INTERNATIONAL STANDARD

ISO 24817

First edition
2015-08-01

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

Industries du pétrole, de la pétrochimie et du gaz naturel — Réparations en matériau composite pour canalisations: Conformité aux exigences de performance et conception, installation, essai et inspection

Reference number
ISO 24817:2015(E)

Contents

Page

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

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 6, *Processing equipment and systems*.

This first edition cancels and replaces ISO/TS 24817:2006, which has been technically revised.

Introduction

The objective of this International Standard is to ensure that pipework, pipelines, tanks, and vessels repaired using composite systems that are qualified, designed, installed, and inspected using this International Standard 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 International Standard 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.

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

1 Scope

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

ISO 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*

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.

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

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.

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 International Standard 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, valves.

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, 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.

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

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

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

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 International Standard 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 International Standard 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 International Standard is not a defect assessment standard. Within this International Standard, no statements are made regarding whether a specific defect is acceptable or unacceptable for repair. The standard assumes that a defect assessment has already been performed to, for example ASME B31G or API RP 579. The starting point for this International Standard 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 International Standard 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;

— 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, 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 International Standard 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 International Standard 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.

The composite materials constituting the repair laminate considered within this International Standard 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 International Standard are specified in the relevant clauses of this International Standard.

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

a) substrate, (component, e.g. pipe, pipeline tank, 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 International Standard 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 International Standard (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 (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 must 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 (Annex A). Risk assessment and an overview of site conditions should be supplied by the owner.

The status of the pipework during repair application, e.g. live, no pressure but full, 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 International Standard, 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 (7.5.7).

Repairs to lines suffering internal corrosion or erosion must 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 International Standard 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 (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 International Standard. The repair system supplier shall demonstrate competence of the installers via evidence of training and experience (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 (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 (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

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) (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 re-validated (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.

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, 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 International Standard 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 International Standard 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 2 years.

Short design lifetimes (2 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 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	✓	✓	✓
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)

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.

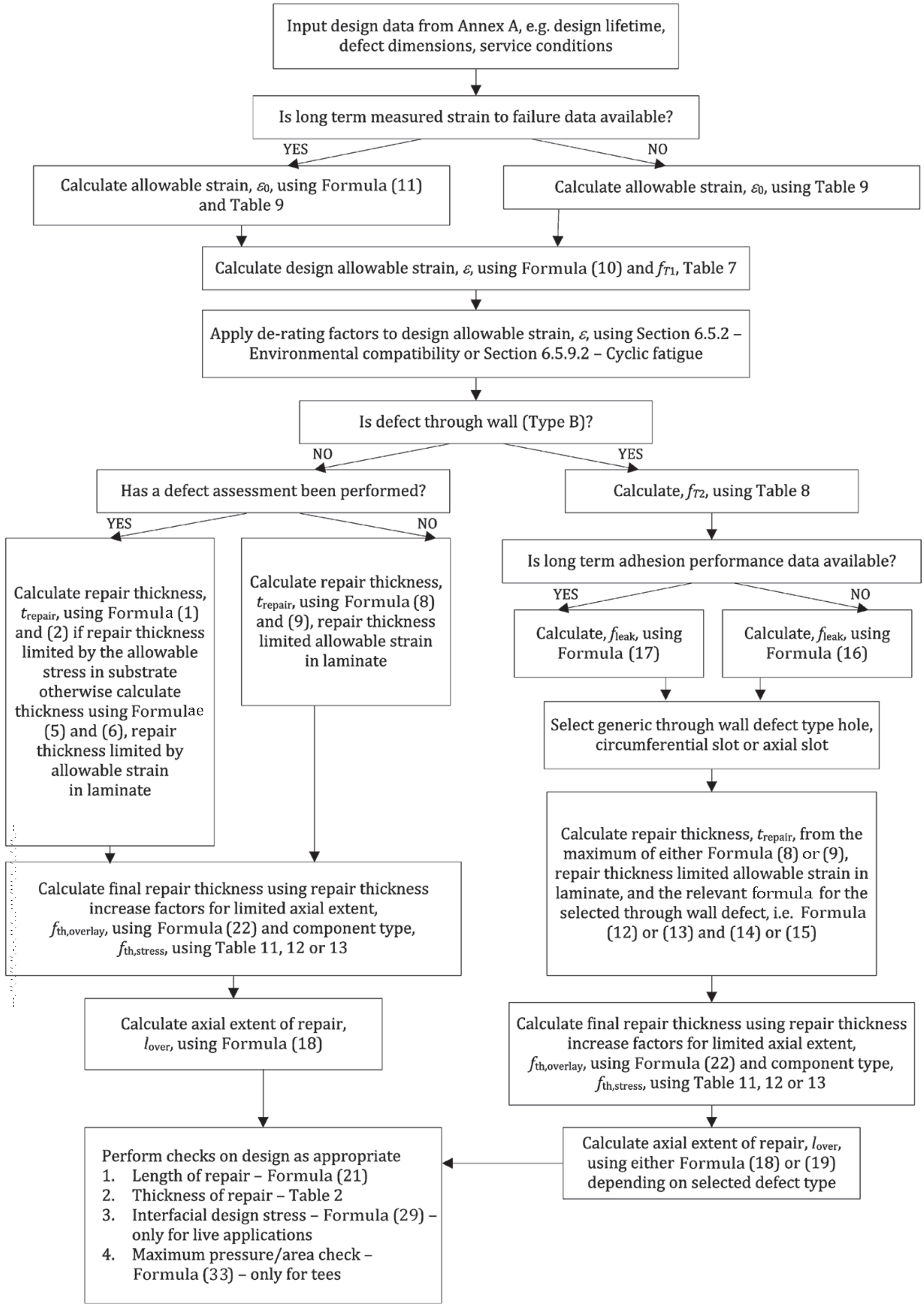


Figure 1 — Flowchart summarizing repair system design process

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, 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 the 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 2 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 that 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.

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 this Clause.

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 Formulae (12), (13), (14), and (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.

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):

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

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

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

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)];

ν 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:

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

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

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

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):

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

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

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

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.

If the repair is applied at zero internal pressure, i.e. $p_{live} = 0$, and axial loads can be neglected, i.e. buried pipelines, then Formula (5) can be rearranged to give:

$$t_{min} = \frac{D}{2\varepsilon_c E_c}\left(p_{eq} - p_s\right) \tag{7}$$

The design repair thickness, t_{design}, shall be taken as the maximum value determined from either Formula (5) or Formula (6).

Formulae (5) to (7) are valid for repair thickness $t_{\text{design}} < \frac{D}{12}$.

The assumptions made in deriving Formulae (5) to (7) are that the substrate is elastic and only contributes to the load-sharing up to the allowable stress (of the substrate).

7.5.5 Design based on repair laminate allowable strains (defect type A)

Use of the design method in this subclause is appropriate if the contribution of the substrate is to be ignored in the calculation for load-carrying capability and if short-term material properties are to be used.

In the circumferential direction, the minimum repair laminate thickness, t_{min} (expressed in millimetres), due to internal pressure, bending, and axial thrust, is given by:

$$t_{\text{min,c}} = \frac{1}{\varepsilon_{\text{c}}}\left(\frac{p_{\text{eq}}D}{2}\frac{1}{E_{\text{c}}} + \frac{F_{\text{eq}}}{\pi D}\frac{\upsilon}{E_{\text{c}}}\right) \tag{8}$$

In Formula (8), the contribution of F_{eq} shall be taken as positive.

In the axial direction, the minimum repair laminate thickness, tmin (expressed in millimetres), due to internal pressure, bending and axial thrust, is given by:

$$t_{\text{min,a}} = \frac{1}{\varepsilon_{\text{a}}}\left(\frac{F_{\text{eq}}}{\pi D}\frac{1}{E_{\text{a}}} - \frac{p_{\text{eq}}D}{2}\frac{\upsilon}{E_{\text{c}}}\right) \tag{9}$$

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;

D is the original external diameter, expressed in millimetres;

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

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

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

ε_{a} is the allowable repair laminate axial strain, expressed in millimetres per millimetre;

ε_{c} is the allowable repair laminate circumferential strain, expressed in millimetres per millimetre.

In Formula (9), the contribution of F_{eq} shall be taken as positive.

The design repair thickness, t_{design}, shall be the maximum value of $t_{\text{min,c}}$ and $t_{\text{min,a}}$ determined from Formulae (8) and (9).

Formulae (8) and (9) are valid for repair thickness $t_{\text{design}} < \frac{D}{12}$.

For occasional loads (short-duration loads), Class 1 minimum repair design lifetime (2 year) strains shall be used; see Table 9.

The allowable strains presented in Table 9 shall only be used if the short-term strain to failure of the repair laminate is greater than 0,01; otherwise, performance data from 7.5.6 shall be used. The short-term strain to failure can be derived from the test carried out to determine the tensile properties of the laminate (Table 4).

The thermal expansion coefficient for a repair laminate is different from that of the substrate, resulting in the generation of thermal stresses within the repair laminate when the design temperature is different from the installation temperature. This effect shall be considered in the design assessment by subtracting the thermally induced strains from the allowable strains. The temperature factor, f_{T1}, shall be applied to the allowable strain before subtraction. The allowable repair laminate thermal strains in the circumferential and axial directions, ε_c and ε_a, shall be calculated by:

$$\varepsilon_c = f_{T1}\varepsilon_{c0} - \left|\Delta T\left(\alpha_s - \alpha_c\right)\right|$$
$$\varepsilon_a = f_{T1}\varepsilon_{a0} - \left|\Delta T\left(\alpha_s - \alpha_a\right)\right| \quad (10)$$

where

ε_{a0} is the allowable repair laminate axial strain (no temperature effect (see Table 9)], expressed in millimetres per millimetre;

ε_{c0} is the allowable repair laminate circumferential strain [no temperature effect (see Table 9)], expressed in millimetres per millimetre;

f_{T1} is the temperature de-rating factor (see Table 7);

α_a is the repair laminate thermal expansion coefficient, axial direction, expressed in millimetres per millimetre degree Celsius;

α_c is the repair laminate thermal expansion coefficient, circumferential direction, expressed in millimetres per millimetre degree Celsius;

α_s is the substrate thermal expansion coefficient, expressed in millimetres per millimetre degree Celsius;

ΔT is the difference between design and installation temperatures, expressed in degree Celsius.

Table 9 — Allowable strains for composite laminates as a function of repair design lifetime

Modulus	Allowable strain Class 1	Allowable strain Class 2	Allowable strain Class 3
For $E_a > 0,5\ E_c$			
— Continue-1 ε_{c0}	0,004 214*10$^{-0,011\ 35\ t_{lifetime}}$	0,003 634*10$^{-0,008\ 13\ t_{lifetime}}$	0,003 061*10$^{-0,004\ 4\ t_{lifetime}}$
— ε_{a0}	0,004 214*10$^{-0,011\ 35\ t_{lifetime}}$	0,003 634*10$^{-0,008\ 13\ t_{lifetime}}$	0,003 061*10$^{-0,004\ 4\ t_{lifetime}}$
For $E_a < 0,5\ E_c$			
— ε_{c0}	0,004 214*10$^{-0,011\ 35\ t_{lifetime}}$	0,003 634*10$^{-0,008\ 13\ t_{lifetime}}$	0,003 061*10$^{-0,004\ 4\ t_{lifetime}}$
— ε_{a0}	0,002 768*10$^{-0,022\ 1\ t_{lifetime}}$	0,001	0,001

The values in Table 9 include a service factor for safety equivalent to 0,67.

7.5.6 Design based on repair-allowable stresses determined by performance testing (defect type A)

Use of the design method in this subclause is appropriate if performance-based test data are available.

Annex E provides three methods for the determination of long-term failure strain of the repair laminate.

The allowable repair laminate circumferential strain, ε_c, (expressed in millimetres per millimetre) is given by Formula (11):

$$\varepsilon_c = f_{\text{perf}} f_{T2} \varepsilon_{\text{lt}} \quad (11)$$

where

ε_{lt} is the lower confidence limit of the long-term strain, expressed in millimetres per millimetre (see Annex E);

f_{perf} is the service de-rating factor (see Table 10);

f_{T2} is the temperature de-rating factor (see Table 8).

If allowance for the substrate is not to be included, then Formula (8) shall be used to calculate the minimum repair thickness in the circumferential direction.

If allowance for the substrate is to be included, then Formula (5) shall be used to calculate the minimum repair thickness in the circumferential direction.

Table 10 — Service factor, f_{perf}, for performance data of repair systems

Service factor	Class 1	Class 2	Class 3
1 000 h data	$0{,}878 \cdot 10^{-0{,}012\,2}\ t_{\text{lifetime}}$	$0{,}692 \cdot 10^{-0{,}007}\ t_{\text{lifetime}}$	$0{,}612 \cdot 10^{-0{,}004\,3}\ t_{\text{lifetime}}$
Design life data	$1{,}045\,5 \cdot 10^{-0{,}009\,65}\ t_{\text{lifetime}}$	$0{,}873 \cdot 10^{-0{,}005\,75}\ t_{\text{lifetime}}$	$0{,}76 \cdot 10^{-0{,}002\,73}\ t_{\text{lifetime}}$

7.5.7 Design of repairs for through-wall defects (defect type B)

A defect within a substrate shall be considered through-wall if the wall thickness at any point of the affected area is determined to be less than 1 mm at the end of its life.

Use of the design method in this subclause is appropriate if the defect within the substrate is through-wall or deemed to become through-wall at the end of its life. The requirements of this subclause are in addition to those described in 7.5.4, 7.5.5 or 7.5.6.

The dimension of the through-wall defect to be used in the design shall be based on the estimated size of the defect at the end of the required design life of the repair system.

In some circumstances, it may not be possible to prepare the substrate completely adjacent to the repair. Often a protective metal plate is used to protect the damaged substrate during surface preparation, e.g. grit blasting. In these circumstances, the dimension of the defect shall be taken as the unprepared substrate surface area (including metal plate plus any fairing material).

Also, if filler material is used over the defect, e.g. if a repair is to encompass a flange, then the size of the defect shall be taken as the surface area of the pipework covered by the filler material.

For a circular or near-circular defect, the minimum thickness for a repair laminate, t_{min} (expressed in millimetres), shall be calculated using Formula (12):

$$p = f_{T2} f_{leak} \sqrt{\left\{ \frac{0{,}001 \gamma_{LCL}}{\frac{(1-\upsilon^2)}{E_{ac}} \left\{ \frac{3}{512 t_{min}^3} d^4 + \frac{1}{\pi} d \right\} + \frac{3}{64 G t_{min}} d^2} \right\}} \quad (12)$$

where

E_{ac} is the combined tensile modulus $\sqrt{E_a E_c}$, expressed in megapascals;

G is the shear modulus of the repair laminate, expressed in megapascals;

p is the design internal pressure, expressed in megapascals;

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

d is the diameter of defect, expressed in millimetres;

t_{min} is the thickness of repair laminate, expressed in millimetres;

γ_{LCL} is the 95 % lower confidence limit of energy release rate, expressed in joules per square metre (see Annex D);

f_{T2} is the temperature de-rating factor, see Table 8;

f_{leak} is the service de-rating factor [see Formula (16)].

Plugging of the through-wall defect in the tests performed to determine the value of γ_{LCL} (Annex D) is not allowed.

Formula (12) is valid for defect sizes where

D is the substrate external diameter, expressed in millimetres;

t is the substrate wall thickness, expressed in millimetres.

For non-circular defects that have an aspect ratio <5, Formula (12) shall be used where the value of d (effective defect diameter) is selected such that it contains the defect.

For the case of 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 to be used in the design calculation is required.

For a circumferential slot type defect, the minimum thickness for a repair laminate, t_{min} expressed in millimetres, is calculated using the smallest value of repair thickness calculated from both Formula (13) and Formula (14):

$$p = f_{T2} f_{leak} \sqrt{\left\{ \frac{0{,}001 \gamma_{LCL}}{\frac{(1-\upsilon^2)}{E_{ac}} \left\{ \frac{1}{24 t_{min}^3} w^4 + \frac{\pi}{4} w \right\} + \frac{3}{16 G t_{min}} \frac{\left(\frac{4}{5} + \frac{\upsilon}{2} \right)}{(1+\upsilon)} w^2} \right\}} \quad (13)$$

$$p=\frac{f_{T2}f_{\text{leak}}}{D}\sqrt{0{,}008E_{\text{ac}}t_{\text{min}}\gamma_{\text{LCL}}} \tag{14}$$

where w is the axial width of the slot, expressed in millimetres.

Formulae (13) and (14) shall be used to assess the repair thickness required where the defect to be repaired is a pinhole in a weld. The slot width selected shall be sufficient to include the full width of the weld and any fairing material used in the repair application procedure.

For an axial slot type defect having a circumferential width of the slot, $w = \phi D$ expressed in millimetres, the minimum thickness for a repair laminate, t_{min} expressed in millimetres, is calculated using Formula (15):

$$p=f_{T2}f_{\text{leak}}\sqrt{\left\{\frac{0{,}001\gamma_{LCL}}{\frac{(1-\upsilon^2)}{E_{\text{ac}}}\left[\frac{\pi D}{8}\varphi+\frac{D^4}{384t_{\text{min}}^3}\varphi^4+\frac{D^4(\frac{E_{\text{ac}}}{4G}+2)}{11\,520t_{\text{min}}^3}\varphi^6\right]}\right\}} \tag{15}$$

where the limit on the applicability of Formula (15) is given by $\phi < 1$, where ϕ is the angle subtended by the axial slot, expressed in radians.

It is recommended that the size of defect used in Formulae (12) to (15) should be at least 15 mm.

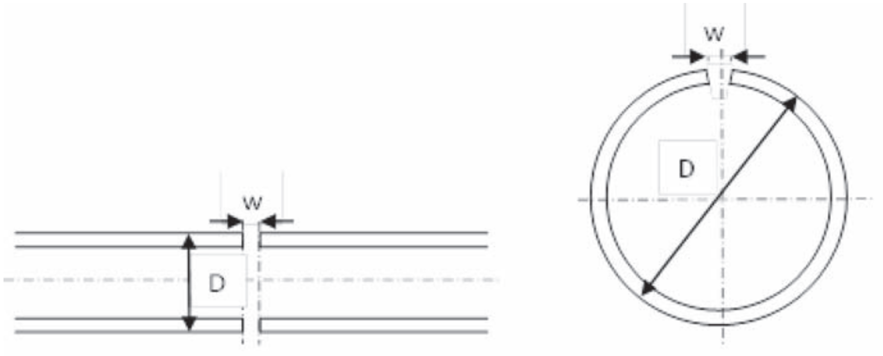


Figure 2 — Sketch showing details of circumferential and axial slots

The value of the service factor, f_{leak}, shall be set to:

Class 1	Class 2	Class 3	
$f_{\text{leak}}=0{,}83\times10^{-0{,}020\,88(t_{\text{lifetime}}-1)}$	$f_{\text{leak}}=0{,}75\times10^{-0{,}018\,56(t_{\text{lifetime}}-1)}$	$f_{\text{leak}}=0{,}666\times10^{-0{,}015\,84(t_{\text{lifetime}}-1)}$	(16)

where t_{lifetime} is the repair design lifetime, expressed in years.

If long-term performance test data is available in accordance with Annex E, then the service factor, f_{leak}, shall be calculated using:

Class 1	Class 2	Class 3	
$f_{\text{leak}}=0{,}83f_{\text{D}}$	$f_{\text{leak}}=0{,}75f_{\text{D}}$	$f_{\text{leak}}=0{,}666f_{\text{D}}$	(17)

where f_{D} is the degradation factor [defined in Formula (G.4)].

The design repair thickness, t_{design}, shall be the maximum value of the minimum repair thickness determined from one of Formulae (12), (13), (14) or (15), iteratively, and the design repair thickness derived in 7.5.4, 7.5.5 or 7.5.6.

7.5.8 Axial extent of repair

The design thickness of the repair laminate shall extend beyond the damaged region in the substrate by the larger of 50 mm or l_{over} expressed in millimetres, where l_{over} is given by Formula (18) or Formula (19):

For slot type defects:

$$l_{over} = 2\sqrt{Dt} \tag{18}$$

For circular type defects:

$$l_{over} = 4d \quad \text{where} \quad d < 0,5\sqrt{Dt} \tag{19}$$

where

- d is the diameter of defect, expressed in millimetres;
- D is the original external diameter of substrate, expressed in millimetres;
- t is the thickness of substrate, expressed in millimetres.

If the equality in Formula (19) is not satisfied, then Formula (18) shall be used. Annex H presents a look-up table of axial extent of repair as a function of both diameter and defect size.

The total axial length of the repair, l (expressed in millimetres), is given by Formula (20):

$$l = 2l_{over} + l_{defect} + 2l_{taper} \tag{20}$$

The ends of the repair laminate shall be tapered if axial loads are present. These axial loads can result solely from end effects due to internal pressure or can result from system loads such as bending or thermal expansion. A minimum taper of approximately 5:1 is recommended.

To check that the axial extent of the repair, l_{over}, is sufficient to ensure that the applied axial load can be transferred from the substrate to the repair, Formula (21) shall be satisfied:

$$l_{over} > \frac{3E_a \varepsilon_a t_{design}}{\tau} \tag{21}$$

where

- E_a is the axial modulus of repair laminate, expressed in megapascals;
- ε_a is the allowable axial strain of repair system, expressed in millimetres per millimetre;
- $t_{min,a}$ is the minimum thickness of repair laminate for axial applied loads, expressed in millimetres [see either Formulae (2) or (6) or (9)];
- τ is the lap shear strength, expressed in megapascals (see Annex B).

If the geometry of the section to be repaired is such that it is not possible to achieve the required axial extent of repair, l_{over}, plus the axial length of taper, l_{taper}, the following shall apply. The following shall be treated as a special design case and the analysis shall be completed prior to application of the repair system.

To account for the limited axial extent [i.e. less than calculated from Formula (18) or (19)] of available substrate ($l_{available}$), the design repair thickness, t_{design}, determined from either 7.5.4, 7.5.5, 7.5.6, or 7.5.7 shall be increased by the repair thickness increase factor, $f_{th,overlay}$, defined as:

$$f_{th,overlay} = \left(\frac{l_{over}}{l_{available}} \right)^{2/3} \quad (22)$$

where $t_{design} = f_{th,overlay}\, t_{design}$, original.

The above design procedure represents a conservative approach to determining the axial extent of repair beyond the defect. A more detailed engineering stress analysis of the adhesive layer demonstrating that the axial load can be transmitted between the repair and the substrate may be performed if it is required to optimize the repair design in terms of the repair thickness. This more detailed analysis shall also demonstrate that the average principal stress (averaged over the stressed part of the adhesive layer) is less than three times the average principal stress value from lap shear test data (see Table 4).

The axial extent of design thickness of repair, l_{over}, shall be at least 25 mm and $f_{th,overlay}$ shall be no greater than 2,5.

If there is limited axial extent of available substrate, it will not be possible to taper the repair laminate. For this case, the transition between the repair laminate and the restraining substrate, e.g. flange face, shall be as smooth as possible to minimize stress concentrations. However, where possible, the repair laminate should always be tapered, particularly when axial loads are present, in order to minimize edge stresses within the repair laminate.

The total axial length of the repair for reduced axial extent is therefore as given below:

For one-side reduced axial extent:

$$l = l_{over} + l_{defect} + l_{taper} + l_{available} \quad (23)$$

For two-sided reduced axial extent:

$$l = l_{defect} + l_{available,1} + l_{available,2} \quad (24)$$

where the larger of the two values of $f_{th,overlay}$ is taken to determine the design thickness of the repair [Formula (22)].

When applying repairs over components, e.g. flanges, clamps, etc., to achieve the appropriate total axial length of repair, the axial profile of the repair shall be as smooth as is practically possible to reduce sharp changes in diameter, thus minimizing local stress concentrations. This may result in a thickening of the repair to ensure a smooth axial profile.

When applying repairs up to raised faces, the transition from the repair to the raised face shall be contoured to avoid sharp changes in directions. If required, a more detailed analysis should be performed to demonstrate the axial length of repair is sufficient to transfer the load between the substrate and the repair.

7.5.9 Optional design considerations

7.5.9.1 Impact

The repair system supplier shall demonstrate that the repair to a through-wall defect (type B defect) is capable of withstanding a low-velocity 5 J impact representative of a dropped tool. The demonstration test shall be carried out in accordance with the procedure described in Annex F. This test shall be used to define the minimum repair thickness when the repair is exposed to the possibility of third-party impacts, 7.5.14.

7.5.9.2 Cyclic loading

Cyclic loading is not necessarily limited to internal pressure loads. Thermal and other cyclic loads shall also be considered when assessing cyclic severity.

If the predicted number of pressure or other loading cycles is less than 7 000 over the design life, then cyclic loading shall not be considered (in accordance with ISO 14692).

If the predicted number of pressure or other loading cycles exceeds 7 000 over the design life, then cyclic loading shall be considered.

If the predicted number of pressure or other loading cycles exceeds 150 * 10^6 over the design life, then in Formulae (27) and (28), N shall be set to 150 * 10^6.

For 7.5.4 and 7.5.5, the composite laminate allowable strain in both circumferential and axial directions, ε_c and ε_a, (see Table 9), shall be de-rated by the factor, f_c, i.e.:

$$\begin{aligned} \varepsilon_c &= f_c \varepsilon_{c,non-cyclic} \\ \varepsilon_a &= f_c \varepsilon_{a,non-cyclic} \end{aligned} \tag{25}$$

where

$\varepsilon_{a,non\text{-}cyclic}$ is the allowable strain in the axial direction [as defined in Formula (10)] prior to de-rating for cyclic loading, expressed in millimetres per millimetre;

$\varepsilon_{c,non\text{-}cyclic}$ is the allowable strain in the circumferential direction [as defined in Formula (10)] prior to de-rating for cyclic loading, expressed in millimetres per millimetre.

f_c is given by:

when $R_c > 0{,}4$:

$$\begin{aligned} f_c &= 1{,}25\left(\frac{R_c - 1}{\log(150\times10^6) - \log(7\ 000)}\right)\log(N) \\ &+ 1 - \tan\left[1{,}25\left(\frac{R_c - 1}{\log(150\times10^6) - \log(7\ 000)}\right)\right](\log(7\ 000) \end{aligned} \tag{26}$$

when $R_c \le 0{,}4$:

$$\begin{aligned} f_c &= \left(\frac{-0{,}75}{\log(150\times10^6) - \log(7\ 000)}\right)\log(N) \\ &+ 1 + 0{,}75\left(\frac{\log(7000)}{\log(150\times10^6) - \log(7\ 000)}\right) \end{aligned} \tag{27}$$

where

R_c is the cyclic loading severity, defined as the ratio of minimum pressure to maximum pressure: $R_c = \frac{p_{min}}{p_{max}}$;

N is the number of loading cycles.

For 7.5.7, the service factor, f_{leak}, in Formulae (12), (13), (14), (15) or (17) shall be replaced by:

$$f_{leak} = 0{,}333 f_c \tag{28}$$

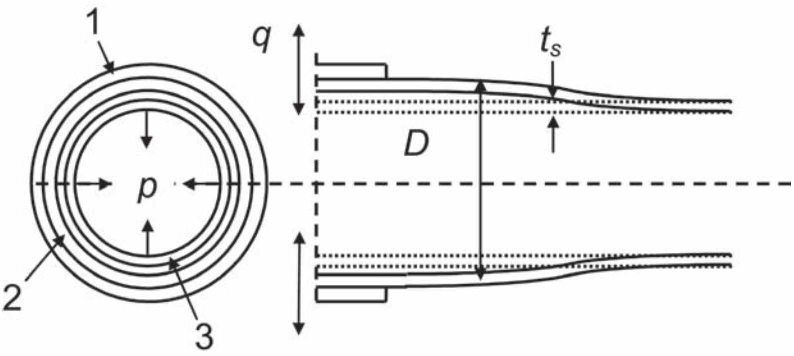
Formulae (27) and (28) are intended primarily for cyclic internal pressure loading, but may be applied with caution to axial and thermal loads provided they remain tensile, i.e. the formulae are not applicable for reversible loading.

7.5.9.3 Live repairs

If repairs are applied to substrates under live conditions, then the strength and fracture toughness of the bond at the interface between the repair laminate and substrate shall be assessed for the specific case during operation when the internal pressure, p_{after}, after repair system is applied is less than the internal pressure, p_{live}, within the substrate during application of the repair, i.e. $p_{\text{after}} < p_{\text{live}}$.

To assess the strength of the bond of the repair interface, the tensile stress acting on the bond, q (expressed in megapascals), shall be compared to the minimum bond strength defined in Annex B (lap shear strength).

Figure 3 schematically describes the key variables, where, q is the tensile pressure acting on the interface between the repair laminate and the steel substrate when the pipe is depressurised. This tensile stress is due to the fact that the steel substrate contracts more than the composite laminate.



Key

1 repair

2 pipe before repair (live)

3 pipe after repair

p design internal pressure

q tensile pressure (stress) on the interface

D external pipe diameter

t_s minimum remaining substrate wall thickness

Figure 3 — Schematic diagram of live repair

The tensile stress, q (expressed in megapascals), acting on the interface is given by Formula (29):

$$q = (p_{\text{live}} - p_{\text{after}})\left(1 - \frac{E_s t_s}{(E_s t_s + E_c t_{\text{design}})}\right) - (\alpha_c - \alpha_s)(T_{\text{live}} - T_{\text{after}})\frac{2E_c t_{\text{design}}}{D} \tag{29}$$

where

p_{live} is the internal pressure when repair is applied, expressed in megapascals;

p_{after} is the internal pressure after repair is applied, expressed in megapascals;

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

E_s is the tensile modulus of the substrate, expressed in megapascals;

t_{design} is the thickness of repair laminate, expressed in millimetres;

α_c is the repair laminate thermal expansion coefficient, circumferential direction, expressed in millimetres per millimetre degree Celsius;

α_s is the substrate thermal expansion coefficient, expressed in millimetres per millimetre degree Celsius;

T_{live} is the temperature when repair is applied, expressed in degree Celsius;

T_{after} is the temperature after repair is applied, expressed in degree Celsius;

D is the external diameter of substrate, expressed in millimetres.

The value of q shall be less than the short-term lap shear strength divided by a factor of three (see Annex B). This assessment is approximate but will provide a conservative result.

7.5.9.4 Fire performance

The requirements for fire performance shall be identified by the owner in the repair feasibility assessment. Flame spread and smoke generation shall also be considered in the assessment. Due account shall be taken of the response of the repair system. In many cases, additional fire protection is not necessary, as the substrate may still be able to perform satisfactorily during the short duration of a fire event. However, conduction from the metal substrate can cause the temperature of the repair laminate to exceed its design temperature, limiting the performance of the repair system.

Strategies for achieving fire performance include the following:

— application of additional repair material such that enough basic composite laminate will remain intact for the duration of the fire event;

— application of mineral wool;

— application of intumescent external coatings;

— application of intumescent and other energy-absorbent materials within the repair laminate;

— use of resin formulations with specific fire retardant properties.

Further guidance on the design and testing of composite laminates for fire performance is contained in ISO 14692.

Further guidance on the fire test performance properties of repair laminates, smoke index, flame spread index, and fuel contribution index is contained in ASTM E84.

7.5.9.5 Cathodic disbondment

For repairs to substrates that are cathodically protected, it may be required to demonstrate that the repair will not disbond due to the cathodic protection system.

ASTM G8 shall be used to demonstrate that the repair system is not susceptible to disbondment under an imposed electrical current.

7.5.9.6 Electrical conductivity

For repairs to metallic substrates, it is likely that the properties of the substrate will satisfy electrical conductivity requirements.

If the substrate is insulating, e.g. composed of FRP, and electrical conductivity (build-up of static charge) requirements are specified, the electrical conductivity properties of the repair system shall be measured to ensure that the original characteristics of the substrate are restored.

Electrical conductivity testing shall be carried out in accordance with ISO 14692.

7.5.9.7 External loads

The minimum repair thickness, t_{min} (expressed in millimetres), to resist external pressure or vacuum applied to the repair system is given by:

$$t_{min} = \left(\frac{2lD^{3/2}p_e}{3\sqrt{2}E_c} \right)^{0,4} \quad (30)$$

The minimum repair thickness, t_{min} (expressed in millimetres), to resist soil loads to prevent collapse of a buried repaired substrate is given by:

$$t_{min} = D\left[\frac{3(1-\upsilon^2)p_{ext,soil}}{2E_c} \right]^{1/3} \quad (31)$$

where $$p_{ext,soil} = \frac{4}{\pi D}\left[D(h+\frac{D}{2}) - \frac{\pi D^2}{8} + \frac{1}{3}(h+\frac{D}{2})^2 \right]\gamma_{soilg}$$

where

p_e is the external or vacuum pressure, expressed in megapascals;

$p_{ext,soil}$ is the external soil pressure, expressed in megapascals;

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

D is the external diameter of substrate, expressed in millimetres;

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

h is the burial depth (to centreline), expressed in millimetres;

l is the length of the repair taken as $l_{defect} + 2l_{over}$, expressed in millimetres;

γ_{soilg} is the specific weight of soil, expressed in megapascals per millimetre.

The design repair thickness, t_{design}, shall be the maximum value of the minimum repair thickness determined from Formula (30) or (31) and the design repair thickness derived in 7.5.

Further guidance on trench back-fill and other loadings can be obtained from ISO 14692 and AWWA M45.

7.5.10 Dent and/or gouge type defects

All gouges shall be removed by grinding. The remaining dent and, if relevant, the remaining wall thickness after gouge removal shall be assessed by the relevant defect assessment code or standard to determine the MAWP, p_s. The design of the repair shall follow 7.5.4.

7.5.11 Fretting type defects

When designing a repair where fretting is an issue, then the fretting resistance of the repair shall be considered including the use of an outer protective layer, such as an elastomeric or rubber pad placed between the repair laminate and the fretting surface.

7.5.12 Delamination or blister type defects

The design of the repair for delamination or blister type defects (within the substrate) shall follow 7.5.5, i.e. it shall be assumed that the repair system withstands the applied load with no allowance for the remaining strength of the pipe substrate.

7.5.13 Repair of other components

Qualification of the repair system for other components shall be as defined in B.7.

7.5.13.1 Piping system components

The following piping system components are considered:

— bends;

— tees;

— reducers;

— flanges.

The repair design procedure for each piping system component is a comparative approach based on the equivalent straight pipe component (same diameter and thickness). The repair design process is to calculate the thickness of the repair for an equivalent straight pipe section followed by a further calculation for the repair thickness increase factor, which accounts for the stress intensification due to the geometry of the component.

The first step in the design approach is to calculate the thickness of the repair for the equivalent pipe section of the component as described in 7.5, $t_{design,straightpipe}$ (expressed in millimetres). This repair thickness includes both the repair strength calculation (7.5.4 or 7.5.5), as well as the leak sealing calculation (7.5.7), if appropriate. Performance data can be used if available following 7.5.6. The second step is to calculate the repair thickness increase factor based on the stress intensity factor corresponding to the piping system component, $f_{th,stress}$.

The design repair thickness, $t_{design,component}$ (expressed in millimetres) is given by Formula (32):

$$t_{design,\ component} = t_{design,\ straight\ pipe} f_{th,stress} \tag{32}$$

Table 11 presents repair thickness increase factors, $f_{th,stress}$, for each piping component.

Table 11 — Repair thickness increase factors for piping system components

Piping system component	Repair thickness increase factor $f_{th,stress}$
Bend	1,2
Tee	2
Flange	1,1
Reducer	1,1

The axial length of the repair shall be calculated from 7.5.8.

For tees, the main diameter is defined as that pipe that contains the defect. This pipe diameter shall be used to calculate the repair thickness from the equivalent straight pipe section. The repair thickness increase factor is then applied to this repair thickness.

The axial length of repair shall be based on the (larger) dimension of the piping system component and applies to both the axial length of repair along the main body and branch (where appropriate).

For the repair of tees, the maximum allowable design pressure, p (expressed in megapascals), for the repair laminate design thickness, $t_{design,component}$ (expressed in millimetres), shall be restricted to:

$$p \leq \frac{2E_c \varepsilon_c t_{design,component}}{D + D_b} \qquad (33)$$

where

ε_c is the circumferential design strain of the composite repair system;

D is the external diameter of main body, expressed in millimetres;

D_b is the external diameter of branch, expressed in millimetres;

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

7.5.13.2 Tank and vessel components

The following tank and vessel components are considered:

a) cylindrical vessels:

— end dome (circular and torisphoidal), main body connection;

— supports/saddles/rigid attachments;

— tees/nozzles;

b) spherical vessels:

— supports/saddles/rigid attachments;

— tees/nozzles.

For tanks and vessels, there are currently few applications, implying less validation of the proposed empirical rules for the design of the repair system.

The repair design procedure for each vessel component is the same as that described in 7.5.13.1. Table 12 and Table 13 present repair thickness increase factors for cylindrical and spherical tank and vessel components respectively.

The axial extent of the repair shall be calculated from 7.5.8.

Table 12 — Repair thickness increase factors for cylindrical vessel components

Cylindrical vessel component	Repair thickness increase factor $f_{th,stress}$
End dome, main body connection	1,1
Supports, saddles, rigid attachments	1,5
Tees, nozzles	2

Table 13 — Repair thickness increase factors for spherical vessel components

Spherical vessel component	Repair thickness increase factor $f_{th,stress}$
Supports, saddles, rigid attachments	1,5
Tees, nozzles	2

The axial extent of repair shall be based on the (larger) dimension of the main body and applies to the axial length of repair along both the main body and branch (where appropriate).

For the repair of tees or nozzles, the maximum allowable design pressure, p (expressed in megapascals), for the repair laminate design thickness, $t_{design,component}$ (expressed in millimetres), shall be restricted to:

$$p \leq \frac{2E_c \varepsilon_c t_{design,component}}{D + D_b} \tag{34}$$

where

ε_c is the circumferential allowable design strain, expressed in millimetres per millimetre;

D is the external diameter of main body, expressed in millimetres;

D_b is the external diameter of branch, expressed in millimetres;

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

Patch repairs are acceptable provided it is demonstrated that the performance is equivalent to a fully circumferential repair and that the axial extent of the repair is at least that defined in 7.5.13.4.

7.5.13.3 Clamps and other repair systems

Clamps are generally applied over defects much smaller than themselves. The clamp protrudes or stands off a set height from the pipework. The size of the effective defect is a function of the geometry of the clamp or repair system. Often the outer surface of the clamp is not smooth, e.g. bolts, etc., implying it may not be possible to achieve a large enough outer surface area for adequate bonding.

If good bonding between the repair laminate and the full outer surface of the clamp can be demonstrated, 360° around the circumference and along the full length of the clamp, e.g. through coupon pull-off tests or qualification tests on the clamp casing material, then the effective size of the defect shall be a fully circumferential defect at each end of the clamp of axial extent 1,5 times the stand-off height. Either Formula (13) or Formula (14) shall be used to calculate, iteratively, the minimum repair thickness, t_{min} (expressed in millimetres).

If good bonding between the repair laminate and the clamp surface cannot be demonstrated 360° around the circumference and along the full length of the clamp, e.g. for clamps with axially orientated flanges or other tightening mechanisms, then the effective size of the fully circumferential defect shall be the axial extent of the clamp plus an axial distance of three times the stand-off distance. Formula (13) shall be used to calculate the minimum repair thickness, t_{min} (expressed in millimetres). The final repair thickness shall be calculated using Formula (32) where $f_{th,stress}$ is taken as 1,5.

The same principle as outlined for clamps shall also apply to the repair of non-engineered repair systems.

The size of the defect shall be taken as the total axial length of the existing repair (axial extent of repair plus taper length) and Formula (13) or Formula (14) shall be used to calculate the minimum repair thickness, t_{min} (expressed in millimetres). The final repair thickness shall be calculated using Formula (32) where $f_{th,stress}$ is taken as 1,1.

The axial extent of the repair to either clamps or non-engineered repairs shall be calculated using Formula (18).

7.5.13.4 Patches

Repair patches are used when it is impractical for the repair to encompass the full circumference of the component. Typically these components are limited to large diameter (greater than 600 mm) pipework, pipelines or vessels.

The thickness of the repairs shall be calculated according to 7.5 with reference to the relevant component type.

The axial extent of the patch repair shall be the same in both the axial and circumferential directions. The axial extent of the repair shall be calculated according to 7.5.8.

7.5.14 Design output

The outputs of the design calculations for the repair system are the following:

— thickness of the repair laminate, t_{design}, expressed in millimetres and number of layers, n;

— total axial repair length, l, expressed in millimetres;

— axial extent of repair, l_{over}, expressed in millimetres;

— cure schedule required, expressed in minutes or hours at temperature in degree Celsius.

The design thickness of the repair shall be expressed as number of layers, n, for installation purposes, in accordance with Formula (35):

$$n=\frac{t_{design}}{t_{layer}} \quad (35)$$

where t_{layer} is the thickness of an individual layer of repair laminate, expressed in millimetres.

The minimum design thickness for the repair laminate is given by

— type A repairs. The greater thickness of either two layers or 2 mm whichever is the greater, and

— type B repairs. That qualified by testing as described in 7.5.9.1. Where the potential for external third-party accidental impacts is agreed by the owner to be unlikely the minimum thickness requirement may be relaxed to the greater of two layers or 2 mm.

7.6 Re-qualification of the repair system

7.6.1 Overview

If a change or modification to the repair system has occurred, then the testing specified in 7.6.2 and 7.6.3 shall be completed.

If the modified repair system is found to be of lower performance than the original repair system, then it shall be treated as a new system and validated according to 7.4.5.

If the modified repair system is found to be of higher performance than the original repair system, then it may be treated as a new system and validated according to 7.4.5, or the qualification data from the original repair system may be used.

7.6.2 For type A defect repairs

Re-qualification tests shall include the testing specified in B.2.

If the repair system has been validated according to B.6, then the repair system shall be subject to the survival testing specified in E.2.1.

7.6.3 For type B defect repairs

Re-qualification tests shall include the testing specified in B.2 and B.3.

— Note that only three tests are required and results shall be compared with γ_{LCL} of the original repair system, D.4.

8 Installation

8.1 Storage conditions

Storage of material shall comply with the repair system supplier's instructions. MSDS sheets shall be retained for reference. All materials shall be stored and controlled according to national safety regulations (e.g. OSHA, COSHH, or similar regulations).

All materials shall be clearly labelled with relevant health and safety data, batch number, expiry date, and any other relevant technical information.

Control of the temperature during storage shall be maintained. (Shelf lives can be reduced significantly if temperatures are allowed to exceed those specified by the repair system supplier.)

Reinforcements shall be stored to ensure that condensation, due either to storage of material below the dew point or on movement between areas at different temperatures, does not occur.

Shelf lives quoted by the repair system supplier shall be observed.

Disposal of time-expired material shall be carried out in compliance with local regulations and according to repair system supplier's instructions.

8.2 Documentation prior to repair application

8.2.1 Method statement

Each repair shall be covered by a method statement which is often generic in nature that describes the main procedures to be carried out prior to and during repair system application.

Typically the method statement, provided by the repair system supplier, includes the following information.

a) **Health and Safety**, comprising

   1) list of materials to be handled including copies of MSDS sheets and COSHH statements,

   2) details of protective measures to be adopted, and

   3) list of hazards associated with equipment to be repaired and equipment in the vicinity of the repair site with protective measures.

b) **Quality Assurance**, comprising

   1) generic overall QA plan, and

   2) generic details of hold/inspection points in the repair application procedure (see 8.4).

c) **Installation procedure**, including generic overview of installation procedure.

d) **Environmental**, including information on disposal of unused material.

8.2.2 Work pack

Each repair shall also be covered by a work pack which is specific and relates directly to the procedures to be performed prior to and during repair system application.

Typically the work pack, provided by the repair system installer, includes the following information.

a) **Scope of work**, including specific details of the design conditions and status of the component requiring repair,

b) **Health and Safety,** including MSDS sheets for the materials to be used and related COSHH statements,

c) **Risk assessment,** including details of tool box talk with site personnel,

d) **Repair details,** including drawing of planned repair, thickness, and dimensions of repair and cure schedule,

e) **Installer qualification level,** defining whether a supervisor is required for the specific application.

f) **Specific installation instructions,** including any amendments to the generic installation instructions provided in the method statement. These instructions shall include

— acceptable environmental conditions of site at time of repair,

— material storage,

— surface preparation,

— resin system mixing,

— laminate lay-up for the component geometry,

— laminate consolidation procedure (fibre wetting),

— cure schedule as defined in 7.5.3, and

— key hold points.

Further details of these requirements are listed in Annex J. The key hold points to be observed during repair system installation are dependent on the repair class and are summarized in Table 14.

a) **Quality Assurance**, comprising and specific amendments to the generic QA plan provided in the method statement, e.g. details of any materials tests to be carried out, if specified by the owner (see Annex B).

b) **Installer certification,** comprising a named list of the installers and their individual qualification certifications.

8.3 Installer qualifications

Personnel involved in the installation of a repair system shall be trained and qualified in accordance with Annex I.

8.4 Installation procedure

The repair system supplier shall provide full installation instructions.

Table 14 — Hold points during installation of a repair system

Hold point	Class	Checked by
Method Statement	All classes	Installer
Materials Preparation		Installer
— reinforcement	All classes	
— resin	All classes	
Environmental conditions		Installer
— relative humidity	All classes	
— dew point	All classes	
— component surface temperature	All classes	

Table 14 *(continued)*

Hold point	Class	Checked by
Surface Preparation — inspection — surface profile test — mechanical test (stipple test)	 All classes Class 3 Class 3	 Installer (Class 1) Supervisor (Classes 2 and 3)
Filler Profile	All classes (where appropriate)	Installer
Stage Check on Reinforcement fibre or cloth orientation	Class 3	Installer
Tests on Repair Laminate — cure (and post-cure) through hardness test or time-temperature measurements taken from the repair — thickness — repair axial extent and taperlength — external inspection (see Table 16)	 All classes All classes All classes All classes	 Installer (Class 1) Supervisor (Classes 2 and 3)
QA records	All classes	Installer (Class 1) Supervisor (Classes 2 and 3)
Pressure Test		Inspection authority

8.5 Repair completion documentation

The following documentation shall be provided by the repair system installer to the owner on completion of the repair. All records should be retained by both the owner and repair system installer for the duration of the repair design lifetime.

a) **Repair Details**, comprising:

   1) repair reference number;

   2) location of repair.

b) **Repair Design**, comprising details of laminate lay-up:

   1) design data (Annex A) and calculations;

   2) repair sketch;

   3) number of layers;

   4) repair area covered including axial extent;

   5) orientation of individual layers of reinforcement (this may be presented as a written description or a drawing incorporating standard details such as overlap and taper dimensions and length information).

c) **Material records**, comprising:

   1) repair system supplied;

   2) resin type and quantity;

   3) reinforcement type and quantity;

4) batch number of materials.

d) **Repair Application**, comprising:

1) details of surface preparation procedure, including method of application, equipment used and inspection and testing method;

2) details of actual defect size and location;

3) details of the environmental conditions including dew point temperature, ambient temperature, substrate temperature and relative humidity and any relevant limitations;

4) details of the filler used to achieve a smooth outer profile prior to the application of the laminate;

5) details of time limitations between stages of the repair, e.g. between surface preparation and lamination;

6) details of the mixing of the resin and hardener;

7) details of lay-up procedure including orientation of the repair laminate, including also if the repair laminate was applied in stages;

8) details of curing schedule and comparison with specified cure schedule (if carried out - usually Class 3 repair only).

e) **Quality control records**, comprising:

1) repair reference number;

2) visual inspection report;

3) thickness measurement;

4) repair axial extent measurement;

5) curing details (time, temperature) and if performed post curing details, temperature and time;

6) personnel (installer) applying the repair system;

7) Barcol or Shore hardness measurement (if carried out);

8) DSC measurement (if carried out);

9) bond strength measurement (if carried out);

10) Inspection and NDT results (if carried out).

f) **Independent inspection**, comprising test report (if carried out).

g) **Service inspection**, comprising details of service inspection intervals and repair condition monitoring guidance (Clause 9).

8.6 Live repairs

Repairs to defects that are not through-wall within live substrates may be performed, provided that the associated hazards are fully considered in the repair feasibility assessment (7.1) for the operation, e.g. for grit blasting and heat blankets. This shall include any hazards to surrounding live equipment in addition to that being repaired.

Repairs to defects that are through-wall within live substrates may be performed provided that all leaks can be stopped by alternative means reliably for the duration of the repair application and cure time and that the leak sealing methods are fully considered in the derivation of the repair thickness in accordance with 7.5.7, 7.5.9.3, and 7.5.13.3.

Post-curing using elevated temperature heating should not be undertaken on live pipes unless it can be demonstrated the required post cure temperature can be achieved within the repair laminate.

8.7 Repair of clamps, piping components, tanks, or vessels

Guidance for the surface preparation of clamps, piping components, tanks, and vessels is the same as for repairs on straight pipe (see Annex J).

The axial profile of the repair laminate in the transition from the main pipe body to the component causing the protuberance should be at least tapered with taper dimension of 3 (axial direction) to 1 (radial direction). The precise details of the repair, e.g. repair laminate lay-up and orientation relative to clamps, piping components, tanks, or vessels, shall be provided by the repair system supplier. The arrangements at the edges of the repair, e.g. tapering, profiling onto raised faces, shall also be provided by the repair system supplier.

8.8 Environmental considerations

Only repair materials that allow for satisfactory disposal according to prevailing environmental regulations shall be used as described in the method statement, 8.2.

Information and procedures for disposing of unused chemicals, resins, and waste shall be provided by the repair system supplier. Incineration in the open air shall not be performed.

9 Testing and inspection

9.1 General

This subclause provides guidance on the post-installation operational issues of repair systems. The installation of a repair system should not influence or prevent any internal inspections (e.g. from pigging inspection tools) that are performed on the substrate.

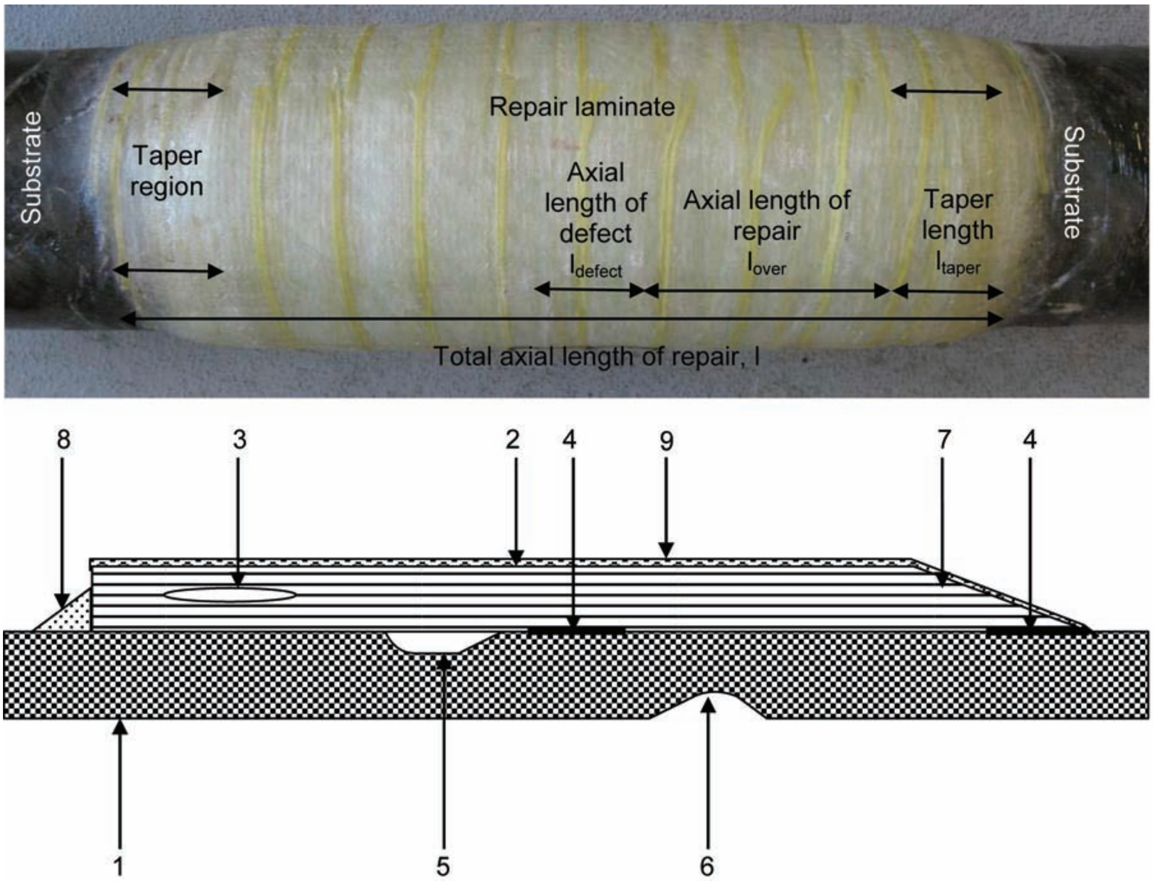
The main issues for the non-destructive examination of a repair system are the following:

— inspection of the repair laminate;

— inspection of the bond between the repair laminate and the substrate;

— inspection of the substrate underneath the repair laminate.

The basic structure of a repair system in this context is considered in Figure 4.



Key

1 substrate, pipe wall
2 repair laminate
3 internal laminate defect
4 interface delamination de-bond
5 external defect (with filler)
6 internal defect
7 taper of laminate (extends beyond overlay l_{over})
8 adhesive fillet
9 resin rich surface layer

Figure 4 — Schematic of a repair system (not to scale) and location of defects

9.2 Allowable defects for the repair system

The defect types and respective allowable limits for the different sections of the repair system are given in Table 15 prior to application of the repair and in Table 16 for after installation of the repair and in service.

The defects that are listed for the repair laminate and resin-rich layer are likely to arise during installation, as opposed to being caused as a result of deterioration in service. As a result, process control and monitoring of the repair material as it is being applied is the primary means of assuring good quality. The information given in Table 16 is typical of that used for composite process equipment, e.g. GRP piping (see ISO 14692).

The defects that are listed for the interface between the repair laminate and the substrate refer primarily to the loss of adhesion. As with the repair laminate, the defects listed for the interface are generated during initial application. In the majority of cases, deterioration during service manifests itself as an interfacial delamination.

Table 15 — Quality assurance checks for the substrate prior to application of the repair

Repair section	Defect	Allowable Limits
Substrate prior to repair application	Check substrate material is that for which the repair has been designed	
	Changes in geometry	Repair area to be free of sharp changes in geometry (all radii > 5 mm), or sharp geometry to be faired-in
	Surface preparation	In accordance with repair system specification
		Axial length to be in accordance with design
	Surface temperature	In accordance with repair design
	Defect	Dimensions do not exceed those for which the repair has been designed
		Defect nature to be that for which the repair has been designed
	Location of repair	Axial extent and positioning to be in accordance with design

Table 16 — Inspection requirements for the repair laminate after installation and in service

Repair section	Defect	Allowable Limits
Interface between pipe and repair at the ends of the repair, including adhesive fillets	Delamination (cracks between the pipe and the repair)	None allowed Tap test may help identify presence of delaminations
Surface of Repair (Resin-rich layer)	Cracks	None that penetrate into the repair laminate
	Foreign matter and, blisters	Maximum 10 mm in width, 1,5 mm in height
	Pits	Maximum 25 mm in diameter, 1,5 mm in depth No limit for depths shallower than 1mm
	Wrinkles	No step changes in thickness in height greater than the lower of 1,0 mm or 20 % of the Repair Laminate design thickness
	Pin holes	None deeper than resin-rich layer
	Resin colour	Uniform
	Dry spots	None
	Finishing materials	None (should be fully removed before inspection is completed)
Repair laminate	Fibre orientation	As specified in design
	Un-impregnated/dry fibre	None
	Exposed cut edges/ fibres	None
	Foreign matter	None
	Axial extent and positioning of the repair	As specified in the design
		Does not extend beyond prepared surface
	Impact damage	None

Table 16 *(continued)*

Repair section	Defect	Allowable Limits
	Delamination within laminate	None allowed Tap test may help identify presence of delaminations

The defects that are listed for the substrate relate to those that have been repaired and to possible continued degradation of the wall thickness after repair, due to internal corrosion or erosion. Monitoring of the remaining wall thickness may be required to ensure that the repair system continues to operate within the original design assumptions.

Table 17 presents a pictorial representation of some of the typical defect types that can occur in a repair system after installation and during service. The photographs in Table 17 are intended to aid the interpretation of the defects listed in Table 16 and their respective allowable limits.

Table 17 — Pictorial description of defects after installation and in-service

	
Interfacial delamination	Interfacial delamination
	
Impact damage – glass fibre based repair	Impact damage – carbon fibre based repair
	
Dry fibres	Exposed fibres

9.3 Repair of defects within the repair system

Repairs containing defects that exceed the limits in Table 15 and Table 16 should be removed and another repair system applied. However, on agreement with the owner, local removal of the damaged area and re-application of the repair system materials to this area are allowable if the repair system supplier can demonstrate that this will restore the full performance of the repair.

Dry areas in the resin-rich surface layer should be repaired by abrading and cleaning the affected area and then wetting out with more resin.

9.4 Inspection methods

The repair system supplier should provide guidance on techniques and methods for inspecting the repair system. Further guidance could be provided by inspection technology companies. Inspection techniques may be applied immediately after the repair system application as a base line measurement or during the repair design lifetime. In most cases, the requirement is not to inspect the composite laminate, but to inspect the defect within the substrate with the overall aim of demonstrating the integrity of the complete system, i.e. substrate and repair.

9.5 Repair system maintenance and remedial options

9.5.1 Overview

The appropriate maintenance and replacement strategy for repair systems is a function of the type of original defect in the substrate. A risk assessment shall be completed to determine the appropriate strategy and shall consider the guidance given in this subclause. Annex L provides informative guidance on how to manage the overall integrity of repair system applications.

9.5.2 Condition of the repair - visual inspection

Visual inspection of the repair laminate for defects in accordance with Table 16 and Table 17 is recommended as part of the maintenance strategy. If defects are located, then further assessment shall be made in conjunction with the repair system supplier. The frequency of inspection should be determined in accordance with the risk assessment.

A photograph of the repair should be taken and retained for comparison with future inspections.

Table 18 — Pictorial guide to coating requirements at ends of repairs

	
Coating at end of repair present and good condition	Coating at end of repair has not been installed and corrosion has started

Where the pipe is coated, then in addition to the inspection detailed above the inspector shall confirm that an additional coating covering the ends of the repair is present and in good condition, Table 18. If no coating over the ends of the repair is present and the pipe substrate is in good condition then a coating should be installed. If corrosion is visible at the ends of the repairs then the fitness for purpose of the repairs shall be considered by a re-assessment of the design requirement.

9.5.3 Condition of the pipe substrate

9.5.3.1 External defects

For external defects, it is assumed that further deterioration of the defect is stopped on application of the repair laminate. Therefore, the maintenance strategy should be to ensure that the repair laminate remains intact, i.e. the repair laminate is not damaged or partially delaminated from the substrate.

Inspection of the pipe beneath the repair should be considered for all Class 3 repairs. Radiography and eddy current techniques have been successful in interrogating the pipe beneath the repair; further advice can generally be obtained from the repair system supplier and specialist inspection companies. It is recommended that a baseline inspection is completed after installation of the repair because it is much simpler to identify changes than to interpret the information gained by subsequent inspections.

For Class 3 repairs with design lifetimes greater than two years, consideration should be given to confirming that internal corrosion has not commenced. If internal corrosion is determined as active then a suitable strategy to mitigate the threat should be determined (e.g. change in process conditions, use of inhibitors or reduced life of repair etc.).

9.5.3.2 Internal or through-wall defects

For internal corrosion or through-wall defects, further deterioration or growth of the defect may continue despite application of the repair laminate. Therefore in addition to the requirements set out in 9.5.3.1, the maintenance strategy should ensure that the internal defect does not grow to a size greater than assumed in the design or that the repair laminate does not delaminate from the substrate. Therefore information of the acceptable defect size determined by design shall be retained and be readily available.

The frequency of inspection should be determined in accordance with the risk assessment.

Inspection of the pipe beneath the repair shall be considered for all Class 3 repairs the objective being to demonstrate the defect in the pipe remains within the acceptable limit determined by design. Again, radiography and eddy current techniques have been successful in interrogating the pipe beneath the repair; further advice can generally be obtained from the repair system supplier and specialist inspection companies. It is recommended that a baseline inspection is completed after installation of the repair because it is much simpler to identify changes than to interpret the information gained by subsequent inspection.

9.5.4 Remedial options

If the assessment determines that replacement is required, then remedial options include the following:

— removal of the repair (e.g. through ultra-high-pressure water jetting or grit blasting) and replacement;

— repair of the repair laminate. In this case, the damaged repair laminate should be considered as the defect for design purposes and a new repair designed according to 7.5;

— localized repair of the damaged area (see 9.3).

— In the event of interfacial failure of a repair system, the preferred course of action is to remove the repair laminate. The repair of a failed repair by the simple application of additional material, particularly if the leak is caused by a delamination at the repair laminate/substrate interface, is unlikely to be successful and is not recommended.

9.5.5 Extension (re-validation) of repair design lifetime

The decision to extend the repair design lifetime shall be documented along with supporting records which shall be retained for future reference (records shall include the risk assessment, original and any revised design assessments and the original installation documentation for the repair).

9.5.5.1 Class 1 and 2 repairs

For extending the lives of Class 1 and 2 repairs, it may be considered sufficient just to leave repairs in place if failure of the repair leads to a benign leak. If the fluid presents a hazard or the consequence of failure is unacceptable then the requirements for extending the lives of Class 3 repairs, 9.5.5.2, shall be followed.

9.5.5.2 Class 3 repairs

It is possible to re-validate or extend the lifetime of Class 3 repairs. To re-validate the lifetime of a repair, the design and installation details must be available (these shall include records of the surface preparation of the substrate and the design and cure of the repair met the original specifications) and the installation records must be sufficient to demonstrate the repair was installed in full compliance with the repair supplier's procedures. It is recommended that repair design lifetimes are only re-validated up to a maximum of 20 years (from the time the repair was installed). Re-validation of the repair design lifetime is performed by re-designing the repair based on the required lifetime and the most up to date inspection data on the defect of concern. This re-design may result in a thicker repair than currently installed which implies that extra layers of repair material must be added to the existing repair.

For re-validation of lifetimes greater than 20 years, only a moderate lifetime extension is recommended, i.e. increments of no more than 5 years. It is further recommended that the repair and the substrate underlying the repair are fully inspected before considering re-validation.

Re-validation of the repair design lifetime is performed by re-designing the repair based on the required lifetime and the most up to date inspection data on the defect of concern (9.5.3). This re-design may result in a thicker repair than currently installed which implies that extra layers of repair material must be added to the existing repair.

9.5.6 Future modifications

Existing repair systems may be modified, but only after a design re-assessment performed by the repair system supplier. Modifications considered include extension of length of repair or thickness as a result of increased corrosion activity, newly discovered defects or a change in operating parameters. The principles set out in 9.5.5 shall be followed.

10 System testing

System pressure testing should be specified by the owner if required or as recommended by the relevant design standard for the substrate.

All repairs shall be cured in accordance with the repair system supplier instructions before system testing.

The repaired system shall be flushed with an appropriate medium prior to testing.

The recommended procedure for hydro-testing is as follows. The hydro-test should be performed at 1,1 times the design pressure for a period of at least 60 min, during which any changes in pressure and temperature shall be recorded. Any signs of leakage from the repair laminate shall be cause for rejection of the repair system.

In some circumstances, the owner may specify a hydro-test to 1,5 times the design pressure instead of the requirements of the previous paragraph. All supports and anchors shall be in place prior to pressure testing. Temporary supports or restraints should be added if necessary.

If the test pressure exceeds the pressure for which the repair system has been designed, then this higher pressure shall be considered as a separate design case. For the purposes of the design calculation, the hydro-test condition shall be treated as an occasional load.

Further guidance on system testing can be found in ASME PCC-2 Article 5.1 or other relevant documents.

11 Decommissioning

Reference should be made to the risk assessment prior to decommissioning of a repair system. If necessary, a separate risk assessment should be carried out.

The removal of repair material may be achieved by mechanical means (e.g. grit blasting, high-pressure water jetting). Procedures should be put in place to contain any dust that may be generated. Care should be taken to avoid damage to adjacent equipment that is to remain in service.

Annex A
(normative)

Design data sheet

This annex provides an example of a design data sheet. This data sheet shall form the basis of the scope of work provided by the owner to the repair system supplier, and shall be used in the preparation of the design of the repair. One sheet shall be completed for each repair required.

Customer Details			
Contact			
Company			
Address			
Postcode		Country	
Telephone			
Fax			
E-mail			
Job Reference			

Pipe Details				
Installation				
Location				
Quantity (number of)				
Pipe identification				
Pipe reference				
Pipe specification				
Material/Grade				
External diameter (mm)				
Original wall thickness (mm)				
Pipe contents				
Design temperature (°C)	Minimum		Maximum	
Operating temperature (°C)	Minimum		Maximum	
Pipe coating (existing)				
Existing repair on pipe for leak sealing				

Repair class and lifetime	
Repair class	
Repair design lifetime (years)	
Other data	

Loading	Operating	Design	Test	Comments
Pressure rating (MPa)				
Axial Load (kN)				
Bending moment (Nm)				
Shear load (kN)				
Torsion (Nm)				
Other loads (N)				
NOTE 1 Any original design calculations, piping isometrics should be appended to this datasheet.				
NOTE 2 Loads should be defined as either sustained or occasional in the comments column.				

Details of Defect Area
Attach drawings of pipe system, inspection reports, digital photographs, etc. where available. Indicate any access restrictions and proximity to other equipment.

Repair Specification				
Type of defect				
Nature of defect				
Current size	Area (mm^2)		Depth (mm)	
Projected size	Area (mm^2)		Depth (mm)	
Cause	Corrosion		Erosion	
Effect	External		Internal	
	Perforated			
MAWP (MPa)				

Anticipated Conditions during Implementation of Repair				
Pipe temperature (°C)	Minimum		Maximum	
Ambient temperature (°C)	Minimum		Maximum	
Pipe pressure (MPa)				
Pipe contents				
Humidity (%)				

External environment	
Constraints	

Facilities to be Provided by Client/Installation (surface prep., etc.)

Other Information
NOTE This should include any remarks on previous repairs, fire protection requirements, etc.

Prepared by:

Date:

Annex B
(normative)

Qualification data

B.1 General

This annex describes the qualification data that the repair system supplier shall provide.

It is a requirement that all qualification tests be carried out using the same substrate material, surface preparation procedure, repair laminate, filler material, adhesive and application method (see Clause 5).

B.2 Data for repair laminates

For all repair classes, the following data are required:

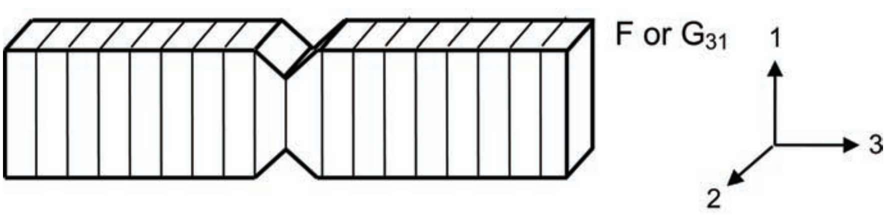
— ply or layer thickness of the repair laminate;

— tensile modulus strain to failure and strength in the circumferential direction, determined by test according to Table 4;

— tensile modulus, strain to failure and strength in the axial direction determined by test according to Table 4;

— Poisson's ratio in the circumferential direction (i.e. load direction circumferential, contraction axial), determined by test according to Table 4;

— shear modulus, determined by test according to Table 4. The test specimen geometry is shown in Table 4 and Figure B.1. This figure presents the orientation of the test sample as defined in ASTM D5379. Alternatively, the shear modulus of the resin may be used;



Key

1 direction parallel to laminate lay-up (see ASTM D5379, G_{31} for details)

Figure B.1 — Test specimen geometry from ASTM D5379

— Barcol or Shore hardness determined by test according to Table 4;

— glass transition temperatures (T_g) or heat distortion temperatures (HDT) for the resin system, determined by test according to Table 4 for a range of relevant cure times and temperatures. The T_g of a system is not a unique value but will vary with cure temperature and time held at temperature. Where materials are intended for service at above ambient temperature (i.e. >40 °C) then values of T_g shall be measured for a range of cure temperatures at, for example, 10 °C or 20 °C intervals, and the relevant value shall be used in the repair design, 7.5.3. The installed repair will then be subject to the same cure schedule to ensure the required T_g has been achieved. Many polymer systems exotherm as they cure and this can generate a temperature increase and a high value of T_g. The peak temperature achieved during curing shall be measured where the stated T_g is more than 30 °C above the cure temperature and this peak must be replicated on site.

— thermal expansion coefficient in the axial and circumferential directions, determined by test according to Table 4.

B.3 Data for interface adhesion strength

The objectives of the following tests are not to produce data for use in design. The intent is to demonstrate that an adhesive bond can be achieved of adequate strength and durability for the repair laminate. Note that short-term strength measurements are not necessarily a good indicator of long-term performance.

For all repair classes, data on the short-term lap shear strength determined by test according to Table 4 are required. This short-term test shall be used to determine the average shear strength (minimum value 5 MPa) or the locus of failure (composite laminate remaining on a minimum of 30 % of the bonded area). The substrates used in this test should be identical and be of the same material and lay-up as the repair laminate. Alternatively, it shall be demonstrated that the adhesive bond is stronger than the shear strength of the repair laminate by assessing the surface of the substrate material used in a lap shear specimen after testing.

For Class 3 repairs, if evidence of long-term durability of the adhesive bond between the repair laminate and the substrate is required and performance-based testing has not been carried out to provide data for design (see 7.5.6), the long-term lap shear strength shall be determined by test according to Table 4. This test shall be carried out following immersion in water (or other relevant medium) at the design temperature for 1 000 h. The average shear strength determined from this test shall be at least 30 % of the value from the short-term lap shear test determined above.

B.4 Requirements for repairs to substrates with non through-wall defects (Type A design case)

The objective of the short-term pipe spool survival test, in accordance with Annex C, is to define the maximum percentage wall loss that shall be repaired.

B.5 Requirements for repairs to substrates with through-wall defects (Type B design case)

For all repair classes, the following data are required:

— fracture toughness parameter γ_{LCL}, determined by test in accordance with Annex D:

— impact performance, determined by test in accordance with Annex F which determines the minimum acceptable thickness of repair;

— degradation factor (optional) Annex G.

B.6 Performance testing

The supplier may carry out performance testing to determine design allowables in accordance with Annex E. The long-term strain to failure design allowables are determined by either the following:

— 1 000-h survival;

— regression testing;

— representative repair laminate coupon regression testing.

B.7 Other components

A single test for each representative pipework components (only bends and tees shall be considered) identical to one of those described in Annex D (same diameter, wall thickness and one selected defect size), shall be performed on components other than straight pipe sections to demonstrate the repair system performance.

A 90° bend shall be selected as the representative component for pipe bends. The defect location shall be as indicated in Figure B2.

An equal tee shall be selected as the representative component for pipe tees. The defect location shall be as indicated in Figure B.2.

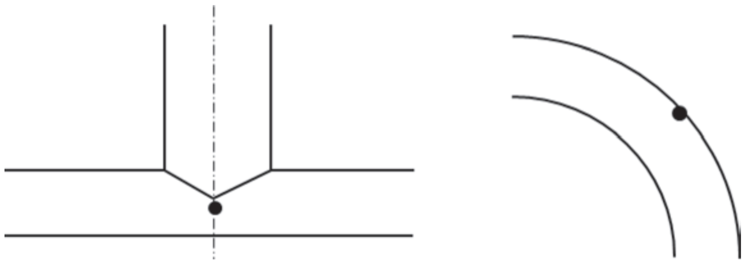


Figure B.2 — Defect location within component

The repair system shall be considered qualified if the failure pressure of the test is greater than or equal to the failure pressure of the equivalent straight pipe section for the appropriately design repair system.

B.8 Summary qualification test reports

The following Table shall be presented by a repair supplier to demonstrate compliance with this International Standard.

Repair system name		
Qualification test temperature (°C)		
Repair curing conditions (temperature and time)	Cure Temperature (°C)	Cure time (hrs)
B.2 – Repair laminate data		
Ply or layer thickness (mm)		
Circumferential direction – tensile modulus (GPa)		
Circumferential direction – strain to failure (mm/mm)		
Circumferential direction – tensile strength (MPa)		
Axial direction – tensile modulus (GPa)		
Axial direction – strain to failure (mm/mm)		
Axial direction – tensile strength (MPa)		

Poisson's ratio in the circumferential direction			
Shear modulus (GPa) (refer to Figure B.1)			
Barcol or Shore hardness (of cured laminate)			
Glass transition or heat distorion temperature (°C)	Cure Temperature (°C)	Cure time (hrs)	T_g (°C)
Peak exotherm temperature measured for Tg sample (°C)			
Circumferential direction – thermal expansion coefficient (mm/mm/°C)			
Axial direction – thermal expansion coefficient (mm/mm/°C)			
B.3 – Repair/laminate/substrate interface/surface preparation technique			
Short-term lap shear strength (MPa)			
Long term lap shear strength (MPa)			
B.4 – Short-term pipe spool survival test			
Report on short-term pipe spool survival test as described in C.3			
B.5 is only required to be completed for qualification of Type B repairs			
B.5 Requirements for repairs to substrates with through wall defects			
Report on energy release rate calculation, γ_{LCL} as described in D.5 (including surface preparation method)			
Report on impact performance as described in F.3 (quoting repair thickness and number of layers)			
Optional repair on measurement of degradation factor described in G.4			
B.6 Performance testing - optional			
Report on performance testing as described in E.3			
B.7 Other components			
Tee			
Bend			

Annex C
(normative)

Short-term pipe spool survival test

C.1 General

This annex describes the test method for qualification of repairs to non through-wall defects (Type A defect). The purpose of the test is to determine the maximum percentage wall loss that can be repaired.

C.2 Method

The following test shall be completed using a metallic pipe of at least 100 mm diameter and minimum length of six times the diameter in addition to the length of the repair.

A defect shall be machined into the pipe. The defect shall have an axial length, *l*, of at least one half of the pipe diameter and a circumferential width, *w*, of at least one-quarter of the pipe diameter. The depth of the defect shall be 80 % of the original wall thickness. A radius may be machined outside the edge of the defect, but the dimensions of machined area shall not exceed 2*l* nor 2*w,* as shown in Figure C.1. To avoid stress concentrations, the interior and exterior corners should be machined with a radius. The edge of the repair shall be at least three times the pipe diameter away from the ends of the pipe spool.

The test pressure of the spool, p_f (expressed in megapascals), shall be calculated using Formula (C.1):

$$p_f = \frac{2ts_a}{D} \tag{C.1}$$

where

t is the wall thickness of the undamaged spool, expressed in millimetres;

D is the external pipe spool diameter, expressed in millimetres;

s_a is the measured yield stress or mill certification, expressed in megapascals.

A repair laminate shall be applied to restore the pipe spool to pressure, p_f. The minimum thickness of the repair shall be calculated using Formula (C.2):

$$t_{repair} = \frac{1}{E_c \varepsilon_{short}} \left(\frac{p_f D}{2} - s_a t_s \right) \tag{C.2}$$

where

t_s is the remaining wall thickness of the pipe spool at the defect, expressed in millimetres;

E_c is the tensile modulus in the circumferential direction of the composite laminate expressed in megapascals;

ε_{short} is the short-term failure strain limit of the composite laminate, defined as 0,008.

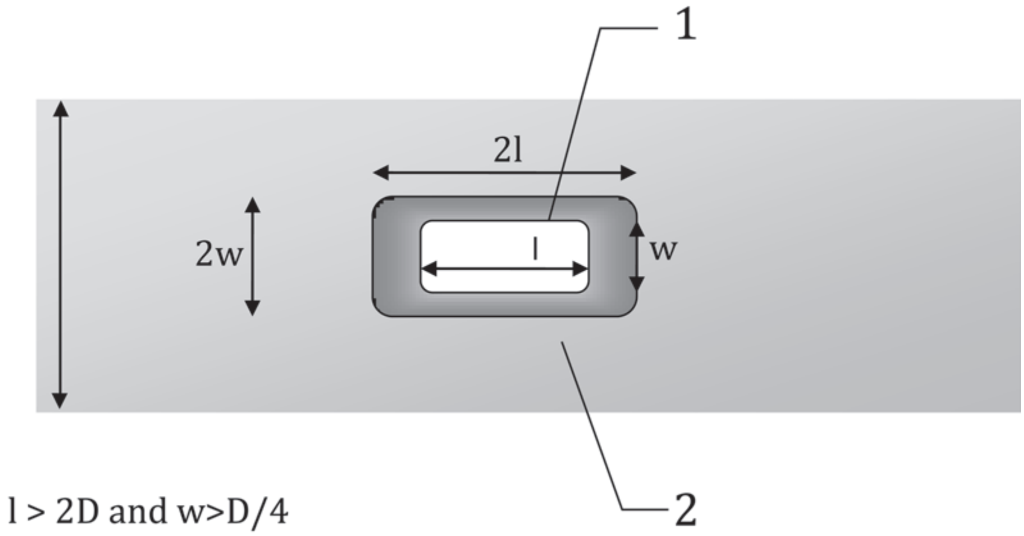
The actual repair thickness shall be determined by dividing this calculated thickness by the individual layer or wrap thickness. The required number of wraps of the repair shall be this number rounded up to the next integer. The actual repair thickness shall be the number of wraps times the individual wrap thickness.

The repaired spool shall be pressurized to p_f. Pressure testing shall be in accordance with ASTM D1599.

Successful demonstration requires the repaired pipe spool to survive the pressure loading to p_f. If successful, then the repair system shall be considered qualified for repair of defects up to the selected depth of defect used in the test.

C.3 Report

A report shall be prepared giving the test conditions, details of the repair system and the individual test results and the maximum wall loss that can be repaired.



Key

1 defect

2 machined area (including taper)

Figure C.1 — Defect dimensions

Annex D
(normative)

Measurement of γ_{LCL} for through-wall defect calculation

D.1 General

This annex describes the test method for measurement of the toughness parameter (energy release rate) for the repair laminate/substrate interface, γ_{LCL}, to be used in Formulae (11), (12), (13), and (14) in 7.5.7.

D.2 Method

Sections of metallic pipe of minimum diameter 100 mm and minimum thickness 3 mm shall be used. To represent typical defects, circular holes shall be drilled through the wall thickness and the repair laminate applied following the qualification application procedure. The repair system shall be applied with the defects in the 6 o'clock orientation.

The metallic pipe section used for the preparation of the test specimen should be appropriate for the anticipated failure pressure of the repair. Yielding of the pipe prior to failure should not occur.

Internal pressure shall be applied, and the value at which the repair begins to leak shall be recorded.

The test shall be carried out at the qualification test temperature.

The test pressure shall be increased in accordance with ASTM D1599.

A minimum number of nine tests shall be carried out, covering a minimum of three hole sizes, typically of diameters 10 mm, 15 mm, and 25 mm. For the larger diameters, the defect may be simulated by using a smaller hole and a circular polymeric release film of the appropriate diameter placed over the hole prior to application of the repair laminate. The holes shall not be filled or sealed by any means (mechanical or chemical) prior to application of the repair.

Failures should take the form of delamination of the repair laminate from the substrate, followed by leaking from the edge of the repair laminate. At small hole sizes, failure can occur through weeping of the test fluid through the thickness of the laminate or through yielding of the substrate. In this event, these tests should be disregarded and a new test carried out using a larger hole size. All failure points should relate to the delamination failure mechanism.

D.3 Calculation of γ_{LCL}

The value of γ_{LCL}, expressed in joules per square metre, shall be calculated by fitting Formula (11) in 7.5.7 to the data.

The following procedure shall be followed, using Formulae (D.2) through (D.6), where:

n is the number of observed data points $[A(d_i), p_i]$;

p_i is the pressure, expressed in megapascals, at failure of observation i, where i = 1,n;

$A(d_i)$ is the function of defect size and repair laminate properties of observation i, where i = 1,n;

$A(d_i)$ is defined as shown in Formula (D.1):

$$p_i = A(d_i)\sqrt{\gamma_i} \tag{D.1}$$

where

$$A(d_i) = \sqrt{\left\{\frac{0{,}001}{\frac{(1-\upsilon^2)}{E_{\mathrm{ac}}}\left\{\frac{3}{512t_i^3}d_i^4 + \frac{1}{\pi}d_i\right\} + \frac{3}{64Gt_i}d_i^2}\right\}} \tag{D.2}$$

and where

E_{ac} is the combined tensile modulus of the repair laminate $\sqrt{E_{\mathrm{a}}E_{\mathrm{c}}}$, expressed in megapascals;

G is the shear modulus of the repair laminate, expressed in megapascals;

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

d_i is the diameter of defect, expressed in millimetres;

t_i is the thickness of the repair laminate, expressed in millimetres.

The mean energy release rate, Υ_{mean}, is calculated using Formula (D.3):

$$\gamma_{\mathrm{mean}} = \left(\frac{\sum_{i=1}^{n} A(d_i)p_i}{\sum_{i=1}^{n} A(d_i)^2}\right)^2 \tag{D.3}$$

The lower confidence limit of the energy release rate, γ_{LCL}, is calculated using Formula (D.4):

$$\gamma_{\mathrm{LCL}} = \left[\frac{\sum_{i=1}^{n} A(d_i)p_i}{\sum_{i=1}^{n} A(d_i)^2} - t_v\sigma\sqrt{\frac{1}{\sum_{i=1}^{n} A(d_i)^2}}\right]^2 \tag{D.4}$$

where σ is the variance of measurement of pressure and is given by Formula (D.5):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(p_i - A(d_i)\sqrt{\gamma_{\mathrm{mean}}})^2}{(n-2)}} \tag{D.5}$$

and where tv is the Student's t value and is based on a two-sided 0,025 level of significance, i.e. 95 % lower confidence limit. Values of t_v are given as a function of number of variables, n, in Table D.1.

Table D.1 — Student's *t* value for double-sided 0,025 level of significance

Number of variables *n*	Degrees of freedom *n*-2	Student's *t*(0,025)
7	5	2,841

Table D.1 *(continued)*

Number of variables *n*	**Degrees of freedom** *n*-2	**Student's** *t*(0,025)
8	6	2,752
9	7	2,685
10	8	2,634
11	9	2,593
12	10	2,560
13	11	2,533
14	12	2,510
15	13	2,490
16	14	2,473
17	15	2,458
18	16	2,445

The value of γ_{LCL} calculated from Formula (D.4) shall be used in Formulae (12) to (15).

D.4 Qualification of other substrates

If the repair system has been fully qualified for one substrate, then a simplified qualification procedure is available for other substrates. In this procedure, only three tests are required to be completed. The three tests should be identical to three of the nine tests in terms of repair thickness and defect size used in the full qualification test programme.

The value of γ for this substrate, substrate 2, $\gamma_{LCL,substrate\ 2}$, is given by Formula (D.6):

$$\gamma_{LCL,substrate2} = \gamma_{LCL,substrate1} \frac{\gamma_{mean,substrate2}}{\gamma_{mean,substrate1}} \quad (D.6)$$

In this formula, "mean" implies the average of the three tests.

D.5 Test report

A report shall be prepared giving the test conditions (including test temperature) and details of the repair method, including the materials of construction and surface preparation technique, the individual data points and the derived value of γ_{LCL}.

Annex E
(normative)

Measurement of performance test data

E.1 General

If suppliers carry out performance-based testing then this annex shall be followed. Suppliers do not have to carry out performance testing to qualify their system; it is an option for them to choose.

This annex describes the test methods for measurement of design allowables to be used in 7.5.6. The test methods options are the following:

a) survival testing, in which the repair system is subjected to a period of sustained load for 1 000 h;

b) regression testing based on a series of tests on the repair system over different time periods and extrapolation to design life;

c) regression testing of representative coupons, followed by confirmation of long-term coupon test results with survival testing.

All tests shall be carried out at the qualification test temperature.

E.2 Methods

E.2.1 Survival testing

Sections of pipe of minimum diameter 100 mm and minimum thickness 3 mm shall be used and the repair system applied.

A value of internal pressure, ptest (expressed in megapascals), shall be applied (as defined by the repair system supplier) and sustained for 1 000 h. If any deterioration of the repair laminate in the form of cracking or delamination occurs, then the repair system shall have failed the test. Three identical tests shall be performed, and repair system qualification is only achieved if the repair laminate survives all three tests.

If yielding of the substrate underneath the repair has not occurred then the 95 % lower confidence long-term strain, $\varepsilon_{\mathrm{lt}}$ (expressed in mm/mm), is calculated using Formula (E.1):

$$\varepsilon_{\mathrm{lt}} = \frac{p_{\mathrm{test}} D}{2\left(E_{\mathrm{c}} t_{\mathrm{min}} + E_{\mathrm{s}} t_{\mathrm{s}}\right)} \tag{E.1}$$

Otherwise, the 95 % lower confidence long-term strain, $\varepsilon_{\mathrm{lt}}$ (expressed in mm/mm), is calculated using Formula (E.2):

$$\varepsilon_{\mathrm{lt}} = \frac{1}{t_{\mathrm{min}} E_{\mathrm{c}}} \left(\frac{p_{\mathrm{test}} D}{2} - s_{\mathrm{a}} t_{\mathrm{s}} \right) \tag{E.2}$$

where

E_{c} is the circumferential modulus of the repair laminate, expressed in megapascals;

E_{s} is the modulus of the substrate, expressed in megapascals;

D is the external diameter of test spool, expressed in millimetres;

s_a is the measured yield stress of the surface, or the mill certification yield stress;

t_{min} is the thickness of repair laminate, expressed in millimetres;

t_s is the thickness of substrate test spool, expressed in millimetres.

Further guidance on survival pressure testing procedures may be obtained from ASTM D1598.

E.2.2 Regression testing

Sections of pipe of minimum diameter 100 mm and minimum thickness 3 mm shall be used and the repair system applied.

A series of test specimens shall be subject to sustained pressures of different values. The time at which the repair laminate shows signs of deterioration defined as cracking or delamination shall be recorded. The results shall be plotted (log/log) and the required long-term pressure shall be determined by a regression analysis using the 95 % lower confidence limit and extrapolation to design life.

If yielding of the substrate underneath the repair has not occurred then the conversion from test pressure, p_{test} (expressed in megapascals) to strain, ε_{lt} (expressed in mm/mm), within the repair laminate for each data point shall be carried out using Formula (E.3):

$$\varepsilon_{lt} = \frac{p_{test} D}{2\left(E_c t_{min} + E_s t_s\right)} \tag{E.3}$$

Otherwise, the 95 % lower confidence long-term strain, ε_{lt} (expressed in mm/mm), is calculated using Formula (E.4):

$$\varepsilon_{lt} = \frac{1}{t_{min} E_c}\left(\frac{p_{test} D}{2} - s_a t_s\right) \tag{E.4}$$

where

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

E_s is the modulus of the substrate, expressed in megapascals;

D is the external diameter of test spool, expressed in millimetres;

s_a is the measured yield stress of the surface, or the mill certification yield stress;

t_{min} is the thickness of repair laminate, expressed in millimetres;

t_s is the thickness of substrate test spool, expressed in millimetres.

At least 18 results are required in order to perform the regression analysis. ASTM D2992 provides further guidance on the long-term testing of composite materials and ISO 14692 provides guidance on the analysis of the data to calculate s_{lt}.

E.2.3 Representative coupon testing

Representative coupons of the repair laminate shall be made up and tested in a manner comparable to the actual repair system laminate, where representative means having identical laminate constituents, volume fraction and fibre orientation. Comparable loading means coupons shall be loaded identically to the in-service repair laminate (e.g. uni-axial tension or bi-axial tension).

At least 18 coupons shall be tested under constant load to failure (data points in terms of number and length of time of testing in accordance with ASTM D2992, with the statistical analysis of data in accordance with ISO 14692).

The output of these coupon tests is the regression gradient, *G*, in terms of either the logarithm of the stress or the logarithm of strain plotted against the logarithm of time.

To determine the long-term failure stress or strain of the repair system, five medium-term tests (in accordance with ASTM D1598) shall be performed on sections of pipe of minimum diameter 100 mm and minimum thickness 3 mm. In these tests, the pressure is fixed and the time to failure recorded. It is recommended to select a test pressure so that failure occurs after about 1 000 h.

The lower confidence limit (in terms of time) for these five tests is calculated according to the mean failure time minus 2 standard deviations. The long-term design strength (or strain) of the repair system is the extrapolation of the lower confidence limit to the repair design lifetime, using the measured regression gradient from the coupon tests.

Further guidance on survival pressure testing procedures may be obtained from ASTM D1598.

Further guidance on long-term testing and data interpretation may be obtained from ISO 14692.

E.3 Test report

A report shall be prepared giving the test conditions (including test temperature) and details of the repair method, including the materials of construction and surface preparation technique, the individual data points and the derived performance design data.

Annex F
(normative)

Measurement of impact performance

F.1 General

This annex describes the test method for measurement of impact performance. The repair system supplier shall demonstrate that the repair is capable of withstanding the impact from a low velocity 5 J impact representative of a dropped tool. This test is used to determine the minimum thickness of the repair in situations where third-party impacts are considered likely to occur.

F.2 Method

A test specimen identical to one of the nine from Annex D shall be used.

The repair shall be subject to a 0,5 kg weight with a 12,5 mm hemispherical indenter dropped from a height of 1 m. The pipe shall be supported so that the hole is in the 12 o'clock orientation and the weight shall strike the repair at the position above the hole in the test pipe. The test pipe shall be empty for the duration of the impact test.

The impacted specimen shall then be subject to a pressure test as described in Annex D. The γ value of the test shall be calculated according to Annex D. The calculated γ value shall be no less than γ_{LCL}.

F.3 Test report

A report shall be prepared giving the test conditions (including test temperature), details of the repair system, the individual data points and the derived performance.

Annex G
(normative)

Measurement of the degradation factor

G.1 General

This annex describes the test method for measurement of the degradation factor for the repair of through-wall defects (defect Type B) using a low-speed loading rate test. In 7.5.7, a service factor for down-rating the predicted failure pressure is set at 0,333 for a 20-year design life. This factor is based on the product of two effects, the degradation from short-term to long-term failure of the repair laminate plus a safety factor, taken from ISO 14692, of 0,67. In 7.5.7, the default value for the degradation factor is set at 0,5.

G.2 Method

Sections of metallic pipe of minimum diameter 100 mm and minimum thickness 3 mm shall be used. Circular holes shall be drilled through the wall thickness, and the repair system applied. All samples shall be laminated with the holes in the 6 o'clock orientation (to minimize the ingress of resin into the defect). A minimum defect size of 25 mm is recommended.

The steel pipe section used for the preparation for the test specimen should be appropriate for the anticipated failure pressure of the repair. Yielding of the metallic pipe prior to failure should not occur.

The thickness of all repairs shall be identical to that used in Annex D.

Internal pressure shall be applied and the pressure value at which the repair begins to leak shall be recorded.

The test shall be carried out at the qualification test temperature.

The test pressure shall be increased daily until the specimen fails. The loading rate shall be such that failure occurs after approximately 1 000 h.

The loading rate for the low-speed loading rate test shall be defined using Formula (G.1):

$$p(t) = p_0 + p_1 t \tag{G.1}$$

where

p_0 is the initial pressure, expressed in megapascals;

p_1 is the fixed linear increase in pressure, expressed in megapascals per hour;

t is the time, expressed in hours.

It is recommended to set the initial pressure, p_0 (expressed in megapascals), to $p_0 = 0{,}1 p_{\text{sthp}}$ and the linear increase in pressure, p_1 (expressed in megapascals per hour), to $p_1 = 0{,}9 * 10^{-3} p_{\text{sthp}}$.

Five tests shall be carried out in total.

Failures should take the form of delamination of the repair laminate from the substrate, followed by leaking from the edge of the repair laminate.

G.3 Calculation of the degradation factor

The short-term failure pressure, p_{sthp} (expressed in megapascals) shall be calculated using Formula (G.2):

$$P_{sthp} = \sqrt{\left\{ \frac{0{,}001\gamma_{mean}}{\frac{(1-\upsilon^2)}{E_{ac}}\left\{\frac{3}{512t^3}d^4 + \frac{1}{\pi}d\right\} + \frac{3}{64Gt}d^2} \right\}} \quad \text{(G.2)}$$

where

E_{ac} is the combined tensile modulus $\sqrt{E_a E_c}$, expressed in megapascals;

G is the shear modulus of the repair laminate, expressed in megapascals;

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

d is the diameter of defect, expressed in millimetres;

t is the thickness of repair laminate, expressed in millimetres;

γ_{mean} is the mean energy release rate [Formula (D.3)], expressed in joules per square metre.

The average failure pressure of at least five medium-term tests shall be calculated and defined as p_{mthp}

The regression gradient, B, shall be calculated according to Formula (G.3):

$$B = \frac{1}{\left(\frac{\log\left(\frac{p_{sthp}}{p_1}\right)}{\log\left(\frac{p_{sthp}}{p_{mthp}}\right)} \right) - 1} \quad \text{(G.3)}$$

The degradation factor, f_D, shall be calculated using Formula (G.4), where it is assumed that the design life of the repair is 20 years:

$$f_d = 10^{-5{,}24B} \quad \text{(G.4)}$$

G.4 Test report

A report shall be prepared giving the test conditions (including test temperature), details of the repair system, the individual data points and the derived value of the degradation factor.

Annex H
(informative)

Axial extent of repair look-up table

Table H.1

Pipe parameter				**Defect size diameter** *d* mm					
				5	10	15	20	25	slot
Pipe size inch	**Pipe outside diameter** *D* mm	**Wall thickness** *t* mm	**Schedule**	**Axial length** *t* mm					
2	60,3	3,9	40	50	50	50	50	50	50
		5,5	80	50	50	50	50	50	50
3	88,9	5,5	40	50	50	50	50	50	50
		7,6	80	50	50	52	52	52	52
4	114,3	6	40	50	50	52	52	52	52
		8,6	80	50	50	60	63	63	63
6	168,3	7,1	40	50	50	60	67	67	67
		11,0	80	50	50	60	80	80	80
8	219,1	6,4	20	50	50	60	75	75	75
		7	30	50	50	60	78	78	78
		8,2	40	50	50	60	80	85	85
		10,3	60	50	50	60	80	95	95
		12,7	80	50	50	60	80	100	106
10	273	6,4	20	50	50	60	80	84	84
		7,8	30	50	50	60	80	92	92
		9,3	40	50	50	60	80	100	101
		12,7	60	50	50	60	80	100	118
		15,1	80	50	50	60	80	100	128
12	323,8	6,4	20	50	50	60	80	91	91
		8,4	30	50	50	60	80	100	104
		10,3	40	50	50	60	80	100	116
		14,3	60	50	50	60	80	100	136
		17,5	80	50	50	60	80	100	151
16	406,4	6,4	10	50	50	60	80	100	102
		7,9	20	50	50	60	80	100	113
		9,5	30	50	50	60	80	100	124
		12,7	40	50	50	60	80	100	144

Table H.1 *(continued)*

Pipe parameter				Defect size diameter *d* mm					
				5	10	15	20	25	slot
Pipe size inch	**Pipe outside diameter** *D* mm	**Wall thick-ness** *t* mm	**Schedule**	**Axial length** *t* mm					
		16,7	60	50	50	60	80	100	165
		21,4	80	50	50	60	80	100	187
20	508	6,4	10	50	50	60	80	100	114
		9,5	20	50	50	60	80	100	139
		12,7	30	50	50	60	80	100	161
		15,1	40	50	50	60	80	100	175
		20,6	60	50	50	60	80	100	205
		26,2	80	50	50	60	80	100	231
24	610	6,4	10	50	50	60	80	100	125
		9,5	20	50	50	60	80	100	152
		14,3	30	50	50	60	80	100	187
		17,5	40	50	50	60	80	100	207
		24,6	60	50	50	60	80	100	245
		31	80	50	50	60	80	100	275
30	762	7,9	10	50	50	60	80	100	155
		12,7	20	50	50	60	80	100	197
		15,9	30	50	50	60	80	100	220
36	914	7,9	10	50	50	60	80	100	170
		12,7	20	50	50	60	80	100	215
		15,9	30	50	50	60	80	100	241
		19	40	50	50	60	80	100	264

Annex I
(normative)

Installer qualification

I.1 General

The repair of substrates using repair systems differs considerably from other repair techniques, and the quality of the installation depends strongly on satisfactory craftsmanship. Training and certification of personnel is therefore a key element to the execution of a successful repair. This annex outlines the minimum requirements for training, qualification and approval of installers and supervisors.

Courses and training should be defined by the repair system supplier in accordance with this annex.

I.2 Basic skills/experience

a) Installer

The candidate shall be a minimum of 18 years of age and fulfil either of the following experience requirements:

— 3 month (full time) documented training with the repair system supplier;

— a minimum 2 years' documented installer experience with polymer systems or on site experience with mechanical crafts.

To obtain the necessary experience to become an installer, the trainee shall follow the training course as defined by the repair system supplier. Training shall involve both practical and theoretical aspects of repair systems. If the installer is to be qualified for different geometries, they shall need to demonstrate competence for that geometry type.

b) Supervisor

For entry to the supervisor course, the candidate shall fulfil either of the following experience requirements:

— have a minimum of 2 years' experience in repair systems, shall have completed at least 12 repair applications within the 2-year time frame and shall be in possession of a current specific approval certificate for an installer of repair systems. In addition, the candidate shall be able to demonstrate experience of repairing straights, tees, elbows, diameters <2" and >12" and using the full range of the suppliers repair systems;

— shall be the repair system supplier's technical supervisor representative. The repair system supplier shall be able to demonstrate the competence of the candidate proposed for the supervisors role.

I.3 Installer training

The basic installer training course shall give a theoretical and practical introduction to the most important elements in the installation of a repair system.

a) Coursework

The course shall include training in the following:

— terminology, types of repair;

— health, safety and environment;

— surface preparation;

— material application;

— different repair geometries (if applicable);

— control of repair conditions;

— quality assurance and control.

b) Practical – qualification testing

Installers shall be qualified for each specific repair system and a selection of component types, e.g. straight pipe and tee. Qualification shall be carried out on the basis of repair class (see Table 2). Installers approved for a given class can undertake repairs at a lower level, i.e. approval to Class 3 permits repairs at Classes 1 and 2, etc.

After relevant training, Class 1 repairs can be installed unsupervised; Class 2 and Class 3 repairs shall be supervised

All specific qualification tests shall be carried out in accordance with a written procedure, relevant to the specific repair system and approved by the repair system supplier.

c) Defect type A qualification test

The repair shall be applied to a pipe of at least 100 mm diameter. The repair shall pass visual inspection completed in accordance with Table 14 witnessed by the supervisor or instructor.

d) Defect type B qualification test

In addition to the requirements for defect type A repairs, a test specimen identical to one of the nine from Annex D shall be prepared. The specimen shall be subject to a pressure test as described in Annex D. The γ value of the test shall be calculated according to Annex D. The calculated γ value shall be no less than γ_{LCL}.

I.4 Supervisor Training

The supervisor training course shall give a detailed theoretical overview to the further important elements in the design, installation, inspection and health safety of a repair system.

The course shall include training in the following:

— supervisor’s duties and responsibilities;

— evaluation methods used in repair design;

— methods of pipe defect assessment;

— health and safety;

— installation checklist and hold points;

— inspection of repairs.

I.5 Certificate

At the completion of an installer or supervisor course, a successful candidate should be issued a certificate and identity card containing passport-type photographic evidence of the qualified individual (or alternative means of positive identification that the installer or supervisor has the appropriate valid qualifications) providing details of the repair system, the class to which qualification has been achieved and the geometries on which they are qualified to install repairs. The certificate should also identify the name of the company providing the training and issuing the certificate.

The employer of the repair system installer shall keep a record of the completed training.

I.6 Validity

The type-specific qualification is valid for a period of one year.

Qualified personnel continually working (at least one repair a month or at least 10 repairs in any one year) in the application of compliant repair systems will not require a revalidation of their competency.

Qualified personnel who have not installed a compliant repair system for more than one year will have to re-qualify prior to applying further repair systems.

The Installer or Supervisor shall be responsible for and use their personal logbook of all repair applications as evidence of their frequency and history of repair. This shall be signed off by the supervisor and by the owner's representative as appropriate.

Annex J
(informative)

Installation requirements and guidance

J.1 General

The guidance given in this annex is intended to complement that given by the repair system supplier and to emphasize the key operations necessary for a successful repair.

The repair system supplier should provide full installation instructions.

Full instructions for each repair system application should be given in the method statement prepared in each instance.

J.2 Surface preparation

Surface preparation is the single most important operation in the achievement of a successful repair.

Surface preparation methods are not interchangeable. The procedure used for surface preparation is an integral part of a repair system and an alternative preparation should not be used in lieu of that which has been qualified by the supplier.

The surface preparation should extend over the whole surface onto which the repair laminate is to be applied, and should be in accordance with the specific repair system.

There are a number of surface preparation methods, but they normally entail cleaning and degreasing followed by surface abrasion. This may (or may not) be accompanied a subsequent chemical treatment stage. A surface roughness gauge or other measurement technique should be used to check that the prepared surface is as required by the method statement.

ISO 8501, ISO 8502, and ISO 8503 provide methods of assessing these factors, and ISO 8504 provides guidance on the preparation methods that are available for cleaning steel substrates.

Any chemicals used for surface preparation should be within their recommended shelf life, freshly mixed (where appropriate) and applied strictly in accordance with the repair system supplier's instructions.

The time period between the completion of the surface preparation stage and the application of the repair laminate should be as short as possible but not longer than 4 hours.

Prepared surfaces should be protected from contamination prior to the application of the initial coating or repair laminate. Any sign of deterioration of the prepared surface due to handling, the presence of water or other influence should be cause for rejection, and the surface preparation procedure repeated.

The specified surface preparation method should not be replaced by another method without explicit guidance from the repair system supplier, who should have qualified the alternative as part of a different repair system.

J.3 Laminate lay-up

The details of the lay-up procedure should be specified by the repair system supplier.

The lay-up procedure includes the following:

a) filler compounds;

b) primer application;

c) resin, adhesive preparation;

d) reinforcement orientation;

e) overlaps between neighbouring layers;

f) overlaps between individual layers;

g) consolidation of the layers;

h) finishing layer, outer coating;

i) taper details;

j) corrosion protection continuity (if appropriate) between the edge of the repair and the pipe coating;

k) cure schedule.

Ideally, repair laminates should not be applied when the temperature of the surface is less than 3 °C above the dew point of the surrounding air or when the relative humidity of the air is greater than 85 %, unless local conditions dictate otherwise. Guidance on the estimation of the probability of condensation can be found in ISO 8502-4. Also, the substrate surface temperature, ideally should always be more than 5 °C.

J.4 Cure

As the cure of a repair laminate is strongly influenced by temperature and the correct mixing of resin constituents prior to application, the limits of application as defined by the repair system supplier should not be exceeded without approval from the repair system supplier.

Where elevated temperatures are required for cure, the temperature should be monitored throughout the curing process.

The time for full cure is dependent on the type of resin used in the repair and on the ambient conditions. The extent of cure shall be measured DSC (differential scanning calorimetry) where required. Barcol or Shore hardness testing can provide an indication that the repair system has hardened. Acceptance values shall be provided by the repair system supplier. Hardness measurements alone shall not be relied upon to indicate full cure for repairs to Class 3 systems but in addition the cure schedule specified in 7.5.3 shall be demonstrated to have been achieved.

The repaired substrate may be returned to service only after the specified cure schedule has been achieved.

Annex K
(informative)

Design considerations

This annex is informative and is intended to provide guidance on the design process for determining the thickness and axial extent of composite repair systems. In particular the guidance is aimed at which design options to select and how to choose the generic defect type if the defect is through-wall. Essentially, this annex provides details on how to select the correct path through the design flowchart presented in Figure 1.

The basic design process for repair systems involves answering three questions:

a) Is the thickness sufficient to ensure that the repair laminate can withstand the applied loads?

b) Will the repair remain bonded to the pipe substrate?

c) Is the axial extent of repair beyond the defect sufficient to ensure load transfer?

The output of the design process is the thickness of the repair and its axial extent beyond the defect. Typically, the thickness of a repair system will not be greater than 25 mm and its extent beyond the defect will range from approximately 50 mm to 250 mm depending on pipe diameter and wall thickness of the component.

Question a) involves calculating the repair thickness with the assumption that thin walled pipe theory applies, i.e. that the strain is constant through the cross-section of the repair laminate. The design criterion used in this analysis is the long term allowable strain.

Question b) involves calculating the repair thickness for Type B (through-wall defects) only. The design calculation is based on a fracture mechanics solution using a measured energy release rate (Annex D). Essentially the solution is comparable to the analysis of a thick coating blow-off test. For Type A type defects, it is assumed that the measured minimum lap shear strength measured as part of the repair system qualification (Annex B) will provide sufficient adhesion.

Question c) involves calculating the extent of the repair beyond the defect. This calculation is based on two effects, one to ensure that the length of repair is sufficient to transfer the load, the other is to ensure that the repair encompasses the stress perturbation within the substrate caused by the defect.

The maximum thickness derived from answering questions a) and b) is taken as the final design repair thickness.

The design allowable used to calculate the repair thickness is based on strain. Repair system suppliers are encouraged to measure the long-term failure strain of the repair system. This long-term failure strain is then converted into a design allowable by applying de-rating factors for fatigue, environment and safety. If long-term measured values are not available, then conservative default long-term values are provided.

To calculate the repair thickness based on adhesion considerations, a facture mechanics approach is adopted. This calculation is required if it is anticipated that the defect requiring repair will grow through-wall within the repair design lifetime. The design allowable in this case is the critical energy release rate. This is a measured parameter and importantly is a function of the substrate material, the surface preparation procedure and the composite laminate. In this calculation for repair thickness, the size and geometry of the through-wall defect is required. Three generic geometric types are considered within the standard. A circular through-wall defect is intended to cover pitting type and general wall loss corrosion. A conservative value of 25 mm diameter is recommended for the defect size for a long lifetime repair. A fully circumferential slot is intended to cover weld corrosion or the over-wrapping of clamps. The width of the slot should be selected by measuring the width of the weld typically in the range from 10 mm to 25 mm. The final option is an axial slot. This defect type is intended to cover 6 o'clock corrosion where again the width of the slot should be conservatively assumed to be between 10 mm and 25 mm for a long lifetime repair.

Careful consideration is required before repairing GRP lines because the damage in the pipe may be more extensive than visible on the surface and may affect a longer length of pipe than is immediately obvious; advice of the GRP pipe manufacturer and repair system supplier should be sought before a repair is installed.

Figure 1 presents an overview of the various options available when designing a repair system.

The starting point in the design process is to define the design allowable strain. The starting point for this derivation is whether or not measured long term failure strain data for the composite laminate is available. If it is then Formula (11) should be used to calculate the allowable strain for the lifetime of the repair. If not then default values should be used as defined in Table 8. The design allowable strain should then be determined from Formula (10) to take account of the effects of temperature. Finally if environmental compatibility and cyclic fatigue effects are relevant then the design allowable strain should be then de-rated by the relevant factors as determined by either 7.5.2 or 7.5.9.2 respectively.

The next decision in the design process is to determine whether or not the defect will be become through-wall during the repair design lifetime.

For non through-wall defects, the design process continues as follows;

If a defect assessment has been performed or if reliable inspection data of the minimum remaining wall thickness of the pipe or vessel wall is available then the repair thickness should either be calculated using Formula (1) and (2) if the design allowable is based on the maximum allowable stress within the wall of the pipe or vessel or Formulae (5) and (6) if the design allowable is based on the composite laminate design allowable strain. The final repair thickness is determined by multiplying the repair thickness by factors for limited axial extent of repair, f_{overlay}, Formula (22) and component type, f_{stress}, Table 11, Table 12 or Table 13. The axial extent of the repair should be determined from Formula (18).

For through-wall defects the design process continues as follows.

The temperature de-rating factor, f_{T2}, should be determined from Table 7. If long-term adhesion data is available then the repair design lifetime de-rating factor, f_{leak}, should be calculated from Formula (17). If not then f_{leak} should be determined from Formula (16). These parameters are required for the adhesion fracture mechanics calculation that determines the repair thickness. The generic type of through-wall defect should be selected either, hole, circumferential slot or axial slot. The repair thickness based on adhesion considerations should then be calculated from the relevant equation for the selected generic through-wall defect type, i.e. Formula (12), (13), (14) or (15). Formula (8) and (9) should then be used to determine the thickness of the repair based on strength considerations. The repair thickness is the maximum of that calculated from either Formula (12), (13), (14) or (15) or Formula (8) and (9). The final repair thickness is determined by multiplying the repair thickness by factors for limited axial extent of repair, f_{overlay}, Formula (22) and component type, f_{stress}, Table 11, Table 12 or Table 13. The axial extent of the repair should be determined from Formula (18) or (19) depending on the chosen generic through-wall defect type.

Finally three checks on the final design result are required to be made, length of repair using Formula (21), interfacial tensile stresses when the repair application is live using Formula (29) and for a tee a check related to the pressure and area of the tee, Formula (33).

Two worked examples follow providing an overview of the process for the design calculation of a repair. Worked example 1 is for a Defect type A and worked example 2 is for a Defect type B.

Worked example 1

This example considers the design of a composite repair system for a 406,4 mm inch pipeline with external corrosion up to 80 % of the original wall loss with a required design lifetime of 10 years. The extent of the corrosion in the pipe axial direction is 200 mm. The service of this line is Class 3 and the surface preparation of the pipeline will be to Sa2.5. External collapse resistance or resistance to soil loading is not required.

The design conditions, dimensions, material properties and installation conditions of the pipeline are:

Design pressure (MPa)	5
Design temperature (°C)	60
Pipe diameter, D (mm)	406,4
Pipe wall thickness, t (mm)	12,7
Grade of steel	API 5L Gr B
Allowable stress, σ_s (MPa)	161,66
Thermal expansion coefficient, α_s (mm/mm/°C)	$12 * 10^{-6}$
Installation temperature, $T_{install}$ (°C)	20
Internal pressure during repair application, P_{live} (MPa)	0

The material properties of the installed composite repair system are:

Modulus - hoop, $E_{\mathbf{c}}$ (MPa)	36,000
Modulus - axial, $E_{\mathbf{a}}$ (MPa)	36,000
Poissons ratio, v	0,27
Glass transition temperature, $T_{\mathbf{g}}$ (°C)	80
Thermal expansion coefficient, $\alpha_{\mathbf{c}}$, (m/m/°C)	−0,000 001
Layer thickness of the repair laminate, $t_{\mathbf{layer}}$ (mm)	1,25
Lap shear strength (MPa)	15

The above information represents the input design data as described in the flowchart summarizing the repair system design process (Figure 1). The following paragraphs follow the steps outlined in Figure 1.

Step 1	Long-term measured strain to failure data are not available	
Step 2	Determine relevant T_g from 7.5.3: Class 3, 10 year life requires $T_g \geq (60+20) = 80$ °C Calculation f_{T1} based on (T_m-T_d) = 20 °C where T_m is the T_g for the system when cured at 20 °C (installation temperature) not the ultimate value which will include an exotherm. Also confirm the system will cure to a T_g of greater than 80 °C when heated to 60 °C	
Step 3	Calculate ε_{c0} and ε_{a0} using Table 9	$\varepsilon_{c0} = \varepsilon_{a0} = 0{,}002\ 77$
Step 4	Calculate design allowable strain, ε_c and ε_a, using Formula (10) and f_{T1} from Table 7	$f_{T1} = 0{,}7$ $\varepsilon_c = \varepsilon_a = 0{,}001\ 4$
Step 5	Apply de-rating factors – no factors need to be applied	
Step 6	The defect is not through wall, i.e. the defect is Type A	
Step 7	A defect assessment has been performed based on the remaining wall thickness of the steel pipe to calculate the MAWP, P_s	$P_s = 2t\sigma_s/(D\text{-}t) = 2{,}03$ MPa
Step 8	Calculate repair thickness (limited by allowable strain in laminate) using Formulae (5) and (6)	$t_{min,c} = 12{,}02$ mm $t_{min,a} = 4{,}64$ mm
Step 9	Calculate final repair thickness noting that component type is a straight pipe, $f_{th,stress} = 1$ (Table 11) and no restriction on axial extent, $f_{th,overlay} = 1$ [Formula (22)]	$t_{design} = 12{,}02$ mm $n = 10$

Step 10	Calculate extent of repair, l_{over} using Formula (18). Also calculated are the taper length (5:1 ratio on design repair thickness) and total length of repair	l_{over} = 144 mm l_{taper} = 60 mm l_{total} = 607,6 mm
Step 11	Checks on design Length of repair – Formula (21) Thickness of repair – Table 2 Interfacial stress – Formula (29) Pressure/area – Formula (33)	l_{min} [Formula (21)] = 121 mm which is less than calculated value of 144 mm – check ok $D/6$ = 67,7 mm which is greater than repair thickness of 12,02 mm – check ok P_{live} = 0 no check required Component is not a tee therefore check not required

Worked example 2

This example considers the design of a composite repair system for a 168,3 mm inch equal tee suffering internal corrosion. The required design lifetime of the repair is 5 years and within this lifetime it is expected that the internal corrosion will become through wall. The surface preparation of the equal tee will be to Sa2.5 but on the branch where the corrosion is at its most severe an area on the branch surface will be covered by a thin plate during the surface preparation process to prevent puncturing of the branch. The thin plate extends the full circumference of the branch and extends axially for 50 mm. Furthermore, a flange face is a further 45 mm from the edge of the thin plate which the proposed composite repair is not required to encapsulate. The service of this line is Class 2.

The design conditions, dimensions, material properties and installation conditions of the tee:

Design pressure (MPa)	1
Design temperature (°C)	30
Tee diameter, D (mm)	168,3
Tee wall thickness, t (mm)	7,1
Thermal expansion coefficient, α_s (mm/mm/°C)	$12 * 10^{-6}$
Installation temperature, $T_{install}$ (°C)	20
Tee material	Carbon steel

The material properties of the installed composite repair system are:

Modulus - hoop, E_c (MPa)	24,000
Modulus - axial, E_a (MPa)	8,000
Poissons ratio, ν	0,27
Shear modulus, G (MPa)	2,000
Glass transition temperature, T_g (°C)	70
Thermal expansion coefficient, α_c, (m/m/°C)	$25 * 10^{-6}$
Layer thickness of the repair laminate, t_{layer} (mm)	0,8
Qualification test temperature, T_{qual} (°C)	20
Energy release rate (for carbon steel), γ_{LCL} (J/m^2)	227
Lap shear strength (MPa)	15

The above information represents the input design data as described in the flowchart summarizing the repair system design process (Figure 1). The following paragraphs follow the steps outlined in Figure 1.

Step 1	Long-term measured strain to failure data is not available	
Step 2	Determine relevant T_g from 7.5.3: Class 2, 5 year life requires $T_g \geq (30 + 20) = 50°C$ Calculation f_{T1} based on a T_g of 70°C as repair has been post cured with heat blankets set at 50°C	
Step 3	Calculate ε_{c0} and ε_{a0} using Table 9	ε_{c0} = 0,003 3 ε_{a0} = 0,001
Step 4	Calculate design allowable strain, ε_c and ε_a, using Formula (10) and f_{T1} from Table 7	f_{T1} = 0,719 ε_c = 0,002 2 ε_a = 0,000 59
Step 5	Apply de-rating factors – no factors need to be applied	
Step 6	The defect is through wall, i.e. the defect is Type B	
Step 7	Calculate f_{T2} from Table 8	f_{T2} = 0,719
Step 8	Long term adhesion performance data is not available	
Step 9	Calculate f_{leak} from Formula (16)	f_{leak} = 0,632
Step 10	A circumferential slot of 50 mm axial width is selected	w = 50 mm
Step 11	Calculate repair thickness using Formulae (8) and (9)(strength of repair calculations) and Formulae (13) and (14) (through wall defect calculation)	$t_{min,c}$ = 1,77 mm $t_{min,a}$ = 7,33 mm $t_{min,through\ wall}$ = 5,06 mm
Step 12	Calculate final repair thickness noting that component type is a tee, $f_{th,stress}$ = 2 (Table 11) and that there is a restriction on axial extent, $f_{th,overlay}$ = 1.07 [Formula (22)]	t_{design} = 15,72 mm n = 20
Step 13	Calculate extent of repair, l_{over} using Formula (18) for all three branches. Also calculated are the taper lengths (5:1 ratio on design repair thickness)	l_{over} = 50 mm l_{taper} = 78,6 mm (for the unrestricted branches) l_{total} = 425,5 mm (for the unrestricted branches)
Step 14	Checks on design Length of repair – Formula (21) Thickness of repair – Table 2 Interfacial stress – Formula (29) Pressure area – Formula (33)	l_{min} [Formula (21)] = 15 mm which is less than calculated value of 50 mm – check ok $D/6$ = 28,05 mm which is greater than repair thickness of 15,72 mm – check ok P_{live} = 0 no check required Pressure requirement, P_{req} (N/mm^2) [Formula (30)] = 6,9 which is greater than design pressure – check ok

Annex L
(informative)

Management of the integrity of composite repair systems to pipework and vessels

L.1 Engineered composite repairs: Owner responsibilities

If the output of the risk assessment is that an engineered composite repair is the optimum solution, then there are a number of tasks that should be proactively managed. Figure L.1 depicts an overview of owner roles and responsibilities during the repair process and service life of the repair. These are denoted by **Task 1, Task 2, Task 3, Task 4 and Task 5.**

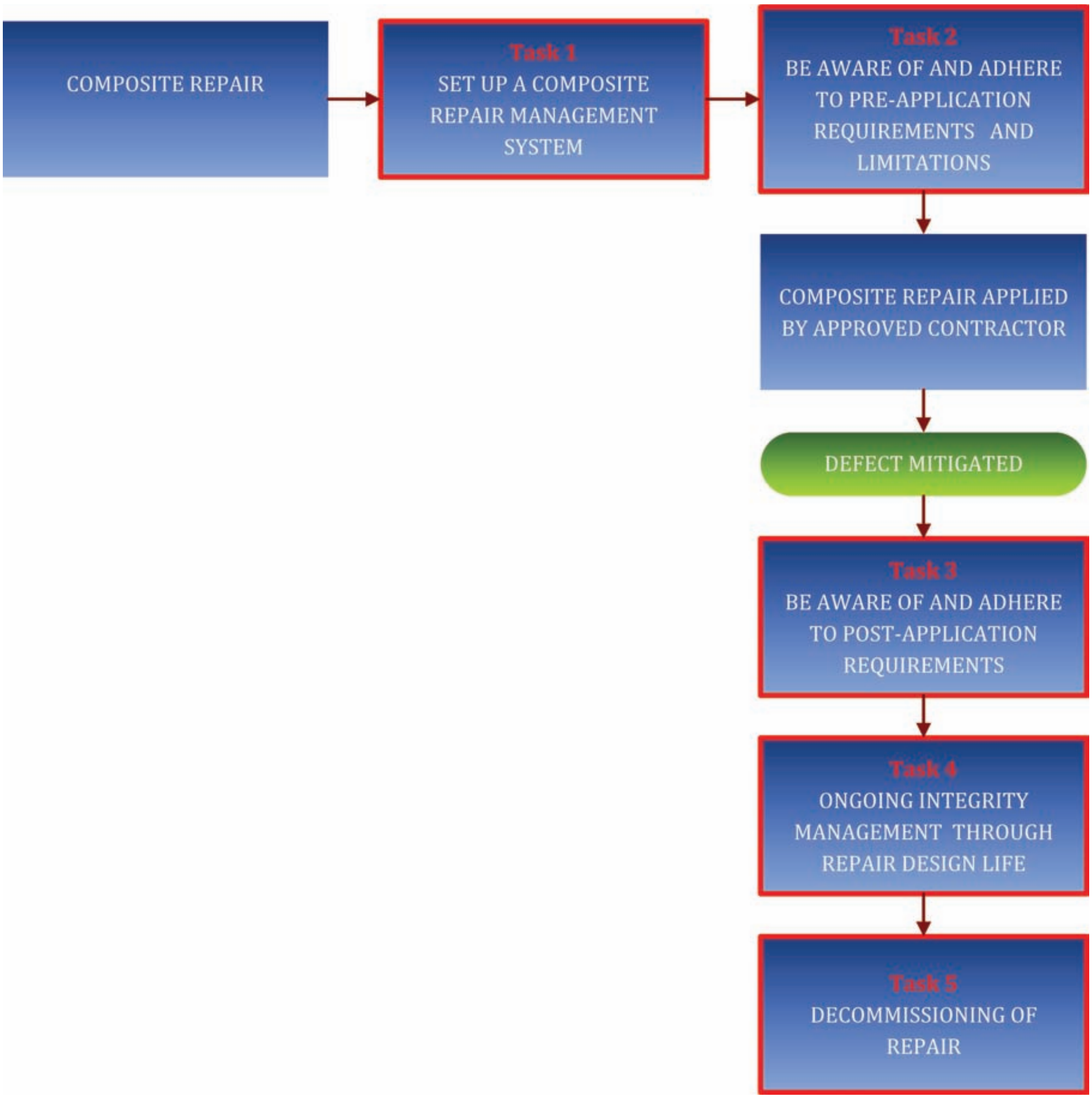


Figure L.1 — Repair system process flowchart

The intended design life of the repair should be specified at the outset. This will be limited by a range of factors including ongoing degradation mechanisms. The inspectability of the repaired system will be a significant consideration in determining whether integrity can be verified throughout the design life of the repair.

L.1.1 Composite repair management system — Task 1

The owner should have a procedure which details the roles and responsibilities of key personnel during the repair system process. The owner should have responsibility for developing the scheme of inspection to ensure the integrity of the repair, often in conjunction with an approved inspection body. In all cases, roles and responsibilities should be clearly defined.

There should also be an owner nominated individual who will coordinate the repair application. This person should ensure that surface preparation is carried out to the required standard and the repair is applied within correct timescales (see L.1.2). Further, the same individual should ensure that continuity of corrosion protection (see L.1.3) is addressed along with any other post application activities.

It should be ensured that all required quality assurance (QA) documentation is provided by the repair system supplier (see 8.2.2 and 8.5).

L.1.2 Pre-application requirements — Task 2

Surface preparation is key to the integrity of any engineered composite repair. The properties of the bond between the substrate and the composite is essential to ensure the transfer of loads (and to provide leak-sealing if applicable) and is highly influenced by the standard of surface preparation. J.2 specifies that the repair should be carried out within 4 h of the surface preparation taking place. There are key hold points specified in Table 14 for the repair installer/supervisor to follow.

For through-wall defects an appropriate method of leak sealing shall be employed prior to the application of the repair. This is to isolate the repair material from the system fluids which when in ccontact could adversely affect repair performance.

L.1.3 Immediately post-application requirements — Task 3

The repair process should not be considered complete until continuity of corrosion protection is provided at the ends of the repair. This is normally the responsibility of the owner but dialogue with the repair system supplier should ensure compatibility of the paint system applied with the repair system. The ends of the repair are a potential initiation point for corrosion in the most important load transfer area of the repair (see Figure L.2).

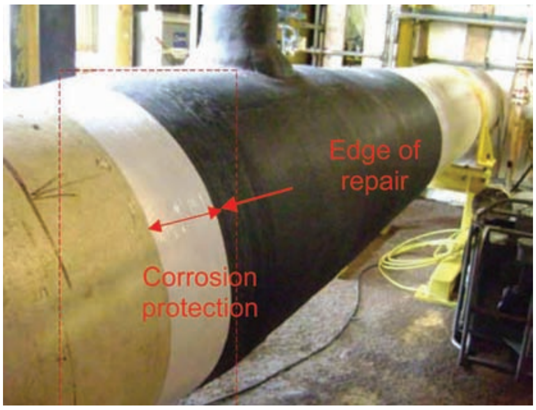


Figure L.2 — Corrosion protection reinstated between installed wrap and original paint coating; lack of corrosion protection leading to corrosion at edges of the repair

It is advised that photographs be taken of the completed repair to allow the owner appointed individual to provide final approval/sign off. In this regard, it may be appropriate to liaise with the repair system supplier to establish whether what has been installed is consistent with what was originally envisaged. While it is accepted that only limited information can be discerned from a photograph, it would nevertheless highlight obvious non-conformances such as a discontinuity in the corrosion protection at the edges of the repair as discussed above. It should be noted that in some cases the repair stricture or compression tape may be left in place after completion but that this can hamper visual inspection (see L.1.4).

The owner appointed individual should ensure that the repair is added to a register of such repairs and that an inspection scheme has been established prior to signing off the repair. This may require a baseline inspection to be carried out immediately after the repair has been applied. Further, consideration should be given to updating various engineering documentation (e.g. P&IDs) such that there is no ambiguity as to where the wraps are located and their criticality.

L.1.4 On-going integrity management through repair design life — Task 4

When determining the extent and periodicity of inspection, consideration should be given to the nature of the degradation mechanisms of the substrate which resulted in the requirement of the engineered composite repair, as well as the consequences of failure. Accordingly, a risk-based inspection (RBI) type approach is advised. It should be noted that while the engineered composite repair itself may have been designed and a warranty provided for up to 20 years, this does not necessarily guarantee integrity of the repair system as a whole for that period of time.

9.1 highlights that the key areas for the non-destructive eexamination (NDE) of a composite repair system are the following:

— Inspection of the repair laminate;

— Inspection of the bond quality between the repair laminate and the substrate;

— Inspection of the substrate underneath the repair laminate.

For repairs to substrates suffering from external corrosion, consideration should be given to any changes to process conditions that may result in the substrate being exposed to a different degradation mechanism than was envisaged when the repair was designed and installed. The ongoing external corrosion risk should be managed by appropriate external visual inspections, supplemented by NDE as appropriate.

For repairs to substrates where internal corrosion remains a threat, the repair design lifetime will be dictated by the rate of corrosion of the substrate. While conservative assumptions on corrosion rates may be made at the composite repair design stage, this must be validated by NDE at appropriate intervals to ensure integrity of the substrate. It is possible that unforeseen corrosion may occur due to, for example, changes in operating conditions. In the event of this leading to failure, this would most likely result in a leakage from the edge of the composite repair.

In addition, consideration of the susceptibility of the composite material to newly introduced degradation mechanisms should be considered. For example, the repairs may require to be protected where there is risk of impact damage or awareness training provided to personnel working in the area.

There is currently no validated inspection technique to inspect the integrity of the bond, emphasizing the importance of appropriate surface preparation. Visual inspection should be targeted at the edges of the repair as this is most likely to be the initial site of delamination which is externally visible.

It should be noted that the addition of composite repairs presents additional long-term integrity management issues and these should be considered at the initial risk assessment stage.

L.1.5 Decommissioning of engineered composite repair — Task 5

Adequate systems of work and documentation must be maintained (in particular a repair register) such that it is clearly apparent when the design lives of repair systems are approaching and action is required. Again, this process which should be managed such that a timely, informed decision can be made with respect to whether a further repair or replacement is appropriate.

Bibliography

[1] ISO 8501, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness*

[2] ISO 8502, *Preparation of steel substrates before application of paints and related products — Tests for the assessment of surface cleanliness*

[3] ISO 8503, *Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates*

[4] ISO 8504, *Preparation of steel substrates before application of paints and related products — Surface preparation methods*

[5] ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*

[6] ISO 14129, *Fibre-reinforced plastic composites — Determination of the in-plane shear stress/shear strain response, including the in-plane shear modulus and strength, by the plus or minus 45 degree tension test method*

[7] ISO 15310, *Fibre-reinforced plastic composites — Determination of the in-plane shear modulus by the plate twist method*

[8] ISO 15649, *Petroleum and natural gas industries — Piping*

[9] Boiler ASME and Pressure Vessel Code Section IIIND-3672.6(a), *Piping Design/General Requirements/Expansion and Flexibility/Stresses/Stress Range*

[10] Boiler ASME and Pressure Vessel Code Section IIIND-3611.2, *Piping Design/General Requirements/Acceptability Stress Limits*

[11] ASME PCC-2, *Repair of Pressure Equipment and Piping*

[12] ASME B31.1, *Power Piping*

[13] ASME B31.3, *Process Piping*

[14] ASME B31.4, *Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids*

[15] ASME B31.5, *Refrigeration Piping*

[16] ASME B31.8, *Gas Transmission and Distribution Piping Systems*

[17] ASME B31.9, *Building Services*

[18] ASME B31.11, *Slurry Transportation Piping Systems*

[19] ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

[20] ASTM D790, *Standard Test Method for Flexural Properties of Un-reinforced and Reinforced Plastics and Insulating Materials, 2003*

[21] ASTM D903, *Standard Test Method for Peel or Stripping Strength of Adhesive Bonds*

[22] ASTM D1763, *Standard Specification for Epoxy Resins*

[23] ASTM D2105, *Standard Test Method for Longitudinal Tensile Properties of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube*

[24] ASTM D2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

[25] ASTM D2837, *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials*

[26] ASTM D3846, *Standard Test Method for In-Plane Shear Strength of Reinforced Plastics*

[27] ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*

[28] ASTM F412, *Standard Terminology Relating to Plastic Piping Systems*

[29] AWWAC-150/A21.51, *Standard for Thickness Design of Ductile Iron Pipe*

[30] AWWA C-151/A21.51, *Standard for Ductile Iron Pipe, Centrifugally Cast, for Water or Other Liquids*

[31] AWWA C-200, Stan*dard for Steel Water Pipe 6 in and Larger*

[32] AWWA M-11, *Steel Pipe - A Guide for Design and Installation*

[33] BS 8010, *Code of practice for pipelines*

[34] CSWIP, CSWIP-GRP-1-96 and CSWIP-GRP-2-96, as per ISO 8503

[35] DNV Certification Scheme http://www.dnv.nl/focus/vakbekwaamheid/

[36] Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable - www.hse.gov.uk/risk/theory/alarp1.htm

[37] ASME B31G, *Manual, Determining Remaining Strength of Corroded Pipelines: Supplement to B31 Code-Pressure Piping*

[38] AWWA M45, Fibreglass Pipe Design

[39] BS EN 13121, *GRP tanks and vessels for use above ground*.

[40] ASME FFS-1/API*RP 579, Fitness-For-Service (Recommended Practice)*

[41] ASME PCC-2-2011*Part 5 Article 5.1, Pressure and tightness testing of piping and equipment*

ICS 75.180.20

Price based on 85 pages