焊剂带在超窄间隙电弧区的位置与约束电弧的关系

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摘 要：当超窄间隙中用于约束电弧的焊剂带与电弧具有不同的相对位置时，焊剂带会对电弧产生不同的约束效果，因而焊剂带在电弧区的位置是约束电弧的关键。通过分析焊剂带在电弧区的位置，结果表明焊剂带在电弧区有效约束电弧应满足三个位置条件，即在电弧横向焊剂带应紧贴两侧壁；在电弧长度方向焊剂带应具有合适的焊剂带作用长度；在超窄间隙纵向焊丝端头应与焊剂带中心线对中。此外，当焊接电流大于240A时，焊剂带易在电磁力作用下紧贴焊丝表面而造成电弧攀升，采用撑开焊剂带的方法可有效控制焊剂带在电弧横向的位置。

关键词：焊剂带约束电弧；超窄间隙焊接；焊剂带位置
中图分类号：TG444.7 文献标识码：A 文章编号：0253－360X（2011）01－0013－03

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0 序 言

超窄间隙焊接时电弧很不稳定，易沿间隙侧壁向上攀升[1]。Nakamura利用研制的控制装置使焊丝固液端头沿间隙上下周期性运动，从而可防止电弧攀升，但在焊接过程中电弧的阴极斑点仅分布于间隙两侧壁加热，而间隙底部不能被有效加热，以致上下两道焊缝交界处未熔合[2,3]。通过向超窄间隙中电弧的两侧连续送入焊剂带以约束电弧的方法，不仅有效解决了电弧易沿间隙侧壁向上攀升的问题，而且还可有效控制电弧的加热区，从而获得了成形良好的超窄间隙焊缝[3]。然而，试验发现焊剂带在电弧区的位置是约束电弧的关键[4]，要想实现稳定、可靠的超窄间隙焊接，就必须有效控制焊剂带在电弧区的位置，因此有必要深入认识焊剂带在电弧区的位置与约束电弧的关系。

结合焊剂带约束电弧超窄间隙焊接的特点，分析了焊剂带在电弧横向、电弧长度方向和超窄间隙纵向的位置对约束电弧的影响，得到了焊剂带在电弧区可有效约束电弧的三个位置条件。

1 焊剂带在超窄间隙电弧横向的位置

在焊接参数确定的条件下，如图 1a所示，接近电弧处的两侧焊剂带应紧贴侧壁，这样才能确保在电弧将焊剂带熔化的前提下，电弧直接加热到未被焊剂带所覆盖的间隙侧壁部位，从而使焊剂带起到有效防止电弧沿侧壁发生攀升的作用。如图 1b所示，若焊剂带与电弧中心距离 d过小，则焊剂带与侧壁间将存在较大的间隙，这时电弧将在无须熔化焊剂带的情况下，直接进入焊剂带与侧壁间形成的间隙内对侧壁加热，以致焊剂带无法对电弧起到有效约束的作用而使电弧沿侧壁发生攀升。

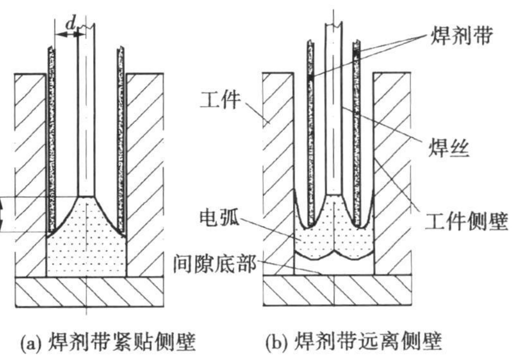

图 1 焊剂带在超窄间隙电弧横向的位置
Fig. 1 Position of flux strips in traverse orientation of arc of ultra_narrow gap

流经电弧的电流所产生的磁场是影响焊剂带在超窄间隙电弧横向位置的主要因素。由于焊剂带的独特结构，即中间为薄钢带，薄钢带两面为涂敷的焊

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剂，所以在流经电弧区的电流所产生的磁场作用下，电弧两侧的焊剂带会被吸引而贴在焊丝表面，以致焊剂带与侧壁间形成较大间隙而使电弧发生攀升．为了确定磁场对焊剂带在电弧横向位置的影响，采用图 2所示试验装置对不同电流所对应的单侧焊剂带偏移量 δ进行了测量．如图 2所示，在两条焊剂带的内表面距离为 W_d的情况下，以铜丝代替焊丝并使铜丝与工件表面接触，这样可使铜丝在短时间内通以较大电流时不致形成电弧，从而便于测量．焊剂带端头与工件表面留有约 1 mm的间隙，给铜丝通以不同大小的电流，就能测得不同大小的电流所对应的单侧焊剂带偏移量 δ．每次给铜丝的通电时间约为 3~4 s．表 1和表 2分别为在平板表面和超窄间隙内测得的单侧焊剂带偏移量 δ，其中表 1的 $W_d = 7$ mm，表 2的 $W_d = 4$ mm，所用焊剂带厚度为 0.6~0.8 mm．由表 1可以看出，能够使位于平板表面的焊剂带贴在焊丝表面的最小焊接电流约为 220 A．由表 2可以看出，能够使位于超窄间隙中的焊剂带贴在焊丝表面的最小焊接电流约为 240 A．这表明由于超窄间隙两侧的工件对焊剂带产生了磁

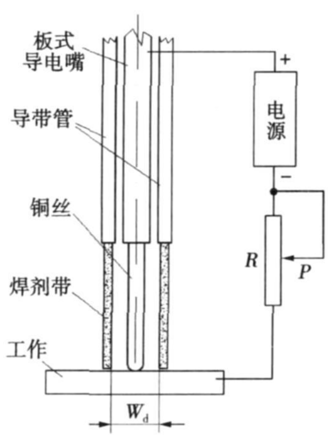


图 2 磁场对焊剂带在电弧横向位置影响的试验装置

Fig. 2 Experiment instrument for influence of magnetic field on position of flux strips in traverse orientation of arc

表 1 平板表面单侧焊剂带偏移量

Table 1 Displacement of single flux strip on plate

电流 I/A	单侧焊剂带偏移量 δ/mm
150	0.5
190	0.9
210	1.4
220	焊剂带紧贴焊丝表面
230	焊剂带紧贴焊丝表面
300	焊剂带紧贴焊丝表面

表 2 超窄间隙中单侧焊剂带偏移量

Table 2 Displacement of single flux strip in ultra_narrow gap

焊接电流 I/A	单侧焊剂带偏移量 δ/mm
144	0
176	0
220	0
240	焊剂带紧贴焊丝表面
260	焊剂带紧贴焊丝表面
300	焊剂带紧贴焊丝表面

屏蔽作用，从而减小了电磁场对焊剂带的吸引力，所以在其它条件相同的情况下，超窄间隙中能够使焊剂带贴在焊丝表面的最小电流要比平板表面的大．

实际上，适合于焊剂带约束电弧超窄间隙焊接的电流范围为 240~260 A[4]，由表 2可知在这一焊接电流范围内焊剂带易被吸引而贴在焊丝表面，从而导致电弧发生攀升．为了防止焊剂带被电磁力吸引而导致电弧攀升，采用图 3所示撑开焊剂带的方法可有效保证焊剂带紧贴间隙侧壁．

如图 3所示，β为板式导电嘴上的两楔形面夹角，L_1为焊剂带与板式导电嘴的接触点 B距导带管口 A的距离，通过减小 L_1使焊剂带被撑开，并在间隙两侧壁的限制下使 B点与 C点间的焊剂带受力而紧贴侧壁，因此只有在电磁场对焊剂带的吸引力大于 BC段焊剂带的弹性变形力时焊剂带才能贴在焊丝表面．

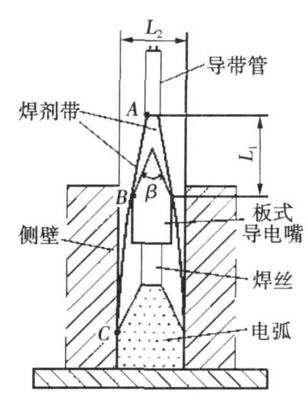


图 3 焊剂带撑开示意图

Fig. 3 Schematic diagram of supporting flux strips

结果表明，当采用该方法使焊剂带被撑开后，在 220~280 A的电流范围内，焊剂带都能紧贴侧壁表面而不致被电磁场吸引而贴在焊丝表面．可见，采用撑开焊剂带的方法可有效限制焊剂带在电弧横向的位置，完全避免因焊剂带被电磁力吸引而贴在焊丝表面所导致的电弧攀升．

2 焊剂带在超窄间隙弧长方向的位置

在电弧的长度方向，如图 1a所示，进入间隙的焊剂带尽管较长，但对电弧起约束作用的仅为与电弧接触的焊剂带作用长度 l_c，只要焊剂带作用长度 l_c > 0即可对电弧具有约束作用，所不同的仅仅是电弧的受约束程度．为了保证电弧对间隙三个方向的有效加热，尤其是对侧壁根部的有效加热，如图 4所示，在其它焊接参数确定的情况下，通过增加焊剂带的送进速度，使焊剂带熔化端头的位置由 D点移动到 E点，即焊剂带作用长度 l_c增加到一合适的长度范围，因而电弧直接加热侧壁的高度也将由 h_m 减小到 h_n，从而使电弧被约束在间隙底部的一定空间范围内对间隙的三个方向有效加热．反之，若焊剂带作用长度 l_c较短，此时尽管电弧也不易发生攀升，但电弧的阴极斑点将集中分布于间隙两侧壁，因而电弧对间隙底部无法有效加热，以致上下两道焊缝交界处明显未熔合；若焊剂带作用长度 l_c过长，则电弧直接加热侧壁的高度为零，以致电弧加热不到侧壁而出现侧壁熔合不良[4]．由此可知，在电弧长度方向焊剂带必须形成合适的作用长度 l_c．

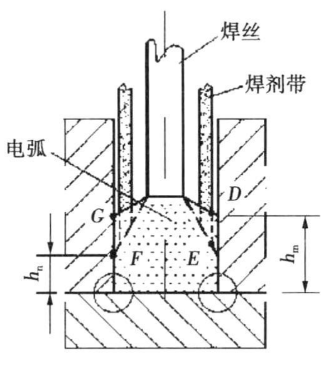
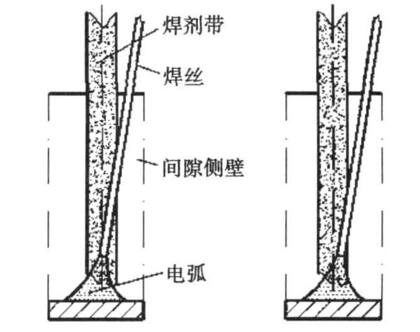


图 4　焊剂带约束电弧示意图

Fig. 4　Schematic diagram of flux strips constricting arc

3 焊剂带在超窄间隙纵向的位置

为了能够撑开焊剂带以控制焊剂带在电弧横向的位置，如图 5a所示，焊剂带与焊丝间应形成一夹角，这样就可在利用图 3所示焊剂带撑开方法时，导带管管口下端不与焊丝发生干涉．图 5a即为电弧约束良好时焊剂带与焊丝在超窄间隙纵向应具有的相对位置，此时焊丝端头与焊剂带中心线对中；图 5b为电弧约束不良时焊剂带与焊丝在超窄间隙纵向的相对位置，此时焊丝端头偏离焊剂带中心线，因而焊剂带对电弧的约束效果减弱，电弧易沿侧壁发生攀升．在实际焊接过程中，由于弧长的波动和焊剂带定位误差的影响，在超窄间隙纵向焊丝端头一般都要偏离焊剂带中心线，只不过由于偏离的程度很小，所以焊剂带能够对电弧产生良好的约束作用．可见，焊剂带在超窄间隙纵向能够有效约束电弧的条件为焊丝端头与焊剂带中心线应对中．此外，采用尽量宽的焊剂带，即在确保电弧将焊剂带完全熔化的前提下，通过增加焊剂带的宽度，可减小因焊丝端头偏离焊剂带中心线所导致的电弧攀升倾向．



(a) 焊丝端头与焊剂带中心线对中　(b) 焊丝端头偏离焊剂带中心线

图 5　焊剂带在超窄间隙纵向的位置

Fig. 5　Position of flux strips in lengthways orientation of arc of ultra_narrow gap

4 结　论

（1）焊剂带在电弧区的位置是约束电弧的关键，在进行焊剂带约束电弧超窄间隙焊接时，焊剂带在电弧区应满足三个位置条件，即在电弧横向焊剂带应紧贴两侧壁；在电弧长度方向焊剂带应具有合适的焊剂带作用长度；在超窄间隙纵向焊丝端头应与焊剂带中心线对中．

（2）能够使位于超窄间隙中的焊剂带贴在焊丝表面的最小焊接电流约为 240 A．在电弧横向采用撑开焊剂带的方法，可有效防止因焊剂带被电磁力吸引而贴在焊丝表面所导致的电弧攀升．

参考文献：

[1] Zhu Liang, Zheng Shaoxian, Chen Jianhong. Development of ultra_narrow gap welding with constrained arc by flux band[J]. China Welding, 2006, 15(2): 44－49.

[2] Nakamura T, Hiraoka K. Ultra_narrow GMAW process with newly developed wire melting control system[J]. Science and Technology of Welding and Joining, 2001, 6(6): 355－362.

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裂纹.

(4)对于新型耐热钢,焊后应采用适当方法降低焊接残余应力,以减少应力集中对材料焊接接头处的损伤.

参考文献:

[1] Allen D J, Harvey B, Brett S J. Four crack-an investigation of the creep performance of advanced high alloy steel welds[J]. International Journal of Pressure Vessels and Piping, 2007, 84(1-2): 104-113.

[2] Takashi Watanabe, Masaaki Tabuchi, Masayoshi Yamazaki, et al. Creep damage evaluation of 9Cr-1Mo-V-Nb steel welded joints showing type Ⅳ fracture[J]. International Journal of Pressure Vessels and Piping, 2006, 83(1): 63-71.

[3] Francis J A, Mazur W, Bhadeshia H K D H. Type Ⅳ cracking in ferritic power plant steels[J]. Materials Science and Technology, 2006, 22(12): 1386-1395.

[4] 张国栋, 薛吉林, 周昌玉. 基于正交试验设计的高温管道焊接工艺优化[J]. 焊接学报, 2008, 29(11): 53-56.
Zhang Guodong, Xue Jilin, Zhou Changyu. Optimization on welding procedure of high temperature pipeline based on orthogonal test design[J]. Transactions of the China Welding Institution, 2008, 29(11): 53-56.

[5] 王崇斌, 徐 沁. 亚临界和超临界锅炉高温过热器用 NF616 钢性能[J]. 锅炉技术, 1995, 26(12): 13-20.
Wang Chongbin, Xu Qin. Properties of NF616 steel in HT superheater of sub-critical and super-critical boilers[J]. Boiler Technology, 1995, 26(12): 13-20.

[6] 蒋文春, 巩建鸣, 唐建群, 等. 焊接残余应力下氢扩散的数值模拟[J]. 焊接学报, 2006, 27(11): 57-60, 64.
Jiang Wenchun, Gong Jianming, Tang Jianqun, et al. Numerical simulation of hydrogen diffusion under welding residual stress[J]. Transactions of the China Welding Institution, 2006, 27(11): 57-60, 64.

[7] 乔亚霞, 武英利, 徐联勇. 9%-12% Cr高等级耐热钢的Ⅳ型开裂研究进展[J]. 中国电力, 2008, 41(5): 33-36.
Qiao Yaxia, Wu Yingli, Xu Lianyong. Research progress on type Ⅳ cracking of 9%~12% Cr high-grade heat-resisting steel[J]. Electric Power, 2008, 41(5): 33-36.

[8] 王红鸿, 张汉谦, 孙 咸. 9% Cr-1% Mo耐热钢焊缝金属显微组织特征解析[J]. 焊接学报, 2008, 29(9): 91-95.
Wang Honghong, Sun Hanqian, Sun Xian. Analysis of microstructure characteristic of 9% Cr-1% Mo heat resistant steel weld metal[J]. Transactions of the China Welding Institution, 2008, 29(9): 91-95.

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[3] 郑韶先, 朱 亮, 张旭磊, 等. 焊剂带约束电弧在超窄间隙中的加热特性[J]. 焊接学报, 2008, 29(5): 57-60.
Zheng Shaoxian, Zhu Liang, Zhang Xulei, et al. Heating characteristic of constricting arc with flux strips in ultra-narrow gap welding[J]. Transactions of the China Welding Institution, 2008, 29(5): 57-60.

[4] 郑韶先, 朱 亮, 黄斌维, 等. 焊剂带约束电弧用于超窄间隙的焊接[J]. 机械工程学报, 2009, 45(2): 219-223.
Zheng Shaoxian, Zhu Liang, Huang Binwei, et al. Constricted arc by flux strips applied to ultra-narrow gap welding[J]. Chinese Journal of Mechanical Engineering, 2009, 45(2): 219-223.

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MAIN TOPICS, ABSTRACTS & KEYWORDS

Research and development of a new submerged arc welding wire for X100 pipeline steel ZHANG Min, LÜ Jinbo, WANG Chao, LI Jihong (School of Material Science and Engineering, Xi'an University of Technology, Xi'an 710048, China). p 1—4, 8

Abstract: According to the nucleate mechanics of acicular ferrite and bainite in high strength low alloy steels (HSLA) welded deposit, Mn-Ni-Mo-Cr was chosen as main alloy elements and Ce, Ti, B as micro-alloy elements which accelerate the nucleate of acicular ferrite. The content of C, Si, P, S, N elements was reduced and C to be the level of ultra-low carbon to meet the large energy input welding, and to ensure the content of Mn, Mo, Cr to compensate for intensity loss brought by reduced C, Si. By in addition, Ti and B were added to avoid producing excessive acicular ferrite which would reduce the intensity or cause segregation of alloy elements to decrease the toughness of weld joint and proper Cu to enhance the ability of weld joint to resist the atmospheric corrosion. As the results, the developed welding wire matching flux SJ101-G, had the microstructure of deposited metal was acicular ferrite and lath bainite mainly in which a small amount of granular bainite precipitated and dispersed.

Key words: SAW; acicular ferrite; granular bainite; strength and toughness

Microstructure and high-temperature wear-resistance of nitrogen-alloying hardfacing alloy YANG Ke[1,2], YU Shengfu[3], YANG Hua[4] (1. College of Mechanical and Electrical Engineering, Hehai University, Changzhou, Jiangsu 213022, China; 2. Province Key Lab of Advanced Welding Technology, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu 212003, China; 3. College of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China; 4. Shanghai Jihaowang Shipbuilding Technology Development Co., Ltd, Shanghai 200136, China). p 5—8

Abstract: The hardfacing alloy of martensitic stainless steel added nitrogen as alloying element was made, and the microstructure and high-temperature wear-resistance was also studied. It is found that the hardfacing alloy has two main phases of martensite and carbonitrides. The high-temperature wear mechanism between hardfacing alloy of the martensitic stainless steels and the low-carbon steel was abrasive wear because the effect of oxide formation on the surface of the low-carbon steel. The oxide was sticking on the surface of hardfacing alloys and increasing the abrasive wear damage. The results showed that carbonitride particles distributed homogeneously in the hardfacing alloy and had a good strengthening effect on the hardness and high-temperature wear resistance.

Key words: martensitic stainless steel; hardfacing alloy; carbonitride; high-temperature wear

Effects of rare earth Ce on microstructures of Ag30CuZnSn-3Ga-2In filler metal LAI Zhongmin[1], WANG Jianxin[1], LIU Fangyan[2] (1. Province Key Lab of Advanced Welding Technology, Jiangsu University of Science and Technology, Jiangsu Zhenjiang 212003, China; 2. Lucas Milhaupt (Suzhou) Co., Ltd, Jiangsu Suzhou 215122, China). p 9—12

Abstract: The cadmium-free silver filler metal Ag30CuZnSn-3Ga-2In has excellent comprehensive property. In this paper, the effects of rare earth, called usually "vitamin" of metals, Ce on microstructures of Ag30CuZnSn-3Ga-2In filler metal were studied. Results showed that the rare earth Ce did not dissolve into Ag based solid solution and Cu based solid solution, but could form rare earth phase which acted as the particle of "out-of-phase nucleation" in the filler metal matrix. Enrichment phenomena could be confirmed for rare earth Ce in the grain boundary. It is found that rare earth Ce can fine grain, strengthen grain boundary and exhibit the formation of Cu_6Sn_5 for the silver filler metals bearing Ga and In. It is found that adding 0.1% rare earth Ce can improve the microstructure of the Ag30CuZnSn-3.0Ga-2.0 filler metals greatly.

Key words: rare earth Ce; silver filler metal; microstructure; out-of-phase nucleation

Relationship between position of flux strips in arc zone of ultra-narrow gap and constricting arc ZHENG Shaoxian[1], ZHU Liang[1], CHEN Jianhong[2] (1. School of Mech-Electronic Technology, Lanzhou Jiaotong University, Lanzhou 730070, China; 2. State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China). p 13—15, 20

Abstract: When flux strips applied to constrict arc have different relative positions with arc in ultra-narrow gap, flux strips can cause different constricting effects on arc, so the position of flux strips in the arc zone is the linchpin of constricting arc in time of ultra-narrow gap welding with flux strips constricting arc. By analyzing the position of flux strips in the arc zone, the results indicate only when three positional conditions are satisfied, flux strips can efficiently constrict arc: firstly flux strips need cling to sidewalls in the direction of radial of arc; secondly flux strips need proper action length in the direction of arc length; thirdly the tip of wire needs be located in the center of flux strips. Furthermore, under arc current exceeds 240 A, flux strips can easily cling to the surface of wire because of action of electromagnetic force, the position of flux strips in the direction of radial of arc can be located efficiently by supporting flux strips.

Key words: flux strips constricting arc; ultra-narrow gap welding; position of flux strips

Effect of welding residual stress on type IV creep failure of P92 steel JIANG Yunjian[1,2,3], JING Hongyang[1,2], XU Li-