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Standard Practice for
Ultrasonic Testing of Polyethylene Butt Fusion Joints[1]

This standard is issued under the fixed designation E3044/E3044M; 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.

ε[1] NOTE—Subsection 5.2 corrected editorially in September 2016.

1. Scope

1.1 This standard practice establishes procedures for ultrasonic testing (UT) of butt fusion joints in polyethylene pipe. Although high density polyethylene (HDPE) and medium density polyethylene (MDPE) materials are most commonly used, the procedures described may apply to other types of polyethylene.

NOTE 1—The notes in this specification are for information only and shall not be considered part of this specification.

NOTE 2—This standard references HDPE and MDPE for pipe applications as defined by Specification D3350.

1.2 This standard practice does not address ultrasonic examination of electrofusion joints (coupling joints), socket joints, or saddles.

1.3 This practice provides two ultrasonic examination procedures. Each has its own merits and requirements for examination and shall be selected as agreed upon in a contractual document.

1.3.1 *Examination Procedure A, Time of Flight Diffraction (TOFD),* uses a pair of probes, one transmitting and the other receiving. The procedure requires access to both sides of the joint from one surface. Provided that position encoding is used, the procedure can be conducted by semi-automated or automated means that provide recoded imaging.

1.3.2 *Examination Procedure B, Phased Array Ultrasonic Testing (PAUT),* uses low velocity refracting wedges or water gaps to produce angled compression mode pulses. The procedure can be applied where access is limited to one side of the joint from one surface. Provided that position encoding is used, the procedure can be conducted by semi-automated or automated means that provide recoded imaging.

1.4 The practice is intended to be used on thicknesses of 9 to 60 mm (0.375 to 2.4 in.) and diameters 100 mm (4 in.) and greater. Greater and lesser thicknesses and lesser diameters may be tested using this standard practice if the technique can be demonstrated to provide adequate detection on mockups of the same wall thickness and geometry.

1.5 This practice does not specify acceptance criteria.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *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.*

2. Referenced Documents

2.1 The following documents form a part of this practice to the extent specified herein.

2.2 *ASTM Standards:*[2]

D3350 Specification for Polyethylene Plastics Pipe and Fittings Materials
E494 Practice for Measuring Ultrasonic Velocity in Materials
E543 Specification for Agencies Performing Nondestructive Testing
E1316 Terminology for Nondestructive Examinations
E2373 Practice for Use of the Ultrasonic Time of Flight Diffraction (TOFD) Technique
E2700 Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays
F2620 Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

2.3 *ASNT Standards:*[3]

ASNT Practice SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.

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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 American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.4 *Aerospace Industries Association Document:*

NAS 410 Certification and Qualification of Nondestructive Testing Personnel[4]

2.5 *ISO Standard:*

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel[5]

3. Terminology

3.1 *Definitions*—Related terminology is defined in Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *butt-fusion joint, n*—a joint made by holding the prepared squared ends of two pipes or pipe and fitting against a heated plate per the conditions of a qualified fusion procedure, which allows for the ends to be brought together after forming the proper melt, and then allowing the joint to cool while maintaining the appropriate applied force. It is recommended that fusion procedures comply with Practice F2620.

3.2.2 *cell classification, n*—for polyethylene pipe resin, this is a six digit code and letter describing the primary properties that are considered important in the manufacture of PE piping, in the heat fusion joining of this material, in defining the long-term performance capabilities and color/UV stability. The classification categories are defined in Specification D3350.

3.2.3 *dimension ratio (DR), n*—this is the average outside pipe diameter divided by the minimum wall thickness.

NOTE 3—The wall thickness increases when the DR decreases.

NOTE 4—Standard Dimension Ratio (SDR) is an ANSI term to describe specific DRs in the series, for example, DR9, DR11, DR17 and others.

3.2.4 *high density polyethylene (HDPE), n*—a tough, flexible, thermoplastic resin made by polymerizing ethylene, having a density range of >0.940 g/cm^3 to 0.955 g/cm^3 per Specification D3350.

3.2.5 *material designations, n*—a shortened code to identify the pipe materials short-term and long-term properties.

NOTE 5—For polyethylene, the "PE-XXXX" material designation represents the density (first digit), slow crack growth resistance (second digit) and hydrostatic design stress (HDS, last two digits) where Specification D3350 is the reference.

3.2.6 *medium density polyethylene (MDPE), n*—a tough, flexible, thermoplastic resin made by polymerizing ethylene, having density range of >0.926 g/cm^3 to 0.940 g/cm^3 per Specification D3350.

4. Summary of Practice

4.1 This practice provides a general description of the procedures to carry out ultrasonic examination of polyethylene butt fusion joints in pipeline systems.

4.2 This practice uses sound waves to inspect butt fusion joints of polyethylene pipe in order to identify and size internal fusion joint flaws with the intent to non-destructively assess overall joint quality.

4.3 Two procedures are described in this practice that have principles common to those found in Practices E2373 and E2700 where Time of Flight Diffraction and Phased-Array contact testing are described.

4.4 Examination results using this practice may be used in combination with acceptance criteria based on workmanship or fitness for purpose.

5. Significance and Use

5.1 This practice is intended primarily for the automated or semi-automated ultrasonic examination of butt fusion joints used in the construction of polyethylene piping systems.

5.2 Polyethylene piping has been used in lieu of steel alloys in the petrochemical, power, water, gas distribution and mining industries due to its reliability and resistance to corrosion and erosion. Recently, polyethylene pipe has also been used for nuclear safety-related cooling water applications.

5.3 Two ultrasonic techniques have proven useful to provide examination of fusion joint integrity; Ultrasonic time-of-flight-diffraction (TOFD) and phased array ultrasonic testing (PAUT). These techniques are often considered complementary but may be used independently of each other. The choice of the technique used may depend on a variety of parameters including diameter, thickness, surface access, detection capabilities near surfaces, and quality level required.

5.4 The joining process can be subject to a variety of flaws including, but not limited to: lack of fusion, particulate contamination, inclusions, and voids.

5.5 Polyethylene material can have a range of acoustic characteristics that make butt joint examination difficult. Acoustic velocity of the material is similar to that commonly used for ultrasound wedge materials, making it difficult to use these materials to achieve appropriate refraction of sound at the interface. Polyethylene materials are highly attenuative, which often limits the use of higher ultrasonic frequencies. It also exhibits a natural high frequency filtering effect. An example of the range of acoustic characteristics is provided in Table 1. The table notes the wide range of acoustic velocities reported in the literature. This makes it essential that the reference blocks are made of the same cell classification as that examined. This shall be confirmed by measuring the acoustic velocity of the pipe being examined. When using PAUT as the examination

TABLE 1 Polyethylene Velocity and Attenuation[A]

Compression Mode Velocity (m/s) (in./µs)	Attenuation @2 MHz (dB/mm) (dB/in.)	Attenuation @5 MHz (dB/mm) (dB/in.)
2100 to 2670 (0.082 to 0.105)	0.6 to 1.5 (15.2 to 38)	1.1 to 2.3 (27.9 to 58)

[A] A range of velocity and attenuation values have been noted in the literature **(1-9)**. The boldface numbers in parentheses refer to the list of references at the end of this standard.

[4] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.

[5] 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.

technique, the acoustic velocity of the reference block shall be within ±50 m/s of the examined pipe material being examined.

5.6 Polyethylene is reported to have a shear velocity of 987 m/s. However, due to extremely high attenuation in shear mode (on the order of 5 dB/mm (127 dB/inch) at 2 MHz) no practical examinations are carried out using shear mode (**6**).[6]

5.7 Due to the wide range of applications, joint acceptance criteria for polyethylene pipe are usually project-specific.

5.8 A typical butt fusion joint in polyethylene pipe has a pronounced bead profile similar to that illustrated in Fig. 1 where the bead is shown on the outer and inner surface of the pipe.

5.9 TOFD, when used on polyethylene, is simplified in that mode-converted signals are virtually eliminated due to the high attenuation of the shear mode. However, the near surface and far surface dead zones associated with TOFD may be considered limitations if determined to be excessive for the detection requirements.

5.10 PAUT can be used to address the near surface dead zone that occurs with TOFD.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be used shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation shall be in accordance with paragraph 7.3.11 and 7.5.8 unless otherwise specified.

6.6 *Timing of Examination*—The timing of the examination shall be in accordance with Section 8 unless otherwise specified.

6.7 *Extent of Examination*—The extent of examination shall include the volume of the joint 10 mm (⅜ in.), as a minimum, either side of the fusion line unless otherwise specified in the contract.

6.8 *Reporting Criteria*—Reporting criteria for the examination results shall be in accordance with Section 8 unless otherwise specified. Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

6.9 *Re-examination of Repaired/Reworked Items*—Re-examination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Apparatus and Procedures

7.1 *Electronic Instruments and Probes:*

7.1.1 The type of instrument(s) used for the examinations specified in Section 7 shall conform to the requirements of Practices E2373 and E2700 as applicable.

7.1.2 Probes used shall produce pulses with two to three cycles with a nominal center frequency in the range of 1 MHz to 5 MHz. Refracting wedges should be of a low acoustic velocity and low attenuation material so as to produce a positive refraction relative to the angle of incidence. Water-gap techniques may be suitable to achieve these conditions.

7.1.3 Wedges shall be contoured to match the pipe curvature when the gap between the wedge and pipe exceeds 0.5 mm (0.02 in.). This is typically required when examining pipe with diameters less than 500 mm (20 in.).

7.2 *Standardization Blocks and Other Equipment:*

7.2.1 *Mechanics:*

7.2.1.1 Mechanical holders shall be used to ensure that probe spacing is maintained at a fixed distance from the joint centerline. The mechanical holders shall also ensure that alignment to the intended scan axis on the examination piece is maintained to a tolerance agreed upon between contracting parties.

7.2.1.2 Probe motion may be achieved using motorized or manual means but in all cases, the mechanical holder for the probes shall be equipped with a positional encoder that is synchronized with the sampling of A-scans. Data acquisition shall not exceed 1 mm (0.04 in.) per A-scan sample for pipe

[6] The boldface numbers in parentheses refer to a list of references at the end of this standard.

FIG. 1 Typical Bead Profile for Polyethylene Butt Fusion Joint

diameters up to 500 mm (20 in.) and shall not exceed 2 mm (0.08 in.) per A-scan sample for pipe diameters greater than 500 mm (20 in.).

7.2.2 *Reference Blocks:*

7.2.2.1 Ultrasonic reference blocks are used to standardize the ultrasonic equipment. The ultrasonic characteristics of the reference blocks, such as attenuation, noise level, surface condition, and sound velocity, should be similar to the material to be examined per A1.3. Standardization verifies that the instrument and search unit are performing as required and establishes a detection level for discontinuities. The temperature of the reference blocks shall be within ± 10°C (± 20°F) of the surface of the joined pipe at the time of examination.

NOTE 6—Environmental conditions at the time of examination may result in some areas of the pipe surface being significantly warmer than others (e.g., exposed to sun versus in shade). This may require standardization at different temperatures.

7.2.3 *Reference Reflectors:*

7.2.3.1 Flat-bottomed holes, (FBH), Side Drilled Holes (SDH) and notches shall be used as reference targets. SDH shall be used to establish distance amplitude corrections for PAUT applications. Notches and FBH shall be used to establish sensitivity and resolution capabilities of the system. Other discontinuities (e.g., areas of dis-bond or lack of fusion, etc.) may be used in addition to the required targets. Examples of reference block designs are provided in Annex A1.

7.2.3.2 Sufficient reflectors shall be used to allow assessment of volume coverage, extent of dead zones and to establish reference sensitivity when the lateral wave or backwall is not present.

7.2.4 *Examination of Pipe Material:*

7.2.4.1 Prior to the butt fusion joining process, the pipe material approximately 25 to 50 mm (1 to 2 in.) on each side of the joint should be scanned using a 0° compression mode. Possible conditions or imperfections that may be identified in the pipe material during this examination include:

(1) Material thickness out of tolerance;

(2) Point reflectors such as poor mixing, porosity, carbon black accumulation, segregation, voids and contamination;

(3) Laminations or inclusions.

7.2.4.2 Such findings or any other indications of poor pipe material quality shall be noted and documented.

NOTE 7—Linear discontinuities such as surface gouges may be identified by TOFD or PAUT signals or during visual assessments of the surface condition for examination.

7.3 *Examination Procedure A, Time of Flight Diffraction (TOFD):*

7.3.1 When TOFD is selected as the examination procedure for polyethylene butt fusion joints, the general procedures described in Practice E2373 are applicable. However, modifications to the recommended probes may be needed due to the shorter wavelength of the compression mode in polyethylene and its relatively high attenuation.

7.3.2 A project-specific examination procedure, detailing the equipment and setup used, shall be submitted and approved as part of the contractual agreement.

7.3.3 Probe selection for polyethylene butt fusion joints are found in Tables 2 and 3. These are recommendations and may be modified for specific materials and project requirements.

7.3.4 For thickness ranges in polyethylene pipe over 25 mm (1 in.), the beam divergence from a single element is not likely to provide sufficient intensity for good detection over the entire thickness. For thickness 25 mm (1 in.) and greater, the examination piece should be divided into multiple zones. An example of a multi-zone TOFD configuration for 60 mm thick material is illustrated in Fig. 2. Table 3 indicates the recommended number of TOFD zones without specifying angles. Probe angles and probe diameter and frequency shall be selected to ensure full volume coverage.

7.3.5 For thicknesses greater than about 60 mm (2.4 in.), other probe frequencies and angles may be required to achieve adequate volume coverage and flaw detection.

7.3.6 Technique capabilities shall be demonstrated on suitably designed reference blocks.

7.3.7 TOFD examination sensitivity may be established using either the responses from the diffraction targets or by material grain noise. When using the diffraction targets, sensitivity shall be at a level such that the signal to noise ratio is not less than 3:1 for the pipe material.

7.3.8 When the lateral wave is used to establish reference sensitivity, its amplitude shall be set to produce a non-saturating signal between 40% and 90% of the screen height. Electronic noise in the region prior to the lateral wave shall be at least 6 dB lower than the material noise after the lateral wave.

7.3.9 Successful standardization of the TOFD channels will produce clearly defined images of the diffraction notches with the software-calculated depths to their tips within 0.5 mm (0.02 in.) of the actual depths.

7.3.10 Where demonstrated for one-sided access and where demonstrated to improve near-surface detections, one-sided TOFD (for example, angled dual compression probes or back-scatter TOFD) may be used.

7.3.11 The scanning area shall be clear of conditions which may interfere with the movement of the probes, the coupling liquid, or the transmission of acoustic energy into the material.

7.4 *TOFD Examination Sequence:*

7.4.1 If required by the specification, prior to the joining process, assess the pipe material for conformance to quality as per the considerations described in 7.2.4.

7.4.1.1 Standardize the apparatus for:

(1) Acoustic velocity of material examined and used for standardization;

(2) A-scan range for each TOFD zone used;

(3) Reference sensitivity for each TOFD zone used; and

(4) Encoder accuracy error not greater than 10 mm (0.4 in.).

TABLE 2 For Thickness Ranges up to 25 mm (1 in.)

Nominal Wall Thickness mm (in.)	Nominal Frequency (MHz)	Element Size mm (in.)	Recommended Angles
<12 (0.5)	2 to 5	6 to 9 (0.25 to 0.375)	65 to 70°
12 to <25 (0.5 to 1.4)	1 to 5	6 to 12.5 (0.25 to 0.5)	60 to 70°

TABLE 3 For Thickness Ranges over 25 mm up to 60 mm (1 in. to 2.4 in.)

Nominal Wall Thickness mm (in.)	Nominal Frequency (MHz)	Element Size mm (in.)	Recommended Zones
25 (1) to 50 (2)	1 to 5	6 to 12.5 (0.25 to 0.5)	2
>50 to 60 (2 to 2.4)	1 to 5	6 to 12.5 (0.25 to 0.5)	3

7.4.1.2 Place the probes in the scanner holders ensuring correct probe center spacing (PCS) for each pair and symmetrical placement with respect to the joint centerline.

7.4.1.3 Place the scanner on the joint being examined such that the first probe pair is at the reference position of the joint and ensure couplant is adequate.

7.4.1.4 Begin data acquisition and commence the scan at a speed that is slow enough to prevent missed data lines. Missing lines in the B-scan display shall not exceed 5 % of the scan lines to be collected, and no adjacent lines shall be missed.

7.4.1.5 When the full length of the scan has been completed, with an agreed-upon scan overlap, stop the data acquisition and save the data to file.

7.4.1.6 Review the TOFD data for quality (e.g. missing data lines, constant coupling, adequate overlap, etc.). Repeat the scan if quality issues are identified.

7.4.1.7 Evaluate the TOFD data and report the findings and status of the joint with respect to the acceptance criteria.

7.5 *Examination Procedure B, Phased Array Ultrasonic Testing (PAUT):*

7.5.1 When PAUT is selected as the examination procedure for butt fusion joints, the general procedures described in Practice E2700 are applicable; however, modifications to the recommended probes and wedges may be needed due to the use of the relatively high attenuation of polyethylene and the need to use only the compression mode.

7.5.2 A project-specific examination procedure, detailing the equipment and setup used, shall be submitted and approved as part of the contractual agreement.

7.5.3 Since shear modes are not useful in the examination of polyethylene joints, the refracting wedges for a PAUT probe should be selected to be effective in steering the beam between 30° to 85° in compression mode.

7.5.4 When used in pairs mounted on both sides of the joint, PAUT probes may also be used to facilitate the TOFD technique. When PAUT probes are not used to facilitate TOFD, the lateral wave will not be available to monitor coupling quality. Coupling quality may be an issue when hard wedges are used instead of water-gap or conformable membranes. An extra delay law may be used for a 0° beam to monitor coupling quality. When using phased-array probes for TOFD, it is recommended to use aperture sizes similar to those in Tables 2 and 3.

7.5.5 For thick sections of polyethylene pipe, the attenuation may prevent useful results from being obtained for the near surface by means of reflection off the far surface. Under these conditions, a fixed or small angular sweep of high-angle compression mode can be used.

7.5.6 PAUT options for polyethylene joint examination are illustrated in Fig. 3.

7.5.7 When demonstrated to improve detections, other phased-array delay-law sequences such E-scans may be added.

7.5.8 The scanning area shall be clear of conditions which may interfere with the movement of the probes, the coupling liquid, or the transmission of acoustic energy into the material.

7.6 *PAUT Examination Sequence:*

7.6.1 If required by the specification, prior to the joining process, assess the pipe material for conformance to quality as per the considerations described in 7.2.4.

7.6.2 Standardize the apparatus for:

7.6.2.1 Acoustic velocity of material examined and used for standardization;

7.6.2.2 A-scan range for each angle used;

7.6.2.3 Reference sensitivity for each delay law used; and

7.6.2.4 Encoder accuracy error not greater than 10 mm (0.4 in.).

7.6.3 Place the probe(s) in the scanner holder(s) ensuring correct standoff from the joint centerline.

7.6.4 Place the scanner on joint being examined such that the probe(s) is (are) at the reference position of the joint and ensure couplant is adequate.

7.6.5 Begin data acquisition and commence the scan at a speed that is slow enough to prevent missed data lines. Missing lines in the display shall not exceed 5 % of the scan lines to be collected, and no adjacent lines shall be missed.

7.6.6 When the full length of the scan has been completed with an agreed scan overlap, stop the data acquisition and save the data to file.

7.6.7 Review the acquired data for quality (for example, missing data lines, constant coupling, adequate overlap, etc.). Repeat the scan if quality issues are identified.

7.6.8 Evaluate the data and report the findings and status of the joint with respect to the acceptance criteria.

8. Report

8.1 *Examination Displays*—The examination data produced as a permanent record shall consist of a complete B, C, or D scan, or combinations thereof, constructed from the collected A-scans. In addition, details of the component and examination shall be reported, including, as a minimum:

8.1.1 The reference point;

8.1.2 Joint identification number;

8.1.3 The direction of scanning;

8.1.4 Date and time of examination;

8.1.5 Material examined, (for example, material cell classification);

8.1.6 Dimensions (for example, outside diameter and dimension ratio (DR or SDR));

8.1.7 Extent of examination;

8.1.8 Indication evaluations;

8.1.9 Indication sizes, locations and amplitude as applicable;

8.1.10 Equipment used; and

8.1.11 The name and qualifications of the operator.

8.2 Alternate archival record formats may be approved by the contracting agency. For B-scan data displays, colors should be selected to include the noise level to aid in characterizing flaws. Colors used shall provide a rapid means of identifying

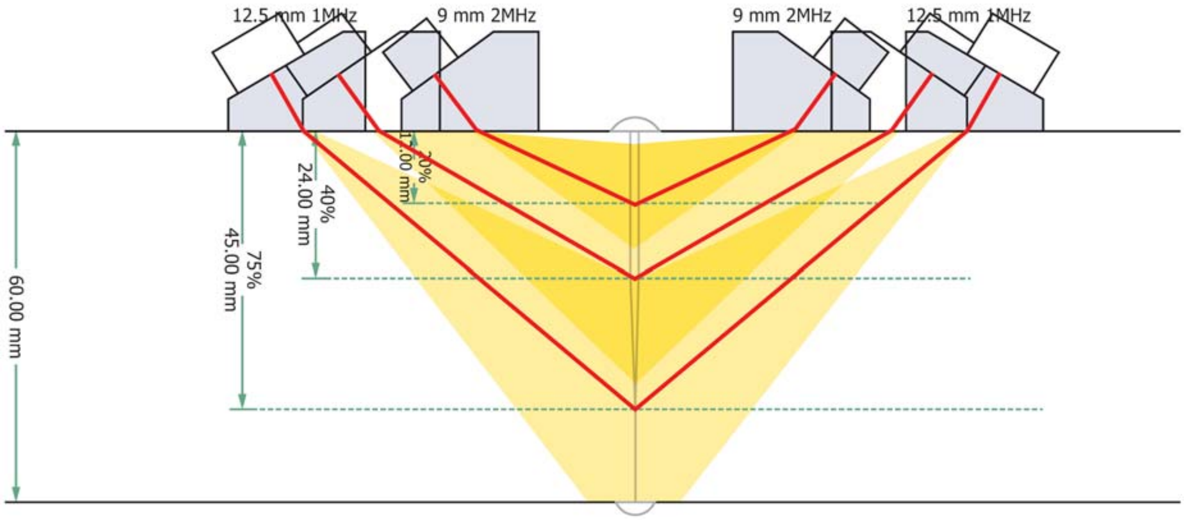

FIG. 2 Example of Multiple TOFD Zones

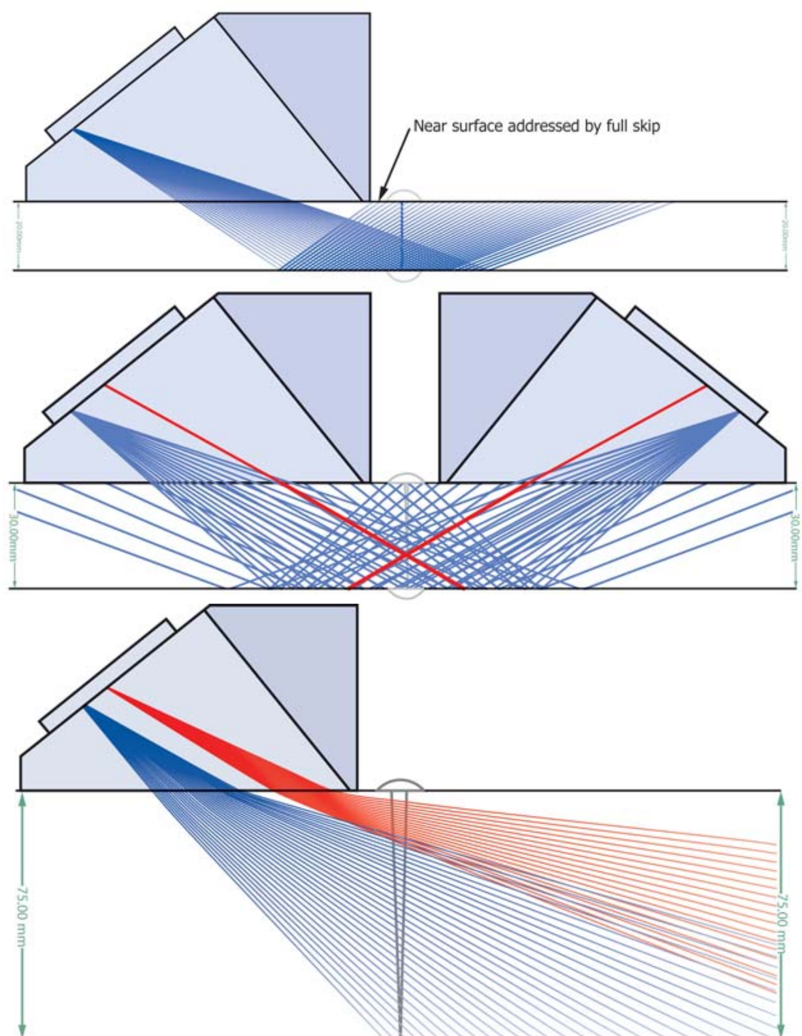

FIG. 3 Examples of PAUT Applications for Butt-Fusion Joints

areas of concern. Colors on monitor displays and colors or gray scales used on printouts should be selected to provide useful information to the operator. Any hardcopy presentation should contain sufficient resolution and contrast so that the rationale for flaw evaluations can be easily seen by the contracting agency's representative.

8.3 *Time of Examination*—For examination during production joining, ultrasonic examination of the joint should be carried out as soon as possible after the joint has been completed with suitable allowance for the internal temperature to equal the external temperature of the joint. Typically this is when the joint surface has cooled to ambient temperature (for example, within 10°C (20°F) of the reference block). Evaluation of a joint and the associated examination data should be completed prior to commencement of the examination of the subsequent joint.

9. Keywords

9.1 phased array; polyethylene; time of flight diffraction; ultrasonic

ANNEX

(Mandatory Information)

A1. REFERENCE SENSITIVITY BLOCKS

A1.1 Establishing reference sensitivity is required to ensure that a repeatable minimum detection level can be assured. This annex provides a description of the minimum targets required to establish reference sensitivity and volume coverage. When suitably configured, the reference sensitivity blocks can be used in a dynamic mode to demonstrate that the required volume is being inspected.

A1.2 Flaw detection in polyethylene butt fusion joints is based on different principles for TOFD and PAUT. For TOFD, detection is generally based on forward scattered pressure. For pulse-echo PAUT, detection is based on backscattered pressure. This requires that the targets used provide suitably oriented surfaces to simulate the orientation of flaws of concern without presenting interfering signals.

A1.3 Reference blocks shall be made from polyethylene pipe. For thickness up to 60 mm, a reference block pipe thickness shall be ± 10% of the nominal thickness of the pipe to be examined or 6 mm (0.25 in.) for thickness over 60 mm. A reference block may be used for examinations in the range of curvature from 0.9 to 1.5 times the reference block diameter. Alternatively they shall be made from pipe sections having the same thickness, diameter and acoustic velocity as the pipe being examined. The reference block need not have a butt-fusion joint in it and may be made from two sections so as to allow inside notches to be machined.

A1.4 *TOFD Blocks*:

A1.4.1 Minimum TOFD targets are described in Table A1.1.

A1.4.2 In addition to the targets listed in Table A1.1, other targets may be added. More V-notches may be used, and are recommended, to assess depth resolution capabilities. When the V-notch diffractor target is not clearly separated from the lateral wave or backwall dead zones, additional V-notches with increasing depths shall be used to assess the number of extra TOFD zones required or whether phased array pulse-echo options are required to ensure full volume coverage of the examination setup.

A1.4.3 The reference block shall have sufficient dimensions to allow the probes to be moved over the examination surface in the direction to be scanned on the examination piece. A dynamic scan of the reference block shall demonstrate detection of the required targets and any additional targets agreed upon by the contracting parties.

TABLE A1.1 Minimum TOFD Targets for Polyethylene Reference Block

Target	Size	Location
V-notch	2 mm wide × 10 mm long (5⁄64 × 3⁄8 in.) Machined to a depth of 10% and 20% of the thickness from the inside surface to maximum 5 mm (0.2 in.)	Inside surface centerline[A]
V-notch	2 mm wide × 10 mm long (5⁄64 × 3⁄8 in.) Machined to a depth of 10% and 20% of the thickness from the outside surface to maximum 5 mm (0.2 in.)	Outside surface centerline

[A] Centerline in Tables A1.1 and A1.2 refers to the theoretical joint centerline.

A1.4.4 Fig. A1.1 illustrates how such a reference block may be designed. Fig. A1.1 indicates a design using a pipe section cut in half to allow milling of the targets from the inside surface. A lower half-cylinder that allows the two halves to be secured and a full circumference formed is indicated to support the scanning apparatus and facilitate dynamic standardization. Illustrated targets include the mandatory 10% V-notches and 20% V-notches. With the reference block constructed in two halves, it is also feasible to add more targets in the lower half-cylinder. Other designs are acceptable provided they can demonstrate the required volume coverage and contain at least those targets identified in Table A1.1.

A1.5 *PAUT Blocks*:

A1.5.1 Minimum PAUT targets are described in Table A1.2.

A1.5.2 More FBH and SDH may be used. The square notches shall be used to determine gate positioning to ensure correct volume coverage.

A1.5.3 The near-surface square notch may be used as a single point DAC target to set reference sensitivity for high angle compression mode delay laws designed to detect near surface flaws.

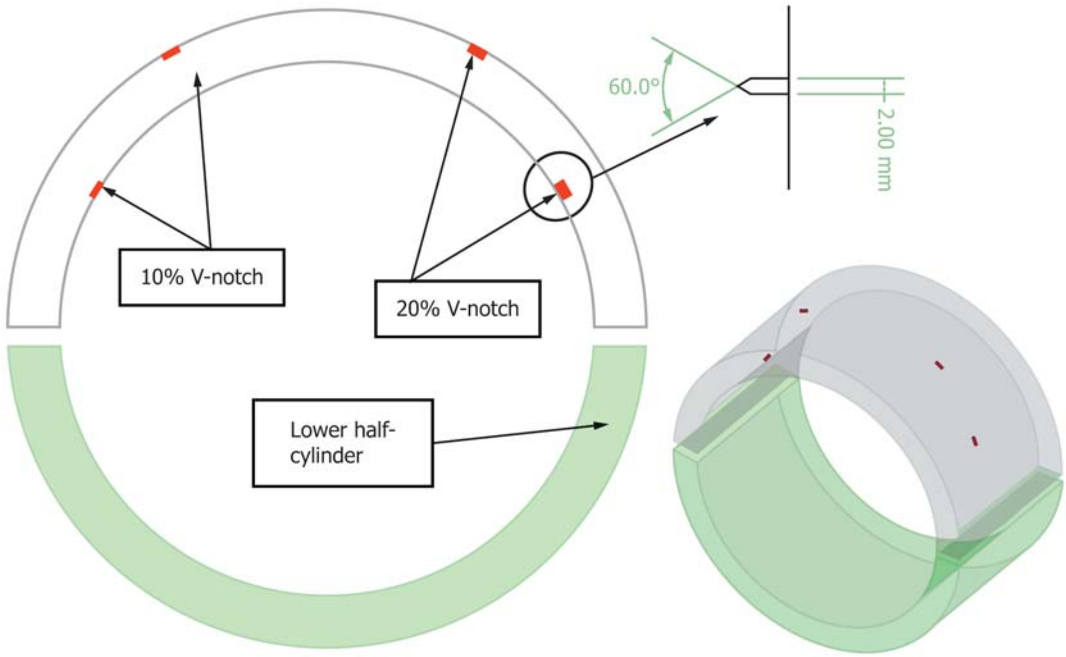

FIG. A1.1 Example of Minimum Reference Block Targets for TOFD Examination

TABLE A1.2 Minimum TOFD Targets for Polyethylene Reference Block

Target	Size[A]	Location[B]
Square-notch	2 mm wide × 10 mm long (5⁄64 × 3⁄8 in.) Machined to a depth of 10% of the thickness from the inside surface to maximum 5 mm (0.2 in.)	Inside surface centerline
Square-notch	2 mm wide × 10 mm long (5⁄64 × 3⁄8 in.) Machined to a depth of 10% of the thickness from the outside surface to maximum 5 mm (0.2 in.)	Outside surface centerline
Flat bottom holes	3 mm (1⁄8 in.) diameter 1 at 2 mm (0.08 in.) ligament to inside surface 1 at 2 mm (0.08 in.) ligament to outside surface 1 at 50% thickness (more 3 mm (1⁄8 in.) diameter FBH at other depths are recommended for thicker sections)	Milled to end at centerline
Side drilled holes	3 mm (1⁄8 in.) diameter At 25% and 75% thickness (more 3 mm (1⁄8 in.) diameter SDH at other depths are recommended for thicker sections)	Drilled parallel to centerline

[A] Tolerance on all dimensions ± 0.2 mm (0.01 in.).
[B] Tolerance on locations ± 0.5 mm (0.02 in.).

A1.5.4 SDH shall be used to construct a minimum two-point DAC using time-corrected gain for the sectorial scan. The equalized responses from SDH shall be such that the amplitude responses are between 50% to 80% screen height. This shall be considered the reference sensitivity for the sectorial scan. Sufficient gain shall be added to the reference sensitivity to ensure that the back-scattered responses from the FBH are visible with a signal to noise ratio of at least 3:1 with no FBH response less than 40% screen height.

NOTE A1.1—When constructing a TCG using side-drilled holes, sensitivity for each beam is equalized to compensate for wedge-path differences, material path distance and echo-transmittance differences. Using a side drilled hole provides an ideal reflector that produces a maximum response at perpendicular incidence for each angle in an S-scan. When gain is added to increase the response level of the FBH, the responses will not be equal because the FBH are not ideal reflectors. When several FBH are detected within the angular range of an S-scan, setting the response from the FBH producing the lowest response to 40% screen height will result in the other FBH having responses greater than 40%.

A1.5.5 Fig. A1.2 illustrates how such a reference block may be designed. Other designs and multiple blocks are acceptable provided they can demonstrate the required volume coverage and contain at least those targets identified in Table A1.2.

A1.5.6 The reference block shall have sufficient dimensions to allow the probes to be moved over the examination surface in the direction to be scanned on the examination piece. A dynamic scan of the reference block shall demonstrate detection of the required targets and any additional targets agreed upon by the contracting parties.

A1.5.7 Fig. A1.2 indicates a design using a pipe section cut in half to allow milling of the targets from the inside surface. A lower half-cylinder is indicated that allows the two halves to be secured and a full circumference formed to support the scanning apparatus and facilitate dynamic standardization. Illustrated targets include the mandatory 10% square-notches and 3 mm (0.12 in.) diameter side drilled holes at 25% and 75% depths and the FBH. The ends of the FBH targets are aligned with the theoretical centerline of the fusion joint in the reference block and are arranged with three drilled from one side (upstream facing) and three drilled from the other side (downstream facing). This symmetrical arrangement of targets permits the verification of detection capability for both upstream and downstream probes when using a two-probe configuration. With the reference block constructed in two halves, it is also feasible to add more targets in the lower half-cylinder.

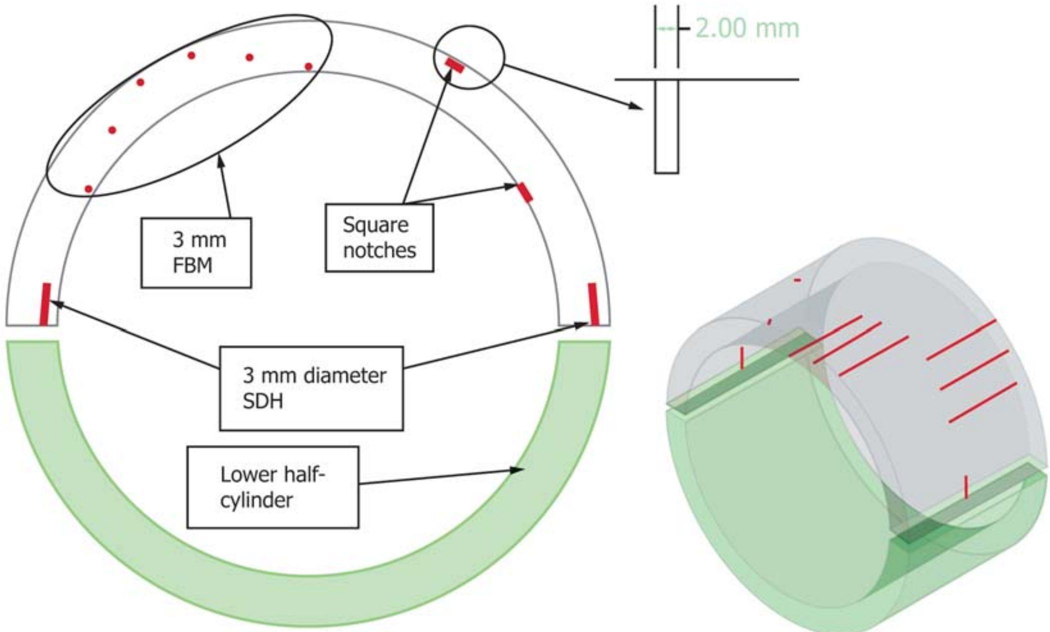

FIG. A1.2 Example of Reference Block Targets for PAUT Examination

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