

FeAlCuCrNiNb_x 系高熵合金堆焊层的组织及性能分析

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摘要: 为了研究 Nb 元素含量对 FeAlCuCrNiNb_x($x = 0.4, 0.6, 0.8, 1.0$, x 为摩尔比) 高熵合金的组织结构及性能的影响, 采用熔化极气体保护焊技术在碳钢板表面制备出 FeAlCuCrNiNb_x 高熵合金堆焊层, 而后对堆焊层进行显微组织、物相组成、显微硬度、耐磨性和耐蚀性分析. 结果表明, FeCuCrAlNiNb_x 高熵合金堆焊层呈现以 Fe-Cr 相为基的 BCC 固溶体和少量 MC 共晶碳化物. 组织为典型的枝晶结构, 由灰色的枝晶 (DR) 及白色的枝晶间 (ID) 结构组成. 对于耐磨性, 加入适量的 Nb 元素可以显著提高堆焊层的显微硬度和耐磨性, 当 Nb 摩尔比为 0.8 时, 显微硬度最高, 耐磨性最好, 最大硬度值达到 602 HV, 磨损量最小为 0.30 g. 对于耐蚀性, 加入一定量的 Nb 元素后极化曲线中自腐蚀电流密度减小, 腐蚀速率减慢, 耐蚀性增强, 均优于 304 不锈钢, 当 Nb 摩尔比为 1.0 时, 堆焊层合金耐蚀性最好.

关键词: 高熵合金; 微观组织; 显微硬度; 磨损性能; 电化学腐蚀

中图分类号: TG 422 **文献标识码:** A **doi:** 10.12073/j.hjxb.20191015001

0 序言

传统理念上的合金是以一种或两种金属元素作为主要元素(含量大于 50%), 其余的金属或非金属元素作为微量元素对合金性能进行改善. 随着元素种类的增多, 合金中会析出复杂的中间相, 合金性能会严重降低^[1-2]. 1995 年 Huang 等人^[3] 提出了新型多组元高熵合金设计理念, 制备成的高熵合金具有较高的混合焓, 形成的相数远低于普通合金, 且会形成简单的体心立方和面心立方结构的固溶体, 原因可能是合金内的混乱程度过高阻碍了金属间化合物的形成. 多组元高熵合金是一种新型的合金材料, 经计算得到合理的合金配比, 可以获得兼具高硬度、耐磨性和耐蚀性等各种优异性能的合金^[4-5].

Nb 作为微合金化元素具有较高的强度, 可以改变合金的力学性能, 对合金可以产生沉淀强化以及细小颗粒相的细晶强化作用^[6]. 高熵合金的制备技术包括真空熔铸法、粉末冶金技术、表面改性技术等; 块状高熵合金主要采用真空电弧炉熔炼和熔铸等方法制备^[7], 目前涉及 Nb 元素的研究讨论基本在铸造熔炼方法的基础上探讨合金的组织性和

能^[8]. 但合金尺寸有限, 主要为小型块件, 使用的金属元素大都比较昂贵, 所以制造成本较高. 因此在低价的碳钢板表面上制备出大块高熵合金对实际应用具有很大的意义, 文中研究重点为采用熔化极气体保护焊方法制备含 Nb 元素的高熵合金, 并对其组织结构及性能进行研究讨论.

1 试验方法

试验所采用的是纯度大于 99.9% 的 Al, Cu, Cr, Ni, Nb 合金粉末配制药芯焊丝的药粉, 药粉需要事先烘干, 因为药粉极易吸收水分, 药粉使用前要经过严格检验, 潮湿的药芯焊丝易产生气孔、裂纹等缺陷.

合金粉末按照预先设计好的比例(x 值的摩尔比为 0.4, 0.6, 0.8, 1.0, 记作 Nb_{0.4}, Nb_{0.6}, Nb_{0.8}, Nb_{1.0}), 配制成不同成分配比的药粉加入钢带中经轧制和拉拔制成 $\phi 2.4$ mm 的药芯焊丝, 药粉填充率为 35%, 钢带成分如表 1 所示. 对低碳钢板表面采用机械打磨的方法去除氧化皮, 并用无水乙醇擦拭干净, 而后将制备的高熵药芯焊丝采用熔化极气体保护焊堆焊到低碳钢表面形成试件. 堆焊工艺参数为: 堆焊电流 160 A, 堆焊电压 24 V, 堆焊速度 8 cm/min, 保护气流量 12 L/min^[9].

收稿日期: 2019 - 10 - 15

基金项目: 国家重点研发计划 (2017YFB1103603); 辽宁省自然科学基金联合基金项目 (20180510030).

表 1 H08A 钢带的化学成分 (质量分数, %)

Table 1 Chemical compositions of H08A steel strip

C	Si	Mn	S	P	Fe
<0.01	≤ 0.03	0.30~0.55	≤ 0.03	≤ 0.03	余量

采用 X-ray diffraction(XRD) 衍射仪分析了堆焊层的相结构,具体参数为:纯铜靶材、管电压 40 kV、管电流 30 mA、扫描速率 4°/min、扫描范围 20°~90°。采用配备能谱仪(EDS)的 SU8010 型场发射扫描电子显微镜对晶粒结构的相组成进行观测。采用显微硬度计研究了在 9.8 N 载荷作用下 15 s 的显微硬度,采用湿沙橡胶轮磨损试验机对堆焊层耐磨性进行测试,试验参数为:石英砂粒径为 250 μm,转速 240 r/min,磨损时间 5 min。采用 BL410F 型电子天平(1 mg)对试样磨损前后质量进行测试。采用 VSP-300 电化学工作站,以饱和甘汞电极为参比电极,铂电极为辅助电极,扫描速度 10 mV/min,测定了 3.5%NaCl 溶液中高熵合金堆焊层的极化曲线。

2 试验结果与分析

根据热力学及几何学角度,Zhang 等人^[10]将 Hume-Rothery 定律应用于多组元高熵合金的成分设计。结合多组元合金的原子尺寸差 δ 、混合焓 ΔH_{mix} 、混合熵 ΔS_{mix} 等参数提出了固溶体相形成规则。

$$\Delta S_{\text{mix}} = -R \sum_{i=1}^n C_i \ln C_i \quad (1)$$

$$\Delta H_{\text{mix}} = \sum_{i=1, i \neq j}^n 4\Delta H_{ij}^{\text{mix}} C_i C_j \quad (2)$$

$$\delta = 100 \sqrt{\sum_{i=1}^n C_i \left(1 - \frac{r_i}{\bar{r}}\right)^2} \bar{r} = \sum_{i=1}^n r_i C_i \quad (3)$$

式中: C_i , C_j 为第 i, j 种组分的摩尔分数; $\Delta H_{ij}^{\text{mix}}$ 为 i 和 j 二组元的液态混合焓; r_i 为第 i 组分的原子半径。当 $1\% < \delta < 6.6\%$, $-15 \text{ kJ/mol} < \Delta H_{\text{mix}} < 5 \text{ kJ/mol}$, $12 \text{ J/(mol}\cdot\text{K)} < \Delta S_{\text{mix}} < 17.5 \text{ J/(mol}\cdot\text{K)}$ 时,合金易形成固溶体结构。Guo 等人^[11]用价电子浓度(V_{EC})预测面心立方(FCC)固溶体和体心立方(BCC)固溶体的形成规律,即

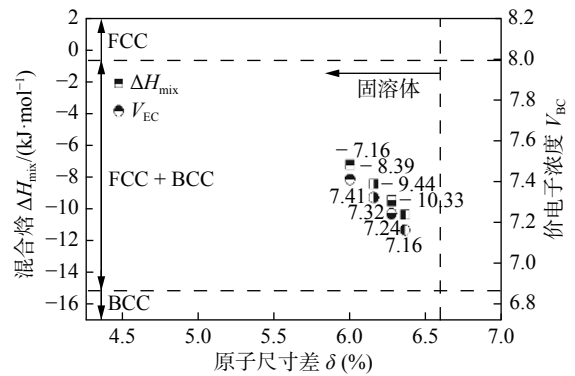
$$V_{\text{EC}} = \sum_{i=1}^n C_i (V_{\text{EC}})_i \quad (4)$$

式中: C_i 为第 i 组分的摩尔分数; $(V_{\text{EC}})_i$ 是第 i 种组分的原子核外价电子数。 $V_{\text{EC}} > 8.0$ 时,有利于 FCC 固溶体的形成, $V_{\text{EC}} < 6.87$ 时,有利于 BCC 固溶体的形成, $6.87 < V_{\text{EC}} < 8.0$ 时, BCC 和 FCC 两固溶体趋于共存。试验各成分参数值如表 2 所示。根据图 1 高熵合金中相应参数可知,该试验所设计体系为高熵合金,可能 BCC 和 FCC 两固溶体共存。

表 2 各成分的理论参数值

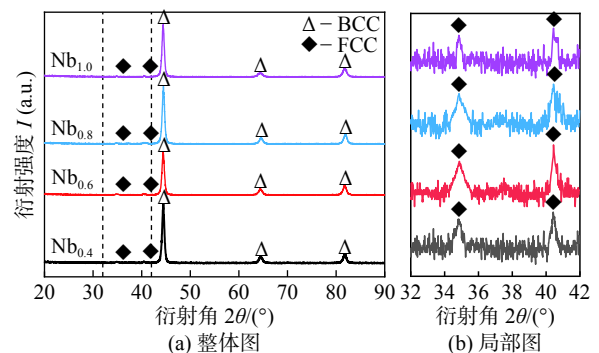
Table 2 Theoretical parameter values of each component

成分	混合熵 $\Delta S/(\text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1})$	原子尺寸差 $\delta(\%)$	混合焓 $\Delta H/(\text{kJ}\cdot\text{mol}^{-1})$	价电子浓度 V_{EC}
Nb _{0.4}	14.58	5.98	-7.16	7.41
Nb _{0.6}	14.77	6.14	-8.39	7.32
Nb _{0.8}	14.87	6.26	-9.44	7.24
Nb _{1.0}	14.90	6.35	-10.33	7.16

图 1 FeAlCuCrNiNb_x 系高熵合金各成分参数值Fig. 1 Component parameter values of FeAlCuCrNiNb_x high entropy alloy

2.1 Nb 含量对相结构的影响

图 2 为 FeAlCuCrNiNb_x 系高熵合金堆焊层 X 射线衍射对比分析。由图 2 可知,堆焊层由 BCC 固溶体和少量 MC 共晶碳化物组成,堆焊层合金主体

图 2 FeAlCuCrNiNb_x 系高熵合金 X 射线衍射对比分析图Fig. 2 X-ray diffraction analysis of FeAlCuCrNiNb_x high entropy alloy. (a) overall picture; (b) partial view

为 BCC 固溶体, 通过 PDF 标准卡片对比可得, 此衍射峰与 Fe-Cr 相吻合, 表明 FeAlCuCrNiNb_x 系高熵合金在堆焊过程中形成的 BCC 固溶体应以 Fe-Cr 相为主. 而在衍射峰 $2\theta = 34.730^\circ$ 和 $2\theta = 40.316^\circ$ 附近出现的小峰为 FCC 固溶体, 如图 2b 为图 2a 中虚线部分放大图, 可得少量的 MC 共晶碳化物. 经对比 MC 共晶碳化物的 X 射线衍射峰主要为 NbC 相 (PDF:32-1383)^[12], 随着 Nb 含量的增加, MC 共晶碳化物先增加后减少, 衍射峰没有发生偏移现象, 与之前理论参数值计算相吻合.

2.2 Nb 含量对微观组织的影响

图 3 为不同 Nb 含量的 FeAlCuCrNiNb_x 系高熵合金堆焊层的组织形貌. 堆焊层为典型的枝晶组织, 其组织由灰色的枝晶 (DR) 及白色的枝晶间 (ID) 结构组成, EDS 成分分析如表 3 所示, DR 富含 Fe 元素、Cr 元素、Ni 元素而贫化 Cu 元素, ID 富含 Cu 元素、Nb 元素而 Fe 元素、Cr 元素、Ni 元素有部分烧损. 通过 Nb 含量来判断析出相是 NbC (图 3 的相关标识区), 因为 Nb 是强碳化物形成元素, C 含量误差较大, 且基体在高能电弧的稀释作用下使得 Fe 含量升高^[13]. 结合 XRD 分析可知, 堆焊层组织主要为体心立方结构的 Fe-Cr 相, 小颗粒块状的 NbC 弥散分布于 Fe-Cr 基体中^[12], 随着 Nb 含量的增加, 组织中晶界先增多后减小, 晶粒先减小后增大, $x = 1.0$ 时, 晶粒尺寸大小不一, 分布不均匀. 由于 Nb 是高熔点元素, 在电弧堆焊中需要的能量也高, 基体在高能量的电弧中, 熔池流动性更好, 随着 Nb 含量的增加, 在 MC 共晶碳化物中聚集的 Nb 元素逐渐回溶于 BCC 固溶体中^[6].

2.3 Nb 含量对硬度和耐磨性的影响

图 4 为 FeAlCuCrNiNb_x 系高熵合金堆焊层横截面显微硬度分布. 从图 4 可以直观的看到, 横截面显微硬度随着 Nb 含量的增加呈先增大后减小的趋势, 当 Nb_{0.8} 时显微硬度值最高, 为 602 HV, 约为基材硬度的 2.6 倍. 另外, 热影响区显微硬度与焊缝表面显微硬度变化趋势相同, 并且热影响区的显微硬度都比焊缝表面显微硬度小. 图 5 为 FeAlCuCrNiNb_{0.8} 高熵合金横截面组织形貌, 由于热影响区属于不完全结晶区, 吸收的热量大多用于晶粒生长, 使得晶粒易粗大, 致使其韧性、显微硬度降低^[14]. 而焊缝为完全结晶区, 组织细化程度要优于热影响区, 因此热影响区显微硬度比焊缝显微硬度小.

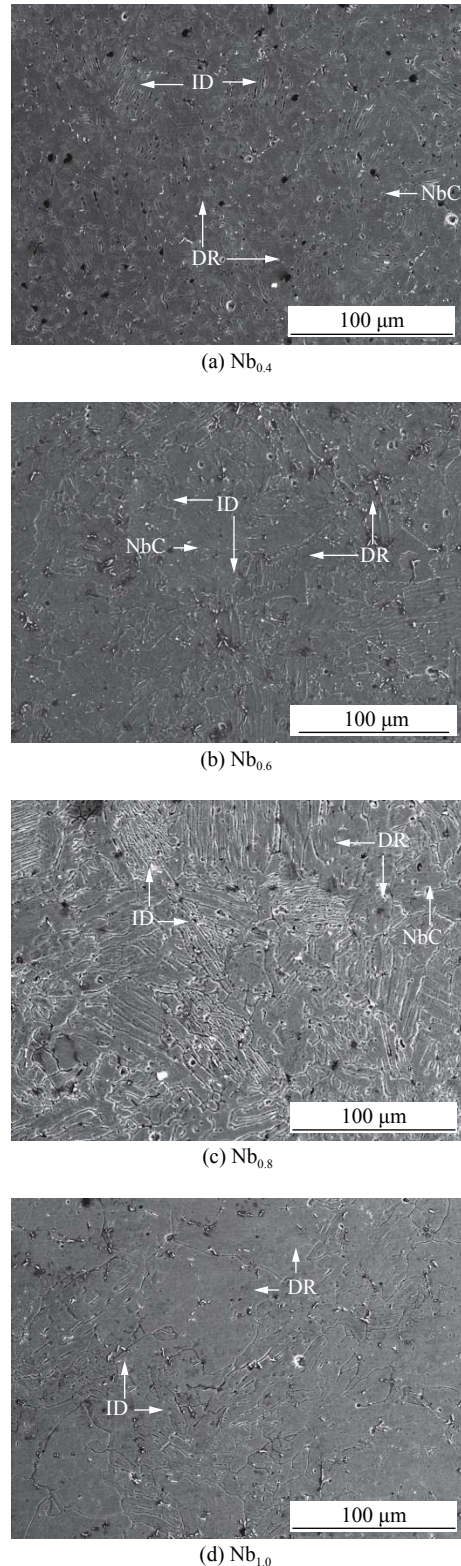


图 3 不同 Nb 含量的 FeAlCuCrNiNb_x 系高熵合金组织形貌

Fig. 3 Microstructure of FeAlCuCrNiNb_x high entropy alloy with different Nb content. (a) Nb_{0.4}; (b) Nb_{0.6}; (c) Nb_{0.8}; (d) Nb_{1.0}

图 6 为 FeAlCuCrNiNb_x 系高熵合金堆焊层平均显微硬度与磨损量对比, 堆焊层显微硬度值随着 Nb 含量的增加呈现先增大后减小的趋势. Nb_{0.8}

表 3 FeAlCuCrNiNb_x 高熵合金堆焊层不同区域的元素含量 (原子分数, %)

Table 3 Element content of different regions in FeAlCuCrNiNb_x high entropy alloy surfacing layer

合金	区域	Fe	Al	Cu	Cr	Ni	Nb	C
FeAlCuCrNiNb _{0.4}	沉淀物	44.38	22.74	1.75	2.69	2.29	10.85	15.30
	DR	74.05	1.99	6.69	8.56	7.13	1.58	—
	ID	69.84	1.58	13.02	5.92	6.49	3.15	—
FeAlCuCrNiNb _{0.6}	沉淀物	16.91	15.37	2.17	2.76	3.60	42.66	16.53
	DR	73.47	2.12	5.91	8.15	7.41	2.94	—
	ID	66.92	2.96	11.50	7.73	6.79	4.10	—
FeAlCuCrNiNb _{0.8}	沉淀物	11.70	11.77	1.66	2.23	3.36	49.58	19.70
	DR	71.93	1.71	6.84	8.90	7.52	3.10	—
	ID	66.62	2.48	11.91	7.93	6.47	4.59	—
FeAlCuCrNiNb _{1.0}	沉淀物	16.69	18.25	2.18	2.84	2.98	38.39	18.67
	DR	73.99	1.96	6.18	8.22	7.37	2.28	—
	ID	69.36	1.90	12.38	6.55	6.09	3.72	—

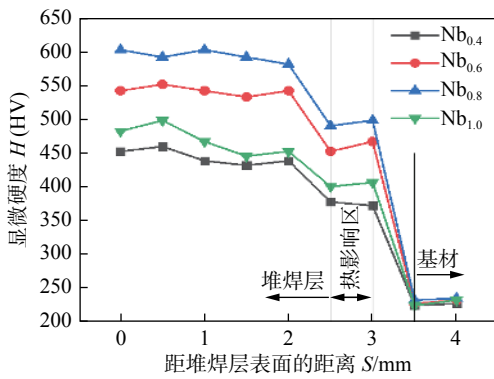


图 4 FeAlCuCrNiNb_x 高熵合金显微硬度分布

Fig. 4 Microhardness distribution of the FeAlCuCrNiNb_x high entropy alloy

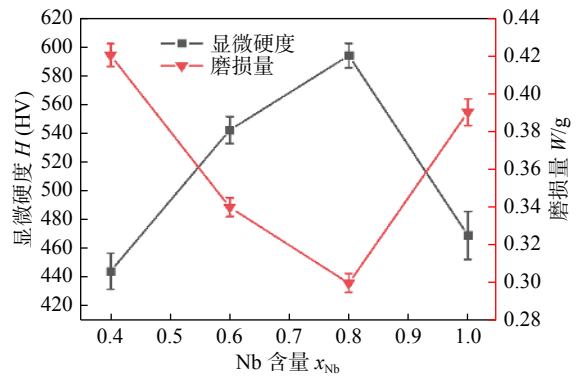


图 6 FeAlCuCrNiNb_x 高熵合金平均硬度和磨损量

Fig. 6 Comparison of microhardness and wear mass loss of the FeAlCuCrNiNb_x high entropy alloy

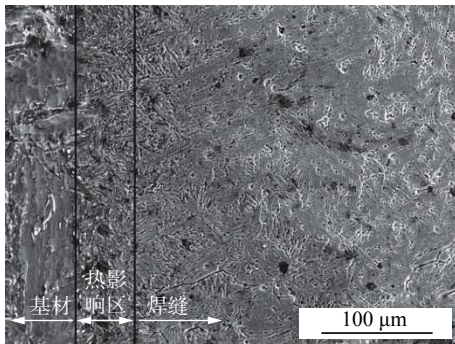


图 5 FeAlCuCrNiNb_{0.8} 高熵合金横截面组织形貌

Fig. 5 Cross-sectional microstructure of the FeAlCuCrNiNb_{0.8} high entropy alloy

时,平均硬度最大,为 596 HV,磨损量曲线呈先减小后增大的趋势,且磨损量最小,为 0.30 g. 这说明此材料晶粒越小硬度越高,合金的耐磨性越好. 基

体的平均硬度为 232 HV,均低于各成分堆焊层合金的平均硬度,Nb 是强碳化物形成元素,原子半径相对较大,发生晶格畸变,使得位错运动受阻,致使高熵合金硬度远高于基体^[15].

合金中晶体结构为 BCC 的 Fe-Cr 固溶体产生固溶强化作用,以及细小颗粒的 NbC 相沉淀作用,使得合金显微硬度升高. 比较各元素原子半径 R 和 Fe-Cr 晶格间隙可知存在如下关系: $R(\text{Nb}) > R(\text{Al}) > R(\text{Cu}) > R(\text{Ni}) > R(\text{Cr}) > R(\text{Fe}) >$ 晶格间隙.

由于 Fe, Cr 原子尺寸差、电负性小于其它原子,因此其它金属原子不可能以间隙固溶体方式存在于晶胞内,极有可能以置换固溶体形式存在于堆焊层中. 相对于其它元素, Nb 原子半径较大,加入一定量的 Nb 元素可能产生置换固溶体,随着 Nb

元素增多合金体系的熵值也会随着增大,使得各组元之间的相容性增大,促进固溶体相的形成,从而抑制金属间化合物的析出.高熵合金中存在较多的就是固溶体相,各组元的原子差异,使得固溶体晶格畸变加大,固溶强化效果增大,Gibbs 自由能降低,合金的强度、硬度显著提高,合金混乱程度增加,元素偏析程度降低,相更稳定^[16].试验合金体系存在两种强化机理分别为固溶强化和沉淀强化,两种机制共同作用强化了高熵合金的性能.

2.4 Nb 含量对耐蚀性的影响

图 7 为 FeAlCuCrNiNb_x 系高熵合金堆焊层与 304 不锈钢在 3.5%NaCl 溶液中的极化曲线.由图 7 可知,不同 Nb 含量的 FeAlCuCrNiNb_x 系高熵合金的自腐蚀电位和自腐蚀电流密度均不一致,随着 Nb 含量的升高,堆焊层合金自腐蚀电流密度逐渐减小,合金的腐蚀速率逐步减慢^[17],如表 4 所示. FeAlCuCrNiNb_{1.0} 耐蚀性最好,具有最低的自腐蚀电流密度,约为 $7.7707 \times 10^{-6} \text{ mA/cm}^2$,具有最高的自腐蚀电位,约为 -0.72832 V .与 304 不锈钢相比,堆焊层具有更好的耐蚀性能,304 不锈钢虽腐蚀

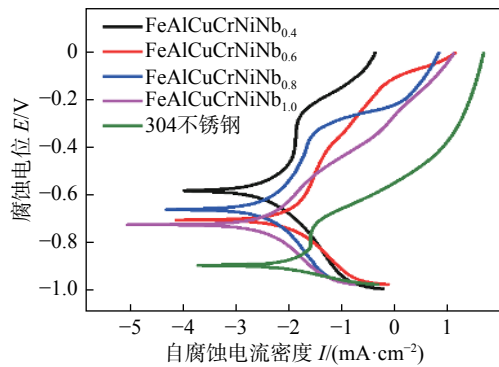


图 7 不同 Nb 含量的高熵合金在 3.5%NaCl 溶液中的极化曲线

Fig. 7 Polarization curves of high entropy alloy with different Nb contents in 3.5% NaCl solution

表 4 FeAlCuCrNiNb_x 高熵合金自腐蚀电位和电流密度

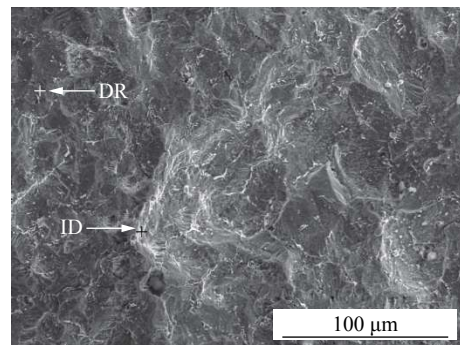
Table 4 Self-corrosion potential and current density of the FeAlCuCrNiNb_x high entropy alloy

合金	腐蚀电位 E/V	自腐蚀电流密度 $I/(\text{mA} \cdot \text{cm}^{-2})$
304 不锈钢	-0.900 8	1.6486×10^{-4}
FeAlCuCrNiNb _{0.4}	-0.583 7	8.9807×10^{-5}
FeAlCuCrNiNb _{0.6}	-0.707 73	6.3084×10^{-5}
FeAlCuCrNiNb _{0.8}	-0.663 73	4.1929×10^{-5}
FeAlCuCrNiNb _{1.0}	-0.728 32	7.7707×10^{-6}

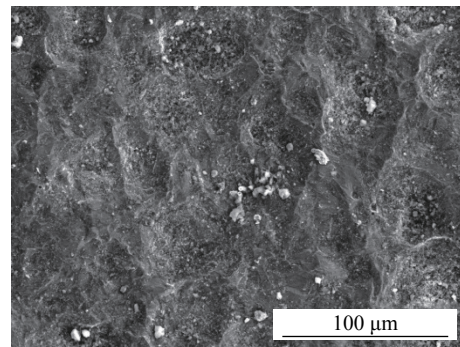
电位稍高,腐蚀开始较难,但自腐蚀电流密度最大,腐蚀速率最快.一般来说,低自腐蚀电流密度、宽的钝化区间和“正”自腐蚀电位可以表现出优秀的耐蚀性能^[18-19].自腐蚀电位是反映反应热力学的参数,电位越高,腐蚀反应开始越困难.自腐蚀电流密度是反映反应动力学的物理参数;自腐蚀电流密度越小,腐蚀速率就会越慢^[20].

图 8 为 FeAlCuCrNiNb_x 系高熵合金堆焊层腐蚀形貌 SEM 图.从图 8 可知,FeAlCuCrNiNb_x 系高熵合金的耐蚀性强于 304 不锈钢,304 不锈钢表面腐蚀坑居多,腐蚀形貌不规整,耐蚀性能较差.而 FeAlCuCrNiNb_x 系高熵合金组织腐蚀多发生在枝晶间区,由 DR 和 ID 的 EDS 成分对比可知合金在枝晶间区发生了偏析,使得贫 Cu 的枝晶区和富 Cu 的枝晶间区形成了原电池,枝晶间区容易先被腐蚀掉.电化学腐蚀过程中合金的物相越少,结构越单一,合金的耐蚀性越高^[21].一方面,BCC 固溶体主要含有大量的 Fe-Cr 相,Cr, Ni 元素在氧化介质中易于钝化,有利于合金表面钝化膜的形成,从而阻止堆焊层合金腐蚀的进一步进行;另一方面,单一的固溶体可以使得合金耐蚀性能提高^[22].

通过上述分析发现:对于耐磨性而言,随着



(a) FeAlCuCrNiNb_{0.6}



(b) 304 不锈钢

图 8 腐蚀形貌

Fig. 8 Corrosion morphology. (a) FeAlCuCrNiNb_{0.6}; (b) 304 stainless steel

Nb 元素含量增多,通过固溶强化和沉淀强化共同作用,合金的耐磨性呈先升高后下降的趋势, $x = 0.8$ 时耐磨性最好;而对于耐蚀性而言,增加 Nb 元素含量会使合金耐蚀性有所提高, $x = 1.0$ 时合金耐蚀性最好。

3 结论

(1) FeAlCuCrNiNb_x 高熵合金体系以 Fe-Cr 固溶体为主,其晶体结构为体心立方。另有少量 MC 碳化物析出,随 Nb 含量增加而先增多后减少。

(2) 随着 Nb 元素含量增多,合金晶粒尺寸呈先变小后增大的趋势。当 $x = 0.8$ 时晶粒最小,晶界最多,力学性能达到最佳匹配,此时显微硬度最大为 602 HV,磨损量为 0.30 g。堆焊层合金存在固溶强化和沉淀强化两种机制。

(3) 对于合金的耐蚀性而言,随着 Nb 含量的增加,耐蚀性增强,当 $x = 1.0$ 时合金耐蚀性最好,优于常用 304 不锈钢。

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obtained best mechanical properties, i.e. elongation and tensile strength are 16.5% and 252 MPa, reaching 75% and 90% of the base material, respectively.

Key words: AZ31 magnesium alloy; friction stir welding; technological parameters; microstructure; mechanical properties

Microstructure and property analysis of FeAlCuCrNiNb_x high-entropy alloy surfacing layer SU Yunhai, LIANG Xuewei, DENG Yue, LIU Yunqi (Shenyang University of Technology, Shenyang, 110870, China). pp 38-43,50

Abstract: In order to study the effect of Nb element content on the structure and properties of FeAlCuCrNiNb_x ($x = 0, 0.4, 0.6, 0.8, 1.0$) high-entropy alloy, the FeAlCuCrNiNb_x high-entropy alloy was prepared on the surface of carbon steel sheet by the technique of gas metal arc welding. The microstructure, phase composition, microhardness, wear resistance and corrosion resistance of surfacing layer were analyzed. The results show that: the surfacing layer of FeCuCrAlNiNb_x high-entropy alloy is composed of Fe-Cr phase-based BCC solid solution and a few of MC eutectic carbide. The structure is a typical dendrite structure, which is composed of gray dendrite (DR) and white interdendrite (ID) structure. For wear resistance, addition amounts of Nb can significantly improve the microhardness and wear resistance of surfacing layer. The optimal properties of surface layer were obtained when the molar ratio of Nb element is 0.8, which maximum microhardness value is 602 HV, the minimum wear is 0.30 g, respectively. For the corrosion performance, with increase of Nb element addition amounts, the self-corrosion current density become to reduce, the corrosion rate become to slow, and the corrosion resistance enhances. All of these are better than 304 stainless steel. When the molar ratio of Nb element is 1.0, the corrosion resistance of the surfacing alloy is the best.

Key words: high-entropy alloy; microstructure; microhardness; wear resistance; electrochemical corrosion

Laser scanning welding of 2060 Al-Li alloy with filler wire

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Abstract: In order to solve the problems of porosity

and insufficient tensile strength of aluminum lithium alloy weld, a method of laser scanning welding with filler wire was proposed. Taking 2060 Al-Li alloy with 2 mm thickness as research objects, the suppression effect of laser scanning welding with filler wire on welding defects of Al-Li alloy was investigated. A high-speed camera system was built to explore the mechanism and the change of the dynamic evolution of the molten pool. The influence of scanning parameters on the formation of porosity in weld seam and the mechanism of inhibiting porosity of laser scanning welding with filler wire technique were investigated. Response surface methodology was applied to explore the influence of process parameters on tensile strength. The quantitative relationship between process parameter combination, tensile strength and the optimal parameter combination were proposed. The maximum tensile strength of the weld is 382 MPa, which is 76.4% of the base metal. The research shows that the flow of the molten pool is stable, and meanwhile the eruption of the keyhole is weak and showing the periodicity, in the process of “∞” shaped laser scanning welding with filler wire. And the process of “∞” shaped laser scanning welding with filler wire can effectively inhibit weld porosity and improve the welding quality of Al-Li alloy.

Key words: laser scanning welding with filler wire; molten pool characteristics; porosity; tensile strength

Effect of In element on spreadability and micro-interface of Zn15Al5Cu solder YAN Yanfu, LI Chaojun, REN Xiaofei, GU Tianliang (Henan University of Science and Technology, Luoyang, 471000, China). pp 51-55

Abstract: In order to obtain brazing material for copper and aluminum brazing with good performance, Zn15Al5Cu_xIn ($x = 0, 1, 3, 5$) brazing material is prepared by adding different quality In. Through scanning electron microscope (SEM), energy disperse spectroscopy (EDS) and other analytical testing methods, the spreadability of Zn15Al5Cu_xIn solder on Al, Cu plates and the change of interface composition were studied. The results show that the addition of an appropriate amount of In can significantly improve the wettability of Zn15Al5Cu solder on Cu and Al base metals. When the amount of In added is 5%, the Zn15Al5Cu5In solder has the largest spread area on the Al base material, reaching 251 mm², which is 42.6% higher than that of the base solder; When the In addition amount is 3%, the