TECHNICAL SPECIFICATION

ISO/TS 18226

First edition
2006-10-01

Plastics pipes and fittings — Reinforced thermoplastics pipe systems for the supply of gaseous fuels for pressures up to 4 MPa (40 bar)

Tubes et raccords en matières plastiques — Systèmes de canalisations en matière thermoplastique renforcée pour la distribution de combustibles gazeux à des pressions allant jusqu'à 4 MPa (40 bar)

Reference number
ISO/TS 18226:2006(E)

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Published in Switzerland

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 18226 was prepared by Technical Committee ISO/TC 138, *Plastics pipes, fittings and valves for the transport of fluids*, Subcommittee SC 4, *Plastics pipes and fittings for the supply of gaseous fuels*.

Introduction

A reinforced thermoplastics pipe (RTP) comprises a thermoplastics liner with continuous reinforcement and a thermoplastics outer cover. An RTP “system” comprises runs of RTP, along with the fittings required to connect them to each other and to the other components of a conventional gas transmission system.

This Technical Specification is applicable for operating pressures up to 4 MPa (40 bar). However it may be used for guidance in the development of RTP systems for higher operating pressures. It is intended to accommodate the upgrading of the performance of RTPs and to provide a framework within which future development can take place.

RTP can be used in both new pipe systems and in the replacement of corroded metallic pipes.

The principal load-bearing components of the RTP are high-strength reinforcing members in the form of fibres, yarns, tapes or wire, which generally carry load only in tension. The reinforcing element may take the form of helically-wound yarns or fibre-reinforced tapes, in which the matrix may be a thermoplastics resin.

In the most frequently employed configuration of reinforcement, dry (non-impregnated) aramid-fibre yarns are encapsulated in a tape of polymer resin or adhesive. It is also possible to employ other classes of reinforcement, such as glass, carbon or textile fibres, or metallic wire or strip.

The reinforcement may or may not be bonded to the liner or to the outer cover.

Several types of fitting design are possible, with joints made by mechanical means, electrofusion or other methods of bonding or welding.

Plastics pipes and fittings — Reinforced thermoplastics pipe systems for the supply of gaseous fuels for pressures up to 4 MPa (40 bar)

1 Scope

This Technical Specification describes the use of reinforced thermoplastics pipe (RTP) systems for transmission of gaseous fuels at maximum operating pressures up to and including 4 MPa (40 bar)[1], and service temperatures in the region – 50 °C to 120 °C, depending on the liner and cover materials.

This Technical Specification relates to transmission systems in which wear and damage to the liner are restricted by limiting pigging operations to soft pigging only.

The recommendations in this Technical Specification are confined to RTP and its associated in-line fittings and end-fittings. Where the other system components (elbows, tees, valves, etc.) are of conventional construction, they will be governed by existing standards and codes of practice.

This Technical Specification specifies a qualification testing procedure for RTP systems. It also provides a procedure for reconfirmation of the design basis that may be used for product variants where changes have been made in design, materials or the manufacturing process.

This Technical Specification provides informative annexes relating to quality assurance, product marking, handling and storage.

2 Normative references

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

ISO 4433-1:1997, *Thermoplastics pipes — Resistance to liquid chemicals — Classification — Part 1: Immersion test method*

ISO 4433-2:1997, *Thermoplastics pipes — Resistance to liquid chemicals — Classification — Part 2: Polyolefin pipes*

ISO 4433-3:1997, *Thermoplastics pipes — Resistance to liquid chemicals — Classification — Part 3: Unplasticized poly(vinyl chloride) (PVC-U), high-impact poly(vinyl chloride) (PVC-HI) and chlorinated poly (vinyl chloride) (PVC-C) pipes*

ISO 4433-4:1997, *Thermoplastics pipes — Resistance to liquid chemicals — Classification — Part 4: Poly (vinylidene fluoride) (PVDF) pipes*

ISO 4437, *Burried polyethylene (PE) pipes for the supply of gaseous fuels — Metric series — Specifications*

1) 1 bar = 0,1 MPa = 10^5 Pa.

ISO 9080:2003, *Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation*

ISO 12162:1995, *Thermoplastics materials for pipes and fittings for pressure applications — Clarification and designation — Overall service (design) coefficient*

ISO 12176-1:1998, *Plastics pipes and fittings — Equipment for fusion jointing polyethylene systems — Part 1: Butt fusion*

ISO 14531-1, *Plastics pipes and fittings — Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 1: Pipes*

ISO 14531-2, *Plastics pipes and fittings — Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 2: Fittings for heat-fusion jointing*

ISO 14531-3, *Plastics pipes and fittings — Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 3: Fittings for mechanical jointing (including PE-X/metal transitions)*

ISO 14531-4, *Plastics pipes and fittings — Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels — Metric series — Specifications — Part 4: System design and installation guidelines*

ASTM D2992-01, *Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings*

3 Terms, definitions and abbreviations

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

3.1 General terms and definitions

3.1.1
aramid
class of high-strength organic fibre "aromatic amide"

EXAMPLES Twaron[2)], Kevlar[2)].

3.1.2
application-related service factor(s)
multiplication factor(s) applied to the manufacturer's nominal pressure rating, to allow for effects such as cyclicity

3.1.3
ballooning
inflation of the cover of an RTP, by pressurised gas, that has accumulated in the reinforcing layer

3.1.4
blistering
damage in polymer materials caused by the release of absorbed gas on sudden decompression

3.1.5
carbon fibre
class of high-strength graphite-based reinforcing fibre

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2) Twaron and Kevlar 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.

3.1.6
cyclic
fatigue
service conditions where the internal pressure fluctuates

3.1.7
dynamic
service condition involving external time-dependent loads

3.1.8
elevated temperature test
constant-pressure survival test aimed at verifying that no undesirable failure mode can occur between the end of the qualification test period and the end of the design life

3.1.9
end-fitting
joint that occurs at either end of a run of RTP, where it is connected to other parts of the system

3.1.10
fitting
coupler
pipe joint

3.1.11
glass fibre
high-strength inorganic reinforcement based on E-glass or S-glass

3.1.12
in-line fitting
pipe joint between adjacent lengths of RTP

3.1.13
lower prediction limit
97,5 % lower prediction limit of the mean regression curve

3.1.14
minimum required strength
lower prediction limit at 20°C in a thermoplastics pipe at 50 years in accordance with ISO 9080:2003, rounded down in accordance with ISO 12162:1995

3.1.15
Principal
party that initiates and pays for a project, or his agent

NOTE The Principal will generally specify the technical requirements of a project.

3.1.16
principal mode
only failure mode that shall be permitted in the pressure testing of RTP

3.1.17
product family
group of RTP products having certain similarity characteristics

3.1.18
product-family representative
member of a product family, chosen for full qualification

3.1.19
product variability factor
factor, allowing for product variability, applied to the Lower Prediction Limit (LPL) pressure, to give the Manufacturer's Nominal Pressure Rating (MNPR)

3.1.20
product variant
member of the same product family, to which certain permissible changes have been made

3.1.21
rapid crack propagation
undesirable fracture mode, in which a crack propagates along a pipeline at very high speed

3.1.22
regression analysis
statistical procedure to establish a design rating from pressure test results carried out over a period of 104 h (or a number of pressure cycles)

3.1.23
safety class
classification associated with a particular probability of failure

3.1.24
stress rupture
static fatigue
failure, as a result of a period under steady stress or pressure

3.1.25
survival test
constant-pressure test, to demonstrate that a product performs at least as well as the qualified product

3.2 Temperature- and pressure-related definitions

3.2.1
design temperature
maximum operating temperature of the RTP system

3.2.2
FAT pressure
Factory Acceptance Test pressure

3.2.3
LPL pressure
pressure obtained by extrapolating the LPL to the design life

3.2.4
long-term hydrostatic pressure
pressure obtained by extrapolating the mean regression curve to the design life

3.2.5
manufacturer's nominal pressure rating
pressure obtained by multiplying the LPL pressure by the product variability factor

3.2.6
maximum service pressure
pressure obtained by multiplying the manufacturer's nominal pressure rating by application-related service factors

3.2.7
maximum operating temperature
maximum temperature to which the piping is expected to be exposed during normal operational activities, including start-up and shut-down operations, but excluding abnormal situations such as a fire

3.2.8
minimum operating temperature
minimum temperature to which the piping is expected to be exposed during normal operational activities, including start-up and shut-down operations and controlled blow-out, but excluding abnormal situations such as piping rupture

3.2.9
qualification test temperature
temperature at which pressure tests are carried out to establish the lower prediction limit

NOTE The design temperature shall not exceed this temperature.

3.2.10
short-term hydrostatic pressure
pressure corresponding to the LPL pressure at a prescribed time of 100 h or less

3.2.11
short-term burst pressure
burst pressure measured in a short-term test, where pressure is increased at a prescribed rate at Standard Laboratory Temperature (SLT)

3.2.12
standard laboratory temperature
temperature of 23 °C ± 2 °C

3.2.13
survival test pressure
pressure for a 1 000 h survival test

NOTE This is the pressure of the LPL line at 1 000 h.

3.3 Abbreviations

ASTM American Society for Testing and Materials

API American Petroleum Institute

BS British Standard

CEN Comité Européen de Normalisation

COV Coefficient of Variation

DVS German Standard

EN European Standard

ESC Environment-Sensitive Cracking

FAT Factory Acceptance Test

F Regression relationship constant

G Regression line gradient

IGE	Institution of Gas Engineers
ISO	International Standard Organization
LPL	Lower Prediction Limit
LTHP	Long-Term Hydrostatic Pressure
MNPR	Manufacturer's Nominal Pressure Rating
MRS	Minimum Required Strength
MSP	Maximum Service Pressure
PA11	Polyamide 11 (Trade name Rilsan[3])
PE	Polyethylene
PE-X	Cross-linked polyethylene (also referred to as XLPE)
PM	Principal Mode of failure
PVDF	Polyvinylidene fluoride
PVF	Product Variability Factor
QA	Quality Assurance
RCP	Rapid Crack Propagation
RTP	Reinforced Thermoplastic Pipe
SLT	Standard Laboratory Temperature
STBP	Short-Term Burst Pressure
STHP	Short-Term Hydrostatic Pressure
UV	Ultraviolet
WIS	Water Industry Specification

4 Performance requirements

4.1 Materials

4.1.1 Liner materials

Liner materials shall conform to an appropriate Standard for gas applications (i.e. ISO 4437 and EN 1555 in the case of polyethylene, and ISO 14531 for PE-X). For polyethylene and PE-X liners, the MRS shall be at least 8 MPa.

3) Rilsan is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Other thermoplastics materials (for example, PVDF and PA11) may be used, provided they conform to the material requirement of a relevant ISO pipe standard and that fitness for the purpose has been established. In all cases, materials shall be evaluated and classified in accordance with ISO 12162:1995 (see Annex E, E.2).

The liner shall possess RCP resistance at a stress equal to a minimum of 1,5 times the stress induced at the MSP and minimum operating temperature (see E.3.2).

The liner material shall have adequate resistance to blistering. A suitable procedure is described in API Spec 17J, Section 6.2.3.2.

4.1.2 Cover materials

Cover materials shall conform to the material requirements of a relevant ISO pipe standard, for example ISO 4437 or ISO 14531, and fitness for the purpose shall be established.

In the case of pipes that may be exposed to sunlight during storage or service the manufacturer shall demonstrate that the cover possesses adequate resistance to UV and to UV-transmissions when the reinforcement is susceptible to UV-damage.

4.1.3 Reinforcements

The manufacturer shall provide the data required to demonstrate the short-term and long-term load-bearing capability of the reinforcement, as described in Annex A.

The manufacturer shall ensure that the tape supplier operates an effective quality plan relating to all aspects of tape manufacture. The following characteristics shall be considered in the quality plan: reproducible strength, dimensional consistency, evenness and reproducibility of cord spacing.

4.2 Pipes and fittings

Each type of RTP pipe body shall be qualified by means of the regression procedure described in Annex E. The fittings used for these tests may be fittings as used in the field or re-usable test end-fittings. At least one regression point shall be measured in excess of 10 000 h, with field end-fittings attached to both ends of the pipe body.

The regression test results shall be used to determine the regression-line gradient, the LTHP and the LPL for the RTP system, using the statistical procedure described in ISO 9080:2003.

In addition to the regression tests, every field fitting/pipe body combination shall pass an elevated temperature test, as described in Annex C, to verify the integrity of the fitting/pipe body connection.

The manufacturer shall inform the Principal of any substantial change to the fittings and/or pipe body.

The manufacturer shall prove and guarantee that any change to the field fittings or to the re-usable test end-fittings does not invalidate the results of qualification tests.

RTP products shall be divided into product families, as described in Annex E. Each product family shall have a representative named the product-family representative. Other products within the family are termed “product variants”.

The qualification test temperature shall be greater than or equal to the design temperature.

Other qualification issues are examined in Annex E.

4.3 Re-qualification

Re-qualification may be required when any change to the RTP system is made by the manufacturer. The manufacturer shall inform the Principal if any changes to the previous qualified RTP product family have occurred.

Depending on the level of change, the following re-qualification options are defined:

— unimportant – previous qualification remains valid;

— minor – (partial) re-qualification will be required in accordance with Annex E;

— major – (full) re-qualification will be required in accordance with Annex E.

The manufacturer and Principal shall agree on the classification of each change.

NOTE Currently, major or minor changes cannot be defined with greater precision.

5 Process and quality control

The manufacturer shall produce a quality plan relating to all aspects of the manufacturing process. The quality assurance procedure for RTP is described in Annex F. It requires that either batch tests or a hydrotest be carried out on the product or, where required by the application, both types of test.

6 Dimensions and marking

6.1 Dimensions

The nominal size of the pipe shall be the internal diameter of the liner expressed in millimetres (mm). The preferred nominal size shall be a multiple of 25 mm, enabling an approximate correspondence to be maintained with inch sizes.

6.2 Marking

The required information shall be permanently marked on the pipe body, in a colour that contrasts that of the pipe, the height of the characters being at least 5 mm (10 mm on pipes larger than 150 mm in diameter). The required markings should be repeated at reasonable intervals to be agreed with the Principal.

The following information shall be given on the RTP pipe body:

— Manufacturer's name or trademark.

— The word, “GAS” or “GAZ”.

— ISO/TS 18226.

— Nominal pipe size in mm.

— Product identification code.

Markings shall be durable and non-damaging.

The Principal may request additional markings if necessary.

7 Handling, storage and installation

The manufacturer shall provide the Principal with written instructions on the handling, storage and installation requirements of the RTP system.

Annex A
(informative)

Description of RTP Products

A.1 General

An RTP 'system' comprises runs of RTP, along with the fittings required to connect them to each other and to the other components of a conventional gas transmission system. The essential components of such a system are

— a thermoplastics liner, the main function of which is to contain the fluid being transmitted,

— an even number of balanced helical windings of continuous reinforcement, to resist the applied pressure and other loads; these can be applied using a number of possible processes, including helical tape-wrapping, filament winding and braiding,

— an outer protective thermoplastics cover, and

— a system of fittings to enable runs of RTP to be connected to one another and to other components.

A.2 Liner

The thermoplastics liner may be manufactured in-line with the RTP production process or supplied as a separate component. It may, on occasion, be necessary to join lengths of liner by butt fusion. When this is done, it should be carried out according to a recognised standard, for example EN 1555-1, EN 1555-2, EN 1555-3, EN 1555-4 or EN 1555-5, using butt fusion equipment meeting ISO 12176-1. The procedure should be documented and a QA system should be in place to ensure that the properties of the joint are equal to those of the parent pipe.

To fulfil its function of containing the transported fluid, the liner material should have adequate resistance to degradation from all the components of the fluid. Resistance to degradation includes

— resistance to physical interaction, which may cause leaching, excessive swelling, plasticisation and consequent loss of properties,

— resistance to chemical attack, and

— resistance to wear and abrasion by suspended solids.

The liner should also possess sufficient ductility to enable it to withstand the strains imposed upon it during RTP manufacture, storage and deployment (which may involve reeling or axial loads). It should also be able to resist long-term loads imposed upon it by joints and fittings without excessive creep. Furthermore, it should be capable of withstanding the strains imposed during pressurisation and, where appropriate, cyclic pressurisation.

The liner acts as a barrier to limit the diffusion of gas or vapour. The accumulation of gas at the interface between the liner and the reinforcing layer must not lead to blistering of the cover, or to collapse of the liner, if the RTP is suddenly depressurised. Certain corrosive gaseous species may also have an undesirable effect on the reinforcement. In situations where significant diffusion takes place through the liner, the RTP system may be equipped with a means of venting the gas, for instance at the fitting.

The liner does not normally contribute to the strength of an RTP except under rare loading conditions; for instance, if the RTP is subjected to external pressure.

With certain designs of fitting, the liner may form part of the load path from the reinforcement to the fitting. In these cases, the material may be subjected to significant local stresses, which it must resist without failure or undue deformation.

This procedure applies only to thermoplastics liner materials (including cross-linked thermoplastics, such as PE-X). In the majority of cases, the liner will be a single component, but multi-layer liners, containing for instance a thermoplastics barrier layer, are permitted.

Typical thermoplastics materials that may be used in RTP manufacture are: polyethylene (PE), cross-linked polyethylene (PE-X), polyamide 11 (PA-11) and polyvinylidene fluoride (PVDF).

The liner material should contain no filler, only appropriate additives, well-dispersed in the parent polymer.

A.3 Reinforcement

The principal load-bearing components of the RTP are high-strength reinforcing members in the form of fibres, yarns, tapes or wire. These generally carry load only in tension. The reinforcing element may take the form of helically wound fibre-reinforced tapes, in which the resin may be either a thermoplastics or a hot-melt adhesive.

The most frequently employed reinforcement comprises dry (non-impregnated) aramid fibre yarns, which may be encapsulated in a polymer resin or adhesive to form a tape. It is also possible to employ other reinforcements that have been fully or partially impregnated by thermoplastics resin, metallic strip or wire.

Factors to be considered in relation to the reinforcement include

— the effects of the void content in the reinforcement on gas accumulation,

— fibre-fibre friction wear and damage in the dry fibre case, and

— tape/tape friction wear and damage.

It is also necessary to consider possible effects of environment on the reinforcement. Environment-induced failure can arise through the diffusion of corrosive or sensitising agents through the liner, penetration of agents along the reinforcement (having entered in the region of the end-fitting or through external damage) and, in rare cases, diffusion of agents through the cover.

The response of the reinforcement to all possible external environments (water, air, chemicals or photo-oxidation) as a result of cover damage (or at the cut ends of pipe during storage) also needs to be taken into account. This should preferably include long-term stress rupture data in the appropriate environment.

Reinforcements should preferably run continuously from one end of the pipe to the other. If reinforcements do require to be joined (for instance, tape joints in the case of tape reinforcement) this needs to be specified, and a well-defined jointing procedure laid down. Pipes with such discontinuities are given special consideration in the qualification procedure.

A.4 Cover

The purpose of the cover is to protect the internal components, most especially the reinforcement, from damage. Depending on the field of application (e.g. above ground, buried, inside an existing pipe, or subsea) there are several potential sources of damage. These include abrasion, compression or gouging during coiling and deployment, environmental attack from chemical species or photo-oxidation, external damage during trenching and back-filling, external interference and the effects of land movement.

The cover will generally be applied to the RTP by a process of extrusion and may or may not be welded to the thermoplastics component of the reinforcement.

Although the cover does not contribute significantly to the load-bearing capacity of the RTP under normal working conditions, it is subject to significant strains that arise from the deformation of the underlying components when the RTP is pressurised. These strains may be magnified in the vicinity of the end-fittings, due to the restraining effect of the latter.

The cover is also subject to flexural strains during deployment and to thermal strains during its lifetime.

With certain designs of end-fitting, the cover may form part of the load path from the reinforcement to the fitting. In this case, the cover material may be subjected to significant local stresses, which it must be shown to resist without failure or undue deformation.

A.5 Fittings

The function of the fittings is to connect RTP runs to one another and to other components, allowing free passage of fluid along the line without leakage, while permitting the transmission of loads from the RTP to the other system components. In certain applications, fittings may be required to allow pigging of the flowline. Different types of fitting design are permissible, in which a joint is made by mechanical means, electrofusion or other methods of bonding or welding.

Since the reinforcement takes most of the loads in an RTP system, the fitting design must provide a load path from the reinforcement into the fitting. This load path may be achieved by directly gripping or bonding the reinforcement or by frictional or shear transfer involving other components of the RTP.

In addition to the loads mentioned above, the fittings shall also be capable of resisting loads due to deployment, ground movement, thermal stress and external interference.

The manufacturer should provide the necessary documentation and training to enable fittings to be installed in a consistent and reproducible manner.

At least one set of fittings shall be specified and qualified for each RTP product.

The construction of the fitting shall be fluid-tight, to prevent the pressurising medium from leaking into the surrounding environment or into the reinforcing layer. In certain designs of RTP, however, the fitting may also fulfil the function of allowing diffused volatiles to escape. In these circumstances, the rate of flow of diffused volatiles should be estimated and taken account of in the system design.

A.6 Bonded and non-bonded construction

Different types of RTP design are possible, in which the liner, reinforcement and cover may or may not be bonded together. Bonding can influence several aspects of performance, including flexibility, response to permeated gas and load transfer in fittings.

Annex B
(informative)

Liner material durability considerations

B.1 Ageing

Ageing of thermoplastics polymers is temperature-dependent and occurs on exposure to particular environments. For liner materials, the behaviour is highly dependent on the composition of the fluid being carried. Ageing may result in changes to properties such as strength and ductility and can involve embrittlement, cracking or softening. The mechanisms may be different for different polymers. Typically they may involve

— environment-sensitive cracking (ESC),

— absorption of species from the carried fluid,

— leaching of low-molecular-weight material or plasticiser from the polymer, or

— chemical changes to the molecular structure of the polymer.

ESC is an embrittlement process that can be activated by specific fluid components. In polyethylene, susceptibility to ESC is decreased by increasing molecular weight or lowering crystallinity.

Absorption of species from the fluid carried results in plasticisation, which reduces strength and stiffness. These species may also react chemically with the polymer, often resulting in a loss of molecular weight through chain scission. In the special case of polyamides, this can occur through hydrolysis, a reaction that is strongly influenced by the water content of the fluid.

The first requirement for consideration for use as a liner is that the material have "satisfactory resistance" to the fluids carried, in accordance with ISO 4433. In addition, the polymer manufacturer should provide detailed information relating to the degradation mechanisms that operate in the presence of the particular fluids to be transported. This information should be in a form that can be used to predict lifetime and residual integrity. For example, if the polymer is subject to hydrolysis, as is the case for Polyamide 11, ageing models should be available to predict the residual lifetime and integrity as a function of time, temperature and fluid composition.

B.2 Retention of properties

The liner needs to retain a minimum level of strength over the design life.

The failure mode of the polymer, when tested in tension, shall always be ductile, i.e. there should be yield before break. There shall be no local cracking or crazing. This applies across the range of temperatures and fluids under consideration.

The grade of polymer used for the liner should have documented creep and stress rupture characteristics at a range of temperatures encompassing the qualification temperature, and for a time period of at least 10 000 h. This documented behaviour needs to be in a form that can be used to estimate a time/temperature equivalence factor for the polymer.

The stress rupture regression characteristic of the polymer, log (failure stress) versus log (time to failure), should be documented and examined for linearity according to ISO 9080:2003. Certain polymers are known to display two-stage stress rupture curves, in which there is a transition in failure mechanism at moderate times or high temperature. The data and characteristics produced should be examined for the presence of "Knees", and used to determine the potential of the material to fail prematurely within the time and temperature conditions specified for use. Only materials which do not exhibit a knee in ISO 9080 datasets before 1 year should be used. In the case of polyethylene, only established ‘pipe' grades of material with well-documented performance (such as PE80 and PE100) should be used.

The value of the elongation at yield of the liner material, measured in a tensile test, according to ISO 527-2:1993, 1BA (or ASTM D638), should be provided at both the maximum and minimum operating temperature. Where appropriate, the polymer should be saturated in the fluid to be transported.

Under all conditions, the maximum liner strain at the LTHP should be less than 80 % of the strain to yield of the liner polymer. In the case of polyethylene liners, this should be no more than 6 %, as stipulated in API Spec 17J.

Annex C
(informative)

Rationale for the elevated temperature test

It is necessary to establish that no failure mode, associated with thermoplastics components of the RTP, can occur at times between the end of the qualification test period and the end of the design life. Such a failure mode could, for example, involve

— strain rupture of the liner,

— failure of part of the liner in or near the coupling as a result of local stresses, or

— failure of the axial load capacity of the coupling as a result of stress relaxation of the thermoplastics components.

To accelerate undesirable failure modes into the region where they would be observed during a reasonable qualification testing period requires knowledge of the failure modes of the thermoplastics polymer and the time-temperature equivalence of these failure modes. The grade of polymer used for the liner should therefore possess well-documented creep and stress rupture characteristics over a range of temperatures exceeding the qualification temperature, and over a time period that is long enough to allow any possible undesirable failure modes to be observed. This period should be at least 10 000 h, or possibly more in the case of longer design lives (50 years or more).

The pressure at which the elevated temperature test should be carried out should relate directly to the regression curve at the qualification temperature. This pressure should therefore be the LPL.

The most relevant data are stress rupture measurements on pressurised pipe samples covering a range of temperatures, fitted in accordance with the standard extrapolation method laid down in ISO 9080:2003. Under these conditions, thermoplastics can display two types of failure mode:

— ductile failure, associated with prolonged creep and gross deformation, or

— brittle failure, associated with crack propagation at long times or high temperatures, sometimes associated with chemical effects.

Each of these modes is characterised by a different value of activation energy and a different form of temperature dependence. This needs to be borne in mind when considering the requirements for an accelerated test at elevated temperature. Ductile failure processes, in general, require a smaller temperature change to produce a given shift in time-scale than brittle processes.

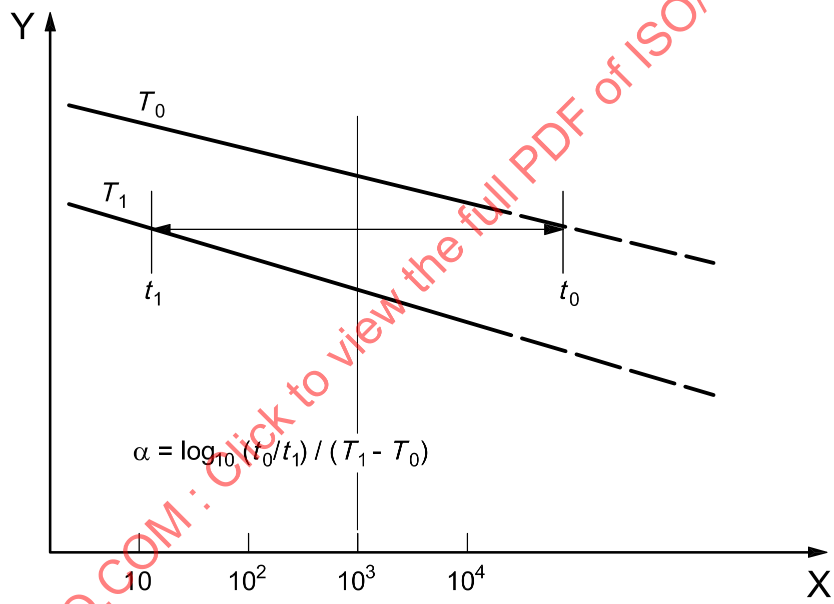
Figure C.1 shows schematically two sets of ductile failure data at different temperatures. A time/temperature equivalence factor, α, in decades/°C, can be found by comparing the horizontal distance between the two curves. It should be noted that this factor may vary somewhat with timescale, since the curves often have different values of slope. It is recommended that, when comparing curves, this be done over a logarithmic timescale, with 1 000 h taken as the median point, as shown. For polyethylenes showing ductile stress rupture behaviour, equivalence factors, in the range 0,2 to 0,3 decades/°C, are usually found, as shown in Table C.1.

When brittle failure is encountered, α is generally much lower, in the range 0,05 to 0,075 decades/°C, as shown in Table C.1.

Table C.1 — Time/temperature equivalence factors for different processes in PE

Type of process	**Equivalence factor**, α decades/°C
Pipe stress rupture Stage 1 (ductile failure)	0,2 to 0,3
Pipe stress rupture Stage 2 (brittle failure)	0,05 to 0,075

ISO 9080:2003 gives recommendations concerning "acceleration factors" for use in elevated temperature testing. These are based conservatively on the lowest observed values of α, namely 0,05 decades/°C. In the case of thermoplastics materials for RTP, it is reasonable to use such a factor only when it is possible that a brittle failure mode may occur. However, it is generally undesirable to use material that may display such a characteristic in RTP if it can be avoided.



Key

X log (time)

Y log (hoop stress)

Figure C.1 — Schematic pipe stress rupture data for a polymer showing ductile behaviour at two temperatures, and calculation of the time/temperature equivalence factor, α

The activation energy corresponding to the ISO 9080:2003 default value is close to the theoretical energy to break bonds in the backbone chain of the polymer. It should be reasonable, therefore, to use this as a default value for any polymer that is likely to show brittle behaviour.

Many crystalline polymers, including the older pipe grades of polyethylene, show a transition from ductile to brittle failure at long times or high temperatures. Since alternative materials are available, such polyethylenes should not be used in any part of an RTP.

The preferred grades of polyethylene are "pipe" grades that have been shown to display consistently ductile regression behaviour. Polyethylenes should be specified with MRS (minimum required strength, extrapolated to 50 years at 20 °C) in excess of 8 MPa. Generic grades of material of this type are often referred to as PE80 and PE100, corresponding to MRS values of 8 MPa and 10 MPa, respectively.

When fully ductile grades of PE are used in RTP, it is permissible to employ a time/temperature equivalence factor significantly larger than 0,05 decades/°C. It is recommended that a value of 0,11 decades/°C be used. This value is considered conservative for pipe grade PE for two reasons.

a) It is below the observed range of values for ductile processes.

b) The values in Table C.1 were determined from rupture measurements under constant hoop stress, whereas the actual loading regime of the thermoplastics elements in RTPs corresponds more closely to stress relaxation under constant strain, which is much less onerous.

NOTE 1 It may be that, following experience with RTP development, the value of α may be revised upwards in due course.

It is recommended that the maximum value of temperature increase employed in the elevated temperature test be 25 °C, in order to avoid unforeseen changes in the failure mechanism, and to minimise the possibility of failures due to reinforcement failure. Exceeding this value is permissible, however, as it is likely to lead to results that are conservative.

NOTE 2 Manufacturers may find it convenient to employ higher temperatures for development purposes with new end-fitting designs.

For polymers other than PE, which show consistently ductile long-term behaviour, it is recommended that a conservative α value be derived in a similar way to that described here. If, however, there is any possibility of a transition to brittle behaviour occurring (as has been observed for instance with PVDF), it is recommended that the default lower value of $\alpha = 0,05$ decades/°C be employed. When this low value is employed, it may be necessary to use temperature increases greater than 25 °C in order to achieve reasonable testing times in the elevated temperature test.

Annex D
(normative)

Test procedures

This annex contains information relating to the test requirements for regression testing of product-family representatives.

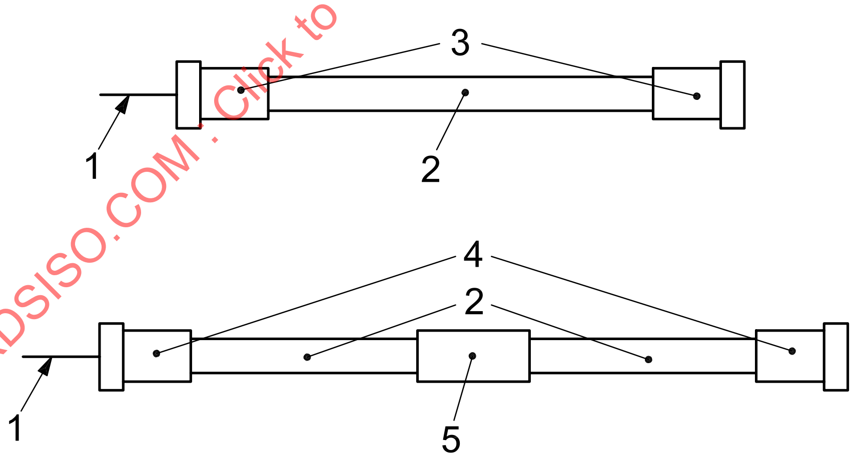
The qualification test temperature shall be greater than or equal to the design temperature.

The fittings used for these tests may be either field fittings or re-usable test end-fittings. However, at least one regression point shall be measured in excess of 10 000 h, with field end-fittings attached to both ends of the pipe body.

Pressure tests shall be conducted with water as the pressurising fluid. All qualification tests shall be conducted with unrestrained ends, so that the full pressure-induced axial load is borne by the test spool.

Where it is necessary to introduce discontinuities or joints of any type into the manufactured RTP, samples containing examples of these discontinuities shall **either** be employed in the full qualification procedure **or** be treated as a product variant. Examples of discontinuities are joints in the reinforcing tape. Liner butt welds are exempt from this, provided the appropriate procedures are followed to ensure consistent high weld quality. Discontinuities of this type shall also be subjected to the elevated temperature test.

With each test spool, there shall be an unrestrained length of RTP between fittings corresponding to at least six times the nominal diameter. Possible test configurations are shown in Figure D.1.



Key

1 pressure line

2 pipe body

3 fittings to be qualified

4 test-end fittings

5 fitting (connector) to be qualified

Figure D.1 — Possible configurations for pressure testing of RTP and fittings

If the fitting can be used as an end-fitting then an appropriate test piece is a single length of RTP between two such fittings. Alternatively, if fittings are used to connect two (or more) runs of RTP then a test piece shall comprise two (or more) runs of RTP connected by fittings, along with two further blank end-fittings. In the latter case, where two or more lengths of pipe body are pressurised simultaneously, it is permissible, following the failure of one of the lengths of pipe body, to assemble a new spool piece and continue the test, at the same pressure, on the unfailed length(s). This is permissible, provided that the failure of one spool piece does not result in visible external damage to the others (for instance cover damage, or visible external distortion due to violent movement on failure). It is also permissible to pressurise two or more spool pieces to the same pressure simultaneously, by connecting them together. Following failure of one of them, the others may be re-pressurised to the same pressure and the test continued, provided there is no visible external damage.

Appropriate safety precautions should be observed during the pressure testing of RTP. There are hazards on failure due to high-pressure fluid jets and the release of significant levels of strain energy.

Depending on the type of manufacturing process used, test specimens may be taken either from straight pipe or from pipe that has been coiled.

Annex E
(normative)

Qualification protocol

E.1 Qualification

E.1.1 Introduction

Each type of RTP pipe body shall be qualified by means of the regression procedure described in this clause.

The qualification test temperature shall be greater than or equal to the design temperature.

The fittings used for these tests may be either field fittings or re-usable test end-fittings. However, at least one regression point shall be measured in excess of 10 000 h, with field end-fittings attached to both ends of the pipe body.

The regression procedure assumes that the applied pressure, P, and the failure time, t_f, are related by an equation of the form:

$$P = F \cdot t_f^{-G} \qquad \text{(E.1)}$$

F and G are constants that describe the regression behaviour. For the procedure to be used, G shall be a positive number, greater than 0,015.

The regression test results shall be used to determine the regression-line gradient, the long-term hydrostatic pressure (LTHP) and the lower prediction limit (LPL) for the RTP system, using the statistical procedure described in ISO 9080:2003.

In addition to the regression tests, every field fitting/pipe body combination shall pass the elevated temperature test stipulated in this Annex, to verify the integrity of the fitting/pipe body connection.

The manufacturer shall inform the Principal of any substantial change to the fittings and/or pipe body.

The manufacturer shall prove and guarantee, to the satisfaction of the Principal, that any change to the field fittings or to the re-usable test end-fittings does not invalidate the results of qualification tests.

E.1.2 Product families

RTP products shall be divided into product families. Each family shall have a representative named the product-family representative. The product-family representative shall have an inner diameter of at least 75 mm.

Other products within the family are termed “product variants”.

A product family is a range of RTP product variants having the same regression-line slope. Product family members should have the following features in common.

— General design. Changes in the diametric dimensions of the RTP pipe body are allowed. However, changes to the internal diameter shall be within the range, – 40 mm to + 60 mm, of the qualified product.

— Winding angle (within ± 1°).

— The same number of reinforcing layers.

— Grades of thermoplastics in the liner and reinforcing layer (if any).

— Reinforcement. For fibre reinforcements, this implies the same fibre grade, yarn and cord architecture, or weave architecture if woven. For cords, the cord spacing and area density of reinforcement may be changed by ± 15 %. Where the reinforcement is in the form of tape, the tape width may be changed, provided the other features remain the same.

Following changes to the internal diameter, the new LPL shall be calculated by multiplying the previous LPL by the ratio of the old liner internal diameter, divided by the new liner internal diameter.

NOTE The load transmission in fittings may be altered by changes in the cover polymer, but adverse changes could be highlighted by the elevated temperature test stipulated in this Annex.

E.1.3 Permissible and non-permissible failure modes

According to this qualification procedure, only one failure mode is acceptable, namely tensile failure of the reinforcement. This failure mode is designated the Principal Mode of failure (PM) and the design of the RTP shall ensure that, under conditions of internal pressure, this mode always occurs prior to the others.

The PM shall be taken to be reinforcement failure in the main body of the pipe, leading to loss of integrity and rupture of the liner and outer cover. If, for instance, the reinforcement consists of fibres embedded in a thermoplastics resin, the permissible failure mode is tensile failure of the fibres. Likewise, in the case of wire or strip reinforcement, the permissible mode is tensile fracture of the wire or strip.

It is recognised that the fitting may exert a constraint on the expansion of the RTP, which can result in slightly higher local stresses in the reinforcement. This can have the effect of localising the point of failure near to the fitting. This type of reinforcement failure is permitted, provided it can be shown to have started outside the fitting.

If any failure mode other than the PM is observed, this invalidates the test. Any such failure shall be thoroughly investigated by the manufacturer to determine the cause, and the necessary steps shall be taken to prevent a recurrence of such a failure mode.

NOTE Examples of non-permissible failure modes are

— failure of the liner (leading to pressurisation of the reinforcement and rupture of the outer cover),

— failure involving a fitting, especially failure involving the ejection of the RTP from the fitting,

— leakage of fluid from any part of the RTP system [with the exception of gas that has diffused through thermoplastics component(s) of the RTP].

Failure of the outer cover during a pressure test shall also be regarded as a non-permissible mode, even if this does not result in loss of pressure. Cover failure exposes the reinforcement to the external environment, which can lead to premature loss of integrity.

E.1.4 Qualification of the product-family representative: determination of the Lower Prediction Limit (LPL)

The relationship between internal pressure and time to failure shall be determined by a series of stress rupture tests under constant pressure at the qualification test temperature, as described in Annex D. The results of the stress rupture tests shall be used to construct a regression relationship, from which the Lower Prediction Limit (LPL) shall be determined.

At least 18 failure points are required for this procedure. The failure times for RTP shall be distributed as described in Table E.1, which shows the minimum numbers of points in each time interval. All other points shall correspond to failure times greater than 100 h.

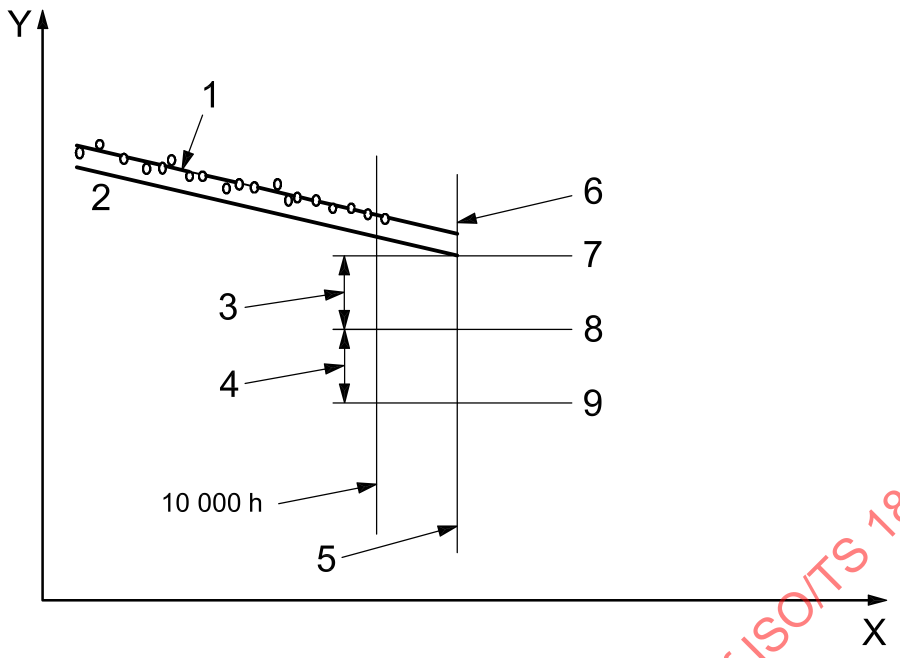
Specimens that have not failed at the end of the test period may be included as failure points, if this increases the LPL. The LPL shall be calculated with and without the unfailed sample points to ascertain whether this is the case.

Table E.1 — Requirements concerning the number of failure points at different failure times in regression testing of RTP at the qualification temperature

Time interval *h*	**Minimum number of failure points**
Up to 100 h	2
100 to 300 h	2
300 to 3 000 h	4
3 000 to 10 000 h	3
Over 10 000 h	1

The long-term hydrostatic pressure (LTHP) is obtained, as shown in Figure E.1, by extrapolating the mean regression line until it meets the design lifetime. The LPL is obtained by extrapolating the 97,5 % lower prediction limit of the regression relationship until it meets the design lifetime. The statistical procedure to be used shall be equivalent to that laid down in ISO 9080:2003, with the exception that data from only one temperature shall be used and the number of data points may be different.

When planning a programme of qualification tests, it should be borne in mind that increasing the number of tests beyond the recommended minimum number enables the variance of the test results to be estimated more accurately, raising the value of the LPL and increasing the efficiency of the design. It should also be borne in mind that increasing the test times beyond 10 000 h improves the accuracy of extrapolation and again increases the efficiency of the design, especially when long lifetimes such as 50 years are required.



Key

X log (time)

Y log (pressure)

1 regression line (principal mode)

2 97,5 % lower prediction limit

3 Product Variability Factor

4 Application-Related Service Factor

5 design life

6 Long-Term Hydrostatic Pressure (LTHP)

7 Lower Prediction Limit (LPL)

8 Manufacturer's Nominal Pressure Rating (MNPR)

9 Maximum Service Pressure (MSP)

Figure E.1 — Regression analysis procedure to determine the LPL

NOTE Figure E.1 shows the significance of the statistically-based Product Variability Factor used to obtain the MNPR and the Application-Related Service Factor used to obtain the MSP.

E.1.5 Short-term burst pressure (STBP)

In addition to the regression measurements, a short-term burst test described in F.4.1 may be used to determine the short-term burst pressure, STBP, of the product-family representative. The STBP may be required for use as the baseline for the optional batch pressure test, described in Annex F. The STBP shall be determined by testing five samples. Samples shall be from the same production batch as the product-family representative.

The STBP shall be taken as the pressure value above which 97,5 % of results can be expected to lie. This shall be calculated from the mean burst pressure minus 2,57 times the standard deviation of the tested samples.

Testing for the STBP shall be done at the Standard Laboratory Temperature (SLT).

E.1.6 Qualification of product variants: 1 000 h conformity test

The 1 000 h conformity test offers a less onerous route to qualification for variants where this criterion is satisfied.

To allow for permitted changes in diameter and reinforcement concentration, the test pressure, P_{1000}, must be calculated by scaling the LPL pressure of the qualified product, as follows:

$$P_{1000} = P_{1000,\text{LPL}} \left(\frac{D_{\text{QP}}}{D_{\text{Var}}} \right) \left(\frac{\rho_{\text{Areal}_{\text{Var}}}}{\rho_{\text{Areal}_{\text{QP}}}} \right) \qquad \text{[E.2]}$$

where

$P_{1000,\text{LPL}}$ is the LPL pressure for 1 000 h time to failure in the qualified product;

D_{QP} is the mean reinforcement diameter of the qualified product;

D_{Var} is the mean reinforcement diameter of the variant;

$\rho_{\text{Areal}_{\text{QP}}}$ is the mass of reinforcement per unit cylindrical area (at mean reinforcement diameter) in the qualified product;

$\rho_{\text{Areal}_{\text{Var}}}$ is the mass of reinforcement per unit cylindrical area (at mean reinforcement diameter) in the variant.

The conformity test requires two spool pieces of the product variant to be subjected to a constant-pressure survival test at P_{1000} at the qualification test temperature. The criterion is satisfied if both samples survive for 1 000 h. Variants shall also pass the elevated temperature test described in this Annex.

If the criterion is not satisfied then the full qualification procedure is required.

E.1.7 Fittings

All fitting/pipe body combinations shall be qualified by the elevated temperature test and the axial load test. Joints shall be made up in accordance with the manufacturer's instructions.

NOTE The purpose of the elevated temperature test is to ensure that no non-permissable failure modes relating to thermoplastics components of the RTP occur at times between the end of the regression test period and the end of the design life. The rationale of the test, which is described in greater detail in Annex C, involves the use of elevated temperature to accelerate the onset of possible undesirable failure modes, so that they could be observed within a reasonable test period.

E.1.7.1 Elevated temperature test

Elevated temperature survival tests shall be carried out on all fitting/pipe body combinations, product-family variants and products where the pipe body may contain discontinuities (such as tape joints). These tests shall be carried out under constant pressure for a time period, t_{test}, at a temperature ΔT above the qualification test temperature. The test pressure shall be equal to or greater than the LPL derived from the regression analysis described in this Annex.

These tests may be carried out in a temperature-controlled oven or water bath. When a water bath is used for RTP with aramid fibre reinforcement, care should be taken to avoid problems with hydrolysis, by ensuring that water does not enter into contact with the aramid fibres.

When a new RTP product is under development, the LPL, which takes over 10 000 h to determine, may not be known accurately at the time of commencement of the elevated temperature test. In these circumstances, an estimate should be made of the LPL from the results currently available. This estimate should preferably be an upper, rather than a lower estimate.

If, on completion of the full programme of regression tests, the LPL is found to be higher than the estimated value, the elevated temperature test should be repeated using the true value of the LPL.

NOTE The rationale for the elevated temperature test is discussed in Annex C. The purpose of this test is to accelerate the rate at which deleterious time-dependent processes in the polymeric components take place.

The values of t_{test} and ΔT shall be chosen by the manufacturer and are related by Equation E.3.

$$\Delta T = \frac{1}{\alpha} \log \left(\frac{t_{lifetime}}{t_{test}} \right) \qquad \text{[E.3]}$$

where $t_{lifetime}$ is the design lifetime.

In the case of pipe-grade PE, such as PE80 or PE100, which do not display a transition from ductile to brittle regression behaviour, a value of 0,11 decades/°C shall be assumed for α. For other polymers a value shall be determined, as discussed in Annex C, or a default value of 0,05 decades/°C shall be assumed.

Table E.2 shows examples of values of t_{test} and ΔT for the case of α = 0,11 decades/°C.

Table E.2 — Examples of temperature shifts and survival test periods for RTP containing pipe-grade polyethylene (α = 0,11 decades/°C), for different design lifetimes

Lifetime $t_{lifetime}$	Temperature shift ΔT	Survival test period t_{test}
20 years	20 °C	1 100 h
20 years	25 °C	312 h
50 years	20 °C	2 760 h
50 years	25 °C	780 h

For each fitting type to be qualified, at least two fitting-to-pipe body joints shall be tested. The length of the RTP spool piece between joints shall be at least six times the nominal diameter. To pass the test, all specimens shall survive without leakage for the full test period.

It is possible that specimens may fail by fibre breakage (the PM) before the end of the test period. Failures of this type are most probably due to the temperature dependence of the regression behaviour of the reinforcement. If such failures do occur, the test shall be repeated using a reduced value of ΔT and a correspondingly longer test survival period, as given in Equation E.3. This should, if necessary, be repeated until a value of ΔT is found where all the specimens survive the test.

Failure by any mode other than the PM in these tests shall constitute failure of the qualification.

Following the elevated temperature test, each test piece shall be de-pressurised and stored at SLT for at least 24 h. (If a water bath has been employed, the test pieces should be taken out.) The test pieces shall then be pressurised to 1 MPa (10 bar) at SLT and examined for leakage. There shall be no visible leakage over a 24 h period.

E.1.7.2 Axial load capacity and axial load test

For each product-family representative, the manufacturer shall quote the maximum allowable short-term axial load in the un-pressurised condition, pipe body plus end-fitting. This value shall be given for the maximum and minimum operating temperature.

In situations where service conditions require the pipe body to be subjected to tension, the manufacturer shall demonstrate that the pipe body is capable of sustaining the applied load.

Two test samples with fittings shall be shown to pass this test. It is permissible in this test to assemble the samples in-line to form a single test piece. The length of pipe between fittings shall not be less then six times the internal diameter of the pipe. The test shall consist of subjecting the test sample, with fittings present, to an axial load equal to the quoted test load for a period of 20 min at the design temperature.

Following this, a short-term burst test shall be carried out. The result of this test shall be at least equivalent to the short-term burst value used for quality assurance (see Annex F).

E.1.7.3 Non-thermoplastics components of the fittings

It shall be demonstrated that no failure will occur in any non-thermoplastics parts of the end-fittings during the lifetime of the RTP. This shall be accomplished using stress analysis, accepted corrosion prediction models or other means, in accordance with recognised standards.

To eliminate the possibility of fitting failure during qualification testing, the design factor for metallic fitting components shall be such that these components do not fail at the short-term burst pressure of the system.

Following qualification, it is permissible to redesign these components so that the design factor is the same as for metallic components in other parts of the system. This may only be done if there is no change to the shape of the parts in contact with the RTP components, and no resulting change to the stresses in those components.

In the case of end-fittings that connect RTPs to other parts of the system, the design of those regions of the end-fitting not directly involved in the connection to the RTP shall be in accordance with the rules affecting the rest of the system.

The design of the metallic parts of fittings should allow for surge pressures and transients up to one and a half times the maximum service pressure. Greater transients may sometimes be permitted, as stated by the manufacturer.

E.1.8 Product variability factor

To take account of permitted variations in product performance, a Product Variability Factor (PVF) shall be applied to the LPL pressure to obtain the Manufacturer's Nominal Pressure Rating (MNPR).

The MNPR, allowing for product variability is given by

$$\text{MNPR} = \frac{\text{LCL}\,(1+\beta\nu)}{1{,}1\,(1-1{,}96\nu)} \qquad \text{(E.4)}$$

where the coefficient of variation, ν, at the design life is given by

$$\nu = \frac{1-\text{LCL}/\text{LTHP}}{1{,}96} \qquad \text{(E.5)}$$

Factor, β, which is the inverse probability function, depends on the “Safety Class” of the product. Each Safety Class is associated with a particular probability of failure and determined by the system-related factors described in the design guideline. Values are given in Table E.3 for the different Safety Classes.

Table E.3 — Probability of failure and value of β associated with different Safety Classes

Safety Class	Probability of failure	β
Low	10^{-5}	– 4,26 505
Normal	10^{-6}	– 4,75 366
High	10^{-7}	– 5,19 969

NOTE The statistical procedure upon which the Product Variability Factor Determination is based is discussed in Det Norske Veritas Project Recommended Standard Composite Components Report No. 2002-0124.

E.2 Application of specific rating factors

These rating factors relate to requirements that are specific to particular RTP project applications.

E.2.1 Rating factors

To obtain the Maximum Service Pressure (MSP), additional reduction factors shall be applied to the MNPR. These factors include

— a cyclic service de-rating factor, to account, where appropriate, for the effect of cyclic service conditions, and

— a lower temperature up-rating factor to account for lower operating temperatures than the qualified test temperature.

In certain applications, further area-related factors may be applied.

E.2.2 Pressure variation

Because applied pressure reduces the lifetime of RTP in a cumulative manner, it is permissible for the MSP to be exceeded for short periods during transient conditions.

Pressure excursions up to one and a half times the MSP may be permissible, provided the allowable stress in the fittings permits this. However, the de-rating procedure for cyclic service, described in E.2.3, shall always be employed in this case, to ensure that the MSP is suitably de-rated for fatigue effects.

When sustained periods at different pressures, some of which may be greater than the MSP, are envisaged, the total contribution of these periods shall be calculated in accordance with Miner's Law. The lifetime at a particular pressure is given by:

$$t_{\mathrm{f}_i} = \left(\frac{F}{P_i}\right)^{\frac{1}{G}} \tag{E.5}$$

The cumulative effect of periods at different pressure is therefore given, in accordance with Miner's Law, by:

$$\sum \frac{t_i}{t_{\mathrm{f}_i}} = F^{-\frac{1}{G}} \sum t_i P_i^{\frac{1}{G}} \tag{E.6}$$

Therefore, during use, the following inequality shall not be exceeded:

$$\sum t_i P_i^{\frac{1}{G}} \leqslant t_L \cdot \mathrm{MSP}^{\frac{1}{G}} \tag{E.7}$$

Where the pressure varies smoothly over a period of time, an integral version of this summation may be employed to calculate the cumulative contribution.

NOTE Experience with the application of Miner's Law to RTP is limited. However, information to date suggests that this is an acceptable method of taking account of time-dependent loads and properties.

E.2.3 Cyclic-pressure service

This procedure is used to qualify RTP systems for cyclic-pressure service. All tests shall be carried out on the product-family representative at the qualification test temperature. All tests shall be carried out on an RTP system with field fittings.

The procedure described here is intended to provide an efficient route to qualification in situations where the service loading contains a component of fatigue. In cases where the loading is mainly of a fatigue nature, a full cyclic regression analysis shall be carried out at the qualification temperature in accordance with ASTM D2992-01, Procedure A.

The procedure described below shall be used in situations where the cyclic component of pressure is not accurately predictable. Six samples shall be subjected to an accelerated fatigue regime of 50 000 cycles at the MSP. The minimum pressure in the fatigue cycle shall be no greater than 5 % of the maximum pressure and the cycling frequency shall not exceed 0,1 Hz. The de-rating factor for fatigue is only valid up to the number of cycles tested. If more than 50 000 cycles are expected in service, the number of cycles in the test shall be increased accordingly.

Dynamic loads, other than those due to pressure loading (i.e. axial loading or bending) are not covered by this procedure.

No sample may fail during the accelerated fatigue procedure.

Following this, four of the samples shall be subjected to a constant-pressure rupture test at a pressure, P_{1000}, at the qualification test temperature.

$$P_{1000} = \mathrm{LPL} \times 10^{G*(\mathrm{Log(design\ lifetime)} - 3)} \tag{E.8}$$

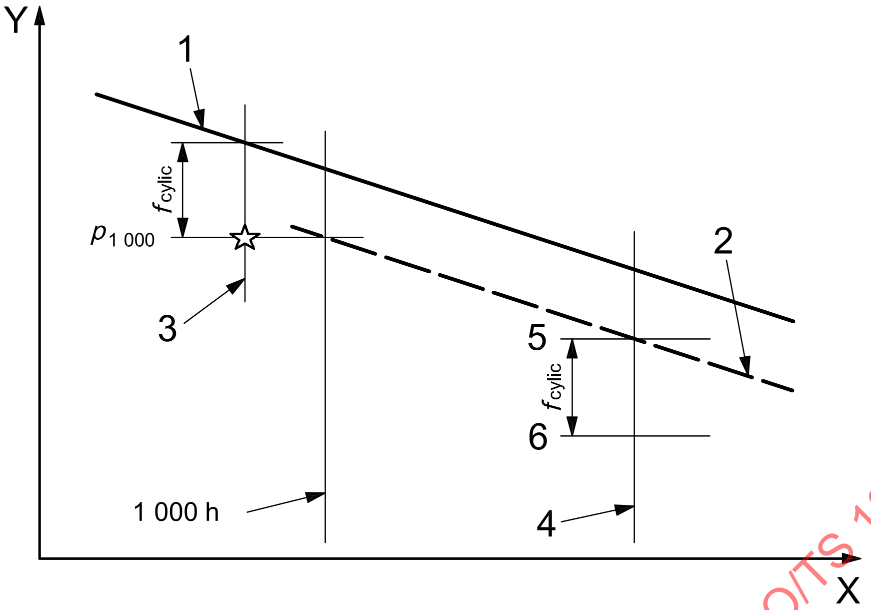
where the design lifetime is in hours. G is the regression gradient of the of the product-family representative.

The mean survival time of the samples shall be calculated. All samples must fail by the PM.

The constant static pressure equivalent to the mean survival time shall be calculated from the regression curve, as shown in Figure E.2. The fatigue de-rating factor, f_{cyclic}, shown in the figure is the ratio of this pressure to P_{1000}. For cyclic-pressure service, therefore, the LPL should be reduced by the factor, f_{cyclic}

$$\mathrm{LPL}_{\mathrm{service}} = f_{\mathrm{cyclic}} \times \mathrm{LPL} \tag{E.9}$$

The remaining two samples from the accelerated fatigue tests should pass the elevated temperature test stipulated in this Annex to confirm the integrity of the fittings under fatigue conditions.



Key

X logtime to failure

Y log pressure

1 regression line (principal mode)

2 97,5 % lower confidence limit

3 failure time at P_{1000} after pressure cycling

4 design life

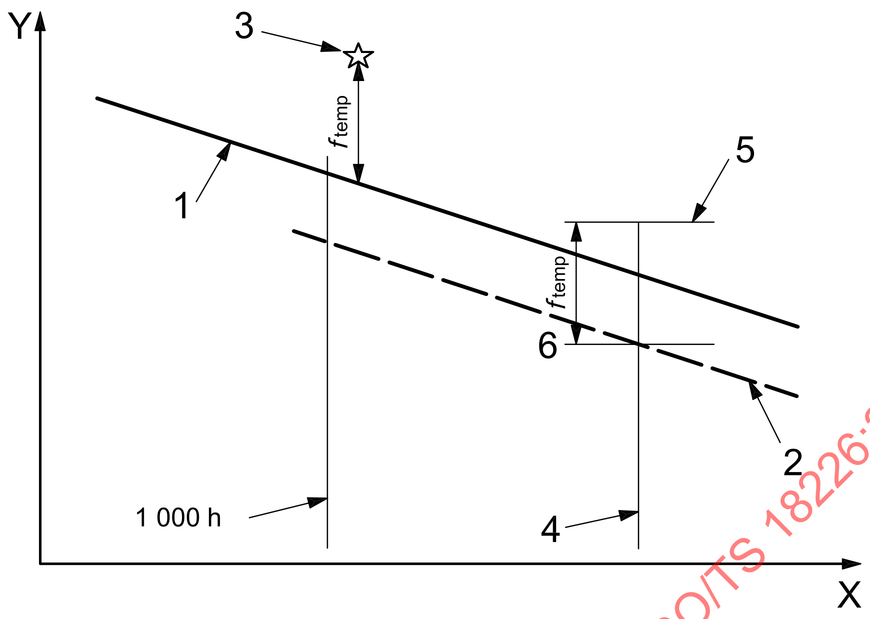
5 LPL (static)

6 LPL (cyclic)

Figure E.2 — Procedure for determining the de-rating factor for cyclic-pressure loading

E.2.4 Reduced maximum service temperature

In situations where the maximum service temperature is lower than the qualification temperature, an up-rated value of the LPL may be used that requires a less onerous testing procedure than that needed for the initial qualification, as shown in Figure E.3. Three RTP samples shall be subjected to a constant-pressure rupture test. The pressure chosen should produce failure times in excess of 1 000 h. The mean life should be determined. All failures should be by the PM.



Key

X log time

Y log pressure

1 regression line (principal mode)

2 97,5 % lower confidence limit

3 average failure time at low temperature

4 design life

5 low temperature LPL

6 LPL at qualification temperature

Figure E.3 — Procedure for establishing an up-rating factor when the maximum service temperature is lower than the qualification temperature

The regression-line pressure corresponding to the mean life shall be determined.

E.2.4.1 The up-rating factor is then the ratio of the regression-line pressure to the pressure employed in the tests

$$\mathrm{LPL}_{\mathrm{temp}} = f_{\mathrm{temp}} \times \mathrm{LPL} \qquad \text{(E.9)}$$

In most cases, this procedure is expected to be conservative, because the regression-line slope should decrease with decreasing temperature.

E.2.5 Gas diffusion

The manufacturer shall provide information relating to the rate of gas diffusion through the liner wall at the system design pressure and temperature, which shall include the permeation coefficient (as a function of temperature) of the liner material (and outer cover, if different), and the volume flow rate of gas through inner liner and outer cover per unit length of pipe.

The manufacturer shall demonstrate that the design of the RTP pipe body and fittings is such that diffused volatiles do not build up in the reinforcing layer to a level that could result in damage.

E.2.6 Gas-tightness of fittings

The gas-tightness of each fitting type shall be demonstrated by pressurisation and de-pressurisation tests involving two RTP joints for each type of fitting. These tests shall be carried out at both the maximum and minimum service temperatures.

The joints should be prepared using the same technique as would apply in practice. The RTP spool shall be pressurised with gas to 1/10 of the MSP and checked for leaks at the beginning and end of a period of at least 6 h. The pressure shall then be increased to the working pressure and the procedure repeated for a further period of at least 6 h, finally de-pressurising. The RTP shall then be subjected to a further three similar cycles. There shall be no leakage at any time.

The pressurising gas shall be air or nitrogen. Leakage testing may be carried out using a soap/water solution, by observing pressure loss or by other suitable means.

E.3 Other qualification Issues

The Principal shall specify which of the procedures stated below shall be followed by the manufacturer.

E.3.1 Minimum bend radius

Service bend radii in excess of 25 times the pipe body Internal diameter are permissible and require no special qualification. Smaller bend radii are a special issue and require testing to establish a de-rating factor.

The manufacturer shall quote the recommended storage bend radius of the pipe.

E.3.2 Rapid crack propagation

In the case of RTP based on aramid fibre, employed at temperatures above – 50°C, RCP involving failure of the reinforcement is not regarded as a significant hazard.

To avoid the possibility of RCP occurring in the liner alone, it shall be demonstrated that the liner possesses RCP resistance at a pressure corresponding to that part of the total pressure borne by the liner at one and a half times the operating pressure at ambient temperature. This corresponds to the condition that would apply in a field hydrotest. It shall also be shown that RCP does not occur in the liner at the maximum working strain and the minimum operating temperature.

E.3.3 Impact resistance

The manufacturer shall quote the impact resistance of the RTP pipe and, if required by the Principal, shall demonstrate this through an appropriate standard falling-weight test.

In applications of RTP where it is necessary to verify impact resistance, a performance-based test should be devised. This shall be related to an existing impact testing procedure, such as ISO 3127:1994. Where there is concern about non-visible damage after impact, a leakage test and burst test should be carried out.

E.3.4 External pressure

The maximum external pressure to which the RTP shall be exposed shall be specified by the manufacturer.

E.3.5 Static electricity

RTP should be treated with respect to static electricity, in the same way as non-reinforced thermoplastics pipes manufactured with the same type of polymer.