WSA XXX Water Industry Standard for polymeric spray lining materials used for the renovation of drinking water pipes

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PREFACE

This Standard was prepared by the Water Services Association of Australia (WSAA). It was published on the **[to be included in published version].**

The objective of this Standard is to provide performance requirements for in-situ polymeric spray linings intended for the renovation of pipeline systems used for the supply of drinking water.

NOTE: Products complying with this Standard may also be suitable for the renovation of water pipes used for other applications such as recycled water, fire services and irrigation.

Selection, design and installation and commissioning requirements are covered by WSAA Manual for selection and application of cured-in-place pipe (CIPP) and spray liners for use in water pipe.

CONTENTS

FOREWORD

This Standard addresses the performance requirements of polymeric spray lining materials and finished products used in the renovation of drinking water pipelines. It is intended to provide manufacturers and specifiers with a means of demonstrating fitness for purpose.

This Standard differs from those applicable to conventionally installed piping systems in that it is required to verify certain characteristics of the components as manufactured as well as in the installed condition. In accordance with ISO terminology these have been identified as the “M” stage for the collective materials used to fabricate the liner and the “I” stage for the liner as installed.

ISO terminology has also been adopted for describing the structural classification with Class A being fully structural, Classes B and C being semi-structural and Class D providing an internal barrier layer (refer to appendix B for class requirements). Spray linings are usually Class B, C or D. Class D spray linings typically have a wall thickness 1-1.5mm, whilst Class B or C spray linings have a typical wall thickness of 3-6mm (depending on pipe diameter).

The service life of products conforming to this Standard will be dependent upon the condition of the host pipe, the quality of the liner material and its application, and the service conditions. The material and process selection should therefore be in accordance with the requirements of the asset owner with respect to extending the service life of the host pipeline.

The type of polymer is not specified in the Standard but typically two-part epoxy, polyurethane or polyurea have been used for relining water pipes. All materials used are required to meet the performance requirements of this Standard including effect on drinking water.

As part of its product appraisal process, WSAA may request details of previous successful installations or require contractors to undertake trial installations. Such trial details may include:

- The host pipe diameter and length, material and service conditions;
- The lining material
- Specified thickness and measurements of applied liner thickness;
- The water off time (time from water off to supply restoration);
- Disinfection regime;
- Contractor details and date of installation;
- Where relevant, details of any subsequent rectification work applied to the renovation;
- Internal CCTV examination of the lined pipe including joints, service connections, hydrants and liner ends. CCTV shall include a view into service connections, hydrants and other fittings; and
- Pressure test, or leak test, results.

1. SCOPE AND GENERAL

1.1. SCOPE

This Standard specifies the performance requirements and test methods for solvent free, in-situ polymeric spray linings for use in the renovation of drinking water pipelines. It is applicable to the spray lining of host pipes including, but not limited to, asbestos cement, cement mortar lined metallic, unlined metallic, and reinforced concrete pipes.

The Standard is applicable to semi-structural (Class B and Class C) and non-structural (Class D) spray linings as defined in Appendix B.

It is applicable to the spray lining intended to be installed in accordance with the WSAA Manual for selection and application of cured-in-place (CIPP) and spray liners for use in water pipe.

NOTES:

(i) Spray lining resin systems for the renovation of water pipes made of materials not listed in this standard may require additional testing. For example, assessment of the liner adhesion to alternate substrates and chemical compatibility between the liner and pipe material.

(ii) No minimum pressure rating is specified for spray-lining applications as the appropriate pressure requirements will be stipulated by the Water Agency on a case-by-case basis.

(iii) This Standard does not set requirements for abrasion resistance or impact resistance. This Water Industry Standard only considers application in water pipes, where no significant impacts due to abrasion or impact occurs.

1.2. CONFORMITY REQUIREMENTS

Methods for demonstrating conformity with this Standard shall be in accordance with Appendix A.

Product certification, when required, shall be undertaken in accordance with WSA TN-08.

Note: The word 'shall' is used in this Standard to designate a mandatory requirement.

1.3. LIMITATIONS

This Standard applies to spray lining products that rely on a degree of structural integrity of the host pipe to both withstand external loads and resist internal pressure.

1.4 NORMATIVE REFERENCES

The following are the normative documents referenced in this Standard:

AS

681.1 Elastomeric seals- Material requirements for pipe joint seals used in water and drainage applications Part 1: Vulcanized rubber.

1199.1 Sampling procedures for inspection by attributes — Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection.

1281 Cement mortar lining of steel pipes and fittings

1646 Elastomeric seals for waterworks purposes.

4087 Metallic flanges for waterworks purposes.

4321 Fusion-bonded medium-density polyethylene coating and lining for pipes and fittings

AS/NZS

1145.2 Determination of tensile properties of plastics materials - Test conditions for moulding and extrusion plastics

2280 Ductile iron pipes and fittings

2566 Buried flexible pipelines – Part 1: Structural design

3894.9 Site testing of protective coatings, Method 9: Determination of adhesion

4020 Testing of products for use in contact with drinking water.

4158 Thermally-bonded polymeric coating on valves and fittings for water industry purposes.

ASTM

D4541 Test 11295 method for Pull-off Strength of Coatings using Portable Adhesion Testers.
D570 Standard Test Method for Water Absorption of Plastics.
D638 Standard Test Method for Tensile Properties of Plastics.
D696 Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C with a Vitreous Silica Dilatometer.
D790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced. Plastics and Electrical Insulating Materials.
D1599 Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings.
D2290 Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe.
D2369 Standard Test Method for Volatile Content of Coatings.
D2992 Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings.
D3567 Standard Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings.
D4541 Standard test method for Pull-Off Strength of Coatings using Portable Adhesion Testers.
D7028 Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA).

D7234 Test method for Pull-off Adhesion Strength of Coatings on Concrete using Portable Pull-off Adhesion Testers.
E289 Standard Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry.
E831 Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis.
F1612 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube.
F3182 Standard Practice for the Application of Spray-Applied Polymeric Liners Inside Pipelines for Potable Water.

AWWA
Structural Classifications of Pressure Pipe Linings – Suggested Protocol for Product Classification

AS ISO/IEC
17025 General requirements for the competence of testing and calibration laboratories.

ISO
62 Plastics — Determination of water absorption.
178 Plastics — Determination of flexural properties.
527-1 Plastics — Determination of tensile properties — Part 1: General principles.
899-1 Plastics — Determination of creep behaviour — Part 1: Tensile creep.
899-2 Plastics — Determination of creep behaviour — Part 2: Flexural creep by three-point loading.
7509 Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes — Determination of time to failure under sustained internal pressure.
10928 Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Methods for regression analysis and their use.
11295 Classification and information on the design and applications of plastics lining systems used for renovation and replacement.
11297-4 Plastics piping systems for renovation of underground drainage and sewerage networks under pressure — Part 4: Lining with cured-in-place pipes.
11298.4 Plastics piping systems for renovation of underground water supply networks — Part 4: Lining with cured-in-place pipes.
11359-2 Plastics – Thermomechanical analysis (TMA) – Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature
13003 Fibre-reinforced plastics — Determination of fatigue properties under cyclic loading conditions.
15306 Glass-reinforced thermosetting plastics (GRP) pipes — Determination of the resistance to cyclic internal pressure.

Water UK
IGN 4-02-02 Code of Practice: *In Situ* Resin Lining of Water Mains
WIS 4-02-01 Operational Requirements: *In Situ* Resin Lining of Water Mains

WSAA
TN-08 Product conformity assessment requirements.

1.5. **TERMS AND DEFINITIONS**

For the purpose of this Standard, the following terms and definitions apply:

1.5.1. Average thickness
The mean of measurements taken to record liner thickness at the "I" stage in accordance with section 3.5 Liner Thickness

1.5.2. Curing
process of resin polymerisation, which typically occurs at ambient temperature.

1.5.3. Declared value
limiting value of a characteristic declared in advance by the lining system supplier, which becomes the requirement for the purpose of assessment of conformity.

1.5.4. Specified thickness
the specified final wall thickness of the liner resin system once installed and cured ('I' stage) and includes multiple applications/passes where used

1.5.5. Dry film thickness (DFT)
the dry film thickness of a coating remaining on the surface and above the peaks of the surface profile when the coating or system has hardened and cured.

1.5.6. Liner thickness
the liner wall thickness following installation and curing ('I' stage), measured in accordance with section 3.5 Liner Thickness

1.5.7. Lining with sprayed polymeric materials
lining with a sprayed two-part polymeric resin system material that forms a continuous coating after resin system cure.

1.5.8. Minimum thickness
the minimum wall thickness required in the product supplier's documentation (recommended to be no less than 1 mm)

1.5.9. Product stages
the liner material as installed and the component materials from which it is made can be considered as two distinct stages as follows:

1.5.9.1. "M" Stage
the stage as manufactured before any site processing or mixing of the components.

1.5.9.2. "I" stage
the stage as installed. That is, the final configuration of the material after site processing and installation.

1.5.10. Resin system
thermosetting resin including the curing agent(s) and any fillers or other

additives in specified proportions.

1.5.11. Renovation
work incorporating all or part of the original fabric of the pipeline, by means of which its current performance is improved.

1.5.12. Renovated pipeline system
the existing pipeline system plus the installed liner used to renovate it.

1.5.13. Simulated installation
an installation of a lining system into a simulated host pipeline, using representative equipment and processes, to provide samples for testing which are representative of the actual installation.

1.5.14. Simulated host pipeline
a section of pipeline, which is not part of an operational network, but which replicates the environment of the operational network.

1.5.15. Service conditions

1.5.15.1. Maximum service temperature
the maximum sustained temperature at which the spray-lining system is intended to operate.

1.5.15.2. Nominal pressure (PN)
the alphanumeric designation for the nominal pressure class, designated in bars, which is the maximum sustained hydraulic internal pressure for which the pipe is designed in the absence of other loading conditions. For example, PN12 indicates a nominal pressure of 12 Bar or 1,200 kPa.

1.5.15.3. Maximum allowable operating pressure
the maximum pressure that can be sustained, with a design factor, by the type or class of pipe for its estimated useful life under the anticipated working conditions.

1.5.16. Surface area-to-volume ratio
the surface area per unit length of the liner in direct contact with the drinking water divided by the volume of water per unit length.

1.6. NOTATION

The following symbols and abbreviations are used in the Standard:

AC	Asbestos cement
CML	Cement mortar lining
“I”	as installed
“M”	as manufactured
EP	Epoxy
PEUU	Polyurea
PU	Polyurethane
DN	Nominal size

PN Nominal pressure

2. MATERIAL REQUIREMENTS "M" stage

2.1. MATERIALS SPECIFICATION – RESIN SYSTEM

2.1.1. Colour

Where colour is used to provide a visual evaluation of the quality of the mixing, the individual resin system components shall be of clearly distinguishable colours which, when mixed correctly, provide a different distinctive colour.

Other methods of demonstrating the efficiency of the mixing of components may be nominated by the supplier.

2.1.2. Composition

The manufacturer shall:

(i) Nominate the chemical family of the spray-lining resin. For example, epoxy, polyurethane, or polyurea as appropriate;

(ii) Nominate the type of any fillers used;

(iii) Provide a specification for each resin system component listing relevant properties including specified values and tolerances. The properties shall include those listed in Table 1 and Table 2. Any other material properties relevant to the particular spray-lining system shall also be specified;

(iv) Specify the type of in-line mixer and lining application head required and whether a heated umbilical is necessary; and

(v) Specify the solvent to be used for cleaning.

TABLE 1 MATERIAL PROPERTIES FOR RESIN SYSTEM

Material component	Material type
Resin system: — resin type — filler type — curing agent type	 PU, PEUU, or EP None, inorganic or organic Heat-initiated, light-initiated, or ambient cure

TABLE 2 PROPERTIES OF THE INDIVIDUAL COMPONENTS OF THE RESIN SYSTEM

Property	Test Method	Conditions	Specification	
			Part A	Part B
Density	As specified by the supplier	As specified by the supplier	As specified by the supplier	As specified by the supplier

Property	Test Method	Conditions	Specification	
			Part A	Part B
Colour				

2.2. **STORAGE AND TRANSPORT**

The manufacturer of the spray lining resin system shall provide instructions regarding the storage and transport of the components including shelf life and any storage temperature limitations.

2.3. MARKING

Marking shall be applied to the outside of the spray lining component containers as delivered to the installation site. Marking shall include:

- reference to this Standard;
- manufacturer's name and/or trademark;
- resin system;
- batch number;
- expiry date;
- component identification, e.g. 'Part A', or 'Part B';
- mix ratio of the components; and
- application, i.e. Drinking Water.

2.4. FITTINGS AT THE "M" STAGE

2.4.1. Fittings for use in water supply shall comply with the requirements of the Water Supply Code of Australia (WSA 03). Water Agencies may require products and materials to be "approved" and/or product and material suppliers to be "accredited" and may have limitations on some products. Unless otherwise approved by the Water Agency, only Water Agency "approved" products and materials shall be used. See Water Agency websites for details.

2.4.2. Fittings for use in conjunction with spray linings shall have a service life expectancy not less than the lining system(s) with which they are intended to be used.

2.4.3. Fittings shall comply with AS/NZS 4020. A scaling factor, where applied, shall be determined in accordance with Appendix B of AS/NZS 4020. Successful evaluation of a fitting shall qualify all products comprising the same materials, provided they have an equal or lower surface area-to-volume ratio.

2.4.4. Flanges shall have a drilling pattern in accordance with AS 4087.

2.4.4. Steel fittings shall made from stainless steel and shall comply with the stainless steel requirements in AS 4181 or shall be made to AS 1579 and coated with a fusion bonded polyethylene (FBPE) coating in accordance with AS 4321 and either a FBPE lining (AS 4321) or cement mortar lining in accordance with AS 1281. Ductile iron fittings shall made to AS/NZS 2280 and be protected against corrosion by a thermally bonded coating applied in accordance with AS/NZS 4158..

2.4.5. Brass fittings shall be low lead and resistance to dezincification and comply with AS 1565 and AS 2345.

2.4.6. Mild steel, ductile iron, GRP and PVC fittings shall comply with the relevant WSAA Product Specification.

3. MATERIAL REQUIREMENTS “I” stage

This clause specifies the requirements for the completed liner installation.

3.1. MATERIALS SPECIFICATION – CURED RESIN

TABLE 3 PROPERTIES OF THE CURED RESIN

Property	Test Method	Conditions
Glass transition temperature	ASTM D7028, ISO 11359-2	Recorded value
Water absorption	AS3862 AS 4321 App D	Recorded value
Contact with drinking water	AS/NZS 4020	Must pass AS/NZS 4020 requirements
Liner thickness	Section 3.5	Varies by method refer section 3.5

3.2. EFFECT ON DRINKING WATER

Spray lined pipe shall comply with AS/NZS 4020 with a scaling factor of 1.0. It shall be tested after the minimum curing period and the curing regime used shall be included in the test report. Successful evaluation of a product shall qualify all lower surface area-to-volume ratios, i.e. larger diameters, of the same composition in the product range.

NOTE: The liner may be tested as a finished product using in-the-product exposure. Alternatively, the resin system may be tested alone as a coating. Both techniques are described in AS/NZS 4020, Appendix A.

3.3. SURFACE IRREGULARITIES

Surface irregularities such as slumping or ringing shall be minimised. For structural performance, the liner shall not introduce surface irregularities in addition to those of the existing pipeline, which exceed the average thickness by ±10% (±0.1 x average thickness). The height of irregularities shall be measured from the internal surface of the liner. A derating factor of 0.67 shall be required if surface irregularities are present.

For uncovered joints (or joints not spanned by spray lining) leakage may occur at the joints or through the CML. Refer section 3.4 Spanning of Existing Holes and Gaps for additional requirements.

3.4. SPANNING OF EXISTING HOLES AND GAPS

A spray liner can be installed for a number of purposes at varying thicknesses, but when installed as a Class B or Class C liner, it must meet the following hole and gap spanning requirements. For a standard 3mm thick application (to achieve the minimum Class C requirements): spray liners shall span holes during application up to a diameter of 3 mm and gaps that are up to 3mm wide and up to 3mm deep.

Note that a liner's ability to span holes and gaps will vary depending on the thickness of the liner, with higher thickness spanning larger holes and gaps during installation. Where holes and gaps are larger than 3mm a thicker layer of spray lining can be applied at the joints or multiple passes can be used to achieve a greater liner thickness, e.g. 6 mm. Alternatively, to ensure that joints are spanned, a filler material can be inserted into gaps at the joints prior to liner installation. This will ensure a consistent internal pipe surface prior to spray lining. The filler material must be compatible with the spray liner and comply with AS/NZS 4020 requirements.

CCTV shall be used to check whether all holes and gaps are spanned as part of post lining CCTV quality control.

Products may be deemed acceptable if they do not span joints, however there is a high risk that leakage will still occur through the joints or CML if it is not spanned by the spray liner. Judgement on whether a liner is suitable if joints are not spanned shall be made by the asset owner based on the primary purpose of the spray lining.

3.5. LINER THICKNESS REQUIREMENTS

This section specifies what liner thickness measurements are required to be undertaken as well as liner thickness requirements. Where applicable, measurements are taken from spray lining machine records, from measurements at pipe ends, from cut-out sections, and by an automated ultrasonic device, as detailed herein.

This section be read in conjunction with Section 1.5.

3.5.1. SPRAY LINING MACHINE RECORDS

Where a spray lining machine is used, all the measurement records shall be used to assess compliance with the following requirements.

Frequency: every lined pipe.

Pass criteria:

- The average lining thickness shall be greater than or equal to the specified thickness.
- 95% of the coating thickness measurements shall be greater to or equal to the specified thickness.
- All measurements shall be greater than or equal to 90% of the specified thickness.
- All measurements shall be greater than or equal to the minimum thickness.

Report: Varies by machine. It shall include all calculated measurements and shall demonstrate that all the pass criteria have been met. If that is not the case all non-complying measurements shall be highlighted.

3.5.2 LINER THICKNESSES AT PIPE ENDS

At each end of the lined pipe lining thicknesses shall be measured as detailed herein. Where the entry and/or exit is smooth, the measurements can be made directly. Where that is not feasible, hand-held ultrasonic liner thickness measurements shall be made at a suitable distance inside the pipe to avoid entry/exit end variations.

Frequency: At each end of every lined pipe.

Measurement location: 4 measures at clock positions: 3, 6, 9 and 12 o'clock on both pipe end faces (8 total measurements).

Measurement equipment: micrometer, calliper or ultrasonic gauge capable of measuring to within 0.1 mm.

Pass criteria:

- The average lining thickness shall be greater than or equal to the specified thickness.
- No more than 1 of the 8 measurements shall be less than the specified thickness.
- All measurements shall be greater than or equal to 90% of the specified thickness.
- All measurements shall be greater than or equal to the minimum thickness.

Report: It shall include all measurements and shall demonstrate that all the pass criteria have been met. If that is not the case all non-complying measurements shall be highlighted.

3.5.3 LINED PIPE THICKNESSES

Direct measurements shall be taken from within the lined pipe by cutting out sections or by the use of a robot-mounted ultrasonic sensing device. Currently robot-mounted ultrasonic sensing devices are only available for DN450 to 600mm diameter pipes.

One of the two following testing methods shall be undertaken.

Cut out method	Robot-mounted ultrasonic sensor
Frequency: • One cut out per 500m for pipes ≤DN250 • One cut out per 2km for pipes >DN250	Frequency: Measurement of • One shot per 500m for pipes ≤DN250 • One shot per 2km for pipes >DN250
Measurement location: 4 measures at clock positions: 3, 6, 9 and 12 o'clock on both pipe end faces (8 total measurements).	Measurement location: Continuously at the crown of the pipe.
Measurement equipment: micrometer, calliper or ultrasonic gauge capable of measuring to within 0.1 mm.	Measurement equipment: robot-mounted ultrasonic sensor
Pass criteria:	Pass criteria:

- The average lining thickness shall be greater than or equal to the specified thickness.
- No more than 1 of the 8 measurements shall be less than the specified thickness.
- All measurements shall be greater than or equal to 90% of the specified thickness.
- All measurements shall be greater than or equal to the minimum thickness.

- The average lining thickness shall be greater than or equal to the specified thickness.
- 95% of the coating thickness measurements shall be greater to or equal to the specified thickness.
- All measurements shall be greater than or equal to 90% of the specified thickness.
- All measurements shall be greater than or equal to the minimum thickness.

Report requirements:

It shall include all measurements and shall demonstrate that all the pass criteria have been met. If that is not the case all non-complying measurements shall be highlighted.

3.6 ACCEPTABLE BEND RADIUS

The supplier shall declare the minimum longitudinal radius the spray lining system is capable of negotiating without creating surface irregularities beyond those specified in Section 3.3 or other defects that will reduce the liner's load capacity under operational pressure, or reduce the expected life below the design life (typically ≤22.5°).

4 OTHER MATERIALS

4.1. ADHESIVES AND SEALANTS

Adhesives, where used to fix and / or seal the liner to the host pipe material shall be compatible with the spray-liner resin system and meet the requirements for contact with drinking water.

4.2. EFFECT OF OTHER MATERIALS ON LINER CLASS

In order to classify a liner in accordance with the classifications system as described in Appendix B, the complete lining system shall be considered, including any fittings and other materials that are required install the liner.

5. MECHANICAL PROPERTIES

5.1. GENERAL

A spray liner is expected to meet different structural performance requirements based on its class, see Appendix B for class requirements and Appendix A for testing conformity. However, once installed, the liner and host pipe combined are required to withstand all stresses arising from the normal operation of the system, without leakage, and for the intended design life of the liner. In particular, the installed system shall have sufficient strength and stiffness to resist:
- external loading including soil and traffic loadings;
- loading due to ground water;
- internal water pressure

- vacuum pressure when dewatering the lined pipe; and
- pressure transients.

The product supplier must provide sufficient product properties evidence to enable a design that will meet these requirements. Refer table A1 for testing requirements.

For Class B installations all the following tests are applicable. For Class C installations all the following test are applicable, except Clause 5.6. For Class D installations only Clause 5.5 is applicable.

NOTE: For the purpose of type testing, samples may be taken either from actual installations or from simulated installations. If anisotropic properties are noted, testing must be conducted for both axial and hoop directions.

5.2. TENSILE PROPERTIES

5.2.1. GENERAL

Tensile properties shall be determined using the methods given in any or all of the following standards: ASTM D638; ISO 527-1; AS 1145.2

5.2.2. NUMBER OF SAMPLES FOR TYPE TESTING

Five samples of the same size and classification shall be used conforming to 5.2.1. Test samples shall be cut from liners having the same nominal size and layer thickness as field installed pipes, alternatively samples can be cut from flat sheets of the same thickness and cut using either CNC machining or waterjet cutting.

5.2.3. REQUIREMENTS

The following properties shall be declared:

- Ultimate tensile strength of liner (σ_t), in MPa
- Tensile modulus of elasticity (E_t), in GPa
- Poisson's ratio of the liner (ν_L), unitless

5.3. FLEXURAL PROPERTIES

5.3.1. GENERAL

Flexural properties shall be determined using the methods given in any or all of the following standards: ASTM D790; ISO 178.

5.3.2. NUMBER OF SAMPLES FOR TYPE TESTING

Five samples of the same size and classification shall be used conforming to 5.3.1. Test samples shall be cut from liners having the same nominal size and thickness as field installed pipes, alternatively samples can be cut from flat sheets of the same thickness and cut using either CNC machining or waterjet cutting.

5.3.3. REQUIREMENTS

The following properties shall be declared:

- Ultimate flexural strength of liner (σ_f), in MPa
- Offset yield strength at 0.2% strain, in MPa
- Strain at ultimate flexural strength, in %
- Strain at failure or 5% (if not failed), in %
- Flexural modulus of elasticity (E_f), in GPa

If break occurs, treat the stress at break as the ultimate flexural strength (if highest strength).

5.4. BURST PRESSURE

5.4.1. GENERAL

Pipe burst pressure shall be determined using ASTM D1599 Procedure A.

Failure pressure can be converted into tensile stress by using Barlow's formula:

$$\sigma_t = \frac{P(D_L + T_L)}{2T_L}$$

where σ_t is the hoop tensile stress in MPa, P is the internal pressure in MPa, D_L is the mean external diameter of the liner in mm and T_L is the minimum liner thickness in mm.

5.4.2. NUMBER OF SAMPLES FOR TYPE TESTING

One sample shall be used. Test samples shall be cut from liners consistent with field installation dimensions, including the same nominal diameter size and liner thickness conforming to 5.4.1.

5.4.3. REQUIREMENTS

The following properties shall be declared:

- Pipe burst pressure, in MPa
- Tensile strength, in MPa
- Liner thickness (minimum, maximum and average), in mm
- Liner diameter, in mm

The tensile strength from burst pressure testing shall not be less than 80% of the ultimate tensile strength in hoop direction from 5.2.3. If imperfections, such as slumping or ringing are present, tensile strength from burst pressure shall be compared with the factor of safety for imperfections (N_i) (Section 3.3).

5.5. ADHESION

5.5.1. GENERAL

Adhesion tested on a variety of surfaces, including CML (if CML lined pipe) shall be determined using any or all of the following standards: ASTM D4541 for metal, ASTM D7234 for AC and CML, or Pull off adhesion testing to AS 3894.9 for all spray liner classes that require adhesion for sealing (e.g. at ends or service connections) or bonding to the host pipe (Class C).

5.5.2. NUMBER OF SAMPLES FOR TYPE TESTING

Five samples of the same size and classification shall be used.

5.5.3. REQUIREMENTS

The following properties shall be declared:

- Adhesive strength (σ_{ad}), in MPa
- Substrate the liner is adhered to

5.6. VACUUM

5.6.1. GENERAL

Vacuum pressure tests shall be conducted at a minimum -80 kPa to -95 kPa for a duration of 5 hours. Ends shall be sealed with external pipe end clamps.

5.6.2. NUMBER OF SAMPLES FOR TYPE TESTING

One lined-pipe sample consistent with field installation dimensions and host pipe material, including the same nominal diameter size and layer thickness shall be used.

5.6.3. REQUIREMENTS

The testing in air in accordance with 5.6.1, the test sample shall not show signs of liner debonding.

5.7. THERMAL EXPANSION/CONTRACTION

5.7.1. GENERAL

Coefficient of thermal expansion and contraction, shall be determined using any or all of the following standards: ASTM E831, ISO 11359-2.

5.7.2. NUMBER OF SAMPLES FOR TYPE TESTING

One sample shall be used.

5.7.3. REQUIREMENTS

The following properties shall be declared:

- Coefficient of thermal expansion/contraction (α), in mm/mm/°C.

5.8. TENSILE RUPTURE STRENGTH

5.8.1. GENERAL

Tensile rupture strength properties shall be determined using any or all of the following standards and methods:
Method A: ASTM D2990; ISO 899-1 (tensile creep rupture) with ISO 10928 (regression analysis);
Method B: ASTM D2992-Hydrostatic Design Basis (HDB) long term testing; ISO 7509 (time to failure under sustained internal pressure), with ISO 10928 (regression analysis), AS 3571.2.

5.8.2. NUMBER OF SAMPLES FOR TYPE TESTING

≥18 samples of the same size and classification shall be used. The tests samples shall conform to 5.2 (Method A) and 5.4 (Method B). Minimum time to failure points shall correspond to those from the above standards (5.8.1).

5.8.3. REQUIREMENTS

The following properties shall be declared:

- Tensile rupture strength of liner ($\sigma_{tl,r}$), in MPa
- Stress vs. time curve (log-log plot)
- 97.5% lower confidence limit line
- Regression and lower confidence lines shall be extrapolated to a minimum of 438,000 hours

The properties shall be taken from the lower confidence level of 97.5%.

5.9. TENSILE CREEP MODULUS

5.9.1. GENERAL

Tensile creep modulus properties shall be determined using any or all of the following standards:

Method A (creep): ASTM D2990; ISO 899-1 (tensile creep).

Method B (stepped isothermal method): ASTM D6992 (SIM)[1]

The test samples shall conform to 5.2.1. Method A is the preferred method; however, Method B can be used for testing at different stress/pressure levels provided the liner has conducted Method A testing for a minimum of 3,000 hours for comparison (minimum 1 sample).

5.9.2. NUMBER OF SAMPLES FOR TYPE TESTING

≥3 samples of the same size and classification for each pressure/stress level. Samples shall be testing at a stress within the elastic range, similar to the stress experienced in the field (use Equation 11 in Appendix C to determine stress, alternatively use a stress between 3 to 10 MPa).

1.1.1. TIME INTERVAL AND TEST DURATION

For Method A, measurements should be recorded at the minimum following time intervals: 1, 6, 12, 30 minutes, 1, 2, 5, 10, 30, 60, 100, 300, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 80000, 90000, and 10,000 hours. Testing shall be conducted for a minimum of 10,000 hours.

For Method B, measurements should be recorded at the following time intervals: 2 readings per second during the initial loading ramp and minimum of two readings per minute during constant load portions. Dwell time steps shall be run for a minimum of 10,000 seconds. A minimum of six different temperature steps should be used below the glass transition temperature (Tg) of the material.

[1] Note that this standard was developed for geosynthetics materials. It is considered to be applicable to thermo-setting materials. However, further testing may be required to confirm its applicability.

5.9.3. REQUIREMENTS

The following properties shall be declared:

- Tensile creep modulus of liner (E_{tl}), in GPa
- Creep retention factor (CRF), where $CRF = \frac{E_{tl}}{E_t}$
- Creep modulus vs. time curve (log-log plot)
- Master creep modulus versus log time curve at the step one reference temperature (Method B only)
- Master Creep strain vs. log time curve at the step one reference temperature (Method B only)
- Results shall be extrapolated to a minimum of 438,000 hours

5.10. FLEXURAL CREEP MODULUS

5.10.1. GENERAL

Flexural creep modulus properties shall be determined using any or all of the following standards: ASTM D2990; ISO 899-2 (flexural creep).

The test samples shall conform to 5.3.1.

Note: Flexural creep modulus and tensile creep modulus may be substituted if only one test method is conducted.

5.10.2. NUMBER OF SAMPLES FOR TYPE TESTING

≥3 samples of the same size and classification for each pressure/stress level. Samples shall be tested at a stress within the elastic range, similar to the stress experienced in the field (use Equation 11 in Appendix C to determine stress, alternatively use a stress between 3 to 10 MPa).

1.1.2. TIME INTERVAL AND TEST DURATION

Measurements should be recorded at the minimum following time intervals: 1, 6, 12, 30 minutes, 1, 2, 5, 10, 30, 60, 100, 300, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 80000, 90000, and 10,000 hours. Testing shall be conducted for a minimum of 10,000 hours.

5.10.3. REQUIREMENTS

The following properties shall be declared:

- Flexural creep modulus of liner (E_{fl}), in GPa
- Creep retention factor (CRF), where $CRF = \frac{E_{fl}}{E_f}$
- Creep modulus vs. time curve (log-log plot)
- Results shall be extrapolated to a minimum of 438,000 hours

5.11. FATIGUE STRENGTH

5.11.1. GENERAL

Fatigue strength properties shall be determined using any or all of the following standards:

Method A (fatigue strength): ISO 13003 with ISO 10928 (regression analysis).
Method B (cyclic hydrostatic strength): ASTM D2992; ISO 15306 with ISO 10928 (regression analysis).
The test samples shall conform to 5.2.1 (Method A) and 5.4.1 (Method B).

5.11.2. NUMBER OF SAMPLES FOR TYPE TESTING

≥18 samples of the same size and classification shall be used. Minimum number of cycles to failure points must correspond to those from the above standards (4.11.1).

5.11.3. REQUIREMENTS

The following properties shall be declared:

- Tensile fatigue strength of liner ($\sigma_{tl,f}$), in GPa
- Fatigue stress vs. number of cycles to failure (log-log plot)
- 97.5% lower confidence limit line
- Regression line and lower confidence line shall be extrapolated to a minimum of 10,000,000 cycles

The properties shall be taken from the lower confidence level of 97.5%.

5.12. TESTING AND CONDITIONING TEMPERATURES

All mechanical characteristics specified in this document shall, unless otherwise specified, be determined at a temperature of 23 ± 2 °C. For long-term service temperatures greater than 25 °C, type tests shall, unless otherwise specified, be carried out within 5 °C of, but at not less than the design service temperature in order to establish re-rating factors to be used in design.

Humidity (water) can have an impact on spray liners causing the material to plasticise (lower elastic modulus and lower strength values, with increased ductility). Sample testing should be conducted in water following AS3862, ASTM D570 or ISO 62 for saturation times. Saturation times shall be recorded as part of test results. Wet properties (or dry properties with corrected wet derating factors) shall be used in design.

Test samples shall be tested underwater (with immersion period) (for 5.8, 5.9, 5.10, 5.11), or samples shall be saturated based on ASTM D570 or ISO 62 saturation times an immediately tested (for short-term tests, 5.2, 5.3, 5.4). Alternatively, a wet strength reduction factor, ϕ_s, shall be used where testing is conducted for strength properties (5.2, 5.3, 5.4, 5.8, 5.11) on dry samples and compared with wet samples.

$$\phi_s = \frac{\sigma_{t,wet}}{\sigma_{t,dry}}$$

where $\sigma_{t,wet}$ is the tensile strength of the liner under wet conditions and $\sigma_{t,dry}$ is the tensile strength of the liner under dry conditions. The wet strength reduction factor shall be a factor from 0 to 1.

For creep modulus (5.9, 5.10), test samples shall be tested underwater (with immersion period). A wet creep reduction factor, ϕ_c, shall be used if samples are conducted dry, to compare with wet samples.

$$\phi_c = \frac{E_{l,wet}}{E_{l,dry}}$$

$E_{l,wet}$ is the creep modulus for wet samples and $E_{l,dry}$ is the creep modulus for dry samples. The wet creep modulus reduction factor shall be a factor from 0 to 1.

5.13.TEST REQUIREMENTS

When tested in accordance with the methods given in Table A1, the mechanical characteristics of pipe samples taken from actual or simulated installations shall conform to these tables.
Testing standards and sample type/size used shall be declared.
Where requirements are specified in Sections 5.2 to 5.12 and Table A1 are declared values, these declarations shall be documented for each liner product, with supporting test data or references to such data, in the installation manual for that product.

The extensions into the lateral pipe of Class A, B and C lateral connection collars shall be considered as pipes.

Declared values refer to the 97.5% lower confidence limit value of the test results as determined from the results of tests on a set of the specified number of test samples.
Other international or national Standard tests may be applied where the test conditions are identical to the nominated methods or sufficiently similar as to produce essentially equivalent results.

6. SAMPLING

The supplier shall document the method used for acquiring samples for testing for installation quality control purposes. The samples may be obtained by means of one of the following methods:

(i) a simulated installation;

(ii) an installation; or

(iii) any other method that can be demonstrated to replicate the characteristics of samples cut from the actual pipe wall.

The test requirements and associated standards are listed in Section 5.2 to 5.12 and Appendix A, Table A1

7. ADDITIONAL CHARACTERISTICS

7.1. RECONNECTION TO THE EXISTING NETWORK

The supplier shall provide detailed written instructions regarding the type of end seals and any connection fittings to be used when connecting the cured lined pipe to the existing water network.

All terminations shall be water tight when tested in accordance with AS/NZS 2566.2, Section 6. Refer Manual for selection and application of cured-in-place pipe (CIPP) and spray liners for use in water pipe for additional requirements.

7.2. RECONNECTION OF EXISTING SERVICES

For spray liners, service connection and lateral reinstatement should not be required, unless a blockage occurs. Where a blockage occurs reinstatement of the service or lateral should follow the guidelines outlined in the Manual for selection and application of cured-in-place pipe (CIPP) and spray liners for use in water pipe. Reinstated service connections shall be water tight as per AS/NZS 2566.2, Section 6.

7.3. CONNECTION OF NEW SERVICES

The supplier shall provide detailed written instructions regarding the connection of new services to a pipeline renovated using the spray liner product. The method of connecting new services may vary based on the host pipe material and class requirements of the liner.

7.4. CONNECTION OF NEW OFFTAKES

The supplier shall provide detailed written instructions regarding the connection of new offtakes to pipeline renovated using the spray lining product. The method of connecting new offtake may vary based on the host pipe material and class requirements of the liner.

7.5. REPAIR OF RENOVATED PIPELINE

The supplier shall provide detailed written instructions regarding the repair of pipelines renovated using the spray lining product. The method of repair may vary based on the host pipe material and class requirements of the liner.

7.6. CHEMICAL RESISTANCE

The liner shall have chemical resistance to the solution used in the disinfection of water pipelines, which is 20 ppm of free chlorine.

7.7. OTHER

The supplier shall nominate any other requirements for the successful installation of their product.

8. PRODUCT DOCUMENTATION

8.1. GENERAL

Technical information relating to the spray lining system and correct installation methods shall be readily available to aid the user and installer. The information may be in the form of a technical manual or equivalent document and be written in plain English and supplemented by figures and diagrams as applicable. The information provided shall satisfy the requirements of a warranty as referenced in the Plumbing Code of Australia (PCA) and those requirements of the AS/NZS 3500 series of Standards.

The information shall consider the requirements in the WSAA Manual for selection and application of cured-in-place pipe (CIPP) and spray liners for use in water pipe. Where deviation from the requirements of this manual is necessary this shall be highlighted for the review and approval of the asset owner.

8.2. PRODUCT DATA

Product data shall be available that identifies critical product characteristics and as a minimum include

a) Diameter range for application.
b) Pipe length range for application.
c) Minimum and maximum overcoat times (for multi-layer applications).
d) Safety Data Sheets (SDS).
e) Details of the maximum hole and gap spanning ability of the product.
f) The structural capabilities of the product in accordance with Appendix B.
g) OHS requirements.
h) Any derating factors to be applied to physical characteristics measured under laboratory conditions when designing a pipeline renovation.

8.3. INSTALLATION INSTRUCTIONS

The manufacturer shall provide installation instructions including, but not limited to, details of:

a) Equipment to be used, e.g. type of spray lining rig.
b) Preparatory works, e.g. obstruction removal, surface cleaning.
c) Handling and installation details.
d) The mixing ratio of the components by mass or volume as appropriate, including the acceptable ratio tolerance.
e) The temperature band within which the components and blend must be maintained.
f) Working time, i.e. the time within which the mixed resin system must be installed.
g) Curing times and whether these are thickness dependent.
h) Maximum and minimum curing temperatures.
i) Any restrictions on the site ambient conditions that might adversely affect the application of the lining.
j) Minimum and maximum thickness to be applied with each pass and time interval permitted between multiple passes.
k) Liner termination procedure required to avoid leakage.
l) Procedure to avoid leakage at connections including tapping bands and under pressure cut-ins.
m) Final inspection and testing.
n) Requirements for new offtakes and new services.
o) Requirements for repair of lined pipeline.
p) Expected blockage rate for service connections.

NOTES:

1. Where appropriate, a derating factor may be applied to short-term physical properties in order to estimate long-term characteristics. Where the material properties are temperature sensitive, a temperature-derating factor may be required when the renovated pipe is subjected to elevated service temperatures. Where material properties are sensitive to water saturation or humidity, a water derating factor shall be required.
2. When pipes have CML water can migrate through the CML when under pressure. Additional steps may be required to prevent leakage when CML is present.

APPENDIX A

MEANS FOR DEMONSTRATING CONFORMITY WITH THIS STANDARD

(Normative)

A1 SCOPE

This Appendix sets out a means for consistent demonstration of conformity with this Standard through the use of a minimum sampling and testing frequency plan. Where variations to this plan are made, demonstration of conformance with the minimum requirements may be necessary.

A2 RELEVANCE

The long-term performance of pipeline systems is critical to the operating efficiency of water agencies in terms of operating licences and customer contracts. The long-term performance of plumbing systems is similarly critical to the durability of building infrastructure, protection of public health and safety and protection of the environment.

A3 DEFINITIONS

A3.1 Acceptable quality level (AQL)

When a continuous series of lots or batches is considered, the quality level which, for the purpose of sampling inspection, is the limit of a satisfactory process average (see AS 1199.1).

NOTE: The designation of an AQL does not imply that a manufacturer has the right knowingly to supply any non-conforming unit of product.

A3.2 Material or compound batch

A clearly identifiable quantity of a particular material or compound.

A3.3 Production batch

A clearly identifiable collection of units, manufactured consecutively or continuously under the same conditions, using material or compound to the same specification.

A3.4 Lot

A clearly identifiable subdivision of a batch for inspection purposes.

A3.5 Sample

One or more units of product drawn from a batch or lot, selected at random without regard to quality.

NOTE: The number of units of product in the sample is the sample size.

A3.6 Sampling plan

A specific plan, indicating the number of units of components or assemblies to be inspected or tested.

A3.7 Process verification test (PVT)

A test performed by the manufacturer on materials, components, joints or assemblies at specific intervals to confirm that the process continues to be capable of producing components conforming to the requirements of the relevant Standard.

NOTE: Such tests are not required to release batches of components and are carried out as a measure of process control.

A3.8 Batch release test (BRT)

A test performed by the manufacturer on a batch of components, which has to be satisfactorily completed before the batch can be released.

A3.9 Type testing (TT)

Testing performed to prove that the material, component, joint or assembly is capable of conforming to the requirements of the relevant Standard.

A4 MINIMUM SAMPLING AND TESTING FREQUENCY PLAN

A4.1 General

Table A1 sets out the minimum sampling and testing frequency plan for a manufacturer to demonstrate compliance to this Standard. Where variations to this plan are made, demonstration of conformance with the minimum requirements may be necessary.

A4.2 Testing

Testing shall be conducted by a testing laboratory or facility that fulfills the requirements of AS ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories.

NOTE: AS ISO/IEC 17025 can apply to first-party, i.e. manufacturer or supplier, second-party or third-party testing laboratories and facilities.

A4.3 Retesting

In the event of a test failure, the products manufactured since the previous test(s) conforming to the requirements outlined in Table ZA1 shall be quarantined as a batch. A further set of samples shall be selected randomly from the quarantined batch using a sampling plan to AS 1199.1. If the retest requirements are met, the batch may be released and compliance with this Standard for the quarantined batch may be claimed.

Should a failure on retesting occur, then the quarantined batch shall be rejected and claims and/or marking indicating conformity to this Standard shall be suspended until the cause of the failure has been identified and corrected.

A4.4 Rejection after retest

In the event of a quarantined batch being rejected after retesting, it may be subjected to 100% testing for the failed requirement(s), and only those items found to comply may be claimed and/or marked as conforming with this standard.

TABLE A1 MINIMUM SAMPLING AND TESTING FREQUENCY PLAN

Characteristic	Clause	Requirement	Test Method	Frequency
MATERIAL PROPERTIES FOR RESIN SYSTEM				
Resin type	2.1.2, Table 1	PU, PEUU, or EP	Declared value	At any change in material formulation, design or process
Filler type	2.1.2, Table 1	None, inorganic or organic	Declared value	
Curing agent type	2.1.2, Table 1	Heat-initiated, light-initiated, or ambient cure	Declared value	
PROPERTIES OF RESIN COMPONENTS (UNCURED)				
Density	Table 2	Declared value	Declared value	At any change in material formulation, design or process. Test results considered valid for 5 years.
Colour	2.1.1	Declared value	Visual inspection	
PROPERTIES OF CURED RESIN				
Glass transition temperature	Table 3	Recorded value	ASTM D7028-07 or ISO 11359-2-99	At any change in material formulation, design or process. Test results considered valid for 5 years.
Water absorption	Table 3	Recorded value	AS3862	
Contact with drinking water	Table 3	Must pass AS/NZS 4020 requirements	AS/NZS 4020	
Liner thickness	3.5	Varies by method refer clause 3.5	Clause 3.5	Varies by method refer clause 3.5
PERFORMANCE REQUIREMENTS				
Surface irregularities	3.3	Average thickness not exceeded by ±10%	Visual inspection - Post CCTV inspection	Every installation
Hole spanning	3.4	Spans up to 3mm diameter holes	See Section 3.4	At any change in material formulation, design or process. Test results considered valid for 5 years.
Gap spanning	3.4	Spans up to 3mm gaps, width and depth	See Section 3.4	
Water tightness	2.4.6	All fittings, terminations and connections are water tight	AS/NZS 2566.2, Section 6	As per water agency testing frequency requirements
Contact with drinking water	2.4.2 Table 3 3.2 4.1	All system components meet standard requirements	AS/NZS 4020	At any change in material formulation, design or process. Test results considered valid for 5 years.
Elastomeric seals	4.1	Compliance with AS 1646 and AS 681.1	Product certification to AS 1646 and AS 681.1	

TABLE A2 MECANICAL TYPE AND BATCH TESTING AND TESTING FREQUENCY PLAN

Characteristic	Clause	Requirement	Test Method	Frequency
Type tests (TTs)				
Performance	5.2	Tensile properties	ASTM D638 ISO 527-1 AS 1145.2	At any change in material formulation, design or process. Test results considered valid for 5 years.
	5.3	Flexural properties	ASTM D790 ISO 178	
	5.4	Resistance to short-term hydraulic pressure	ASTM D1599	
	5.5	Adhesion (for Class C, and Class B and A if adhesion is required for sealing or bonding to host pipe)	ASTM D4541 ASTM D7234 AS 3894.9	
	5.6	Vacuum (for Class B and A only)	See Section 5.6	
	5.7	Thermal expansion/contraction	ASTM E831 ISO 11359-2	
	5.12	Wet strength reduction factor	AS3862 or testing underwater and compared with testing in air	
Type tests (TTs) long-term				
Performance	5.8	Tensile rupture strength	ISO 13003 ASTM D2992 ISO 15306	At any change in material formulation, design or process. Test results considered valid for 10 years.
	5.9	Tensile creep modulus	ASTM D2990 ISO 899-1 ASTM D6992	
	5.10	Flexural creep modulus	ASTM D2990 ISO 899-2 ASTM D6992	
	5.11	Fatigue strength	ISO 13003, ASTM D2992 ISO 15306	
	5.12	Wet creep reduction factor	AS3862 and testing underwater and compared with testing in air	

*One of flexural or tensile properties shall be tested and shall meet the declared values ultimate tensile/flexural strength of the liner and tensile/flexural elastic modulus from mechanical type tests.

APPENDIX B
(Normative)

STRUCTURAL CLASSIFICATION OF LINERS

Piping systems used for the renovation of pressure pipelines are classified in ISO 11295 in accordance with their structural performance as follows.

B1 CLASS A (Note this Class of pipe is not included in this WSAA Standard)

i. Can survive internally or externally induced failure of the host pipe.
ii. The long-term pressure rating is equal to or greater than the maximum allowable operating pressure of the renovated pipeline.
iii. The liner has sufficient inherent ring stiffness to be self-supporting when depressurised.
iv. Is capable of spanning gaps and holes long-term at the maximum allowable operating pressure.
v. Provides an internal barrier to the corrosion, abrasion and/or tuberculation / scaling of the host pipe and to the contamination of the pipe contents by the host pipe. Generally it also reduces the surface roughness for improved hydraulic performance.

B2 CLASS B

i. The liner has sufficient inherent ring stiffness to be self-supporting when depressurised.
ii. Is capable of spanning gaps and holes long-term at the maximum allowable operating pressure.
NOTE: The liner becomes sufficiently close fit during installation or during initial operation for transfer of the internal pressure stress to the host pipe.
iii. Provides an internal barrier to the corrosion, abrasion and/or tuberculation / scaling of the host pipe and to the contamination of the pipe contents by the host pipe. Generally it also reduces the surface roughness for improved hydraulic performance.

B3 CLASS C

i. The liner relies on adhesion to the host pipe to be self-supporting when depressurised.
ii. Is capable of spanning gaps and holes long-term at the maximum allowable operating pressure.
NOTE: The liner becomes sufficiently close fit during installation or during initial operation for transfer of the internal pressure stress to the host pipe.
iii. Provides an internal barrier to the corrosion, abrasion and/or tuberculation / scaling of the host pipe and to the contamination of the pipe contents by the host pipe. Generally it also reduces the surface roughness for improved hydraulic performance.

B4 CLASS D

i. The liner relies on adhesion to the host pipe to be self-supporting when depressurised.
ii. Provides an internal barrier to the corrosion, abrasion and/or tuberculation / scaling of the host pipe and to the contamination of the pipe contents by the host pipe. Generally it also reduces the surface roughness for improved hydraulic performance.

APPENDIX C

DESIGN METHODOLOGY FOR A SPRAY LINER

(Normative)

SCOPE

This Appendix sets out a means for consistent demonstration of conformity with this Standard to determine either: (a) the specified thickness required for a liner for the intended service life or (b) predict the service life of a lined pipe. The following limit states (Figure 2) are used for each class of liner (See Appendix B).

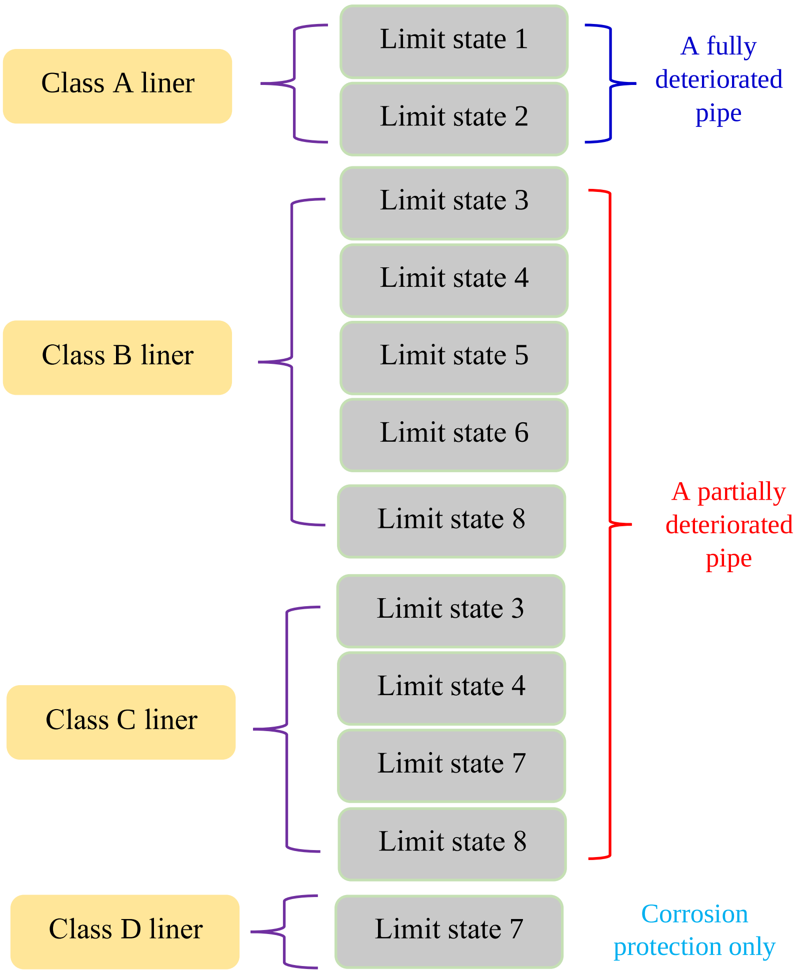

Figure 2. Lined pipe analysis for different classes of linings

FULLY DETERIORATED HOST PIPE

LIMIT STATE 1: INTERNAL PRESSURE (HOOP FAILURE)

For internal pressure check, the maximum stress in the liner σ_{max} (MPa) shall not be larger than the tensile strength of the liner in the hoop direction

$$\sigma_{max} \le \sigma_{tl}(t) \quad (1)$$

where σ_{tl} is the long-term strength of the liner and is the lesser value of either: the tensile rupture strength[2] $\sigma_{tl,r}$ (MPa) or fatigue[3] strength $\sigma_{tl,f}$ (MPa) determined by Section 5.8 or 5.11 respectively.

The maximum stress is generally induced by the maximum allowable pressure as follows (ASTM F1216 2016)

$$\sigma_{max} = \frac{P_{max} \cdot \left(\frac{D_L}{T_L} - 1\right) \cdot N}{2} \quad (2)$$

where P_{max} is the maximum allowable pressure, which is the larger of the operating pressure P (MPa) and the sum of the operating pressure P and cyclic surge pressure P_C (MPa) divided by 1.4 $(P + P_C)/1.4$ (AWWA M45 2013), D_L is the external diameter of the liner (mm), T_L is the wall thickness of the liner (mm), N is a factor of safety and includes the factor of safety, which considers the effect of liner imperfections and uncertainty in parameters involved in analysis.

LIMIT STATE 2: BUCKLING UNDER EXTERNAL LOADS (SOIL, HYDROSTATIC LOADS, LIVE LOADS) EXCLUDING INTERNAL PRESSURE

This limit state applies when the pipe is out of service, e.g. pressure in the pipe is removed for maintenance or the pipe is under vacuum pressure, or when the total external pressure is greater than the operating pressure, P. For buckling check, the total external pressure on pipes q_t shall be no larger than the liner capacity for total external pressure q_{tc} (MPa)

$$q_t \le q_{tc}(t) \quad (3)$$

The total external pressure on pipes q_t (MPa) can be determined as follows (ASTM F1216 2016)

$$q_t = \frac{9.81 \cdot H_w + \gamma_S \cdot H \cdot R_W}{10^6} + w_q \quad (4)$$

where H_w is the height of water above pipe, measured from pipe crown (mm), γ_S is the soil unit weight (kN/m^3), H is the pipe burial depth (mm), R_W is the water buoyancy factor (unitless) and can be determined based on Equation (5)

$$R_W = 1 - 0.33 \cdot \frac{H_w}{H} \ge 0.67 \quad (5)$$

where w_q is the live load (pressure) at the burial depth (MPa) from AS 2566.1 (1998), Equation 4.7.2(1). It should be noted that if $q_t \le P$, the internal operational pressure governs the design (Equation (2)) (AWWA 2019) and buckling under external loads does not need to be checked.

The liner capacity for total external pressure q_{tc} is calculated using Equation (6)

[2] Note the value of $\sigma_{tl,r}$ can be taken at a time corresponding to the estimated service life. For example, if a liner service life is 50 years, and in that time 50 years of continuous or intermediate pressure (fluid or ground pressure) will be applied on the liner, a σ_{tl} value corresponding to 50 years would be conservative. Alternatively, an estimated duration of internal operating pressure can be used. Note: see 4.12 for testing temperature.

[3] Note the value of $\sigma_{tl,f}$ can be taken at a time corresponding to the likely number of recurring cyclic surge pressure cycles estimated for service life. For example, if we assume that a minimum of two surge pressure cycles occur during a day (pump start-up and pump shutdown) the minimum pressure transient cycles to be experienced by a liner in a 50-year service life would be 36,500. From this number we can estimate the $\sigma_{tl,f}$ of the liner.

$$q_{tc}(t) = \frac{1}{N}\left[\frac{8 \cdot R_W \cdot B' \cdot E_s \cdot C \cdot CRF(\beta t) \cdot E_L \cdot {T_L}^3}{3 \cdot D^3}\right]^{\frac{1}{2}} \quad (6)$$

$$B' = \frac{1}{1 + 4e^{\frac{-0.213H}{10^3}}} \quad (7)$$

where E_s is the soil modulus[4] (MPa) (AS 2566.1 1998), C is the ovality reduction factor and it is defined as follows

$$C = \left[\left(1 - \frac{\Delta}{100}\right) \Big/ \left(1 + \frac{\Delta}{100}\right)^2\right]^3 \quad (8)$$

where Δ is the ovality of the original pipe (%), $CRF(\beta t)$ is the creep retention factor at time βt, β is the fraction of liner service life when out of service[5], E_L is the short-term modulus of elasticity of the liner (Section 4.3) (GPa).

where CRF can be found from creep modulus of the liner (from Section 4.9 and 4.10)

PARTIALLY DETERIORATED HOST PIPE

LIMIT STATE 3: HOLE SPANNING

A through-wall hole (defect) may form at a zone of graphitization, by a corrosion pit that penetrates through the pipe wall, or at a disconnected service line.

For hole spanning checks, the maximum stress in the liner σ_{max} shall be no larger than the tensile strength of the liner σ_t.

$$\sigma_{max} \le \sigma_{tl}(t) \quad (9)$$

where $\sigma_{tl}(t)$ is the lesser value of either: the long-term tensile strength σ_{tl} (MPa) or long-term fatigue strength of the liner $\sigma_{tl,f}$ (MPa).

The σ_{max} can be determined using the hole spanning equation (Fu et al. 2021a) as follows

$$\frac{\sigma_{max}}{P_{max}} = \frac{1.45 \cdot \left(\frac{E_p}{CRF(\mathrm{t}) \cdot E_L}\right)^{-0.183} \cdot \left(\frac{T_L}{D}\right)^{-1.13} \cdot (1 - 0.068 \cdot f) \cdot N}{\left[1 + 21.94 \cdot \exp\left(-20.63 \cdot \frac{d}{D}\right)\right]\left[\frac{T}{D} + 2 \cdot \left(\frac{T}{D}\right)^{-0.052}\right]} \quad (10)$$

where E_p and E_L are the modulus of elasticity of host pipe material and the liner respectively (GPa). D and T are the internal diameter (mm) and wall thickness (mm) of the host pipe, f is the friction coefficient of the interface between the host pipe and the liner[6], d is the diameter of the hole (defect) in the host pipe (mm).

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[4] E_s can be taken from the higher range of values of E'_e and E'_n in Table 3.2 due to the soil being in its natural state (trenchless installation with still in-situ soil and host pipe can be assumed as soil is in a dense state).

[5] A percentage of time out of service is used in this case as in most cases the lined pipe will not be subjected to both vacuum and external loads over a significant period of time, for example 14 days maximum. The creep modulus $(CRF \cdot E_L)$ will not experience vacuum and soil loads (host pipe will support a lot of these loads) for the whole service life. Also, the elastic creep modulus will tend to recover when the internal pressure is removed.

[6] The friction coefficient ranges between 0 to 0.577 and depends on the adhesion of the liner to the host pipe (or CML). The recommended ranges of friction coefficients for the interfaces between host pipes and polymeric liners are as follows: AC or CML 0.1–0.2 and Metallic 0.3–0.4.

LIMIT STATE 4: GAP SPANNING

Gaps in deteriorated cast iron pipes may exist due to past pipe repairs, joints or formed due to axial soil movements induced by thermal effects, thrust and/or horizontal vehicle loads etc. In addition, ring fractures or joint failures may occur in pipes subjected to axial tension and/or bending and these ring fractures and failed joints can be considered as gaps with zero width.

For gap spanning checks, the maximum stress in the liner σ_{max} shall be no larger than the tensile strength of the liner σ_t.

$$\sigma_{max} \leq \sigma_{tl}(t) \quad (11)$$

where σ_{max} can be a combination of axial, or principal, short-term or long-term tensile stress (MPa).

Three sub-limit states are considered, namely, liner covering existing gap under internal pressure, formation of gaps for lined pipes under internal pressure and lined pipes with ring fractures under internal pressure and bending as shown in Figure 3.

4-1 Liner covering existing gaps under internal pressure

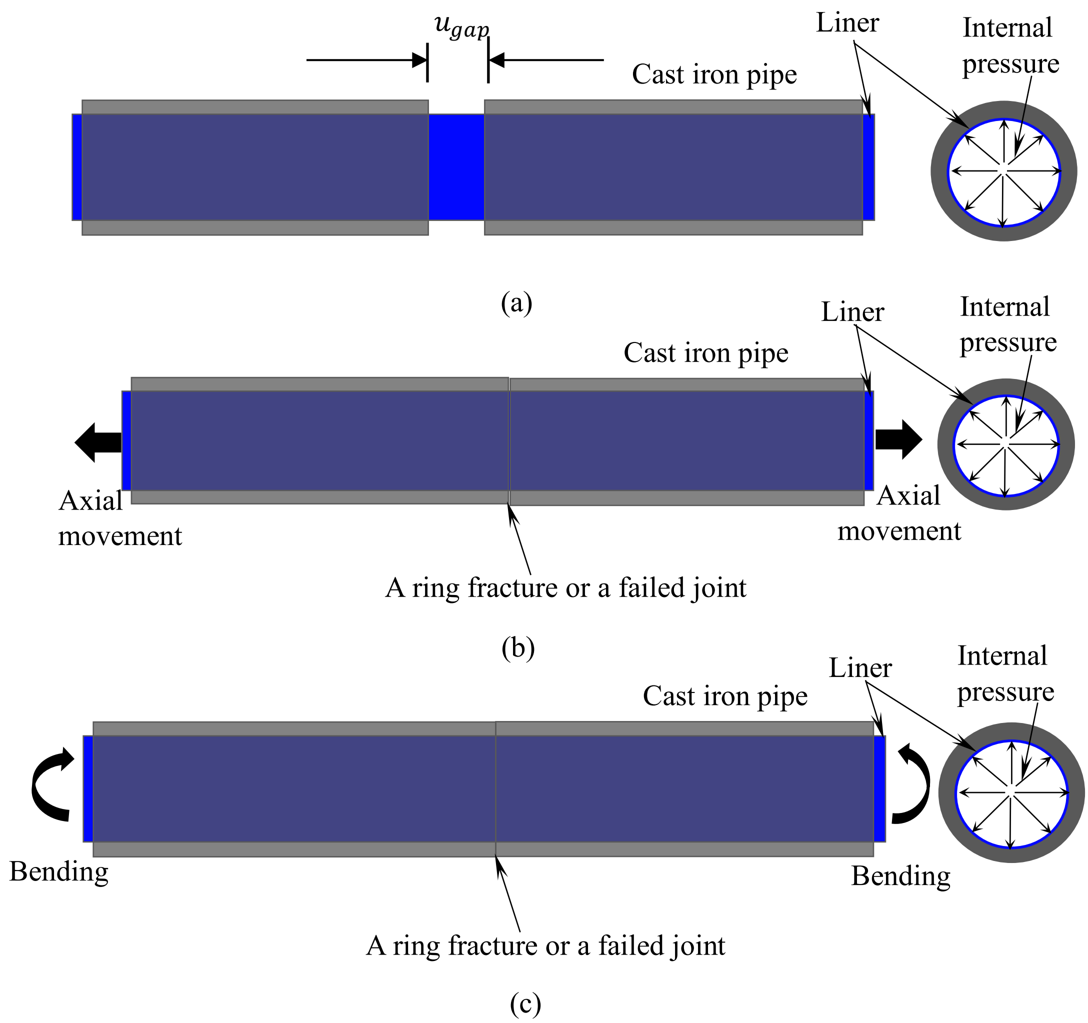

Figure 3. Pressurised cast iron pipes lined with polymeric liners: a) Liner covering existing gaps under internal pressure; (b) Formation of gaps for pressurised lined pipes under axial movements; (c) A lined pipe with a ring fracture under internal pressure and bending

The existing gaps are considered to be formed due to pipe repairs, joints or other causes. When an existing gas is present in a host pipe, the maximum stress in the liner σ_{max} can be determined using the equation as follows (Fu et al. 2021b)

$$\frac{\sigma_{max}}{P_{max}} = \frac{2.33 \cdot \frac{u_g}{t_L} \cdot (1 + 0.52 \cdot f - 0.15 \cdot f^2)\left(1 - 0.02 \cdot \left(\frac{E_p}{CRF(\mathrm{t}) \cdot E_L}\right)^{0.5}\right) \cdot N}{1 + 0.39 \cdot exp\left(-2.7 \cdot \frac{CRF(\mathrm{t}) \cdot E_L}{P_{max} \cdot N}\right)} \qquad (12)$$

where u_g is the existing gap width of host pipe (mm). Note: Equation (12) is only valid for a gap width of up to 35 mm. For gap widths greater than 35 mm, the pipe should be treated as fully deteriorated (see fully deterioration pipe - Limit state 1).

4-2 Formation of gaps for pressurised lined pipes under axial movements

After a ring fracture has developed in the host pipe, a gap might be formed due to thermal effects, thrust, horizontal vehicle loads or other loads. During the gap formation process, the maximum stress in the liner σ_{max} will develop and can be calculated by the following equation (Fu et al. 2021b)

$$\frac{\sigma_{max}}{P_{max}} = 31.5 \cdot \left(\frac{u_{gp}}{T_L}\right)^{0.5} \cdot f^{0.4} \cdot \left(\frac{CRF(\mathrm{t}) \cdot E_L}{P_{max} \cdot N}\right)^{0.43} \cdot \left(\frac{E_p}{CRF(\mathrm{t}) \cdot E_L}\right)^{-0.02} \cdot N \qquad (13)$$

where u_{gp} is the width of the gap formed due to the axial movement or axial pulling force (mm).

4-3 Lined pipes with ring fractures under internal pressure and bending

The limit state applies when there is a ring fracture or failed joint in the host pipe and the lined pipe is under combined internal pressure and bending. The bending can be caused by ground movements from reactive soils or frost or other sources.

The maximum stress in the liner for a lined pipe with a ring fracture under internal pressure and bending can be calculated using the following equation (Fu et al. 2021b)

$$\frac{\sigma_{max}}{P_{max}} = \frac{\left(\frac{T_L}{D}\right)^{-0.246} (1 + 0.53 \cdot f - 0.3 \cdot f^2)\theta^{0.82} \left(\frac{CRF(t) \cdot E_L}{P_{max} \cdot N}\right)^{0.81} \left(\frac{E_p}{CRF(t) \cdot E_L}\right)^{0.053} \cdot N}{\frac{T}{D} + 0.043 \cdot \left(\frac{T}{D}\right)^{-0.508}} \qquad (14)$$

where θ is the rotation angle of the pipe (°)[7]. Note that this formula was derived based on linear elastic liner properties and therefore underestimates the load capacity of liners with high plasticity.

LIMIT STATE 5: BUCKLING UNDER EXTERNAL PRESSURE

For this limit state, pressure pipes are considered to be depressurized periodically either due to routine maintenance or cyclical events. Note that this is for partially deteriorated host pipe. The polymeric liner is considered to take only the groundwater load while the host pipe takes the soil and surcharge load.

For buckling under external pressure check, the groundwater load P_G (MPa) shall be no larger than the groundwater load capacity P_{GC} (MPa)

$$P_G \leq P_{GC}(t) \qquad (15)$$

[7] The recommended range of rotation angle is 0–1°. For a rotation angle greater than 1°, a Class A liner or flexible liner would be recommended.

The external pressure capacity is determined by the following equation (ASTM F1216 2016)

$$P_{GC} = \frac{2000 \cdot K \cdot CRF(\beta t) \cdot E_f}{(1-\nu_L^2)} \cdot \frac{C}{\left(\frac{D}{T_L} - 1\right)^3} \quad (16)$$

where K is the enhancement factor of the soil and existing pipe adjacent to the liner. A minimum value of 7 is recommended where there is full support of the existing pipe (ASTM F1216 2016), β is the fraction of liner service life when out of service, E_f is the short-term flexural modulus of elasticity (GPa), ν_L is the Poisson's ratio of the liner.

For rigid host pipes, the applied external pressure on the liner P_G can be expressed as follows

$$P_G = \left(\frac{\gamma_w \cdot (H_w + D_M)}{10^6} + P_v\right) \cdot N \quad (17)$$

where γ_w is the unit weight of water (kN/m^3), H_w is the height of groundwater above pipe (mm), measured from pipe crown, D_M is the mean diameter of the host pipe (mm), P_v is the vacuum pressure (MPa).

For flexible host pipes, 50% of the live load is considered to be transferred to the liner (AWWA 2019). This is a conservative estimate since host pipes are assumed to be structurally sound for a Class B design and most host pipes are rigid.

The applied external pressure

$$P_G = \left(\frac{\gamma_w \cdot (H_w + D_M)}{10^6} + P_v\right) \cdot N + w_q \cdot N/2 \quad (18)$$

LIMIT STATE 6: THERMAL EFFECTS

When both liner ends are anchored, the lining system must have sufficient strength in the axial direction to withstand thermal end loads as follows

$$10^3 \cdot \alpha \cdot E_A \cdot \Delta T \cdot N \leq \sigma_A \quad (19)$$

where α is the coefficient of thermal expansion and contraction (mm/mm/°C), E_A is the liner tensile or compressive modulus in the axial direction (GPa), ΔT is the temperature change (°C), σ_A is the short-term tensile or compressive strength of the liner (MPa). Note either tensile or compression can be used but not a combination of the two.

LIMIT STATE 7: ADHESION CHECK

Note that a pipe might be depressurised due to routine maintenance, normal operation or cyclical events such as pressure transients. Therefore, given these circumstances, adhesion between the host pipe and liner needs to be checked.

For adhesion check, the external pressure on the liner P_N (MPa) shall be no larger than the adhesion strength of the liner to host pipe substrate σ_{ad} (MPa).

$$P_N \leq \sigma_{ad} \quad (20)$$

where P_N can be determined for two different load combinations.

7-1 Combination of external water pressure and vacuum

The external pressure on the liner P_N is the same as P_G as determined in Equation (17).

7-2 Combination of external water pressure and thermal loads

The external pressure on the liner P_N can be expressed as follows

$$P_N = \frac{\gamma_w \cdot (H_w + D_M) \cdot N}{10^6} + 10^3 \cdot \alpha \cdot E_{fh} \cdot \Delta T \tag{21}$$

LIMIT STATE 8: UNIFORM REDUCTION OF PIPE WALL THICKNESS (FOR AC PIPES ONLY)

Due to lime leaching, the effective wall thickness of the AC pipe will reduce over time. Consequently, the maximum stress in the liner σ_{max} will increase over time. To ensure safety, the maximum stress in the liner σ_{max} (MPa) should not exceed the tensile strength of the liner σ_t.

$$\sigma_{max} \le \sigma_{tl}(t) \tag{22}$$

The maximum stress in the liner σ_{max} can be expressed as follows

$$\sigma_{max} = \frac{E_L P_{max} D_L}{2\left(E_p T + E_L T_L\right)} \tag{23}$$

It should be noted that for limit state 8, the maximum stress in the AC pipe σ_p (MPa) should not exceed the tensile strength of the AC host pipe material $\sigma_{t,AC}$ (MPa).

$$\sigma_p \le \sigma_{t,AC} \tag{24}$$

Otherwise, the liner should be designed as the standalone liner, i.e., the host pipe is considered to be fully deteriorated.

The maximum stress in the AC pipe σ_p can be expressed as follows

$$\sigma_p = \frac{E_p P_{max} D_L}{2\left(E_p T + E_L T_L\right)} \tag{25}$$

Notation

C	Ovality reduction factor
CRF	Creep retention factor
d	Diameter of the hole (defect) in the host pipe (mm)
D	Internal diameter of the pipe (mm)
D_L	External diameter of the liner(mm)
D_M	Mean diameter of the host pipe (mm)
E_A	Short-term tensile or compressive modulus of the liner (GPa)
E_L	Short-term modulus of elasticity of the liner (GPa)
$E_{l,dry}$	Dry creep modulus of the liner (GPa)
$E_{l,wet}$	Wet creep modulus of the liner (GPa)

E_f Short-term flexural modulus of elasticity of the liner (GPa)

E_{fl} Flexural creep modulus of the liner (GPa)

E_p Modulus of elasticity of host pipe material (GPa)

E_s Soil modulus (MPa)

E_t Short-term tensile modulus of elasticity of the liner (GPa)

E_{tl} Tensile creep modulus of the liner (GPa)

f Friction coefficient of the interface between the host pipe and the liner (unitless)

H Pipe burial depth (mm)

H_w Height of water above pipe, measured from pipe crown (mm)

K Enhancement factor

N Factor of safety

P_{max} Maximum allowable pressure (MPa)

P Operating pressure (MPa)

P_c Recurring cyclic surge pressure (MPa)

P_G Groundwater load (MPa)

P_{GC} Groundwater load capacity (MPa)

P_N External pressure on the liner (MPa)

P_v Vacuum pressure (MPa)

q_t Total external pressure on pipes

q_{tc} Liner capacity for total external pressure

R_W Water buoyancy factor (unitless)

T Pipe wall thickness allowing for uniform corrosion (mm)

T_L Liner thickness (minimum) (mm)

u_g Existing gap width of host pipe (mm)

u_{gp} Gap formed due to axial movement or pulling force (mm)

w_q Live load (pressure) at the burial depth (MPa)

α Coefficient of thermal expansion/contraction (mm/mm/°C)

β Fraction of liner service life when out of service

γ_s Soil unit weight (kN/m^3)

γ_w Unit weight of water (kN/m^3)

Δ Ovality of the original pipe (%)

ΔT Temperature change (°C)

θ Rotation angle (°)

ν_L Poisson's ratio of liner (unitless)

σ_A Short-term tensile or compressive strength of the liner (MPa)

σ_{ad} Adhesion strength of the liner to host pipe substrate (MPa)

σ_f Short-term flexural strength of the liner (MPa)

σ_{max} Maximum stress in the liner (MPa)

σ_p Maximum stress in the AC host pipe (MPa)

$\sigma_{t,AC}$ Ultimate tensile strength of AC (MPa)

σ_t Short-term tensile strength of the liner (MPa)

$\sigma_{t,dry}$ Dry tensile strength of the liner (MPa)

$\sigma_{t,wet}$ Wet tensile strength of the liner (MPa)

$\sigma_{tl,r}$ Tensile rupture strength of the liner (MPa)

σ_{tl} Long-term strength of the liner and is the lesser value of either: the tensile rupture strength, $\sigma_{tl,r}$ (MPa) or fatigue strength, $\sigma_{tl.f}$ (MPa)

$\sigma_{tl.f}$ Fatigue strength (MPa)

ϕ_c Wet creep reduction factor

ϕ_s Wet strength reduction factor

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