FM Approvals

CLASS NUMBER 1613

Examination Standard for Polyethylene (PE) Pipe and Fittings for Underground Fire Protection Service

October 2022

Foreword

This standard is intended to verify that the products and services described will meet stated conditions of performance, safety and quality useful to the ends of property conservation. The purpose of this standard is to present the criteria for examination of various types of products and services.

Examination in accordance with this standard shall demonstrate compliance and verify that quality control in manufacturing shall ensure a consistent and reliable product.

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1 INTRODUCTION

1.1. PURPOSE

1.1.1. This standard states testing and certification requirements for polyethylene (PE) pipe and fittings for underground fire service water mains.

1.1.2. Testing and certification criteria may include performance requirements, marking requirements, examination of manufacturing facility(ies), audit of quality assurance procedures, and a surveillance program.

1.2. SCOPE

1.2.1. This standard encompasses the design and performance requirements for NPS (Nominal Pipe Size) 4 in. through 36 in. nominal size PE pipe and fittings for use in underground fire service mains. Other sizes may be considered for certification on a case-by-case basis.

1.2.2. In cases where metric sized PE pipe and fittings are to be examined for certification, test criteria comparable to the United States equivalent size shall be used.

1.2.3. The certification agency will consider PE pipe and fittings which are designed in accordance to national or international standards. Only after verification is made that the products to be reviewed are in conformance to ANSI/AWWA C906 or other nationally or internationally recognized standards will certification testing commence. All certification testing is to be conducted on production samples.

1.3. BASIS FOR REQUIREMENTS

1.3.1. The requirements of this standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.3.2. The requirements of this standard reflect tests and practices used to examine characteristics of PE pipe and fittings for the purpose of obtaining certification. PE pipe and fittings having characteristics not anticipated by this standard may be certified if performance equal, or superior, to that required by this standard is demonstrated.

1.4. BASIS FOR CERTIFICATION

Certification is based upon satisfactory evaluation of the product and the manufacturer in the following major areas:

1.4.1. Examination and tests on production samples shall be performed to evaluate:

- the suitability of the product;
- the performance of the product as specified by the manufacturer and required for certification;
- the durability and reliability of the product.

1.4.2. An examination of the manufacturing facilities and audit of quality control procedures may be conducted to evaluate the manufacturer's ability to consistently produce the product which is examined and tested, and the marking procedures used to identify the product. Subsequent surveillance may be required by the certification agency in accordance with the certification scheme to ensure ongoing compliance.

1.5. BASIS FOR CONTINUED CERTIFICATION

The basis for continual certification may include the following based upon the certification scheme and requirements of the certification agency:

- production or availability of the product as currently certified;
- the continued use of acceptable quality assurance procedures;
- satisfactory field experience;
- compliance with the terms stipulated by the certification;
- satisfactory re-examination of production samples for continued conformity to requirements; and
- satisfactory surveillance audits conducted as part of the certification agency’s surveillance program.

1.6. EFFECTIVE DATE

The effective date of this examination standard mandates that all products tested for certification after the effective date shall satisfy the requirements of this standard.

The effective date of this standard is eighteen (18) months after the publication date of the standard for compliance with all requirements.

1.7. SYSTEM OF UNITS

Units of measurement used in this standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Conversion of U.S. customary units is in accordance with ANSI/IEEE/ASTM SI 10.

Two units (liter and bar), outside of but recognized by SI, are commonly used in international fire protection and are used in this standard.

1.8. NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies:

ANSI A21.10, *American National Standard for Thickness Design of Cast Iron Pipe*

ANSI/IEEE/ASTM SI 10, *American National Standard for Metric Practice*

ANSI/AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Waterworks*

ISO 6259:, *Thermoplstics pipes – Determination of tensile properties*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D883, *Standard Terminology Relating to Plastics*

ASTM D1238, *Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer*

ASTM D1598, *Standard Test Method for Time-to-Failure of Plastic Pipe under Constant Internal Pressure*

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

ASTM D1603, *Standard Test Method for Carbon Black in Olefin Plastics*

ASTM D2290, *Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe*

ASTM D2412, *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*

ASTM D2837, *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*

ASTM D2839, *Standard Practice for Use of a Melt Index Strand for Determining Density of Polyethylene*

ASTM D3350, *Standard Specification for Polyethylene Plastic Pipe and Fittings Materials*

ASTM D4218, *Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique*

ASTM F2620, *Standard Practice for Heat Fusion Joining of Polyethylene Pipe and FittingsASTM F2880-14, Standard Specification for Lap-Joint Type Flange Adapters for Polyethylene Pressure Pipe in Nominal Pipe Sizes ¾ in. to 65 in.*

ASTM F412, *Standard Terminology Relating to Plastic Piping Systems*

ASTM F714, *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter*

PPI TR-3, *Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe*

PPI TR-4, *PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings For Thermoplastic Piping Materials or Pipe*

NSF/ANSI 61: *Drinking Water Systems Components - Health Effects*

1.9. TERMS AND DEFINITIONS

Generally, terminology relating to PE pipe and fittings shall be in accordance with ASTM D883, Standard Terminology Relating to Plastics and ASTM F412, Standard Terminology Relating to Plastic Piping Systems, respectively. Any terminology not included

within, or in contradiction to, those documents will be separately defined where used in the certification examination of PE pipe and fittings. For purposes of this standard, the following terms apply:

Accepted — This term refers to installations acceptable to the authority enforcing the applicable installation rules (Authority Having Jurisdiction). Acceptance is based upon an overall evaluation of the installation. Acceptance is not a characteristic of a product. It is installation specific. A product accepted for one installation may not be acceptable elsewhere.

Design Factor (DF) — The design factor is used to reduce the hydrostatic design basis (HDB) determined according to ASTM D2837 and PPI TR-3 to arrive at the hydrostatic design stress (HDS) from which the pressure class (PC) is calculated. The design factor accounts for typical process variation, dimensional tolerances and other sources of variability that can impact the long-term performance of HDPE pipe. The design factor used in this standard for PE2708, PE3710 and PE4710 compounds is 0.63. The design factor used in this standard for PE2606, PE2706, PE3608, PE3708, PE4608 and PE4708 is 0.50.
NOTE: The design factor is not the inverse of the safety factor. The time to failure of HDPE at a particular temperature is related to stress through a power law relationship i.e. time to failure increases dramatically with a small reduction in stress.

Dimension Ratio (DR) — The ratio of the average outside diameter of outside diameter-controlled plastic pipe to the minimum specified wall thickness of the pipe, rounded to the nearest tenth (eg. DR 13.5).

Electrofusion Joints — A joint where the mating surfaces, typically a pipe outside diameter and the inside diameter of a coupler, are first mated and then brought to the material melt temperature by means of heating elements embedded in the socket. Once cooled, the result is an electrofused joint.

Hydrostatic Design Basis (HDB) — The categorized long-term hydrostatic strength in the circumferential or hoop direction established in accordance with ASTM D2837 and PPI TR-3. The HDB is established at a specific reference temperature, usually 73°F and 140°F and represents the constant hoop stress that induces ductile rupture in the pipe in 100,000 hours (~11.4 years) at the specified reference temperature.

Hydrostatic Design Stress (HDS) — The maximum allowable hoop stress in the pipe wall for pipe that is subjected to sustained long-term hydrostatic pressure. The hydrostatic design stress is determined by multiplying the hydrostatic design basis by the design factor for water service. HDS ratings for PE materials are published in PPI TR-4.

Long Term Hydrostatic Strength (LTHS) — Plastic materials exhibit a time-dependent response to stress. This occurs in a predictable fashion. If samples of plastic pipe are pressurized to various levels, they will fail after periods of time proportional to those pressures. The specific relationship is that the logarithm of the time to failure is negatively proportional to the logarithm of the stress.

$$\log T = a - b \log S$$

Where a and b are constants.
This stress, S, is the hoop stress in the material due to internal pressure at a constant temperature. ASTM D2837, *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*, details test procedures for obtaining this relationship. The relationship is then used to determine a particular maximum S that should not cause failure until at least after a minimum desired life. That S is termed the Long Term Hydrostatic Stress (*LTHS*) for the material in question.

Polyethylene (PE) — A polymer prepared by the polymerization of no less than 85 percent ethylene and no less than 95 percent of total olefins by weight, plus compounding ingredients.

Pressure Class — For polyethylene pipe or tubing, the PC is a numerical classification for maximum sustained internal water pressure water at 80°F (27°C) and lower service temperature with specified maximum allowances for pressure surges. Pressure Class is defined as:
Where:

- PC - Pressure Class
- DR - Dimension Ratio = D_o/t
- HDB - Hydrostatic Design Basis for water, as determined in AWWA C906.
- DF - Typical Design Factor. For example, 0.63 for PE4710.
- t - Minimum Pipe Wall Thickness
- D_o - Average Outside Diameter for IPS and DI sizes; minimum outside diameter for ISO sizes.

Pressure Pipe for Water Distribution and Transmission	Underground pipe used to carry water from a source of supply and distribute it throughout a distribution system or a service area. For the purposes of this standard, distribution and transmission pipe is limited to nominal sizes 4 inches through 36 inches; other sizes will be evaluated on a case-by-case basis.
Production Run	The length of time a particular piece of extrusion equipment is set up to produce a certain size and class of pipe.
Safety Factor (SF)	The safety factor in this standard is the ratio of the actual hoop stress at the allowed operating pressure and temperature to the hoop stress that will cause a ductile failure at the operating temperature. For example, PE 4710 Safety factor is greater than 2 relative to the allowed operating stress.
Working Pressure (WP)	The maximum anticipated, sustained operating pressure applied to the pipe exclusive of hydraulic transient pressures.

2 GENERAL INFORMATION

2.1. PRODUCT INFORMATION

2.1.1. Nominal sizes of PE pipe and fittings for underground fire protection service addressed in this standard are limited to sizes 4 in. through 36 in. Other sizes shall be evaluated on a case-by-case basis.

2.1.2. PE pipe and fittings are manufactured from materials with specific properties. They are thermoplastic compounds prepared by combining the base polymer, polyethylene or a copolymer of ethylene and higher olefins, with stabilizers, colorants, anti-oxidants and ultra-violet (UV) screens for processing, property control, and coloring.

2.1.3. PE resin is usually either extruded (pipes) or fabricated or molded (fittings) of specific thermoplastic formulations, in conformance to nationally or internationally recognized standards.

2.1.4. In order to meet the intent of this standard, PE pipe and fittings must be examined on a model-by-model, type-by-type, manufacturer-by manufacturer, and plant-by-plant basis. This is predicated on the basis that identical designs, fabricated in identical materials by different manufacturers or, even by different plants of the same manufacturer, have been seen to perform differently in testing. Sample PE pipe and fittings, selected in conformance to this criterion, shall satisfy all of the requirements of this standard.

2.2. CERTIFICATION APPLICATION REQUIREMENTS

The manufacturer shall provide the following preliminary information with any request for certification consideration:

- a complete list of all models, types, sizes, and options for the products or services being submitted for certification consideration;
- general assembly drawings, one complete set of manufacturing drawings, hydrostatic design basis (HDB) calculations, anticipated marking format, brochures, sales literature, specification sheets, installation, operation and maintenance procedures, and
- number and location of manufacturing facilities making the products submitted for certification.

All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level. All documents shall be provided with English translation.

2.3. REQUIREMENTS FOR SAMPLES FOR EXAMINATION

2.3.1. Following authorization of a certification examination, the manufacturer shall submit samples for examination and testing based on the following:

- Sample requirements to be determined by the certification agency

2.3.2. Requirements for samples may vary depending on design features, results of prior or similar testing, and results of any foregoing tests.

2.3.3. The manufacturer shall submit samples representative of production. Any decision to use data generated using prototypes is at the discretion of the certification agency.

2.3.4. It is the manufacturer’s responsibility to provide any special test fixtures which may be required to evaluate the PE pipe and fittings.

2.3.5. If there are failures encountered during the examination testing, the certification agency will provide the manufacturer with information regarding what testing will need to be repeated and any additional sample requirements.

3 GENERAL REQUIREMENTS

3.1. REVIEW OF DOCUMENTATION

3.1.1. During the initial investigation and prior to physical testing, the manufacturer's specifications, technical data sheets, and design details shall be reviewed to assess the ease and practicality of installation and use. The certification examination results may further define the limits of the final certification.

3.1.2. The manufacturer's dimensional specifications and/or design drawings shall fully describe the product. All critical dimensions shall be indicated with allowed upper and lower tolerance limits clearly shown.

3.2. PHYSICAL OR STRUCTURAL FEATURES

3.2.1. PE Pipe and fittings shall be designed for a minimum rated working pressure of 150 psi (1035 kPa).

3.2.2. Nominal sizes of PE pipe and fittings shall be 4 inches through 36 inches; other sizes may be evaluated on a case-by-case basis.

3.2.3. PE pipe and fitting materials shall be formed using High Density Polyethylene with a cell classification of Type III or Type IV as defined in ASTM D3350, *Standard Specification for Polyethylene Plastic Pipe and Fittings Materials*. When other materials are submitted, special tests may be necessary to verify their suitability. Material shall be assigned a hydrostatic design basis (*HDB*) for water at 73.4°F (23°C). This value shall be derived from sustained pressure tests conducted per ASTM D1598, *Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure*, and evaluated per ASTM D2837, *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*.

The testing shall have been performed on pipe made of the same raw material as that of the pipe submitted for certification and produced on equipment and under conditions equivalent to those to be used in its commercial production. The hydrostatic design stress (*HDS*) shall then be determined in accordance with ASTM D1598, *Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure*, and ASTM D2837, *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*. The actual safety factor used shall be adjusted, if necessary, to provide at least a projected 50 year life at the rated pressures and temperature.

The manufacturer shall submit the long term hydrostatic test data used to calculate the *HDS*. The certification agency will verify the calculations and the suitability of the data per the applicable ASTM Standard.

When the PPI has listed the material in question to have an *HDS* meeting these requirements, even when that listing is based upon a documented equivalency to other pipe rather than on direct testing to the pipe submitted for certification, that *HDS* shall be acceptable, and submission of calculations and test data is not required.

3.2.4. Clean rework materials derived from a manufacturer's own pipe or fitting product may be used by the same manufacturer for similar purposes provided that:

- The cell classification of the rework material is identical with the material to which it will be added;
- The finished products meet the requirements specified by the purchaser and comply with all requirements of this standard.

3.2.5. All pipe and fittings shall be designed and manufactured in accordance with the dimensional and other requirements of the recognized national or international standard for the products in question. Where such a standard does not exist, the manufacturer shall be prepared to submit detailed documentation, including dimensional drawing and *HDB/HDS* calculations. A special investigation by the certification agency will determine if the products may be considered for certification.

3.2.6. The maximum pressure rating for PE pipe shall be determined using procedures outlined in AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*, as applicable. A manufacturer need not take full advantage of the properties of the material in establishing pressure ratings. That is, more conservative ratings than those derived from this calculation may be assigned.

3.2.7. Pressure ratings for PE fittings cannot be easily determined. Fittings submitted for use with a given pipe must be of compatible material characteristics and must meet the requirements described in Section 4.4 (Hydrostatic Strength).

3.2.8. Testing shall use production pipe and fittings assembled according to the manufacturer's published instructions. All joining techniques submitted shall be tested in all sizes and pressure classes submitted for certification. However, all fitting configurations need not be tested for qualification of a given line. The certification agency will designate those items to be tested which, in its judgment, adequately sample the products submitted for certification.

3.2.9. All performance tests described in Section 4, unless otherwise noted, shall be run at an ambient temperature of 73.4°F ± 3.6°F (23°C ± 2°C). When tests are conducted at temperatures above 80°F (27°C) required pressure values may be adjusted downwards according to the thermal de-rating factors shown in Table 3.2.9.

Table 3.2.9 Thermal De-Rating Factors for PE Pipes and Fittings

Pipe Surface Temperature		*Multiply the Pressure Rating or Pressure Class at 80°F (27°C) by These Factors*
°F	*°C*	
81-90	(28-32)	0.9
91-100	(32-38)	0.8

Note: The de-rating factors assume sustained elevated pipe and fluid temperatures. When the contents of the PE pressure pipe under test are only intermittently and temporarily raised above the service temperature shown, a de-rating may not be needed.

3.2.10. Polyethylene pipe and fittings are generally joined by butt fusion, electrofusion, flanges, mechanical joints, or swaged fittings. Other joining methods will be examined on a case-by-case basis.

3.2.11. Polyethylene fittings may be manufactured using the injection molding process, with or without the internal heating element used in electrofusion fittings. Fittings may also be manufactured by fabrication using pipe or other forms of PE material joined together to make the final product shape. Fittings used to transiton between joint style or pipe materials (i.e. PE x steel pipe) may also be manufactured using a swaging process. Where possible, fabricated fittings should be manufactured using certified PE pipe.

3.3. MATERIALS

3.3.1. All materials used in the fabrication of the PE pipe and fittings discussed in this examination standard shall be suitable for the intended application. Raw materials shall be evaluated in accordance with the appropriate sections of the manufacturer's Quality Assurance Manual plus any applicable national and/or international standards.

3.3.2. Polyethylene is a thermoplastic that is manufactured by polymerization of the monomer ethylene.

PE pipe and fittings shall be manufactured by polymerization of no less than 85 percent ethylene and no less than 95 percent of total weight of total olefins and additional compounding ingredients.

3.3.3. Because of the possibility of connection to potable water systems, PE pipe and fittings addressed in this standard shall use only material suitable for potable water service, as listed for this service by the NSF International (NSF) or other nationally recognized and accredited testing laboratory. Tests shall be made in accordance with requirements equivalent to those of NSF Standard Number 61, *Standard for Drinking Water Systems Components - Health Effects*, at minimum.

3.4. MARKINGS

3.4.1. Pipe markings shall be repeated at a minimum interval of 5 ft (1.5 m) along the pipe, and shall clearly be marked, as a minimum, with the following information:

- Manufacturer's name or trademark;
- Nominal size and outside diameter base (e.g., 6 DIPS, 6 IPS);
- Pressure class;
- Dimension ratio, (if applicable);
- Standard material code designation (e.g. PE4710);
- Recognized standard to which the pipe is designed and manufactured;
- Specific production code, including day, month, year, shift, plant and extruder of manufacture, as applicable; and
- Certification agency's mark of conformity.

3.4.2. Each fitting's markings shall include, as a minimum, the following information:

- Manufacturer's name, or trademark;
- Nominal size and outside diameter base;
- Pressure class;
- The letters "PE";
- Mold cavity identification, (if applicable);
- Recognized standard to which the fitting is designed and manufactured;
- Specific source code, indicating location of manufacture, as applicable; and
- Certification agency's mark of conformity.

3.4.3. The model or type identification shall correspond with the manufacturer's catalog designation and shall uniquely identify the certification agency's mark of conformity.

3.4.4. The order of these markings is optional, as long as all are present.

3.4.5. Additional markings are allowed if arranged in such a way as not to interfere with the legibility of the required markings.

3.4.6. The certification agency's mark of conformity shall be displayed visibly and permanently on the product and/or packaging as appropriate and in accordance with the requirements of the certification agency. The manufacturer shall exercise control of this mark as specified by the certification agency and the certification scheme.

3.4.7. PE pipe and fittings that are produced at more than one location shall be identified as the product of a particular location.

3.4.8. All markings shall be legible and durable throughout the useful life of the product.

3.5. MANUFACTURER'S INSTALLATION AND OPERATION INSTRUCTIONS

3.5.1. The installation instructions, including any special dimension requirements shall be furnished by the manufacturer. Instructions shall be provided in each shipping container

3.5.2. The installation instructions identified in Section 3.5.1 shall be made available in multiple languages in support of the regions where the product is intended to be sold.

3.5.3. The manufacturer shall provide installation instructions which clearly address the following:

- Indicate that the PE pipe and fittings qualified under this standard and certified by the certification agency are restricted to underground service;
- Define requirements of installation including assembly of pipe sections, couplings, and other components;
- Define laying and back filling procedures. Adequate compaction of soil is of particular importance;
- Define thrust blocking and other restraint requirements;
- Define suitable methods for transition connections to other materials.

3.5.4. Butt fusion of unlike wall thicknesses is address in ASTM F2620. When acceptable to the AHJ, end users most consult the pipe or fitting manufacturer for applicable butt fusion procedures for components with dissimilar wall thicknesses.

3.5.5. The certification agency shall determine the minimum acceptable extent of these instructions based upon the specific nature of the PE pipe and fittings submitted for certification. Any instructions specific to certification constraints shall be labeled as such. Instructions required by the certification agency may be included in a more general instruction publication, provided that it is clearly stated that certification of these products is contingent upon observance of the certification constraints. Instructions shall be furnished by the manufacturer.

3.6. CALIBRATION

3.6.1. Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified and traceable to an acceptable reference standard and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and the next due date. A copy of the service provider's accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory should be available.

3.6.2. When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

3.7. TOLERANCES

Tolerances on units of measure shall be as described in Appendix B, unless otherwise specified in this standard.

4 PERFORMANCE REQUIREMENTS

4.1. EXAMINATION

4.1.1. Requirement

The PE pipe and fittings shall conform to the manufacturer's drawings and specifications and to certification requirements.

4.1.2. Test/Verification

The samples shall be examined and compared to drawings and specifications. It shall be verified that the samples conforms to the physical and structural requirements described in Section 3, General Requirements.

4.2. BEND BACK (PIPE ONLY)

4.2.1. Requirement

A bend-back test shall be conducted on all PE material formulations used in production of products submitted for certification. The test specimen shall give no indications of brittle-like cracking or crazing when examined by the naked eye.

4.2.2. Test/Verification

A total of five specimens shall be prepared from finished pipe. Specimens shall be 1-1/4 in. (31.75 mm) wide, 6 in. (150 mm) long and 3/8 in. (9.5 mm) thick (or pipe wall thickness if wall is less than 3/8 in.). If thickness is machined to produce the required specimen, the pipe inside surface shall not be disturbed. Specimens shall be conditioned to 73.4°F ± 3.6°F (23°C ± 2°C) prior to testing and the test shall be conducted at this temperature.

The specimen shall be bent over itself so that the outside surfaces of the specimen are in full contact with each other, beginning at a distance no greater than 3/8 in. (9.5 mm) from the crotch of the bend (see Appendix E, Figure E-1). The time from beginning to end of the bending operation shall be five minutes or less. The bent inside surface shall be examined in a well-lit area for signs of cracking or crazing. No cracking or crazing visible to the naked eye is allowed.

4.3. ELONGATION AT BREAK (PIPE ONLY)

4.3.1. Requirement

An elongation at break test shall be conducted on all PE material formulations used in production of products submitted for certification. The elongation at break for each test sample shall exceed 400 percent.

4.3.2. Test/Verification

A total of five specimens shall be prepared from the pipe material in accordance with ASTM D638-, *Standard Test Method for Tensile Properties of Plastics*, Type III or Type IV. Specimen thickness shall be pipe thickness, or 0.55 in. (14 mm), whichever is less, for Type III specimens; and pipe thickness, or 0.13 in. (3.2 mm), whichever is less, for Type IV specimens. If thickness is machined to produce the required specimen, the pipe inside surface shall not be disturbed. Specimens shall be conditioned to 73.4°F ± 3.6°F (23°C ± 2°C) prior to testing and the test shall be conducted at this temperature. The specimen shall be tested using a cross-head separation of 2 in. (50.8 mm) per minute.

ISO 6259-3 Type 1 test specimens are an acceptable alternative for this test. Other test criteria methods will be reviewed on a case by case basis. In all cases, elongation at break shall be greater than 400 percent.

4.4. HYDROSTATIC STRENGTH (PIPE AND FITTINGS)

4.4.1. Requirement

Hydrostatic strength test shall be conducted on all classes and sizes of pipe and fittings. The test specimen shall attain a hydrostatic pressure equal to or greater than 3.2 times the rated working pressure for a period of 5 minutes without leakage, rupture, ballooning or weeping.

4.4.2. Test/Verification

One sample of each size and cell classification of pipe and fitting submitted for certification, shall be subjected to a hydrostatic strength test. Test samples shall be conditioned to 73.4°F ± 3.6°F (23°C ± 2°C) prior to testing and the test shall be conducted at this temperature. At a minimum, pipe segments shall be at least 2 diameters long and in no case less than 1 ft (305 mm) long. Test pressure shall be 3.2 times the rated working pressure. Pressure shall be maintained for 5 minutes.

4.5. STIFFNESS FACTOR (PIPE ONLY)

4.5.1. Requirements

Pipe submitted for certification shall have sufficient stiffness to remain intact and not leak when exposed to external forces caused by earth and heavy vehicle loads. Stiffness factors shall be determined on representative samples in accordance with references in Section 1.8. Pipe deflection shall be determined using the Spangler Equation and the measured stiffness factors. Deflection of the pipe shall not exceed 5 percent of the inside diameter of the pipe for all depths of bury from 2.5 ft (0.75 m) to 8 ft (2.44 m).

The Spangler Equation used to determine pipe deflections is:

$$\Delta y = \frac{(D_l W_e + W_l) K r^3}{EI + 0.061 E' r^3}$$

Also:

$$PS = \frac{F}{\Delta y} \qquad SF = EI = \frac{0.149 F r^3}{\Delta y}$$

Where:

- y - Vertical deflection of pipe, inches
- D_l - Deflection Lag Factor = 1.25
- We - Earth loads on pipe per unit length, (As specified in Table 1-8 of ANSI A21.1-)
- W_l - Live load on pipe per unit length, (As specified in Table 1-8 of ANSI A21.1-)
- K - Bedding Constant = 0.1
- r - Mean pipe radius, inches
- E - Modulus of elasticity of pipe material, psi
- I - Moment of Inertia of Pipe Wall per unit length, in^3
- E´ - Modulus of Soil Reaction = 400 psi (Minimum)
- PS - Pipe Stiffness
- F - Force applied to produce a given deflection, lb_f/inch of length
- SF - Stiffness Factor

4.5.2. Tests/Verification

Compliance shall be verified by test of a minimum of three 6 in. to 9 in. (150 to 230 mm) long samples of each size and class of pipe submitted for certification. Each specimen shall be subjected to the force necessary to produce a 5 percent deflection of pipe measured by multiplying the average inside diameter from a minimum of three measurements by 0.05. The force necessary to produce this deflection shall be used in the above equations to determine the Pipe Stiffness. Using this value for the Pipe Stiffness, pipe deflection shall be determined for all depths of bury from 2.5 ft (0.75 m) to 8 ft (2.44 m). Pipe deflections shall not exceed 5 percent of the inside diameter for all depths of bury. W_e, (earth loads on pipe per unit length) and W_l, (live load on pipe per unit length), as specified in Table 1-8 of ANSI A21.1 have been reproduced in Appendix C, Table C-1 of this standard.

A sample calculation is shown in Appendix C.

4.6. RING-TENSILE STRENGTH (PIPE ONLY)

4.6.1. Requirements

Ring-tensile Strength tests shall be conducted on all PE material formulations used in production of products submitted for certification in accordance with ASTM D2290, *Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe*. The tensile strength shall not be less than 2,500 psi (17.2 MPa) for PE2606, PE2706 and PE2708 materials and not less than 2,900 psi (20.0 MPa) for PE3608, PE3708, PE3710, PE4608, PE4708, PE4710 and PE100 materials. Minimum tensile strength for other materials shall be established as part of the certification process.

4.6.2. Tests/Verification

A total of five specimens shall be prepared from the pipe material in accordance with ASTM D2290, *Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe*; Procedure B. Samples shall be cut from full diameter, full thickness pipe, 0.50 in. (12.7 mm) long. Two areas of reduced section shall be machined, 0.125 in. (3.2 mm) in radius.

Test specimens shall be measured and mounted in a suitable test fixture. They shall be loaded at 0.50 in./min. (12.7 mm/min.) and the yield and ultimate loads recorded.

Apparent tensile strength at yield shall be calculated and compared to the criterion.

5 OPERATIONS REQUIREMENTS

5.1. DEMONSTRATED QUALITY CONTROL PROGRAM

5.1.1. A quality control program is required to assure that subsequent PE pipe and fittings produced by the manufacturer, at an authorized location, shall present the same quality and reliability as the PE pipe and fittings examined. Design quality, conformance to design, and performance are the areas of primary concern.

- Design quality is determined during the examination and tests and may be documented in the certification report.
- Continued conformance to this standard is verified by the certifier's surveillance program.
- Quality of performance is determined by field performances and by periodic re-examination and testing.

5.1.2. The manufacturer shall demonstrate a quality assurance program which specifies controls for at least the following areas:

- existence of corporate quality assurance guidelines;
- incoming quality assurance, including testing;
- in-process quality assurance, including testing;
- final inspection and tests;
- equipment calibration;
- drawing and change control;
- packaging and shipping;
- handling and disposition of non-conforming materials.

5.1.3. Documentation/Manual

There should be an authoritative collection of procedures/policies. It should provide an accurate description of the quality management system while serving as a permanent reference for implementation and maintenance of that system. The system should require that sufficient records are maintained to demonstrate achievement of the required quality and verify operation of the quality system.

5.1.4. Drawing and Change Control

The manufacturer shall establish a system of product configuration control that shall allow no unauthorized changes to the product. Changes to critical documents, identified in the certification report, may be required to be reported to, and authorized by the certification agency prior to implementation for production.

Records of all revisions to all certified products shall be maintained.

5.2. SURVEILLANCE AUDIT PROGRAM

5.2.1. An audit of the manufacturing facility may be part of the certification agency's surveillance requirements to verify implementation of the quality assurance program. Its purpose is to determine that the manufacturer's equipment, procedures, and quality program are maintained to ensure a uniform product consistent with that which was tested and certified.

5.2.2. Certified products or services shall be produced or provided at, or provided from, location(s) disclosed as part of the certification examination. Manufacture of products bearing a certification mark is not permitted at any other location prior to disclosure to the certification agency.

5.3. INSTALLATION INSPECTIONS

Field inspections may be conducted to review an installation. The inspections are conducted to assess ease of application, and conformance to written specifications. When more than one application technique is used, one or all may be inspected at the discretion of the certification agency.

5.4. MANUFACTURER'S RESPONSIBILITIES

The manufacturer shall notify the certification agency of proposed changes in product construction, design, component, raw materials, physical characteristics, coatings, component formulation or quality assurance procedures prior to implementation of such changes.

5.5. MANUFACTURING AND PRODUCTION TESTS

All tests shall be run at an ambient temperature of 73.4°F ± 3.6°F (23°C ± 2°C) unless otherwise noted. For tests conducted at higher temperatures, the de-rating factors shown in Table 3.2.9 may be applied.

5.5.1. Test Requirement No. 1 - Elevated Temperature Sustained Pressure Test (Pipe Only)

The manufacturer shall conduct an elevated temperature sustained pressure test as defined in ASTM D1598, *Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure*, and AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. This test shall be conducted at the beginning of production and semi-annually thereafter. The pipe shall not rupture, balloon, or weep.

5.5.2. Test Requirement No. 2 - Dimension and Tolerances (Pipe and Fittings)

Pipe - The manufacturer shall measure critical pipe dimensions, at least once per hour or once per length of pipe, whichever is less frequent.

Fittings - The manufacturer shall measure critical fitting dimensions, at least once per hour.

5.5.3. Test Requirement No. 3 - Bend Back Test (Pipe Only)

The manufacturer shall conduct a Bend-Back Test daily, or at least once per production run, whichever is more frequent. The test shall be conducted per the requirements of AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. The Elongation at Break Test may be substituted for this test.

5.5.4. Test Requirement No. 4 - Elongation at Break Test (Pipe Only)

The manufacturer shall conduct an Elongation at Break Test daily, or at least once per production run, whichever is more frequent. The test shall be conducted per the requirements of AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. The Bend Back Test may be substituted for this test.

5.5.5. Test Requirement No. 5 - Ring–Tensile Strength Test (Pipe Only)

The manufacturer shall conduct a Ring-Tensile Test at least once per production run. This test shall be conducted per the requirements of AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. The sample must meet the minimum requirements shown in Section 4.6.1. The Quick Burst Test or the Five-Second Pressure Test as defined in AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Waterworks*may be substituted for this test.

5.5.6. Test Requirement No. 6 - Quick Burst Test (Pipe Only)

The manufacturer shall conduct a Quick Burst Test at least once per production run. This test shall be conducted per the requirements of ASTM D1599, *Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing and Fittings*. The sample shall meet the minimum requirements of AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Waterworks*for Quick Burst Testing. The test pressure at failure, shall not be less than that which results from a minimum hoop stress value of 2,500 psi (17.2 MPa) for PE2708 and PE3608 materials. For PE100 and PE4710 materials, the minimum hoop stress value shall be 2,900 psi (20.0 MPa). The Ring-tensile Strength Test or the Five-Second Pressure Test may be substituted for this test.

5.5.7. Test Requirement No. 7 - Carbon Black Content Test (Pipe and Molded Fittings)

The manufacturer shall conduct a Carbon Black Content Test daily, or for each production run of pipe, whichever is more frequent. The test shall be performed in accordance with AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Waterworks*and ASTM D1603, *Standard Test Method for Carbon Black in Olefin Plastics* or ASTM D4218, *Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique*, or equivalent methods. For colored pipe, the quantity of UV stabilizer shall be verified either by direct analytical measurement or by verification of the blend percentages at the same frequency as carbon black levels.

5.5.8. Test Requirement No. 8 - Five Second Pressure Test (Pipe and Fittings)

Pipe - The manufacturer shall conduct a Five-Second Pressure Test at least once per production run at a pressure equal to 3.2 times the pressure class of the pipe. The Ring-Tensile Strength Test or the Quick Burst Test may be substituted for this test.

Fittings - The manufacturer shall conduct a Five-Second Pressure Test, at a pressure equal to 3.2 times the pressure class of the fitting, on the first fitting of a particular outside diameter and style and every fiftieth fitting thereafter for fabricated fittings. Injection molded fittings shall be tested once per production run.

5.5.9. Test Requirement No. 9 - Melt-flow index Test (Pipe and Molded Fittings)

Specimens taken from the pipe shall be tested in accordance with ASTM D1238, *Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer*, and AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. This test shall be run at least once per day.

5.5.10. Test Requirement No. 10 - Density Test (Pipe and Molded Fittings)

Specimens taken from the pipe shall be tested in accordance with ASTM D2839-, *Standard Practice for Use of a Melt Index Strand for Determining Density of Polyethylene*, and AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution*. This test shall be run at least once per day, or once per lot of pre-compounded PE material, whichever is more frequent.

6 BIBLIOGRAPHY

ANSI/AWWA C901, *Polyethylene (PE) Pressure Pipe and Tubing, 1/2 in (13 mm) through 3 in (76 mm), for Water Service*

ASTM D618, *Standard Practice for Conditioning Plastics for Testing*

ASTM D1505, *Standard Test Method for Density of Plastics by the Density-Gradient Technique*

ASTM D1600, *Standard Terminology for Abbreviated Terms Relating to Plastics*

ASTM D1603, *Standard Test Method for Carbon Black in Olefin Plastics*

ASTM D2122, *Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings*

ASTM D2444, *Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)*

ASTM D2487, *Standard Classification of Soils for Engineering Purposes, (Unified Soil Classification System)*

ASTM D2657, *Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings*

ASTM D2683*, Standard Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing*

ASTM D2774, *Standard Practice for Underground Installation of Thermoplastic Pressure Piping*

ASTM D3035, *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter*

ASTM D3261*, Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing*

ASTM F3124, *Standard Practice for Data Recording the Procedures used to Produce Heat Butt Fusion Joints in Plastic Piping Systems or Fittings*

ASTM 4976, *Standard Specification for Polyethylene Plastics Molding and Extrusion Materials*

ASTM F905-0, *Standard Practice for Qualification of Polyethylene Saddle Fusion Joints*

ASTM F1055, *Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethelene (PEX) Pipe and Tubing*

ASTM F1290, *Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings*

AWWA Manual M55*, PE Pipe - Design and Installation*

ISO 161-1 *Thermoplastic Pipe for the Conveyance of Fluids, Nominal Outside Diameters and Nominal Pressures, Part 1 Metric Series*

ISO 4427, *Polyethylene (PE) pipes and fittings for water supply*

ISO/IEC 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*

PPI TN-42, *Recommended Minimum Training Guidelines for PE Pipe and Butt Fusion Joining Operators for Municipal and Industrial Projects*

PPI MAB Generic Elecrofusion Procedure for Field Joining of 12 inch and Smaler Polyehtlene (PE) Pipe

APPENDIX A:

Appendix A is intentionally blank

APPENDIX B: TOLERANCES

Unless otherwise stated, the following tolerances shall apply:

Angle	± 2°
Frequency (Hz)	± 5 percent of value
Length	± 2 percent of value
Volume	± 5 percent of value
Volume Per Unit Area	± 5 percent of value
Pressure	± 5 psi (± 35 kPa)
Temperature	± 4°F (± 2°C)
Time	+ 5/-0 seconds +0.1/-0 minutes

Unless stated otherwise, all tests shall be carried out at a room (ambient) temperature of 73.4°F ± 3.6°F (23°C ± 2°C).

APPENDIX C: SAMPLE CALCULATION

Shown below is a sample stiffness factor calculation for 10 inch IPS, DR 11, AWWA C906, *Polyethylene (PE) Pressure Pipe and Fittings, 4 in. Through 65 in. (100 mm Through 1650 mm), for Water Distribution,* PE pressure pipe:

The average of three outside diameter (*OD*) measurements was found to be 10.755 inches.

The average of three wall thickness (*t*) measurements was found to 0.981 inches.

The average of three sample length (*l*) measurements was found to be 8.052 inches.

The sample inside diameter (*ID*) was calculated as follows:

$$ID = OD - 2(t) = 8.793 \text{ inches.}$$

The maximum allowable pipe deflection (y_{max}) was calculated as follows:

$$Y_{max} = (0.05) \times ID = 0.440 \text{ inches.}$$

The sample was placed in a compression test apparatus and the force required to deflect the pipe 0.440 inches was found to be 1650 lbs.

Re-writing the Spangler Equation from Section 4.5.1, we know that:

$$\Delta y = \frac{(D_l W_e + W_l) K r^3}{EI + 0.061 E' r^3} \quad \text{Eq. 1}$$

Also, from ASTM D2412-, *Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading*, we know that pipe stiffness (*PS*) and stiffness factor (*SF*) are related as follows:

$$PS = \frac{F}{\Delta y} \quad \text{Eq. 2}$$

$$SF = EI = \frac{0.149 F r^3}{\Delta y} \quad \text{Eq. 3}$$

Substituting the pipe stiffness and other constants and knowing that the values of the earth loads (W_e) and live loads (W_l) from Table 1-8 of ANSI A21.1-, (reproduced in Table D-1 of this standard), are given in lb/lin ft the Spangler Equation can be re-written as:

$$\Delta y = \frac{(1.25 W_e + W_l)\left(K/12\right) r^3}{0.149 r^3 (PS) + 24.4 r^3} \quad \text{Eq. 4}$$

Simplifying yields:

$$\Delta y = 0.00833 \frac{(1.25 W_e + W_l)}{0.149 (PS) + 24.4} \quad \text{Eq. 5}$$

Knowing the force required to deflect the pipe 5 percent of its *ID*, and realizing that F is the force required to produce a given deflection per linear inch, we can determine the pipe stiffness as follows:

$$PS = \frac{F}{\Delta y} = \frac{\frac{1650}{8.052}}{0.440} = 465.7 \quad \text{Eq. 6}$$

Substituting into Eq. 5 yields:

$$\Delta y = 0.0000888(1.25W_e + W_l) \qquad \text{Eq. 7}$$

Using the W_e (448) and W_l (972) values from Table 1-8 of ANSI A21.1 we can now check the percent deflection for a depth of bury of 2.5 ft.

$$\Delta y = 0.0000888(1.25W_e + W_l)$$

$$\Delta y = 0.0000888(1.25(448) + 972)$$

$$\Delta y = 0.136\ inches$$

Percent Deflection = 0.136/8.793 *x* 100 = 1.5 percent

ACCEPTABLE

Using the W_e (1,645) and W_l (189) values from Table 1-8 of ANSI A21.1 we can now check the percent deflection for a depth of bury of 8 ft.

$$\Delta y = 0.0000888(1.25W_e + W_l)$$

$$\Delta y = 0.0000888(1.25(1645) + 189)$$

$$\Delta y = 0.199\ inches$$

Percent Deflection = 0.199/8.793 *x* 100 = 2.3 percent

ACCEPTABLE

Table C-1 Earth Loads (*We*) and Live Loads (*W*)*

Pipe Size in.	Depth of Cover							
	2-1/2 ft.		3-1/2 ft.		5 ft.		8 ft.	
	W_e lb/lin ft	W_l lb/lin ft	W_e lb/lin ft	W_l lb/lin ft	W_e lb/lin ft	W_l lb/lin ft	W_e lb/lin ft	W_l lb/lin ft
4	226	297	324	162	471	81	765	54
6	309	567	448	324	657	189	1,075	94
8	380	783	557	486	824	297	1,356	148
10	448	972	666	621	992	378	1,645	189
12	511	1,161	770	756	1,159	459	1,950	243
14	568	1,217	868	807	1,318	540	2,218	270
16	617	1,307	959	879	1,470	590	2,381	324
18	665	1,400	1,042	964	1,616	632	2,533	364
20	714	1,524	1,119	1,076	1,755	729	2,686	410
24	814	1,662	1,256	1,159	2,011	769	2,994	462
30	963	1,925	1,457	1,356	2,340	918	3,459	564
36	1,121	2,182	1,668	1,577	2,628	1,090	3,927	632

*Extracted from Table 1-8, ANSI A21.1, American National Standard for Thickness Design of Cast-Iron Pipe.

APPENDIX D: SAMPLE LISTING

Product Designation	*Nominal Pipe Size, in.*	*Pressure Rating, psi (kPa)*	*Remarks*
AWWA C906 Pipe, Class 200	4, 6, 8, 10, 12, 14, 16 and 18	200 (1380)	a
AWWA C906 Pipe, Class 250	4, 6, 8, 10, 12, 14, 16 and 18	250 (1725)	a
Molded Tees, Class 200	2, 3, 4, 6	200 (1380)	a
Molded 90° Elbows, Class 250	2, 3, 4, 6	250 (1725)	a
Flange Adapter, IPS, Class 200	2, 3, 4, 6, 8, 10, 12, 14, 16, 18	200 (1380)	a
Molded Concentric Reducer, Class 200	3×2, 4×3, 6×4, 8×6, 10×8, 12×10, 14×12, 16×14, 18×16	200 (1380)	a
Branch Saddle Reducing Tee, Class 200	3×2, 4×2, 4×3, 6×2, 6×3, 6×4, 8×2, 8×3, 8×4, 8×6, 10×2, 10×3, 10×4, 10×6, 10×8, 12×2, 12×3, 12×4, 12×6, 12×8, 12×10, 14×2, 14×3, 14×4, 14×6, 14×8, 14×10, 16×2, 16×3, 16×4, 16×6, 16×8, 16×10, 16×12, 18×2, 18×3, 18×4, 18×6, 18×8, 18×10, 18×12	200 (1380)	a

Remarks:

a. Pipe and fittings may be directly connected together by the butt fusion process. Manufacturer fusion instructions must be strictly followed for a proper fusion joint. The pipe and fittings may also be joined to other FM Approved steel flanged pipe and fittings by using the listed flange adapters.

APPENDIX E: FIGURES

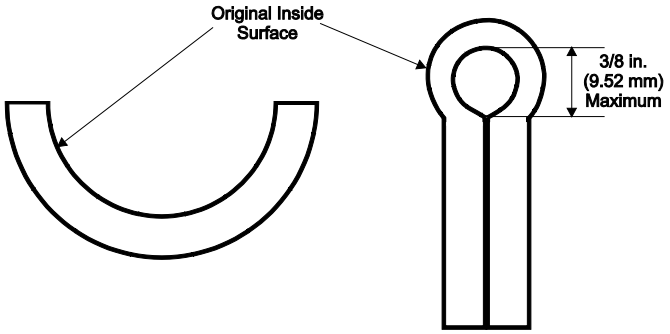

Figure E-1. Bend Back