



Cladding-Technology-Shanxi-Co.,-Ltd- CLADDING-MPS-024-Explosion- Cladding-Layer-Process-Specification

爆炸复合堆焊工艺控制与结合质量检验管理程序

Explosive Cladding Process Control and Bond Quality Inspection Management Procedure

文件编号 Document No.: CLADDING-MPS-024

版本号 Revision: A/0

生效日期 Effective Date: 2024-01-15

编制 Prepared by	审核 Reviewed by	批准 Approved by
工艺工程部	质量部	总经理
Process Engineering	Quality Department	General Manager

1. 目的 Purpose

本程序旨在规范科雷丁技术（山西）有限公司爆炸复合堆焊工艺中炸药量控制、间隔距离设定及结合质量检验的管理要求，确保爆炸复合板材及管件产品的结合强度、界面质量符合技术标准与客户要求。



This procedure aims to standardize the management requirements for explosive charge control, standoff distance setting, and bond quality inspection in the explosive cladding process of CLADDING Technology (Shanxi) Co., Ltd., ensuring that the bond strength and interface quality of explosively bonded plates and pipe products meet technical standards and customer requirements.

2. 适用范围 Scope

本程序适用于公司爆炸复合堆焊生产线，涵盖以下产品与工艺环节：

This procedure applies to the explosive cladding production line of the company, covering the following products and process stages:

- 爆炸复合板制造（碳钢/不锈钢、碳钢/钛、碳钢/镍基合金等）
- Explosive clad plate manufacturing (carbon steel/stainless steel, carbon steel/titanium, carbon steel/nickel-based alloy, etc.)
- 爆炸复合管件制造（法兰堆焊复合、钢管堆焊复合）
- Explosive clad pipe manufacturing (flange cladding composite, steel pipe cladding composite)
- 爆炸复合轴套管、模具修复件
- Explosive clad shaft sleeves and mold repair components
- 炸药量计算与配比、间隔距离设定、爆轰参数控制
- Explosive charge calculation and proportioning, standoff distance setting, detonation parameter control
- 结合质量检验（超声波检测、拉伸试验、弯曲试验、金相分析）
- Bond quality inspection (ultrasonic testing, tensile testing, bend testing, metallographic analysis)

3. 职责 Responsibilities

3.1 工艺工程部 Process Engineering Department

- 负责爆炸复合堆焊工艺参数设计，包括炸药量计算、间隔距离确定、爆轰方向与速度设定
- Responsible for explosive cladding process parameter design, including explosive charge calculation, standoff distance determination, detonation direction and velocity setting
- 编制爆炸复合工艺卡，明确各产品规格的工艺参数要求
- Prepare explosive cladding process cards specifying process parameter requirements for each product specification
- 负责工艺参数变更的技术评审与验证
- Responsible for technical review and verification of process parameter changes

3.2 生产部 Production Department

- 严格按照工艺卡执行炸药装药、间隔距离调整及爆轰操作



- Execute explosive loading, standoff distance adjustment, and detonation operations strictly according to process cards
- 负责爆炸作业现场的安全管理与防护设施配置
- Responsible for safety management and protective facility configuration at explosive operation sites
- 记录生产过程中的关键参数与异常情况
- Record key parameters and abnormal conditions during production

3.3 质量部 Quality Department

- 负责爆炸复合产品结合质量的检验与判定
- Responsible for inspection and judgment of bond quality of explosively clad products
- 制定并执行超声波检测、力学性能试验、金相分析等检验方案
- Develop and execute inspection plans including ultrasonic testing, mechanical property testing, metallographic analysis, etc.
- 出具检验报告，对不合格品进行标识与处置
- Issue inspection reports, identify and dispose of non-conforming products

3.4 安全环保部 Safety and Environmental Protection Department

- 负责爆炸作业的安全审批与现场监督
- Responsible for safety approval and on-site supervision of explosive operations
- 监督炸药储存、运输、使用及废料处置的合规性
- Supervise compliance of explosive storage, transportation, usage, and waste disposal

4. 管理内容与程序 Management Content and Procedures

4.1 炸药量控制 Explosive Charge Control

4.1.1 炸药量计算原则

爆炸复合堆焊的炸药量应根据覆层材料、基体材料、板厚、复合宽度及目标爆轰速度进行计算，计算公式如下：

The explosive charge for explosive cladding shall be calculated based on the cladding material, base material, plate thickness, cladding width, and target detonation velocity. The calculation formula is as follows:

参数 Parameter	符号 Symbol	单位 Unit	说明 Description
炸药线密度	q	g/cm	单位长度炸药质量



覆层厚度	h_1	mm	覆层材料厚度
基体厚度	h_2	mm	基体材料厚度
爆轰速度	D	m/s	目标爆轰速度
炸药密度	ρ	g/cm^3	所用炸药密度
装药宽度	b	mm	炸药装药宽度

炸药线密度计算公式：

Explosive linear density calculation formula:

$$q = (\rho \times b \times D^2) / (2 \times (h_1 + h_2) \times 1000)$$

4.1.2 常用材料炸药量参考值

覆层材料 Cladding Material	基体材料 Base Material	覆层厚度 Cladding Thickness (mm)	炸药线密度 Explosive Linear Density (g/cm)	爆轰速度 Detonation Velocity (m/s)
304 不锈钢 Stainless Steel 304	Q235 碳钢 Carbon Steel Q235	3-6	8-15	2000-2800
316L 不锈钢 Stainless Steel 316L	Q345 低合金钢 Low-alloy Steel Q345	4-8	10-18	2200-3000
纯钛 Pure Titanium	Q235 碳钢 Carbon Steel Q235	2-4	6-12	1800-2500
哈氏合金 Hastelloy	碳钢 Carbon Steel	3-6	12-20	2500-3200
镍基合金 Nickel- based Alloy	不锈钢 Stainless Steel	4-10	15-25	2800-3500

4.1.3 炸药装药要求

- 炸药应采用连续装药方式，装药密度均匀，不得出现断药、空腔现象
- Explosives shall be loaded continuously with uniform density, without gaps or voids
- 装药宽度应比覆层宽度大 10-20mm，确保边缘结合质量
- The charge width shall be 10-20mm larger than the cladding width to ensure edge bond quality
- 炸药与覆层之间应铺设隔离层（通常为橡胶或泡沫材料），厚度为 2-5mm



- A separator layer (usually rubber or foam material) shall be placed between the explosive and the cladding, with a thickness of 2-5mm
- 装药完成后应进行外观检查，确认装药质量符合要求
- After loading, visual inspection shall be performed to confirm that the charge quality meets requirements

4.2 间隔距离控制 Standoff Distance Control

4.2.1 间隔距离定义

间隔距离（Standoff Distance）是指覆层板与基体板之间的初始间距，是影响爆炸复合结合质量的关键参数。

The standoff distance refers to the initial gap between the cladding plate and the base plate, which is a key parameter affecting the bond quality of explosive cladding.

4.2.2 间隔距离计算

间隔距离应根据材料组合、板厚及目标结合波形进行确定，计算公式如下：

The standoff distance shall be determined based on the material combination, plate thickness, and target bond waveform. The calculation formula is as follows:

$$S = K \times (h_1 + h_2) \times (D / 1000)$$

其中：

Where:

- S: 间隔距离，mm
- S: Standoff distance, mm
- K: 材料系数，碳钢/不锈钢组合取 0.8-1.2，碳钢/钛组合取 0.6-1.0
- K: Material coefficient, 0.8-1.2 for carbon steel/stainless steel combination, 0.6-1.0 for carbon steel/titanium combination
- h_1 : 覆层厚度，mm
- h_1 : Cladding thickness, mm
- h_2 : 基体厚度，mm
- h_2 : Base thickness, mm
- D: 爆轰速度，m/s
- D: Detonation velocity, m/s

4.2.3 间隔距离调整要求

- 间隔距离调整精度应控制在 $\pm 0.5\text{mm}$ 以内
- Standoff distance adjustment accuracy shall be controlled within $\pm 0.5\text{mm}$
- 调整完成后应使用塞尺或专用量具进行多点测量确认



- After adjustment, multi-point measurement confirmation shall be performed using feeler gauges or special measuring tools
- 对于长尺寸板材，应分段测量间隔距离，每段长度不超过 2m
- For long plates, standoff distance shall be measured in sections, with each section not exceeding 2m
- 间隔距离调整记录应纳入工艺文件存档
- Standoff distance adjustment records shall be included in process documents for archiving

4.3 爆轰参数控制 Detonation Parameter Control

4.3.1 爆轰方向与速度

产品规格 Product Specification	爆轰方向 Detonation Direction	爆轰速度 Detonation Velocity (m/s)	起爆方式 Initiation Method
复合板 Clad Plate	纵向 Longitudinal	2000-3500	单端起爆 Single-end initiation
复合管件 Clad Pipe	轴向 Axial	1800-2800	单端起爆 Single-end initiation
法兰复合件 Flange Clad Component	径向 Radial	1500-2200	多点起爆 Multi-point initiation

4.3.2 爆轰约束条件

- 基体板应牢固固定在约束装置上，防止爆轰过程中发生位移
- The base plate shall be firmly fixed on the constraint device to prevent displacement during detonation
- 约束装置应能承受爆轰冲击载荷，不得发生变形或损坏
- The constraint device shall be able to withstand detonation impact loads without deformation or damage
- 爆轰区域应设置防护屏障，确保人员与设备安全
- Protective barriers shall be set up in the detonation area to ensure personnel and equipment safety

4.4 结合质量检验 Bond Quality Inspection

4.4.1 超声波检测 Ultrasonic Testing

超声波检测是爆炸复合产品结合质量的主要检验方法，检验要求如下：

Ultrasonic testing is the main inspection method for bond quality of explosively clad products. The inspection requirements are as follows:



检验项目 Inspection Item	标准要求 Standard Requirement	检测方法 Test Method	判定准则 Acceptance Criteria
结合率 Bonding Rate	≥95%	A 型脉冲反射法 Type A pulse echo method	未结合面积占比≤5% Unbonded area ratio ≤5%
界面波形 Interface Waveform	连续波形 Continuous waveform	斜探头检测 Angled probe testing	波形连续，无断续现象 Continuous waveform without interruption
缺陷尺寸 Defect Size	单点≤3mm	定量检测 Quantitative testing	单个未结合点直径≤3mm Single unbonded point diameter ≤3mm

4.4.2 力学性能试验 Mechanical Property Testing

试验项目 Test Item	标准要求 Standard Requirement	试样规格 Specimen Specification	试验方法 Test Method
拉伸试验 Tensile Test	抗拉强度≥覆层与基体中较低者 Tensile strength ≥ lower of cladding and base	板状试样 Plate specimen	GB/T 26519 GB/T 26519
弯曲试验 Bend Test	180°弯曲无开裂 180° bend without cracking	板状试样 Plate specimen	GB/T 26519 GB/T 26519
剪切试验 Shear Test	剪切强度≥150MPa Shear strength ≥150MPa	圆棒试样 Round bar specimen	GB/T 26519 GB/T 26519

4.4.3 金相分析 Metallographic Analysis

- 在复合界面处截取金相试样，观察结合界面形态
- Metallographic specimens shall be cut at the bond interface to observe the interface morphology
- 合格界面应呈现波状结合特征，波峰波谷清晰可见
- Qualified interface shall show wavy bond characteristics with clearly visible peaks and valleys
- 界面处不得存在明显孔洞、夹杂或未结合区域
- No obvious pores, inclusions, or unbonded areas shall exist at the interface
- 金相分析结果应拍照记录并纳入检验报告
- Metallographic analysis results shall be photographed and included in the inspection report



4.4.4 检验频次与抽样方案

产品类型 Product Type	检验频次 Inspection Frequency	抽样方案 Sampling Plan
复合板 Clad Plate	每批次每规格 100%超声波检测 100% UT per batch per specification	力学性能试验每批次≥3 组 Mechanical test ≥3 sets per batch
复合管件 Clad Pipe	每批次 100%超声波检测 100% UT per batch	力学性能试验每批次≥2 组 Mechanical test ≥2 sets per batch
法兰复合件 Flange Clad Component	每件 100%超声波检测 100% UT per piece	力学性能试验每批次≥2 组 Mechanical test ≥2 sets per batch

4.5 不合格品处置 Non-conforming Product Disposition

当结合质量检验不合格时，应按以下程序处置：

When bond quality inspection fails, the following procedure shall be followed:

1. 质量部出具不合格品报告，标识不合格区域

Quality Department shall issue a non-conforming product report and identify the non-conforming area

2. 工艺工程部分析不合格原因，确定处置方案

Process Engineering Department shall analyze the cause of non-conformance and determine the disposition plan

3. 处置方案包括：

Disposition plans include:

- 返工：调整工艺参数后重新爆轰复合
- Rework: Re-detonation cladding after adjusting process parameters
- 补焊：对局部未结合区域进行 TIG 或 MIG 补焊
- Repair welding: TIG or MIG repair welding for local unbonded areas
- 降级使用：降低产品等级或改变用途
- Downgrade: Reduce product grade or change application
- 报废：无法修复时予以报废处理
- Scrap: Scrap when unrecoverable

4. 返工或补焊后应重新进行结合质量检验

Bond quality inspection shall be re-performed after rework or repair welding

5. 不合格品处置记录应纳入质量档案



Non-conforming product disposition records shall be included in quality archives

5. 监督考核 Supervision and Assessment

5.1 监督检查

- 工艺工程部每月对炸药量计算、间隔距离调整进行抽查，抽查比例不低于 20%
- Process Engineering Department shall conduct monthly spot checks on explosive charge calculation and standoff distance adjustment, with a spot check ratio of no less than 20%
- 质量部每月对结合质量检验结果进行统计分析，识别质量趋势
- Quality Department shall conduct monthly statistical analysis of bond quality inspection results to identify quality trends
- 安全环保部每季度对爆炸作业安全情况进行检查评估
- Safety and Environmental Protection Department shall conduct quarterly inspection and assessment of explosive operation safety

5.2 考核指标

考核指标 Assessment Indicator	目标值 Target Value	考核周期 Assessment Period
结合率合格率 Bonding Rate Qualification Rate	≥98%	月度 Monthly
一次检验合格率 First-pass Inspection Qualification Rate	≥95%	月度 Monthly
工艺参数执行符合率 Process Parameter Compliance Rate	100%	月度 Monthly
安全事故发生率 Safety Accident Rate	0	季度 Quarterly

5.3 持续改进

- 对检验不合格案例进行分析，制定纠正预防措施
- Analyze inspection failure cases and develop corrective and preventive measures
- 定期评审工艺参数，优化炸药量与间隔距离设定
- Regularly review process parameters and optimize explosive charge and standoff distance settings
- 收集客户反馈，持续改进结合质量水平
- Collect customer feedback and continuously improve bond quality level



6. 相关文件与记录 Related Documents and Records

6.1 相关文件

文件编号 Document No.	文件名称 Document Title
CLADDING-MPS-001	爆炸复合堆焊工艺规程 Explosive Cladding Process Specification
CLADDING-MPS-015	超声波检测作业指导书 Ultrasonic Testing Work Instruction
CLADDING-MPS-018	力学性能试验管理程序 Mechanical Property Testing Management Procedure
CLADDING-MPS-022	不合格品控制程序 Non-conforming Product Control Procedure

6.2 记录表格

记录编号 Record No.	记录名称 Record Title	保存期限 Retention Period
CLADDING-FRM-024-01	炸药量计算记录表 Explosive Charge Calculation Record	3 年 3 Years
CLADDING-FRM-024-02	间隔距离调整记录表 Standoff Distance Adjustment Record	3 年 3 Years
CLADDING-FRM-024-03	超声波检测报告 Ultrasonic Testing Report	产品寿命期 Product Life
CLADDING-FRM-024-04	力学性能试验报告 Mechanical Property Test Report	产品寿命期 Product Life
CLADDING-FRM-024-05	金相分析报告 Metallographic Analysis Report	产品寿命期 Product Life
CLADDING-FRM-024-06	不合格品处置记录表 Non-conforming Product Disposition Record	3 年 3 Years



7. 附则 Supplementary Provisions

7.1 本程序由工艺工程部负责解释和修订

This procedure shall be interpreted and revised by the Process Engineering Department.

7.2 本程序自发布之日起生效实施

This procedure shall take effect from the date of issuance.

7.3 本程序每年评审一次，必要时进行修订

This procedure shall be reviewed annually and revised when necessary.

文件修订记录 Document Revision History

版本号 Revision	修订日期 Revision Date	修订内容 Revision Content	修订人 Revised by
A/0	2024-01-15	首次发布 Initial Release	工艺工程部 Process Engineering

科雷丁技术（山西）有限公司

CLADDING Technology (Shanxi) Co., Ltd.