耦合电弧钨极 GPCA-TIG 焊工艺

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摘 要: 将耦合电弧钨极和 GPCA 焊方法结合，形成了耦合电弧钨极 GPCA-TIG 焊方法，该方法可实现深熔深高速焊接. 对比分析了在较高焊接速度时常规 TIG 焊、耦合电弧钨极 TIG 焊和耦合电弧钨极 GPCA-TIG 焊的焊缝表面成形和截面形貌，发现耦合电弧钨极 GPCA-TIG 焊可避免咬边和驼峰焊道的产生，并且焊缝熔深有所增加. 耦合电弧钨极 GPCA-TIG 焊工艺试验表明，焊缝熔深和熔宽随焊接速度的减小和外喷嘴位置的升高而增大，随着弧长和外层氧气流量的增加先增加后略有减小; 随着焊接速度的减小，弧长和外层氧气流量的增大，焊缝咬边减轻，外喷嘴相对高度变化时焊缝均未出现咬边.

关键词: 耦合电弧钨极; GPCA 焊; 焊缝成形; 咬边; 驼峰焊道
中图分类号: TG444 **文献标识码:** A **文章编号:** 0253-360X(2014)03-0019-04

0 序 言

钨极氩弧焊(TIG)是一种应用非常广泛的高品质焊接方法，该方法焊接过程稳定、焊缝成形良好，但也存在熔敷效率低、焊缝熔深小、焊接速度慢的缺点，制约了其在高效焊接生产中的应用[1]. 而简单地通过提高焊接电流并不能实现稳定的高速度、大熔深焊接. 焊接速度的提高会导致焊缝成形差，由于电弧压力较大，出现咬边及驼峰焊道等缺陷[2].

文中提出一种新的焊接方法——耦合电弧钨极 GPCA-TIG 焊，将耦合电弧钨极和 GPCA 焊相结合，可实现深熔深高速度焊接. 该方法的特点在于使用了耦合电弧钨极，这种钨极类似于空心钨极[3]和双钨极[4]，可明显减小电弧压力，改善高速焊接成形. GPCA 焊(gas pool coupled activating welding)是一种双层气体焊方法，焊枪内层气体为惰性保护气体，外层气体为含活性元素 O 的活性气体，通过调节内外喷嘴的相对高度，改变外层活性气体与熔池金属的耦合程度，控制熔池金属中活性元素的引入区域和引入量[5]. 活性元素 O 的引入可通过改变熔池金属表面张力温度系数改变液态金属 Marangoni 对流方向，增加熔深[6]，同时还可减小熔池金属表面张力，改善焊缝表面成形[7].

耦合电弧钨极 GPCA-TIG 焊方法综合了耦合电弧钨极和 GPCA 焊的优点. 耦合电弧钨极与空心钨极相比，加工更方便，成本更低; 与双钨极相比，所需焊接设备少，焊枪更紧凑. GPCA-TIG 焊与 A-TIG 焊方法相比，省去了手工涂覆活性剂工序，便于实现生产自动化，同时可实时通过焊枪细调外层气体与熔池的耦合度，便于工程应用.

文中将耦合电弧钨极 GPCA-TIG 焊应用于不锈钢 TIG 焊，与常规 TIG 焊比较，研究了各主要焊接工艺参数对焊缝表面成形和熔深熔宽的影响，这对于推动该方法的研究和应用具有重要的意义.

1 试验方法

采用耦合电弧钨极 GPCA-TIG 焊接方法，进行工件表面熔焊，使用自行设计的 GPCA-TIG 焊枪和耦合电弧钨极，内层保护气体为氩气，外层活性气体为氧气，试板选用 SUS304 奥氏体不锈钢板，板厚为 5 mm. 定义焊枪外喷嘴出口边缘位置高于内喷嘴出口边缘位置时为正值，反之为负值. 基础焊接工艺参数如表 1 所示，内外喷嘴相对位置关系如图 1a 所示. 每组试验中，将所关注的工艺参数作为变量，其它参数保持不变. 耦合电弧钨极如图 2 所示.

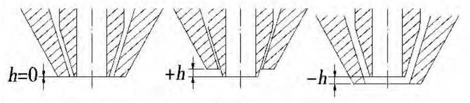
焊前清除试板表面油污，焊后拍照记录焊缝表面成形，待试板冷却，取样、打磨、腐蚀，观察焊缝截面形貌. 文中比较了常规 TIG 焊、耦合电弧钨极 TIG 焊和耦合电弧钨极 GPCA-TIG 焊的焊缝表面成形和截面形貌，并研究了各个焊接参数的变化对焊缝表

收稿日期: 2013-07-01
基金项目: 甘肃省自然科学基金资助项目(1010RJZA037); 国家自然科学基金资助项目(51265029)

表1 耦合电弧钨极 GPCA-TIG 焊基础工艺参数

Table 1 Basic parameters of coupling arc electrode GPCA-TIG welding

焊接电流 I/A	焊接速度 v/(mm·min^{-1})	钨极直径 d/mm	钨极伸出长度 L_1/mm	弧长 L_2/mm	内层氩气流量 q_1/(L·min^{-1})	外层氩气流量 q_2/(L·min^{-1})	外喷嘴高度 h/mm
280	500	3.2	3	5	10	10	+2

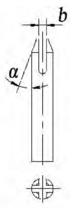


(a) 内外喷嘴位置示意图

(b) 焊枪实物图

图1 GPCA-TIG 焊枪

Fig. 1 GPCA-TIG welding torch

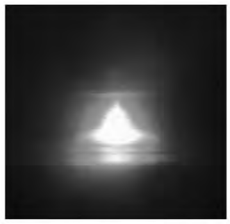


(a) 耦合电弧钨极示意图

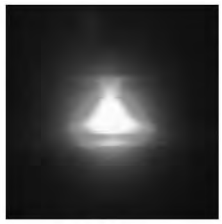
(b) 耦合电弧钨极实物图

图2 耦合电弧钨极

Fig. 2 Coupling arc electrode



(a) 常规 TIG 焊



(b) 耦合电弧钨极 TIG 焊

图3 电弧形态

Fig. 3 Arc shape

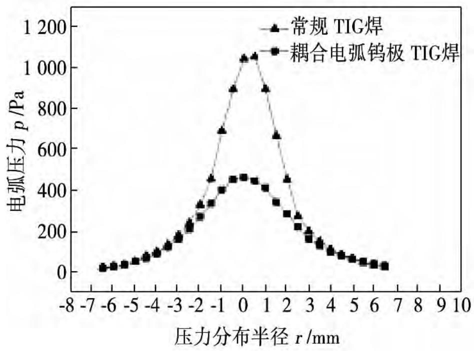


图4 耦合电弧钨极 TIG 焊与常规 TIG 焊电弧压力比较

Fig. 4 Comparison of arc pressure between coupling arc electrode TIG welding and traditional TIG welding

面成形和截面形貌的影响规律.

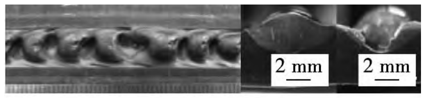
2 试验结果及分析

2.1 电弧形貌

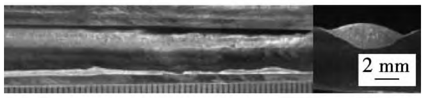
图3是耦合电弧钨极TIG焊和常规TIG焊的电弧形态. 耦合电弧钨极的四根小电极起弧以后,由于电磁力的作用而相互吸引,导致电弧在四根小电极的内侧燃起,并沿内侧向上攀爬,电弧顶部截面积较常规TIG焊电弧增大,而下底面截面积没有明显变化,这使得电磁力导致的轴向推力减弱,电弧压力减小,测量结果如图4所示.

2.2 焊缝表面和截面形貌

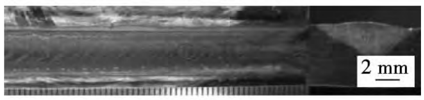
如图5所示,焊接速度为500 mm/min,焊接电流为280 A时,使用常规TIG焊所得到的焊缝表面成形较差,出现严重的驼峰焊道,使用耦合电弧钨极TIG焊的焊缝没有出现驼峰,但是仍有严重的咬边,而使用耦合电弧钨极GPCA-TIG焊得到了良好的焊缝表面成形,并未出现驼峰和咬边.



(a) 常规TIG 焊



(b) 耦合电弧钨极TIG 焊



(c) 耦合电弧钨极GPCA-TIG 焊

图5 三种焊接方法焊缝表面和截面形貌对比

Fig. 5 Weld surface appearances and cross-section shapes under different welding conditions

使用常规 TIG 焊的焊缝截面出现严重的驼峰焊道. 使用耦合电弧钨极 TIG 焊，电弧压力减小，焊缝熔深减小，没有出现驼峰焊道，但有严重的咬边. 分析认为原因有以下几种可能，使用耦合电弧钨极 GPCA-TIG 焊，由于耦合电弧钨极电弧压力较小，对熔池液态金属的挖掘力和后排力减小；活性元素 O 的引入使得熔池液态金属表面张力减小，提高了其与母材间的润湿性；活性元素 O 的引入使熔池在沿焊接方向上的流动方向变为由周边向中心，在熔池后方产生向内的金属流动有利于熔池金属回填电弧压力所产生的凹陷，消除驼峰. 这些因素共同作用避免了咬边和驼峰的产生. 与前两种方法相比，由于活性元素 O 的引入，金属流动形式的改变，熔池底部形状有向下突出的趋势，且与耦合电弧钨极 TIG 焊相比，熔深增加.

2.3　主要工艺参数对耦合电弧钨极 GPCA-TIG 焊缝成形的影响

由于涉及到高速焊接焊缝表面成形质量的判定，所以用咬边，即焊缝表面相对于母材处表面凹陷的量来判定成形好坏，如图 6 所示，如咬边凹陷量 b 大于 a，则以凹陷量较大者 b 的值作为评定值.

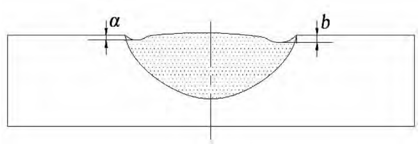


图 6　焊缝咬边示意图

Fig. 6　Schematic of weld undercut

2.3.1　焊接速度的影响

图 7 所示，焊缝熔深和熔宽随着焊接速度的增大有显著的减小，熔深减小幅度大于熔宽减小幅度. 焊接速度为 300 mm/min 时，厚度为 5 mm 试板被焊透，焊接速度为 1 200 mm/min 时，由于焊接热输入较小，焊缝熔深只有 0.62 mm. 焊接速度为 300 和 500 mm/min 时，焊缝未出现咬边，随着速度继续增大，开始出现咬边，咬边量约为 0.3 mm. 速度增大到 1 200 mm/min 时，焊缝熔宽较小，不发生咬边[7].

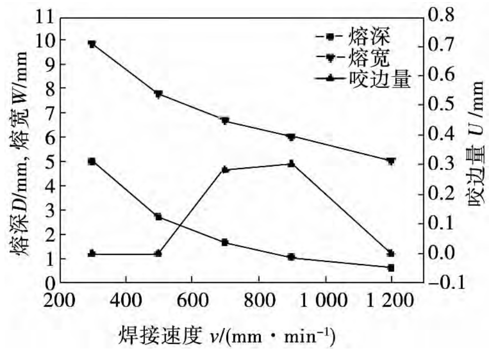


图 7　焊接速度的影响

Fig. 7　Influence of welding speed

2.3.2　电弧弧长的影响

随着弧长的增大，电弧下底面略有增大，焊缝熔宽增加（图 8），当弧长增大到一定值以后，由于阳极表面处电流密度减小，电弧外围温度减小，不足以使金属熔化，因此熔宽略有减小. 焊缝熔深在弧长为 5 mm 时达到最大值 2.74 mm，这是因为随着弧长的增加，外层活性气体与熔池耦合度增大，活性元素 O 的作用使得熔深增加. 而弧长为 6 mm 时，熔深减小，分析认为有两种可能的原因，一是由于弧长过大，电弧挺度减小，电弧压力减小，从而熔深减小；二是由于弧长继续增大，电弧外侧面积增大，外层氧气与电弧的耦合量过大，活性元素 O 的量超出了增加熔深的合适范围 0.007% ~0.03%[8]，反而使熔深减小.

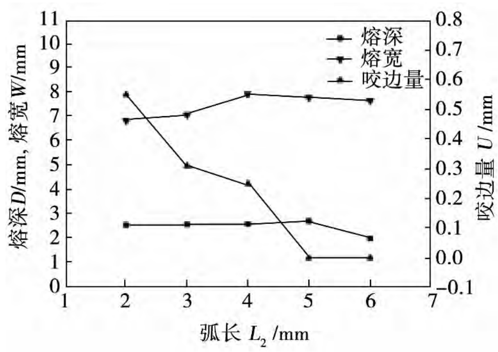


图 8　弧长的影响

Fig. 8　Influence of arc length

咬边量随着弧长的增大而减小. 弧长增加，电弧压力减小，有利于避免咬边和驼峰的产生[9]；同时由于弧长增加，电弧外侧面积增大，外层活性气体氧气与电弧的耦合面积将增大，活性元素 O 加入量的增大使熔池液态金属表面张力减小，固液相有更好的润湿性，有利于避免咬边的产生.

2.3.3　外层氧气流量的影响

随着氧气流量的增加，焊缝熔深和熔宽略有增加（图 9），咬边减轻，当氧气流量大于 10 L/min 时，焊缝表面没有出现咬边，成形良好，但是熔深略有减小，分析认为可能的原因是由于进入熔池 O 元素含量超出了合适范围 0.007% ~0.03%[8]，使得熔池金属向内流动趋势减小，熔深减小. 氧气流量的增大，使得活性元素 O 减小表面张力的作用增强，提高了熔池液态金属与母材金属的润湿性，更利于避

免咬边的产生.

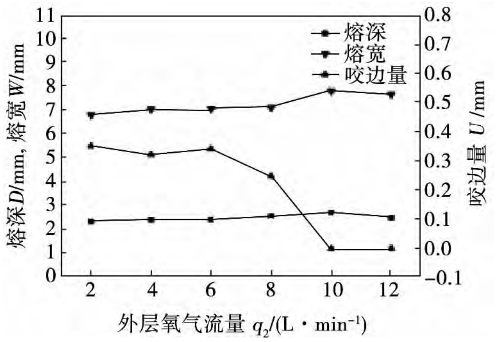


图9 外层氧气流量的影响
Fig. 9 Influence of flow rate of outer gas O_2

2.3.4 外喷嘴相对内喷嘴位置的影响

随着外喷嘴相对于内喷嘴位置的升高,焊缝熔深和熔宽均增大. 外喷嘴内壁与内喷嘴外壁为相互平行的锥面,当外喷嘴相对位置升高时,内喷嘴与外喷嘴之间的间隙减小,外层气体通道截面积减小,如图1a所示. 在气体流量不变的情况下,外层气体挺度增大,向电弧中心更加集中,增大了与电弧和熔池的耦合量,熔池Marangoni对流向内流动趋势增强;同时活性元素O加入量的增大使得熔池温度升高[10],这两个因素分别导致焊缝熔深和熔宽增大. 外喷嘴的位置从低于内喷嘴的 -2 mm位置上升到高于外喷嘴的 +2 mm位置,焊缝表面成形良好,均未出现咬边和驼峰焊道.

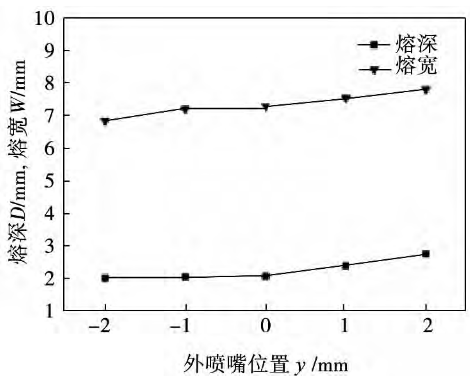


图10 外喷嘴位置的影响
Fig. 10 Influence of relative heights of outer nozzle

3 结 论

(1) 与常规TIG焊和耦合电弧钨极TIG焊相比,耦合电弧钨极GPCA-TIG焊接方法在较高速度焊接时可避免咬边和驼峰焊道的形成,获得良好的焊缝成形;与耦合电弧钨极TIG焊相比,熔深增加.

(2) 耦合电弧钨极GPCA-TIG焊焊缝熔深和熔宽随焊接速度减小和外喷嘴位置升高而增大,随着弧长和外层氧气流量的增加先增加后略有减小,熔深最大时弧长为5 mm,外层氧气流量为10 L/min.

(3) 随着焊接速度增加,焊缝出现咬边,当速度过大时,由于热输入小,熔宽较小,焊缝不出现咬边. 随弧长和外层氧气流量的增加,咬边减轻. 外喷嘴的相对位置变化时,均不出现咬边.

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this basis, a welding test was carried out by using the 80% Ar + 20% CO_2 mixture gas as protective gas. The results showed that the bypass arc burned stably on the oxide film of bypass droplet formed by CO_2 in protective gas, so the electromagnetic force and the gravity promoted the bypass metal transfer together and the size of the bypass droplet was significantly reduced.

Key words: gas metal arc welding; protective gas; metal transfer

Investigation on coupling arc electrode GPCA-TIG welding process HUANG Yong[1,2], HAO Yanzhao[2], LIU Ruilin[2] (1. State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China; 2. Key Laboratory of Non-ferrous Metal Alloys and Processing, The Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, China). pp 19 – 22

Abstract: A new method named coupling arc electrode GPCA-TIG welding is proposed, which combines coupling arc electrode and GPCA welding method, and with which deep penetration and high-speed welding can be achieved. In this paper, the weld surface appearances and weld cross-section shapes with traditional TIG, coupling arc electrode TIG and coupling arc electrode GPCA-TIG welding are studied. It is found that in the coupling arc electrode GPCA-TIG welding, the weld undercut and humping bead can be avoided, and meanwhile the weld depth increase. The results of the coupling arc electrode GPCA-TIG process shows that the weld depth and width increase with the decreasing of weld speed and the rising of outer nozzle position; with the increasing of arc length and flow rate of the outer gas O_2, the weld depth and width firstly increase and then decrease. The weld undercut is weaken with the increasing of welding speed, arc length and flow rate of the outer gas O_2. A good weld surface appearance can always be obtained with any outer nozzle position.

Key words: coupling arc electrode; GPCA welding; weld shape; weld undercut; humping bead

Digital control of capacitance charge-discharge pulse in electro-spark deposition power supply HAN hongbiao, LI Xiangyang (School of Mechatronics Engineering, Henan University of Science and Technology, Luoyang 471003, China). pp 23 – 26, 70

Abstract: The discharge voltage of traditional depositing power supply cannot be continuously adjusted, which limits the application range of electro-spark deposition and the efficiency of electro-spark deposition. In order to overcome this shortage, a digital control of capacitance charge-discharge pulse in electro-spark deposition power supply was developed. This power supply consists of CPU, rectifier and filter circuit, charge and its drive circuit, charge voltage comparison circuit, discharge and its drive circuit, motorial electrode, etc. With alternate charge and discharge process of this power supply, discharge voltage and discharge energy as well as discharge frequency can be adjusted steplessly. Experimental results show that the SCR of this power supply can be shut off safely when a short circuit occurs between the electrode and the workpiece, which greatly improves the efficiency of pulse output. The adjustment of discharge parameters is convenient, thus the power supply meets the requirements of various process condition.

Key words: electro-spark deposition; digital control; voltage regulation

Synthesis and characterization of carbon nanotubes reinforced TiNi composite solder QI Junlei, WAN Yuhan, ZHANG Lixia, FENG Jicai (State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China). pp 27 – 30

Abstract: Low temperature PECVD method was employed for in-situ preparation of CNTs reinforced TiNi composite brazing powder on Ni-TiH2 base material, in order to solve the problems such as poor dispersity of CNTs, poor structural integrity and reaction of C and Ti. The composite brazing powder was characterized by XRD, SEM, Raman and TEM. Analysis shows that the low temperature PECVD method has not only guaranteed the structural integrity and uniform dispersity of CNTs, but also inhibited the decomposition of TiH2 at high temperatures and further inhibited the reaction between C and Ti, which realized the reinforcement of CNTs to TiNi brazing powder. The reinforcement of CNTs could release the residual stress in brazed joints, improve the properties of the joints and further achieve the reliable joining and high-temperature application of ceramic, composites and metal.

Key words: carbon nano tube; composite material; low temperature preparation; soldered seam

Plasticity and creep performance of low-Ag SnAgCuBi-xNi/Cu solder joint YANG Miaosen, SUN Fenglian, ZOU Pengfei (School of Materials Science Engineering, Harbin University of Science and Technology, Harbin 150040, China). pp 31 – 34

Abstract: In order to study the effect of Ni on plasticity and creep performance of low-Ag SnAgCuBi-xNi/Cu (x = 0, 0.05, 0.1, 0.15, 0.2) solder joint, the indentation work and indentation creep were measured and analyzed by nanoindentation method. The results show that adding Ni could improve the hardness of solder joint. Adding amounts of 0.05% and 0.1% Ni is helpful to improve the plasticity performance but produce almost no impacts on creep. A further Ni adding amount (0.15% and 0.2%) can improve the creep resistance at the expense of plasticity. It is found that Ni can improve high temperature stability of SnAgCuBi/Cu solder joints. The creep resisting performance of the solder joints is improved with Ni element increasing after 400 h aging at 150 ℃. The hardness of solder joints is improved with the Ni addition. The plasticity performance of solder joints with 0.1% Ni content is better than others.

Key words: nanoindentation; plasticity; creep; hardness

Finite element analysis of shot peening treatment to improve welding pesidual stress of 7A52 aluminum alloy HUANG Zhiye, CHEN Furong (College of Materials Science and Engineering, Inner Mongolia University of Technology, Hohhot 010051, China). pp 35 – 40