Designation: F3183 – 16

Standard Practice for Guided Side Bend Evaluation of Polyethylene Pipe Butt Fusion Joint[1]

This standard is issued under the fixed designation F3183; 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 provides information on apparatus, specimen preparation and procedure for conducting a guided three point side bend evaluation of a transverse specimen cut from a coupon removed from a butt fusion joint in polyethylene pipe having a wall thickness 1.00 in. (25.4 mm) and thicker. See Fig. 1. This practice provides a means to assess ductility of a butt fusion joint by applying a lateral (side) bending strain across a specimen taken from the full butt fusion cross-section, from outside diameter to inside diameter.

1.2 No test values are provided by this practice. The result is a non-numerical report. Criteria for test result evaluation are provided in standards or codes that specify the use of this practice by comparison to benchmark laboratory results, or by comparison to example results presented in Appendix X1 to this practice.

1.3 *Units*—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.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—Laboratory methods that are commonly used for testing polyethylene butt fusion joints include Test Method D638 and Test Method F2634.

NOTE 2—This practice has been developed for use on butt fusion joints in polyethylene pipe with a wall thickness of 1.00 in. or greater. The practice may be used on butt fusion joints in polyethylene pipe with thinner wall thicknesses. However, the applicability of the practice should be determined by the user of the practice.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D638 Test Method for Tensile Properties of Plastics

D1600 Terminology for Abbreviated Terms Relating to Plastics

D2122 Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings

F412 Terminology Relating to Plastic Piping Systems

F2634 Test Method for Laboratory Testing of Polyethylene (PE) Butt Fusion Joints using Tensile-Impact Method

3. Terminology

3.1 *Definitions*—Unless otherwise specified, definitions and abbreviations are in accordance with Terminologies D1600 and F412.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bend angle, n*—The included angle between the surfaces of the side bend specimen on each side of the loading nose that is formed by the deflection of the side bend specimen when the loading nose extends the side bend test specimen through the test fixture rotatable supports.

3.2.2 *bend test coupon, n*—A transverse section of butt fused polyethylene pipe extending from the pipe outside wall to the pipe inside wall and having approximately equal lengths of pipe on each side of a centrally located butt fusion joint. The side bend test specimen is produced from the bend test coupon. See Fig. 1.

3.2.3 *combined fusion bead zone, n*—A transverse through-wall section of the side bend specimen that is bounded by imaginary planes that extend across the pipe wall from the inner and outer fusion bead surfaces of Pipe A and Pipe B fusion beads. See Fig. 2. Butt fusion joints typically produce beads that extend (roll) over the pipe ends both inside and outside of the joint.

[1] This test method is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.40 on Test Methods.

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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.

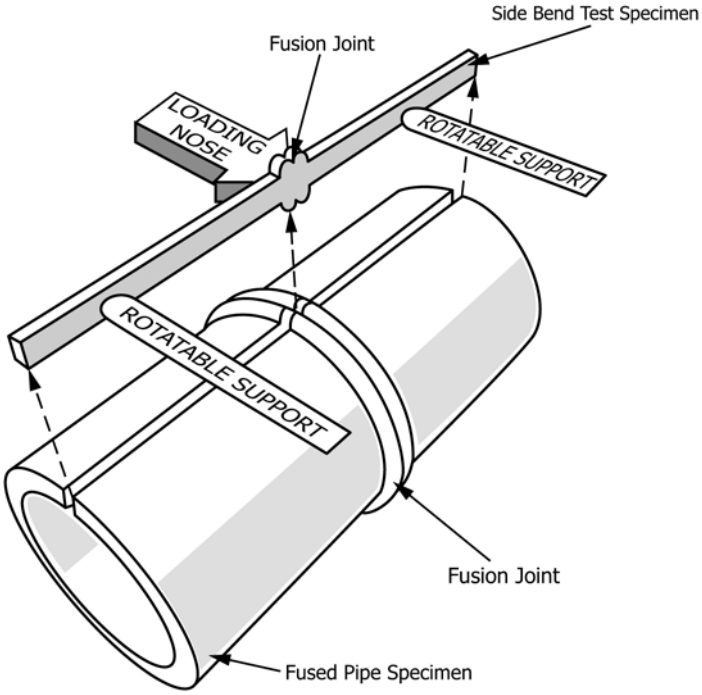

FIG. 1 Guided Side Bend Conceptual Schematic

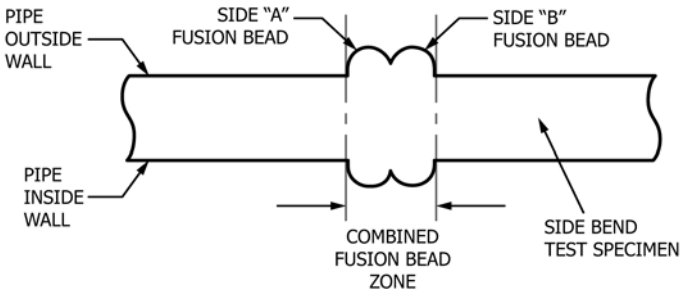

FIG. 2 Combined Fusion Bead Zone

3.2.4 *ductility, n*—The ability of a material to deform plastically before fracturing.

3.2.5 *loading nose, n*—A bar located equidistant between and opposite to rotatable supports and having a cylindrical forward surface. The loading nose is extended at a uniform rate of displacement in between the rotatable supports to bend the side bend test specimen. See Fig. 3.

3.2.6 *R/t, n*—A dimensionless number representing the ratio of the loading nose radius, *R*, in inches (or mm) to the measured thickness, *t*, in inches (or mm) of the side bend test specimen.

3.2.7 *rotatable supports, n*—Two cylindrical bars spaced equidistant from and parallel to the loading nose that turn freely on their central longitudinal axis and support the side bend test specimen.

3.2.8 *side bend test specimen, n*—A transverse section of the wall of butt fusion joined pipe that is machined (planed) from a bend test coupon.

4. Summary of Practice

4.1 This practice provides a means to assess the relative ductility of sections of polyethylene butt fusion joints from pipe having a wall thickness of about 1 in. (25.4 mm) or greater using a three point bend testing procedure. This practice applies a bending strain to the transverse side of a through-wall side bend test specimen prepared from a bend test coupon taken from a butt fusion joint.

NOTE 3—When applied to the testing of welds in metals, this type of three-point bending is commonly called side bend.

4.2 Typically, bend test coupon pairs are cut from a position around the pipe and the position directly opposite on the other

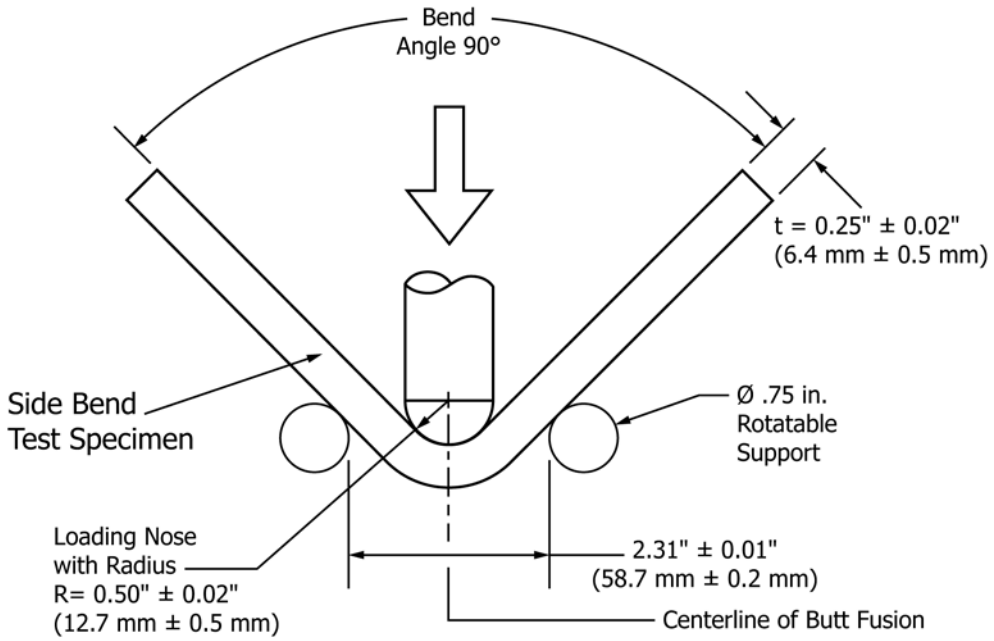

FIG. 3 Schematic of Guided Side Bend Apparatus

half of the butt fusion joined pipe sample. Optionally, segmenting larger diameter butt fusion joined pipes into four or more equal sections (quadrants, sixths, eighths, etc.) provides additional bend test coupon pairs.

5. Significance and Use

5.1 This standard practice is a procedure to evaluate the ductility of side bend test specimens that are a transverse section of the pipe wall and butt fusion. Side bend test specimens are prepared from bend test coupons from sample polyethylene pipe butt fusion joints that are made using polyethylene pipe having a wall thickness of about 1 inch (25.4 mm) and greater. A three-point bend is applied to the side bend test specimen by pressing the side bend test specimen into a gap between two rotatable supports with a loading nose. The bending load is applied such that the bending strain is transverse to the plane of the fusion joint.

5.2 Equipment for cutting bend test coupons, preparing side bend test specimens and conducting this practice is available for laboratory and for field use.

5.3 Benchmark criteria for evaluating field testing results are developed by testing a statistically valid number of sample butt fusions in a controlled environment, preferably using equipment for field use. Guided side bend test results from field tests are then evaluated by comparison to benchmark test results from the controlled environment.

6. Apparatus

6.1 *The Side Bend Fixture*—An apparatus to securely hold all of the essential parts and the side bend test specimen in a stable configuration while the practice is conducted. The testing fixture shall provide for accurate visual alignment of the side bend test specimen relative to the centerline of the loading nose, and shall provide visual determination of side bend test specimen bend angle. The testing fixture shall be constructed such that full and continuous contact of the side bend test specimen with the loading nose is maintained as the test is performed. The essential parts are as follows:

6.1.1 *Rotatable supports*—Two cylindrical bars each having a diameter of 0.75 ± 0.01 in. (17.6 ± 0.3 mm) that are mounted in the testing fixture such that they can rotate freely along their longitudinal axis. The length of each rotatable support shall assure that the test specimen does not contact the sides of the testing fixture when installed in the fixture or during the procedure. The separation distance between the facing edges of the rotatable supports shall be 2.31 ± 0.01 in. (58.7 ± 0.2 mm). The longitudinal centerlines of the rotatable supports shall be horizontally and vertically parallel to each other. The minimum rotatable support length shall be at least the width of the test specimen plus the fusion beads that extend beyond the width of the test specimen plus 0.25 in. (6.4 mm). See Fig. 3 and Fig. 4.

6.1.2 *Movable member*—A component to which the loading nose is attached and that extends and retracts the loading nose through the space between the rotatable supports at a uniform and steady rate of travel. The movable member shall provide straight-line travel at a right angle to the centerline of the rotatable supports and at a right angle to a plane across the centerlines of the rotatable supports. The moveable member shall have sufficient strength so that deflection from straight line travel during operation is minimized to the extent practical. The rate of travel in extension shall be 3.0 ± 1.0 in./min (76.2 ± 25.4 mm/min)

6.1.3 *Loading nose*—The loading nose applies force across the full width of the side bend test specimen (plus the fusion beads) and bends the specimen between the two rotatable supports. The loading nose is a cylindrical bar having a radius of 0.50 ± 0.02 in. (12.7 ± 0.2 mm) for its full length where it

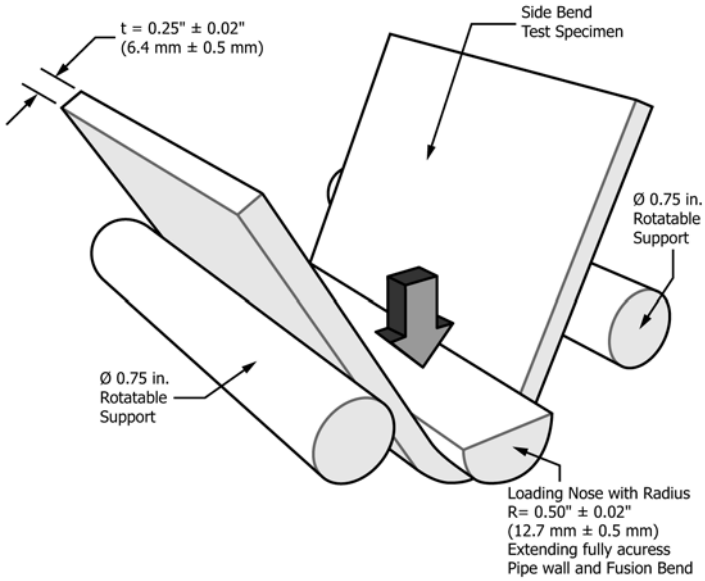

FIG. 4 Three Dimensional Schematic of Side Bend Apparatus

contacts the test specimen. The loading nose shall contain permanent centerline indicators on both ends to facilitate visual alignment of the center of the loading nose to the center of the combined fusion bead zone in the side bend test specimen. The minimum length of the loading nose shall be at least the width of the test specimen plus the fusion beads that extend beyond both sides of the width of the test specimen plus 0.25 in (6.4 mm). The centerline of the loading nose cylindrical radius shall be aligned vertically and horizontally parallel to the centerlines of the rotatable supports.

6.1.4 *Actuator*—A mechanism that powers the movable member to which the loading nose is attached.

6.1.5 *Timing Device*—The apparatus shall be equipped with a timing device accurate to ± 1 s per 60 s period.

6.1.6 The maximum sample butt fused pipe wall thickness shall be clearly marked on the apparatus.

6.2 *Additional equipment:*

6.2.1 Sawing or cutting equipment is required to cut the sample butt fusion into segments, and to cut the bend test coupons from the sample butt fusion segments.

6.2.2 Machining equipment such a feed-through type electric planer is required to prepare the side bend test specimens from bend test coupons. A hand-held planer should not be used.

7. Side Bend Test Specimens

7.1 Side bend test specimens are prepared from bend test coupon pairs that are cut from a sample butt fusion. The sample butt fusion is two approximately equal lengths of polyethylene pipe that are joined in the middle by a butt fusion. The two pipe lengths shall be at least 6.0 in (152.4 mm) so that the overall length of the sample butt fusion equals or exceeds the 12.0 in. (305 mm) minimum overall length of the bend test coupon. Measure and record the wall thickness of Pipe A and Pipe B from each side of the sample butt fusion in accordance with Test Method D2122. The sample butt fusion shall be conditioned at 65° to 75° F (18° to 24° C) in air for not less than four hours, or in water for not less than one hour before cutting the test coupons. See Fig. 5.

7.2 *Bend Test Coupons:*

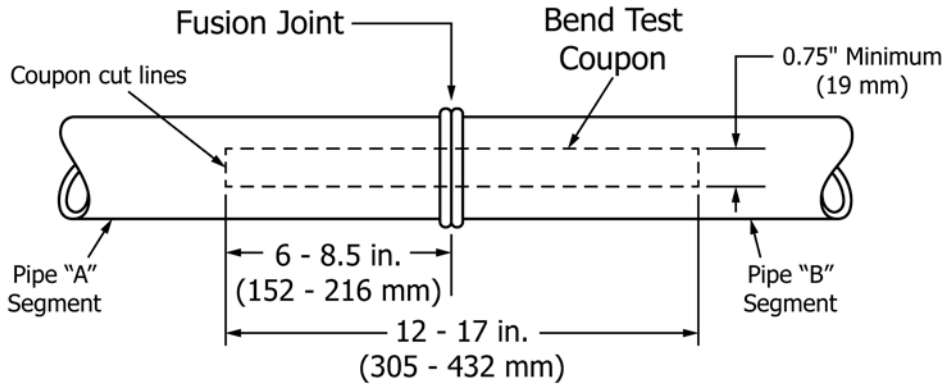

FIG. 5 Side Bend Coupon from Pipe

7.2.1 Cut pairs of bend test coupons from the sample butt fusion, one from one half of the sample butt fusion, and the other from a position directly opposite on the other half of the sample butt fusion. The cut width of the bend test coupon shall be approximately 0.75 in. (17.6 mm). The cut length of the bend test coupon shall include 6.00 to 8.50 in. (152.4 to 216 mm) of pipe on either side of the fusion joint for an overall length of 12 to 17 in. (305 to 432 mm). The bend test coupon shall include the full pipe wall thickness and the internal and external fusion beads. The inside and outside surfaces from the sample butt fusion shall be unaltered. Care shall be taken to retain the inside and outside fusion beads. If fusion beads are removed, the bend test coupon shall not be used.

NOTE 4—Optionally segmenting larger diameter sample butt fusions into four or more equal segments (quadrants, sixths, eighths, etc.) provides additional bend test coupon pairs.

7.2.2 Each bend test coupon shall be marked, labeled, tagged or otherwise identified so that information relating to the sample butt fusion joint such as date, time, operator, location relative to its position within the fusion machine, joining procedure, pipe material, pipe size, etc., are cross-referenced and documented. For purposes of this practice, location relative to position within the fusion machine shall mean that the upper most point in the butt fusion joint while still in the butt fusion machine shall be considered 12:00 o'clock. The lowest point in the butt fusion joint while still in the butt fusion machine shall be designated 6:00 o'clock. The point closest to the fusion machine operator on the horizontal across the butt fusion face and perpendicular to the axis of the pipe being joined shall be designated 3:00 o'clock. The point furthest from the fusion machine operator on the horizontal across the butt fusion joint and perpendicular to the axis of the pipe being joined shall be designated 9:00 o'clock.

7.3 *Side Bend Test Specimens:*

7.3.1 A single side bend specimen shall be machined from each side bend coupon. See Fig. 6.

7.3.2 Each side bend test specimen is machined from the bend test coupon by removing equal amounts from the 0.75 in (19 mm) width of the bend test coupon to achieve a uniform thickness of 0.25 +/- 0.02 in. (6.4 +/- 0.5 mm) as shown in Figures Fig. 6, Fig. 7, and Fig. 8.

NOTE 5—A commercial electrically-powered planer is useful for test specimen machining. Alternate the side bend coupon surface that is in contact with the planer blade with each pass through the planer. Care should be taken to initially remove material in reasonably small increments (0.10 in. or 2.54 mm), and to reduce the amount of material removed with each pass to 0.010 in. or 0.254 mm as the thickness of the coupon approaches the required thickness. Planer blades should be clean, sharp, and free of nicks and gouges that may produce an irregular surface. Care should also be taken to insure that the planer blade is parallel to the feed roller of the planer.

7.3.3 The machined side bend test specimen surfaces shall be clean, smooth and parallel showing no signs of gouging, scratching, saw cuts or other surface markings. Marks left by machining operations shall be carefully removed with a fine file or abrasive, and the filed surface shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen.

7.3.4 The fusion beads shall be retained within the side bend test specimen. Removal of the fusion beads shall be cause for rejection of the side bend test specimen.

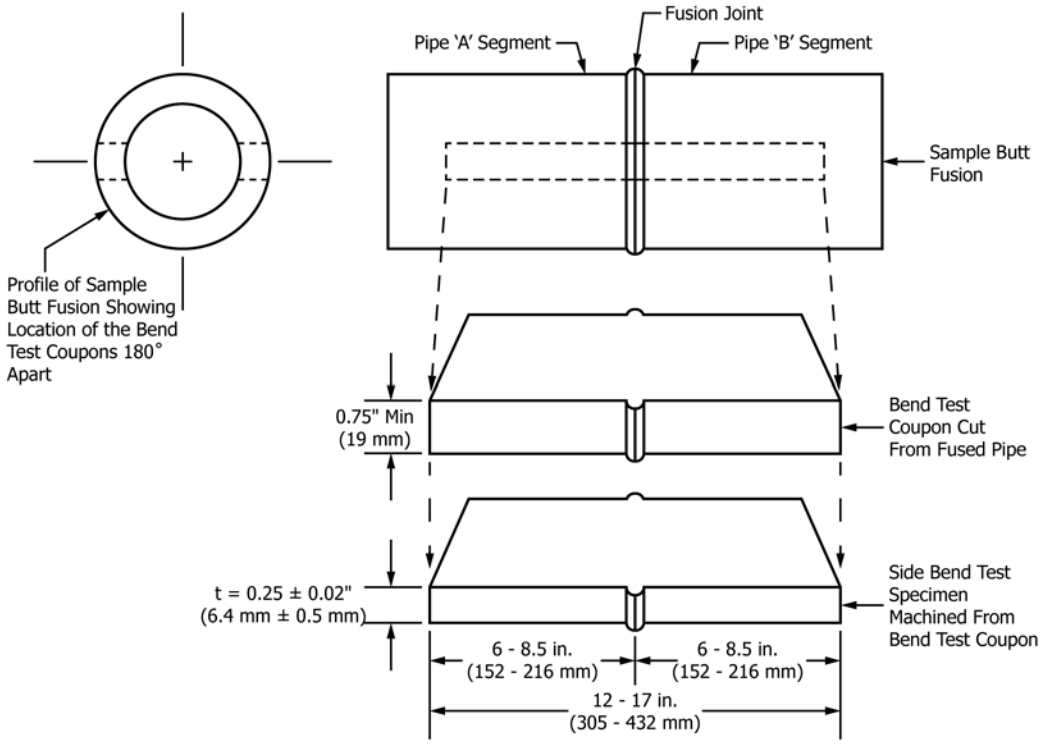

FIG. 6 Side Bend Preparation Sequence

FIG. 7 Electric Planer for Side Bend Specimen Preparation

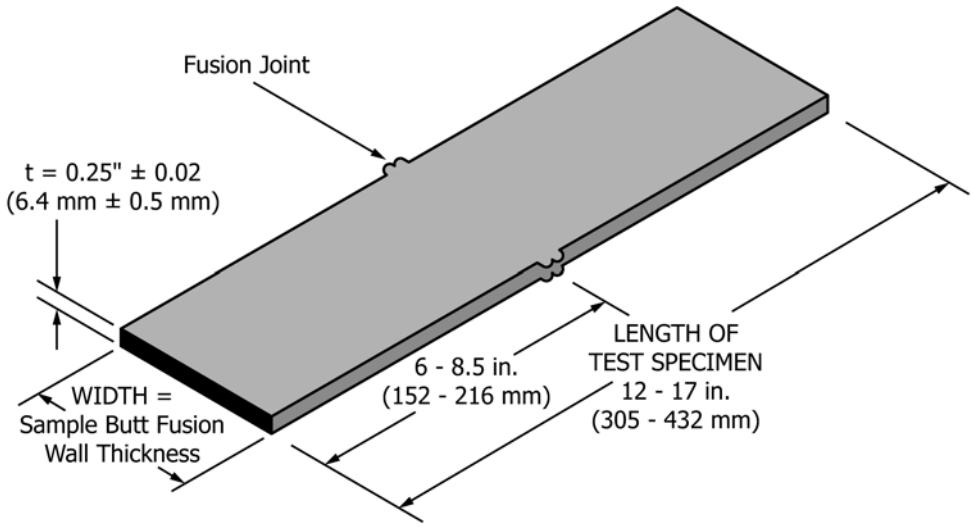

FIG. 8 Side Bend Specimen

7.3.5 Each side bend test specimen shall be marked, labeled, tagged or otherwise identified in a manner consistent with 7.2.2 so that information relating to the sample butt fusion joint such as date, time, operator, location relative to its position within the fusion machine as described in 7.2.2, joining procedure, pipe material, pipe size, etc., and testing results obtained on each side bend test specimen are cross-referenced and documented

8. Conditioning

8.1 After preparation in accordance with 7.3 and prior to testing, side bend test specimens shall be conditioned at 65 to 75° F (18 to 24°C) in air for not less than four hours, or in water for not less than one hour. At the time of testing, the temperature of the side bend test specimen shall be 65 to 75° F (18 to 24°C). Test specimen temperature shall be verified with a calibrated surface pyrometer.

8.2 When removed from the conditioning environment, side bend test specimens that are tested in the field shall be protected against heat transfer from hot or cold surfaces, and shall be protected against temperature change from direct sunlight and wind.

NOTE 6—Conditioning of side bend test specimens in the field may be performed in a temperature controlled vehicle or building or container of water. Testing should be conducted within 5 minutes of removal from the conditioning environment.

9. Procedure

9.1 Conduct side bend testing in air at a temperature of 65-75° F. When conducting field tests, exposed side bend test equipment could be at a temperature well above or below 65°-75° F(18°-24° C). If very hot or cold, heat transfer to the specimen could affect results. Measure the temperature of the environment, apparatus and specimen at the time of the testing using a pyrometer or other temperature measurement device accurate to ± 2° F (1° C).

9.2 In accordance with Test Method D2122, measure the side bend test specimen thickness, *t*, in the combined fusion

bead zone. Make at least two measurements with a micrometer caliper accurate to ± 0.001 in. (0.02 mm) approximately at each end of the combined fusion bead zone.

9.3 Position the side bend test specimen with the width resting on the two rotatable supports in the side bend test fixture. The side bend test specimen shall be centered on the length of the rotatable supports, and the butt fusion joint shall be centered in the space between the rotatable supports. Slowly lower the loading nose to just contact the surface of the side bend test specimen. Visually align the centerline of the butt fusion joint in the side bend test specimen to the centerline indicator marks on both ends of the loading nose.

9.4 Simultaneously engage the actuator to extend the loading nose and start the timer.

9.5 Stop the actuator and the timer when the loading nose bends the specimen to a bend angle of 90° or the joint breaks whichever occurs first. Record the bend angle achieved. Record the time for movement of the loading nose.

9.5.1 During deflection of the side bend test specimen, loading nose extension shall be a continuous movement rate of 3.0 ± 1.0 in./ min (76.2 ± 25.4 mm/min).

9.5.2 Care shall be taken to insure that the surface of the specimen remains in full and continuous contact with the outer diameter of the loading nose as it is deflected. During the test, if a gap, visible to the naked eye, develops between the loading nose surface and the side bend test specimen, the test procedure shall be discontinued, the side bend test specimen removed and testing of a new side bend test specimen shall be initiated. See Note 7.

NOTE 7—The generation of a gap between the side bend test specimen and the outer diameter of the loading nose during the deflection process can result in "hinging" of the side bend test specimen. This could result in a highly intensified bend strain giving an improper or inaccurate result.

9.6 Retract the loading nose and remove the side bend test specimen from the test apparatus.

9.7 Visually inspect the combined fusion bead zone for the test result, and record the time duration of the test and the test result.

NOTE 8—Test results may be evaluated against benchmark criteria in accordance with 5.3, or example test results by type in Appendix X1. Additionally, it should be noted that upon removal from the apparatus and prior to visual inspection, the bend angle on the side bend test specimen may increase slightly. This relaxation is considered normal and should not be considered a basis for rejecting the validity of the test or the test results obtained"

10. Test Report

10.1 The side bend test report for each side bend test specimen tested shall include the following information:

10.1.1 The time and date, and the location where the side bend test procedure was performed. The location is the place where testing is performed; that is, the address of the laboratory or the controlled shop environment, or the location at a field job-site.

10.1.2 The name, identification and affiliation of the person conducting the side bend test procedure.

10.1.3 The information from the sample butt fusion, including the manufacturer(s) of each pipe, the pipe size and dimension ratio, the name, identification and affiliation of the fusion operator, and the date and location where the sample butt fusion was produced. Report the measured wall thickness of each pipe and, if available, the manufacturer(s) production codes, print line , and pipe manufacturing standard (such as ASTM D2513, ASTM D3035, ASTM F714, etc.)

10.1.4 Identification of the bend test coupon in accordance with 7.2.2.

10.1.5 Identification of side bend test specimen in accordance with 7.3.5.

10.1.6 The radius, *R*, of the loading nose.

10.1.7 Calculate and report the average bend test specimen thickness, *t*. Where *t* is determined as the sum of the side bend test specimen thickness measurements taken on each side of the side bend test specimen in accordance with 9.2, divided by the number of measurements taken on that specimen. Calculate and report the *R/t* ratio by dividing the loading nose radius, *R*, by the average side bend test specimens thickness, *t*.

10.1.8 The bend angle achieved, and whether the side bend test specimen broke.

10.1.9 The test temperature in accordance with 9.1.

10.1.10 The side bend test specimen test result in accordance with 9.7.

10.1.11 The side bend test time in accordance with 9.5.

11. Interpretation of Results

11.1 Test results obtained are non-numerical and are comparisons against requirements in codes and standards in accordance with 1.2, or benchmark criteria in accordance with 5.3, or example results as shown in Appendix X1.

11.2 Interpretation of test results as it may pertain to acceptability or qualification of the fusion procedure used to produce the butt fusion joint or the qualification of the fusion operator performing the fusion procedure is outside the scope of this practice.

11.3 When side bend test results do not meet the requirements of 11.1, the user should investigate to determine the cause by evaluating the side bend test procedure utilized, the butt fusion procedure, adherence to the butt fusion procedure, the capability of the fusion equipment, or the pipe material characteristics to determine the root cause of the result.

12. Keywords

12.1 bend test coupon; butt fusion joint test; fusion joint ductility; guided side bend test specimen; three point bend test; three point guided side bend test

APPENDIXES

X1. EXAMPLE SIDE BEND TEST RESULTS

(Nonmandatory Information)

X1.1 Upon completion of the side bend procedure, the side bend specimen is removed from the fixture and visually examined.

X1.2 Ductile results are achieved if upon deflection to the specified bend angle, the specimen does not break, split or tear in the combined fusion bead zone of the butt fusion joint as shown in Fig. X1.1A.

X1.3 Non-ductile results are achieved if upon deflection to the specified bend angle, the specimen breaks, splits or tears in the combined fusion bead zone of the butt fusion joint with little or no evidence of plastic deformation before fracture as shown in Figure Fig. X1.1B or Fig. X1.1C.

Figure X1.1A - Type I side bend result showing ductile deflection with no indication of tears, splits or breaks

Figure X1.1B - Type II side bend result showing partial tear within the combined fusion bead zone

Figure X1.1C - Type III test result showing break within the combined fusion bead zone

FIG. X1.1 Example of Side Bend Test Results

X2. TYPICAL SIDE BEND TEST RECORD (See Fig. X2.1.)

Example Side Bend Record

Project/Laboratory reference: _____

Individual side bend specimen: _____

Pipe Information:

Side "A" Pipe Information
Manufacturer _____
Nominal OD _____ Dimension Ratio _____
Product designation _____
Average wall thickness _____
Print line information _____
Production standard _____

Side "B" Pipe Information
Manufacturer _____
Nominal OD _____ Dimension Ratio _____
Product designation _____
Average wall thickness _____
Print line information _____
Production Standard _____

Fusion Information:

Fusion Operator _____
Fusion Operator Affiliation _____
Date of fusion _____ Location of fusion _____
Fusion equipment used _____
Fusion parameters (see Practice F2620)
Temperature of heater plate (deg F) _____
Fusion Pressure (psi, if applicable) _____ Heat Soak (sec) _____
Cooling time (sec) _____ Dwell time (sec) _____
Other fusion information _____

Side Bend Information:

Side bend procedure operator _____
Side bend operator affiliation _____
Side bend procedure date _____ Side bend procedure location _____
Side bend coupon identification _____
Side bend specimen identification _____
Location of side bend specimen within fusion machine _____
Side bend specimen thickness measurements (two minimum) _____
_____
Average Thickness of side bend test specimen, t (inches) _____
Loading nose diameter (inches) _____ Loading nose radius, R (inches) _____
Calculated R/t _____ Maximum bend angle achieved, (deg) _____
Temperature of side bend specimen at time of procedure (deg F) _____
Side bend test time _____
Side bend result (circle one if applicable): Type I Type II Type III
Side bend results notes/comments: _____
_____
_____
_____
_____

FIG. X2.1 Example of Side Bend Test Report

X3. TYPICAL CALCULATED STRAINS FOR VARIOUS COMBINATIONS OF SIDE BEND SPECIMEN THICKNESS, *t*, AND RADIUS, *R*

X3.1 The guided side bend test imposes a lateral strain on the test specimen that creates a strain at the outer fiber of the deformed test specimen that exceeds the elastic strain limit of the parent material from which the pipe is produced. In the case of polyethylene, the elastic strain limit from tension tests ranges from around 9% to around 13% depending on the parent material. The strain created at the outer fiber of the side bend test specimen is estimated as follows:

X3.1.1 When prepared in accordance with this practice, the guided side bend test specimen is a representative cross section of the butt fusion joint.

X3.1.2 For purposes of this specification, the strain at the outer fiber of the deflected test specimen is estimated by:

$$\varepsilon(OF_C - NF_C)/(NF_C)*100 \qquad (X3.1)$$

where:

ε = Strain, %
OF_C = Deflected outer fiber circumference, in. (mm)
NF_C = Deflected neutral fiber circumference, in (mm)

X3.1.3 The neutral fiber, *NF*, is defined as a plane that is oriented across the entire width and thickness of the side bend test specimen that upon deflection is neither in compression or tension. For purposes of this specification, the plane of the neutral fiber is assumed to be at the mid-point of the specimen thickness. Fibers above the neutral fiber (toward the Ram surface) are in compression and fibers below the neutral fiber (away from the Ram surface) are in tension. For the side bend test specimen, the neutral fiber diameter, NF_D, is assumed to be twice the radius of the loading nose plus the side bend test specimen thickness, *t*.

X3.1.4 The outer fiber diameter, OF_D, is assumed to be twice the radius of the loading nose plus two times the side bend test specimen thickness, *t*.

X3.1.5 The side bend test practice assumes that the test specimen is wrapped in a full and continuous fashion around the surface of the loading nose upon deflection during the test procedure.

X3.1.6 It should be noted that the strain calculation of section X3.1.2 is an approximation only and does not take into consideration the viscolelastic response of the specimen upon deflection. The calculation is presented only as a basis for overall understanding and background on this practice.

X3.1.7 Laboratory investigations may involve varying side bend test specimen thickness and loading nose radius. Table X3.1 presents approximate outer fiber bending strain values that were calculated using equation Eq X3.1. for selected combinations of loading nose radius and side bend test specimen thickness.

TABLE X3.1 Typical Strain Approximations

Loading Nose Radius in. (mm)	Specimen Thickness in. (mm)	Neutral Fiber Diameter in. (mm)	Outer Fiber Diameter in. (mm)	Neutral Fiber Circumferential Length, in. (mm)	Outer Fiber Circumferential Length, in. (mm)	Estimated Maximum Strain, ε (%)	R/t
0.250 (6.4)	0.25 (6.4)	0.750 (19.3)	1.00 (25.4)	1.18 (30.0)	1.57 (39.9)	33.0	1.0
0.250 (6.4)	0.50 (12.7)	1.000 (25.4)	1.50 (38.1)	1.57 (39.9)	2.36 (60.0)	50.0	0.5
0.500 (12.7)[A]	**0.25 (6.4)**	**1.250 (31.7)**	**1.50 (38.1)**	**1.96 (49.8)**	**2.36 (60.0)**	**20.0**	**2.0**
0.500 (12.7)	0.50 (12.7)	1.500 (38.1)	2.00 (50.8)	2.36 (60.0)	3.14 (79.8)	33.0	1.0
0.750 (19.0)	0.25 (6.4)	1.750 (44.5)	2.00 (50.8)	2.75 (69.9)	3.14 (79.8)	14.2	3.0
0.750 (19.0)	0.50 (12.7)	2.000 (50.8)	2.50 (63.5)	3.14 (79.8)	3.93 (99.8)	25.2	1.5
1.000 (25.4)	0.25 (6.4)	2.250 (57.2)	2.50 (63.5)	3.53 (89.7)	3.93 (99.8)	11.3	4.0
1.000 (25.4)	0.50 (12.7)	2.500 (63.5)	3.00 (76.2)	3.93 (99.8)	4.71 (119.6)	20.0	2.0

[A] **Bold** font indicates nose radius and side bend test specimen thickness in accordance with this practice.