INTERNATIONAL STANDARD

ISO
12736

First edition
2014-12-15

Petroleum and natural gas industries — Wet thermal insulation coatings for pipelines, flow lines, equipment and subsea structures

Industries du pétrole et du gaz naturel — Revêtements pour isolation thermique humide de canalisations, lignes d'écoulement et structures sous-marines

Reference number
ISO 12736:2014(E)

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Contents

Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*.

Introduction

Users of this International Standard are advised that further or differing requirements can be required for individual applications.

Petroleum and natural gas industries — Wet thermal insulation coatings for pipelines, flow lines, equipment and subsea structures

1 Scope

This International Standard defines the minimum requirements for qualification, application, testing, handling, storage and transportation of new and existing wet thermal insulation systems for pipelines, flowlines, equipment and subsea structures in the petroleum and natural gas industries. The purpose of these systems is to provide external corrosion protection and thermal insulation.

This International Standard is applicable to wet thermal insulation systems submerged in seawater.

This International Standard is not applicable to thermal insulation in the annulus of a steel pipe-in-pipe system.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 34 (all parts), *Rubber, vulcanized or thermoplastic — Determination of tear strength*

ISO 37, *Rubber, vulcanized or thermoplastic — Determination of tensile stress-strain properties*

ISO 62, *Plastics — Determination of water absorption*

ISO 178, *Plastics — Determination of flexural properties*

ISO 527 (all parts), *Plastics — Determination of tensile properties*

ISO 813, *Rubber, vulcanized or thermoplastic — Determination of adhesion to a rigid substrate — 90 degree peel method*

ISO 844, *Rigid cellular plastics — Determination of compression properties*

ISO 868, *Plastics and ebonite — Determination of indentation hardness by means of a durometer (Shore hardness)*

ISO 1133 (all parts), *Plastics — Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics*

ISO 1172:1996, *Textile-glass-reinforced plastics — Prepregs, moulding compounds and laminates — Determination of the textile-glass and mineral-filler content — Calcination methods*

ISO 1183 (all parts), *Plastics — Methods for determining the density of non-cellular plastics*

ISO 1817, *Rubber, vulcanized or thermoplastic — Determination of the effect of liquids*

ISO 2781, *Rubber, vulcanized or thermoplastic — Determination of density*

ISO 2808:2007, *Paints and varnishes — Determination of film thickness*

ISO 2811-1, *Paints and varnishes — Determination of density — Part 1: Pyknometer method*

ISO 2884 (all parts), *Paints and varnishes — Determination of viscosity using rotary viscometers*

ISO 3104, *Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity*

ISO 3219, *Plastics — Polymers/resins in the liquid state or as emulsions or dispersions — Determination of viscosity using a rotational viscometer with defined shear rate*

ISO 4590, *Rigid cellular plastics — Determination of the volume percentage of open cells and of closed cells*

ISO 4624, *Paint and varnishes — Pull-off test for adhesion*

ISO 4649, *Rubber, vulcanized or thermoplastic — Determination of abrasion resistance using a rotating cylindrical drum device*

ISO 4897, *Cellular plastics — Determination of the coefficient of linear thermal expansion of rigid materials at sub-ambient temperatures*

ISO 6502, *Rubber — Guide to the use of curemeters*

ISO 7619-1, *Rubber, vulcanized or thermoplastic — Determination of indentation hardness — Part 1: Durometer method (Shore hardness)*

ISO 7822:1990, *Textile glass reinforced plastics — Determination of void content — Loss on ignition, mechanical disintegration and statistical counting methods*

ISO 8301, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 8502-3, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness — Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)*

ISO 8502-4, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness — Part 4: Guidance on the estimation of the probability of condensation prior to paint application*

ISO 8503-1, *Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates — Part 1: Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces*

ISO 11357 (all parts), *Plastics — Differential scanning calorimetry (DSC)*

ISO 14896, *Plastics — Polyurethane raw materials — Determination of isocyanate content*

ISO 15711, *Paints and varnishes — Determination of resistance to cathodic disbonding of coatings exposed to sea water*

ISO 21809-1:2011, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 1: Polyolefin coatings (3-layer PE and 3-layer PP)*

ISO 21809-3:2008, *Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 3: Field joint coatings*

EN 253, *District heating pipes — Preinsulated bonded pipe systems for directly buried hot water networks — Pipe assembly of steel service pipe*

ASTM D4060, *Standard test method for abrasion resistance of organic coatings by the taber abraser*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
applicator
company which undertakes the coating application in accordance with the provisions of this International Standard

3.2
certificate of analysis
batch certificate issued by the manufacturer

Note 1 to entry: It is a document that contains the results of tests performed by the manufacturer.

3.3
conformity certificate
certificate of conformity issued by the manufacturer

3.4
cool down time
time taken for a fluid contained within a pipeline to reach a pre-determined temperature from specific start temperatures (internal and external) when fluid flow is stopped

3.5
cutback
uncoated area defined in terms of length at the ends of each pipe which is required to prevent damage to the coating system when the pipe sections are welded together

3.6
end of life
condition of parameter of interest at the end of the service life

3.7
end user
company that owns and/or operates the production system

3.8
equipment
components other than pipelines and flowlines through which fluid flows from the well to the processing facility

EXAMPLE   Valve, manifold, christmas tree.

3.9
field joint
uncoated area that results when two pipe sections, or a pipe section and a fitting with coating cutbacks, are assembled by welding

3.10
field joint coating
coating applied after two pipe sections with coating cutbacks have been assembled, by welding, in the field or a fabrication site

3.11
field joint designer
company that proposes the field joint system for qualification in accordance with this International Standard

3.12
flowline
pipe that transfers fluid from an oil or gas well to the riser foot of a processing facility

3

3.13
heat transfer coefficient
U-value
rate of heat transfer from a reference surface under the influence of a thermal gradient

Note 1 to entry: Expressed in $W.m^{-2}.K^{-1}$.

3.14
insulation system
specific combination of pre-treatment, anti-corrosion coating, insulation and protective outer sheath to achieve the corrosion protection and insulation properties as described in this International Standard

3.15
layer
materials applied to the surface to be insulated in units of discrete thickness to build up the insulation system

3.16
manufacturer
company responsible for the manufacture of coating materials

3.17
material data sheet
form containing data regarding the physical and mechanical properties of a particular material used in the coating process including guidelines and recommendations for its processing and use

3.18
material safety data sheet
form intended to provide workers and emergency personnel with procedures for handling and working with the material in a safe manner including physical data such as flash point, toxicity, first aid

3.19
maximum rated pressure
external pressure for which the insulation layers are designed, according to the system supplier

3.20
maximum and minimum rated temperature
conditions for which the insulation layers are designed, according to the system supplier

3.21
pipeline
pipe that transfers fluid from a processing or storage facility to another location be it another processing facility, refinery, chemical plant or end user

3.22
PI tape
precision vernier periphery tape that allows the direct and accurate measurement of the diameter of tubular objects without the need for callipers or micrometers

3.23
pre-production test
PPT
series of tests performed immediately before the start of production, designed to demonstrate that the requirements of a previously qualified coating system are achieved, as outlined in this International Standard and as outlined by the purchaser

3.24
procedure qualification test
PQT
series of tests designed to demonstrate that the coating materials, coating applicator, coating equipment and coating procedure can meet the requirements as outlined in this International Standard and as outlined by the purchaser

3.25
purchaser
company responsible for providing the product order requirements

3.26
service life
specified period of use of the insulation coating in service

3.27
stalk
continuous string of welded and field joint coated pipe, which is prepared in readiness for pipe spooling onto a reel lay barge

Note 1 to entry: A number of stalks will normally be required to make up a flowline or pipeline.

3.28
stalk tie-in
weld connection followed by field joint coating, which is completed between stalks during pipe spooling

3.29
subsea structure
structural foundation or template for the positioning, support and protection of various items of production equipment

EXAMPLE   Manifolds, trees.

3.30
syntactic foam
insulation material formed by dispersing hollow particles within a polymer matrix

Note 1 to entry: Polyurethane, epoxy, phenolic and PP, silicone are examples of polymers.

3.31
system supplier
company that proposes the insulation system for qualification in accordance with this International Standard

3.32
thermal conductivity
k-value
ability of a material to conduct heat, generally quantified in terms of the heat flow through a unit length of material under the influence of a standardized temperature difference

Note 1 to entry: Expressed in $W.m^{-1}.K^{-1}$.

3.33
unit of production
quantity of three layer polypropylene coated pipes, at the same stage in the coating sequence, where the final insulation thickness is built up by multiple application of the constituent layers

Note 1 to entry: The constituent layers are the insulation layers and the top coat.

4   Abbreviated terms

3LPP	three layer polypropylene
4LPP	four layer polypropylene
APS	application procedure specification
CD	cathodic disbondment
CP	cathodic protection
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
FBE	fusion bonded epoxy
FJC	field joint coating
GSPP	glass syntactic polypropylene
GSPU	glass syntactic polyurethane
HDPE	high density polyethylene
ID	internal diameter
ITP	inspection and test plan
MFR	melt flow rate
OD	outer diameter
PE	polyethylene
PP	polypropylene
PU	polyurethane
RH	relative humidity
SPU	syntactic PU
UV	ultraviolet

5   General recommendations and requirements

A quality management system and an environmental management system should be applied to assist compliance with the requirements of this International Standard.

NOTE   ISO/TS 29001 gives sector-specific guidance on quality management systems and ISO 14001 gives guidance on the selection and use of an environmental management system.

The applicator shall be responsible for complying with all of the applicable requirements of this International Standard. It shall be permissible for the purchaser to make any investigation necessary in order to have assurance of compliance by the applicator and to reject any material and/or coating that does not comply.

6 Qualification dossier

6.1 General

A qualification dossier of the proposed insulation system in accordance with this clause shall be presented by the system supplier for review, when requested by purchaser. The requirements of this clause shall apply to all layers present in the insulation system. The content of such a dossier shall be in accordance with 6.2 and 6.3.

Historical data may be included in this qualification dossier and will be subject to review and approval by purchaser.

6.2 Content of qualification dossier

The system supplier shall provide qualification documentation which shall include the following as a minimum.

a) System summary:

    1) description of the insulation system tested;

    2) maximum rated temperature and pressure;

    3) minimum and maximum temperature guidelines for storage, handling, installation and corresponding recommendations.

b) Insulation system materials:

    1) material or layer technical data sheet and material safety data sheet;

    2) recommended shelf life and storage instructions;

    3) material, or layer when applicable, conformity certificate and material certificate of analysis from the manufacturer with the following information:

        i) product name and manufacturer;

        ii) manufacturing plant;

        iii) date of manufacture;

        iv) batch number;

        v) properties to be tested with every batch and corresponding conformity ranges;

        vi) date of issue;

        vii) signature of authorized personnel (with name and function);

    4) test data for each individual layer, in accordance with Clause 7.

c) As applied coating: qualification data for the application process, in accordance with Clause 9.

d) Full scale testing: test data for the complete system as applied, in accordance with Clause 8.

6.3 Anti-corrosion coating documentation

The purpose of this International Standard is not to define a proper qualification program for anti-corrosion coating. The wet insulation system supplier can select any anti-corrosion coating suitable for the maximum rated temperature of its insulation system and with which the system will pass the qualification requirements of this International Standard.

If the anti-corrosion coating selected by the end user is different from the one used by the system supplier for qualification, both parties shall agree on a test program to ensure that anti-corrosion coating and wet insulation are compatible up to the maximum rated temperature of the insulation system.

7 Layer test requirements

7.1 General

Each layer of the insulation system or each insulation material shall be tested as specified in this clause.

Table 1 specifies general properties to be tested for each layer where applicable.

Table 2 specifies properties to be tested on a case by case basis by agreement with the purchaser.

Each property measurement shall be documented along with the acceptance criteria for use in Clause 9.

Requirements for the qualification of repair materials shall be by agreement.

Table 1 — General properties

Layer property	Test specification	Test temperature 23°C ± 2°C	Maximum rated temperature	Minimum rated temperature
Thermal conductivity	ISO 8301	✓	✓	
Specific heat capacity	ISO 11357	✓	✓	
Hydrostatic compressive behaviour	Annex A	✓	✓	
Water absorption	ISO 62, ISO 1817[a]	✓	✓	
Density	ISO 1183	✓		
Tensile properties	ISO 527, ISO 37[b]	✓	✓	✓
Hardness	ISO 868	✓		
DSC	ISO 11357-2	Temperature range		
DMA	N/A	Temperature range		
[a] ISO 1817 for elastomers.				
[b] ISO 37 for elastomers.				

Table 2 — Specific properties

Material property	Test specification	Test temperature 23°C ± 2°C	Maximum rated temperature	Minimum rated temperature
Compressive strength	ISO 844	✓	✓	✓
Abrasion resistance	ASTM D 4060 / ISO 4649 [a]	✓		
Coefficient of linear thermal expansion	ISO 4897		✓	✓
UV resistance	See 7.2.5			
[a] ISO 4649 for elastomers				

7.2 Ageing tests

7.2.1 General

The purpose of the ageing tests is to estimate the thermal, chemical and mechanical stability for the material's service life. The tests shall account for:

— all expected ageing phenomena, (including thermal and chemical ageing);

— the failure mechanism of the insulation material,

— any water absorption and pressure effects.

For certain materials, physical changes can produce results in tensile testing that are not indicative of chemical change. In such cases additional testing may be performed in order to explain and to understand the extent and criticality of these physical changes. This may include the use of general and material specific analysis techniques that lie outside of this specification. The results of such investigative work shall be included in the test dossier.

End of life properties should be determined and considered based on relevant application specific acceptance criteria. These shall be defined and explained by the system supplier with the ageing test results.

For each individual layer (or material) available in a range of density, the ageing tests are required only for one density, provided the data in Table 1 are documented for the relevant range of density.

In order to estimate the potential degradation of an insulation system due to wet ageing, two tests shall be performed:

— determination of the water absorption kinetic of each layer in the insulation system (7.2.2);

— determination of the degradation of the thermo-mechanical properties of each layer due to water ageing (7.2.3).

Ageing tests are not required for anti-corrosion and adhesive layers.

An optional full insulation system ageing test may be carried out in accordance with 7.2.4 to verify the long term behaviour.

7.2.2   Water absorption kinetic test

The objective shall be the determination of the end of life, through thickness, water profile.

Ageing media shall be either fresh water or seawater. Artificial seawater, if used, shall be prepared in accordance with ISO 15711.

The test shall be performed as follows:

— four temperatures:

  — 4°C;

  — maximum rated temperature minus 30°C;

  — maximum rated temperature minus 15°C;

  — maximum rated temperature (as defined in 6.2);

— duration: 1 year;

— pressure: maximum rated pressure (as defined in 6.2);

— 5 samples of each size per ageing temperature;

— sample sizes for ageing tests shall be (50 x 50 x 4) mm and (50 × 50 × 8) mm. Moulded samples should be used whenever possible;

— weighing intervals: 1, 2 weeks and 1, 3, 6 and 12 months. After removal from water, samples shall be dried with a clean dry cloth or filter paper and weighed. These six data points shall be reported on a graph and the absorption kinetic (diffusion coefficient and saturation) of the material(s) shall be determined. The test media shall be replaced at each sampling interval.

NOTE 1   Using the classical diffusion law (Fick), these data allow (knowing the through thickness temperature profile) an estimation of the end of life through thickness water profile of the structure (see detailed guidance as information in Annex K).

NOTE 2   In the case of non-Fickian diffusion (Langmuir, loss of weight), more complex analysis can be performed in order to estimate the through thickness long term behaviour of the insulation system (see Annex K).

7.2.3   Wet heat ageing behaviour

The potential degradation shall be verified by testing of tensile properties at 23°C ± 2°C. Flexural testing may be carried out in place of tensile testing for brittle materials.

Sample preparation shall be fully described.

Tensile tests shall be performed in accordance with ISO 527 for thermoplastics or ISO 37 Type 1 for elastomers. Flexural testing for brittle materials shall be performed in accordance with ISO 178.

Ageing media shall be either fresh water or seawater. Artificial seawater, if used, shall be prepared in accordance with ISO 15711.

The ageing test shall be performed as follows:

— three temperatures:

— maximum rated temperature minus 30°C;

— maximum rated temperature minus 15°C;

— maximum rated temperature (as defined in 6.2).

— duration: 1 year;

— pressure: maximum rated pressure (as defined in 6.2);

— 5 samples per ageing temperature and sampling step;

— sampling intervals: 1, 3, 6 and 12 months.

Before mechanical testing, samples shall be kept in water (identical to the one used for the ageing test) at 23°C ± 2°C for a period of 24 h minimum, and tested immediately after being taken out of water.

At sampling intervals, samples shall be dried after removal from water with a clean dry cloth or filter paper, weighed and tested in accordance with relevant standard without any reconditioning (no drying of samples). The test media shall be replaced at each sampling interval.

7.2.4   Full insulation system ageing test (optional)

An approximately 1 m long tube, minimum 25 mm in diameter and coated with approximately 50 mm of the full insulation system (see Figure 1 for details), shall be used for the full insulation system ageing test.

Ageing media shall be either fresh water or seawater. Artificial seawater, if used, shall be prepared in accordance with ISO 15711.

The ageing test shall be performed as follows:

— internal temperature: maximum rated temperature (as defined in 6.2);

— external temperature: 20°C ± 3°C;

— duration: 1 month to 6 months;

— pressure: atmospheric pressure (or under pressure if necessary);

— in case of seawater, CP will be provided with a sacrificial anode.
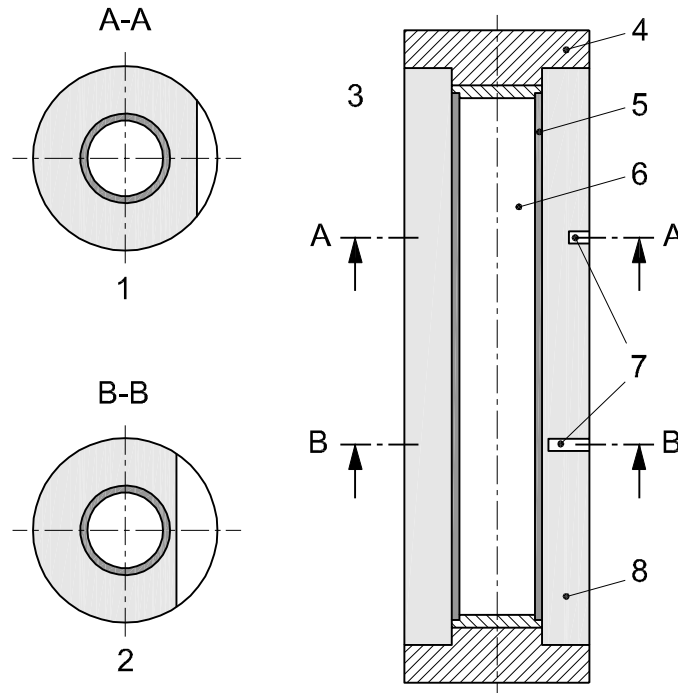
Key

1 notch depth: half of the thickness through thickness
2 notch depth: full thickness down to the anticorrosion layer
3 water temperature = + 20°C ± 3°C
4 end closure
5 steel tube
6 fluid at maximum rated temperature
7 4 mm width cracks
8 insulation system

Figure 1 — Schematic of the full insulation system ageing test

After ageing, any visible degradation (e.g. crack, indication of local hydrolysis) shall be assessed. Additional physical and chemical testing can be performed and the results provided within the qualification dossier.

7.2.5 Weathering and UV resistance

Data shall be provided by the insulation system supplier to demonstrate that the system can resist UV exposure. Alternatively, specific storage conditions or protection from atmospheric exposure shall be detailed by the insulation system supplier.

NOTE   Weathering and UV resistance is a concern during storage of components or pipes and for parts exposed to atmospheric conditions. This effect is mainly superficial and concerns the outer layers of the insulation system.

8   Insulation system test requirements

8.1   General

In this clause, the properties that shall be tested for the complete insulation system are defined.

A detailed test program shall be prepared by the system supplier in accordance with Table 3 to define the design basis of the insulation system in terms of pressure and temperature range, installation

constraints and thermal performance. This design basis shall then be used for comparison with the specific conditions for which the system is planned to be used. If specific conditions are outside the design basis then purchaser or end user may decide to test specific properties following the guidelines of 8.2.

The parameters for the tests in Table 3 shall be defined by the insulation system supplier (pressure, temperature etc.).

Testing shall be carried out on the complete system applied in accordance with Clause 9.

If applicable, testing shall include a field joint applied in accordance with the requirements of Clause 10.

8.2   Full scale test program

8.2.1   Test summary

The test program for flowlines, risers, jumpers and subsea equipment shall include, but shall not be limited to, the tests shown in Table 3 and described in 8.2.2 to 8.2.7.

Table 3 — Full scale tests

	Flowlines	Risers	Jumpers	Subsea equipment	Field joint
Baseline tests (optional)					
Cathodic disbondment test (8.2.2)	✓	✓	✓	✓	✓
Adhesion test (8.2.2)	✓	✓	✓	✓	✓
Installation requirements					
Bend test (8.2.3)	✓	✓	✓ [b]		✓ [c]
Simulated tensioner test (8.2.5) (optional)	✓	✓			✓
In-service requirements					
Simulated cyclic bend test (8.2.4)[a]	✓	✓	✓		✓
Impact test (8.2.6)	✓	✓	✓	✓	✓
Temperature/pressure simulated service tests					
Factory applied (8.2.7)	✓	✓	✓		
Field joints (8.2.8)	✓	✓	✓	✓	✓
Subsea equipment (8.2.9)				✓	
[a] If relevant for flowlines due to vortex induced vibrations in free spans or pipe movements on seabed.					
[b] Optional test.					
[c] As per the flowline, riser, jumper, subsea requirement.					

8.2.2   Baseline tests (optional)

If required by the purchaser, the following tests shall be carried out on the complete insulation system prior to any simulated installation or in-service tests in order to establish the baseline:

— CD test at 23°C for 28 days, or as specified by the purchaser, in accordance with the relevant International Standard for the anti-corrosion coating;

— adhesion testing to be detailed by the system designer to include any/all of:

— peel test as per ISO 21809-1:2011, Annex C, or ISO 813;

— pull off test as per ISO 4624;

— ring shear test as per Annex I.

NOTE   The objective is to test before and after some of the simulated tests listed in this clause, in order to compare the values and check for any possible degradation. The corresponding acceptance criteria are material and application dependant.

8.2.3   Simulated bend test

The objective of the test is to determine if the factory applied and field joint coating systems display any visible or audible signs of distress, for example, cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product when subjected to bending during spooling or installation operations. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate. These visible or audible signs of distress shall be recorded.

Where appropriate, the test string should comprise a field joint coated girth weld positioned such that it experiences the maximum strain during bend test.

The test procedure should be as defined in Annex B. The parameters needed to perform the test shall be defined by the insulation system supplier.

After sectioning along the maximum as-bent strain axes, the coating systems shall not display any through thickness cracking, or through thickness separation between the line pipe and the field joint. Cracking around anode pad brackets shall be assessed on a case by case basis. Effects such as disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product shall be recorded.

Optionally, adhesion test and CD test (8.2.2) may be carried out for comparison with baseline tests.

8.2.4   Cyclic (fatigue) bend test

The objective of the test is to determine if the factory applied and field joint coating systems display any visible or audible signs of distress, for example, cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product when subjected to cyclic bending. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate. These visible or audible signs of distress shall be recorded.

The test procedure shall be as described in Annex C. The parameters needed to perform the test shall be defined by the insulation system supplier.

During execution of the test, the variations in the axial strains and temperatures in the test pipe shall be reviewed for anomalies.

After sectioning along four positions (3, 6, 9 and 12 o'clock), the coating systems shall not display any through thickness cracking or through thickness separation between the line pipe and the field joint. Cracking around anode pad brackets shall be assessed on a case by case basis. Effects such as disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product shall be recorded.

8.2.5   Simulated tensioner test (optional)

The objective of the test is to determine the coefficients of friction between the tensioner pads and the coating system for a range of temperatures and compressive/squeeze loadings. In addition, the objective is to determine if slippage occurs between the tensioner pads and the field joint coating system when subjected to the required axial and compressive/squeeze loadings.

The test procedure shall be as described in Annex D. The parameters needed to perform the test shall be defined by agreement between the insulation system supplier and the pipelay vessel owner.

There shall be no cracking or damage to design thickness of coating systems, including field joint coating systems, that is detrimental to the thermal performance and corrosion protection of the system.

Coefficients of friction between the tensioner pads and the coating system shall be determined for a range of temperatures and compressive/squeeze loadings.

8.2.6   Impact test

The objective of the test is to confirm that the coating system will not display any visible or audible signs of distress, for example, cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product when subjected to impact test. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate. These visible or audible signs of distress (if any) shall be recorded.

The test procedure shall be as described in Annex E. The parameters needed to perform the test shall be defined by the insulation system supplier. If trawl board testing is required, the test procedure as described in DNV RP F111 should be used.

There shall be no cracking or damage to design thickness of coating systems, including field joint coating systems, that is detrimental to the thermal performance and corrosion protection of the system.

8.2.7   Simulated service test (factory applied coating)

The objectives of the test are to:

— confirm that the U-value of the insulation system is in accordance with the expected design basis as defined by the insulation system supplier in 8.1 when subjected to the specified temperature gradient through its thickness and hydrostatic pressure under short term conditions (typically a minimum of 7 days after thermal stability has been established);

— optionally, confirm that the cool down time of the insulation system is in accordance with the expected design basis as defined by the insulation system supplier in 8.1;

— demonstrate that the hydrostatic compressive properties of the insulated system are in accordance with the design basis as defined by the insulation system supplier in 8.1.

The test procedure shall be as described in Annex F.

Measured U-value, and cool down time if determined, of the insulation system shall be in accordance with the design basis as defined by the insulation system supplier in 8.1.

Measured radial compression of the insulation system shall be in accordance with the design basis as defined by the insulation system supplier in 8.1.

Optionally, the test piece may be sectioned after completion of the test. After sectioning, the coating systems shall not display any visible signs of distress, for example, cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing, as deemed detrimental to the product. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate. These visible or audible signs of distress shall be recorded.

8.2.8   Simulated service test (field joint)

The objectives of the test are to:

— identify potential hot water degradation mechanisms within insulation system, especially at the interface with the parent coating (coating on both sides of the field joint, at the cutback areas);

— optionally, confirm that the cool down time and the U-value of the insulation system when subjected to a temperature gradient through its thickness and hydrostatic pressure under short term real time conditions are in accordance with design basis as defined by the insulation system supplier in 8.1;

— demonstrate that the hydrostatic compressive properties of the insulated system are in accordance with the design basis in accordance with 8.1.

The test procedure shall be as described in Annex G.

Hot water degradation mechanisms within insulation system, especially at the interface with the parent coating (coating on both sides of the field joint, at the cutback areas), shall be identified and reported.

If measured, cool down time and U-value shall be within the design basis as defined by the insulation system supplier in 8.1.

Measured radial compression of the coating system shall be in accordance with the design basis as defined by the insulation system supplier in 8.1.

Optionally, the test piece may be sectioned after completion of the test. After sectioning, the coating systems shall not display any visible signs of distress, for example; cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate.

8.2.9   Simulated service test (subsea equipment) (optional)

The objectives of the test are to:

— identify potential mechanical and/or structural failure mechanisms of the insulation system due to geometrical/dimensional section changes in the structure of trees, manifolds, etc.;

— demonstrate that the compressive properties of the insulated system are in accordance with the design basis as defined by the insulation system supplier in 8.1;

— optionally, confirm that the cool down time and U-value of the insulation system when subjected to a temperature gradient through its thickness and hydrostatic pressure under short term real time conditions are in accordance with design basis as defined by the insulation system supplier in 8.1.

The test procedure shall be as described in Annex H.

The coating systems shall not display any through thickness cracking or through thickness separation along the construction joint. Effects such as disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product shall be recorded.

Measured radial compression of the insulation system shall be in accordance with the design basis as defined by the insulation system supplier in 8.1.

After sectioning, the coating systems shall not display any visible signs of distress, for example, cracking, disbondment, stress whitening, deformation, blistering, separations between layers or tearing as deemed detrimental to the product. In addition, there should be no disbondment of the insulation system and/or anti-corrosion coating from the steel substrate. These visible signs of distress shall be recorded.

If measured, the U-value and cool down time of the insulation system shall be in accordance with the design basis as defined by the insulation system supplier in 8.1.

Optionally, adhesion test or peel test (8.2.2) may be carried out for comparison with baseline tests.

If specified, samples of the insulation material shall be taken from the test piece after completion of the simulated service testing and subjected to the material property testing described in 7.1.

9   Application process and quality control

9.1   General

This clause defines the requirements for control of the application of insulation systems. The generic types of systems listed here are the ones which are already well known in the industry. For each type

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of system, the corresponding tables shall be used as minimum requirements to be followed by the applicator during application.

If other system types are used, this clause should be used as guidance for the development of specific application process and quality control requirements.

9.2 Qualification of operators

Personnel involved in the coating operation shall be trained and qualified in accordance with applicator training programs and quality assurance systems.

The qualification training program and training records for personnel shall be available to the end user and purchaser for review.

Alternatively, the qualification of coating personnel may be obtained via a certification organization, by demonstration at a PQT or during PPT as agreed with end user or as defined in ISO 21809-3. The system supplier of the insulation materials and equipment may provide technical assistance to the coating personnel.

9.3 Application procedure specification (APS)

The thermal insulation system application shall be performed in accordance with an APS.

The APS shall document the following:

a) statement of applicable scope;

b) step by step description of the application;

c) critical process parameters which convert or affect material properties;

d) procedures for special processes not covered by items b) and c);

e) inspection and test plan;

f) references to specifications (if applicable) and materials used in the application of the wet insulation system;

g) coating repair procedures.

EXAMPLE   A special process which would require its own detailed procedure [see item d) above] could be a subsea structure where, due to complex geometry, the application technique requires the use of moulds.

9.4 Procedure qualification test (PQT)

If requested by the end user or purchaser, the APS shall be qualified by a PQT. Test methods, acceptance criteria and frequencies for PQT shall be specified in the ITP.

The PQT should be carried out in presence of the end user and/or purchaser (or their representative) if requested.

The applicator may request the material manufacturer or system supplier to assist during the PQT to ensure the correct use of the coating material(s) and to train applicator's personnel.

Qualification tests shall be carried out on representative pipes or subsea components.

All tools and equipment (e.g. for induction heating, abrasive blasting, coating application and inspection) to be used for PQT shall be of the same type as those to be used for the actual coating.

The applicator shall submit a complete report of the qualification test results to the purchaser for approval.

Relevant parameters for the application process recorded during PQT shall be implemented during PPT and production. The allowable ranges for these parameters should be agreed between applicator and

purchaser. If these parameters fall outside the agreed ranges, additional testing may be agreed between purchaser and applicator demonstrating equal or better performance when compared to PQT and PPT.

9.5 Pre-production test (PPT)

If required by the end user or purchaser, a PPT shall be performed at start of production to verify the PQT or any previous qualification or historical data.

Tests methods, acceptance criteria and frequencies for PPT shall be specified in a dedicated ITP.

The PPT shall be carried out in presence of the end user and/or purchaser (or their representative) at the start of operations when equipment and personnel are mobilised on site.

9.6 Production tests

9.6.1 General

The applicator shall perform inspection and testing during production in accordance with an ITP to verify the surface preparation, raw materials and coating application.

The ITP shall be prepared by the applicator and shall be approved by the purchaser and end user prior to the start of production, and prior to the start of any PQT and/or PPT. The ITP shall identify all inspection activities and tests, their frequency and the relevant inspection authorities.

A repair procedure shall be established for each insulation system and tested at PQT stage.

9.6.2 Polypropylene insulation system

9.6.2.1 General

A multi-layer polypropylene insulation system is typically a combination of an anti-corrosion coating, an insulation layer(s) of syntactic/foam/solid polypropylene, and a solid polypropylene top coat.

For each of these layers, the minimum requirements in 9.6.2.2 to 9.6.2.5 shall apply.

9.6.2.2 Three layer polypropylene

The 3LPP coating, applied over the grit blasted steel, shall be in conformance with ISO 21809-1:2011.

9.6.2.3 Four layer polypropylene

A 4LPP consists of FBE primer, adhesive, PP foam and solid PP top coat.

If a 4LPP coating is applied over the grit blasted steel, the FBE and adhesive shall be in accordance with ISO 21809-1:2011, Clause 10, and the appropriate inspection tests of ISO 21809-1:2011, Clause 11, for the surface preparation, FBE and adhesive layers.

9.6.2.4 Polypropylene insulation material

The insulation material shall meet the requirements of Table 4.

Table 4 — Minimum inspection and testing for PP insulation layer application

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density	kg/m^3	ISO 1183	Within the manufacturer's certificate of conformity	Each batch	Each batch	Each batch

Table 4 *(continued)*

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
MFR	grams per 10 min	ISO 1133	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density (glass microspheres)	g/cm^3	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Crush strength (glass microspheres)	MPa	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3°C above dew point	Each pipe	Each pipe	Start of each shift
Visual inspection of previously coated surface (if applicable)	-	Visual Inspection	Pipe surface shall be free from moisture and contamination	Each pipe	Each pipe	Each pipe
Heating of previous coated surface (if applicable)	°C	Infrared pyrometer or equivalent	Acceptable range to be established during PQT	Each pipe	Each pipe	All pipes checked with infrared pyrometer and recorded once per hour
Laboratory testing						
Interlayer adhesion test between insulation layers (if applicable – on full thickness)	MPa	ISO 527	Cohesive break within layers after tensile tests. Alternatively, shear tests acceptable if thickness allows (test in accordance with Annex I)	Each pipe	2 pipes	Once per day
Density control (GSPP)	kg/m^3	ISO 1183	Nominal density ± 10 kg	Each pipe	2 pipes	Once per day
Density control (PP foam)	kg/m^3	ISO 1183	Nominal density ± 40 kg	Each pipe	2 pipes	Once per day
Mass ratio of glass microspheres (GSPP)	%	As per Annex J	Acceptable range to be established during PQT	Each pipe	2 pipes	Once per day
Glass microspheres density after processing (GSPP)	%	As per Annex J	Acceptable range to be established during PQT	Each pipe	2 Pipes	Once per day
Entrapped air ratio (GSPP)	%	As per Annex J	Acceptable range to be established during PQT	Each pipe	2 Pipes	Once per day
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Compressive Strength	MPa	ISO 844	In accordance with Table 1 at 23°C ± 2°C	Each pipe	N/A	N/A
Tensile strength and elongation at break	MPa %	ISO 527	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Hydrostatic test (GSPP)	%	Annex A	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Final inspection						
Coated pipe surface temperature control after cooling		Measurement with contact thermocouple	< 80 °C	Each pipe	Each pipe	Three times per shift
Thickness control		Measurement with PI tape or electronic equipment.	As specified	Each pipe on 5 locations along the pipe	Each pipe on 5 locations along the pipe	Each pipe on 5 locations along the pipe

9.6.2.5   Polypropylene top coat

The top coat shall meet the requirements of Table 5.

Table 5 — Minimum inspection and testing for PP top coat layer application

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density	kg/m^3	ISO 1183	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
MFR	grams per 10 min	ISO 1133	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3°C above dew point	Each pipe	Each pipe	Start of each shift
Control of previous coated surface (if applicable)	-	Visual inspection	Pipe surface shall be free from moisture and contamination. No flat spots, dents, air bubbles.	Each pipe	Each pipe	Each pipe
Heating of previous coated surface (if applicable)	°C	Infrared pyrometer or equivalent	Acceptable range to be established during PQT	Each pipe	Each pipe	All pipes checked with infrared pyrometer and recorded once per hour
Top coat application						
Top coat coating thickness	mm	Measurement with PI tape or electronic equipment	As specified	Each pipe (5 locations along the pipe)	Each pipe (5 locations along the pipe)	1st pipe then every 20th pipe
Laboratory testing						
Adhesion between layers	-	Visual inspection at pipe ends (cutback)	No delamination between layers	Each pipe	Each pipe	Each pipe
Elongation at break	%	ISO 527	≥ 400	Two test (on 3 test pieces)	Two test (on 3 test pieces)	Each batch of PP (on 3 test pieces)
Final inspection						
Total coating thickness	mm	Measurement with PI tape or electronic equipment	As specified	Each pipe (5 locations along the pipe)	Each pipe (5 locations along the pipe)	Each pipe on 5 locations along the pipe
Ovality	%	Calliper and PI tape	$(OD_{max}-OD_{min})/OD_{PI\ tape} < 2\ \%$	Each pipe	Each pipe	1st pipe then every 20th pipe
Concentricity		Straight edge ruler or electronic equipment at cutback area	±10 % of nominal thickness	Each pipe, 8 measurements	Each pipe, 8 measurements	Once every 20 pipes
Hardness	Shore D	ISO 868	≥ 60	Two test	One test	Once per shift
Cutback	mm	measurement	By agreement	Each pipe	Each pipe	Each pipe

9.6.3 Polyurethane insulation systems

9.6.3.1 Polyurethane applied in liquid form

Polyurethane is applied in liquid form using suitable dispensing equipment. It can be either in solid/foam or syntactic form.

The insulation should be applied over a suitable anti-corrosion coating.

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The insulation system shall meet the requirements of Table 6.

Table 6 — Minimum inspection and testing requirements for PU

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density (polyol)	Relative to water at 1,0	Manufacturer's method	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Viscosity (polyol)	cPs	ISO 3104 or ISO 3219	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Gel time of mixed system (polyol + Iso)	s	Manufacturer's method	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness of cured system	Shore A or Shore D	ISO 868	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Isocyanate content	%	ISO 14896	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density (glass microspheres)	g/cm^3	Manufacturer's method	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Crush strength (glass microspheres)	%	Manufacturer's method	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3°C above dew point	Each item	Each item	Start of each shift
Anti-corrosion coating surface preparation	-	Visual	If applicable, abrasion with sand paper grit 50 minimum and dust vacuum cleaning (alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used)	Each item	Each item	Each item
Adhesion promoter application (if required)						
Pot life	min	stop watch	Cure time check in accordance with manufacturer's recommendation	Each batch	Each batch	Each batch
Mix ratio	Ratio by weight	Weight measurement	Ratio and tolerance according to Manufacturers recommendation	Start of PQT	Start of PPT	Each shift
Visual appearance	-	Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	Each item	Each item	Each item
PU application						
Mix ratio	Ratio by weight	Weight measurement	as per manufacturer's recommendation with a maximum of ± 2 %.	Start of PQT	Start of PPT	Once per shift or at start of each pouring.

a	Not applicable for foams.
b	In case of massive structure for subsea (typically Christmas trees), the minimum item and mould temperature might be defined during PQT.

Table 6 *(continued)*

Property	Units	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Verification of raw material properties by a "cup shot"	Visual	Cured 0,5 l (approximately) fixed mass sample at 23 °C	Good mixing. No air, no discolouration from unmixed components, etc.	Start of PQT	Start of PPT	Start of each shift
Gel time check (machine dispensed)[a]	s	Stop watch	For information (to be used as reference for maximum pour time limitations)	once	once	Once per shift or start of each pouring
Visual inspection of the mould prior to moulding	-	Visual	Clean, no adhering PU	Each item	Each item	Each pipe
Raw material processing temperature	°C	Thermocouple	As per manufacturer's recommendation	once	once	Once per shift
Mould temperature[b]	°C	Thermocouple	Acceptable range to be established during PQT	Each item	Each item	Monitor continuously and record once per hour
Anticorrosion coating surface temperature[b]	°C	Contact thermometer	Acceptable range to be established during PQT	Each item	Each item	Monitor continuously and record once per hour
Minimum demoulding time	s	Stop watch	Acceptable range to be established during PQT	Each item	Each item	Monitor continuously and record once per hour
Laboratory testing						
Density test	kg/m^3	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	Once for PPT (for GSPU and foam only)	Once per shift (for GSPU and foam only)
Tensile strength and elongation test	MPa %	ISO 527	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	N/A	N/A
Compressive strength test	MPa	ISO 844	In accordance with Table 2 at 23°C ± 2°C	Once for PQT	once for PPT	once at production start up
Thermal conductivity test	W/(mK)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	N/A	N/A
Hydrostatic test (GSPU)	%	Annex A	In accordance with Table 1 at 23°C ± 2°C	Once per PQT	N/A	N/A
Mass ratio of glass microspheres (GSPU)	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Glass microspheres density after processing (GSPU)	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Entrapped air ratio (GSPU)	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Adhesion pull off test	MPa	ISO 4624	Acceptable range to be established during PQT. Alternatively, shear tests acceptable if thickness allows (test in accordance with Annex I)	Each item	Each item	Per agreement
Final inspection						

[a]   Not applicable for foams.

[b]   In case of massive structure for subsea (typically Christmas trees), the minimum item and mould temperature might be defined during PQT.

Table 6 *(continued)*

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Hardness	Shore A or Shore D	ISO 868	within manufacturer's certificate of conformity range	Each item	Each item	Each item
Insulation thickness	mm	PI tape or electronic equipment	As specified	Each item	Each item	Each item
Concentricity (for pipes only)	%	Straight edge ruler or electronic equipment at cutback area	±10 % of nominal thickness	Each item, 8 measurements	Each item, 8 measurements	Once per shift (or as applicable)
Ovality (for pipes only)	%	Calliper and PI tape	$(OD_{max}\text{-}OD_{min})/OD_{PI\,tape} < 2\,\%$	Each item	Each item	1st pipe then every 20th pipe (or as applicable)
Cutback	mm	Measurement	By agreement	Each item	Each item	Each item
Removal of release agent	-	Visual		Each item	Each item	Each item
Visual inspection	-	Visual	Mouldings are free from large air traps, porosity, debris, knit lines, cavities and disbondments at joints and substrate interfaces. Cosmetic surface faults may be accepted	Each item	Each item	Each item

a Not applicable for foams.

b In case of massive structure for subsea (typically Christmas trees), the minimum item and mould temperature might be defined during PQT.

9.6.3.2 PU foam application using spray or injection method with extruded polyolefin outer jacket

The insulation system shall meet the requirements of Table 7.

Table 7 — Minimum inspection and testing requirements

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (PU - Manufacturer's data)						
Density (polyol)	Relative to water at 1,0	Manufacturer	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Viscosity (Polyol)	cPs	ISO 3104 or ISO 3219	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Cream and string time (PU foam)	s	Manufacturer	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Isocyanate content	%	ISO 14896	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Raw material testing (polyolefin outer jacket - Manufacturer's data)						
Density	kg/m^3	ISO 1183	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
MFR	g/10 min	ISO 1133	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Carbon black content (HDPE)	%	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3°C above dew point	Each pipe	Each pipe	Start of each shift

Table 7 *(continued)*

Property	Units	Test method	Requirements	Frequency		
				PQT	PPT	Production
Anti-corrosion coating surface preparation		Visual	If applicable, abrasion with sand paper grit 50 minimum and dust vacuum cleaning (alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used)	Each pipe	Each pipe	Each pipe
Coating application						
Pipe pre-heat temperature	°C	Infrared pyrometer or equivalent	Within manufacturer's recommendation or within PQT range	Each pipe	Each pipe	Twice per shift
Mix ratio	Ratio by weight	weight measurement	±2 % from manufacturer's data sheet	Once	Once	Once per shift
Laboratory testing						
Density	kg/m³	ISO 1183	in accordance with Table 1 at 23°C ± 2°C	one pipe	one pipe	Once per shift
Closed cell content	%	ISO 4590	Within PQT range	one pipe	one pipe	Once per shift
Compressive strength	MPa	ISO 844	in accordance with Table 1 at 23°C ± 2°C	one pipe	one pipe	Once per week
Thermal conductivity	W/(mK)	ISO 8301	in accordance with Table 1 at 23°C ± 2°C	one pipe	one pipe	Once per week
Final inspection						
Insulation thickness	mm	PI tape or electronic equipment	as specified	Each pipe	Each pipe	Each pipe
Insulation cutback	mm	Tape measure	By agreement	Each pipe	Each pipe	Each pipe
Axial shear test	MPa	EN 253	Cohesive break within foam	One pipe	One pipe	by agreement
Polyolfin jacket thickness (on cutback area)	mm	Callipers	as specified	Each pipe	Each pipe	Each pipe

9.6.4   Silicone insulation systems

Silicone insulation systems shall only be applied over an anti-corrosion coating.

It may be cast in place or applied as pre-cast forms with thickened uncured material used as an adhesive.

The insulation system shall meet the requirements of Table 8.

Table 8 — Minimum inspection and testing requirements for silicone

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Viscosity	cPs	ISO 2884	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Gel time	min	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness of cured system	Shore A	ISO 868	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch

Table 8 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Specific gravity	kg/m³	ISO 1183-1	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Tensile properties (modulus, elongation at break, tensile strength at break)	MPa %	ISO 37	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density (glass microspheres)	g/cm³	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Crush strength (glass microspheres)	MPa	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Start of each shift
Anti-corrosion coating surface preparation		visual	If applicable, abrasion with sand paper grit 50 minimum and dust vacuum cleaning (alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used)	Each item	Each item	Each item
Adhesion promoter application						
Over coating time	min	-	Time check in accordance with manufacturer's recommendation	Each item	Each item	Each item
Visual appearance		Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	Each item	Each item	Each item
Silicon application						
Mix ratio	Ratio by weight	Weight measurements	±5 % from manufacturer's data sheet.	One item	One item	Once per shift or at start of each pouring.
Verification of raw material properties by a "cup shot"	Visual	Cured 0,5 l (approximately) fixed mass sample at 23 °C	Good mixing. No air, no discolouration from unmixed components, etc.	Start of PQT	Start of PPT	Start of each shift
Visual inspection of the mould		Visual	Clean	Each pipe	Each pipe	Each item
Laboratory testing						
Density	kg/m³	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	Once	Once	Once per shift
Tensile strength and elongation at break	MPa %	ISO 37	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Compressive Strength	MPa	ISO 844	In accordance with Table 2 at 23°C ± 2°C	Each pipe	N/A	N/A
Adhesion (pull off)	MPa	ISO 4624	As agreed during PQT	Each item	Each item	By agreement

Table 8 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once	Once	N/A
Compressive strength test	MPa	ISO 844	In accordance with Table 2 at 23°C ± 2°C	Once for PQT	once for PPT	once at production start up
Final inspection						
Hardness	Shore A	ISO 868	In accordance with Table 1 at 23°C ± 2°C	Each item	Each item	Each item
Insulation thickness	mm	PI Tape or electronic equipment or vent port	As specified	Each item	Each item	Each item
Concentricity (for pipes only)	%	Straight edge ruler or electronic equipment at cutback area	±10 % of nominal thickness	Each pipe, 8 measurements	Each pipe, 8 measurements	Once per shift (where applicable)
Ovality (for pipes only)	%	Calliper and PI tape	(OD max-OD min)/ OD_{PItape} < 2 %	Each pipe	Each pipe	1st pipe then every 20th pipe (where applicable)
Cutback	mm	Tape Measurement	By agreement	Each item	Each item	Each item
Visual inspection		Visual and optical microscope	Free of voids blisters and separation from parent coating. Cosmetic surface faults may be accepted	Each item	Each item	Each item

9.6.5 Rubber insulation systems

9.6.5.1 General

Multi-layer rubber insulation systems may consist of:

— bonding primer(s);

— corrosion protection/thermal barrier inner layer;

— thermal insulation layer (i.e. pre-vulcanised half shells);

— mechanical protection outer layer.

Rubber insulation systems may be applied directly onto steel or on top of a corrosion coating.

9.6.5.2 Rubber coating on steel

The insulation system shall meet the requirements of Table 9.

Table 9 — Minimum inspection and testing requirements for rubber on to steel

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						

a   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

b   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

c   A test duration of 48 h instead of 28 days may be used for PPT and production testing provided the temperature is increased to 65°C and a comparison of results is performed during PQT.

Table 9 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Vulcanisation Characteristics	Nm	ISO 6502 (Rheometer)	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness	Shore A or D	ISO 7619-1	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density	g/cm³	ISO 2781	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Start of each shift
Steel surface inspection prior to blasting		Visual inspection	No mill imperfections. (Such as slivers, scabs, burrs, weld spatter)	Each item	Each item	Each item
Cleanliness grade	Sa	ISO 8501-1	Grade Sa 2½	Each item	Each item	Each item
Surface profile	Grade	ISO 8503-1 Comparative method	Medium grade (G) and compatible with pipeline steel.	Each item	Each item	Each item
Rubber primer application						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Each item
Over coating time	min	-	Time check in accordance with manufacturer's recommendation	Each item	Each item	Each item
Visual appearance		Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	Each item	Each item	Each item
Rubber application						
Vulcanization temperature	°C	Contact thermometer	According to manufacturer procedure or acceptable range to be established during PQT	Each item monitored	Each item monitored	Each item monitored
Vulcanization time	min	Stop watch	Acceptable range to be established during PQT	Each item	Each item	Each item
Vulcanization pressure (where applicable)	MPa	Manufacturer specific	Acceptable range to be established during PQT	Each item	Each item	Each item
Laboratory testing						
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once [a]	Once [a] (a)	N/A

[a]   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

[b]   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

[c]   A test duration of 48 h instead of 28 days may be used for PPT and production testing provided the temperature is increased to 65°C and a comparison of results is performed during PQT.

Table 9 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Specific heat capacity	J/g.K	ISO 11357	In accordance with Table 1 at 23°C ± 2°C	Once [a]	Once [a]	N/A
Tensile strength and elongation at break	%; MPa	ISO 37	In accordance with Table 1 at 23°C ± 2°C	Once [b]	Once [b]	N/A
Tear strength	N/mm	ISO 34	Within manufacturer's certificate of conformity range	Once [b]	Once [b]	N/A
Density	g/cm^3	ISO 2781	According to manufacturer's certificate of conformity range	Once	Once	N/A
Cathodic disbondment	mm	ISO 21809-1:2011, Annex H	28 days at 23°C < 7	Once	Once [c]	By agreement [c]
Adhesion test/ peel test on test plate / test area / cut back area	N/mm	ISO 813	Acceptable range to be established during PQT	Each vulcanization batch		
Final inspection						
Hardness	Shore A	ISO 7619-1	In accordance with Table 1 at 23°C ± 2°C	Each item	Each item	Each item
Total insulation thickness	mm	PI Tape or electronic equipment	as specified	Each item	Each item	Each item
Concentricity (for pipes only	%	Straight edge ruler or electronic equipment at cutback area	±10 % of nominal thickness	Each item, 8 measurements	Each item, 8 measurements	Once every 20 pipes (or as applicable)
Ovality (for pipes only)	-	Calliper and PI tape	$(OD_{max}-OD_{min}) / OD_{PItape} < 2\ \%$	Each item	Each item	1st pipe then every 20th pipe (or as applicable)
Cutbacks		Visual — Tape measurement	By agreement. No disbondment between layers or defects/voids	Each item	Each item	Each item
Visual inspection		Visual	Free from defects. Cosmetic faults may be accepted	Each item	Each item	Each item

[a]   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

[b]   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

[c]   A test duration of 48 h instead of 28 days may be used for PPT and production testing provided the temperature is increased to 65°C and a comparison of results is performed during PQT.

9.6.5.3   Rubber coating on other materials

The insulation system shall meet the requirements of Table 10.

Table 10 — Minimum inspection and testing requirements for rubber on to other materials

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						

[a]   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

[b]   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

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Table 10 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Vulcanisation Characteristics	Nm	ISO 6502 (Rheometer)	According manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness	Shore A	ISO 7619-1	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density	kg/m^3	ISO 2781	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Start of each shift
Surface conditions prior to blasting		Visual inspection	No oil, grease or similar contaminations	Each item	Each item	Each item
Substrate surface preparation		Visual	If applicable, abrasion with sand paper grit 50 minimum and dust vacuum cleaning (alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used)	Each item	Each item	Each item
Rubber primer application						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Each item
Over coating time	min	-	Time check in accordance with manufacturer's recommendation	Each item	Each item	Each item
Visual appearance		Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	Each item	Each item	Each item
Rubber application						
Vulcanization temperature	°C	Contact thermometer couple	Acceptable range to be established during PQT	Each item monitor-red	Each item monitor-red	Each item monitored
Vulcanization time	min	Stop watch	Acceptable range to be established during PQT	Each item	Each item	Each item
Vulcanization pressure (where applicable)	MPa	Manufacturer specific	Acceptable range to be established during PQT	Each item	Each item	Each item
Laboratory testing						
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once [a]	Once [a]	N/A
Specific heat capacity	J/kg.K	ISO 11357	In accordance with Table 1 at 23°C ± 2°C	Once [a]	Once [a]	N/A
Tensile strength and elongation at break	%; MPa	ISO 37	In accordance with Table 1 at 23°C ± 2°C	Once [b]	Once [b]	N/A
Tear strength	N/mm	ISO 34	Within manufacturer's certificate of conformity range	Once [b]	Once [b]	N/A

[a]   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

[b]   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

Table 10 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Density	g/cm^3	ISO 2781	According to manufacturer's certificate of conformity range	Once	Once	N/A
Adhesion test/ peel test on test plate (from corresponding substrate)	N/mm	ISO 813	Acceptable range to be established during PQT	Each vulcanization batch	Each vulcanization batch	Each vulcanization batch
Final inspection						
Hardness	Shore A	ISO 7619-1	In accordance with Table 1 at 23°C ± 2°C	Each item	Each item	Each item
Total insulation thickness	mm	PI Tape or electronic equipment	as specified	Each item	Each item	Each item
Concentricity (for pipes only)	%	Straight edge ruler or electronic equipment at cutback area if possible	±10 % of nominal thickness	Each item, 8 measurements	Each item, 8 measurements	Once every 20 pipes (or as applicable)
Ovality (for pipes only)	-	Calliper and PI tape	$(OD_{max}-OD_{min}) / OD_{PI\text{-}tape} < 2\%$	Each item	Each item	1st pipe then every 20th pipe (or as applicable)
Cutbacks		Visual Tape measurement	By agreement. No disbondment between layers or defects/voids	Each item	Each item	Each item
Visual inspection		Visual	Free from defects. Cosmetic faults may be accepted	Each item	Each item	Each item

a   Middle layer only, due to the difficulty of machining proper samples from thin inner and outer layer.

b   Middle and outer layer only, due to the difficulty of machining proper samples from thin inner layer.

9.6.6   Epoxy insulation systems

Epoxy insulation systems shall only be applied over an anti-corrosion coating.

The insulation system shall meet the requirements of Table 11.

Table 11 — Minimum inspection and testing requirements for epoxy systems

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Wet density	kg/m^3	ISO 2811-1	Within the manufacturer certificate of conformity range	Once for PQT	N/A	Each batch
Gel time of system	h	0,5 l mass at 23 °C	Within the manufacturer certificate of conformity range	Each batch	N/A	Each batch
Hardness of cured system	Shore A/D	ISO 868	Within the manufacturer certificate of conformity range	Each batch	Each batch	Each Batch
Density (glass microspheres)	kgm^3	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Crush strength (glass microspheres)	MPa	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch

Table 11 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Hydrostatic Compression	MPa	In accordance with Annex A	within manufacturer's original tolerances	Once for PQT	N/A	As agreed
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Start of each shift
Anti-corrosion coating surface preparation		Visual	If applicable, abrade with sandpaper grit 50 and dust vacuum cleaning. Alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used.	Each item	Each item	Each item
Epoxy application						
Mix ratio	Ratio by weight	Weight measurement	As per manufacturer's recommendation with a maximum of ± 5 %.			
Verification of raw material properties by a "cup shot"	Visual	Cured 0,5 l fixed mass sample at 23 °C	Good mixing. No air, no discolouration from unmixed components, etc.	Start of PQT	Start of PPT	Start of each shift
Visual inspection of mould prior to filling	Visual	-	Clean, with no debris	Each Item	Each item	Each item
Mould temperature	°C	Thermocouple	Acceptable range to be established during PQT	Each Item	Each item	Each item
Exotherm temperature during moulding	°C	Thermocouple	Acceptable range to be established during PQT The exotherm should be checked at the centre of the maximum thickness during cure	One item	One item	N/A
Laboratory testing						
Cured density	kg/m^3	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	Every batch of raw material	Once per shift
Glass transition temperature	°C	ISO 11357-2	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	Every batch of raw material	At agreed intervals
Mass ratio of glass microspheres	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Glass microspheres density after processing	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Entrapped air ratio	%	As per Annex J	Acceptable range to be established during PQT	Each item	2 items	Once per shift
Tensile strength and elongation at break	MPa %	ISO 527	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Adhesion	MPa	ISO 4624	Pull off test > 5 MPa or acceptable range to be established during PQT	Each item	Each item	At agreed intervals
Thermal conductivity test	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	Every batch of raw material	N/A
Hydrostatic Compression	MPa	In accordance with Annex A	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	Every batch of raw material	N/A
Final inspection						
Hardness	Shore D	ISO 868	in accordance with Table 1 at 23°C ± 2°C	Each item	Each item	Each item
Insulation thickness	mm	PI tape	as specified	Each item	Each item	Each item

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Table 11 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Concentricity (for pipes)	%	Straight edge ruler or electronic equipment at cutback area	±10 % of nominal thickness	Each item	Each item	Once per shift (or as applicable)
Ovality (for pipes)	%		$(OD_{max}-OD_{min})/OD_{PI\text{-}tape} < 2$	Each item	Each item	1st pipe then every 20th pipe (or as applicable)
Cutback	mm	Tape measurement	By agreement	Each item	Each item	Each item
Visual inspection		Visual	Mouldings are free from large air traps, porosity, debris, knit lines, cavities and disbondments at joints and substrate interfaces. Cosmetic surface faults may be accepted	Each item	Each item	Each item

9.6.7 Phenolic insulation systems

Phenolic insulation systems shall only be applied over an anti-corrosion coating.

Syntactic phenolic resin-based insulation generally comprises individual material layers:

— a tie coat that provides a tacky interlayer to hold the syntactic foam core material and to give good bond integrity to the substrate. The tie coat shall be applied to an anti-corrosion coating;

— phenolic insulation foam consisting of microspheres dispersed and supported within a phenolic resin matrix. For regular shapes such as piping and large planar surfaces, the material is applied as complete pieces in the form of pre-formed tiles. Specified thicknesses are built up by applying tiles layer upon layer using tie coat to facilitate interlayer adhesion. For irregular shapes such as tees, flanges or sections with change in cross-section, the material is applied by cutting consolidated tiles into shapes as required;

— composite top coat that provides an impact resistant, hard wearing outer skin;

— flow coat of catalysed resin.

The insulation system shall meet the requirements of Table 12.

Table 12 — Minimum inspection and testing requirements for phenolic systems

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density (formulated system)	kg/m³	ISO 1183	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Daily
Hardness (formulated system)	Shore D	ISO 868	within manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Reactivity (formulated system)	h	Manufacturer	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Glass microspheres density	kg/m³	Manufacturer's method	Within manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Crush strength glass microspheres	MPa	Manufacturer's method	Within manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						

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Table 12 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point Ambient air temperature: between 15°C and 40°C Substrate temperature: between 15°C and 40°C Relative humidity: < 90 %	Each item	Each item	Start of each shift
Anti-corrosion coating surface preparation	-	visual	If applicable, abrade with sandpaper grit 50 and dust vacuum cleaning. Alternative methods of mechanical surface preparation may be agreed according to the anticorrosion layer used.	Each item	Each item	Each item
Adhesion promoter application						
Wet film Thickness	microns	ISO 2808:2007, method 1A Comb gauge	150 - 300	Each item	Each item	Each item
Over coating time	min	-	Time check in accordance with manufacturer's recommendation	Each item	Each item	Each item
Degree of Tack	Manual	-	According to manufacturer's recommendations	Each item	Each item	Each item
Phenolic application						
Mix ratio	Ratio by weight	Calibrated weight	as per manufacturer's recommendation with a maximum of ± 2 %	Each batch	Each batch	Each batch
Efficacy of blending		Visual	Uniform colour to be achieved	Each mix	Each mix	Each mix
Cure time for each individual layer	Shore 00	ISO 868	Acceptable range to be established during PQT	Each layer	Each layer	Each layer
Interlayer adhesion test (pull off test) on test plates	MPa	Manufacturer specific	Acceptable range to be established during PQT	Each item	Each item	As agreed
Visual inspection		Visual	Look for defects, voids, bubbles between layers	Each item	Each item	Each item
Top skin						
Mix ratio	Ratio by weight	Calibrated weight	as per manufacturer's recommendation with a maximum of ± 2 %	Each item	Each item	Each item
Glass mat wetting		Visual	Free from voids, dry mat or air pockets	Each item	Each item	Each item
Hardness	Shore D	ISO 868	Acceptable range to be established during PQT	Each item	Each item	Each item
Top coat application						

Table 12 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Wet film thickness	microns	ISO 2808:2007, method 1A Comb Gauge	150 - 300	Each item	Each item	Each item
Laboratory testing						
Density test	kg/m³	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	Each batch	Each batch	At agreed inter-vals
Thermal conductivity	W/(mK)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Each batch	Each batch	At agreed inter-vals
Tensile strength and elongation at break	MPa %	ISO 527	In accordance with Table 1 at 23°C ± 2°C	Each batch	Each batch	At agreed inter-vals
Compression strength		ISO 844	In accordance with Table 2	Each batch	Each batch	NA
Adhesion pull off test	MPa	ISO 4624	Acceptable range to be established during PQT	Each item	Each item	Per agreement
Hydrostatic compres-sion		Annex A	In accordance with Table 1 at 23°C ± 2°C	Each batch	Each batch	NA
Final inspection						
Hardness	Shore D	ISO 868	In accordance with Table 1 at 23°C ± 2°C	Each batch	Each batch	Each batch
Insulation Thickness (dry)	mm	Inspection ports (minimum of four ports per m²)	As specified	Each part	Each part	At agreed inter-vals
Visual inspection		Visual	Look for defects, voids, bubbles between layers	Each item	Each item	Each item
Cutback	mm	Tape measure-ment	By agreement	Each item	Each item	Each item

9.7   Final documentation

The applicator shall provide the following documentation:

— wet insulation system design report;

— application procedures including repairs;

— ITP;

— qualification test report and records in accordance with this International Standard;

— manufacturing inspection report and records in accordance with this International Standard;

— raw material technical and safety data sheets;

— raw material certificates;

— tally records and/or finished goods reports.

10 Requirements for field joints

10.1 General

This clause defines the minimum requirements for qualification, application process, and final overall performance of the field joint coating system for wet thermal insulation coating.

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Selection and application of the field joint coating should be in accordance with ISO 21809-3 where applicable.

The functional requirements of the field joint coating are to:

— provide corrosion protection (as per 6.3);

— provide contribution to overall thermal insulation;

— be suitable for all phases of pipe fabrication and pipe lay;

— be suitable for the service environment for the design life;

— remain adhered to the factory applied coating.

10.2 Specific information relevant for field joint design and qualification

For field joints the following should be considered to ensure the quality and relevance of the qualification test:

— pipe lay method (S lay, J lay, reeling);

— mechanical stress during laying;

— cutback design;

— field joint arrangement (collar, maximum OD, etc.);

— wet thermal insulation coating (including thickness tolerance);

— required mechanical protection.

10.3 Qualification requirements

The insulation layers or materials used for the field joint system shall comply with the relevant requirements of Clauses 6, 7, 8 and 10.

All parameters for the testing, such as maximum rated temperature, pressure and test parameters for Clause 8, shall be specified by the field joint designer.

10.4 Qualification of operators

Qualification of operators shall be in accordance with 9.2.

10.5 Field joint coating APS/PQT/PPT

Field joint coating application process and quality control shall comply with the requirements of 9.3, 9.4 and 9.5.

PPT shall be carried out at field joint construction location.

PQT/PPT tests shall be carried out on representative factory coated pipes having the same diameter and thickness as the production pipes.

NOTE   Rejected pipe or pipe that has been used for other testing (e.g. welding qualification) is not considered representative.

Tests shall be carried out on test zones distributed along a pipe coated with the actual parent (plant-applied) coating. The length of the test zones shall be equivalent to the field joint coating length. If a weld is not present, a circumferential cap weld shall be added at the centre of each of the test zones to simulate the field weld. Unless otherwise specified, at least three test zones shall be coated.

Mainline, anode and stalk tie-in procedures shall be considered in the qualification program.

Special joints or specific joint design shall be considered in the qualification process.

All tools and equipment (e.g. for induction heating, abrasive blasting, coating application and inspection) to be used for PQT/PPT shall be of the same type as those to be used for the actual field joint coating.

Coating repairs and stripping of defective FJC shall be included in PQT (except if coating repairs are not allowed).

The time for coating application during PQT shall be consistent and repeatable with the estimated field joint coating time in the field. Any significant differences in the PQT environment compared to actual production conditions should be considered, e.g. number of work stations, similarities or differences in lifting equipment.

The applicator shall submit a complete report of the PQT and PPT test results to the purchaser for approval.

10.6 Production tests

10.6.1 Polypropylene field joint using injection moulded technique

An injection moulded polypropylene field joint shall comply with the requirements of ISO 21809-3 and the requirements of Table 13.

The coating consists of three layers:

— an epoxy resin layer, applied in the form of powder by flocking or by electrostatic spray, or in liquid form applied by spraying;

— a layer of modified PP powder applied by spraying (used as adhesive);

— an insulation layer of PP applied by injection into a mould; injection may be performed in successive mouldings:

— intermediate moulded sections including free end(s);

— field joint between previously moulded sections and/or parent coating.

Table 13 — Polypropylene field joint using injection moulded technique

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density	kg/m^3	ISO 1183	Within the manufacturer's certificate of conformity	Each batch	Each batch	Each batch
MFR	grams per 10 min	ISO 1133	Within the manufacturer's certificate of conformity	Each batch	Each batch	Each batch
PP application parameters						
Chamfer and overlap preheat temperatures and dwell time	°C/min	Applicator's method	Acceptable range to be established during PQT	Once	Once	Each joint
PP injection temperature	°C	Applicator's method	Acceptable range to be established during PQT	once	Once	Each joint
Injection pressure	MPa	Applicator's method	Acceptable range to be established during PQT	Once	Once	Each joint
Hold time/hold pressure	min/MPa	Applicator's method	Acceptable range to be established during PQT	Once	Once	Each joint
Minimum demould time	min	Applicator's method	Acceptable range to be established during PQT	Once	Once	Each joint
Quenching time	min	Applicator's method	Acceptable range to be established during PQT	Once	once	Each joint
Laboratory testing						

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Table 13 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Density	kg/m³	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	3 joints	3 joints	By agreement
Peel test	N/mm	ISO 21809-1	On steel: in accordance with ISO 21809-1 for 3LPP On overlap: cohesive failure	3 joints	3 joints	N/A
Adhesion with parent coating (field joint) and previously moulded section (intermediate moulding)	MPa	ISO 527	Cohesive failure after tensile tests	3 joints	3 joints	N/A
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	3 joints	N/A	N/A
Compressive strength	MPa	ISO 844	In accordance with Table 1 at 23°C ± 2°C	3 joints	N/A	N/A
Tensile strength and elongation at break	MPa/%	ISO 527	In accordance with Table 1 at 23°C ± 2°C	3 joints	N/A	N/A
Bend test		Annex B	In accordance with 8.2.3	3 joints	N/A	N/A
Sectioning of field joint		Cut open one joint. Look for voids and defects (such as unfused knit line and air entrapment).	By agreement	3 joints	N/A	N/A
Cathodic disbondment test	mm	ISO 21809-1:2011, Annex H	In accordance with Table 3	Once per PQT	By agreement	N/A
Final inspection						
Overall Coating Visual	-	Visual	Free from blisters, voids, cracks, disbondment and irregularities	Each joint	Each joint	Each joint
Overlap length (field joint)	mm	Calibrated rule	50 mm minimum	Each joint	Each joint	Each joint
Overlap thickness (field joint)	mm	Vernier and straight edge	As specified	Each joint	Each joint	First joint
Thickness control (intermediate moulding)	mm	Measurement with PI tape or electronic equipment	As specified	Each joint	Each joint	First joint
Concentricity (intermediate moulding)	% of nominal thickness	Straight edge ruler or electronic equipment at cutback area	±10 %	Each joint	Each joint	First joint
Cutback (intermediate moulding)	mm	Straight edge ruler	As specified	Each joint	Each joint	First joint

10.6.2 Polyurethane field joint using casting technique

A cast polyurethane joint consists of:

— anti-corrosion coating (liquid epoxy or fusion bonded epoxy);

— adhesion promoter (if applicable);

— insulation layer of polyurethane.

A cast polyurethane field joint shall comply with the requirements of Table 14.

Table 14 — Polyurethane field joint using casting technique

Property	Unit	Test method	Requirements	Frequency PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Density (polyol)	Relative to water at 1,0	Manufacturer	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Viscosity (polyol)	cPs	ISO 3104 or ISO 3219	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Gel time of mixed system (polyol + Iso)	min	Manufacturer	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness of cured system (polyol + Iso)	Shore A or Shore D	ISO 868	within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Isocyanate content	%	ISO 14896	Within the manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Steel surface preparation						
Substrate temperature	°C	ISO 8502-4	3 °C above dew point	Start of PQT	Start of PPT	Each joint
Cleanliness of blast cleaned surface	-	ISO 8501-1	SA 2½	3 joints	3 joints	Each joint
Surface profile	Segment	ISO 8503-1	3 to 4	3 joints	3 joints	1st joint then every 20th joint
Dust level	Class and size	ISO 8502-3	2	3 joints	3 joints	1st joint then every 20th joint
Liquid epoxy application						
Substrate pre-heat temperature	°C	Contact thermometer	Acceptable range to be established during PQT	3 joints	3 joints	Each joint
Epoxy mix ratio	-	Weight verification	Ratio and tolerance according to Manufacturers recommendation	Start of PQT	Start of PPT	Each shift
Epoxy application	-	Visual	Full even coverage	3 joints	3 joints	Each joint
Epoxy thickness	Microns	ISO 2808	Within manufacturer's recommendation	3 joints	3 joints	Each joint
Epoxy cure temperature	°C	Infrared	Acceptable range to be established during PQT	3 joints	3 joints	Each joint
Epoxy curing time	min		Acceptable range to be established during PQT	3 joints	3 joints	Each joint
Preparation following application of fusion bonded epoxy (see ISO 21809-3)						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	Each item	Each item	Each item
Anti-corrosion coating surface preparation	-	-	If applicable, abrade with sandpaper grit 50 and dust vacuum cleaning. Alternative methods of mechanical surface preparation may be agreed.	3 joints	3 joints	Each joint
Adhesion promoter application (Sometimes adhesion promoter is applied directly to the steel)						
Surface pre-heat temperature	°C	Contact thermometer	Acceptable range to be established during PQT	3 joints	3 joints	Each joint
Pot life	min	stop watch	Cure time check in accordance with manufacturer's recommendation	Start of PQT	Start of PPT	Each shift
Visual appearance	-	Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	3 joints	3 joints	Each joint

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Table 14 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Adhesion promoter mix ratio		Weight verification	Ratio and tolerance according to Manufacturers recommendation	Start of PQT	Start of PPT	Each shift
Preparation of parent applied insulation						
Inspection of parent applied coating	-	Visual	Free from oil, grease, dust, debris, other contamination and defects	3 joints	3 joints	Each joint
Parent applied coating surface preparation (all parent applied insulation systems)	-	Visual	Abrasion of chamfer area	3 joints	3 joints	Each joint
Surface treatment (PP applied coating only)	Dynes	Surface treatment pens	> 45	3 joints	3 joints	Each joint
Post surface treatment inspection (PP parent applied coating only)	-	Visual	No wax formation on the PP chamfer and overlap area	3 joints	3 joints	Each joint
Polyurethane application						
Verification of raw materials properties by a "cup shot"		Visual	No air, no discoloration from unmixed components, etc.	3 joints	3 joints	Each joint
Mould temperature	°C	Thermocouple	Acceptable range to be established during PQT	3 joints	3 joints	Each joint
Mix ratio	-	Weight measurement of each component	as per manufacturer's recommendation with a maximum of 2 %.	Start of PQT	Start of PPT	Each shift
Minimum demould time	min	Stopwatch	According to manufacturer's recommendation	3 joints	3 joints	Each joint
Laboratory testing						
Density	kg/m^3	ISO 1183	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	By agreement	By agreement
Thermal conductivity	W/(mK)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	By agreement	N/A
Tensile strength and elongation at break	MPa %	ISO 527	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	By agreement	N/A
compressive strength	MPa	ISO 844	In accordance with Table 1 at 23°C ± 2°C	Once for PQT	By agreement	N/A
Cathodic disbondment	mm	ISO 21809-1:2011, Annex H	In accordance with Table 3	Once per PQT	By agreement	N/A
Final Inspection						
Visual	-	Visual	Free from blisters, voids, cracks, disbondment and irregularities	3 joints	3 joints	Each joint
Hardness	Shore A or Shore D	ISO 868	Within manufacturer's certificate of conformity range	3 joints	3 joints	Each joint
Overlap length	mm	Calibrated rule	50 minimum	3 joints	3 joints	Each joint
Insulation thickness	mm	PI tape of electronic equipment	> 4 mm compared to parent coating	3 joints	3 joints	Once per shift
Adhesion to parent applied coating on each component material/layer interface (selection of peel test or pull test shall be agreed with purchaser)	N/mm	ISO 21809-3:2008, Method D2	Acceptable range to be established during PQT	3 joints	3 joints	Once per shift (on overlap only)
	MPa	ISO 4624		3 joints	3 joints	Once per shift (on overlap only)

Table 14 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Adhesion to steel, liquid epoxy paint or FBE (selection of peel test or pull test shall be agreed with purchaser)	N/mm	ISO 21809-3:2008, Method D2	Acceptable range to be established during PQT	3 joints	3 joints	N/A
	MPa	ISO 4624		3 joints	3 joints	N/A
Density and void control	Visual	Optical microscope	No bubbles in sample poured in a cup.	3 joints	3 joints	Once per shift

10.6.3 Elastomeric field joint coatings

ISO 21809-3 covers elastomeric field joint coatings, but is mostly relevant for single layer coatings (corrosion protection only).

Multi-layer systems may consist of:

— bonding primer(s);

— corrosion protection/thermal barrier inner layer;

— thermal insulation layer (i.e. pre-vulcanised half shells);

— mechanical protection outer layer.

The insulation system shall meet the requirements of Table 15.

Table 15 — Elastomeric field joint coatings

Property	Unit	Test method	Requirements	Frequency		
				PQT	PPT	Production
Raw material testing (Manufacturer's data)						
Vulcanisation Characteristics	Nm	ISO 6502 (Rheometer)	According manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Hardness	Shore A or D	ISO 7619-1	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Density	g/cm^3	ISO 2781	According to manufacturer's certificate of conformity range	Each batch	Each batch	Each batch
Substrate preparation						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	3 joints	3 joints	Each joint
Steel surface inspection prior to blasting		Visual inspection	No mill imperfections. (Such as slivers, scabs, burrs, weld spatter)	3 joints	3 joints	Each joint
Cleanliness grade	Sa	ISO 8501-1	Grade Sa 2½	3 joints	3 joints	Each joint
Surface profile	Grade	ISO 8503-1 Comparative method	Medium grade (G) and compatible with pipeline steel.	3 joints	3 joints	Each joint
Preparation of parent applied insulation						
Inspection of parent applied coating	-	Visual	Free from oil, grease, dust, debris and contamination	3 joints	3 joints	Each joint

Table 15 *(continued)*

Property	Unit	Test method	Requirements	Frequency		
				PQT	**PPT**	**Production**
Parent applied coating surface preparation (all parent applied insulation systems)	-	Visual	Abrasion of chamfer area	3 joints	3 joints	Each joint
Post surface treatment inspection (parent applied coating only)	-	Visual	Free from oil, grease, dust, debris and contamination on the chamfer and overlap area	3 joints	3 joints	Each joint
Rubber primer application						
Environmental conditions and substrate temperature	°C	ISO 8502-4	Minimum 3 °C above dew point	3 joints	3 joints	Each joint
Over coating time	min	-	Time check in accordance with manufacturer's recommendation	3 joints	3 joints	Each joint
Visual appearance		Visual	Within manufacturer's recommendation. Comparative visual test panels from PQT.	3 joints	3 joints	Each joint
Rubber application						
Vulcanisation temperature	°C	Contact thermocouple	According to manufacturer procedure or within PQT range	Each item monitored	Each item monitored	Each item monitored
Vulcanisation time	min	Stop watch	Acceptable range to be established during PQT	Each item	Each item	Each item
Laboratory testing						
Thermal conductivity	W/(m.K)	ISO 8301	In accordance with Table 1 at 23°C ± 2°C	Once	Once	N/A
Specific heat capacity	J/g.K	ISO 11357	In accordance with Table 1 at 23°C ± 2°C	Once	Once	N/A
Tensile strength and elongation at break	MPa %	ISO 37	In accordance with Table 1 at 23°C ± 2°C	One test	N/A	N/A
Tear strength	N/mm	ISO 34	Within manufacturer's certificate of conformity range	Once	Once	N/A
Density	kg/m³	ISO 2781	According to manufacturer's certificate of conformity range	Once	Once	N/A
Adhesion test/ peel test on test plate or separate test area	N/mm	Manufacturer recommended method	Acceptable range to be established during PQT	Once	Once	N/A
Final inspection						
Hardness	Shore A	ISO 7619-1	In accordance with Table 1 at 23°C ± 2°C	3 joints	3 joints	Each joint
Total coating thickness	mm	PI Tape or electronic equipment	As specified	3 joints	3 joints	Each joint
Concentricity (for pipes only)		Visual and compare with factory coated pipe.		Each joint	Each joint	First joint
Ovality (for pipes only)	-	Calliper and PI tape	$(OD_{max}-OD_{min})$ / $OD_{PItape} < 2\%$	Each joint	Each joint	First joint
Visual inspection		Visual	Free from defects. Cosmetic faults may be accepted	Each joint	Each joint	Each joint

10.7 Final documentation

The applicator shall provide the following documentation:

— field joint insulation system design report;

— application procedures including repairs;

— ITP;

— qualification test report and records in accordance with this International Standard;

— manufacturing inspection report and records in accordance with this International Standard;

— raw material technical and safety data sheets;

— raw material certificates;

— tally records and/or finished goods reports.

11 Handling, storage and transportation requirements

Handling, storage and transportation shall not induce any damage to the insulation or the substrate of the coated components exceeding the limits of the relevant specifications. The handling device should not contain any sharp pointed parts such as bolts and rivets. Chains and wire rope should not be used as these may cut and scratch the insulation surface. Impact against sharp metal edges should be avoided as this may cut or break the material surface. Insulated parts should be handled using wide slings, padded end hooks or padded lift forks.

In case of extreme storage temperature, appropriate protection measures should be taken.

Nylon or similar soft straps should be used. The insulated parts should not be cropped or dragged, and bare cables, chains or metal hooks should not be permitted to come into contact with the insulation surface. The insulation should not come into contact with soil.

Stacking of insulated pipes should be limited to avoid damage of the coating. The maximum stacking height for the coated pipes should be in accordance with the manufacturer's recommendations and shall be submitted to end user for approval.

Pipes which have been identified as potentially defective shall be clearly identified to prevent their unintended use. Provision shall be made for repair of pipe coating damaged in the field.

Annex A
(normative)

Hydrostatic compressive behaviour/Tri-axial test procedures

A.1 Hydrostatic test or Tri-axial test

Both types of tests are used in the industry. The test procedure shall be selected by the system supplier

A.2 Hydrostatic collapse test and creep test

A.2.1 Hydrostatic collapse test

The primary objective of this test is to determine the volume change of a sample of material at a specified temperature when subjected to increasing hydrostatic pressure.

There are several approaches that may be used to measure the volume change of a sample of material when subjected to increasing hydrostatic pressure in a test cell:

— measurement of the volume of water required to be injected into the test cell to induce a change in pressure;

— measurement of the apparent buoyancy of the test specimen;

— measurement of the reduction in the axial length of the test specimen.

The test shall be performed in water (fresh water or artificial seawater prepared in accordance with ISO 15711), in a test cell at a specified temperature, on a representative volume of material (typically ≥ 50 cm^3).

The hydrostatic pressure shall be increased at a constant rate (e.g. 1 MPa/min) and the hydrostatic pressure and the volume change of the test specimen recorded continuously throughout the duration of the test period.

Two parameters shall be determined from this test:

— bulk modulus: the slope of the curve of the percentage volume change versus hydrostatic pressure;

— collapse pressure: hydrostatic pressure corresponding to a sudden and significant change in the gradient of the percentage volume change versus hydrostatic pressure curve.

A typical set of results is shown in Figure A.1.
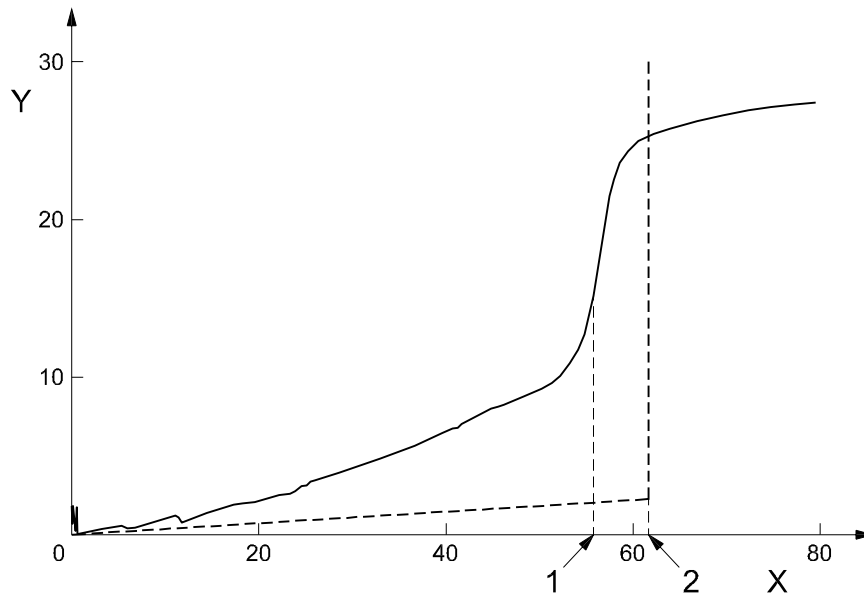
Key

1   crush pressure mat2

2   crush pressure mat1

X   pressure, in MPa

Y   volume change, in %

Figure A.1 — Typical volume reduction as a function of pressure

A.2.2 Hydrostatic compression creep test

The primary objective of this test is to determine the volume change (and water uptake) of a sample of material when it is simultaneously subjected to a constant hydrostatic pressure and exposed to a specified temperature over a period of time.

There are several approaches that may be used to measure the volume change (and water uptake) of a sample of material when subjected to a constant hydrostatic pressure in a test cell:

— measurement of the volume of water required to be injected into the test cell to compensate for any reduction in pressure;

— measurement of the apparent buoyancy of the test specimen;

— measurement of the reduction in the axial length of the test specimen.

The test shall be performed in water (fresh water or artificial seawater prepared in accordance with ISO 15711), in a test cell at a specified hydrostatic pressure and temperature, on a representative volume of material (typically ≥ 50 cm^3).

The typical duration of the test is the time needed to establish a stabilized condition (100 h minimum).

The hydrostatic pressure shall be increased at a constant rate (e.g. 1 MPa/min) up to the specified pressure and the hydrostatic pressure and the volume change of the test specimen shall be recorded continuously throughout the duration of the test period.

Weighing of the test specimen prior to and immediately on completion of the test can provide information on the extent of the water uptake of the material during the test period.

A.3 Tri-axial compression and creep test

A.3.1 Test description

The tri-axial test method is aimed at determining the compression and creep of samples that are constrained in two dimensions. This test closely mimics the true nature of the forces and degrees of freedom that apply on a bonded coating system on pipe. The base of the chamber represents the OD of the pipe, while the walls of the chamber mimic the hoop and axial constraint from other identical bonded material. The hydrostatic loading is applied through a piston.

A.3.2 Method

Test samples shall be machined so that they fit snugly into the test fixture at the intended test temperature. These are cylindrical samples with a diameter tolerance of ± 0,02 mm and parallel faces. This is very important as lack of parallelism represents dead volume. The samples shall be taken from thick pipe insulation (as thick as possible) and built to a final thickness of 51 ± 1 mm.

NOTE   It is important to have representative material as, for example, foams will have a coarser structure close to interfaces that will give a very large initial compression if this region is over represented in the test.

The deflection of the G-clamp shall be determined (for each cell) and taken into account during the test as the deflection is significant relative to the test deflections.

The gas pressure versus load relationship shall be determined against a calibrated load cell for each piston.

Three replicates shall be used for each condition.

A.3.3 Initializing

The test shall be started by partially filling the cell.

The samples shall be greased with a very thin layer of silicone grease (on the curved faces only) and placed in the cell.

The piston shall be mounted with the central purge port open.

Excess water shall be purged from the cell until the piston rests on the sample.

The system shall be heated to the desired temperature.

The piston shall be actuated to make initial contact.

The purge valve shall be closed.

The displacement gauge shall be zeroed

A.3.4 Start of test

The pressure shall be increased in steps of 1,5 MPa, reading the displacement at one minute intervals before proceeding.

The cell shall be rotated 90° and back before each reading to ensure that the sample does not hang on the wall.

The pressure shall be increased to full test pressure and the final displacement reading taken.

The displacement shall be read off three times the first 24 h, twice the second 24 h and once daily after this time.
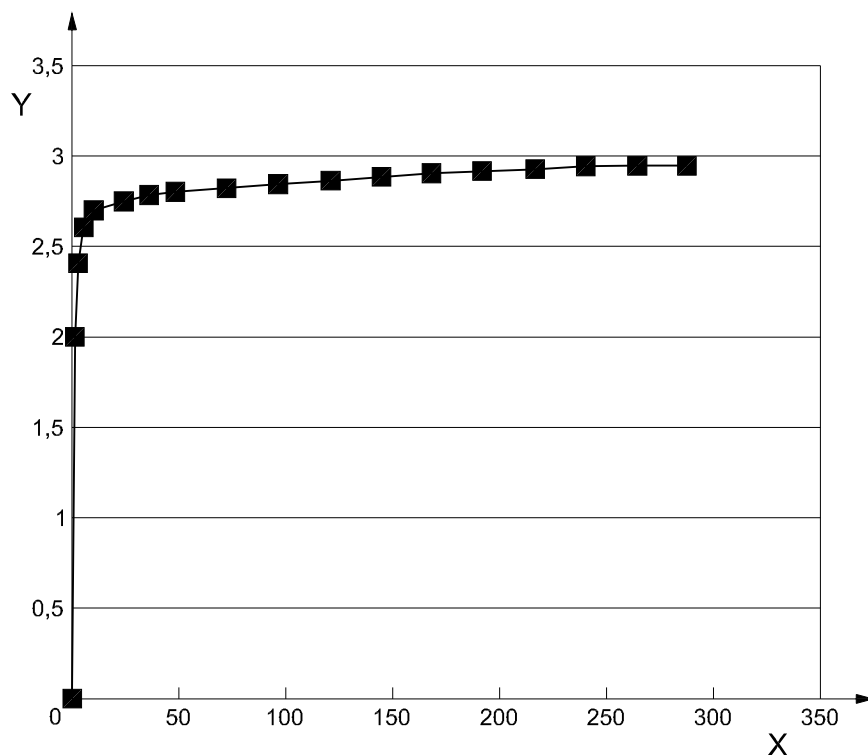
A.3.5 End of test

The pressure shall be reduced followed by the temperature. Samples shall be retrieved and their dimensions and density measured.
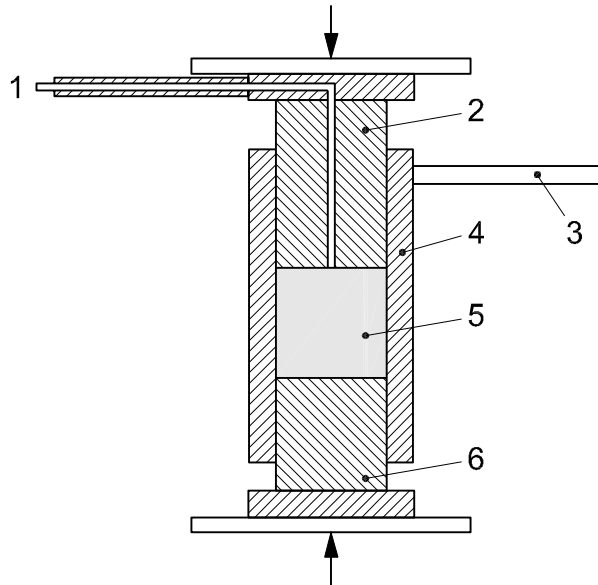
Key

1   venting port
2   rotatable piston
3   handle
4   cylinder walls and heater
5   sample
6   rotatable base

Figure A.2 — Typical set up for tri-axial test

Key

X   time, in h

Y   displacement, in %

Figure A.3 — Typical results for tri-axial test

A.3.6 Interpretation

A spreadsheet may be used to plot and interpret the data, from which the following shall be obtained:

— tri-axial modulus: calculated volume change as a function of pressure;

— initial compression: mechanical response (expressed as a volume change) shown by the sample during the first 24 h of test;

— 20 year creep: end of life creep using a log law;

— creep rate/decade: slope of the steady-state creep curve plot against the log of time;

— final density (test): recalculated density against the volume change and the initial density;

— final density (20 year): extrapolated density over a 20 year period.

Annex B
(normative)

Simulated bend test

The method for the bend test shall be the curved former type with a fixed end.

When designing the test, consideration should be given to:

— minimum bend radius;

— test temperature;

— rate of bending;

— time at minimum bend radius;

— number of bend cycles.

These parameters shall be determined by the system supplier.

A minimum of one straight section of coated pipe shall be subject to cycles of bending and straightening using a test arrangement of the form shown Figure B.1 to simulate the cycles of bending and straightening experienced during installation.

The test shall be performed as follows.

a) Pipe shall be conditioned at test temperature, if not ambient, for a minimum period of 24 h prior to bending. Prior to conditioning, thermocouples shall be attached to steel pipe and the coating system. On completion of the conditioning period, an insulation blanket shall be wrapped around external surface of coating system along length of pipe and the ends of the pipe shall be blanked off.

b) Pipe shall be placed in the test arrangement and temperature measurements recorded as appropriate (steel temperature and temperature in the middle of the insulation layer - at least half a meter of the end of the insulation layer).

c) Loading shall be applied to bend pipe around the bending former. The radius of the bending former shall be defined by the system supplier.

— Rate of bending shall be measured and recorded.

— Pipe shall be held bent around the bending former to allow visual inspection of the tension surface of the coating system(s) and to confirm that the pipe is in contact with the surface of the curved former. Any lift off, due to a field joint coating standing proud of the line pipe coating, from the former shall be noted and recorded.

— The period that the pipe needs to be held bent around the surface of the bending former shall be specified, i.e. normally a minimum of 5 min.

d) All loads shall be removed and the pipe allowed to take up its residual deflected shape.

e) If applicable, the pipe shall then be bent in the reverse direction around a straightening former whose radius shall be calculated using the dimensional and material properties of the steel pipe.

— Rate of bending shall be measured and recorded.

— Pipe shall be held bent around the straightening former to allow visual inspection of the tension surface of the coating system(s) and to confirm that the pipe is in contact with the surface of the

curved former. Any lift off, due to a field joint coating standing proud of the line pipe coating, from the former shall be noted and recorded.

— The period that the pipe needs to be held bent around the surface of the straightening former is only as long as it takes to perform the inspection described above.

f)   All loads shall be removed from the pipe.

g)   If during installation the external surface of the coating system is alternatively subjected to the maximum tensile and the maximum compressive strains, the pipe shall be rotated through an angle of 180° about its longitudinal axis prior to a further cycle of bending and straightening.

h)   Steps c) to f) above shall be repeated until the magnitude of accumulated strains in the extreme fibre of the steel pipe experienced during the test is at least equal to those experienced by the pipe during installation, e.g. in the case of the reel method, spooling, installation, recovery, re-installation, etc.
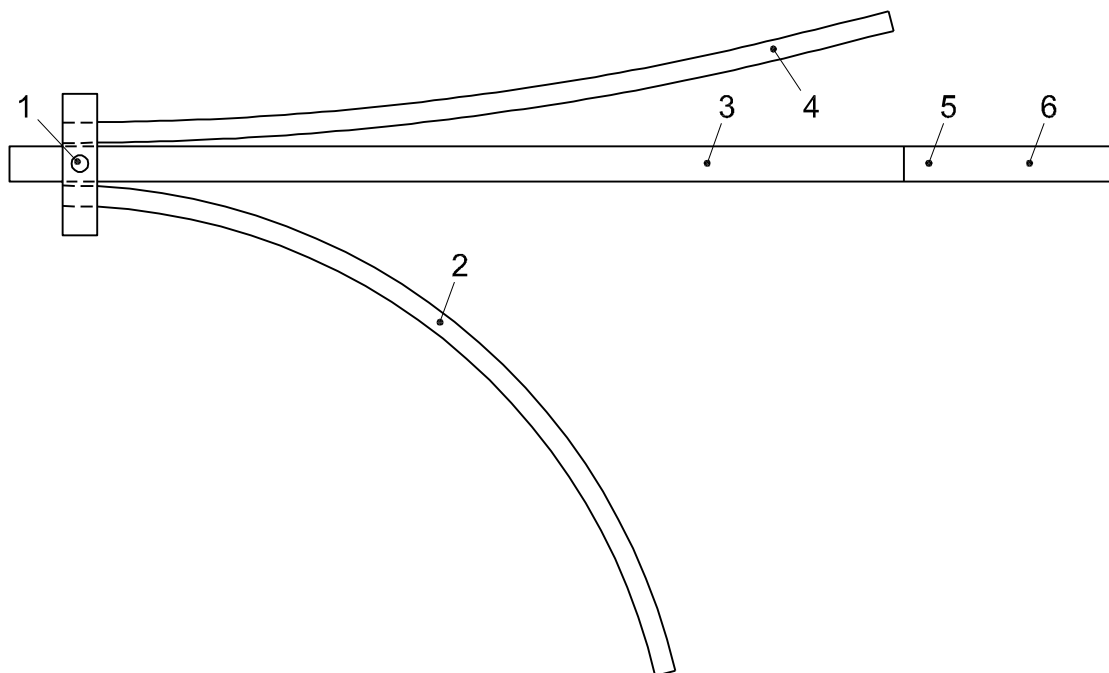
Key

1   pinned connection
2   bending radius
3   12 m (nominal length)
4   straightening radius
5   optional pullhead extension assembly
6   3 m (nominal length)

Figure B.1 — Bend test principle

Annex C
(normative)

Cyclic (fatigue) bend test

When designing the test, consideration should be given to:

— maximum/minimum extreme fibre strain levels;

— test temperature;

— loading frequency;

— number of bend cycles;

— residual curvature effects.

These parameters shall be determined by the system supplier.

The dimensional layout of coated pipe length supplied for a simulated cyclic bend (fatigue) test shall be as shown in Figure C.1.

Steel plates shall be welded into each end of coated pipe length to permit flow of water through the coated pipe length to be maintained during test to minimize self-heating during the test. The temperature variations in the cooling system and the external surface of the test pipe shall be monitored throughout the test.

Eight strain gauges shall be bonded to the external surface of the coating system at 45° intervals around the circumference of the pipe at mid-length to monitor the axial strain experienced during test.

Coated pipe length shall be tested in air at ambient temperature in rotating bending using the established resonance technique. The test machine shall be used to generate a rotating bending moment in the coated pipe length which is a maximum in the centre of the coated pipe length (at the strain gauge locations) and decays to zero at the ends of the coated pipe length. The cyclic bending moment is sinusoidal in form, with zero mean.

Strain range in the extreme fibre of the steel pipe and the total number of cycles shall be specified for the test by the system supplier. The test is conducted at the specified strain range based on the average of the measurements from the eight strain gauges positioned at mid-length of the pipe.

On completion of the test, the external surface of the coated pipe length shall be subjected to an external visual inspection and if required the coated pipe length shall be sectioned.

Dimensions in metres
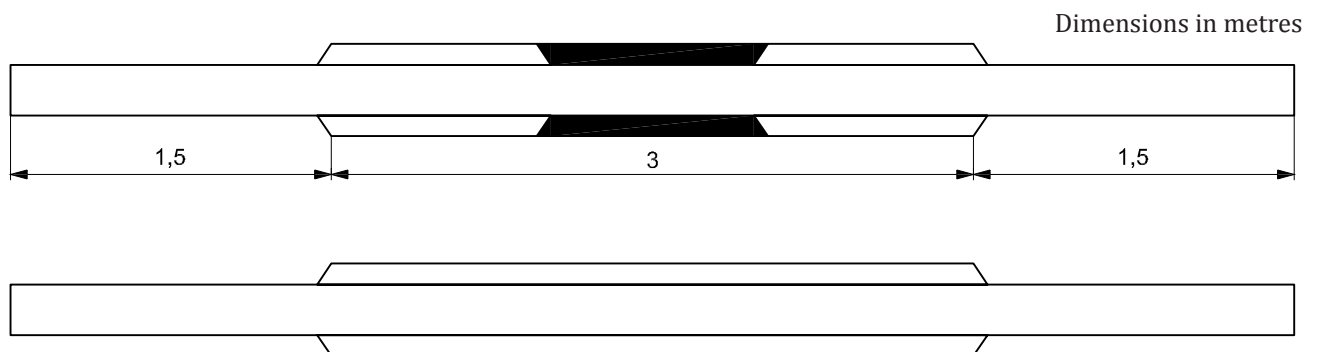
Figure C.1 — Pipe configuration

Annex D
(normative)

Simulated tensioner test

When designing the test, consideration should be given to:

— the tensioner/clamp pads to be used;

— test temperature;

— test loadings and slippage criteria.

These parameters shall be determined by the system supplier and the pipelay vessel owner.

A minimum of one straight short length (typically 2 m) of coated pipe shall be subject to simulated tensioner test.

A test arrangement of the form shown in Figure D.1 shall be used to simulate the interaction between pads in the tensioner module(s) on the pipelay vessel and the pipe coating system(s). In all cases, the tensioner pads used in the test arrangement shall be obtained from the pipelay vessel.

External surface of the coating system and the contact surface of the pads shall be wetted before application of the compressive/squeeze loadings. A range of temperatures shall be included in the test program.

For each temperature, coated pipe length to be positioned between the sets of tensioner pads and specified compressive/squeeze loading to be applied. The reduction in thickness of the coating system to be measured and the outline of the footprints of the tensioner pads to be marked on the external surface of the coating systems.

The vertical axial load is applied in either an upward or downward direction. The axial loading is increased until widespread slippage occurs between the coated pipe length and the contact surfaces of the tensioner pads.

The test shall be repeated for a range of temperatures and compressive/squeezes loadings to obtain a series of friction coefficients for the coating system and the tensioner pads.

The compressive/squeeze loading required for a given pipelay tension shall be obtained using the friction coefficient from the tests on the line pipe coating described above. This compressive/squeeze loading shall be applied to a length of pipe including a field joint area at the required temperature.

The specified axial loading shall be applied to the test pipe with field joint and no slippage should occur between the tensioner pads and the field joint system.

On completion of the test, the external surface of the coated pipe length shall be subjected to an external visual inspection and if required the coated pipe length to be sectioned.
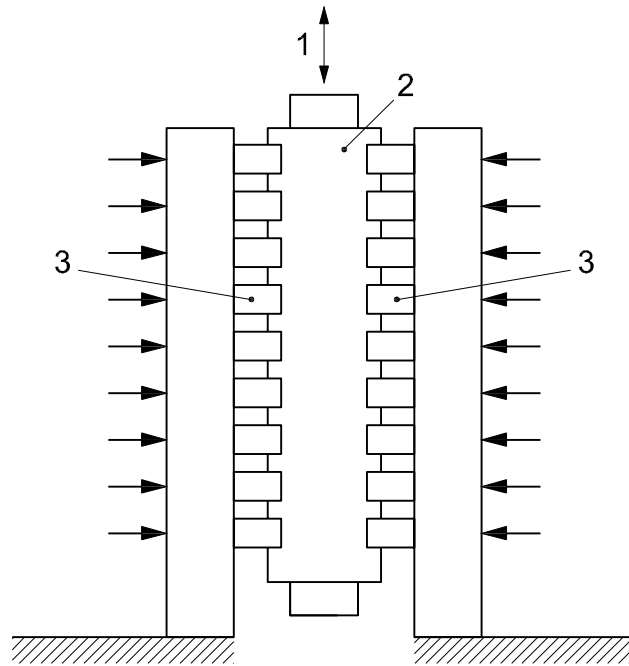
Key

1   applied loading
2   length of coated pipe
3   pipelay vessel tensioner pads, typically 2-, 3- or 4-pad configuration

Figure D.1 — Test principle
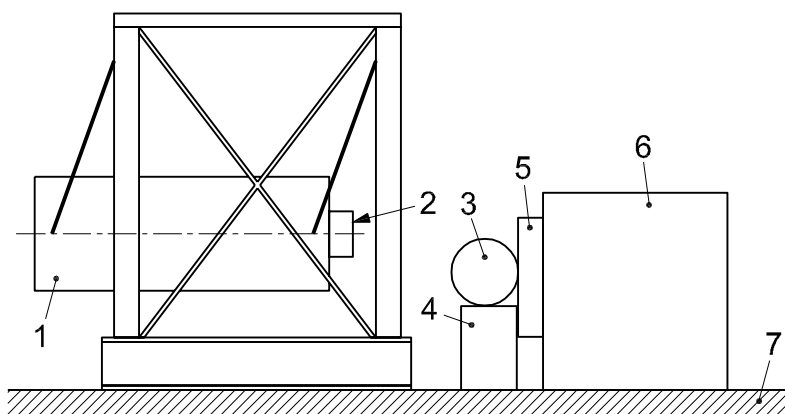
Annex E
(normative)

Simulated impact test

The test shall be performed on one straight pipe section.

Three areas of each coated pipe length shall be subjected to the simulated impact test using the test arrangement shown in Figure E.1. A structural steel framework or similar shall be positioned directly behind the point of impact. The striking face of the impact hammer shall make contact with the coated length of pipe at the 3/9 o'clock position.

The impact energy shall be is 12 kJ (mass of hammer 1 700 kg). The shape of the striking face of the hammer should either be rounded with a radius of curvature of 10 mm or 25 mm, or a flat face 50 mm wide with rounded vertical edges. The striking angle with respect to the axis of the coated pipe length shall be either 90° or 60°. Three independent sites shall be selected along the coated pipe length.

The coating at each test site shall be inspected for any signs of visible distress and a photographic record made.

Coated rings containing the test sites shall be cold cut from the coated pipe length and then cut longitudinally through the points of impacts to determine the depth of penetration into the coating and the extent of the resulting of damage.

Key

1   hammer
2   striking face
3   test pipe
4   support
5   interchangeable angled support assemblies
6   buffer
7   anchorage points

Figure E.1 — Test principle

Annex F
(normative)

Simulated service test (factory applied coating)

When designing the test, consideration should be given to:

— temperature of internal surface of the steel pipe;

— temperature of external surface of the coating system;

— hydrostatic pressure;

— temperature range over which cool down time shall be measured;

— duration of the period during which the test pipe is subjected to a combination of hydrostatic pressure and a temperature gradient;

— requirement for temperature and pressure cycling.

These parameters shall be defined by the system supplier.

Dimensional layout of coated pipe length supplied for a simulated service test conducted under hydrostatic pressure shall be as shown in Figure F.1.

A multi-zone cylindrical heater array, or similar, incorporating heating elements and thermocouples shall be provided and installed within bore of coating pipe length. Cylindrical heater array shall be connected to process control/data acquisition system(s).

Temperature measurement devices, arranged in groups of four, shall be bonded to the external surface of the coating system within central measurement zone at four clock positions.

Displacement transducers or strain gauges shall be installed, at four clock positions, to measure variations in the radial thickness of coated pipe length within the central measurement zone during test.

Attention shall be given to the water cooling and water management system used in the test, particularly in long term tests, i.e. test durations of between 28 days and 90 days and those involving damaged coating systems.

On completion of mobilization of the test, stabilized conditions shall be established in the presence of cooling alone.

Average temperature of the internal surface of the steel pipe shall be increased incrementally in a minimum of 3 steps, typically 50 % and 75 % of the target temperature, until specified test temperature is reached. At each increment of temperature, stabilized conditions shall be allowed to develop and for any nonlinearity in the response of the coating system(s) on the test pipe to increasing temperature to be reported.

When stabilized conditions are achieved (defined as constant power output to all zones of the system for a period of 3 days) at the specified test temperature, the hydrostatic pressure of the water (fresh water or artificial seawater prepared in accordance with ISO 15711) inside the pressure vessel shall be gradually increased to the specified test pressure. Any abnormal behaviour that occurs during this process shall be reported.

Test conditions shall be maintained (temperature ± 1 °C, pressure ± 0,5 MPa) over the specified duration of the test, e.g. typically 7 days after the thermal stabilization has been achieved. Data acquisition system shall be used to record all the measurements from the test with respect to time, i.e. as a minimum internal and external temperatures (to be recorded during the whole duration of the test), electrical power inputs to zones, hydrostatic pressure and variations in radial thicknesses of coated pipe length.

On completion of the test and/or at one or more agreed points during test, a cooldown simulation using an active cooldown cycle approach may be required. The group of heating elements in central measurement zone in coated pipe length shall be switched off at the start of the cooldown cycle but the groups of heating elements in both adjoining guard zones shall remain active throughout the cooldown cycle. Heating elements in the guard zones shall be programmed to track the average temperature of the internal surface of the steel pipe in the central measurement zone ± a programmable temperature offset, e.g. −1,0 °C to −0,5 °C.

When the average temperature in the central measurement zone within the coated pipe length has fallen to either specified test temperature or until it remains unchanged for a period of 24 h, the process may be repeated if confirmation of repeatability of the cooldown cycle is required.

On completion of the cooldown cycle, the hydrostatic pressure shall be either reduced to atmospheric pressure or maintained at the specified test pressure and the average temperature of the pipe wall shall be again increased to the specified test temperature and held until completion of the test period.

Analysis of the water (salinity and pH) present in the pressure vessel may be carried out at the commencement, during and on completion of long term tests and the results reported.

On completion of the test, the external surface of the coated pipe length shall be subjected to an external visual inspection and if required the coated pipe length may be sectioned.

Key
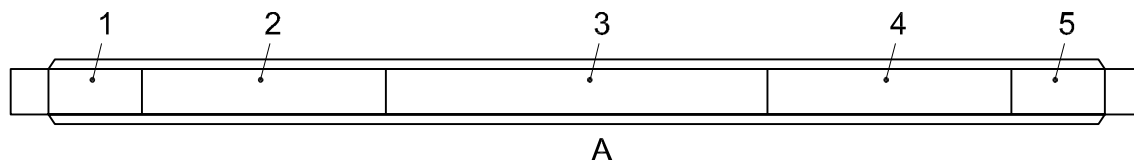
1	zone 1
2	zone 2
3	zone 3
4	zone 4
5	zone 5
NOTE 1	Zone 3 central measurement zone typical length is 10 × steel pipe ID.
NOTE 2	Zones 2 and 4 guard zones length is at least 25 % of length of zone 3.
NOTE 3	Zones 1 and 5 additional guard zones require for short pipe lengths.

Figure F.1 — Pipe configuration

Annex G
(normative)

Simulated service test (field joint)

When designing the test, consideration should be given to:

— construction details of the test piece with respect to cutback design and field joint;

— temperature of internal surface of the steel pipe;

— temperature of external surface of the coating systems;

— hydrostatic pressure;

— temperature range over which cool down time shall be measured;

— duration of the period during which the test pipe is subjected to a combination of hydrostatic pressure and a temperature gradient;

— requirement for temperature and pressure cycling;

— if the test duration is of longer term, i.e. longer than 28 days, then consideration shall be given to the environmental conditions within the pressure vessel, particularly in the case of intentionally damaged coating systems or when coating breakdown is anticipated.

These parameters shall be defined by the field joint designer.

Dimensional layout of coated pipe length supplied for a simulated service test conducted under hydrostatic pressure shall be as shown in Figure G.1.

A multi-zone cylindrical heater array, or similar, incorporating heating elements and thermocouples shall be provided and installed within bore of coating pipe length. Cylindrical heater array shall be connected to process control/data acquisition system(s).

Temperature measurement devices, arranged in groups of four, shall be bonded to the external surface of the coating system within infilled field joint area at four clock positions.

Displacement transducers or strain gauges shall be installed, at four clock positions, to measure variations in the radial thickness of coated pipe length within infilled field joint area (adjoining lengths of factory applied coating system) during test.

Attention shall be given to the water cooling and water management system used in the test, particularly in long term tests, i.e. test durations of between 28 days and 90 days and those involving damaged coating systems.

On completion of mobilization of test, stabilized conditions shall be established in the presence of cooling alone.

Average temperature of the internal surface of the steel pipe shall be increased incrementally in a minimum of 3 steps, typically 50 % and 75 % of the target temperature, until specified test temperature is reached. At each increment of temperature, time shall be allowed for stabilized conditions to develop and for any nonlinearity in the response of the coating system(s) on the test pipe to increasing temperature to be reported.

When stabilized conditions are achieved (defined as constant power output to all zones of the system for a period of 3 days) at the specified test temperature, the hydrostatic pressure of the water inside the

pressure vessel shall be gradually increased to the specified test pressure. Any abnormal behaviour that occurs during this process shall be reported.

Test conditions shall be maintained (temperature ± 1 °C, pressure ± 0,5 MPa) over the specified duration of the test, e.g. typically 28 days. Data acquisition system shall be used to record all the measurements from the test with respect to time, i.e. as a minimum, internal and external temperature, electrical power inputs to zones, hydrostatic pressure and variations in radial thicknesses of coated pipe length.

On completion of the test and/or at one or more agreed points during test, a cooldown simulation using an active cooldown cycle approach may be required. The group of heating elements in infilled field joint area within coated pipe length shall be switched off at the start of the cooldown cycle but the groups of heating elements in both adjoining guard zones shall remain active throughout the cooldown cycle. Heating elements in the guard zones shall be programmed to track the average temperature of the internal surface of the steel pipe in the infilled field joint area ± a programmable temperature offset, e.g. −1,0 °C to −0,5 °C.

When the average temperature in the infilled field joint area within the coated pipe length has fallen to either specified test temperature or until it remains unchanged over a period of 24 h, the process may be repeated if confirmation of repeatability of the cooldown cycle is required.

On completion of cooldown cycle, the hydrostatic pressure is either reduced to atmospheric pressure or it shall be maintained at the specified test pressure and the temperature of the pipe wall shall be again increased to the specified test temperature and held until completion of the test period.

Analysis of the water (salinity and pH) present in the pressure vessel shall be carried out at the commencement, during and on completion of long term tests and the results shall be reported.

On completion of the test, the external surface of the coated pipe length shall be subjected to an external visual inspection and if required the coated pipe length shall be sectioned.

Key
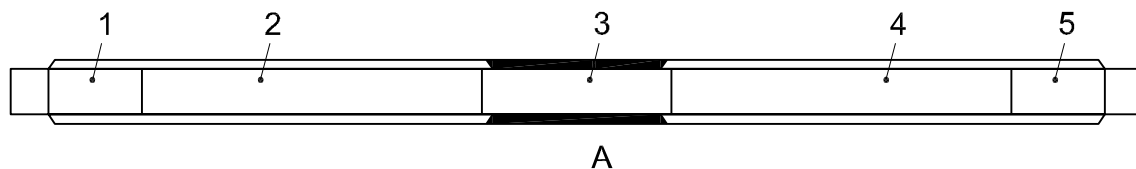
1	zone 1
2	zone 2
3	zone 3
4	zone 4
5	zone 5
A	field joint coating
NOTE 1	Zone 3 central measurement zone length of infilled field joint area.
NOTE 2	Zones 2 and 4 guard zones length is at least twice of length of zone 3.
NOTE 3	Zones 1 and 5 additional guard zones require for short pipe lengths.

Figure G.1 — Pipe configuration

Annex H
(informative)

Simulated service test (subsea equipment)

Dimensional layout of coated pipe length supplied for a simulated service test conducted under hydrostatic pressure shall be as shown in Figure H.1 or alternatively in Figures H.2, H.3 and H.4.

The design detailed in Figures H.2, H.3 and H.4 is provided as a more rigorous test. The additional complexity of the simulated service test piece presents a greater challenge in the application of the insulation, such as may be experienced when applying insulation to complex pieces of subsea equipment. Also, this provides for a more realistic simulated service test due to the thermal and hydrostatic pressure stresses on the complex geometry.

The insulated simulated service test piece may include a number of additional features, such as hot/wet interfaces at the simulated sensor and end cap, exposed surfaces of the actuator stems on the valve block and manufactured faults in the joints between mouldings. If these are of interest, they may be included in the design of the insulation, but this design shall be carried out in accordance with the applicator's best practices to ensure a realistic and fair test. Figure H.4 is provided for example only, to demonstrate some of these features and how they may be realized.

A heating system shall be provided to ensure that all the internal surfaces of the test piece are evenly raised to the specified temperature coating pipe length.

Temperature measurement devices shall be attached to the coated test piece.

Displacement transducers shall be installed as appropriate.

The external surfaces of the coating system(s) shall be reduced to and maintained at a surface temperature of 4 °C ± 2 °C.

On completion of mobilization of test, stabilized conditions shall be established in the presence of cooling alone.

The temperature and pressure variations to which the coating system(s) shall be subjected is shown graphically in Figure H.5.

On completion of the test, the external surface of the coated test piece shall be subjected to an external visual inspection and if required, the coated test piece shall be sectioned for further examination and testing.
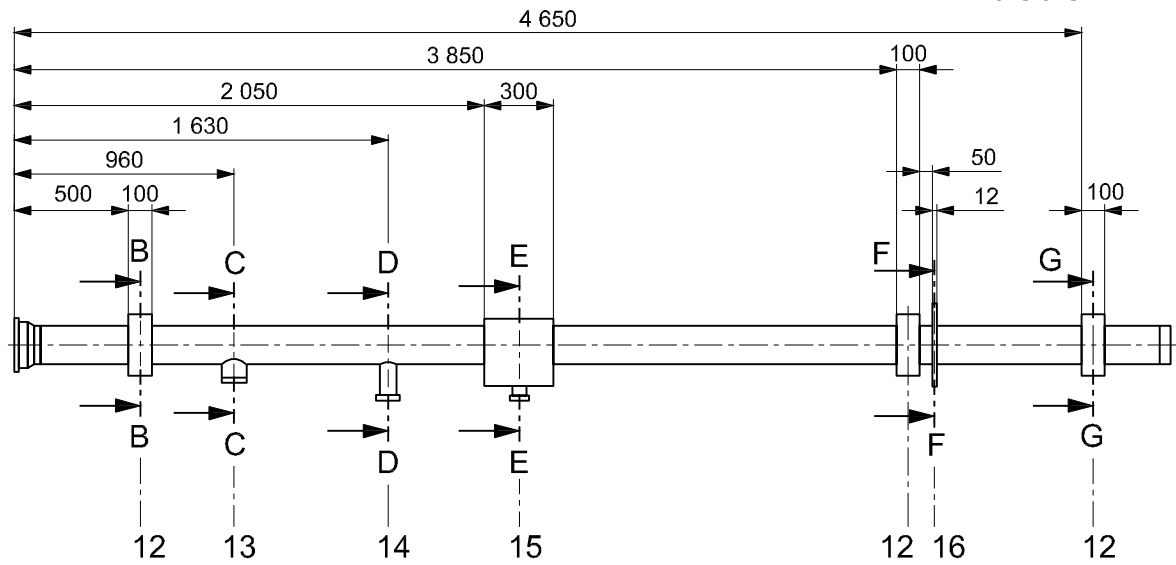
Dimensions in millimetres
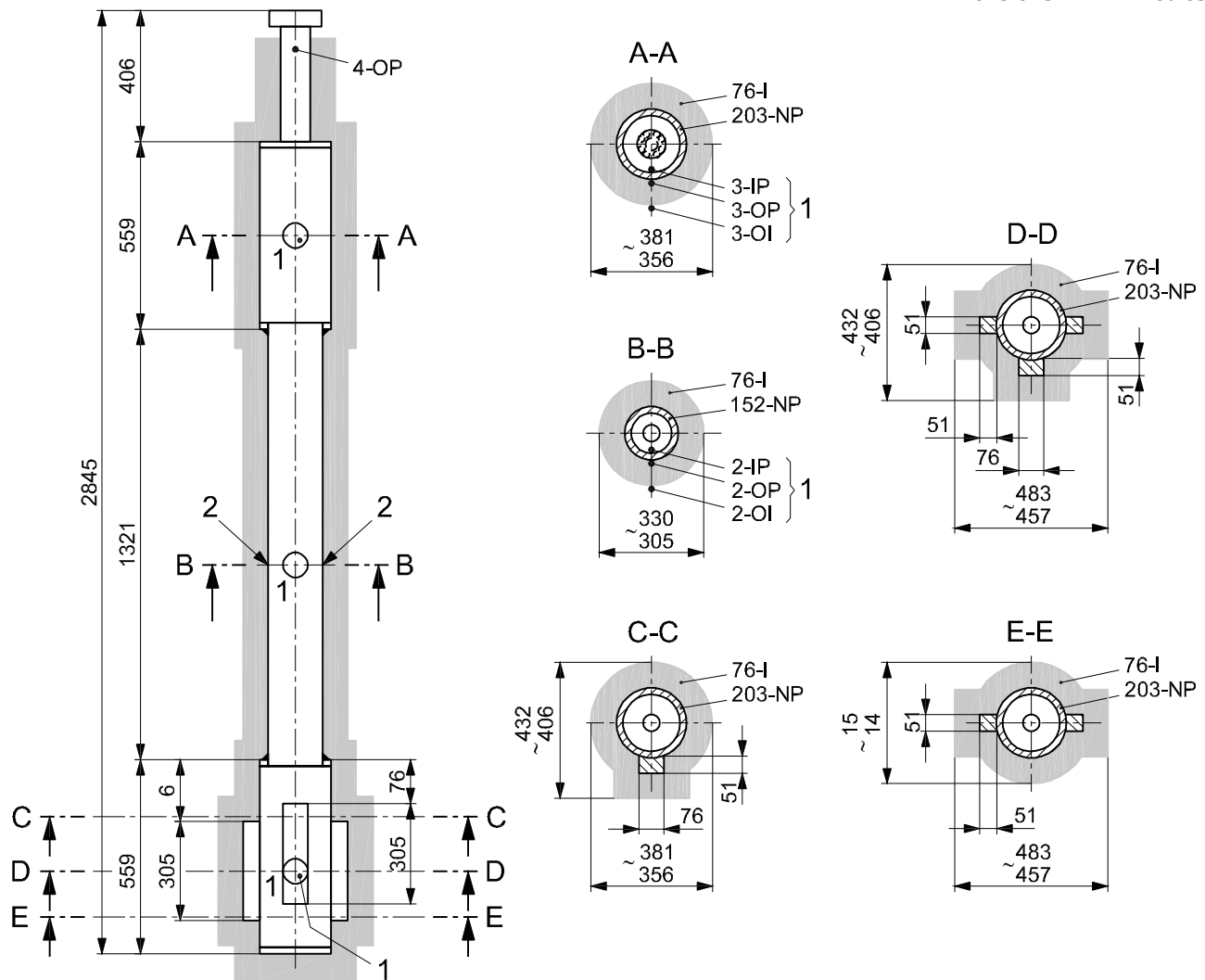
Key

1   thermocouples
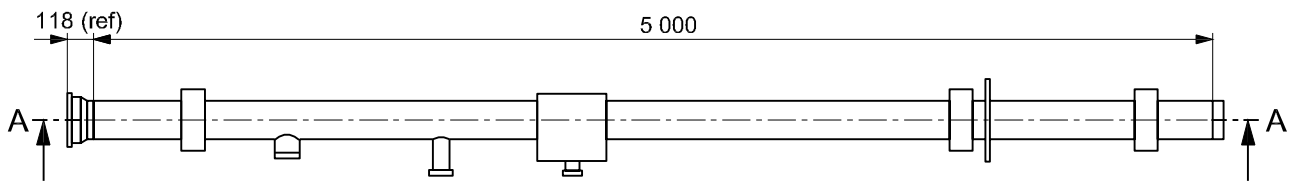
2   cast joint

I   insulation

NP   nominal pipe

Figure H.1 — Simulated service test piece - Type 1
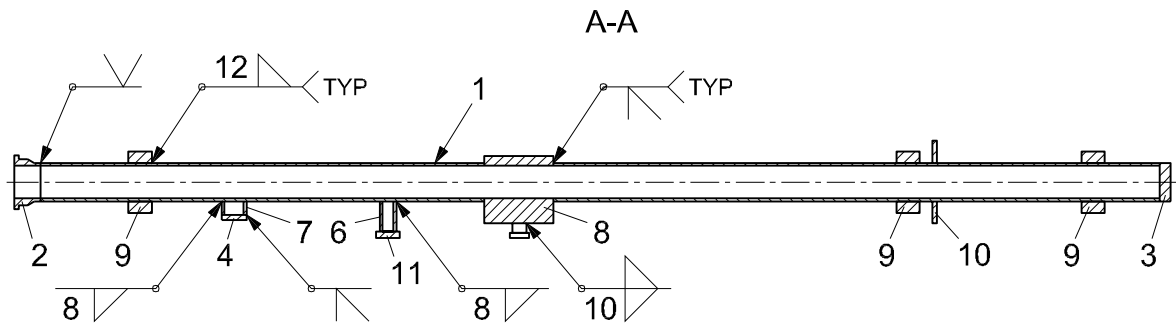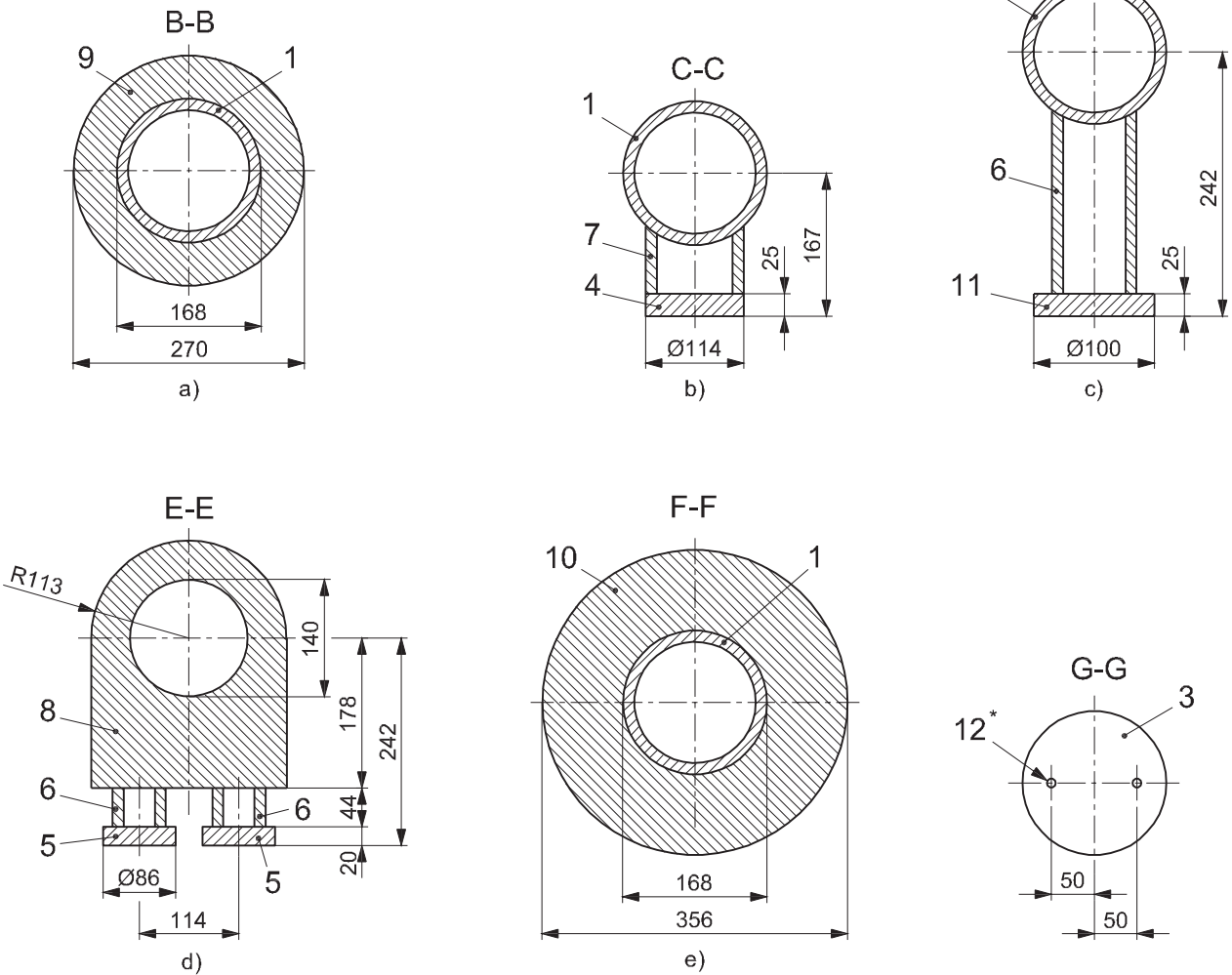
Dimensions in millimetres

a)

b)

A-A

Figure H.2 — Simulated service test piece - Type 2 (bare steel only)

Dimensions in millimetres

Key

Item	Bill of material — Description	Quantity
1	168,3 mm OD × 14,3 mm WT (see NOTE 4)	5 m
2	Grayloc 6GR52 Schedule 160 BTM 139,68 mm ID (see NOTE 2)	1
3	141 mm diameter × 50 mm thick end cap (see NOTE 3)	1
4	168,3 mm diameter × 25 mm thick end plate (see NOTE 3)	1
5	86 mm diameter × 25 mm thick end plate (see NOTE 3)	2
6	73,0 mm OD × 14 mm WT (see NOTE 6)	0,19 m
7	114,3 mm diameter pipe Schedule 160 (see NOTE 5)	0,15 m
8	(291 × 226 × 300) mm thick plate (see NOTE 3)	1
9	270 mm OD × 170 mm ID × 100 mm thick plate (see NOTE 3)	3
10	356 mm OD × 170 mm ID × 12 mm thick plate (see NOTE 3)	1
11	100 mm diameter × 25 mm thick end plate (see NOTE 3)	1

NOTE 1   Equipment test specimen configuration to be confirmed during detailed design.

NOTE 2   Flange type and rating to be confirmed during detailed design.

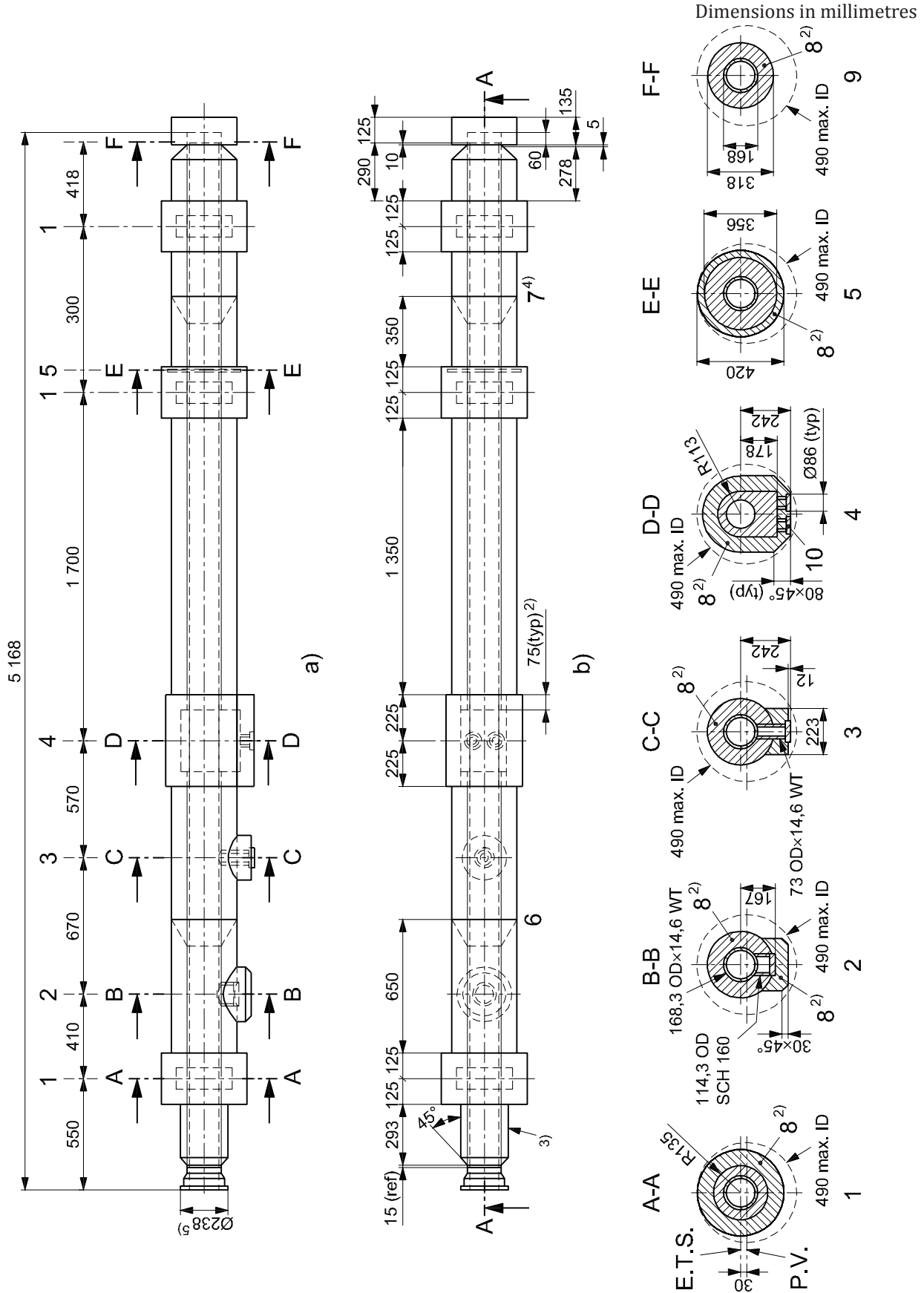NOTE 3   All plate to be ASTM A36 unless noted otherwise.

NOTE 4   Pipe material to be API 5L X52 or better.

NOTE 5   Pipe material to be API 5L X42 or better.

NOTE 6   Pipe material to be API 5L X65 or better.

**Figure H.3 — Simulated service test piece (bare steel component detail and notes)**

Dimensions in millimetres

a)

b)

Key

1　　　　simulated flange

2	simulated nozzle
3	simulated sensor
4	simulated valve
5	damage propagation stop
6	good joint
7	disbonded joint
8	insulation
9	end cap
10	simulated actuator
a)	elevation on equipment test specimen (ETS)
b)	plan on equipment test specimen (ETS)
NOTE 1	Insulation system is in accordance with approved manufactures application procedure.
NOTE 2	Typical insulation systems thickness is 75 mm.
NOTE 3	Reduced insulation (25 mm thick to cool pipe).
NOTE 4	3 mm physical disbondment around circumference.

Figure H.4 — Simulated service test piece - Type 2 (insulated and notes)
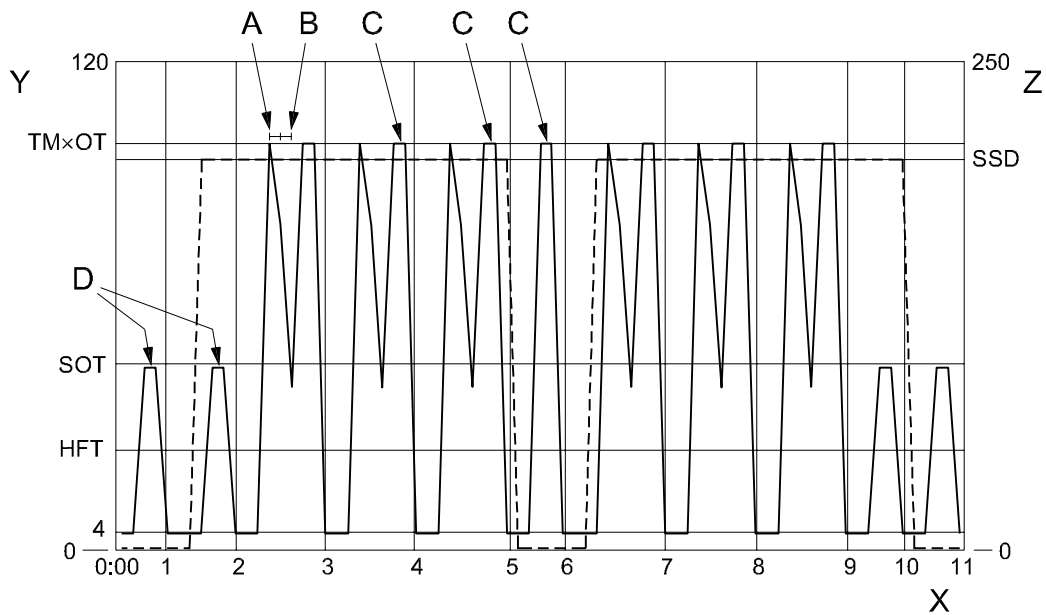
Key

1 to 11	day1 to day 11
A	1,5 h natural cooldown
B	1 h forced cooldown
C	1,5 h steady state
X	test days/time
Y	temperature
Z	pressure
SOT	minimum safe operating temperature
HFT	hydrate formation temperature
TM×OT	test maximum operating temperature
SSD	sea-water service depth
————	test specimen temperature
– – – – –	vessel pressure

Figure H.5 — Simulated service test temperature and pressure

Annex I
(normative)

Ring shear test procedure

The following procedure covers the shear test to be carried out on the thermal insulation coating system.

One minimum 25 mm wide ring shall be cold cut from the test pipe and subject to the shear test.

The insulation on the pipe shall be supported by an outer ring and then the pipe shall be pushed at a speed of 1 mm/min, relative to the insulation until failure occurs, (see Figure I.1).

The gap between the OD of the pipe and the ID of the support ring shall be agreed depending on the interface to be checked.

The force per unit area of the bonded surface required to cause failure of adhesion between the pipe and insulation shall be measured using suitable equipment, and recorded.
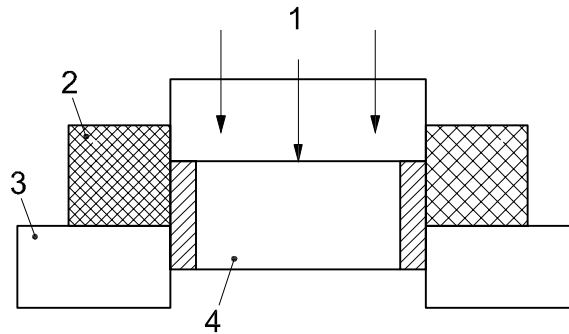
Key

1   steel pipe forced against coating until failure
2   insulation coating
3   supports for coating
4   steel pipe

Figure I.1 — Test principle

Annex J
(normative)

Determination of mass ratio of glass microspheres, density of glass microspheres after processing and entrapped air ratio for glass syntactic materials

J.1 General

This annex describes the method to be used for the determination of the following parameters:

— Mass of glass microspheres (M_a) and corresponding mass ratio (M_{ar})

— Density of glass microspheres (d_a) after processing

— Air entrapment in the glass syntactic material (V_v) and corresponding ratio (V_{vr})

It shall be noted that the potential presence of non-organic additives, such as anti-caking agents is not considered in the calculation or the experimental process. It can be considered that non organic additives will not impact the volume loss due to glass breakage during processing (as it is a relative and not absolute value). The main objective of this annex being to better monitor the processing and microsphere damages (and not to control the composition of the material itself), the presence of such additive is not considered as a first order parameter.

J.2 Mass of glass microspheres in the glass syntactic material

The mass ratio of glass microspheres in the glass syntactic material, M_{ar}, shall be calculated using Formula (J.1):

$$M_{ar} = \frac{M_a}{M_t} \qquad\qquad (J.1)$$

where

M_t is the mass of glass syntactic material sample used for M_a determination (g);

M_a is the mass of glass microspheres in the glass syntactic material sample (g).

The mass of the glass syntactic material sample, M_t, shall be determined by weighing in a four-figure balance.

The mass of the glass microspheres, M_a, shall be determined experimentally from a calcination method, according to ISO 1172:1996, Method A. The muffle furnace temperature shall be within the range of 450°C to 500°C.

J.3 Density of glass microspheres in the glass syntactic material after processing

The density of the glass microspheres (ash) in the glass syntactic material sample, d_a, measured in grams per cubic centimetres, is determined by gas pycnometer measurements according to ISO 7822:1990, Figure 2.

J.4 Air entrapment in the processed glass syntactic material

The air entrapment in a glass syntactic material sample, V_v, measured in cubic centimetres, is calculate from Formula (J.2):

$$V_\mathrm{v} = \frac{V_\mathrm{th}\left(d_\mathrm{sg,th} - d_\mathrm{gs}\right)}{d_\mathrm{gs}} \tag{J.2}$$

where

V_th is the theoretical volume of the glass syntactic material sample, measured in cubic centimetres;

d_gs is the density of the glass syntactic material sample, measured in grams per cubic centimetres;

$d_\mathrm{gs,th}$ is the theoretical density of the glass syntactic material sample, measured in grams per cubic centimetres.

The ratio of air entrapment in the glass syntactic material sample is then calculated from Formula (J.3):

$$V_\mathrm{vr} = \frac{V_\mathrm{v}}{V_\mathrm{th}} \tag{J.3}$$

Combining Formulae (J.2) and (J.3), the ratio of air entrapment in the glass syntactic material sample, V_vr, can be expressed as Formula (J.4):

$$V_\mathrm{vr} = \frac{d_\mathrm{gs,th} - d_\mathrm{gs}}{d_\mathrm{gs}} \tag{J.4}$$

The theoretical density of the glass syntactic material sample, $d_\mathrm{gs,th}$, is defined by Formula (J.5):

$$d_\mathrm{gs,th} = \frac{M_\mathrm{t}}{V_\mathrm{th}} \tag{J.5}$$

where M_t is the mass of glass syntactic material sample, measured in grams.

The theoretical volume of the glass syntactic material sample, V_th, is given by Formula (J.6):

$$V_\mathrm{th} = V_\mathrm{a} + V_\mathrm{p} \tag{J.6}$$

where

V_a is the volume of the glass microspheres, measured in cubic centimetres;

V_p is the volume of the polymer matrix, measured in cubic centimetres.

The mass of the polymer matrix, M_p, measured in grams, is given by Formula (J.7):

$$M_p = M_t - M_a \tag{J.7}$$

Considering the volume equal to the mass per density, using the Formulae (J.5), (J.6) and (J.7), the ratio of air entrapment in the glass syntactic material sample, V_{vr}, can be expressed in terms of known variables using Formula (J.8):

$$V_{vr} = \frac{\dfrac{M_t}{\dfrac{M_a}{d_a} + \dfrac{M_p}{d_p}} - d_{gs}}{d_{gs}} \tag{J.8}$$

where d_a is the density of the glass microspheres in the glass syntactic material sample, measured in grams per cubic centimetres

Alternatively, using Formula (J.1), the ratio of air entrapment in the glass syntactic material sample, V_{vr}, can be expressed in terms of known variables using Formula (J.9):

$$V_{vr} = \frac{\dfrac{1}{\dfrac{M_{ar}}{d_a} + \dfrac{1 - M_{ar}}{d_p}} - d_{gs}}{d_{gs}} \tag{J.9}$$

The density glass syntactic material sample d_{gs}, is determined by gas pycnometer measurements.

The density of the glass microspheres (ash), d_a, is determined by gas pycnometer measurements according to ISO 7822:1990, Figure 2.

The mass of the glass microspheres, M_a, is determined as described in Clause J.2.

The mass of the glass syntactic material sample, M_t, is determined by weighing in a four-figure balance.

The air entrapment in the processed glass syntactic material is determined according to ISO 7822:1990, Method A, with the following exceptions:

— density of glass reinforcement in ISO 7822:1990, 7.1.3, shall be taken as d_a;

— resin content of composite in ISO 7822:1990, 7.1.5, shall be taken as M_p [where M_p is derived from known variables M_t and M_a as defined in Formula (J.5)].

Annex K
(informative)

# End of life through thickness water profile calculation

K.1 General

This annex describes the way to analyse the results of the water absorption kinetic (7.2.2) in order to evaluate the end of life through thickness water profile of the structure.

The analysis presented hereafter is based on Fick diffusion and is done considering one dimensional diffusion and large coated plate in contact with water on one face. This analysis can be easily adapted for pipe coating, multilayer system, etc. More complex analyses using finite element analysis could be performed for more complex geometry and more complex water absorption kinetics.

K.2 Flowchart

K.2.1 Step 1: Reporting of the absorption curves at three temperatures

In Figure K.1, the square of the time divided by the thickness of the sample is reported on the x-axis and the % absorbed water is reported on the y-axis.
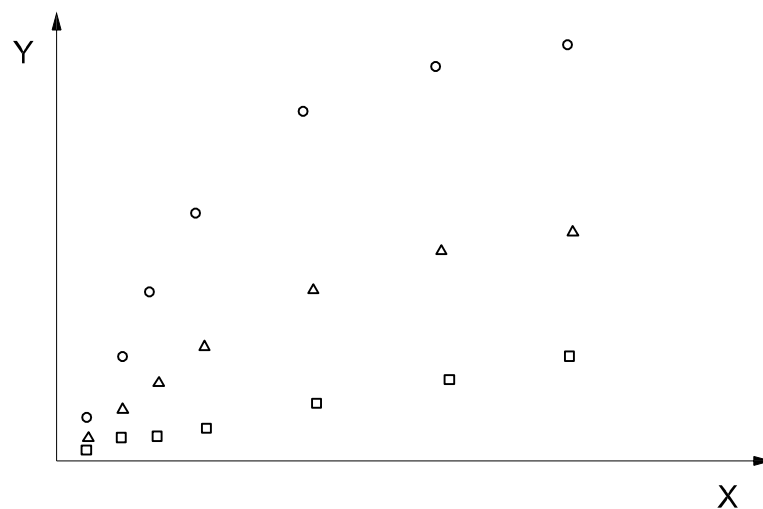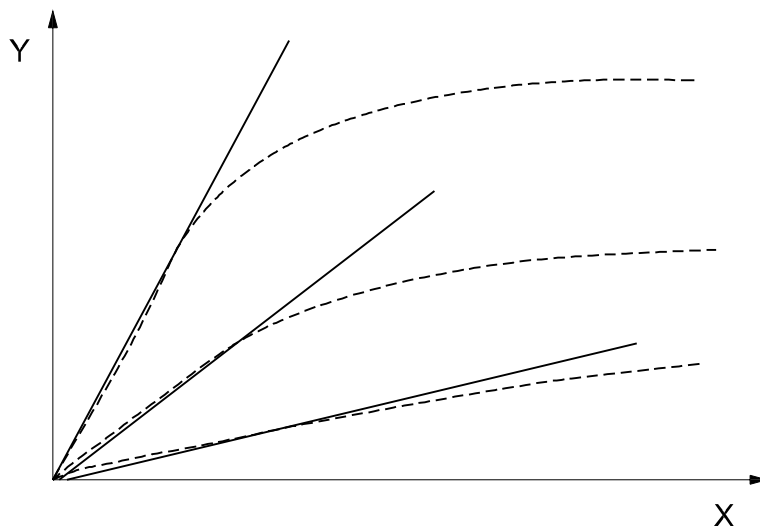

Key

X	square of time, t, in h
Y	% water
○	T_{max}
△	T_{mid}
□	T_{min}

Figure K.1 — Absorption curves

K.2.2 Step 2: Determination of the diffusion coefficients

Fitting of the curve by Fick's law can be performed in order to determine the diffusion coefficient and the saturation level (see Figure K.2).

Key

X square of time, t, expressed in hours

Y % water

Figure K.2 — Determination of absorption coefficient

In a simple way, the initial slope of the curve gives access to the diffusion coefficient in accordance with Formula (K.1):

$$\frac{M_t}{M_\infty} = \frac{2}{l}\sqrt{\frac{D \times t}{\neq}} \qquad (K.1)$$

where

M_t is the mass of time t

M_∞ is the mass at saturation

l is the half thickness of the specimen, expressed in metres

D is the diffusion coefficient, expressed in square metres per second

t is the time, expressed in seconds

K.2.3   Step 3: Determination of Arrhenius parameter for diffusion coefficients

The three diffusion coefficients obtained on step 2 are reported on an Arrhenius plot with $1/T(°\text{K})$ on the x-axis and $\ln(D)$ on the y-axis (see Figure K.3).
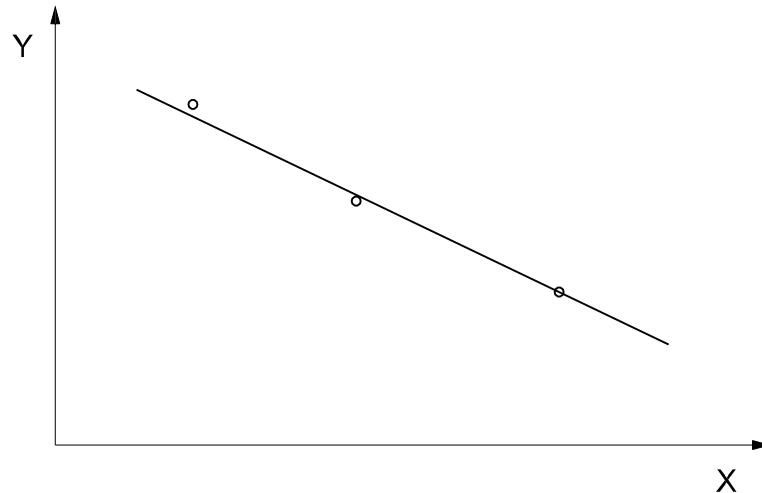
Key
X $1/T$
Y $\ln(D)$

Figure K.3 — Determination of the activation energy

By linear fitting of the curve, the parameters *a* and *b* of Formula (K.2) can be obtained:

$$D = a \cdot e - b \cdot T \tag{K.2}$$

For example, for epoxy coating, *a* = 0,000 000 8, *b* = 3 927 for a diffusion coefficient of $1{,}05 \times 10^{-12}$ (m^2/s) at 20 °C.

K.2.4 Step 4: Estimation of the temperature profile through the thickness of the coating

In first approximation, considering only the conduction phenomena for a coated plate, the temperature profile is linear and can be determined from the water temperature and the inner temperature (fluid temperature). For coated pipe, the profile is in accordance with Formula (K.3).

$$T(r) = T_i - \left(T_i - T_e\right) \frac{\ln \dfrac{r}{r_i}}{\ln \dfrac{r_e}{r_i}} \tag{K.3}$$

where

r is the location

$T(r)$ is the temperature at *r* point
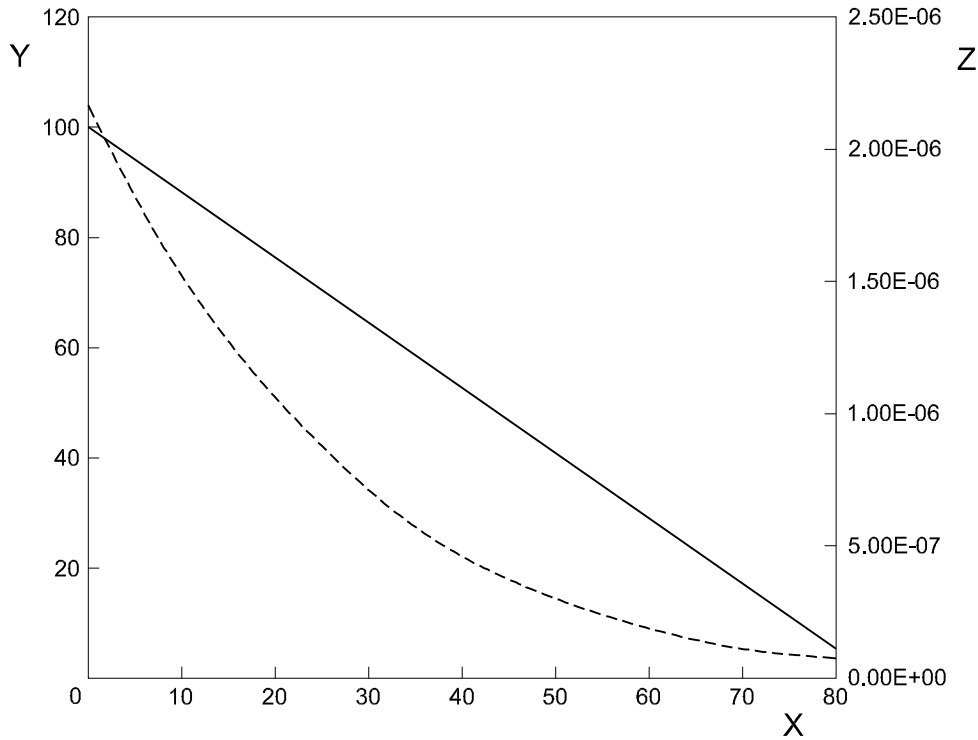
T_i is the inner temperature (fluid temperature)

T_e is the external temperature (water temperature)

r_i is the internal radius

r_e is the external radius

Knowing the temperature profile, the trough thickness diffusion coefficient can be determined using Formula (K.2) (see Figure K.4).

Key

X   distance from steel pipe, expressed in millimetres

Y   temperature, expressed in Celsius degrees

Z   diffusion coefficient, expressed in square millimetre per seconds

─────   temperature

─ ─ ─ ─   diffusion coefficient

Figure K.4 — Temperature profile through thickness of the coating

K.2.5   Step 5: Estimation of the water profile evolution by applying Fick's law

The through thickness saturation level can be obtained by solving the mass balance equation in accordance with Formula (K.4):

$$\frac{\partial C}{\partial t} = -\frac{\partial J}{\partial x} \tag{K.4}$$

where the constitutive expression for mass flux, J, is Fick's law, as expressed in Formula (K.5):

$$J = -D\frac{\partial C}{\partial x} \tag{K.5}$$

where

C is the penetrant concentration

D is the diffusion coefficient

The solving of the system can be done using function solving partial differential equation.

With, in the case of coated plate in contact with water on one face, the following boundary conditions:

— external surface coating = saturation

— coating surface in contact with steel = null gradient concentration

An example of result for a 30 years extrapolation is given on the following curve for a 80 mm coated plate, inner temperature 100 °C, external temperature 4 °C, material with the same Fick's law parameter than epoxy coating (see Figure K.5).
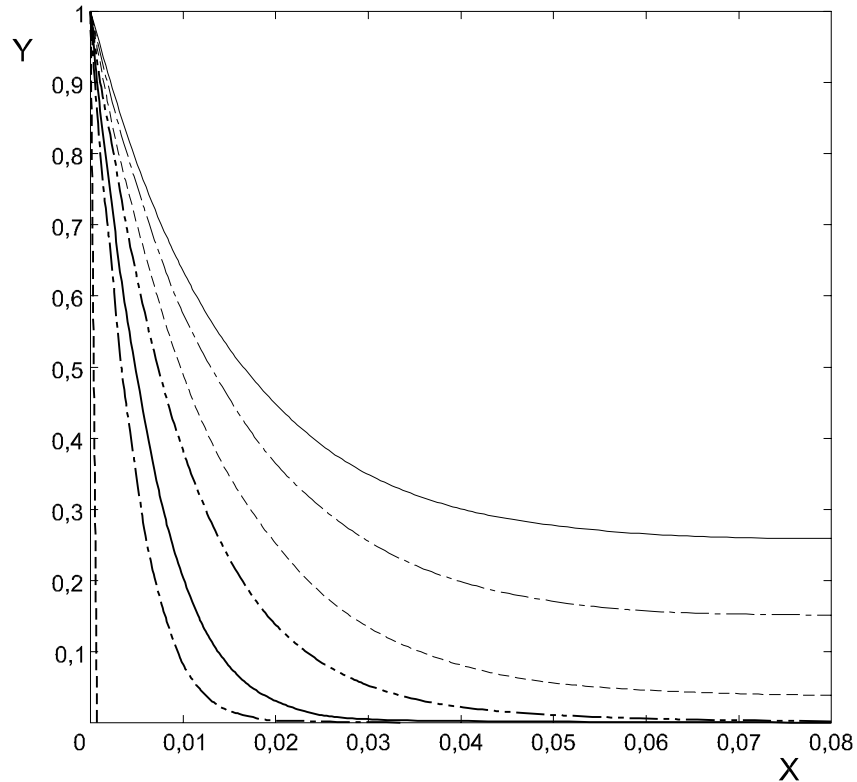
Key

X	thickness, expressed in metres
Y	level of saturation
_ _ _ _	initial
—.—	1 year
———	2 years
—..—	5 years
_ _ _ _	10 years
—.—	20 years
———	30 years

Figure K.5 — Estimation of the water profile

Figure K.5 provides information on the level of saturation of the material through the thickness of the coating. The level of saturation is equal to 1 when the material is saturated. Water profile can be directly estimated by knowing the water concentration at saturation level.

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