

ZG4Cr25Ni20 与 1Cr5Mo 异种钢接头的焊接

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摘 要 从 ZG4Cr25Ni20 与 1Cr5Mo 的成分和性能入手, 分析它们各自的焊接特性及其异种钢接头的焊接特点, 确定试验参数并通过试验制订合理的焊接工艺, 在南京炼油厂制氢装置的转化炉焊接工程实践中取得了良好的效果。

主题词 铸钢 不锈钢 焊接 工艺 试验 应用

1 前言

乙烯裂解炉、制氢转化炉都要将介质加热到 800℃ 以上的高温, 要求辐射炉管具有较高的热强性、抗氧化性以及良好的抗高温蠕变性能, 设计往往选用 ZG4Cr25Ni20 离心浇铸管或其他高铬镍合金作为辐射炉管, 选用 1Cr5Mo 材质作为两端法兰设置在炉体外部, 这就出现了异种钢接头的焊接问题。

ZG4Cr25Ni20 管为离心浇铸的高碳高铬镍奥氏体不锈钢管, 1Cr5Mo 为珠光体耐热钢, 两

种材料化学成分不同, 金相组织不同, 物理性能不同, 焊接性能相差甚远, ZG4Cr25Ni20 的焊接容易产生焊接热裂纹, 1Cr5Mo 的焊接容易产生焊接冷裂纹, 焊材的选择应考虑到熔合区稀释产生的脆性层和碳迁移形成的扩散层, 如何保证 ZG4Cr25Ni20/1Cr5Mo 异种钢接头的焊接质量是本文的核心。

2 ZG4Cr25Ni20 与 1Cr5Mo 的性能特点

ZG4Cr25Ni20 与 1Cr5Mo 两种钢材的成分和性能参见表 1~表 3。

表 1 两种钢材的化学成分

含量(%)	C	Mn	Si	Cr	Ni	P	S	Mo
ZG4Cr25Ni20	0.35~0.45	≤1.5	0.50~2.00	23~27	19~22	≤0.04	≤0.040	≤0.5
1Cr5Mo	≤0.15	≤0.6	≤0.50	4.00~6.00		≤0.035	≤0.030	0.5~0.6

表 2 两种钢材的机械性能

参数	σ_b (MPa)	σ_s (MPa)	δ_5 (%)
ZG4Cr25Ni20	≥449	≥255	≥10
1Cr5Mo	≥408	≥204	≥22

表 3 两种钢材的线胀系数

ZG4Cr25Ni20		1Cr5Mo	
温度范围 (℃)	线胀系数 ($10^{-6}/℃$)	温度范围 (℃)	线胀系数 ($10^{-6}/℃$)
20~400	17.0	0~485	12.5
20~800	18.0	0~540	12.7
20~1000	19.0	0~650	13.0
20~1200	19.5	0~705	13.1

(1) ZG4Cr25Ni20 是高碳高铬镍离心浇铸管, 室温下金相组织为奥氏体加一次碳化物; 热强性、抗高温氧化性、抗高温蠕变性都很好; 但焊接性能较差, 由于碳、镍含量高, 焊接时容易产生热裂纹; 而导热系数小, 线膨

胀系数大, 容易诱发热裂纹。

低温焊接时要进行不超过 100℃ 的预热, 非低温焊接时不要求预热, 层间温度不超过 100℃, 焊后不进行热处理。

(2) 1Cr5Mo 是铬钼中合金耐热钢, 室温下为珠光体组织, 供货材料应为退火状态; 同种钢的焊接使用同质焊条即热 507 焊条手工电弧焊焊接。当不能进行热处理或热处理十分困难时, 也可使用奥氏体不锈钢焊条如奥 302、奥 307 等进行焊接。

用热 507 焊条焊接时, 要求焊接工件预热到 250~350℃, 层间温度保持在 250~350℃, 焊后及时进行 750~780℃ 回火热处理。若不能及时进行热处理, 可先进行 300~350℃ 后

热处理,再尽可能快地进行 750~780℃ 回火热处理。

1Cr5Mo 的焊接性能较差,空冷淬硬倾向大,容易出现马氏体组织,焊前需确认材料处在退火状态,焊接时注意防止出现冷裂纹。

表 4 ERNiCr-3、NCF-HK 化学成分

含量(%)	C	Mn	Fe	P	S	Si	Cu	Ni	Co	Ti	Cr	Cb 或 Ta	其余
ERNiCr-3	0.10	2.5~3.5	3.0	0.03	0.015	0.50	0.50	≥67.0	≤0.12	0.75	18.0~22.0	2.0~3.0	0.50
NCF-HK	0.35	2.30				0.74		19.53			25.48		

表 5 ERNiCr-3、NCF-HK 机械性能

参 数	σ_b (MPa)	δ_5 (%)
ERNiCr-3	550	≥30
NCF-HK	653~714	13~18

这两种材料均能满足 ZG4Cr25Ni20 和 1Cr5Mo 钢的焊接需要,但有一定差别。这两种焊接材料的焊缝金属均为奥氏体组织,奥氏体钢与珠光体钢焊接存在珠光体钢母材对奥氏体焊缝稀释作用,这种稀释作用有可能使奥氏体化不强烈的焊缝金属产生马氏体脆性层,甚至产生裂纹,奥氏体化强烈的焊缝金属则脆性层宽度小,甚至不产生脆性层。而镍是决定奥氏体化最为主要的元素,镍含量的多少直接决定脆性层的宽度(如图 1)。

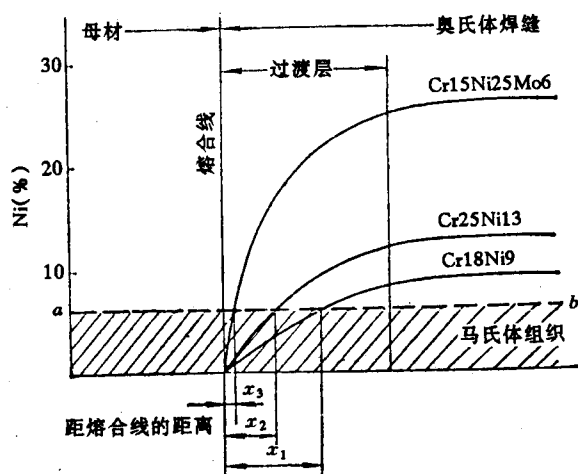


图 1 奥氏体焊缝中镍含量对脆性层宽度的影响

由图 1 可见脆性层的宽度 x 与焊缝中含镍量成反比:当填充金属为 1Cr18Ni9 时,脆

3 异种钢接头焊接的工艺分析

3.1 焊接材料的选择

选用镍基焊丝 ERNiCr-3 或 NCF-HK 焊条(即 ZG4Cr25Ni20 专用焊条),其化学成分和机械性能分别见表 4、表 5。

性层宽度是较大的(x_1);当使用奥氏体焊接材料时,脆性层宽度将显著缩小(x_2);当使用镍基焊接材料时,脆性层会趋于消失(x_3)。因此选用镍基焊丝 ERNiCr-3 时,焊缝中不出现脆性层,而选用 NCF-HK 时焊缝中则有可能出现较薄的脆性层。

镍基焊丝与 NCF-HK 焊条对阻止碳扩散防止使用过程中形成焊缝增碳、珠光体钢母材脱碳都有较强的能力,但镍基焊丝含镍量更高,其能力更强,故选用镍基焊丝更好。

3.2 焊接方法和电流的选择

异种钢焊接时,焊接方法的选择要考虑熔合比的影响,要尽量减小熔合比,以降低对焊缝的稀释作用。采用非熔化极气体保护焊时,可得到最小的熔合比。采用高铬镍焊条手工电弧焊时,熔合比也比较低,而且变化范围小,焊缝成分也较稳定。这两种焊接方法都可以满足要求。

焊接电流的选择要考虑到对熔合比的影响及对焊接裂纹的影响。采用较小的电流焊接,可以减小熔合比,减少 1Cr5Mo 对焊缝金属的稀释,小电流焊接对 ZG4Cr25Ni20 可降低热裂纹倾向。

3.3 预热温度和层间温度

用镍基焊丝或高铬镍焊条焊接异种钢接头,对于母材 ZG4Cr25Ni20 侧,低温焊接时进行不超过 100℃ 的预热,非低温焊接时不必进行预热、层间温度控制在 100℃ 以下;而对 1Cr5Mo 一侧,考虑到其淬硬倾向大,易形成马氏体组织而发生裂纹,每层施焊前必须对

1Cr5Mo 法兰单独进行 150~200℃ 的预热, 焊后在 1Cr5Mo 侧进行保温缓冷。

3.4 接头内应力和焊后热处理

从表 3 中可知 ZG4Cr25Ni20 的线膨胀系数远高于 1Cr5Mo 的线膨胀系数, 由于相差悬殊, 会在焊接熔合区产生较大的残余应力, 这种因线膨胀系数不同所产生的残余应力是不能依靠热处理办法予以消除的, 如果一定要对其进行焊后热处理, 还会带来其他问题, 故不应该进行消除应力热处理。

解决该问题要从如何获得较为合理的应力分布入手, 要尽量选择线膨胀系数接近的合适焊材。在焊接过程中由于焊接材料两侧母材的线膨胀系数不一样, 两侧的应力状态不同, 其中珠光体通过塑性变形降低应力的能力较弱,

所以使高温应力集中在奥氏体一侧较为有利, 也就是说应选用线膨胀系数与珠光体钢即 1Cr5Mo 钢的线膨胀系数较接近的焊接材料。由线膨胀系数相差造成的焊接应力在 1Cr5Mo 一侧较小, 而在 ZG4Cr25Ni20 一侧的应力较大, 这样对整个焊接接头有利。镍基焊丝的线膨胀系数 0~400℃ 时为 $14.5 \times 10^{-6} \text{mm}/(\text{mm} \cdot ^\circ\text{C})$, 这一数值与 1Cr5Mo 的线膨胀系数值较为接近, 而 NCF-HK 材质与 ZG4Cr25Ni20 很接近, 其线膨胀系数与 ZG4Cr25Ni20 的线膨胀系数接近, 因此选用镍基合金焊丝比选用 NCF-HK 焊条更为合适。

4 焊接工艺试验

4.1 工艺试验参数

通过分析确定采取的参数见表 6。

表 6 工艺试验参数

焊 接 材 料		试 件 规 格 (mm)	焊接方法	焊道层次	焊 接 电 流 (A)	电 弧 电 压 (V)	氩 气 流 量 (L/min)
牌 号	直径(mm)						
ERNiCr-3	2.4	D 127×12	GTAW	1 其 余	90~95 115~120	10~11 10~11	6~11
ERNiCr-3 NCF-HK	2.4 3.2	D 127×12	GTAW SMAW	1 其 余	90~95 110~125	11~12 23~24	6~11

1Cr5Mo 侧每层焊前预热 150~200℃, ZG4Cr25Ni20 侧不预热, 层间温度控制在 100℃ 以下, 不进行热处理。

4.2 焊接工艺试验结果

(1) 拉力试验结果见表 7。

(2) 弯曲试验结果见表 8。

表 7 拉力试验结果数据

焊接方法	接头强度 σ_b (MPa)	断裂位置	母材 σ_b (MPa)
GTAW	582;607;607;571	母材	408(最小值)
	592	焊道	
	551	熔合线	
GTAW + SMAW	539;546;561;531	母材	

表 8 弯曲试验结果数据

焊 接 方 法	弯 轴	断 裂 角 度
GTAW	3S	108°;108°;105°;57°;63°;58.5°
GTAW + SMAW	3S	55°;57°;42°;43°

(3) 工艺试验焊接接头外观成型良好, 表

面着色检查 (PT) 未发现裂纹, X 射线检查, 全部为 I 级片 (JB928-67 标准) 符合要求。

(4) 对 ZG4Cr25Ni20/1Cr5Mo 异种钢全 GTAW 焊接接头进行 650℃ 短时高温拉伸试验, 所有试件均在 1Cr5Mo 母材侧断裂, 试验结果见表 9。

4.3 焊接工艺试验结果分析

(1) 焊接接头强度均远高于 1Cr5Mo 的强度极限 (408MPa) 和 ZG4Cr25Ni20 的强度极限 (449MPa), 且大部分断裂位置在母材上, 说明接头强度性能良好。

(2) 对于 ZG4Cr25Ni20 国标中没有弯曲试验项目要求, 但我们对其进行了弯曲性能试验, 当弯曲角达到 23° (D=3S) 时整个试件断裂。而 ZG4Cr25Ni20/1Cr5Mo 异种钢接头的弯曲性能高于这种母材 (表 9)。

表 9 短时高温拉伸试验比较

试 件		试验温度(℃)	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ_5 (%)	ψ (%)
焊接接头	试件 1	650	205.8	181.2	21.85	91.24
	试件 2	650	202.1	170.3	20.14	91.93
	试件 3	650	209.4	191.1	19.35	91.24
	平均值	650	205.8	180.9	20.45	91.47
1Cr5Mo		650	183.5	76.5	46.0	91.0
ZG4Cr25Ni20		600	438	299.8	24.0	

(3) 表 7、表 8 两种不同焊接方法的拉断、弯曲结果数值, 一种是用镍基焊丝, 非熔化极氩弧焊封底和填充的焊接接头, 另一种是用镍基焊丝氩弧焊封底、NCF-HK 焊条手工电弧焊填充的焊接接头。尽管两者都能满足要求, 但前者的焊接接头强度较大, 弯曲角度也大, 充分说明采用镍基焊丝打底和填充的焊接接头更好。可惜的是, 只做了镍基焊丝焊接接头的短时高温拉伸试验, 没有做 NCF-HF 焊条手工电弧焊接头的短时高温拉伸试验, 无法比较其短时高温拉伸结果。

(4) 试验结论: 采用上述工艺试验参数, 两种焊接材料均能使焊接接头达到要求, 焊接工艺可行。在两种焊接材料中, 以选用 ERNiCr-3 焊丝更好。

5 焊接要点和措施

ZG4Cr25Ni20/1Cr5Mo 异种钢接头焊接难度较大, 除了必须按照工艺评定取得的资料遵守一般的焊接要求进行焊接外, 还要注意如下焊接作业要点和措施。

(1) 离心浇铸管表面存在一层疏松层, 内表面已加工去除, 外表面若未加工去除, 焊口两侧一定要加工去除干净。

(2) 定位焊必须在焊口处于自由状态进行, 焊点应保证熔透, 并且有一定长度, 点焊后打磨成缓坡状, 弧坑处应全部磨去, 仔细检查若发现裂纹即行去除。

(3) 为减小熔合比, 在保证熔合的前提下, 应控制焊接接头输入热量。

(4) 氩弧焊要在坡口内起弧, 施焊时应压

低电弧, 少摆动; 收弧时电流须逐渐衰减, 且将收弧点引至坡口一侧。

(5) 手工电弧焊起弧采用快速划擦法, 可避免起弧点出现气孔, 严禁用短弧焊接。

(6) 焊道层间清渣采用砂轮打磨, 不得使用尖锤敲击, 母材 ZG4Cr25Ni20 一侧不少于 100mm 范围内必须涂敷白垩粉, 防止焊接过程中污染产生裂纹。

(7) 封底焊后一定要经 PT 检查合格后方能进行填充焊。

(8) 尽量减少焊缝返修次数, 避免产生裂纹, 并延长使用寿命。

6 结束语

经过异种钢接头的焊接分析、工艺试验, 取得合理的焊接工艺参数, 并用于实际施焊, 解决了 ZG4Cr25Ni20/1Cr5Mo 接头焊接问题, 在南京炼油厂轻油制氢装置两台转化炉中分别采用了全部 ERNiCr-3 焊丝氩弧焊焊接和 ERNiCr-3 焊丝封底 NCF-HK 焊条填充焊接(由于供货原因)各 216 道焊口, 一次合格率达 92%。自 1986 年投产使用至今从未发生问题, 实践证明了上述工艺的可行性。

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· SUMMARY OF SPECIAL TOPICS ·

(1) Review and Prospect of China Spherical Vessel Construction (to be continued again)

Han Wei (Beijing)

This article introduces the history of China industrial spherical vessel since starting construction in 1958 and summarizes the development of China spherical vessel construction. It also shows some technical achievements coming up to the world advanced level and analyzes the difference to the world advanced technology level. Finally it forecasts the development prospect of China spherical vessel construction technology in 21st century.

Key words: Spherical tank, Spherical shell, Construction, Technique, Developing history, Review

(3) Selection of Fireproof Coating in Steel Structure of Petro - chemical Enterprise

Chen Shuzong (Beijing)

Since the late 1980s, the fireproof coating has been used in steel structure of petro - chemical enterprise. Due to various products in market, according to the problem on selecting fireproof coating, the article induces and raises some practicable methods on selection of fireproof coating.

Key words: Petrochemical industry, Equipment, Fire hazard, Extinguishing and protection, Coating material, Selection

(7) Type Selection of Inner Floating Disc in Storage Tank for Both Product Oil and Crude Oil

Liao Jiangui (Dagang, Tianjin) & *Gao Shusheng*

The aluminum assembling inner floating disc, researched and developed by our country, has been applied widely in oil storage tank with inner floating roof, but it has not been used in tank that stores condensation wax crude oil. In contrast with type selection, the paper indicates that measure of improving structure can make inner floating disc suitable to store product oil, crude oil with good physical characters and condensation wax crude oil.

Key words: Oil tank, Covered floating roof, Design, Selection

· WELDING TECHNOLOGY ·

(9) Submerged Arc Auto - welding in Reversal Installation of Vertical Storage Tank

Liu Lixin (Daqing, Heilongjiang), *Wang Zhiqiang* & *Liu Lianzeng*

The article reports the successful application of submerged arc welding technology in horizontal - position seam welding of two large storage tanks by reversal installation method, and introduces the character of domestic welding equipment, welding material selecting, welding process and contrast to cost of handing electric arc welding

Key words: Tank, Submerged arc welding, Weld inspection, Process parameter, Application

(12) Heterogeneous Steel Joint Welding of ZG4Cr25Ni20 and 1Cr5Mo

Zheng Xianglong (Nanjing, Jiangsu)

Regarding to the component and property of ZG4Cr25Ni20 and 1Cr5Mo, through analyzing the welding performance of the two materials and heterogeneous steel joint, determining terminal parameter, and working out the welding process, the technology of heterogeneous steel joint welding has good

effect in welding of conversion oven of hydrogen maker in Nanjing refinery.

Key words: Cast steel, Stainless steel, Welding, Technology, Testing, Application

(16) Property Analysis and Welding Process Control of 15CrMoR Thick Steel Plate Welding Joint
Li Fuheng (Beijing)

The conical section of reactor of refiner needs to be weld by 15CrMoR steel plate in thickness of 78mm. Through property examination of welding process and mechanical analysis of thick plate joint, according to several usual welding defects in thick plate welding, the researcher formulates process control measure and meets the requirements for reactor welding.

Key words: Reactor, Stainless steel, Welding, Performance test, Process parameter

· CONSTRUCTION & INSTALLATION ·

(19) Engineering Technology of Water Injection Pipeline Under Sea in Seashore Oilfield

Wang Zhiguo (Dongying, Shandong), *Liu Changjiang* & *Liu Hongsheng*

According to the technical difficulty of the engineering of water injection pipeline undersea in seashore oilfield, the article reports the character and application effect of inner coating protective cover with glass fiber reinforced plastic, and summarizes the construction method of dragging pipeline under sea bed and technology experience of pipe joint.

Key words: Beach, Oil field, Water flooding, Pipe line, Land, Offshore construction, Technique

(24) Summary of Installation and Calibration on DCS *Chen Shujun* (Jiaozhou, Shandong)

Compared with our practical experiences, this article introduces DCS's field installation program and how to calibrate it.

Key words: Oil refinery, Automation, Equipment, Mounting, Method

(27) Successful Research on Coal Ash Concrete Road Surface

Sun Keqin (Kalamayi, Xinjiang) & *Lou Jianjiang*

(28) Application of Wire Direction Control System in Directional Drilling Crossing

Fan Peiyan (Xuzhou, Jiangsu)

The paper introduces the working principle and character of wire direction control system that is the important matching equipment with directional drilling machine. By actual experience the article summarizes the technical point of wire direction control system in directional crossing engineering.

Key words: Pipeline crossing, Directional control, System, Detector, Construction, Application

(31) Inner and Outer Reversal Installation Engineering of Washing Oil Tank

Ji Haitao (Daqing, Heilongjiang) & *Liu Hai*

· ANTI CORROSION & THERMAL INSULATION ·

(33) Spraying of Fire Resistant Fiber on the Liner of Atmospheric Oven

Wang Tong (Lanzhou, Gansu) & *He Chunming*

Taking oven liner of constant pressure reduce unit in Lanzhou oil refinery for example, the article introduces the technical character and operating method of fire resistant fiber coating process. In contrast with fire resistant brick as oven liner, the fire resistant fiber coating process improves the oven liner quality, speeds up construction and reduces the labor strength.

Key words: Heat resistance, Fiber, Spray coating, Atmospheric pressure, Burner, Lining, Application, Feature

(36) The Technology of Multi-frequency Current Detection in Pipe and Its Application

Xue Dengcun (Renqiu, Hebei) & *Li Jingzhan*

The technology of multi-frequency current detection in pipe is a new technology which the destroy and the leak of the protective coating of pipe under ground can be found. The basic principles and detective system has been introduced. The outer protective coating of the petroleum pipeline from the first factory of Meng to the first factory of A of the Aershan oil field was detected in this technology. Not only the destroy of the protective coating was found, but the destroyed coating was repaired in time, and the basis of the repaired plan of the pipeline was provided. This method has several characteristics of easy to operate and accurate pointing and high detected degree of accuracy.

Key words: Oil pipeline, Corrosion control, Thermal insulation, Injury, Detection, Technique, Application

(39) Application of Rolling Fast Heating Oven in Prefabrication of Anti-corrosion and Thermal