Designation: F2019 – 22

Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Pulled in Place Installation of Glass Reinforced Plastic Cured-in-Place (GRP-CIPP) Using the UV-Light Curing Method[1]

This standard is issued under the fixed designation F2019; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers the procedures for the reconstruction of pipelines and conduits (4 in. to 72 in. (100 mm to 1830 mm) diameter) by the pulled-in place installation of a resin-impregnated, glass fiber tube into an existing pipe or conduit followed by its inflation with compressed air pressure (see Fig. 1) to expand it firmly against the wall surface of the host structure. The photo-initiated resin system in the tube is then cured by exposure to ultraviolet (UV) light. When cured, the finished cured-in-place pipe will be a continuous and tight fitting pipe within a pipe. This type of reconstruction process can be used in a variety of gravity flow applications such as sanitary sewers, storm sewers, process piping, electrical conduits, and ventilation systems.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C1920 Practice for Cleaning of Vitrified Clay Sanitary Sewer Pipelines

D543 Practices for Evaluating the Resistance of Plastics to Chemical Reagents

D578 Specification for Glass Fiber Strands

D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D1600 Terminology for Abbreviated Terms Relating to Plastics

D2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

D3567 Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings

D5813 Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems

F412 Terminology Relating to Plastic Piping Systems

F1216 Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube

F1417 Practice for Installation Acceptance of Plastic Non-pressure Sewer Lines Using Low-Pressure Air

2.2 *ISO Standards:*[3]

11296-4 Plastics piping systems for renovation of underground non-pressure drainage and sewerage networks – Part 4: Lining with cured-in-place pipes

[1] This practice is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.67 on Trenchless Plastic Pipeline Technology.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

***A Summary of Changes section appears at the end of this standard**

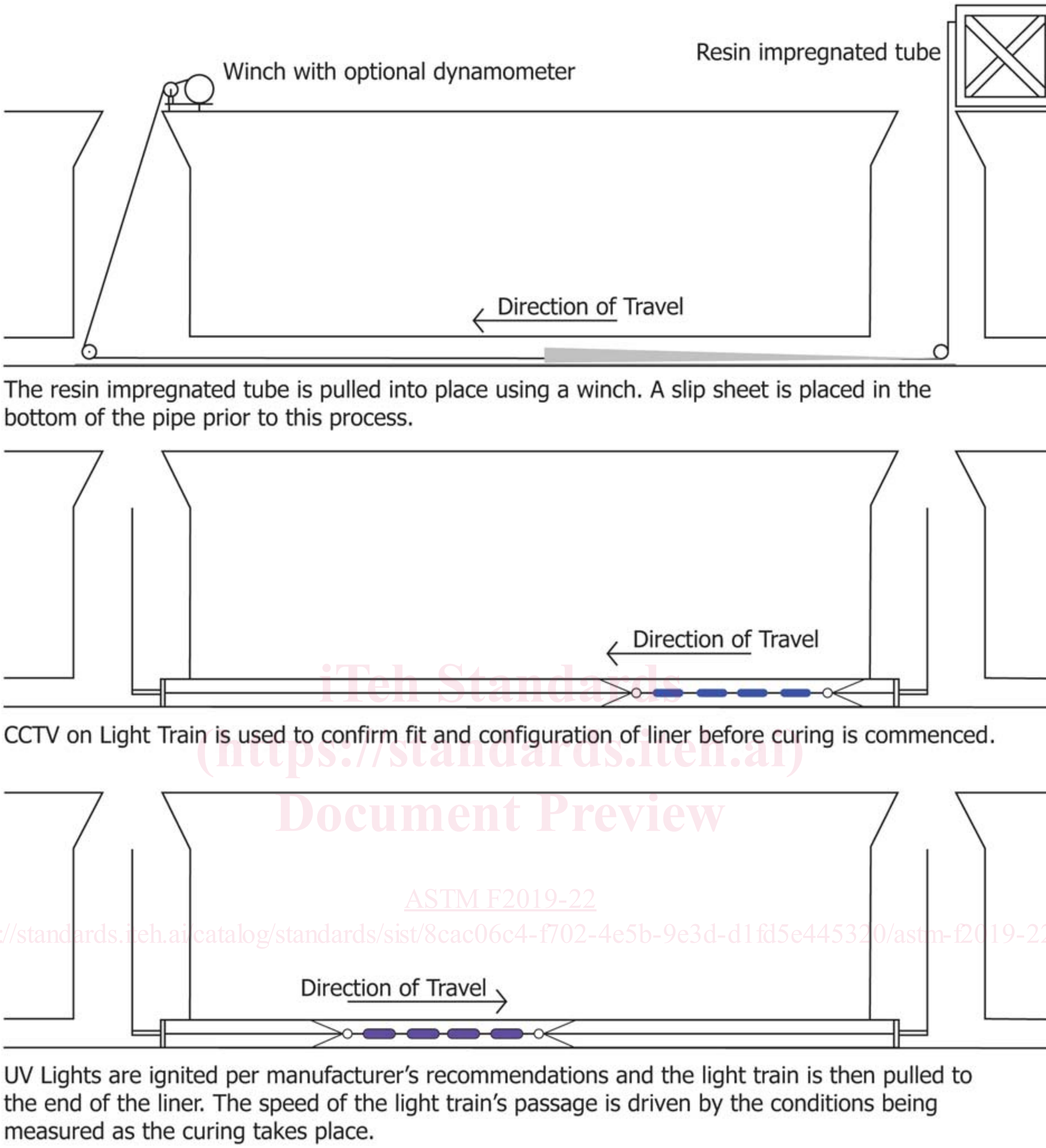

FIG. 1 UV Cured-In-Place Pipe Installation Method (Air/Steam)

7685 Plastics piping systems – Glass-reinforced thermosetting plastics (GRP) pipes – Determination of initial specific ring stiffness
178 Plastics – Determination of Flexural Properties
9001 Quality Management Systems

2.3 *AWWA Standard:*
Manual on Cleaning and Lining Water Mains, M28[4]

2.4 *NASSCO Standard:*
Recommended Specifications for Sewer Collection System Rehabilitation[5]

3. Terminology

3.1 *General:*

3.1.1 Definitions are in accordance with Terminology F412. Abbreviations are in accordance with Abbreviations D1600, unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration hose*—a UV-transparent, styrene or equivalent-impermeable inner film or inner coating installed inside the resin-impregnated glass fiber tube to facilitate the inflation of the tube, causing it to be pressed firmly against the wall of the existing pipe or conduit until the resin is cured. Unless installed specifically to remain in place, the calibration hose shall be removed when the installation is finished.

3.2.2 *cured-in-place pipe (CIPP)*—a hollow cylinder consisting of a glass reinforced plastic (GRP) fabric tube with cured thermosetting resin. External films are included. The CIPP is formed within an existing pipe and takes the shape of the pipe.

3.2.3 *delamination*—a separation after curing between the layers of a multi-layered glass fiber fabric wall in the CIPP.

3.2.4 *dry spot*—an area of the fabric tube, where the finished CIPP is deficient or devoid of resin.

3.2.5 *fiberglass composite*—a structural material that results from combining fiberglass layers, thermosetting resin, and other individual processing components that are within the finished CIPP structure to derive the desired material and mechanical properties. The cured combination being resistant to normal sewer effluents as tested in accordance with 6.4.1 and 6.4.2 of Specification D5813.

3.2.6 *glass fiber tube*—flexible fiberglass materials formed into a tubular shape which is saturated with resin prior to installation and holds the resin in place as a permanent part of the installed cured-in-place pipe as further described in 5.2.1.

3.2.7 *lift*—a portion of the CIPP that is a departure from the existing conduit wall forming a section of reverse curvature in the CIPP.

3.2.8 *sliding sheet*—a plastic sheeting material installed prior to the resin saturated glass fiber tube covering the lower portion of the circumference of the existing pipe to reduce sliding resistance and to protect the uncured resin saturated glass fiber tube while being drawn into the host pipe.

3.2.9 *photo-initiated resin*—a thermosetting resin system that employs a photo-initiator molecule to absorb ultraviolet (UV) light radiation and utilizing that energy to then initiate the polymerization of the resin system.

3.2.10 *qualification test*—one or more tests used to prove the design of a product; not a routine quality control test.

3.2.11 *quality control test*—one or more tests used by the manufacturer of the CIPP system during its manufacture or assembly.

3.2.12 *quality assurance testing*—one or more tests used to verify the physical properties of the finished, or as-installed, CIPP.

4. Significance and Use

4.1 This practice is for use by designers and specifiers, regulatory agencies, owners and inspection organizations who are involved in the rehabilitation of conduits through the use of a resin-impregnated glass fiber tube, pulled in place through an existing pipe or conduit, subsequently inflated and then cured by a designed exposure to UV-light. As for any standard practice, modifications may be required for specific job conditions.

5. Recommended Materials and Manufacture

5.1 *General*—The glass fiber tube, resin system and outer film or external pre-liner shall produce a GRP-CIPP that meets the requirements of this practice. The supplier of the UV Light cured GRP-CIPP System shall be an ISO 9001 certified producer or have implemented a quality system similar to that in the ISO 9001 requirements.

5.2 *CIPP Wall Composition*—The wall shall consist of a corrosion resistant fiberglass fabric tube (Fig. 2) saturated with a thermosetting (cross-linked) resin.

5.2.1 *Glass Fiber Tube*—The glass fiber tube shall consist of at least two separate layers of fiber material made of corrosion resistant (E-CR or equivalent) glass fibers in accordance with Specification D578. Where a removable calibration hose is used, the internal surface shall consist of a resin rich layer for high chemical and abrasion resistance. The glass fiber tube shall further be constructed with longitudinal unidirectional glass roving of sufficient strength to negotiate a pulling force at least equal to one-half the weight of the liner. The glass fiber tube shall tolerate circumferential changes in the existing conduit. So as to produce a close-fit installation in deformed host pipes and to minimize causing wrinkles in the finished CIPP, the glass fiber tube shall be undersized according to the manufacturing method of the tube such that it will upon its expansion in the host pipe fully fit the interior of said host pipe with minimal or no annular spaces or cavities between the host pipe and the liner which is essential in order to guarantee the fit condition assumed by the engineer in the wall thickness design calculations.

5.2.2 *External Films*—The external films shall consist of one or more layers of tube-shaped plastic films which are resistant and impermeable to moisture, UV-Light and styrene or equivalent.

[4] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

[5] Available from National Association of Sewer Service Companies, 423 W. King Street, Suite 3000, Chambersburg, PA 17201.

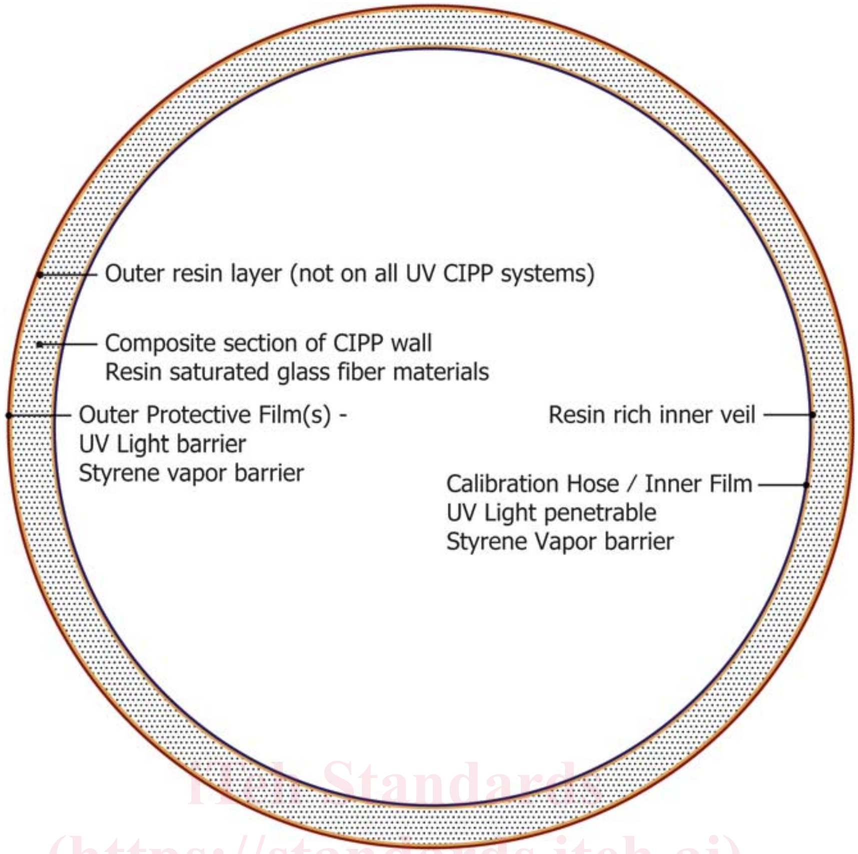

FIG. 2 Composition of Fabric Tube (UV cure)

5.2.3 *Calibration hose*—The calibration hose (inner film or coating; see Fig. 2) which is installed during the construction of the fabric tube, shall consist of a tube-shaped plastic film or resin-saturated coated felt tube that is UV-transparent, resistant and impermeable to moisture, styrene resistant and impermeable, and able to resist temperatures up to 285 °F (140 °C) while exposed to the installation pressure sufficient to keep the fabric tube tight against the pipe wall. It shall further release easily from the inside wall for removal (in the case of an inner plastic film), when the installation is finished.

5.2.4 *Resin*—The resin system shall consist of a chemically resistant polyester or vinyl ester thermoset (UV-light-cured) resin and catalyst system or an epoxy resin and hardener that is compatible to the installation process. For UV-light cured systems a photo-initiator system must be added to the resin prior to the impregnation. The photo-initiator system shall be tuned to the UV-curing equipment used or vice-versa.

5.2.5 *Properties*—The cured CIPP product shall at least have the initial structural properties given in Table 1. These physical properties should be determined in accordance with Section 7 of this practice.

5.2.6 *CIPP Wall Structure*—The thicknesses and relative positions of each component layer of the CIPP wall, including tolerances, shall be specified as declared values by the CIPP system manufacturer. The composite's structural wall thickness shall be the total wall thickness minus the inner veil resin thickness and the external layer thickness that is made up of any resin migration, processing aids, etc.

TABLE 1 CIPP Initial Structural Properties[A]

Property	Test Method	Minimum value, psi	(MPA)
Flexural Strength[B]	D790	Declared Value, but not less than 15 000	Declared Value, but not less than 103
Flexural Modulus[B]	D790	Declared Value, but not less than 725 000	Declared Value, but not less than 5000

[A] The values in Table 1 are for test results on field specimens per product manufacturer's technical data sheet. The purchaser shall consult the manufacturer for the long-term structural properties.
[B] The value indicates minimum strength in the circumferential direction

5.2.6.1 *Wall Thickness*—The mean wall thickness, e_m, of the composite's structural wall section shall not be less than the design wall thickness. The minimum wall thickness, e_{min}, of the composite wall thickness shall not be less than 80 % of the design wall thickness, or 3.0 mm, whichever is the greater value.

5.2.7 *Chemical Resistance*—The inner surface of the cured resin/fabric matrix shall be evaluated in a laminate for qualification testing of long term chemical exposure to a variety of chemical effluents and should be evaluated in a manner consistent with 6.4.1 and 6.4.2 Specification D5813. The edges of the test coupons shall be sealed for this testing.

6. Installation Recommendations

6.1 *Cleaning and Pre-Inspection:*

6.1.1 *Safety*—Prior to entering access areas such as manholes, and performing inspection and cleaning operations, an evaluation of the atmosphere to determine the presence of toxic or flammable vapors or lack of oxygen shall be undertaken in accordance with local, state or federal safety regulations.

6.1.2 *Cleaning the Pipeline*—All internal debris shall be removed from the original pipeline. The pipes shall be cleaned with hydraulically powered equipment, high velocity jet cleaners, or mechanically powered equipment in accordance with manufacturers guidelines, Practice C1920 for VCP pipes or NASSCO Recommended Specifications for Sewer Collection System Rehabilitation, as applicable.

6.1.3 *Line Obstructions*—The original pipeline should be clear of obstructions such as solids, dropped joints, protruding service connections, collapsed pipe, and reductions in the cross-sectional area that may hinder or prevent the installation and curing of the resin impregnated fabric tube. Where the inspection reveals an obstruction that cannot be removed by conventional sewer cleaning equipment, then a robot with a cutter or other suitable tool should be used to remove the obstruction.

6.1.4 *Inspection of Pipelines*—Inspection of pipelines shall be performed by experienced personnel trained in locating breaks, obstacles and service connections by closed circuit television or man entry. The interior of the pipeline shall be carefully inspected to determine the location of any conditions that prevent proper installation of the impregnated tube, such as protruding service taps, collapsed or crushed pipe, and reductions in the cross-sectional area. These conditions shall be noted and corrected prior to the installation.

6.1.5 *Pre-Measurement of Service Connections:*

6.1.5.1 A pre-measuring of all service locations shall be performed by experienced personnel. These measurements shall be made using a primary method and a back-up method; such as the counter value from the cable reel and a taped identification on the cable itself from a reference point on the manhole ring. Visible indentations at the lateral connections may not be readily identified.

6.1.5.2 The measurements shall be noted in a log also containing information about the clockwise position of the opening.

6.1.6 *Bypassing:*

6.1.6.1 Where bypassing the flow is required around the sections of pipe designated for reconstruction, the bypass shall be made by plugging the line at the up-stream end of the pipe to be reconstructed and pumping the flow to a downstream point or adjacent system.

6.1.6.2 The pump and bypass lines shall be of adequate capacity and size to handle the flow. Services within the reach shall be temporarily out of service.

6.1.7 Public advisory services shall be required to notify all parties whose service laterals are out of commission and to advise against water usage until the lateral line is back in service.

6.2 *Installation Methods:*

6.2.1 *Sliding Sheet and Winch Cable*—Upon verification of the removal of all debris and protrusions a sliding foil and a winch cable may be pulled through the line. The sliding sheet shall cover approximately the lower third or up to half of the circumference of the pipe, as recommended by the CIPP system manufacturer. At the upstream end it is locked in place by being inserted underneath the plug used to block the flow in the manhole or other suitable anchoring arrangement.

6.2.2 *Pulling Head or Pulling Manifold and Invert Roller*—The liner is connected to the winch cable by forming a pulling head or using a pulling manifold. A pulling head can be made by turning the end of the liner over into a loop. If a pulling manifold is used it shall be attached to the end of the liner with sufficient strength to transfer the pulling force. It contains a mounting point for the air/stream hose. During the mounting of the pulling manifold care shall be taken to provide an airtight fit of the calibration hose to the manifold. If a pulling head has been used it shall be dismantled after pulling in the liner. Then a manifold is mounted airtight into the calibration hose. An invert guide roller is placed in the winch manhole. The invert roller shall allow the pulling head or manifold to enter the manhole before the pulling is terminated. A swivel connection to the pulling cable must be added to avoid twisting the liner.

6.3 *Resin Impregnation:*

6.3.1 *Resin Impregnation*—The glass fiber tube shall be totally impregnated with resin (wet-out) in the manufacturer's plant under quality controlled conditions. The impregnation equipment shall contain devices to secure a proper distribution of the resin. Certification documentation concerning date, type of resin, liner thickness, temperature, type of glass fiber, liner type, manufacturing date and last installation date shall be attached to the impregnated fabric tube or provided by the CIPP manufacturer.

6.4 *Storage and Transportation:*

6.4.1 *UV-cured CIPP*—The impregnated liner shall be stored, transported, and installed inside maximum and minimum temperatures not less than 45 °F (7 °C) or higher than 95 °F (35 °C) when being installed on site. UV cured CIPP shall be stored in accordance with the manufacturer's recommendations.

6.5 *Pulling Resin Impregnated Tube into Position*—The wet-out fabric tube shall be pulled in place using a power winch. The fabric tube shall be pulled into place through an existing manhole or other approved access point to fully extend to the designated manhole or termination point. If the product is sensitive to pulling speed, the pulling speed should be monitored and not exceed the manufacturer's specification. When entered into the access point the fabric tube shall be folded as recommended by the CIPP system manufacturer and placed on top of the sliding sheet. Care shall be exercised not to damage the tube during the pulling phase, especially where curved alignments, multilinear alignments, multiple off-sets, protruding elements and other friction producing pipe conditions are present. As site conditions dictate, a lubricating fluid such as a soapy water solution or biodegradable mineral oil may be poured or sprayed onto the sliding sheet at the liner insertion point. The pulling shall be considered completed when the pulling head or manifold and 2 ft to 3 ft (0.7 m to 1.0 m) of impregnated tube has entered the termination point.

The powered winch used in the pull-in process shall be capable of achieving a constant line-pull value set by the operator with the means to measure the pulling force changes and initiating any adjustments of the pay in or pay out to maintain this preset value; and keeping this force below the CIPP system's recommendation for the tube being installed.

6.6 *Curing Methods-Ultraviolet Light Curing:*

6.6.1 *Installation Set-Up:*

6.6.1.1 The inlet air hose shall be connected to the installation equipment which shall be equipped with a positive displacement blower or an air compressor (the latter requiring the ambient air temperature to be above 41 °F (5 °C) and rising) of sufficient volumetric capacity to expand the impregnated fabric tube tightly against the host pipe using the CIPP system manufacturer's recommended level of internal pressure. While the tube expands under pressure, a multi-lamp ultraviolet light curing assembly shall be drawn through the pipe. During this travel through the expanded liner, the installer shall use the CCTV camera(s) mounted on the light train to verify that the liner is properly fitted to the host pipe without any wrinkles or fins that should be avoidable given the current cross-sectional configuration (geometry) of the host pipe. If these defects are found, they shall be corrected before proceeding on to the UV-light curing process.

6.6.1.2 The ultraviolet curing lights shall be tuned or optimized for the photo initiator system of the resin; or conversely the initiator system of the resin shall be optimized to the output of the ultraviolet curing lights.

6.6.2 *Processing*—Travel through the pipe shall be at a pre-determined speed per the CIPP system manufacturer's recommendations, provided to the owner's representative for each installation length, which will facilitate the cross-linking/polymerization of the CIPP resin. Air pressure shall be adjusted to sufficient pressure to hold the impregnated fabric tube tight to the pipe wall throughout the resin hardening process taking into account any additional pressure needed to overcome any external hydrostatic pressure from any visible signs of groundwater infiltration. The recommended pressure shall be maintained by adjustment of the outlet valve.

6.6.3 *Curing Control*—A full protocol for time, rate of travel of the ultraviolet light train assembly, pressures, temperature of the liner, and the amount and power of the lamps in operation shall be maintained as documentation for the correct curing of the fabric tube. The protocol shall be recorded automatically from the beginning of inflation of the liner until the end of the curing. It shall also show the basic information in a header, such as project name, address, section, and date, to clearly identify the renovated section.

6.7 *Workmanship*—The finished CIPP shall be continuous over the entire length of an installation and be free of dry spots, lifts, and delaminations. Where these conditions are present the CIPP shall be evaluated for its ability to meet the applicable requirements of Section 7. Where the CIPP does not meet the requirements of Section 7 or specifically stated requirements of the purchase agreement, or both, the affected portions of the CIPP shall be removed and replaced with an acceptable repair as specified in 6.2 of Specification D5813.

6.8 *Service Connections*—After the new CIPP has been installed, the existing service connections shall be reinstated. This shall be done without excavation and in cases of non-man-entry sized pipes from the interior of the pipeline by the means of a television camera and a remotely controlled cutting device. Service connections shall be reinstated to at least 95 % of the original area as it enters the host pipe or conduit. All laterals where a plug by the end of the lateral was not visible by the pre-inspection, shall be reinstated, if the purchase agreement does not specify it differently.

6.9 *End Seals*—the annular space at all locations where the CIPP enters and exits a manhole or other access structure shall be made leak-tight by the installation of a pre-formed hydrophilic material designed for sanitary sewer service that fully circles the circumference and has sufficient width to accommodate any irregularities in the host pipe wall surface. The location of its placement will be such that the seal is made within the confines of the manhole wall and back from the end of the host pipe by at least 1.5 in.

NOTE 1—A seal is not being made between the existing pipe and the fabric tube at the service connections due to the external film. If total elimination of infiltration and inflow is desired, other means, which are beyond the scope of this standard, may be necessary to seal service connections and to rehabilitate service lines and manholes.

7. Recommended Inspection Practices

7.1 For each installation length as designated by the purchaser in the purchase agreement, the preparation of CIPP samples shall be required as given below:

7.1.1 The samples shall be cut from a section of cured CIPP taken at an intermediate manhole or at the termination point that shall be installed through a like diameter section of conduit or other tubular restraining means provided the invert channel is essentially straight through. The specimens shall allow circumferential (hoop) directions of the Fiberglass reinforcement in the CIPP. Five specimen with a width of 2 in. (50 mm) are needed. The overall length of the field sample must be able to produce this number of specimens. The samples are to be tested in a curved beam configuration where the minimum beam width is 2 in. (50 mm). The specifics of the individual specimen obtained from this sample are discussed in Appendix X2. Alternatively, the installer can prepare either a restrained or a flat plate sample above ground using the same conditions that were experienced by the liner inside the pipe being renewed (level of pressurization, stretch, light intensity, and duration of exposure). Preferably, a lamp (or lamps) shall be taken from the light train used to affect the curing.

7.1.2 The CIPP samples shall be large enough to provide the recommended five specimens for flexural testing. Where five suitable specimens cannot be obtained from the sample; on approval by the project engineer, the lab may be allowed to conduct the flexural testing using a minimum of three specimens. The flexural specimen shall be prepared in accordance with X2.3. Individual specimens shall be clearly marked for easy identification and retained until final disposition for CIPP acceptance, or both, has been given.

7.1.2.1 *Short Term Flexural Properties*—The initial tangent modulus of elasticity and flexural strength from field prepared samples shall be measured in accordance with Test Method D790, Test Method 1—Procedure A as modified by Appendix X2 and shall meet or exceed the requirements of Table 1 within the 16:1 length to depth constraints. The flexural properties must be measured in the hoop direction as this is by design typically the direction of the primary reinforcement which is needed to deliver the dominant in-place performance of the liner. The short term flexural strength shall be the value at first break; meaning the first break in the glass fiber portion of the CIPP. Breaks in the curvature of the stress-strain curve attributable to the resin rich inner veil's cracking are to be ignored.

7.1.3 *CIPP Wall Thickness*—The method of obtaining the CIPP wall thickness measurements on restrained samples shall be in a manner consistent with 8.1.2 of Specifications D5813. Thickness measurements shall only incorporate the layers making up the compose section of the CIPP (Fig. 2) and be in accordance with Practice D3567 for samples prepared in accordance with 7.1 and 7.2. Make a minimum of eight measurements at evenly spaced intervals around the circumference of the restrained sample avoiding including any point(s) where the liner is obviously thicker due to an overlapping of the structural layers of the laminate, but making sure to pick up the obvious minimum thickness around the circumference of the liner. The average composite wall section thickness shall be calculated using all measured values and shall meet or exceed the stated minimum design thickness per the engineer's wall thickness calculation . The minimum composite section wall thickness at any point shall not be less than 80.0 % of the average specified design thickness as agreed between purchaser and seller. See Sections 6 and 7 of D3567 or X2.3.1 in Appendix X2, or both for more information on making these measurements

NOTE 2—A local reduction in wall thickness may reduce the in service safety factor.

7.2 *Pipe Leakage Testing:*

7.2.1 *Gravity Pipe:*

7.2.1.1 If required by the owner in the contract documents or purchase order, gravity pipes shall be tested using an ex filtration test method where the CIPP, after it is cooled down to ambient temperature and the calibration hose is removed, but before the laterals are re-opened, is plugged in both ends. The testing shall be performed with either air or water

7.2.1.2 Air testing shall be in accordance with Test Method F1417.

NOTE 3—It is impractical to test pipes above 36 in. diameter for leakage due to the technology available in the pipeline rehabilitation industry. Man entry inspection of larger pipes shall detect major leaks.

NOTE 4—The allowable leakage for gravity pipe testing is a function of loss at end seals and by water testing of compression of air trapped in the pipe.

7.3 *Inspection and Acceptance*—The installation shall be visually inspected to assure compliance with 6.7 or by closed circuit television where visual inspection cannot be accomplished by man-entry. Variations from the true line and grade and geometry of the cross-section shall be consistent with that of the pre-lining condition of the original piping. No infiltration of ground water shall be observed through the CIPP. In cases of visible leakage, repairs shall be made in accordance with the CIPP system manufacturer and in agreement with the owner. All service openings shall be accounted for and be unobstructed.

7.3.1 When flexural testing is conducted using curved beam specimen a value of 85 % or higher of the flexural properties used in the wall thickness design calculations shall be considered as passing. See Note X2.2 for the explanation of this allowance for restrained sample test values.

8. Keywords

8.1 cured-in-place pipe (CIPP); glass reinforced plastic (GRP); rehabilitation; steam cured; UV-cured; UV-light-cured

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CONSIDERATIONS

X1.1 *General Guidelines*—The focus of structural liner design is the identification of the smallest (that is, most efficient) liner thickness that can provide an adequate safety factor against both buckling and material failures. Existing relevant literature has established that a flexible, thin-walled liner without a bond to the existing pipe will be in a state of combined radial axial compression and flexure. The dominant loading will come from the external hydrostatic pressure when the pipe is below the phreatic surface of the groundwater. It is also established that this dominant axial compressive loading can lead to circumferential shortening of the liner over the life of this loading depending on the liner's stiffness (that is, flexural modulus) which, in turn, will produce an opportunity for a "blister" to form in the arc element of the overall cross-section where the largest radius exists (that is, flattest arc). The failure of the flexible liner will be by a localized buckling of this arc element.

X1.1.1 Contained within the proceedings of the ASCE's annual Pipelines Conferences are several peer reviewed papers for calculating the needed wall thickness of a flexural lining systems installed in circular and non-circular geometries using a Modified-Glock buckling analysis. This analysis methodology was the result of work produced by the French government and presented to ASCE by Olivier Thépot, their principal investigator, beginning in 2001. Because of this methodology's ability to use the stiffness of the lining material in a real-world manner, it allows the engineer to take advantage of the UV-light cured CIPP systems which by design must employ glass fiber materials which produce a stiffness on the order of