

加速时效对 T91/T23异种钢 TLP 接头组织与性能的影响

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摘 要: 在氩气保护下, 采用 FeNiCrSiB非晶中间层, 对 T91马氏体耐热钢和 T23低合金贝氏体耐热钢进行了瞬时液相扩散连接, 并在 700 °C对接头进行了不同时间的加速时效试验, 分析了时效后接头组织与性能的变化。结果表明, 时效后 T91/T23异种钢 TLP接头力学性能合格, 焊缝处强度高于低强度母材 T23一侧; 随时效时间延长, 焊缝处主要合金元素 Fe、Ni、Cr发生扩散并形成了较为连续的浓度分布梯度, 增强了接头处组织成分的均匀性, 使焊缝的冲击韧性不断升高, 保证了服役时接头力学性能的稳定。

关键词: 异种钢; 瞬时液相扩散连接; 加速时效; 组织; 力学性能

中图分类号: TG115.28 文献标识码: A 文章编号: 0253-360X(2010)08-0089-04



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0 序 言

T91和 T23是两种常用的锅炉用耐热钢, 主要用于制造发电机组的高温过热器、再热器等部件。由于二者工作温度不同, 为了降低生产成本, 就出现了 T91与 T23异种钢的焊接问题^[1]。T91为马氏体耐热钢, 具有优良的高温强度、韧性、焊接性、抗氧化及抗热疲劳性能, 主要用于临界、亚临界锅炉的过热器、再热器的高温段^[2]。T23钢因含碳量低, 焊接性能优异, 不需焊前预热与焊后热处理, 可明显减薄钢管壁厚, 优化传热效率和简化制造工艺, 是用于制造大型电站锅炉过热器、再热器等极具竞争力的候选钢种之一^[3]。瞬时液相扩散连接 (transient liquid phase bonding, TLP)作为一种先进的连接方法, 许多研究者已经对其连接工艺做了大量优化研究^[4-5]。但有关耐热钢 TLP接头高温长期时效或高温长期运行对其组织和性能的影响还未见报道。文中通过高温加速时效的方法来模拟实际服役效果, 研究时效过程中 T91与 T23异种钢 TLP接头室温下力学性能、显微硬度、组织的变化及接头元素的扩散行为。

1 试验方法

试验材料为电站锅炉用 T91钢和 T23钢, 其规

格均为 $\phi 44.5 \text{ mm} \times 7 \text{ mm}$, FeNi40Cr5Si6B7非晶中间层。试验在开放式瞬时液相扩散连接机上进行, 采用双温工艺^[9]即首先加热至 1 260 °C, 保温 30 s, 然后在 1 230 °C保温 3 min, 连接压力为 6 MPa。接头时效温度为 700 °C, 时效时间为 100, 300, 500 h。接头的拉伸试验参照国家标准 GB2651—2008《焊接接头拉伸试验方法》进行, 弯曲试验按国家标准 GB2653—2008《焊接接头弯曲及压扁试验方法》进行, 接头力学性能合格的标准为拉伸试样在母材断裂, 面弯和背弯的弯曲角大于 90°。冲击试验按照国家标准 GB29—1994《金属夏比缺口冲击试验方法》进行。利用 TUKON—2100B型显微维氏硬度计测量焊缝两侧显微硬度分布, 载荷为 0.98 N。GX71金相显微镜进行组织观察, Oxford X射线能谱仪进行成分线扫描分析。

2 试验结果与分析

2.1 接头力学性能分析

T91/T23异种钢 TLP接头在 700 °C分别时效 0 (焊后未时效)、100、300、500 h, 其室温下力学性能试验结果见表 1。

接头经过不同时间的时效后, 拉伸试样的断裂位置始终位于远离焊缝的低强度母材 T23一侧, 母材发生明显的颈缩, 弯曲试验结果始终能保持合格。表明时效前后接头强度始终高于基体, 并且接头韧性较好, 焊缝性能优良。

表 1 不同时效时间后力学试验结果

Table 1 Results of mechanical test at different aging times

时效时间 t/h	抗拉强度 R _m /MPa	拉伸断裂位置	发生颈缩	弯曲试验
0	596	T23 母材	是	合格
100	510	T23 母材	是	合格
300	463	T23 母材	是	合格
500	415	T23 母材	是	合格

图 1 为接头不同时效时间后焊缝中心附近显微硬度的变化。由图 1 可知,时效前接头处硬度分布并不平缓,焊缝中心两侧极短的距离(小于 100 μm)内两侧基体硬度有着较大的起伏,说明原中间层中元素在连接过程中扩散距离并不大,两侧材料在连接过程中发生熔合的区域较窄;焊缝 T91 侧由于发生了马氏体相变,其显微硬度明显升高(供货态为回火马氏体,显微硬度为 249 HV_{0.1}),达到 470~480 HV_{0.1},远离焊缝方向因马氏体相变逐渐消失,硬度相对近焊缝处较低;焊缝 T23 侧硬度出现下降,分析认为焊接热循环使该处组织发生变化,造成硬度降低。由图 1 还可知,随着时效时间的延长,两侧基体以及焊缝中心的硬度都有了不同程度的降低。时效 500 h 后, T23 侧硬度有了明显的下降,其范围在 115~125 HV_{0.1}之间,相比焊后状态降幅达 50%,表明此时 T23 母材已接近使用寿命的后期。值得注意的是时效前母材 T23 靠近焊缝处所形成的“软化区域”硬度继续下降的速率并没有比 T23 基体硬度下降的速率快,因此在时效过程中也没有成为接头性能的薄弱环节。对于 T91 侧母材其抗回火能力要明显高于 T23 钢,在时效 300 h 时,硬度几乎没有变化,即使时效 500 h 后, T91 母材硬度也是仅有小幅下降,表明 T91 母材在时效过程中保持了较高的强度。对于焊缝中心,虽然硬度总体呈下降趋势,但时效过程中两侧母材近焊缝处都有着较 T23 母材更高的硬度,因此在 T23 侧母材使用寿命

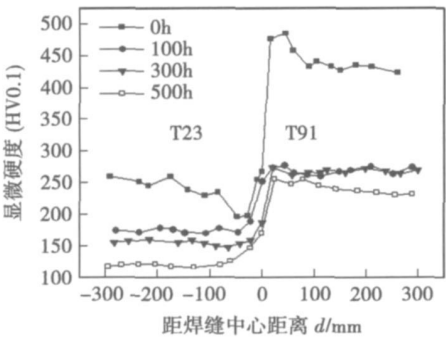


图 1 不同时效时间后接头焊缝中心附近显微硬度曲线
Fig. 1 Hardness curves of joint at different aging times

接近后期的时候,焊缝强度高于 T23 侧母材,没有成为该类接头性能的弱化区域。这与接头力学试验得到的结果是一致的。

表 2 为接头不同时间时效后焊缝及母材的冲击试验结果。接头焊缝处的冲击韧度随着时效时间的延长而不断升高,因在高温时效时随时间的延长,焊缝处主要合金元素 Fe、Ni、C 发生扩散并形成了较为连续的浓度分布梯度,增强了接头处组织成分的均匀性,同时连接过程中形成的脆性相也未聚集长大,使冲击韧度不断升高。T91 母材在时效前即焊后状态下,因 T91 钢淬透性极好,在连接过程经历热循环而发生了马氏体相变,导致冲击韧度较低,在 700 ℃经 100 h 回火后发生了回复和再结晶,使冲击韧度明显提高,并随时效时间的延长,组织发生了晶粒长大使冲击韧度又不断下降。T23 母材在时效前也经历了一次焊接热循环,晶粒发生了明显粗化,具有较低的冲击韧度,经 700 ℃回火并随时间的延长,首先从基体中析出大量弥散的碳化物,使冲击韧度不断提高,当时效至 500 h 时,贝氏体球化明显,碳化物严重长大^[6],导致冲击韧度下降。

表 2 不同时效时间后冲击吸收功

Table 2 Results of impact test at different aging times

时效时间 t/h	焊缝 A _{KV} /J	T91 母材 A _{KV} /J	T23 母材 A _{KV} /J
0	30.8	111.2	111.7
100	32.3	202.9	114.7
300	39.2	173.5	120.5
500	43.2	160.7	108.8

2.2 接头显微组织分析

T91/T23 异种钢 TLP 接头不同时间时效后接头显微组织见图 2。由图 2 可知,时效前接头焊缝处(图 2a)原中间层扩散的较为充分,焊缝两侧基体熔合较好,没有明显的“钎焊”特征,中间层元素在焊缝中心没有残留。当时效 100 h 时,焊缝两侧区域出现明显的扩散层(图 2b),说明在焊后状态下焊缝中心附近原中间层元素保持着相对较高的浓度,所以在时效过程中原中间层中 Fe、Ni、C 等元素在浓度梯度的作用下分别向两侧基体进行进一步的扩散,同时由于两侧基体均为体心立方结构,晶格常数差别不大,三种元素相对于两侧基体的浓度梯度几乎一致,因此时效过程中元素向两侧基体扩散速率也差别不大。当时效 300 h 时,焊缝区域已没有明显的扩散层(图 2c),两侧基体“犬牙交错”紧密地结合在一起,表明原中间层已完全扩散,使焊缝的冲击韧性明显提高。当时效 500 h 时,焊缝两侧组织界线不明显

(图 2 d),且 T23侧母材贝氏体组织特征变化明显,表明在时效过程中 T23侧母材的退化使焊缝处组织发生了一定程度的变化.两侧基体中元素发生互扩散,使焊缝两侧化学成分均匀化,使焊缝的冲击韧度继续升高.

2.3 接头主要元素的扩散行为

图 3 为 T91/T23异种钢接头不同时间时效后接头主要元素分布,时效前 Fe元素在焊缝区域明显存在一个“凹坑”,说明此处还存在着其它元素的富

集;N元素由于在 Fe基体中溶解度较大,扩散较快,元素浓度下降明显,但在焊缝中心仍存在着元素的相对富集;C元素在焊缝两侧明显存在一个“台阶”,这也说明了焊接过程中扩散的距离并不大.当时效 100 h时,Fe元素在焊缝处的“凹坑”消失,Ni元素已没有了富集,C元素的“台阶”变得连续,总之,各元素的分布均趋于平缓,形成了较为连续的长度梯度,说明时效促进了元素的进一步扩散,提高了接头组织和成分的均匀化.当时效 300 h和 500 h

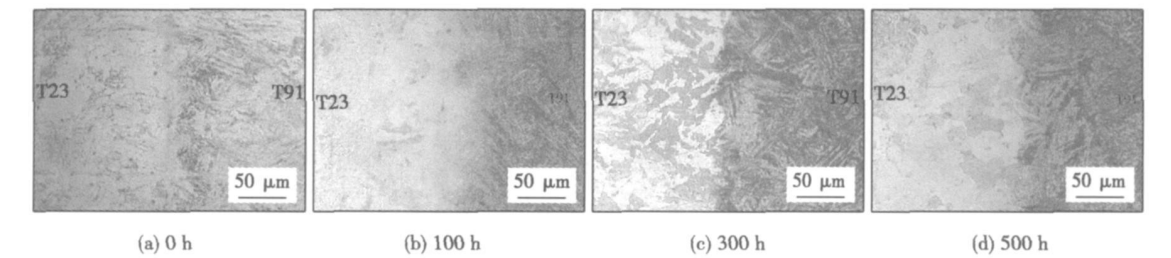


图 2 不同时效时间后焊缝区域显微组织的变化
Fig. 2 Microstructures of joint at different aging times

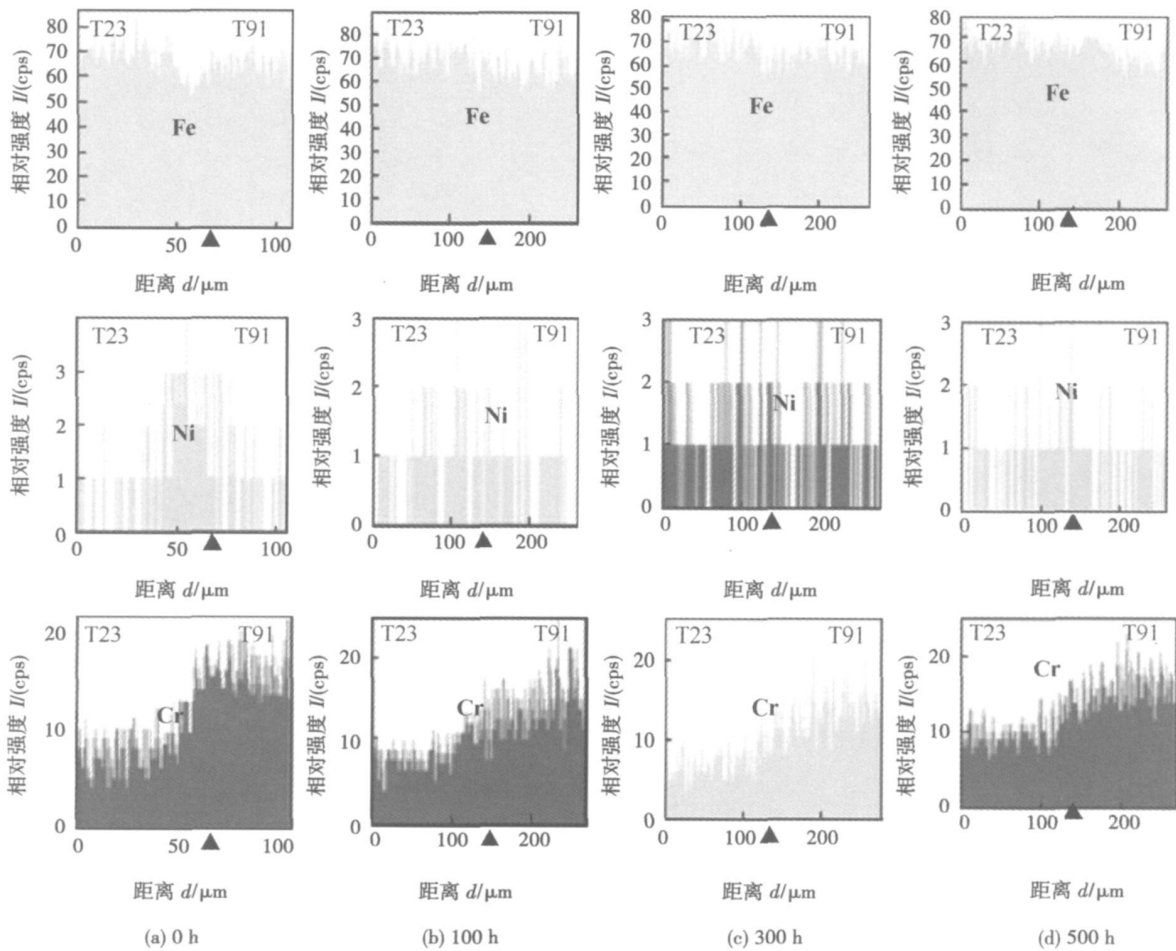


图 3 接头不同时效时间后接头区域主要元素分布(▲-焊缝中心位置)
Fig. 3 Element distribution in bonding region of joint at different aging times

时,各元素的分布情况变化不明显,说明在形成连续的浓度梯度后,各元素的扩散明显减弱,这也有助于接头组织和性能的稳定.从图 3 中还可知,不同时间时效后 C 元素分布曲线上出现个别峰值,表明生成了少量铬的化合物,即脆性相.尽管中间层加入了非金属元素 Si 而 S 在 Ni-Si-Cr 中的溶解度较大,所以在接头中不易形成含硅的脆性相.而 B 元素在接头中的表现与硅有所不同,因为 B 在 α -Fe-C 和 N 中的溶解度均极小,大大低于所使用中间层中 B 的含量.因此, B 元素对接头性能的影响较大. B-Si-Ni-Fe-C 的电负性分别为 2.1 8 1.9 1.8 和 1.7.按照电负性, B 元素与 C 元素形成化合物的倾向大于 Fe 和 N 元素,由此判断接头处形成的铬的化合物应为铬硼化物^[7].虽然脆性相的存在会降低接头的塑韧性,但只要存在量少并且分散分布,就不会对接头的性能产生较大影响.从 C 元素分布曲线来看,尽管接头存在着少量脆性相,但时效过程中并没有聚集长大,因此接头在时效过程中保持了较好的力学性能.

3 结 论

- (1) T91/T23 异种钢 TLP 接头经 700℃高温时效 500 h 后, T23 侧母材组织变化导致硬度下降明显,使用寿命接近后期,而 T91 侧母材性能下降缓慢,接头焊缝处 Fe-Ni-C 元素在浓度梯度作用下发生互扩散,形成较为连续的浓度梯度.
- (2) 时效不同时间后,接头的拉伸与弯曲性能始终合格,断裂位置均位于远离焊缝的母材 T23 一侧,焊缝处的强度保持高于低强度的 T23 母材.
- (3) 时效过程中,接头组织成分均匀化逐渐增强,同时连接过程中形成的脆性相并未聚集长大,使

焊缝的冲击韧度随时效时间的延长而不断升高,保证了服役时接头力学性能的稳定.

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Abstract The model and sample data that able to reflect the stability of the different welding process parameters were obtained through analyzing welding voltage signals in aluminum alloy pulsed MIG welding by approximate entropy. On this basis a method that predicts the approximate entropy of the voltage signals by generalized regression neural network (GRNN) was proposed. The structure and algorithm of the GRNN prediction model were introduced and the prediction experiments on ample data were done. The results show that the average error of the predictive value is 9.08%, the accuracy rate of it is 90.92%, and the results meet the forecast accuracy of aluminum alloy pulsed MIG welding process stability.

Key words pulse MIG voltage signal approximate entropy stability generalized regression neural network Pattern Recognition

Effects of molding process parameters for SLS technology on sintered performance of wood-plastic composite materials

XN Zongsheng², GUO Yanling (1. Mechanical and Electrical Engineering College Northeast Forestry University Harbin 150026 China; 2. Mechanical and Electrical Engineering Department Heilongjiang Institute of Technology Harbin 150050 China). P 81—84

Abstract With raw materials such as wood powder, hot melt adhesive and polypropylene, the wood-plastic composite materials are made by selective laser sintering (SLS) technology and molded with the HRPS-III laser rapid prototyping machine. The orthogonal optimization method is used for experimental design. The wood-plastic composite materials are sintered with different process parameters (laser power, laser beam scanning speed, scan spacing and preheating temperature). A group of process parameters, which guarantee not only the quality and efficiency of the sinter processing, but also reasonable match of optimization forming, are obtained by using variance analysis method. The results show that the sintered density increases as the scanning speed and the scan spacing decreases, and laser power becomes larger and preheating temperature grows.

Key words wood-plastic composite materials selective laser sintering technology molding process parameters sintered density parameter optimization

Characteristics of voltage and current waveforms of constricted arc with flux strips in ultranarrow gap ZHU Liang, MIAO Hongli, JIN Jiang, Li Yuanbo (State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials Lanzhou University of Technology Lanzhou 730050 China). P 85—88

Abstract For understanding the behavior of constricted arc with flux strip in ultranarrow gap metal arc welding tests were carried out on I groove deposited with the flux strips. Results

show that the height of lower sidewalls uncovered by flux strips controls the height of sidewalls melted by arc. When the height of lower sidewalls uncovered by flux strips is very small, the arc only heats the bottom of the groove, and the arc length is longer while short circuit ends and the arc reignites. Therefore, the voltage is higher as arc reignites, and then rapidly decreases, meanwhile the current peak of short circuit is larger. When the height of lower sidewalls uncovered by flux strips increases, the heating range of the arc expands from the bottom of the groove to its sidewalls, and the arc length is shorter as the arc reignites. Therefore, the voltage is lower as arc reignites, and then slowly decreases, even doesn't decrease. At the same time, the frequency of short circuit increases, the current peak of short circuit lowers, and the probability of instantaneous short current increases.

Key words ultranarrow gap welding arc constricted with flux strips arc voltage waveform

Effect of accelerating ageing on microstructure and properties of TLP joint of T91/T23 dissimilar steel GE Lilong, LIU Yang, JING Xiaotian, HUANG Jianxin (School of Materials Science & Engineering Xi'an University of Technology Xi'an 710048 China). P 89—92

Abstract By using Fe-Ni-Cr-B amorphous alloy as filler metal, the dissimilar steel pipes of T91 and T23 were welded through transient liquid phase (TLP) bonding under the protection of argon atmosphere. The weld joints were rapidly aged at 700 °C for different times. The changes of the microstructures and mechanical properties of the weld joints after ageing were analyzed. The results show that the aged T91/T23 TLP joint can meet the requirements of mechanical properties, and the strength of the weld joint is higher than that of the side of T23 base metal. With increasing the ageing time, the main alloying elements (Fe, Ni, Cr) in the weld joint are diffused, and a continuous concentration gradient is formed. These microstructural changes can improve the uniformity of microstructure and composition of the joint and enhance the impact toughness and mechanical property stability of the weld joint during service.

Key words dissimilar steel transient liquid phase bonding accelerating ageing microstructure property

Analysis on impact property of welded joint HAZ of 980 MPa high strength steel CAO Rui, FENG Wei, PENG Yurui, DU Wanhong, TAN Zhiling, CHEN Jianhong (1. State Key Laboratory of Gansu Advanced Non-Ferrous Metal Materials Lanzhou University of Technology Lanzhou 730050 China; 2. Harbin Welding Institute Harbin 150080 China; 3. Division of Structural Materials, Central Iron and Steel Research Institute, Beijing 10081, China). P 93—96

Abstract Single and multiple thermal cycles of welded joint heat-affected zone (HAZ) for NiCrMoV 980 MPa low carbon bainite high strength steel are simulated by welding thermal simulation technique. The impact properties of HAZ are studied at room temperature and -50 °C. Based on observations of microstructures and fracture surfaces for various HAZ, the experimental results indicate that the impact property of coarse grain