
**Thermoplastic pipes for the
conveyance of fluids — Inspection of
polyethylene butt fusion joints using
phased array ultrasonic testing**

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 5, *General properties of pipes, fittings and valves of plastic materials and their accessories — Test methods and basic specifications*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Thermoplastic pipes for the conveyance of fluids — Inspection of polyethylene butt fusion joints using phased array ultrasonic testing

1 Scope

This document describes the phased array ultrasonic testing (PAUT) of polyethylene butt fusion (BF) joints, including pipe-to-pipe, pipe-to-fitting and fitting-to-fitting joints, used for the conveyance of fluids. This document provides a test, whereby the presence of imperfections such as voids, inclusions, lack of fusions, misalignment and particulate contamination in the BF joints can be detected. The document is only applicable to polyethylene pipes and fittings without a barrier to ultrasonic waves.

This document also provides requirements for procedure qualification and guidance for personnel qualifications, which are essential for the application of this test method.

This document also covers the equipment, the preparation and performance of the test, the indication assessment and the reporting for polyethylene BF joints. The assessment of ultrasonic indications and acceptance criteria are not covered in this document.

NOTE 1 At the present time, laboratory experiences exist on the use of PAUT for polyethylene BF joints and/or reference blocks of wall thickness between 8 mm to 100 mm^{[1] to [5]}. Recently, field experience on BF joints in PE80 and PE100 materials has been reported^[6].

NOTE 2 Round robin testing has shown that PAUT is a viable method for enhancing the integrity assessment of BF joints^[7].

NOTE 3 PAUT techniques for cold fusion detection are known to be available. However further research, verification and experience are needed to transfer the technique into an ISO Standard. This document does not provide any information regarding the detection of cold fusions.

2 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 edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5577, *Non-destructive testing — Ultrasonic testing — Vocabulary*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 13953, *Polyethylene (PE) pipes and fittings — Determination of the tensile strength and failure mode of test pieces from a butt-fused joint*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

- 3.1 cold fusion**
insufficient joint integrity caused by the incomplete intermolecular diffusion of polymer chains for proper molecular entanglement at the joint interface due to reasons other than contamination, which does not create any PAUT indication(s) at the joint interface
- 3.2 inclusion**
foreign material trapped in the fusion joint
- 3.3 lack of fusion**
absence of intermolecular diffusion of polymer chains for molecular entanglement at the interface, resulting in a non-destructive testing indication at the joint interface
- 3.4 melt fusion zone MFZ**
zone containing the fusion interface and having boundaries on either side of the interface which reflect the limits of crystalline melting during the BF jointing process
- Note 1 to entry: The MFZ is shown in [Figure 1](#).
- 3.5 misalignment**
offset between the axis of the pipes/fittings to be jointed
- 3.6 particulate contamination**
fine particles, e.g. airborne dust, or coarse particles, e.g. sand and grit, that are present at the fusion interface
- 3.7 surface imperfection**
imperfection on the ID or OD surface of the butt fusion joint
- 3.8 void**
empty space (or air pocket) in a BF joint
- 3.9 phased array image**
one-, two-, or three-dimensional display, constructed from the phased array data
- 3.10 phased array set-up**
probe arrangement defined by probe characteristics (e.g. frequency, probe element size, beam angle, wave mode), *probe position* ([3.11](#)), and the number of probes
- 3.11 probe position**
point between the front of the wedge (or probe) and the BF centre line
- 3.12 scan increment**
distance between successive data collection points in the direction of scanning
- 3.13 false call**
reporting an imperfection when none exists

4 Information required prior to testing

4.1 Items required for procedure

Information on the following items is required:

- purpose and extent of testing;
- reference sample;
- requirements for getting access to the BF joints, the surface condition of the pipe; and the temperature range;
- personnel qualifications;
- reporting requirements;
- manufacturing or operation stage of BF joints at which the testing is to be carried out.

4.2 Specific information required by the operator before testing

Before any testing of a fusion joint begins, the operator shall have access to all the information as specified in 4.1 together with the following additional information:

- a) written test procedure;
- b) all relevant joint dimensions.

4.3 Written test procedure

For all testing, a written test procedure is required. This test procedure shall include at least the following information:

- a) purpose and extent of testing;
- b) reference sample;
- c) requirements for access to the BF joints and surface conditions and temperature;
- d) personnel qualifications;
- e) reporting requirements;
- f) equipment requirements and settings (including but not limited to frequency, sampling rate, pitch between elements and element size);
- g) evaluation of indications;
- h) environmental and safety issues;
- i) documented testing strategy or scan plan.

NOTE The testing strategy gives information on the probe placement, movement, and component coverage that provides a standardized and repeatable methodology for fusion joint testing. The scan plan gives information on the volume tested for each BF joint.

5 Personnel qualifications

Personnel performing testing in accordance with this document shall be qualified to an appropriate level in accordance with ISO 9712 or an equivalent standard in the relevant industrial sector.

In addition to a general knowledge of ultrasonic testing, the operator shall be familiar with and have practical experience in the use of phased array systems on polyethylene BF joints. Specific theoretical and practical training and examination of personnel shall be performed on representative polyethylene BF joints containing natural or artificial reflectors similar to those expected. These training and examination results shall be documented.

6 Equipment

6.1 General

For the selection of system components (hardware and software), ISO 13588^[8] and ISO/TS 16829^[9] give useful information.

Ultrasonic equipment used for phased array testing should comply with the requirements of ISO 18563-1^[10], ISO 18563-2^[11] and ISO 18563-3^[12] when applicable.

The complete equipment, i.e. ultrasonic instrument, probe, cables and display monitor, shall be capable of the repetition of test results.

6.2 Ultrasonic instrument and display

The instrument shall be able to select an appropriate portion of the time base within which A-scans are digitized. It is recommended that a sampling rate of the A-scan should be at least six times the nominal probe frequency.

6.3 Ultrasonic probes

Only longitudinal wave mode can be used.

Any type of phased array probe can be used if it satisfies the range and sensitivity setting requirements of [Clause 7](#) with the phased array equipment.

The most suitable ultrasonic probe frequency should be selected in accordance with the pipe wall thickness. [Table 1](#) shows the recommended frequencies for each thickness range. However, the optimal frequency can deviate from these values depending on the attenuation and thickness of the sample to be tested.

The gap between the test surface and the bottom of the wedge shall not be greater than 0,5 mm.

Table 1 — Selection of probe frequency

Recommended frequency MHz	Wall thickness mm
1,0 to 2,25	60 to 100
2,25 to 4,0	30 to 60
4,0 to 5,0	8 to 30

NOTE In general, higher frequencies provide better resolution and lower frequencies provide better penetration.

6.4 Scanning mechanisms

To achieve consistency of the images (collected data), guiding mechanisms and scan encoder(s) shall be used.

6.5 Couplant

In order to generate proper images, a couplant should be used which provides a constant transmission of ultrasound between the probe and the material. The same couplant used for calibration shall be used for the testing. Any couplant used should be cleaned off after testing.

7 Range and sensitivity settings

7.1 Settings

7.1.1 General

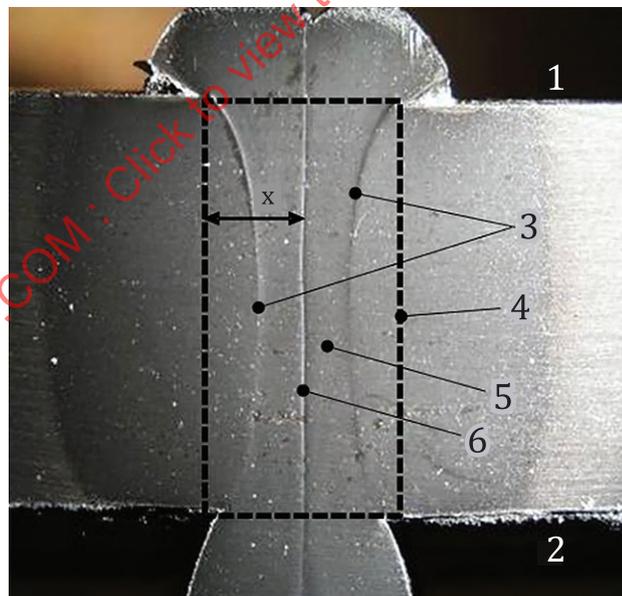
Setting of range and sensitivity shall be carried out prior to each testing period in accordance with this document. Any change of the phased array set-up, e.g. probe position and steering parameters, will require a new setting. The set-up should be optimized on the reference reflectors to give a signal-to-noise ratio minimum of 6 dB.

7.1.2 Range setting — Test volume

The range in the depth direction shall cover the full joint thickness in the fusion zone.

The range in the axial direction shall cover the MFZ on both sides of the BF centre line. As a general guidance, for wall thicknesses <100 mm, the test area width is 10 mm or 1/5 of the wall thickness from either side of the fusion zone, whichever is smaller (see [Figure 1](#)).

The range in the circumferential direction shall include the full circumference.



Key

- 1 outside of joint
- 2 inside of joint
- 3 MFZ boundary
- 4 test area
- 5 MFZ
- 6 fusion interface
- x width of test area

Figure 1 — Test area

7.1.3 Sensitivity setting

After selection of mode (E-scan, S-scan) the following shall be carried out:

- a) sensitivity shall be set for each beam generated by the phased array probe;
 - 1) when a probe with wedge is used, the sensitivity shall be set with the wedge in place,
 - 2) when beam focussing is used, the sensitivity shall be set for each focused beam;
- b) use of angle-corrected gain (ACG) or time-corrected gain (TCG) shall be applied to enable the display of signals for all beam angles and all distances with the same amplitude.

NOTE Different testing techniques of PAUT for BF joints (e.g. fixed angles, E-scans and S-scans at fixed probe position) can be employed as shown in [Table 2](#).

Table 2 — Description of testing techniques for BF joints^[7]

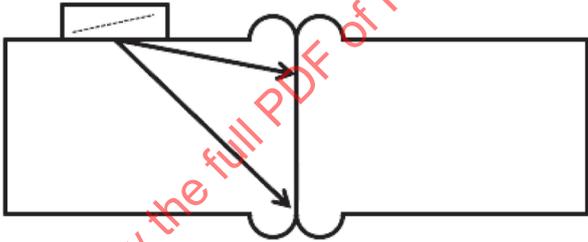
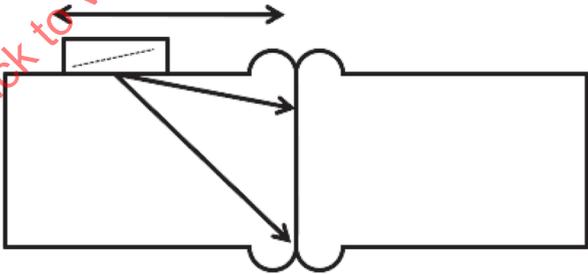
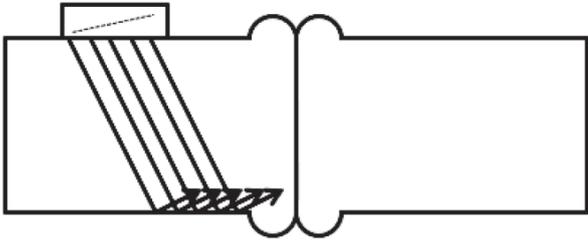
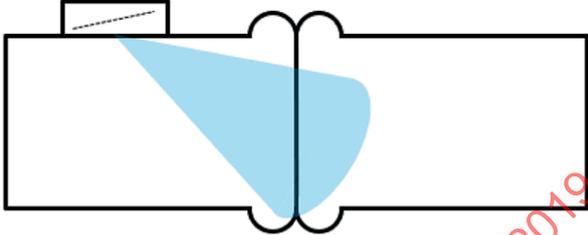
Testing technique	Test set-up	Example of sketches
Fixed angles at fixed probe position to BF joint (line scans)	Not suitable as a single technique; multiple scans at different angles are needed	
Fixed angles with raster scanning	One side	
E-scan at fixed probe position (line scan)	One side with two angles	

Table 2 (continued)

Testing technique	Test set-up	Example of sketches
S-scan at fixed probe position (line scan)	One side	

7.2 Reference sample

7.2.1 General

The temperature of the reference sample shall be the same as the temperature ± 5 °C of the test object at the time of testing and shall be kept in the same environment as the test object throughout the test. A reference block satisfying the conditions in 7.2.2 shall be used as the reference sample.

7.2.2 Reference block

Reference blocks shall be used to determine the adequacy of the settings (e.g. coverage, sensitivity). Recommendations for reference blocks are shown in Annex A.

A transfer correction should be applied to cover the difference in curvature and surface roughness of the reference block and the test object.

The reference block used shall be of the same material classification as the pipe/fitting being inspected. The thickness of the reference block shall be at least equal to the thickness of the joint to be tested. The length and width of the reference block shall be chosen such that all relevant reflectors can be properly scanned.

7.2.3 Reference reflectors

Side-drilled holes (SDHs) and surface notches shall be used as reference reflectors for the testing of polyethylene BF joints.

For a thickness < 30 mm, at least three reflectors are recommended; for a thickness > 30 mm, at least five reflectors are recommended.

7.3 Checking of the settings

The range and sensitivity shall be checked prior to testing, every 4 h of testing and at the end of the testing period, or if the temperature of the joint changes by > 10 °C. Any change in the response of the reference reflector > -4 dB from the reference sensitivity level should merit re-configuring the equipment and re-scanning all the joints since the previous acceptable calibration.

The reference sensitivity level shall be established over the range of interest using SDHs as shown in Table A.1.

8 Equipment checks

A check of the equipment shall be performed daily before and after testing to verify that all relevant channels, probes, and cables of the ultrasonic phased array system are functional. If any item of the system fails, corrective action shall be taken and the system shall be retested.

9 Test procedure

9.1 Procedure qualification

Procedure qualification is required for testing polyethylene BF joints. The procedure shall be demonstrated to perform in an acceptable way on BF joints containing representative imperfections (lack of fusion, particulate contamination), which have been shown to reduce the integrity of the joint as shown by destructive testing.

The procedure qualification requires the manufacturing of a series of samples of polyethylene BF joints for each pipe wall thickness range to be tested, some with imperfection and some without (see [Table 3](#)). Some examples for implanting imperfections to BF joints are given in [Annex B](#).

The following categorized sample joints shall be tested in a blind fashion:

- Category A: 2 fusion joints, each containing 8 embedded planar lack of fusion imperfections (thickness of 25 μm or less), randomly distributed around the circumference. For each pipe wall thickness range, 2 planar imperfections for each size given in [Table 3](#) shall be used.
- Category B: 8 fusion joints where:
 - 1) 4 fusion joints contain no imperfections, using conditions that have been proven to generate no brittle failures when tested to ISO 13953;
 - 2) 4 fusion joints contain fine particulate contamination (particle size $<50 \mu\text{m}$) evenly distributed and dispersed around the whole fusion joint circumference and proven to generate brittle failures when tested according to ISO 13953.

For the procedure to be qualified for the detection of imperfections:

- 14 or more of the embedded planar lack of fusion imperfections (Category A) shall be detected with no false calls. To be considered a detected imperfection, the reported circumferential position of the imperfection shall be within 20 mm of the true circumferential position. All other reported indications shall be considered false calls,
- 3 or more of the 4 fusion joints containing fine particulate contamination (Category B2) shall be classified correctly as having imperfections,
- for the fusion joints containing no imperfections, there shall be no false calls.

Procedure qualification is only required once for each pipe wall thickness range ([Table 3](#)) unless the procedure or any of the test equipment is changed.

Table 3 — Pipe wall thickness ranges and associated sizes of embedded planar imperfections for the qualification of test procedures

Range	Wall thickness of pipe/fitting	Imperfection diameters
	mm	mm
A	8 to <30	1, 2, 3, 4
B	30 to 60	2, 3, 4, 8
C	>60	3, 4, 8, 12

9.2 Scan increment

The scan increment setting along the circumference of the joint is dependent upon the wall thickness of the BF joint to be tested. For thicknesses <60 mm, the scan increment shall be no more than 1 mm. For thicknesses >60 mm, the scan increment shall be no more than 2 mm.

9.3 Component geometry

If parts of the fusion zone cannot be tested in the axial or circumferential direction due to complex geometry, these areas shall be reported.

9.4 Preparation of scanning surfaces

The test surface shall be prepared so that it is free from contamination, e.g. dirt, dust, or ice. Ensure that the surface is not damaged during surface preparation. The test surface shall be examined visually and the position of any surface damage shall be reported.

9.5 Component temperature

The test should be conducted sufficiently after the end of the cooling time specified in the jointing procedure such that temperature equilibrium is assured throughout the joint thickness.

9.6 Testing

Before starting the test, a proper ultrasonic coupling between the probe and the pipe shall be achieved and maintained throughout the scan.

The zero datum (starting position) shall be recorded and the ultrasonic probe shall be moved around the circumference of the BF joint to test the entire circumference and depth of the fusion zone. Any areas that could not be tested shall be reported.

The scanning speed shall be chosen such that satisfactory images are generated. The scanning speed is dependent on factors such as number of delay laws, scan resolution, signal averaging, pulse-repetition frequency, data acquisition frequency, and volume to be tested. Missing data lines indicate that too high a scanning speed has been used. A maximum of 5 % of the total number of lines collected in one single scan may be missed but no adjacent lines shall be missed.

If the axial and/or circumferential length of a joint is scanned in more than one section, an overlap of at least 20 mm between the adjacent scans shall be applied. The testing in the circumferential direction shall include the full joint circumference plus at least 25 mm to accommodate potential encoder error.

Reportable indications are those caused by voids, cracks, lack of fusion, inclusions, surface imperfections, misalignment, and particulate contamination within the test volume.

9.7 Data storage

Ultrasonic testing shall be performed using a device employing computer-based data acquisition. All A-scan data covering the test volume shall be stored for a period as agreed by the parties involved.

10 Interpretation and analysis of test data

10.1 General

Interpretation and analysis of the test data are typically performed as follows:

- a) assess the quality of the test data (see [10.2](#));
- b) identify relevant indications (see [10.3](#));

- c) classify relevant indications (see [10.4](#));
- d) determine location and size of the indications (see [10.5](#));
- e) assess the indications (see [10.6](#)).

10.2 Assessing the quality of the test data

The phased array test shall be performed such that satisfactory images are generated which can be evaluated. Satisfactory images are defined by appropriate:

- a) coupling;
- b) range setting;
- c) sensitivity setting;
- d) signal-to-noise ratio;
- e) data acquisition (scan length, missed lines, coverage).

It shall be ensured that the signal is not saturated within the test volume.

Assessing the quality of phased array images requires skilled and experienced operators (see [Clause 5](#)). If the operator deems the scan data quality as not meeting the requirements of the procedure, a rescan shall be carried out.

10.3 Identification of relevant indications

The phased array technique provides images of both imperfections in the fusion zone and geometric features such as BF beads and pipe/fitting walls. In order to identify indications of geometric features, knowledge of the joint dimensions is necessary.

To decide whether an indication is relevant (caused by an imperfection), patterns or disturbances shall be evaluated considering the shape and signal amplitude relative to the noise level.

10.4 Classification of relevant indications

Amplitude, location and pattern of relevant indications may contain information on the type of imperfection. Relevant indications should be classified as agreed by the parties involved.

10.5 Determination of location and size of indications

The location of an indication in the circumferential and depth directions in the fusion zone shall be determined from the acquired data. The length of an indication is defined as the dimension along the circumference of the joint and the height of an indication is defined as the dimension in the through wall direction.

10.6 Assessment of indications

The assessment of indications can be based on signal amplitude, equivalent reflector size or reflector pattern, or on other features. The amplitude drop can be used to determine the size of an indication. The height of an indication in the through-wall direction should be determined at the scan position of maximum extent. The maximum amplitude and size of each indication should be evaluated according to the specified acceptance criteria agreed by the parties involved.

11 Test report

The test report shall include all specific test requirements, procedural details and results for a particular test. The test report shall include at least the following information.

- a) Reference to this document, i.e. ISO/TS 22499.
- b) Information relating to the inspection:
 - 1) test report number;
 - 2) names, signatures and qualifications of personnel;
 - 3) date of tests.
- c) Information relating to the test object:
 - 1) identification of the test object (e.g. pipe-to-pipe, pipe-to-fitting or fitting-to-fitting);
 - 2) joint dimensions (nominal OD, thickness);
 - 3) type of material;
 - 4) location of fusion joint(s) examined;
 - 5) condition and temperature of surface.
- d) Information relating to equipment:
 - 1) manufacturer and type of phased array instrument and software revision, including scanning mechanism with identification numbers if required;
 - 2) manufacturer, type and frequency of phased array probes, including number and size of elements, pitch and gap between elements, material and angle(s) of wedges (if any), with identification numbers if required;
 - 3) details of reference block(s) with identification numbers if required;
 - 4) type of couplant used.
- e) Information relating to test technique:
 - 1) reference to a written qualified procedure;
 - 2) purpose and extent of test;
 - 3) details of datum and coordinate systems;
 - 4) method and values used for range and sensitivity settings;
 - 5) details of signal processing and scan increment settings;
 - 6) scan plan;
 - 7) access limitations and deviations from this document, i.e. ISO/TS 22499, if any.
- f) Information relating to phased array settings:
 - 1) testing technique;
 - 2) electronic increment (E-scans) or angular increment (S-scans);
 - 3) focus;
 - 4) virtual aperture size, i.e. number of elements and element width;

- 5) element numbers used for focal laws.
- g) Information relating to test results:
 - 1) reference to the phased array raw data file(s);
 - 2) phased array images of at least those locations where relevant indications have been detected on hard copy, all images or data available in soft copy;
 - 3) tabulated data recording the classification, location and size of relevant indications and results of evaluation;
 - 4) record of all areas not tested.

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Annex A (informative)

Example of reference reflectors and reference blocks

A.1 Reference reflectors

For a thickness $t < 30$ mm, at least three reference reflectors are recommended. The reflectors may be machined in one or more blocks (see [Figures A.1](#) and [A.2](#)).

For a thickness $t > 30$ mm, at least five reference reflectors are recommended. The reflectors may be machined in one or more blocks (see [Figures A.1](#) and [A.2](#)).

The tolerances for all the dimensions of the reference reflectors are as follows:

- side-drilled hole (SDH):
 - diameter: $\pm 0,5$ mm
 - length: ± 5 mm
 - angle: $\pm 2^\circ$
 - depth: $\pm 1,0$ mm
- surface notch (rectangular):
 - depth: $\pm 0,2$ mm
 - width: $\pm 0,2$ mm
 - length: ± 5 mm

The recommended reference reflectors for different wall thicknesses are described in [Table A.1](#).

NOTE Other types of reference blocks are available, e.g. in ASTM E3044M^[13].

Table A.1 — Dimensions and positions of SDH and notch reflectors on the reference block

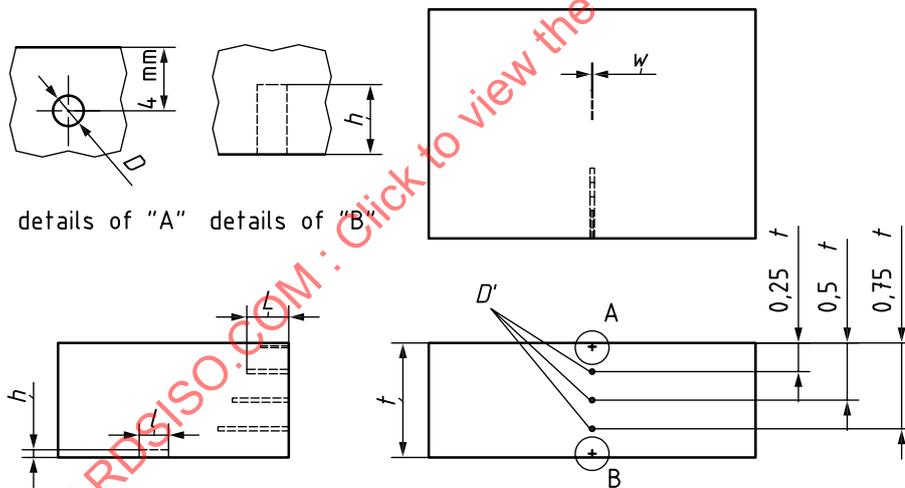
Dimensions in millimetres

Thickness	SDH			Notch (bottom surface)		
	Depth to hole centre	Diameter D	Length L	Depth h	Length l	Width w
$8 < t < 30$	4	2	30	1	30	1
	$0,5 t$	2,5	60			
$30 \leq t < 60$	4	3	30	2		
	$0,25 t$		45			
	$0,5 t$		60			
$60 \leq t \leq 100$	$0,75 t$	4,5	75	2		
	4		30			
	$0,25 t$		45			
	$0,5 t$		60			
	$0,75 t$		75			

NOTE The depth refers to a distance from the surface.

A.2 Reference blocks

A.2.1 Reference block with SDHs and a surface notch — Single block use



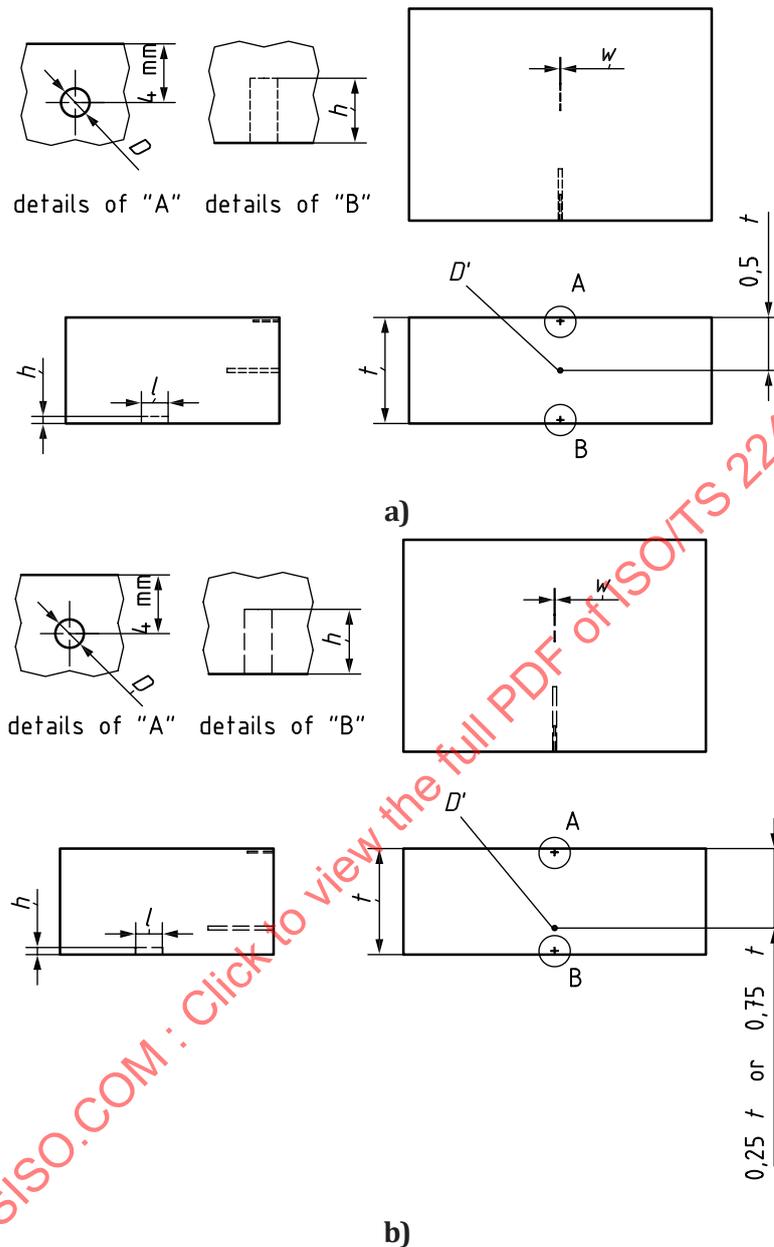
Key

- D' diameter of SDHs at positions $0,25 t$, $0,5 t$ and $0,75 t$
- D diameter of SDH 4 mm below the surface
- L length of SDH
- h depth of notch from the bottom surface
- l length of notch at the bottom surface
- t thickness
- w width of notch at the bottom surface

NOTE The top SDH, 4 mm below the surface, can be replaced by a surface notch of dimensions given in [Table A.1](#).

Figure A.1 — Diagram of a single reference block containing SDHs at positions $0,25 t$, $0,5 t$, $0,75 t$ and a notch at the bottom surface

A.2.2 Reference block with SDHs and a surface notch — Multiblock use



Key

- D' diameter of SDHs at positions $0,25 t$, $0,5 t$ and $0,75 t$
- D diameter of SDH 4 mm below the surface
- L length of SDH
- h depth of notch from the bottom surface
- l length of notch at the bottom surface
- t thickness
- w width of notch at the bottom surface

NOTE 1 Detail A shows an SDH located 4 mm below the test surface, with a diameter of 2 mm and a length of 30 mm.

NOTE 2 Detail B shows a notch at the bottom of the reference block (see [Table A.1](#) for dimensions).

NOTE 3 The top SDH, 4 mm below the surface, can be replaced by a surface notch of dimensions given in [Table A.1](#).

Figure A.2 — Diagram of multi-reference blocks containing SDHs and a bottom surface notch (a) SDH at $0,5 t$ and (b) SDH at $0,25 t$ (or $0,75 t$) position

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