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Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection

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Preface

This Standard was prepared by the Standards Australia Committee ME-092, Materials, equipment, structures and related services for petroleum, petrochemical and natural gas industries.

The objective of this document is to give requirements and recommendations for the qualification and design, installation, testing and inspection for the external application of composite repair systems to corroded or damaged pipework, pipelines, tanks and vessels used in the petroleum, petrochemical and natural gas industries.

This document is identical with, and has been reproduced from, ISO 24817:2017, *Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection*.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries,* Subcommittee SC 6, *Processing equipment and systems*.

This second edition cancels and replaces the first edition (ISO 24817:2015), which has been technically revised.

This corrected version of ISO 24817:2017 incorporates the following correction:

— in 7.5.7, Formula (15), "$D4$" has been replaced by "D^4".

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Introduction

The objective of this document is to ensure that pipework, pipelines, tanks and vessels repaired using composite systems that are qualified, designed, installed and inspected using this document will meet the specified performance requirements. Repair systems are designed for use within the petroleum, petrochemical and natural gas industries, and also within utility service applications. The main users of this document will be plant and equipment owners of the pipework and vessels, design contractors, suppliers contracted to provide the repair system, certifying authorities, installation, maintenance and inspection contractors.

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Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection

1 Scope

This document gives requirements and recommendations for the qualification and design, installation, testing and inspection for the external application of composite repair systems to corroded or damaged pipework, pipelines, tanks and vessels used in the petroleum, petrochemical and natural gas industries.

2 Normative references

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

ISO 75-3, *Plastics — Determination of temperature of deflection under load — Part 3: High-strength thermosetting laminates and long-fibre-reinforced plastics*

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

ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

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

ISO 10952, *Plastics piping systems — Glass-reinforced thermosetting plastics (GRP) pipes and fittings — Determination of the resistance to chemical attack for the inside of a section in a deflected condition*

ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature and glass transition step height*

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

ISO 14692, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping*

ASTM C581, *Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Reinforced Structures Intended for Liquid Service*

ASTM D543, *Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents*

ASTM D696, *Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between Minus 30°C and 30°C with a Vitreous Silica Dilatometer*

ASTM D1598, *Standard Test Method for Time-to-Failure of Plastic Pipe under Constant Internal Pressure*

ASTM D1599, *Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings*

ASTM D2583, *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*

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

ASTM D3039, *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*

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ASTM D3165, *Standard Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies*

ASTM D3681, *Standard Test Method for Chemical Resistance of Fiberglass (Glass-Fiber-Reinforced Thermosetting Resin) Pipe in a Deflected Condition*

ASTM D5379, *Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method*

ASTM D6604, *Standard Practice for Glass Transition Temperatures of Hydrocarbon Resins by Differential Scanning Calorimetry*

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

ASTM E1640, *Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis*

ASTM E2092, *Standard Test Method for Distortion Temperature in Three-Point Bending by Thermomechanical Analysis*

ASTM G8, *Standard Test Methods for Cathodic Disbonding of Pipeline Coatings*

BS 7910, *Guide to methods for assessing the acceptability of flaws in metallic structures*

EN 59, *Methods of testing plastics — Glass reinforced plastics — Measurement of hardness by means of a Barcol impressor (BS 2782-10, Method 1001, Measurement of hardness by means of a Barcol impresser)*

EN 1465, *Adhesives* — Determination of tensile lap shear strength of rigid-to-rigid bonded assemblies

3 Terms and definitions

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

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

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

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

3.1
anisotropic
exhibiting different physical properties in different directions

3.2
Barcol hardness
measure of surface hardness using a surface impresser

3.3
blister
air void between layers within the laminate visible on the surface as a raised area

3.4
composite
thermoset resin system that is reinforced by fibres

3.5
crack
split in the laminate extending through the wall (perpendicular to the surface) such that there is actual separation with opposite surfaces visible

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3.6
cure
curing
setting of a thermosetting resin system, such as polyester or epoxy, by an irreversible chemical reaction

3.7
cure schedule
time-temperature profile qualified to generate a specified T_g or HDT

3.8
defect type A
defect within the substrate, not through-wall and not expected to become through-wall within the repair design lifetime of the repair system

3.9
defect type B
through-wall defect or a defect within the substrate where at the end of service life the remaining wall thickness is less than 1 mm

3.10
defined lifetime
actual application or service lifetime of the repair

3.11
delamination
area between the repair laminate and the substrate which should be bonded together but where no bond exists, or an area of separation between layers in the repair laminate

3.12
design lifetime
maximum application lifetime of the repair

3.13
differential scanning calorimetry
DSC
method of determining the glass transition temperature of a thermosetting resin

3.14
dry spot or un-impregnated/dry fibre
area of fibre not impregnated with resin, with bare, exposed fibre visible

3.15
engineered repair
repair which has been designed and applied under a specified, controlled process so that under the design conditions, there is a high degree of confidence that the repair will maintain its integrity over the design lifetime

3.16
exposed fibre
area of fibre not impregnated with resin that projects from the body of the repair

3.17
foreign matter
any substance other than the reinforcing fibre or other materials that form part of the repair system

3.18
finishing materials
final layer of material to help compact the repair laminate, typically a polymeric film or a fabric

Note 1 to entry: They should be fully removed after the repair has hardened and before the repair is inspected or painted.

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3.19
glass transition temperature
temperature at which a resin undergoes a marked change in physical properties

3.20
hardener
component added to a thermosetting resin to effect cure

3.21
heat distortion temperature
HDT
temperature at which a standard test bar deflects by a specified amount under a given load

3.22
installer
person who is qualified to apply a composite repair system

3.23
filler material
material used to repair external surface imperfections prior to the application of the composite laminate

3.24
laminate
repair laminate
part of a repair system that is the composite

Note 1 to entry: Most composites considered in this document are composed of discrete lamina or layers which are wrapped or stacked, one on top of the other. This stacked construction is the laminate.

3.25
layer
individual layer or wrap within the composite laminate

3.26
leak
condition of a substrate wall that can allow the contents to make contact with and act directly upon the (composite) repair laminate

Note 1 to entry: This does not refer to a fluid leaking through a hole or breach in the substrate.

3.27
occasional load
load that occurs rarely and during a short time

Note 1 to entry: Occasional loads typically occur less than 10 times in the life of the component and each load duration is less than 30 min.

3.28
owner
organization that owns or operates the substrate to be repaired

3.29
pin hole
pin-prick hole in the resin rich surface, not extending into the laminate

3.30
pipeline
pipe with components subject to the same design conditions used to transport fluids between plants

Note 1 to entry: Components include bends, flanges and valves.

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3.31
pipework
interconnected piping subject to the same set or sets of design conditions

3.32
piping
piping system
assemblies of piping components used to convey fluids within a plant

Note 1 to entry: Components include pipe, fittings, flanges, gaskets, bolting and valves. A piping system is often above ground but sometimes buried.

3.33
pit
depression in the surface of the laminate

3.34
ply
single wrap or layer (lamina) of a repair laminate

3.35
post cure
additional elevated-temperature cure applied after resin has hardened to ensure the required glass transition temperature is achieved

3.36
qualification application procedure
application procedure used to apply the repair system for the qualification tests

3.37
qualification test temperature
test temperature at which qualification testing of the repair system is performed

3.38
reinforcement
fibre embedded in the resin system

Note 1 to entry: Possible fibre materials include aramid, carbon, glass, polyester, or similar materials. Reinforcement results in mechanical properties superior to those of the base resin.

3.39
repair system
system comprised of the substrate, composite material (repair laminate), filler material, adhesive and including surface preparation and installation methods, used for repair of pipework

3.40
repair system installer
company that installs the repair system

3.41
repair system supplier
company that designs and supplies the repair system

3.42
resin system
all of the components that make up the matrix portion of a composite

Note 1 to entry: Often this includes a resin, filler(s), pigment, mechanical property modifiers and catalyst or hardener.

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3.43
risk
event encompassing what can happen (scenario), its likelihood (probability) and its level or degree of damage (consequences)

3.44
substrate
surface on which a repair is carried out

Note 1 to entry: The surface may belong to original pipework, pipework component, pipeline, tank, or vessel.

3.45
supervisor
experienced installer who is qualified by successfully completing the supervisor training course

3.46
Shore hardness
measure of surface hardness using a surface impresser or durometer

3.47
thermoset resin system
resin system that cannot be melted or remoulded following polymerization

3.48
wrinkle
wavy surface or distinct ridge in the laminate where the reinforcing fabric has creased during application

4 Symbols and abbreviated terms

4.1 Symbols

α_s thermal expansion coefficient of substrate

α_c thermal expansion coefficient of the repair laminate for either the axial or circumferential directions

c crack length

D original external diameter

D_b original external branch, tee, nozzle diameter

d diameter (or diameter of the equivalent circle) of the through-wall defect

ΔT difference between operation and installation temperatures

E_c tensile modulus of the composite laminate in the circumferential direction

E_a tensile modulus of the composite laminate in axial direction

E_{ac} combined tensile modulus $\sqrt{E_a E_c}$

E_s tensile modulus of substrate

ε_c circumferential design strain

ε_{c0} allowable circumferential strain

ε_a axial design strain

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ε_{a0}	allowable axial strain
σ_{lt}	lower confidence limit of the long-term strain determined by performance testing
ε_t	thermal strain
ε_{short}	short-term failure strain of the composite laminate
F_{ax}	applied axial load
F_{eq}	equivalent axial load
F_{sh}	applied shear load
f_c	service factor for cyclic fatigue
f_D	degradation factor for the long-term performance of repairs to through-wall defects
f_{leak}	service factor for repairs to through-wall defects
f_{perf}	service factor for performance data
$f_{th,overlay}$	repair thickness increase factor for reduced available overlap length
$f_{th,stress}$	repair thickness increase factor for piping system or vessel component
f_{T1}	temperature de-rating factor for composite laminate allowable strains
f_{T2}	temperature de-rating factor for through-wall defect repair design
ϕ	angle subtended by axial slot
G	shear modulus of the composite laminate γ toughness parameter (energy release rate) for the composite laminate, steel interface
γ_{soilg}	specific weight of soil
h	burial depth
I	second moment of area
l	total axial length of repair
$l_{available}$	available landing area (axial extent) of undamaged substrate
l_{over}	axial extent of design thickness of repair
l_{defect}	axial length of defect
l_{taper}	axial length of taper
N	number of cycles
M_{ax}	applied axial moment
M_{to}	applied torsional moment
n	number of wraps or layers or repair laminate
p	required design internal pressure
p_{after}	internal pressure after repair system is applied

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p_e	external design pressure
p_{eq}	equivalent design pressure
$p_{ext,soil}$	external soil pressure
p_{live}	internal pressure within the substrate during application of the repair
p_{min}	minimum (internal pressure) load (or stress) of the load cycle
p_{max}	maximum (internal pressure) load (or stress) of the load cycle
p_{mthp}	medium-term hydrostatic test pressure
p_s	maximum allowable working pressure (MAWP)
p_{sthp}	short-term hydrostatic test pressure
p_0	initial test pressure
p_1	fixed linear increase in test pressure
q	tensile stress
R_c	cyclic loading severity, defined as: $R_c = \frac{p_{min}}{p_{max}}$
s	allowable stress of the substrate material
s_a	measured yield stress of substrate or mill certification yield stress
T_d	required design temperature
T_g	glass transition temperature
T_m	maximum operating temperature of repair system
T_{amb}	ambient (qualification) test temperature
T_{test}	qualification test temperature
t	original wall thickness of substrate
$t_{lifetime}$	repair design lifetime
t_{layer}	thickness of an individual wrap or layer of repair laminate
t_b	wall thickness of branch, tee
t_f	wall thickness of flange
t_{design}	design thickness of repair laminate
t_{min}	minimum thickness of repair laminate
t_s	minimum remaining substrate wall thickness
τ	lap shear strength
ν	Poisson's ratio for the repair laminate
w	(axial) width of circumferential slot defect

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4.2 Abbreviated terms

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
API	American Petroleum Institute
AWWA	American Water Works Association
BS (BSI)	British Standards Institute
CFRP	carbon fibre-reinforced plastic
COSHH	regulations for control of substances hazardous to health
CSWIP	certification scheme for welding inspection personnel
DSC	differential scanning calorimetry
FRP	fibre-reinforced plastic
GRP	glass-reinforced plastic
HDT	heat distortion temperature
MAWP	maximum allowable working pressure
MSDS	materials safety data sheets
NDT	non-destructive testing
OSHA	Occupational Safety and Health Act
PCC	Post-Construction Committee
SMYS	specified minimum yield strength

5 Applications

The qualification and design, installation, testing and inspection procedures for composite repair systems in this document cover situations involving the repair of damage commonly encountered in oil, gas, utility pipework systems and vessels. The procedures are also applicable to the repair of pipelines, caissons and storage tanks with appropriate consideration.

Procedures in this document cover the repair of metallic and GRP pipework, pipework components, pipelines originally designed in accordance with a variety of standards, including ISO 15649, ISO 13623, ISO 14692, ASME B31.1, ASME B31.3, ASME B31.4, ASME B31.8 and BS 8010.

This document is not a defect assessment standard. Within this document, no statements are made regarding whether a specific defect is acceptable or unacceptable for repair. The document assumes that a defect assessment has already been performed to, for example ASME B31G or API RP 579. The starting point for this document is that a decision has been taken to repair a given defect with a composite repair system and the output from the defect assessment, e.g. MAWP or minimum remaining wall thickness is used as input for the repair design. This document is concerned with the subsequent activities of repair qualification, design, installation and inspection.

Repair systems are applied to restore structural integrity. The following repair situations are addressed:

— external corrosion, where the defect is or is not through-wall. In this case, the application of a repair system will usually arrest further deterioration;

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— external damage such as dents, gouges and fretting (at supports);

— internal corrosion, erosion, where the defect is or is not through-wall. In this case, corrosion and/or erosion can continue after application of a repair system, and therefore the design of the repair system shall take this into account, i.e. the size of the defect at the end of the required design life of the repair should be taken as the size of the defect when designing the repair;

— crack like defects, where the defect is or is not through wall. It is a requirement that the length of the crack is known and will not increase during the lifetime of the repair. For through wall cracks, the crack should be modelled as a Type B defect, either a circumferential or axial slot (depending on the crack orientation). For non-through wall cracks, the crack should be modelled as Type A defect, see 7.5.4;

— strengthening and/or stiffening in local areas.

As a general guide, Table 1 summarizes the types of defect that can be repaired using repair systems.

Table 1 — Guide to generic defect types

Type of defect	Applicability of repair system (metal pipes)	Applicability of repair system (GRP pipes)
General wall thinning	Y	Y
Local wall thinning	Y	Y
Pitting	Y	Y
Gouges/Dents	R	R
Blisters	Y	R
Laminations	Y	R
Circumferential cracks	Y	R
Longitudinal cracks	R	R
Through-wall penetration	Y	R

Y Implies generally appropriate.

R Implies can be used, but requires extra consideration, i.e. will the composite repair reduce locally the stresses acting on the defect. For the case of gouges/dents or cracks, it will be required to assess whether application of the repair will stop future crack growth or whether a conservative assumption about the ultimate length of the crack is required. If either assessment is negative, then application of a composite repair is not appropriate.

Services that are covered within the scope of this document include those normally found in an oil and gas production or processing installation. These include the following:

— utility fluid, diesel, seawater, air;

— chemicals (liquids);

— production fluids, including liquid hydrocarbons, gaseous hydrocarbons and gas condensates.

The upper temperature limit is defined in 7.5.3.

The lower temperature limit is dependent on the type of repair laminate being used. This limit is determined by the design requirements presented in 7.5.3.

The upper pressure limit is a function of defect type (internal, external, or through-wall), defect dimensions (depth and extent), pipe diameter, design temperature and repair design lifetime. Therefore, a unique number cannot be quoted but rather the limit is derived for a given set of conditions by calculations in accordance with this document using the qualification test data.

The lower pressure limit, e.g. vacuum conditions, is determined by the design requirements presented in 7.5.9.7.

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The composite materials constituting the repair laminate considered within this document are typically those with aramid (AFRP), carbon (CFRP), glass (GRP), or polyester (or similar material) fibre reinforcement in a polyester, vinyl ester, epoxy, or polyurethane polymer matrix. Other fibre and matrix types are also permissible once qualified.

The pipework and vessel substrates considered within the standard include carbon steel, 6 moly steel, stainless steel, duplex steel, super duplex steel, GRP, Cunifer, aluminium, galvanised steel and titanium. Careful consideration is required before repair of GRP lines because the damage in the pipe may be more extensive than is visible on the surface and may affect a longer length of the pipe than is immediately obvious; advice of the GRP pipe manufacture and repair system supplier shall be sought before a repair is installed.

6 Summary of key issues

The key issues to be considered by the owner to ensure that a repair system complies with the requirements of this document are specified in the relevant clauses of this document.

The repair system is defined as the combination of the following elements and procedures:

a) substrate, (component, e.g. pipe, pipeline tank and vessel outer surface);

b) surface preparation;

c) application of filler material;

d) application of primer layer;

e) application of repair laminate;

f) curing procedure.

This document does not provide guidance on when to use a repair system. It starts from the point that a decision to use a repair system has already been taken and gives guidance on how to use repair systems effectively covering testing, design, installer training, installation and through to maintenance of a repair in service.

There are six key areas of the repair process that shall be considered.

Repair system qualification

The owner shall confirm the repair system proposed has been tested in accordance with the requirements of this document (see Clause 7). This would typically require the supplier to submit test reports or to provide third-party verification that testing has been completed.

Qualification testing is specific to a particular pipe material and method of surface preparation for that material. The owner shall confirm that testing has been completed for the pipe material of interest and the method of surface preparation being considered.

Enquiry stage

All relevant data, e.g. design conditions, corrosion mechanisms, inspection data and surface preparation limitations, shall be passed from the owner to the repair system supplier (see 7.4). Full details of design temperatures and pressures shall be provided. Upset conditions shall be considered, for example, if steaming of the line is expected, then this shall be noted.

Any limitations on working conditions shall be identified and supplied to the repair system installer/supplier through completion of the Design data sheet form (see Annex A). Risk assessment and an overview of site conditions should be supplied by the owner.

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The status of the pipework during repair application, e.g. live, no pressure but full and empty, shall be defined and passed on from the owner to the repair system supplier. Details of the expected surface temperature and local humidity shall also be provided.

A photographic record of the defect prior to repair design/application should be kept by the owner.

Design of repair

The correct design procedure shall be followed as defined in Figure 1.

When designed in accordance with this document, repair systems can provide strengthening of lines to relatively high pressures for Type A defects but can only be used at lower pressures for Type B defects. The limits for Type B defects are strongly affected by the size of defect assumed.

The selection of the generic through-wall defect and size for design, i.e. the selection of the correct dimension, may not simply be the size of the actual defect but rather may be either the dimension of the unprepared surface area neighbouring the defect or if filler is used over the defect, the dimension of the defect is the surface area of filler (see 7.5.7).

Repairs to lines suffering internal corrosion or erosion should consider the defect size expected at the end of the repair service life. The repairs would generally be less resistant to erosion than a metal pipe and repair life would normally be restricted to the point that the defect goes through-wall.

The repair system supplier shall demonstrate how the repair system will satisfy the design requirements of this document regarding temperature where the pipe has an elevated design temperature but generally operates at ambient or has an elevated design temperature but the repair is installed at ambient (see 7.5.3).

Installer training

Correct installation will ultimately determine successful performance of a repair as defined in Table 14.

Repair installers shall have been trained in the application of the specific repair system in use.

The owner shall confirm that repair installers have been trained in compliance with the requirements of this document. The repair system supplier shall demonstrate competence of the installers via evidence of training and experience (see Annex I).

Installation of repair

In terms of the performance of the repair system, the adhesion of the repair to the substrate is the key technical issue. The surface preparation procedure should be the same as that qualified by testing and assumed in the design. The pipe surface shall be dry and at a temperature above the dew point or otherwise in compliance with the conditions validated by repair qualification testing.

The actual defect size should be confirmed as being within the limits assumed in the design (e.g. physical dimension, unprepared surface area or surface area of filler).

QA measurements shall be recorded (as per the repair system supplier's method statement), as the repair is being applied (see Table 14). The repair shall be fully cured before the pressure is brought back to normal operating conditions. The repair system supplier shall provide details on how to assess the cure status of the repair laminate (see Table 14).

A photographic record of the repair application should be kept by the repair system supplier.

The completed QA measurements and photographs (if available) shall be submitted to and retained by the owner and the repair system supplier shortly after installation is completed.

The ends of the repairs, where they extend on to base metal, as a minimum should be painted over to prevent corrosion to the pipe at this location.

Inspection and maintenance of repair

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If considered necessary, the repair should be inspected on a regular basis to ensure the integrity of the repair and that it is operating within the assumptions used in the design of repair (i.e. the defect size is less than assumed in design) (see Clause 9). It may be appropriate to complete a baseline inspection immediately after application against which future inspections can be compared and changes identified.

At the end of the repair design lifetime, either the spool onto which the repair is situated should be removed, the repair removed, or the repair design lifetime revalidated (see 9.5).

7 Qualification and design

7.1 Repair feasibility assessment

The following factors shall be considered by the owner and repair system supplier when assessing the feasibility of designing and installing a repair system:

— assessment of the nature and location of the defects;

— design and operating conditions for the substrate and contents (including pressure, temperature, sizes and combinations thereof);

— repair design lifetime (see 7.3);

— geometry of the substrate being repaired;

— hazards associated with system service;

— availability of personnel with the necessary skills;

— ease with which it is practicable to execute surface preparation operations;

— performance under upset and major incident situations, including impact, abrasion, fire, explosion, collision and environmental loading;

— operational measures, including (if relevant) permits, gas testing and fire protection requirements to ensure safety in the vicinity of the repair area;

— failure modes;

— inspectability (both visual and non-destructive) and maintenance of the repair;

— repair system materials.

For clarification, the assessment is not intended as a means to predetermine that the repair system is the appropriate strategy or remedial action, but rather to assess the feasibility associated with applying the repair system.

The information and data describing any hazards shall be included in the method statement (8.2) to be used on site.

Since the application of these repair systems typically changes the mode of failure from rupture of the substrate to a leak, the consequences of failure will therefore be reduced.

The objective of the assessment shall be to establish the class of the repair (7.2), which determines the detail of the design method (7.5) to be carried out, together with the requirements for supporting documentation. This also determines the design margin or factor of safety to be used in the design.

Guidance on performing the assessment can be obtained from Reference[36].

7.2 Repair class

Each repair shall be allocated to a particular class as defined in Table 2.

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Class 1 repairs cover design pressures up to 2 MPa (20 bar), design temperatures up to 40 °C and are appropriate for the majority of the utility service systems. This class is intended for those systems that do not relate directly to personnel safety or safety-critical systems.

Class 2 repairs cover design pressures up to 2 MPa (20 bar) and design temperatures up to 100 °C but exclude hydrocarbons. This class is appropriate for those systems that have specific safety-related functions.

Class 3 repairs cover all fluid types and pressures up to the qualified upper pressure limit. This class is appropriate for systems transporting produced fluids.

Applications in which the service conditions are more onerous or not included in the above shall be designated as Class 3.

Table 2 — Repair class

Repair class	Typical service	Design pressure	Design temperature
Class 1	Low specification duties, e.g. static head, drains, cooling medium and sea (service) water	<2 MPa	<40 °C
Class 2	Fire water/deluge systems	<2 MPa	<100 °C
Class 3	Produced water and hydrocarbons, flammable fluids, gas systems Class 3 also covers operating conditions more onerous than described above.	Limited to repairs designed in compliance with this document and of a thickness equivalent to <D/12	Defined in 7.5.3

The qualified upper pressure limit is a function of defect type (internal, external or through-wall), defect dimensions (depth and extent), pipe diameter, design temperature and repair design lifetime. Therefore, a unique number cannot be quoted but rather the limit is derived for a given set of conditions by calculations in accordance with this document using the qualification test data from either Annex C for Type A defects and Annex D for Type B defects.

7.3 Repair design lifetime

The repair design lifetime (in years) of the repair system shall be defined by the owner in the repair data sheet (Annex A). It may be limited by the defect type and service conditions, e.g. internal corrosion.

The minimum design lifetime of the repair shall be two years.

Short design lifetimes (two years) may be appropriate to those situations where the repair is required to survive until the next shutdown.

Long design lifetimes (up to 20 years) may be appropriate to those situations where the repair is required to reinstate the substrate to its original design lifetime or to extend its design life for a specified period.

The repair design lifetime is the maximum application lifetime of the repair. The actual application or service lifetime, often termed the defined lifetime, maybe less than the repair design lifetime.

Once the repair design lifetime has expired, the owner shall either remove or revalidate the repair system as described in 9.5.

7.4 Required data

7.4.1 Background

The following data shall be supplied for each repair application. The detail to which these requirements are fulfilled is determined by the output of the repair feasibility assessment. Original equipment design

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data, maintenance and operational histories shall be provided by the owner and material qualification data shall be provided by the repair system supplier. The availability of relevant data shall feature as part of the repair feasibility assessment.

7.4.2 Original equipment design data

Original equipment design data is required, consisting of the following:

a) piping line lists or other documentation showing process design conditions and a description of the piping class, including material specification, wall thickness, and pressure and temperature ratings;

b) piping isometric drawings and, if appropriate, the output of a piping flexibility calculation;

c) specification of all operating mechanical loads not included in the above, including upset conditions;

d) original design calculations;

e) regulatory requirements, e.g. fire performance.

7.4.3 Maintenance and operational histories

Maintenance and operational histories are required, consisting of the following:

a) documentation of any changes in service conditions, including pressure, temperature, internal fluids and corrosion rate;

b) past service conditions;

c) summary of all alterations and past repairs local to the substrate of concern;

d) inspection reports detailing the nature and extent of damage to be repaired.

7.4.4 Service condition data

Service condition data are required, consisting of the following:

a) repair design lifetime requirements/expectations;

b) required design and operating pressures (internal and external)/temperatures;

c) expected future service conditions;

d) if applicable, MAWP as calculated according to the requirements of ASME B31G, API 579, BS 7910 or other applicable standard. This shall be carried out taking into account the current position and any possible further degradation in the future.

An example of a design data sheet is presented in Annex A.

7.4.5 Repair system qualification data

The documentation and qualification data related to repair systems that shall be provided for the repair system are shown in Table 3.

Details of the qualification data to be provided are given in Annex B.

Table 3 — Documentation and data requirements

Documentation requirement	Class 1	Class 2	Class 3
Material documentation and data	✓	✓	✓

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Table 3 *(continued)*

Documentation requirement	Class 1	Class 2	Class 3
Surface preparation documentation	✓	✓	✓
Short-term test data	✓	✓	✓
Long-term test data		✓	✓

Clarification of the terms used in Table 3 is as follows:

a) Material documentation and data

This shall include a statement of the resins and reinforcements used and any standards to which they are supplied. Basic data on material compatibility with the working environment shall also be available. It shall be ensured that any chemical interaction between the resin (and associated curing agents) and substrate will not cause further degradation of the substrate. Also, attention shall be given to CFRP laminates and the potential for bimetallic (galvanic) corrosion of the substrate.

b) Surface preparation

The durability of a bonded assembly under applied load is determined to a large extent by the quality of the surface preparation used. Details of the surface preparation procedure and how it is to be implemented shall be provided as used in the qualification tests.

c) Short-term test data

These shall include tensile strength and modulus in both the hoop and axial directions and the strength of the (adhesive) bond between the repair laminate and the substrate.

d) Long-term lap shear durability test data

These shall include the strength of the adhesive bond between the repair laminate and substrate, and optionally the ultimate tensile strain of the repair laminate. Long-term is defined as greater than or equal to 1 000 h where the sample has been exposed to a water environment and a temperature greater than or equal to the design temperature. Above a temperature of 100 °C, the environment can be dry.

Table 4 lists the data required to comply with Class 3 requirements. Annex B contains the full details of the qualification data requirements.

Table 4 — Qualification test requirements

	Material property	Test method
Mechanical properties	Young's modulus	ISO 527-1, ISO 527-4 (or ASTM D3039)
	Poisson's ratio	ISO 527-1, ISO 527-4 (or ASTM D3039)
	Shear modulus	ASTM D5379
	Thermal expansion coefficient	ISO 11359-2 (or ASTM D696)
	Glass transition temperature of resin or heat distortion temperature of resin cured at relevant temperatures	ISO 11357-2 (or ISO 75-3, ASTM D6604, ASTM E1640, ASTM E831), ASTM E2092
	Barcol or Shore hardness	ISO 868 or EN 59 (or ASTM D2583)
Adhesion strength	Lap shear	EN 1465 (or ASTM D3165)

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Table 4 *(continued)*

	Material property	Test method
Performance data	Long-term strength (optional)	Annex E
	Energy release rate (optional)	Annex D
	Short-term pipe spool survival test	Annex C
	Impact survival test	Annex F
	Degradation factor (optional)	Annex G

7.5 Design methodology

7.5.1 Overview

There are two design cases.

a) Defect type A (non through-wall defect) design case

The defect is within the substrate, not through-wall and not expected to become through-wall within the repair design lifetime of the repair system, requiring structural reinforcement only. One of the following three design methods shall be used to determine the repair laminate thickness, t_{design}:

1) include allowance for the substrate (see 7.5.4);

2) exclude allowance for the substrate (see 7.5.5);

3) long-term performance test data (see 7.5.6).

b) Defect type B (through-wall defect) design case

The substrate requires structural reinforcement and sealing of through-wall defects (leaks). For substrates with active internal corrosion, the repair laminate shall be designed on the assumption that a through-wall defect will occur if the remaining wall thickness at the end of service life is expected to be less than 1 mm. Both of the following design methods shall be used:

1) the design method in 7.5.7;

2) the design method for the defect type A design case.

The greater repair thickness from the defect type A design case or the design method in 7.5.7 shall be taken as the repair laminate thickness, t_{design}.

7.5.9 and 7.5.13 shall be considered for each design case and applied where appropriate, with the largest thickness being taken as the repair laminate thickness, t_{design}.

The flowchart presented in Figure 1 provides an overview of the above described design process. Further informative guidance on the repair design process is given in Annex K. Within Annex K, two worked examples (for a Type A and Type B defect) are provided.

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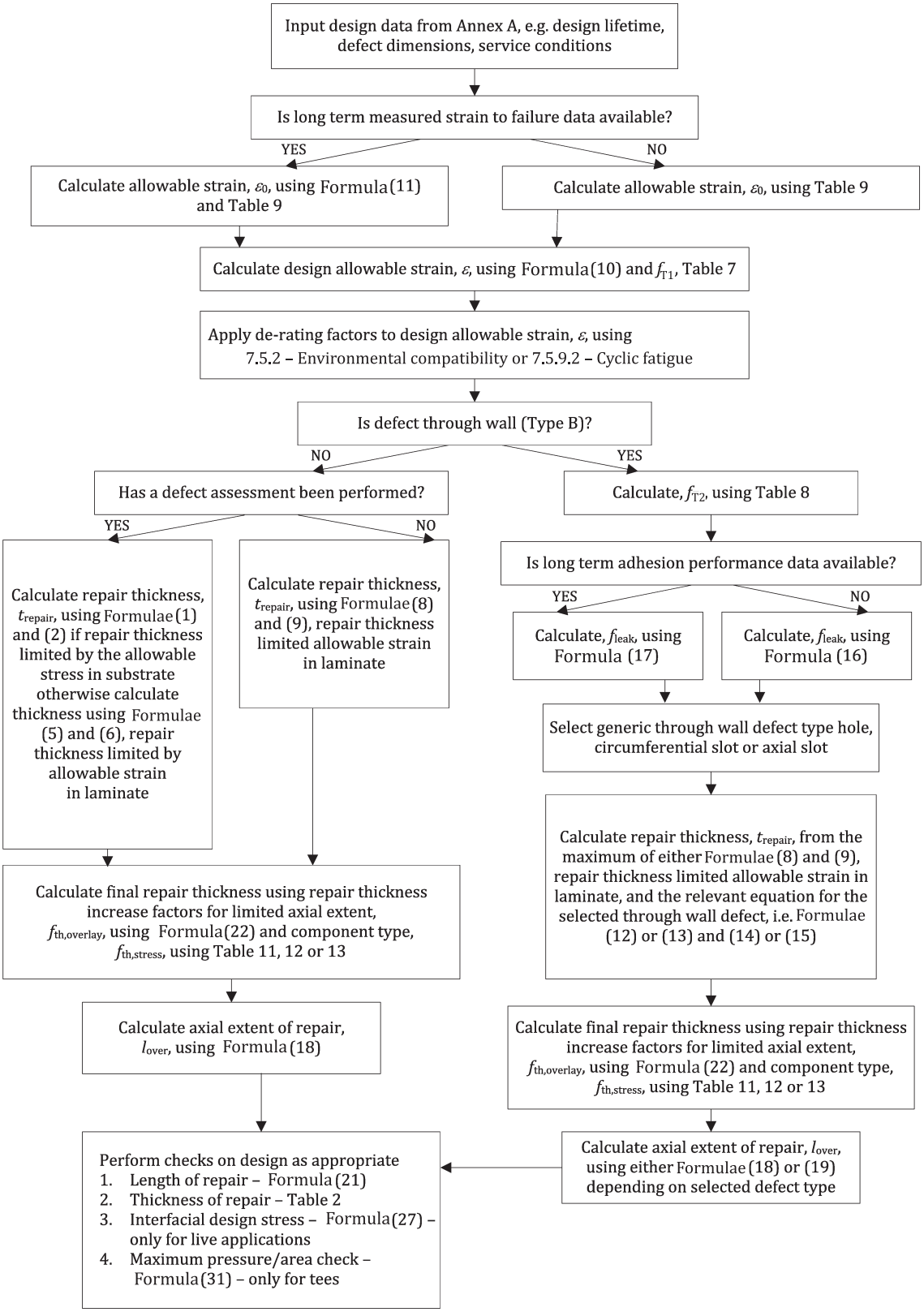

Figure 1 — Flowchart summarizing repair system design process

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7.5.2 Environmental compatibility

The suitability for use of the repair system in the service environment shall be based on the following considerations. The service environment is the environment that contacts the repair laminate. It may be either the external or internal environment.

The qualification of the repair system (7.4.5) demonstrates that the repair system is compatible with aqueous (wet) and hydrocarbon environments at the qualification test temperature. In general, thermoset resins are compatible with a wide range of environments, but consideration shall be given when the environment is strongly acidic (pH < 3,5), strongly alkaline (pH > 11), highly saline or is a strong solvent, e.g. methanol, glycol, benzene and toluene in concentration greater than 25 %.

Resistance to UV degradation and weathering (where appropriate) shall be provided by data from the resin supplier.

When the environmental compatibility of the repair system is unknown, then the repair system supplier shall provide one of the following to demonstrate compatibility:

— environmental compatibility data or experience of previous applications from the resin supplier, demonstrating that the environment is no more aggressive than aqueous or hydrocarbon environments at the design temperature;

— if no compatibility data from the resin supplier is available, then specific environmental testing is required. One of the following test procedures, ISO 10952, ASTM D543, ASTM C581, ASTM D3681 or equivalent, comparing the exposure of the specific environment and aqueous environment to the repair laminate at the design temperature shall be performed. The repair system shall be considered compatible to the specific environment if the test results from the specific environment are no worse than for the aqueous environment.

When particulate erosion is the cause of the degradation process of the substrate and the repair laminate is in contact with the eroding medium, then the repair laminate can suffer material loss. The repair system supplier shall demonstrate the survival of the repair system for the specified repair design lifetime assuming a conservative estimate of the loss of laminate material. Without experimental data on the erosion rate, a maximum repair design lifetime of no more than two years is recommended. Alternatively, a metal plate can be placed over the affected area prior to application of the repair laminate to minimize material loss (of the laminate), wherein the design of the repair the dimensions of the plate are taken as the size of the defect.

When considering the repair to GRP pipes or vessels, the chemical interaction between both solvent used to clean the surface and also the uncured resin constituents of the repair material and the GRP material should be considered.

7.5.3 Design temperature effects

The thermal properties of the repair system shall satisfy the requirements given in Table 5. The value of T_g or HDT used shall be determined in Annex B for a repair system cured at a temperature no greater than the design temperature of the repair, T_d. The cure schedule (time and temperature profile) required to achieve this shall be specified. The temperature limit of a repair system shall be defined with reference to T_g unless the repair system does not show this transition in which case the temperature limit shall be defined with reference to HDT. Repairs that are applied to systems that are depressurised and drained may be heated (post-cured) to give the required value of T_g or HDT. The heating cycle used shall have been demonstrated to achieve the required value of T_g or HDT during qualification testing.

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Table 5 — Thermal property requirements for repair systems

Repair class	Defect type A limit	Defect type B limit	
		Repair design lifetime ≤ 2 years	Repair design lifetime > 2 years
Class 1 and 2	$T_g \geq T_d + 20$ °C HDT ≥ $T_d + 15$ °C	$T_g \geq T_d + 20$ °C HDT ≥ $T_d + 15$ °C	
Class 3		$T_g \geq T_d + 20$ °C HDT ≥ $T_d + 15$ °C	$T_g \geq T_d + 30$ °C HDT ≥ $T_d + 20$ °C

Hardness can give an indication of cure and, where measured, shall be no less than 90 % of the minimum obtained from repair system qualification in accordance with Table 4. Hardness alone shall not be relied upon to demonstrate cure for repair to Class 3 systems; reference shall also be made to the cure schedule.

For a repair system where the defect within the substrate is not through-wall, the temperature limit can be relaxed to T_g less 20 °C or HDT less 15 °C. T_g or HDT shall be measured in accordance with Table 4. Table 6 summarizes the upper temperature limit of the repair when cured to as specified in Clause 7.

Table 6 — Service temperature limits for repair systems

	Defect type A limit T_m	Defect type B limit T_m	
		Repair design lifetime ≤ 2 years	Repair design lifetime > 2 years
Class 1 and 2	T_g – 20 °C	T_g – 20 °C	T_g – 20 °C/HDT – 15°C
Class 3	HDT – 15 °C	HDT – 15°C	T_g – 30 °C/HDT – 20°C

The temperature de-rating factor, f_{T1}, to account for elevated design temperature application used in Formula (10) is given in Table 7, where T_m is the upper temperature limit for the system (as defined in Table 6), in degree Celsius.

Table 7 — Temperature de-rating factor for composite laminate allowable strains, f_{T1}

Temperature factor; f_{T1}	$0{,}000\,062\,5(T_m - T_d)^2 + 0{,}001\,25(T_m - T_d) + 0{,}7$

The additional requirements for repairs to through-wall defects are qualified through performance testing. To allow for higher design temperatures than the qualification test temperature, Table 8 defines the temperature de-rating factor, f_{T2}, that shall be applied to Formula (12) to Formula (15), where T_{amb} is the ambient test temperature, in degree Celsius and T_{test} is the qualification test temperature, in degree Celsius.

Table 8 — Temperature de-rating factor for through-wall defects (Type B defect) and performance test data, f_{T2}

Temperature factor; f_{T2}	$0{,}000\,062\,5[T_m - T_d - (T_{test} - T_{amb})]^2 + 0{,}001\,25[T_m - T_d - (T_{test} - T_{amb})] + 0{,}7$

The formulae presented in Table 7 and Table 8 are based on similar temperature de-rating factors as defined in EN 13121.

Where a repair will generally be operating at a lower temperature than T_d, then the T_g value associated with this lower operating temperature shall be checked and the relevant value of f_{T1} derived. The lower of the values of f_{T1} obtained shall be used in the design of the repair. In this case, it is assumed the repair system will cure to a satisfactory level when the temperature in the line increases. If this temperature increase is expected to be relatively fast (i.e. <30 min), then the repair system supplier shall be advised of this. The repair system supplier shall demonstrate this rate of heating is acceptable by test; otherwise, the repair shall be post-cured using external heating. Post-curing shall only be undertaken on pipes which are depressurised and drained.

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7.5.4 Design based on substrate load sharing (defect type A)

Use of the design method in this subclause is appropriate if the contribution of the substrate is to be included in the calculation for load-carrying capability.

7.5.4.1 Limited by allowable stress in the substrate

Formulae (1) and (2) shall be used when it is assumed that the repair thickness is limited by the allowable stress in the substrate.

In the circumferential direction, the minimum repair laminate thickness, $t_{\min}$ (expressed in millimetres), is given by Formula (1):

$$t_{\min,c} = \frac{D}{2s} \cdot \left(\frac{E_s}{E_c} \right) \cdot \left(p_{eq} + \frac{2\upsilon F_{eq}}{\pi D^2} - p_s \right) \tag{1}$$

In the axial direction, the minimum repair laminate thickness, $t_{\min}$ (expressed in millimetres), is given by Formula (2):

$$t_{\min,a} = \frac{D}{2s} \cdot \left(\frac{E_s}{E_a} \right) \cdot \left(\frac{2F_{eq}}{\pi D^2} - \upsilon \frac{E_a}{E_c} p_{eq} - p_s \right) \tag{2}$$

where

E_a is the axial modulus of the repair laminate, expressed in megapascals;

E_c is the circumferential modulus of the repair laminate, expressed in megapascals;

E_s is the modulus of substrate, expressed in megapascals;

D is the original external diameter, expressed in millimetres;

F_{eq} is the equivalent axial load, expressed in newtons [see Formula (4)];

υ is the Poisson's ratio of the repair laminate (see Annex B for definition);

s is the allowable stress of the substrate material, expressed in megapascals;

p_{eq} is the equivalent internal pressure, expressed in megapascals [see Formula (3)];

p_s is the MAWP, expressed in megapascals, which is defined according to the relevant defect assessment code;

t_s is the minimum remaining substrate wall thickness, expressed in millimetres.

NOTE It is possible that when using Formula (2), that negative repair thickness values are calculated. This implies that the remaining wall thickness is sufficient to withstand the applied loads in the axial direction.

In Formula (2), the contribution of F_{eq} shall be taken as positive.

p_{eq} and F_{eq} are defined as:

$$p_{eq} = p\left[1 + \frac{16}{\left(\pi D^2 p\right)^2}\left(F_{sh} + \frac{2}{D}M_{to}\right)^2\right] \quad for \quad p \geq \frac{4}{\pi D^2}\left(F_{sh} + \frac{2}{D}M_{to}\right)$$

$$p_{eq} = p + \frac{4}{\pi D^2}\left(F_{sh} + \frac{2}{D}M_{to}\right) \quad for \quad p < \frac{4}{\pi D^2}\left(F_{sh} + \frac{2}{D}M_{to}\right) \tag{3}$$

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$$F_{eq} = \frac{\pi}{4} pD^2 + \sqrt{F_{ax}^2 + 4F_{sh}^2} + \frac{4}{D}\sqrt{M_{ax}^2 + M_{to}^2} \quad (4)$$

where

p is the required internal design pressure, expressed in megapascals;

F_{sh} is the applied shear load, expressed in newtons;

M_{to} is the applied torsional moment, expressed in newton millimetres;

F_{ax} is the applied axial load, expressed in newtons;

M_{ax} is the applied axial moment, expressed in newton millimetres.

The design repair thickness, t_{design} (expressed in millimetres), shall be the maximum value of $t_{min,c}$ and $t_{min,a}$ determined from Formulae (1) and (2).

If the purpose of the repair system is to strengthen an undamaged section to carry additional bending or other axial loads, the value of F_{eq} shall be taken to be the increased total axial load requirement and the value of p_s shall be the MAWP after the defect has been assessed.

Formulae (1) and (2) are valid for repair thickness $t_{design} < \frac{D}{12}$.

The assumption made in deriving Formulae (1) and (2) is that the substrate is elastic.

7.5.4.2 Limited by allowable strain in the repair laminate

Formulae (5) and (6) shall be used when it is assumed that the repair thickness is limited by the allowable strain of the repair laminate (see 7.5.5). In the circumferential direction, the minimum repair laminate thickness, t_{min} (expressed in millimetres) is given by Formula (5):

$$\varepsilon_c = \frac{1}{E_c t_{min}}\left(\frac{p_{eq}D}{2} + \upsilon\frac{F_{eq}}{\pi D}\right) - \frac{p_s D}{2E_c t_{min}} - \frac{p_{live}D}{2\left(E_c t_{min} + E_s t_s\right)} \quad (5)$$

In the axial direction, the minimum repair laminate thickness, t_{min} (expressed in millimetres), is given by Formula (6):

$$t_{min,a} = \frac{1}{\varepsilon_a}\left(\frac{F_{eq}}{\pi D}\frac{1}{E_a} - \frac{p_{eq}D}{2}\frac{\upsilon}{E_c}\right) \quad (6)$$

where

p_{live} is the internal pressure during repair installation, expressed in megapascals;

ε_c is the allowable repair laminate circumferential strain, expressed in millimetres per millimetre, as derived in 7.5.5 or 7.5.6;

ε_a is the allowable repair laminate axial strain, expressed in millimetres per millimetre, as derived in 7.5.5 or 7.5.6.

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