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长输管道全位置激光-电弧复合焊接技术

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摘 要: 采用激光-电弧复合焊接技术开展管道的全位置激光-电弧复合焊接可行性研究. 结果表明,激光-电弧复合焊接工艺能够适应管道环焊缝焊接的要求. 在从0°~180°的焊接过程中,通过调整焊接参数,均能够获得成形良好的焊缝. 金相观察表明,母材和焊材熔合良好; 焊接接头中心区狭长,具有激光焊的特点; 热影响区具有电弧焊的特点; 金相组织不受位置影响. 焊接接头的硬度接近母材,抗拉强度接近或超过母材; 在无内部缺陷的情况下,弯曲试验和冲击试验结果满足现行标准要求.

关键词: 管道; 全位置焊接; 激光-电弧复合焊; 激光焊
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0 序 言

随着国内能源需求的增长和能源工业的发展,石油天然气的需求量大大增加. 管道运输作为最经济的油气输送方式,受到更大重视. 为了提高输送效率,油气管道正朝着大口径、高钢级、厚壁的方向发展. 传统的电弧焊技术受单层焊接厚度的限制,很难进一步提高焊接效率. 激光-电弧复合焊技术焊接速度快、熔深大,应用于管道焊接,将大大提高焊接效率,并降低耗材[1].

油气管道的野外现场焊接方法是管道相对固定,焊接小车沿轨道行走,带动焊炬围绕管壁运动,从而实现管道全位置焊接. 在焊接过程中,焊炬的角度不断变化,因此全位置焊接工艺有平焊、立焊和仰焊的特点. 随着焊炬位置的不断变化,焊缝成形受到影响[2]. 文中通过试验分析了全位置激光-电弧复合焊的焊接参数及焊缝的性能.

1 试验方法

图1为复合焊炬,用于夹持激光聚焦头和电弧焊炬. 激光与电弧采用旁轴复合方式,激光聚焦头和电弧焊枪前后排列,激光聚焦头在前,电弧焊枪在后. 激光束与电弧呈30°夹角[3]. 激光束与焊丝距离3 mm. 复合焊炬安装于一台自行设计的轨道牵引小车上,在轨道小车的牵引下沿环形轨道行走. 激光器选用YLS-6000光纤激光器,最大输出功率6 kW. 激光由光纤传输,波长1 070 nm,焦点直径0.4 mm. 电弧焊机型号为TransPuls Synergic 4000,最大焊接电流400 A. 保护气体为80% Ar+20% CO_2. 试件采用X65管线钢制作,管道直径813 mm,壁厚12.5 mm,管道端面坡口夹角20°,坡口钝边厚度6 mm.

图1 复合焊夹具
Fig. 1 Hybrid welding fixture

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采用下向焊工艺，从 0 点到 6 点(0° ~ 180°) 一次完成(图 2) ．激光光斑与焊丝的距离为 3 mm，以使激光和电弧形成单一熔池．试件在 0° ~ 180°之间分作 6 段，按照位置采用不同试验参数．试验参数如表 1 所示．焊接完成后分别在距焊接起点 0°，45°，90°，135°，180°等 5 个位置截取一段焊缝制作成标准试件，测试焊缝力学性能．

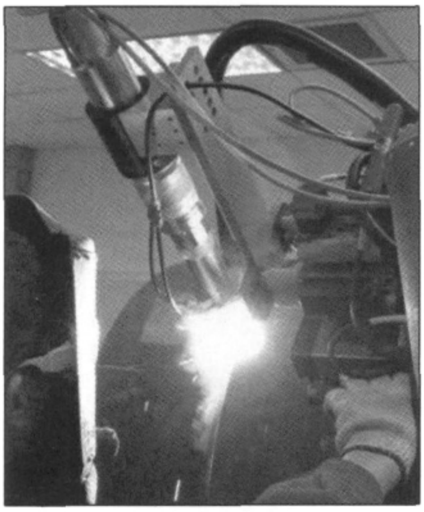


图 2　管道激光-电弧复合焊

Fig. 2　Pipeline laser-arc hybrid welding

表 1　管道激光-电弧复合焊工艺参数

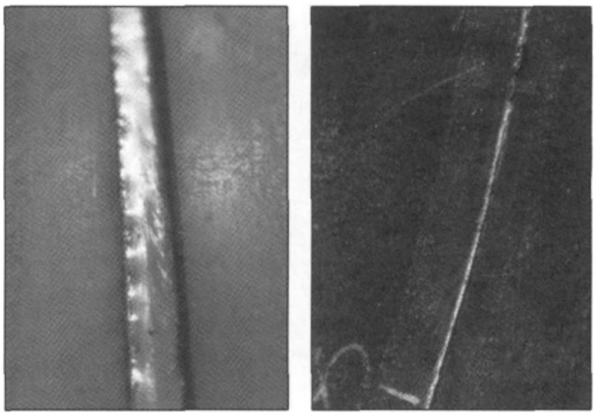
Table 1　Processing parameters for pipeline laser-arc hybrid welding

位置 $\theta/(°)$	激光功率 P/kW	焊接速度 $v_w/(\mathrm{m \cdot min^{-1}})$	电弧电压 U/V	送丝速度 $v_f/(\mathrm{m \cdot min^{-1}})$
0 ~ 30	5.2	1.2	24.5	10
30 ~ 60	5.2	1.2	24.5	10
60 ~ 90	5.3	1.1	25	9
90 ~ 120	5.3	1.1	25	9
120 ~ 150	5.4	1.0	25.5	8
150 ~ 180	5.4	1.0	25.5	8

2　试验结果与分析

激光与电弧的功率匹配对试件上段焊缝成形影响较大．电弧电流较大时，在 0° ~ 60°之间，焊缝背面常形成焊瘤．在仰焊位置，焊缝背面常形成凹陷[4]．因此在仰焊位置降低焊接速度，给予焊丝熔液充分的凝固时间，以避免焊缝凹陷．

工件装卡精度是影响焊缝质量的重要因素．若对口间隙和错边量控制在一定范围内，则焊缝成形较好．当对口间隙大于 0.8 mm 或错边量大于 1 mm 时，焊口常出现未熔透、咬边、焊缝内凹等缺陷．焊缝的宏观金相表明，不同位置的焊缝形状变化趋势基本一致，与所处位置关系不大．



(a) 正面　　(b) 背面

图 3　部分焊缝的正面和背面

Fig. 3　Front surface and back surface of welding seam

2.1　焊缝力学性能测试

在焊接接头的不同位置测量硬度．测量位置及结果如图 4 和表 2 所示．结果显示，焊接接头区硬度略高于母材，热影响区硬度有所波动．

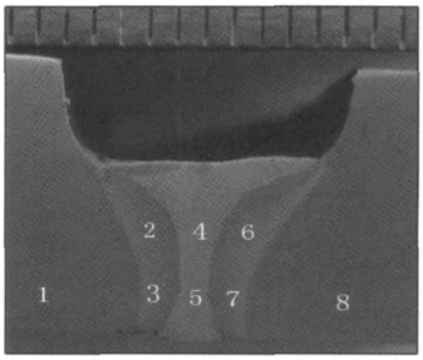


图 4　硬度测试位置

Fig. 4　Hardness testing positions

表 2　焊接接头不同位置硬度值(HV)

Table 2　Hardness test result

	位置	硬度
母材	1	227
	8	232
热影响区	2	238
	3	237
	6	225
	7	227
焊缝	4	235
	5	238

拉伸试验结果如表3所示. 试件的断裂大多发生在母材上,且断裂位置距离焊缝和热影响区较远. 发生断裂的位置通常伴随着内部气孔、未熔透等缺陷. 熔合线附近较易发生断裂,断裂处通常伴随熔合不良缺陷. 这些试验结果说明,内部缺陷是降低焊缝抗拉强度的主要因素. 在无内部缺陷的情况下,焊缝的抗拉性能强于母材.

表3 不同位置焊接接头抗拉强度
Table 3 Tensile test result

试样编号	尺寸 L/mm	拉伸载荷 F/kN	抗拉强度 R_m/MPa	断裂位置	取样位置 θ/(°)
T1	6.22×25.10	110.05	705	母材	45
T2	6.40×24.72	108.75	685	母材	90
T3	6.38×24.70	109.45	690	母材	135

在-10 ℃的低温条件下测试低温冲击韧性. 测试数据如表4所示,熔合区的冲击性能强于焊缝区. 分别对焊接接头进行刻槽锤断试验和弯曲试验,试件未出现明显缺陷.

表4 焊缝不同区域冲击吸收功
Table 4 Impact test result

缺口位置	试件尺寸 (a×b×c)/mm	编号	冲击吸收功 单值 $A_{KV,-10℃}$/J	冲击吸收功 平均值 $\bar{A}_{KV,-10℃}$/J
焊缝	3.5×10×55	1	58	51
		2	45	
		3	50	
熔合区	3.5×10×55	1	61	56
		2	53	
		3	53	

2.2 试验结果分析

激光焊的一个比较突出的问题是焊接接头冲击韧度较差. 在激光-电弧复合焊中,电弧对母材具有预热作用,同时由于电弧的热影响区较大,使复合焊熔合区的降温速度低于纯激光焊熔合区的降温速度,从而降低了接头硬度,增加了韧性.

空间位置对焊接接头成形有一定的影响,在130°~180°区段,焊缝的背面余高低于其它区段的余高. 这是因为受重力影响,熔滴未能到达接头顶部. 焊接接头的不同位置的金相组织差别不大,剖面形状变化趋势基本一致.

在平焊到立焊的变化过程中,焊缝成形对激光与电弧的能量匹配比较敏感,电弧功率过大时焊缝背面易出现焊瘤. 在立焊到仰焊的变化过程中,焊缝成形对焊接速度比较敏感,速度过快时,深层的熔液来不及凝固,常导致焊缝背面下陷.

工件装夹精度是影响接头质量的重要因素. 在对口间隙或错边量过大的地方,接头背面常出现内凹、未熔等缺陷. 这是因为根部间隙过大时,焊丝的熔化金属不能流到根部填充间隙,而只能通过熔化的母材金属来填充,使得根部金属量不足而出现内凹[5];错边量过大时,熔化金属漫向母材较低一侧,导致母材较高一侧未能接触熔液导致熔合不良. 试验发现,间隙在0.8 mm,错边量在1 mm之内能获得成形良好的焊接接头.

3 结 论

(1) 激光-电弧复合焊接技术对工位具有比较强的适应能力,可以满足全位置焊接的要求.

(2) 接头内部缺陷是影响焊缝性能的主要原因. 降低内部缺陷将是实现全位置激光-电弧复合焊技术工业化应用的一项主要研究工作. 在未来的工作中,需要更深入地研究壁厚、坡口型式、激光与电弧的能量配比等因素对接头性能的影响.

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Abstract: The effects of the titanium on the resistivity, melting temperature, spreadability, microstructure, and shear strength of Zn-22Al filler metal were studied. The results indicated that with the addition of Ti, the resistivity and the melting temperature rose slightly, and the spreadability was significantly improved especially when the content of Ti was 0.03%. However, the addition of excessive amount of Ti would deteriorate the spreadability of Zn-22Al filler metal. It has been found that Ti could refine the microstructure of the filler metal, and the size of η-Zn phase decreases remarkably. When the content of Ti exceeds 0.15%, the η-Zn phase tends to become coarse, and the shear strength of Cu/Al joint reaches the peak value 84.64 MPa when brazed with Zn-22Al-0.03Ti filler metal.

Key words: Zn-Al filler metal; spreadability; microstructure; mechanical property

Inhomogeneity for A7N01 aluminum alloy welded joint

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Abstract: Inhomogeneity for A7N01 alloy welded joint was investigated in terms of microstructure, microhardness, tensile properties and fatigue life. Experiment results show that microstructure and microhardness of base metal, weld metal and HAZ are much different. Microhardness for weld metal is about HV75 which is the lowest compared with HV110 for base metal and HAZ in which microhardness changes significantly. The ultimate tensile strength and yield strength of base metal is higher than that of weld metal and HAZ. Notched specimens were used in fatigue test to study the inhomogeneity of the joint. Experiment results demonstrate that there is less difference in fatigue crack initiation life for the three micro-zones, and the ratio of fatigue initiation life to the total faitgue life is contant for each micro-zone. However, the difference of fatigue life is remarkable that weld metal has the shortest total fatigue life and base metal has the longest one.

Key words: A7N01 aluminum alloy; inhomogeneity; fatigue crack initiation life; local properties

Design of failures monitoring system in pulsed gas melted arc welding power source

LI Fang, HUA Xueming, WU Yixiong (School of Materials Science and Engigneering, Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiao Tong University, Shanghai 200240, China). pp 101-104, 109

Abstract: In order to solve the problem of diagnosing welding power source and ensure the safety, the fault tree of GMAW-P welding power source system is built and the hierarchical control technology is used. Modules of fault trees can be used to reduce the computational cost of basic operation. The result shows that this method is easily to be processed by the computer, and the efficiency of diagnosis is improved. The result of this new failures monitoring system shows that the intelligence of welding power source is improved and it has wide applicatious.

Key words: pulsed gas metal arc welding; weld power source; fault tree; digitize

Controlling of hardness of cast iron joint by manual arc welding

XU Jinfeng, REN Yongming, ZHAI Qiuya (School of Materials Science and Engineering, Xi'an University of Technology, Xi'an 710048, China). pp 105-109

Abstract: Repairing of casting defect for iron casting has great economic significance. The relationship between welding parameters and joint microstructure along with hardness is investigated by micro-alloyed gray cast iron homogenous electrodes and DC welding machine. The results show that the welding parameters have significant effects on joint microstructure and hardness. Keeping the welding current constant, the higher the preheating temperature is, the more uniform the temperature distribution is and slower the cooling rate of joint is, the much easier gray cast iron microstructure forms. Keeping the preheat temperature constant, with the increase of welding current, welding heat input increases and the cooling rate of joint decreases, which is easy to form gray cast iron microstructure with non-chilled phase. The welding parameters should be controlled in the upper right zone of welding current-preheat temperature-microstructure type diagram. By strictly controlling of welding current and preheat temperature, and using small current to make a rendering combined with high-current continuous welding process, the microstructure and hardness of joint can be effectively controlled, obtaining the homogenous weld with excellent machinability.

Key words: casting defect; cooling rate; welding current; preheat temperature; machinability

Research on all-position laser-arc hybrid welding for long-distance transportation pipeline

ZENG Huilin, PI Yadong, WANG Xinsheng, WANG Shixin, ZHANG Jie (Institute of Oil and Gas Pipeline, Langfang 065000, China). pp 110-112

Abstract: Using laser-arc hybrid welding method to weld pipeline butt will improve the efficiency of pipeline construction. The feasibility of welding pipeline butt by laser-arc hybrid welding process was discussed through experiments. Experiment results showed that hybrid welding meet the requirements for girth welding. From 0 to 180 degree, by using different parameters union, the welding joint is satisfactory. Metallographic image showed the base material and welding material fused soundly, the cross section of welding seam was as narrow as that of the laser welding, and the heat affected zone was of the same characteristic of arc welding. Metallurgical structure is not affected by position variation. The hardness value and tensile strength of welding seam is close to or exceed that of the base material. The result of bending test and impact test are qualified in the case that there are no internal defects.

Key words: pipeline; all position welding; laser-arc hybrid welding; laser welding