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ISO 13478

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Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Full-scale test (FST)

Tubes en matières thermoplastiques pour le transport des fluides — Détermination de la résistance à la propagation rapide de la fissure (RCP) — Essai grandeur nature (FST)

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 13478 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*.

This second edition cancels and replaces the first edition (ISO 13478:1997), which has been technically revised.

Introduction

Test methods that measure the resistance of internally pressurized plastics pipes to rapid fracture propagation (RCP) have been standardized: ISO 13477 [1] and this International Standard. The S4 method specified in ISO 13477 utilizes short lengths of pipe to determine a critical RCP pressure or temperature for the pipe. Longer pipes up to 20 m in length are the basis of this full-scale test (FST) method for measurement of these critical parameters. On the one hand, the S4 method uses internal baffles to prevent rapid decompression of the internal test pressure, thus ensuring that the high-speed crack tip is exposed to the full pipe pressure throughout the test. The FST, on the other hand, has no baffles installed and is more related to field service. The crack tip is subjected to a reducing pressure by decompression effects as the crack propagates. This arrangement reflects the RCP mode of failure of long pipelines and is assumed to be the reference test method. The critical RCP values derived from each test are different but can be correlated experimentally. A mathematical equation for correlation has been developed for polyethylene (PE) pipes (see ISO 13477).

Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Full-scale test (FST)

1 Scope

This International Standard specifies a full-scale test (FST) method for determining the arrest or propagation of a crack initiated in a thermoplastics pipe at a specified temperature and internal pressure. The method is also suitable for the determination of defined critical pressure, critical stress and critical temperature parameters.

It is applicable to the assessment of the performance of thermoplastics pipes intended for the supply of gases or liquids. In the latter case, air could also be present in the pipe.

2 Normative references

The following referenced documents are indispensable for the application 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 1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General method*

ISO 3126, *Plastics piping systems — Plastics components — Determination of dimensions*

ISO 11922-1, *Thermoplastics pipes for the conveyance of fluids — Dimensions and tolerances — Part 1: Metric series*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 11922-1 and the following apply.

3.1
critical pressure
p_c
highest crack-arrest pressure below the lowest crack-propagation pressure

3.2
critical hoop stress
σ_c
highest crack-arrest hoop stress below the lowest crack-propagation hoop stress

3.3
critical temperature
T_c
lowest crack-arrest temperature above the highest crack-propagation temperature

3.4
crack arrest
event characterized by the length of the longest crack that is less than or equal to 90 % of the length of the test pipe

3.5
rapid crack propagation
RCP
event characterized by the length of the longest crack that is greater than 90 % of the length of the test pipe

4 Symbols

p test pressure, in bar [1)]

p_c critical pressure, in bar [1)]

σ_c critical hoop stress, in megapascals (MPa)

T_c critical temperature, in degrees Celsius (°C)

d_{em} mean outside diameter of test pipe, in millimetres

D average of the mean outside diameters, d_{em}, of the pipe sections, in millimetres

e_t mean wall thickness of the test pipe along the (main) crack, in millimetres.

5 Principle

A thermoplastics pipe, maintained at a specified temperature and containing a fluid at a specified test pressure, is subjected to an impact designed to initiate a crack. The crack can then arrest within a short distance or continue to propagate at high speed along the pipe.

The test temperature and test pressure are as defined in the referring standard and are related to the intended operating conditions.

The pressurizing fluid is identical to that used in the intended application, or else is a substitute fluid, e.g. air or nitrogen, which gives equivalent results.

The test simulates the performance of a buried pipe in service under conditions which do not retard the rate of decompression of the pressurizing fluid through any fracture.

The pipe is subsequently examined to determine whether arrest or propagation of the crack has occurred.

From a series of such tests at different pressures but at a constant temperature, a critical pressure or critical stress for crack propagation can be determined (see Annex A).

Similarly, by testing at a series of temperatures while maintaining a constant pressure or hoop stress, the critical temperature for RCP can be determined (see Annex B).

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1) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

6 Test parameters

It is assumed that the following parameters will be set by the referring product standard:

a) the diameter(s) and series of the pipe(s) to be tested;

b) the pressurizing fluid (7.4), e.g. gas, water, water plus air or nitrogen;

c) the test pressure(s);

d) the test temperature(s).

7 Materials

7.1 Methylated spirits or ethanol, for use as a cooling fluid (see 8.4.3).

7.2 Solid carbon dioxide, for use as a cooling agent (see 8.4.3).

7.3 Washed gravel, with a size range of 20 mm to 40 mm diameter (see Clause 10).

7.4 Pressurizing fluid, which shall be as specified in the referring standard.

NOTE 1 It is satisfactory to use nitrogen or air as the pressurizing fluid instead of natural gas, as the measured pressure for rapid crack propagation (RCP) will be only slightly less than that obtained with natural gas. The decompression speed (velocity of sound) at 0 °C of nitrogen and air is 337 m/s and 334 m/s, respectively, compared with approximately 430 m/s for natural gas.

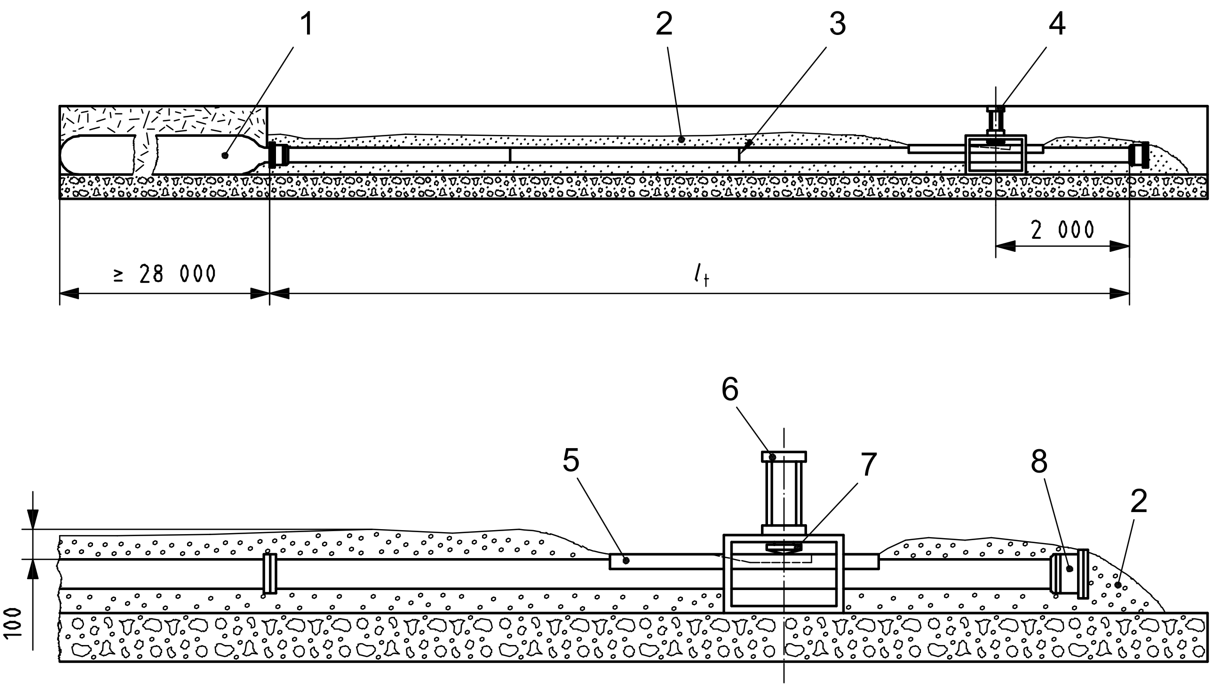
NOTE 2 In water-pipeline systems, which contain water only, the phenomenon of crack propagation is unlikely to occur. However, when entrained air bubbles or air pockets are present, it is possible. It is usual to test with between 5 % and 10 % by volume of air in the water to determine the resistance to crack propagation. A test on water pipe using 100 % gas, air or nitrogen is more likely to result in RCP and therefore will be expected to give a pessimistic result (also see Reference [2] for RCP testing of pipes filled or partially filled with water).

8 Apparatus

8.1 Temperature-controlled trough, capable of accommodating the overall pipe length normally of 14 m to 20 m (also see Clause 9). The trough shall have means for maintaining the temperature specified by the referring standard to within ± 1,5 °C along the whole test pipe length. The temperature may be controlled by recirculation of water or air around the test pipe (see Figure 1). The temperature shall be monitored at intervals along the test length. If necessary, the water shall contain antifreeze to avoid ice build-up around the test pipe.

NOTE Temperature monitoring along the test length at intervals not exceeding 3 m and around the pipe at the 3 o'clock and 9 o'clock positions has been found to be satisfactory.

Dimensions in millimetres



Key

l_t test length (overall pipe length, l, 14 m to 20 m)
1 steel pipe reservoir
2 gravel
3 required butt-fusion joints
4 initiation ring
5 cooling trough
6 pneumatic piston
7 blade
8 end cap

Figure 1 — Example of test facility for full-scale rapid crack propagation

8.2 Steel-pipe reservoir, connected to the test pipe at one end of the trough. The steel pipe shall have a bore diameter greater than or equal to the test-pipe bore diameter. The pipe reservoir shall have a minimum length of twice that of the test pipe and a minimum volume of three times that of the test pipe.

Axial alignment of the reservoir with the test pipe is preferred.

8.3 Pressurization equipment, for pressurizing the test pipe and steel reservoir (8.2) with the test fluid (7.4) to within ± 2 % of the test pressure specified by the referring standard.

8.4 Crack-initiation equipment, for driving a metal blade (8.4.2) through the test pipe at high speed.

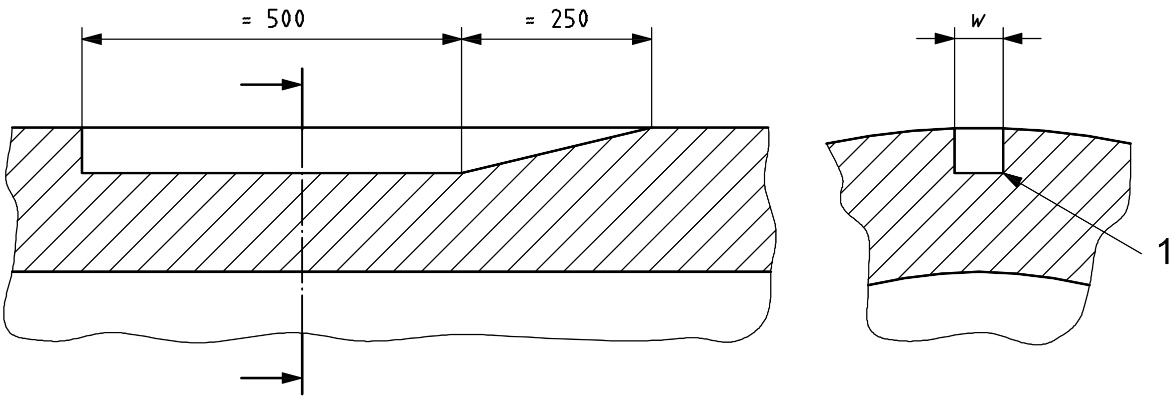
8.4.1 Router, capable of machining a longitudinal slot to an appropriate depth in the test-pipe wall for approximately 500 mm and then gradually decreasing the groove depth to zero over approximately 250 mm (see Figure 2).

NOTE Normally, the slot is machined whilst the test pipe is in the trench.

8.4.2 Metal blade, which can be aligned with the external slot in the test pipe and be driven through the residual pipe-wall thickness.

NOTE A 400 mm long steel blade driven by a fast-acting pneumatic impact piston has been found to be suitable for polyethylene pipe (see Figure 3).

Dimensions in millimetres



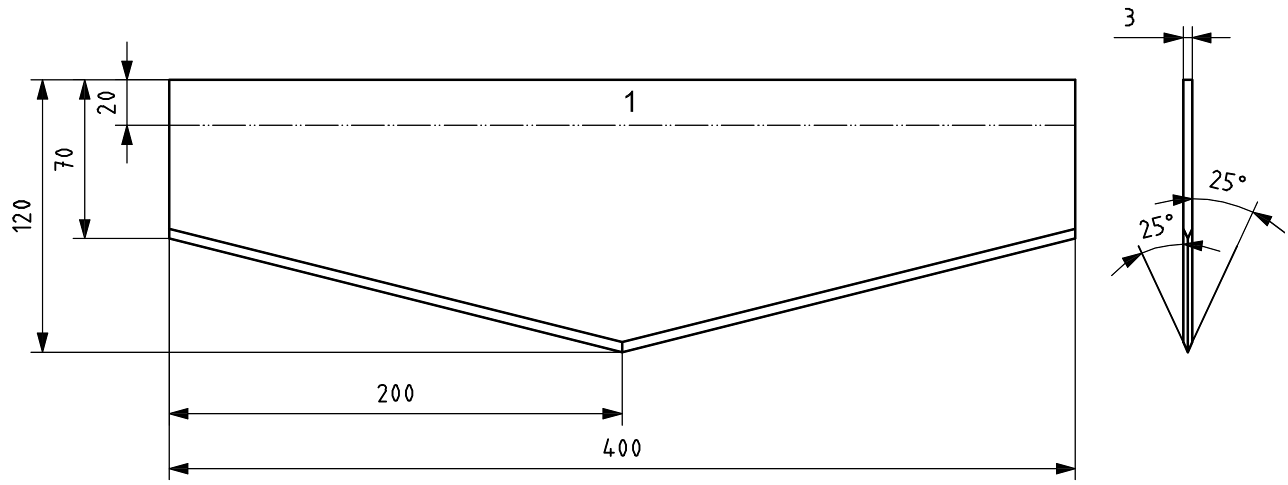
Key

w slot width (8 mm to 25 mm, depending on the wall thickness)

1 rounded corners at bottom of slot

Figure 2 — Slot machined in external surface of pipe wall

Dimensions in millimetres



Key

1 part of blade gripped in blade holder

NOTE Blade sharpened by light grinding.

Figure 3 — Steel blade found to be suitable for initiating crack in polyethylene pipe

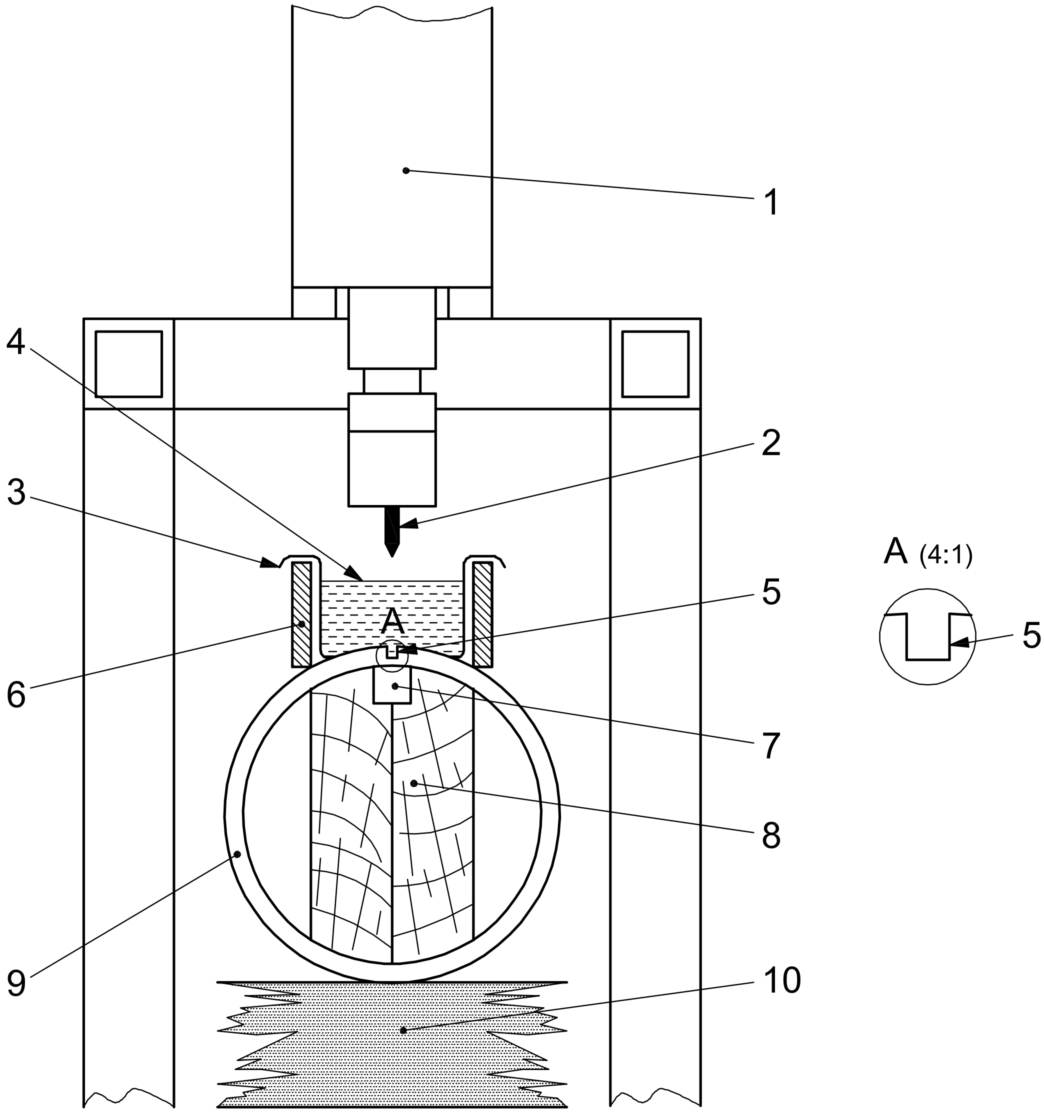
8.4.3 Crack initiation cooling system, used to apply methylated spirits or ethanol, cooled by solid carbon dioxide, to the top of the pipe in order to cool the slot and a strip of pipe on either side and approximately 1 m in the direction of the steel-pipe reservoir.

It is recommended that a wooden frame be used, resting on the top of the pipe and lined with a thin polyethylene sheet, to contain the cooling fluid (see Figure 4). The slot, under the polyethylene (PE) sheet, is filled with methylated spirits or ethanol to avoid ice formation.

8.4.4 Close-fitting wooden plug, approximately 0,5 m long, used to support the test pipe internally beneath the slot sufficiently to prevent severe pipe distortion during crack initiation (see Figure 4).

The top of the wooden plug shall have a recess containing compressible foam. The foam shall be compressed to maintain close contact with the pipe bore beneath the slot, even during pressurization.

NOTE The compressed foam will ensure that the wooden plug stays in position. Moreover, it will enable the full thickness of the slot ligament to be properly cooled by the cooling fluid above by insulating this part of the pipe bore from the pressurizing fluid (see 8.4.3).



Key

1 pneumatic impact cylinder
2 blade
3 polyethylene sheet
4 cooling fluid
5 machined slot
6 wooden trough
7 compressible insulating foam
8 wooden plug
9 PE pipe
10 wooden support, if required

Figure 4 — Example of crack-initiation position

9 Test-pipe preparation

If required, joint straight sections of pipe together by butt fusion to produce an overall pipe length of, normally, 14 m to 20 m (see following for test pipes with high RCP resistance).

When testing pipes with high RCP resistances, 4 m of the overall pipe length may be replaced by 5 m to 6 m of a crack-initiation pipe of a lower RCP resistance but of the same nominal diameter and wall thickness. A butt-fusion joint shall be used to join the two pipes. It is not necessary to remove the external or internal weld beads. Crack initiation shall then be approximately 2 m from the end of the initiation pipe.

Measure the test pipe length and, if applicable, the initiation pipe length. Measure the location of any butt-fusion joints.

Insert the wooden plug (8.4.4) and locate it underneath the position where the slot will be produced. The centre of the slot shall be at least 2 m from the pipe end.

To the end of the test pipe nearest the slot, fit an end cap, which will safely withstand the end load from the test pressure (see Figure 1).

Lay the test pipe in the trough and connect the other end of the test pipe to the steel-pipe reservoir (8.2). Ensure visually that the test pipe is straight and aligned with the steel reservoir.

Within the zone supported by the wooden plug, use the router to machine, in the external surface of the test pipe, a longitudinal slot having a depth that is constant for approximately 500 mm. Then decrease the depth gradually to zero over approximately 250 mm in the direction of the steel-pipe reservoir (see Figure 2). The width of the slot shall be 8 mm to 25 mm, with the greater widths for the thicker pipe wall thicknesses.

Sharp corners at the bottom of the slot should be avoided, in order to minimize stress concentrations and the possibility of premature crack initiation. For deep slots, several machining passes of the router can be required and, if appropriate, of different widths to produce a stepped slot.

The slot depth shall be chosen to create a sufficiently high stress to initiate a high-speed crack in the remaining ligament, which will be at a temperature of approximately –60 °C. However, the slot shall not be so deep that premature failure during pipe pressurization represents a safety hazard.

NOTE A ligament stress of 20 MPa to 25 MPa has been found to be suitable for polyethylene pipes. In general, it is then not possible to pressurize the test pipe unless the slot ligament is also cooled and maintained at approximately –60 °C.

10 Conditioning and backfill

Place the washed gravel (7.3) around the pipe, covering it to a maximum depth of 100 mm, except for the top of the pipe around the crack-initiation position so as to avoid interference with the slot cooling system.

If a water recirculation system around the test pipe is used, place cross-beams lightly on the crown of the pipe at intervals of 1 m to 1,5 m and fasten them to the trench wall to ensure that the pipe will not rise and thus create significant bending stresses when the trough is filled with water. Omit the cross-beams where they would interfere with the wooden frame (see 8.4.3). Fill the trough with water, if necessary containing a suitable quantity of antifreeze, to just below the level of the gravel.

In order to obtain the required test temperature, as specified in the referring standard, circulate the water or air along the trough, through the gravel and around the cooling system until the test temperature is established to within ± 1,5 °C all along the test pipe and, if applicable, the initiation pipe.

The conditioning time shall be at least that according to ISO 1167-1 for the appropriate pipe wall thickness. Consideration should be given to increasing the conditioning times, if the conditioning is by means of air. No matter what the means of conditioning, it shall not affect the properties of the test pipe.

Maintain the test temperature within the tolerance range for a minimum period of 1 h immediately before testing in accordance with Clause 11. The temperature shall be measured at intervals of 2 m to 3 m alternating along either side of the test pipe from the end of the wooden frame to the steel-pipe reservoir.

11 Test procedure

11.1 Cool the crack-initiation slot with the mixture of methylated spirits or ethanol and solid carbon dioxide (see 8.4.3) at approximately – 60 °C and hold for at least 1 h to ensure that the full wall thickness around the slot and 1 m in the direction of the steel-pipe reservoir are adequately cooled.

11.2 For testing with water, water/air or water/nitrogen mixtures, first fill the test pipe with the required quantity of water. Pressurize the test pipe and reservoir with air/nitrogen to the test pressure to within ± 2 %. If the air/nitrogen is not entering the pipe at approximately the specified test temperature or the re-compression in the test pipe raises the temperature, then an additional pipe-conditioning period will be required to ensure that the test pipe is uniformly at the test temperature both internally and externally [3].

Ensure that there is sufficient cooling fluid (see 8.4.3) to maintain the temperature of the slot ligament at –60 °C during the additional cooling period, as the pressurized pipe cannot be approached.

WARNING — Once the test pipe starts to be pressurized, then there is a potentially serious hazard from premature bursting of the pipe and thrown gravel.

NOTE It is very unlikely that the ligament below the machined notch will be able to sustain the test pressure without rupture, unless the ligament is kept at approximately –60 °C.

11.3 Initiate cracking by driving the metal blade at high speed through the cooled slot where the groove slot is at full depth and the pipe is supported by the wooden plug (see Figure 2).

11.4 Recover the test pipe and measure the longitudinal distance travelled by all the cracks from the centre of crack-initiation. When a crack-initiation pipe is used (see Clause 9), the crack lengths are measured from the butt-fusion joint between the initiation pipe and the test pipe.

NOTE Avoidance of crack termination by the crack travelling completely around the pipe circumference so that it rejoins the original crack (termed “ring-off”) has been successfully achieved in larger diameter PE pipes by means of a taut steel wire zigzagged across the pipe and anchored to the trench wall. The wire was placed at a height of 150 mm to 300 mm over the top of the test pipe for a distance of approximately 6 m, starting from the crack-initiation position (see Figure 1). During the test, the pipe can move about excessively in the trench so that a bending moment can be generated ahead of the running crack tip, causing it to deviate and, on occasion, ring-off. Restricting the pipe movement by the wire helps to avoid this excessive movement and hence the ring-off.

12 Validity of results

For each test pipe, the longest crack shall meet all of the following conditions:

a) the crack shall travel beyond the cooled (–60 °C) section of pipe round the slot, i.e. approximately 1,5 m from the centre of initiation;

b) the crack shall not terminate by travelling completely around the pipe circumference so that it rejoins the original crack;

c) the crack shall not terminate at a butt-fusion joint within the test pipe;

d) when using a crack-initiation pipe (see Clause 9), the crack shall propagate completely along the initiation pipe and enter the test pipe.

13 Test report

The test report shall include the following information:

a) reference to this International Standard (i.e. “ISO 13478”) and to the referring standard;

b) details necessary for complete identification of the test pipe and, if used, the crack-initiation pipe, including the manufacturer, the polymer used for manufacture, the production date and the identification marking on the pipe;

c) nominal pipe diameter and SDR or pipe series;

d) overall pipe length and, if used, the crack-initiation pipe length;

e) test pressure;

f) test temperature;

g) location(s) of the butt-fusion joint(s), if any;

h) when testing with water, water/air or water/nitrogen mixtures, details of the proportions and how they were determined;

i) axial crack lengths;

j) statement as to whether RCP or arrest occurred (see definitions);

k) date of test;

l) details of any factors which could have affected the results, such as any incidents or any operations not specified in this International Standard.

Annex A
(normative)

Determination of critical pressure (or hoop stress)

A.1 General

The following method is recommended for determining, at a given temperature, the critical pressure (or hoop stress) above which a high-speed crack initiated through the wall of a thermoplastics pipe will propagate steadily along the pipe.

A.2 Principle

A series of tests at various pressures but at a constant temperature is used to determine the critical pressure (or critical hoop stress) at which there is a sharp transition from abrupt arrest of an initial crack to continued steady propagation of the crack.

A single test, which results in crack arrest, indicates that the critical pressure for propagation is greater than the test pressure.

A.3 Procedure

A.3.1 General

Using a range of test pressures, and following the procedure in Clause 11, obtain sufficient results conforming to Clause 12 and

a) at least one test result with the longest crack being at least 90 % of the test length, i.e. rapid crack propagation;

b) at least one test result with crack arrest.

NOTE The critical pressure for rapid crack propagation needs to be exceeded to validate the crack-initiation system; otherwise it is impossible to distinguish between the arrest conditions and some defect in the crack-initiation system. However, one test is sufficient to demonstrate the validity of the crack-initiation system if crack propagation occurs along the special initiation pipe and into the test pipe. The minimum critical pressure/stress is established if crack arrest then occurs within the required length of the test pipe.

A.3.2 Critical hoop stress

A.3.2.1 Preparation

Using a π-tape, measure the mean outside diameter, d_{em}, in accordance with ISO 3126, at 3 m to 4 m intervals along the test pipe.

Include at least one measurement of each pipe section used to make up the test pipe using butt-fusion joints.

Calculate and record the average of these results as D.

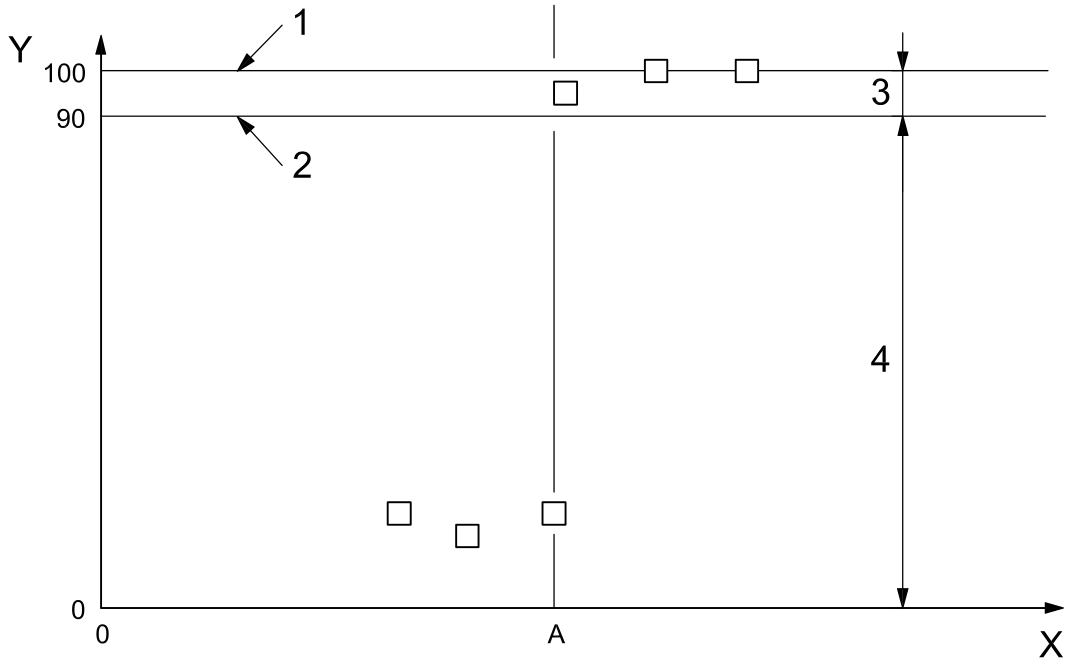
A.3.2.2 After testing

Measure the wall thickness, in accordance with ISO 3126, at intervals along the test pipe adjacent to the crack path, or main crack path if there is more than one. Record the individual wall-thickness values, and calculate and record the mean value, e_t.

A.4 Analysis for determining critical pressure

Plot a graph of test pressure against crack length (see Figure A.1).

Indicate on the graph the critical pressure, p_c.



Key

X test pressure or hoop stress

Y crack length, %

A p_c or σ_c

1 test length

2 90 % test length line

3 propagation area (see 3.5)

4 arrest area (see 3.4)

Figure A.1 — Typical test-data plot to determine the critical pressure (p_c) or critical hoop stress (σ_c)

A.5 Analysis for determining critical hoop stress

For each test pipe, calculate the hoop stress, σ, in megapascals, using Equation (A.1):

$$\sigma = \frac{p(D - e_t)}{20 e_t} \tag{A.1}$$

where

p is the test pressure, in bar [2)];

D is the average of the mean outside diameters, d_{em}, of the pipe sections, in millimetres (see A.3.2.1);

e_t is the mean wall thickness of the test pipe along the (main) crack, in millimetres.

Plot a graph of crack length against hoop stress (see Figure A.1).

Indicate on the graph the critical pressure, σ_c.

It is recommended that the test pressures be chosen alternately above and below the expected value of p_c or σ_c.

A.6 Test report — Additional requirements

A.6.1 In the case of critical-pressure determinations, the test report shall include the following additional information: the estimated critical pressure, p_c, in bar [2)].

A.6.2 In the case of critical hoop stress determinations, the test report shall include the following additional information:

a) the individual wall thicknesses of the test pipe measured along the (main) crack path, in millimetres;

b) the mean wall thickness, e_t, of the test pipe along the (main) crack path, in millimetres;

c) the mean outside diameters, d_{em}, of the test pipe, in millimetres;

d) the average, D, of the mean outside diameters, d_{em}, of the test pipe, in millimetres;

e) the estimated critical hoop stress, σ_c, in megapascals.

2) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

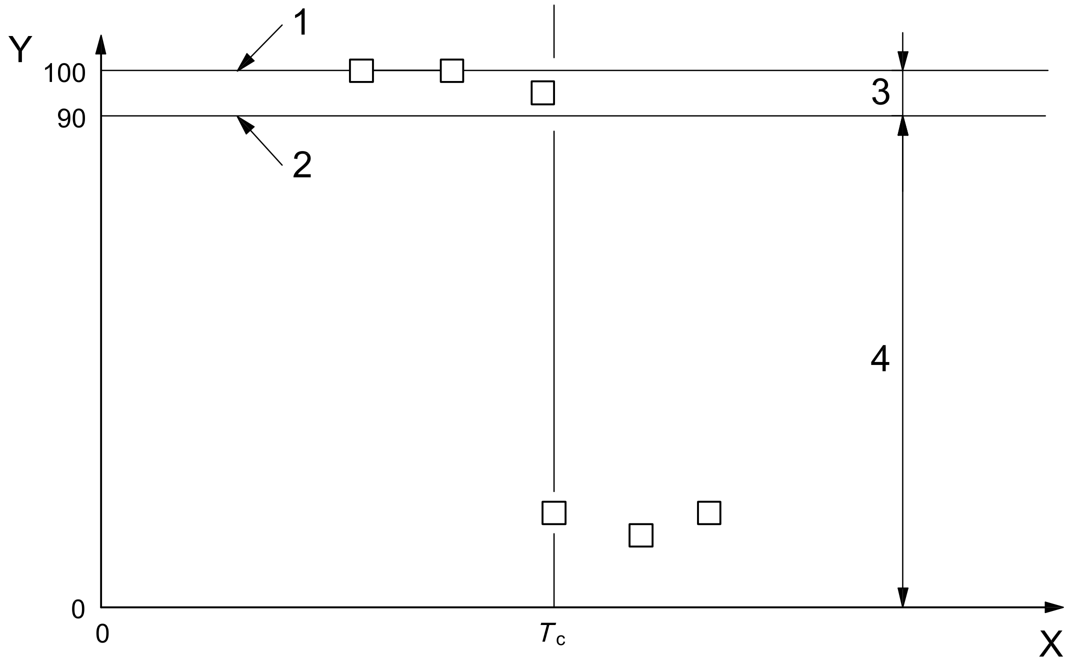
Annex B
(normative)

Determination of critical temperature

A series of tests similar to those in Annex A, on a particular type of thermoplastics pipe, may be conducted at a constant pressure or constant hoop stress to determine the critical temperature, T_c (see Figure B.1).

This can be a useful technique, as it is almost always possible to obtain both crack-arrest and propagation conditions and therefore the critical temperature. In comparison, for some thermoplastics pipes, at temperatures at or above 0 °C, rapid crack propagation may not be possible at any pressure and so the critical pressure/stress cannot be determined.

A single test resulting in crack arrest indicates that the critical temperature for crack propagation is lower than the test temperature.



Key

X test temperature
Y crack length, %
1 test length
2 90 % test length line
3 propagation area (see 3.5)
4 arrest area (see 3.4)

Figure B.1 — Typical test-data plot to determine critical temperature, T_c

Bibliography

[1] ISO 13477, *Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Small-scale steady-state test (S4 test)*

[2] GREIG, J.M. *Rapid crack propagation in hydrostatically pressurized 250 mm polyethylene pipe*, in Proc. 7th International Conference Plastics Pipes, Bath, England, September 1988, pp. 12.1–12.7

[3] VANCROMBRUGGE, R. *Fracture properties in plastic pipe*, 5th International Conference Plastics Pipes, 8-10 September 1982, University of York

[4] ROBERTSON, T.S. Propagation of brittle fraction in steel, *Journal of the iron and steel institute*, December 1953, pp. 361-374

[5] WOLTERS, M. and KETEL, G. *Some experiences with the modified Robertson test used for the study of Rapid Crack Propagation in PE-pipelines*. Proceedings of the 8th Plastics Fuel Gas Pipe Symposium, November 29-December 1, 1983, New Orleans, USA

[6] GREIG, J.M. Fracture propagation in 250 mm and 315 mm polyethylene gas pipes, *British Gas Engineering Research Station Report* No. E472, December, 1985

[7] LEEVERS, P.S., VENIZELOS, G. and IVANKOVIC, A. Rapid Crack Propagation along Pressurized PE Pipe: Small Scale Testing and Numerical Modelling, *Plastics Pipes* VIII, PRI, pp. D1/7 (1-11), Koningshof, The Netherlands, 21-24 September 1992

[8] VANSPEYBROECK, P. *Evaluation of test methods for determining rapid crack propagation properties of pressurized polyethylene gas pipes*, International Conference on pipeline reliability, Calgary, Alberta, June 1992

[9] LEEVERS, P.S. *International Journal of Fracture* (73,109), 1995

[10] VANSPEYBROECK, P. *Test methods for determining rapid crack propagation properties of pressurized polyethylene (gas) pipes*. 2nd International Pipeline Technology Conference, Ostend, Belgium, 11-14 September 1995

[11] BROWN, N. LU, X., INGHAM, E.J. and MARSHALL, G.P. *Small Scale Laboratory Test for Resistance to RCP*, Proc. International Symposium on Plastics Pipes, American Gas Association, Orlando, FL, USA, October 20-23 1999

[12] LEEVERS, P.S. and GREENSHIELDS, C.J. Correlation between full scale and S4 tests for rapid crack propagation in plastics gas pipe, *Plastics, Rubber and Composites, Processing and Applications*

[13] VANSPEYBROECK, P. RCP, *After 25 years of debates, finally mastered by two ISO-tests*, 11th International Conference Plastics Pipes, 3-6 September 2001, Munich, Germany

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