



Cladding-Technology-Shanxi-Co.,-Ltd- CLADDING-MPS-002-Cladding-Elbow- MPS

堆焊弯头全流程工艺规范

Process Specification for Cladded Elbow Manufacturing

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1 目的 Purpose

本文件规定了科雷丁技术（山西）有限公司堆焊弯头从母材成形、表面预处理、TIG/MIG 精密堆焊、固溶热处理到机加工成形的全流程工艺规范，确保堆焊弯头产品满足 ASME B16.9、GB/T 12459 等标准要求，实现合金层与母材冶金结合良好、稀释率可控、表面质量达标。



This document specifies the complete process specification for cladded elbow manufacturing at CLADDING Technology (Shanxi) Co., Ltd., covering base material forming, surface preparation, TIG/MIG precision cladding, solution heat treatment, and machining to finished dimensions, ensuring cladded elbow products meet ASME B16.9 and GB/T 12459 standards requirements with sound metallurgical bonding between alloy layer and base material, controlled dilution rate, and qualified surface quality.

2 适用范围 Scope

本文件适用于公司生产的碳钢、低合金钢母材堆焊不锈钢、双相不锈钢、镍基合金等耐蚀合金层的弯头产品，涵盖 DN15-DN1200 规格范围，适用压力等级 Class 150-Class 2500。

This document applies to elbow products manufactured by the company with carbon steel and low alloy steel base materials clad with corrosion-resistant alloy layers including stainless steel, duplex stainless steel, and nickel-based alloys, covering DN15 to DN1200 size range and pressure ratings from Class 150 to Class 2500.

3 职责 Responsibilities

- | 部门 Department | 职责 Responsibilities |
- | 工艺技术部 Technology Department | 制定工艺规程、编制作业指导书、工艺参数确认 |
- | 生产部 Production Department | 按工艺要求组织生产、设备操作、过程记录 |
- | 质量管理部 Quality Management Department | 过程检验、成品检验、不合格品控制 |
- | 设备部 Equipment Department | 设备维护保养、工装夹具管理 |
- | 仓储部 Warehouse Department | 原材料验收、半成品标识流转 |

4 管理内容与程序 Management Content and Procedures

4.1 母材成形 Base Material Forming

4.1.1 原材料要求 Raw Material Requirements

母材应符合 GB/T 3077 或 ASTM A335 标准，化学成分、力学性能满足设计要求。材料入库前需查验材质证明书，进行光谱分析确认，不合格材料不得使用。

Base material shall comply with GB/T 3077 or ASTM A335 standards, with chemical composition and mechanical properties meeting design requirements. Material certification shall be verified before warehousing, and spectral analysis shall confirm composition. Non-conforming materials shall not be used.



4.1.2 弯头成形工艺 Elbow Forming Process

弯头采用热推弯或冷弯工艺成形，具体参数如下：

Elbows shall be formed by hot push bending or cold bending process with the following parameters:

| 参数 Parameter | 热推弯 Hot Push Bending | 冷弯 Cold Bending |

| 加热温度 Heating Temperature | 1050-1150°C | - |

| 弯曲半径 Bending Radius | $R \geq 1.5D$ | $R \geq 1.5D$ |

| 减薄率 Thinning Rate | $\leq 12.5\%$ | $\leq 8\%$ |

| 椭圆度 Ovality | $\leq 8\%$ | $\leq 5\%$ |

成形后弯头应进行外观检查，表面不得有裂纹、折叠、过烧等缺陷。

Formed elbows shall undergo visual inspection with no cracks, folds, or overheating defects on the surface.

4.2 堆焊前预处理 Pre-cladding Surface Preparation

4.2.1 坡口加工 Groove Preparation

堆焊区域坡口采用机械加工或等离子切割方式制备，坡口形式为 V 型或 U 型，具体参数：

Cladding area groove shall be prepared by machining or plasma cutting, with V-type or U-type groove configuration:

| 项目 Item | 参数要求 Specification |

| 坡口角度 Groove Angle | $60^\circ \pm 5^\circ$ |

| 钝边高度 Root Face | 1-2mm |

| 间隙 Gap | 0-2mm |

| 表面粗糙度 Surface Roughness | $Ra \leq 6.3\mu m$ |

4.2.2 表面清理 Surface Cleaning

堆焊前必须清除坡口及两侧各 20mm 范围内的油污、铁锈、氧化皮等杂质，采用丙酮或酒精擦拭，确保露出金属光泽。

Before cladding, oil, rust, oxide scale and other impurities within 20mm on both sides of the groove shall be removed by wiping with acetone or alcohol to expose metallic luster.

4.2.3 预热 Preheating

根据母材碳当量确定预热温度， $Ceq \geq 0.4\%$ 时预热至 100-150°C，预热范围不小于焊缝两侧各 100mm。



Preheating temperature shall be determined based on base material carbon equivalent. When $C_{eq} \geq 0.4\%$, preheat to 100-150°C with preheating range not less than 100mm on both sides of the weld.

4.3 堆焊工艺 Cladding Process

4.3.1 焊丝选择 Wire Selection

根据设计要求选择相应合金成分的堆焊焊丝，常用焊丝规格如下：

Cladding wire shall be selected according to design requirements with corresponding alloy composition. Common wire specifications:

合金类型 Alloy Type	焊丝牌号 Wire Grade	直径 Diameter	标准 Standard
304 不锈钢 304 SS	ER308L	Φ2.4-Φ3.2mm	AWS A5.4
316L 不锈钢 316L SS	ER316L	Φ2.4-Φ3.2mm	AWS A5.4
双相钢 Duplex SS	ER2209	Φ2.4-Φ3.2mm	AWS A5.9
镍基合金 Ni-based	ERNiCrMo-3	Φ2.4-Φ3.2mm	AWS A5.11

4.3.2 TIG 堆焊工艺参数 TIG Cladding Parameters

TIG 堆焊适用于打底焊道及薄层精密堆焊，工艺参数：

TIG cladding is suitable for root pass and thin layer precision cladding with the following parameters:

参数 Parameter	数值范围 Value Range
焊接电流 Welding Current	120-180A
电弧电压 Arc Voltage	10-14V
焊接速度 Welding Speed	80-150mm/min
氩气流量 Argon Flow Rate	12-18L/min
单道厚度 Single Pass Thickness	1.5-2.5mm
稀释率 Dilution Rate	≤25%

4.3.3 MIG 堆焊工艺参数 MIG Cladding Parameters

MIG 堆焊适用于中间层及盖面层的高效熔敷，工艺参数：

MIG cladding is suitable for efficient deposition of intermediate and cap layers with the following parameters:

参数 Parameter	数值范围 Value Range
焊接电流 Welding Current	200-320A



电弧电压 Arc Voltage	22-28V
焊接速度 Welding Speed	200-400mm/min
保护气体 Shielding Gas	Ar+CO₂(75%+25%)
气体流量 Gas Flow Rate	15-25L/min
单道厚度 Single Pass Thickness	2.5-4.0mm
稀释率 Dilution Rate	≤30%

4.3.4 堆焊层数与厚度控制 Layer Number and Thickness Control

堆焊总厚度根据设计要求确定，一般不小于 3mm。多层堆焊时，层间温度控制在 150-250℃，每层堆焊后需清除熔渣和飞溅。

Total cladding thickness shall be determined according to design requirements, generally not less than 3mm. For multi-layer cladding, interpass temperature shall be controlled at 150-250℃, and slag and spatter shall be removed after each layer.

4.3.5 堆焊顺序 Cladding Sequence

弯头堆焊采用分段退焊法，每段长度 100-150mm，堆焊方向沿弯头轴线方向，避免热输入集中导致变形。

Elbow cladding shall adopt segmented back-step welding method with each segment length of 100-150mm, cladding direction along elbow axis to avoid deformation caused by concentrated heat input.

4.4 热处理 Heat Treatment

4.4.1 固溶处理 Solution Treatment

堆焊完成后，弯头应进行固溶热处理，消除焊接应力，改善组织性能：

After cladding, elbows shall undergo solution heat treatment to eliminate welding stress and improve microstructure properties:

| 合金类型 Alloy Type | 加热温度 Heating Temperature | 保温时间 Holding Time | 冷却方式 Cooling Method |

| 304/316 不锈钢 SS 304/316 | 1050-1100℃ | 1h/25mm | 水冷 Water Quenching |

| 双相不锈钢 Duplex SS | 1020-1060℃ | 1h/25mm | 空冷 Air Cooling |

| 镍基合金 Ni-based Alloy | 1040-1120℃ | 1h/25mm | 水冷 Water Quenching |

4.4.2 应力消除 Stress Relief

对于不能进行固溶处理的合金，可采用应力消除处理：

For alloys that cannot undergo solution treatment, stress relief treatment may be adopted:



合金类型 Alloy Type 温度 Temperature 时间 Time
不锈钢 Stainless Steel 850-900°C 1-2h
镍基合金 Ni-based Alloy 700-800°C 1-2h

4.5 机加工 Machining

4.5.1 加工余量 Machining Allowance

堆焊层加工余量根据堆焊厚度确定，一般单边留 2-3mm:

Machining allowance for cladding layer shall be determined according to cladding thickness, generally 2-3mm per side:

堆焊厚度 Cladding Thickness 加工余量 Machining Allowance
3-5mm 2mm
5-8mm 2.5mm
8-12mm 3mm

4.5.2 加工要求 Machining Requirements

机加工应采用专用工装夹具，避免夹伤堆焊层。切削参数应适当降低，防止堆焊层剥落:

Machining shall use special fixtures to avoid damaging the cladding layer. Cutting parameters shall be appropriately reduced to prevent cladding layer spalling:

加工工序 Machining Operation 切削速度 Cutting Speed 进给量 Feed Rate
粗车 Rough Turning 80-120m/min 0.3-0.5mm/r
精车 Finish Turning 120-180m/min 0.1-0.2mm/r
钻孔 Drilling 60-100m/min 0.1-0.3mm/r

4.5.3 尺寸精度 Dimensional Accuracy

机加工后弯头尺寸精度应符合以下要求:

Machined elbow dimensional accuracy shall meet the following requirements:

项目 Item 精度要求 Accuracy Requirement
外径 Outer Diameter $\pm 0.5\text{mm}$
内径 Inner Diameter $\pm 0.5\text{mm}$
壁厚 Wall Thickness $\pm 0.3\text{mm}$
角度 Angle $\pm 0.5^\circ$
表面粗糙度 Surface Roughness $Ra \leq 3.2\mu\text{m}$



5 质量检验 Quality Inspection

5.1 外观检验 Visual Inspection

堆焊层表面应均匀致密，不得有裂纹、气孔、夹渣、未熔合等缺陷。表面粗糙度 $Ra \leq 12.5\mu m$ 。

Cladding layer surface shall be uniform and dense, with no cracks, porosity, slag inclusion, or lack of fusion defects. Surface roughness $Ra \leq 12.5\mu m$.

5.2 尺寸检验 Dimensional Inspection

堆焊层厚度、弯头几何尺寸应符合图纸要求，检测方法采用超声波测厚仪或机械加工后测量。

Cladding layer thickness and elbow geometric dimensions shall comply with drawing requirements, detected by ultrasonic thickness gauge or measurement after machining.

5.3 无损检测 Non-destructive Testing

堆焊层应进行 100% 渗透检测或磁粉检测，发现裂纹等缺陷应返修。

Cladding layer shall undergo 100% penetrant testing or magnetic particle testing. Cracks and other defects shall be repaired.

5.4 化学成分分析 Chemical Composition Analysis

堆焊层化学成分应符合设计要求，采用光谱分析或化学分析方法检测。

Cladding layer chemical composition shall comply with design requirements, detected by spectral analysis or chemical analysis method.

5.5 力学性能试验 Mechanical Property Testing

堆焊层及熔合区应进行硬度试验，硬度值应符合标准要求。

Cladding layer and fusion zone shall undergo hardness testing, with hardness values meeting standard requirements.

6 不合格品控制 Non-conforming Product Control

6.1 缺陷分类 Defect Classification

| 缺陷类型 Defect Type | 判定标准 Acceptance Criteria | 处理措施 Disposal Method |

| 裂纹 Cracks | 不允许 Not Permitted | 打磨清除后重新堆焊 |

| 气孔 Porosity | $\Phi \leq 1mm$, 间距 $\geq 3mm$ | 打磨清除后补焊 |



| 夹渣 Slag Inclusion | 不允许 Not Permitted | 打磨清除后重新堆焊 |

| 未熔合 Lack of Fusion | 不允许 Not Permitted | 打磨清除后重新堆焊 |

6.2 返修要求 Repair Requirements

返修前需编制返修方案，经技术部门审批后实施。返修区域应打磨至露出金属光泽，返修后重新进行检验。

Repair procedure shall be prepared and approved by technology department before implementation. Repair area shall be ground to expose metallic luster, and re-inspection shall be conducted after repair.

7 记录与标识 Records and Identification

7.1 过程记录 Process Records

生产过程中的关键参数应如实记录，包括：

Key parameters during production shall be truthfully recorded, including:

- 母材材质证明 Base material certification
- 堆焊工艺参数记录 Cladding process parameter records
- 热处理曲线 Heat treatment curves
- 检验报告 Inspection reports
- 不合格品处理记录 Non-conforming product disposal records

7.2 产品标识 Product Identification

堆焊弯头应进行唯一性标识，包括产品编号、规格型号、生产日期、操作者等信息。

Cladded elbows shall have unique identification including product number, specification model, production date, and operator information.

8 安全与环保 Safety and Environmental Protection

8.1 安全防护 Safety Protection

操作人员应佩戴防护眼镜、焊接面罩、防护手套等劳动防护用品，作业现场应配备灭火器材。

Operators shall wear protective goggles, welding masks, protective gloves and other personal protective equipment. Fire extinguishing equipment shall be provided at work sites.



8.2 环境保护 Environmental Protection

焊接烟尘应通过除尘设备处理，废焊丝、废切削液等废弃物应分类收集，交由有资质的单位处理。

Welding fumes shall be treated through dust removal equipment. Waste welding wire, waste cutting fluid and other waste shall be classified and collected, and disposed by qualified units.

9 附则 Supplementary Provisions

9.1 文件管理 Document Management

工艺技术部负责编制、修订和解释，每年评审一次，必要时进行修订。

This document shall be prepared, revised and interpreted by the Technology Department, reviewed annually, and revised when necessary.

9.2 相关文件 Related Documents

- CLADDING-MPS-001 增材制造工艺规范 Additive Manufacturing Process Specification
- CLADDING-MPS-003 法兰堆焊工艺规范 Flange Cladding Process Specification
- CLADDING-MPS-004 钢管堆焊工艺规范 Pipe Cladding Process Specification

9.3 修订记录 Revision History

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