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Resiline 320 Watermain Rehabilitation Manual

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1.0 Resiline Introduction and Overview

1.1 Introduction

As watermains age and deteriorate their performance gradually diminishes. Poor performance means an increase in the number of annual breaks and water loss, higher maintenance costs, reduced water quality, hydraulic capacity loss, and higher energy costs to run the system. This in turn reduces customer satisfaction and requires water utilities to increase water user fees so that they can replace these old pipelines using the very disruptive and expensive traditional open-cut construction method. Over the past 50 plus years, trenchless pipeline renovation methods have been developed as an alternative to open cut replacement. Trenchless pipeline renovation offers many advantages: faster construction; lower construction cost; lower impact on businesses and residences; reduced traffic delays; and a significant reduction (70 to 90 percent) in Greenhouse gas emissions. Thus, the adoption of trenchless renovation methods will allow water utilities to do more with limited financial resources, to do more faster, while at the same time, improve the system performance and the environment. Thus, the adoption of trenchless renovation methods is more sustainable than the open-cut replacement.

The Spray-in-Place Pipe (SIPP) lining method has been developed to renovate deteriorated potable water pipelines with a same day return to service. SIPP development began in 1982 in the United Kingdom. Over the next 40 years, many advancements in materials and spray equipment have occurred. Resiline 320 offers to the water industry a superior same day return to service watermain rehabilitation product that incorporates 40 plus years of SIPP watermain lining research and knowledge.

The American Waterworks Works Association (AWWA 2014) and the International Organization for Standardization (ISO) 11295 classify watermain lining renovation methods into four classes and three structural categories. Table 1.1 shows the AWWA and ISO classes and structural categories.

Table 1.1 AWWA (2014) and ISO 11295 product classification.

	Fully Structural	Semi Structural		Non-Structural
AWWA	Class IV	Class III	Class II	Class I
ISO	Class A	Class B	Class C	Class D

The four classes are AWWA Class I to Class IV and ISO Class A to D where ISO Class A is equivalent to AWWA Class IV and ISO Class D is equivalent to AWWA Class I. AWWA Class I and ISO Class D are classified as Non-structural linings while AWWA Class II and III (ISO Class C and B) are classified as semi-structural linings. AWWA Class IV (ISO Class A) are classified as fully structural linings. AWWA linings classifications were originally proposed in the AWWA M28 Watermain Rehabilitation Manual 3rd edition. In 2019, AWWA published the Committee report "Structural Classifications of Pressure Pipe Linings Suggested Protocol for Product Classification". This report provides an industry consensus overview on how to transition the AWWA M28 structural classification system from a qualitative concept to a quantitative process of product selection, including initial thoughts on recommended quality assurance processes during construction. Also in 2019, AWWA published ANSI/AWWA Standard C620-19 "Spray-In-Place Polymeric Lining for Potable Water Pipelines 4 In. (100mm) and Larger.

The Resiline 320 Watermain Rehabilitation Manual has been developed to help consultants, engineers, and Water Utilities with the adoption of the Resiline 320 SIPP watermain rehabilitation process. The manual provides information on the SIPP lining process, Resiline 320 material properties and thickness design, product capabilities and limitations, project quality assurance and quality control (QA/QC), design reconciliation, lined pipe repair, and warranty.

Resiline 320 is a moisture tolerant product, meeting the AWWA C222-08 requirement for moisture uptake with a 21-day water absorption value of less than two percent (Robinson 2022). The finished linings are hard, glossy, and free of surface tack or greasiness.

1.2 Resiline Company

Resimac is a specialist materials manufacturer based in the UK and was established in 2009. The company operates in over 50 countries across five continents. Resimac provides a range of epoxy, polyurethane and silicon coatings and repair materials to Oil and Gas, Petrochemical, Marine, Pulp and Paper, Power Generation, Chemical and Water industries. Also, Resimac produces coating and lining systems for the interior and exterior of both drinking water and foul water/sewage networks and pipelines. Products for internal lining application are supplied and supported through the Company's Resiline pipe lining division.

Resiline is the specialist pipe lining division of Resimac, UK and supplies internal linings for drinking water pipelines. Resiline has developed a new product for the SIPP market called "Resiline 320", which has both white and dark blue product components that combine to give a mid-blue high gloss finish coating within a host pipe (shown in Figure 1.1). The Resiline 320 was designed to give film thicknesses up to 3 mm in a single pass installation and has rapid curing characteristics that facilitate return to service after as little as 60 minutes from completion of lining.

Figure 1.1: Typical final product appearance of the Resiline 320 SIPP product.

1.3 Pressure Pipe Lining Products

For years, Cement Mortar Lining (CML) was used as the conventional choice to renovate unlined cast iron pipe for mains with diameter greater than 100 mm. Studies by WRc (1997) and field experiences have shown that in soft waters, CML material can deteriorate. This in turn results in iron pipe corrosion that can adversely affect the water quality for a sustained period.

In the United Kingdom, polyurethane, epoxy, and polyurea products were developed as a water pipe lining materials to replace CML. Polyurea products have a primary advantage over currently available products as they have a rapid cure time, which enables same day return-to-service. The same day return to service offers the possibility of not constructing the costly and disruptive bypass piping systems prior to lining (Rockaway & Ball, 2007).

Resiline 320 is an aliphatic isocyanate-based, polyurea material that is free from both bisphenol A (BPA) and Volatile Organic Compound (VOC). The Resiline 320 is a next generation, state of the art, spray lining material developed for the global potable water industry. After material application to the host pipe, the Resiline 320 product has an initial setting time of about 15 minutes. Also, after completion of lining, a final setting time of only 60 minutes is needed to ensure that same day return to service is possible.

Resiline 320 can be utilised either as a non-structural, corrosion barrier lining (Class I) or as a high build, semi-structural lining (Class II and Class III).

1.4 Mechanical Properties

Table 1.2 and Appendix 1 provide Resiline 320 typical dry properties. Resiline 320 has a tensile strength of 45.5 MPa (6,600 psi), flexural strength value of 70.5 MPa (10,200 psi) and a flexural modulus of 2000 MPa (290,000 psi) when dry. ASTM D1599 burst testing found a 3mm thick liner has a short-term burst pressure of 17.6 Bar (255psi) (Robinson 2022).

Table 1.2: Typical Resiline 320 Dry Properties.

Test	Standard	Resiline 320 Typical Value
Tensile Strength (at Break)	ASTM D638-14/BS EN ISO 527-2	45.5 MPa (6,600 psi)
Tensile Elongation	ASTM D638-14/BS EN ISO 527-2	4.2%
Flexural Strength	ASTM D790-17/BS EN ISO 178	70.5 MPa (10,200 psi)
Flexural Modulus	ASTM D790-17/BS EN ISO 178	2000 MPa (290,000 psi)
Burst Pressure	ASTM D1599-18	17.6 Bar (255psi) (6” @3.0mm thickness)
Hardness	ASTM D2240-15	83 Shore D
Abrasion Resistance	ASTM D7028/ASTM D4060	150 mg loss per 1000 cycles (CS17 wheel, 1 kg load)
Water Absorption	ASTM D570	1.45% (28 days)
BPA Free	EPA Method 1311	Yes
VOC Free	EPA Method 24	Yes

Test results obtained from extracted field samples may vary according to site application and environmental conditions.

Resiline 320 has a slight reduction in tensile strength, flexural strength, and modulus when wet.

Table 1.3 provides Resiline 320 design material properties. These design values can be used to determine an appropriate liner thickness noted in Sections 4 and 5.

Table 1.3: Typical Resiline 320 Liner Design Properties.

Test	Resiline 320 Typical Design Values
Tensile Strength (at Break)	41.5 MPa (6,000 psi)
Flexural Strength	65 MPa (9,400 psi)
Flexural Modulus	1724 MPa (250,000 psi)
50 year Tensile Creep Rupture Strength	12.5 MPa (1813 psi)
50 year Flexural Creep Rupture Strength	22.5MPa (3263 psi)
Poisson Ratio	0.4

The field installed liner design values and the liner thickness should be verified through a Quality Assurance & Quality Control (QA/QC) program noted in Section 4 of this manual. If QA/QC testing indicates that the liner material properties are below Table 1.3 reported values, a design reconsolidation can be performed (see Section 6 of this report).

1.5 Potable Water Approvals/Certifications

NSF International is an organization that certifies that materials used in drinking water systems do not pose a chemical health risk to consumers. Certification to NSF International/American National Standards Institute/Canada (NSF/ANSI/CAN) Standard 61-2018 is required for a specific product or chemical to be used for potable water applications. Section 5 of NSF/ANSI/CAN 61 specifically addresses evaluations of spray on linings used in pipeline rehabilitation intended for immediate return to service.

The Resiline 320 meets NSF/ANSI/CAN 61-2018 for pipe diameters 200 mm (4 in) and greater, liner thickness up to 9mm, and a maximum pipe surface area/volume ratio of 61 sq in/L. The NSF/ANSI/CAN certificate is provided in Appendix II. This certificate shows that Resiline 320 meets NSF/ANSI/CAN 61 requirements and thereby poses no health risks when used in potable water systems.

2.0 Watermain Pipe Rehabilitation

2.1 Application and Process

Resiline 320 is a two-component (white and dark blue) low viscosity material that is fully mixed in the spray head to form a light blue lining on the pipe wall. The lining can be sprayed to form a lining thickness up to 3.0mm per application and multiple applications are possible up to a total thickness of 9 mm.

The lining process consists of the completion of the six sequential steps shown in Figure 2.1 and discussed in the following sections.

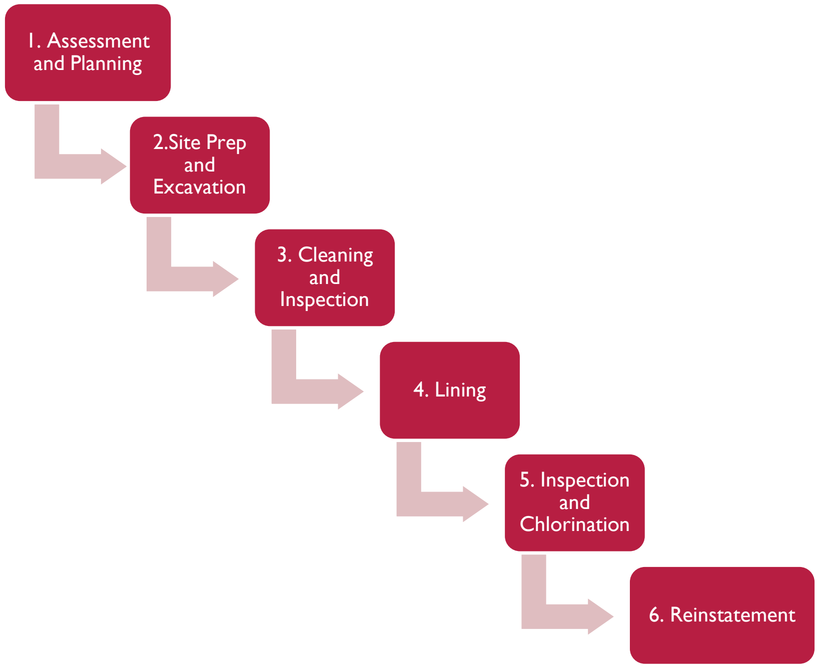

Figure 2.1: The six sequential step lining process.

2.2 Assessment and Planning

The rehabilitation process begins with the careful selection of pipe segments for rehabilitation. Pipe type, age, trench, and bedding materials, along with the number and type of breaks can be used as a proxy for the pipe condition and to build a SIPP lining program.

The state or presence of the following items may be revealed during condition assessment:

- leaking valves and ferrules
- leaking curb stop
- location and type of breaks
- un-repaired perforations
- pipe graphitization
- standing water
- bends (6°- 22.5° depending on pipe diameter)
- access points

Pipe segments should be selected so that work can be completed sequentially in a localized area.

Specific details addressed during this project planning phase include environmental and regulatory compliance, easement restrictions, traffic controls and determining the strategic location of access pits. It also includes the performance of above ground and subsurface utility surveys in all proposed pit locations.

The excavation of test pits should also be considered in locations where the ground water table location, pipe type and/or diameter is uncertain or if the purchaser wishes to consider non-destructive or destructive testing of the host pipe consistent with AWWA C620. Checks for soil contamination may be warranted depending on local risk and knowledge.

Soil contamination with aromatic hydrocarbons (benzene, toluene, xylene) should be avoided but contamination with aliphatic hydrocarbons - gasoline/petrol, other alkanes, lubricating oils should not generally present an issue. Contact the lining manufacturer for further guidance with respect to soil contaminants.

It is essential to determine all valve and hydrant locations along the length of the pipe to be lined. Once surface and subsurface surveys are completed, the thickness of the coating and lengths of pipe sections can be determined.

Most drinking water system owners will have experienced utility conflicts in the past and appreciate the need for accurate utility locates in the design process. Although lining projects involve minimal excavation, the value of obtaining and applying utility locates in the design stage cannot be overstated. Locating access pits requires careful consideration of several factors such as:

- Extent of the lining project.
- Location of valves, butterfly valves, tees, fittings, and hydrants.
- Location of pipe bends more than 22.5 degrees, offset or displaced joints, and elevation changes.
- Room to set up lining and cleaning equipment. The lining rig must generally be located in-line with the watermain.
- Extent of the service interruption.
- Watermain depth and shoring design.
- Pedestrian and vehicle traffic.
- Location of watermains, water services, as well as other utilities and services that would complicate the installation of access pit shoring and obstruct workers within the access pits.
- Length of lining sections. Continuous lining lengths of 180 m have been successfully completed. The condition of the host pipe and the pipe geometry (sags and bends) can affect the quality of lining. Lining lengths greater than 120 meters require special consideration to ensure performance requirements are achieved. Poorly made

It is also important to identify and exercise valves to be used to isolate the system. Abandoned open gate valves may be cleaned through, if desired, and lined in place. When pressurized watermains will remain connected to the host pipe, that will be lined, and valves will be used for isolation, all isolation valves must be confirmed to be leak free. Alternatively, it may be necessary to install an access pit at fittings where abutting mains will remain pressurized.

Water sources to be used for flushing the pipe during cleaning, if necessary, should also be identified.

A detailed work schedule is then created to minimize impact on traffic, businesses, and homeowners.

Prior to commencement of the lining work, impacted homeowners and businesses should be notified so that they are fully aware of the work that will be completed and the timing of the work. This notification should include the following information.

- Description of the lining process and work to be completed.
- Date and time of work.
- Estimated water outage time.
- Project contact information.

2.3 Site Preparation and Excavation

It is recommended that a contractor or installer should physically check all the dimensions supplied by the project owner to ensure accuracy.

All underground utilities must be marked at access pit locations. Traffic, pedestrian, and worker safety equipment must be installed prior to the commencement of the access pit excavation. Access pit dewatering equipment should also be installed if required and a Hazard Risk Analysis performed.

To minimize the impact to businesses and homeowners, access pits can be excavated one day prior to lining. The work area must be in compliance with all federal, provincial, and local regulations. Subject to local health authorities, pits may need to remain until microbiological tests allow final connections to be completed.

The installation of engineered shoring, in access pits greater than 1 meter (3 feet) in depth, is recommended. In addition to trench safety, a properly constructed and shored trench will provide a clean, dry workspace. This will ensure sanitary working conditions are maintained around open watermain pipe ends. Shoring of timber or steel are common and may be prefabricated or fabricated on-site. Timber shoring is most easily adapted to accommodate other utilities, service connections, and obstructions.

Pits should have minimum unobstructed internal dimensions of 2.4 to 3 meters (8 to 10 feet) along the pipe (dependent on mains depth) and 1.8 meters (6 feet) across the pipe to provide a safe workspace and clearances required to deflect the lining rig umbilical. Larger pits may be required depending on local conditions. Pits should also extend at least 0.6 meters (2 feet) beneath the watermain to ensure adequate clearances for restraint harnesses, use of tools, and to prevent trench water from entering the pipe.

At least one sump should be provided near the corner of the pit to enable dewatering with a submersible pump and clean, clear stone should be placed to a depth of 50 mm (2 inches) on the pit floor to provide safe footing and prevent pipe contamination. Guarding and traffic markers should be installed around the pit. The pit access ladders should be properly secured and a means to lift heavy materials into and out of the pit should be provided.

Pit shoring should large enough to accommodate thrust blocks. Larger pits may be required for the provision of watermain end caps, blocking, and temporary connections through backflow preventers.

Once the pipe is isolated and all services are closed, a 1.3 m (4 feet) section of the pipe is cut out and removed. The pipe is then drained of water to provide equipment access.

It is critical that all isolation valves do not leak. Leakage from service connections and abutting watermains into the host pipe can affect the quality of the lining installation by the formation of pinholes and material slumping. Consistent with AWWA C620 this is typically the responsibility of the purchaser.

Service connections may be turned off at the curb stop or inside the premises. Customers should be informed in advance and steps taken to ensure the isolation does not damage any plumbing appurtenances. If service isolations will be done using curb stop, they should be test operated and repaired, if necessary, prior to lining. Where valves inside premises are used to isolate, arrangements should be made in advance with building owners to ensure valves will be accessible and functional when lining begins.

The pipe end that is not being lined can be capped and recharged if proper safety restraints are in place.

2.4 Pipe Cleaning and Inspection

The host pipe must be cleaned and prepared for the lining. This includes removal of encrustation, tuberculation and accumulated loose or adhered materials. This removal of interior deposits and sediment will result in improved water flow and efficiency.

Approved pipe cleaning technologies for surface preparation before the application of the Resiline 320 include water jetting, rack-feed boring, drag scraping, and air-borne abrasive stone cleaning. If required by local regulation, capture all debris for proper disposal. In the case of asbestos host pipes verify compliance with local, state, and federal regulations.

To verify the pipe condition and that the pipe is acceptable for lining, a closed-circuit television (CCTV) camera should be placed inside the pipe (CCTV V1). A pan and tilt CCTV camera is the preferred method of inspection. CCTV surveys should be recorded and provided to the owner or the project engineer. This CCTV should show and record all services, bends, sags, water infiltration locations, and leaking services.

The use of a plunger, squeegee or foam swab may be required to remove the last of the sediment, dust, and/or standing water.

Repeat the cleaning process until the pipe is prepared to an approved condition to receive the Resiline 320 lining.

According to AWWA C210, when using abrasive blast cleaning method such as the new Tomahawk™ System, the steel pipe surfaces shall be abrasive blast cleaned to achieve a near-white metal surface conforming to SSPC-SP 10/NACE No. 2. However, irrespective of the cleaning method, the minimum specification by AWWA C620 and ASTM F3182 must be achieved - a clean metal surface conforming to the SSPC-SP 7/NACE NO. 4 standard for the pipeline and SSPC-SP 6/NACE NO.3 standard for service connections and terminations.

3.0 Pipe Lining

3.1 Overview

Traffic is controlled by mounting various traffic diversion signs on site and traffic calming is deployed if necessary. Worker and public safety must be ensured during access point excavation, dewatering, and pipe lining. Lining activities for the Resiline 320 involves both preparatory and lining activities. In preparing for the lining application, the equipment to be used on site is assessed for any faults and wear.

Resiline 320 lining process includes: 1) rig set up, 2) liner installation (single or multiple pass), 3) curing (this involves waiting), 4) post-lining inspection, 5) opening of service connections (if required), 6) flushing of the lined pipe, 7) final inspection, and 7) sampling and testing.

3.2 Environmental Factors

To ensure the proper cure of Resiline 320, environmental parameters must be within specifications:

- Resiline 320 should not be applied on substrates that are below 3 ˚C (37 ˚F)
- Prior to insertion of the lining hose into the main, both components shall be circulated through the hoses for sufficient time to attain a uniform temperature of 20-30 ˚C (68 ˚F - 86 ˚F)
- Material temperatures in the lining rig must be 20-30 ˚C (68 ˚F - 86 ˚F)
- Material temperatures in storage shall not exceed 40 ˚C (104 ˚F)

3.3 Pre-Lining Weight Validation

The lining rig utilises flow meters to monitor the volumetric accuracy of material delivery during lining. A quality assurance procedure to confirm that the lining rig pumping and monitoring system are working correctly shall be in place before every lining application. This is a manual weight checking procedure of the dispensed material components taken from the rig weight checking station. The lining rig shall be set in long recirculation mode and pumping at the flow rate at which the lining is intended to be performed. A minimum of three weight checks shall be taken at time intervals of at least three minutes apart. A minimum of 500g of base component shall be collected for each weight check. The results of these manual weight checks shall be entered into the sequential control lining rig computer system. The last weight check should be undertaken not more than one hour before lining is intended to commence otherwise the weight check process should be repeated.

The mix ratio is calculated as follows: 100: [Weight of Activator]/[Weight of Base] x 100.

The results must all be within +/-5% of the Resiline published mix ratio by weight (100:72.5)

If any of the weight checks do not comply with this quality check, weight checking should be repeated until three consecutive results meet this requirement.

Lining should not commence until the accuracy of mix ratio delivery of the lining rig has been confirmed through the weight check procedure.

3.4 Lining Rig Set-up

An umbilical is used to transfer material to the spray head. It is critical to maintain tension on the umbilical between the retrieval end (near the rig) of the pipe and the umbilical drum on the rig to help maintain a uniform spray lining throughout the length of the pipe. Following the weight check the lining rig umbilical needs to be winched through the pipe to be lined. This is accomplished after the CCTV camera tractor pulls the winch cable from the rig retrieval pit to the lining start pit.

The lining rig needs to be setup so that the umbilical is straight and inline with the lined pipe. Rollers should be installed as shown in Figure 2.2, to ensure the smooth pulling of the lining umbilical. A supporting structure may need to be installed, so that pulleys supporting the lining umbilical can be secured to prevent catenary sag in the umbilical. Catenary sag can contribute to variation in lining thickness.

Figure 2.2: Lining umbilical with rollers.

Ensuring adequate tension in the umbilical by use of a properly designed tensioner system will help reduce umbilical bouncing. Excessive umbilical bouncing can result in the spray head having jerking movements that will create uneven linings thickness and possibly voids in the lining.

Following the guidelines below will help to minimize lining issues:

- Station rollers between the pipe end and umbilical drum at various heights. Run the umbilical over or under the rollers to apply the necessary pressure to help maintain tension while the umbilical is being wound on the drum during the lining process.
- For larger spans, if the lining rig cannot be moved closer to the retrieval pit, a series of rollers should be used to help maintain proper tension in the umbilical.
- Use tensioners that are adjustable in height to properly account for pit depth variations and job specific tension needs.
- A minimum of one roller should be attached to the rig to aid in guiding the umbilical onto the drum.
- A pipe end roller should also be used on the end of the pipe to help maintain tension and minimize wear on the umbilical.

Every site situation is different so various customized tensioner configurations may be needed depending upon retrieval pit geometry, retrieval pit depth, rig location relative to the retrieval pit, and other factors depending on the job site.

3.5 Application of Resiline 320

Once the lining umbilical is pulled through the pipeline into the lining start pit, the spray head assembly is attached by workers located in the pit. All in pit workers must have appropriate Protective Personnel Equipment (PPE). With the two resin lines, in the closed position, the head is checked for the proper spin Revolutions per Minute (RPM) using a digital tachometer then shut down. The proper head spin RPM is dependant on the lining head size, lining cone used, and pipe size being lined. Please see your equipment manufacturer documentation for the proper head spin RPM information.

After spin verification, the spray head is brought back up to full speed and the two resin lines are fully opened. This process takes place in a suitable container (pail) so that there will be no spillage of the components and that all resin spray will be contained within the container/pail. This spin up process is undertaken to ensure that the spray head and mixer are working correctly and material stabilisation- i.e. the correct consistency and color is obtained within the pail. A minimum spin up time of 30 seconds or the time established in a spin up test, must elapse after the opening of the resin lines and the start of the material pumping.

Following full spin up, a dip card is inserted into the resin spray to collect a small sample of the spray material. This is to ensure, the lining head operator, that proper spraying and mixing is occurring before the commencement of the lining process. The lining process consists of starting the lining rig winch and transferring the lining head into a clean pail. The clean pail is used to contain the spray until the spray head enters the pipe being lined.

The umbilical and spray head are pulled back through the pipe at a controlled and specified rate to apply the lining at a uniform thickness of up to 3.0 mm. The umbilical pull-back rate depends on the lining thickness, pipe diameter and lining rig. Throughout the lining process the resin mix ratio, temperature, flow rate, coating thickness, hose speed, and length lined should be continuously monitored as shown in Figure 2.3.

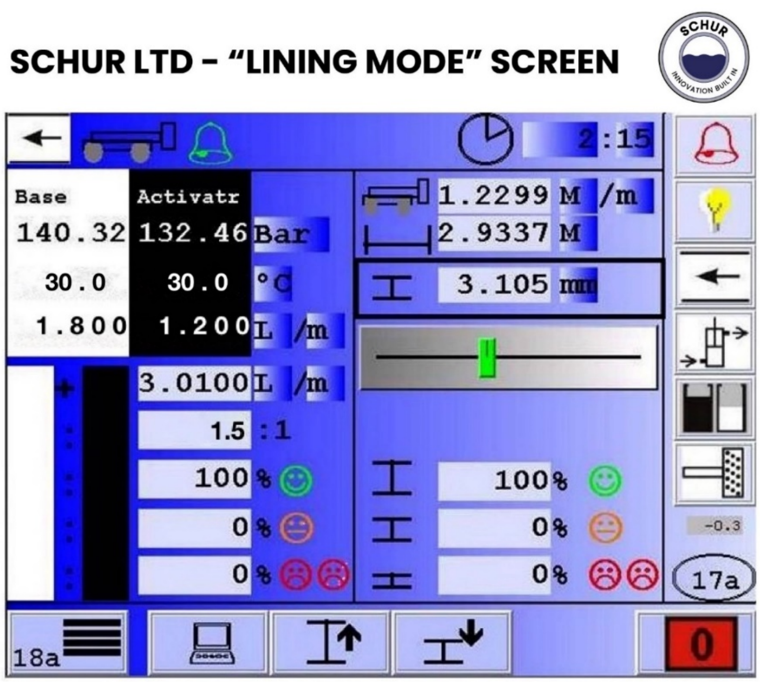

Figure 2.3: Lining Rig Monitoring during the lining process.

At the end of the lining process and prior to the spray exiting the pipe, workers in the pit with PPE, should guide the spray head out of the pipe and into a pail, to control the spray. An exit dip card of the sprayed material is then taken as a QA sample before the lining rig is shut down.

3.5.1 CCTV Post Lining Inspection V2

A CCTV inspection of the lining can commence 15 minutes after completion of the lining. This video should be recorded and made available for inspection by the owner and/or their representatives. After each lining application, a CCTV inspection is completed to record and note items such as: 1) the condition of the lining around services, 2) lining defects such as pin holes and water intrusion, and 3) soft uncured material. All lining faults should be recorded as per C620 Section 4.5.9.

3.5.2 Multiple Lining Pass Applications

The lining process noted in Section 2.4 and CCTV inspection noted in Section 2.5 are repeated until the design thickness is achieved or a total of 9mm is applied.

3.6 Inspection and Chlorination

3.6.1 CCTV Post Lining Inspection V3

A final pipe CCTV inspection, CCTV V3, should be completed and recorded. All lining faults should be recorded as per C620 Section 4.5.9.

3.6.2 Services

During each spray pass, Resiline 320 can build up on protruding services and can potentially restrict the openings of the service connection. It may also completely cover and block service connections. The service connection size, circumferential location, protrusion depth into the distribution pipe wall, and the thickness of applied lining amount of material will affect the amount of lining build up and potential service restriction. If the service is restricted, a robotic cutter can be used to open the service. Care must be used not to damage the service, lining, and pipe when drilling out a service. After cutting the lining material away, service back flushing may be required to remove the debris from the connection. The pipe may also need to be flushed to remove debris.

3.6.3 Disinfection

Disinfection of water pipes after lining is a common industry practice. The lining shall be allowed to fully cure for a minimum of 60 minutes before disinfection and flushing. The pipe shall be secured by capping the ends to prevent contamination.

When selecting a specific disinfection method, Resimac advises to contact the local municipality, utility department or government agency with jurisdiction over the project. The main types of disinfection methods include the spray method, tablet method, continuous feed method, and slug methods. Some of these methods require the use of chlorine with quantity ranging from 25 mg/L to 200 mg/L and exposure time ranging from 30 minutes to 72 hours. AWWA C-651 provides further guidance on disinfection of watermains.

3.7 Reconnection

3.7.1 End Seals

As per AWWA C620 it is a recommended best practice to end seal any pipes that are cut after the lining is installed due to the localized force applied to the lining at the cut edge. Only Resimac qualified end sealing solutions shall be used to seal ends of a pipe that is lined with Resiline 320. The material shall be locally certified for potable water contact, and suitable for end sealing applications when used in conjunction with the Resiline 320.

Following the application, a visual inspection shall be made of the applied end sealer after it has cured to help ensure there is no crack or break in the applied Resiline 320. If any crack or gaps are visible in the applied end seal, the area extending beyond the crack shall be abraded to complete a fresh application of the approved end seal.

3.7.2 Pipe Connection

NSF/ANSI 61 approved mechanical fittings for PVC or ductile iron pipes may be used to reconnect entry and exit points of a lined pipe. Care should be taken to properly support the lined protruding pipe sections during reinstatement. Any removed service connection should be replaced with fittings that have a shoulder support attached to the main.

3.7.3 Valve and Appurtenances

All valves should be inspected upon reconnection to ensure proper working condition. All valves and appurtenances should be installed and rigidly supported. Any damaged items must be repaired or replaced before they are reinstalled. Hydrants should be connected to the pipe at the original location. The outside of the hydrant, above the finished ground line, should be thoroughly cleaned to remove all dirt, debris, and dust.

3.7.4 Pit Restoration

Bid specification requirements typically define the project scope to meet all state, local and federal conditions. The conditions that must be followed to comply with each operation and procedure include, but are not limited to:

- Access point backfilling
- Surface restoration and site clearing
- Waste disposal

3.7.5 Cathodic Corrosion Protection

For metallic pipe, the installation of sacrificial anodes connected to the existing pipe is a proven method to reduce the annual number of pipe breaks and to stop the internal and external corrosion process. The development of a Cathodic Protection program should be considered. This program could, at a minimum, consist of the installation of zinc anodes, connected to the lined pipe, at all access pit locations prior to backfilling. Soil resistivity measurements, on soil samples collected when pits are excavated, can also be used to develop a pipe Cathodic Protection program.

4.0 Process Quality Assurance and Quality Control

4.1 Overview

The implementation of a Quality Assurance and Quality Control (QA/QC) program will ensure that the installed liner meets or exceeds the lining program design objectives. It is imperative that the customer identify and establish the lining design objectives before the lining program starts. These objectives could be: 1) improve water quality, 2) reduce leakage, 3) extend the pipe service life, 4) reduce the number of breaks, 5) bridge holes and gaps, etc. It is imperative that the QA/QC program aligns with the lining program design objectives. The QA/QC program should also meet the requirements specified in the AWWA C620 Standard.

4.2 Resin Mix Verification

As noted in Section 2.5.2, the resin weight should be verified prior to the start of the lining. Documentation should be provided to the owner or the owner's representative to verify that the appropriate resin mix ratio was achieved.

Lining rig printouts and dip cards, for each lining pass, can also be provided to the owner or the owner representative to verify the lining was performed within specification.

4.3 CCTV Inspections

CCTV inspections are to be performed and recorded after the pipe is cleaned (V1), after each lining application (V2) and prior to reconnection of the lined watermain to the distribution system (V3). Resiline recommends the use of a pan and tilt color CCTV camera for all inspections. All CCTV surveys should be performed at a rate that allows for the observation of the pipe and liner in accordance with the AWWA Standard C620. Copies of all videos should be provided to the owner or the owner representative at the end of the project or in accordance with the contract requirements.

4.3.1 Post-Cleaning Inspection (V1)

Pipeline surface cleaning and preparation is critical for non-structural and semi-structural system performance. Visual inspection, with the aid of a CCTV camera, is required after cleaning and before lining. This inspection will allow for an evaluation of the pipe surface to be lined. This will ensure that a high-quality lining can be constructed.

The CCTV inspection shall ensure that the pipe wall surfaces are clean, free of standing water, deposits, and other debris or contaminants that will prevent the lining from bonding to the pipe wall.

Irrespective of the cleaning method, the minimum specification by ASTM F3182 must be achieved - a clean metal surface conforming to the SSPC-SP 7/NACE No. 4 standard for the pipeline, and SSPC-SP 6/NACE No.3 standard, for service connections and terminations. As noted in Section 2.4, when using abrasive blast cleaning method, the pipe surfaces shall be cleaned to achieve a near-white metal surface conforming to SSPC-SP 6/NACE No. 2.

The pipe must also be free of dripping/seeping water. Leaking services must be fixed prior to commencement of lining.

4.3.2 Post Lining and Services Inspection (V2)

Following each lining application, a CCTV inspection shall be performed to ensure that a high-quality lining is constructed. The goal of these inspections is to ensure the lining is in accordance with AWWA C620 Section 4.5.9 and as such has no significance lining faults such as: uncured linings; collapsed or disbonded linings; slumped linings; pinholes; blisters; cracks; incomplete lining; water damage; speckled lining, and over-lining. It is also to inspect the lining condition at services; pipe joints; hydrants and valves and service restrictions/blockages.

4.3.3 Final Lining Inspection (V3)

Prior to the pipe reinstatement, a final CCTV survey (V3) shall be completed and recorded. This survey shall confirm the condition of the services and the lining is free of faults, and that the pipe, services, and hydrant leads are free of debris and potential contamination.

4.4 Liner Verification

4.4.1 Test Samples

Insitu "as constructed" test samples shall be obtained for third party testing. Test samples can be obtained by cutting a 1-meter-long (3 feet) section of lined pipe or by adding a like size internal diameter pipe or form to the end of the pipe section to be lined. All pipe ends must be end sealed in accordance with Section 2.7.1. All pipe samples should have a recorded chain of custody.

The number of test samples should be specified in the contract documents.

4.4.2 Liner Thickness

Liner thickness measurements shall be performed along the end of each pipe sample. A minimum of eight measurements shall be taken at evenly spaced intervals around the circumference of the sample to ensure that minimum and maximum thicknesses have been determined. The mean liner thickness should be equal to or greater than the design thickness. The liner minimum thickness must be equal to or greater than 87.5 percent of the design thickness.

4.4.3 Liner Host Pipe Bond

The finished liner product is expected to fit tightly to the host pipe at all observable points. Since the liner may be installed using multiple passes, layers of the liner shall be uniformly bonded so that they act as a uniform section. The liner shall not be able to separate from its layers with a probe or point of a knife blade such that the knife blade moves freely between the layers.

4.4.4 Mechanical Properties

Test specimens shall be cut from the pipe samples to verify that the installed liner meets or exceeds the mechanical properties used to determine the liner design thickness.

The materials of the finished liner are required to conform to the minimum structural standards for noted in ASTM F1216. The measured values of samples exhumed from the field will determine if the field product meets the product design standards. ASTM F1216 specifies a minimum of 31 MPa (4,500 psi) and 1,724 MPa (250,000 psi) for the flexural strength and modulus respectively and 21 MPa (3,000 psi) for tensile strength.

4.4.4.1 Tensile Properties

Tensile testing shall be completed in accordance with ASTM D638. Type I coupons should be cut from the liner sample along the sample longitudinal axis. At least five sample shall be tested, and the tensile strength reported. If the reported tensile values are below the design values, a design reconciliation should be considered (see Section 6).

4.4.4.2 Flexural Properties

Flexural test specimens should be cut along the test samples longitudinal axis in accordance with ASTM D790. At least three test specimens shall be tested with a span to depth ratio of at least 16 to 1 and the flexural modulus and flexural strength reported. If the flexural properties are less than the design values, a design reconciliation should be considered (see Section 6).

4.5 Project Documentation

The following is a list of suggested project documentation and forms to be delivered to the project owner or their representative. These documents and forms are representative of those typically used in the industry. The contractor is responsible for determining what documents are appropriate for the intended use and proper application. Resiline makes no representation that the documents or forms below are suitable for any specific project.

- Mechanical test results (if required)
- Pre- and post-entry dip cards
- Printouts from the coating rig
- Post-inspection CCTV recording in a format acceptable to the owner

5.0 Liner Design

Most pressure pipe liners are designed in accordance with ASTM F1216 Non-Mandatory Appendix X1 Section X1.3. The design formulae incorporated in F1216 reflects two different design objectives: 1) *Partially Deteriorated Pressure Condition*, and 2) *Fully Deteriorated Pressure Pipe Condition.*

Section X1.3.1 defines a Partially Deteriorated as an underground liner designed to support external hydrostatic loads due to groundwater, as well as, to withstand the internal pressure in spanning across any holes in the original pipe wall. The results of Eq X1.1 are compared to those from Eq X1.6 or Eq X1.7, as directed by Eq X1.5, and the largest of the thicknesses is selected. In an above-ground design condition, the liner is designed to withstand the internal pressure only by using Eq X1.5-X1.7 as applicable.

Section X1.3.2 defines Fully Deteriorated as an underground liner designed to withstand all external loads and the full internal pressure. The design thicknesses are calculated from Eq X1.1, Eq X1.3, Eq X1.4, and Eq X1.7, and the largest thickness is selected. If the pipe is above ground, the liner is designed to withstand internal pressure only by using Eq X1.7.

Using Resiline 320 design values provided in Table 1.2, with an AASHTO HS20 surface truck load live load ASTM F1216 Partially and Fully Deteriorated lining thickness can be determined for a system that operates at 6.2 Bar (90 psi), a 25mm (1 inch) diameter hole and full vacuum load of -1 bar (-15 psi). Appendix III and Table 4.1 provides Partially and Fully deteriorated pressure pipe designs using a Factor of Safety of 2, pipe depth at 1.5 and 2.5m below the ground surface, the ground water table located at the ground surface. These design condition are deemed to establish conservative liner thickness for the majority of North America watermains.

Table 4.1: Resiline ASTM F1216 Partially and Fully Deteriorated liner thickness requirements for a water pipe with 25mm circular pipe hole, 1.5 and 2.5m below the ground surface, water table at the ground surface, and 6.2 Bar (90 psi) operating pressure, full vacuum of -1 bar (-15 psi) and AASHTO HS20 surface truck load.

Pipe Internal Diameter (mm)/(inches)	Pipe depth = 1.5m		Pipe depth = 2.5m	
	Partially Deteriorated Thickness (mm)	Fully Deteriorated Thickness (mm)	Partially Deteriorated Thickness (mm)	Fully Deteriorated Thickness (mm)
150/6	3.2	6.8	3.3	6.8
200/8	4.2	9.0	4.3	9.0
250/10	5.3	Greater than 9mm	5.4	Greater than 9mm
300/12	6.3	Greater than 9mm	6.5	Greater than 9mm
350/14	7.4	Greater than 9mm	7.6	Greater than 9mm
400/16	8.4	Greater than 9mm	8.6	Greater than 9mm

Appendix III provides details on ASTM F1216 Non-Mandatory Partially and Fully Deteriorated Pressure equations. These equations can be used to determine the Resiline 320 liner thickness for conditions that are different than those used in Table 4.1.

6.0 Design Reconciliation

A design reconciliation is the process conducted post-construction to assess whether the design objective(s) for the installation have been met whereby the installed product's characteristics (i.e., all visual and testing results) are reconciled with the pre-construction design values. When deviations are present that compromise the performance of the liner, this reconciliation is completed to assess the net impact of post-construction deviations present including fit, finish, and mechanical properties (i.e., values both above and below original design values) on the installed product's ability to conform to the requirements in the design.

The Resiline 320 application process has inherent potential for variances ranging from anomalies in the host pipe to variances in physical liner properties. In instances where no visual deviations are noted and all installed liner properties meet or exceed design values, the installations shall not require a Design Reconciliation.

In instances where deviations are more than the stated minimum values or some of the installed properties are less than the design values, a Design Reconciliation can often resolve minor Contract deviations and can be used to confirm that the installed liner still meets the overall design intent despite the presence of variances. A Design Reconciliation should be carried out by a party acceptable to the owner. The design review shall utilize the measured values for the installed product and liner thickness from the testing to confirm that the overall balance out in terms of obtaining the necessary equivalent structural resistance for the installation.

7.0 Lined Pipe Repairs

It is a recommended best practice to end seal any pipes that are cut after the lining is installed due to the localized force applied to the lining at the cut edge. Only Resimac qualified end sealing solutions shall be used to seal ends of a pipe that is lined with Resiline 320. The material shall be locally certified for potable water contact, and suitable for end sealing applications when used in conjunction with the Resiline 320.

Following the application, a visual inspection shall be made of the applied end sealer after it has cured to help ensure there is no crack or break in the applied Resiline 320. If any crack or gaps are visible in the applied end seal, the area extending beyond the crack shall be abraded to complete a fresh application of the approved end seal.

8.0 Warranty Statement

Resimac warrants that the product delivered to the buyer will comply with specification or description given in any agreement. In the absence of such specification or description the product shall be of normal industrial quality.

Except as provided in this condition, no representation, warranty condition of term, expressed or implied, statutory, or otherwise as to the quality of the product, its fitness for any purpose or compliance with any sample or description or in any other respect shall apply to any agreement or to any delivery made thereunder.

Resimac shall not be responsible for any injury loss or damage, howsoever caused, arising directly or indirectly from the storage, application, or use of the product. The Buyer is an expert in its field and any representation, advice or recommendation given by Resimac, its servants or agents as to the mode of storing, applying, or using the product is given without liability on the part of Resimac its servants or agents. Resimac's liability for all direct loss or damage resulting to the Buyer from defective product or from any other cause whatsoever shall be limited to the purchase price of the product, unless Resimac shall have replaced such defective product with product conforming in all respects with the Agreement, in which Resimac shall be under no further liability to the buyer.

No representation, warranty or indemnity is implied that the product does not infringe any letters patent, trademarks, registered designs, or other industrial property rights.

If any statutory provisions shall avoid or make unenforceable any of the provisions of the forgoing paragraphs, such paragraphs shall be deemed to apply with the exclusion of such of the provisions thereof which shall be void or unforeseeable. Notwithstanding anything to the contrary in the contract Resimac does not seek to exclude liability for negligence in manufacture or supply of goods delivered to the buyer which negligence causes death or personal injury.

References

ASTM International Standard D638, *Standard Test Method for Tensile Properties of Plastics*, 2014. ASTM International, West Conshohocken, PA.

ASTM International Standard D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, 2017. ASTM International, West Conshohocken, PA.

ASTM International Standard D1005, *Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers*, 2020. ASTM International, West Conshohocken, PA.

ASTM International Standard D5813, *Standard Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems*, 2018. ASTM International, West Conshohocken, PA.

ASTM International Standard F1216 *Standard Practice for Renovation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin – Impregnated Tube*, 2016. ASTM International, West Conshohocken, PA.

ASTM International Standard F2831, *Standard Practice for Internal Non-Structural Epoxy Barrier Coating Material Used in Rehabilitation of Metallic Pressurized Piping Systems*, 2011. ASTM International, West Conshohocken, PA.

ASTM International Standard F3182 *Standard Practice for the Application of Spray-Applied Polymeric Liners Inside Pipelines for Potable Water*, 2016. ASTM International, West Conshohocken, PA.

AWWA C210 *Liquid-Epoxy Coatings and Linings for Steel Water Pipe and Fittings*, 2015. American Water Works Association. Denver, CO.

AWWA C222 *Polyurethane Coatings and Linings for Steel Water Pipe and Fittings*, 2018. American Water Works Association. Denver, CO.

AWWA C620 *Spray-In-Place Polymeric Lining for Potable Water Pipelines 4 In. (100mm) and Larger*. 2019. American Water Works Association. Denver, CO.

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AWWA *Structural Classifications of Pressure Pipe Linings Suggested Protocol for Product Classification. Committee Report*, 2019. American Water Works Association, Denver, CO.

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Rockaway, T. and Ball.T., 2007. *Guidelines to Mininmize Downtime Pipe Lining Operations.* Denver, Colo: AwwaRF and AWWA.

SSPC-SP 10 /NACE No. 2-2006, Near-White Metal Blast Cleaning, 2006. The Association for Materials Protection and Performance Product Number: 21066-SG.

SSPC- SP 6/NACE No. 3, Commercial Blast Cleaning, 2006. The Association for Materials Protection and Performance Product Number: 21067-SG, ISBN: 1-57590-109-9.

SSPC-SP 7/NACE No. 4 Brush-Off Blast Cleaning, 2006. The Association for Materials Protection and Performance Product Number: 21068-SG, ISBN: 1-57590-102-1

Water Industry Specification UK: WIS 4-02-01 and IGN 4-02-02 (2014): In Situ Resin Lining of Water Mains - Operational Requirements and Code of Practice : Water UK.

Appendix I Resiline 320 Material Properties

1) Technical Data Sheet
2) Robinson P.C.E Ltd Technical Report "*Assessment of Resiline 320 as a Non-structural and Semi-Structural Lining for Potable Water Mains*". 24th January 2022.

Technical Data Sheet

Resiline 320

Two component liquid applied polyurea lining

- Based on next generation aliphatic poly-isocyanate technology.
- Ideal for in-situ lining and renovation of pipelines and pipe networks.
- For use on drinking water pipelines and pipe networks.
- Apply to 4” (100mm) diameter upwards.
- Apply to iron, steel, asbestos cement, concrete and PVC.

Surface Preparation

The surface should be suitably cleaned to remove all loose or adhered deposits caused from corrosion and mains deterioration processes.
Suitable cleaning processes include:

- Power boring
- Drag scraping
- Abrasive pigging
- Pressure scraping
- Pressure jetting
- Vortex of air technique

Irrespective of the cleaning method adopted, the surface of the pipe shall be smooth, clean, free from; dust, debris and standing water.

Please Note:- *For pipelines above 300mm (11”) internal diameter, the proposed cleaning and pipeline preparation method should be appropriate to achieve the rehabilitation outcome required. Where adhesion is required, a minimum adhesion of 1.7MPa as measured in accordance with ASTM D4541-17 is recommended*

Application

- **Resiline 320** should not be applied on substrates that are below 3°C (37°F).
- Prior to insertion of the lining hose into the main, both components shall be circulated through the hoses for sufficient time to attain a uniform temperature of 20-30°C (68°F - 86°F).
- Material temperatures in the lining rig must be 20-30°C (68°F - 86°F).
- **Resiline 320** should be applied in thicknesses of 1mm (40mil) to 9mm (0.35”)

Application (continued)

- Linings from 1mm (40mil) up to 3mm (120mil) thickness can be applied in a single pass operation.
- Linings up to a maximum of 9mm (0.35”) may be applied in multiple passes of approximately equal thickness with each pass not exceeding 3mm (120mil).
- The applicator should set the lining rig to apply an additional 10% of material during lining to allow for any potential uneven movement of the spray head.
- On Completion of the lining operation, the spinner cone should be cleaned by immersion in MEK (Methyl Ethyl Ketone).
- All solvent washings should be removed from site by the applicator for subsequent disposal as hazardous waste.

Cure Time

Initial set	2 minutes
CCTV inspection	15 minutes
Disinfection and return to service procedures	60 minutes
Minimum overcoating	60 minutes
Maximum overcoating	6 hours

Mix Ratio

By Volume:	3:2
By Weight:	100:72.5

Colour & Appearance

Mixed Material:	Mid Blue Liquid
Base Component:	White Thixotropic Liquid
Activator Component:	Blue Thixotropic Liquid

Pack sizes

Base and Activator are supplied separately in either 10 litre pails or 200 litre drums. The Material is also supplied in 250ml twin pack cartridges for end repairs on cut pipes.

Storage

The product must be stored in the original sealed containers at temperature not exceeding 40°C (104°F). The product shall be used within 18 months of the date of manufacture.

Resiline
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Tel: +44 1845 577498 Email: info@resiline.co.uk

Certified to NSF/ANSI/CAN 61

Technical Data Sheet

Disposal

Base and Activator components are considered hazardous materials and must be disposed of as such. Please refer to local or national regulations for the disposal of hazardous materials.

Other technical documents

Safety Data Sheets - Base and Activator
Use Instructions

Please note: *for any project or application information please refer to the Resiline technical team for instructions and recommendations on info@resiline.co.uk or +44 (0) 1845 577498.*

Test Data

Test Standard	Resiline 320
Tensile Strength ASTM D638-14	45.5 MPa
Tensile Elongation ASTM D638-14	4.2 %
Flexural Strength ASTM D790-17	70.5 MPa
Flexural Modulus ASTM D 790-17	2000 MPa
Hardness ASTM D2240-15	83 Shore D
Abrasion Resistance ASTM D4060-19	150mg loss per 1000 cycles (CS17 wheel, 1kg load)
Water Absorption ASTM D570-98	1.4% @ 21 Days
Adhesive Strength ASTM D4541-17	27.5 MPa
Burst Pressure (6” diameter @ 3mm) ASTM D1599-18	17.6 bar
Projected 50 Year Tensile Creep Rupture Strength ASTM D2990-17	12.5 MPa
Projected 50 Year Flexural Creep Rupture Strength ASTM D2990-17	22.5 MPa
BPA Free EPA Method 1311	Yes
VOC Free EPA Method 24	Yes

Test results obtained from extracted field samples may vary according to site application and environmental conditions.

Legal Notice:

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Certified to NSF/ANSI/CAN 61

ROBINSON P.C.E. LTD

Confidential Technical Report

Assessment of Resiline™320 as a Non-Structural and Semi-Structural Lining for Potable Water Mains

Author: Ian Robinson

Prepared for: Resiline, a Division of Resimac Ltd.

Report No: PCE/TR 013, Issue 2

Date: 24th January 2022

Robinson P.C.E. LTD

Company No. **11288665**

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Executive Summary

Resiline™320 has been developed as a rapid setting, in-situ applied spray lining for the rehabilitation of pipeline infrastructures conveying potable water. The product is based on aliphatic poly-isocyanate based poly-urea technology, which confers reliable curing in thin (1mm) films at low temperatures and much reduced sensitivity towards moisture when compared to (lower cost) conventional aromatic poly-isocyanate based polyurethane materials.

Robinson P.C.E. LTD was engaged by Resimac Ltd. to undertake an assessment of the material in the context of its proposed use, both as a non-structural (corrosion protection) lining and as a semi-structural lining. The product has been found to demonstrate excellent corrosion resistance and durability in accelerated exposure tests, and in this respect could be expected to exhibit a level of long-term performance comparable to that of other aliphatic poly-isocyanate based materials which have been used with success over many years in the UK water industry.

The product appears to offer considerable potential as a semi-structural lining (Class II/Class III per AWWA M28 definitions[1]) and also exhibits sufficient long term tensile (creep rupture) strength to enable the lining to be designed to act as the primary pressure containment, depending upon pipe diameter and operating pressure constraints. When deployed as a semi-structural lining, the following long term ("50 year") properties would be applicable for design purposes:

Flexural Strength – 22.5 MPa

Tensile strength – 12.5 MPa

1. Material Properties

In all cases, testing was undertaken on material which had been sprayed inside an appropriate PVC host pipe and subsequently de-bonded, or spray applied to test plates affixed to the internal surface of a suitable host pipe. Spray application was undertaken via a commercially available “SR1000” Lining Rig supplied by Schur Ltd.

1.1 Tensile Properties

Tensile properties were determined in accordance with ISO 527-2: 2012 using Type 1B specimens and a test speed of 5mm/Minute. The results are tabulated and shown graphically below.

Specimen No.	Tensile Strength (MPa)	Strain at Break (%)
1	45.6	4.1
2	45.4	4.2
3	45.3	4.6
4	44.9	3.8
5	45.6	4.0
Mean	**45.5**	**4.2**

Table 1: Tensile Properties (dry)

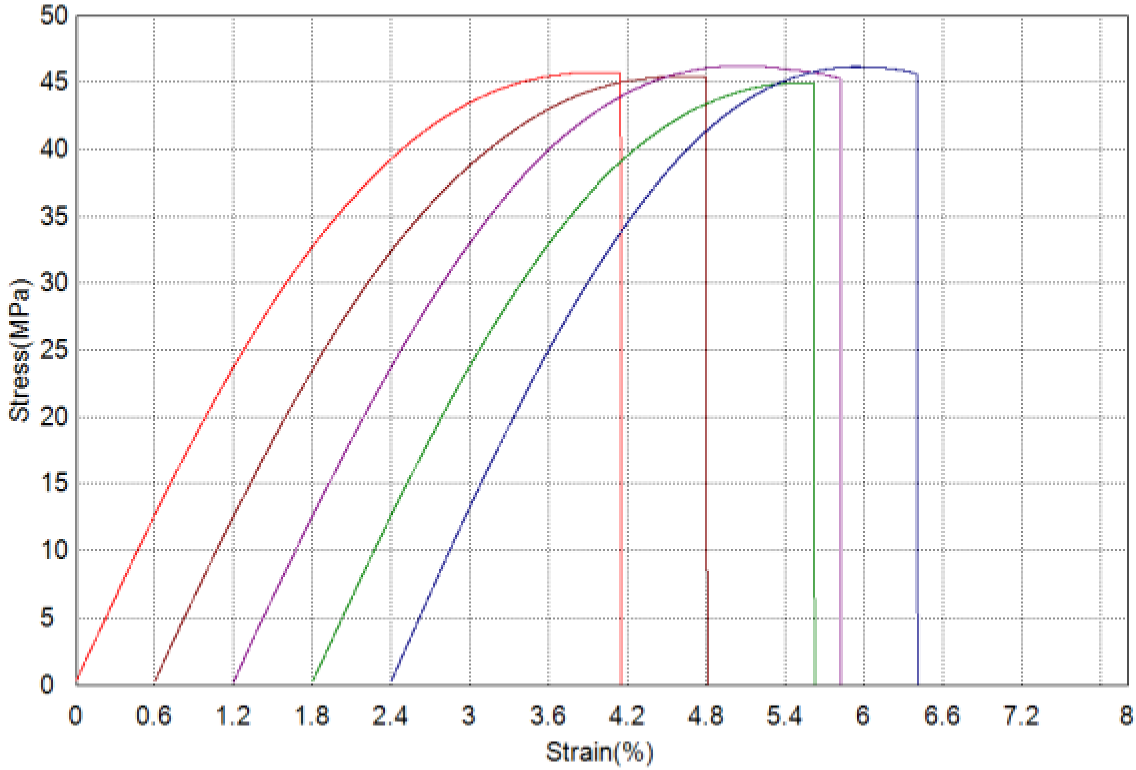

Figure 1: Tensile Properties (dry)

Tensile properties were also determined on material which had been immersed in tap water for minimally 28 days. The results are tabulated and shown graphically below.

Specimen No.	Tensile Strength (MPa)	Strain at Break (%)
1	43.5	5.5
2	43.4	5.5
3	40.0	5.2
4	42.9	4.2
5	38.5	6.5
Mean	**41.5**	**5.4**

Table 2: Tensile Properties (wet)

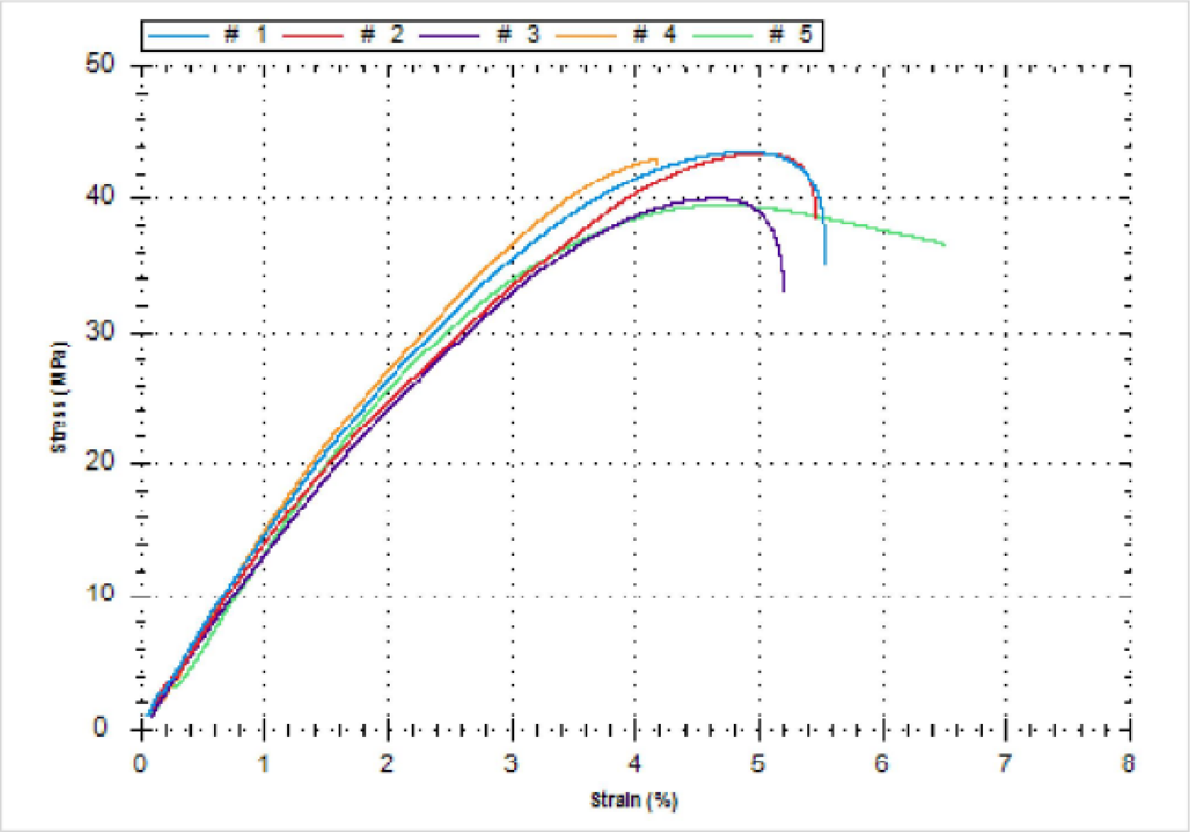

Figure 2: Tensile Properties (wet)

1.2 Flexural Properties

Flexural properties were determined in accordance with ISO 178: 2019 using a test speed of 1mm/Minute. The results are tabulated and shown graphically below.

Specimen No.	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	72.5	1905
2	73.5	2375
3	67.5	2010
4	64.0	1680
5	76.5	2050
Mean	**70.5**	**2000**

Table 3: Flexural Properties (dry)

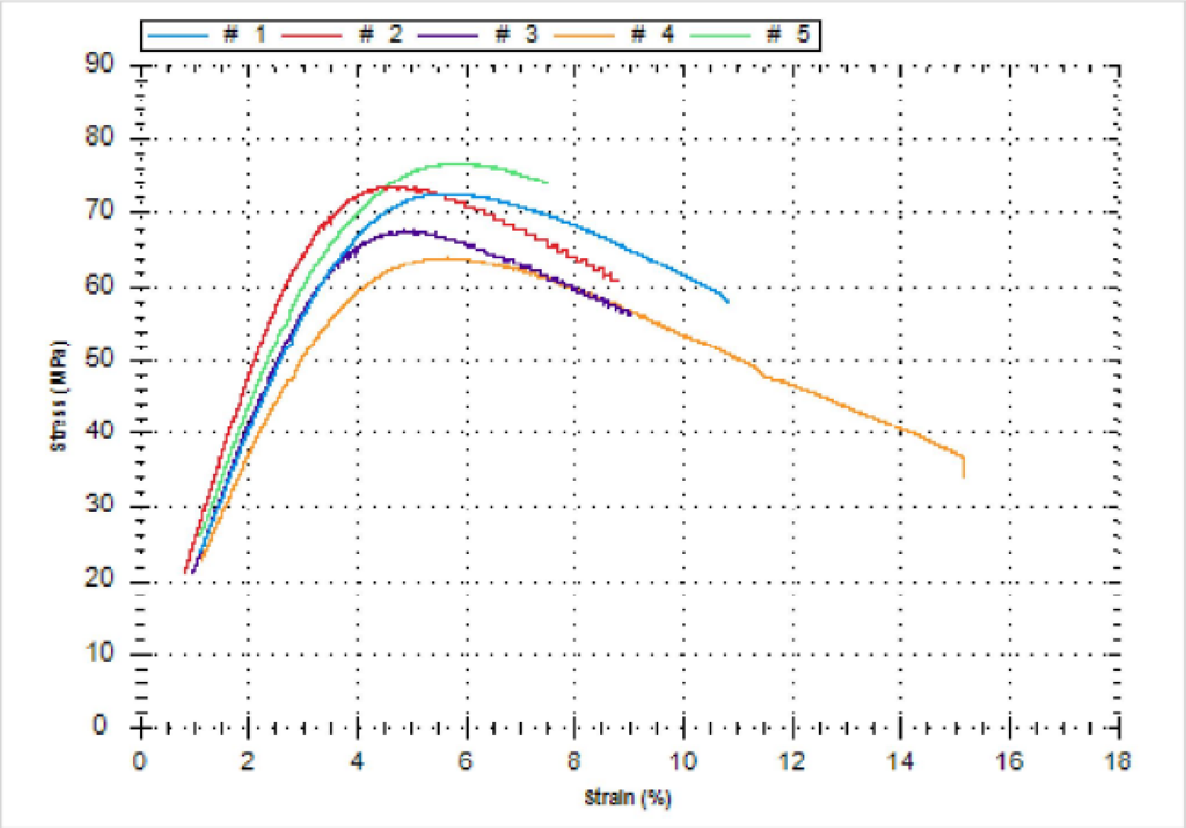

Figure 3: Flexural Properties (dry)

Flexural properties were also determined on material which had been immersed in tap water for minimally 28 days. The results are tabulated and shown graphically below.

Specimen No.	Flexural Strength (MPa)	Flexural Modulus (MPa)
1	61.0	1600
2	72.0	1980
3	68.5	1865
4	65.0	1575
5	62.5	1535
Mean	**65.0**	**1700**

Table 4: Flexural Properties (wet)

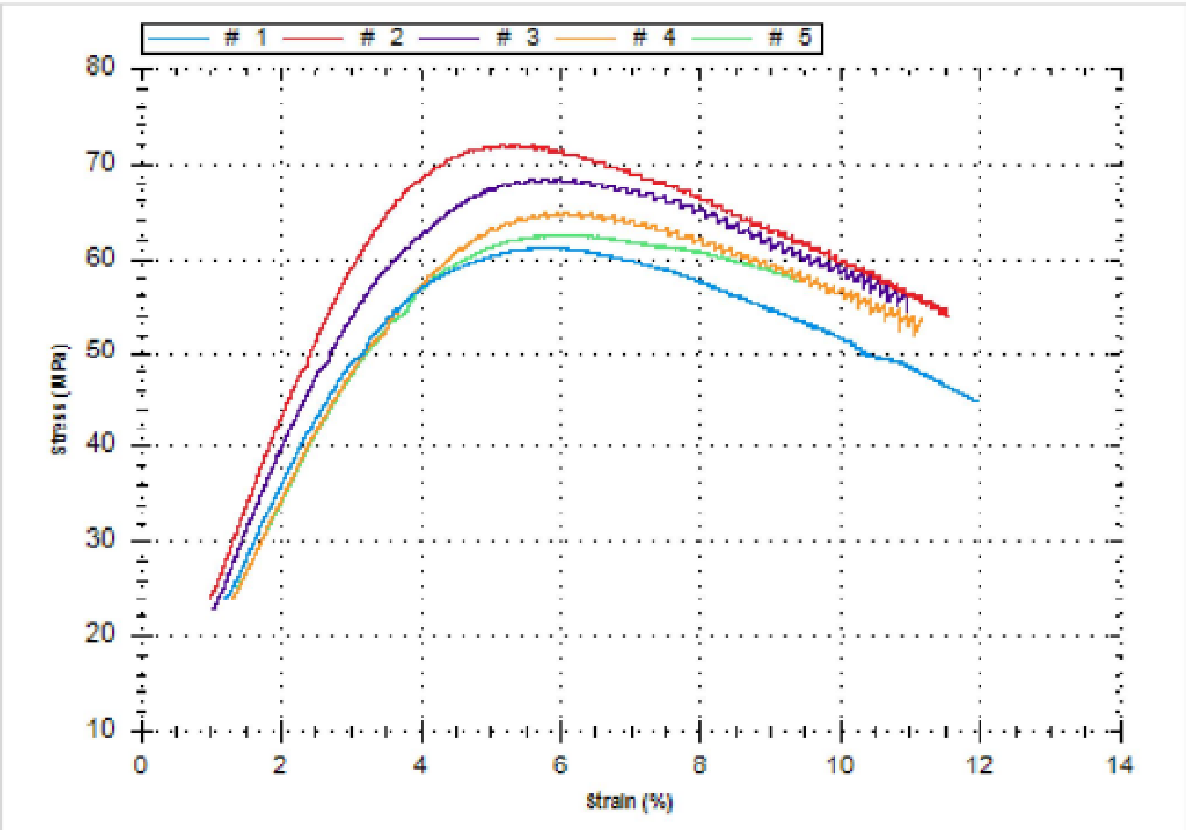

Figure 4: Flexural Properties (wet)

1.3 Hardness

Durometer hardness (Shore D) was determined on nominally 3mm thickness plaques of material in accordance with ASTM D2240-15. The results are tabulated below.

Test No.	Hardness (Shore D)
1	83
2	82
3	83
4	83
5	84
Mean	**83**

Table 5: Shore D Hardness

1.4 Adhesion

150mm x 100mm x 6mm thickness mild steel plates were abrasive blast cleaned to SA 2.5 surface cleanliness (ISO 8501/4) with a mean surface profile of 70-80 microns. Resiline™320 was spray applied to give a mean thickness of 1.25mm.

Pull-off adhesion testing was undertaken in accordance with ASTM D4541-17 utilizing 14mm diameter test "dollies". The results are tabulated below.

Test No.	Adhesion (MPa)	Mode of Failure
1	30.0	70% cohesive/30% adhesive to substrate
2	28.7	70% cohesive/30% adhesive to substrate
3	23.9	30% cohesive/70% adhesive to substrate
Mean	**27.5**	-

Table 6: Pull-off Adhesion

Figure 5: Pull-off Adhesion

1.5 Abrasion Resistance

Abrasion resistance testing was undertaken in accordance with ASTM D4060-19 (CS 17 wheels, 1Kg load) over a period of 3 x 1000 sequential cycles. The results are tabulated below.

Test No.	Weight Loss per 1000 Cycles (mg)
1	150
2	130
3	170
Mean	**150**

Table 7: Taber Abrasion Resistance

2. Durability Testing

2.1 Water Absorption

Water uptake was determined on 3mm thickness plaques of material over a period of 21 days @ 20ºC in accordance with ASTM D570-98. In order to determine the saturation water uptake, testing was continued for a total period of >12 months. In addition, by way of comparison, a duplicate determination was undertaken @ 40ºC. The results are shown graphically below.

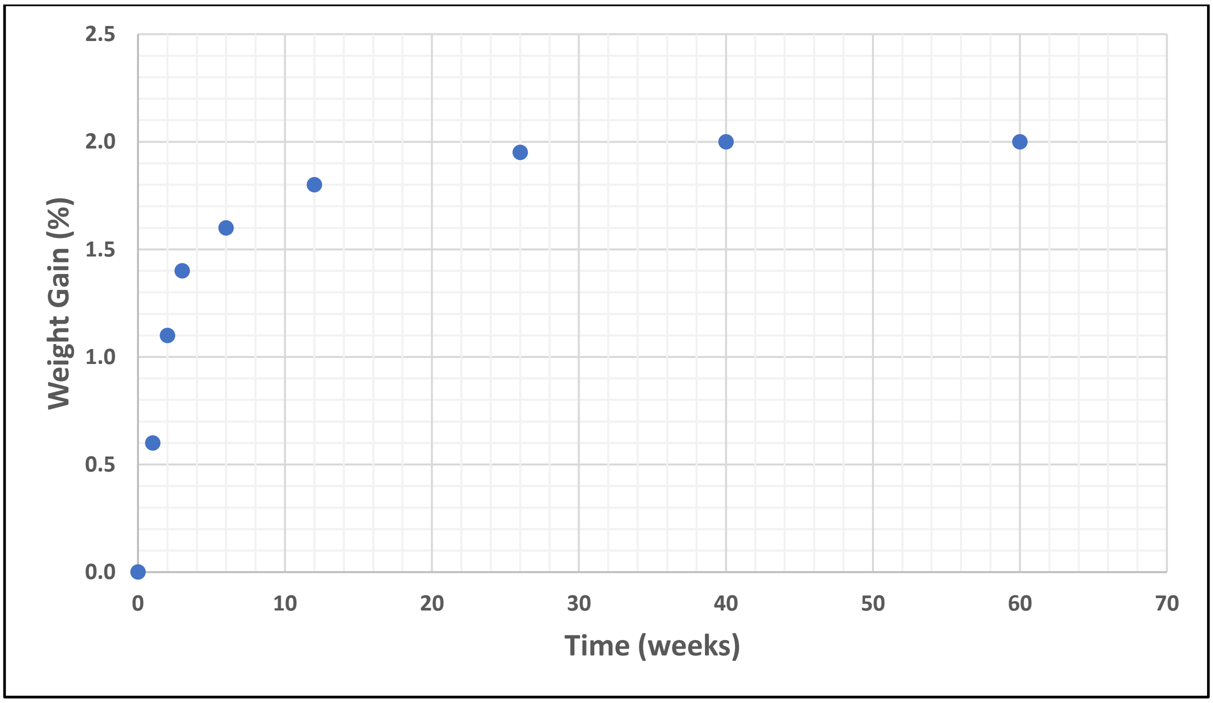

Figure 6: Water Absorption @ 20º C

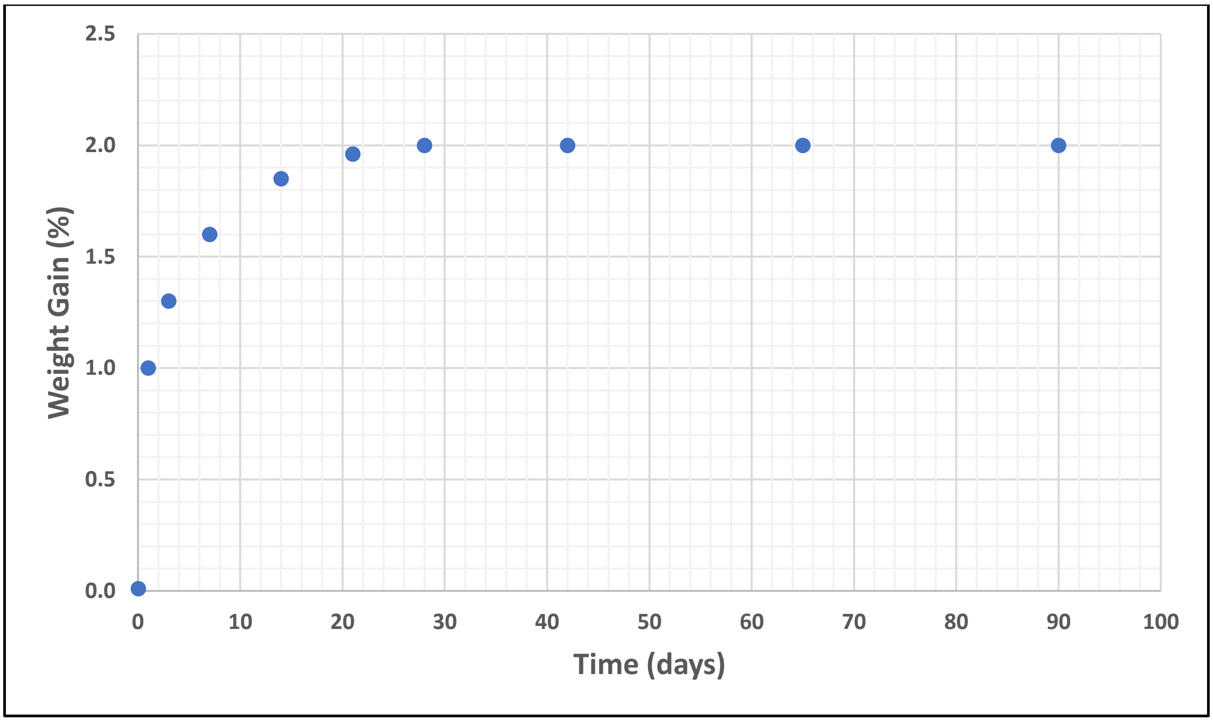

Figure 7: Water Absorption @ 40º C

As can be seen from the above, the material exhibits a water uptake of circa 1.4% after 21 days @ 20ºC, with a saturation water uptake of circa 2%. These results are comparable to those exhibited by products historically used with success in the UK water industry such as the Copon™ Hycote 169 and Scotchkote™2100/2400 products formerly marketed by E. Wood Ltd. and 3M Company.

2.2 Resistance to Chloramine Disinfectants

Mono-chloramine is routinely utilized as a disinfectant within potable water distribution networks, particularly in North America, at concentrations of up to a maximum of 5ppm. No standard exists which pertains specifically to the chloramine resistance of spray lining materials, however, ASTM D6284-17, "Standard Test Method for Rubber Property – Effect of Aqueous Solutions with available Chlorine and Chloramine", is well known as a test method for assessing the resistance of rubber-like materials used as seals or gaskets in potable water distribution networks. D6284-17 was therefore adopted as the basis for undertaking an assessment, with an exposure period of 500 hours (21 days) @ 70ºC.

A standard mono-chloramine stock solution was prepared per ASTM D6284 Section 8.5.3 to provide a total residual chlorine content of 50 ppm. Tap water from the client's facility in Topcliffe, North Yorkshire, was utilized as a control for comparison purposes.

Test plaques measuring 100 mm x 50 mm were cut from a nominally 3mm thickness RESILINE™320 lining to provide a surface area of 10,000 mm^2 per test specimen.

Prior to immersion in the test solutions the mass of the samples was determined, and hardness measurements performed per ASTM D2240-15. On completion of the 500 hours exposure period the test specimens and test solutions were visually assessed per ASTM D6284, Section 13, and the mass and hardness measurements repeated.

The results are tabulated below.

Test Fluid	Visual Rating	Change in Mass (Δ*M*)	Change in Hardness (Δ*H*)
Tap Water	No change, Rating = A	+3.8%	-1 (83 → 82 Shore D)
Mono-chloramine	No change, Rating = A	+3.6%	-1 (83 → 82 Shore D)

RESILINE™320 appears to exhibit excellent resistance to mono-chloramine solution, with no differences being observed in comparison to immersion in chloramine-free tap water over the duration of the exposure period. Using the empirical derivation of the Arrhenius equation that reaction/degradation rates double for every 10ºC rise in temperature, and assuming that the average mains water temperature is 10-12ºC, 500 hours exposure @ 70ºC, with a mono-chloramine concentration x10 of that found in practice, could be considered as being equivalent to >>30 years real life exposure.

2.3 Neutral Salt Spray Exposure

150mm x 100mm x 6mm thickness mild steel plates were abrasive blast cleaned to SA 3 surface cleanliness (ISO 8501-1) with a mean surface profile of 70-80 microns. Resiline™320 was spray applied to give a film thickness of 1.1-1.3mm.

The test panels were subjected to 5000 hours neutral salt spray exposure in accordance with ASTM B117-18 at SGS UK Ltd. An interim assessment was performed after 3000 hours exposure. A full copy of the test report is attached as Appendix A to this report.

Figure 8: 5000 Hours Neutral Salt Spray Exposure (after removal of surface rust staining)

Historically applied epoxy resin linings, which were extensively installed in the UK in the 1980's/1990's, were all subjected to 3000 hours neutral salt spray exposure as part of a UKWIR Research Project[2]. Subsequently, the '1st Generation' Rapid Setting Polymeric Lining, Copon™ Hycote 169, developed and marketed by E. Wood Ltd, was subjected to the same test protocol. All materials were generally found to exhibit limited deterioration in this test, with the Copon™ material being particularly outstanding. A research project undertaken by AWWA[3] assessed the performance of all these materials and correlated the laboratory testing results against the condition of exhumed linings which had been in the ground for upwards of 20 years. The conclusion was that these materials, when correctly installed, could be anticipated to exhibit a useful service life of 40-60 years. Given the performance of Resiline™320 when subjected to 5000 hours neutral salt spray exposure, it can reasonably be concluded that the material should perform at least as well as products historically utilized with success as non-structural, corrosion barrier linings in the UK water industry.

3. Structural Properties

3.1 Pressure Burst Testing

Nominally 1metre length, stand-alone Resiline™320 linings were prepared by lining 150mm internal diameter PVC host pipes and carefully removing the host. A series of short-term pressure burst tests were performed in accordance with ASTM D1599-18. Pressure was increased gradually so as to induce failure after a period of between 60 and 90 seconds. The results are tabulated below.

Specimen No.	Mean Lining Thickness (mm)	Failure Pressure (Bar)	Time to Failure (Secs)
1	3.0	17.6	68
2	3.0	18.0	75
3	3.0	17.4	80
4	3.0	17.6	78
5	3.0	17.3	68
Mean	**3.0**	**17.6**	**74**

Table 8: Pressure Burst Testing Results

Figure 9: Pressure Burst Test Samples

Figure 10: Pressure Burst Testing

Whilst these burst tests are merely short-term tests, and therefore of only limited value in assessing the long-term structural capability of the material per se (see *Section 4.2*), they do provide a useful measure of the consistency of the material and associated spray lining process. In addition, they provide a useful check on the validity of Barlow's equation in correlating the limiting hoop stress for the material against the measured tensile strength.

Per Barlow's equation, the mean burst pressure of 17.6 bar (1.76 MPa) corresponds to a maximum allowable hoop stress of 44.0 MPa, which gives good agreement with the short-term tensile strength determined in laboratory testing.

Barlow's Equation: **σ = P.D/2t**

Where σ = Allowable hoop stress
P = Internal pressure
D = External pipe diameter
t = Wall thickness

3.2 Creep Rupture

3.2.1 General

When assessing the structural capability of a liner, two possible modes of action can be considered:

Firstly, the liner may function in a semi-structural capacity where the internal pressure load is transferred globally to the host pipe but the liner is required to provide pressure containment across any (small) pre-existing holes or voids in the pipe wall and any holes/voids which may form post-installation as a result of ongoing external corrosion of the metallic host. For a relatively rigid material such as Resiline™320, the material can essentially be assumed to span any such holes or voids as a circular clamped plate fixed at the edge, in which case Timoshenko plate theory pertains and the spanning capacity can be calculated from the following (ASTM F1216 - Equation X1.6):

$$P = \frac{5.33}{(DR-1)^2}\left(\frac{D}{d}\right)^2 \frac{\sigma_L}{N}$$

Where P = Pressure
D = Pipe diameter
DR = Dimensional ratio (= D/t, where t = liner thickness)
d = Hole diameter
σ_L= Long term flexural strength
N = Factor of safety

Alternatively, the liner may be required to act as the primary pressure containment in situations where the host pipe is anticipated as being no longer able to function in that capacity at some stage during the design life of the rehabilitated system. In such a scenario, the structural capacity can be calculated from the following (ASTM F1216 - Equation X1.7):

$$P = \frac{2\sigma_{TL}}{(DR-2)\,N}$$

Where P = Pressure
DR = Dimensional ratio (= D/t, where t = liner thickness)
σ_{TL} = Long term flexural strength
N = Factor of safety

It is evident from the above equations that "time corrected" (long term) values for the flexural and tensile strength of the material are required, rather than those derived from standard short-term tests.
This can be explained by the phenomenon of creep - the time dependent deformation of polymeric materials when unrestrained and subject to constant stress.

A well-established methodology for deriving long term strength properties is creep rupture testing, which is undertaken by determining the time to failure (rupture) of test specimens subjected to multiple continuous stress levels. The data is plotted graphically as stress against the logarithm of time to failure, and linear regression analysis (least squares method) utilized to produce a “best fit” trend line which can be extrapolated out to the desired service-life time point.

Furthermore, it is essential to acknowledge that all 2-part, thermosetting polymeric materials absorb water when immersed, resulting in reduced strength and stiffness compared to the dry state. Thus, for any proposed water pipe lining (which may be required to have a service life upwards of fifty years) it is necessary to ensure that all tests are undertaken on test specimens which have attained a fully water saturated state. In the case of Resiline™320 this represents a water uptake of circa 2% w/w (see *Section 3.1*). In order to achieve saturation within a reasonable time period, all test specimens were conditioned in tap water at 40ºC for a period of 21 days prior to testing (this exposure schedule had been established as effecting 2% w/w water uptake – see *Section 3.1*). To maintain water saturation during testing, all specimens were sealed in polyethylene bags for the duration of the tests.

3.2.2 Flexural Creep Rupture

Flexural creep rupture testing was undertaken in accordance with the principles of ISO 899-2: 2003 over a period of 10,000+ hours. The test specimens were nominally 100mm x 12mm x 3.2mm, cut from sheet material detached from steel plates which had been sprayed by affixing to the internal surface of a 300mm diameter host pipe. The results are tabulated and shown graphically below.

Specimen No.	Applied Stress (MPa)	Time to Failure (hours)
1	55.0	0.33
2	55.0	0.38
3	52.5	1.25
4	52.5	1.50
5	50.0	4.20
6	50.0	3.20
7	47.5	9.50
8	47.5	8.00
9	45.0	32.0
10	45.0	42.0
11	40.0	220
12	40.0	330
13	35.0	2300
14	35.0	2700
15	30.0	13000*
16	30.0	16000*
*Denotes tests still in progress – failure times are estimated		

Table 9: Flexural Creep Rupture – Results

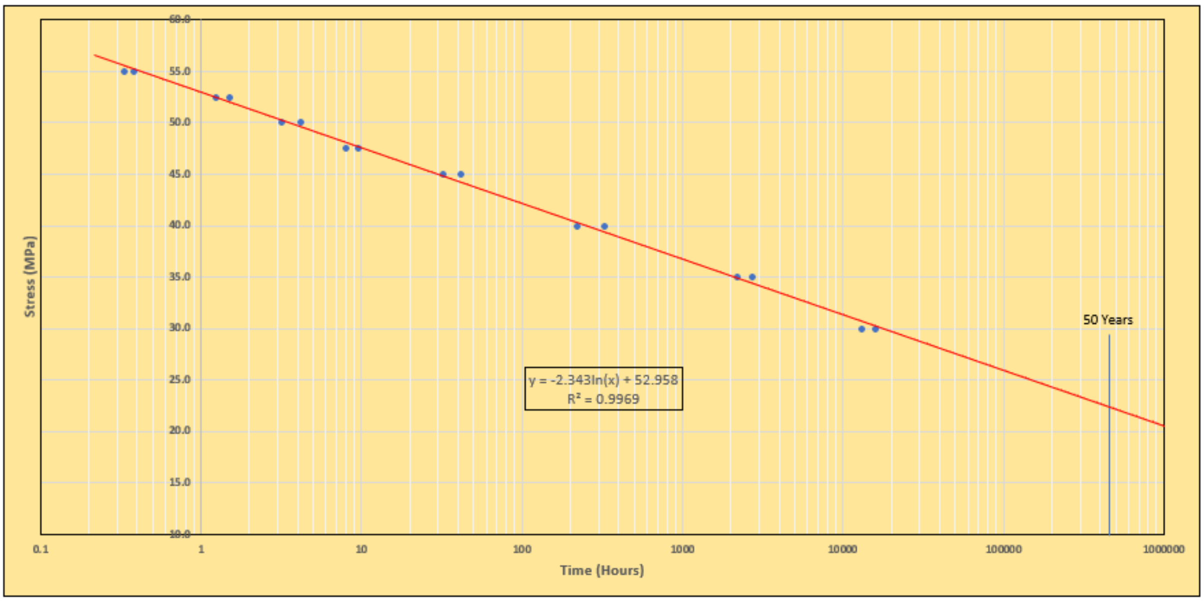

Figure 11: Flexural Creep Rupture – Linear Regression Analysis

Based on extrapolation of the regression line out to the 50-year time point, a long-term flexural strength value of 22.5 MPa would be applicable for design purposes under aqueous conditions.

3.2.3 Tensile Creep Rupture

Tensile creep rupture testing was undertaken in accordance with the principles of ISO 899-1: 2017 over a period of 10^6 seconds. [Such shorter duration tests have, in the writer's experience, been demonstrated to afford a very good correlation with results derived from longer term tests.] The test specimens were Type 1B per ISO 527-2: 2012, machined from sheet material detached from steel plates which had been sprayed by affixing to the internal surface of a 300mm diameter host pipe. The results are tabulated and shown graphically below.

Specimen No.	Applied Stress (MPa)	Time to Failure (seconds)
1	40.0	180
2	40.0	240
3	39.0	390
4	39.0	330
5	37.5	750
6	37.5	600
7	36.5	1260
8	36.5	1500
9	35.0	4200
10	35.0	3400
11	33.0	13200
12	33.0	16800
13	30.0	72200
14	30.0	57600
15	27.5	246000
16	27.5	324000
17	25.0	936000
18	25.0	1220000

Table 10: Tensile Creep Rupture – Results

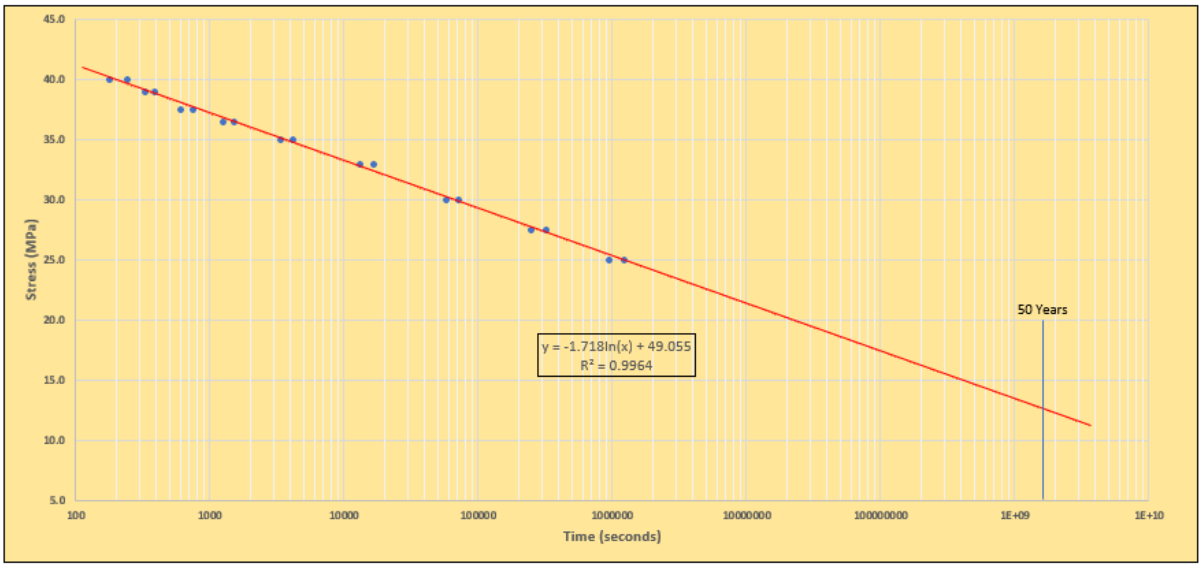

Figure 12: Tensile Creep Rupture – Linear Regression Analysis

Based on extrapolation of the regression line out to the 50-year time point, a long-term tensile strength value of 12.5 MPa would be applicable for design purposes under aqueous conditions.

4. Referenced Standards

ISO 527-2: 2012 *Plastics – Determination of Tensile Properties*

ISO 178: 2019 *Plastics – Determination of Flexural Properties*

ISO 899-1: 2017 *Plastics – Determination of Creep Behavior (Tensile Creep)*

ISO 899-2: 2003 *Plastics – Determination of Creep Behavior (Flexural Creep)*

ISO 8501-4: 2020 *Preparation of Steel Substrates before Application of Paints and Related Products - Visual Assessment of Surface Cleanliness*

ASTM D2240-15 *Standard Test Method for Rubber Property – Durometer Hardness*

ASTM D4541-17 *Standard Test Method for Pull-Off Strength of Coatings using Portable Adhesion Testers*

ASTM D4060-19 *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*

ASTM D570-98 *Standard Test Method for Water Absorption of Plastics*

ASTM D6284-17 *Standard Test Method for Rubber Property – Effect of Aqueous Solutions with Available Chlorine and Chloramine*

ASTM B117-18 *Standard Practice for Operating Salt Spray (Fog) Apparatus*

ASTM D1599-18 *Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing and Fittings*

ASTM F1216-16 *Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated tube*

5. References

1. American Water Works Association, *Rehabilitation of Water Mains (M28),* AWWA (2014).

2. United Kingdom Water Industry Research Ltd, *Development of a Water Industry Specification for Epoxy Resin Linin*g, UKWIR (1997).

3. Awwa Research Foundation, *Service Life Analysis of Water Main Epoxy Lining,* AwaaRF (2006).

[End of Text]

Report prepared by:

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TECHNICAL REPORT No: MAN262654-001

Report No:	MAN262654-001
Issue No:	1
Date Tested:	See Section 4
Date Reported:	09/11/2021

Neutral Salt Spray testing of Resiline 320 in accordance with ASTM B117

1. Samples:

Steel sample panels coated with RESILINE 320 were provided to SGS laboratories, by the client, for 3000 and 5000 hours exposure to ASTM B117 neutral salt spray fog.

2. Application Data

Mild steel test panels were prepared by abrasive blast cleaning with chilled iron grit to provide a surface cleanliness of Sa3 as per ISO 8501-1, with a surface profile of nominally 75 microns.
RESILINE 320 was applied to the test panels by centrifugal spray via a SR 1000 Lining Rig provided by Schur Ltd. to provide a film thickness of 1.3 - 1.5 mm. To facilitate application by centrifugal spray the test panels were affixed to the internal surface of 300mm diameter PVC pipe.
Test panel preparation was undertaken on 25th March 2021 at Schur Ltd.'s premises in Rawtenstall and witnessed by Robinson P.C.E. Ltd.

3. Test Conditions:

Neutral Salt Spray Test (ASTM B117):

- **Test Panel**: 150mm x 100mm
- **Panel Scribe**: 1mm x 100mm as a X-cut
- **Salt Spray Cabinet**: Ascott CC1000ip(S/N MIS0244)
- **Salt Solution**: 5% NaCl
- **Cabinet Temperature**: 35°C
- **pH of condensate**: 6.5 – 7.2
- **Fall-out rate**: 1 – 2 ml/hour

4. Results

After the required test exposure duration, the samples were rinsed with de-ionised water and then dried before being visually assessed.

Test dates

Testing started:	15/04/2021
3000 hours end:	18/08/2021
5000 hours end:	09/11/2021

4.1 Dry film thickness:

- Gauge used: Elcometer 456 (MIS0121)

Test	Sample Panel No.	Minimum (µm)	Maximum (µm)	Mean (µm)	Standard Deviation
3000hr NSS	1	1080	1300	1187	79.4
	2	1160	1350	1237	72.8
	3	1110	1290	1185	58.9
5000hr NSS	4	1110	1230	1158	47.5
	5	1280	1460	1385	69.5
	6	1080	1270	1195	70.6

4.2 Post-test assessment:

Test	Sample Panel Number	Visual Assessment
3000 hours Neutral Salt Spray Test (ASTM B117)	1	No visual defects on all panels. Using tape test there was no delamination from the scribe on all test panels.
	2	
	3	
5000 hours Neutral Salt Spray Test (ASTM B117)	4	No visual defects on all panels. Using tape test there was no delamination from the scribe on all test panels.
	5	
	6	

Photographic evidence of the assessments is documented in Appendix A.

- *END OF TEXT* -

Interim report by:

D.W. Lester.

David Lester, Project Leader
Coatings & Polymers

Approved by:

C. Booth, Operations Manager
Coatings & Polymers

APPENDIX A – PHOTOGRAPHS

Samples Pre-Test

Samples after 3000 hours NSS

Samples Pre-Test

Samples after 5000 hours NSS

Appendix II Resiline 320 NSF/ANSI/CAN 61 Certificate

Certified Product Listing

For:
Drinking Water System Components – Health Effects

Company:
Resimac Limited
Unit B, Park Barn Estate, Station Road
Topcliffe, Thirsk YO7 3SE, United Kingdom

Plant Location:
Eaglescliffe, Stockton-on-Tees, United Kingdom

Standards:
NSF/ANSI/CAN 61 - 2018

Certificate:
Issued Date: 02/13/2020

Material/Product:
In-Situ Rapid Setting Polymeric Lining

Contact Temperature:
23 ± 2°C

Models:
Resiline 320

Material Characteristics:

Minimum pipe diameter (inches): 4

Maximum pipe surface area/volume ratio (sq in/L): 61

Maximum dry film thickness per coat (mils): 9 mm

Is additional coating required (e.g. top coat, primer, intermediate coat)? (Y/N): No

Total cure time and temperature: 1 hour at 3°C

Shortest cure time between coats or layers: 90 seconds

Final cure time: 1 hour

Mix ratio: 1.52:1 vol

Colors: Blue

Is this paint/coating system intended to be applied to a pipe? (Y/N): Yes
(1) Certified for use on a new pipe? (Y/N): Yes
(2) Certified for use on a pipe intended for immediate return to service? (Y/N): Yes

Appendix III ASTM F1216 Non-Mandatory Partially and Fully Deteriorated Pressure Design.

ASTM F1216 Liner Design Method

1. Introduction

In North America, pressure pipe liners are commonly designed in accordance with Section X1.3 of ASTM F1216-21 Non-Mandatory Design Appendix X1 - Design Considerations. This design method incorporates two design objectives: 1) the Partially Deteriorated host pipe condition where the liner is required to only bridge holes and gaps in the pipe wall, over the pipe design life of 50 plus years; and 2) the Fully Deteriorated host pipe condition where the liner must resist all internal and external pressures for the liner design life of 50 plus years.

In the partially deteriorated condition, it is assumed that the original pipe will support the soil and surcharge loads throughout the design life of the rehabilitated pipe while in fully deteriorated condition the host pipe is assumed not to be structurally sound or is expected to reach this condition over the design life of the rehabilitated pipe.

Figure 1 shows external loads that are considered when designing a partially deteriorated or fully deteriorated liner.

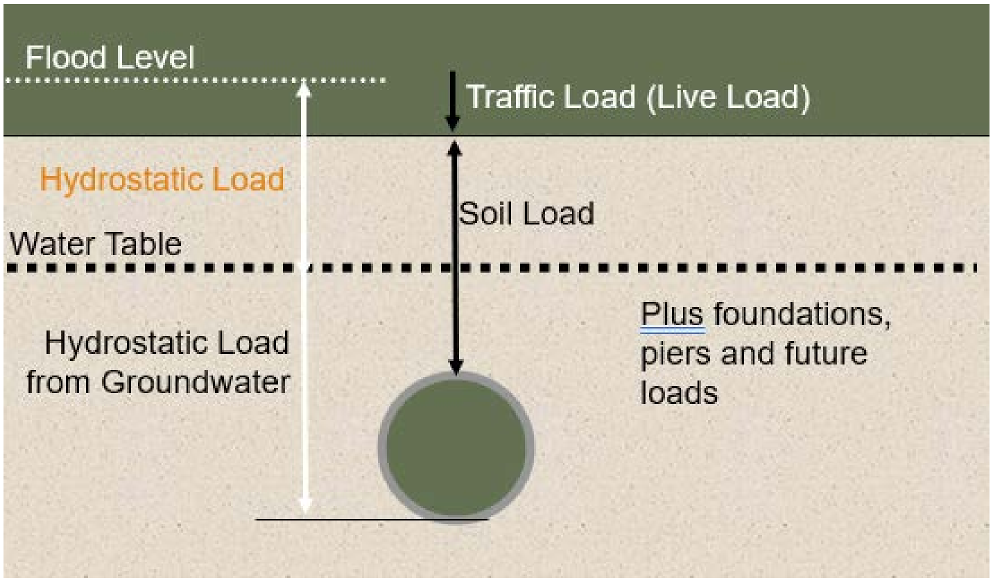

Figure 1 Pipe and liner external loads.

2. Partially Deteriorated Liner Design

For the partially deteriorated condition, the required liner thickness is the largest thickness obtained from Equations X1.1 and X1.6 or X1.7.

2.1. Equation X1.1

Equation X1.1 ensures the liner has sufficient buckling resistance to withstand the hydrostatic ground water pressure.

$$P = \frac{2KE_s}{(1-\nu^2)} \times \frac{1}{(DR-1)^3} \times \frac{C}{N} \qquad X1.1$$

where,

P = Groundwater pressure, MPa (psi).

K = Enhancement Factor of the liner adjacent to the host pipe. A minimum value of 7.0 is recommended where there is full support of the existing pipe.

E_s = Liner ASTM D790 short-term Flexural Modulus of Elasticity MPa (psi) = 1724 MPa or 250,000 psi.

v = Poisson's ratio which is 0.4 for Resiline 320.

DR = Liner Dimension Ratio = D/t (Internal pipe diameter divided by the liner thickness).

C = Ovality Reduction Factor = $([1-q/100]/[1+q/100]^2)^3$ where q = existing pipe ovality in percent which is typically 2 percent for watermains.

N = Factor of Safety which is typically 2.

The liner thickness is determined by solving for the liner thickness in the DR term.

Watermains are normally under internal working pressure during normal operating conditions. Watermains can have no internal pressure during commissioning or when put out of service for repair and maintenance. Since the no internal pressure time will normally be relatively short (i.e., days to weeks) the Resiline short-term ASTM D698 flexural modulus can be used in Equation X1.1.

2.2. Equation X1.6

Equation X1.6 determines the liner thickness required for a circular hole in the pipe wall. This equation assumes a thin flat plate liner spans a circular hole with the flat plate fixed at the edge and subjected to uniform internal pressure.

$$P = \frac{5.33}{(DR-1)^2} \times \left(\frac{D}{d}\right)^2 \times \frac{\sigma_L}{N} \qquad X1.6$$

where:

DR = Liner Dimension Ratio = D/t (Internal pipe diameter divided by the liner thickness).

D = Host pipe mean inside diameter, mm (in).

d = Diameter of hole or opening in original pipe wall, mm (in).

σ_L = Liner long-term (50-year time-corrected) ASTM D790 Flexural Strength = 22.5 MPa (3263 psi).

N = Factor of Safety which is typically 2.

Since the liner will be normally under internal pressure the 50-year long-term Flexural modulus is typically used in Equation X1.6. Robinson 2022 reports rupture testing and states that the 50-year long-term flexural strength value of 22.5 MPa (3263 psi) would be applicable for the design of Resiline 320 in potable water applications.

The maximum X1.6 pressure can not exceed the maximum hoop stress pressure given by Equation X1.7. Equation X1.5 provides the limit for Equation X1.6.

2.3. Equation X1.5

$$\frac{d}{D} \leq 1.83\left(\frac{t}{D}\right)^2 \qquad X1.5$$

If Equation X1.5 is not satisfied, Equation X1.7 must be used. In this equation t is the liner thickness determined from Equation X1.6, D is the mean host pipe internal diameter, and d is the hole diameter.

2.4. Equation X1.7.

Equation X1.7 ensures that the liner hoop stress is greater than the internal stress created by the internal water working or nominal pressure.

$$P = \frac{2\sigma_{TL}}{(DR-2)N} \qquad X1.7$$

where:

P= Internal water working pressure or nominal operating pressure MPa (psi).

σ_{TL} = Long-term 50-year time corrected ASTM D698 tensile strength = 12.5 MPa (1813 psi).

DR = Liner Dimension Ratio = D/t (Internal pipe diameter divided by the liner thickness).

N = Safety Factor which is typically 2.

As for Equation X1.6, the liner thickness is determined by solving for the liner thickness in the DR term. Since the liner will be under internal pressure the long-term tensile strength is used. Testing, by Robinson 2022, shows that the 50-year tensile creep rupture value of 12.5 MPa (1813 psi) is applicable for the design of Resiline 320 in potable watermain applications.

3. *Fully Deteriorated Liner Thickness.*

For the fully deteriorated condition, the required liner thickness is the largest thickness obtained from Equations X1.1, X1.3, X1.4 and X1.7.

3.1. Equation X1.3

Equation X1.3 is used to determine the required thickness withstanding all the external loads such as hydrostatic groundwater, soil, live, and internal vacuum.

$$q_t = \frac{1}{N}\left[\frac{32 R_w B' E'_s C}{1} \times \left(\frac{E_s I}{D^3}\right)\right]^{\frac{1}{2}} \quad \text{X1.3}$$

where,

q_t = Allowed total external pressure on the liner MPa (psi).

= $0.433H_w$ + $wHR_w/144$ + W_s, - W_{vacuum} (Imperial Units).

= $0.00981H_w$ + $wHR_w/1000$ + W_s - W_{vacuum} (SI Units).

where

Hw = Height of water over the top of pipe m (ft).

H = Height of soil above the top of pipe, m (ft).

R_w = Water Buoyancy Factor = 1 – 0.33 (H_w/H) with a minimum value of 0.67.

w = Soil Density, kN/m^3 (lb/ft^3) typically taken as 18.5 kN/m^3 (120 lb/ft^3).

W_s = Live Load pressure at the top of the host pipe, MPa (psi). This includes truck or railway live loads. For the Resiline designs an AASHTO HS20 truck live load was assumed.

W_{vacuum} = Internal vacuum pressure. Full vacuum is -1 bar = -0.10 MPa = 15 psi.

B' = Coefficient of Elastic Support = $1(1+4e^{-0.065H})$ inch-pound units or $1(1+4e^{-0.213H})$ SI units.

I = Liner Moment of Inertia, mm^4/mm $(in.^4/in)$ = (1 unit length* t^3)/12 where t is liner thickness.

C = Ovality Reduction Factor = $([1\text{-}q/100]/[1+q/100]^2)^3$ where q = existing pipe ovality in percent which is typically 2 percent for watermains.

N = Factor of Safety which is typically 2.

E'_s = Modulus of Soil Reaction, MPa (psi) which varies from 4.8 to 10.35 MPa (700 to 1500 psi). For the Resiline designs, a value of 6.9 MPa (1000 psi) was used. This value is deemed to be representative of compacted backfill normally placed around a watermain.

E_S = Liner short-term ASTM D790 Flexural Modulus of Elasticity, MPa (psi) = 1724 MPa (250,000 psi).

D = Host pipe mean inside diameter, mm (in).

As for Equation X1.1 the water main is expected to be pressurized most of the liners design life and will be only out of service for short periods of time. For this reason, the ASTM D790 short-term flexural modulus of 1734 MPa (250,000 psi) is used in Equation X1.3. Since watermains are designed and constructed as round pipes, the maximum pipe ovality is limited at 2 percent.

3.2. Equation X1.4

Equation X1.4, as specified in the ASTM F1216 design method, ensures the liner has sufficient ring stiffness.

$$\left(\frac{EI}{D^3}\right) = \left(\frac{E}{12(DR)^3}\right) \geq 0.093 \text{ (inch-pound units)} \quad \text{or} \qquad \text{X1.4}$$

$$\left(\frac{EI}{D^3}\right) = \left(\frac{E}{12(DR)^3}\right) \geq 0.00064 \quad \text{(SI units)} \qquad \text{X1.4}$$

where:

E = Liner initial ASTM D790 flexural modulus, MPa (psi) = 1724 MPa (250,000 psi).

I = Liner Moment of Inertia, mm^4/mm $(in.^4/in)$ = (1 unit length* t^3)/12 where t is liner thickness.

D = Host pipe mean inside diameter, mm (in.).

DR = Liner Dimension Ratio = D/t (Internal pipe diameter divided by the liner thickness).

4. Resiline 320 Design Examples

4.1. Partially Deteriorated Design Condition

The partially deteriorated condition assumes that the host pipe will continue to carry all earth and live loads over the design life (i.e., 50+ years) and the SIPP liner will span a maximum hole size in the host pipe wall. For this example, the hole size is set at 25 mm in a 150 mm diameter watermain that is located 1.5m below the ground surface and has an operating or working pressure of 0.62 MPa (90psi). Equation X1.6 can be used to determine the liner thickness.

$$\mathrm{P} = \frac{5.33}{(\mathrm{DR}-1)^2} \times \left(\frac{D}{\mathrm{d}}\right)^2 \times \frac{\sigma_\mathrm{L}}{\mathrm{N}} \qquad \text{X1.6}$$

where:

P= 0.62 MPa (90 psi).

D= 150 mm.

d= 25mm.

σ_L= 12.5 MPa (1813 psi).

N= 2.

Using the above values yields DR = 59.97. This DR results in a X1.6 liner thickness (t) of 2.5 mm.

Using the X1.6 thickness of 2.5 mm, Equation X1.5 is checked to ensure that

$$\frac{d}{D} \leq 1.83 \left(\frac{t}{D}\right)^2$$

For the above conditions d/D = 0.167 which is less than 0.236. Therefore, Equation X1.5 is satisfied.

Lastly, the liner thickness to satisfy Equation X1.1 is determined.

$$\mathrm{P} = \frac{2K\mathrm{E}_s}{(1-\nu^2)} \times \frac{1}{(\mathrm{DR}-1)^3} \times \frac{C}{\mathrm{N}} \qquad \text{X1.1}$$

where:

P= is the groundwater pressure above the pipe invert. If the ground water table is at the ground surface P = 1.5m of water head.

K = 7.

v = 0.4.

C = Ovality Reduction Factor = ([1-q/100]/[1+q/100]^2)^3. If q = 2% then C = 0.836.

N =2.

Using the above values yield DR = 46.88 and a X1.1 liner thickness t= 3.2mm.

For this example, the Partially Deteriorated design yield the following liner thickness (t).

X1.6 = 2.5mm, X1.5 is satisfied for X1.6 = 2 .5 mm, and X1.1 = 3.2 mm.

Thus, the Partially Deteriorated design thickness for a 25mm hole in a 150mm pipe is the largest of X1.1 and X1.6 which is 3.2 mm.

4.2. Fully Deteriorated Design Example

For a fully deteriorated design the liner thickness is determined by taking the greatest thickness from Equations X1.1, X1.3, X1.4 and X1.7.

For a 150mm diameter pipe, located 2.5m below the ground surface, and the ground water table at the ground surface, Equation X1.1 can be used to determine the required liner thickness.

$$\mathrm{P} = \frac{2K\mathrm{E}_s}{(1-\nu^2)} \times \frac{1}{(\mathrm{DR}-1)^3} \times \frac{C}{\mathrm{N}} \qquad \text{X1.1}$$

where:

P= the groundwater pressure above the pipe invert = 2.5 m of water head.

K = 7.

v = 0.4.

C = Ovality Reduction Factor = ([1-q/100]/[1+q/100]^2)^3. If q = 2% then C = 0.836.

N =2.

Using the above values yield DR = 45.45 and X1.1 liner thickness t= 3.3 mm.

The required liner thickness to meet Equation X1.3 can be determined with an AASHTO HS20 surface live load and the liner subjected to a full vacuum.

$$\mathrm{q_t} = \frac{1}{N}\left[\frac{32\mathrm{R_w}B'\mathrm{E'}_s C}{1} \times \left(\frac{\mathrm{E}_s I}{\mathrm{D}^3}\right)\right]^{\frac{1}{2}} \qquad \text{X1.3}$$

where:

qt = 0.00981Hw + wHRw/1000 + Ws - Wvacuum (SI Units).

Hw = Height of water over the top of pipe m = 2.5 – 0.150 = 2.35m.

H = Height of soil above the top of pipe, m = 2.5 – 0.150 = 2.35m.

Rw = Water Buoyancy Factor = 1 – 0.33 ($Hw/$H) = 0.67 lower limit.

w = Soil Density = 18.85 kN/m^3.

Ws = Live Load, MPa (psi). According to AWWA M45 an AASHTO HS 20 truck will increase the stress on the top of the pipe by 0.0118 MPa.

Wvacuum = the Internal Vacuum pressure. Full vacuum = -0.1 MPa.

Using the above the Total Pressure qt = 0.1616 MPa.

Using:

B' = Coefficient of Elastic Support = 1(1+4$e^{-0.213H}$) = 0.2921.

C = Ovality Reduction Factor. With q =2 percent C = 0.836.

N = Factor of Safety which is typically 2.

$E's$ = 6.9MPa (1000 psi). This value is deemed to be representative of compacted backfill normally placed around a watermain.

E_S = Liner short-term ASTM D790 Flexural Modulus of Elasticity = 1724 MPa (250,000 psi).

D = Host pipe mean inside diameter = 150mm.

Using the above values, the Moment of inertia of the liner I = 6.67 mm4/mm.

This Moment of Inertia yields an X1.3 liner thickness = 4.2 mm.

Equation X1.4, as specified in the ASTM F1216 design method, ensures the liner has sufficient ring stiffness.

$$\left(\frac{EI}{D^3}\right) = \left(\frac{E}{12(DR)^3}\right) \geq 0.00064 \quad \text{(SI units)} \qquad \text{X1.4}$$

where:

E = Liner initial ASTM D790 Flexural Modulus = 1734 MPa (250,000 psi).

D = Host pipe mean inside diameter = 150 mm.

Using the above values, the DR is determined to be 60. This DR results in a X1.4 liner thickness of 2.5 mm.

Equation X1.7 ensures that the liner hoop stress is greater than the internal stress created by the interal water working or nominal pressure.

$$P=(2\sigma_{TL})/(DR-2)N \qquad X1.7$$

If:

P= Internal water working pressure or nominal operating pressure = 0.62 MPa (90 psi).

σ_{TL} = Long-term 50-year time corrected ASTM D698 Tensile Strength = 12.5 MPa (1813 psi).

N = Safety Factor which is typically 2.

Using the above values, the DR is determined to 22.06. This DR results in a X1.7 liner thickness of 6.8 mm.

The Fully Deteriorate design results in the following required Resiline 320 Liner thickness.

X1.1 = 3.3 mm

X1.3 = 4.2 mm

X1.4 = 2.5 mm

X1.7 = 6.8 mm

Thus, the Fully Deteriorated Resiline 320 liner thickness is 6.8mm