

阀门球芯 316L 不锈钢小空间 TIG 焊接工艺

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摘要: 采用填丝的 TIG 焊接方法对不锈钢球芯流道口进行小空间全位置自动焊接。通过设计可进行小空间作业的 TIG 焊枪, 配合送丝机气保托罩紫铜散热夹与小车行走装置, 搭建自动化焊接平台。在阀门球芯的小空间内多重氩气保护下, 开展不锈钢球芯流道口 V 形焊缝的焊接。焊前清理焊缝及周围区域的杂质油污, 焊接时使用高纯氩进行严格的惰性气氛保护, 获得各项性能均符合技术要求的焊缝。焊后对焊缝区域进行微观组织和力学性能的测试评定, 分析缺陷的产生及原因, 并改善焊接工艺参数。测试焊缝、热影响区附近及母材位置的硬度, 绘制相应的工艺曲线, 获得最佳的工艺参数组合。

关键词: TIG 焊接; 阀门球芯; 316L 不锈钢; 显微组织
中图分类号: TG444

0 前言

随着人们日益增长的生活条件, 工业制品、航空航天、汽车、船舶等多个方面都有着长足的进步。它与人们的生活逐渐相关, 例如用于水管和液化石油气炉的减压阀, 各种机械设备, 例如内燃机、压缩机、气动变速箱、泵、波压变速箱、车辆, 船舶和其他机械设备不可缺少的组成部分。通常, 用于含有腐蚀性的液体的阀门用塑料、不锈钢、耐蚀合金(如铜镍钼合金、钛合金和铅合金等)或用铸铁等耐蚀材料制造。球阀在管道上主要作用为切断、分配和改变介质流动方向。在正常生产中, 由于球阀内部的焊接质量需求, 通常采用传统的 TIG 焊接方法, 但是传统的手工焊接方法往往被球阀的内部结构、焊接位置、焊接工艺等各种因素影响了焊后焊缝的质量和性能, 并且经常打开和关闭阀门, 切换高压和低压, 并且交替从高温到低温的时间等, 还需使球阀焊接位置具有一定的硬度要求。最重要的是焊接空间比较狭长, 寻常的焊接方法难以达到所需施焊的焊接位置, 所以效率也相对较低。为了提高球阀焊接效率及焊接质量, 哈尔滨工业大学先进焊接与连接国家

重点实验室研制一种适用于球阀内小空间焊接的 TIG 焊枪焊接 316 不锈钢球阀, 且制定了可行的焊接工艺^[1]。

1 试验材料及设备

球芯直径 240 mm, 孔口直径 150 mm, 孔口高度 190 mm, 质量 30 kg, 球心及阀体材质见表 1。试验材料不锈钢板材是厚度为 4 mm 的 022Cr17Ni12Mo2, 不锈钢焊丝选择 316L 不锈钢焊丝, 焊丝直径为 $\phi 0.8 \sim \phi 1.6$ mm, 主要力学性能见表 2。由于焊接的内部空间特别狭小, 需要设计能够进入球芯内部且具备自动送丝功能的 TIG 焊枪。

表 1 球芯材质

阀体	A351 CF8/A182 F304	A351 CF8M /A182 F316
球芯	A182 F304 (表面喷涂 WESCO4)	A182 F316 (表面喷涂 WESCO4)

表 2 316L 不锈钢主要力学性能

抗拉强度 R_m /MPa	屈服强度 R_{el} /MPa	断后伸长率 A (%)
485	170	30

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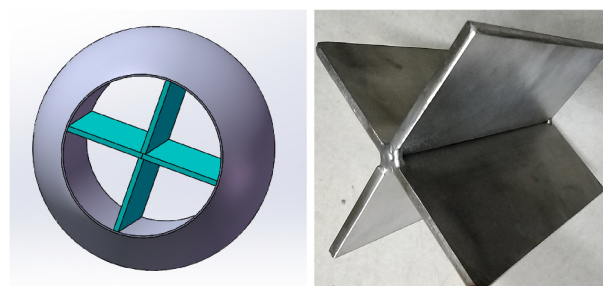
试验前需要清理流道口表面的杂质及在不锈钢板材的边源部位开坡口, 以加大熔深, 在试验过后观察焊

缝的形貌,进行焊接工艺优化,在无明显的焊接缺陷情况下将得到的试件进行金相检验及力学性能测试^[2-5]。

优化 TIG 焊流道口的焊接工艺参数。分析不同的焊接工艺参数下(焊接电流,行走台车的行进速度,SB10C/D 双驱送丝机的送速度以及焊接过程中焊机 Panasonic YC-500wx4N 的输出功率)的焊接接头性能,分析各工艺参数对焊接接头的影响,优化工艺。

焊接材料为 5 mm 厚不锈钢板,在清理完成后,满足 V 形焊缝的需要打磨焊材边缘部分开 1 mm 倒角,加强焊接质量。根据球阀内壁直径计算出符合内经空间尺寸的流道口尺寸,使用电火花线切割进行切割边缘部分。提前将板材进行十字焊接点固防止焊接时变形,除了垂直于板材的两端进行了点固外上下两端也进行了填丝点固,以防止多道焊缝热量高输入引起的变形增大刚性。然后再与球形件进行焊接,点固球芯

焊接结构模拟如图 1a 所示,内部流道口十字板如图 1b 所示。



(a) 球芯焊接结构

(b) 流道口十字板点固

图 1 球芯焊接结构和流道口十字板

按照表 3 的焊接工艺参数焊接后(保护气体为 98% Ar + 2% CO₂),试件的变形量非常小,对变形的抑制作用,角变形量为 0.085 mm,所形成的焊缝没有飞溅、咬边、焊穿等焊接缺陷。

表 3 焊接工艺参数

基值电流 I_b/A	脉冲电流 I_t/A	脉冲频率 $f/(Hz \cdot s^{-1})$	送丝速度 $v_f/(mm \cdot s^{-1})$	焊接速度 $v_w/(mm \cdot s^{-1})$	气体流量 $Q/(L \cdot min^{-1})$
240	360	1	60	2.6	15

2 焊接工艺

调节球阀整体垂直度使电弧高度稳定,焊缝均匀。由于球形阀门焊接时会有较大的焊接热输入,热影响易导致变形及裂纹的产生,因此研究焊接顺序十分重要,为了确保球形阀门焊接变形量最小,采用焊接顺序遵循对称焊接,焊缝焊接顺序如图 2 所示。

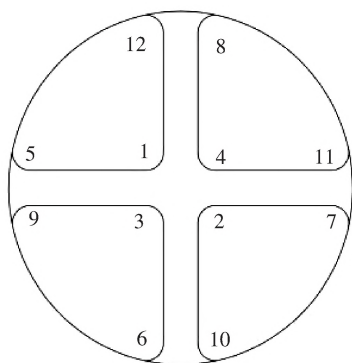


图 2 焊缝焊接顺序

2.1 焊接电流对流道口焊缝成形的影响

根据板材的厚度尺寸先预测焊接电流的大小,基

值电流为 200 A,脉冲电流为 320 A,再增加几组试验,每组电流增大幅度 20 A,调整后的焊接电流见表 4,其他保持不变的参数见表 3。改变其中一组变量,在这个过程当中材料内部所产生的变化及应力变形都是由材料本身的热胀冷缩的这一特性所导致。在焊前和焊后,必须对焊缝和热影响区进行清理,目的是清理焊缝周围的水分、油污等杂质,保证焊缝性能。为了保证焊接质量,确保反面熔敷金属不被氧化,加入拖罩需用氩气始终保护^[6]。焊前准备完成后,可用丙酮清洗坡口处的油污等杂质,焊中每完成一道焊缝,使用不锈钢丝刷对焊缝处的焊渣和氧化皮进行清理。

表 4 调整后的焊接电流

编号	基值电流 I_b/A	脉冲电流 I_t/A
1	220	340
2	240	360
3	260	360

在焊接过后得到了截然不同的 3 组试验效果如图 3 所示。1 号焊接电流过小,出现了明显的余高过大等焊接缺陷,如图 3a 所示;2 号焊缝成形达到初期目的,如图 3b 所示;3 号焊接电流过大出现了过烧,咬边等缺

陷,如图 3c 所示。因此可知,功率对变形值的控制有着至关重要的作用^[7]。

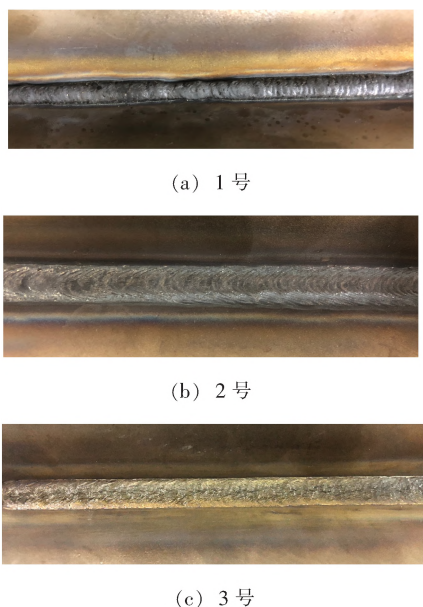


图3 调整焊接电流后的试验效果

2.2 焊接速度对不锈钢薄板焊缝成形的影响

在相同功率下,无法判定在速度上升的过程中,是否存在先降低再升高的情况,所以利用单一变量法来进行补充试验,并且测量焊接完成之后的变形量结果,加入脉冲后电弧收缩及电弧力也相应增大,同时电弧作用面积减小,电弧能量密度更集中,从而提升焊接生产效率。调整后的焊接速度见表 5,其他保持不变的参数见表 3,进行 3 组焊接试验。

表 5 调整后的焊接速度

编号	焊接速度 $v_w / (\text{mm} \cdot \text{s}^{-1})$
4	2.7
5	2.5
6	2.6

4 号焊接速度过快,出现了烧穿、未熔合等缺陷;5 号焊接速度过慢,出现咬边、下塌等缺陷;6 号焊缝表面成形良好,焊接结果如图 4 所示。



图4 宏观焊缝表面成形良好

3 结果与讨论

为了对比焊接工艺及质量的成果,为此增加了普通手工焊接的对比试验(焊接工艺参数不变)便于观察及研究焊接接头的微观组织,将在焊接完成后的不锈钢板上采取使用数控电火花线切割机切割金相检验所需的试件,金相试件的线切割方向,焊缝处取样制备金相试件,进行金相组织观察、硬度分析等,然后分析其及宏观组织结构特性。

3.1 腐蚀分析

该次试验所使用的是 316L 奥氏体不锈钢,试样磨光依次采用 180 号、320 号、600 号、1 000 号、1 200 号、1 500 号、2 000 号水磨砂纸磨光→试样抛光采用 $1.5 \mu\text{m}$ 粒度的金刚石喷雾抛光剂抛光)→抛至试样表面光亮无划痕后吹干。金相试样制备的关键在于 316L 奥氏体不锈钢材质较软,抛光时需控制好湿度和力度,磨抛时采用多道水磨砂纸打磨后用较轻力度短时间抛光^[8]。金相试件首先需要进行化学试剂的腐蚀之后将已抛光过后的试件进行腐蚀试验,实验时选择的腐蚀溶液是:5 g FeCl_3 + 50 mL HCl + 100 mL H_2O 。

试件分别采取具体腐蚀条件对抛光之后的试件进行腐蚀处理,腐蚀效果将采取光学显微镜进行拍照分析及手工焊、自动焊方式的金相高倍照片对比如图 5 所示。

由金相照片可以看到,奥氏体不锈钢焊缝金相试样经过不同工艺处理后得到金相显微组织。可以看出奥氏体不锈钢焊缝的焊态试样主要由奥氏体和铁素体两相构成,其中灰白色枝晶为奥氏体基体,黑灰色的游离铁素体以非连续网状分布在奥氏体枝晶间,金相显微组织表现为典型的 316 奥氏体不锈钢的焊缝组织特征,当腐蚀时间没有超过 1 min 的时候,能够清楚的看到金相组织的显微照片,能看到清晰的晶粒与晶界。也可以很好的看到自动焊相对于手工焊的优势。

3.2 力学性能分析

使用数字型显微硬度计分别在焊缝、熔合线、热影响区、母材处确定一条测试线,进行逐点测试,测试前进方向为:焊缝—熔合线—热影响区—母材,如图 6 所示。载荷为 200 N,保持 10 s 维氏硬度,得到维氏硬度分布图如图 7 所示,热影响区和焊缝区域的硬度均大于母材硬度。

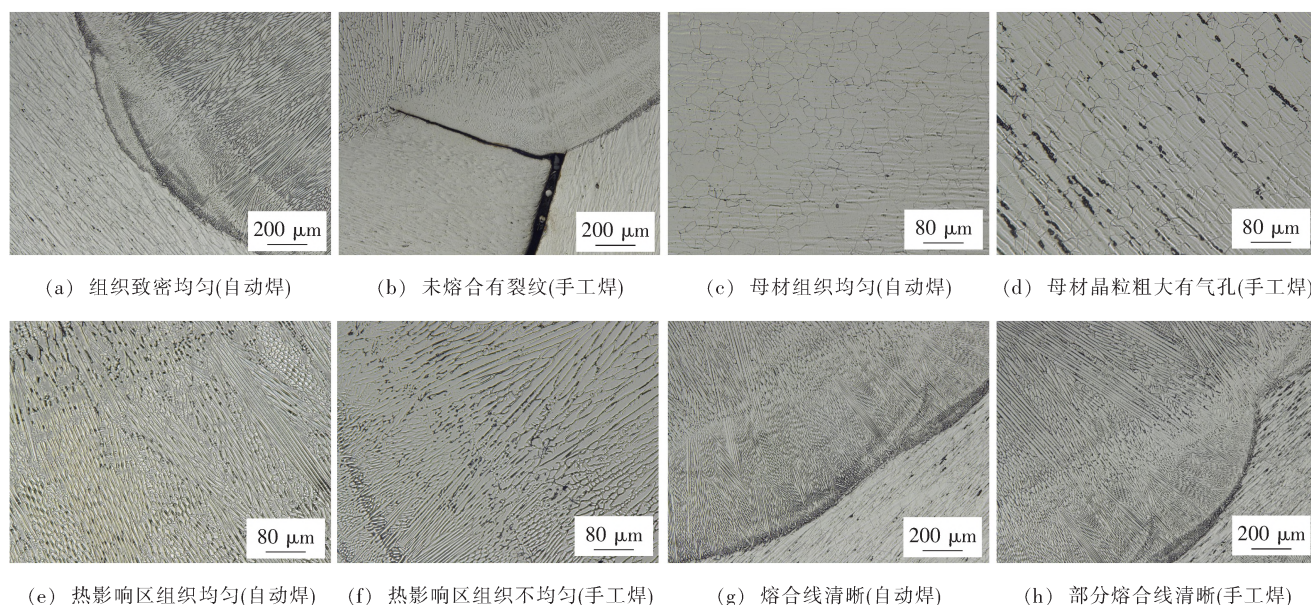


图5 试件腐蚀后所得到的金相照片

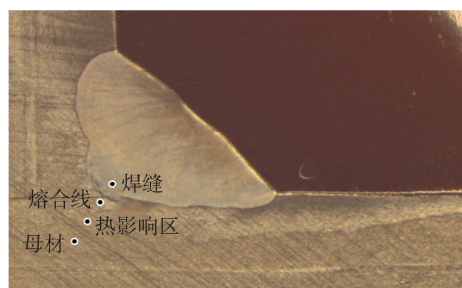


图6 硬度计打点位置图

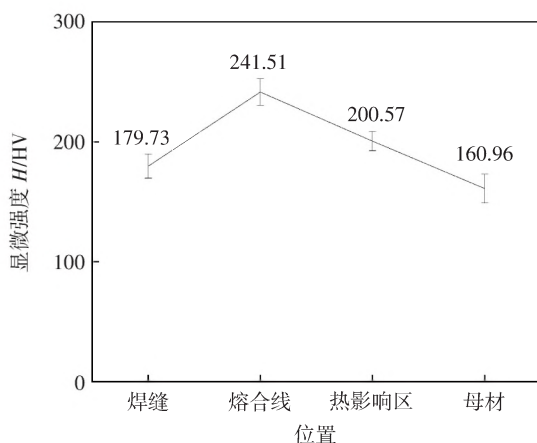


图7 维氏硬度分布图

4 结论

(1) 316L 不锈钢阀门球芯焊接过程中, 焊接工艺参数对焊缝变形的影响最大, 其次是保护气体, 最后是对变形量的控制; 经过相应的试验与分析, 对于该次试验所形成的焊缝所使用的最佳焊接工艺参数为: 基值

电流为 240 A、脉冲电流为 360 A、脉冲频率为 1 Hz/s、焊接速度为 2.6 mm/s、送丝速度为 60 mm/s、保护气体流量为 5 L/min。

(2) 母材的硬度值最低, 焊缝的区域明显加强, 其它区域达到预想的硬度要求。

(3) 焊缝周围的组织分布较好且均匀, 说明在焊接过程中保护效果较好。不锈钢焊接工艺参数的确定, 为以后的大批量焊接提供了技术保证, 安全性得到了有效的提升。

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to reduce the degree of stress concentration, thereby increasing the service life of the wave shield. The influence of the transition arc position and radius on stress distribution was analyzed by finite element simulation. The simulation results showed that the stress concentration of the welded structure weakened the fatigue life of the wave shield, while the arc transition structure had a significant mitigation effect on the stress concentration, and its degree of relief was significantly related to the arc position and radius. As the distance between the arc and the weld bead decreased, or the radius of the arc increased, the stress concentration of the wave shield decreased, and the transition was more obvious from low-cycle fatigue to high-cycle fatigue.

Key words: wave shield, finite element simulation, welded structure, stress concentration

Numerical simulation of droplet transition in ultrasonic-MIG welding

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Abstract Based on theories of fluid mechanics and electromagnetics, the mathematical model of the transition behavior in ultrasonic assisted metal inert gas welding (ultrasonic-MIG) was established by adding ultrasonic vibration and radiation force conditions. FLUNET software was used to simulate the droplet growth, deformation and shedding under different welding currents and ultrasonic amplitudes. The simulation results showed that the droplet profile change and shedding time were in good agreement with the related test results. Compared with conventional MIG, the drop size of ultrasonic-MIG droplet was smaller and the transition frequency was faster under the condition of low current, while the drop time and size of ultrasonic-MIG droplet changed less obviously under the condition of high current. The dropping time of ultrasonic-MIG droplet was affected by ultrasonic amplitude, and the increase of ultrasonic amplitude could shorten the droplet transition period to some extent.

Key words: ultrasonic-MIG, droplet transition, numerical simulation, ultrasonic radiation force

Analysis of on-orbit welding operation condition and interface technology for space station

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Abstract In order to implement on-orbit welding technology in space station, the working conditions of on-orbit welding were analyzed from aspects of man, machine, material, method, ring and measurement. Furthermore, the interface and technical requirements for different on-orbit welding technologies were analyzed to ensure that on-orbit welding could match with the station's energy, load and extreme environment. This paper provides a reference for further research on on-orbit welding technology and equipment.

Key words: on-orbit welding, on-orbit manufacturing, space station

Testing methods of ferrite content and its universality

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Abstract The magnetic testing is the most effective and accurate method. However, due to the different manufacturing process and calibration principle, the magnetic testing instrument is not universal. In order to effectively evaluate the weld quality, the secondary standard samples were manufactured by multi-layer surfacing in this study. And the ferrite content of secondary standard samples were tested and analyzed by magnetic, diagram and metallographic testing methods respectively. The calibration curves of the secondary standard samples tested by domestic and imported magnetic testing instruments were obtained. The research result showed that results of magnetic method and the metallographic method were close, whereas the deviation of the diagram method was relatively large. In addition, the calibration curves of different instruments by using the secondary standard samples could achieve a unified evaluation of the testing results.

Key words: ferrite content, magnetic testing method, multi-layer surfacing, secondary standard samples

TIG welding process of 316L stainless steel valve core in small space

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Abstract TIG welding with filler wire was used in all position automatic welding of channel of stainless steel valve ball core in small space. An automatic welding platform was built by designing a TIG welding gun for small space operation and installing with wire feeder air protection cover red copper heat cooler and trolley walking device. Under the protection of multiple argon in small space of valve ball core, the weld of stainless steel valve ball core in V-shaped welding position was carried out. Cleaning up impurities and oil stains of the weld and its surrounding area before welding, using high purity argon for strict inert atmosphere protection during welding, it was to obtain weld with all performances that met technical requirements. After welding, microstructure and mechanical properties of the weld were tested and evaluated, the generation and cause of defects was analyzed, the process parameters were improved. Hardness of the weld, HAZ and the parent metal was tested and the corresponding process curve was drew to obtain the best combination of process parameters.

Key words: TIG welding, valve ball core, 316L stainless steel, microstructure

Weld defect detection of aluminum alloy based on digital radiography

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Abstract Digital radiography method was used to detect welded joints of aluminum alloy with different thickness. The process parameters such as voltage, current, exposure time and magnification were optimized to make the detection sensitivity meet the standard requirements. On this basis, digital radiography and film radiography were respectively carried out on fusion weld and friction stir welded joint of aluminum alloy to obtain the typical defect images. The morphology distribution, size and properties of the defects were compared and analyzed. The defect detection ability of digital radiography was analyzed and the reliability of digital radiography detection results was verified. The result showed that the detection sensitivity of digital radiography was superior to the standard requirements. Meanwhile, the defect detection capability of digital radiography was basically the same as that of film radiography, and the dimension error was less than 5%.

Key words: digital radiography, film radiography, testing sensitivity, defect, contrast test

Effect of ultrasonic impact method on performance of micro-arc spark deposited coating

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Abstract Micro-arc spark deposited samples were prepared under the same conditions and mechanism. Before and after ultrasonic impact treatment, experimental methods such as tensile test, microhardness test, residual stress test, X-ray test, corrosion resistance test and microstructure observation test, were carried out on these samples to study the effect of ultrasonic impact treatment on the performance of micro-arc spark deposited coatings by comparative analysis. The result showed that by ultrasonic impacting on the micro-arc spark deposited coating, defects such as porosity, loose, and incomplete fusion could be reduced so as to densify the deposited coating and improve its tensile strength, which could effectively improve the stress distribution of the surface strengthened layer and make the surface appear in a state of compressive stress. Choosing deposition materials with stronger corrosion resistance to repair local damage and corrosion defects on the surface of aircraft parts and performing ultrasonic impact treatment would greatly improve corrosion resistance of aircraft parts.

Key words: micro-arc spark deposition, ultrasonic impact treatment, performance of coating

Effect of plate thickness on shear strength and fatigue strength of laser lap welded joints for stainless steel car body

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Abstract In order to investigate on effect of plate thickness on shear strength and fatigue strength of stainless steel laser lap welded joints, tensile tests and fatigue tests on stainless steel laser lap welded joints with two different plate thicknesses of 0.8 mm + 2 mm and 2 mm + 2 mm were conducted. The results showed that shear strength and fatigue strength of the 2 mm + 2 mm joint were higher than those of 0.8 mm + 2 mm. It was found by failure analysis that tensile fracture of the two joints was caused by shear fracture of weld, and fatigue cracks originated in heat-affected zone near the weld nugget on the inner surface of the incompletely welded plate. The crack propagated along the edge of the weld nugget to the outer surface of the incompletely welded plate until it penetrated the incompletely welded plate. It could be seen from the finite element force analysis of welded joints that the difference in the degree of stress concentration between the two joints was the main reason for the difference in their shear strength and fatigue strength.

Key words: stainless steel, laser lap welding, plate thickness, shear strength, fatigue strength