Cured-in-Place Pipe Liners for Pressure Applications – What the Industry is Doing to Standardize Structural Design and Seal at Services and Ends

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ABSTRACT
Cured-in-place pipe (CIPP) was initially created to repair aging gravity sewer systems. The addition of glass reinforcing layers to the felt tube in the 1990s provided CIPP with the structural integrity necessary to be used in the rehabilitation of pressurized pipeline applications. The use of CIPP for pressure applications requires internally reconnecting and sealing existing service lateral connections, preferably by internal methods to minimize excavation. There are two significant aspects related to CIPP pressure pipe liners that the industry needs to address to provide consistent design and performance:
- Quantitative Structural Classifications
- Hydrostatic integrity at service connections and end terminations

Currently, the industry has limited guidance documents related to the design of Structural CIPP liners, and designs from different vendors for a specified capability may vary substantially and may not relate well to the product being used. AWWA’s Structural Classification Committee is nearing completion of a White Paper that highlights design, installation and QA/QC aspects that will guide the industry and educate owners and designers. A lack of hydrostatic integrity at service connections can result in leakage and/or migration of water into the annulus between the CIPP and the host pipe. As leakage, it is not often apparent during the initial proof testing of the CIPP liner. Minor leaks in the annular space between the liner and host pipe can worsen over time, creating a pipeline that not only lacks the hydrostatic integrity to meet design objectives but one that may also suffer from a reduced effective design life overall.

This paper provides an update on the AWWA Structural Classification White Paper, a review two of the most commonly accepted internal service reconnection methods; mechanical and adhesive, and end seal approaches. It also reviews testing data that was generated during an ongoing research and development project into service reconnection methods, as well as from other investigations.

1 INTRODUCTION

Currently in North America the majority of cured-in-place pipe (CIPP) watermain lining is accomplished by inverting or pulling a resin-impregnated liner into an existing host pipe. Host pipe materials vary, with cast iron, ductile iron (internally coated or bare), polyvinyl chloride (PVC), asbestos cement (AC) and steel making up the majority of watermains in the ground.

The CIPP pressure pipe liners generally consist of a waterproof membrane, reinforcement of glass fiber with felt or woven polyester, and a thermosetting resin. The complete lining system, not individual components, must meet ANSI/NSF 61 requirements. Depending on the product, liners are currently cured using hot water or steam. Ultraviolet light systems are also under development.

Each lining system has unique characteristics that define the liner thickness, impregnation or wetout process, method of installation, and cure method. These factors ultimately determine the pressure capability of the lining system.

A second significant focus for the industry is the ability of lining systems to provide a reliable seal between the host pipe and the liner at the two locations where it is most critical for watermains: the end termination of the lined segments; and, the existing service connections.

2 INDUSTRY FOCUS

As watermain lining continues to grow in acceptance and implementation, owners and engineers are requesting more detail on how various products can be classified and proven to provide specified levels of service from a structural perspective. American Water Works Association has responded to this industry request by forming a subcommittee of manual M28 – Watermain Rehabilitation to provide quantifiable objectives to guide the industry through a White Paper on Structural Classifications of Linings - Suggested Protocol for Product Classification.

A liner’s bond to the host pipe and at service connections, has many competing requirements. Continuous bond to the host pipe can make the liner susceptible to failure with brittle failure of the host pipe.
while some methods of service connection reinstatement depend on bond locally for hydrostatic integrity. A variety of investigations have defined the degree of bond or adhesion that can be achieved, depending on the level of surface preparation achieved on the interior face of the host pipe.

2.1 CURRENT INDUSTRY PROCESS FOR DESIGNING STRUCTURAL CIPP LINERS

Designs for structural liners often state “designed to AWWA M28 and/or ASTM F1216” (ASTM F1216 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a resin-Impregnated Tube). AWWA’s Manual M28, 3rd Edition provides an overview of pressure pipe rehabilitation or renovation technologies, as well as discussion on implementing projects. It also includes an Appendix that qualitatively defines pressure pipe structural classification requirements. Table 1 presents the criteria that are used to determine structural classification without a quantitative basis to confirm the liner’s capability. A similar qualitative ISO standard is used in Europe and other parts of the world.

<table>
<thead>
<tr>
<th>LINER CHARACTERISTICS</th>
<th>NON-STRUCTURAL</th>
<th>SEMI-STRUCTURAL</th>
<th>FULLY STRUCTURAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERNAL CORROSION BARRIER</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>BRIDGES HOLES/GAPS AT PIPE OPERATING PRESSURE</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>INHERENT RING STIFFNESS</td>
<td>(depends on adhesion)</td>
<td>NO</td>
<td>YES*</td>
</tr>
<tr>
<td>LONG-TERM INDEPENDENT PRESSURE RATING</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>SURVIVES “BURST” FAILURE OF HOST PIPE</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>

* Minimum requirement is for liner to be self-supporting when pipe is depressurized

Table 1. M28 Structural Classification

In M28, four liner classes are identified to address specific pipe problems, and each can be defined by a set of qualitative requirements reflecting the problem to be solved.

Class I:
- nonstructural liners – host pipe must carry all internal and external loads;
- minimal if any ability to span holes, cracks and gaps;
- must bond or adhere to the host pipe;
- protect host pipe from internal corrosion, or deterioration caused by the fluid carried;

Class II & III:
- semi structural or interactive liners;
- close or tight fit when properly installed;
- pressure capacity is less than maximum allowable operating pressure (MAOP) of the system;
- designed to span holes and gaps at specified pressures;
- Class II liners have minimal hoop strength and are required to bond to the host pipe to prevent collapse when depressurized;
- Class III liners have sufficient hoop strength to be self-supporting when depressurized.

Class IV:
- fully structural or structurally independent;
- hoop strength, independent of host pipe is equal or greater than all anticipated short-term loads, independent of host pipe;
- long term hoop strength independent of host pipe is equal to or greater than the specified MAOP;
- long term load carrying capacity is sufficient to withstand all anticipated external or internal loads;
- able to survive failure of host pipe.

ASTM F1216 is the specification that was introduced in 1998 to provide the original design basis for CIPP liners. It was initially developed for isotropic materials and low-pressure applications. In today’s pressure pipe lining arena, much higher pressure capabilities are demanded, and to achieve these requirements, liners must include reinforcing materials in addition to the felts used in gravity applications. The resultant materials exhibit anisotropic as opposed to isotropic behaviour

F1216 includes circumferential design checks only for:
- buckling due to external hydrostatic loads – gravity;
- buckling due to earth/live loads – gravity;
- hole and gap spanning – pressure Class II & III;
- full hoop stress – pressure Class IV;
- minimum stiffness requirement related to fully deteriorated gravity design.

Several conditions support development and implementation of a more robust design process to address some of the basic deficiencies in F1216:
- Axial as well as circumferential design checks
- The possible effect of bond with the host pipe inherent in the design
- Wide variance in thermal regime
- Use of strain limited materials
- Significant exposure to non-steady state pressure regimes
- Exposure to higher pressures (>700 kPa or 100 psi)

2.1.1 AWWA STRUCTURAL CLASSIFICATION SUBCOMMITTEE REPORT IMPLICATIONS AND RECOMMENDATIONS

The AWWA Structural Classification subcommittee has taken the current qualitative concepts and advanced them to measurable, quantitative terms supported by existing
standards and specifications. A key consideration is to ensure that the design objectives for a specific application can be accomplished by the selected product. At present, it can be difficult to match products to specific applications.

A simple, logical process proposed has three components:

- **Problem Definition Statements** prepared by the Owner/Engineer define the host pipe and issue to be resolved and quantify the loads to be considered.
- **Type testing** – carried out by the lining system manufacturer/supplier to determine short and long term mechanical and potentially, chemical resistance properties.
- **Acceptance testing** using field samples to ensure the delivered product meets the design objectives.

Considering this process, the existing qualitative M28 Structural Classification definitions in Table 1 can be used to develop a guideline with quantifiable objectives. Examples of defined objectives for Liner Characteristics from Table 1 include:

- **Internal corrosion barrier:**
  - Hydrostatic leakage test
  - Visual inspection

- **Bridge Holes and Gaps:**
  - Visual inspection
  - ASTM D4541
  - Long term flexural strength

- **Inherent ring stiffness:**
  - Visual inspection
  - ASTM D2990 – Standard Method for Tensile, Compressive and Flexural Creep and Creep Rupture of Plastics to confirm long term flexural modulus, or creep

- **Long term independent pressure @ MAOP:**
  - ASTM D2992 – Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for “Fiberglass” (Glass Fiber Reinforced Thermosetting Resin) Pipe and Fittings
  - ASTM D2990 – tensile creep,

In addition to the list considerations, industry standard tests to confirm material physical properties are required and stipulated in well-defined and sound project specifications. A test carried out to ASTM D2290 – Standard test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe is recommended in some cases to confirm in-place hoop strength of liner system (Figure 2).

As discussed, the key for establishing long term pressure capability of a liner, or other plastic pipe, is hydrostatic design basis (HDB) testing. Unfortunately, at this time, very limited HDB testing has been reported for CIPP liners. The short-term standard that the industry will default to is related to ASTM D1599. In the absence of HDB testing, the pressure capability of given lining system will be the short term burst results, with larger safety factors (e.g. ~4) applied. That implies that the acceptable operating pressure of the liner will be a maximum of ¼ the short term burst pressure.
accomplish the type testing and acceptance testing guidelines.

The CIPP pressure pipe lining industry is expected to follow the lead set by other products including metallic and fiberglass pipe standards. A current draft design standard for carbon fiber reinforced polymer (CFRP) products provides a much more comprehensive approach that CIPP lining will utilize to reflect the more complex design requirements.

2.2 WATERTIGHT SEAL AT CRITICAL LOCATIONS

Following the AWWA Subcommittee White Paper on Structural Classifications, a proposal is being prepared to undertake a similar AWWA project to address provision of watertight seals at services and end connections.

CIPP pressure pipe lining systems are designed to make full contact with the host pipe when installed and cured. They are expanded from flat products using a variety of installation procedures or systems to address this requirement. A leak tight seal at service connections, and at the liner end terminations is required and this can only be achieved if the lining system provides a tight fit. Figure 3 illustrates an annular space between the liner and host pipe. This can result in a leak if it occurs at a service connection, or with some end termination systems.

![Figure 3. Illustration of Annular Gap in Lined Pipe](Image)

The CIPP lining process for pressure pipes includes: inspection and cleaning, plugging services, installing liner, hydrostatic pressure test, reinstating services, disinfection and reconnection to the existing system.

Internal reinstatement, or opening, of the service connections must accommodate a range of fitting sizes. Most typically, these include ½, ¾ and 1 inch (12 mm, 19 mm and 25 mm). However, commercial or industrial service connections may be 2 inches (50 mm) or larger. It may be reasonable to expect to have the capability of reinstall a 2 inch connection, but larger sizes will require excavation, or reliance on the bond between liner and host pipe.

Currently, the most common practice employed is to simply drill open the service and rely on the adhesion of resin to the host pipe to create the leak tight bond. Currently there is no specific guidance to define what constitutes a competent seal, methods to confirm that a suitable bond has been achieved. Several existing applications have determined the pull off force required for their specific needs. While these are not directly related to CIPP systems, they do provide valuable information.

Spray-in-place (SIPP) lining systems, require a minimum of 200 psi (1380 kPa) pull off force, although in this case it is the bond required to address surges in the lined pipe. In hand-applied CFRP systems 1000 psi (6895 kPa) is a target for steel pipe, and in the case of concrete pipe the concrete material is expected to fail before the bond. In fusion bonded epoxy applications, 3000 psi (20,685 kPa) is specified. In these three examples, significant effort must be expended in preparing the host pipe interior wall to achieve adhesion with the resin.

In existing watermains, the limited access available, (e.g. distance from entry points to the service), results in challenges to provide acceptable surface conditions conducive to bonding in the area adjacent to services and the protrusions that may exist. A mechanical system to reinstall services robotically from within the pipe could eliminate the need for reliance on adhesion.

2.2.1 TYPICAL CONDITIONS AND MATERIALS INEXISTING WATER MAINS – IMPACTS ON INTERNAL SERVICE REINSTATMENT

The majority of the North American water distribution pipe inventory consists of three pipe materials, as illustrated in Table 2. Water distribution mains are considered to be 6 to 10-inches (150 – 250 mm) in diameter for the purposes of these discussions. The composition of pipe networks varies both geographically and with system age. Unlined cast iron pipe, manufactured to a range of specifications was the most common water main material until the 1940s. Asbestos cement pipe was introduced in North America in the late 1930s and was a popular material through the 1970s. Ductile iron pipe was invented in 1955 (first AWWA Standard in 1965) and continues to be a common water main material. In addition to these major categories, steel pipe of various configurations has been used in some instances, and polyvinyl chloride (PVC) pipe is popular in some areas.

<table>
<thead>
<tr>
<th>Material</th>
<th>Miles (km)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron (Cl)</td>
<td>816,000 (1,313,000)</td>
<td>51</td>
</tr>
<tr>
<td>Ductile iron (DI)</td>
<td>448,000 (721,000)</td>
<td>28</td>
</tr>
<tr>
<td>Asbestos cement (AC)</td>
<td>176,000 (283,000)</td>
<td>11</td>
</tr>
<tr>
<td>Other</td>
<td>176,000 (283,000)</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,616,000 (2,600,000)</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 2. Water Distribution Systems by Material (Reference: Aegion Internal communication combining research conducted by various organizations in North America)
Each pipe material has unique mechanisms, depending on environmental conditions, that can lead to deterioration or failure. The basis for this discussion is installation of a fully structural liner CIPP liner, that limits the excavation required to provide a reliable, rejuvenated water main distribution system. In addition to the physical pipe material service connection reinstatements; the terminations of the lined segments where connections to the existing system are required are a significant challenge. Ultimately, a robust, leak-free product is required. CIPP pressure pipe liners are designed as continuous, leak-free pipes that meet structural requirements specific to the system being rehabilitated.

Service connections can be either directly threaded into the host pipe (Figure 4), or installed through a saddle configuration (Figure 5). In the case of direct connections, the threads of the corporation stop can be flush/recessed into the pipe wall or they can protrude into the inner diameter of the pipe. The threads of a corporation stop installed in a saddled connection terminate in the saddle, and cannot provide a bonding surface.

2.2.2 ADHESIVE BOND TYPE SERVICE REINSTATEMENT

Surface preparation of the host pipe wall can have a significant impact on the bond that can be achieved between the host pipe and the liner. Current surface preparation techniques used in the industry include:

- Simple pull through abrasion process to remove deposits or tuberculation using, foam or reinforced foam pigs, disks, stiff wire brushes or metal tines with aggressive edges
- Mechanical system using a rotating rod with a cutting or abrasive head, such as rack bore feeding
- Pressure flushing – ranging from 2,000 psi (13,790 kPa) to over 10,000 psi (68,950 kPa)
- Hydraulically (pressurized water) powered chain flails or abrasive heads

The results that can be achieved depend on the severity and characteristics of the deposits that require removal and the process employed. Pressure pipe lining applications demand removal of localized corrosion or tuberculation pieces that protrude from the pipe wall to prevent creation of localized stress points. In some cases a form of mechanical interlock that may result at these locations. In the past, this has mistakenly been promoted as adhesion.

Recent investigations and tests highlight what can be achieved inside pipes through aggressive surface preparation using material blasting techniques, such as sand blasting. However, conventional blasting in long lengths of water mains is typically cost-prohibitive. The evaluation of the Tomahawk cleaning system, an aggressive airborne particle process that uses a high volume low pressure vacuum to pull crushed granite of various gradations through water mains, has been successfully deployed in spray-on lining applications and shows promise for CIPP lining.
Bond and Water Tightness Test Results with Varying Degree of Surface Preparation

Some existing processes can ensure a solid resin bond. However, they may be material specific and not necessarily consistent or feasible across all material types. Several examples provide insight into what can be achieved with appropriate effort.

As a component of product evaluation in a non-municipal application, the bond and resulting water tightness of highly prepared stainless steel end termination fittings was tested. Fusion-bonded epoxy (FBE) was applied to the interior of the stainless steel spool pieces using industry standards that included garnet blasting to near white metal finish in accordance with SSPC-SP10. This is a commonly used corrosion protection coating method for metallic pipes, but it is not feasible for long lengths of in-service municipal pipelines.

Figure 6 shows the configuration of the test sample, with prepared end termination pieces, manufactured to accommodate Victaulic couplings attaching blind-flanged ends, with the CIPP liner extending through to the face of the stainless steel spool at both ends. The test included two conditions:

- Pressurizing the longitudinally unrestrained sample to 300 psi (2070 kPa), holding for 5 minutes with no leakage
- Increasing the pressure to 600 psi (4140 kPa) and finally holding for 5 more minutes. Leakage was allowable in the liner material but failure was not permitted.

The sample passed the 600 psi test with no leakage in the pipe material or the fittings. Subsequent to the initial tests, the sample was taken to burst at 1600 psi (11,000 kPa) with no leakage at the fittings.

The Tomahawk cleaning system was evaluated using a 6-inch (150 mm) cast iron pipe installed during the 1950s in Calgary, Alberta. 50-foot (15 m) long sections with pipe segments joined using pipe repair clamps were constructed. A SSPC-SP6/NACE #3 Commercial Blast Cleaned Surface was achieved. Figure 7 illustrates a typical result, with the surface free of tuberculation or other deposits, and exhibiting a rough surface profile. The airborne abrasive cleaning system was not able to remove the corrosion in the pitted areas, which contributed to the surface preparation level accomplished.

An additional test was undertaken with the Tomahawk-prepared samples. 16 corporation stops were drilled into the pipe samples prior to CIPP lining. Water tightness of the seal around the services was assessed by drilling 3 –3/16 inch (5 mm) holes spaced around the corporation stop. One hole was directly opposite the corporation stop (180 degrees around the circumference, approximately 9 inches (230 mm) around the circumference), with the other two located on each side of the corp stop at 9 inches (230 mm) along the longitudinal axis of the pipe. Plastic threaded plugs were inserted into the 3/16 inch (5 mm) holes to prevent resin from escaping during the installation and cure process. Two sections of pipe were lined and the plugs were removed prior to pressure testing to 300 psi to assess water tightness at the service connections. No leakage was observed at any of the 3/16-inch (5 mm) holes and 15 of 16 services were water tight.

Testing is underway with a variety of adhesive materials in conjunction with a proprietary end termination process to optimize mechanical interlock and surface profile, both features that improve water tightness and reliability. Further, tests are being undertaken to assess the shear capability of bond between several epoxy resins and spool ends. The results are expected to yield valuable data to feed into the development of improved adhesive bonding systems for service reinstatement.

These activities indicate that increased effort and attention to detail are required to achieve a good, quantifiable bond. Not all of existing processes and results are applicable or necessary in the municipal market.
Although some specialized epoxy resins are designed to cure and provide some bond in wet or humid conditions, typical epoxies exhibit superior performance under dry conditions.

2.2.3 MECHANICAL TYPE SERVICE REINSTATEMENT

A proprietary mechanical internal reinstatement system introduced in the mid 2000s, has been employed in limited commercial applications. The system, known commercially as iTAP™, involves installing a hollow bolt, or T nut, into the drilled-out service. The T nut is essentially screwed into a drilled-out service connection, with self-tapping threads cutting into the existing brass corporation stop. The threads are left-handed to prevent loosening the service during installation. Using a mechanical style system eliminates the need for the liner to bond or adhere to the host pipe/service connection in order to form a seal. However, the variations in service connection configurations results in several challenges that must be considered. Figure 8 illustrates the T-nut, and Figure 9 shows installed T-nuts.

- Saddled services that have experienced side loading post installation.

2.2.4 OPERATIONAL CAPABILITIES FOR MECHANICAL SERVICE REINSTATEMENT

In order for mechanical service reinstatement to be most effective, robotic service reinstatement equipment for mechanical service installation must be capable of addressing a large variety of conditions that can be encountered. A significant concern in smaller water mains is the ability of the robots to travel through the pipe once the mechanical fittings have been installed. The robotic equipment must either be small enough to pass under the protruding threads or the threads must be milled flush to the ID of the host pipe.

When saddled services are installed, the drilled hole in the host pipe is inherently smaller than the inner diameter of the corporation valve. If a mechanical type fitting is proposed for this situation, the design must address this condition to permit installation. A significant concern with saddled services is the distance from the liner interior surface to the corporation stop threaded into the saddle. Potential options to address these installations include the ability to open up the drilled hole or expand the reinstated connection after insertion into the corporation stop.

To maximize the distance that can be reinstated per each launch pit, the robotic equipment should also be able to navigate through many of the other features commonly found in the host pipe such as bends, joints, fittings and tees.

The installation of mechanical fittings includes an extra step compared to current plug and drill internal service reinstatement. Current robots can carry only one fitting at a time, for either plugging before lining or installing a mechanical fitting. Optimized systems have to address these restrictions to provide a robust, reliable system without significant increases in cost.

2.2.5 ONGOING RESEARCH TO PROVIDE RELIABLE MECHANICAL SERVICE REINSTATEMENT

A privately funded research and development project is currently underway with the focus of improving existing mechanical service reinstatement reliability and efficiency. It is designed to reduce the overall travel required to install the plugs required to prevent resin migration during lining, as well as installation of the mechanical fitting. This ongoing project is focused on resolving the technical and economic boundaries related to internal mechanical service reinstatement. The project considers reliability and long-term service, along with ease and economy of installation.

Projected commercialization of this system is early 2019.

2.2.6 SEALING LINER ENDS

Various methods are used to provide a seal at the ends of lined pressure pipes. Some processes simply cut the liner flush with the host pipe and apply a quick set epoxy.
over the liner end as well as the host pipe. The intent is to seal any annular space between the host pipe and the liner. The lined pipe is reconnected to the watermain system by a standard mechanical joint fitting clamped onto the lined host pipe.

Another system commonly used is the installation of an expandable internal end seal. The liner is cut flush with the host pipe, and then cut back within the lined host pipe. The internal seal is expanded against the host pipe and is designed to step up onto the liner. This technique provides a more secure seal. In early applications, the seal was installed against the existing host pipe. Many contractors prefer to install a new segment of host pipe to terminate the lined section and provide a solid pipe to expand the internal seal against. Figure 10 illustrates an internal end seal.

A third system involved installation of a sacrificial PVC spool at the end of the lined pipe. This PVC was removed after lining, and a compression style reducing mechanical joint was installed directly onto the liner, and onto the joining piping.

A proprietary system was developed to provide a more reliable end termination for lined pressure pipes. In this scenario, a fiberglass spool piece (GRP), specifically sized to match the interior diameter of the host pipe, and the outside diameter of either the host pipe or the connecting pipe material is attached to the end of host pipe. The interior of the fiberglass spool is suitably prepared to ensure bond between the spool piece and the liner. This provides a new segment of pipe to connect to the existing system, as well as a superior leak tight connection. Figure 11 illustrates this system.

3.0 SUMMARY

The watermain lining industry is at a point where both the assignment of structural classification and the requirements for providing a reliable seal at service connections and liner end terminations are evolving rapidly. AWWA’s Structural Classification White PaperPaper will provide long needed quantifiable guidance for designers and owners to be able to specify product requirements and confirm that design intent has been met for each project. The ongoing research and industry-lead committee on bond and seal at services and liner end terminations will also eliminate confusion and misconceptions in the industry.