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Oil and gas industries including lower carbon energy — Wet thermal insulation systems for pipelines and subsea equipment —

Part 1: Validation of materials and insulation systems

Industries du pétrole et du gaz, y compris les énergies à faible teneur en carbone — Systèmes d'isolation thermique en milieu humide pour conduites et équipements sous-marins —

Partie 1: Validation des matériaux et des systèmes d'isolation

Reference number
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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 document 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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This document was prepared by Technical Committee ISO/TC 67, *Oil and gas industries including lower carbon energy*, Subcommittee SC 2, *Pipeline transportation systems,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Oil and gas industries including lower carbon energy,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition of ISO 12736-1, together with ISO 12736-2 and ISO 12736-3, cancels and replaces ISO 12736:2014.

The main changes are as follows:

— clearer delineation between validation and projects;

— introduction of material classes;

— modification of material property testing requirements, including detailed thermal conductivity testing requirements;

— introduction of additional long-term testing requirements;

— introduction of additional system testing requirements, including system interfaces;

— removal of project specific testing requirements;

— addition of requirement for risk-based analysis of the system long-term performance;

— modifications of the format and content requirements of the final validation dossier;

— addition of Annex A with guidance for using this document.

A list of all parts in the ISO 12736 series can be found on the ISO website.

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

Oil and gas industries including lower carbon energy — Wet thermal insulation systems for pipelines and subsea equipment —

Part 1: Validation of materials and insulation systems

1 Scope

This document specifies requirements for the validation of wet thermal insulation systems applied to pipelines and subsea equipment in the oil and gas industry.

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

This document is not applicable to:

— maintenance works on existing installed wet thermal insulation systems;

— qualification for anti-corrosion coating;

— thermal insulation in the annulus of a steel pipe-in-pipe system.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 34-1, *Rubber, vulcanized or thermoplastic — Determination of tear strength — Part 1: Trouser, angle and crescent test pieces*

ISO 34-2, *Rubber, vulcanized or thermoplastic — Determination of tear strength — Part 2: Small (Delft) test pieces*

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

ISO 178, *Plastics — Determination of flexural properties*

ISO 179-1, *Plastics — Determination of Charpy impact properties — Part 1: Non-instrumented impact test*

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

ISO 604, *Plastics — Determination of compressive properties*

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

ISO 6721-1, *Plastics — Determination of dynamic mechanical properties — Part 1: General principles*

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

ISO 8302, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

ISO 11357-1, *Plastics — Differential scanning calorimetry (DSC) — Part 1: General principles*

ISO 11357-4, *Plastics — Differential scanning calorimetry (DSC) — Part 4: Determination of specific heat capacity*

ISO 11359-2, *Plastics — Thermomechanical analysis (TMA) — Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

ISO 12736-2, *Oil and gas industries including lower carbon energy — Wet thermal insulation systems for pipelines and subsea equipment — Part 2: Qualification processes for production and application procedures*

ISO 12736-3, *Oil and gas industries including lower carbon energy — Wet thermal insulation systems for pipelines and subsea equipment — Part 3: Interfaces between systems, field joint systems, field repairs, and pre-fabricated insulation*

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

ISO 80000-1, *Quantities and units — Part 1: General*

ASTM D575, *Standard Test Methods for Rubber Properties in Compression*

ISO 80000-1, *Quantities and units — Part 1: General*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
agreed
specified in the purchase order

Note 1 to entry: To be discussed by the *system provider* (3.37) and *system purchaser* (3.38) with input from end user as required.

3.2
application procedure specification
APS
quality specification document, or group of specifications, describing procedures, method, equipment, tools, etc. used for *system* (3.35) application

3.3
batch
quantity of *material* (3.18) produced in a continuous manufacturing operation using raw materials of the same source or grade

3.4
blown foam
insulation *material* (3.18) formed by incorporating a gas phase into a polymer matrix

3.5
certificate of analysis
document provided by the manufacturer that indicates results of specific tests or analysis, including test methodology, performed on a specified lot of the manufacturer's product and corresponding conformity ranges

3.6
construction joint
interface (3.13) where both *systems* (3.35) are identical

3.7
cutback
length of item left uncoated at each end for joining purposes

Note 1 to entry: Welding is an example of joining purposes.

3.8
field joint
uncoated area that results when two pipe sections, or a pipe section and a *fitting* (3.9), with *cutbacks* (3.7) are assembled by welding or other methods

3.9
fitting
receptacle on a piece of *subsea equipment* (3.33), which interfaces to a *pipeline* (3.22)

3.10
high molecular weight precursor thermoset
material (3.18), which is a polymeric compound that remains malleable until application of sufficient heat to cause network formation and then does not flow upon reheating

EXAMPLE Butyl rubber.

3.11
inorganic syntactic foam
insulation *material* (3.18) formed by dispersing inorganic hollow particles within a polymer matrix

3.12
inspection and test plan
ITP
document providing an overview of the sequence of inspections and tests, including appropriate resources and procedures

3.13
interface
location where two *systems* (3.35) meet and affect each other

Note 1 to entry: A *field joint* (3.8) *system* (3.35) has two interfaces.

Note 2 to entry: In the case of multilayer *systems* (3.35), interfaces can be made up of multiple sub-interfaces.

3.14
jumper
short section of *pipeline* (3.22) that transfers fluid between two pieces of *subsea equipment* (3.33)

3.15
liquid precursor elastomeric thermoset
material (3.18), which is a polymeric compound with its glass transition below ambient temperature, that is produced via the combination of one or more components that can be pumped and flow as liquids and that react to create a crosslinked polymer that does not flow upon reheating

EXAMPLE Liquid precursor silicone rubber.

3.16
liquid precursor non-elastomeric thermoset
material (3.18), which is a polymeric compound with its glass transition above ambient temperature, that is produced via the combination of one or more components that can be pumped and flow as liquids and that react to create a crosslinked polymer that does not flow upon reheating

EXAMPLE Liquid epoxy.

3.17
mainline
portion of a *pipeline* (3.22) that is not a *field joint* (3.8)

3.18
material
polymeric compound applied to the *substrate* (3.34) protected or insulated in units of discrete thickness (layers) to build up a *system* (3.35)

3.19
material manufacturer
entity responsible for the manufacture of one or more *materials* (3.18) utilized in a *system* (3.35)

3.20
material maximum and minimum rated temperature
maximum and minimum temperature to which a particular *material* (3.18) can be continuously exposed, as per *system provider* (3.37) recommendation, during storage or in service as part of a *system* (3.35)

Note 1 to entry: For multi-layer systems, the material maximum rated temperature can be less than the *system maximum rated temperature* (3.36).

3.21
maximum rated pressure
maximum hydrostatic pressure to which the *system* (3.35) can be exposed, according to the *system provider* (3.37)

3.22
pipeline
flowline
tubular piping used to convey fluids

Note 1 to entry: Pipeline includes *jumpers* (3.14), *risers* (3.28) and *field joints* (3.8).

3.23
pre-fabricated insulation
section of stand-alone insulation, which is factory manufactured into its final form and then installed in the field by mechanically fastening or bonding to a corrosion protected structure

3.24
pre-production trial
PPT
series of tests performed immediately before the start of production, designed to demonstrate that the requirements of the *validated* (3.43) *system* (3.35), the *procedure qualification trial* (3.25) or both are achieved

Note 1 to entry: Requirements for PPT shall be as outlined in ISO 12736-2 or ISO 12736-3 and as *agreed* (3.1).

3.25
procedure qualification trial
PQT
series of tests designed to demonstrate that the *materials* (3.18), *system provider* (3.37), equipment and procedures can produce a *system* (3.35) in accordance with the *validation dossier* (3.44) and meet specific *project* (3.26) requirements

Note 1 to entry: Requirements for PQT shall be as outlined in ISO 12736-2 or ISO 12736-3 and as *agreed* (3.1).

3.26
project
scope of work *agreed* (3.1) upon contractually between *system purchaser* (3.38) and *system provider* (3.37)

3.27
R-lay
reel-lay
method of *pipeline* (3.22) installation in which long *stalks* (3.32) of pre-insulated pipes are pre-assembled by welding and application of *field joint* (3.8) *system* (3.35) onshore before being spooled onto large reels onboard the installation vessel, which then lays the pipes by unspooling the reel offshore

3.28
riser
vertical portion of a *pipeline* (3.22), including the bottom bend, arriving on or departing from an offshore surface installation

3.29
safety data sheet
SDS
DEPRACATED: material safety data sheet
document intended to provide workers and emergency personnel with procedures for handling and working with a *material* (3.18) utilized in the manufacture of the *system* (3.35) in a safe manner including physical data and first aid, etc.

Note 1 to entry: Physical data can include flash point and toxicity.

3.30
service life
specified period of use for a *system* (3.35) in service

3.31
solid/solid filled
insulation *material* (3.18) that systematically does not contain voids or hollow particles

3.32
stalk
continuous string of welded and *field joint* (3.8) coated pipe, which is prepared in readiness for pipe spooling onto a *R-lay* (3.27) barge

Note 1 to entry: A number of stalks will normally be required to make up a *pipeline* (3.22).

3.33
subsea equipment
components from a subsea production system, including subsea processing items and structures, meant to control hydrocarbons, not including *pipelines* (3.22)

EXAMPLE Valve, connector, manifold, christmas tree, flowline end termination.

3.34
substrate
surface to which a *material* (3.18) is applied or will be applied

3.35
system
all of the various *materials* (3.18) and the combination thereof, which can include layers of anti-corrosion, insulation, adhesive, and protective materials, as defined by cross-section to the underlying *substrate* (3.34) at a single point, which function together to act as a *wet thermal insulation* (3.45)

3.36
system maximum and minimum rated temperature
maximum and minimum temperature to which a particular *system* (3.35) can be continuously exposed, as per *system provider* (3.37) recommendation, during storage or in service

3.37
system provider
legal entity which is selling the applied *system* (3.35)

3.38
system purchaser
entity which is purchasing the applied *system* (3.35)

3.39
thermal conductivity
k-value
conductivity
heat flow through a unit length of *material* (3.18) under the influence of a thermal gradient

Note 1 to entry: Thermal conductivity is expressed in $W \cdot m^{-1} \cdot K^{-1}$.

3.40
thermoplastic
material (3.18), which is a polymeric compound that solidifies upon cooling and can flow and be reformed upon reheating

EXAMPLE Polypropylene.

3.41
tie-in field joint
connection of a *pipeline* (3.22) to a facility or *subsea equipment* (3.33), to other pipelines, or the connecting together of different sections of a single pipeline

3.42
U-value
overall heat transfer coefficient
rate of heat transfer from a reference surface under the influence of a thermal gradient

Note 1 to entry: U-value is expressed in $W \cdot m^{-2} \cdot K^{-1}$.

3.43
validation
demonstration of *material* (3.18) and *system* (3.35) performance during storage, handling and operation, within a specified envelope of use, as determined by the *system provider* (3.39)

3.44
validation dossier
collection of documentation and test reports, prepared in accordance with specific requirements, which provides detailed information on the proposed *system* (3.35), method of application, the *materials* (3.18) which form said *system* (3.35), and demonstration of *system* (3.35) performance

Note 1 to entry: Specific requirements are found in 7.6.

3.45
wet thermal insulation
system (3.35) that provides external corrosion protection and thermal insulation, and that is in direct contact with surrounding seawater

4 Symbols and abbreviated terms

4.1 Symbols

E_{kin}	impact energy (kinetic energy), expressed in joules
g	standard gravity, equivalent to 9,81 metres per seconds squared
H	pendulum height, expressed in metres
m_h	mass of hammer, expressed in kilograms
$Q_{ave,i}$	average value of heat flux transducers signals for sample *i*, where *i* = 1, 2, or 3, expressed in microvolts
Q_{lower}	lower plate heat flux transducer signal, expressed in microvolts
$Q_{Lower,Average}$	average lower plate heat flux transducer signal, expressed in microvolts
$Q_{Ref\ Mat\ ave}$	average value of heat flux transducers signals for reference material sample, expressed in watts per microvolts
$Q_{Ref\ Mat\ ave,i}$	average value of heat flux transducers signals for reference material sample *i*, where *i* = 1 or 2, and 1 is typically the thinner sample, expressed in watts per microvolts
Q_{upper}	upper plate heat flow, expressed in microvolts
$Q_{Upper,Average}$	average upper plate heat flow, expressed in microvolts
S_{Cal}	calibration factor, expressed in watts per microvolts
S_{Cal1}	single-thickness calibration factor, proportional factor between the electrical signal and heat flow, expressed in watts per microvolts
S_{Cal2}	two-thickness calibration factor, proportional factor between the electrical signal and heat flow, expressed in watts per microvolts
$S_{Cal,Lower}$	lower plate calibration factor, expressed in watts per microvolts
$S_{Cal,Upper}$	upper plate calibration factor, expressed in watts per microvolts
$\bar{R}_{ave}$	total average measured thermal resistance across all samples, expressed in metre square degrees kelvin per Watt
$R_{ave,i}$	average measured thermal resistance of sample *i*, where *i* = 1, 2, or 3, expressed in metre square degrees kelvin per Watt
R_{cal}	calibration contact resistance, expressed in metre square degrees kelvin per watt
$2R_{Cal,Lower}$	lower plate calibration contact resistance, expressed in metre square degrees kelvin per watt
$2R_{Cal,Upper}$	upper plate calibration contact resistance, expressed in metre square degrees kelvin per watt

$2R_{sample}$	contact resistance of the sample, expressed in metres square degrees kelvin per watt
ΔT	average temperature difference across the sample(s), expressed in degrees Celsius
T_{lower}	lower plate temperature, expressed in degrees Celsius
T_{upper}	upper plate temperature, expressed in degrees Celsius
$x_{ave,i}$	average measured thickness of sample *i*, where *i* = 1, 2, or 3, expressed in metres
$\bar{x}_{ave}$	total average measured thickness across all samples
$x_{Ref\ Mat\ ave}$	average thickness of the reference material sample, expressed in metres
$x_{Ref\ Mat\ ave,i}$	average thickness of reference material sample *i*, where *i* = 1 or 2, and 1 is typically the thinner sample, expressed in metres
$\lambda_{Ref\ Mat}$	thermal conductivity of the calibration reference material, expressed in watts per metre kelvin
$\lambda_{sampleA1}$	single thickness sample thermal conductivity, Test Type A1 specimen, expressed in watts per metre kelvin
$\lambda_{sampleA2}$	single thickness sample thermal conductivity, Test Type A2 specimen, expressed in watts per metre kelvin

4.2 Abbreviated terms

APS	application procedure specification
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
ID	inner diameter
ITP	inspection and test plan
LVDT	linear variable differential transformer; linear variable displacement transformer; linear variable displacement transducer
OD	outer diameter
SI	International System of units
SST	simulated service test
QC	quality control
UV	ultraviolet

5 Conformance

5.1 Rounding

Unless otherwise stated in this document, observed or calculated values shall be rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting value, in accordance with ISO 80000-1.

NOTE For the purpose of this provision, the rounding method of ASTM E29 is equivalent to ISO 80000-1:2022, Annex B, Rule A.

5.2 Conformity to requirement

Systems for quality and environmental management, and the competence of testing and calibration laboratories, should be used.

NOTE The following documents can be used:

— ISO 29001 gives sector-specific requirements with guidance for the use of quality management systems;

— ISO 14001 gives requirements with guidance for the use of environmental management systems;

— ISO/IEC 17025 gives general requirements for the competence of testing and calibration laboratories.

The system provider shall be responsible for conforming with all the applicable requirements for the application of this document. The system purchaser shall be allowed to make any investigation necessary to ensure conformity by the system provider and to reject any material and/or system that does not conform with this document.

6 Material classes

The materials covered by this document are classified in Table 1. Each material used to make up the system shall be classified into the appropriate class by the system provider.

If other materials, not fitting the classes within Table 1, are used, the system provider shall identify the class that most closely represents the material and shall provide a gap analysis to the requirements for that class to be included in the validation dossier.

Table 1 — Material classes

	Solid/solid filled	Blown foam	Inorganic syntactic foam
Thermoplastics	1A	1B	1C
Liquid precursor non-elastomeric thermosets	2A	2B	2C
Liquid precursor elastomeric thermosets	3A	3B	3C
High molecular weight precursor thermosets	4A	4B	4C

7 Materials and system validation testing

7.1 General

This clause specifies the test requirements for validation of wet thermal insulation systems and for the materials used within such single or multi-layer systems.

The test data generated shall be considered when conducting a risk analysis in accordance with 7.5.

Material testing as described in 7.2 is based upon material maximum and minimum rated temperatures. System testing as described in 7.3 is based upon system maximum and minimum rated temperatures.

In the case of system testing (see 7.3), not all possible system variations regarding relative material layer thicknesses and build-up of multiple similar layers can be assessed during initial validation of a system. At least one representative system design, as proposed and justified by the system provider, shall be evaluated.

7.2 Material validation testing

7.2.1 General

Materials shall be tested as specified in Table 2, which specifies general properties to be tested for materials in an unexposed state, where applicable. Exposures to be performed on materials and testing to be performed post-exposure, where applicable, are described in 7.2.2. The method for sample preparation should be representative of the method used by the system supplier in manufacture of the system. If required, samples shall be machined from a larger section of material to ensure all test surfaces are representative of the through thickness of the material.

Material validation tests as specified in 7.2 are not required for materials with purely anti-corrosion and/or adhesive functionality. Validation of inter-layer adhesion performance is described in 7.3.3.2 and 7.3.4. Anti-corrosion materials are addressed in 7.7.

In the case of material types B (blown foam) and C (inorganic syntactic foam) per Table 1, both the minimum target density and the maximum target density, which can be the solid form, shall be tested for each individual material commercially offered in a range of target densities.

Table 2 — General properties and testing requirements for unexposed materials

Material property	Test specification	Applicable classes [a]												Test temperature [b]		
		Class 1			Class 2			Class 3			Class 4					
		A	B	C	A	B	C	A	B	C	A	B	C	23 °C ± 2 °C	Max	Min
Thermal conductivity	Annex B	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Specific heat capacity	ISO 11357-4	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Hydrostatic or triaxial compressive bulk modulus	Annex C	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Hydrostatic collapse pressure	Annex C			√			√			√			√	√	√	
Triaxial compression and creep performance	Annex C		√			√			√			√		selected temperatures and pressures as necessary to characterize the proposed operational window		
	Annex C at maximum rated pressure			√			√			√			√	√	√	
Density	ISO 1183 (all parts)	√	√	√	√	√	√	√	√	√	√	√	√	√		
Tensile properties	ISO 527 (all parts)	√	√	√	√	√	√							√	√	√
	ISO 37							√	√	√	√	√	√	√	√	√
Flexural properties [c]	ISO 178	√	√	√	√	√	√	√	√	√	√	√	√	√		
Tear strength	ISO 34-1 and ISO 34-2							√	√	√	√	√	√	√	√	
Notched Charpy impact strength	ISO 179-1	√	√	√	√	√	√	√	√	√				√		√
Hardness	ISO 868	√	√	√	√	√	√	√	√	√	√	√	√	√		
DSC	ISO 11357-1	√	√	√	√	√	√	√	√	√	√	√	√	Temperature range		
DMA	ISO 6721-1	√	√	√	√	√	√	√	√	√	√	√	√	Temperature range		
Compressive strength	ISO 844 or ISO 604	√	√	√	√	√	√							√	√	√
	ASTM D575							√	√	√	√	√	√	√	√	√

[a] As per Table 1.

[b] Test temperature is referenced to the material maximum and minimum rated temperatures.

[c] Required only if used for establishing the effects of wet or dry heat exposure per 7.2.2.3 and 7.2.2.4

Table 2 *(continued)*

Material property	Test specification	Applicable classes [a]												Test temperature [b]		
		Class 1			Class 2			Class 3			Class 4					
		A	B	C	A	B	C	A	B	C	A	B	C	23 °C ± 2 °C	Max	Min
Coefficient of linear thermal expansion	ISO 11359-2	√	√	√	√	√	√	√	√	√	√	√	√	Temperature range		

[a] As per Table 1.

[b] Test temperature is referenced to the material maximum and minimum rated temperatures.

[c] Required only if used for establishing the effects of wet or dry heat exposure per 7.2.2.3 and 7.2.2.4

7.2.2 Small-scale exposure testing for materials

7.2.2.1 General

The purpose of small-scale exposure testing is to provide material test data to be considered when assessing the potential risks involved with using the material under specific service conditions in accordance with 7.5.

The tests shall consider:

— water absorption and pressure effects;

— expected degradation phenomena (e.g. thermal, chemical, radiative);

— the dominant failure mechanism of the material in service.

For certain materials, physical changes can produce results in mechanical testing that are not indicative of chemical breakdown. In such cases, additional testing may be performed to understand and explain 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 validation dossier.

Four tests shall be performed:

a) determination of the potential for water absorption of each material in the insulation system (see 7.2.2.2);

b) determination of the change in the mechanical properties of each material due to water exposure (see 7.2.2.3);

c) determination of the change in the mechanical properties of each material due to dry heat exposure (see 7.2.2.4);

d) demonstration that the material of the outer-most layer of the system is resistant to UV exposure, if applicable (see 7.2.2.5).

7.2.2.2 Water absorption test

Water absorption at temperature and pressure shall be established by evaluating for changes in sample mass.

Sample preparation shall be fully described.

Exposure media shall match that utilized in 7.2.2.3. If natural seawater is used, the composition shall be analysed and the results shall be included in the test report. Exposure media shall be replaced at each sampling period.

The water absorption test shall be performed taking into account the following conditions:

a) at least four temperatures:

   1) 4 °C or 23 °C;

   2) material maximum rated temperature

   3) two additional temperatures not less than 30 °C below the material maximum rated temperature and not less than 10 °C apart, preferably:

      i. 15 °C below the material maximum rated temperature;

      ii. 30 °C below the material maximum rated temperature;

   4) if the validation envelope is to be extended by 15 °C or less, testing is only at the new material maximum rated temperature;

b) duration: 1 year;

c) pressure: sufficient to prevent boiling of exposure media for Class A materials and maximum rated pressure for Class B and C materials;

d) five samples per exposure temperature;

e) sample sizes for exposure: 50 mm × 50 mm, tested at a single thickness within a range of 2 mm to 8 mm, chosen at the discretion of the system provider;

f) minimum weighing intervals: before exposure, 1 week, 2 weeks, 1 month, 3 months, 6 months, and 12 months.

In order to ascertain the amount of water initially contained within the material under ambient conditions, an additional set of unexposed control samples may be weighed, dried in an oven maintained at 50 °C ± 5 °C for 24 hours, and re-weighed.

The exposure may utilize:

— several sets of parallel samples, one set for each sampling interval, in which case, after removal from water, the samples shall be dried with a clean dry cloth or filter paper and immediately weighed to the nearest 0,001 g within 24 hours; or

— a single set of samples, to be withdrawn for each sampling interval and, after removal from water, the samples shall be dried with a clean dry cloth or filter paper and immediately weighed to the nearest 0,001 g before being returned to the exposure medium to continue exposure within 24 hours.

7.2.2.3 Wet heat exposure

The effects of wet heat exposure shall be established 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 and flexural testing shall be performed in accordance with the relevant International Standard as listed in Table 2. Exposure media shall be either deionized water or seawater. If artificial seawater is used, it shall be prepared in accordance with ISO 15711. If natural seawater is used, the composition shall be analysed and the results shall be included in the test report. Exposure media shall be replaced at each sampling period.

The wet heat exposure test shall be performed taking into account the following conditions:

a) at least three elevated temperatures, the same as utilized in 7.2.2.2, including the material maximum rated temperature;

b) duration: 1 year;

c) pressure: greater than or equal to vapour pressure for Class A materials and maximum rated pressure for Class B and C materials;

d) five samples per exposure temperature and sampling interval;

e) minimum sampling intervals: 1 month, 3 months, 6 months, and 12 months.

Before the start of exposure, samples shall be weighed. A set of unexposed control specimens shall be tested in accordance with the relevant standard.

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

At sampling intervals, the surface of the samples shall be dried after removal from the water with a clean dry cloth or filter paper, weighed, and tested without any reconditioning (no drying of samples). Change in mass (water absorption) shall be reported along with mechanical test results.

7.2.2.4 Dry heat exposure

The effects of dry heat exposure shall be established 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 and flexural testing shall be performed in accordance with the relevant International Standard as listed in Table 2. Exposure media shall be high purity nitrogen with a nitrogen content of ≥99,99 %. Exposure media shall be replaced at each sampling period.

The dry heat exposure test shall be performed taking into account the following conditions:

a) at least one temperature identical to the material maximum rated temperature used in 7.2.2.3;

b) duration: 1 year;

c) pressure: atmospheric;

d) five samples per exposure temperature and sampling interval;

e) minimum sampling intervals: 1 month, 3 months, 6 months, and 12 months;

f) use of a suitable exposure vessel, sealed to prevent nitrogen leakage during the exposure duration.

A set of unexposed control specimens shall be tested in accordance with the relevant standard.

Before mechanical testing, samples shall be cooled to 23 °C ± 2 °C in nitrogen for at least a period of 24 h and tested immediately after being removed from the nitrogen exposure vessel.

7.2.2.5 Weathering and UV resistance

Data shall be provided by the system provider to demonstrate that the material of the outer-most layer of the system can resist UV exposure. Alternatively, specific storage conditions or protection from atmospheric exposure shall be detailed by the system provider.

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-most layer of the system, hence underlying layers do not need to be tested.

7.3 System validation testing

7.3.1 General

The system provider shall produce a generic APS and ITP relevant for the application of the specific system for the purposes of full-scale testing. In the case of systems for field joints, the APS shall also include information that can provide an idea of the expected time for application of the system to the field joint.

Full scale testing shall be performed in accordance with Table 3 to demonstrate generally applicable installation and operational performance of the system. Demonstration of the full-scale performance of the system that is specific to a particular commercial project is detailed in ISO 12736-2 and ISO 12736-3.

Testing data for the guidance of ITP requirements in subsequent commercial projects, as covered in ISO 12736-2 and ISO 12736-3, shall be generated during the production of system samples for full scale testing, in addition to the testing required in Table 2 and Table 3.

Pre-fabricated insulation can form part of a system, but these systems are typically bespoke and highly specific to a project with specific considerations in contrast to direct applied insulation. As such, system validation of pre-fabricated insulation is outside the scope of this document and only material validation as described in 7.2 is considered.

7.3.2 System test requirements

The test program for systems to be applied on pipelines and subsea equipment shall include the tests shown in Table 3 and described in 7.3.3. Each test may be performed on a separate specimen. In the case of systems for field joints, system validation shall be done on a pipe specimen coated with a representative mainline system that matches the expected material classes to which the field joint system is expected to be interfaced with, but which might not be identical to the mainline system in the project phase. The mainline system for field joint system validation shall be as proposed by the system provider.

Table 3 — Full scale tests for systems

	Pipelines [a]	Field joints / Interfaces	Jumpers	Subsea equipment
Installation tests				
Simulated bend test [b] (7.3.3.1)	√	√ [c]		
System shear resistance test, 23 °C ± 2 °C (7.3.3.2)	√			
Adhesion test to substrate, 23 °C ± 2 °C (7.3.3.3)		√		
Interface/sub-interface adhesion strength, 23 °C ± 2 °C (7.3.3.4)		√		√ [d]
In-service tests				
System shear resistance test, as per temperature profile at system maximum temperature (7.3.3.2)	√		√	
Impact test (7.3.3.5)	√		√	
Simulated service test for pipelines (7.3.3.6)	√		√	
Simulated service test for subsea equipment (7.3.3.7)				√
Small-scale full system exposure test (7.3.4)	√		√	√

[a] Excluding field joints and jumpers.

[b] Only applicable for systems expected to be installed by R-lay.

[c] Not applicable for tie-in field joints in validation; to be considered at project phase only, see ISO 12736-3.

[d] Testing of construction joints.

7.3.3 Full scale test program for systems

7.3.3.1 Simulated bend testing for systems applied to pipelines

The objective of the simulated bend test is to provide a benchmark example or examples of successful bending performance to provide insight into the potential capability associated with installation of a pipeline coated with the system by R-lay.

Effects due to varying stiffness (e.g. strain concentration at the field joints) are known to have a significant effect on the local strain level and therefore the bending capacity of the combined mainline pipe and field joint systems. Where a mainline system is subjected to a bending test as part of a field joint system test, the combined test shall also be considered to meet the requirements of the stand-alone mainline system test.

Depending on the nature of the wet thermal insulation system, the test parameters used when performing the simulated bend test can have a bearing on the outcome of the test. The following information is provided as guidance to aid the selection of appropriate parameters for demonstration of bending performance appropriate for the intended pipe installation methods to be utilized with the system:

— Pipe diameter, pipe wall thickness, system thickness and bend radius will determine the strain that develops in the pipe and system during the test. Table 4 provides examples of the estimated strain for a uniform section of wet thermal insulation system for a specified set of parameters.

— Test temperature is important for materials that transition from ductile to brittle over the temperature range of interest. The temperature will depend on the geographic location where the pipe bending activities occur. Material temperatures during pipe bending are typically within the range of — 10 °C to 40 °C.

— Bending test speed will determine the strain rate that develops in the system during the test and represents the rate that the pipe will be spooled onto the pipelay vessel or the pipelay rate. Bending rates for spooling in the range of 15 $m \cdot min^{-1}$ to 25 $m \cdot min^{-1}$ are typical.

— For R-lay, allowing the pipe to be held in the fully bent condition during the bend test is aimed at revealing any latent failure or effects that can occur in the system and represents the storage period after the pipe has been loaded onto the drum onboard the pipelay vessel. If required, a period of 5 minutes is typically used when performing a hold activity as part of the bend test but up to 24 hours can be appropriate.

— For R-lay, the number of cycles (i.e. bending and then straightening) carried out during the test is required to simulate the action of loading the pipe onto the drum onboard the vessel, reverse bending during pipelay and recovery and re-lay during pipelay operations.

The test procedure shall be as specified in Annex D. The parameters needed to perform the test shall be specified by the system provider with the intent to provide some demonstration of the bending capacity of the system. With the various potential combinations of pipe diameter, system thickness, bending radii, bending speeds, temperatures, etc., the precise delineation of the available acceptable window for bending of a particular system is not possible. At least one test shall be performed.

Table 4 — Strain estimated in 100 mm of insulation

Steel pipe OD	Nominal strain (%) in system outer fibre versus bend former radius for R-lay						
m	10,5 m	9,75 m	9 m	8,225 m	8 m	7,5 m	5,77 m
0,168 3	1,72	1,85	2,01	2,19	2,25	2,40	3,09
0,219 1	1,96	2,10	2,28	2,48	2,55	2,72	3,50
0,273 1	2,20	2,37	2,56	2,80	2,87	3,06	3,94
0,323 9	2,43	2,62	2,83	3,09	3,17	3,37	4,34
0,355 6	2,58	2,77	2,99	3,27	3,36	3,57	4,59

Table 4 *(continued)*

Steel pipe OD	Nominal strain (%) in system outer fibre versus bend former radius for R-lay						
m	10,5 m	9,75 m	9 m	8,225 m	8 m	7,5 m	5,77 m
0,406 4	2,81	3,02	3,26	3,56	3,65	3,89	4,99

7.3.3.2 System shear resistance testing for systems applied to pipelines

Insulation systems generally comprise of an anti-corrosion layer, to which the insulation is either fused or bonded. In addition, some insulation systems can comprise of multiple applied insulation layers and an outer jacket. Each layer has its own inherent shear strength and each interlayer bond has its own associated level of adhesion. During both the fabrication and installation processes for and operation of pipelines, the insulation system can be subject to thermal and mechanical loads, which can overstress weak materials or bonds. The purpose of the shear adhesion test is to evaluate the load at which slippage or tearing occurs within the insulation or between the material layers along the interlayer bonds. The test shall identify the system layer or interlayer bond that has the lowest shear resistance.

The test procedure shall be in accordance with Annex E. The parameters required to perform the test shall be specified by the system provider. Two test temperatures shall be evaluated:

a) with the full system at 23 °C ± 2 °C;

b) as per the temperature profile through the system when the system is being operated at the system maximum rated temperature.

A series of support rings can be required, which are specific to the sample dimensions, to test all the material layers and critical interlayer bonds.

7.3.3.3 Adhesion test to substrate

A measure of adhesion strength to the substrate (e.g. anti-corrosion coating) shall be provided. The appropriate substrate is chosen by the system provider. The test method shall be as appropriate for the materials, to be chosen by the system provider.

7.3.3.4 Interface/sub-interface adhesion strength

A measure of adhesion strength shall be provided for each interface/sub-interface of the field joint system insulation materials to the mainline system insulation materials. The test method shall be as appropriate for the materials, to be chosen by the system provider.

7.3.3.5 Impact testing for systems applied to pipelines

The purpose of the impact test is to evaluate the system's ability to withstand likely impacts during a pipeline's storage, installation and service life. Impacts from handling, installation, rock dumping and contact with fishing gear shall be considered, if applicable.

The test procedure shall be in accordance with Annex F. The parameters needed to perform the test shall be specified by the system provider, based on which load is to be simulated (e.g. handling impact, installation impact, fishing gear impact). For fishing gear impact, DNV-RP-F111 can be utilized for guidance of the appropriate impact energy in relation to the region where pipes are expected to be installed and the type of fishing gear used in that region.

7.3.3.6 Simulated service test for pipelines

The objective of the simulated service test for pipelines is to validate the in-service performance of the system under short-term conditions when subjected to system maximum rated temperature and maximum rated pressure in terms of:

a) integrity of the system;

b) thermal insulation capacity (U-value);

c) hydrostatic compressive properties.

To simulate in-service conditions, a coated pipe sample shall be subjected to internal heating and external cooling and pressure in water. The test procedure shall be in accordance with Annex G at the system maximum rated temperature and maximum rated pressure.

The measured U-value of the system shall be in accordance with the expected design basis as specified by the system provider, within the uncertainty of the U-value measurement. Radial compression shall be in accordance with expectations, within the uncertainty of the compression measurement, or less than expected. The expected performance is obtained through numerical calculation by using test data for each individual material obtained as described in 7.2 in conjunction with the under-evaluation coated pipe configuration at the temperatures/pressure of the test.

7.3.3.7 Simulated service test for subsea equipment

The objective of the simulated service test for subsea equipment is to confirm that the system can be successfully applied in large volume applications as well as to evaluate the mechanical integrity of the system when subjected to system maximum rated temperature and maximum rated pressure.

Complex subsea equipment, such as trees or manifolds, have unique challenges related to the complex geometries and application of potentially large coating volumes, which can create challenges for coating integrity in service upon application of hydrostatic pressure coupled with thermal effects on material mechanical properties with application of internal heating and thermal expansion, which is not well represented by the simple pipe geometry of 7.3.3.6.

To validate in-service integrity of the system for this application, a coated sample with a construction joint and geometry more representative of challenges associated with coating of subsea equipment shall be subjected to internal heating and external cooling and pressure in water. In addition, both representative thermal and pressure cycles shall be also applied to stress the system and evaluate for risks to the system integrity. The test procedure shall be in accordance with Annex H.

7.3.4 Small-scale full-system exposure test

For verification of expected system exposure effects, an unpressurized small-scale exposure of the system shall be performed in accordance with Annex I.

7.4 System repairs

Imperfections during application and damage to the system during storage, or handling during transportation or installation can occur. Potential procedures and suitable materials for repair of the system should be considered. The types of damage that can feasibly be repaired as well as imperfections that can be considered only cosmetic shall be identified. Validation of repairs concerns only repairs within a system or at construction joints. Repairs across interfaces where the two systems are dissimilar do not require validation and are considered at the project phase only as addressed in ISO 12736-3.

The following requirements apply if a system repair is considered to be feasible:

a) The materials to be used and the general procedure for effecting the repair shall be documented.

b) Repair materials, if different from the materials in the system to be repaired, shall be characterized for density, thermal conductivity and specific heat capacity in accordance with Table 2. Validation of long-term performance according to 7.2.2 is not required.

c) Any repair material shall be applied to a specimen of the matching material(s) of the system to be repaired. The adhesion across the bond(s) shall be evaluated. The test method shall be as appropriate for the materials, to be chosen by the system provider. The mode of failure shall be reported.

Further evaluation of repairs shall be done on a project basis in accordance with ISO 12736-2 or ISO 12736-3.

For repair of anti-corrosion coatings, please refer to 7.7.

7.5 Validation of long-term performance

Validation of long-term performance does not predict product life-time, because a universally accepted and applicable method does not exist for subsea wet thermal insulation systems. Instead, long-term performance of the system at the system provider designated system maximum rated temperature is validated via a data-driven, risk-based analysis.

Long-term material exposure data generated in 7.2.2 specifically evaluates the potential for chemical changes and identification of failure modes in the materials during service both under normal expected operation (see 7.2.2.4) as well as under failure conditions where water has been allowed to ingress into the system (see 7.2.2.3). It also provides water uptake data (see 7.2.2.2) to evaluate the extent of water ingress in normal operation or under failure conditions through the materials. Unpressurized long-term system exposure, as per 7.3.4, cannot be considered to be fully representative of system performance in all cases due to the lack of pressure, but it does provide some demonstration of expected system performance and effects, including material interlayer bonds and adhesives. The risk analysis should always be done from the system viewpoint and should take into account all of the data generated for the validation dossier, which can provide insight as to the likelihood of failure conditions occurring or for other non-chemical material changes (e.g. compressive creep).

Potential failure conditions in cases where repairs to the system have been implemented and potential risks associated with repair processes should be considered. This can involve the identification of flaws to be considered superficial, i.e. not affecting system performance, and thus not suitable for repair.

As the criteria for any risk-based analysis requires knowledge of the acceptable level of risk, and the likelihood for certain failure modes can change based upon project specific conditions, the acceptance of the results from testing presented in the validation dossier will depend on the risk tolerance level and specialized knowledge of each individual system purchaser for each individual commercial project.

The system provider shall provide an analysis of these results, in a format of their own choice, based on their own risk tolerance level to provide guidance as to the expected long-term system performance. Based on the validation dossier, the system purchaser can determine their own temperature and pressure limits for usage, which may not match to those given in the validation dossier for materials and/or system.

7.6 Technical validation dossier

7.6.1 General

The system provider shall prepare the technical validation dossier of the proposed wet thermal insulation system and the materials which make up this system.

For systems with known track record, any deviations from required testing as described in this document shall be identified via a gap-analysis for discussion on a project basis in accordance with ISO 12736-2 and ISO 12736-3.

With the exception of thermal conductivity measurements per Annex B, validations carried out according to ISO 12736:2014[1)] are valid, provided such validation was started before publication of this document.

1) Withdrawn.

7.6.2 Content of the validation dossier

7.6.2.1 Technical validation documentation

The system provider shall provide technical validation documentation that at least includes the following, except where otherwise stated:

a) System summary:

   1) description of the materials and the system tested (including the anti-corrosion coating considered);

   2) system maximum rated temperature and maximum rated pressure as specified by the system provider and explanation of the drivers for the ratings;

   3) system minimum and maximum temperature guidelines for storage, handling, installation and corresponding recommendations and installation restrictions, if applicable;

   4) anti-corrosion coating proof of performance in accordance with 7.7.

      NOTE This item is not relevant for pre-fabricated insulation.

b) Insulation materials:

   1) classification of insulation materials as per Table 1;

   2) material maximum and minimum rated temperature for each insulation material as specified by the system provider and explanation of the drivers for the ratings;

   3) SDS for each insulation material;

   4) recommended shelf life and storage instructions;

   5) certificate of analysis from the material manufacturer, for each insulation material as used in the validation testing, with the following information:

      i) product name and manufacturer;

      ii) manufacturing plant;

      iii) date of manufacture;

      iv) batch number;

      v) properties tested with every batch and corresponding conformity ranges and applicable standards;

      vi) date of issue;

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

   6) summary of test data as per Table 2 for each individual insulation material;

   7) full test data for each individual insulation material in accordance with 7.2.

c) As applied system: APS, ITP and QC report for the application process of the complete system, with the exception of pre-fabricated insulation, including test data relevant for the establishment of ITP requirements on a project basis.

d) Full scale testing: test procedures and test results for the complete system as applied, with the exception of pre-fabricated insulation, in accordance with 7.3.

e) Consideration of repairs to the insulation materials in accordance with 7.4: the maximum level of damage that can feasibly be repaired along with a documented repair procedure and recommended repair materials including results of adhesion in accordance with 7.4.

f) Identification of potential risks to long-term system performance and mitigations in accordance with 7.5.

g) Gap analysis to the requirements of this document in accordance with Clause 6 and 7.6.1.

h) Any additional relevant historical data.

7.6.2.2 Test reports

The test reports to be added to the validation dossier shall contain at least the following information:

a) a reference to this document (i.e. ISO 12736-1:2023);

b) the test laboratory (e.g. name and address);

c) the date of each test;

d) all details necessary to identify the materials and the system (e.g. manufacturer, names or reference numbers of the products, batch numbers, applicator);

e) source of test specimens and manner of manufacture;

f) the procedures followed for the tests carried out and the duration of each test, including year of publication for any relevant standards;

g) the results for each test sample;

h) any deviation from the test methods specified;

i) any unusual features observed.

The test report shall explicitly state that the test equipment and procedure was in accordance with the relevant International Standards in Table 2.

The test report shall be signed by the person performing the tests and by the laboratory manager or by another authorized representative of the laboratory.

7.7 Anti-corrosion coating documentation

It is not the purpose of this document to specify a qualification program for anti-corrosion coatings. The wet thermal insulation system provider can select any anti-corrosion coating suitable for the system maximum rated temperature and with which the system will provide the desired performance.

Proof of performance of the proposed anti-corrosion coating as per a specific industry standard shall be presented as part of the validation dossier, with the exception of the validation dossier for pre-fabricated insulation.

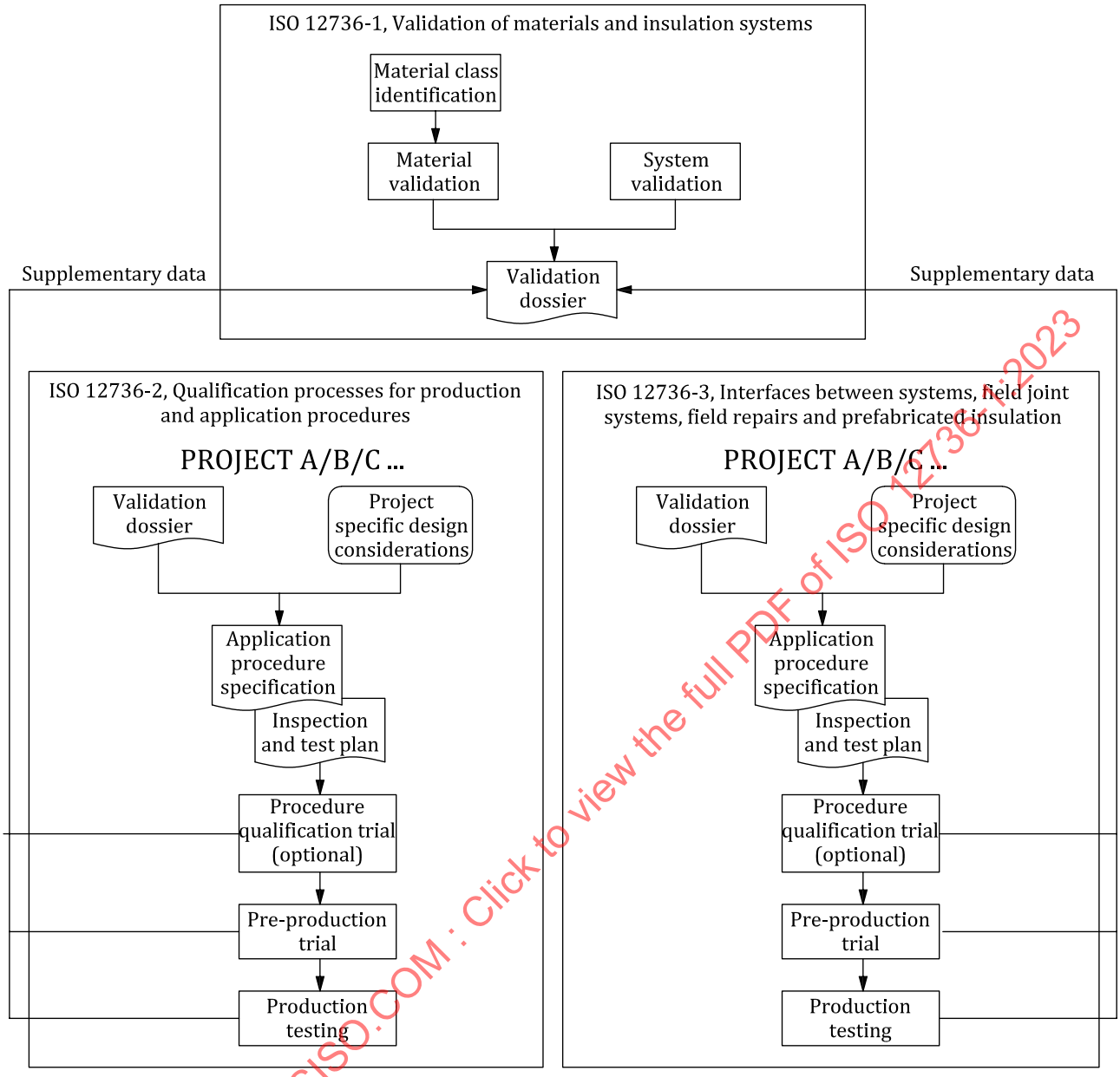
Annex A
(informative)

Guidelines for using this document

A.1 General

The intention of this annex is to provide guidelines for using this document.

The relation between this document and ISO 12736-2 and ISO 12736-3 is represented in Figure A.1.



ISO 12736-1 focuses on requirements for the validation of the material(s)and the wet thermal insulation system. The deliverable from ISO 12736-1 is a validation dossier for the wet thermal insulation system.

ISO 12736-2 focuses on the requirements for the project specific qualification, production, and repair of wet thermal insulation systems applied to pipelines in a factory and subsea equipment. The input for ISO 12736-2 is the validation dossier from ISO 12736-1. The results of the PQT, PPT and production testing are fed back into the validation dossier.

ISO 12736-3 focuses on the requirements for the project specific qualification and production of the interfaces between wet thermal insulation systems and field repairs. The input for ISO 12736-3 is the validation dossier from ISO 12736-1. The results of the PQT, PPT and production testing are fed back into the validation dossier.

Figure A.1 — Relation between this document and ISO 12736-2 and ISO 12736-3

A.2 Material classes

Wet thermal insulation is provided by materials that are applied to the steel substrate of the pipeline or subsea equipment. These materials can be applied in discrete layers which make up a system. Table 1

identifies the known classes of materials. All insulation materials presently used for wet thermal insulation are defined by this class system.

The performance of new innovative insulation materials and technologies, when developed at an industrial level, should be compared to the current technologies and defined in accordance with the classes presented in Table 1.

A.3 Material validation

An insulation material in an insulation system is validated to the material maximum rated temperature and maximum rated pressure as specified by the system provider and as detailed in this document.

The material maximum rated temperature is not necessarily the same as the system maximum rated temperature. This is because the specific material being validated might not, when part of a system, experience the system maximum rated temperature due to the thermal gradient through the system from the hottest point (in contact with the steel) to the coldest point (in contact with the sea water).

Based on the validation dossier, the system purchaser can determine their own temperature and pressure limits for usage which may not match to those given in the validation dossier (either for materials and/or system).

The as-applied general properties as specified in Table 2 are the first part of the validation of the material.

Subsequently, small-scale exposures are required to validate the material per 7.2.2. For Class A materials, wet heat exposure at pressure sufficient to prevent boiling is suitable to address potential chemical changes and there is no need to assess for material collapse as with Class B and C materials.

The validation testing of the material is considered the responsibility of the system provider.

A.4 Wet thermal insulation system validation

Pre-fabricated insulation can form part of a system, but these systems are typically bespoke and highly specific to a project with specific considerations in contrast to direct applied insulation. As such, system validation of pre-fabricated insulation is outside the scope of this document and only material validation is considered.

The wet thermal insulation system application is the responsibility of the system provider.

As stated in 7.7, it is not the purpose of this document to specify a qualification program for the anti-corrosion coating. The system provider can select a suitable anti-corrosion coating with which the insulation materials will provide the desired performance.

In order to validate the system, the system provider is required to apply the full wet thermal insulation system, including all materials from anti-corrosion to outer sheath (if applicable) as it would be expected to be applied during a commercial project. An initial APS and ITP are required for the application process. The types of testing that would be expected during project qualification of the wet thermal insulation system, as described in ISO 12736-2:2023, Clause 8 and ISO 12736-3:2023, Clause 8, can be used as input for the initial APS and ITP.

Validation of the system provides insight into its expected installation and operational performance, but can evaluate neither all possible system variations, regarding relative material layer thicknesses and build-up of multiple similar layers, nor commercial project specific requirements. For systems applied to field joints, not all potential variations of interface can be considered. If required, installation and operational performance can be confirmed on a commercial project basis, as needed as per ISO 12736-2:2023, 7.3.2 and ISO 12736-3:2023, 7.3.2. Certain tests, such as clamp and tensioner testing, stinger roller testing and simulated cyclic bend testing for fatigue, depend significantly on commercial project parameters and are therefore not included in validation. For system validation, the system provider is responsible for selecting the relevant parameters.

Potential pipeline installation method(s) and operating envelope (i.e. temperature, pressure), which specify the test program to be performed by the system provider to validate the wet thermal insulation system, depend on the location for use; i.e. pipelines (including risers but excluding field joints and jumpers), field joints, jumpers, or subsea equipment. The system provider is responsible for identifying the applicable tests from Table 3.

System installation tests considered for inclusion within the validation dossier, as listed in Table 3, include simulated bend tests (see 7.3.3.1), system shear resistance testing at ambient temperature (see 7.3.3.2) for pipelines, excluding field joints and jumpers, and adhesion testing for field joints (see 7.3.3.3 and 7.3.3.4).

The pipeline simulated bend test in system validation is required only for pipeline systems, including field joint systems, which are expected to be installed by R-lay. Bending requirements for other forms of pipeline installation are considered only at the project stage. Where a mainline system is subjected to a bending test as part of a field joint system test, the combined test is also considered to meet the requirements of the stand-alone mainline system test.

In-service system tests considered for inclusion within the validation dossier, as listed in Table 3, include system shear resistance testing at operating temperature (see 7.3.3.2), impact testing (see 7.3.3.5), simulated service testing (see 7.3.3.6 and 7.3.3.7), and small-scale full system exposure testing (see 7.3.4).

Impact testing (see 7.3.3.5) is performed on pipelines to evaluate for resistance to damage during handling or operation. This is not required for wet thermal insulation applied to subsea equipment, as these structures are protected by detailed handling procedures/lifting plans and protective structures in operation.

Simulated service testing of pipelines (see 7.3.3.6) for the full-system is performed on a pipe geometry to validate the in-service performance of the system under short-term conditions. The system is exposed to heat in the pipe interior and externally to cold water under pressure. The test evaluates the physical integrity of the system under temperature and pressure as well as the measured system U-value and compression in comparison to the theoretical system values based on small-scale material tests from Table 2. If more than one system is included in the test, such as inclusion of a field joint system, it should be ensured that the systems are isolated from each other during the test and do not affect one another.

Simulated service testing of the full-system for subsea equipment (see 7.3.3.7) is performed on a more complex geometry, representing sharp angles and large applied insulation volumes with a construction joint, to better represent the unique challenges of the application that can affect the integrity of the system. Thermal and pressure cycling is also performed to stress the system and better evaluate for risks to the system integrity. The testing geometry has been simplified compared to the method described in ISO 12736:2014 to represent the most problematic areas. It is recognized that the geometry is not truly representative of all subsea equipment. Additional testing may be requested on a project level as per ISO 12736-2:2023, 7.3.2. At the system supplier's discretion, the straight section of the specimen can be instrumented similarly to Annex G to also measure for U-value and dimensional changes to the system under short-term conditions.

The transient behaviour of the system (e.g. time to cool-down to a specified temperature) is not included in simulated service testing due to the large effect of the pipeline or subsea equipment contents on the test results. Multi-zonal heating is required for the test to minimize axial heat flow due to end effects and thus the interior contents of the pipe during the test is neither representative of the pipe contents in service nor straightforward to characterize.

Small-scale full system exposure testing (see 7.3.4) is to provide test data, which can be considered when assessing the potential risks involved with using the system under specific service conditions including the expected response of system interlayer bonds (i.e. insulation to anti-corrosion coating, material layer to material layer) when exposed to defects allowing water ingress during service.

A.5 System repairs

As stated in 7.4, to demonstrate consideration of the potential for repair of the applied system in case of imperfections during application or damage to the system during storage or handling, the system provider is required to indicate whether the system is repairable and what level of flaw should be considered superficial, i.e. not affecting system performance.

Validation of repairs considers only repairs within a system or at construction joints. Repairs across interfaces where the two systems are dissimilar do not require validation and are considered at the project phase only as described in ISO 12736-3.

In the case of systems that are considered to be repairable, the system provider is also required to document the procedure for effecting the repair and suitable repair materials. The system provider is then required to characterize the repair materials for at least thermal conductivity, specific heat capacity and density as per Table 2. Testing of the bond strength of the repair material(s) to the insulation material(s) that make up the system is also required.

A.6 Validation dossier

The output of the validation testing for the materials, the wet thermal insulation system, and system repairs, described in 7.2, 7.3 and 7.4, respectively, creates the validation dossier. The preparation of this validation dossier is the responsibility of the system provider. See 7.6.2 for the requirements of this validation dossier.

Historical data can also be included to supplement the test data within the validation dossier.

The data generated in the preparation of the validation dossier is utilized to characterize expected envelopes for installation and operation as well as to identify risks to long-term system performance and mitigations as per 7.5. The result of this analysis is also included within the validation dossier.

The validation dossier can be considered a standalone document that provides the system purchaser with the information required to determine if a wet thermal insulation system is suitable for the commercial project under consideration.

Annex B
(normative)

Thermal conductivity testing

B.1 General

Thermal conductivity is a key material property that directly influences required system design thicknesses to achieve target thermal insulation performance. As such, it can potentially have a significant effect on overall project economics, especially in the case of insulation for long flowlines[12]. It has been demonstrated that a variation as small as 0,001 $W \cdot m^{-1} \cdot K^{-1}$ is equivalent to a potentially significant change in the system cost.[12] It was also noted that a variation in thermal conductivity on this order is not detectable in any system performance testing.

Testing of thermal conductivity is a challenging endeavour with the potential for large uncertainties. For thermal insulations with conductivity values in the 0,01 $W \cdot m^{-1} \cdot K^{-1}$ to 1,00 $W \cdot m^{-1} \cdot K^{-1}$ range, steady state unidirectional measurement techniques, such as the guarded hot plate and heat flow meter techniques are preferred.[11] The guarded hot plate test method as detailed in ISO 8302 is an absolute test method which, if well performed, can have an uncertainty as low as 1,0 % [7],[11]. The heat flow meter test method as detailed in ISO 8301 is a comparative test method which, if well performed and utilizing a certified reference material with an uncertainty of 1 % to 2 %, can have an associated uncertainty of about 3 %.[11] However, poorly conducted tests can easily have uncertainties of 10 % or even higher [10].

Given the importance of the thermal conductivity property and the large potential for variation in measurements, this annex provides requirements and guidance for the application of ISO 8301 and ISO 8302 to the testing of wet thermal insulation. These measurements can be split into four separate test types:

— A1: measurements for the purpose of generating design values for high k-value materials (≥0,1 $W \cdot m^{-1} \cdot K^{-1}$) (see 7.2);

— B1: measurements for the purpose of project procedure qualification for high k-value materials (≥0,1 $W \cdot m^{-1} \cdot K^{-1}$) (see ISO 12736-2 and ISO 12736-3);

— A2: measurements for the purpose of generating design values for low k-value materials (<0,1 $W \cdot m^{-1} \cdot K^{-1}$) (see 7.2);

— B2: measurements for the purpose of project procedure qualification for low k-value materials (<0,1 $W \cdot m^{-1} \cdot K^{-1}$) (see ISO 12736-2 and ISO 12736-3).

It is preferred to be able to sample directly from the applied system, but this requires the testing of small sample sizes due to pipe curvatures or other features that are found in typical system geometries.

ISO 8301 conformant heat flow meter test instruments capable of testing 2” diameter specimens are available for the thermal conductivity range of ≥0,1 $W \cdot m^{-1} \cdot K^{-1}$. This does not apply for the range <0,1 $W \cdot m^{-1} \cdot K^{-1}$, where commercial instruments utilize larger samples sizes, typically 8” square or 12” square, due to challenges with heat losses at sample edges in small samples with low k-value.

ISO 8302 guarded hot plate instruments utilize larger sample sizes. Recommended dimensions are 0,3 m or 0,5 m square or diameter with sizes 0,2 m or 1 m square or diameter in special cases. The testing for guarded hot plate measurements requires experienced personnel. This testing is much more complex and expensive than heat flow meter tests [11].

As a result, testing for test types A1 and B1 shall be in accordance with ISO 8301 and testing for test types A2 and B2 shall be in accordance with either ISO 8301 or ISO 8302. Testing for the purpose of generating design values (see 7.2) shall be stringent to minimize potential errors. Testing for the

purpose of project procedure qualification can be relaxed, as the purpose is to confirm that the design thermal conductivity has been achieved to within an uncertainty of ±10 %, as further detailed in ISO 12736-2.

This annex focusses on testing of test types A1 and A2 for validation. Project-based testing of test types B1 and B2 is described in ISO 12736-2.

B.2 Calibration reference materials

In testing via heat flow meters, identifying appropriate reference standards in the range of interest for materials used in wet thermal insulation is complicated: nominally approximately 0,03 $W \cdot m^{-1} \cdot K^{-1}$ to 0,25 $W \cdot m^{-1} \cdot K^{-1}$. ISO 8301 requires that calibration standards have been issued by a "recognized standard laboratory".

NOTE Development of reference standards is performed by international organizations, such as the Institute for Research and Reference Materials (IRRM) and national organizations like National Physical Laboratory (NPL), National Institute of Standards and Technology (NIST), Laboratoire National de Metrologie et d'Assai (LNE) or National Institute of Advanced Industrial Science and Technology (AIST). These organizations can supply certified standards with an estimated uncertainty.

Offerings from recognized standard laboratories are limited and are generally available at only very high thermal conductivities (>1 $W \cdot m^{-1} \cdot K^{-1}$) or very low thermal conductivities (around 0,03 $W \cdot m^{-1} \cdot K^{-1}$) with variable levels of associated uncertainty.[11] Certified reference standards typically have uncertainties up to 2 % but analysis reference materials can have uncertainties as high as 6,5 %.[9] The polymethylmethacrylate reference material, available from NPL, sits within the range of interest for wet thermal insulation (0,190 4 $W \cdot m^{-1} \cdot K^{-1}$), but has an associated uncertainty of 4,0 %.[8] These calibration reference standards are only available in larger sample sizes as would be utilized in ISO 8302 guarded hot plate testing. While these samples can be machined into smaller specimens, there is the potential for additional uncertainty due to possible sample heterogeneity.

Even when testing with a calibration standard that has low uncertainty, accuracy of the test will still be compromised if the calibration standard is not similar in density, thermal resistance, thickness, and foam structure (open versus closed cell content) to the material of interest. The calibration standard with the closest thermal resistance to the specimen to be tested is typically the most preferred.

The conclusion is that ideal reference standards for testing of thermal conductivity for wet thermal insulation do not currently exist. As such, it becomes necessary to extend the definition of acceptable calibration reference standards from the strict definition as applied in ISO 8301 to:

a) those issued by a recognized standard laboratory;

b) those issued by the heat flow meter manufacturer;

c) those transfer standards with a certified value as tested by ISO 8302 obtained from a recognized standard laboratory.

If the transfer standard is to be machined from a larger test piece and cannot be tested directly, it shall be demonstrated that the specimens produced from the larger test piece have identical thermal resistance to within ±1 %.

Table B.1 provides a non-exhaustive list of commercially available calibration reference materials.

Table B.1 — Commercially available calibration reference materials

Type of reference standard	Identification/Description[a]	Thermal conductivity $W \cdot m^{-1} \cdot K^{-1}$	Temperature range °C
Certified or standard reference materials (CRM/SRM)	SRM NIST 1453 Expanded polystyrene board	0,033	8 to 40
	SRM NIST 1450d Fibrous glass board	0,032	7 to 67
Analysis reference materials (RM)	NPL Fe09 Pure iron	83,5	100 to 500
	SRM 8420 Electrolytic iron – rod form	77,9	−271 to 727
	NPL 2S09 Inconel® 600	14,6	100 to 500
	NPL 2S09 Stainless Steel 304	14,3	100 to 500
	Pyroceram™ 9606 – BCR 724 Glass ceramic	3,84	−75 to 752
	BCR-039C Pyrex® glass	1,143 8	−75 to 195
	NPL 05/01 Perspex®	0,190 4	−10 to 60
	IRMM-440 Resin bonded glass fibre board	0,031 6	−10 to 50
Equipment manufacturer supplied	Pyroceram™	4,091	0 to 100
	Pyrex®	1,073	−10 to 110
	Vespel®	0,376	−10 to 110
	Polycarbonate	0,216 3	−5 to 105
	Perspex®	0,187 2	−10 to 60

[a] Inconel®, Pyroceram™, Pyrex®, Perspex® and Vespel® are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

B.3 Testing requirements

B.3.1 Test type A1 – Design testing of high k-value materials (≥0,1 $W \cdot m^{-1} \cdot K^{-1}$)

B.3.1.1 General

Testing for test type A1 shall be in accordance with ISO 8301 with the specifications and modifications as described in B.3.1.2 to B.3.1.4

B.3.1.2 Equipment

Test equipment shall conform to ISO 8301 and accept 55 mm ± 5 mm diameter specimens. Calibration of the equipment shall be performed in accordance with B.4.2. Equipment shall be capable of performing sample thickness measurements to the nearest 0,01 mm, with applied platen pressure and at the test temperature.

B.3.1.3 Samples

For materials in the high k-value range (≥0,1 $W \cdot m^{-1} \cdot K^{-1}$), potential errors due to surface contact resistance between the sample and sensors should be considered. Thus, testing of multiple thicknesses is necessary to estimate this error.

Samples shall be preferentially obtained from applied material. For specimens not taken from coated pieces, the method of manufacture shall be clearly stated and should produce test pieces of demonstrated similar density and void structure to coated pieces.

Samples shall be 55 mm ± 5 mm in diameter and shall be of three thicknesses covering a range of at least 10 mm with no thickness <5,0 mm. There shall be two replicate samples at each thickness. Each sample should have smooth flat surfaces. Samples with hardness ≥90 Shore A shall demonstrate a parallelism of ±0,01 mm as determined by thickness measurements in five different locations as per Figure B.1. Flatness shall be determined by placing the sample on a known flat surface, with a light source behind the sample. There shall be no visible light between the flat surface and the sample surface. For samples with hardness <90 Shore A, the provisions in Clause B.6 apply.

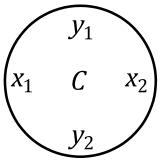


Figure B.1 — Test type A1/B1 thickness measurement pattern

B.3.1.4 Testing

Each sample shall be tested in triplicate in accordance with ISO 8301 within the temperature range of interest. Between replicate measurements, the sample shall be removed and remounted. For testing at elevated temperatures, the provisions in Clause B.5 apply. For calculations, the provisions in Clause B.8 shall apply.

B.3.2 Test type A2 – Design testing of low k-value materials (<0,1 $W \cdot m^{-1} \cdot K^{-1}$)

B.3.2.1 General

No test equipment is currently available to test small samples within the thermal conductivity range of <0,1 $W \cdot m^{-1} \cdot K^{-1}$. Large specimens shall therefore be utilized. Design testing of low k-value materials can be done in accordance with either ISO 8301 or ISO 8302 with the specifications and modifications as described in B.3.2.2 or B.3.2.3, respectively.

B.3.2.2 Testing to ISO 8301

B.3.2.2.1 Equipment

Test equipment shall conform to ISO 8301 and accept 200 mm × 200 mm specimens. Calibration of the equipment shall be performed in accordance with B.4.3. Equipment shall be capable of performing sample thickness measurements with applied platen pressure and at temperature to the nearest 0,01 mm.

B.3.2.2.2 Samples

For testing of materials with a k-value <0,1 $W \cdot m^{-1} \cdot K^{-1}$, larger sample sizes shall be used, which can be difficult to retrieve from applied material. As such, samples shall be preferentially taken from applied material, but may be separately produced in which case they shall be demonstrated to have similar density and, in the case of blown foams, similar cell size, cell number density and open cell content.

Samples shall have a dimension of (200 mm ± 5 mm) × (200 mm ± 5 mm) and shall have a minimum thickness of 20 mm. There shall be three replicate samples.

Each sample should have smooth flat surfaces. Samples with hardness ≥90 Shore A shall demonstrate a parallelism of 2 % over the total surface area (thickness ±1 %), as determined by thickness measurements in 13 difference locations as per Figure B.2. Flatness shall be determined by placing the sample on a known flat surface, with a light source behind the sample. There shall be no visible light between the flat surface and the sample surface. For samples with hardness <90 Shore A, the provisions in Clause B.6 apply.

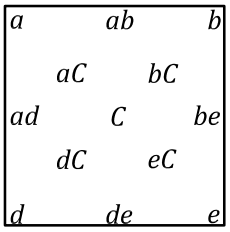


Figure B.2 — Test type A2/B2 thickness square measurement pattern

B.3.2.2.3 Testing

Each sample shall be tested in triplicate in accordance with ISO 8301 within the temperature range of interest. Between replicate measurements, the sample shall be removed and remounted. For testing at elevated temperatures, the provisions in Clause B.5 apply. For calculations, the provisions in Clause B.8 apply.

B.3.2.3 Testing in accordance with ISO 8302

B.3.2.3.1 Equipment

Test equipment shall conform to ISO 8302 and testing shall be performed by a laboratory competent in thermal conductivity measurement in accordance with ISO 8302.

B.3.2.3.2 Samples

For testing of materials with a k-value <0,1 $W \cdot m^{-1} \cdot K^{-1}$, larger sample sizes shall be used, which can be difficult to retrieve from applied material. As such, samples shall be preferentially taken from applied material, but may be separately produced in which case they shall be demonstrated to have similar density and, in the case of blown foams, similar cell size, cell number density and open cell content.

Samples sets shall have dimensions as required for the available equipment and shall have a minimum thickness of 20 mm per each sample. There may be one or two samples in a set, as required for the available equipment. There shall be three replicate sample sets.

Each sample should have smooth flat surfaces. Samples with hardness ≥90 Shore A shall demonstrate a parallelism of 2 % over the total surface area (thickness ±1 %), as determined by thickness measurements in 13 different locations as per Figure B.2 or Figure B.3. Flatness shall be determined by placing the sample on a known flat surface, with a light source behind the sample. There shall be no visible light between the flat surface and the sample surface. For samples with hardness <90 Shore A, the provisions in Clause B.6 apply.

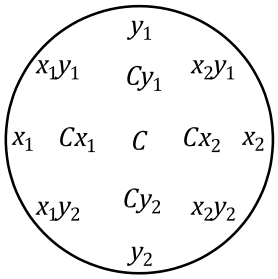


Figure B.3 — Test type A2/B2 circular thickness measurement pattern

B.3.2.3.3 Testing

Each sample set shall be measured in triplicate in accordance with ISO 8302 within the temperature range of interest. Between replicate measurements, the sample sets shall be removed and remounted.

B.4 Calibration for testing in accordance with ISO 8301

B.4.1 General

In addition to good equipment design and manufacture, for accurate results, it is key that the equipment is properly calibrated with a reference material that is similar in density, thermal resistance, thickness, and foam structure (open versus closed cell content) to the material of interest.

In comparing tests utilizing different calibration materials, the one utilizing the calibration material with the value closest to that of the sample of interest should generally be considered to have greater accuracy.

NOTE Appropriate reference materials are described in Clause B.2.

B.4.2 Calibration for high k-value materials (≥0,1 $W \cdot m^{-1} \cdot K^{-1}$)

The calibration procedure described in this subclause is based on a two-thicknesses method where the thermal contact resistance is taken into account for the thermal conductivity determination.

The heat flow meter apparatus shall be calibrated or verified within 96 hours before or after the test using an appropriate calibration standard (reference material). Verification of the calibration may be regularly performed with one or various calibration standards / reference materials aiming to validate the stability of the calibration. The thermal conductivity determined during verification stage shall not differ more than 1 % from calibration stage.

To determine average calibration factors, three calibration runs shall be performed. The calibration run shall be run using standards with documented thermal conductivity at the mean temperatures of interest. Extrapolation to other temperatures is not allowed, while interpolations are not recommended. The temperature gradient or temperature difference between the isothermal plates should be set to 10 °C or 20 °C depending on the thermal properties of the test material (higher thermal resistance of the specimen, higher temperature gradient is needed). The calibration shall be performed with the same temperature gradient (temperature difference between the isothermal plates) expected for the test specimens.

If, due to the surface condition of the test specimen (e. g. unevenness of the surface), the use of a thermal paste or polyimide thin film is required for the thermal conductivity determination (see Clause B.7), the calibration run shall be performed using a thin film of thermal paste / polyimide thin film applied with the same procedure as the test specimen. The use of thermal paste for thermal conductivity determinations should be avoided if possible. In general, calibration shall be performed under the same testing conditions as the test specimen.

Calibration runs shall be performed using at least two specimens of the reference material with different thicknesses. The difference in thickness shall be ≥3 mm. More than two specimens of reference materials with different thicknesses may be used to reduce the calibration uncertainty.

During the calibration runs, the upper and lower plate temperatures (T_{Upper} and T_{Lower}) and the upper and the lower heat flux transducer signals (Q_{Upper} and Q_{Lower}) shall be continuously recorded.

The existence of thermal equilibrium shall be verified by observing and recording:

a) the transducer output of the heat flux transducer, in which the output shall vary by less 1,5 % in respect to the mean value;

b) the mean temperature of the specimens;

c) the temperature at both surfaces, in which temperatures shall vary by less than 0,5 °C in respect to the mean value.

The thermal equilibrium shall be satisfied in at least 16 successive blocks / observations.

Average heat flux transducer signals ($Q_{Upper,Average}$ and $Q_{Lower,Average}$) shall be determined using information from the last six blocks / observations.

Using three different runs, the calibration factors for the lower and upper plates (S_{Cal}) and the calibration contact resistance (R_{Cal}) shall be calculated in accordance with Clause B.8.

The calibration factors ($S_{Cal,Upper}$, $S_{Cal,Lower}$) and calibration surface contact resistances ($2R_{Cal,Upper}$, $2R_{Cal,Lower}$) shall be calculated for both plates using $Q_{Upper,Average}$ and $Q_{Lower,Average}$ data, respectively.

B.4.3 Calibration for low k-value materials (<0,1 $W \cdot m^{-1} \cdot K^{-1}$)

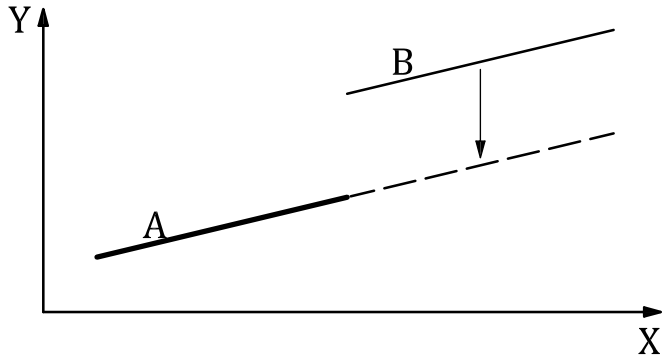
The calibration procedure for low k-value materials shall be as the calibration procedure for high k-value materials (see B.4.2), with the exemption that the calibration shall consist of testing only a single thickness of the reference material. Only calibration factors, and not calibration contact resistances, shall be calculated for both the upper and lower platens.

B.5 Testing at elevated temperatures

The information provided in this annex is primarily focused on testing at ambient temperature. Testing at elevated temperatures introduces additional complexities, which reduces the precision of the test even further. This includes issues related to edge losses, further reduced options for calibration reference materials, thermal expansion of the sample, softening and deformation of the specimen, and potential differences in the temperature response of calibration materials versus the materials of interest.

For testing at elevated temperature, it is recommended to utilize the calibration material with the closest thermal conductivity to the material in question at ambient temperature (calibration material A). If the preferred calibration material is not capable of testing up to the highest temperature of interest, then the calibration material with the next closest thermal conductivity to the material in question at ambient temperature and capable of testing through the full temperature range of interest (calibration material B) can be utilized directly, if it can be shown that the difference in results at ambient temperature when utilizing calibration material A versus B is within ±3 %. If the result at ambient temperature when utilizing calibration material A versus calibration material B is not negligible, then testing should be performed against calibration material A up to the highest possible temperature. Additional testing shall be performed against calibration material B in a temperature range overlapping that of calibration material A and up to the highest temperature of interest. The thermal conductivity results with temperature against calibration material B shall then be vertically translated until it best overlaps with results from calibration material A to provide thermal conductivity values over the full range of interest as shown in Figure B.4

In cases where heating results in softening of the specimen, provisions in Clause B.6 should also be considered.



Key

X	temperature (°C)	A	results with calibration material A
Y	thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	B	results with calibration material B

Figure B.4 — Correction for testing at elevated temperature

B.6 Testing of soft samples (<90 Shore A)

Soft samples with a Shore A hardness of <90 can be very difficult to prepare to a high-dimensional tolerance. They additionally have a tendency for continuous or excessive sample deformation during the test due to the applied platen pressure. Testing variance can be reduced by the utilization of thicker specimens, to minimize the effect of surface contact resistance on the measurement, and a rigid support around the specimen during the test to prevent lateral movement and reducing overall deformation.

For specimens with hardness of <90 Shore A, specimens should be prepared as closely as possible to the requirements given in B.3.1 and B.3.2. Additionally, specimens for testing of high k-value (≥0,1 W·m-1·K-1) shall be a minimum of 15 mm in thickness.

Design of the rigid support surrounding the specimen should be such that the specimen sits snug within the support. The height of the support shall be the thickness of the specimen less 1,5 mm ± 1 mm. The material chosen for the support shall have a thermal conductivity of <0,5 $W \cdot m^{-1} \cdot K^{-1}$, preferably <0,3 $W \cdot m^{-1} \cdot K^{-1}$, and shall be suitable for the temperature range of interest.

Measurement of specimen thickness for the purposes of calculating thermal conductivity shall be performed under the same applied pressure and temperature as the test condition. In-situ thickness measurement is a feature of many heat flow meters.

B.7 Special considerations for specimen surface condition

B.7.1 General

In special cases where imperfect surface conditions cannot be avoided, the recommendations in B.7.2 and B.7.3 are provided. If recommendations are used, these should be clearly documented in the report (see also Clause B.9).

B.7.2 Rough or uneven surface

In some cases, it can be difficult to achieve a smooth and flat specimen surface. For soft specimens (Shore A hardness <90), the pressure from the testing platens is expected to deform the specimens and minimize any surface contact resistance errors. For harder specimens (Shore A ≥ 90), it can be necessary to utilize a thin film of thermal paste to minimize surface contact resistance. The thermal conductivity of the thermal paste shall be the same or greater than the thermal conductivity of the test specimen.

In choosing a suitable thermal paste, the usable temperature range and chemical compatibility with the specimen to be tested should be considered. When applying thermal paste, it should be applied sparingly to fill-in any small gaps that can exist between the sample and the test platens and should not form a continuous layer.

In the case of test type A1, so long as all specimens are of similar surface quality, the use of thermal paste is not needed as surface contact resistance is determined and removed in calculations. Where specimens are of differing surface quality or in the case of test type B1 where the surface condition of the specimen and the calibration reference specimens differ, the use of thermal paste will reduce measurement error.

In the case of test type A2 and test type B2 specimens, the use of thermal paste might not be needed as the thermal resistance of the entrapped air at uneven interfaces between the specimen and the test platens can be on the same order as the specimen itself. Thermal paste need not be utilized, if it has been previously demonstrated that testing with or without thermal paste results in the same results with ±3 %.

B.7.3 Tacky surfaces

In some cases, the material surface can be tacky, especially at high temperature, which risks damage to the testing platens. If this is the case, thin film sheets of polyimide (0,025 4 mm to 0,050 8 mm) can be utilized between the specimen and testing platens. Highly conductive films, such as aluminium, are not recommended as the creation of a continuous highly conductive plane can result in cross-talk between sensors on test platens.

In the case of test types A1 and B1, the thermal resistance of the polyimide film is similar to the specimen and introduces minimal error given the thickness of the film in relation to the specimen. The effect of the film is included in any calculations for surface contact resistance.

In the case of test types A2 and B2, the thermal resistance of the thin polyimide film is negligible in comparison to the thermal resistance of the sample and introduces minimal error.

B.8 Calculations

B.8.1 Calculations for test type A1

The two-thickness calibration factor shall be calculated in accordance with Formula (B.1):

$$S_{\mathrm{Cal}_2} = \frac{\Delta T \times \lambda_{\mathrm{Ref\ Mat}} \times \left(Q_{\mathrm{Ref\ Mat\ ave},1} - Q_{\mathrm{Ref\ Mat\ ave},2}\right)}{Q_{\mathrm{Ref\ Mat\ ave},1} \times Q_{\mathrm{Ref\ Mat\ ave},2} \times \left(x_{\mathrm{Ref\ Mat\ ave},2} - x_{\mathrm{Ref\ Mat\ ave},1}\right)} \tag{B.1}$$

The three-thickness sample contact resistance shall be calculated in accordance with Formula (B.2):

$$2R_{\mathrm{sample}} = \bar{R}_{\mathrm{ave}} - \left(\frac{\sum_{i=1}^{3} \left[\left(x_{\mathrm{ave},i} - \bar{x}_{\mathrm{ave}}\right)\left(R_{\mathrm{ave},i} - \bar{R}_{\mathrm{ave}}\right) \right]}{\sum_{i=1}^{3} \left(x_{\mathrm{ave},i} - \bar{x}_{\mathrm{ave}}\right)^2} \right) \times \bar{x}_{\mathrm{ave}} \tag{B.2}$$

where $R_{\mathrm{ave},i} = \dfrac{\Delta T}{Q_{\mathrm{ave},i} \times S_{\mathrm{Cal}_2}}$

The three-thickness sample thermal conductivity shall be calculated in accordance with Formula (B.3):

$$\lambda_{\mathrm{sampleA1}} = \sum_{i=1}^{3} \left[\frac{x_{\mathrm{ave},i}}{\dfrac{\Delta T}{Q_{\mathrm{ave},i} \times S_{\mathrm{Cal}_2}} - 2R_{\mathrm{sample}}} \right] \div 3 \tag{B.3}$$

B.8.2 Calculations for test type A2

The single thickness calibration factor shall be calculated in accordance with Formula (B.4):

$$S_{\mathrm{Cal}_1} = \frac{\Delta T \times \lambda_{\mathrm{Ref\ Mat}}}{Q_{\mathrm{Ref\ Mat\ ave}} \times x_{\mathrm{Ref\ Mat\ ave}}} \tag{B.4}$$

The single thickness sample thermal conductivity shall be calculated based on the single thickness calibration in accordance with Formula (B.5):

$$\lambda_{\mathrm{sampleA2}} = \frac{x_{\mathrm{ave}}}{\frac{\Delta T}{Q_{\mathrm{ave}} \times S_{\mathrm{Cal}_1}}} \tag{B.5}$$

B.9 Reporting

The report of the results of each thermal conductivity test shall include the following information with all data to be reported in SI units:

a) identifiers to allow traceability back to the individual measurements taken during the test performed, including:

   1) name;

   2) physical description;

   3) hardness;

   4) method of manufacture;

   5) test type (A1 or A2);

   6) any other pertinent identification of the material;

b) thickness and parallelism of the specimen as received and as tested;

c) use of thermal grease or protective film;

d) for conditioned specimens:

   1) the method and environment used for conditioning;

   2) the mass loss of the specimen during conditioning and testing, in percentage of conditioned mass;

   3) the mass regain of the specimen during test, in percentage of conditioned mass, if measured.

e) manufacturer and model of equipment used;

f) average temperature gradient in the specimen during test as computed from the temperatures of the hot and cold surfaces;

g) mean temperature of the test;

h) heat flux values and direction through the specimen;

i) thermal conductance, average and variation, in units of $W \cdot m^{-1} \cdot K^{-1}$ to three decimal places;

j) duration of the measurement portion of the test;

k) date of test, the date of the last heat meter calibration, and the type or types of materials used for calibration;

l) validation of the heat meter calibration.

The specimens used in calibration shall be identified as to the type, thickness, thermal resistance, date of specimen certification, source of certification, expiration date of calibration, and the certification test number. Where applicable a statement of the laboratory accreditation of the test facility, including the date of the latest audit, shall be included.

B.10 Accuracy and variance

When testing in accordance with ISO 8301, accuracy of this testing is highly dependent on accuracy of the equipment utilized in addition to the available calibration material. This affects accuracy due to uncertainty in the measured thermal conductivity of the calibration material as well as the error associated with utilizing a calibration material of insufficiently similar density, thermal resistance, thickness or foam structure to the specimen of interest. The effect of calibration material properties relative to specimen properties on the accuracy of the measurement has not been well quantified.

Variance in testing between laboratories has been shown to be potentially high (>>0,001 $W \cdot m^{-1} \cdot K^{-1}$) if calibration and testing procedures are not carefully controlled. Samples have been evaluated across multiple identical model instruments at various laboratories at 30 °C according to ISO 8301 and the manufacturer's instruction manual. Results of these round robins are given in Table B.2

Table B.2 — Round robin results – Testing in accordance with ISO 8301

Sample type	Description	Parallelism mm	Number of test instruments	Average value $W \cdot m^{-1} \cdot K^{-1}$	Minimum value $W \cdot m^{-1} \cdot K^{-1}$	Maximum value $W \cdot m^{-1} \cdot K^{-1}$	Range %
A	65 Shore A rubber	±0,09	16	0,277 6	0,262 8	0,293 6	±5,5
B	70 Shore D solid thermoplastic	±0,005	15	0,157 2	0,150 7	0,162 7	±3,8
C	65 Shore D inorganic syntactic thermoplastic	±0,005	10	0,177 5	0,173 5	0,181 9	±2,4

For hard samples (≥90 Shore A), it has been possible to reduce the inter-laboratory variance as given in Table B.3, if utilizing the same type of calibration reference material and the test type B1 testing procedure provided in ISO 12736-2:2023, along with well-prepared samples.

Table B.3 — Round robin results – Testing to ISO 12736-2:2023, test type B1

Sample type	Description	Parallelism mm	Number of test instruments	Average value $W \cdot m^{-1} \cdot K^{-1}$	Minimum value $W \cdot m^{-1} \cdot K^{-1}$	Maximum value $W \cdot m^{-1} \cdot K^{-1}$	Range %
B	70 Shore D solid thermoplastic	±0,005	6	0,159 5	0,157 5	0,161 9	±1,4
C	65 Shore D inorganic syntactic thermoplastic	±0,005	4	0,177 0	0,175 7	0,178 8	±0,9

For soft samples (<90 Shore A), it has also been possible to reduce the inter-laboratory variance as given in Table B.4, if utilizing the same type of calibration reference material and the test type B1 testing procedure provided in ISO 12736-2:2023, along with a thicker specimen (18 mm to 20 mm) and a rigid support ring.

Table B.4 — Round robin results – Testing to ISO 12736-2:2023, test type B1 with considerations for soft samples as per Clause B.6

Sample type	Description	Parallelism mm	Number of test instruments	Average value $W \cdot m^{-1} \cdot K^{-1}$	Minimum value $W \cdot m^{-1} \cdot K^{-1}$	Maximum value $W \cdot m^{-1} \cdot K^{-1}$	Range %
Purple	25 Shore A silicone elastomeric thermoset	±0,08	11	0,299 9	0,289 9	0,303 9	±3,6
Grey	70 Shore A silicone elastomeric thermoset	±0,20	11	0,234 9	0,227 0	0,243 4	±3,5
Black	90 Shore A natural rubber elastomeric thermoset	±0,05	11	0,324 5	0,317 0	0,334 6	±2,7

There is currently no similar information available for testing of test type A1, test type A2, and test type B2.

Annex C
(normative)

Hydrostatic compressive behaviour/Tri-axial test procedures

C.1 Hydrostatic test or tri-axial test

Both hydrostatic and tri-axial tests are used in the petroleum and natural gas industries, but they are not equivalent. The hydrostatic compressive behaviour test can be utilized to obtain compressive bulk modulus and/or hydrostatic collapse pressure. The tri-axial behaviour test can be utilized to obtain compressive bulk modulus and/or tri-axial creep performance. The test procedure providing the relevant information shall be selected by the system provider.

C.2 Hydrostatic compression test

C.2.1 General

Subsea insulation materials are subject to 3-dimensional hydrostatic compressive loads in deep water service conditions. Therefore, the hydrostatic compressive behaviour (collapse pressure and bulk modulus) of such materials are critical design inputs. In particular, inorganic syntactic foam materials include some form of inorganic hollow filler (e.g. glass microspheres), which collapse at a specific hydrostatic pressure. This pressure is required for the system provider to determine the material maximum operating water depth.

In general, where inorganic hollow fillers are used and where the hydrostatic collapse pressure of the filler is below the pressure limits of the pressure vessel, there is an unambiguous collapse pressure largely due to the catastrophic failure of the filler. However, due to the vast combinations of inorganic hollow filler grades and matrix systems available, there can be instances where an ambiguous failure point results. In these cases, the system provider shall specify the hydrostatic collapse pressure with appropriate technical justification.

The hydrostatic compression test can provide both the hydrostatic collapse pressure of the material and, when subjected to increasing hydrostatic pressure at a specified temperature, the volume reduction of the material allowing the bulk modulus to be calculated.

Two test set-ups may be used:

— set-up A: motorized pump activated hydrostatic pressure vessel (see C.2.2);

— set-up B: piston activated hydrostatic pressure vessel (see C.2.3).

C.2.2 Set-up A: motorized pump activated hydrostatic pressure vessel

The test set-up A is a hydrostatic compression test rig comprising:

a) motorized pump: small bore linear displacement pump, which produces a constant and linear pressurization response;

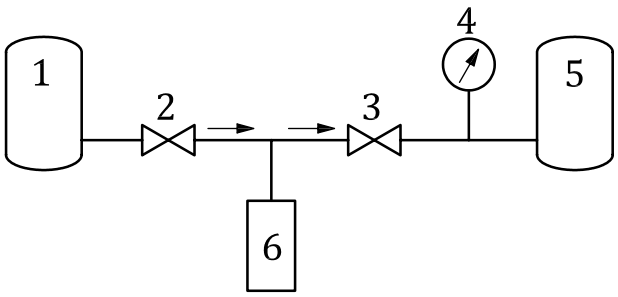
b) hydrostatic compression test vessel;

c) associated reservoir, pipe-work and needle valves;

d) calibrated pressure transducer;

e) computer with data logging and graphing software.

Figure C.1 illustrates a basic layout for a typical motorized pump activated hydrostatic pressure vessel. A reservoir is connected by means of valves and fittings to a vessel that is to be pressurized. A gauge is shown to represent the pressure transducer. By placing an LVDT to measure piston stroke in the pressure generating unit, the pumped volume for the test can be measured. Hence, the volume versus pressure relationship is established



Key

1	fluid reservoir	4	pressure transducer
2	needle valve	5	test chamber
3	needle valve	6	motorized small bore linear displacement pump with integrated LVDT

Figure C.1 — Motorized pump activated hydrostatic pressure vessel

C.2.3 Set-up B: piston activated hydrostatic pressure vessel

The test set-up B is a hydrostatic compression test rig comprising:

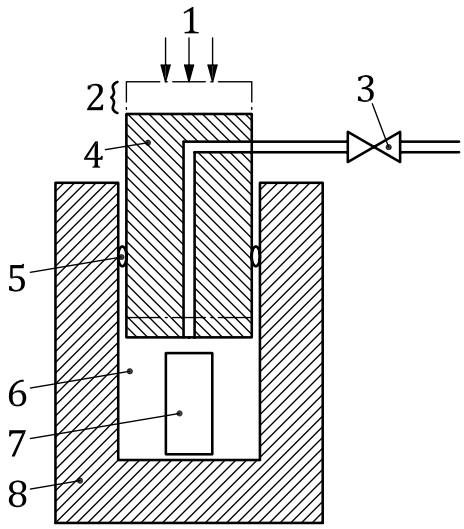
a) hydrostatic compression test vessel with piston;

b) associated pipe-work and needle valves;

c) universal testing machine (tensiometer) with calibrated load cell;

d) computer with data logging and graphing software.

A typical hydrostatic piston activated pressure vessel is shown in Figure C.2. A sample is placed into the hydrostatic pressure vessel along with the test medium and the lid is secured. The cylinder piston is driven into the pressure vessel using a universal testing machine (or some other means) at a controlled rate, recording load and piston displacement. The hydrostatic compressive stress is calculated as force/piston cross sectional area. By measuring cross head displacement of the tensiometer, the change in volume in the cell can be determined. Hence, the volume versus pressure relationship can be established.



Key

1	load	5	O-ring seal
2	displacement	6	test fluid
3	bleed valve	7	specimen
4	loading piston	8	vessel body

Figure C.2 — Piston activated hydrostatic pressure vessel

C.2.4 Hydrostatic compression test parameters

The hydrostatic compression test shall be conducted using water, either fresh water or artificial seawater prepared in accordance with ISO 15711, as the test fluid in a test cell at the specified temperature. The minimum sample volume shall be 25 cm^3. Typically, samples are in the form of a right circular cylinder of minimum dimensions 50,8 mm long and 25,4 mm diameter. The test chamber shall be sized so that the test fluid volume is at least equal to the initial specimen volume.

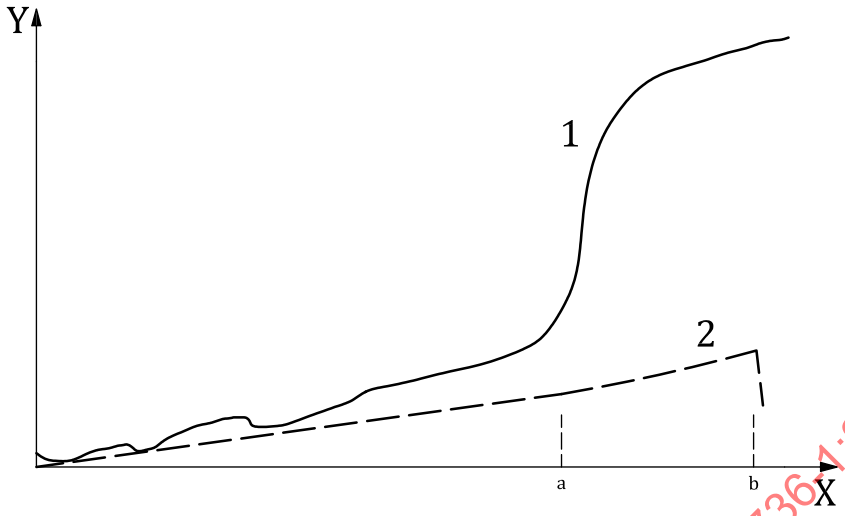
The samples shall be normalized at the test temperature for a minimum of 24 h in the test fluid before application of pressure to ensure that the material is in a stable condition.

For determination of both the hydrostatic collapse pressure and bulk modulus, the hydrostatic pressure shall be increased at a constant rate (e.g. 1 $MPa \cdot min^{-1}$). The hydrostatic pressure and volume change of the test specimen shall be recorded continuously throughout the duration of the test period. Two parameters can be determined from this test:

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

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

A typical set of results for two materials containing hollow glass microspheres is shown in Figure C.3.



Key

X	pressure (MPa)	1	material 1 data	a	Hydrostatic collapse pressure material 1.
Y	volume change (%)	2	material 2 data	b	Hydrostatic collapse pressure material 2.

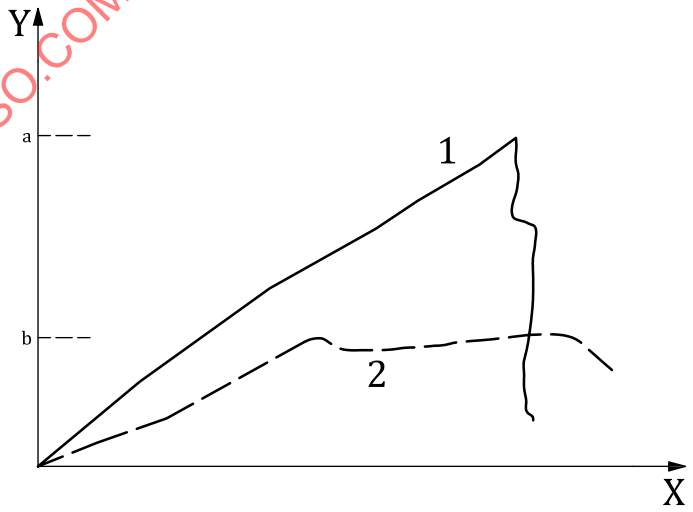
Figure C.3 — Typical chart of volume reduction as a function of pressure

For determination of only the hydrostatic collapse pressure for materials with catastrophic failure mechanism, a simplified test can be run.

The hydrostatic pressure shall be increased at a constant rate (e.g. 1 MPa·min^{-1}) and the hydrostatic pressure shall be recorded continuously throughout the duration of the test period. One parameter can be determined from this test:

— hydrostatic collapse pressure: hydrostatic pressure corresponding to the onset of a sudden, significant, and non-reversible change in the gradient of the pressure vs time curve.

A typical set of results for two materials containing hollow glass microspheres is shown in Figure C.4.



Key

X	time (s)	1	material 1 data	a	Hydrostatic collapse pressure material 1.
Y	pressure (MPa)	2	material 2 data	b	Hydrostatic collapse pressure material 2.

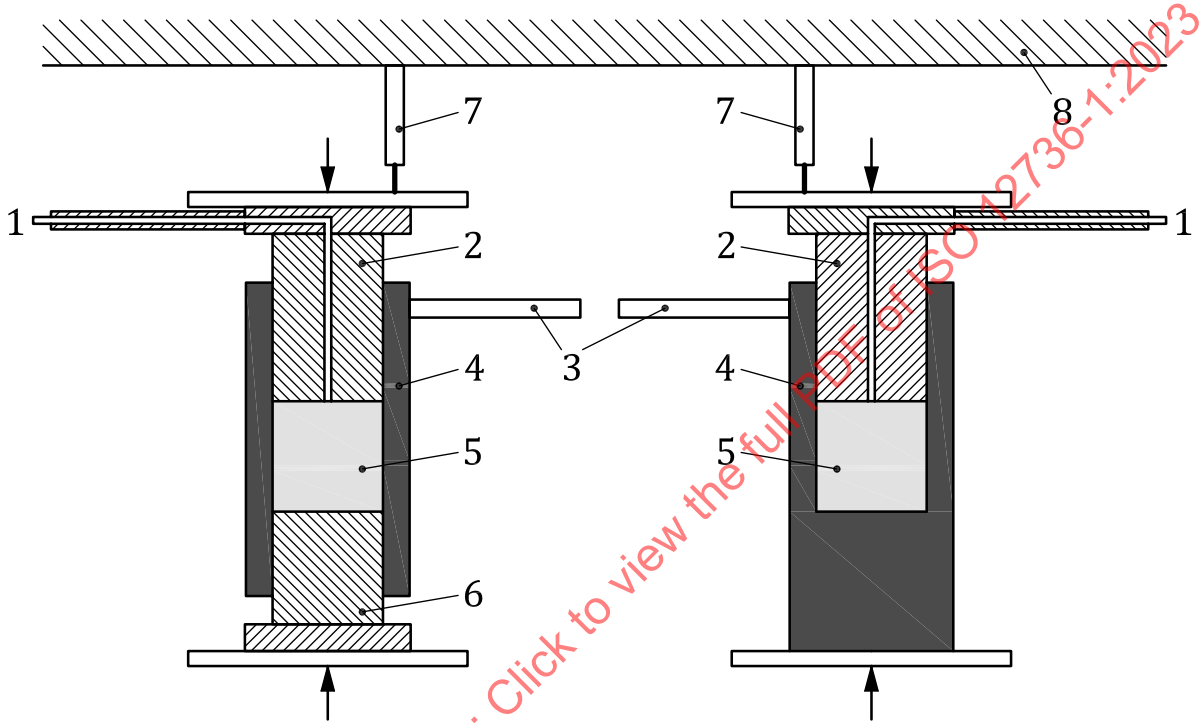
Figure C.4 — Typical chart of pressure as a function of time

C.3 Tri-axial compression and creep test

C.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 system on pipe. The base of the chamber represents the OD of the pipe, whilst the walls of the chamber mimic the hoop and axial constraint from other identical bonded material. The tri-axial loading is applied through a piston.

Figure C.5 shows a typical set up for tri-axial tests.



Key

1	venting port	5	sample
2	rotatable piston	6	rotatable base
3	handle	7	displacement gauge
4	cylinder walls and heater	8	fixed surface

Figure C.5 — Typical set up for tri-axial tests

C.3.2 Method

Test samples shall be machined so that they fit snugly into the test fixture at the intended test temperature. Thermal expansion of the cylinder and sample should be taken into account. Samples shall be cylindric with a diameter tolerance of ±0,02 mm and parallel faces, as lack of parallelism represents dead volume. The samples shall be taken from thick pipe insulation (as thick as possible) and shall be stacked to build up to a final sample height of 50 mm to 55 mm. Stacking of more than three samples to meet the height requirement is not recommended.

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

Conformance of the supporting structure shall be determined for each cell and shall be taken into account during the test, as the deflection is significant relative to the sample test deflections.

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

At least three replicates shall be used for each condition.

C.3.3 Initializing

The test shall be started by partially filling the cell with a suitable lubricant to which the sample is inert and does not appreciably absorb.

Samples shall be measured for dimensions and density prior to testing. The samples shall then be lubricated with a very thin layer of lubricant (on the curved faces only) and placed in the cell.

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

Excess lubricant 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 with minimal pressure to make initial contact. The purge valve shall be closed.

The displacement gauge reading shall be zeroed or recorded as the initial 'zero' point.

C.3.4 Start of test

The pressure shall be increased in steps, typically 1,5 MPa, and the displacement shall be read at one-minute intervals at the minimum before proceeding. The number of pressure steps shall be at least four.

Measures shall be taken, where necessary, before each reading to ensure that the sample does not hang on the wall (i.e. by rotation of the cell).

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

The displacement shall be read off a minimum of three times the first 24 h, twice the second 24 h, once daily for the remainder of the initial 7-day period, and every second day after this time.

C.3.5 End of test

After a minimum of 1 000 hours, the pressure shall be reduced followed by the temperature. Samples shall be retrieved, and their dimensions and density shall be re-measured.

C.3.6 Interpretation

The data shall be interpreted obtaining the following parameters:

a) tri-axial (bulk) modulus: the inverse slope of the curve of the percentage volume change versus pressure;

b) initial compression: mechanical response (expressed as a volume change in %) shown by the sample during loading;

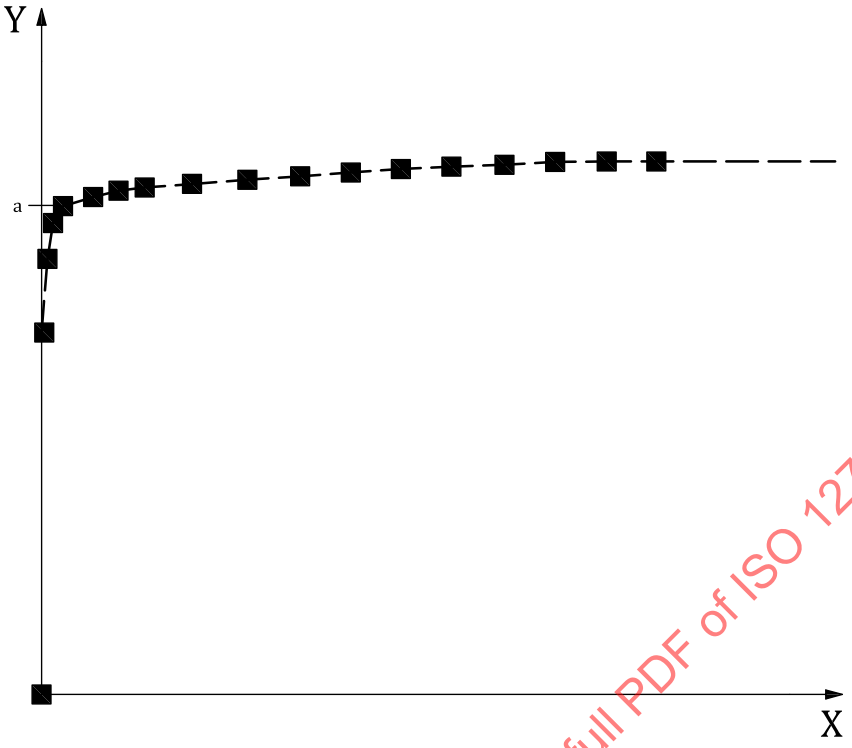
c) 20-year creep: extrapolated creep after 20 years using a log law, excluding the initial compression result;

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

e) calculated final density (after test period): recalculated density against the volume change and the initial sample mass;

f) calculated final density (20 year): extrapolated density over a 20-year period.

A typical set of results for tri-axial tests is shown in Figure C.6.



Key

X	time (h)	a	Initial compression (%).
Y	volume change (%)	log	extrapolation of creep

Figure C.6 — Typical results for tri-axial test

C.4 Accuracy and variance

No data is available to make a statement on precision of these test methods. No statement may be made about the bias of these test methods, as there is no standard reference material or reference test method that is applicable.

Annex D
(normative)

Simulated bend test

D.1 Test procedure

The method for the bend test shall be the curved former type with a fixed end, shown in Figure D.1, or the centrally loaded curved former type with moving ends, shown in Figure D.2. In the case of the centrally loaded curved former type, the former can move towards the pipe or the pipe can move towards the former.

Where a field joint coating is incorporated in the bend test string of the centrally loaded curved former type test, the placement of the field joint shall be offset from the centre of the test pipe to avoid excessive compressive loads acting on the field joint coating and ensure the bending moment travels across the full width of the field joint in one direction only.

When designing the test, the following parameters shall be considered:

a) minimum bend radius;

b) test temperature;

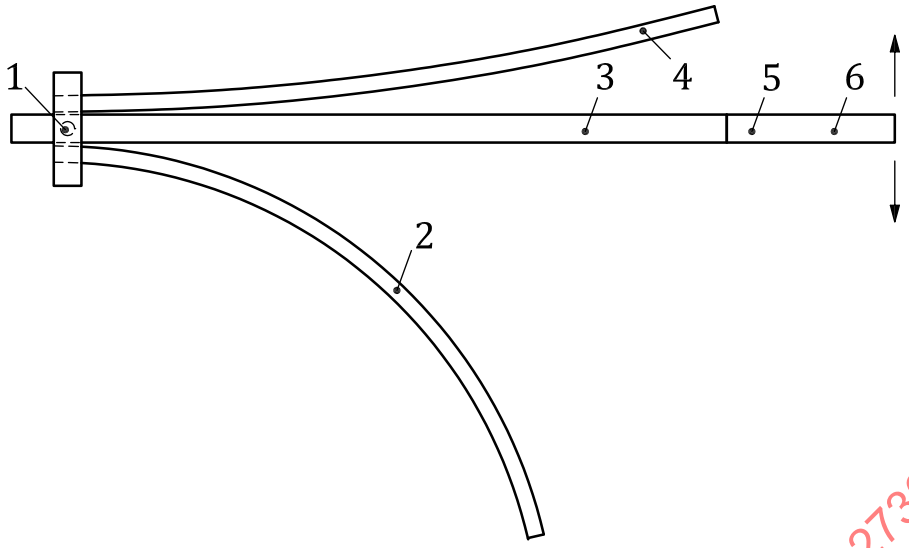
c) rate of bending;

d) holding time at minimum bend radius;

e) number of bend cycles.

These parameters shall be determined by the system provider.

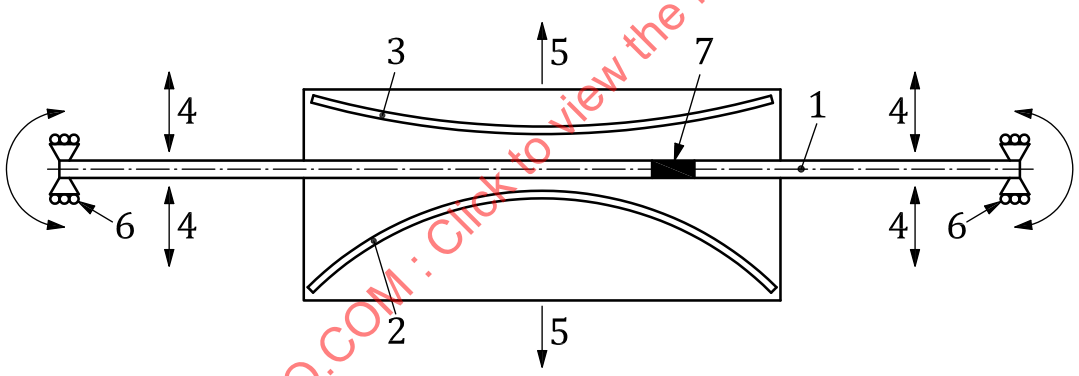
A minimum of one straight section of coated pipe shall be subject to cycles of bending and straightening using a test arrangement of the form shown in Figure D.1 or Figure D.2 to simulate the cycles of bending and straightening experienced during installation.



Key

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

Figure D.1 — Fixed end curved former bend test principle



Key

1 test string
2 bending radius
3 straightening radius
4 pipe travel (moving pipe case)
5 carriage/former travel (moving former case)
6 sliding support/constraint/rig pull head
7 field joint

Figure D.2 — Centrally loaded curved former bend test principle

The test shall be performed as follows:

1) 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 the steel pipe and the wet thermal insulation system. On completion of the conditioning period, an insulation blanket shall be wrapped around the external surface of the system along the length of the pipe and the ends of the pipe shall be blanked off.

2) Pipe shall be placed in the test arrangement. Temperature measurements shall be recorded as appropriate (e.g. steel temperature and temperature in the middle of the insulation layer, at least 0,5 m from the end of the insulation layer along the pipe length).

3) Loading shall be applied to bend pipe around the bending former. The radius of the bending former shall be specified by the system provider.

   — Rate of bending, extent of travel and temperature shall be measured and recorded.

   — Pipe shall be held bent around the bending former to allow remote visual inspection of the tension surface of the system(s) and to confirm that the pipe is in contact with the surface of the curved former. Any lift off 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, normally a minimum of 5 min. If inspection of the tension surface of the system(s) and visual confirmation that the pipe is in contact with the surface of the curved former is required, the insulation blanket may be removed before the reeling operation is started.

4) All loads shall be removed. The pipe shall be allowed to take up its residual deflected shape. Close visual inspection of the tension/compression surfaces of the system(s) shall be carried out once there is no stored energy and it is safe to approach.

5) If applicable, the pipe shall then be bent in the reverse direction around a straightening former, with a larger radius than the bending former, to straighten the 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 system(s) and to confirm that the pipe is in contact with the surface of the curved former. Any lift off 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.

6) All loads shall be removed from the pipe.

7) If during installation the external surface of the 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.

8) Steps 3) to 6) 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 R-lay: spooling, installation, recovery, re-installation).

9) After bending, the wet thermal insulation system shall be sectioned along the maximum as-bent strain axes. The system shall not display any through thickness cracking. Effects, such as disbondment, stress whitening, deformation, blistering, separations between layers or tearing, shall be recorded. Defects can occur as a direct result of the process of sectioning the pipe (e.g. excessive heat build-up, release of residual stress in the system). Appropriate cutting equipment, such as a band saw with blade cooling or a dedicated sectioning procedure to relieve residual stress in the system before cutting, can be required.

D.2 Accuracy and variance

The bend test is designed to provide a working procedure for examination of the effects of certain conditions on subsea wet thermal insulation systems. The effects will be in terms of appearance, which are non-quantitative. No information is presented about either precision or bias, since test results are non-quantitative.

Annex E
(normative)

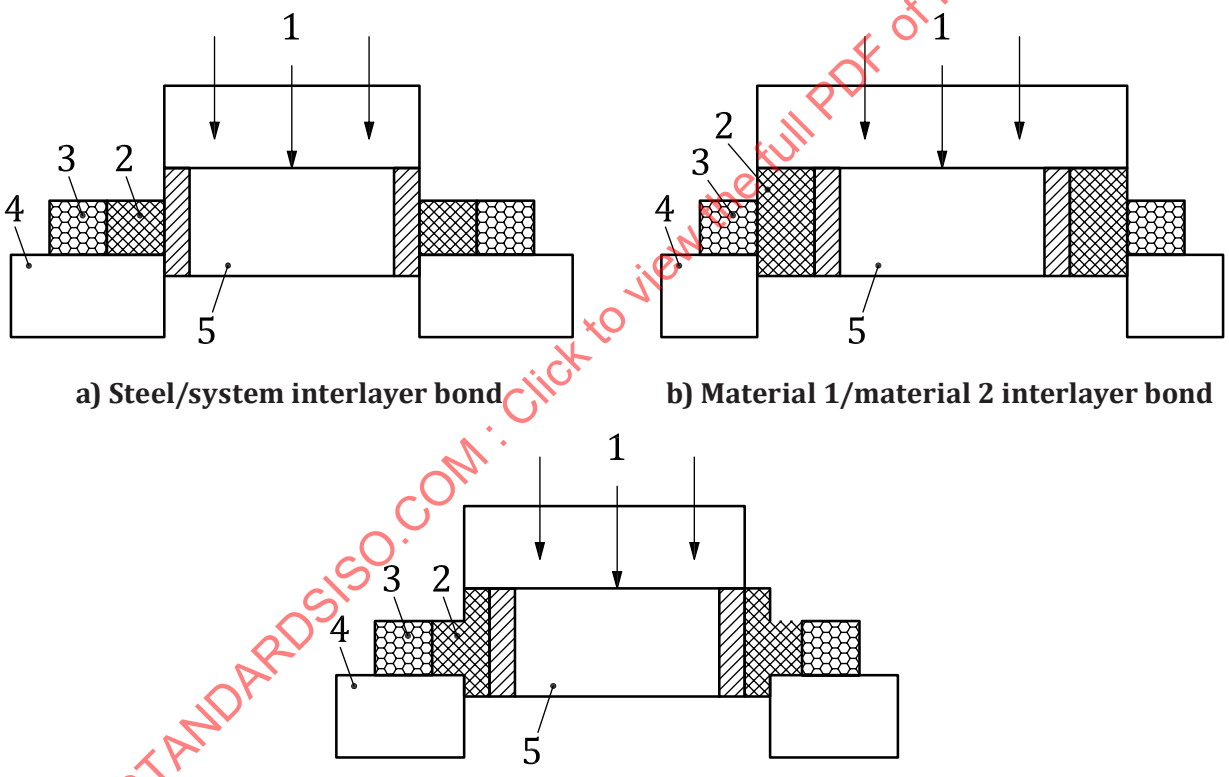
System shear resistance test

E.1 Test procedure

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

One minimum 25 mm wide ring shall be cold cut from the test pipe and subject to the shear test for each material layer or interlayer bond to be tested. If the wet thermal insulation specimen width is reduced to accommodate the maximum load capacity of the tensile frame, it shall not be reduced to <10 mm.

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^{-1}, relative to the insulation until failure occurs, as illustrated in Figure E.1.



a) Steel/system interlayer bond **b) Material 1/material 2 interlayer bond**

c) Within material 1 layer

Key

1	push plate	4	supporting ring
2	material 1	5	steel pipe
3	material 2		

Figure E.1 — Test principle

The gap between the OD of push plate and the ID of the support ring shall be selected by the system provider to prevent buckling of the sample during the test and to ensure a shear loading.