Advancements in Quality Control with Air-Vortex-Applied Coating Systems

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Outline

1. Background
2. Resins used with coating "systems"
3. Testing & certification of coating "systems"
4. Host pipe integrity assessment
5. Installation Prep
6. Accountability
7. Certified Contractors
8. Resin mixing
9. Resin application
10. Post-construction inspection
11. Data logging & as-built submittals
12. Operations & Maintenance, & Life-cycle Asset Management

Background: Air Vortex Applied Coatings

Used to apply coatings since the early 1990s.

A resin slug is distributed around the lumen of the pipe as pushed forward by an air vortex.

The lumen of long lengths of inaccessible small diameter pipe, including pipes with branches, can be remotely coated with these methods.

Background (cont.)

The technology and engineering controls involved have advanced to increase quality control and performance of air vortex applied coatings.

QMS for "Field Manufacturing"


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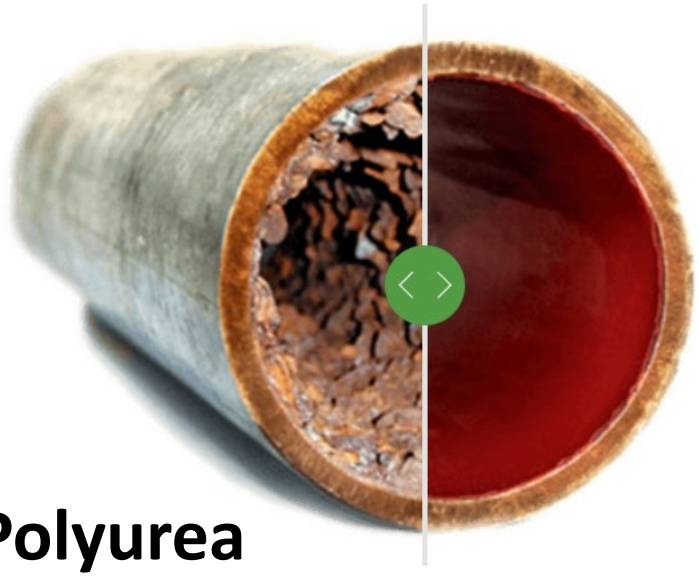
**PMG LISTING CRITERIA FOR
INTERNAL EPOXY BARRIER COATING MATERIAL
FOR REHABILITATION OF METALLIC FUEL GAS PIPE**

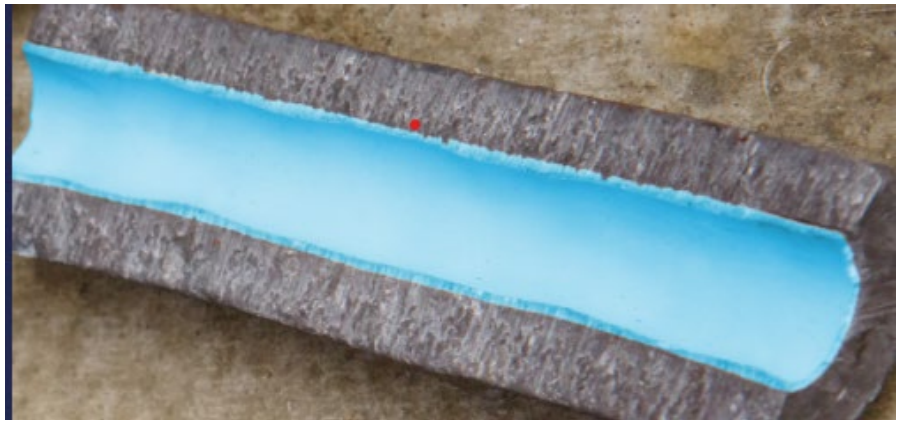
LC1045

Approved Date: December 2020

The new ICC-ES Listing Criteria, LC1045, awarded in December 2020 has contributed a thorough documentation of the many advancements in Quality Control which have culminated in reliable coating of in-building gas pipes.

Resins





Epoxies & **Polyurethane / Polyurea**

1990s epoxy formulation continues to be **NSF 61 certified** by ALS/Truesdail

Advancements in **permeability, cissing & pinhole avoidance**.

Epoxies better for **longer shots**

Hybrid Polyurethane/Polyurea provides flexibility for **malleable pipes**

Resin formulations are blended in an **ISO 9001 QMS** manufacturing facility

System Testing & Certifications

Designation: F2831 – 19

Standard Practice for
Internal Non Structural Epoxy Barrier Coating Material Used In Rehabilitation of Metallic Pressurized Piping Systems[1]

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Testing & Certifications (cont.)

Gas Industry validation requirements are exceptionally stringent: LC1045 3.0 System Qualification Requirements

3.2 Qualification Testing Submittals: The qualification (validation) test data used to qualify a coating system for use is not project performance specific, but rather system design specific. These tests shall be recognized as qualification tests to be performed once for each class of installed coating and do not require repeating unless the materials and/or methods are altered; qualification testing requirements are explicitly not intended to be used as post-construction field verification requirements.

3.2.1 Thickness Measurement: After curing, the coating thickness shall be measured using an appropriate device for determining Dry Film Thickness (DFT) of coatings. Coatings shall meet the minimum required thickness within the allowable tolerance range [e.g. 250 microns (allowable tolerances of +1000/-90)]. DFT readings shall be taken from at least four points evenly distributed around the test sample. For example: 3, 6, 9, & 12 o'clock for pipe samples.

3.2.2 Pull-off Adhesion Strength Test: A manufacturer's plate sample shall be laboratory tested for resistance to pull-off of the epoxy barrier coating in accordance with ASTM D4541. The minimum pull-force adhesion shall be 2500 psi, as per Protocol 2. (Note that the precision and bias statements for this test show considerable variability across round robin testing results.)

3.2.3 Hardness Test: A manufacturer's plate sample shall be laboratory tested in accordance with ASTM D2240 for durometer hardness. The hardness of the coating shall comply with the manufacturer's published tolerances.

3.2.4 Chemical Resistance Test: Manufacturer prepared samples shall be laboratory tested according to ASTM D 543, Practice B for resistance to the chemicals listed in table 1. Weight of the test specimens shall not increase by more than 14% nor decrease by more than 3% and test specimens shall retain at least 80% both of its hardness, when measured in accordance with Test Method ASTM D2240, and of peeling strength, when measured in accordance with Test Method ASTM D3167.

Table 1: Chemical Resistivity List of Reagents

Liquids	Test Composition
Water (External and Internal)	Freshly prepared distilled water (in accordance with Practice D 543)
Gasoline (External)	Gasoline-Automotive Spark-Ignition Engine Fuel per Specification D 4814
Gas Condensate (Internal)	70 % volume isooctane + 30 % volume toluene
Methanol	20 % volume methanol + 80 % volume distilled water
Triethylene Glycol	10 % volume triethylene glycol + 90 % volume distilled water
Brine Solution	10 % mass NaCl solution made up with a balance of distilled water
Mineral Oil	100 % White Mineral Oil USP, specific gravity 0.830 to 0.860, Saybolt at 100°F: 125 to 135 s, in accordance with Practice D 543
Isopropanol	10 % volume isopropanol + 90 % volume distilled water
Sulfuric Acid	5 % weight (of total solution) H_2SO_4 in distilled water
Surfactants	5 % mass (of solution weight) dehydrated pure white soap flakes (dried 1 h at 105°C) dissolved in distilled water, in accordance with Practice D 543
Mercaptans	2 % volume tertiary butyl mercaptan + 98 % volume mineral oil, white, USP

Testing & Certifications (cont.)

Gas Industry validation requirements are exceptionally stringent:

3.2.5 Gas Blistering: A manufacturer's test panel shall be laboratory tested for gas blistering and appearance in accordance with ASTM D714.

3.2.5.1 Humidity resistance: A manufacturer's test panel shall be laboratory tested with 100% relative humidity exposure as specified in ASTM D2247 for 500 hours. There shall be no blistering or delamination.

3.2.7 Salt spray resistance: A manufacturer's test panel shall be subjected to salt spray conditioning as specified in ASTM B117 for 500 hours. There shall be no blistering, delamination.

3.2.8 Gas Permeability: A manufacturer's test panel shall be subjected to laboratory testing for gas permeability in accordance with ASTM D1434. For reference data only because there is no pass or fail requirement.

3.2.9 Evolved Gas Analysis: A manufacturer's test panel shall be subjected to laboratory testing for evolved gas analysis in accordance with ASTM E2105.

3.2.10 Rating Class Determination: A manufacturer's test panel shall be subjected to micro-sectioning in accordance with CAN-CSA-Z245.20 to evaluate the rating class.

3.2.11 Cissing and Pin Holing: A manufacturer's test panel shall be subjected to laboratory testing for Holiday Detection in accordance with Method A of ASTM G62.

3.2.12 Cure Schedule **Determination**: The manufacturer's Recommended Cure Schedules shall be supported by laboratory validation testing in accordance with ASTM D5402 with a minimum of 10 "double rubs" using isopropyl alcohol in order to qualitatively validate an adequate cure schedule for safe return to service.

3.2.13 Validation of Construction Thickness: The ability to deliver the specified coating thickness shall be scientifically validated.

3.2.13.1 A test assembly simulating typical site conditions shall be set up for coating application utilizing a 1-inch-diameter pipe that is 50 feet in length. Fittings shall be used to simulate an actual installation.

3.2.13.2 The test assembly shall be coated in accordance with the coating tables in the manufacturer's installation instructions.

3.2.13.3 The coated assembly shall be allowed to cure at room temperature for 24 hours.

3.2.13.4 The thickness of the coating shall be measured at both the last fitting and at the outlet end of the test assembly. The minimum "as-built" coating thickness shall be as specified by the manufacturer [e.g. 250 microns] with an allowable tolerance of +1000 / -90 microns.

3.2.13.5 A mathematical evaluation of the coating tables in the manufacturer's installation instructions shall be performed, based on the test results for the 1-inch pipe, to confirm that the minimum coating thickness can be provided.

Testing & Certifications (cont.)

LC1045 4.0 As-Built Quality Control / Verification Testing Requirements

4.0 QUALITY CONTROL / VERIFICATION TEST METHODS AND REQUIREMENTS

Post-construction, representative samples from the project shall verify as-built compliance with the key performance property requirements.

4.1 Post-Construction Thickness Verification: Field thickness verification measurements shall be performed at every entry and exit point with Dry Film Thickness (DFT) readings taken from at least four points evenly distributed around the pipe ends to verify performance compliance of the epoxy barrier coating material with the required minimum thickness. The minimum "as-built" coating thickness shall be as specified by the manufacturer [e.g. 250 microns] with an allowable tolerance of +1000 / -90 microns.

4.2 Verifying Safe Return to Service

4.2.1 CCTV visual inspection: The contractor shall internally inspect as much of the coated piping system as is practical with a CCTV camera system to visually confirm proper application. A recording of the CCTV inspections shall be provided.

4.2.2 Epoxy cure verification: Adequate curing for safe return to service shall be field verified at every entry and exit point with 10 "double rubs" with isopropyl alcohol inside the coated pipe, as per ASTM D5402.

4.2.3 Pressure test: Prior to acceptance and return to operation, all sections of the coated piping system shall be pressure tested in accordance with the requirements of Section 406 (IFGS) "Inspection, Testing, and Purging" of the ICC International Fuel Gas Code.

Pipe Integrity / Applicability for Use

LC1045 2.0 Condition Assessment Requirements

2.3 Condition Assessment and Applicability for Use: The system manufacturer's installation instructions shall specify the required host pipe condition assessment measures.

2.3.1 Host Pipe Condition Assessment – External: A visual external piping survey of as close to 100% as possible of the existing, exposed (not concealed within the structure of the building) pipework to be coated shall be undertaken to identify any signs of external corrosion or damage.

2.3.1.1 Wall Thickness Loss – External: Where external corrosion is identified, an assessment of its extent shall be completed by estimating the % loss of wall thickness. The estimated % loss of wall thickness shall be calculated by dividing the depth of any external corrosion by the wall thickness of the pipe.

Example:

Depth of corrosion measured with a pit gauge = 2mm

Wall thickness of pipe without corrosion = 2.9mm

% loss of wall thickness = (2/2.9) x 100 = 68%

Any external corrosion location with calculated wall thickness loss greater than 50% shall be deemed unsuitable for coating. Note: Localized pin-holing that does not exceed the Permissible Leakage Limit requirements, as described below, may be coated.

2.3.1.2: Inaccessible Pipes: Where entry to any location within the building prevents the external visual inspection of the pipework, a decision will be made after consultation with the building and/or asset owner as to whether to proceed with the coating process.

2.3.2 Host Pipe Condition Assessment – Internal: By assessing the level of internal corrosion and cleaning requirements, combined with measuring the pre-renovation leakage rate of the pipe, the installing contractor can further assess the host pipe condition to determine applicability for coating.

2.3.2.1 Permissible Leakage: The coating system manufacturer's installation instructions shall include a means of Pressure Loss Analysis with Permissible Leakage Limit requirements for the host piping system as an additional assessment of the condition of the host pipe and the applicability for coating.

2.3.2.1.1 **Permissible Leakage Calculator:** The system manufacturer shall provide a scientifically validated Permissible Leakage Calculator for use with their coating system to determine whether the barrier coating can be successfully applied to the interior of a host pipe system. The Permissible Leakage Calculator shall rely upon site measured pressure drops in proportion to the volume of the pipe to determine a volume threshold ($m^3\ hr^{-1}$) which shall dictate applicability for use.

2.3.2.1.2 **Leakage Point Repairs:** Localized host pipe repairs can be utilized to bring the permissible leakage within acceptable tolerances.

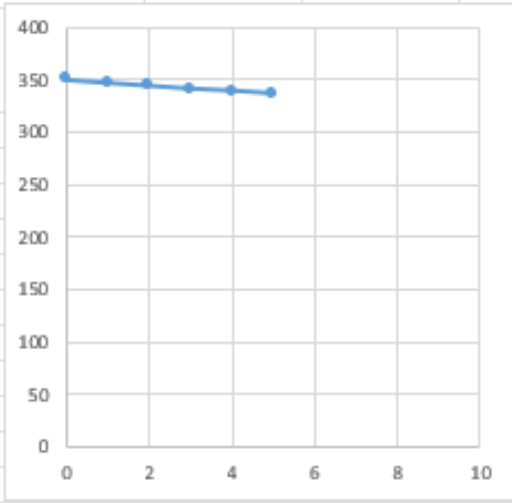
Host Pipe Leakage Rate Calculator (Applicability for Use)

NETWORK DETAILS

Pipeline Section	Nominal size	Outside diameter, mm	Thickness, mm	Inside Diameter, mm	Section Length, m	volume, m^3
Steel	1"	34.2	3.2	27.8	5.65	0.003
Steel	3/4"	27.2	2.6	22.0	5.00	0.002
Copper 28mm	28mm	28.0	0.9	26.2	17.00	0.009
predicted volume					**V, m^3**	**0.014**

PNEUMATIC REPORT

Test Details	Time, min	Test pressure, mbar	dp/dt	instantaneous leakage rate, $m^3\ h^{-1}$
test start	0	350.0	---	---
	1	347.0	180.0	0.0019
	2	344.0	180.0	0.0019
	3	341.0	180.0	0.0019
	4	339.0	120.0	0.0013
	5	336.0	180.0	0.0019
	6		0.0	0.0000
	7		0.0	0.0000
	8		0.0	0.0000
	9		0.0	0.0000
test end	10		0.0	0.0000



Predicted leakage rate	**Q, $m^3\ h^{-1}$**	**0.0019**
Test Pass / Fail		**Pass**

3. Settings

atmosperic pressure	P_{atm}, mbar	1013.25

Quality Assurance

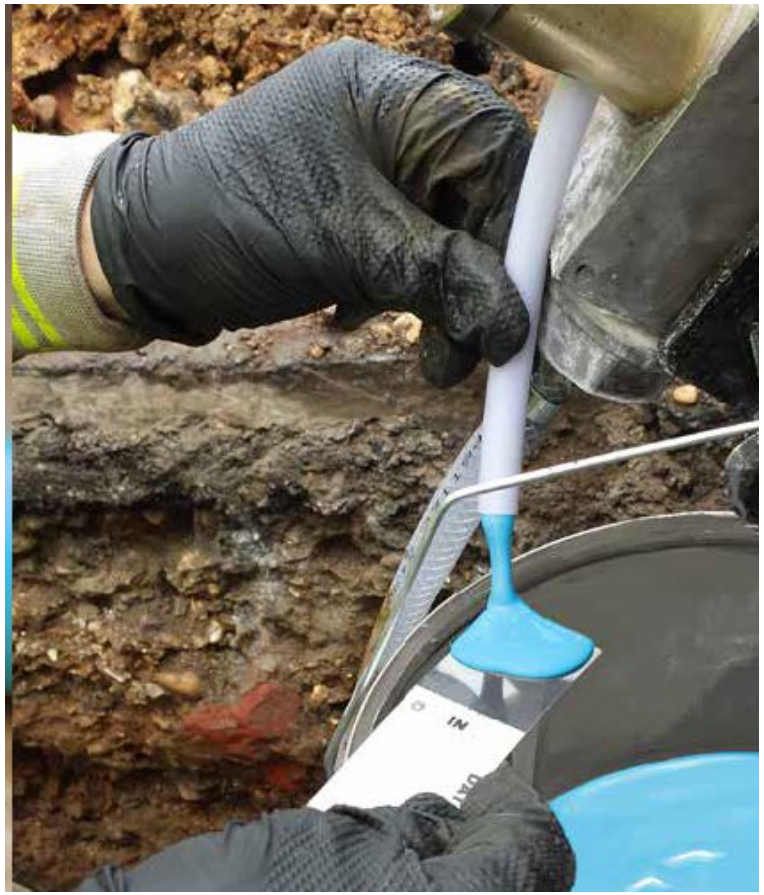
"The Confidence that Quality will be Achieved"

- System independently Validated & Verified
- Certified Contractors
- Trained & Certified Personnel
- Approved Rig - Independently Certified
- Supplier Method Statements followed
- Utilizing Approved Materials
- End-to-End Traceability
- Fully Automated

Quality Control

"Fulfilling Quality Requirements"

- Operator cannot proceed if tolerances not met.
- Comprehensive Audit Trail
- Dip Cards retained for 7 years
- Detailed Automated Report:
  - Specific site address
  - Length, diameter and type of pipe being treated
  - Flow rate before and after cleaning
  - Temperature of pipe material
  - Rig and operator identification numbers
  - Amount of resin applied



Coating Installation Prep

All air used shall be essentially moisture and oil free

- Required use of filtration and desiccant drier systems

An abrasive medium is blown through the host pipe to scour it clean.

After cleaning, the pipe bore is to be clean, dry and free from dust and debris

Coating Installation Prep (cont.)

Calculating shot distances & establishing a shot plan

Proper cleaning

2.4.1.1.1 As a minimum requirement, the cleaned surface, when viewed without magnification, shall be free of visible concentrations of oil, grease, dirt, mill scale, rust, and previously applied, disbonded coatings. Evenly dispersed, very light shadows, streaks, and discolorations caused by stains of mill scale, rust and old coatings shall be permitted to remain on no more than 33 percent of the surface. Slight residues of rust and old coatings shall be permitted to be left in the craters of pits if the original surface is pitted.

Measuring the anchor tooth

2.4.1.1.2 After host pipe preparation, the contractor shall use a visual field comparator as per ISO 8503-1 and manufacturer's specifications to verify proper anchor tooth at a minimum of either 4 locations or 25% of the entry and exit points, whichever is greater.

Accountability

Proper implementation of Engineering Controls for successful Project Management requires accountability checks.

Review of **Materials & Methods Submittals**

Review of **Contractor's Qualifications Submittal**

Review of Contractor's **Project Management Plans**, including:

- QC
- Health & Safety measures, &
- recommended Hold & Inspect points

Hold & Inspect Points

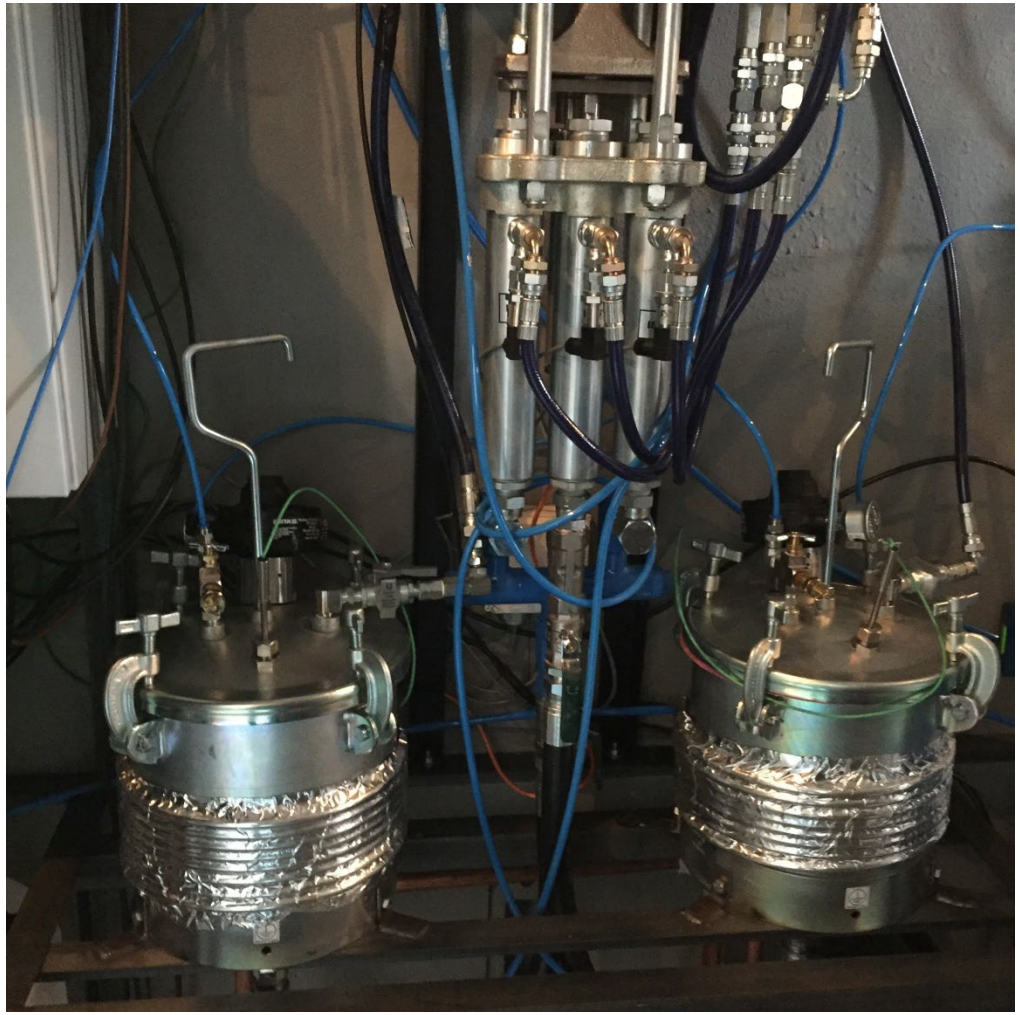
- Personnel training & certifications review
- Required equipment availability & condition review
- Initial pipe condition review
- Post-cleaning pipe condition review
- Proper site conditions (ex – humidity & temp) review
- Resin mixing data review
- Resin shot data review
- Resin curing data review
- As-built compliance review
- As-built records & submittals

Resin Mixing

- Confirm the resin is not expired
- Equipment shall have automatic data logging as part of the on-site QMS
- Where possible, weighing of resin should be automated by the QMS equipment to reduce operator error.
- Dip cards are collected to confirm and record proper mix

Resin Shooting

- The on-site QMS software shall provide alerts to prelude installation if:
  - the temperature or the humidity are outside of specified ranges.
  - The resin tanks do not have sufficient volume of materials to complete the planned shot distance.
- Weight checks shall be logged prior to the 1st shot of the day and the last.



Coating Inspection

- Once the cure period has started, print out is examined for anomalies
- The print out contains key information entered by the Rig Operator:
- **Overview** – info required for traceability such as batch numbers, rig number & operator, site location, pipe length & diameter
- **Cleaning Operations** – air speed, pressure & temperature. Can see if there is a restriction or blockage within the pipe
- **Weight Check Mode** – Pass or Fail
- **Coating Mode** –material temperatures, flows and pressures, Air flow speed, temperature & air pressure
- **Blowdown** – monitors & records air speed, air pressure & air temp
- **Coating End** – summary of the coating with total volumes pumped, average material & air temps during coating

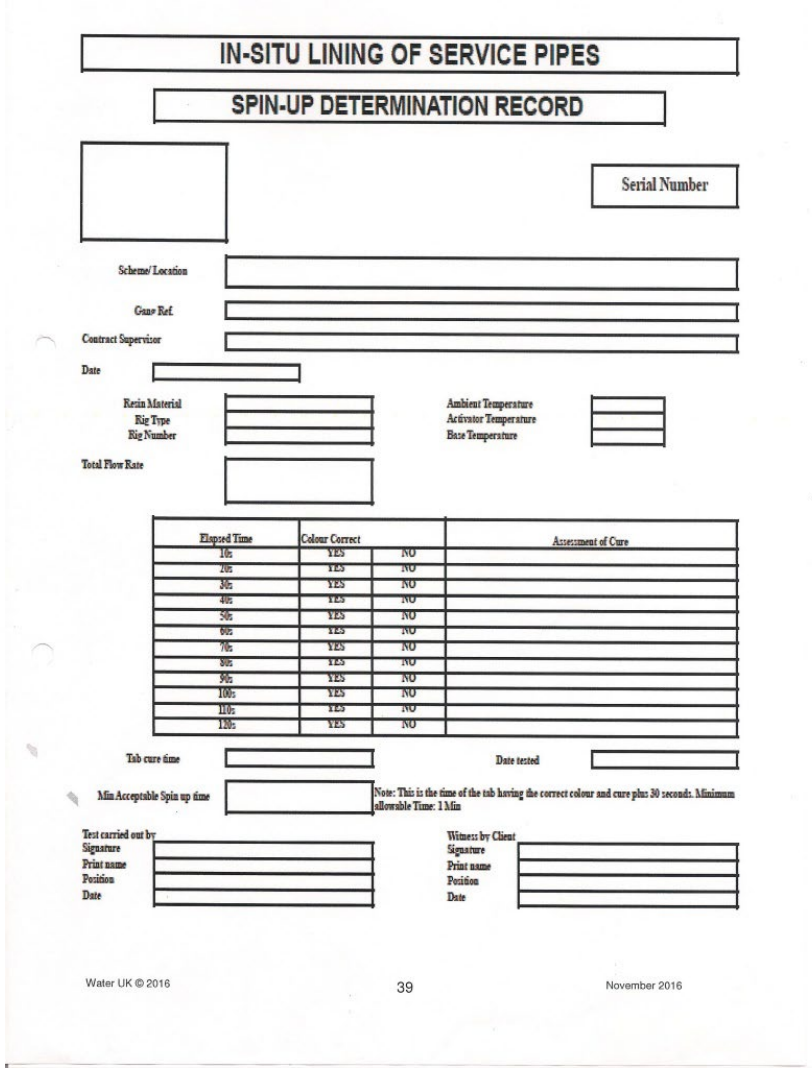
Post-Cure Inspection

- After minimum 2 hr cure, the **dip card** & both **ends of the pipe** are inspected for:
  - **Uniformity**
  - **Quality**
  - **Thickness**
  - **Hardness**
- Any defects noted must be recorded on the Service Pipe Record
- Under no circumstances shall a pipe exhibiting any **lack of cure, mixing, or material proportioning** be returned to service
  - Such defects require the affected length to be replaced

Sample Data Log & Record Sheets

Date: 10/11/11 Time: 10:38
Machine Operator: L Watson
Batch Number:
Base N32345
Acti N32346
Location:
35 IS8
Oakwell mount
Pipe length: 2.8 M
Pipe Dia. 13.5 mm
Volume Req. 0.1199 Litre

S7-224XP: 1.24 HMI K30m:1.22 L3
####################################
Line Mode Th 10/11/11 10:40
0:08 Pressures Temps Flows Totals
Base 29.636Bar 34.609øC 0.1690 0.0225
Base 33.011Bar
Acti 14.894Bar 24.101øC
Air 7.4523Bar 42.851øC 308.99M/S
0:18 Pressures Temps Flows Totals
Base 34.763Bar 34.453øC 0.2092 0.0597
Base 34.599Bar
Acti 15.574Bar 24.101øC
Air 7.5179Bar 42.382øC 302.19M/S
0:28 Pressures Temps Flows Totals
Base 33.697Bar 34.335øC 0.2076 0.0945
Base 33.539Bar
Acti 15.183Bar 24.140øC
Air 7.5414Bar 42.070øC 296.35M/S
0:38 Pressures Temps Flows Totals
Base 31.810Bar 34.179øC 0.2060 0.1277
Base 32.390Bar
Acti 14.988Bar 24.101øC
Air 7.5671Bar 41.875øC 292.81M/S
####################################
Blow Down Th 10/11/11 10:41
0:28 Pressures Temps Speed
Air 6.8019Bar 40.156øC 374.88M/S
0:58 Pressures Temps Speed
Air 6.5937Bar 39.726øC 375.07M/S
1:28 Pressures Temps Speed
Air 6.5820Bar 40.117øC 381.32M/S
1:58 Pressures Temps Speed
Air 6.5828Bar 40.507øC 384.86M/S
2:28 Pressures Temps Speed
Air 6.5843Bar 40.820øC 386.75M/S
####################################
Line End
Totals: Material Air Time
Spray Up 0.3378L 60
Line 0.1402L 0M3 0:43
Blow Down ------ 0M3 2:32
####################################
End



IN-SITU LINING OF SERVICE PIPES

SPIN-UP DETERMINATION RECORD

Serial Number

Scheme/ Location

Gang Ref.

Contract Supervisor

Date

Resin Material
Rig Type
Rig Number

Ambient Temperature
Activator Temperature
Base Temperature

Total Flow Rate

Elapsed Time	Colour Correct		Assessment of Cure
10s	YES	NO	
20s	YES	NO	
30s	YES	NO	
40s	YES	NO	
50s	YES	NO	
60s	YES	NO	
70s	YES	NO	
80s	YES	NO	
90s	YES	NO	
100s	YES	NO	
110s	YES	NO	
120s	YES	NO	

Tab cure time

Date tested

Min Acceptable Spin up time

Note: This is the time of the tab having the correct colour and cure plus 30 seconds. Minimum allowable Time: 1 Min

Test carried out by
Signature
Print name
Position
Date

Witness by Client
Signature
Print name
Position
Date

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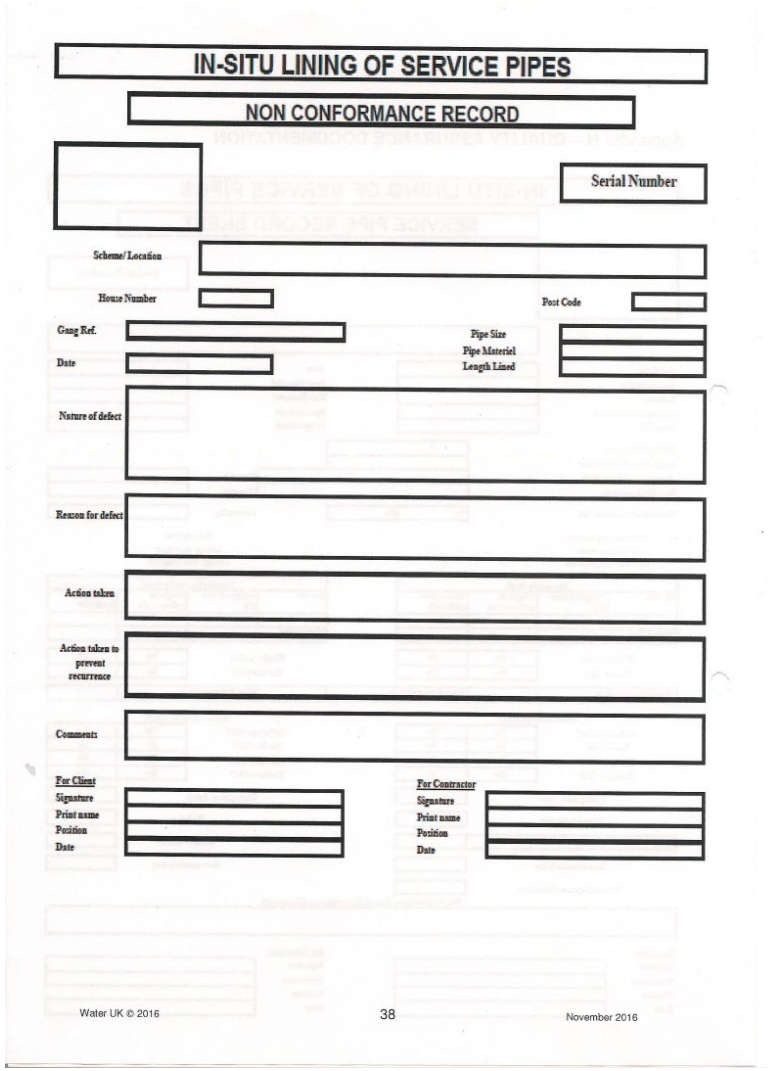

IN-SITU LINING OF SERVICE PIPES

NON CONFORMANCE RECORD

Serial Number

Scheme/ Location

House Number

Post Code

Gang Ref.

Date

Pipe Size
Pipe Materiel
Length Lined

Nature of defect

Reason for defect

Action taken

Action taken to prevent recurrence

Comments

For Client
Signature
Print name
Position
Date

For Contractor
Signature
Print name
Position
Date

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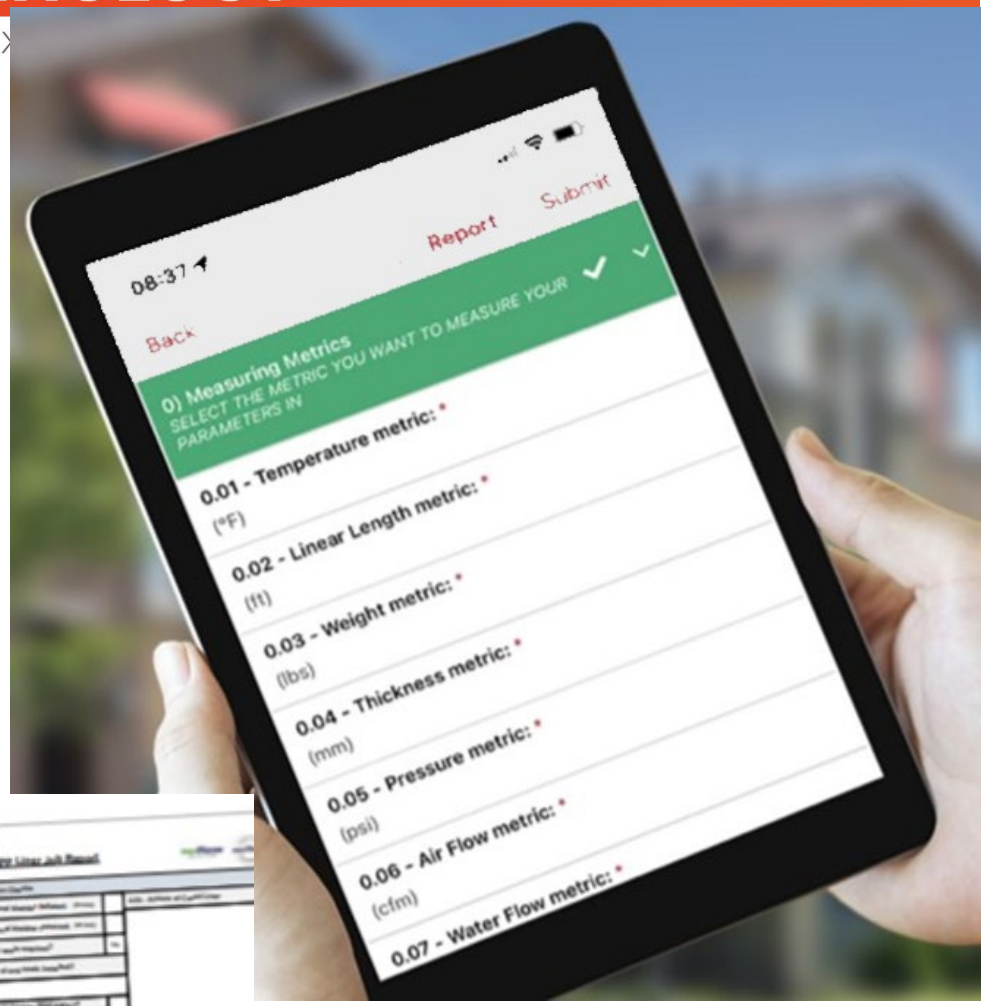
As-built Submittals

- A complete report is compiled with as-built drawings and photos, data logs, & capture of key quality control data.
- This Job Report is submitted to the Owner at project close.



Questions?

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