



Cladding-Technology-Shanxi-Co.,-Ltd- CLADDING-ITP-015-Cladding-High- Temperature-Pipe-Fitting-ITP

ITP-015 高温堆焊管件检验与试验计划

ITP-015 Inspection and Test Plan for High-Temperature Cladded Pipe Fittings

文件编号 Document No.	CLADDING-ITP-015
版本号 Version	A/0
发布日期 Issue Date	2025-01-15
编制 Prepared by	质量管理部 Quality Management Dept.
审核 Reviewed by	技术部 Technical Dept.
批准 Approved by	总经理 General Manager



1. 目的 Purpose

本检验与试验计划（ITP）旨在规范科雷丁技术（山西）有限公司高温堆焊管件产品的高温蠕变试验、组织稳定性检验与硬度检验的程序、方法及验收标准，确保堆焊管件在长期高温服役条件下的结构完整性与性能可靠性，满足客户及行业标准要求。

This Inspection and Test Plan (ITP) is established to standardize the procedures, methods and acceptance criteria for high-temperature creep testing, microstructural stability inspection and hardness testing of high-temperature clad pipe fittings produced by Cladding-Technology-Shanxi-Co.,-Ltd, ensuring structural integrity and performance reliability of clad pipe fittings under long-term high-temperature service conditions, and meeting customer and industry standard requirements.

2. 适用范围 Scope

本 ITP 适用于公司采用 TIG 堆焊、MIG 堆焊及电弧增材制造工艺生产的各类高温堆焊管件产品，包括但不限于：

This ITP applies to all types of high-temperature clad pipe fittings produced by the company using TIG cladding, MIG cladding and arc additive manufacturing processes, including but not limited to:

- 法兰堆焊管件 Flanged clad pipe fittings
- 管件堆焊产品 Clad pipe fitting products
- 钢管堆焊产品 Clad steel pipe products
- 轴套管堆焊产品 Clad shaft sleeve products
- 模具堆焊修复产品 Clad mold repair products

适用工况条件：设计温度 $\geq 400^{\circ}\text{C}$ 的高温高压管道系统，涉及石化、电力、冶金等行业的高温介质输送管道。

Applicable service conditions: High-temperature and high-pressure piping systems with design temperature $\geq 400^{\circ}\text{C}$, involving high-temperature medium conveying pipelines in petrochemical, power and metallurgical industries.

3. 职责 Responsibilities

部门/岗位 Department/Position	职责 Responsibilities
质量管理部 Quality Management Dept.	负责本 ITP 的编制、修订与解释；组织实施各项检验与试验；编制检验报告并存档
技术部 Technical Dept.	负责确定检验方案、工艺参数及验收标准；提供



	技术支持与问题处理
生产部 Production Dept.	负责按工艺要求完成堆焊作业；配合取样与试验准备工作
设备管理部 Equipment Management Dept.	负责检验设备的维护保养与计量校准
总经理 General Manager	负责本 ITP 的批准与资源保障

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

4.1 检验项目总览 Overview of Inspection Items

序号 No.	检验项目 Inspection Item	检验阶段 Inspection Stage	检验方法 Inspection Method	抽样比例 Sampling Ratio	责任部门 Responsible Dept.
1	高温蠕变试验 High-Temperature Creep Test	成品检验 Final Inspection	蠕变试验机测试 Creep Testing Machine Test	每批次 1 件 /100 件 Each batch 1 pc/100 pcs	质量管理部 Quality Management Dept.
2	组织稳定性检验 Microstructural Stability Inspection	成品检验 Final Inspection	金相显微镜分析 Metallographic Microscope Analysis	每批次 1 件 /100 件 Each batch 1 pc/100 pcs	质量管理部 Quality Management Dept.
3	硬度检验 Hardness Test	过程检验/成品检验 Process/Final Inspection	洛氏/维氏硬度计 Rockwell/Vickers Hardness Tester	100%全检 100% Full Inspection	质量管理部 Quality Management Dept.

4.2 高温蠕变试验 High-Temperature Creep Test

4.2.1 试验目的 Test Purpose

验证堆焊管件在高温长期载荷作用下的抗蠕变性能，评估堆焊层与母材结合区在高温服役条件下的结构稳定性，确保产品满足设计使用寿命要求。



Verify the creep resistance of cladded pipe fittings under long-term high-temperature loading, evaluate the structural stability of the cladding layer and base metal bonding zone under high-temperature service conditions, and ensure the product meets the designed service life requirements.

4.2.2 试验设备 Test Equipment

设备名称 Equipment Name	型号/规格 Model/Specification	精度要求 Accuracy Requirement	校准周期 Calibration Cycle
高温蠕变试验机 High-Temperature Creep Testing Machine	额定温度 $\geq 800^{\circ}\text{C}$ Rated Temperature $\geq 800^{\circ}\text{C}$	温度控制精度 $\pm 1^{\circ}\text{C}$ Temperature Control Accuracy $\pm 1^{\circ}\text{C}$	12 个月 12 months
引伸计 Extensometer	量程 0-10mm Range 0-10mm	分辨率 0.001mm Resolution 0.001mm	12 个月 12 months
热电偶 Thermocouple	K 型/K-type	精度 $\pm 1.5^{\circ}\text{C}$ Accuracy $\pm 1.5^{\circ}\text{C}$	6 个月 6 months

4.2.3 试样制备 Specimen Preparation

试样从堆焊管件成品上截取，试样尺寸应符合 GB/T 2039-2012 《金属蠕变持久试验方法》要求：

Specimens shall be cut from finished cladded pipe fittings, and specimen dimensions shall comply with GB/T 2039-2012 "Method for Metal Creep and Rupture Testing":

- 试样标距长度：50mm Specimen gauge length: 50mm
- 试样直径：6mm Specimen diameter: 6mm
- 试样数量：每批次不少于 3 件 Number of specimens: not less than 3 pcs per batch
- 试样方向：堆焊层与母材界面方向 Specimen orientation: cladding layer and base metal interface direction

试样制备要求：

Specimen preparation requirements:

- 试样加工应采用线切割或精车工艺，避免产生加工硬化 Specimen machining shall use wire cutting or precision turning process to avoid work hardening
- 试样表面粗糙度 $Ra \leq 3.2\mu\text{m}$ Specimen surface roughness $Ra \leq 3.2\mu\text{m}$
- 试样两端应加工螺纹，便于装夹 Both ends of specimen shall be threaded for clamping

4.2.4 试验条件 Test Conditions

参数 Parameter	条件 Condition	备注 Remarks
--------------	--------------	------------



试验温度 Test Temperature	按产品设计温度+50℃或 600℃ (取较高值) According to design temperature +50℃ or 600℃ (whichever is higher)	依据客户技术要求 According to customer technical requirements
试验应力 Test Stress	材料屈服强度的 30%-50% 30%- 50% of material yield strength	依据设计载荷确定 Determined according to design load
试验时间 Test Duration	不少于 1000 小时 Not less than 1000 hours	加速试验可适当缩短 Accelerated test may be appropriately shortened
环境介质 Environment	空气或惰性气体保护 Air or inert gas protection	依据实际工况 According to actual service conditions

4.2.5 试验步骤 Test Procedure

1. 将试样安装于蠕变试验机，确保试样轴线与加载方向一致 Install the specimen on the creep testing machine, ensuring the specimen axis is consistent with the loading direction
2. 安装引伸计，调整至初始读数零点 Install the extensometer and adjust to initial zero reading
3. 启动加热系统，以 5℃/min 的速率升温至目标试验温度 Start the heating and raise temperature to target test temperature at a rate of 5℃/min
4. 温度稳定后（波动 $\leq\pm 1^{\circ}\text{C}$ ），施加试验载荷 After temperature stabilization (fluctuation $\leq\pm 1^{\circ}\text{C}$), apply test load
5. 记录初始变形量，开始计时 Record initial deformation and start timing
6. 按以下时间节点记录变形数据： Record deformation data at the following time intervals:
 - 0-100 小时：每 10 小时记录一次 0-100 hours: record once every 10 hours
 - 100-500 小时：每 50 小时记录一次 100-500 hours: record once every 50 hours
 - 500 小时以上：每 100 小时记录一次 Above 500 hours: record once every 100 hours
7. 试验结束后，记录最终变形量及断裂情况（如发生断裂） After test, record final deformation and fracture condition (if fracture occurs)
8. 绘制蠕变曲线（应变-时间曲线） Plot creep curve (strain-time curve)

4.2.6 验收标准 Acceptance Criteria

检验项目 Inspection Item	合格标准 Acceptance Criteria
稳态蠕变率 Steady-state creep rate	$\leq 1 \times 10^{-6}\%/h$ （依据材料等级确定） $\leq 1 \times 10^{-6}\%/h$ (determined according to material grade)
1000 小时总蠕变量 Total creep strain at 1000h	$\leq 0.5\%$ （依据设计要求确定） $\leq 0.5\%$ (determined



	according to design requirements)
蠕变断裂时间 Creep rupture time	≥设计寿命的 1.5 倍 ≥1.5 times of designed service life
堆焊层与母材结合区 Creep deformation at cladding-base interface	无界面开裂、无分层现象 No interface cracking, no delamination

4.3 组织稳定性检验 Microstructural Stability Inspection

4.3.1 检验目的 Inspection Purpose

评估堆焊管件在高温长期服役后堆焊层及热影响区的组织稳定性，验证堆焊工艺参数选择的合理性，确保产品在使用过程中不会因组织劣化导致性能下降。

Evaluate the microstructural stability of cladding layer and heat affected zone of cladded pipe fittings after long-term high-temperature service, verify the rationality of cladding process parameter selection, and ensure that the product will not suffer performance degradation due to microstructural deterioration during use.

4.3.2 检验设备 Inspection Equipment

设备名称 Equipment Name	型号/规格 Model/Specification	精度要求 Accuracy Requirement
金相显微镜 Metallographic Microscope	放大倍数 50-1000 倍 Magnification 50-1000x	分辨率≤0.2μm Resolution ≤0.2μm
扫描电镜（可选） SEM (Optional)	分辨率≤1nm Resolution ≤1nm	用于微观组织分析 For microstructural analysis
试样抛光机 Specimen Polishing Machine	转速 0-3000rpm Speed 0-3000rpm	抛光精度≤0.01μm Polishing accuracy ≤0.01μm

4.3.3 试样制备 Specimen Preparation

试样从堆焊管件成品上截取，包含堆焊层、热影响区和母材三个区域：

Specimens shall be cut from finished cladded pipe fittings, including three zones: cladding layer, heat affected zone and base metal:

- 试样尺寸：20mm×20mm×10mm Specimen size: 20mm×20mm×10mm
- 取样位置：堆焊层与母材界面区域 Sampling position: cladding layer and base metal interface area
- 试样数量：每批次不少于 2 件 Number of specimens: not less than 2 pcs per batch



试样制备流程:

Specimen preparation procedure:

9. 切割取样 Cutting sampling
10. 镶嵌（必要时） Mounting (if necessary)
11. 粗磨（180#-800#砂纸） Coarse grinding (180#-800# sandpaper)
12. 精磨（1000#-2000#砂纸） Fine grinding (1000#-2000# sandpaper)
13. 抛光（金刚石抛光膏） Polishing (diamond polishing paste)
14. 腐蚀（依据材料选择腐蚀剂） Etching (select etchant according to material)

常用腐蚀剂:

Common etchants:

- 不锈钢堆焊层：王水（HCl:HNO₃=3:1） Stainless steel cladding layer: aqua regia (HCl:HNO₃=3:1)
- 碳钢母材：4%硝酸酒精溶液 4% nitric acid alcohol solution for carbon steel base metal
- 镍基合金：HCl+H₂O₂混合液 HCl+H₂O₂ mixed solution for nickel-based alloy

4.3.4 检验内容 Inspection Content

检验项目 Inspection Item	检验方法 Inspection Method	检验要求 Inspection Requirements
堆焊层组织 Cladding layer microstructure	光学显微镜观察 Optical microscope observation	组织均匀，无粗大晶粒，无异常析出相 Uniform microstructure, no coarse grains, no abnormal precipitates
热影响区组织 HAZ microstructure	光学显微镜观察 Optical microscope observation	晶粒尺寸≤基体材料的 1.5 倍 Grain size ≤1.5 times of base material
堆焊层与母材结合界面 Cladding-base metal interface	光学显微镜/SEM 观察 Optical microscope/SEM observation	结合良好，无未熔合、无裂纹 Good bonding, no lack of fusion, no cracks
碳化物析出 Carbide precipitation	金相分析 Metallographic analysis	无连续网状碳化物析出 No continuous network carbide precipitation
σ相检测 Sigma phase detection	金相分析/EBSD 分析 Metallographic analysis/EBSD analysis	σ相含量≤1%（面积分数） Sigma phase content ≤1% (area fraction)



4.3.5 高温时效试验（加速组织稳定性验证） High-Temperature Aging Test (Accelerated Microstructural Stability Verification)

为加速验证组织稳定性，对试样进行高温时效处理：

To accelerate microstructural stability verification, specimens shall undergo high-temperature aging treatment:

参数 Parameter	条件 Condition
时效温度 Aging temperature	650°C-700°C（依据材料确定） 650°C-700°C (determined according to material)
时效时间 Aging time	100 小时 100 hours
冷却方式 Cooling method	随炉冷却 Furnace cooling

时效后组织检验要求：

Post-aging microstructural inspection requirements:

- 堆焊层组织无明显粗化 Cladding layer microstructure shows no obvious coarsening
- 热影响区无异常相析出 No abnormal phase precipitation in HAZ
- 界面结合状态良好 Interface bonding condition is good
- 硬度下降幅度 $\leq 10\%$ Hardness reduction $\leq 10\%$

4.3.6 验收标准 Acceptance Criteria

检验项目 Inspection Item	合格标准 Acceptance Criteria
堆焊层晶粒度 Cladding layer grain size	符合 GB/T 6394 规定，晶粒度 ≥ 5 级 Complies with GB/T 6394, grain size $\geq$ Grade 5
热影响区晶粒尺寸 HAZ grain size	$\leq$ 基体材料原始晶粒尺寸的 1.5 倍 ≤ 1.5 times of original base material grain size
界面结合状态 Interface bonding condition	无未熔合、无裂纹、无气孔 No lack of fusion, no cracks, no porosity
异常相含量 Abnormal phase content	σ 相 $\leq 1\%$ ， χ 相 $\leq 0.5\%$ Sigma phase $\leq 1\%$, chi phase $\leq 0.5\%$
时效后硬度变化 Hardness change after aging	下降幅度 $\leq 10\%$ Reduction $\leq 10\%$



4.4 硬度检验 Hardness Test

4.4.1 检验目的 Inspection Purpose

验证堆焊管件堆焊层的硬度分布均匀性，确保堆焊层硬度满足设计要求，同时验证堆焊工艺对母材性能的影响在可控范围内。

Verify the hardness distribution uniformity of cladding layer of clad pipe fittings, ensure cladding layer hardness meets design requirements, and verify that the impact of cladding process on base metal properties is within controllable range.

4.4.2 检验设备 Inspection Equipment

设备名称 Equipment Name	型号/规格 Model/Specification	精度要求 Accuracy Requirement	校准周期 Calibration Cycle
洛氏硬度计 Rockwell Hardness Tester	HRS-150A	精度 $\pm 1\text{HRC}$ Accuracy $\pm 1\text{HRC}$	12 个月 12 months
维氏硬度计 Vickers Hardness Tester	HV-1000	精度 $\pm 2\text{HV}$ Accuracy $\pm 2\text{HV}$	12 个月 12 months
里氏硬度计（便携式） LeeB Hardness Tester (Portable)	TLS300	精度 $\pm 1.5\%$ Accuracy $\pm 1.5\%$	12 个月 12 months

4.4.3 检验方法 Inspection Method

硬度检验采用布氏硬度（HBW）或洛氏硬度（HRC）方法，依据堆焊层厚度和材料类型选择：

Hardness testing shall use Brinell hardness (HBW) or Rockwell hardness (HRC) method, selected according to cladding layer thickness and material type:

堆焊层厚度 Cladding Layer Thickness	硬度测试方法 Hardness Test Method	试验力 Test Force
$\geq 3\text{mm}$	洛氏硬度 HRC Rockwell Hardness HRC	150kgf
1-3mm	维氏硬度 HV10 Vickers Hardness HV10	98.07N
$< 1\text{mm}$	维氏硬度 HV5 Vickers Hardness HV5	49.03N



4.4.4 检验位置与数量 Inspection Positions and Quantity

硬度检验位置应覆盖堆焊层全厚度方向：

Hardness inspection positions shall cover the full thickness direction of cladding layer:

检验位置 Inspection Position	测试点数 Number of Test Points	间距要求 Spacing Requirement
堆焊层表面 Cladding layer surface	每 100mm 长度不少于 3 点 Not less than 3 points per 100mm length	点间距 $\geq 3\text{mm}$ Point spacing $\geq 3\text{mm}$
堆焊层中部 Cladding layer middle	每 100mm 长度不少于 2 点 Not less than 2 points per 100mm length	点间距 $\geq 3\text{mm}$ Point spacing $\geq 3\text{mm}$
堆焊层与母材界面 Cladding-base metal interface	每 100mm 长度不少于 2 点 Not less than 2 points per 100mm length	距界面 0.5-1mm From interface 0.5-1mm
热影响区 Heat affected zone	每 100mm 长度不少于 2 点 Not less than 2 points per 100mm length	距界面 1-3mm From interface 1-3mm
母材 Base metal	每 100mm 长度不少于 2 点 Not less than 2 points per 100mm length	距界面 $\geq 5\text{mm}$ From interface $\geq 5\text{mm}$

4.4.5 检验步骤 Inspection Procedure

15. 清洁试样表面，去除氧化皮、油污等 Clean specimen surface, remove scale, oil stains, etc.
16. 选择合适硬度计和试验力，进行设备校准 Select appropriate hardness tester and test force, calibrate equipment
17. 按检验位置图进行硬度测试，记录各点硬度值 Conduct hardness testing according to inspection position diagram, record hardness values at each point
18. 对堆焊层进行剖面硬度测试（必要时）： Conduct cross-section hardness testing of cladding layer (if necessary):
 - 制备金相试样 Prepare metallographic specimen
 - 从堆焊层表面至母材逐点测试硬度 Test hardness point by point from cladding layer surface to base metal
 - 测试间距 0.5mm Test spacing 0.5mm
19. 绘制硬度分布曲线 Plot hardness distribution curve



20. 计算各区域硬度平均值和极差 Calculate average hardness and range for each zone

4.4.6 验收标准 Acceptance Criteria

检验区域 Inspection Zone	合格标准 Acceptance Criteria
堆焊层硬度 Cladding layer hardness	符合设计要求，偏差 $\leq\pm 10\%$ Meets design requirements, deviation $\leq\pm 10\%$
堆焊层硬度均匀性 Cladding layer hardness uniformity	极差 $\leq 15\%$ Range $\leq 15\%$
热影响区硬度 HAZ hardness	$\leq$ 堆焊层硬度的 80% $\leq 80\%$ of cladding layer hardness
母材硬度 Base metal hardness	符合母材标准要求，硬度下降 $\leq 10\%$ Meets base metal standard requirements, hardness reduction $\leq 10\%$

典型材料硬度要求：

Typical material hardness requirements:

堆焊材料 Cladding Material	硬度要求 Hardness Requirement
309L/309MoL 不锈钢堆焊层 309L/309MoL stainless steel cladding layer	HBW 150-220
316L 不锈钢堆焊层 316L stainless steel cladding layer	HBW 140-210
镍基合金 625 堆焊层 Nickel-based alloy 625 cladding layer	HBW 200-280
镍基合金 825 堆焊层 Nickel-based alloy 825 cladding layer	HBW 160-240
碳化钨堆焊层 Tungsten carbide cladding layer	HRC 45-55

5. 检验记录与报告 Inspection Records and Reports

5.1 记录要求 Record Requirements

所有检验与试验活动应如实记录，记录内容应包括：

All inspection and test activities shall be truthfully recorded, and records shall include:



- 产品名称、规格、批号 Product name, specification, batch number
- 检验日期、检验人员 Inspection date, inspector
- 检验设备名称、编号、校准状态 Inspection equipment name, number, calibration status
- 检验条件（温度、应力等） Inspection conditions (temperature, stress, etc.)
- 原始数据 Original data
- 计算结果 Calculation results
- 检验结论 Inspection conclusion

5.2 报告内容 Report Content

检验报告应包括以下内容：

Inspection report shall include the following content:

- 报告编号 Report number
- 产品基本信息 Product basic information
- 检验项目清单 Inspection item list
- 检验方法与标准 Inspection methods and standards
- 检验结果汇总 Inspection results summary
- 蠕变曲线图（如适用） Creep curve diagram (if applicable)
- 金相组织照片（如适用） Metallographic microstructure photos (if applicable)
- 硬度分布图（如适用） Hardness distribution diagram (if applicable)
- 检验结论与判定 Inspection conclusion and judgment
- 检验人员签字 Inspector signature
- 审核人员签字 Reviewer signature

5.3 记录保存 Record Retention

检验记录与报告保存期限不少于产品质保期，且不少于 10 年。

Inspection records and reports shall be retained for not less than the product warranty period, and not less than 10 years.

6. 不合格品处理 Nonconforming Product Disposition

6.1 不合格判定 Nonconformance Determination

出现以下情况之一，判定为不合格：

Any of the following conditions shall be determined as nonconforming:

- 高温蠕变试验结果超出验收标准 High-temperature creep test results exceed acceptance criteria



- 组织稳定性检验发现异常组织或界面缺陷 Microstructural stability inspection reveals abnormal microstructure or interface defects
- 硬度检验结果超出验收标准 Hardness test results exceed acceptance criteria
- 检验过程中发现其他影响产品性能的缺陷 Other defects affecting product performance discovered during inspection

6.2 不合格处理流程 Nonconformance Disposition Procedure

21. 标识与隔离：对不合格品进行标识并隔离存放 Mark and segregate: mark nonconforming products and store separately
22. 原因分析：技术部组织分析不合格原因 Cause analysis: Technical Department organizes analysis of nonconformance cause
23. 处置方案：根据原因分析结果确定处置方案 Disposition plan: determine disposition plan based on cause analysis results
 - 返工 Rework
 - 返修 Repair
 - 让步接收 Concession acceptance
 - 报废 Scrap
24. 处置实施：按批准的方案执行处置 Implementation: execute disposition according to approved plan
25. 重新检验：处置完成后重新进行相关检验 Re-inspection: conduct relevant inspection after disposition
26. 记录归档：不合格处理全过程记录归档 Record archiving: archive records of entire nonconformance disposition process

7. 监督考核 Supervision and Assessment

7.1 内部审核 Internal Audit

质量管理部每年至少组织一次本 ITP 执行情况的内部审核，审核内容包括：

Quality Management Department shall organize at least one internal audit per year on the implementation of this ITP, audit content includes:

- ITP 执行符合性 ITP implementation compliance
- 检验记录完整性 Inspection record completeness
- 设备校准有效性 Equipment calibration effectiveness
- 人员资质符合性 Personnel qualification compliance



7.2 考核指标 Assessment Indicators

考核项目 Assessment Item	目标值 Target Value
ITP 执行率 ITP execution rate	100%
检验记录完整率 Inspection record completeness rate	100%
设备校准及时率 Equipment calibration timeliness rate	100%
检验人员持证率 Inspector certification rate	100%

8. 附则 Supplementary Provisions

8.1 相关文件 Related Documents

- CLADDING-QP-001 质量手册 Quality Manual
- CLADDING-WI-005 堆焊工艺规程 Cladding Process Specification
- CLADDING-ITP-001 堆焊管件外观检验与试验计划 ITP for Cladded Pipe Fitting Visual Inspection
- CLADDING-ITP-010 堆焊管件无损检测与试验计划 ITP for Cladded Pipe Fitting NDT
- GB/T 2039-2012 金属蠕变持久试验方法 Method for Metal Creep and Rupture Testing
- GB/T 6394-2017 金属平均晶粒度测定法 Method for Determination of Average Grain Size of Metals
- GB/T 230.1-2018 金属洛氏硬度试验 Metal Rockwell Hardness Testing

8.2 修订记录 Revision History

版本号 Version	修订日期 Revision Date	修订内容 Revision Content	修订人 Reviser
A/0	2025-01-15	首次发布 First issue	质量管理部 Quality Management Dept.

8.3 文件控制 Document Control

本文件受控管理，未经质量管理部批准，任何单位和个人不得复制、外传。



This document is under controlled management. No individual or unit shall copy or disseminate without approval from Quality Management Department.

编制 Prepared by: _____ 日期 Date: _____

审核 Reviewed by: _____ 日期 Date: _____

批准 Approved by: _____ 日期 Date: _____