Specification for Unbonded Flexible Pipe

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Specification for Unbonded Flexible Pipe

1 Scope

API 17J defines the technical requirements for safe, dimensionally and functionally interchangeable flexible pipes that are designed and manufactured to uniform standards and criteria. Minimum requirements are specified for the design, material selection, manufacture, testing, marking, and packaging of flexible pipes, with reference to existing codes and standards where applicable. See API 17B for guidelines on the use of flexible pipes.

API 17J applies to unbonded flexible pipe assemblies, consisting of segments of flexible pipe body with end fittings attached to both ends. API 17J does not cover flexible pipes of bonded structure. API 17J does not apply to flexible pipe ancillary components. Guidelines on flexible pipe ancillary components are given in API 17L1, API 17L2, and other API documents.

API 17J does not apply to flexible pipes that include nonmetallic tensile and pressure armor wires.

The applications addressed by API 17J are sweet and sour service production, including export and injection applications. Production products include oil, gas, water, and injection chemicals. API 17J applies to both static and dynamic flexible pipes used as flowlines, risers, and jumpers. API 17J does not apply to flexible pipes for use in choke and kill line applications. Annex H of API 17B provides recommendations for the application of fiber reinforced polymer materials for pressure armor and tensile armor in unbonded flexible pipe.

NOTE 1 See API 16C for choke and kill line applications.

NOTE 2 API 17K provides guidelines for bonded flexible pipe.

If product is supplied bearing the API Monogram and manufactured at a facility licensed by API, the requirements of Annex A apply.

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.

API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*

API Specification 17D, *Specification for Subsea Wellhead and Christmas Tree Equipment*

API Recommended Practice 17L2, *Recommended Practice for Flexible Pipe Ancillary Equipment*

API Technical Report 17TR1, *Evaluation Standard for Internal Pressure Sheath Polymers for High Temperature Flexible Pipes*

API Technical Report 17TR2, *The Ageing of PA-11 in Flexible Pipes*

ASME *Boiler and Pressure Vessel Code* [1], *Section IX: Welding and Brazing Qualifications*

ASTM A29 [2], *Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for*

1 ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.
2 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM A182, *Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

ASTM A480, *Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip*

ASTM A668, *Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use*

ASTM A751, *Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products*

ASTM C177, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus*

ASTM C518, *Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus*

ASTM D256-10, *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*

ASTM D570, *Standard Test Methods for Sampling and Chemical Analysis of Fatty Alkyl Sulfates*

ASTM D638-10, *Standard Test Method for Tensile Properties of Plastics*

ASTM D664-09a, *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration*

ASTM D695, *Standard Test Method for Compressive Properties of Rigid Plastics*

ASTM D789, *Standard Test Methods for Determination of Relative Viscosity of Polyamide (PA)*

ASTM D792-08, *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement*

ASTM D974-08e1, *Standard Test Method for Acid and Base Number by Color-Indicator Titration*

ASTM D1044-08, *Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion*

ASTM D1238, *Standard Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer*

ASTM D1418, *Standard Practice for Rubber and Rubber Latices—Nomenclature*

ASTM D1505, *Standard Test Method for Density of Plastics by the Density-Gradient Technique*

ASTM D2990, *Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*

ASTM D4060, *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*

ASTM D5028, *Standard Test Method for Curing Properties of Pultrusion Resins by Thermal Analysis*

ASTM D6869, *Standard Test Method for Coulometric and Volumetric Determination of Moisture in Plastics Using the Karl Fischer Reaction (the Reaction of Iodine with Water)*

ASTM E328, *Standard Test Methods for Stress Relaxation Tests for Materials and Structures*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

ASTM E831, *Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*

ASTM E1269, *Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry*

ASTM E1356, *Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry*

ASTM G48-03, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*

DNV [3], *GL IMO Resolution A 753 (18)* (Recommended by DNV-GL3 in lieu of withdrawn DNV Classification Note 6.1.)

EN 287-1 [4], *Qualification test of welders—Fusion welding—Part 1: Steels*

EN 10204:2004, *Metallic products—Types of inspection documents*

ISO 62 [5], *Plastics—Determination of water absorption*

ISO 148-1, *Metallic materials—Charpy pendulum impact test—Part 1: Test method*

ISO 178, *Plastics—Determination of flexural properties*

ISO 179 (all parts), *Plastics—Determination of Charpy impact properties*

ISO 307, *Plastics—Polyamides—Determination of viscosity number*

ISO 527-1, *Plastics—Determination of tensile properties—Part 1: General principles*

ISO 527-2, *Plastics—Determination of tensile properties—Part 2: Test conditions for moulding and extrusion plastics*

ISO 604, *Plastics—Determination of compressive properties*

ISO 899-1, *Plastics—Determination of creep behaviour—Part 1: Tensile creep*

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

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

ISO 3384, *Rubber, vulcanized or thermoplastic—Determination of stress relaxation in compression at ambient and at elevated temperatures*

ISO 6506-1, *Metallic materials—Brinell hardness test—Part 1: Test method*

ISO 6507-1, *Metallic materials—Vickers hardness test—Part 1: Test method*

ISO 6508-1, *Metallic materials—Rockwell hardness test—Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

ISO 6892, *Metallic materials—Tensile testing at ambient temperature*

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 9352, *Plastics—Determination of resistance to wear by abrasive wheels*

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3 Det Norske Veritas GL, Veritasveien 1, 1322 Høvik, Oslo, Norway, www.dnvgl.com.

4 European Committee for Standardization, CEN Management Centre, Rue de Stassart 36, B-1050 Brussels, Belgium, www.cenorm.be.

5 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 10474:1991, *Steel and steel products—Inspection documents*

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 13847, *Petroleum and natural gas industries—Pipeline transportation systems—Welding of pipelines*

Lloyds Fire Test [6], *Lloyds Register of Shipping, Fire Testing—Memorandum ICE/Fire OSG 1000/499*

NACE MR0175 [7], *Petroleum and Natural Gas Industries - Materials for use in H_2S-Containing Environments in Oil and Gas Production*

NACE TM 01-77, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments*

3 Terms, Definitions, Acronyms, Abbreviations, and Symbols

3.1 Terms and Definitions

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

3.1.1
ancillary components
Components that are attached to the flexible pipe in order to perform one or more of the following functions:

a) to control the flexible pipe behavior;

b) to provide a structural transition between the flexible pipe and adjacent structures;

c) to avoid excessive curvature;

d) to attach other structures to the flexible pipe, or the flexible pipe to other structures, or to connect flanges or proprietary connectors to the flexible pipe (e.g. stud bolts and nuts and clamps);

e) to protect or repair the flexible pipe;

f) to provide a seal between the flexible pipe and an I-tube or J-tube inner wall (in order to prevent corrosion inhibited seawater escaping).

3.1.2
annulus
Space between two extruded polymer layers, for example, the internal pressure sheath and external sheath that is sealed in the end fitting.

NOTE Permeated gas and liquid are generally free to move and mix in the annulus.

3.1.3
antibuckling tape
A polymer, fabric, wire, fiber, or other reinforcement wound around the tensile armors, compressing the wires/strips against the pipe body to resist radial buckling of these wires/strips.

6 Lloyd's Register EMEA, 71 Fenchurch Street, London EC3M 4BS, United Kingdom, www.lr.org.

7 NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org.

3.1.4
antiwear layer
Nonmetallic layer, either extruded thermoplastic sheath or tape wrapping, normally used to minimize wear between structural layers.

3.1.5
bellmouth
Part of a guide tube, formed in the shape of a bellmouth, and designed to prevent overbending of the flexible pipe.

3.1.6
bend limiter
Any device used to restrict bending of the flexible pipe.

NOTE Bend limiters include bend restrictors, bend stiffeners, and bellmouths.

3.1.7
bend radius
Radius of curvature of the flexible pipe measured from the pipe centerline.

NOTE Storage and operating minimum bend radius (MBR) are defined in 5.3.1.

3.1.8
bend restrictor
Mechanical device that functions as a mechanical stop and limits the local radius of curvature of the flexible pipe to a minimum value.

3.1.9
bend stiffener
Ancillary conical shaped component that locally reduces bending stresses and curvature of the pipe to acceptable levels; usually attached to either an end fitting or a support structure where the flexible pipe passes through the bend stiffener.

3.1.10
bend stiffener latching mechanism
A structure or mechanism that allows a riser bend stiffener to be connected to a structure allowing the bending to be transferred from the riser bend stiffener to that structure.

3.1.11
bending stiffness
The resistance to bending from an applied bending moment—product of the effective elastic modulus and moment of inertia of the flexible pipe. The bending stiffness may vary with tension, pressure, and temperature.

3.1.12
bonded pipe
Flexible pipe in which the steel reinforcement is integrated and bonded to a vulcanized elastomeric material where textile material is included in the structure to obtain additional structural reinforcement or to separate elastomeric layers.

3.1.13
buckling of tensile armors
Buckling of the tensile armors in the radial (birdcaging) or lateral direction caused by axial compression (true wall compression), associated or not with pipe bending, twist, or torsion and affected by the annulus condition (flooded or dry).

3.1.14
burst disk
Weak points in the outer sheath designed to burst when the gas pressure in the annulus exceeds a specified value.

NOTE The weak point is induced by reducing the thickness of the sheath over a localized area.

3.1.15
carcass
Interlocked metallic construction that is normally used as the innermost layer in rough bore pipes to prevent, totally or partially, collapse of the internal pressure sheath or pipe due to pipe decompression, external pressure, tensile armor pressure, and mechanical crushing loads.

NOTE The carcass may be used externally to protect the external surface of the pipe; this is referred to as "abrasion protection."

3.1.16
choke and kill line jumpers
Flexible pipe jumper located between a marine drilling riser steel choke line and kill line and blowout preventer.

3.1.17
connector
Device used to provide a leak-tight structural connection between the end fitting and adjacent piping. Connectors include bolted flanges, clamped hubs, and proprietary connectors.

NOTE They may be designed for diver-assisted makeup or for diverless operation using either mechanical or hydraulic apparatus.

3.1.18
crossover
Flexible flowline crossing another pipe already laid on the seabed.

NOTE 1 The underlying pipe may be a steel pipe or another flexible pipe.

NOTE 2 It is normally necessary to support the overlying pipe to prevent overbending or crushing of the new or existing pipes.

3.1.19
crushing loads
Compressive guidance-induced loads or localized compressive loads imposed on the pipe during its installation (laying or retrieval operations) by typical laying equipment such as tensioners, wheel, sheave, chute, gutter, and handling collars or during the operating conditions where the line is bent under tension onto a radius such as J-tube bend, bellmouth, and mid-water arch gutter.

3.1.20
design differential pressure
The difference between design external pressure and design pressure.

NOTE Design pressure is defined in 4.4.2.

3.1.21
design external pressure
Maximum external pressure applied to a pipe during installation, operation, or retrieval, after considering tidal and wave effects, which is the maximum pressure acting external to a sheath layer.

NOTE It can be either the full external pressure or the maximum annulus pressure acting on a sheath, whichever is larger.

3.1.22
design methodology
A consistent approach to the design of a component or system.

3.1.23
design methodology verification report
Evaluation report prepared by an independent verification agent (IVA) at the time of an initial review, for a specific manufacturer, confirming the suitability and appropriate limits on the manufacturer's design methodologies, manufacturing processes, and materials.

NOTE This report may include occasional amendments or revisions to address extensions beyond previous limits or revisions of methodologies.

3.1.24
design tension
Maximum tensile load applied to a pipe during installation, operation, or retrieval, after considering the associated internal fluid density and pressure.

3.1.25
differential pressure
The difference between the local internal pressure and the external hydrostatic pressure at each cross section.

3.1.26
dry conditions
Tested in air at conditions defined by the international standard atmosphere.

3.1.27
dynamic application
Service in which flexible pipe is exposed to a large number of cyclically varying loads and deflections during permanent operation.

3.1.28
end fitting
Structural/mechanical device for terminating the different pipe layers in such a way as to transfer the load between the flexible pipe and the connector and seal all internal and external fluid containment layers.

3.1.29
event, abnormal operation
An event due to infrequent loads (e.g. pressures in excess of the design, accidental conditions).

3.1.30
event, extreme operation
An event that produces responses having a low probability of being exceeded in the lifetime of the riser [e.g. an event with a return period (RP) of 100 years].

3.1.31
event, extreme temporary
An event of short duration due to infrequent loads (e.g. pressures and environments in excess of operating plan, accidental conditions).

3.1.32
event, normal operation
An event such as plan of operation; normal; in-place pressure testing; connected operation; and integrity, maintenance, and repair.

3.1.33
event, normal temporary
An event of limited duration, such as transport, installation, retrieval, and field test.

3.1.34
event, survival
An event involving conditions that exceed extreme design events where fluid containment is just maintained (i.e. material strength utilization is permitted to reach unity).

3.1.35
fishscaling
Tendency of a wire or strip to not lay flat against the underlying layer, often caused by improper preforming during armor winding. Fishscaling can occur in the tensile armor, pressure armor, or carcass layers.

3.1.36
flexible flowline
Flexible pipe, wholly or in part, resting on the seafloor or buried below the seafloor, and used in a static application. The term flowline is used in this document as a generic term for flexible flowlines.

3.1.37
flexible pipe
pipe
Assembly of a pipe body and end fittings where the pipe body is composed of a composite of layered materials that form a pressure-containing conduit and the pipe structure allows large deflections.

NOTE 1 Normally, the pipe body is built up as a composite structure composed of metallic and polymer layers.

NOTE 2 The term “pipe” is used in this document as a generic term for flexible pipe.

3.1.38
flexible riser
A flexible pipe connecting a platform/buoy/ship to a flowline, seafloor installation, or another platform where the riser may be freely suspended (free, catenary), restrained to some extent (buoys, chains), totally restrained, or enclosed in a tube (I- or J-tubes).

3.1.39
independent verification agent
IVA
Independent party or group, selected by the manufacturer, who is responsible for the review and certification of the indicated product concept (e.g. pipe and end fitting concept) and flexible pipe, associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results, and other information provided by the manufacturer to establish the range of applicability.

NOTE An agent may also be called upon to witness some measurements and tests related to material qualification, manufacturing process control, validation of design methodologies, and prototype tests.

3.1.40
insulation layer
Additional layer added to the flexible pipe to increase the thermal insulation properties, usually located between the outer tensile armor layer and the outer sheath.

3.1.41
intermediate sheath
Extruded polymer layer located between internal pressure and outer sheaths, which may be used:

- as a barrier to external fluids in smooth bore pipes;
- as an antiwear layer;
- as a barrier from external fluids for insulation layers, avoiding water absorption and creep and thus avoiding reduction in the pipe thermal exchange coefficient (TEC); or,
- in avoiding flooding of an inner annulus when an outer annulus is flooded due to an outer sheath breach.

3.1.42
internal pressure sheath
Polymer layer excluding any sacrificial layers that ensures internal-fluid integrity. This layer may consist of a number of sublayers, excluding sacrificial layers.

3.1.43
jumper
Short flexible pipe used in subsea and topside, static, or dynamic applications. Dynamic topside jumpers also includes the class of flexible pipe whose dynamic response derives from vessel motion only (e.g. turret applications).

3.1.44
lateral buckling
Failure mode of a flexible pipe often associated with a combination of reverse end-cap loading and localized dynamic bending, whereby the tensile armor wires buckle in the lateral or in-plane direction.

3.1.45
lay angle
Angle between the axis of a spiral wound element (e.g. armor wires) and a line parallel to the flexible pipe longitudinal axis.

3.1.46
laying tension
Maximum tensile load to which the pipe shall be subjected during installation or retrieval operations.

3.1.47
load, accidental
Loads that are a consequence of unplanned occurrences.

3.1.48
load, environmental
Loads that are imposed directly or indirectly by the ocean or atmospheric environment.

3.1.49
load, functional
Loads that are a consequence of the system's existence and use without consideration of environmental or accidental effects.

3.1.50
new pipe design
A new pipe design is characterized by one, or both, of the following:

a) pipe concept whose constituting materials, design methodologies, manufacturing processes, and prototype testing results have not been reviewed and accepted by an IVA;

b) a pipe concept whose required performance, for a specific application, has not been accepted by an IVA or the purchaser.

3.1.51
operation plan
Purchaser-specified plan of operation for the flexible pipe.

3.1.52
outer sheath
Polymer layer used to protect the pipe against penetration of seawater and other external environments, corrosion, abrasion, and mechanical damage. This layer may consist of a number of sublayers.

3.1.53
ovalization
Out-of-roundness of the pipe, calculated as follows:

$$\frac{D_{\text{max}} - D_{\text{min}}}{D_{\text{max}} + D_{\text{min}}}$$

where D_{max} and D_{min} are maximum and minimum pipe diameter, respectively.

3.1.54
overall heat transfer coefficient
OHTC
A measure of the overall ability of the pipe cross section to transfer heat.

NOTE OHTC is the heat transferred per unit area per unit temperature. The area is usually taken as the internal surface area over which the transfer of heat takes place

3.1.55
permanent operation
Operational condition in which pipe is only subjected to frequent loading and where pressures are less than or equal to the design pressure.

3.1.56
piggyback
Two pipes attached at regular intervals with clamps, where either or both of the pipes can be flexible.

3.1.57
pipe concept
A pipe concept is characterized by the following combination of parameters:

a) function (intended use or application);

b) structure of layers, sequence and number of layers in the pipe body, type of wire cross section, etc.;

c) end fitting's structural body, details of sealing systems, anchoring system, and vent system.

3.1.58
pressure armor layer
Structural layer with a lay angle close to 90° that increases the resistance of the flexible pipe to internal and external pressure and mechanical crushing loads; structurally supports the internal pressure sheath; and typically consists of an interlocked metallic construction, which may be reinforced by an overlying flat metallic spiral layer.

3.1.59
prototype test
Test to establish or verify a principal performance characteristic for a particular pipe design, which may be a new or established design, and to also validate manufacturer design methodology and so provide a basis for the IVA verification.

3.1.60
qualification testing
Testing by which the structural, functional, fabrication, and reliability performance of a pipe concept, its components, or materials used may be evaluated in order to demonstrate suitability for the specified service life in a specific application.

NOTE The qualification test can also be used to validate the manufacturer's design methodology for a new pipe design.

3.1.61
quality
Conformance to specified requirements.

3.1.62
quality assurance
Planned, systematic, and preventive actions that are required to ensure that materials, products, or services meet specified requirements.

3.1.63
quality control
Inspection, test, or examination to ensure that materials, products, or services conform to specified requirements.

3.1.64
rough bore
Flexible pipe with a carcass as the innermost layer.

3.1.65
service life
Period of time during which the flexible pipe is designed to fulfil all specified performance requirements.

3.1.66
smooth bore
Flexible pipe with an internal pressure sheath as the innermost layer.

3.1.67
sour service
Service conditions with a H_2S content exceeding the minimum specified by NACE MR0175.

NOTE 1 Sour service condition in the bore does not always lead to sour service conditions in the pipe annulus.

NOTE 2 Design pressure is used to assess bore conditions; operating pressure is used to assess annulus condition.

3.1.68
static application
Flexible pipes not exposed to significant cyclically varying loads or deflections during permanent operations.

3.1.69
survival
Survival of a component means that the component does not fail, but it can present one or more kinds of degradation that could jeopardize its specified performance or service life.

3.1.70
sweet service
Service conditions that have a H_2S content less than that specified by NACE MR0175.

3.1.71
system
Fluid conveyance system, connected to field equipment in both extremities, in operation or ready to operate, for which the flexible pipe(s) is the primary component and includes ancillary components and accessories attached directly or indirectly to the pipe(s).

3.1.72
tensile armor layer
Structural layer with a lay angle typically between 20° and 55°, which consists of helically wound metallic wires and is used to sustain, totally or partially, tensile loads and internal pressure.

NOTE Tensile armor layers are typically counter-wound in pairs.

3.1.73
tensioner
Mechanical device used to apply tension or support a pipe by applying radial loads to the pipe with moving tracks during its installation or retrieval.

3.1.74
thermal exchange coefficient
TEC
Coefficient that provides the heat loss (expressed in Watts) of 1 m of pipe when subjected to 1 °C difference between its internal and external surfaces.

NOTE The TEC is typically determined for conditions corresponding to the design water depth and steady state annulus environment (intact and seawater flooded) and accounting for water absorption in the insulation layers.

3.1.75
torsional balance
Pipe characteristic that is achieved by designing the structural layers in the pipe, such that axial and pressure loads do not induce significant twist or torsional loads in the pipe.

3.1.76
torsional limp stiffness
The ability of a flexible pipe to resist twist, at constant tension, when subjected to torsion loads applied in the opposite direction to the lay angle of the outermost tensile armors.

3.1.77
true wall force
The axial force acting in the pipe wall.

3.1.78
unbonded flexible pipe
A pipe construction that consists of separate unbonded polymeric and helical reinforcement layers, which allows relative movement between layers.

3.2 Acronyms, Abbreviations, and Symbols

CIV	corrected inherent viscosity
DSC	differential scanning calorimeter
FAT	factory acceptance test
HAZ	heat-affected zone
HIC	hydrogen-induced cracking
HV	hardness on Vickers scale
ID	internal diameter
IPU	integrated pipe umbilical
IVA	independent verification agent
LR	locking radius
MBR	minimum bending radius
MPI	magnetic particle inspection
NDE	nondestructive examination
OBR	operating bend radius
OD	outer diameter

OHTC	overall heat transfer coefficient
OLT	offshore leak test
PA	polyamide
PE	polyethylene
PSL	product specification level
PVC	polyvinyl chloride
PVDF	polyvinylidene fluoride
RAO	response amplitude operator
RP	return period
SIT	structural integrity test
S-N	curves showing stress range vs number of cycles
SR	storage minimum bend radius
SSC	sulfide stress cracking
TAN	titrated acid number
TEC	thermal exchange coefficient
TFL	through flowline
TPE	thermo-plastic elastomer
UHB	upheaval buckling
UV	ultraviolet
WPS	welding procedure specification
XLPE	crosslinked polyethylene
F	design pulling force
F_y	anchoring system capacity
n	permissible stress utilization factor
t	thickness of component
σ_e	equivalent stress (von Mises or Tresca)
σ_t	tensile hoop stress
σ_y	material yield stress
σ_u	material ultimate stress

4 Functional Requirements

4.1 General

The purchaser shall specify the functional requirements for the flexible pipe. The purchasing guidelines in Annex B give a sample format for the specification of the functional requirements.

Functional requirements not specifically required or not specified by the purchaser and that can affect the design, materials, manufacturing, and testing of the pipe shall be specified by the manufacturer and submitted to the purchaser.

If the purchaser does not specify a requirement, and the above does not apply, the manufacturer may assume that there is no requirement.

4.2 Overall Requirements

4.2.1 Flexible Pipe

The minimum overall functional requirements of the flexible pipe that shall be demonstrated by the manufacturer are as follows:

a) the pipe shall provide a leak-tight conduit,

b) the pipe shall be capable of withstanding all design loads and load combinations defined in Section 5,

c) the pipe shall perform its function for the specified service life,

d) the flexible pipe materials shall be compatible with the environment to which the materials are exposed.

4.2.2 End Fitting

The manufacturer shall demonstrate that the end fittings, which are an integral part of the flexible pipe, also meet the following:

a) the end fitting shall provide a structural interface between the flexible pipe and the support structure;

b) when applicable, the end fitting shall provide a structural interface between the flexible pipe and bend-limiting devices, including bend stiffeners, bend restrictors, and bellmouths, such that the bend-limiting devices meet their functional requirements.

4.3 General Design Parameters

The purchaser shall specify any project-specific design requirements, including the requirements of 4.4 to 4.6 and the following:

a) nominal internal diameter (ID);

b) length and length tolerances of flexible pipe, including end fittings—whether length tolerance is defined symmetrically around nominal or skewed to either side should depend on the criticality for the system;

c) service life.

4.4 Internal Fluid Parameters

4.4.1 General

The purchaser shall specify the internal fluid parameters for the application. The parameters listed in Table 1 shall be specified. Expected variations in the internal fluid parameters over the service life shall be specified.

Table 1—Internal Fluid Parameters

Parameter	Comment
Internal pressure	See 4.4.2
Temperature	See 4.4.3
Fluid composition	See 4.4.4
Fluid/flow description	Fluid type and flow regime
Flow rate parameters	Flow rates, fluid density, viscosity, minimum inlet pressure, and required outlet pressure
Thermal parameters	Fluid heat capacity

4.4.2 Internal Pressure Definitions

The internal pressures that are relevant to the design, testing, and operation of an unbonded flexible pipe are defined in Figure 1 and Table 2.

The following internal pressures shall be specified by the purchaser:

a) design pressure,

b) maximum operating pressure,

c) incidental pressure.

The following internal pressures data should be specified by the purchaser:

a) operating pressure profiles along the pipe and through the service life;

b) system design pressure;

c) FAT, OLT, and offshore SIT pressure requirements of the purchaser and/or governing certifying authorities;

d) maximum pressurization rate;

e) maximum depressurization rate or profile change with time;

f) number of extreme pressure cycles (e.g. from the maximum to the minimum operating—or design—pressure and return to the specified operating pressure associated or not to the thermal cycles);

g) minimum pressure (vacuum pressure if relevant).

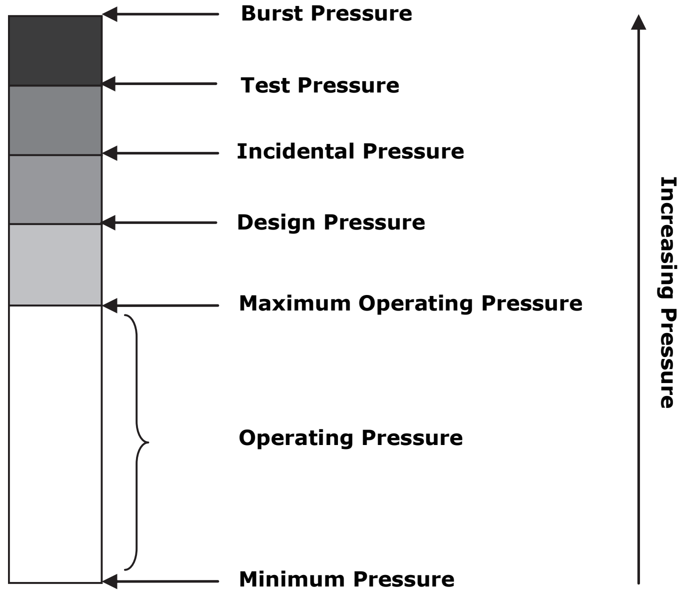

Figure 1—Internal Pressure Definitions

4.4.3 Temperature Definitions

The internal temperatures that are relevant to the design, testing, and operation of an unbonded flexible pipe are defined in Table 3.

The temperatures shown in Table 3 and the duration of the incidental temperature shall be specified by the purchaser.

Operating and design temperatures should be specified on the basis of the following minimum set of permanent operating considerations:

a) upset temperatures (number and range of cycles);

b) gas-cooling effects (time/temperature curve);

c) fluid thermal characteristics;

d) flow characteristics;

e) storage, transport, and installation conditions;

f) number of extreme temperature cycles (e.g. from the maximum to the minimum operating—or design — temperature and return to the specified operating temperature associated or not to the pressure cycles).

Table 2—Internal Pressure Definitions

Pressure [1]	Definition
Minimum pressure	The minimum internal pressure experienced by the pipe during its life (installation and operating conditions). A conservative estimate is to assume a vacuum.
Operating pressure	The internal pressure profile experienced by the pipe during permanent normal operation over its service life.
Maximum operating pressure	The maximum internal pressure, at a reference location [2], to which the pipe is subjected during permanent normal operation.
Design pressure	The maximum internal pressure, at a reference location, including planned shut-in pressure and associated surge.
System design pressure	The lowest maximum internal pressure of the pipe system.
Incidental pressure	The maximum internal pressure, at a reference location, that is unlikely to be exceeded during the life of the pipe, due to abnormal operation, unintended shut-in pressure, surge pressure, or other temporary incidental condition. Unless otherwise specified by the purchaser, the maximum incidental pressure is 1.1 times the design pressure.
Test pressure	
Factory acceptance test (FAT)	The internal pressure applied to the pipe or pipe section during testing after manufacture to test for latent defects. Unless otherwise specified by the purchaser, the FAT pressure is 1.5 times the design pressure for flexible risers and topside jumpers and 1.3 times the design pressure for flexible flowlines and subsea jumpers. If applicable, the maximum differential pressure can be used instead of design pressure.
Offshore leak test (OLT)	The internal pressure applied to the pipe or pipe section during testing after installation to test for leak tightness. Unless otherwise specified by the purchaser, the OLT pressure is 1.1 times either (a) the design pressure of the pipe or (b) system design pressure, whichever is lower.
SIT (on-board integrity test) [3]	The internal pressure applied to the pipe or pipe section during testing on-board the installation vessel to test the structural integrity of the pipe. Unless otherwise specified by the purchaser the structural integrity test (SIT) pressure shall be as per the FAT pressure.
SIT (offshore integrity test) [4]	The internal pressure applied to the pipe or pipe section during testing in situ after installation to test the structural integrity of the pipe. Unless otherwise specified by the purchaser the SIT pressure shall be 1.25 times either (a) the design pressure of the pipe or (b) system design pressure, whichever is lower.
Burst pressure	The pressure at which loss of fluid containment in the pipe occurs due to pipe or end fitting failure.

NOTE 1 The pressure can be a function of location along the pipe and/or time.

NOTE 2 Unless otherwise specified, for injection or export risers the reference location should be at the topside; for production risers the reference location should be at the wellhead or other equipment where the flexible pipe is connected to a manifold, PLET, PLEM, etc.

NOTE 3 The on-board structural integrity pressure test is required if the pipe is fully retrieved and repaired on-board the installation vessel and when the structural integrity of the reinforcement layers or end-termination pressure containment parts have been affected.

NOTE 4 The offshore structural integrity pressure test is required post installation if the pipe is repaired in situ and when the structural integrity of the reinforcement layers or end-termination pressure containment parts have been affected, or to reassess the integrity versus suspected damage /reduced resistance.

Table 3—Temperature Definitions

Temperature	Definition
Operating temperature	The internal (1) temperature profile experienced by the pipe over its service life during permanent normal operation
Maximum/minimum operating temperature	The maximum and minimum internal temperature to which the pipe is subjected during permanent normal operation
Design temperature	The maximum and minimum internal temperature to which the pipe is subjected during permanent operation
Incidental (2) temperature	The maximum and minimum internal temperature that is unlikely to be exceeded during the life of the pipe

NOTE 1 At the inner surface of the pipe.

NOTE 2 Incidental temperatures should be specified on the basis of abnormal operating considerations, including unplanned transient events.

NOTE 3 "Permanent" operating conditions are defined in Table 6.

4.4.4 Fluid Composition

The purchaser shall specify produced fluids (composition of individual phases), injected fluids, and continual and occasional chemical treatments (dosages, exposure times, concentrations, and frequency). In the specification of the internal fluid composition, the following shall be defined:

a) all parameters that define service conditions (for a reference condition), including partial pressure (or concentration; include information about location, temperature and pressure for specified data) of H_2S and CO_2, organic acids (formic, acetic, propanoic), pH of aqueous phase in situ, titrated acid number (TAN) (in accordance with ASTM D664 or ASTM D974), and water content and ionic composition (produced water, seawater, and free water);

b) gases, including oxygen, hydrogen, methane, and nitrogen;

c) liquids, including oil composition, alcohols, and produced water ionic composition;

d) aromatic components;

e) corrosive agents, including bacteria, chlorides, organic acids, and sulphur-bearing compounds;

f) injected chemical products, including alcohols and inhibitors for corrosion, hydrate, paraffin, scale, and wax (including concentrations of dissolved oxygen);

g) solids, including sand, precipitates, scale, hydrates, wax, and biofilm.

h) drilling, completion, or workover fluids (including concentrations of dissolved oxygen).

4.5 External Environment

The purchaser shall specify the project external environmental parameters. The parameters listed in Table 4 shall be considered. The design water depth shall be the maximum water depth to which the pipe section may be exposed.

4.6 System Requirements

4.6.1 Minimum System Requirements

4.6.1.1 General

The purchaser shall specify the system functional requirements of the project. Annex B may be referenced for guidelines. Unless otherwise stated in 4.6.1, the minimum system requirements in 4.6.1.2 to 4.6.1.12 shall be specified by the purchaser.

4.6.1.2 Application Definition

The flexible pipe system shall be specified including flowline, riser or jumper, and ancillaries. The flexible pipe application shall be specified as either static or dynamic, and the expected number of load cycles and magnitudes should be specified for dynamic cases. The flexible pipe global configuration shall be specified.

Table 4—External Environment Parameters

Parameter	Comment
Location	Geographical data for the installation location
Water depth	Design water depth, variations over pipe location, and tidal variations
Seawater data	Density, salinity, pH value, and minimum and maximum temperatures
Air temperature	Minimum and maximum during storage, installation, and operation
Soil data	Description, shear strength or angle of internal friction, friction coefficients seabed scour, soil type description (from soft to hard, sand/clay), thermal conductivity, roughness, grain size, soil stability, liquefaction and submerged/dry unit soil weight, sand waves, and variations along pipe route
Backfill or cover soil	Description of backfill and cover material type, density, and significant properties for use in UHB or related calculations and analysis
Marine growth	Density and thickness variations with water depth
Ice	Maximum ice accumulation or drifting icebergs and ice floes
Sunlight exposure	Length of pipe exposed during operation and storage conditions and time of exposure
Current data	As a function of water depth, direction, and return period, and including the known effects of local current phenomena
Wave data	In terms of significant and maximum waves, associated periods, wave spectra, spreading functions, and scatter diagrams, as a function of direction and return period
Wind data	As a function of direction, height above water level, and return period

4.6.1.3 Corrosion Protection

The corrosion protection requirements for the flexible pipe shall be specified, considering the following:

a) end fitting internal and external corrosion protection;

b) cathodic protection system for the pipe;

c) protection voltage, current source, and current density;

d) protection for storage (on-shore or subsea storage) and installation as applicable;

e) compatibility with corrosion protection systems adjacent to the corrosion protection system of the flexible pipe.

4.6.1.4 Thermal Insulation

Performance requirements of the flexible pipe for heat loss or retention shall be specified. OHTC's shall be based on pipe nominal ID and shall differentiate between the pipe itself and any external effects, such as soil cover for buried pipe.

4.6.1.5 Gas Venting

The purpose of a gas-venting system is to prevent excessive pressure buildup in the annulus of the pipe. If gas venting is required, the following shall be specified:

a) gas-venting system components;

b) vented gas flow rate

c) restrictions on gas-venting locations;

d) interface requirements;

e) gas-monitoring system;

f) underwater vent valves, as applicable;

g) back pressure of the vent system to which the pipe is connected;

h) integrity inspection of annulus.

4.6.1.6 Pigging and Through Flowline (TFL) Requirements

Any performance requirements for allowing tools for pigging, TFL, workover, or other operations through the flexible pipe, including ID, bend radius, and end-fitting transitions shall be specified.

4.6.1.7 Fire Resistance

The purchaser shall specify whether fire resistance is required. If required, the following information should be specified:

a) fire temperature, source, and surrounding material;

b) need to extinguish or cool the pipe structure;

c) fire-extinction method;

d) duration required for pipe survivability;

e) transported medium;

f) heated steel in contact with polymeric material in the flexible pipe;

g) pipe-abandonment facility and its fire protection capability;

h) pipe function;

i) flashpoint of transported medium in the event of a leak;

j) depressurization time.

4.6.1.8 Piggyback Lines

Any piggyback requirements for the flexible pipe shall be specified, including details of the piggyback pipe(s) and pipe-operating conditions.

4.6.1.9 Connectors

The connector requirements for both end fittings in the flexible pipe shall be specified, including, as a minimum, connector type, welding specification, seal type, and sizes.

4.6.1.10 Interface Definitions

Interface details including, but not limited to, the following shall be specified by the purchaser:

a) regulations, codes, and standards, including definition of code breaks;

b) geometric, dimensional, and imposed loading data;

c) purchaser-supplied installation aids and equipment;

d) purchaser-supplied pull-in and connection tools and terminations;

e) vessel/platform interface structures such as I-tubes and bellmouths;

f) interfacing subsea equipment such as christmas tree and manifolds;

g) manufacturer scope of supply.

4.6.1.11 Inspection and Condition Monitoring

The requirements for the manufacturer to design and implement flexible pipe inspection, monitoring, and condition assessment systems and procedures shall be specified by the purchaser.

4.6.1.12 Shipping, Storage, and Handling

Any requirements for shipping, storage, and handling with respect to all conditions, facilities, equipment, and procedures involved shall be specified.

4.6.1.13 Installation and Retrieval Requirements

Performance requirements for installation and retrieval services to be provided shall be specified, considering the following as a minimum.

a) For installation/retrieval by the purchaser, the purchaser shall specify any requirements on load restrictions, clamping/tensioner loads and dimensions, vessel motions, overboarding chute or wheel requirements, installation tolerances, and port facility limitations, as well as transpooling between different vessels.

b) For installation/retrieval by the manufacturer, the purchaser shall specify any requirements for season, environment, vessel limitations, installation tolerances, restrictions due to conflicting activities and installation scope (including trenching, burial, testing, inspection, surveying, and documentation), installation and retrieval with empty or flooded pipe, and number of foreseen installation and retrieval operations.

Requirements for recoverability and reusability of the flexible pipe within its service life shall be specified.

4.6.1.14 Exothermal Chemical Reaction Cleaning

Relevant parameters for the pipe-cleaning operations by means of exothermal chemical reaction shall be specified, considering the following as a minimum:

a) flow rate,

b) pressure variation,

c) maximum heat output,

d) chemical composition,

e) maximum temperature reached by the chemical reaction,

f) temperature profile along pipe,

g) duration of the cleaning operation,

h) number of cleaning operations to be performed during pipe service life.

4.6.2 Flowline and Riser Parameters

Requirements for design and analysis of the flowline and riser (or jumpers) system additional to the requirements of Section 5, shall be specified by the purchaser to the manufacturer considering the parameters listed in Table 5 as a minimum.

5 Design Requirements

5.1 Loads and Load Effects

5.1.1 General

The pipe design is based on the information supplied by the purchaser (see guidelines in Annex B), with reference to the requirements of Section 4.

5.1.2 Definition of Load Classes

Loads are classified as functional (permanent and variable), environmental (external), or accidental. Typical load combinations and load classes are listed in Table 6 and Table 7, respectively.

The design load cases shall be defined to analyze, as applicable, the effect on the flexible pipe of functional, environment, and accidental loads. See API 17B for guidelines on the analysis techniques to be used for the loads given in Table 7.

5.1.3 Load Combinations and Conditions

The flexible pipe design shall be shown to meet the design requirements under the load combinations specified in 5.1.3. All loads that act on the flexible pipe shall be evaluated for the load conditions specified in Table 6. Variation of the loads in time and space and load effects from the flexible pipe system and its supports, as well as environmental and soil conditions, shall be analyzed.

The design load conditions that shall be analyzed are permanent operation (normal and extreme), abnormal, temporary, and survival events. Load combinations shall be as defined in Table 6. Load combinations with a yearly probability of occurrence less than 10^{-4} can be ignored. FAT load combinations shall be defined by the manufacturer based on the FAT procedures. Different load combinations shall be considered for extreme, interference, and fatigue analyses.

Design checks shall be carried out for any temporary conditions, which may include testing (FAT, OLT, SIT), installation, abandonment, retrieval, handling, and storage, specified by the purchaser or the manufacturer, subject to the design criteria as specified in Table 8.

The simultaneous occurrence of different load combinations shall be defined. The probability of specific load combinations may be specified by the purchaser based on project-specific conditions. The probabilities of accidental and installation-related events should be specified by the purchaser. If the purchaser does not specify probabilities, the manufacturer shall propose the probabilities that are used for the individual events. These specified probabilities must be consistent with the probabilities shown in Table 6 and mentioned above.

The design load cases analyzed shall be derived from the load combinations in Table 6.

5.1.4 Design Load Effects

Design loads give rise to tension/compression, bending, and torsion, which shall be considered in pipe design.

In the pipe design, the manufacturer shall account for the effects of internal and external pressures.

Hydrodynamic load effects shall be determined by validated and documented methods that account for the kinematics of the seawater and the interaction effects of the different environmental phenomena. See API 17B for guidelines on analysis methods.

For fatigue analysis, the distribution of loads over the service life of the pipe shall be based on methods that include all load parameters. Simplified methods are acceptable if the resulting load distribution can be shown to be conservative.

Any accidental loads or combinations thereof can damage or render unfit for service a flexible pipe. Load cases that include accidental loads (e.g. increased offsets due to anchor line or thruster failures) and do not violate the requirements of Table 8 define a limit on the safe occurrence of the accidental loads. Some accidental loads (e.g. fire and explosion) might not be easily analyzed in terms of the requirements in Table 8. In such cases, testing shall be used to define safe working times of other limits associated with the accidental load.

Design load cases shall consider intact annulus filled with condensed water, and annulus flooded with deaerated seawater conditions, and associated gas species for each condition. If in agreement with the purchaser the manufacturer demonstrates by design and calculations a low probability of seawater ingress into the annulus, then the manufacturer can consider the flooded annulus condition as an accidental case.

In addition, the annulus flooded with aerated seawater shall be regarded as an accidental case.

Table 5—Flowline and Riser Parameters

Parameter	Details	Flowline	Riser
Flowline routing	— Route drawings, topography, seabed/soil conditions, obstacles, and installed equipment and pipelines.	X	X
Riser configuration	— Specification of any requirements for the configuration, including description (lazy S, steep wave, etc.), layout, and components. — Selection of configuration or confirmation of suitability of specified configuration.		X
Load cases	— Functional, environmental and accidental load cases and combined yearly probability for permanent operation (normal and extreme), abnormal, temporary (e.g. installation), and survival events.	X	X
Guides and supports	— Proposed geometry of guides, I-tubes, J-tubes, hangoff, and bellmouths through which flowline and riser is to be installed and mid-water arches.	X	X
Pipe attachments	— Bend restrictors, bend stiffeners, clamps, buoyancy modules, and attachment methods.	X	X
Connection systems	— Descriptions of upper and lower connection systems, including quick disconnection systems and buoy disconnection systems, connection angles, and location tolerances.	X	X
Protection requirements	— Trenching, rock dumping, mattresses, external coatings, and extent of protection requirements over length of pipe. — Design impact loads, including those from trawl boards, dropped objects, and anchors/anchor chains.	X	X
On-bottom stability	— Allowable displacements.	X	
Upheaval buckling	— Specification of design cases to be considered by manufacturer.	X	
Crossover requirements	— Crossing of pipes (flexible and rigid), including already installed pipes and gas lines.	X	X
Interference requirements	— Specification of possible interference areas. — Definition of allowable interference/clashing.		X
Attached vessel data	— Data for attached floating vessels, including but not limited to the following: a) vessel data, dimensions, drafts, heading, and the like; b) static offsets; c) first- (response amplitude operators for extreme and fatigue analyses) and second-order motions; d) vessel motion phase data; e) vessel motion reference point; f) mooring system interface data; g) position tolerances.		X

Table 6—Load Combinations of Load Classes, Load Conditions

Load Classes [1]	Load Conditions					
	Operating Conditions			**Nonoperating Conditions**		**Survival**
	Permanent		**Abnormal**	**Temporary**		
	Normal	**Extreme**		**Normal**	**Extreme** [2]	
Permanent functional	Permanent functional load associated with the corresponding load condition.					
Variable functional	Max. operating pressure	Design pressure	≤ Max incidental pressure	Purchaser-specified pressure		
	Max./Min. operating temp.	Design temp.	≤ Incidental temp.	Purchaser-specified temperature		
Environmental	Operating plan	$\geq 10^{-2}$	$\leq 10^{-2}$	Seasonal [8]	Specified by purchaser	$\geq 10^{-4}$
Accidental	N/A [4]	X [6] [7]	X	N/A	X	X
Combined probability, P_c [3]	Assoc. [5]	10^{-2}	$\leq 10^{-2}$	Assoc.	$\geq 10^{-2}$	$\geq 10^{-4}$

NOTE 1 See Table 7 for details.

NOTE 2 The environment cannot be controlled or the variable functional loads exceed the maximum incidental values.

NOTE 3 Combined probability of occurrence, P_c, refers to the combination of independent environmental conditions and accidental events only. The occurrence probabilities refer to "yearly probability of occurrence."

NOTE 4 N/A—not applicable.

NOTE 5 "Assoc." implies the functional loads associated with the load condition under consideration.

NOTE 6 For extreme operating condition, the event itself may represent the condition following an accidental event (e.g. with a mooring line failure).

NOTE 7 "X"—to be considered; see Table 7 for details of typical accidental loads.

NOTE 8 Purchaser-specified return period. If not specified assume a three-month return period.

Table 7—Typical Load Classes

Functional Loads	
1)	Loads due to weight and buoyancy of pipe, contents, and attachments, both temporary and permanent.
2)	External pressure.
3)	External soil or rock reaction forces for trenched, buried, or rock dumped pipes.
4)	Static reaction and deformation loads from supports and protection structures.
5)	Temporary installation or recovery loads, including applied tension and crushing loads, impact loads, and guidance-induced loads.
6)	Residual installation loads, which remain as permanent loads in the pipe structure during service.
7)	Loads and displacement due to pressure and tension-induced rotation.
8)	Testing pressures, including installation, commissioning, and maintenance pressures.
9)	Interaction effects of bundled or clamped pipes.
10)	Loads due to rigid or flexible pipe crossings, or spans.
11)	Loads due to positioning tolerances during installation.
12)	Loads from inspection and maintenance tools.
13)	Loads from multiphase flow slugging, where applicable.
14)	Loads from restraint due to packaging (e.g. FAT testing).
15)	Internal pressure as specified in 4.4.2.
16)	Loads from pressure and temperature variations.
Environmental Loads	
1)	Loads caused directly or indirectly (e.g. VIV) by all environmental parameters specified in Table 4.
2)	Second-order slow drift motions and/or vortex induced motions of the floating facility or subsurface equipment to which the flexible riser is attached, where applicable.
Accidental Loads	
Loads and motions caused directly or indirectly by accidental occurrences involving external loads acting on the pipe, including the following.	
1)	Dropped objects.
2)	Trawl board impact.
3)	Internal overpressure.
4)	Compartment damage or unintended flooding of vessel compartment.
5)	Failure of thrusters.
6)	Dynamic positioning system failure.
7)	Anchor line failure.
8)	Failure of turret drive system.
9)	Failure of relevant ancillary equipment that is likely to impact on the configuration of the pipe (e.g. buoyancy or ballast module).
10)	Internal pressure differential across a hydrate plug, where applicable.
11)	Interference between flexible pipe and other structures.

Table 8—Flexible Pipe Layer Design Criteria

Layer	Primary Pipe Failure Mode	Design Criteria	Operating Conditions			Nonoperating Conditions			Survival
			Permanent		Abnormal	Temporary			
			Normal	Extreme		Normal		Extreme	
						Installation	Test		
Internal carcass	Collapse [1] [2]	Load	0.85						
Inner liner smooth bore	Collapse [1]	Load	For each polymer material for both static and dynamic applications, the allowable utilization for collapse shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that load.						
Internal pressure sheath	Rupture	Thinning [3]	The maximum allowable reduction in wall thickness over the service life below the minimum design value, due to deformation into gaps in the supporting structural layer, shall be 30 % under all load combinations.						
		Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain. The maximum allowable bending strain at nominal dimensions shall be 7.7 % for polyethylene (PE) and polyamide (PA), 7.0 % for polyvinylidene fluoride (PVDF) in static applications and for storage in dynamic applications, and 3.5 % for PVDF for operation in dynamic applications [4].						
Pressure armors	Loss of interlock breakage	Stress	0.67	0.85	0.85	0.67	0.91 [9]	0.85	0.97 [5]
	Collapse [1] [2]	Load	0.85						
Tensile armors	Breakage	Stress	0.67	0.85	0.85	0.67	0.91 [9]	0.85	0.97 [5]
	Buckling	Load	0.85						
	Wire disorganization	Displacement	The cumulative radial gap between each tensile armor and its adjacent layers shall not exceed half the wire thickness						
Anticollapse sheath [6]	Rupture	Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain.						
Antibuckling tape	Birdcaging [7]	Stress or strain [8]	0.67	0.67	0.85	0.85	0.85	0.85	0.91
Outer sheath	Rupture	Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain. The maximum allowable bending strain shall be 7.7 % for PE and PA.						

NOTE 1 The collapse resistance shall account for all sources of ovalization, that is, from manufacture, test, installation, and operation (see 5.3.1.3). Maximum permissible ovalization criteria (under load and in unloaded condition) are to be defined by the manufacturer. Guidance can be found in API 17B.

NOTE 2 For rough bore pipe, the stress can reach the material yield strength in one of the carcass or pressure armor layers, provided that the allowable utilization is not exceeded in the other.

NOTE 3 Thinning includes elastic, plastic, and creep-induced reduction in thickness (see 5.3.2.1.2).

NOTE 4 For quasi-dynamic and dynamic-supported applications, higher maximum bending strain shall be allowed for PVDF, if validated by testing. See footnotes to Table 9 for definition of quasi-dynamic and dynamic-supported.

NOTE 5 A margin of 3 % accounts for the allowable variation in utilization due to manufacturing tolerances (see 5.2.4).

NOTE 6 For smooth bore pipes used for gas or gas/liquid applications, design, manufacturing, and factory acceptance test (FAT) requirements for the anticollapse sheath shall be agreed between the purchaser and manufacturer.

NOTE 7 Birdcaging of the tensile armor wires.

NOTE 8 For nonsteel materials used for antibuckling tapes, utilization factors are applied on strength or strain capacity.

NOTE 9 For stress analysis, the maximum internal pressure experienced during FAT, offshore leak test, and structural integrity test shall be considered.

5.2 Pipe Design Methodology

The design methodology shall include the following, as a minimum:

a) theoretical basis, including calculation procedures for the pipe design parameters;

b) calculation method for all pipe layers and components;

c) verification of the theoretical basis with prototype tests. The verification shall include the capacity of all pipe structural layers. Simplified conservative analysis methods for checking of noncritical layers, such as antiwear layers, are acceptable if the method does not influence the reliability of the calculation of stresses in the other layers;

d) basis for stress concentration factors used for the steel materials, including stress concentrations at and within the end-fitting interface, at clamped accessories, and due to contact with rigid surfaces, manufacturing tolerances, and load-induced gaps;

e) manufacturing tolerances, manufacturing-induced stresses or strains, welds, and other effects that influence structural capacity;

f) verification of the service life methodology, subject to the requirements of 5.3.4;

g) all layer material properties in accordance with Table 12, Table 13, and Table 14;

h) qualification of materials in accordance with Table 15 and Table 16 for the pipe and in accordance with 6.2.5 for the end fitting.

Initially and whenever revisions occur, the pipe design methodology shall be verified by an IVA, reviewing and verifying all aspects specified above. The IVA shall establish the range of applicability for each design methodology. The IVA shall verify that the manufacturing process is controlled such that the design requirements are met within the range of applicability of the design methodology. The IVA shall issue a certificate and a report describing the limits and constraints of the design methodology. The design methodology verification report shall be available for review by the purchaser.

The design methodology shall account for the effects of wear, corrosion, manufacturing processes, dimensional changes, creep, and ageing (due to mechanical, chemical, and thermal degradation) in all layers, unless the pipe design is documented to not suffer from such effects.

The utilization levels of Table 8 are based on nominal dimensions and end of life conditions. For the metallic and antibuckling layers, it shall be shown that variations in dimensions within manufacturing tolerances do not change utilization values by more than 3 % above the values specified in Table 8.

The calculation of the thickness for all metallic layers shall include allowances for wear and uniform corrosion rates calculated for the service life.

For a new pipe design the manufacturer shall perform sufficient prototype tests to verify the design methodology and obtain a revision or amendment of the design methodology verification report by an IVA. The manufacturer shall revise or amend the fabrication specification such that the design requirements are met within the range of applicability of the design methodology. The prototype tests shall verify fitness-for-purpose for those design parameters that are outside the previously validated envelope. See API 17B for guidelines on the tests that should be performed and recommendations on the test procedures.

5.3 Pipe Structure Design

5.3.1 Design Criteria

The pipe layers shall be designed to the criteria specified in Table 8, subject to the requirements of Section 5.

The utilization for the internal pressure sheath shall be calculated based on both the maximum allowable creep and maximum allowable strain of the polymer material, subject to the requirements of 5.3.2.1.

The manufacturer shall evaluate buckling failure modes in the carcass, pressure armors, and tensile armors and shall confirm by analysis validated by testing that the layers meet the design requirements. Hydrostatic collapse calculations for the carcass can account for the support provided by the pressure armor layer. The buckling load utilization for the internal carcass shall be calculated as the differential pressure divided by the hydrostatic collapse resistance. The methodology for the calculation of hydrostatic collapse resistance shall be documented and based on the minimum value obtained using a validated design methodology, taking into account all sources of ovalization (i.e. from manufacture, test, installation, operation) and loading in pipe's axial and radial directions.

When applicable, the manufacturer shall evaluate the collapse failure mode associated with the buildup of gas pressure between the pressure sheath and the adjacent sacrificial layers and shall confirm by analysis that all design requirements are met. The manufacturer shall specify any operational limits on decompression rates as a result of this failure mode.

The utilization for the pressure and tensile armor layers shall be calculated as one of the following:

a) stress utilization: stress divided by structural capacity where stress is the calculated average stress in the actual layer;

b) load utilization: applied load divided by load to cause yielding or instability.

The stress shall be calculated using the verified design methodology, see 5.2, subject to the design requirements of 5.3.2. The calculated value shall include dynamic loads and be based on average stress in the layer. The average stress shall be calculated based on distributing the total layer load uniformly over all wires in the layer. The structural capacity shall be selected either as 0.9 times the ultimate tensile strength or as the yield strength. The structural capacity shall not exceed 0.9 times the ultimate tensile strength. The structural capacity used for design shall be either the minimum specified value, or the minimum value as certified by the supplier, provided that it exceeds the minimum specified value.

Local armor wire stresses may exceed average layer stresses (e.g. during bending). As detailed in 5.3.4.3, fatigue analysis shall be based on local armor wire stresses. Damage mechanisms resulting from local wire stresses exceeding the average stress in the layer shall be addressed in design, and these local stresses checked as being acceptable regarding the structural capacity and service life of the pipe.

Potential damage mechanisms include:

a) gross yielding or deformation of armor wire cross sections,

b) crack initiation in higher stress concentration areas of armor wire cross sections.

For methodologies on evaluation of acceptability of local stresses refer to API 17B, Section 5.4.1.

The utilization for the outer sheath shall be calculated based on the maximum allowable bending strain, subject to the requirements of 5.3.2.2.

The storage minimum bend radius (SR) shall be calculated as the minimum bend radius that satisfies all the requirements of Table 8. The bend radius required to cause locking in the interlocked layers shall be calculated [locking radius (LR)]. The SR shall be at least 1.1 times the LR. The SR shall not cause damage or disorganization to other layers.

Table 9 outlines the MBR criteria with respect to the SR and LR that must be satisfied for different load conditions and load type combinations. In addition, for all load conditions and combinations the MBR must not be less than SR.

Note that a larger MBR than the criteria of Table 9 may be required to comply with the design criteria in Table 8 or with the fatigue design requirements and factor of safety shown below.

Table 9—Minimum Bend Radius Design Criteria

Loading Type	Load Condition			
	Operating		Nonoperating	Survival
	Permanent	Abnormal	Temporary	
All types	1.0 × storage minimum bend radius (SR)			
Static	1.1 × locking radius (LR)			
Dynamic supported (1)	1.1 × 1.1 × LR	1.1 × LR		
Quasi-dynamic (2)	1.25 × 1.1 × LR	1.1 × 1.1 × LR		1.1 × LR
Dynamic (3)	1.50 × 1.1 × LR	1.25 × 1.1 × LR		

NOTE 1 Dynamic supported (i.e. a flexible pipe on an arch or in a bellmouth).

NOTE 2 Quasi-dynamic loading includes the following cases typically applying to topside jumpers:

a) no direct wave load on the flexible,

b) predominantly displacement controlled.

NOTE 3 Direct wave loading on the flexible pipe.

Fatigue life calculations shall be performed for intact annulus and annulus flooded with deaerated seawater conditions in accordance with the requirements of 5.3.4. The predicted fatigue life shall have a factor of safety of at least 10 times the service life.

A lower safety factor may be used for the annulus flooded with deaerated seawater condition based on expected operating conditions.

The manufacturer shall demonstrate that the design criteria of Table 8 and all other functional requirements are satisfied considering the predicted reduction in cross section of the structural layers from progressive wear, corrosion, and erosion at the end of the specified service life.

Reliability-based design may be applied as an alternative design method. All relevant design criteria for the reliability-based design cases should then be considered. The safety level applied shall be approved by the purchaser.

5.3.2 Design Requirements for Pipe Layers

5.3.2.1 Internal Pressure Sheath

5.3.2.1.1 Load Case Analysis

As a minimum, the internal pressure sheath shall be analyzed for the following load cases:

a) most critical combination of internal pressure, temperature, operating MBR, and polymer conditions, with annulus at atmospheric pressure or intact annulus or annulus flooded with deaerated seawater;

b) hydrotest pressure at ambient temperature and storage MBR.

5.3.2.1.2 Cyclic Loading Effects

The analysis shall include relevant cyclic loading effects such as hysteresis, relaxation, shrinkage, loss of plasticizer, diffusion of fluids, and absorption of fluids into the polymer matrix. As a minimum, the following shall be included:

a) creep and strain at operating temperature ranges due to bridging of gaps in the reinforcement layer;

b) stress variations from pressure and temperature cycling caused by the fluids inside the pipe bore and the pipe annulus, including unpressurized-pipe scenarios;

c) contact pressure from the adjacent (carcass and armor) layers;

d) creep and strain at operating temperature ranges, due to pipe bending, axial elongation and compression, torsion, and radial expansion;

e) weight of all layers adjacent to the pressure sheath that are not independently supported in the end fitting;

f) changes in material performance or properties due to aging.

5.3.2.1.3 Wall Thickness Calculation

The methodology used for calculating the wall thickness of the internal pressure sheath shall be validated by documented tests or field experience and shall comply with the following minimum requirements.

a) The gap between pressure armor or tensile armor wires, as applicable, used in the wall thickness calculations shall be the maximum gap while bending to the operating MBR (storage MBR for hydrotest) and accounting for manufacturing tolerances.

b) The analysis shall account for thinning of the polymer layer due to bending to the operating MBR (storage MBR for hydrotest), stress concentrations due to thickness variations, effect of deplasticization, swelling and ageing on material properties, manufacturing tolerances, creep behavior of the polymer material, and termination of the layer in the end fitting.

5.3.2.1.4 Mechanical Properties

The manufacturer shall show through analysis (with a methodology validated by testing) that with the minimum mechanical properties of the material and maximum gap in the supporting layer:

a) no failure due to deformation of the polymer into gaps in the adjacent metallic layers shall occur. All deformation calculations shall be based on differential pressure across the internal pressure sheath. Minimum mechanical properties shall take account of the impact of temperature and fluid absorption;

b) the material is capable of handling the associated loads without failure at design minimum temperature and maximum pressure.

5.3.2.1.5 Cracks

The manufacturer shall verify that crack initiation, due to notch sensitivity and stress concentration, does not occur in the material used for the internal pressure sheath. Particular attention should be paid to the potential stress raisers and defects caused by the manufacturing of the main pressure sheath and to any machining marks resulting from end-fitting mounting. For dynamic applications, the effect of sacrificial layers used in multiple internal pressure sheath constructions shall be accounted for. The thickness of the structural pressure sheath layer made of materials susceptible to crack growth (i.e. PVDF) shall be sufficient to ensure that crack growth will not propagate through the thickness of the layer due to thermal cycling, see 4.4.3.f), under typical operating conditions, should the crack initiation occur. Sufficient layer thickness for such materials shall be demonstrated.

5.3.2.1.6 Collapse

For smooth bore pipes without anticollapse sheath, collapse resistance shall be considered in design.

5.3.2.1.7 Multiple Layers

If the internal pressure sheath is composed of multiple layers, then dissimilar materials shall not be used in the multiple layer construction, unless there is documented test evidence that the materials fulfil the design requirements for the specified life and service conditions. A means for prevention of unacceptable gas buildup between adjacent layers shall be incorporated into the design.

5.3.2.2 Outer Sheath

The design of the outer sheath shall account for changes in material performance or properties due to diffusion/absorption of fluids into the polymer matrix and aging, manufacturing imperfections such as notches and cusps, creep and strain at operating temperature ranges due to pipe bending, axial elongation and compression, torque loads, external and annulus pressure, creep into the gaps in the outer tensile layer, installation loads, abrasion, local loads from ancillary components, and temperatures due to adjacent components such as active heating, fiber optic and electric cables and hydraulic hoses in a combined flexible pipe and umbilical structure, insulation from attached appurtenances, soil from self-burial and/or voluntary embedment, and marine growth.

5.3.2.3 Intermediate Sheath

If an intermediate sheath is designed to prevent leakage of annulus fluid outside the layer or to prevent seawater ingress beyond this layer, then the design of this sheath shall meet the requirements of Table 8 for the anticollapse sheath. For dynamic applications, intermediate sheaths shall withstand wear due to relative motion between layers. Wrinkles and cracking due to bending should be avoided. For smooth bore pipes used for gas or gas/liquid applications, design requirements for the anticollapse sheath shall be agreed between the purchaser and manufacturer. In the case of perforated intermediate sheaths (for insulation), the size and spacing of the holes needs to consider the shielding by tensile armors. The requirements of 5.3.2.1.2 shall apply.

Guidance for manufacturing QA and FAT requirements are provided in API 17B.

5.3.2.4 Internal Carcass

The design of the internal carcass shall account for the following:

a) collapse considering:

   i) minimum specified internal pressure;

   ii) maximum external pressure acting on the internal pressure sheath accounting for hydrostatic pressure, annulus pressure (including accounting for a flooded annulus), pressure buildup between polymer layers (in flexible pipes with multilayer constructions), and contact pressures from outer layers;

   iii) maximum pipe ovality including residual ovalization from the installation method; and

   iv) pipe bent to the minimum operational bend radius;

b) fatigue in the carcass;

c) effects induced by thermal expansion and contraction, plasticizer loss, pressure loads, and/or swelling of the internal pressure sheath;

d) erosion and corrosion. The manufacturer shall evaluate the erosion and erosion/corrosion rates for the specified fluid velocities and content over the service life of the pipe and shall document that these rates do not cause failure of the carcass. The allowable erosion shall be validated in accordance with the requirements of 6.2.4.4.

5.3.2.5 Pressure Armors

The pressure armors shall be designed for the required hoop strength and shall account for the control of gaps between wires, the prevention of loss of interlock, plastic deformation, and residual stress from the manufacturing process and from FAT.

5.3.2.6 Tensile Armors

The tensile armors shall be designed for the required axial strength. The design shall also account for any requirements for torsional properties, control of gaps between wires, and hoop strength, in particular for pipe designs that do not include pressure armors, and account for plastic deformation from the manufacturing process. Tensile wires may also need to be designed (i.e. wire geometry and lay angle as well as number of layers) for lengthwise stability (e.g. for buried pipe), as well as for resistance to lateral buckling and/or radial buckling (birdcaging).

The complete pipe structure shall be designed in such a way that the torsional balance and axial compression strength characteristics of the pipe meet the functional requirements.

5.3.2.7 Additional Layers

Thermal-insulation layers shall be designed in accordance with the requirements of 5.4.3.

Antiwear layers shall be designed, by accounting for both aging and wear, to prevent wear between adjacent steel and/or extruded polymer layers for the specified service life, and shall not serve as a sealing layer. The consequences of additional stresses occurring in the tensile armor layers due to local failure of the antiwear layer shall be evaluated and documented as an accidental load case.

Additional external-protection layers, whether polymer or metallic, shall be designed to prevent external damage or wear occurring in the outer sheath, based on the design conditions specified by the purchaser, and shall be designed for the temperatures due to adjacent components such as active heating, fiber optic and electric cables and hydraulic hoses in a combined flexible pipe and umbilical structure, insulation from attached appurtenances, and soil from self-burial and/or voluntary embedment. Addition of second or third outer sheath layers shall consider effects on overall pipe performance.

Antibuckling tapes shall be designed for the required strength to resist the radial buckling of the tensile armor layers. The manufacturer shall demonstrate that the selected materials have the sufficient long-term mechanical capability. The design criteria for allowable stress or strain in the antibuckling tapes shall be in accordance with Table 8. The cumulative radial gap between each tensile armor layer and its adjacent layers shall not exceed half the wire thickness for a pipe subject to axial compression loading (i.e. no bending). The tape structural capacity shall be defined as the minimum strength during the pipe service life derived after accounting for aging and wear.

Active heating, fiber optic cables, and electric and hydraulic hoses in a combined flexible pipe and umbilical structure, such as an integrated pipe umbilical (IPU) described in API 17B, should be designed in accordance with API 17E.

5.3.3 End Fitting

The end fittings shall be designed for reliable termination of all pipe layers, such that leakage, structural deformation, or pull-out of wires, carcass, or extruded layers does not occur for the service life of the pipe, taking account of all relevant factors, including corrosion, shrinkage, creep, ageing, and pressure effects. The end fittings shall be designed for the thermal and pressure cycles defined for the service conditions of the particular dynamic or static application, taking into account all effects listed in 5.3.2. The design methodology for end fittings shall be documented and shall be verified by documented tests and analyses. The methodology shall account for manufacturing tolerances. The design shall account for supporting loads from any ancillary components attached to the end fitting, including bend stiffeners. The design shall also account for temporary or permanent hangoff loads into the end fitting, such as J-tube/I-tube hangoff, or hangoff during vertical lay operations.

The design of the end fitting shall ensure sealing of the internal pressure sheath, the outer sheath, and whenever applicable, any intermediate sheath (e.g. in case of insulated pipes or smooth bore pipes) at the end fitting. The design of the end-fitting crimping/sealing mechanism shall ensure that the combined strain induced by the in-service pull-out forces and installation of the end-fitting seal ring does not result in failure of the sheath over the service life.

End-fitting design and analysis shall demonstrate that there is always a net sealing pressure at the seal between the outer sheath and the end-fitting housing. The analysis is to consider the effects of external pressure, water depth, temperature, and long-term creep/relaxation of the outer sheath material. The internal pressure sheath termination shall be designed in accordance to the guidance provided in API 17TR1.

Any difference between the inner diameter of the end-fitting bore and the inner diameter of the flexible pipe shall be clearly documented and conveyed to the purchaser for sizing and design of pigs.

In the design of the end fitting, axial movements of the carcass relative to the end fitting shall be mechanically restrained.

Accounting for all physically possible load combinations, the design requirements in Equations (1) and (2) shall apply for the pressure-containing parts of, and components subject to tensile loading in, the end fittings:

$$\sigma_{\mathrm{t}} \leq n \times \sigma_{\mathrm{y}} \tag{1}$$

$$\sigma_{\mathrm{e}} \leq n \times \sigma_{\mathrm{y}} \tag{2}$$

where

σ_{t} is the tensile hoop stress;

σ_{e} is the equivalent stress (Von Mises or Tresca);

n is the permissible stress utilization factor as specified in Table 10.

Accounting for all physically possible load combinations, the design requirements in Equation (3) shall apply for the end-fitting anchoring system:

$$F \leq n \times F_{\mathrm{y}} \tag{3}$$

where

F is the design pulling force resulting from design tension and pressure;

F_{y} is the anchoring system capacity;

n is the permissible anchoring system load utilization factor as specified in Table 10.

Table 10—End-fitting Permissible Utilization Factors

Component	Failure Mode	Design Criteria	Operating Conditions			Nonoperating Conditions			Survival
			Permanent		Abnormal	Temporary			
			Normal	Extreme		Normal		Extreme	
						Installation	Test		
Pressure containing	Burst	Stress	0.67	0.85	0.85	0.67	0.91	0.85	0.97
Tensile armor (1)	Breakage	Stress	0.67	0.85	0.85	0.67	0.91	0.85	0.97
Tensile armors anchoring system	— Pull-out — Breakage — Pull-out due to failure of potting compound	Load	0.67	0.85	0.85	0.67	0.91	0.85	0.97

NOTE 1 Design procedures shall consider any changes to steel resistance coming from the mounting process such as microstructure changes from heating/welding or insertion of microcracks or other defects.

For dynamic applications, fatigue life calculations shall be considered for the termination of all metallic and pressure sheath layers, and shall be performed for intact annulus and annulus flooded with deaerated seawater conditions in accordance with the requirements of 5.3.4. The predicted fatigue life shall have a factor of safety of at least 10 times the service life.

A lower safety factor may be used for the annulus flooded with deaerated seawater condition upon agreement with the purchaser.

The thickness of weld overlay material may be included in the wall thickness in end-fitting analyses, provided that the material strength of the weld overlay material is equal or greater than the strength of the parent material and that a validated weld procedure is documented.

The manufacturer shall calculate the burst pressure of the pipe body structure and of the end fitting. This calculation is done based on minimum guaranteed material properties. The manufacturer shall state if the end fitting has a lower calculated burst pressure than the pipe body.

The manufacturer shall have a validated methodology for the determination of the anchoring system capacity.

The manufacturer shall calculate the failure tension capacity of the pipe structure and the end-fitting anchoring system capacity. The manufacturer shall state if the anchoring system capacity of the end fitting is lower than the failure tension of the pipe body.

When the bend stiffener is mounted onto the end fitting, the design methodology shall consider the effect of transition from the pipe body to a fixed condition inside the end fitting in the stress evaluation of the tensile armors.

The effect of any device used inside the end fitting or temporarily used during the assembly to organize the tensile armors or to help in the assembly process shall be accounted for in the design.

5.3.4 Service Life Analysis

5.3.4.1 Service Life—Static and Dynamic Applications

The service life analysis of flexible pipes shall document the properties of the pipe materials for the specified service life, in accordance with the requirements of Section 6. The minimum strength for metallic materials, during the service life of the pipe, shall be used in the design calculations. Polymer materials shall be demonstrated to meet the design requirements of 5.3.2 over the service life. The analysis shall include as a minimum the following:

a) for polymer components, creep, ageing, dimensional changes (shrinkage, swelling), and strain to failure in the operating environment;

b) wear, corrosion, and erosion of steel components.

For annulus flooded with deaerated seawater conditions, the effect of corrosion of steel components in the annulus shall account for permanent contact with water of appropriate salinity and corrosive gas ingress rate. Determination of salinity and corrosive gas ingress rate may consider the presence of multiple exterior sheath layers and insulation.

Intact annulus conditions shall consider condensation of permeated fluids in the annulus that occurs due to all operating temperature scenarios, including shutdown and restart. The design method shall predict the period of time in which the annulus contains condensed fluid. For this period, fatigue calculations shall be based on S-N curves that reflect this environment, as applicable. Otherwise, the manufacturer shall design the pipe assuming this environment for the entire service life.

The general corrosion rate and occurrence of pitting should be documented and used to identify a minimum and most likely service life based upon expected normal operating conditions, assuming the pipe annulus is flooded with seawater during installation.

5.3.4.2 Service Life—Dynamic Applications Only

For dynamic applications, the requirements of 5.3.4.3 and 5.3.4.4 shall apply. In addition, a fatigue analysis shall be performed for pressure armor layers and tensile armor layers that shall take account of all mechanical and dynamic effects that can introduce failure modes into the pipe in the dynamic application. As a minimum, the effects of residual wires stress, wear, fatigue, fretting, material degradation, including corrosion, and degradation and draining of lubricant shall be accounted for. If welds on the pressure and tensile armor wire cannot be avoided in the fatigue-critical areas (e.g. hangoff and touchdown areas), then these welds shall be validated for the fatigue loads expected at the locations of the welds. Such validation can be achieved by testing of welded wire samples to confirm the fatigue performance assumed in the design or by developing S-N curves for welded armor wires for the same annulus conditions.

Service life shall consider, subject to the requirements of 5.3.1 and 5.3.3:

a) degradation of polymer layers in accordance with the requirements of 5.3.4.5;

b) assessment of service life for pressure and tensile armors based on S-N data as per 6.2.4.5;

c) the annulus environment based on permanent operating conditions, in accordance with the requirements of 5.1.4, 5.3.4.1, and 5.3.4.2;

d) the expected changes in cross-sectional dimensions of pressure and tensile armors resulting from wear and corrosion during the service life.

A verified model shall be required to assess the H_2S and CO_2 partial pressures with the associated pH level in the annulus during the service life. If the endurance limit cannot be supported by tests, then an S-N curve without an endurance limit shall be used.

5.3.4.3 Fatigue Analysis of Armor Wires in the Pipe Body

For dynamic applications, fatigue calculations using Palmgren-Miner linear damage theory and S-N data in accordance with 6.2.4.5 shall be performed for the pressure and tensile armors. If it has been demonstrated from testing in accordance with 5.3.4.2 and 6.2.4.5 that wire stresses are below a documented and verifiable endurance limit established by testing and approved by the purchaser, Miner's calculations are not required.

The fatigue life analysis shall also confirm that the internal and intermediate pressure sheaths and outer sheath maintain integrity under the calculated alternating strains.

The design S-N curves, used in the fatigue analysis of the structural pressure and tensile layers for in-air, intact annulus and annulus flooded with deaerated seawater, shall be based on fatigue test data with a statistically significant lower bound design curve that provides 97.5 % probability of survival. The effects of mean stresses shall be considered. The S-N curves shall be either developed or corrected for these mean stress conditions.

The number of test samples and the statistical analysis of the fatigue data shall be in accordance with ASTM E739. The range of the test stress ranges should be sufficiently large to confidently regress the slope of the S-N curve.

The fatigue analysis shall be performed at all critical structural or geometric locations and shall be based on local armor stresses. Local wire stress shall be calculated based on determining the stress at the critical locations of a wire inclusive of the effects of pipe bending and accounting for friction-induced axial stresses.

5.3.4.4 Fatigue Analysis of Armor Wires in the End Fitting

Fatigue analysis of the armor wires in the end fitting shall be in accordance with the requirements of 5.3.4.3.

The fatigue analysis shall account for changes in wire strength, residual stresses and stress concentrations, and wire deformation due to the mounting process.

The design methodology shall consider tensile wire geometry, for example, fishscaling, inside the end fitting, if applicable.

5.3.4.5 Ageing

Service life assessment shall be performed for sheaths and antibuckling and antiwear layers in the pipe structure, taking account of the impact of design operating conditions (e.g. temperature, pH, water cut, methanol, glycol, and other known exposure profiles) on the long-term deterioration of each of those layers. The ageing and deterioration of these layers shall be demonstrated to be suitable for all applications based on known chemical and physical ageing mechanisms. Aging of polymer layers shall be checked for both maximum and minimum thermal insulation including effect from marine growth, burial, bend stiffeners, and other accessories.

Guidelines on ageing of PA-11 as internal pressure sheath are given in API 17TR2. More detailed requirements on ageing tests are listed in 6.2.3.5.

5.4 System Design Requirements

5.4.1 General

The design of the flexible pipe shall account for all system requirements specified in 4.6, as listed in Table 11, and account for additional requirements specified in 5.4.2 to 5.4.8. The design shall meet all interface requirements specified by the purchaser or by the manufacturer.

Table 11—System-related Pipe Design Requirements

General Requirements	Flowline Requirements
Corrosion protection	Flowline routing
Thermal insulation	On-bottom stability
Gas venting	Upheaval buckling (lateral pull-back/pull-through)
Pigging and through flowline requirements	Crossover requirements
Fire resistance	Interference requirements
Piggyback lines	
Connectors	
Interface definitions	
Inspection and condition monitoring	**Riser Requirements**
Installation requirements	Riser configuration
Retrieval requirements	Connection systems
Exothermal chemical reaction cleaning	Vessel data
Erosion	Interference requirements
Abrasion and impact protection	
Shipping, storage, and handling	
Load cases	
Pipe attachments	
Guides and supports	
Protection requirements	

Upheaval buckling, upheaval creep, and termination load capacity of trenched, buried, or rock-dumped pipes shall be checked for pressure and temperature induced axial elongation and forces. The effect of pipe-bending-stiffness variations, resulting from time, temperature, and pressure on the pipe loads, should be analyzed.

For dynamic riser applications, interference/clashing with other components of the system, including risers, mooring lines, and rigid surfaces such as pontoons, vessels, or platforms, shall be checked in the design.

The friction coefficients between the external sheath and adjacent layers for intact and seawater flooded annulus conditions shall be verified to be adequate for design of installation/retrieval tensioner compression forces and for design of devices to be clamped to the pipe.

5.4.2 Corrosion Protection

5.4.2.1 Galvanic Corrosion

Selection of materials shall consider the effect of galvanic corrosion if this can increase utilization factors above allowable limits. If there is the possibility of galvanic corrosion occurring, dissimilar metals shall be isolated from one another with insulation, a coating, or a sufficient corrosion allowance.

5.4.2.2 Surface Treatment

All external steel surfaces shall be prepared and coated in accordance with internationally recognized or purchaser-specified standards for corrosion protection in all environmental conditions specified in Section 4, unless the material is documented to be corrosion-resistant in the specified environment.

5.4.2.3 Corrosion Allowance

Requirements for internal and external corrosion allowances shall be evaluated in accordance with the location, conditions of installation, and the requirements specified in Section 4. The manufacturer shall document this evaluation and its effect on the pipe components.

Corrosion at the end-fitting interface shall not cause damage to any sealing barrier or locking mechanism.

Corrosion-resistant overlay or corrosion-resistant alloys may be used in preference to a corrosion allowance. The manufacturer shall have documented records on the suitability of the corrosion-resistant overlay or alloys for the specified application and environment.

5.4.2.4 Cathodic Protection

Design of a cathodic protection system shall be in accordance with the requirements of 4.6.1.3. If the cathodic protection system is specified to protect the tensile armors, the anodes electrically connected to the end fitting shall be sized accordingly, and there shall be electrical continuity between the tensile armors and the end fitting. The voltage drop to the adjacent anodes shall be confirmed to be acceptable. The cathodic protection system design methodology shall be documented. See ISO 15589-2 or DNV RP B401, and DNV RP F103 for guidelines on the design of cathodic protection systems.

The cathodic protection system shall consider coating damage breakdown to the end fittings and damage to the outer sheath of a flexible pipe. The extent of coating breakdown, outer sheath damage to be considered, and duration of damaged outer sheath before repair shall be agreed with the purchaser.

If a component of the flexible pipe system is reliant on the cathodic protection system of an adjacent structure, then the manufacturer shall have documented justification through calculations in the design report that this adjacent cathodic protection system is both compatible with and has sufficient capacity to give protection for the specified service life. Both the maximum and minimum current conditions shall be checked and particular attention shall be paid to hydrogen-induced cracking (HIC) when using high strength steel.

5.4.3 Thermal Insulation

The materials used for thermal insulation layers shall be selected such that overall heat-transfer coefficient and cooldown times do not degrade below the levels specified in accordance with 4.6.1.4 for the service life. The determination of an acceptable cooldown time shall account for the heat transfer characteristics of the end fitting.

When selecting a thermal insulation material, the deterioration of its physical and mechanical properties under a combination of temperature, hydrostatic pressure, seawater flooded annulus condition, water absorption, and creep of material shall be documented by the manufacturer and accounted for in the design.

The design of the thermal insulation system shall be based on the assumption that the outer protective barrier will be damaged or deteriorated, thereby exposing the insulating material to air and/or seawater. Where the pipe annulus has a sealed intermediate layer, as in some thermal insulated pipe designs, the design of the thermal insulation shall be based on the premise that the innermost annulus has reached steady state intact annulus conditions. Bulkheads or additional polymer sheaths may be used to limit the volume of the pipe structure to be flooded. The design methodology, including outer sheath damage assumptions, shall be documented. End cap effects on sealed insulation shall be calculated and used in design.

Conditions experienced during storage, transportation, handling, installation, and operation shall be analyzed and where necessary performance demonstrated by installation simulation tests. The manufacturer shall verify and document that permanent deformation of the insulation layers, resulting from crushing caused by items including tensioners, reels, sheaves, rollers, self-weight, and impact loads, does not change the heat transfer coefficient or cooldown time, as required, beyond the specified requirements.

5.4.4 Gas Venting

The gas-venting system shall be designed to the requirements of 4.6.1.5 and the following:

a) safe removal of permeated fluids;

b) no uncontrolled pressure buildup outside the pipe if the pipe is located within an enclosed space;

c) chemical resistance of all parts exposed to the permeated fluid and seawater.

The following design requirements shall apply to the gas-venting system:

a) it shall be documented that the valve will open before the outer sheath bursts, when the sheath wall thickness is at the minimum tolerance;

b) the maximum vent system pressure in the annulus shall not collapse or blister the internal pressure sheath during decompression of the bore or annulus;

c) burst disks should only be used as a backup venting system;

d) gas-relief valves used as part of a venting system for a subsea pipe shall not allow ingress of seawater accounting for the maximum hydrostatic pressure;

e) there shall be minimum two vent ports coming out of the end fitting and three vent ports for risers;

f) if gas relief valves are used, two valves per end fitting shall be required as a minimum;

g) the valve design shall account for the specified marine growth conditions.

The gas drainage shall be through the end fitting of the pipe unless otherwise specified in 4.6.1.5.

The design of all layers in the pipe shall allow for permeated gas to be vented.

5.4.5 Pigging and TFL Operations

The flexible pipe shall be designed for the pigging, TFL, workover, and other tool requirements specified in 4.6.1.6. The selection of dimensional tolerances, including ovality, shall account for the specified requirements. See API 17C for guidelines on TFL systems.

The innermost layer (carcass or internal pressure sheath) selected for the pipe design shall be compatible with the specified requirements, and the manufacturer shall have performed documented tests to demonstrate compatibility.

The pipe design should result in a smooth interface between the innermost layer and the end fitting. Any variation in wall thickness caused by corrosion shall not influence pigging operations. End-fitting designs shall be such that a variation in wall thickness as a result of corrosion shall not result in damage to the internal carcass or internal pressure sheath during pigging operations.

5.4.6 Fire Resistance

If fire resistance is required in accordance with 4.6.1.7, the pipe shall be tested in accordance with Lloyds Fire Test, DNV GL IMO Resolution A 753 (18), or API 16C unless previous testing of the design has been performed and documented.

5.4.7 Routing

Pipe crossing on the seabed shall be acceptable as long as appropriate protection measures are taken. These can include the following:

a) separating the pipes with a mattress,

b) entrenching one of the pipes,

c) demonstrating with calculations that the pipes can withstand the crossing loads and the outer sheaths can withstand any abrasive damage.

5.4.8 On-bottom Stability

On-bottom stability analysis shall demonstrate that under extreme functional and environmental loading conditions pipe movements do not exceed limits specified by the purchaser. The functional and environmental loading conditions shall account for the following as a minimum:

a) internal pressure;

b) internal fluid temperature;

c) water depth and wave loading if applicable at pipe depth;

d) current loading at pipe depth;

e) seabed characteristics.

If the purchaser does not establish limits, then the manufacturer shall submit a criterion.

NOTE See DNV RP F109 for guidance on on-bottom stability analysis.

6 Materials

6.1 Material Requirements

6.1.1 General

The requirements of Section 6 shall apply to polymer materials, including additives; flat, round, or shaped metal wire forms; the materials used for the antibuckling layers; and finished or semifinished end-fitting components, as delivered to the pipe manufacturer by suppliers and subject to manufacturing processes as employed by the manufacturer. Section 6 does not cover the use of composite materials for tensile armors, pressure armors, and carcass layers.

The manufacturer shall have on file records of tests demonstrating that the materials selected for a specific application meet the functional requirements specified in Section 4 for the service life, for both operation and installation conditions. The documented test records shall conform to the requirements of 6.2. Where suitable qualification records do not exist, the manufacturer shall conduct testing relevant to the application according to 6.2.

All materials, including antiwear layers, tapes, lubricants, and other manufacturing aids used in the flexible pipe construction, shall be compatible with seawater and permeated gases and liquids at design temperatures. Compatibility can be limited to determination that decomposition of these materials does not create byproducts harmful to functional layers (such as the internal pressure sheath) of the pipe. The manufacturer shall ensure that all lubricants and corrosion protection coating used in the manufacture of the pipe are compatible with all other structural or pressure-sealing materials in the pipe.

The manufacturer shall utilize documented test procedures to determine the material properties specified in Table 12, Table 13, and Table 14.

6.1.2 Polymer Materials

6.1.2.1 General

The material properties specified in Table 12 shall be used to define the prequalified range and combination of exposure and temperature conditions for each of the polymers used in the internal pressure sheath, antiwear layer/tape, intermediate sheath, outer sheath, and insulation layer.

6.1.2.2 Internal Pressure Sheath

The material properties for the internal pressure sheath, as specified in Table 12, shall be determined for a range of temperatures and pressures that shall include the design values.

The manufacturer shall have validated methods for predicting the polymer properties for the specified service life. The manufacturer shall have available for review by the purchaser records of tests and evaluations that demonstrate that the methods yield conservative results.

If the conveyed fluid contains gas, the polymer shall be shown, by testing, not to blister or degrade during rapid depressurization from the maximum operating pressure and temperature conditions. The effect of ageing and swelling on permeability shall be analyzed. The manufacturer shall specify the criteria to be applied to the polymer for assessment of serviceability (embrittlement, creep, shrinkage, swelling, plastic deformation, and other degradation modes and mechanisms that may impact the internal pressure sheath functionality) and quantify its application, using results of testing consistent with the requirements of 6.1.2.2.

6.1.2.3 Intermediate Sheath

The material properties for the intermediate sheath, as specified in Table 12, shall be determined for a range of temperatures and pressures that shall include the design values.

6.1.2.4 Outer Sheath

The manufacturer shall confirm compatibility of the outer sheath with all permeated fluids, ancillary components, and all external environmental conditions specified in 4.5.

6.1.2.5 Insulation Layer

The thermal conductivity of the layer shall be determined for both dry and seawater flooded conditions and for the design and operating temperatures and pressures. The term “dry conditions” means tested in air at conditions defined by the international standard atmosphere.

The manufacturer shall verify with tests that the compressive strength of the insulation material is sufficient to withstand all expected compressive loads within the design requirements of 5.4.3. Flooding of the annulus shall not affect this requirement.

Table 12—Property Requirements for Polymer Materials

Characteristic	Parameter (1)	Internal Pressure Sheath	Intermediate Sheath	Antiwear Layer	Outer Sheath	Insulation Layer (2)
Mechanical/physical properties	Resistance to creep	X (3)	X	X	X	X
	Tensile properties	X	X	M	X	M
	Stress relaxation properties	C	C	—	C	—
	Modulus of elasticity	X	X	—	X	—
	Compression properties	X	X	—	X	X
	Hydrostatic pressure resistance	—	—	—	—	X
	Abrasion resistance	—	—	—	C	—
	Density	X	X	X	X	X
	Fatigue	C	C	—	C	—
	Notch impact test	C	—	—	C	—
Thermal properties	Coefficient of thermal conductivity	X	X	X	X	X
	Coefficient of thermal expansion	X	X	—	X	—
	Heat capacity	X	X	X	X	X
	Brittleness or Glass transition temperature	C	C	—	C	—
Permeation characteristics	Fluid permeability	X	X	—	X	—
	Blistering resistance	X	—	—	—	—
Compatibility and ageing	Fluid compatibility	X	X	X	X	X
	Ageing tests	X	X	X	X	X
	Environmental stress cracking	C	C	C	C	—
	UV weathering resistance	—	—	—	X	—
	Water absorption	—	—	—	—	X

NOTE 1 Test procedures are specified in Table 15. There are no property requirements for manufacturing aid materials.

NOTE 2 The property requirements specified for the insulation layer apply to the use of both polymers and nonpolymers.

NOTE 3 X (required for design), C (comparative, cannot be used directly for design), M (not required for design, for manufacturer's analysis only).

6.1.2.6 Antiwear Layers

The material properties for the antiwear layer, as specified in Table 12, shall be determined for a range of temperatures that shall include the design values.

6.1.3 Metallic Materials

6.1.3.1 General

For the specified application, the manufacturer shall, for each of the characteristics listed in Table 13, confirm by testing the suitability of the selected material and weldments, if applicable. Material selection shall consider corrosive attack appropriate to the environment to which the layer is exposed over the specified service life of the pipe. Materials for sour service applications shall be tested in accordance with 6.2.4.2. All metallic components designed for, or that can be exposed to, cathodic protection shall be made of materials that are resistant to hydrogen embrittlement in the applicable environment.

Table 13—Property Requirements for Metallic Wire and Strip Materials and Weldments

Properties/Characteristics	Parameter (1)	Carcass	Pressure Armor	Tensile Armor
Alloy properties	Chemical composition	X (2)	X	X
	Microstructure	C	C	C
Mechanical properties (4)	Tensile properties (yield strength/ultimate tensile strength)	X	X	X
	Elongation	C	C	C
	Hardness	C	C	C
	Fatigue resistance	X	X	X
	Erosion resistance	X	—	—
Material characteristics (4)	Sulfide stress cracking (SSC) and hydrogen-induced cracking (HIC) resistance	X	X	X
	Corrosion resistance (fluids, chemicals)	X (3)	X	X
	Cracking resistance under cathodic protection	—	—	X

NOTE 1 Test procedures are specified in Table 16.

NOTE 2 X (required for design), C (comparative, cannot be used directly for design), M (manufacturer's analysis).

NOTE 3 Check for SSC and HIC in corrosion resistance test.

NOTE 4 Properties to be determined on wire specimen with plastic strain and residual stress levels representative of wires retrieved from as manufactured pipes.

6.1.3.2 Carcass

If the carcass is to be exposed to tools passing through the pipe, including pigs, TFL, and workover equipment, the wear rate from all expected occurrences shall be calculated or experimentally determined. Additional sacrificial material shall be included in pipes that are expected to experience high wear or abrasion rates. The amount of additional material shall be determined by analysis using wear-rate data and expected occurrence rates.

The material selection for the carcass shall account for the installation conditions, in particular if the pipe is to be temporarily filled with seawater.

6.1.3.3 Pressure and Tensile Armors

For the specified application, the manufacturer shall determine the sensitivity to corrosion (uniform and pitting) and cracking (SSC and HIC) occurring in the carbon steel materials selected for the pressure and tensile armors.

6.1.4 End Fitting

6.1.4.1 Metallic Materials

End-fitting metallic components for primary pressure-containing parts shall be wrought or forged in accordance with the requirements of ASTM A668, ASTM A29, or ASTM A182. For sour service applications, metallic materials shall be in accordance with NACE MR0175.

The manufacturer shall document the chemical composition, manufacturing method, heat treatment, and the tensile, hardness, and Charpy impact properties for the metallic materials in all primary end-fitting components. The chemical composition should be selected to ensure that the components meet the property requirements for the specified service after all manufacturing processes, including welding and weld heat treatments.

The end fitting inclusive of vents, where applicable, shall be resistant to corrosion, either by way of material selection or by means of the combination of a suitable coating and cathodic protection. The material for the end-fitting internal surfaces shall be resistant to erosion due to solids entrained in the conveyed fluid. All metallic components designed for, or that can be exposed to, cathodic protection shall be made of materials that are resistant to hydrogen embrittlement in the applicable environment.

All surfaces exposed to the conveyed fluid shall be verified by tests to be corrosion resistant. Sheath seal rings and flange sealing surfaces shall be corrosion resistant through material or coating selection.

6.1.4.2 Epoxy Material

The epoxy filler material used to embed the tensile armors shall be documented to withstand the temperatures experienced by the end fitting during manufacture and service for the specified service life. Consideration shall be given to the maximum temperatures that can be experienced by the end fitting in enclosed spaces, such as underneath fire insulation and bend stiffeners.

The manufacturer shall document the compressive strength of the epoxy at a temperature between 20 °C and 25 °C and at design minimum and maximum temperatures. Glass-transition temperature, fluid compatibility, and ageing characteristics of the epoxy shall be documented. The epoxy used in testing shall be mixed and cured according to the suppliers' specifications.

6.1.5 Antibuckling Layers

The manufacturer shall document the properties of the material for the antibuckling layers, as specified in Table 14, for a range of temperatures that shall include the design values. The ageing tests shall be documented for both dry, intact annulus and annulus flooded with deaerated seawater conditions and for the operating temperatures. Degradation of strength performance over the specified service life, resulting from temperature (including thermal effect due to unintended insulation, e.g. burial, marine growth, and bend stiffeners), annulus environment, and seawater, where applicable, shall be analyzed.

As thermal properties of this layer are of secondary importance to the overall thermal performance of the pipe, the thermal conductivity and heat capacity of this layer can be determined either by testing or estimated by calculation from raw material data.

6.2 Testing Requirements

6.2.1 General

6.2.1.1 Test Requirements

The physical, mechanical, chemical, and performance characteristics of all materials in the flexible pipe, as specified in Table 12, Table 13, and Table 14, shall be verified by the manufacturer through a documented test program. The program shall confirm the adequacy of each material based on test results and analysis that shall demonstrate the suitability of the material for the specified service life of the flexible pipe. Test procedures listed in Table 15 and Table 16 shall be used to determine the properties specified in Table 12, Table 13, and Table 14. If the test method is not specified in Section 6, guidance may be obtained from API 17A or the manufacturer may use their own methods, subject to the requirements of 6.2.1.4. The qualification of materials by testing shall consider all processes (and their variation) adopted to produce the pipe that can impair the properties and characteristics required by the design. If qualification tests cannot be carried out on processed materials, the manufacturer shall justify in the documented qualification program why the selected material provides equivalent characterization as the processed material. Use of nonprocessed materials shall be subject to IVA or purchaser approval.

Table 14—Property Requirements for Antibuckling Tapes

Properties/Characteristic	Parameter	Antibuckling Tape
Mechanical/physical properties	Resistance to creep	C (1)
	Yield strength/elongation	X
	Ultimate strength/elongation	X
	Stress relaxation properties	—
	Modulus of elasticity	X
	Hardness	—
	Compression strength	—
	Hydrostatic pressure resistance	—
	Impact strength	—
	Abrasion resistance	X
	Density	X
	Fatigue	C
	Notch sensitivity	—
Thermal properties	Coefficient of thermal conductivity	C
	Coefficient of thermal expansion	—
	Softening point	—
	Heat capacity	C
	Brittleness (or glass transition) temperature	—
Permeation characteristics	Fluid permeability	—
	Blistering resistance	—
Compatibility and ageing	Fluid compatibility	X
	Ageing tests	X
	Environmental stress cracking (2)	X
	Weathering resistance	—
	Water absorption	—

NOTE 1 X (required for design), C (comparative, cannot be used directly for design), M (manufacturer's analysis).
NOTE 2 If the material is susceptible to the failure mechanism.

6.2.1.2 Test Data

Test data shall be kept on file for 20 years after delivery to the purchaser or for the service life, whichever is greater.

6.2.1.3 Applicability

Only materials with identical specified chemistry and material manufacturing process (e.g. heat treatment, cold forming, etc.), as used in the qualification testing, shall be regarded as qualified.

Documented operational experience may be accepted as verification of long-term properties in environments that are equal to or less severe than the documented experience. The severity of the environment for metallic components shall be determined by temperatures, stresses, contact pressures, corrosive environments, pH, chloride content, injected chemicals, concentrations of H_2S and CO_2, and other conditions deemed by the manufacturer or purchaser to be detrimental. The environmental factors considered for polymers shall include temperatures, strains, pressures, concentrations of water, aromatics, alcohols, H_2S and CO_2, UV exposure, acidic conditions (lower pH or higher TAN), and other conditions deemed by the manufacturer or purchaser to be detrimental.

6.2.1.4 Test Methods

The test methods shall be as specified in 6.2. Where test methods are not specified, the manufacturer may use their own methods and/or criteria or alternative methods developed by the raw materials supplier. In such cases, the methods and/or criteria shall be documented and the results correlated with the specific material application. Where test methods are specified but alternative methods are preferred to be followed, the manufacturer shall justify in the documented qualification program why the alternative methods used provides equivalent or better characterization than the specified test methods. Nonstandard test methods shall be verified by an IVA or approved by the purchaser.

NOTE Use of equivalent ISO or ASTM standard test procedures does not require justification.

6.2.2 Polymer Materials

6.2.2.1 General

Test procedures listed in Table 15 shall be used to determine the properties specified in Table 12 and Table 14.

6.2.2.2 Samples Used for Qualification Testing

Samples used for qualification testing of polymer sheath, insulation and antiwear materials shall be taken from extruded samples. For thermoplastic materials, molded specimens are not acceptable.

6.2.2.3 Polyvinyl Chloride (PVC) as Insulation Material

If PVC is used as the insulation material, a heat stability test shall be performed at or above the maximum design temperature for a period of at least 30 days.

6.2.3 Polymer Test Procedures

6.2.3.1 General

This section describes tests procedures to be used when no ISO or ASTM standard test procedure is given in Table 15.

6.2.3.2 Fluid Permeability

For fluid permeability tests, the following conditions shall apply as a minimum.

a) Sample: Sample shall be taken from an extruded material.

b) Thickness: Minimum is 1 mm (0.04 in.) (see Note).

c) Diameter: Minimum is 40 mm (1.57 in.) effective diameter (see Note).

d) Temperature: Data required over the design range of the polymer, with sufficient tests to allow interpolation.

e) Pressure: Permeability can be assumed to be independent of pressure.

f) Repeatability: A sufficient number of tests shall be carried out to ensure repeatability. ISO 2556 requires a minimum of three samples for each measurement.

NOTE The test may be carried out using a disc sample with other dimensions provided the ratio diameter over thickness is greater than 20. Alternatively, an extruded tube may be used.

Table 15—Test Procedures for Extruded Polymer (Including Antiwear Layers and Insulation) and Antibuckling Layer Materials

Property/Characteristic	Parameter	Test Procedure [1] [3]		Comments [2]
		ISO or Section Number [2]	ASTM [2]	
Mechanical/ physical properties	Resistance to creep	ISO 899-1	ASTM D2990	Due to temperature and pressure
	Tensile properties and modulus of elasticity	ISO 527-1 ISO 527-2 ISO 527-3	ASTM D638 ASTM D882 ASTM D3759 [5]	—
	Stress relaxation properties	ISO 3384	ASTM E328	—
	Compression properties	ISO 604	ASTM D695	Sample specimens may represent actual layer geometry (sheath/tape)
	Hydrostatic pressure resistance	—	—	Guidance is given in API 17L2
	Abrasion resistance	ISO 9352	ASTM D4060	Or ASTM D1044; this is only a qualitative test for comparison; guidance is given in API 17L1
	Density	ISO 1183 (all parts)	ASTM D792	Or ASTM D1505
	Fatigue	—		ISO 178 [4]
	Notch sensitivity	ISO 179 (all parts)	ASTM D256	—
	Coefficient of thermal conductivity	ISO 8301	ASTM C518	Or ISO 8302/ASTM C177
Thermal properties	Coefficient of thermal expansion	ISO 11359-2	ASTM E831	—
	Heat capacity	ISO 11357-1 ISO 11357-4	ASTM E1269	—
	Glass transition temperature	ISO 11357-2	ASTM E2602 ASTM E1356 ASTM E1640	Method can be based upon differential scanning calorimeter or dynamic mechanical thermal analysis
	Brittleness temperature	ISO 974	ASTM D746	—
	Fluid permeability	6.2.3.2	—	As a minimum to CH_4, CO_2, H_2S, methanol, and H_2O where present; ISO 2556 may be considered as an alternative
Permeation characteristics	Blistering resistance	6.2.3.3	—	—
	Fluid compatibility	6.2.3.4	—	—
Compatibility and ageing	Ageing tests	6.2.3.5	—	—
	UV resistance	—	—	Manufacturer to specify test method; this is only a qualitative test
	Water absorption	6.2.3.6	—	Guidance can be found in ISO 62/ASTM D570
	Environmental stress cracking	ISO 22088	ASTM D1693	—

NOTE 1 The test procedures apply to the property requirements specified in Table 12 and Table 14.

NOTE 2 For the purposes of the requirements for the listed test, the ASTM reference(s) listed is/are equivalent to the associated ISO International Standard, where one is given. Example: For the purposes of the procedure for the resistance-to-creep test, ASTM D2990 is the equivalent of ISO 899-1.

NOTE 3 Where test methods are not specified, the manufacturer may use their own methods as per the requirements of 6.2.1.4.

NOTE 4 The ISO 178 methodology is for guidance only. Testing is for comparable purposes only and is to be preferably strain controlled typically within the range of the operational conditions.

NOTE 5 ASTM D3759 is for films and tapes less than 1 mm thick.

The procedure for the fluid permeability test should typically pressurize one side of the specimen and measure fluid flow at the other side when steady state flow conditions are reached. Tests should characterize the transport of individual permeating species. Diffusion, solubility, and permeation coefficients should be derived. As described in API 17B, these values shall be used in determining the annulus environment for use in-service life evaluation of the armor wires, as required by 5.3.4.

6.2.3.3 Blistering Resistance

Blistering resistance tests shall reflect the design in-service requirements, relating in particular to fluid composition, pressure, temperature, number of decompressions, and decompression rate. Guidance can be found in API 17TR1 for consideration of shielded and constrained test samples. The following conditions shall apply as a minimum.

a) Samples: Samples shall be taken from an extruded polymer sheath.

b) Fluid mixtures: Use gas fluid components of specified environment as documented in the test procedure.

c) Soak time: Use sufficient to ensure > 95 % saturation, as calculated from diffusion coefficients of fluids in the polymer.

d) Test cycles: Use expected number of decompressions in service, or 20 cycles as a minimum.

e) Decompression rate: Use expected decompression rate in service or a minimum 70 bar/min. A lower depressurization rate is acceptable for pressure values below 10 % of the starting pressure.

f) Thickness: Nominal manufactured or as a minimum 6 mm internal pressure sheath wall thickness.

g) Temperature: Use the operating temperature as a minimum.

h) Pressure: Use maximum operating pressure as a minimum.

i) Procedure: After the last depressurization cycle (as a minimum), samples shall be examined at a magnification of 20x for signs of blistering and slitting.

The acceptance criterion shall be that no blistering or slitting is observed.

6.2.3.4 Fluid Compatibility

The manufacturer shall evaluate all constituents of the environment to which the polymer is exposed and perform tests on those components that are considered to possibly have adverse effects on the polymer. The criteria for acceptance shall be verified by an IVA.

Fluid compatibility tests shall be performed to the manufacturers' or material suppliers' documented procedures. These laboratory tests may be used to determine gross incompatibility. These tests shall be based on the design temperature, pressure, and strain. As a minimum, tensile strength, elongation at break, visual appearance, weight, and volume change shall be measured/evaluated. API 17B contains recommendations on test procedures.

6.2.3.5 Ageing Tests

The manufacturer shall have verified ageing models for each polymer in the flexible pipe, where applicable (e.g. for PAs). The models shall be based on laboratory testing and field experience, if available. These models shall predict the deterioration of the polymer under the influence of relevant environmental and load conditions.

The ageing models may include accumulated damage concepts based on blocks of time or operational cycles of temperature/pressure under different exposure conditions. Ageing may be determined by change in either specified mechanical properties or in specified physico-chemical characteristics, which includes reduction in the plasticizer content of the material and uptake of constituents from the fluid environment.

Ageing tests and models shall consider all conditions and combination of conditions that may be relevant for the long-term performance of the polymer for the defined operation. Relevant conditions will be fluid composition, temperature, pressure, treatment chemicals (including dissolved oxygen), and oxygen. In addition to chemical degradation, the ageing tests and models should also, depending on the type of material, address other effects such as deplasticization, fluid absorption, and dimensional stability. Mechanical loads and possible confinement should be taken into consideration where relevant. Transient conditions such as cooldown from gas expansion or treatment resulting in transient heating should be considered where relevant.

For antibuckling layer materials, the assessment of ageing shall include the effect of temperature and annulus environment.

The fluid used in ageing-resistance tests should be representative of the specified internal fluid. Materials that are tensile- or compressive-loaded in service should be tested with similar stresses induced.

6.2.3.6 Water Absorption Test

A water absorption test shall allow for long-term prediction of thermal insulation layer conductivity variation. A relationship should be established for weight gain versus time and for thermal conductivity versus weight gain to allow for extrapolation.

6.2.4 Metallic Materials

6.2.4.1 General

At a minimum, the qualification test program for carcass, pressure armor, and tensile armor layer materials shall include the tests specified in Table 16.

6.2.4.2 SSC and HIC Testing

For sour service static applications, the threshold limits of the steel wire material to HIC and SSC shall be determined following as follows, according to manufacturers' documented criteria.

To determine the resistance of the steel wire material to HIC and SSC, the wires shall be subjected to the NACE TM 01-77 test. The threshold level for the occurrence of SSC and HIC shall be determined by testing multiple specimens to various levels of H_2S and pH. Tensile load tests or four-point bend tests shall be used. Specimens shall be loaded to at least 90 % of the structural capacity. If average wire stress is calculated to exceed 90 % of the structural capacity under permanent extreme or abnormal operating conditions, then the wires shall be qualified for that stress level.

Table 16—Test Procedures for Metallic Materials (Carcass Strip, Pressure Armor, and Tensile Armor Wires) and Weldments

Parameter	Test Procedure	Comments
Chemical composition	ASTM A751/ISO 8457-2	
Tensile properties	ISO 6892	Yield strength/ultimate tensile strength/elongation
Hardness	ISO 6507-1	Sour service applications only (armor wires only)
Sulfide stress cracking (SSC) and hydrogen-induced cracking (HIC) (1) (2)	6.2.4.2	To specified environments (armor wires and carcass materials, if applicable)
Corrosion resistance (fluids, chemicals) (3)	6.2.4.3	To specified environments
Erosion resistance	6.2.4.4	Carcass only
Fatigue resistance	6.2.4.5	Pressure and tensile armors in dynamic applications only
Hydrogen embrittlement	6.2.4.6	Only tensile armor wires where applicable and when exposed to cathodic protection

NOTE 1 Consider SSC and HIC tests for carcass materials, such as duplex stainless steel, that are susceptible to corrosion cracking in environments containing chlorides and H_2S.

NOTE 2 A HIC examination can be carried out after the corrosion test on carcass samples, if required by the purchaser.

NOTE 3 Corrosion tests shall be carried out on the formed material.

The manufacturer shall additionally demonstrate through analysis or testing (duration 720 h) the SSC performance at the actual service conditions of the steel wire material. The actual service conditions comprise the calculated annulus partial pressure of H_2S and the calculated pH in the annulus, in aqueous solution (3 % NaCl minimum) at ambient pressure and temperature. If the manufacturer does not have a verified model for calculating annulus conditions, then pipe bore partial pressures shall be used. Specimens shall be loaded to at least 90 % of the structural capacity. Analysis of the performance from this test may be used to project minimum expected service life for a static application when combined with results of 6.2.4.3 or 6.2.4.4. The CH_4 may be replaced with another inert gas.

Production welds shall be included in steel wires to be validated for sour service applications.

Following a SSC test, the steel wire material susceptibility to HIC should be checked.

6.2.4.3 Corrosion Resistance

Armor wires shall be subjected to the following testing and evaluation, or equivalent documentation provided, and documented in the Design Report 8.4:

a) exposure to aerated seawater (minimum 3 % NaCl), without protective cathodic potential in order to determine corrosion rate, cracking, and localized corrosion;

b) exposure to the predicted annulus environment based on equivalent partial pressures of the transported fluids.

Carcass formed materials shall be tested to specified environments covering installation, storage, and operation to determine the range of applications. The purpose of the test is to determine corrosion rate, cracking, and localized corrosion. Samples should have residual stresses representative of as manufactured pipe.

The corrosion resistance tests may be carried out with a polymer over layer on the sample to simulate the multilayer construction characteristics.

6.2.4.4 Erosion Resistance

The manufacturer shall demonstrate, either with tests or analytical data based on tests, that the innermost layer has sufficient erosion resistance to meet the design requirements for the specified service life; see API 17B for recommendations on erosion tests.

6.2.4.5 Fatigue Resistance

For dynamic applications, steel wires shall be subjected to the fatigue testing and evaluation or equivalent documentation provided. See API 17B for recommendations on fatigue testing methodology. Specimens shall retain as-manufactured surface and only be degreased. The effect of manufacturing process including end-fitting mounting shall be documented.

S-N data shall be documented, justified, or generated for the following testing environments:

a) exposed to air, at atmospheric pressure and ambient temperature;

b) exposed to deaerated seawater (minimum 3 % NaCl), inclusive of H_2S and CO_2 levels for relevant transported fluids at atmospheric pressure and ambient temperature;

c) exposed to the predicted intact annulus environment inclusive of H_2S and CO_2 levels for relevant transported fluids at atmospheric pressure and ambient temperature;

d) consideration should be given to the effects of cathodic protection systems on S-N performance.

NOTE Refer to ASTM E739 (latest revision) for recommendations on the number of samples and statistical analysis to be used to generate S-N data.

6.2.4.6 Hydrogen Embrittlement

The tensile armors shall be subject to testing to confirm that the potential hydrogen evolution resulting from cathodic charging does not result in hydrogen embrittlement. The testing shall be conducted on degreased wire samples immersed in deaerated seawater (minimum 3 % NaCl) with the maximum negative cathodic potential applied. The wire shall be stressed to at least the maximum utilization level expected in service. The cathodic charging shall be applied for a minimum duration of 150 h. Posttest examination shall be conducted to confirm that no blistering or cracking of the wire sample has occurred.

6.2.5 End Fitting

6.2.5.1 Metallic Materials

Test samples used in the qualification of metallic materials for end-fitting components shall be in accordance with the following. The qualification program shall test in accordance with the specified procedure and document the following properties and characteristics of the metallic materials for the primary end-fitting components:

a) chemical composition: ASTM A751;

b) tensile properties: ISO 6892;

c) Charpy impact: 6.2.5.1;

d) hardness: 6.2.5.1;

e) SSC and HIC resistance: 6.2.4.2.

If duplex stainless steel end fittings are specified, they should be tested for pitting resistance in accordance with ASTM G48-03, Method A.

The mechanical properties of forgings shall be determined from test samples that represent the actual component, including being from the same heat and heat treatment batch and having the same forging ratio. The location of test samples shall represent the heaviest thickness and shall be taken in $1/4\,t$ position from outer diameter (OD), where t is the thickness of the component.

If end-fitting components of different dimensions are in the same lot, it is sufficient to test the largest dimensions only, provided the strength requirement is the same in all dimensions.

Charpy V-notch impact testing shall be carried out in accordance with ISO 148-1 for carbon or low-alloy steel forgings. Full-sized Charpy V-notch specimens in accordance with ISO 148-1 shall be used whenever possible. The notch shall be perpendicular to the surface. The test temperature shall be –20 °C (–4 °F) or the design minimum temperature if lower than –20 °C (–4 °F). Energy values shall be in accordance with the manufacturer's specifications, which shall specify minimum single impact energy values and minimum average of three values, acceptable specimen sizes to be 10 mm by 10 mm (0.39 in. by 0.39 in.), 10 mm by 7.5 mm (0.39 in. by 0.30 in.), and 10 mm by 5 mm (0.39 in. by 0.20 in.).

Impact testing is required only for steel materials with thickness above 6 mm and minimum design temperature less than 0 °C (32 °F) or when specified by the purchaser.

The hardness tests of carbon steel forgings and corrosion resistant weld overlays shall be performed in accordance with ISO 6506-1, ISO 6508-1, or ISO 6507-1. The results shall be to manufacturers' specifications, which shall distinguish between sour and sweet service applications. For sour service, hardness values shall be in accordance with NACE MR0175.

6.2.5.2 Epoxy Material

Epoxy samples for testing shall be molded and cured under the same temperature and humidity conditions as when filling the end fitting. The qualification test requirements for the cured epoxy shall be as follows:

a) compression [8] strength or: ASTM D695 (compression) or ASTM D3410 (shear);

b) shear strength;

c) glass transition temperature: ASTM E1356;

d) fluid compatibility: 6.2.3.4;

e) ageing test: 6.2.3.5;

f) degree of cure: DSC to ASTM D5028.

6.3 Quality Assurance Requirements

6.3.1 General

All base materials used in flexible pipe shall be purchased in accordance with either a written material specification or an industry standard. The specification shall include measurable physical, mechanical, chemical, and performance characteristics and tolerances.

All suppliers to the manufacturer shall have a documented quality assurance system.

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8 The manufacturer may choose based on the applicability of the compression or shear data to his/her design methodology.

As a minimum, base materials shall be certified to ISO 10474:1991, Certificate 3.1, (EN 10204:2004, 4.1). Base materials shall be tested in accordance with the requirements specified in Table 17. Test results shall be recorded on material test certificates.

Table 17—Minimum Raw Material Quality Control Test Requirements

Material	Parameter	Frequency	Comments
Polymers	Viscosity	One per batch (1)	Sheath material (PA-12 and PA-11 only); ISO 307 (2) procedure
	Extractables	One per batch	Applies to plasticized materials only
	Impurities	One per batch	Sheath material (3) (with exception of pigmented plastics)
	Density	One per batch	Sheath material (polyethylene only); ASTM D1505 procedure
	Melt flow index	One per batch	Sheath material; ISO 1133/ASTM D1238 procedures
Metallic wires and strips	Chemical composition	One per batch	All wires and strips
	Tensile test	Two per coil (4)	All wires and strips
	Bend test	Two per coil	All wires and strips
	Hardness test	Two per coil	All wires and strips
	Dimensions	Two per coil	All wires and strips; start and end of coil (ASTM A480 procedures for strip)
End fittings	Chemical composition	One per heat (5)	Body material
	Tensile test	Two per heat	Body material
	Charpy V-notch	One set per heat	Body material; subject to 6.2.5.1.4 and 6.2.5.1.5
	Hardness test	One per heat	Body material; subject to 6.2.5.1.6
	Radiography	One	Welded neck only
	Ultrasonic	One	Body material
	Magnetic particle or liquid penetrant	One	Carbon and low-alloy steel surfaces
Antibuckling layer material	Tensile test	One per batch	
	Linear weight		For fiber material only
Epoxy	Compression test	—	See 7.6.4.2

NOTE 1 Only a measurement of viscosity or melt flow index, but not both, is required.

NOTE 2 For the purposes of this provision, ASTM D2857 is equivalent to ISO 307.

NOTE 3 Pigmented plastics cannot be evaluated for impurities.

NOTE 4 A coil is a continuous length of wire from the same forming process, cast, and heat treatment batch. Slitting of mother coils does not change mechanical properties so slit strip does not require further mechanical testing after certification of the mother coil. If intermediate welds used to join coil sections for transport have been validated by the subcontractor in accordance with the manufacturer's procedures, these welds may be kept during winding onto the pipe. If these welds have not been validated, they shall be cut out of the coil during the winding of the pipe.

NOTE 5 Per heat refers to heat treatment batch.

Test results shall conform to the manufacturers' specifications. The results of all tests made by the manufacturer and/or suppliers shall be available for review by the purchaser.

For the internal pressure sheath, polymers shall be 100 % virgin material containing no regrind or other previously processed materials.

Requirements and criteria for surface condition of wires and shaped strips shall be established and documented by the manufacturer. As a minimum, the metallic materials shall have a surface finish free from defects that exceed the acceptance criteria set by the manufacturer and documented in the manufacturing quality plan or fabrication specification.

6.3.2 Documentation Requirements

The manufacturer's written specifications for polymer and metallic materials shall include, as a minimum, the requirements of Table 18.

The specification for end-fitting epoxy material shall include, as a minimum, trademark, grade, and color of resin and hardener, mixing ratio, pot life, molding temperature, and curing temperature and time.

Table 18—Requirements of Material Specifications

Requirements	Metallic Material	Polymer Material
Material composition requirements, with tolerances	X	—
Generic base polymer (in accordance with ASTM D1418)	—	X
Physical and mechanical property requirements	X	X
Allowable melting and forming practices	X	—
Heat treatment procedures	X	—
Storage and age control requirements	X	X
Nondestructive examination requirements	X	X
Acceptance and/or rejection criteria	X	X
Certification and records requirements	X	X
Marking, packaging, handling, and traceability requirements	X	X

6.3.3 Storage

The manufacturer's quality plan shall show procedures for handling, storage, and control of raw materials, which reflects the importance of material cleanliness, dryness, purity, and traceability during each stage of manufacture.

All raw polymer material shall be protected from contamination and water ingress during handling and storage. Contaminated material shall be rejected.

6.3.4 Traceability

Materials shall be traceable and suitably marked for easy identification. In the case of polymer materials, the type of polymer and the supplier's name and designation shall be identified. The marking of primary end-fitting metallic components shall ensure traceability to the base material.

7 Manufacturing Requirements

7.1 Quality Assurance Requirements

7.1.1 General

Manufacturing operations shall be performed in accordance with the manufacturer's written fabrication specifications and manufacturing quality plan, which shall conform to the requirements of Section 7. Processes requiring validation, including welding, heat treatment, and coating, shall be performed in accordance with the requirements of 7.7. The manufacturer shall maintain documentation of the validation of processes that require it, for review by the purchaser or a mutually agreed IVA.

Nondestructive examination (NDE) shall be performed in accordance with the requirements of ISO, ASTM, or equivalent standards.

Quality assurance requirements for materials to be used in the pipe manufacture shall be as specified in 6.3.

7.1.2 Process Control

All the main steps in the manufacturing process shall be subject to inspection. The manufacturer's quality plan shall specify inspection points, inspection methods, and acceptance criteria. Results of all inspections shall be recorded. The manufacturer shall record every nonconformance verified during manufacture of the pipe. All manufacturing nonconformance reports and actions adopted to correct it shall be available for review by the purchaser and included in the as-built documentation; see 8.8. Process control shall be performed as a minimum for the following manufacturing process as applicable:

a) carcass: preparation and winding of flat steel strip, welding of flat steel strip sections, preforming, cold forming of carcass, reeling of interlocked carcass, preheating, and drying prior to extrusions;

b) polymer layers: drying of pellets, extrusion and cooling of polymer, and reeling of sheathed pipe;

c) pressure armors: preparation of wire, feeding of pipe, winding of pressure reinforcement, welding of shaped and flat wire sections, and coil reeling;

d) tensile armors: preparation of wire, feeding pipe, winding of armor wires, welding of armor wires, application of tape, and coil reeling;

e) antibuckling tapes: winding of antibuckling tapes;

f) end fittings: mounting process, preparation and cold or hot forming of the armor wires, and resin injection.

For each manufacturing condition that is outside the qualified manufacturing procedure, qualified engineering personnel shall assess and justify corrective actions and define objective acceptance criteria.

During manufacture, the manufacturer shall take measures to ensure that all measurements are within manufacturer's tolerances.

7.1.3 Handling During Manufacture

The manufacturer shall have documented procedures for handling of intermediate and finished products during manufacture, packing, and storage. The procedures shall ensure that any anomalies resulting from pipe abrasion, mechanical damage, torsion, bending, and crushing when winding/unwinding pipe on reels and carousels or during end-fitting assembly do not exceed manufacturing tolerances.

The condition of all reels, carousels, guides, and rollers shall be such that they do not induce any damage to the pipe. Packing shall be checked for center of gravity to ensure that there is no risk of rotating unbalance that could cause unplanned/uncontrolled reel rotation

The manufacturer shall ensure that contamination of the pipe and end fitting due to foreign material is avoided.

The manufacturer shall use documented procedures for the rewinding of flat or shaped wires from the supplier's shipping reel to the manufacturer's reel or bobbin.

7.2 Carcass

7.2.1 General

Carcass profile conformance to manufacturer's acceptance criteria shall be documented at the start and end of each production run. The occurrence of sharp edges in the formed carcass layer shall be prevented.

For carcass layers made up in sections, or when two sections of carcass are joined, for example, in case of repairs, the join-up procedures for the sections shall be validated for all loads expected at the locations of these connections and documented. The manufacturer shall ensure that the minimum distance between carcass join-up welds shall be specified in the manufacturing quality plan. Carcass join-up welds should be avoided in high bending regions (e.g. bend-stiffener region).

7.2.2 Inspection and Acceptance Criteria

The external surface of the as-formed carcass and armor layers shall be visually examined for flaws, including dents, cracks, scratches, shavings, gouges, corrosion, scaling, discolored areas (blurring, scorching, staining, and the like, except at welds), distorted or buckled strip or wire profile, and significant scoring. Carcass profiles shall be additionally inspected for lack of interlock at the start and completion of each production run. The carcass profile interlocking shall be checked for sufficient freedom of movement to prevent alternating stresses above allowable values. The manufacturer should have acceptance criteria for the allowable freedom of movement.

The outside diameter and ovality shall be measured and interlock checked at the start of the production run. Subsequent to this, these parameters shall be controlled (measured or checked) at least every 10 m for the first 50 m and subsequently at intervals demonstrated by the manufacturer to be acceptable. The manufacturer shall record process data at intervals, agreed with the purchaser, throughout the process. All results shall be recorded and shall be to manufacturer's specifications, which shall conform to the tolerance requirements of 7.8. During the production run, the carcass shall be checked for fishscaling.

Carcass pitch shall be measured and documented after end-fitting termination from both ends. In addition, the average pitch over the length of the finished pipe shall be provided.

7.3 Polymer Extrusions

7.3.1 General

Extrusion of thermoplastic material shall be performed in accordance with the manufacturer's documented procedures. Each extrusion shall be controlled in accordance with an approved setup sheet that provides settings for all essential variables based on the material and sizing of the product. The manufacturer shall have documented records to show that detrimental folding does not occur in the layer for the polymer material and wall thickness to be extruded.

The manufacturer shall ensure that, for rough bore pipes, all extrusions are onto an underlying layer whose external surface conforms to the manufacturer's extrusion procedures. During extrusion, the supplier shall ensure that the carcass pitch is within the specified tolerances.

During extrusion, the following process parameters shall be monitored and recorded and shall conform to the manufacturer's specifications:

a) temperature and pressure (or dew point) of raw material humidity control equipment,

b) extruder-screw feeding rate (or screw revolutions per minute),

c) extruder-barrel temperatures,

d) extruder-barrel pressures,

e) extruder-crosshead temperatures,

f) extruder-crosshead pressures,

g) rate of travel,

h) quenching water temperature.

The manufacturer shall test and ensure that the moisture content of hygroscopic materials is within supplier-specified tolerances prior to commencing the extrusion process. If PA or thermo-plastic elastomer (TPE) is used, the moisture content shall be tested in accordance with ASTM D789 (or ASTM D6869) procedures and shall be to the manufacturer's specifications.

Procedures and tools used for perforation of intermediate layers for gas-venting purposes shall not induce defects in underlying layers. Perforation by melting with heated tooling is preferred.

Cutting procedures shall be documented not to cause crack initiation points or otherwise weaken the area of cutting such that the functional requirements of the polymer layer are violated.

The manufacturer shall document procedures in the fabrication to control the following processes:

a) surface grinding,

b) processes to remove plasticizer,

c) cross-linking,

d) stress relieving,

e) other processes requiring validation.

7.3.2 Inspection and Acceptance Criteria

7.3.2.1 Visual Examination

The manufacturer's specifications shall document acceptance criteria for flaws as a function of category (individual or cluster), size, position in material thickness, distance between flaws, and number. A visual examination of the entire polymer layer external surface shall be performed to identify flaws, including holidays, bubbles, inclusions (black spots), discoloring, surface irregularities, extrusion weld lines, die scratches, die drools, notches, and indentations. All flaws shall be in accordance with the manufacturer-specified acceptance criteria.

The maximum dimensions of each flaw or combination of flaws shall be such that the total remaining thickness of the layer shall be at least equal to the minimum design thickness.

7.3.2.2 Dimensional Measurements

Thickness and diameter measurements, and their location, of the extruded layers shall be recorded at intervals, agreed with the purchaser, throughout the whole extrusion at 90° intervals around the circumference. Diameter measurements shall take due account of the effects of ovality on the measured diameter. The manufacturer shall record process data at intervals, agreed with the purchaser, throughout the extrusion process. Measurements shall be taken after the cooling process.

7.3.2.3 Test Requirements

For extrusion onto a metallic layer, the extruded internal pressure sheath shall be subject to a continuous high-voltage spark test or equivalent test, calibrated to detect a 1 mm (0.04 in.) or smaller hole. The holiday detector shall be calibrated prior to the extrusion of the polymer layer material and thickness that is extruded. The detector shall be provided with an audible alarm.

For each extrusion of the internal pressure and outer sheath layers, a minimum of three samples shall be taken from both initial and final extruded sections and subjected to tensile test in accordance with the procedures specified in Table 15. Additionally, for pressure sheaths, PA samples shall be subjected to corrected inherent viscosity (CIV) measurement in accordance with manufacturer procedures and crosslinked polyethylene (XLPE) coupons shall be tested to check that the cross-linking process has been performed successfully. The samples shall be stored at ambient temperature for a minimum of 6 h prior to testing. All test results shall be recorded and shall conform to the manufacturer's specifications.

7.4 Pressure and Tensile Armor Layers

7.4.1 General

The manufacturer shall have documented procedures for the winding of the pressure armor and tensile armor layers onto the pipe, which shall ensure that the flat, round, or shaped wires are laid to the design requirements. The procedures shall include requirements for the condition of the wires prior to winding and for the condition of the finished layer, such that the layer and underlying or overlying layers meet the manufacturer's specifications.

The procedures shall specify all parameters and allowable tolerances that are to be monitored and recorded at intervals verified by the manufacturer to be acceptable. The recorded values shall conform to manufacturer's specifications. As a minimum, diameter and pitch (for lay angle) shall be measured, as well as the ovality of the pressure armor. During the production run, pressure and tensile armors shall be checked against fishscaling of wires that exceed allowable tolerances.

All welds shall be staggered along the length of the pipe in conformance with the manufacturer's specifications, which shall specify a minimum separation between welds.

Welds on the pressure armor wire should be avoided in the fatigue-critical areas (e.g. hangoff and touchdown areas).

7.4.2 Inspection and Acceptance Criteria

The pressure and tensile armor layers shall be visually examined in accordance with the requirements of 7.2.2.

The outside diameter, pitch (or lay angle), ovality, and the circumference (to check the gap between pressure armor and internal pressure sheath) of the pressure armor shall be measured and recorded at least every 10 m for the first 50 m and subsequently at intervals verified by the manufacturer to be acceptable and during each stop/reversal cycle. Diameter measurements shall take due account of the effects of ovality on the measured diameter. The results shall be within the tolerances specified in 7.8. Armor layers shall be additionally inspected for wires on edge, fishscaling, and wire twist.

7.5 Antiwear, Insulation, and Antibuckling Tape Layers

7.5.1 General

The manufacturer shall ensure that antiwear layers, taped layers used as manufacturing aids, insulation layers, and antibuckling tapes are applied in accordance with documented procedures. The procedures shall include requirements for control and monitoring of antiwear tape or antibuckling tape application and overlap of extruded profiled strip and shall document acceptance criteria for flaws.

7.5.2 Inspection and Acceptance Criteria

The external surface of the antiwear, insulation layers and antibuckling tapes shall be visually examined over the entire length for flaws, including damage, distortion, folds, and lack of interlock (for profiled insulation strip). Identified flaws shall conform to the manufacturer's specifications. Lack of interlock in profiled insulation strip layers shall not be acceptable.

The outside diameter shall be measured and recorded. The pitch and width (between adjacent layers) of antibuckling layers shall be measured and recorded during setup and at each stop for change. These measurements shall be subsequently verified at intervals by the manufacturer to be acceptable. The results shall be within the tolerances specified in 7.8.

7.6 End Fitting

7.6.1 General

All operations in the manufacture, machining, assembly and inspection of end fittings shall be performed in accordance with the manufacturer's specifications, which shall meet the requirements of 7.6. All fitting operations shall be performed by personnel (end fitters) qualified in accordance with the manufacturer's approved procedures. The qualifications of end fitters shall be documented and shall be available for review by the purchaser and by the IVA.

7.6.2 Assembly

Before mounting the end fitting on to the pipe, all exposed surfaces shall be cleaned, dried, visually inspected, and confirmed to be in accordance with the requirements of the manufacturer's specifications. Lubricants used during tensile armor formation shall be fully removed if relevant for the mounting procedure.

In the preparation of the internal pressure sheath under the end-fitting seal ring, any machining of this area shall not introduce unacceptable notches or reduce the thickness of the sheath to less than the minimum design thickness. Acceptance criteria for out-of-roundness, wall thickness variations, and surface roughness in this area shall be specified.

Control features shall be established and documented to ensure that overheating of epoxy or polymer layers is prevented during welding operations.

Any permanent welding procedures (e.g. tack welding) used to maintain the armor wire configuration shall be carried out under controlled conditions. All welded surfaces shall be ground smooth and examined for cracks in order to avoid damage to adjacent layers or components.

Prior to mixing the epoxy resin, all equipment required for the filling operation shall be checked for proper functioning. The mixing and curing of epoxy resin shall be in accordance with the supplier's specifications. Filling shall be carried out in such a way that unacceptable voids do not occur. Gas vent tubes in the end fitting shall not be obstructed by the epoxy. Any resin cure process that requires the heating of the end fitting shall be carried out with proper temperature control.

All tensile armor wire profile forming processes in end-fitting assemblies that change the wire mechanical and geometric characteristics in the end fitting shall be controlled and documented. Wire profile forming processes shall be carried out by using a former as a guide to radius control. During wire forming, the orientation of the wires and distribution of gaps between them shall be controlled. If heating is used during wire forming, temperature shall be controlled and also taken into account during design. These controls shall be part of the manufacturer assembly procedures.

The manufacturer shall have documented procedures in the fabrication specification for dimensional control of the cutting processes for the armor and end-fitting assembly parts to assure that there is no gap that could allow creep of the internal pressure sheath in excess of that specified in Table 8 during hydrostatic pressure testing and in operation.

7.6.3 Inspection and Acceptance Criteria

For the end-fitting assembly, hold points shall be included where visual examination, dimensional control, and component identification are performed. Results from all inspections shall be documented.

For components requiring a specific tightening force or torque, it shall be verified using suitable and calibrated equipment that the specified value has been obtained.

The manufacturer shall use a validated and documented procedure to verify that sufficient epoxy resin has been injected into the end fitting, such that no voids are left in the end fitting that would affect its functional performance. Control of resin injection shall include as a minimum resin composition, mixing process, injection duration, and curing time. The volume injected shall be checked.

7.6.4 Test Requirements

Minimum test and inspection requirements for primary end-fitting components shall be as follows, and all results shall be in accordance with manufacturer's specifications:

a) all surfaces: 100 % visual examination;

b) carbon and low-alloy steel surfaces: 100 % magnetic particle or liquid penetrant inspection when geometry prevents magnetic particle inspection (MPI);

c) weld overlay surfaces: 100 % liquid penetrant, thickness, adhesion, hardness;

d) end-fitting bodies: 100 % ultrasonic test;

e) circumferential butt welds: 100 % radiographic test;

f) coating:

   1) paint and epoxies—thickness, adhesion,

   2) electrochemical deposition coatings—chemical composition, metallography of the interaction between base material and coating, liquid penetrant.

On completion of epoxy resin injection, a minimum of three samples shall be taken from the same mix as used for the end fitting. Results from compression strength tests shall be carried out in accordance with ASTM D695 procedures. The compression strength shall be within the range specified by the manufacturer for the cured epoxy.

7.6.5 Connectors

All end-fitting connectors and components shall be in accordance with API 6A, API 17D, other recognized industry standard, or as specified by the purchaser and shall meet the requirements specified in 4.6.1.9.

7.7 Processes Requiring Validation

7.7.1 Welding

7.7.1.1 Validation

All welding operations shall be performed by qualified welders in accordance with the manufacturer's approved procedures. Welding procedure specifications (WPS's), welding procedure qualification records, and welder qualifications shall be documented and shall be available for review by the purchaser. Welding procedure validation shall be witnessed and approved and records of welder qualification shall be reviewed by an IVA who is qualified to witness and approve the standards and criteria being used. For welding performed with automated processes or for welds that serve only as manufacturing aids, the IVA of welder qualifications may be substituted by an American Society for Nondestructive Testing (ASNT) qualified Level II inspector. The purchaser shall have the option of witnessing the validation of all welding procedures and the qualification of all welders and shall be given appropriate notice of the timing by the manufacturer. Welders shall be qualified and welding procedures shall be validated in accordance with one of the following standards: ASME *Boiler and Pressure Vessel Code* Section IX, EN 287-1, ISO 13847, or equivalent. Procedures shall include acceptance/rejection criteria.

NOTE For the purposes of this provision, API 1104 is equivalent to ISO 13847.

As a minimum, qualification testing for flat, round, and shaped wires to be used for sweet-service applications shall include visual inspection, MPI, two tensile tests and either two-face or side guided-bend tests. The weld tensile test results shall have an ultimate tensile value equal to or greater than the minimum acceptable weld tensile value established by the manufacturer for the design application. Minimum tensile values shall be included in the WPS. The diameter of the guided-bend test mandrel shall be such that sufficient mechanical stress is introduced in the weld zone to show weld quality. For sour service, in addition to the above testing, a macro and hardness survey shall be performed. The macro shall be polished, etched, and examined at a minimum of 10x magnification. Hardness tests shall be performed on the same sample. One test each, as a minimum, shall be made in the fusion or bond line, heat-affected zone (HAZ), edge of HAZ, and unaffected base metal. Hardness test shall be to HV5 or HV10 (ISO 6507-1) or HV500 (ASTM E384). Results of all tests shall be in accordance with the manufacturer's specifications.

The manufacturer shall have documented procedures for storage, handling, and drying of welding consumables.

7.7.1.2 Metallic Layers

Every time there is a change in welding machine setup, a minimum of two test welds shall be made to verify the setup. The samples shall include all production heat treatments. The sample welds shall be subjected to the following tests as a minimum:

a) ultimate strength,

b) hardness (sour service),

c) bend,

d) dye-penetrant or magnetic particle,

e) visual examination as specified below.

The dye-penetrant test is required for nonmagnetic alloys and the magnetic particle test is required for magnetic steel grades, and the test shall be performed after the bend test. Visual examination at 5x magnification of the weld HAZ at the outer surface of the bend may be used as an alternative to the magnetic particle test. The hardness test shall be performed in the area with maximum cold deformation. For carcass strip welds, only visual examination is required. Results from all tests shall be documented and shall be within the manufacturer's specifications.

Production welds shall exhibit a smooth surface across the full strip width and show full penetration. There shall be no cratering, edge washing, or burn-through of the strip. The weld thickness shall be, as a minimum, that of the sheet thickness and shall be maximum 1 mm (0.04 in.) above the surface. The weld shall be consistent across the strip with no undercut at the toes. For carcass join-up welds, the manufacturer shall ensure that all weld metal is ground smooth to prevent damage to extruded overlying layers.

Butt welds for joining carcass and armor layer wires and strips and for carcass join-up welds shall be subjected to the following inspection requirements:

a) carcass strip: 100 % visual examination,

b) carcass join-up: 100 % visual examination,

c) steel wire: 100 % visual examination and magnetic particle test.

The 100 % visual examination shall be performed prior to the steel's passing through the machine forming tools. The external surface of the weld shall also be examined for cracks after passing through the forming tools. Cracks shall not be allowed.

Butt welding of shaped wires shall utilize automatic or semiautomatic welding devices.

7.7.1.3 Polymer Layers

Repair welding of polymer layers, as permitted under the requirements of 7.9, shall be performed in accordance with the manufacturer's validated procedures, which shall be available for review by the IVA and purchaser. The welding procedures shall contain acceptance/rejection criteria.

Inspection of polymer weld repairs shall check that the layer wall thickness and surface conditions conform to the manufacturer's specifications.

7.7.1.4 End Fitting

All circumferential butt and overlay welds shall be performed in accordance with validated and documented procedures. Inspection and test requirements shall be as specified in 7.6.4.

7.7.2 Heat Treatment

Wires and cold-worked or forged components that require heat treatment in order to meet specified requirements for strength, formability, or NACE compliance shall be heat treated in accordance with the manufacturer's specifications. The heat treatment procedures and chart shall be maintained by the manufacturer or subcontractor for review by the purchaser.

7.7.3 Coating

Coatings applied to end-fitting components to limit corrosion due to internal, external, or annulus environments shall be applied in accordance with the manufacturer's documented procedures, which shall include acceptance and rejection criteria.

The procedure for qualification of the electroless nickel coating processes to be applied to the end fitting shall specify the following as a minimum:

a) bath composition;

b) control of temperature and time for heat treatments;

c) hardness test of coating;

d) adhesion test of coating;

e) optical microscopy or a similar method recommended to analyze the cross section of the coated surface;

f) coating thickness measurement;

g) testing to confirm the resistance of coating to corrosion agents (e.g. seawater and CO_2);

h) procedures for checking surface coating for flaws;

i) coating repair method and qualification, if any.

7.8 Manufacturing Tolerances

The manufacturer shall document the tolerances to be used for each layer of the flexible pipe. These tolerances shall be verified in the design process to be acceptable, such that the functional requirements of the individual layers and pipe are unaffected by variations within the specified tolerances and changes in utilizations are in accordance with 5.2. As a minimum, tolerances shall be specified for the following parameters:

a) carcass: external diameter, ovality, and fishscaling;

b) polymer sheaths: thickness and external diameter;

c) pressure and tensile armors: external diameter, pressure armor ovality, pitch (or lay angle), and fishscaling;

d) tensile armors: external diameter, pitch (or lay angle), and fishscaling;

e) antibuckling tapes: pitch (or lay angle) and overlap (between adjacent layers).

The tolerance for the length of the flexible pipe shall be specified.

For pipes without pressure armor, the manufacturer shall demonstrate that tensile armor wire gaps are controlled such that the design requirements are met.

If dimensional criteria are based on manufacturing considerations rather than design considerations, the manufacturer shall document that the criteria used meet the design requirements.

7.9 Repairs

The manufacturer shall have documented, validated procedures for performing repairs, and these procedures shall be available for review by the purchaser. The manufacturer shall document by additional tests and/or calculations that the repairs to the flexible pipe do not compromise the structural or long-term requirements of the pipe. The purchaser shall have the option of witnessing all repairs and shall be given appropriate notice of their timing by the manufacturer.

Repair of the internal pressure sheath is not permitted. Unacceptable defects found in this layer shall result in complete removal of the layer. Removal procedures are subject to review by the purchaser. Rework by machining of the internal pressure sheath may be carried out to remove superficial discontinuities or localized excessive thickness, provided that the final thickness complies with the specified layer tolerances and that a proper surface finish is assured.

Repair of minor flaws in intermediate or external polymer layers, but not any pressure-containing layers, is permitted. Polymer welding shall be performed as specified in 7.7.1.3. All repairs, including offshore repairs of outer sheaths, shall be performed in accordance with validated procedures and shall not introduce defects into underlying layers. The purchaser shall be permitted to inspect all repairs carried out. Outer sheath repair shall not result in OHTC exceeding the requirements of 4.6.1.4 and 5.4.3 due to damage to the insulation.

Any defects in armor metal welds shall be repaired by cutting out the weld and HAZ and rewelding according to the specified procedures. Carcass weld repairs are permitted, provided a validated repair procedure is used and visual inspection confirms the weld repair is acceptable. Inspection requirements for repair welds shall be as specified in 7.7.1.

Procedures for repair of damage to surface protection coatings shall be available for review by the purchaser.

Butt weld repair shall comply with all the applicable required guidelines of API 6A, product specification level (PSL) 2 and PSL 3 unless PSL 4 is specified by the purchaser. (See Table B.1, "Additional Requirements.")

Tooling used for removal of defective layers inclusive of antibuckling tapes shall be such that defects are not introduced into underlying layers. Special care is required when removing an extruded sheath to avoid contact between the knife and underlying armors.

8 Documentation

8.1 General

The minimum documentation that the manufacturer is to have available for the purchaser shall be as specified in Section 8. The documentation requirements for materials and manufacturing shall be as specified in the relevant subsections of this specification.

The manufacturer shall have available for the purchaser the following documents and should have them available at the specified times:

a) pipe datasheet: prior to pipe manufacture;

b) design premise: prior to pipe design;

c) design load report: prior to manufacture;

d) design report: prior to manufacture;

e) manufacturing quality plan: prior to manufacture;

f) fabrication specification: prior to manufacture;

g) as-built documentation: before delivery of the pipe and any time on request;

h) operation manual: prior to delivery;

i) qualification/validation test procedures: prior to test run (if production tests are required);

j) qualification/validation test reports: before commencement of manufacture or before the delivery of (if production tests are required) the pipe, as per contractual agreement.

8.2 Design Premise

The design premise shall contain the parameters specified in Table 19. If the manufacturer has made assumptions on any of the parameters in Table 19, then it shall be specified in the design premise that the values are assumed. The design premise shall include all technical requirements and recommendations contained in the purchaser specification.

Table 19—Documentation Requirements for the Design Premise

Parameter	Comments
Internal fluid parameters	All relevant internal fluid parameters, including, as a minimum, the parameters specified in Table 1.
External environment	All relevant external environment parameters, including, as a minimum, the parameters specified in Table 4.
System description	All relevant system parameters, including as a minimum, the parameters specified in 4.6.
Service life	Including, where relevant, maintenance and replacement programs.
Design load case combination	All potential load cases for the flexible pipe system during manufacture, storage, transport, testing, installation, operation, and retrieval shall be addressed. A matrix showing the load cases to be checked for each component of the flexible pipe system shall be established and shall conform with the requirements of Section 5.
Design accidental events	All accidental events and combinations of accidental other loads (functional and environmental) shall be specified. The load cases shall be included in the load case matrix.
Design criteria	Required safety margins and definitions of structural capacity shall be specified for each layer of the pipe and components and shall conform with the requirements of Section 5.
Analysis methodologies and parameters	These shall include hydrodynamic coefficients, structural parameters, and seabed parameters; regular/irregular wave approach, extreme value; consideration of currents and relative wave-to-vessel headings for fatigue and interference analyses; and verification of critical analysis assumptions.
Software tools	All software tools intended for use for the identified analysis methodologies including global pipe configuration tools and local component stress/strain/deflection tools. The verification and validation of each software tool shall be available for purchaser review.

8.3 Design Load Report

The design load report shall include results from analyses of load cases defined in the design premise. Calculated stresses and strains shall be reported for each design load case. The design load report may be incorporated into the design report.

For dynamic applications, this report shall describe the extreme, fatigue, and interference analyses and shall compare the results from those analyses with the relevant acceptance criteria.

When applicable, the report shall include results from analyses of upheaval buckling and lateral pull-back and document pressure and temperature expansion coefficients and associated internal pressure area, as well as pipe variation of axial and bending stiffnesses with pressure and temperature.

8.4 Design Report

The design report shall contain a detailed description, including drawings, of each pipe component. The description shall include a layer-by-layer description of the pipe, including specification and properties (original mechanical properties, “as-specified” in the mill/subvendor plant, and those considered for dimensioning the pipe, e.g. after forming process in the pipe) materials, wire cross section, lay angle, diameter, thickness, and number of wires.

Unless separate material specification documentation is issued, material specification and data shall be included in the design report. Material data shall include yield or tensile strengths and fatigue parameters for dynamic service (S-N curve slope, intercept, and endurance limit) and shall identify fluid components that can adversely affect the material.

Each component shall be documented to have sufficient structural capacity to sustain the design loads and stresses listed in the design load report, with the safety margin specified in the design premise and agreed with the purchaser.

The design report shall define or record the conditions, features, capacities, or properties listed below for the flexible pipes. The design report shall include schematic drawings of the layer-by-layer pipe structure and end fittings. Wherever mentioned, “permissible” means a maximum load to which the pipe can be subjected without any damage or restrictions for future use including its service life. The cause, origin, and location of the predicted damage or restriction shall be included in the report. The report shall also include:

a) diameters (internal and external);

b) weight per meter (in-air empty and seawater-filled, and in-seawater empty and seawater-filled);

c) internal and maximum differential design pressures;

d) design temperatures;

e) design water depth;

f) MBR (storage and operating);

g) axial stiffness (in both tension and compression, and as a function of pressure and temperature);

h) bending stiffness (as a function of tension, pressure, and temperature);

i) torsional stiffness (as a function of twist direction, tension, pressure, and temperature);

j) collapse resistance of the internal pressure sheath (for smooth bore pipes) when requested by the purchaser;

k) collapse resistance of rough bore structures in bent configurations considering hydrostatic pressure applied to outer sheath, intermediate sheath if applicable, and pressure sheath;

l) permissible tension (as a function of bend radius);

m) permissible axial compression (true wall) under the following conditions:

   — straight/operating bend radius,

   — intact annulus/annulus flooded with deaerated seawater,

   — 0 °/m and 1/2 °/m torsion;

n) permissible crushing (radial), associated with the squeeze effect from the tensile armors, for the pipe section under the loading induced by the specified laying equipment, pipe empty and full of seawater;

o) permissible twist (as a function of relevant parameters if applicable) if required by the purchaser;

p) axial and radial expansion or contraction induced by the maximum design pressure and design minimum and maximum temperature;

q) induced twist due to maximum design pressure and design tension;

r) results of the global, service life and local analyses for the specified installation and service conditions;

s) pipe hydrostatic collapse and buckling resistance for a straight pipe and a pipe at operating bend radius (OBR) at design water depth, considering, the effects of the crushing loads from the specified installation methods, equipment, and conditions and intact annulus and annulus flooded with deaerated seawater;

t) drawings (not including manufacturing drawings), specification and properties of materials, data used in calculations, accurate dimensions regarding interfaces, and design calculations of end fittings, ancillary components and accessories (fatigue included for items subjected to relevant dynamic loading);

u) restrictions imposed by collapse and buckling resistance, such as,

— requirement to install empty/full,

— temporary storage requirements (onshore or on the seabed),

— allowable linear decompression rate.

The IVA's certificate for the design methodology (see 5.2) shall be included in the design report.

8.5 Pipe Datasheet

The pipe datasheet shall provide a detailed description of the layer-by-layer cross-section configuration of the flexible pipe. For each steel layer, the number of wires, lay angle, and structural capacity shall be provided.

In addition, the pipe datasheet shall specify the properties of the flexible pipe as per 8.4.

NOTE Guidelines on the minimum requirements for flexible pipe datasheets are given in Annex C.

8.6 Manufacturing Quality Plan

The manufacturing quality plan shall specify all quality control procedures, including process control, inspection points, manufacturing tolerances, and test procedures, as per Section 7. The manufacturing quality plan may be included in the manufacturer's fabrication specification.

8.7 Fabrication Specification

The manufacturer's fabrication specifications shall ensure that the pipe is in accordance with the design.

The manufacturer's fabrication specifications shall document the following as a minimum:

a) layer-by-layer and step-by-step description of the manufacturing procedures, including quality control, welding, heat treatment, type and extent of NDE and acceptance criteria, FAT procedures, fabrication method, and allowable repair procedures, for the complete flexible pipe (i.e. all layers, sublayers, lubricants, tapes, antibuckling tapes, end fittings, and any other items forming an integral part of the final product);

b) procedures for processes requiring validation;

c) references to specifications and sources of all materials used in the manufacture of the flexible pipe, including the materials used for the manufacture of the layers and materials such as lubricants, corrosion-coating materials, antiwear, and nonmetallic tapes;

d) all parameters related to the quality of the final product that can be monitored during the manufacturing process. Both nominal values and ranges of these parameters shall be specified;

e) procedures for dimensional control of the layer termination processes (e.g. cutting of pressure armor wires) and of end-fitting assembly to avoid gaps into which pressure sheath extrusion can occur during hydrostatic pressure testing and operation;

f) procedures for dimensional control of the cutting processes for the pressure armor and end-fitting assembly parts;

g) all processing that converts or affects material properties, including extrusion, welding, and plastic deformation of metal. The specification shall include a statement of applicable scope, limits on critical process parameters, inspection and test methods, and acceptance/rejection criteria.

The manufacturer's fabrication specifications shall be approved by the engineering and manufacturing personnel designated by the manufacturer. Documents shall be maintained available for check by the IVA (if required). The manufacturer’s fabrication specifications shall be controlled documents and shall be readily available to the process machine operator.

The manufacturer shall keep on file throughout the specified service life of the pipe all documentation pertaining to the pipe manufacture, including manufacturing records, certificates, inspection, and FAT documentation.

8.8 As-built Documentation

The as-built documentation shall include, as a minimum, the following:

a) purchase order reference number;

b) equipment descriptions;

c) references to design specifications and drawings;

d) certificates of conformance for all materials included in the flexible system;

e) dimension control measurements;

f) FAT results;

g) factory acceptance test methods and results for testing of intermediate sheath sealing in end fittings when requested by the purchaser;

h) all reports of nonconformities identified during manufacture, repairs, and inspections performed after repairing, including the traceability of the affected region and its location with respect to the pipe end fitting or position in the accessory;

i) WPS’s and validations;

j) welder qualification records;

k) weld map;

l) NDE operator qualifications and NDE test records;

m) heat treatment records;

n) pipe maximum and minimum OD and length between end fittings;

o) drawings of ancillary components and accessories, indicating dimensions, SWL, weight, and summarized assembly instructions (specified torque bolts);

p) drawings of ancillary components and accessories mounted on the flexible pipe prior to delivery, indicating dimensions, SWL, weight, and summarized assembly instructions (specified torque bolts);

q) the axial capacity of the carcass termination in the end fitting, and as-built geometry of carcass pitch and carcass termination in end fitting and in the first 1.0 m pipe adjacent to the end fitting—on purchaser request.

8.9 Operation Manual

The operation manual shall be prepared for the system and shall address all maintenance tasks and restrictions, and emergency procedures, as specified by the manufacturer or purchaser. The manual shall include the following as a minimum:

a) the pipe datasheets;

b) installation requirements;

c) interface requirements;

d) handling, storage, winding/unwinding procedures, and limitations;

e) gas-venting system description and permeation rate;

WARNING—The maximum pipe retrieval rate should be determined to allow accumulated gas to safely escape the from the pipe annulus.

f) allowable decompression/compression rates and possible restrictions in compression/decompression related to type of structure or service—water gas or multiphase;

g) restrictions on internal fluid components including H_2S, CO_2, acids, bromides, amines, and inhibitors;

h) pigging and TFL capabilities and relevant restrictions (pigging is generally not recommended for smooth bore pipes);

i) allowable maximum loads and top angle (risers);

j) maximum time with seawater or inhibited seawater in pipe and inhibitor requirements;

k) reference for as-built documentation;

l) detailed in-service inspection, monitoring, and maintenance/replacement plan, where relevant;

m) collapse resistance of the internal pressure sheath for smooth bore pipes when requested by the purchaser.

The operation manual shall include all flexible pipe and flexible pipe system limitations identified by the manufacturer having regard to the safety, including temperature limits and testing.

If specified by the purchaser, a separate installation manual shall be supplied, and this shall document the installation procedures.

If specified by the purchaser, a separate repair manual shall be supplied, and this shall document repair procedures, including those applicable during installation. The procedures shall contain the list of required equipment, materials, qualified personnel, logistic, and facilities.

9 Factory Acceptance Tests (FATs)

9.1 General

The flexible pipe shall be subjected to FATs, including gauge, hydrostatic pressure, electrical continuity, electrical isolation, gas-venting system, and sealing tests, as applicable, to verify the manufacture of the pipe to the requirements of this specification. The purchaser shall have the option of witnessing all tests and shall be given appropriate notice of the timing by the manufacturer.

The hydrostatic test shall be required for all pipes. The electrical continuity and electrical isolation tests shall be required for pipes that are cathodically protected. The gauge and electrical isolation tests are applicable only to rough bore structures. The gas-venting system and sealing tests shall be required for pipes that have gas relief valves or ports installed in the end fittings. The sealing tests shall be required for dynamic applications only. Table 20 summarizes the required tests.

NOTE For test samples, not all FAT specified in Table 20 may be required.

The manufacturer's specifications shall specify the minimum time that shall elapse between the completion of the end-fitting mounting (including epoxy curing) and the start of the acceptance tests. The acceptance test program shall comply with this minimum time.

A report for each acceptance test shall be submitted to the purchaser. Current certification/calibration certificates for all test equipment shall be included in the test report. All pressure-recording equipment shall be calibrated against a dead-weight tester at least every three months.

If the acceptance criteria for a test are not met, the cause of the failure shall be investigated and a report submitted to the purchaser. Proposed corrective action shall be included in the report.

9.2 Gauge Test

9.2.1 Purpose

The purpose of the gauge test is to detect blockages and any gross deformations.

Table 20—Factory Acceptance Test

		Gauge Test	Hydrostatic Pressure Test	Electrical Isolation Test	Electrical Continuity Test	Gas-venting System Test	Sealing Test
Without cathodic protection	Rough bore	X (1)	X	n/a (1)	n/a	X	X (2)
	Smooth bore	n/a	X	n/a	n/a	X	X (2)
With cathodic protection	Rough bore	X	X	X	X	X	X (2)
	Smooth bore	n/a	X	n/a	X	X	X (2)

NOTE 1 X—required; n/a—not applicable.
NOTE 2 The sealing test is required for risers and optional for other applications.

9.2.2 Procedure

The gauging pig shall be equipped with disk(s) capable of detecting any unacceptable obstruction.

The minimum diameter of the gauging pig shall be at least 95 % of the nominal ID or 10 mm (0.39 in.) smaller than the ID for pipes with an ID less than 200 mm (7.87 in.). The thickness of the gauging disk shall be between 5 mm and 10 mm (0.20 in. to 0.39 in.).

9.2.3 Acceptance Criteria

The pig shall pass through the bore of the flexible pipe undamaged. Minor scratches and scuffs are acceptable but dents are not.

9.3 Hydrostatic Pressure Test

9.3.1 Purpose

The purpose of the hydrostatic pressure test is to demonstrate that the pipe can hold pressure above a desired level, or to identify latent defects in the pipe.

9.3.2 Procedure

Pressure testing involves pressurizing the bore of the pipe and recording pressure, and temperature variations over time. Pressure and temperature measurement locations shall be selected to ensure correlation between the measurements. Pipe can be left on reel or inside carousel or short sections/jumpers can be in the straight configuration.

The minimum hydrostatic test pressure for flexible flowlines and subsea jumpers shall be 1.3 times the design pressure. For all other applications, including flexible risers and topside jumpers, the minimum hydrostatic test pressure shall be 1.5 times the design pressure. A higher test pressure can be required by local codes or regulators. Unless otherwise specified, potable water, filtered to 100 μm and with a chloride content less than 50 mg/l shall be used for the test fluid. If required to protect the internal carcass material, the water shall be chemically inhibited. A suitable dye may be added to assist in leakage detection.

Trapped air shall be removed from the pipe in accordance with the manufacturer's procedures.

The pressure shall be gradually increased, at a rate not greater than the manufacturer's test procedure, to a level between 100 % and 110 % (see API 17B) of the hydrostatic test pressure and held for a period of at least 2 h to allow for stabilization. This maximum hydrostatic test pressure shall not cause the allowable utilization factors of Table 8 and Table 10 to be exceeded. If necessary, the pressure shall be cycled to this pressure until stabilization is achieved. The pressure shall be considered stabilized when the pressure drop is less than 1 % in a 1 h period. Pressure shall then be increased between the nominal test pressure and the maximum hydrostatic test pressure.

The timing of the hold period shall not start until the equipment and pressure-monitoring gauge have been isolated from the pressure source.

The hydrostatic test pressure shall be held for a period of not less than 24 h. During the test, pressure and temperature (ambient and internal) shall be recorded at least every 30 minutes. Depressurization shall be performed at a rate in accordance with the manufacturer's test procedure.

After depressurization, the end-fitting areas shall be visually examined for any sign of permanent deformation or damage in both the pipe and the end fittings.

If a pig has been used for filling or emptying the pipe, the cups shall be examined for damage and wear. Damage or excessive wear shall be recorded and reported to the purchaser.

9.3.3 Acceptance Criteria

Pressure loss due to all possible sources of pressure fluctuation, including trapped air inside the pipe, pipe volumetric or diameter changes, external temperature fluctuations, additional test fluid added/subtracted accompanied by resetting the clock on the hold period and pressure source/pump shall not exceed 4 % of the pressure at the start of the 24 h period. No leakage shall be observed from the pipe during the test. No permanent deformation or damage shall be observed in the area of the end fittings.

9.4 Electrical Continuity and Electrical Isolation Tests

9.4.1 Purpose

The purpose of the electrical continuity and isolation tests are to ensure that the pipe cathodic protection system will be efficient and the carcass is electrically isolated from the end terminations.

9.4.2 Procedure

The electrical continuity test shall be performed between the two end fittings. Electrical isolation tests shall be performed between the end fittings and the carcass when applicable. Electrical continuity and isolation measurements shall be recorded.

9.4.3 Acceptance criteria

For the electrical continuity test, the electrical resistance between the end fittings shall be less than 10 Ω/km of pipe (for short length jumpers less than 100 m long, this electrical resistance shall be less than 1 Ω).

For the electrical isolation test of rough bore pipes, the electrical resistance between the internal carcass and the end fittings shall be greater than 1 kΩ.

9.5 Gas-venting System Test

9.5.1 Purpose

The purpose of the gas-venting system test is to demonstrate that the gas-relief system, including valves used to relieve pressure buildup in the pipe annulus, functions properly after the hydrotest and after final packing.

9.5.2 Procedure

Air or nitrogen gas shall be pumped into one end fitting at the design pressure for the gas-relief system. Gas release shall be checked at the other end fitting, or pressure test shall be checked at each port following the procedure in 9.6.4. For smooth bore pipe, a vacuum test in accordance to 9.6.2 should be used. The procedure shall be repeated from the opposite end of the pipe.

All valves shall be tested for relief pressure. All valves shall relieve within the manufacturer's specified range of relief pressure.

This procedure might not be feasible for long lengths of pipe. An alternate procedure is acceptable if it can be demonstrated to satisfy the same general requirements. The procedure used shall be documented in the manufacturer's written specification.

The pressure and volume flow rate shall be measured at the outlet port. The flow rate from each valve shall meet at least the manufacturer's specified criterion or other criterion agreed with the purchaser.

9.5.3 Acceptance Criteria

The flow path shall be confirmed at all ports individually.

All valves shall relieve at the manufacturer's specified relief pressure.

9.6 Sealing Test

9.6.1 Purpose

The purpose of the sealing test is to confirm the integrity of the external sheath and sealing/crimping of the external sheath at the end fitting. Either an annulus vacuum or pressure test can be used. This type of sealing test can only be performed for pipes that have gas-venting systems or ports integrated in the end fittings. Note that an annulus pressure test cannot be performed on a smooth bore pipe unless an anticollapse sheath is present or there is a sufficient pressure in the bore.

For flexible risers, a sealing test of the pipe annulus shall be performed after the factory hydrostatic test. The manufacturer shall have a validated test procedure.

The test shall be repeated after load-out for installation on static and dynamic risers and after installation on dynamic risers. The acceptable variations (times, rates, etc.) between tests shall be specified in the procedures and shall be based on the manufacturer's documented experience and consideration of the size, length, and other key characteristics of each pipe.

9.6.2 Procedure for Annulus Vacuum Test

The annulus vent system is isolated to draw a partial vacuum in the annulus space. The annulus pressure is reduced gradually to a pressure specified by the manufacturer and approved by the purchaser, followed by measuring the initial leak-down rate (decay of vacuum over the first hour).

NOTE It is recommended that the annulus pressure is not greater than 500 mbara at both ends of the annulus in FAT and load-out tests.

The vacuum pump is stopped to allow the pressure to stabilize; the stabilization period shall be specified by the manufacturer and approved by the purchaser. The pressure is then held for a period; the hold period shall be specified by the manufacturer and approved by the purchaser.

NOTE It is recommended that the stabilization period is a period not less than 15 minutes and the hold period is a period not less than 4 h.

The annulus volume and associated temperature shall be measured and recorded.

9.6.3 Acceptance Criteria for Annulus Vacuum Test

The pressure increase in the annulus shall be specified by the manufacturer.

NOTE It is recommended that the pressure increase does not exceed 30 mbara during the hold period.

9.6.4 Procedure for Annulus Pressure Test

Slowly charge the vent ports with nitrogen gas to a pressure of 2 bara. The pressure-relief valves should have a low setting of 2 bara to 3 bara.

Allow the pressure in the annulus to stabilize. This should be achieved in 20 to 30 minutes. The pressure is then held for a period of 1 h.

The annulus volume and associated temperature shall be measured and recorded.

9.6.5 Acceptance Criteria for Annulus Pressure Test

The pressure drop shall not exceed 250 mbar during the hold period and shall not drop more than 25 mbar during the final 20 minutes of the hold period.

For pipes with an intermediate anticollapse sheath, the anticollapse sheath crimping seal shall be tested to demonstrate integrity and leak tightness against design external pressure, according to a procedure established by the supplier.

10 Marking and Packaging

10.1 Marking

The flexible pipe marking shall be applied to both end fittings and shall make the pipe identifiable for the specified service life. As a minimum, the following markings shall be applied:

a) designation of API Specification 17J;

b) serial number of pipe;

c) manufacturer name or mark;

d) manufacture date;

e) design pressure (absolute or differential);

f) storage MBR;

g) longitudinal line markup;

h) limp stiffness direction (for avoiding corkscrewing or pigtailing during transpooling, alignment of topside jumpers or subsea connections to goosenecks);

i) design water depth or minimum design water depth if based on differential design pressure.

Additional markings shown in Table 29 of API 17B shall also be considered.

The manufacturer shall propose and provide markings on opposite sides of the pipe that denote the flexible length at a maximum spacing of 10 m for risers and pipelines. The markings shall be large enough and colored so as to be clearly visible against the pipe background under typical ROV illumination.

10.2 Packaging

The flexible pipe shall be packaged in accordance with the manufacturer's specifications. If stored on reels or carousels, the pipe shall not be subjected to a bend radius less than the storage MBR. The end fittings and connectors should be wrapped in heavy-duty protections unless packed in crates with adequate protection. Both ends of the pipe shall be sealed. The manufacturer's specifications shall include procedures for storage and packaging of integral components mounted on the pipe, including bend stiffeners. Storage blinds, ropes/wires, shackles, and other required handling equipment shall be identified in the packaging procedures. The manufacturer's specifications shall include procedures for controlling back tension and closeness of wraps for reels to be used for pipe installation.

The packaging shall be such that the pipe is protected against all expected environmental occurrences when stored outdoors. A protective cover should be used. The flexible pipe, including end fittings, should not protrude beyond the flange diameter of transport reels, such that abrasive damage could occur to the pipe.

If the pipe is to be installed off the reel and free flooded, the inboard end fitting shall be vented.

The manufacturer shall label minimum temperature for storage and unspooling.

Annex A
(informative)

API Monogram Program
Use of the API Monogram by Licensees

A.1 Scope

A.1.1 Applicability

This annex is only normative for product supplied bearing the API Monogram and manufactured at a facility licensed by API; for all other instances it is not applicable.

A.1.2 General

The API Monogram® is a registered certification mark owned by the American Petroleum Institute (API) and authorized for licensing by the API Board of Directors. Through the API Monogram Program, API licenses product manufacturers to apply the API Monogram to products which comply with product specifications and have been manufactured under a quality management system that meets the requirements of API Q1. API maintains a complete, searchable list of all Monogram licensees on the API Composite List website (www.api.org/compositelist).

The application of the API Monogram and license number on products constitutes a representation and warranty by the licensee to API and to purchasers of the products that, as of the date indicated, the products were manufactured under a quality management system conforming to the requirements of API Q1 and that the product conforms in every detail with the applicable standard(s) or product specification(s). API Monogram program licenses are issued only after an on-site audit has verified that an organization has implemented and continually maintained a quality management system that meets the requirements of API Q1 and that the resulting products satisfy the requirements of the applicable API product specification(s) and/or standard(s). Although any manufacturer may claim that its products meet API product requirements without monogramming them, only manufacturers with a license from API can apply the API Monogram to their products.

Together with the requirements of the API Monogram license agreement, this annex establishes the requirements for those organizations who wish to voluntarily obtain an API license to provide API monogrammed products that satisfy the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program requirements.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 1220 L Street, N. W., Washington, DC 20005 or call 202-682-8145 or by email at certification@api.org.

A.2 Normative References

In addition to the referenced standards listed earlier in this document, this annex references the following standard:

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

For Licensees under the Monogram Program, the latest version of this document shall be used. The requirements identified therein are mandatory.

A.3 API Monogram Program: Licensee Responsibilities

A.3.1 Monogram Program Requirements

For all organizations desiring to acquire and maintain a license to use the API Monogram, conformance with the following shall be required at all times:

a) the quality management system requirements of API Q1;

b) the API Monogram Program requirements of API Q1, Annex A;

c) the requirements contained in the API product specification(s) to which the organization is licensed;

d) the requirements contained in the API Monogram Program License Agreement.

A.3.2 Control of the Application and Removal of the API Monogram

Each licensee shall control the application and removal of the API Monogram in accordance with the following:

a) Products that do not conform to API specified requirements shall not bear the API Monogram.

b) Each licensee shall develop and maintain an API Monogram marking procedure that documents the marking/monogramming requirements specified by this annex and any applicable API product specification(s) and/or standard(s). The marking procedure shall:

   1) define the authority responsible for application and removal of the API Monogram and license number;

   2) define the method(s) used to apply the Monogram and license number;

   3) identify the location on the product where the API Monogram and license number are to be applied;

   4) require the application of the date of manufacture of the product in conjunction with the use of the API Monogram and license number;

   5) require that the date of manufacture, at a minimum, be two digits representing the month and two digits representing the year (e.g. 05-12 for May 2012) unless otherwise stipulated in the applicable API product specification(s) or standard(s); and

   6) define the application of all other required API product specification(s) and/or standard(s) marking requirements.

c) Only an API licensee shall apply the API Monogram and its designated license number to API monogrammable products.

d) The API Monogram and license number, when issued, are site-specific and subsequently the API Monogram shall only be applied at that site specific licensed facility location.

e) The API Monogram may be applied at any time appropriate during the production process but shall be removed in accordance with the licensee's API Monogram marking procedure if the product is subsequently found to be out of conformance with any of the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program.

For certain manufacturing processes or types of products, alternative API Monogram marking procedures may be acceptable. Requirements for alternative API Monogram marking are detailed in the, *API Monogram*

Program Alternative Marking of Products License Agreement, available on the API Monogram Program website at http://www.api.org/alternative-marking.

A.3.3 Design and Design Documentation

Each licensee and/or applicant for licensing shall maintain current design documentation as identified in API Q1 for all of the applicable products that fall under the scope of each Monogram license. The design document information shall provide objective evidence that the product design meets the requirements of the applicable and most current API product specification(s) and/or standard(s). The design documentation shall be made available during API audits of the facility.

In specific instances, the exclusion of design activities is allowed under the Monogram Program, as detailed in Advisory # 6, available on API Monogram Program website at http://www.api.org/advisories.

A.3.4 Manufacturing Capability

The API Monogram Program is designed to identify facilities that have demonstrated the ability to manufacture equipment that conforms to API specifications and/or standards. API may refuse initial licensing or suspend current licensing based on a facility's level of manufacturing capability. If API determines that an additional review is warranted, API may perform additional audits (at the organization's expense) of any subcontractors to ensure their conformance with the requirements of the applicable API product specification(s) and/or standard(s).

A.3.5 Use of the API Monogram in Advertising

An API Monogram licensee shall not use the API Monogram and/or license number on letterheads, buildings or other structures, websites or in any advertising without an express statement of fact describing the scope of Licensee's authorization (license number and product specification). The Licensee should contact API for guidance on the use of the API Monogram other than on products.

A.4 Product Marking Requirements

A.4.1 General

These marking requirements shall apply only to those API Licensees wishing to mark applicable products in conjunction with the requirements of the API Monogram Program.

A.4.2 Product Specification Identification

Manufacturers shall mark products as specified by the applicable API specifications or standards. Marking shall include reference to the applicable API specification and/or standard. Unless otherwise specified, reference to the API specifications and/or standards shall be, as a minimum, "API [Document Number]" (e.g., API 6A, or API 600). Unless otherwise specified, when space allows, the marking may include use of "Spec" or "Std", as applicable (e.g., API Spec 6A or API Std 600).

A.4.3 Units

Products shall be marked with units as specified in the API specification and/or standard. If not specified, equipment shall be marked with U.S. customary (USC) units. Use of dual units [USC units and metric (SI) units] may be acceptable, if such units are allowed by the applicable product specification and/or standard.

A.4.4 Nameplates

Nameplates, when applicable, shall be made of a corrosion-resistant material unless otherwise specified by the API specification and/or standard. Nameplate shall be located as specified by the API specification and/or standard. If the location is not specified, then the licensee shall develop and maintain a procedure detailing the location to which the nameplate shall be applied. Nameplates may be attached at any time during the manufacturing process.

The API Monogram and license number shall be marked on the nameplate, in addition to the other product marking requirements specified by the applicable product specification and/or standard.

A.4.5 License Number

The API Monogram license number shall not be used unless it is marked in conjunction with the API Monogram. The license number shall be used in close proximity to the API Monogram.

A.5 API Monogram Program: Nonconformance Reporting

API solicits information on products that are found to be nonconforming with API specified requirements, as well as field failures (or malfunctions), which are judged to be caused by either specification and/or standard deficiencies or nonconformities against API specified requirements. Customers are requested to report to API all problems with API monogrammed products. A nonconformance may be reported using the API Nonconformance Reporting System available at http://compositelist.api.org/ncr.aspx.

Annex B
(informative)

Purchasing Guidelines

B.1 Table B.1 in this annex gives purchasing guidelines for flexible pipes.

B.2 A separate form should be completed for each length of flexible pipe.

B.3 The manufacturer should specify in the design premise the values assumed for all parameters in Table B.1 not specified by the purchaser.

Table B.1—Flexible Pipe Purchasing Guidelines

General Information	
Client:	Client reference:
	Project:
Phone:	Location:
Fax:	
Purchaser's technical contact:	Enquiry date:
Conformance to API 17J required?	Required response date:
General Design Parameters	
Internal diameter (m):	Maximum axial load (kN):
Length required (m):	Maximum effective tension (kN):
Tolerance required on length (m ± m):	Torsional balance requirement (°/m or rad/m):
Pipe structural requirements (MBR, bend stiffness):	Compression strength requirement (kN):
	Design load case probabilities:
Linear mass requirements (kg/m) in air empty:	Installation:
External protection requirements (external carcass):	Permanent operation:
	Abnormal operation:
Service life (years):	Specification of permanent and abnormal load cases, including accidental loads, and definition of load combinations to be used in the design:

NOTE °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TF = through flowline; W = Watt.

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

Internal Fluid Parameters	
General	
Fluid description (oil, gas, water):	Flow regime description (single, phase, slug):
Service definition (sweet/sour):	Fluid heat capacity (kJ/kg/°C):
Flow Rate Parameters	
Fluid density (kg/m^3):	Viscosity (Pa • s):
Flow rate (m^3/day):	
Minimum inlet pressure (MPa):	Required outlet pressure (MPa):
Pressures	
Design pressure [MPa (psi)]:	Operating pressure profile during the service life [MPa (psi)]:
Max./Min. operating pressure and/or [MPa (psi)]:	Incidental pressure [MPa (psi)]: , duration:
Design differential pressure [MPa (psi)]:	Vacuum conditions [MPa (psi)]:
Number and range of pressure cycles expected during the specified service life:	Maximum operational depressurization and pressurization rates:
Temperatures	
Design minimum temperature (°C):	Operating inlet temperature (°C):
Design maximum temperature (°C):	Number and range of temperature cycles expected during the specified service life:
Incidental temperature (°C): , duration:	Upset temperature and cycles (°C):
Fluid Compositional Data	
NaCl content (weight percent of water):	Chlorides content [mg/l]:
Gas-oil ratio (m^3/m^3):	Water cut (volume percent):
TAN (mg KOH/g):	pH of aqueous phase:
Alcohols? ☐ Yes ☐ No	Inhibitors (scale, paraffin)? ☐ Yes ☐ No
Aromatic components? ☐ Yes ☐ No	Injected chemicals? ☐ Yes ☐ No
Corrosive agents? ☐ Yes ☐ No	Solids, precipitates, etc.? ☐ Yes ☐ No
H_2S partial pressure (bar):	NACE MR0175 to apply? ☐ Yes ☐ No
CO_2 partial pressure (bar):	
If available, attach details of full fluid compositional data and expected variation over the service life. Also, attach details of any aromatic components, corrosive agents, inhibitors, alcohols, solids, or injected chemicals in the fluid composition (include concentrations of dissolved oxygen with all injected fluids). Purchaser to be as detailed as possible about what pressures, temperatures, locations, combination, and conditions are associated with any concentrations or other properties.	
NOTE °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TF = through flowline; W = Watt.	

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

External Environment—Static Loads	
Water Depths	
Design water depth (m):	Maximum tidal variation (m):
Minimum tidal variation (m):	Attach details of water depth variation over flexible pipe route.
Soil Data	
Soil description (clay, sand):	Angle of internal friction (degrees), roughness, grain size, soil stability, liquefaction, submerged/dry unit weight:
Soil shear strength (kPa):	Lateral friction coefficient:
Seabed scour/sand waves occur? ☐ Yes ☐ No If available, attach seabed profile.	Longitudinal friction coefficient:
Air Temperatures	
Minimum temperature (°C):	Minimum storage/transport/installation temperature (°C):
Maximum temperature (°C):	Maximum storage/transport/installation temperature (°C):
Seawater Data	
Density:	pH value:
Maximum surface temperature (°C):	Maximum seabed temperature (°C):
Minimum surface temperature (°C):	Minimum seabed temperature (°C):
Upheaval Buckling Data	
Soil stiffness and strength in lateral downward and upward direction considering the effect of trenching and backfill if relevant	Seabed friction, axial and lateral both maximum and minimum
Installation, testing, trenching and protection sequence with corresponding temperature and pressure. (Required for proper UHB and tie-in design)	Capacity of tie-in porches on subsea terminations
Other	
Marine growth to be considered? ☐ Yes ☐ No If yes, attach details.	Sunlight exposure? ☐ Yes ☐ No
Ice effects to be considered? ☐ Yes ☐ No If yes, attach details.	Current data attached? ☐ Yes ☐ No Attached current data should be given as a function of water depth, direction, and return period.
External Environment—Dynamic Loads	
Wave data attached? ☐ Yes ☐ No Attached wave data should be given in terms of significant wave, maximum wave, equivalent periods, spreading functions, scatter diagrams, as a function of direction and return period. For irregular seas, the wave spectrum data should be specified.	Wind data attached? ☐ Yes ☐ No Attached wind data should be given in terms of maximum 3-s, 1-min, 10-min, and 1-h wind speeds, as a function of direction, height above water level, and return period.
NOTE °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TF = through flowline; W = Watt.	

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

General System Requirements	
General	
System description (flowline, riser, jumper, subsea, topsides):	Cathodic protection system required? ☐ Yes ☐ No
Application definition (static, dynamic):	Electrical continuity required? ☐ Yes ☐ No
Pipe bore description (rough, smooth):	End-fitting coatings required? ☐ Yes ☐ No
Corrosion protection requirements	External coating description:
Corrosion protection required? ☐ Yes ☐ No	Internal coating description:
If available, allowable electrical resistance, protection voltage, current source, and current density should be specified.	
Thermal Insulation	
Thermal insulation required? ☐ Yes ☐ No	Required insulation U-valve (W/m^2K):
Required outlet temperature (°C):	Insulation U-valve should be based on pipe ID and be for the pipe alone. Specify any allowances that can be made for external effects such as soil.
Connector	
Lower connector type (flange, pipe):	Attach welding specification seal type and sizes, and responsibility for supply and mounting of components.
Upper connector type (flange, pipe):	
Gas Venting	
Gas-venting required? ☐ Yes ☐ No	Venting location restrictions?
System components (valves, burst disks):	Gas-monitoring system?
Allowable gas permeation rate (l/m/day):	
Other	
Fire resistance required? ☐ Yes ☐ No Specify (Lloyds/DNV/API 16C):	Interface definitions/specifications (see 4.6.1.10):
Pigging, TFL, workover, etc., required? ☐ Yes ☐ No	Exothermal chemical reaction cleaning required? ☐ Yes ☐ No
Piggyback required? ☐ Yes ☐ No If yes, attach details.	Inspection condition monitoring required? ☐ Yes ☐ No If yes, give details of requirements.
Pressure and tensile armor weld location restrictions? ☐ Yes ☐ No	

NOTE °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TFL = through flowline; W = Watt.

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

Flowline Parameters	
General	
Flowline routing description attached? ☐ Yes ☐ No	Guides and supports (I-tubes, J-tubes):
Load cases attached? ☐ Yes ☐ No	Required pipe attachments (bend restrictors, clamps): Attach drawings of all items.
On-bottom stability to be checked? ☐ Yes ☐ No	Crossover requirements? ☐ Yes ☐ No
Upheaval Buckling	
Upheaval buckling to be checked? ☐ Yes ☐ No	Allowable bend radius (m):
Required minimum soil coverage (m):	Load cases attached? ☐ Yes ☐ No
Protection Requirements	
Impact resistance to accidental loads? ☐ Yes ☐ No	Mattresses? ☐ Yes ☐ No
Trenching? ☐ Yes ☐ No	Other? ☐ Yes ☐ No
Rock dumping? ☐ Yes ☐ No	Attach details of specified protection system(s), including general arrangement drawings, possible accidental occurrences (trawl boards, dropped objects, anchors, and so on), design impact loads.
Riser Parameters	
General	
Riser configuration (lazy-S, steep wave): Attach description of riser configuration and general arrangement drawing(s) of all relevant details.	Riser lower connection description (seabed, vessel):
Required pipe attachments (bend stiffeners, buoys): Attach drawings of all items.	Riser upper connection description (platform, tanker):
Interference	
Interference/clashing check required? ☐ Yes ☐ No Attach details of all possible interface areas, including other risers, mooring lines, platform columns, vessel pontoons, tanker heel, and so forth, and specify allowable interferences/clashing.	
Vessel Motion Data	
Vessel motion data attached? ☐ Yes ☐ No	Attached vessel motion data should be specified in terms of the following for the relevant loading conditions. Attached data should include a general layout drawing, showing vessel heading, North point, riser(s) in plan, and mooring lines. — Vessel static and dynamic offsets for all conditions. — Vessel data, dimensions, drafts, etc. — Vessel first- and second-order motions, in terms of heave, surge, sway, yaw, roll, and pitch. — Vessel motion phase data and specification. — Reference point for motions. — Mooring system design, including line properties and anchor locations. — Position tolerances.

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

Additional Requirements	
Materials required in addition to API 17J? If yes, specify details.	☐ Yes ☐ No
Manufacturing required in addition to API 17J? If yes, specify details.	☐ Yes ☐ No
Calculation of axial carcass retention capacity is required If yes, is measurement of pitch at first 1 m of carcass in end fitting required?	☐ Yes ☐ No ☐ Yes ☐ No
Selection of PSL category for 7.9.6 (default is PSL 2 to 3)? If yes, specify details.	☐ Yes ☐ No
FAT required in addition to API 17J? If yes, specify details.	☐ Yes ☐ No
Markings required in addition to API 17J? If yes, specify details.	☐ Yes ☐ No
Prototype tests required? If yes, specify details.	☐ Yes ☐ No
Is external sheath sealing test per 9.6 required for flowlines? If yes, specify which flowlines are to be tested and what documentation is required in 8.8 f).	☐ Yes ☐ No
Additional national authority/government regulations? If yes, specify details.	☐ Yes ☐ No
Purchaser inspection required? If yes, specify details.	☐ Yes ☐ No
General requirements in addition to API 17J? If yes, specify details.	☐ Yes ☐ No
NOTE 1 °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TF = through flowline; W = Watt. NOTE 2 "ppm" is a deprecated unit.	

Table B.1—Flexible Pipe Purchasing Guidelines (Continued)

Delivery, Installation, Retrieval, and Maintenance Requirements
Delivery requirements:
Shipping, packing, and storage requirements:
Documentation requirements:
Purchaser should specify if a separate installation manual is required.
Installation Requirements
Method:
Vessel:
General: Where relevant, the purchaser should specify any requirements for season, environment, vessel limitations, restrictions due to conflicting activities, and installation scope (including trenching, burial, testing, inspection, surveying, and documentation).
Installation Design Criteria
Equipment bend radius (m):
Tensioner crush loads (kN):
Installation/lifting device requirements:
Transport reel used for installation? ☐ Yes ☐ No
Pipe internal fluid at delivery (empty, water filled):
Seawater flooding requirements (exposure time)? ☐ Yes ☐ No
Where relevant, the purchaser should specify details such as length of tensioners, shape of tensioner shoes, number of belts, diameter of wheels, reels, ramp angles, and surface shape.
Installation test requirements:
Installation vessel motions and offsets attached? ☐ Yes ☐ No
Attached details should, in general, reflect data requirements in vessel motion data requirements listed under riser parameters (above).
Retrieval/Reuse
No. of foreseen installation/retrieval operations:
Recovery/reuse requirements:
Maintenance
Maintenance required? ☐ Yes ☐ No If yes, specify details.
NOTE °C = degree Centigrade; °F = degree Fahrenheit; g = gram; K = Kelvin; kg = kilogram; kJ = kilojoule; kN = kilonewton; KOH = potassium hydroxide; kPa = kilopascal; l = liter; m = meter; MBR = minimum bend radius; mg = milligram; MPa = megapascal; ppm = parts per million; TAN = titrated acid number; TF = through flowline; W = Watt.

Annex C
(informative)

Flexible Pipe Datasheet

C.1 Table C.1 in this annex gives guidelines the minimum data to be provided on a flexible pipe datasheet.

C.2 In addition, the manufacturer should also include in the datasheet an isometric schematic of the pipe cross section clearly showing the layer-by-layer construction.

Table C.1—Flexible Pipe Datasheet Minimum Requirements

General Information	
Client	Project
Bore fluid	Water depth (m, ft)
Inner diameter (mm, in.)	Outer diameter (mm, in.)
Design pressure (MPa, psi)	Design temperature (°C, °F)
Operating pressure (MPa, psi)	Operating temperature (°C, °F)

Cross-section Layer-by-Layer Description						
Layer Type	Layer Material	UTS (MPa, ksi)	Structural capacity (MPa, ksi)	Mass (kg/m, lbf/ft)	ID (mm, in.)	T (mm, in.)

Theoretical Pipe Properties	
Internal volume (l/m, cf/ft)	External volume (l/m, cf/ft)
Weight in air empty (kg/m, lbf/ft)	Weight in air full of seawater (kg/m, lbf/ft)
Weight in seawater empty (kg/m, lbf/ft)	Weight in seawater full of seawater (kg/m, lbf/ft)
Specific gravity in seawater empty (–)	Specific gravity in seawater full of seawater (–)
MBR storage (m, ft)	MBR operating (m, ft)
Burst pressure (MPa, psi)	Collapse pressure (MPa, psi)
Damaging pull (kN,, lbf)	Permissible axial compression (kN, lbf)
Bending stiffness (kN-m^2, lbf-ft^2)	
Axial stiffness @ 20 °C (kN, kip)	In tension: In compression:
Torsional stiffness @ 20 °C (KNm^2/deg, kip.ft^2/deg)	Stiff direction: Limp direction:
Overall heat transfer coefficient (w/m^{2}K, Btu/hrft^2°F)	Thermal exchange coefficient (w/mK, Btu/hrft°F)

NOTE UTS = ultimate tensile strength; ID = diameter of inner surface of the layer; t = layer thickness. Manufacturer to specify the temperature at which the properties are stated.

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