P on the oxidation was discussed by scanning electronic microscopy (SEM) and auger electronic spectroscopy (AES) in experiments. Properties were compared between before after oxidation to explore the effect on solders' other properties. The results indicate that P can improve the oxidation resistance of Sn-8Zn-3Bi obviously. P was oxidized which is prior to Zn. A oxide film consisting of P₄O₆ which was tend to volatilize formed on the surface of the solder. The over-all properties of the solder is best with the addition of 0.2wt. %P.

Key words: Sn 8Zn 3Bi; lead free solder, P; oxidation resistance; mechanism

Position identifying of curve welding seam in tele teaching based on force sensing IUU Lijun^{1,2}, GAO Horgming³, WU Lin³(1.