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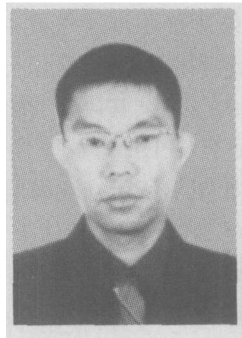
高硬度高耐磨自保护金属芯堆焊焊丝

蒋 [illegible]，　栗卓新，　蒋建敏，　史耀武
(北京工业大学 材料科学与工程学院，北京　100022)



蒋 [illegible]

摘　要：研制一种焊接工艺性能良好的高铬铸铁型自保护金属芯堆焊焊丝，堆焊层硬度大于 60HRC，耐磨性为 Q235钢的 21倍。对其自保护机理进行了研究，当粉芯中金属 Mn含量达到 5%时，可保证焊缝表面不出现气孔，当钛铁含量超过 10%时，焊缝表面出现压坑。堆焊层显微组织为马氏体＋残余奥氏体，在马氏体基体上均匀分布着 M_7C_3 型耐磨硬质相。

关键词：高硬度；高耐磨；自保护金属芯堆焊焊丝
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0 序　言

Fe-Cr-C系耐磨堆焊合金由于硬度高，综合性能好，价格低廉而被广泛应用于耐低应力磨料磨损的工况环境。这种合金的耐磨机制主要靠结晶过程中生成的高硬度初生碳化物 M_7C_3 作为抗磨质点，配合具有较高硬度的过共晶基体实现良好的综合性能。自保护金属芯焊丝代表了当今世界焊接材料发展的方向，日本和美国已把少渣、无渣型金属芯焊丝作为研究和开发的重点之一[1]。由于自保护堆焊焊丝能实现现场焊接以及焊接自动化生产的双重目的，国内外已将其作为一种高效的新型堆焊材料，目前已应用于化工、冶金建筑和机械制造部门。与普通的药芯焊丝和实心焊丝相比，金属芯焊丝具有以下特点：(1) 少渣或无渣。不需清除渣层就可以连续进行多层焊，减少了工人的劳动强度，提高了焊接效率；(2) 熔敷速度快。金属芯焊丝的粉芯中大部分或全部都是金属粉，这必然会大幅度提高焊丝的熔化速度，熔化速度明显高于普通的药芯焊丝和实心焊丝；(3) 品种多、性能好、价格低。金属芯焊丝与普通药芯焊丝的制造方法相同，故兼备药芯焊丝的优点，可以很方便地制造出各种成分的金属芯焊丝，并且能够制造出以实心焊丝的形式不易生产的特殊合金成分的焊丝。作者针对磨煤机磨辊的失效形式，研制了一种焊接工艺性能良好、焊缝成形美观的高硬度高耐磨高铬铸铁型自保护金属芯堆焊焊丝。并对其工艺性能、组织和耐磨性进行了探讨。

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1 试验材料及方法

堆焊焊丝的外皮采用 SPCC低碳冷轧钢带，经多功能焊丝成形机轧制拉拨至 φ2.8mm，用 MZ(D)-1000型多功能焊机施焊，为消除母材影响，在 20mm厚 Q235钢板上连续堆焊三层，在第三层上进行硬度和磨损试验。堆焊工艺参数如表 1所示。用 HR-150A洛氏硬度计测量堆焊层硬度，用 MLS-225型湿式橡胶轮磨粒磨损试验机进行磨损试验。在堆焊层中取 6个 57mm×25mm×5mm磨损试样，磨损试验时，试验参数为橡胶轮转速 240 r/min，橡胶轮直径 178mm，橡胶轮硬度 60HA (邵尔硬度)，载荷 10 kg，磨损时间 250 s，橡胶轮转数约 1 000转，磨料 -40～70目的石英砂。材料的耐磨性能用磨损的失重量来衡量。在试验前、后，将试件放入盛有丙酮溶液的烧杯中，在超声波清洗仪中清洗 3～5min，试验时用 Q235钢作为对比，对比件失重量与测量件失重量之比作为该试样的相对耐磨性。用 PME OLYMPUS TOKYO 金相显微镜观察其组织。

表 1　堆焊工艺参数
Table 1　Hardfacing parameters

电流 I/A	电压 U/V	干伸长 L/mm	焊接速度 v/(cm·min^{-1})
400	30	30	35

固定粉芯中其它成分不变，分别研究粉芯中金属锰和钛铁的含量(质量分数)变化对焊缝成形的影响，每种成分焊丝在 20mm厚 Q235钢板上分别焊一层三道 20 cm长焊缝，焊缝间相互搭接 30%，观察焊缝成形情况。

2 试验结果

高铬铸铁型自保护金属芯堆焊焊丝堆焊熔敷金属的化学成分见表 2。当粉芯中其它成分固定时,5%的金属锰含量可保证高碳高铬自保护金属芯焊丝焊缝表面不产生气孔。当钛铁含量超过 10%时,在焊缝表面会出现压坑。结果见表 3、4。在堆焊层上取六点测试其硬度,测量值见表 5。堆焊层硬度较高,大于 60HRC,且硬度较均匀。堆焊合金的微观组织如图 1所示。堆焊层组织为马氏体+少量残余奥氏体,在马氏体基体上均匀分布着碳化物,为白色六方状 M_7C_3 碳化物。试验结果表明,所研制的自保护金属芯堆焊焊丝经 1 000转磨损后,平均失重量为 0.047 6 g,而在相同条件下 Q235钢的失重量为 1 g。即堆焊层耐磨性为 Q235钢的 21倍。

表 2 堆焊熔敷金属主要化学成分(质量分数,%)

Table 2 Chemical composition of deposited metals

C	Cr	Mn	Si	Ti	B
3.82	27.26	1.28	0.84	0.54	0.68

表 3 粉芯中金属锰含量对焊缝气孔的影响(个)

Table 3 Effect of manganese content on porosity in weld of SSMCW

金属锰含量(%)	焊道 1	焊道 2	焊道 3
1	9	10	8
2	6	5	5
3	4	3	3
4	1	0	2
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

表 4 粉芯中钛铁含量对焊缝压坑的影响(个)

Table 4 Effect of TiFe content on pits in weld of SSMCW

钛铁含量(%)	焊道 1	焊道 2	焊道 3
1	0	0	0
3	0	0	0
5	0	0	0
7	0	0	0
10	0	0	0
13	2	5	3
15	8	11	7
20	15	13	18

表 5 堆焊层的硬度(HRC)

Table 5 Hardness of deposited metals

1	2	3	4	5	6
60.8	61.5	60.6	61.0	60.4	61.0

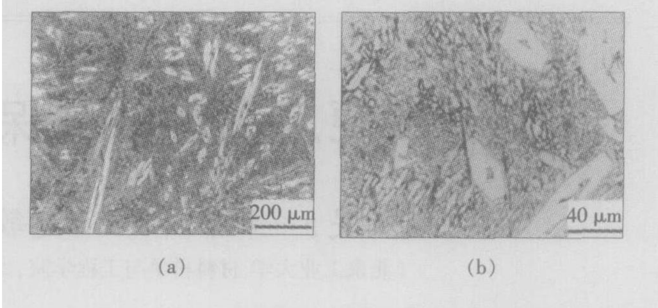

图 1 堆焊合金的微观组织

Fig. 1 Optical micrograph of hardfacing

3 结果分析及讨论

3.1 合金成分对焊缝保护机理的影响

气孔问题是自保护焊丝研制过程中最重要的问题之一,在自保护金属芯堆焊焊丝中,外部无保护气体,焊缝无熔渣保护,且合金成分大,气孔问题就变得尤为突出。

试验研究中发现,粉芯中的金属锰对焊缝中气孔的产生具有决定性的影响,一是因为金属锰的沸点相对较低(2 335 ℃),在焊接电弧温度(3 000 ~5 000 ℃)下,已蒸发为锰蒸气,形成保护气氛,有效阻止有害气体的侵入。二是因为 Mn对 O的亲和力极强,在反应过程中易生成 MnO,浮于熔池表面形成微量熔渣,有效避免了 O对熔池的侵入。

但粉芯中金属锰的过量加入,不仅会使其它合金成分的相对含量降低,还会使焊接烟尘大大增加。因此,在保证焊缝不产生气孔的前提下,应使粉芯中金属锰含量最少。

自保护焊丝中,氮气孔是一个极其重要的问题,由于 Ti与 N的亲和力较强,能在液态熔池中形成 TiN,有效起到脱氮,防止氮气孔产生的作用。但当 Ti的加入过量时,会使焊缝表面形成的微量熔渣的粘度、表面张力变大,透气性变差,从熔池中排出的气体成气泡状停留在液态金属表面与液态熔渣之间的界面上,不能及时冲出熔渣层。为达到力的平衡,气泡内的气体要向四周施以一定的压力,气泡压力愈大留在金属表面上的压痕愈深。随着熔池的冷却凝固,熔渣的粘度、表面张力减小,气泡得以逸出,但此时已在金属凝固表面上形成了压痕。所以,既要防止焊缝出现氮气孔,又要避免焊缝出现压坑,必须把粉芯中 Ti的含量控制在一个合适的范围内。

熔滴在焊丝端部形成到过渡到熔池的过程中,由于熔滴温度很高,对气体的溶解度大大增加,在熔滴过渡无保护的情况下,会将一部分气体带入到熔

池中。粉芯中含有一定量的硅铁、硼铁,在焊接电弧热的作用下,合金中的 B、Si与氧气亲和力比较大,在熔滴过渡时或在熔池中发生强烈的氧化还原反应生成氧化硼与氧化硅,氧化硼和氧化硅化合生成一种低熔点的硼硅酸盐类化合物[2]。这种化合的氧化硼和氧化硅再与其它氧化物发生反应形成硼硅酸盐玻璃状的复杂化合物,包覆着金属液滴,保护熔滴的过渡,并在熔池的强烈搅拌下浮到熔池的液体金属表面形成一层极薄的均匀保护膜,阻止了空气中氧气、氮气等有害气体的渗入,从而保护焊缝金属。

3.2 堆焊层显微组织分析

堆焊层化学成分对其组织及性能有着极其重要的影响[3],如碳化物的体积分数、形状、尺寸、分布形式,以及基体的组成类型等。

所研制堆焊焊丝堆焊层的高硬度和良好的耐磨性是由其显微组织决定的,如图 1所示,堆焊层组织为马氏体 +少量残余奥氏体 +碳化物。在隐针马氏体和少量奥氏体的基体上分布着白色初生碳化物 M_7C_3。这些初生碳化物横截面大致呈六角形,其中六方状碳化物为垂直于磨损面生长,横截面硬度为 1 500 ~1 700 HV,长条状为平行于磨损面或无定向生长,截面硬度一般只有 1 100 ~1 200 HV,它们是 Fe-Cr-C系耐磨堆焊合金中的最主要的耐磨硬质相。由图可见,在堆焊层组织中,碳化物多为垂直于磨损面生长,只有少部分为无定向生长。

M_7C_3 硬质相主要起抗磨损的骨架作用,韧性较好的基体在提高抗裂纹形成和扩展能力的同时,对硬质相还起到可靠的支撑作用。因此,硬质相和基体的良好匹配能够有效地阻碍冲蚀磨粒的切削,从而获得高的耐磨损性能[4]。奥氏体和马氏体所形成的混合组织,是一种理想的耐磨基体[5]。如果是单一的奥氏体基体,则在磨损过程中,基体会发生很大的弹性变形,表面却由于加工硬化而发生断裂;而单一的马氏体基体,由于韧性不足,对碳化物的保护能力不够,在磨损过程中易发生碳化物的脆断和剥落。

由于硬质相的硬度大大高于周围基体,因而在磨料磨损的切向应力作用下,在硬质相与基体之间的界面区,容易产生位错塞积和较大的塑性变形。当应力值达到某一临界值时,将导致裂纹的萌生和扩展,使硬质相从基体剥离导致磨损[6]。因此,硬质相的尺寸、分布和形态对微裂纹的产生和扩展起着重要的作用。如果硬质相细小或呈杆状均匀分布,即碳化物生长方向垂直于磨损面,那么在其界面处形成裂纹所需的应力集中就较大,硬质相颗粒就不易脱离基体。相反,如果硬质相呈较大的长条形叶片状,则其周围易形成严重的应力集中,使硬质相脱离基体,导致耐磨性能下降。

由此可见,获得细小均匀分布的杆状硬质相有助于提高高铬合金堆焊层的耐磨性。这一方面要严格控制堆焊工艺,如热输入不能太大和高温停留时间不能过长等,限制硬质相 M_7C_3 碳化物的过分长大。

4 结 论

(1) 所研制的高铬铸铁型自保护金属芯堆焊焊丝焊接工艺性能良好,无气孔产生。当粉芯中金属锰含量达到 5% 时,可防止焊缝表面产生气孔,钛铁含量小于 10%时,可防止焊缝表面产生压坑。堆焊层硬度 > 60 HRC,耐磨性为 Q235钢的 21倍。

(2) 所研制的高铬铸铁型自保护金属芯堆焊焊丝堆焊层显微组织为马氏体 +少量残余奥氏体,在马氏体基体上均匀分布着白色六方状 M_7C_3 碳化物。

(3) 碳化物 M_7C_3 为堆焊层中最主要的耐磨硬质相,与基体的良好配合使得堆焊层具有高硬度和高耐磨性。

参考文献:

[1] 张文钺. 国外焊接材料的发展动态及加快国产药芯焊丝发展的建议[J]. 材料开发与应用, 2000, 14(2): 30-34.

[2] 汪中玮, 张清辉. 硅硼系无渣堆焊焊条在工业生产中的应用[J]. 焊接技术, 2002, 30(4): 43-44

[3] Zumelzu E, Goyos I, Cabezas C, et al. Wear and corrosion behaviour of high chromium (14% ~30% Cr) cast iron alloys[J]. Journal of Materials Processing Technology, 2002, 128: 250-255.

[4] Dwivedi D K. Microstructure and abrasive wear behaviour of iron base hardfacing[J]. Materials Science and Technology, 2004, 20(4): 1326-1334

[5] Dogan O N, Alman D E, Hawk J A. P/M Fe/Cr/TiC composites: Processing, microstructure and abrasive wear behavior[J]. Advances in Powder Metallurgy and Particulate Materials, 2001, 25(4): 2057-2073

[6] Matsubara Y, Sasaguri N, Shimizu K, et al. Solidification and abrasion wear of white cast irons alloyed with 20% carbide forming elements[J]. Wear, 2001, 250-251(1): 502-510.

作者简介:蒋[illegible] 男, 1977年 9月出生,博士研究生。研究方向为焊接材料研究,发表论文 5篇。

Email: jm0813@emails.bjut.edu.cn

tallic compound

Experimental study on operative performance of high cellulose covered electrode for pipe welding LIU Hai-yun[1,2], LI Zhuo-xin[1], SHI Yao-wu[1] (1. School of Material Science and Engineering, Beijing University of Technology, Beijing 100022, China; 2. College of Material Science and Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, China). p57 – 60

Abstract: Based on SiO_2-TiO_2-MgO-FeO slag system, a great deal of operative performance experiments for high cellulose covered electrode were carried out. The feature of metal transfer of the electrode was revealed. The results showed that operative performance in the vertical down welding can be improved through fine droplet, increasing chemical reactive heat in arc area, raising arc blow force. Using sodium water glass with super low mode, carbonization and press coating problems during manufacture can be solved.

Key words: high cellulose covered electrode; operative performance; pipe welding

Improving corrosion resistance of low carbon steel welded joint by magnetic treatment LIN Jian, ZHAO Hai-yan, CAI Zhi-peng, LIU An-li, WU An-na, YAN Dong-yang (Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China). p61 – 64, 68

Abstract: The effect of magnetic treatment on corrosion resistance of low carbon steel joint was studied. The experiment showed that the etching rating can be reduced by magnetic treatment at a relative level of 2.58%. A finite element analysis was carried out for predicting the residual stress that influenced the corrosion resistance of joint. In addition, a significance test for the change of the etching rating after magnetic treatment was performed. It showed that the change of the etching rating after treatment is out of the range of experimental error with the significance coefficient of 5%. It could be concluded that the corrosion resistance of low carbon steel joint can be improved by magnetic treatment with a significance level of 5%.

Key words: magnetic treatment; etching rating; weld residual stress; numerical simulation; significance test

Friction stir welding of 2219-O aluminum alloy CHEN Ying-chun, LIU Hui-jie, FENG Ji-cai (State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p65 – 68

Abstract: 2219-O aluminum alloy was friction stir welded to investigate the effect of friction stir welding on its microstructure and mechanical properties in this paper. The microstructures of different zones in the joint were analyzed by optical microscopy, and the mechanical properties of the joint were evaluated by means of tensile tests. Microstructural analyses indicated that the weld nugget zone (WNZ) is composed of fine isometric grains because of continuously dynamic recrystallization, and more precipitates formed in this zone. In the thermal mechanical affected zone (TMAZ), the grains have experienced incomplete recrystallization due to seriously plastic deformation, and some small grains begin to nucleate. In the heat affected zone (HAZ), all the grains are coarsened. Tensile tests showed that the tensile strength of the joint is the same as that of the base metal, and the fracture occurs in the base metal when the tool rotation speed was 800 rpm and the welding speed was less than 400 mm/min. On the other hand, when the welding speed was greater than 400 mm/min, the mechanical properties of the joint significantly degrade and the joint fractures at the defect location because of the formation of a defect in the WNZ.

Key words: friction stir welding; aluminum alloy; microstructural characteristics; mechanical properties

Self-shielded metal cored wire for hardfacing with high hardness and abrasion resistance JIANG Min, LI Zhuo-xin, JIANG Jian-min, SHI Yao-wu (School of Material and Engineering, Beijing University of Technology, Beijing 100022, China). p69 – 71

Abstract: The high chromium cast iron type self-shielded metal cored wire (SSMCW) for hardfacing with good operative performance and appearance was developed. The hardness of deposited metal exceeds HRC60, and the wearing resistance is 21 times higher than that of Q235 steel. The mechanism of self-shielding was researched. When manganese content arrives at 5wt% in wire, porosity can be avoided, while TiFe content exceeds 10wt%, pits will appear in the weld of SSMCW. The microstructure of deposited metal consists of martensite and a little residual austenite, and the abrasive resistant hard phase M_7C_3 distributes uniformly in martensite matrix.

Key word: high hardness; high abrasion resistance; self-shielded metal cored wire for hardfacing

Correlation of acoustic signals and weld depth in laser welding LIU Jing-lei[1,2], CHEN Yan-bin[2], XU Qing-hong[2] (1. School of Mechanical and Power Fngineering, East China University of Scicnce and Technology, Shanghai 200237, China; 2. School of Material Science and Engineering, Harbin Institute of Technology, Harbin 150001, China). p72 – 75, 80

Abstract: Laser welding is accompanied with a strong acoustic signal, which contains a considerable amount of information on the welding process and indicates certain aspects of weld quality. The characteristics of weld acoustic signal during laser cladding were analyzed in details. The intensity and power spectrum components of acoustic signals were found to be a match for the weld depth. The dominant power spectra covered by the experimental set up ranged from 2 to 10 kHz, where several obvious spectrum lines were detected. The amplitude of acoustic signals decreases and the acoustic power spectrum lines change from intensive and simple to