不等厚 ULC-BH钢激光拼焊接头硬化机制

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摘 要:采用两种激光光斑加热位置,对不等厚超低碳烘烤硬化钢板进行激光拼焊,分别测定拼焊接头的显微硬度,对比分析其组织性能差异,探讨热影响区硬化软化机制. 结果表明,光斑偏向厚板时,拼焊焊缝两侧组织硬度曲线较为对称,在焊接热循环作用下,热影响区基体中饱和科特雷尔(Cottrell)气团析出细小弥散的 NbC等第二相颗粒, 使得热影响区强硬化;光斑置中时,容易使薄板热输入过渡,析出的第二相颗粒聚集长 大,热影响区重新软化,容易导致冲压时开裂.

关键词:激光拼焊;超低碳烘烤硬化钢;显微硬度;不等厚

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倪加明

0序 言

激光拼焊广泛应用于汽车车身覆盖件和结构组件工业生产,是汽车车身轻量化(ultralight steel auto body ULSAB)的重要技术组成^[1].激光拼焊可以 将不同厚度、强度及表面镀层状况的钢板缝合成冲 压毛坯件,降低车身自重,降低能源消耗,减少尾气 排放,改善车身防撞性能^[23].激光制造拥有高度自 动化和系统集成化,有益于提升生产效率,降低长期 生产成本,作为环境友好型的先进工业制造技术大 量研究.

不等厚超低碳烘烤硬化钢 (ultra low carbon bake hardening stee, l UIC-BH)激光拼焊板焊缝质 量好,拥有如前所述的优点,但仍存在部分不足有待 改善.激光拼焊 UIC-BH钢焊缝硬度较高,容易造 成应力集中;靠近焊缝的薄板热影响区容易过热软 化,导致冲压成形时开裂,相比均匀厚度钢板,冲压 成形性能下降.诸多研究采用模拟改进冲压成形以 适应激光拼焊板的成形性能^[4,5].激光拼焊 UIC-BH钢的热影响区烘烤硬化性因素则考虑较少.

针对不等厚激光拼焊,变化激光加热光斑位置, 调节厚板和薄板焊接热输入,测定接头显微硬度分 布,分析光斑位置对焊缝两侧热影响区组织和性能 影响,探讨激光拼焊热影响区硬化及过时效机制.

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1 试验方法

试验材料为高强度的超低碳钢烘烤硬化汽车用 钢板,厚度分别为 1 mm与 1.5 mm 化学成分如表 1 所示,此类钢板具有较好的成形性能.采用高功率 连续 ^(Q)激光为热源,激光束垂直入射,激光光束 焦点光斑直径约为 0.75 mm 选取厚板上表面为焊 接时激光束焦平面,分别采用光斑置于对接中线和 偏向厚板侧 0.2 mm进行焊接,如图 1所示.

表 1 超低碳烘烤硬化钢的化学成分(质量分数,%) Table 1 Chem ical composition of ULC-BH steel

С	Mn	Р	S	Al	Nb	Fe
0. 0035	0.11	0 007	0 007	0 035	0 058	余量



图 1 激光光斑偏置补偿示意图

Fg 1 Schematic diagram of different laser spot position offset

为分析不等厚激光拼焊钢板接头组织和性能, 观察接头截面宏观形貌,并测量接头截面显微硬度 曲线.采用金相显微镜和扫描电子显微镜分析接头 微观组织,参照已有烘烤硬化机制,分析激光焊接过 程 ULC-BH钢接头热影响区硬化和过时效软化.

2 试验结果

2.1 焊缝成形

激光拼焊薄板时热输入小,焊接速度快,拼焊的 焊缝和热影响区相对于普通焊接均要小.然而,激 光拼焊大比率不等厚板时,两侧板材厚度差异大,两 侧钢板散热性能及母材熔化吸收能量差异,导致激 光焊缝两侧热影响区的组织和力学性能不均.为了 尽量使焊缝两侧组织性能相近,采取激光光斑偏置 厚板措施,以补偿厚度导致的焊接热输入的需求差 异.不同光斑位置所用焊接参数:激光光斑偏置厚 板 0.2 mm时,激光功率为 5.3 W 焊接速度为 2 m/m +激光光斑置中时,激光功率为 5.5 W 焊接 速度为 2 m/m in 置中时熔化厚板光斑面积变小,所 需激光功率增加.所得接头截面形貌如图 2所示.







(b) 偏置厚板



FE 2 Comparison of cross_sections of welded joints with different laser spot position offsets

光斑偏置时薄板的热影响区宽度比光斑置中时 小很多,薄厚接头过渡平缓.说明采用激光光斑偏 置厚板,配比不等厚度两侧板材的激光能量输入,恰 当增多厚板能量输入以满足熔化需要,同时减少薄 板激光能量输入,减轻焊接对其过热影响.是平衡 处理两侧不等厚钢板焊接热输入的有效手段.

2.2 显微硬度

材料的显微硬度能一定程度表征材料强度等力 学性能.为考察激光光斑偏置对焊缝性能影响,分 别测定接头截面显微硬度曲线,测量直线位置为距 底部 0.5 mm的薄板中心线.所得结果绘成曲线如 图 3所示,焊缝组织硬度值均高于母材,厚板靠近焊 缝的热影响区硬度高达 160 HV.光斑偏置时,显微 硬度曲线在焊缝两侧分布较为对称.光斑置中时, 显微硬度曲线在两侧热影响区分布没有对称性,薄 板热影响区存在相当宽范围的硬度下降.分析认 为,光斑置中时,为满足厚板熔化热需求,容易致使 薄板过热.与此不同,基于不等厚两侧散热能力和 熔化热量差异考虑,采用激光光斑偏置厚板措施,有 利于平衡两侧热需求,获得的不等厚接头两侧组织 性能较为对称.



图 3 显微硬度曲线对比

FE3 Microhardness comparison of cross sections of welled pintwith different laser spot position off sets

23 显微组织

为了研究不等厚激光拼焊板光斑置中时薄板热 影响区硬度降低原因,对其焊缝显微组织进行分析. 各区域组织如图 4所示,原始母材为轧制获得的晶 粒均匀铁素体组织,平均晶粒尺寸为 16 µm,焊缝金 属为形态较为复杂的准多边形铁素体组织;焊缝两 侧热影响区组织也为准多边形铁素体组织;焊缝两 侧热影响区组织也为准多边形铁素体组织,薄板热 影响粗晶区的平均晶粒尺寸为 38 µm,厚板粗晶晶 粒尺寸与之相近为 36 µm,然而,薄板过热而产生 大量粗晶粒,热影响粗晶区大,而厚板热影响粗晶區 小.图 5所示为扫描电子显微镜观察到的薄板热影 响粗晶区和母材组织.薄板热影响粗晶区的多边形 铁素体基体上有大量细小的第二相颗粒析出,而母 材铁素体晶粒内没有发现第二相颗粒,第二相颗粒 析出是热影响区组织硬化和软化的重要因素.

3 讨 论

3 1 热影响区硬化微观机制

烘烤硬化钢板母材为晶粒大小均匀的铁素体, 铁素体基体内固溶有大量(原子.室温下,原本固



(c) 厚板热影响区

(d) 原始母材





(a) 粗晶组织



图 5 热影响区硬化微观组织对比 Fig. 5 Microstructure comparison of HAZ before and after heating

溶于基体的 C原子缓慢向位错等缺陷扩散.激光焊 接时,热影响区受热输入和应力应变的双重作用. 应力应变作用下,热影响区位错密度迅速增加,固溶 于基体的 C原子向位错扩散距离缩短.同时,随热 影响区温度升高, C原子扩散激活能增加,向位错扩 散速度加快.最终 C原子钉扎位错,形成 Cottrel 灯,阻碍位错运动,使热影响区硬度增加.是烘烤硬 化钢的高温应变时效性初级阶段.随时效时间延 长,进入高温应变时效第二阶段,饱和的 Cottrel 灯将析出细小的 NbC第二相颗粒.热影响区由于大 量细小弥散的第二相质点从基体中析出,强度和硬 度大幅提升. 偏置厚板焊接时, 热影响区硬度由焊前的 110 HV增至焊后的 160 HV根据德国 DN50150标准换算, 其抗拉强度增加 160 MPa

32 热影响区重新软化微观机制

激光光斑置中焊接时,往往致使薄板热输入过 大,扩散激活能迅速增加,同时高温时间延长,导致 热影响区析出的第二相颗粒大量聚集析出,反而使 其硬度下降,属于高温过时效.根据第二相颗粒与 滑移位错的交互作用机制,同一尺寸第二相在尺寸 很小且与基体保持较好的共格关系时属于位错切过 机制,其强度增量随颗粒尺寸增加而增加;而当其尺 寸增大并与基体的共格关系遭受破坏时属于奥罗万 (Orowan)机制,其强化作用随颗粒尺寸增加而递 减^[9].钢铁材料临界转化尺寸 d可由以下公式计 算,即

$$\frac{d}{\ln \frac{d}{2b}} = 0 \ 209 \frac{GB}{Ky}$$
(1)

式中: G为切变弹性模量; b为位错柏格斯矢量的绝 对值; γ为第二相与基体的界面能. 以析出 NbC第 二相颗粒为例, 参照钢铁材料相关数据, 根据式 (1), 计算的铁素体基体中 NbC颗粒的临界转换尺 寸约为 1.6 ^{mf⁶}. 过热薄板的粗晶区内第二相颗 粒尺寸为几十纳米, 远大于此数值, 故对位错阻碍作 用减弱, 热影响区硬度降低.

4 结 论

(1)激光光斑置中时,不等厚拼焊板焊缝两侧 硬度分布不对称,薄板热影响区硬度降低;光斑偏置 厚板 0.2 mm时,焊缝两侧组织的硬度曲线较为对称.

(2)光斑偏置厚板 0.2 mm时,焊缝和热影响 区为准多边形铁素体组织.焊接热循环作用下,饱 和 Cottrell气团析出细小弥散的 NbC等第二相颗 粒,焊缝和热影响区强硬化.

(3)光斑置中时,薄板热影响区容易热输入过 多,导致第二相颗粒聚集长大,按照 Orowar机制其 强化作用减弱,热影响区硬度和强度下降,容易在后 续冲压过程开裂.

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MAIN TOPICŞ ABSTRACTS & KEYWORDS

Fundamental technology of friction flow welding ILIAN Guohong, LIGuang, WANG Webing, KANG Ju, ZHANG Ligué (1. Beijing Aeronautical Manufacturing Technology Research Institute Aviation Industry Corporation of China, Beijing 100024 China, 2 Shenyang Aerospace University Shenyang 110136 China). p_1-4 8

A bstract On the base of the introduction of the method and principle of the new concept of friction flow welding one of the variant of friction stir welding the fundamental research of this welding process was conducted by regarding to the weldability of the different alum num alloys and the adaptability of various part structures. The testing results show that friction flow welding can get reliable solid state joint within limited thickness by diffusing of the heat plastic flow of the metalmaterial generated by the purposed designed welding tool without central pin. This welding process can be used in joining the butt and kap joints of the thin gauge panel structures repairing surface defect filling keyhole and mod ifying surface performance

K ey words friction stir welding friction flow welding a luminum alloy

Propagating feature of arc ultrasonic and its effect on bond area HE Longbiad³, LI Luming, WUMinsheng⁸(1, National Institute of Metrology Beijing 100013, China, 2, School of Aerospace, Tsinghua University Beijing 100084, China, 3 Department of Mechanical Engineering, Tsinghua University Beijing 100084, China), P 5-8

A b stract The arc ultrasonic welding technology which uses welding arc as the ultrasonic source can refine the grain and improve the welding pint quality. To research the feature of arc ultrasonic propagating in molten pool and base meral and its effect on the bond area the photo elastic system was set up. Welding piece and molten poolwere simulated with optical glass and water channel respectively. With the directive property of arc ultrasonic field the influence of arc ultrasonic on different zone of fusion area was studied. The results show that there are strong oscillating around the bond line and the mechanical effects of ultrasonic refine the structure of fusion area. The structure in the middle of bond zone is refined smaller than in the toe zone for the reason of the directive property of arc ultrasonic

K ey words arc ultrason iç propagat
ę refinem en t $b \mbox{ ond}$ area

D gital wire feeding system with a mature induced voltage feedback FU Q iang², XUE Songbal, YAO Heqing, XU Yong (1. College of Materials Science and Technology Nanjing University of Aeronautics and Astronautics, Nanjing 210016 China, 2. College of Mechanical & Electrical Engineering Hohai University Changahou 213022 China). P9-12

Abstract The relationship between armature induced

voltage and wire feeding motor speed in the limited unipolar mode of reversible pulse with modulation (PWM) speed control system is analyzed and a reversible PWM speed control system based on the digital control of a digital signal processor (DSP) is designed. The control method can eliminate the effect of bad current on the speed of the wire feeding motor by using synchronous sampling of annature voltage at the moment of zero current. The digital PI regulation method is used for adjusting the PWM duty_cycle to keep the annature induced voltage constant and improve the stability of wire feeding. The test results show that the rate varieties of wire feeding under the conditions of variable power network voltage and change of wire feeding tube from straight state to a cycle of ϕ 400 mm at the middle all meet the standard requirements

Key words digital wire feeding system, armature in duced voltage speed control

Optin ization design of Plasma sprayed AlO_{3 p}/NiCrBSi composite coatings HAN Yaowu, SUN Daqian, LIHong mel, GONG Wenbiao, XUAN Zhaozhi (1. College of Materi als Science and Engineering Jilin University Changchun 130022 China 2 College of Materials Science and Engineer ing Changchum University of Technology Changchum 130012 China). P13-16

A bstract By means of the quadratic regression combination design process the regression equations of erosion mass lost rate were established. Effects of plasma spraying paramaters on the erosion resistance of coatings were investigated. The optimum spraying parameters corresponding to the minimum erosion mass lost rate were obtained by using Matlab software. This work provides scientific basis and technology data for practical application of $A_{\rm J} Q_{\rm p}/NiCrBSi$ compsite coatings

 $\label{eq:Keywords} Keywords \quad \mbox{plasma spraying compsile coatings quadratic regression combination design erosion resistance}$

Harden ing mechan ism of tailored bland laser welding differ. ent thickness ULC-BH steels NI Jiaming LIZhuguo, CAI Yan, WUYixiong (Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University Shanghai 200240 China). P17-20

A b stract Ulura low carbon bake hardening (ULC-BH) steel sheets with different thickness were welled by using high power laser beam with different offsets of laser beam heating position. The microhardness of cross section of laser railorwelded blank was determined and its microstructure was observed with optical microscopy and scanning electron microscopy. The hardening and softening mechanism of heat affected zone (HAZ) were analyzed. The results show that with appropriate offset, the microhardness curve of the cross section is symmetrical. Because of weld heat input some dispersive and slight NbC particles are precipitated from the saturated Cottrell atmospheres of bake hardening steel which help to harden the HAZ However without offsetmore laser power is required to melt the thick sheet but thin sheet also receives more power. Surplus heat input results in the obvious precipitate growth and the softening HAZ of the thin side sheet. Stamping cracking always occurs in the HAZ of the thin side sheet.

Keywords taibred bland laser welding ultra bw car. bon bake hardening steel microhardness different thickness

In fluence of current converting speed on **2219** a lum inum alloy VPT IG weld joints CONG Baoqiang QI Bojin (School of Medhanical Engineering and Automation, Beihang University Beijing 100191 China). P 21-24

A bstract A novel arc welding technique with ultrafast convert variable polarity square waveform for alum num alloys was developed. The influence of variable polarity current converting speed on the porosity and mechanical properties of 2219-T87 weld was studied based on the conventional and ultrafast convert variable polarity tungsten nert gas (VPTIG) welding techniques respectively. The experimental results show that compared with the conventional variable polarity welding weld porosity is obviously in proved in the case of the faster current converting speed and less zero crossing time. The number of gas pore is reduced and eliminated indeed. The tensile strength and percentage elongation of the weld joints are respectively enhanced by 8 97% and 12 6% due to the softening of weld bond area

Key words high strength alum num alloy ultrafast con vert variable polarity weld porosity

Thermal dam age analysis of vacuum brazing diam ond with NiCralby LU Jinbin^{1,2}, TANG Feng MENG Pu, WANG Zhixin¹ (1. College of Materials, Chemical Engineering Zhongyuan University of Technology Zhengzhou 450007 China 2 College of Mechanical Engineering Nanjing University of Aeronautics and Astronautics Nanjing 210016 China). P 25-28

A bstract Brazing diamond tools has the characteristics of h gh protude and strong bonding which will be significantly de. graded in brazing with the excessively high temperature and so the thermal damage for the diamond was analyzed. The diamond was brazed in vacuum by using N i-Cr alloy then the surface of sample was observed by SEM and EDS and the heat stress and graphitization on the surface were detected with Laser Raman spectroscopy. The results show that more carbide such as $C_{1}^{*}C_{2}$, $C_{7}^{*}C_{3}$, exists on the diamond surface and a little graphitization and chemical soakage take place on the surface. The tensile stress in the top of diamond is 110 MPa and the compressive stress in the bottom of diamond is 520 MPa

Keywords vacuum brazing diamond NiCralloy theumal damage

U ltrason je residual stress measurement of **300** km/h highspeed train body IU Had², MA ZAL LIU Xuesong, FANG Hongyuan (1 State Key Laboratory of Advanced Welding Production Technology Hathin Institute of Technology Hathin 150001 China, 2 Welding Laboratory CSR Qingdao Silang Locomotive and Rolling Stock Co., Ltd., Qingdao 266111 China). ^p 29-32

A bstract A lum num alloy is used tom ake the high speed train body Because the bearing pressure of the body is large the residual stress distribution is ungently needs to measurement Based on the acoustoe lasticity the residual stress can be meas ured by ultrasonic method Ultrasonic stressmeasurement experimental installation is established with critically refracted longitudinal wave. The residual stress of high-speed train body structure ismeasured by the system. The safety evaluation virtualmodel of welded structure concept is proposed.

Keywords ultrasonic welding residual stress high speed train

Joining test of telerobotic welding rapid tool changing interface DONG Na, LI Haichad, CHEN Youquar, GAO Hongming, WU Lin¹ (1 State Key Laboratory of Advanced Welding Production Technology Harbin Institute of Technology Harbin 150001, China 2 Department of Mechanical Engineering Armor Techn Aue Institute of PLA, Changchun 130117, China). P 33-36

According to the equipment maintenance in Abstract dangerous environment the remote welding robot has to prepare much more than the welding task for the welding and process af ter welding Rapid tool changing interface meets the requirement of kinds of tools changing in the remote maintenance which improves the generability of the remote welding robot but enhances the complexity of teleoperation So the practical application key of rapid tool changing interface is feasibility verification of inter face pining operation. The testing environment is composed of the video feedback force feedback teleoperation by stick and human robot interface etc According to the feedback informa. tion the tool pining was tele handled by the control mode of tele teaching. The teleoperation time and the changing of the force and force moment was recorded Results show that the rap id tool changing interface is competent in the tool pining task

 $K\,ey\,w\,ords$ remote welding robot rapid rool changing interface tele teaching force feedback

Laser butt welding of TN i shape memory a loy sheet CHEN Yuhua KE Liming HUANG Yongde XU Shibng (Na tional Defense Key Disciplines Laboratory of Light A loy Process ing Science and Technology Nanchang Hangkong University Nanchang 330063 China). P 37-40

A b stract The but welding of 0.2 mm thick TN i shape memory alloy (SMA) sheet was carried out by using low power impulse laser and the tensile strength fracture strain phase change process and shape memory effect of welded pint were studied The results show that using low power inpulse laser can realize good butt welding of TN i SMA sheet The tensile strength of welded pint of cold rolled TN i SMA achieves 97% of base metal and fracture strain achieves 95% of base metal W hen the welded pint is annealed after welding its tensile strength is