Foreword

Offshore structures such as Offshore Production Installations (FPSOs, FSOs, etc.) normally remain at their operation site for long periods of time. They have no regular drydocking intervals as ships do, and thus periodic inspections often discover local corrosion such as pitting and/or widely distributed general corrosion. Some substantial corrosion may call for renewal or reinforcement in order to meet structural strength requirements.

Repair by use of steel welding for degraded structural members is conventionally allowed by the current Classification Rules. However, when hot work welding is planned for repairs, it is necessary that the subject tank/location and adjacent tanks are in a gas free condition for compliance with safety requirements. In such cases, it causes a significant impact on the continuous operation of the units and has safety implications. Thus, adhesively bonded composite repairs for both steel structures and piping are generally preferred for site-specific offshore structures, as the repairs can be done without hot work welding. The repair principles may also be applied to other vessel types where permitted.

With the increased use of composites in repairs for primary and secondary structures, these Guidance Notes are essential to provide guidelines on the bonded composite repairs of steel structures and piping, primarily for applications on the site-specific offshore structures.

These Guidance Notes become effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

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# GUIDANCE NOTES ON

## COMPOSITE REPAIRS OF STEEL STRUCTURES AND PIPING

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CHAPTER 1 Composite Repairs of Steel Structures

SECTION 1 General

1 Scope

This Chapter is applicable to the use of composite repairs on site-specific offshore units such as FPSOs and FSOs. It provides guidelines on adhesively bonded composite repairs of the steel structures. It covers assessment, design, qualification, installation and inspection of a bonded repair.

This Chapter does not cover aluminum structures, even though this guidance may also be applicable to aluminum structure repairs.

These Guidance Notes provide an alternative to regular hot work renewal, where the hot work is considered risky to the offshore unit’s operation. Instead of using hot welding, an existing degraded steel structure can be repaired to restore the integrity of the structure by utilizing patches of composite material, steel plates, or other structural materials that are bonded to the degraded steel structure.

1-1/ Figure 1 illustrates the principle of a bonded patch repair. This repair technique can also be used for modification or upgrading of the existing structures by reinforcing structural elements to provide added strength.

Advantages of the bonded patch repair are that they are quick and simple with minimum preparation. Disadvantages are that the repaired section is thicker and heavier than the original, a very careful surface preparation is necessary for good adhesion and repair lifetime, and more frequent in-service monitoring and inspections may be required.

\[\text{FIGURE 1} \]
Bonded Composite Repair for Corroded Substrate Structure

2 Personnel Qualification

Designers of bonded patch composite repairs and personnel engaged in the installation and inspection of the repairs should be qualified with a recognized certification or documented practical experience.

The laminator should receive relevant training to possess appropriate competence in the lamination process.

The entire repair process is manual. Thus, the quality of the bonded patch repair is directly dependent on the skill and experience of the personnel carrying out the repair. The repair procedure documentation should be provided to confirm that the personnel carrying out the repair and inspection are qualified for the job and the repair technology.
3 Risk Assessment

An assessment of the risks associated with the structural deterioration/cracking and repair method should be completed in line with relevant industry best practices. When applying a repair, the following items should be considered:

i) The nature and location of the corrosion or cracking

ii) Geometry of the structural element to be repaired

iii) Design and operating conditions for the structural element and service environment (including impact, abrasion, fire, explosion, collision, and environmental conditions (temperature, exposure to chemicals))

iv) Performance under worst conditions and major incident situations including impact, abrasion, fire, explosion, collision, and environmental loading

v) Hazards associated with repair service

vi) Repair installer skills, surface preparation quality and repair environment

vii) Repair system materials selected

viii) Repair life expected

ix) In-service inspectability

x) Failure modes

4 Documentation for Review

The documentation provided prior to installation of the repair should include:

i) An examination report of the corrosion and/or fatigue cracking and providing information as specified in 1-2/2.

ii) A design report covering the design basis, and the qualification results and design calculations. The design report should document all relevant information collected and all identified issues addressed in the design input, strength analysis, fabrication, and qualification of the bonded patch repair process. Details can be found in 1-3/4.

iii) An installation report should be included with detailed installation and inspection specifications, including the installation procedures, QA/QC manual, installer qualification and inspector qualification. Details can be found in Chapter 1, Section 5.

iv) In-service inspection and maintenance plan for maintaining the integrity of the repair should be provided. Information on the identification of the repair, location, repair lifetime, associated maturation year and survey intervals should be included in the In-Service Inspection Plan (ISIP) for offshore units. Information contained in the In-Service Inspection Plan can be found in Chapter 1, Section 6.

v) Risk Assessment Report (see 1-1/3), including risks of de-bonding and composites strength degradation due to environment, whenever applicable.

5 Term and Definitions

The following terms and definitions are used in this document:

Adhesion. The state in which two surfaces are held together by interfacial forces, which may be chemical and/or mechanical in nature.

Adhesive. A substance used to hold two surfaces together.

Barcol Hardness. A measure of surface hardness using a surface impresser. The Barcol hardness test characterizes the indentation hardness of materials through the depth of penetration of an indentor, loaded on a material surface and compared to the penetration in a reference material.
**Bond Layer.** The adhesive layer between the patch surface and the substrate surface. It may be primer layers, if any.

**Composite.** A material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The composite materials allowed for the bonded repair include, but are not limited to, glass, aramid, or carbon fiber reinforcement in a thermoset polymer (e.g., polyester, polyurethane, phenolic, vinyl ester, or epoxy) matrix.

**Cure/Curing.** Setting of a thermoset resin system, such as epoxy or polyester, by an irreversible chemical reaction.

**Cure Schedule.** Time-temperature dependence profile to achieve a desired hardness with a specified glass transition temperature, $T_g$.

**Curing Time.** Minimum time for a resin in an assembly or an adhesive to cure under heat or pressure, or both.

**Debonding.** Separation along the bond layer.

**Delamination.** Debonding between the repair laminate/patch/substrate and the bonding layer.

**Filler.** Materials used to repair surface imperfections.

**Flash Rusting.** Rusting that occurs uniformly on metal within minutes to a few hours after surface cleaning is complete. The speed with which flash rusting occurs may be indicative of salt contamination on the surface, high humidity, or both. Uniform flash rust is considered inert and a sign of general steel oxidation. If the flash rust evolves into a loose powdery layer, coating adhesion and performance may be compromised.

**Galvanic Corrosion.** Accelerated corrosion of a metal due to an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

**General Corrosion.** Relatively evenly distributed corrosion attacks on a steel surface.

**Glass Transition Temperature ($T_g$).** Temperature below which the polymer turns from a ductile material to a hard and brittle material. $T_g$ of a material characterizes the range of temperatures over which this glass transition occurs.

**Heat Distortion Temperature.** Heat distortion temperature (HDT) is the temperature at which a polymer or plastic test bar deflects by a specified amount under a given load.

**Laminate.** Composite material used in a repair, which is an assembly of layers of fibrous composite materials joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion.

**Localized Corrosion.** Relatively concentrated or spot-wise corrosion attacks on surface (typically pitting, corrosion in way of welds, crevice corrosion, stress corrosion cracking, etc.). Localized corrosion can proceed rapidly and can be dangerous.

**Patch.** A piece of material used to reinforce the degraded substrate. It can be a steel plate or a composite laminate.

**Pipework.** Interconnected piping subject to the same design conditions.

**Piping/Piping System.** Assemblies of piping components used for fluid transportation.

**Ply.** Single wrap or layer of a repair lamination.

**Post Cure.** Additional cure at elevated temperature after a resin has hardened to achieve more complete curing.

**Pot Life.** The maximum elapsed time during which a coating can be effectively applied after all components of the coating have been thoroughly mixed.

**Prepreg.** Pre-impregnated with resin.
Prepreg Lay-up. A lay-up technique that uses a reinforcing fabric which has been pre-impregnated with a resin system. As a result, the prepreg is ready to lay into the mold without the addition of any more resin. For the laminate to cure, it is necessary to use a combination of pressure and heat.

Primer. A coating material applied as the first coat on an uncoated surface, specifically formulated to adhere to and protect the surface as well as to produce a suitable surface for subsequent coats.

Resin System. All of the components that make up cured resin in the matrix portion of a composite.

Shelf Life. The maximum length of time that packaged materials (e.g., coating materials) can be stored, at specified conditions, and still remain in usable condition.

Shore Hardness. Measure of surface hardness using a surface impresser or durometer (see also “Barcol Hardness”).

Substrate. Surface upon which a repair is carried out.

Technical Data Sheet. Information provided by the manufacturer containing detailed technical information relevant to the coating process and its application.

Thermoset Resin System. Resin system cured by polymerization.

6 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>EPA</td>
<td>The Environmental Protection Agency (EPA) is an agency of the United States federal government</td>
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<tr>
<td>FEA</td>
<td>Finite Element Analysis</td>
</tr>
<tr>
<td>FOI</td>
<td>Floating Offshore Installations</td>
</tr>
<tr>
<td>FPI</td>
<td>Floating Production Installations</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiber Reinforced Plastics</td>
</tr>
<tr>
<td>HDT</td>
<td>Heat Distortion Temperature</td>
</tr>
<tr>
<td>IDLH</td>
<td>Immediately Dangerous to Life or Health (IDLH), defined by the US National Institute for Occupational Safety and Health (NIOSH) as exposure to airborne contaminants that is “likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment”.</td>
</tr>
<tr>
<td>ISIP</td>
<td>In-Service Inspection Plan</td>
</tr>
<tr>
<td>IMO FTP Code</td>
<td>IMO Fire Test Procedures Code</td>
</tr>
<tr>
<td>MODU</td>
<td>Mobile Offshore Drilling Units</td>
</tr>
<tr>
<td>MSDS</td>
<td>Materials Safety Data Sheet</td>
</tr>
<tr>
<td>NACE CIP</td>
<td>Coating Inspection Program, NACE International</td>
</tr>
<tr>
<td>NDCV</td>
<td>Nominal Design Corrosion Values</td>
</tr>
<tr>
<td>NDI</td>
<td>Nondestructive Inspection</td>
</tr>
<tr>
<td>OSHA</td>
<td>The Occupational Safety and Health Administration of the United States Department of Labor</td>
</tr>
<tr>
<td>OSV</td>
<td>Offshore Support Vessels</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Insurance</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>RFL</td>
<td>Remaining Fatigue Life</td>
</tr>
<tr>
<td>RIFT</td>
<td>Resin Infusion under Flexible Tools</td>
</tr>
<tr>
<td>RTM</td>
<td>Resin Transfer Molding</td>
</tr>
</tbody>
</table>
SHE  Safety, Health & Environment
SSPC  The Society of Protective Coatings
SSPC-SP  Standard Practice, The Society for Protective Coatings
TDS  Technical Data Sheet
$T_g$  Glass Transition Temperature
USCG  Untied States Coast Guard
UV  Ultraviolet
CHAPTER 1 Composite Repairs of Steel Structures

SECTION 2 Assessment for Repair

1 General

This Section provides guidelines on assessing the criticality of corrosion and fatigue cracking to determine if the bonded composite repair is viable.

Criteria for wastage and renewal can be found in the ABS Rules for Survey After Construction (Part 7). This document is not a substitute.

The inspection and assessment are the first steps in the repair process to determine the corrosion and fatigue cracking criticality, the repair extent, and the repair priority.

The composite repairs covered in this chapter are repairs for the structural deterioration from corrosion (see 1-2/4) and fatigue cracking (see 1-2/5). Mechanical damage to steel structures, as may be caused by grounding, explosion, contact/collision etc., is not covered.

2 Examination Report

Reporting examination of the corrosion and fatigue cracking and providing information about the extent of repairs that are proposed are important steps in making a repair decision.

If the unit’s fitness to proceed is impaired or if there is a chance that the corrosion and fatigue cracking may progress to such an extent as to affect the structural fitness or watertight integrity of the unit at a later date, such corrosion and fatigue cracking should be repaired before the unit resumes operations, depending on the extent and severity of the structural deterioration, the intended service, and expected sea state.

The report should include the following information:

i) Unit name and ABS class number

ii) Date of the most recent inspection, which should have been completed within 15 months of the application of the composite repair

iii) Description of corrosion and fatigue cracking and list of supporting documents:

• Location, sizes and extent of the structural deterioration with drawings and photographs/video
• Thickness gauging data
• Environmental information such as operating pressure, temperature, type of fluid/cargo
• Possible cause of the structural deterioration
• Description of accessibility to the structural deterioration for repairs and further inspection/monitoring

vi) ABS report including the Outstanding Recommendation or Additional Requirement identifying the area requiring repairs
3 Repair Decision

When the deterioration from corrosion and fatigue cracking has been detected and documented, a criticality assessment should be made.

An assessment of the structural deterioration should be evaluated for the criticality to determine whether bonded composite repairs can be applied. The determination on the criticality is based on applicable class Rules. The decision-making process on using the bonded composite repair method is summarized in Figure 1.

**FIGURE 1**
Decision-making Process on Bonded Composite Repair

Start

Assessment

Non-Class Element? Yes

No

Corrosion? Yes

No

Corrosion ≥ Renewal Criteria Yes

No

ABS Engineering Approval of Composite Repair ? Yes

No

Traditional Repair

Composite Repair

Crack No
The degraded element can be critical or non-critical:

- **Non-class elements** are not subject to significant loads, and the structural integrity of the original structure is not compromised by their structural deterioration. Typically, a non-class structural element is not critical and is one where its complete failure does not generate the risk of progressive collapse of the overall structure. Non-class element repairs do not need to be considered in the structural strength evaluation of the unit.

- **Non-critical class elements** are important elements which are required for ABS reviews but would not necessarily need the structural strength evaluation or FEA. However, failure of those “class items” would not lead to rapid loss of structural integrity or cause a reduction in the remaining fatigue life of the unit, such as miscellaneous decks that do not contribute to longitudinal strength.

- **Critical class elements** are subject to significant loads, and failure of these structural elements would result in the rapid loss of structural integrity and produce an event of unacceptable consequence, as defined in 5A-1-4/7.5 of the ABS Rules for Building and Classing Floating Production Installations (FPI Rules). The structural integrity of the degraded element can be restored by transferring loading from the substrate to the patch primarily by shear stresses in the bond layer. The capacity of critical class structural element repairs can be assessed based on small-scale testing or component testing, provided a documented method is used.

The repair criticality can be evaluated based on the structural element criticality and the structural deterioration criticality:

i) **If the degraded element is a non-class element, it may be repaired using patch repair. Such element repair is considered non-critical.**

ii) **If the degraded element is a class element but the extent of the degradation does not compromise the integrity of the element and will not develop to such within the next inspection interval, the repair is considered non-critical.**

iii) **When material diminishment due to corrosion is within allowable limits (see 1-2/4), the repair is considered non-critical.**

iv) **When the corrosion of a critical class element is more than allowable limits (see 1-2/4) (e.g., thickness diminution over an area large enough to affect the unit’s integrity), steel renewal may be required, and such repair is considered critical.**

Any corrosion associated with wastage over the allowable limits or extensive areas of wastage over the allowable limits which would affect the unit’s structural, watertight, fire integrity and/or weathertight integrity should be promptly and thoroughly repaired. Areas to be considered include:

- Bottom structure and bottom plating
- Side structure and side plating
- Deck structure and deck plating
- Watertight or tank bulkheads

The bonded composite repair should not be allowed when the actual section modulus (before repair) is less than 90% of the global section modulus required for new construction or conversion/reassessment.

When a bonded composite repair is considered in lieu of steel structure replacement of an individual element, detailed global or local strength calculations using approved repair design and materials may be needed. For critical class element repairs, FEA is required. Special consideration of the minimum remaining thickness of the degraded critical class element for the bonded patch repair is needed. See details in 1-2/4.2.1 below. A bonded composite repair is not considered for critical class structural elements with complete thickness loss. However, localized pitted holes may be repaired by using a bonded composite, provided that the repair criticality is assessed.

v) **Cracks may often be considered critical. Laminate-based repairs may be considered inappropriate for critical fatigue cracks. For non-critical fatigue cracks, laminate-based repairs may be used to slow down fatigue crack propagation. However, the repair life is not predictable and constant monitoring may be needed to ensure the crack does not grow.**
There are many situations wherein the corrosion is substantial and extensive, such as loss of thickness beyond corrosion margins and limits. In such cases, it may still be justifiable to allow the use of a bonded composite repair, provided the engineering assessment and calculations of the structure before and after repair are completed.

It is important that the repair does not accelerate the structural deterioration, this is done by using best practices for design, qualification, fabrication, inspection and maintenance of the repair. The effect on areas immediately adjacent to the element to be repaired should be considered in case of the repair failure. The repair should not create new issues such as attracting significant new loads or preventing future inspection.

The location of the composite repair should be also assessed regarding safety. It should not be considered in way of transit/escape routes without an adequate protection for people walking through it. Additionally, it should be verified that composite materials are adequate to maintain safety during a fire emergency (i.e., the composite repairs will not melt nor release any noxious component to the atmosphere under high temperatures).

4 Corrosion

4.1 General

This Subsection defines the forms of corrosion and the needs for steel replacement. As described in 1-2/3 for repair decision, when steel corrosion of an individual structural element does not exceed the allowable wastage, a bonded composite repair is allowed as such repair is considered as a non-critical repair. Otherwise, when the steel corrosion exceeds allowable wastage for class element, the bonded composite repair may be considered as a critical repair. The bonded composite repair of corroded elements should fully or partially restore the capacity and/or stiffness.

Corrosion can be divided into the following categories by corrosion forms:

i) General Corrosion. Uniform corrosion with uniform loss of metal over an entire surface. The minimum thickness of hull structural elements may be applied in order to determine average diminution values. Typically, repairs include steel replacement to original scantlings or reinforcement upon special consideration.

ii) Pitting Corrosion. A form of localized corrosion, which is an attack with localized holes or pits on the steel surface. The intensity of the pitting should first be estimated. Typically, pitting repairs include renewal of plates, building up pits by welding, or application of plastic filler compounds.

iii) Grooving Corrosion. Another form of localized corrosion, which is local line material loss normally adjacent to welding joints. Special consideration of the corrosion repair may be needed.

iv) Edge Corrosion. Local material wastage at the free edges of plates and stiffeners. Typically, depending on the severity of such corrosion, reinforcement may be added.

4.2 Corrosion Limits

4.2.1 General Corrosion – Extensive Areas of Corrosion

Extensive Area of Corrosion is corrosion of hard and/or loose scale, including pitting, over 70% or more of the plating surface in question, accompanied by evidence of thinning.

Where substantial corrosion is found, additional thickness measurements in accordance with 7-3-2/7 of the ABS Rules for Survey After Construction (Part 7) are taken to confirm the extent of substantial corrosion. Where extensive areas of wastage exceed allowable margins, renewals or repairs are typically required.

For example, for floating installations of the ship-type, column-stabilized-type, tension leg platforms and spar installations, as well as existing vessels converted to FPIs, the renewal scantlings are in accordance with 5A-1-3/3.11 of the FPI Rules. Care should be taken to distinguish between the reduced as-built scantlings and the ABS Rule-required scantlings. Renewal thickness should be based on ABS Rule-required scantlings.
Once the decision is made for acceptance of the bonded patch repairs in lieu of steel replacement, special consideration for the critical class structural element repair is needed so that the average remaining thickness of the degraded element should not be less than 30% of the as-built thickness (ABS Rule-required scantlings) or 6 mm (0.25 in.), whichever is greater. Use of composite repair for minimum scantlings less than 6 mm (0.25 in.) may be accepted on a case-by-case basis and subject to provision of adequate protection to the substrate steel to avoid any wastage during the remaining service life.

The longitudinal strength evaluation should be made in accordance with the longitudinal strength of the hull girder by using the as-gauged thickness of structural members measured. The decision should be made for renewal and reinforcement, as appropriate, during the surveys.

When calculating the hull girder section modulus, the degraded parts and its shadow areas should be deducted, similar to 3-2-1/Figure 6 of the ABS Rules for Building and Classing Marine Vessels (Marine Vessel Rules).

The individual wastage allowances are typically acceptable, provided the global section modulus (SM) is not less than 90% of the as-built SM at the time of new construction or conversion/reassessment. The bonded composite repair of such corroded individual elements can be critical or non-critical depending on corrosion wastage of class elements and should not to be considered in the calculation of the global section modulus of the unit.

4.2.2 Localized Corrosion – Pitting

**Pitting Corrosion** is a localized corrosion with local material reductions greater than the general corrosion in the surrounding area. Pitting intensity is defined in 7-A-4/Figure 5 of the ABS Rules for Survey After Construction (Part 7).

Localized areas of excessive wastage, pitting or grooving may call for immediate repair according to the ABS survey requirements.

The following minimum renewal thickness due to pitting corrosion is recommended if no applicable ABS Rules are available, such as 5A-2-1/9.5 of the FPI Rules and 7-A1-4/35 of the ABS Rules for Survey After Construction (Part 7), on pitting corrosion for particular types of structures:

1. For plates with a pitting intensity less than 20%, the minimum remaining thickness in pitting should be at least 70% of the original as-built thickness (without voluntary addition) or 1 mm (0.04 in.) less than renewal thickness, whichever greater.
2. For plates with 70-100% pitting intensity (i.e., general corrosion), the average remaining thickness in the worst cross section through the pitting in a plate should not be less than minimum thickness for general corrosion in 1-2/4.2.1 above.
3. For plates with 20-70% pitting intensity, acceptance of the average remaining thickness in the pitted area may be decided based on linear interpolation between i) and ii) above.

The following equation may be used to estimate the average remaining thickness in pitted areas:

\[ t_{ave} = t_{plate} \times (1 - Intensity) + t_{pit} \times Intensity \]

where

- \( t_{ave} \) = average remaining thickness for pitted areas
- \( t_{plate} \) = average remaining thickness outside pitting
- \( t_{pit} \) = average remaining thickness in pitting
- \( Intensity \) = estimated pitting intensity. Pitting intensity is defined in 7-A-4/Figure 5 of the ABS Rules for Survey After Construction (Part 7)

For widely scattered pitting where the remaining thickness in pitting is not less than the value calculated above, filler material such as epoxy resin or glass flake or bonded composite could be used for a non-critical repair. When the overall wastage is sufficient to warrant renewal of the affected plate, the pitting repair using plastic compound filler material should not be considered since it does not contribute to the strength. In such case, a bonded composite repair as a critical repair may be considered.
4.2.3 Localized Corrosion – Grooving

Grooving Corrosion is typically local material loss adjacent to weld joints along abutting stiffeners and at stiffener or plate butts or seams. An example of grooving corrosion is shown in 7-A-4/Figure 4 of the ABS Rules for Survey After Construction (Part 7).

Commonly affected areas are:

- Side frames to shell plate
- Web frame connections to deck and stiffeners
- Webs of side and deck longitudinals
- External shell plates

For stiffeners and plates, the maximum groove breadth is 15% of the web height or 30 mm (1.18 in.), whichever is less. The allowable remaining thickness in the grooved area may be taken as 75% of as-built thickness or $t_{ren} - 0.5$ mm (0.02 in.), whichever less, but not less than 6 mm (0.25 in.).

When the areas are greater than 15% of the web height or 30 mm (1.18 in.), the renewal thickness due to general corrosion, $t_{ren}$ in 1-2/4.2.1 above, can be applied.

The accumulated length of transverse grooves in deck, bottom, longitudinal bulkhead or side plating within the cargo area is limited to 20% of the breadth respective height of the unit. For special unit with large deck openings, the accumulated length of transverse grooves in the passageway may be limited to 10% of the breadth. The allowable remaining thickness in the grooved area may be taken as 75% of as-built thickness or 6 mm (0.25 in.), whichever greater.

Where excessive grooving corrosion beyond the minimum thickness provided above is found, re-welding of grooves or appropriate bonded patch repair, as a critical repair, may be considered.

Where grooving corrosion is found within the minimum thickness provided above, a bonded patch repair as a non-critical repair may be used.

4.2.4 Localized Corrosion – Edge Corrosion

Edge Corrosion is defined as local corrosion at the free edges of plates, stiffeners, primary support members and around openings. An example of edge corrosion is shown in 7-A-4/Figure 3 of the ABS Rules for Survey After Construction (Part 7).

The extent of corrosion on the free edge of the flange and the flat bar of deck longitudinals should be less than 25% of the flange’s breadth or the flat bar height, and the remaining edge thickness should not be less than 70% of the as-built thickness or $t_{ren} - 1.0$ mm (0.04 in.), whichever is less. The average thickness of the breadth or the web height uses the minimum thickness due to general corrosion from 1-2/4.2.1.

Where excessive edge corrosion is found, renewal by inserts would normally be needed. However, alternative repairs with edge reinforcement, such as edge reinforcement from a bonded composite, may be considered.

Where edge corrosion is found above the minimum thickness for renewal, edge repair/reinforcement from a bonded composite is allowed.

5 Fatigue Cracking Repairs

While bonded composite repair is an established repair method for deterioration from corrosion, there are still few examples of fatigue crack repair. As indicated in 1-2/3v), composite repair of critical cracks should not be considered. However, applying the bonded composite repair to fatigue cracks could reduce crack growth considerably by

- Reducing the stresses to a level where the crack propagation is stopped,
- Reducing a rate to acceptable level with consideration of the intended lifetime of the repair, or
- Arresting the crack where the crack size is acceptable at some later time.

In such case, the configuration and placement of the patch relative to the crack and use of efficient crack monitoring systems are important.
CHAPTER 1 Composite Repairs of Steel Structures

SECTION 3 Repair Design

1 General

The design of a bonded patch repair using laminate or steel plate is different from steel welding repair. Bonded composite repair should have design and analyses for all components used in the repair, such as steel or composite laminate patches and adhesive.

To reduce the uncertainty of the repair life, the long-term performance of bonded composite repairs should be fully documented (see 1-3/3.2.4). The goal of such bonded composite repairs is to have a quick repair with or without drydocking. The owner/operator should make their own judgment on the necessity for quick qualification against the reliability of the repair and the risk of needing to upgrade or replace the repair in the future.

2 Repair Design Basis

2.1 Scope

The purpose of a bonded repair is to restore the function of the original structural component. The functional requirements include load capacity, stiffness, dimensional stability, fluid/cargo containment and tightness, and resistance to chemical/UV/temperature/heat insulation. The functional requirements also include, if applicable, wear resistance, electrical resistance, electrochemical properties, vibration and fire/explosion resistance.

The repair design should consider all phases of the repair life, and the repair reliability should be established for each important phase during the installation and operation.

The design basis defines the documentation that is required as the basis for the design of a bonded repair.

2.2 Repair Design Life

The life of the bonded repair should be defined. The life of the bonded repair usually is at least the same as the remaining design life of the steel structure. A shorter life may be used for temporary repairs.

It is noted that there is no established accelerated test method that can reliably predict the lifetime of a bonded repair. The achievable repair life depends on the repair system installed and can be affected by the environment, opposite side corrosion/erosion mechanisms, and external mechanical influences. The corrosion/erosion rate of the opposite side of the repaired area should also be estimated during the repair design.

2.3 Loads

The design basis should specify loads in the design of the repair, such as

- Loads from equipment
- Loads from loading and unloading from ballast water and storage tanks
- Loads from fixed weights
- Weight of other parts of the structure
- Environmental loads (wind, wave, current, tidal, ice, snow, temperature variation, etc.).

The sequence of the loads should be identified. A simplified approach towards design for fatigue capacity may be adopted.
2.4 Environment

Composites are sensitive to chemical and thermal loads. Exposure to UV radiation, large temperature differences, elevated or very low temperatures, crude oil in a tank, sour gases, and marine environment also should be considered. Degradation of the composite materials may lead to accelerated degradation of a laminate patch and bonding. The design should consider and verify that the composite repair is suitable for the intended operating environment. The following should be particularly considered during the repair design:

i) If the repaired surface is subjected to UV light, abrasion, wear and tear, and/or local impacts, the surfaces should be protected by a suitable coating or other protection system.

ii) For bonded repairs exposed to weather, the extreme design temperatures should be determined from maximum and minimum temperatures for the repair. Possible temperature gradients over the length or thickness of the bonded repair should be identified. The lowest temperature should be used for evaluation of fracture toughness of the steel substrate.

iii) The effects of exposure to water/oil should be considered in the material selection for the patch, adhesive, and primers if any. Generally, fresh water causes more degradation than saltwater on most composites.

iv) For repairs designed to operate below the glass transition temperature ($T_g$) of the composite material and the adhesive, the maximum operating temperature should normally not exceed 20°C (36°F) below the glass transition temperature for any of the materials.

v) Most composites are flammable and temperature sensitive. The fire performance of the complete composite structure system with fire protection should be evaluated.

vi) For repairs in ice conditions, abrasion resistance to ice, ice impact and low temperature should be considered during the repair design.

2.5 Electrical Conductivity

Electrical conductivity requirements for the repair should be provided in the design. Nonconductive polymer materials may develop static electricity which can potentially cause a fire or explosion hazard. Specified conductivity requirements should be obtained with the repair solution. If no other specific requirements are given, the recommendations from ISO 14692-2 Section 6.6 should be applied to composite patch repairs.

Carbon fibers used in the patch may cause galvanic corrosion if the fibers contact the steel plates.

2.6 Repair Considerations

A suitable application procedure should be chosen. Chapter 1, Section 5 provides detailed recommendations on Repair Installation and Quality Assurance. Effectiveness of the repair should be verified after installation.

Applying a bonded repair may involve certain safety risks for the personnel performing the work. The repair installation should not involve a fire and chemical hazard.

Environmental conditions during installation are critical to the repair quality.

The following should be considered as a minimum:

i) Accessibility to the surface to be repaired

ii) The time and load condition allowed for repair application and curing

iii) Surface cleaning, such as using steam, water jets, detergents, and abrasive blasting should be provided to meet the surface cleanliness requirements.

iv) Ambient humidity and temperature should be considered during surface preparation, repair installation and curing.

v) The chemical environment at the repair site should also be specified, including exposure to drilling muds, seawater, fresh water and hydrocarbons, gas, or gaseous phases of chemicals.

vi) Ability of the repair to be examined for failures and verified to be sound after installation.
2.7 Failure Modes of the Bonded Composite Repairs

2.7.1 General
The relevant failure modes of bonded composite repairs may need to be considered in repair design (see 1-3/3). The primary modes are debonding and laminate patch failures.

2.7.2 Debonding
2.7.2(a) Bonding Layer Cracking. When a crack is repaired, an initial crack through the thickness of the bonding layer just above the crack to be repaired normally develops very quickly. This crack is arrested when it reaches the reinforced patch.

2.7.2(b) Bonding Layer Fatigue and Debonding Propagation. When the repaired component experiences a cyclic load, a debonding crack may initiate and propagate in the bond layer, thus partially separating the patch from the substrate.

2.7.2(c) Free Edge Cracking. A debonding crack may initiate and propagate from the free edges of the repair, thus partially separating the patch from the substrate.

2.7.2(d) Bonding Layer Fracture. If loading transmitted to the patch exceeds the capacity of the bonding layer, the bonding layer may fracture, resulting in repair failure.

2.7.2(e) Blistering. A fluid can build up on the interfaces between the bonding layer and the substrate/patch due to contamination on the interface and create pressure. When this pressure exceeds the bonding layer adhesion, blistering and then delamination can occur.

2.7.2(f) Creep Rupture. When a permanent load is applied, creep and subsequent creep rupture may cause partial or full separation of the patch from the substrate. This type of failure usually occurs when the service temperature approaches the adhesive’s glass transition temperature, $T_g$.

2.7.2(g) Bonding Layer Property Changes Due to the Service Environments. Temperature and chemical environment changes may reduce the capacity of the bonding layer and lead to premature failure, such as bonding layer/laminate patch swelling, plasticization, or stress.

2.7.2(h) Substrate Corrosion. When the bonding layer is exposed to a corrosive environment, corrosion on the substrate behind the patch repair occurs and can cause premature failure of the bonding layer.

2.7.3 Laminate Patch Failure
If the strain or stress in the patch exceeds a certain critical level, cracks in the laminate patch matrix will start and propagate, which can cause failure of the repair.

3 Repair Design Recommendation

3.1 General
A bonded composite repair consists typically of a patch (composite laminate or steel plate) applied to a metal substrate with an adhesive bond layer, as shown in 1-1/Figure 1. The repair design covers all three components and their interfaces, with the following considerations:

- The reliability of the repair is assessed using design loads (see 1-3/2.3) and the capacity to resist these loads. The capacity may be affected by the environment (see 1-3/2.4).
- The relevant failure mechanisms (see 1-3/2.7) should be considered.
- The safety factors are described in 1-3/3.3 below.
- The characteristic material strength/properties (both characteristic short-term properties and characteristic long-term properties up to the design life) as described in Chapter 1, Section 4 are used for all calculations for composite laminates and adhesives.

Specific recommendations to the Repair Classes A, B and C are given in 1-3/3.2 below.
3.2 Repair Classes

3.2.1 General
There are three (3) repair classes defined by the repair qualification. The repair class is determined based on the structural deterioration criticality, failure mechanism (see 1-3/2.7) and the repair reliability. Class A is recommended for non-class element repairs. Class C is recommended for critical class element repairs for potential bond layer fatigue/creep/cracking debonding failures. For other failure mechanisms, either Class B or C is recommended for class element repairs.

3.2.2 Class A Repairs
Class A repairs are repairs where the integrity and efficiency of the repair are not qualified according to the recommendations provided in these Guidance Notes.

Class A repairs may be accepted for non-class element repairs without having acceptance specifications and having explicit structural analysis of the repair reliability as indicated in 1-3/3.4 below. However, certain design guidelines may be needed for such repairs with the following considerations:

- The repair patch should normally be balanced, and the patch edges should be extended and tapered to reduce potential stress raising.
- The repair extent should normally not be less than 50 times the patch thickness.
- Adhesives used for critical shear load transferring should not exceed the through thickness shear strength of the patch material.

3.2.3 Class B Repairs
Class B repairs are repairs where the qualification is based on small-scale test results or component testing. A larger safety factor and assumption of the debond size/development may be used in the static strength assessment without testing the long-term properties. The static bonding layer capacity and patch capacity should be checked. Initial and long-term efficiency of the repair may be documented.

The same considerations as Class A repairs may be used.

3.2.4 Class C Repairs
Class C repairs are repairs where sufficient documentation is provided to quantify with confidence the reliability of the repair for the intended service life of the structure.

Class C repairs may use the same static strength check as Class B repairs, but a reduced safety factor may be used. The long-term effects of cyclic and permanent loads are specifically considered. The failure modes (see 1-3/2.7) during the design life of the repair and at the end of the design life are estimated.

3.3 Material Safety Factor
The material factor, \( f_s \), is provided as follows:

- For static bond layer capacity checks of Class B repairs, use 1.35 for short term assessment and 1.64 for long term assessment.
- For static bond layer capacity checks of Class C repairs, use 1.35 for short term assessment and 1.00 for long term assessment.
- For static laminate capacity checks, use 1.22 for short term assessment and 1.00 long term assessment. Laminate through thickness fracture safety factor could be 1.5.
- The material fatigue safety factor is normally be taken as 15, which may be reduced if variable amplitude fatigue test results support so.
- For steel plate safety factor, refer to the relevant ABS Rules for the particular structural member to be repaired, loading and environment conditions.
The allowable stress for the laminate, $\sigma$, can be calculated from:

$$\sigma = \frac{\sigma_f}{f_s}$$

where

- $\sigma_f$ = material yielding stress, $0.3\sigma_u$ can be considered as an alternative.
- $\sigma_u$ = material ultimate stress

The material yielding stress and ultimate stress from the nonlinear stress-strain curve is schematically shown in Figure 1.

**FIGURE 1**
Example for Determining Material Allowable from Nonlinear Stress-Strain Curve

3.4 Structural Analysis

3.4.1 General

Bonded composite repairs typically consist of three components: two face plates (patch plate and substrate steel plate), a core/adhesive, the two interfaces between the core/adhesive and two face plates. The following should be considered for structural analysis:

- Corroded steel plate is acting as one of the face plates.
- The patch face plate can be a composite laminate or new steel plate.
- When a laminate face plate is used, laminate can be pre-fabricated or on-site laminated (see 1-5/5).
- A core (bond layer) thickness (see 1-5/4) can be controlled when pre-fabricated laminate or a new steel plate is used.
- When on-site lamination is designed, the primer layer (thin) acts as the adhesive/core layer.
- Some repairs may use two or more layers of different adhesives.

Any other type of bonded patch repair should be considered to be a special composite repair which may need more rigorous analysis and possibly testing.
### 3.4.2 Analysis Types

Analytical and/or numerical calculations may be used in the structural analysis. The finite element analysis (FEA) is commonly used for structural analysis. The decision to use 2-D or 3-D analysis should be made according to the level of significance of the through thickness stresses/through width strains.

The structural analysis should consider the entire lifetime of the structure. Time dependent (degraded) material properties should be used unless it can be shown that there is no degradation over time.

### 3.4.3 Load Conditions

To calculate stresses and strains in the structure, the load and environment conditions (see 1-3/2.3 and 1-3/2.4) and material safety factor (see 1-3/3.3) should be applied with each point in the structure checked against corresponding failure modes.

### 3.4.4 Decision-making on FEA of Composite Repair

Continuing from 1-2/Figure 1 for the decision-making process for bonded composite repair, the decision-making process for FEA of the repair strength checks is provided in 1-3/Figure 2 below for the engineering analysis of the repair strength checks.

Nonlinear FEA for critical areas without the patch repair applied may be needed (see 1-3/Figure 3). This is to replicate the case where the patch becomes delaminated. Progressive collapse should be avoided by controlling the nonlinear elastic and plastic deformations of the structure for the most critical load case (generally the Design Environmental Condition (DEC) cases). The primary structures containing degraded parts should withstand the critical load cases without permanent deformations by any failure mechanism, away from degraded parts. If necessary, local FEA may be developed to demonstrate that the degraded area will not induce progressive failure of adjacent structures.

### 3.4.5 Finite Element Analysis (FEA)

When FEA is used to check local strength for the bonded composite repairs, solid elements for both face plates and bonding layer can be used. The shell element method can also be used, provided that the shell element method will give equivalent result as obtained using 3-D solid elements. 1-3/Figure 4 provides an example of local FEA model with solid elements of a beam repair.

The required global bending moments from the relevant ABS Rules requirement and the loads (see 1-3/2.3) can be applied to a global finite element model. The stress results of the global model are used only to assess the hull girder plating of the deck, side shell, bottom, inner bottom, longitudinal bulkheads, transverse bulkheads and stools or deck box girders. The main supporting members of the hull girder may be evaluated using 2-D fine-mesh local models.

The results of global model analysis are directly employed in the creation and analysis of the required finer mesh, local structural models. Appropriate boundary conditions determined in the global model are imposed onto the local models for appropriate structural continuity and load transfer between the various levels of models. Special considerations may be needed for core shear deformation, local load/corners/joints and radii curved panels.

The local loads may be used in conjunction with the scantling requirements. Detailed local stresses are determined by fine mesh FEA of local structures, based on the results of the global 3-D analysis. 3-1-3/9 of the *ABS Rules for High Speed Naval Craft (HSNC Rules)* can be referred to for guidance on FEA.

3-1-3/11 of the *HSNC Rules* can be referred to when assessing the FEA results for the failure modes of laminate and adhesive materials.
FIGURE 2
Decision-making on Linear FEA of Composite Repair

1. Start
2. Assessment
3. Non-Class Element?
   - Yes
   - No
   - Corrosion?
     - Yes
     - $S_M^gag \geq 0.9 S_{Ma}$?
       - Yes
       - Individual Corrosion > Renewal Criteria?
         - Yes
         - ABS Engineering Approval of Composite Repair?
           - Yes
           - Non-Critical Class Element?
             - Yes
             - FEA and Strength Checks of Composite Repair: equivalent scantling and buckling checks
             - No
             - Do Traditional Repair
           - No
           - Do Composite Repair
         - No
         - Crack
       - No
     - Yes
     - Do Traditional Repair
   - No
   - Do Composite Repair
FIGURE 3
Nonlinear FEA for Decision-making of Composite Repair

- FEA for Degraded Condition Before Repair
  - Degraded Condition Complies with FPI 5A-1-3/3.9
    - Yes: Composite Repair is allowed
      - Strength and Buckling Analysis for Repaired Structure including NDCV
        - No: Redesign Composite Repair
        - Yes: Recover to Design Condition for RFL?
          - Yes: Do Composite Repair
          - No: Non-linear Analysis for Check of Elastic-plastic Behavior
            - Yes: Define Critical Load Cases & Pieces with Elastic-Plastic Behavior
              - Yes: Possibility of Progressive Collapse or Permanent Deformation without Composite Repair?
                - Yes: Do Traditional Repair or Temporary Composite Repair before Traditional Repair
                - No: Do Composite Repair
            - No: Below Tensile Strength?
              - Yes: Non-linear Analysis for Check of Elastic-plastic Behavior
                - Yes: Define Critical Load Cases & Pieces with Elastic-Plastic Behavior
                  - Yes: Possibility of Progressive Collapse or Permanent Deformation without Composite Repair?
                    - Yes: Do Traditional Repair or Temporary Composite Repair before Traditional Repair
                    - No: Do Composite Repair
              - No: Recover to Design Condition for RFL?
                - Yes: Do Composite Repair
                - No: Redesign Composite Repair

FIGURE 4
Example of FEA Mesh for a Beam with Bonded Patch Repair

(a) FEA mesh of a beam with a bonded patch (red)
(b) Cross-sectional view of the repaired section in 1-3/Figure 4(a). Adhesive layer is marked with a red box.
3.4.6 Material Properties

Chapter 1, Section 4 can be referred to for general information on material test and qualification. Material properties of the composite material should be considered for the maximum temperature observed. In case this data is not available the service temperature can be taken.

The adhesive bonding layer (see 1-4/4) is considered as isotropic and can be described by two elastic constants. The most critical parameters may be needed for FEA, such as shear modulus, critical shear stress, and fracture toughness under the service environment specified. For fatigue and fracture modelling, fatigue debonding rate and stress rupture performance (with consideration of the effect of environmental degradation) may be additionally needed in the design basis.

For laminate (see 1-4/5), if used, the mechanical properties used for FEA should be represented with the suitable set of elastic constants tested.

Steel plate properties can use typical values provided or values tested (see 1-4/3).

3.5 Strength Check

3.5.1 General

When recomposing steel structures, the plating thickness and local section modulus of stiffeners should be recomposed to original design values from the relevant ABS Rules. In other words, the recomposed thickness and section modulus should be greater than the design values.

Since the composite material deflects at a different rate than that of the steel, an effectiveness factor applies to the composite materials in order to consider the hot spot areas in the boundaries, which are dependent on the length of the repair.

Therefore, the repaired equivalent thickness and/or section modulus should account for the effectiveness factor. This factor can be obtained either by laboratory tests, or by simplified FEA. In any case, axial compression and tension, bending and shear stress distributions should be verified.

When calculating the hull girder section modulus, the degraded parts and its shadow areas are deducted, similar to 3-2-1/Figure 6 of the Marine Vessel Rules.

3.5.2 Laminate Patch Sandwich Repairs

The shell, deck or bulkhead laminate sandwich repair may be bi-directional (having essentially same strength and elastic properties in the two in-plane principal axes of the shell, deck or bulkhead) or unidirectional (having different strength or elastic properties in the two principal axes of the shell, deck or bulkhead panels). Where the strength and stiffness in the two principal axes of the panel are different, panel bending in each of the panel principal axes should be considered.

For shell plates, calculations of the section modulus, moment of inertia, shear strength, minimum laminate/steel face plate thickness and laminate/steel face plate stability may be needed for bonded patch plating repair strength. Reference can be made to 3-2-3/5.7 of the HSNC Rules. Special consideration of inner steel skin and outer laminate skin of the bonded patch repair may be needed when doing such calculations.

For internal bonded patch repairs, the strength calculations are considered. Reference can be made to 3-2-4/3 of the HSNC Rules. Special consideration of inner steel skin and outer laminate skin of the bonded patch repair may be needed when doing such calculations.

3.5.3 Steel Patch Sandwich Repair

Steel patch sandwich repair can be analyzed in a similar way as described in 1-3/3.5.2 above. However, an analytic analysis as provided in Chapter 1, Appendix 1 can be referred to as a guideline on steel sandwich plate with a continuous elastomer core. Calculations are provided for recommended minimum repair extent and minimum faceplate and core thicknesses. The sandwich plate repair extent, also called development length, is the minimum length of new faceplate needed to extend beyond the corroded area to be repaired. The minimum length is necessary to transfer shear strength through the elastomer core layer from the existing plate to the top faceplate so as to use the full compressive or tensile capacity of the steel faceplate. See 1-A1/Figure 2.
Chapter 1, Appendix 1 also provides calculations of the recommended section modulus of the steel sandwich plate after repair. The typical stiffeners with attached plates are shown in 1-A1/Figure 3 with the reference point at the flange.

4 Design Report

A design report covers the design basis and all relevant information for the design input, analysis, fabrication and qualification of the bonded composite repair.

The design report should contain the following as a minimum:

i) Description and drawing of the corroded area and the relevant part of the structure to be repaired

ii) Description and drawing of the entire repair and the parts to be used for the repair

iii) Identification, trade name, datasheets (technical datasheets and materials safety datasheets), and certifications of all raw materials used for the repair, with a bill of materials prepared by the designer and made available to the repair installer

iv) Design assumptions used in the design basis, including design life, loading conditions and other environmental conditions, and other relevant conditions including applicable limitations

v) Design analysis including evaluation of corroded areas and their criticality, accepted calculations and other documents for compliance with governing technical requirements, and all the material properties used as a basis for the design should be documented with references

vi) Installation and fabrication procedures/specification, including acceptable surface preparation, temperature and humidity, acceptable qualification level of the installer and the inspector, references to specifications, and drawings

vii) Description and evaluation of the identified failure modes and mechanisms

viii) Inspection procedure and inspection schedule for verifying effectiveness after installation

ix) Reference to documentation for repair and modification

x) Documentation of qualification testing, including at least the following information:

a) Purpose of the testing

b) Detailed test description including test set-up, loads, and measured parameters

c) Expected test results

d) Evaluation of the test results

e) Requirements for the choice of material properties

f) Installation/application procedure, including surface preparation, temperature, humidity and cure conditions
CHAPTER 1 Composite Repairs of Steel Structures

SECTION 4 Materials and Qualification

1 General

This Section describes the material properties needed for design and strength analysis. All properties should be obtained directly by measurements or traced back to measurements. Materials or components used for the bonded composite repair of the structures should be certified by ABS.

Repair strength and performance are determined by the components used for the bonded composite repair. These components include bonding material (adhesive, core material), laminate or metal patch, patch/adhesive interface and metal/adhesive interface, which should be clearly specified. All materials should be traceable.

The properties of the adhesive and the patch materials should be tested with consideration of the adhesion between the treated substrate surface and the adhesive/core elastomer for the bonded repairs.

There are three types of relevant material properties:

i) Static properties

ii) Properties under constant permanent static loads or deformations

iii) Properties under cyclic loads or deformations, which are affected by the environmental conditions the material is used in

Static properties could have strength in tension, compression, shear, torsion, flexure, stiffness, toughness, elasticity, plasticity, ductility, and hardness.

Permanent static loads or deformations may lead to creep, stress rupture, and static strength reduction over time.

Cyclic loads or deformations may lead to elastic property reduction, fatigue failure, and static strength reduction over time.

2 Qualification Testing

The tests should include:

- Screening tests recommended for material selection and repair process improvement
- Material characterization tests to obtain the input data required for calculations
- Component testing for direct experimental assessment of the repair

Data from other reputable sources can be used as guidance but is not sufficient for the qualification of a bonded composite repair.
The testing includes the following conditions:

i) The testing condition should be representative of the service environment as specified in Chapter 1, Section 3.

ii) The test specimen should be prepared using the same process as the actual bonded repair.

iii) The patch used in the test specimen should be representative of that specified for the actual repair.

iv) The original steel surface condition (before the surface treatment) should be similar to the surface to be repaired.

v) The surface treatment should be identical to the one used in the application in the field.

vi) The laminate should be produced in the same way as in the actual application.

vii) The raw materials should be identical to those used in the actual application.

viii) The lay-up should be representative of the actual repair.

ix) The adhesive/core elastomer should be the same as in the actual application and should be applied in the same way.

x) The curing schedule of laminate and adhesive/core elastomer should be the same as in the actual application.

The material testing program should also account for the statistical variability in actual composite material properties, both as manufactured and at the end of service life. The determination of the statistical variability of the material properties is detailed in MIL-HDBK-17-1F, in which the term “B-Basis” is defined. The test program should be defined to develop B-Basis values, which are the values at which 90 percent of the population of the data is expected to fall, with a 95 percent confidence.

The minimum requirement for the material test program as indicated 1-4/Figure 1 should be completed for each material, such as adhesive/core resin and laminate, as well as each temperature/other environment conditions. The test requires three (3) batches with two panels each, and within each panel three (3) coupon specimens should be used for developing a B-Basis value.

If “B-Basis” properties could not be used to determine the ultimate strength of the material in 1-3/3.3, an additional 15% reduction to the ultimate strength from a small sample size testing should be used.

Before testing a laminate, the sample should be fully cured or post-cured at a specified temperature for a given period of time. For other reinforcement and resin combinations, the time and temperature for accelerated aging should be determined.
3 Steel Structure and Steel Plate Patch

The steel grade used in the bonded patch repair should comply with the relevant ABS Rules. The information about substrate materials and material properties needed for the design of a bonded repair is defined as follows for most repair designs:

- Yield strength
- Ultimate strength
- Elongation
- Young’s modulus and shear modulus

For complicated or highly specialized designs, some additional information may be necessary. This should be evaluated on a case-by-case basis.

Metallic parts of the bonded patch repair should be effectively grounded to the hull to prevent possible electric shock. Electrical continuity of the metallic structure should be provided.

4 Adhesives or Core Elastomer

The adhesive material, such as elastomer, epoxy, or polyester, is used to bond the patch to the substrate steel corroded surface. Composite patches can be directly laminated to the metal substrate. In this case, the first layer of resin functions as the bonding layer.

Additional information can be found from 2-6-1/5 of the ABS Rules for Materials and Welding (Part 2) for Core Materials and 2-6-1/9 of the ABS Rules for Materials and Welding (Part 2) for Adhesives.

4.1 Bonding Strength

There are several factors affecting bonding strength:

- Adhesive strength and fracture toughness achieved after the adhesive or core elastomer is cured, determined by qualification and long-term property testing including time-dependent fracture
- Installation condition (steel temperatures, relative humidity of the air, load condition during installation)
- Surface roughness and cleanliness (dust, rust, oil/grease, soluble salts, and moisture) achieved before the adhesive or core elastomer is applied
- Void content or air pockets in the bonding layer

These factors are considered in the design and controlled through the installation process. All properties relevant for the analysis should be confirmed by experimental data. Characteristic values from testing should be used for all properties.

4.2 Adhesive Properties

Adhesives used for structural repairs should be in accordance with the manufacturer’s recommendations. The details of all adhesives, including the handling, mixing, and application of adhesives, should be specified on the Material Data Sheet and on the repair plans.

To characterize the adhesive properties, the following information should be provided:

- Constituent adhesive material(s)
- Generic adhesive type (e.g., epoxy, polyester, polyurethane)
- Specific adhesive type (trade name and batch number)
- Catalyst (trade name and batch number)
- Accelerator (trade name and batch number)
- Fillers (trade name and batch number)
Adhesive properties should be obtained from test results of adhesives that represent the adhesive used in the bonded patch repair as closely as possible. The number of testing parameters needed depends on the theoretical models used and safety factors applied. Generally, the most critical parameters may be needed for finite element analysis, such as shear modulus, critical shear stress, and fracture toughness under the service environment specified. For fatigue and fracture modelling, fatigue debonding rate and stress rupture performance (with consideration of the effect of environmental degradation) may be additionally needed in the design basis.

5 Laminate

5.1 General

The laminate composite materials used as the bonded patch contain resin and fiber. The exact ratio and combination of materials depends on the necessary stiffness and strength of the finished repair and on the intended service environment. The laminate is either pre-fabricated or manually laid out onsite.

A composite laminate is made of many constituent materials produced and arranged in a specific way. The laminates should be clearly specified, including a sequence of layers and their stacking sequence, and all materials used in the laminate should be traceable. The basic material properties used for laminate patch repairs are orthotropic ply properties.

Through-thickness properties can be critical for composites but are often not readily available. Through-thickness shear properties of laminates may be obtained by testing.

It is only necessary to obtain properties that are used in the design calculations and failure assessment. A structure may be loaded in such a way that some material properties are not relevant. In that case, the non-relevant properties do not have to be known. Under certain conditions, typical values from existing databases can be used.

Additional information can be found from 2-6-1/7 of the ABS Rules for Materials and Welding (Part 2) for laminates.

5.2 Resins

Resins are typically thermosetting polymer materials either identical to, or readily compatible with, the adhesives used to form the bond between the substrate and the patch laminate.

The resin may also be thermoplastic. Thermoplastic resin materials may offer better resistance to some environmental exposure but may also be more problematic to bond to the steel substrate. Some thermoplastics may need specialized surface preparation in order to obtain proper adhesion to the substrate.

Thermosetting resin materials, such as polyesters, vinyl esters, epoxies and urethanes usually offer desired bonding properties as well as good chemical compatibility.

5.3 Fiber

For most bonded patch repairs designed to perform as a structural part of the hull structure, the needed strength and stiffness necessitate the use of carbon fibers or glass fibers or equivalent.

Patches using carbon fibers are conductive. Carbon fibers are cathodic compared to steel and can cause galvanic corrosion if they come in contact with the steel. They should be separated from the steel substrate. This can be achieved by a layer of resin/adhesive bond for prefabricated patches, or the use of one or more glass fiber layers of as insulating layers for patches laminated directly onto the substrate.
5.4 Relevant Material Properties

Material properties and typical data for composite laminates are obtained by testing or by using the material database provided. The laminate properties can be obtained from test results of laminates that represent the laminate used in the bonded patch repair as closely as possible. Characteristic material values should be used for all properties.

To characterize the properties of the laminate, the following information should be provided:

i) Generic fiber type
ii) Type of weave
iii) Generic resin type (e.g., epoxy, polyester, polyurethane)
iv) Specific resin type (trade name)
v) Material storage condition: temperature, water content of the laminate (wet, dry)
vi) Process: method, temperature, pressure and vacuum, post curing (temperature and time)
vii) Control of fiber orientation, layer sequence and volume fraction
viii) Void content

6 Components

6.1 General

The component may be tested for qualification of bonded repairs based on experimental models of the entire repaired component instead of testing individual material properties. A detailed plan of the experimental program should be provided before conducting the test.

This approach is not able to separate individual parameters from the component test results.

The test piece should be produced in the same size, by the same technology, and by the same qualified applicator. The validity may be extended to other geometries if the patch configuration can be scaled.

The conditions used for the testing may be different from those for the real repair in service. The test data under such different conditions should be evaluated based on appropriate theoretical knowledge, experience in testing, and sound engineering judgement.

6.2 Design Qualification

6.2.1 Design Qualification Based on Component Testing Only

A sufficiently large number of tests should be carried out to define the characteristic strength of the bonded patch repair with a confidence level for the data used with the analytical approach.

6.2.2 Design Qualification Based on Both Analytical and Experimental Models

The theoretical model predictions with conservative assumptions may be combined with experimental model predictions for design qualification.

6.2.3 Testing Crack Growth in Steel

When a bonded patch is used for crack repairs, the most severe load direction for crack growth in the metal should be tested. If multiple load directions are critical, more testing may be necessary when using testing in one load direction is not confident.

One test to failure should be performed to obtain the static strength and failure mechanism. The experimentally observed failure mechanism should be the same as the one predicted in calculations.
7 Properties under Fire

7.1 General
Most composites are flammable and temperature sensitive. The fire performance of the complete composite structure system with fire protection should be evaluated. The relevance of a fire code to composite materials should be checked.

If a laminate (FRP) patch is used for the composite repair, the fire safety requirements should be in accordance with 3-4-1/9 of the Marine Vessel Rules, which permits FRP materials to be used in other machinery spaces, cargo areas, and on-deck areas. FRP materials are not accepted in accommodation, service, control spaces, and areas where smoke and toxicity are a concern.

However, if a steel patch is used for the composite repair, such restriction may not be valid if all adhesive materials used for bonding are sealed by the steel faceplates.

7.2 Fire Reaction
The reaction of a composite to fire is described in terms of flammability, flame spread, smoke development, and emission of toxic gases. Special additives or fillers are often added to composites to improve fire reaction. The influence of such additives or fillers on the basic mechanical properties should be evaluated.

7.3 Fire Resistance
The remaining strength of a composite structure under a fire is described by fire resistance. The temperature-dependent properties can be used.

Chemical reactions, temperature distribution, through thickness properties, and delamination due to fire should be considered for the remaining strength.

7.4 Insulation
The insulation properties with the fire reaction and fire resistance of the composites should be evaluated.

7.5 Properties after Fire
The material properties after the fire should be evaluated.

8 ABS Certification
Materials and components which meet the guidelines in this Section can be certified by ABS with ABS Product Design Assessment certificate or Product Type Approval certificate.

Properties of materials and components should be tested by a nationally or internationally accredited test laboratory in accordance with recognized industry standards. Component testing should be witnessed by the ABS Surveyor.
CHAPTER 1 Composite Repairs of Steel Structures

SECTION 5 Repair Installation and Quality Assurance

1 General

This Section provides general recommendations on the installation/fabrication specification and procedures for bonded composite repair. The detailed repair specification and procedures should be provided for the process of the bonded composite repair installation and inspection. This is important to achieve the desired repair quality.

A QA/QC system should be in place and cover each step signed off by qualified and responsible personnel. The entire repair installation process is a manual process and thus the quality of the bonded repair is directly dependent on the skill and experience of the personnel carrying out the repair. The repair procedure should be provided so that the personnel carrying out the repair design, installation, or inspection are qualified for the job and are competent with the repair technology. See 1-1/2.

The installation/fabrication specification and procedures and the QA/QC manual should be reviewed by ABS Engineering and also be available for the attending ABS Surveyor. The attending ABS Surveyor should verify and monitor that the bonded repair has been inspected and installed in accordance with the installation/fabrication specification and procedures.

2 Repair Specification

The repair specification should include the following as a minimum, which should be agreed upon between the repair parties and should be submitted for ABS review.

i) Materials to be used for the repair, such as steel patch or laminate patch and adhesive components, together with the materials datasheets with information on storage and material handling

ii) Materials certification such as ABS Product Design Assessment/ABS Type Approval

iii) The certification and qualification for the repair installer and inspector

iv) The repair design with a drawing showing the location and structure details (plate thickness, adhesive lay thickness) and including surrounding structures

v) Specification and procedures for the surface preparation and adhesive application, including surface cleanliness, roughness, substrate temperatures, humidity, and curing/post-curing conditions

vi) Inspection procedures and reporting, including nondestructive testing of the repair

vii) Procedures for in-service maintenance and inspection

3 Surface Preparation

Surface preparation should be done appropriately to achieve a satisfactory bond to the substrate. For details on surface preparation techniques and standards, refer to Section 4 of the ABS Guidance Notes on the Application and Inspection of Marine Coating Systems.

The quality of surface cleanliness to be achieved is very different for new steel plates and corroded steel plates. Any substance which prevents adherence to the steel surface is considered a contaminant. Major contaminants at the in-service repair stage include:
• Moisture, water, ice
• Oil, grease
• Soluble salts
• Rusts, mill scale
• Old, loose coating
• Dust/dirt, abrasive

The presence of pitting, corrosion products, cathodic protection products, aged coatings and trapped cargoes should be considered, particularly for localized surface preparation of the most severely affected areas. This is particularly important for outer hull, water ballast tank, and cargo tank repairs.

Generally, in order to meet the necessary surface cleanliness for bonded composite repairs, the correct sequence should be followed depending on cleaning technology used.

Surface cleaning methods include dry abrasive blasting, power tools, water blasting with or without abrasive. When dry blasting and/or grinding are used, the steel surface should be dry with no visible oil, grease, and salts, which should be removed in accordance with SSPC-SP 1, before blasting and/or grinding.

When water blasting or slurry blasting is used, any visible oil and grease should be removed in accordance with SSPC-SP 1 prior to water blasting or slurry blasting. Due to high humidity from wet cleaning methods, light rusting may occur immediately after the steel surface is cleaned. The speed with which the rusting occurs depends on the purity of the water, the amount of oxygen dissolved in the water, the amount of ionic species left on the surface, the temperature, and the drying time. If a degree of surface cleanliness is specified (e.g., Sa 2½) the steel surface should meet the specification before repair application. If rust is visible before application, the surface should be re-cleaned to meet cleaning requirements. Dry air blowing, dehumidification, or other technique may be needed to prevent rust before the bonded patch is applied.

Priming of the cleaned surface may be done to avoid the formation of rust blooms, to reduce the sensitivity to contamination of the surface, and to enhance the bond strength between the steel substrate and the patch. The bond strength of the primed surface should be demonstrated by testing.

Surface cleanliness and roughness is key for the adhesion. The repair specification should include level of surface cleanliness and surface roughness to achieve the necessary bonding strength, which should be demonstrated by testing.

For surfaces to be bonded, surfaces should be treated to the following surface conditions to achieve a good adhesion, unless other conditions are specified and tested:

i) Cleanliness of the surface should be to Sa 2½ according to ISO 8501-1 for blast cleaning or equivalent for the use of other surface cleaning procedures.

ii) Dust, blast abrasives and other loose particles should be removed from the surface.

iii) Oil or grease should be removed from the surface.

iv) Steel temperature and air humidity should be monitored for possible condensation on the steel surface during blasting and fabrication/installation. Normally, as a minimum, steel temperature should be at least 3°C (5.4°F) higher than the air dew point. Relative humidity should not be greater than 80%.

v) If no other evidence is provided, a soluble salt concentration of no more than 50 mg/m² is recommended.

vi) The surface profile of the surface should be in the range 75 to 115 µm (3 to 4.5 mils) according to ISO 8503.

The surface condition requirement can be applicable to the top steel plate surface and the existing steel plate surface. The top steel plate may be prefabricated with a layer of core material applied.

The corroded steel surfaces to be repaired should be treated onboard. Surface cleanliness before repair installation should be carefully verified in accordance with the agreed-upon specification.
4 Adhesive Bonding

4.1 General
Guidance on controlling the bonding formation between the substrate and the patch is provided for both the pre-formed patch method and the site lamination process.

Bonding of patches onto a substrate requires control of a number of key process parameters in order to obtain sufficient bond quality. The most important process parameters are:

- Surface preparation of substrate and patch (see 1-5/3 above)
- Material handling and preparation
- Control of bonding thickness
- Control of patch pressure
- Control of alignment
- Control of adhesive cure temperature and time

4.2 Control of Bonding Thickness
The bonding thickness may influence the strength, particularly the peel strength, of the interface and should be controlled within the limits specified. Correct bonding thickness should be maintained by fixtures or spacers until the adhesive has cured sufficiently to prevent movement of the patch.

If spacers are used for control of bonding thickness and remain embedded in the bond after cure, their effect as local delamination or crack initiators should be accounted for in the design of the bonded repair.

The adhesive and patch should be applied in a way that prevents the formation of air pockets.

For on-site lamination directly onto a substrate, control of bonding thickness is usually not necessary.

4.3 Control of Patch Pressure
During curing, the pressure applied between the patch and the substrate metal surface should be controlled so as not to influence the bonding thickness. A specific pressure should be maintained and controlled in accordance with the procedure specified.

4.4 Control of Alignment
The laminate patch should be installed with the correct fiber orientation relative to the substrate geometry as specified. The patch should be aligned carefully to the substrate. An acceptable alignment tolerance should be specified in the installation procedure.

4.5 Control of Cure Temperature and Cure Time
The cure temperature and cure time of the adhesive should be controlled to obtain sufficient bonding strength in accordance with the technical datasheets of the adhesive, which should be specified in the fabrication procedure.

Barcol hardness tests can be performed on all cured polymeric materials. The hardness test values should fall within the specified values and the values obtained in the qualification testing.

4.6 Pull-off Strength of the Repair
As a means to control the quality of surface treatment and bonding, pull-tabs may be installed at the same time as the repair using the same materials and procedures. After cure, the pull-tabs can be pulled off from the substrate, and the pull-off strength is then used to compare with the specified values.
5 Patch Fabrication

5.1 General

The patches considered in these Guidance Notes are mainly made from fiber-reinforced plastics (FRP), where the resin material may be either thermosetting or thermoplastic. The fabrication of an FRP patch should be built with a consistent quality.

The two main patch fabrication methods are:

i) Pre-fabricated patch (plate or strip), to be bonded onto the corroded substrate surface.

ii) On-site lamination of patch, which is directly applied layer-by-layer onto the corroded substrate surface.

Additional information can be found in Section 2-6-2 of the ABS Rules for Materials and Welding (Part 2) for fabrication.

5.2 Pre-fabricated Patch

Pre-fabricated patches are generally produced in a shop, allowing good quality control. It is important that the pre-fabricated patch matches the substrate geometry, so that no pre-stress is created in the patch.

Many lay-up and fabrication methods are available. The selection of a method is mainly based on patch geometry, production quality, available facilities and tools, the available time, and experience/skill.

5.2.1 Lay-up on Mold

This method uses a mold for wet lay-up. This could be either hand lay-up/wet lay-up onto the mold or prepreg lay-up in/onto the mold. The patch cures in the mold or under vacuum.

Hand lay-up should have the least amount of preparation and the fewest tools but a comparatively skilled operator is necessary to achieve good quality during the impregnation and lay-up process. The operator manually impregnates fiber reinforcement layers and places these onto the mold.

Prepreg lay-up uses pre-impregnated fabric reinforcement with a resin system. The prepreg is ready to lay into a mold without the addition of resin.

Using pre-impregnated reinforcement layers in the lay-up process eliminates the need to handle resins and fiber laying during the fabrication process. It provides better control over the impregnation process and the fiber-resin ratio in the finished laminate and thus a more uniform laminate quality.

5.2.2 Resin Infusion Techniques

Among the most common resin infusion techniques available are RTM (Resin Transfer Molding) in closed molds and RIFT (Resin Infusion under Flexible Tools). Both need precise control of resin amounts and resin flow for uniform wet-out of fibers with careful consideration of resin flow patterns and de-molding after cure. Those methods can provide excellent quality and finish.

5.2.3 Extrusion or Pultrusion

Extrusion or pultrusion techniques can be used to produce flat or curved plates, bars, or strips in any length. This production method can produce large numbers of identical elements with very consistent quality and dimensional accuracy.

5.3 On-site Lamination

For on-site lamination of patches onto substrate surfaces, similar but more careful control of parameters to obtain both sufficient bonding strength and sufficient patch laminate strength may be needed.

The most important process parameters are:

i) Surface Preparation of Substrate. The substrate should be cleaned and prepared to the necessary cleanliness and roughness to allow proper adhesion. Surface preparation is described in 1-5/3.

ii) Handling and Preparation of Constituent Materials. All precursor materials should be stored and handled appropriately according to manufacturer’s instructions and/or technical datasheets.
iii) **Control of Lay-up.** The lay-up sequence, orientation and length of fiber reinforcement layers should be done according to specifications by the designer for correct performance of the patch.

iv) **Control of Wet-out.** When using hand wet lay-up processes, appropriate wet-out may be needed for each applied reinforcement layer.

v) **Control of Cure Temperature and Cure Time.** The correct temperature and time for curing the laminate should be followed in accordance with the resin’s technical datasheets to achieve appropriate bonding strength.

vi) **Certification of Personnel.** Personnel conducting the repair should be qualified in accordance with a recognized standard. See 1-1/2.

6 **Handling and Preparation of Materials**

Correct handling and preparation of materials may be needed in order to obtain the expected quality and mechanical properties of the bonded repair. Specific handling and fabrication instructions may be given by the material supplier. In general, following instructions should be included:

i) Mixing ratio of a two-component resin

ii) Lamination process, which should be completed within the available pot-life of the resin.

iii) Resin component’s storage conditions, such as temperature, relative humidity, and maximum shelf-life

iv) The moisture content of fibers used should be within the allowable range specified by the material supplier and verified by testing. Dry fiber materials should be protected from contamination during storage and transport. Unacceptable contamination includes dust or debris containing abrasive particles (sand, metal particles etc.), and salts.

v) Pre-impregnated fiber mats or tape should be stored and protected from contamination in similar fashion to dry fiber materials.

vi) Specified storage temperature and maximum shelf-life for pre-impregnated fiber mats should be observed to avoid premature onset of the cure process.

Additional information on material handling can be found in the 2-6-3/5 of the ABS Rules for Materials and Welding (Part 2) for specifications and data sheets for materials, 2-6-3/7 of the ABS Rules for Materials and Welding (Part 2) for receiving materials, and 2-6-4/21 of the ABS Rules for Materials and Welding (Part 2) for material receipt, inspection and storage.

7 **Repair Documentation (Technical File)**

The repair installation report, prepared by the repair contractor/installer, should document that the bonded repair was installed in accordance with the design specification and the installation procedures.

The laminate patch manufacturer should document compliance with QA and QC procedures including technical documentation, SHE-related training and competence of application personnel/laminators. Identification of the quality Inspector (QI), final responsible for the repair, as well as his/her certificate should be included.

All materials and consumables listed in the bill of materials should be traceable and material certificates should be available to document the material properties.

8 **Installation Inspection**

The installation procedure should cover surface preparation, environmental conditions, curing conditions, and testing after installation with associated allowable limits for installations/lamination. Inspection and documentation should be carried out by a qualified and certified inspector. A QA/QC system is in place and covers each step documented and signed off by qualified and responsible personnel.
ABS attending surveyor should:

- Verify installer’s qualification and certification for the repair technology
- Verify inspector’s qualification and certification for the repair technology
- Verify repair material storage condition and materials certification
- Monitor surface preparation for meeting cleanliness and roughness requirements before installation
- Monitor during lamination or patch installation process, and curing condition
- Verify NDT inspection after installation (see 1-6/2)
- Verify inspection documentation.
CHAPTER 1 Composite Repairs of Steel Structures

SECTION 6 Inspection, Monitoring and Survey

1 General

ABS survey includes the material/component certification survey, the repair installation survey, and the in-service survey.

ABS survey in certification of materials and components is a part of the ABS Type Approval program and verifies that the material/component is tested by a nationally or internationally accredited test laboratory in accordance with recognized industry standards, as recommended in Chapter 1, Section 4. Component testing should be witnessed by the ABS Surveyor.

The repair installation survey verifies and monitors that the repair installation and inspection are carried out in accordance with the approved installation/fabrication specification and procedures for bonded composite repair and a QA/QC system is in place and covers each step documented and signed off by qualified and responsible personnel, as recommended in Chapter 1, Section 5. The repair installation and inspection should be carried out by qualified and trained personnel.

The in-service survey should be included in the Class survey plan. An in-service inspection strategy and procedure, which may include a remote monitoring/inspection system and guidance on defect investigation and control, should be prepared for the bonded repair. The inspection strategy and inspection interval should be reported to ABS or other relevant authorities and entered into the offshore unit’s survey plans. The survey plan should have the location and extent of the composite repair available during subsequent surveys. This will be particularly important for the underwater aspects, so that the repaired areas can be identified and examined in the future. As an alternative, appropriate means for thickness measurement of the repaired steel from inside the hull may be provided. If substantial corrosion or failure associated with the composite repair occurs, additional actions may be needed to confirm the area is suitable for continuous service.

The failure mechanisms noted in 1-3/2.7 should be identified and listed in the inspection plan. The plan includes the inspection method to be used to detect the various failure mechanisms.

2 Nondestructive Inspection and Monitoring

2.1 Visual Inspection

Any defects hidden behind the patch installed may need special NDI methods to detect. Tapping can be used to detect delamination/debonding effectively. Strain monitoring in the bonding layer may also be used to check the integrity of the patch repairs.

From Chapter 1, Section 3, the failure modes and mechanisms of the repair should be identified during the repair design. The adhesive bonding layer between the substrate and the repair patch is a potential failure location. The efficiency of the repair will be compromised if severe debonding occurs. Delamination of the laminate patch is another failure mechanism that reduces the efficiency of the bonded patch repair.

Complete separation of the patch from the substrate can be easily detected by visual inspection during in-service inspection. Delamination within the patch or separation from the adhesive bond layer occurring around the perimeter of the patch can also be easily detected by visual inspection.
2.2 Steel Substrate

Structural deterioration should be described in terms of its sizes and development over time, which depends on the deterioration type and location in the structure.

Examples of structural deterioration are fatigue cracks and corrosion. Fatigue cracks (1-2/5) are characterized by crack length, and corrosion (1-2/4) may be characterized by corroded area, corrosion depth, and remaining thickness.

Several nondestructive inspection (NDI) methods exist for metal inspections, such as ultrasonic thickness gauging, thermography, and x-ray. Detection and monitoring of the crack beneath the patch can be a challenge. Advanced NDI technologies such as acoustic emission testing may be used to detect crack propagation in service.

If the metal defect is completely covered on one side by the composite patch, NDI may approach from the other side of the steel, or a special NDI plan can be developed for detection of defect through the laminate patch and adhesives.

The ABS Guide on Nondestructive Inspection of Hull Welds can be referred to for NDI methods as well as NDI operator qualifications.

2.3 Bond Layer

Detecting and monitoring bond layer cracking/defect hidden behind the repair may be difficult. At present, no reliable methods for detection and monitoring of initial cracking/defect in the bond layer have been identified.

2.4 Laminate

Delamination in the laminates is an important failure mechanism that reduces stress transfer from the metal substrate into the laminate. NDI may be used to detect this type of failure. Possible appropriate NDI methods are ultrasound, thermography, tap testing and x-ray.

3 Inspection Time

The time between inspections should be related to estimated defect growth rates. As mentioned in Chapter 1, Section 3, the repair should be applied before the defect has grown to an unacceptable size/level. The time between inspections should be less than the time in which the defect can grow to a critical size in case of a repair failure, even if the patch fails immediately after installation.

The defect growth rate and time remaining to reach a critical size/level, including from the opposite side of the repaired area, should be established for the substrate in all repair cases. This information should be available in the design documentation and inspection manual. This may be based on experience from details under similar loading conditions, direct calculations or a combination of these. Finite Element Analyses (FEA) may be used to determine stress distributions and stress concentrations.

The inspection of the installed repair should be considered in the Class surveys and included in the unit’s In-service Inspection Plan (ISIP).

If the original defect is prone to further development after the repair, the repair design should allow for inspection of the defect. If the defect is a fatigue crack, the repair may be designed so that the crack tip is visible, and any further crack development can be detected by visual inspection.
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APPENDIX 1 Sandwich Plate with a Continuous Elastomer Core

1 General
A sandwich plate consists of two plates (steel, aluminum, or other) bonded with an elastomer core. The elastomer core provides continuous support to the plates, prevents local plate buckling, and transfers shear load between the plates so that the plates may achieve full capacity in tension, compression, and bending. The stiffness and strength of the sandwich plate structure is tailored to meet static and dynamic structural requirements by selecting appropriate thicknesses for the sandwich plate.

The sandwich plate utilizes the existing plating of the structure as one of the sandwich plate faceplates to restore or enhance strength of the existing plate. The enhancement includes improvements in fire resistance, impact resistance, vibration/sound characteristics and thermal insulation without cropping of the existing plate.

2 Scope
The sandwich plate can be installed with or without hot work. With consideration of heat input during the sandwich plate installation, the installation method can be one of the following:

- Hot-work by using welding
- Low-heat input solution by using non-direct welding, adhesives and/or stud welded perimeter bars. Low-heat input can be considered in locations where welding may have detrimental effects on coatings on the other side of the plate.
- Solution without hot-work by using adhesives

Appropriate analyses and tests are necessary to demonstrate that the structure repaired and/or modified by the sandwich plate meets the design specification and follows relevant ABS Rules, IMO and flag State regulations.

This Appendix provides recommendations on ABS engineering review procedure and survey verification procedure for the sandwich plate repair.

3 Sandwich Plate Design

3.1 Documents for Review
The sandwich plate design should be submitted for ABS review prior to commencing the repair, reinstatement, reinforcement or enhancement of existing offshore units.

As a minimum, the following information should be submitted for ABS review.

i) Inspection report of the corrosion or fatigue cracking to be repaired or documentation detailing the condition of the area endorsed by the ABS Surveyor (see Chapter 1, Section 2).

ii) An assessment of the condition of the existing structure with details of the as-built scantlings and the current condition (see Chapter 1, Section 2).
iii) The sandwich plate repair design with a drawing showing the location and structure details, including surrounding structures. Engineering analyses and calculation reports which demonstrate that the sandwich plate repair is satisfactory in strength restoration or enhancement in accordance with the ABS Rules (see 1-A1/3.3 through 1-A1/3.5).

iv) Assessment of the local strength and global hull girder strength of the affected structure, both before and after the application of the sandwich plate, may be needed.

v) Specification and procedures of the sandwich plate repair, including the data sheets of materials used, ABS certification for materials and components used, as well as certifications and qualifications of installers and inspectors (see also 1-A1/4.3).

3.2 Repair Design

3.2.1 General

The application of the sandwich plate should meet the intent of the repair for necessary functionalities, scantlings, and strength (local and/or global) with consideration of compliance with relevant ABS Rules and/or IMO regulations. Taking into account the current condition of the existing structures, the extent and location of the application area should be determined. The strength of the affected structure, before and after the sandwich plate application, may be assessed.

The condition of the existing structure should be assessed to determine repair criticality, repair areas and their extents. See Chapter 1, Section 2.

The sandwich plate repair is allowed when general corrosion of the existing steel plate is greater than the allowable corrosion margin from the relevant ABS Rules, provided that the combined effective thickness of the top and bottom plating of the steel sandwich plate meets the minimum thickness required by the relevant ABS Rules.

3.2.2 Sandwich Plate Components

The sandwich plate repair or reinforcement is mainly composed of a new faceplate, an elastomer core, and an existing plate. The sandwich plate components and their functions are summarized in 1-A1/Table 1 below.

3.2.3 Typical Design Details

i) Design details for the sandwich plate repair construction should be provided by the sandwich plate designer and should be reviewed by ABS. The design should include details for transferring loads effectively and smoothly into the surrounding structure without creating stress concentration.

ii) Structural continuity should be maintained.

iii) Proper alignment with underneath frames and longitudinals should be specified. Unless otherwise agreed, the perimeter bar should be positioned above stiffening members.

iv) If welding is carried out during the sandwich plate installation, the welding should comply with the applicable ABS Rules. The heat input from the welding should not affect the elastomer, the bonding, or the capacity of the sandwich plates. The design documentation submitted should include details of the effects of the heat input.

v) Metallic parts of the sandwich plate repair should be effectively grounded to the hull to prevent possible electric shock. Electrical continuity of the metallic structure should be provided.

3.2.4 Materials

The sandwich plate repair quality depends greatly on the qualified materials used and the adhesion achieved from installation. The mechanical properties of materials used for repair may be needed for the repair design calculations. The elastic properties may be needed for stress calculations and ultimate strength properties are used in the failure modes of the repair.
The elastomer core stabilizes the faceplates, prevents local buckling and may transfer the full shear capacity between the faceplate and the existing plate, depending on the design. The elastomer mechanical properties are temperature-dependent and reduce when temperature rises (see the equation in 1-A1/3.3.1). The chemical resistance of the elastomer core material needs to be confirmed with the core material provider for the particular application and design.

Materials (including steel, aluminum, elastomer core, and perimeter seal if any) used for the sandwich plate repair should be certified by ABS. The properties of the cured core elastomer should be determined for ABS certification, such as density, hardness, shear modulus and modulus of elasticity, tensile stress, shear strength, elongation, and glass transition temperature. The faceplates, the optional perimeter bars, and welding consumables should meet the applicable ABS Rules.

Typical tested material properties of the cured core are listed in 1-A1/Table 2 along with the recognized standards used for testing.

For steel plates, the shear modulus 79 GPa (11458 ksi), Young’s modulus 210 GPa (30458 ksi), and Poisson’s ratio 0.3 are typically used for calculations unless other values are provided.

3.2.5 Service Temperature
For service environments with temperatures greater than 110°C (230°F) or less than –60°C (–76°F), property changes of elastomer core materials and steels should be considered in the design and strength analysis. The elastomer core and steel may become brittle at extreme low temperatures. At high temperatures, the elastomer core could become soft.

3.2.6 Fire Safety
With consideration of the fire properties in 1-4/7, the fire performance of the complete sandwich plate should be evaluated for compliance with the relevant fire codes and regulations, such as SOLAS Chapter II-2/Regulation 17.

The steel faceplates of the sandwich plate provide a non-combustible barrier to a fire from either side of the sandwich plate. The elastomer core provides an effective heat insulation. In the event of a fire, the elastomer core remains stable and releases no gases until the faceplate temperature reaches up to a certain temperature, such as 400°C (752°F). When the faceplate temperature rises above a certain temperature, such as 400°C (752°F), on the fire side, the elastomer core could release some gases from the fire side through the Temperature Control Pressure Release Valves (TCPRVs). Only the fire exposed side’s elastomer-steel interface layer will be affected.
# Chapter 1 Composite Repairs of Steel Structures

## Appendix 1 Sandwich Plate with a Continuous Elastomer Core 1-A1

### TABLE 1
**Recommended Sandwich Plate Components and Their Functions**

<table>
<thead>
<tr>
<th>Sandwich Plate Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>New faceplate</td>
<td>Reinforces the structure.</td>
</tr>
<tr>
<td>Elastomer core</td>
<td>Provides continuous support to the plates, prevents local plate buckling and transfers sufficient shear strength between the plates so that the full-strength capacity of the faceplate may be achieved.</td>
</tr>
<tr>
<td>Existing plate</td>
<td>The existing plate, as a faceplate of sandwich plate, to be repaired or reinforced.</td>
</tr>
<tr>
<td>Perimeter bar, if any</td>
<td>The perimeter bars, generally aligned with main framing, should welded or adhesively bonded to both the existing plate and the new faceplate to form cavities for the elastomer core.</td>
</tr>
<tr>
<td>Spacer, if any</td>
<td>Polyurethane spacers should be used where needed to maintain spacing between the faceplate and the existing plate for the necessary core thickness. Spacers should be located at support members or in curved sections.</td>
</tr>
<tr>
<td>Venting and injection holes, plugs, if any</td>
<td>Injection holes should be used for injecting the elastomer in between the new faceplate and the existing plate. The venting holes should be used for releasing the trapped air. The plugs for holes, made of material compatible with the new faceplate, should typically be welded into place after the injection is completed. In hot work applications, the plugs may be fitted using structural adhesive.</td>
</tr>
<tr>
<td>Cavity (Before Injection)</td>
<td>Bounded by the perimeter bars, if any, the new faceplate, and the existing plate. The cavity formed should be designed for a single injection of the elastomer core unless for large vertical cavities such as on bulkhead and side shell.</td>
</tr>
<tr>
<td>Expanded Metal Mesh</td>
<td>May be used for deep dish casting (thick cores) to restrict shrinkage or expansion of the core caused by temperature changes</td>
</tr>
</tbody>
</table>

### TABLE 2
**Typical Core Material Properties and Test Standards**

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Standard</th>
<th>Typical Core Material Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ISO 845 or equivalent</td>
<td>≥ 1000 kg/m³ (62.4 lb/ft³) at Room Temperature (RT)</td>
</tr>
<tr>
<td>Glass Transition temperature, $T_g$</td>
<td>ASTM E1356 or equivalent</td>
<td>&gt; 75°C (167°F)</td>
</tr>
<tr>
<td>Hardness</td>
<td>ISO 7619-1 or ASTM D 2240 or equivalent</td>
<td>Shore D ≥ 65 at RT</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>ISO 6721-2 or equivalent</td>
<td>$G ≥ 312 – 2.47,\text{MPa}$, $T$ is test temperature range $-20^\circ\text{C}$ to $+80^\circ\text{C}$ $G ≥ 45.25 – 0.197,\text{ksi}$, $T$ is test temperature range $-4^\circ\text{F}$ to $+176^\circ\text{F}$</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>ISO 527-2 or ASTM D638 or equivalent</td>
<td>0.36</td>
</tr>
<tr>
<td>Tensile stress</td>
<td>ISO 527 or ASTM D638 or equivalent</td>
<td>≥ 20 MPa (2.9 KSI) at RT and ≥ 5 MPa (0.73 KSI) at $+80^\circ\text{C}$ (176°F)</td>
</tr>
<tr>
<td>Elongation</td>
<td>ISO 527 or ASTM D638 or equivalent</td>
<td>Min. 10% at $-20^\circ\text{C}$ (-4°F) and min. 20% at RT</td>
</tr>
<tr>
<td>Bond shear strength</td>
<td>ASTM D429 or equivalent</td>
<td>≥ 2.7 MPa (0.39 ksi) for shot blasted or ≥ 4 MPa (0.58 ksi for grit blasted at RT</td>
</tr>
</tbody>
</table>

### 3.3 Sandwich Plate Repair Extent

The extent of sandwich plate repair is equal to the length of the corroded area plus the development length on each side in the longitudinal direction and transverse direction (see 1-A1/Figure 1). The development length is the minimum length of the new faceplate needed to transfer the load through the elastomer core layer from the existing plate to the top new faceplate to utilize the full compressive or tensile capacity of the faceplate.
The development length can be calculated from the equations in 1-A1/3.3.1 and 1-A1/3.3.2 below. The greater value from these equations can be used as the minimum development length. The sandwich plate should extend beyond the repaired area in all directions by the development length calculated. Service temperature should be considered carefully in the development length calculations.

Sufficient longitudinal length of the new faceplate should be provided for the repair for considering hull girder strength enhancement.

3.3.1 Development Length – Bond Strength

\[ L_d = \frac{C_y - V_r}{f_b \tau_b} \]  

in mm (in.)

where

- \( C_y \) = \( A_s \sigma_y \) in N (lbf)
- \( A_s \) = cross sectional area of the difference between the original existing plate thickness and the reduced thickness of the existing plate, in mm²/mm (in²/in)
- \( \sigma_y \) = yield stress of the faceplate, in MPa (ksi)
- \( V_r \) = shear capacity transferred from the existing plate to the faceplate through the welds in N/mm (lbf/in)
- \( f_b \) = bond shear resistance factor based on the development of safety coefficients for adhesively bonded joint designs
- \( \tau_b \) = bond shear strength factor of the core material, MPa (ksi)
- \( \tau_b = \) maximum shear capacity of the core material, MPa (ksi)
- \( f_b = \) For current ABS Type-approved SPS Elastocore 9010/100, 13.5\( f_b \) in MPa (1.96\( f_b \) in ksi) and 1-A1/Table 3 can be used.

### TABLE 3

<table>
<thead>
<tr>
<th>Temp, °C (°F)</th>
<th>-40 (-40)</th>
<th>-20 (-4)</th>
<th>0 (32)</th>
<th>20 (68)</th>
<th>40 (104)</th>
<th>60 (140)</th>
<th>80 (176)</th>
<th>100 (212)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_b )</td>
<td>1.31</td>
<td>1.28</td>
<td>1.21</td>
<td>1.00</td>
<td>0.71</td>
<td>0.48</td>
<td>0.33</td>
<td>0.19</td>
</tr>
</tbody>
</table>
3.3.2 Development Length – Numerical Analysis

\[ \ell_d = m_1 m_2 \ell_n \text{, in mm (in.)} \]

where

\[
m_1 = \frac{16t_{\text{core}} + 480}{800} \quad \text{for } 20 \text{ mm} \leq t_{\text{core}} \leq 50 \text{ mm}
\]

\[
m_1 = \frac{16t_{\text{core}} + 18.9}{31.5} \quad \text{for } 0.79 \text{ in.} \leq t_{\text{core}} \leq 2.0 \text{ in.}
\]

\[
m_2 = \frac{-2.5E_{\text{core}} + 2000}{800} \quad \text{for } 200 \text{ MPa} \leq E_{\text{core}} \leq 375 \text{ MPa}
\]

\[
m_2 = \frac{-2.5E_{\text{core}} + 290}{116} \quad \text{for } 29 \text{ ksi} \leq E_{\text{core}} \leq 54 \text{ ksi}
\]

\[
m_2 = \frac{-0.7E_{\text{core}} + 1325}{800} \quad \text{for } 375 \text{ MPa} \leq E_{\text{core}} \leq 750 \text{ MPa}
\]

\[
m_2 = \frac{-0.7E_{\text{core}} + 192}{116} \quad \text{for } 54 \text{ ksi} \leq E_{\text{core}} \leq 109 \text{ ksi}
\]

\[ t_{\text{core}} = \text{core thickness, in mm (in.)} \]

\[ E_{\text{core}} = \text{modulus of elasticity of the core, in MPa (ksi)} \]

\[ \ell_n = \text{normalized base development length, in mm (in.)} \]

\[
\ell_n = 0.4 \frac{\sigma}{\sigma_y} \ell_{\text{db}} \quad 0 \leq \sigma < 0.5 \sigma_y
\]

\[
\ell_n = \left[ \frac{\sigma}{\sigma_y} - 0.3 \right] \ell_{\text{db}} \quad 0.5 \sigma_y \leq \sigma < 0.9 \sigma_y
\]

\[
\ell_n = \left[ \frac{\sigma}{\sigma_y} - 0.75 \right] 4\ell_{\text{db}} \quad 0.9 \sigma_y \leq \sigma \leq \sigma_y
\]

\[
\frac{\sigma}{\sigma_y} = \frac{t_{\text{as}} - t_{\text{face}}}{t_{\text{ex}}}
\]

\[
\ell_{\text{db}} = 50t_{\text{as}} + 400 \quad \text{for } t_{\text{as}} \leq 12 \text{ mm}
\]

\[
\ell_{\text{db}} = 25t_{\text{as}} + 700 \quad \text{for } t_{\text{as}} > 12 \text{ mm}
\]

\[
\ell_{\text{db}} = 50t_{\text{as}} + 15.75 \quad \text{for } t_{\text{as}} \leq 0.5 \text{ in.}
\]

\[
\ell_{\text{db}} = 25t_{\text{as}} + 27.56 \quad \text{for } t_{\text{as}} > 0.5 \text{ in.}
\]

\[ t_{\text{as}} = \text{as-built plate thickness of existing plate, in mm (in.)} \]

\[ t_{\text{ex}} = \text{remaining plate thickness of existing plate, in mm (in.)} \]

\[ t_{\text{face}} = \text{new faceplate net thickness, in mm (in.)} \]
3.4 Faceplate Thicknesses and Core Thickness

The combination of the faceplate net thicknesses and the core thickness should be used to confirm that the sandwich repair meets the strength requirements given in the relevant ABS Rules. For special consideration of the minimum remaining thickness of the existing faceplate for the sandwich repair of critical class elements, refer to 1-2/4.2.1. Local areas with defects (pitting, grooving, etc.) in excess of these limits may be acceptable for the sandwich repair.

The final faceplate thickness used for the repair may include the required corrosion allowance and the owner’s addition with consideration of repair installation handling requirements.

\[ t_{\text{final}} = t_{\text{net}} + t_{\text{cor}} + t_{\text{add}} \text{ mm (in.)} \]

where

- \( t_{\text{final}} \) = faceplate thickness used for repair, in mm (in.)
- \( t_{\text{net}} \) = minimum net thickness of the faceplate based on strength calculations, in mm (in.)
- \( t_{\text{cor}} \) = corrosion allowance for the top side of the faceplate, in mm (in.), in accordance with the relevant ABS Rules
- \( t_{\text{add}} \) = owner’s addition, in mm (in.)

In order to have appropriate steel plate installation handling and appropriate elastomer curing, the minimum faceplate thickness recommended for the repair construction and the minimum elastomer core thickness recommended for appropriate curing are given in 1-A1/Table 4.

The sum of the net thicknesses of the top faceplate and the existing corroded plate thickness should not be less than the as-built thickness of the existing plate at a given location for steel structure restoration repairs.

### TABLE 4
Recommended Minimum Thicknesses of Faceplate and Elastomer Core for Handling and Curing

<table>
<thead>
<tr>
<th>Construction Layer</th>
<th>Minimum Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel faceplate</td>
<td>3.0 mm (0.12 in.) for installation handling</td>
</tr>
<tr>
<td>Elastomer core *</td>
<td>15.0 mm (0.59 in.) for the sandwich plates not contacting seawater</td>
</tr>
<tr>
<td></td>
<td>25.0 mm (1 in.) for the sandwich plates contacting seawater</td>
</tr>
</tbody>
</table>

* Note: The elastomer core cures under the specified curing temperature range. Too little elastomer thickness is not favorable for an appropriate curing because the faceplates could absorb most of the heat from the elastomer core during curing.

3.5 Local Section Modulus

The local section modulus after the sandwich plate repair may be calculated for strength requirements. Typical stiffeners with attached plates are shown in 1-A1/Figure 2 with the reference point at the flange. Refer to Part 5A & 5B, Part 1, Chapter 3, Section 7/3.1 “Reference point” – Figure 24 of the Marine Vessel Rules.
FIGURE 2
Reference Point for Calculation of Section Modulus and Hull Girder Stress for Local Scantling Assessment

3.5.1 Effective Section Modulus for Reference Point at the Flange
The effective section modulus after the sandwich plate repair, $SM_{s,eff}$, for the reference point shown in 1-A1/Figure 2, can be calculated by the following equation:

$$SM_{s,eff} = \alpha_s S_M \text{ mm}^3 (\text{in}^3)$$

where

$$S_M = \text{section moduli of the sandwich plate with stiffener for reference point at the stiffener flange, in mm}^3 (\text{in}^3)$$

$$\alpha_s = \text{factor of effective section moduli } S_{M,eff}$$

$$= \frac{1}{\beta_s} \left[ 0.99 - 30 \left( \frac{t_p t_{tp}}{r t} \right) \right]$$

$$= 1.0 \quad \text{when the stiffener web extends to the faceplate}$$

$$\beta_s = 1.02 \quad \text{for bulb flats}$$

$$= 1.093 - 0.0045 \frac{b h s}{w t \ell} \quad \text{for angles}$$

$$= 1.005 - 1.3 \frac{r}{h} \quad \text{for T-bars}$$

$$r = \text{radius of gyration of the existing section (stiffener and existing plate), in mm (in.)}$$

$$t_c = \text{core thickness, in mm (in.)}$$

$$t_p = \text{new faceplate thickness, in mm (in.)}$$

$$\ell = \text{span of the stiffener, in mm (in.)}$$

$$s = \text{stiffener spacing, in mm (in.)}$$
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$h$ = depth of the stiffener, in mm (in.)

$w$ = web thickness, in mm (in.)

$b$ = flange width, in mm (in.)

$t$ = flange thickness, in mm (in.)

### 3.5.2 Effective Section Modulus for Reference Point at the Faceplate

The effective section modulus, $SM_{f, eff}$, for the reference point at the faceplate can be calculated by the following equation:

$$SM_{f, eff} = \alpha_f SM_f \text{ mm}^3 \text{ (in}^3\text{)}$$

where

$SM_f$ = section modulus of the sandwich plate with stiffener for reference point at the faceplate, in mm$^3$ (in$^3$)

$\alpha_f$ = factor of effective section moduli $SM_{f, eff}$

$$\alpha_f = \frac{1}{\beta_f} \left[ 0.97 - 0.4 \left( \frac{t_c}{r} \right) \right]$$

$\beta_f$ = 1.0 when the stiffener web extends to the faceplate

$\beta_f$ = 1.07 for bulb flats

$\beta_f$ = $1.32 - 0.0034w \ell s^{-1}$ for angles ($\ell, s, w$ in mm)

$\beta_f$ = 1.054 for T-bars

$\beta_f$ = 1.07 for bulb flats

$\beta_f$ = $1.32 - 0.08636w \ell s^{-1}$ for angles ($\ell, s, w$ in in.)

$\beta_f$ = 1.054 for T-bars

$\ell, s,$ and $w$ are defined in 1-A1/3.5.1.

### 4 Sandwich Plate Installation Process

#### 4.1 General

A pre-project planning meeting should be held with the attending ABS Surveyor prior to commencement of work, to confirm that all parties involved clearly understand the procedures, sequence of work, and inspection hold points. This Subsection provides general guidelines for the sandwich plate repair installation. Any deviation from these guidelines should be reviewed by ABS to confirm that installation quality meets the design specification.

#### 4.2 Materials

The materials of the faceplates, perimeter bars, and welding consumables (if welding is used) should be certified by ABS. The elastomer core component materials, together their technical datasheets, should also be certified by ABS.

#### 4.3 Personnel Qualification

The repair installation and inspection should be carried out by qualified and certified personnel.
4.4 Surface Preparation

The surfaces that form the internal sandwich plate cavity should be treated to the necessary surface roughness and cleanliness before injection of the elastomer. The elastomer should have very stringent surface preparation to achieve proper adhesion and interface bond strength.

i) Existing fittings in the sandwich plate repair area (such as ladders, railings and wheel stops) should be removed.

ii) Local defects (pitting, holes) in the existing plate should be repaired to the satisfaction of the attending Surveyor, if necessary, at this stage.

iii) Unless otherwise approved in the design documents, doubler plates and existing surface-mounted fittings (pads, container/cargo securing arrangements) in the sandwich plate repair area should be removed.

iv) All contaminants such as dust, debris, oil/grease, water/moisture and possible salts should be removed from both the existing corroded plate surface and the new faceplates in accordance with SSPC SP2 or equivalent prior to abrasive dry blasting.

v) All existing coatings in the area to be repaired should be removed. Necessary surface cleanliness and roughness should have ISO 8501-1 Sa2.5 (SSPC 10) cleanliness with a minimum of 60 µm (2.4 mils) roughness or as recommended by the elastomer core manufacturer. Hard angular grit blasting is recommended to achieve a better surface profile. For surface preparation of small areas, other methods such as abrasive disk, wire brush or needle gun can also be used. Cleaned surfaces should be appropriately handled and protected before the cavities are formed and closed.

vi) Light and uniform flash rust (discoloration) may occur after surface cleaning is complete and before the faceplate is placed. Uniform light flash rusting may be allowed with demonstration tests showing that the necessary adhesion can be achieved. However, local (non-uniform) flash rust should be removed by sweep dry blasting or mechanical means (such as wire brushing) prior to closing the sandwich plate cavity. Non-uniform flash rust indicates the presence of salts.

vii) Any surface defects identified after surface preparation, should be repaired to the satisfaction of the attending ABS Surveyor. The ABS Surveyor should verify the remaining thickness and areas to be repaired after blast cleaning and compare with the data from the gauging reports. Any significant differences found should be brought to the attention of ABS.

viii) Use of primer or corrosion inhibitor is not permitted unless allowed by the manufacturer with demonstration tests showing that the necessary adhesion and shear strength can be achieved.

4.5 Preparation of the Perimeter Bars and Steel Pads/Foundations

After surface preparation of the existing plate to be repaired, perimeter flat bars, if needed, should be welded or adhesively glued or in any combination of both to the existing structure. The bar height should be equal to the nominal elastomer core thickness.

Welded butts and seams in the existing plating should be ground smooth in way of perimeter bar crossings.

When using glued perimeter bars, the design documentation should demonstrate that the strength of the proposed sandwich plate meets design specification appropriate for the application.

The dimensions and tolerance of the perimeter bars and the welding should be specified in the design documents in accordance with established repair standards and ABS Rule requirements.

Continuous welding or gluing to the existing structure should be provided to prevent leakage between any cavities formed.

Steel pads for subsequent attachment of fitting or lashing points should be installed in accordance with the design documentation.

Metallic parts of the sandwich plate repair should be effectively grounded to the hull to prevent possible electric shock. Electrical continuity of the metallic structure should be confirmed.
4.6 **Placement of Spacers**
Before installing the faceplate, elastomer or steel spacers, if necessary, should be used to control spacing between the existing plate and the faceplate to maintain the specified core thickness and to prevent sagging of the faceplate. The spacers are normally placed over existing framing members.

4.7 **Placement and Attachment of the Faceplate**
Prior to closing the cavity, the internal surfaces of the faceplate and the existing plate should be inspected to confirm that the surface preparation is in accordance with the specification agreed.

The faceplates should be welded or adhesively glued to the perimeter bars. Butt welds of the faceplates should be used to provide continuity of the faceplates and tightness of cavities. However, high strength bolts and adhesive can also be used.

4.8 **Temporary Restraint System**
Where necessary, depending on the cavity size and plate thickness, restraint frames or beams may be used on the faceplate to prevent out-of-plane deflections caused by the elastomer injection pressure and curing. Restraints can be held in place using clamps and powered magnets or dogs and wedges.

4.9 **Preparation of the Cavity for Injection**
Venting and injection holes with valves and overflow funnels or pipes/buckets on the faceplates should be arranged as determined by the installer. The injection port should be located at the lower end. The venting ports should be arranged at the upper end away from the injection port to evacuate air from the cavity as it is filled.

Before injecting the elastomer, the following steps should be completed:

i) All cavities should be pressure tested to verify boundary tightness by raising the relative pressure, such as to 0.1 bars (1.45 psi) for welded sandwich plate or to 0.05 bars (0.73 psi), for adhesively bonded components. This raised pressure should be maintained for a certain period of time, such as at least one minute. Any failed weld or adhesive bonding should be repaired, and the air tightness of the cavity should be retested.

ii) All cavities should be conditioned by blowing dry air through injection ports and the venting ports. All cavities should then be sealed at the valves.

iii) The temperature of the sandwich plates and bars should be at least 3°C (5.4°F) higher than the dew point. In cold weather, it may be necessary to warm the faceplates.

4.10 **Injection of Elastomer**
The elastomer injection process should be confirmed with the injection engineer with written procedures provided. The injection machine calibration should be current.

The components of the elastomer are to be mixed at the ratio provided in the technical data sheets. No thinner is allowed. Depending on the equipment used, the elastomer parts may be inline mixed and injected through the injection port into the cavity dynamically under controlled conditions (elastomer component temperature and plate temperature). Thermal blankets may be provided in cold environments to maintain a minimum plate temperature before and during injection.

After injection, during the curing cycle of the elastomer, an exothermic reaction could raise the temperature of the plating, up to 40°C (104°F) or higher. Equipment operators should receive appropriate training before performing injection.

The time period for the elastomer to maintain liquid form after mixing is critical to the elastomer injection process. Pot life for each batch of material should be tested and specified in its datasheets. Pot life can be affected by the liquid core temperature, plate temperature, elastomer core thickness, and ambient temperature.

Elastomer core expansion after curing is measured in a measuring jug with the level marked right after injection into the jug. The expansion should be between 1% and 12% in volume.
4.11 Hardness Check for Cured Elastomer Core

A Shore D Hardness test of the cured elastomer core should be conducted for each injection to confirm that the elastomer core is properly cured, as specified in 1-A1/Table 2. The cured test samples are obtained from each injection.

4.12 Removal of Restraint System and Sealing the Cavities

Once the elastomer core has been injected and cured, the restraint beams, injection and venting valves, and pipes are removed. Generally, all holes for injection and venting are sealed by inserting a plug into each hole by either welding, adhesive, or screw. In the case of installations that involve no hot-work, plugs are set into adhesive. Where specified in the approved design documentation, temperature-controlled pressure relief valves (TCPVRs) should be fitted.

4.13 Nondestructive Testing and Repairs

Each cavity filled with cured elastomer should be tested for voids or air pockets by “tap” testing, “Sonalis” testing, or other methods. Tap testing is a reliable method for detecting voids in the elastomer core. Voided areas give a metallic ringing sound when tapped, while bonded areas give a dull thud sound. Other mapping methods may also be used, so long as they are of equal or greater effectiveness.

The test spacing should be identified in the agreed specification. Initial test spacing is typically 250 mm (10 in.).

The maximum permissible void size should also be specified (such as 50 times the faceplate thickness) in the approved documentation with consideration of buckling and shear strength requirements. Voids larger than the maximum permissible void size should typically be repaired using the repair procedure described below:

- The perimeter of the void is established by testing and marking the faceplate. Depending on void shape and size, holes are drilled near the edge of the void for injection and ventilation.
- The void is then filled with elastomer through the injection port using handheld equipment that is gravity fed.
- Injection ports and vent ports are closed and sealed.

All voids tested below the maximum void size should be mapped and provided to ABS for future surveys.

4.14 Corrosion Protection of the Exposed Surface of Steel Plates

Based on the corrosion prevention specifications, the external exposed surface of the faceplates may be prepared and coated in accordance with the agreed coating specification. When specified, the inspector should inspect the coating process of the exposed surfaces of the faceplates in accordance with the specification.

5 Inspection and Survey

For general recommendations on material certification survey, installation survey, and in-service survey, refer to Chapter 1, Section 6.

An ABS Surveyor should verify:

i) A pre-project planning meeting should be held with the attending ABS Surveyor prior to commencement of work to confirm that all parties involved clearly understand the procedures, sequence of work, and inspection hold points.

ii) The faceplates, perimeter bars, and welding consumables should meet applicable ABS Rules and certification requirements.

iii) The elastomer core/component materials used for the repair match their valid certificates and data sheets. The manufacturing date, shelf life, and storage condition of all materials should be within the manufacturer’s recommendations.

iv) Any defect identified before and after surface preparation and any defect resulting from the removal of temporary attachments should be repaired to the ABS Surveyor’s satisfaction.
v) Inspection and documentation of the repair installation should be carried out by a qualified and certified inspector in accordance with recommendation provided in 1-A1/4. The inspector should be responsible for all inspections, testing, and documentation. The inspection report of the sandwich plate repair should be prepared by the inspector and submitted to the ABS Surveyor for review and incorporation into ABS records. The report should be kept on board and maintained throughout the life of the unit for reference during future surveys.
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CHAPTER 2 Composite Repairs of Piping

SECTION 1 General

1 Scope

This Chapter provides guidelines on composite repairs of steel piping (see 2-1/2) for offshore assets. The intention of these guidelines is to provide a simplified procedure for applying the industry standards ISO 24817 and ASME PCC-2.

The focus of this Chapter is composite repairs of steel piping. However, it is also applicable to repairs of nonmetallic substrate materials.

The key aspects considered herein are listed below:

- Design of repair
- Repair system qualification, which typically considers qualification testing specific to a pipe material and method of surface preparation for the repair system to be used
- Repair Installation and Quality Assurance
- In-service Inspection, Monitoring and Maintenance

2 Piping

The term “piping” refers to assemblies of piping components and pipe supports of the piping system as defined in Section 4-6-1 of the Marine Vessel Rules. The piping consists of following components:

- Straight pipes
- Tubes
- Pipe Fittings such as sleeves, elbows, tees, bends, flanges, reducers, etc., which are used to join together sections of pipe.

Valves and pumps are not covered in this Chapter.

3 Repair Application

The following situations are considered for repair:

- External corrosion, where the corrosion may or may not be through-wall (in this case, the corrosion is arrested by the repair)
- External mechanical damage, such as dents, gouges, fretting, or wear
- Internal corrosion/erosion, where the deterioration may or may not be through-wall (continuous corrosion is taken into account after the repair)
- Crack-like defects, which may or may not be through wall cracks

The composite repairs may also provide local structural strengthening of piping.

This Chapter does not cover the piping damage assessment.
4 **Environment**

Internal fluid and external environment can affect the performance of the repair system. Internal fluid includes flammable fluids, toxic fluids, corrosive fluids, and hazardous and noxious liquid substances as defined in 4-6-1/3.23 through 4-6-1/3.29 of the *Marine Vessel Rules*.

Original design pressure/temperature and maximum allowable working pressure are important information for the repair system design. The pressure/temperature limits of the repaired piping component are dependent on the damage type and the repair system applied. These limits are determined by the testing and qualification specifications.

5 **Repair System**

The repair system consists of the following elements:

- Piping component substrate, which is the surface of the pipework and can be metallic or GRP
- Surface preparation
- Repair materials (laminate, resin, reinforcement (filler), adhesive for bonding) and application method
- Curing process

6 **Repair Life**

The achievable repair life depends on the repair system installed and can be affected by the environment, internal corrosion/erosion mechanisms, and external mechanical influences.

7 **Personnel Qualification**

Designs of the repairs should be undertaken by a technically competent person acceptable to the owner.

Personnel involved in the installation of the piping system repair should be trained and qualified. The repair quality depends strongly on the repair workmanship. Training and certification of the repair personnel is key to an expected repair quality. Personnel qualifications for repair installer and repair supervisor should be in accordance with ISO 24817 Annex I or ASME PCC-2 Article 4.2 Mandatory Appendix IV. The installation service provider should keep the qualification record.

The repair installation should be inspected by a certified and qualified inspector. The certification and qualification of the inspector should be reviewed by ABS Engineering and verified by the attending ABS Surveyor.

8 **Risk Assessment**

A risk assessment should be completed with the risk level and the repair life defined. The repair system application to a piping could typically change the piping failure mode and reduce the probability of failure.

The following items should be considered for risk assessment:

- Defect type, size, and location to be repaired
- Piping component geometry
- Design, operating conditions (including pressure, temperature, sizes), fluid contents, and failure modes
- Performance under worst conditions and major incident situations including impact, abrasion, fire, explosion, collision, and environmental loading
- Hazards associated with service
- Repair installer skills, surface preparation quality and repair environment
• Repair system materials selected and repair life expected
• In-service inspectability

9 Documentation for Review

The documentation provided prior to installation of the repair should include:

i) System plan and contents of System Plans for the piping component to be repaired, see 4-6-1/9 of the Marine Vessel Rules.

ii) Repair Assessment providing information as specified in 2-3/2.

iii) Repair design including design basis, the repair system qualification results and design calculations as specified in Chapter 2, Section 3.

iv) Repair installation and inspection procedures as specified in Chapter 2, Section 4 and Chapter 2, Section 5.

v) An In-Service Inspection Program deemed appropriate for maintaining the integrity of the repair system should be provided. Information on in-service inspection, monitoring, and maintenance can be found in Chapter 2, Section 5.

vi) Risk Assessment Report (see 2-1/8).

The documentation for the repair should be submitted for ABS Engineering review and be available for the attending ABS Surveyor to verify that the quality assurance and documentation for repair installation is done appropriately.

The information of the repair, identification, location, date of installation, material used, repair lifetime, associated maturation year and survey intervals should be included in the unit’s In-Service Inspection Plan (ISIP).

10 References

• ASME PCC-2 (2018), Repair of Pressure Equipment and Piping, Part 4 – Nonmetallic and Bonded Repairs

• BS EN ISO 24817 (2017), Composite repairs for pipework – Qualification and design, installation, testing and inspection

11 Terms, Definitions, and Abbreviations

For terms and definitions, see 1-1/4. For abbreviations, see 1-1/5.
CHAPTER 2 Composite Repairs of Piping

SECTION 2 Repair Design

1 General

Designs of repairs should be undertaken by a technically competent person acceptable to the owner. ABS should review the repair design before commencement of any repair work.

2 Repair Assessment

The repair assessment is used to determine if the composite repair system is feasible to the piping damage and to decide the repair class (2-3/1).

The following information should be provided for the repair assessment:

- Damage location, damage type, failure modes
- Piping system operational histories and cargo carried, maintenance/repair histories, piping inspection reports, condition assessment data
- Original piping system design data, including design calculations, load specification, pipe geometry/size/pressure/temperature, hazard and safety requirements, regulatory requirements
- Repair design life (see 2-2/4) and service condition (design and operation pressure/temperature)
- Accessibility for inspection, surface preparation, repair application, maintenance of the repair
- Repair system, including repair materials and their qualification, installer’s qualification and skills

Original piping system design data, maintenance/repair/operational histories can be provided by the owner/operator. The materials and qualifications can be provided by the repair system provider and installer.

3 Defect Types

3.1 General

There are two types of defects, Type I defects and Type II defects.

The ends of the repair should be tapered if the repair thickness is governed by axial loads. A minimum taper of approximately 5:1 should be used. The overlap length should also be designed to be sufficient to transfer the axial load.

3.2 Type I Defects

Type I defects are for non-through-wall defects that are not expected to become through-wall defects during the repair design lifetime.

The repair laminate thickness, the number of wraps, and the axial length of the repair should be determined by ISO 24817/7.5.3 - 7.5.6, 7.5.8 (all repair Classes) or ASME PCC-2 Article 4.1/3.4.3-3.4.5, 3.48 (repair Class C) or ASME PCC-2 Article 4.2/3.4.1, 3.4.3 (repair Classes A and B). This repair is considered as structural reinforcement only.
3.3 **Type II Defects**

Type II defects are for through-wall defects including defects where the remaining wall thickness is expected to be less than 1.0 mm (0.04 in.) at the end of service life with consideration of active internal corrosion. The repair laminate thickness or the number of wraps should be determined by ISO 24817/7.5.7 (all repair Classes) or ASME PCC-2 Article 4.1/3.4.6 (repair Class C) or ASME PCC-2 Article 4.2/3.4.2 (repair Classes A and B) in addition to defect Type I above.

The repair impact performance should be considered for repairs to leaking piping systems (see ASME PCC-2, Part 4/3.4.7).

4 **Repair Design Lifetime**

The repair design lifetime (in years) is the maximum service lifetime of the repair, which should be defined by the owner in the repair design with consideration of the repair risk level, defect type, and service condition (e.g., internal corrosion). It should also be identified in the Risk Assessment.

The repair design lifetime can be between 2 and 20 years. A short design lifetime (minimum 2 years) is for situations where the repair survives until the next scheduled shutdown/drydocking. A long design lifetime (up to 20 years) is for situations where the repair extends/reinstates the original design life of the component.

Once the lifetime of the repair has expired, the Owner must either remove or revalidate the repair system (2-5/3.6).

A temporary or emergency repair is usually needed for quick repairs to avoid shutdown and downtime. Its repair life is usually expected to be a very short period before a longer lifetime (a short design lifetime or long design lifetime) repair is scheduled.

5 **Repair Design Considerations**

5.1 **General**

Fluids carried by the piping systems include utility fluid, diesel, seawater, liquid chemicals, and production fluids. Service temperature after repair depends on the glass transition temperature ($T_g$) or heat distortion temperature (HDT) of the repair system.

5.2 **Environmental Compatibility**

The service environment should be considered in determining the suitability of the repair system application. The repair system supplier should provide the following environmental compatibility data:

- Compatibility with fluid carried at specified temperature, especially for strong acidic (pH < 3.5), strong alkaline (pH > 11), highly saline, or strong solvent environment.
- Resistance to UV exposure and weathering, if appropriate
- Erosion estimation, if any

The environmental compatibility data can either be available from previous application experience or specific environmental testing in accordance with ISO 10952, ASTM D543, ASTM C581, ASTM D3681 or equivalent. The service environment of the repair system should not be more aggressive than the environment tested/demonstrated.

5.3 **Temperature Effects**

The glass transition temperature ($T_g$) or heat distortion temperature (HDT) for a repair system should be determined for the repair system design temperature ($T_d$).

$T_g$ or HDT should not be greater than $T_d$.

For all repair Classes, $T_d$ should be at least 20°C (36°F) less than $T_g$ for both Types I and II defects (or at least 15°C (27°F) less than HDT).
However, for Type II defect Class C repairs with design life greater than 2 years, \( T_d \) should be at least 30°C (54°F) less than \( T_g \) (or at least 20°C (36°F) less than HDT).

The cure schedule should be specified and demonstrated to meet the required \( T_g \) value. Hardness testing may be used to test curing and may be \( \geq 90\% \) of the minimum value from the repair system qualification tests.

### 5.4 Fire Performance

The necessary fire performance should be identified during the repair design. Flame spread and smoke generation should also be considered. Relevant flag Administration regulations, standards (i.e., ISO 14692, ASTM E84) and codes (i.e., IMO FTP Code) may be used for testing.

Composite repairs are permitted where plastic piping is allowed as per the fire endurance requirement from Section 4-6-3 of the Marine Vessel Rules or A1-2/27 of the ABS Rules for Facilities on Offshore Installations (Facilities Rules).

### 5.5 Cathodic Disbondment

Cathodic disbondment resistance may be considered if the repair is to be cathodically protected.

### 5.6 Electrical Conductivity

If the repair is to meet electrical conductivity requirements, the electrical conductivity properties should be tested to meet the original design specifications. 4-6-2/9.15 of the Marine Vessel Rules can be referenced for static electricity control.

### 5.7 Weight Change

Repair system installation may cause design weight/load changes, which should be considered during the repair design.

### 6 Design Calculation Output

The outputs of the design calculations of the repair laminate are the following, which are used for the repair installation:

1. **Number of layers, \( n \):**

   \[
   n = \frac{t_{repair}}{t_{layer}}
   \]

   \( n \) should be not less than 2 and should be rounded up to the nearest integer number

   where

   \( t_{repair} = \) repair laminate thickness

   \( t_{layer} = \) layer thickness

2. **Total axial repair length**

3. **Repair design output should also include details of laminate lay-up, repair area covered, and orientation of individual layers of reinforcement with information of overlap and taper length information.**
CHAPTER 2  Composite Repairs of Piping

SECTION 3  Repair System Qualification

1  Repair Class

The repair class is defined as Class A, B or C in 2-3/Table 1, which is different from classes of piping systems categorized by service pressure and temperature range.

<table>
<thead>
<tr>
<th>Repair Class</th>
<th>Typical Service</th>
<th>Design Pressure</th>
<th>Design Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Low specification duties for the majority of the utility service systems (e.g., static head, drains, cooling medium, sea (service) water(^{(1)}), diesel, and other utility hydrocarbons). This class is for the systems that do not relate directly to personnel safety or safety-critical systems or non-IDLH fluids.</td>
<td>&lt; 1.6 MPa (232 psi)</td>
<td>&gt;-20ºC (-4ºF) and &lt; 45°C (113ºF)</td>
</tr>
<tr>
<td>Class B</td>
<td>Fire water(^{(1)})/deluge systems. This class is for systems that have specific safety-related functions.</td>
<td>&lt; 2 MPa (290 psi)</td>
<td>&lt; 100°C (212ºF)</td>
</tr>
<tr>
<td>Class C</td>
<td>Produced water and hydrocarbons(^{(1)}), flammable fluids(^{(1)}), gas systems. This class covers operating conditions more onerous than described.</td>
<td>Qualified upper limit(^{(2)})</td>
<td>Qualified upper limit</td>
</tr>
</tbody>
</table>

Notes:

1. Where non-metallic piping repair is used for a steel fire main, sea water service and flammable fluids piping, the limitations regarding location as well as fire testing requirements should be considered. Refer to the relevant ABS Rules, such as 4-6-3/Table 1 of the Marine Vessel Rules or A1-2/Table 3 of the Facilities Rules.

2. The qualified upper limit pressure is derived from a function of defect type (internal, external, or through-wall), defect dimension (depth and extent), pipe diameter, design temperature, and repair design lifetime.

2  Repair System Qualification

2.1 General

The following repair system qualification data should be provided:

- Material properties for all repair classes
- Surface preparation data for all repair classes, such as cleanliness level and roughness grade
- Test data for short-term for all repair classes
- Test data for long-term repairs for Classes B and C

All tests should be carried out by using the same substrate material, surface preparation, repair laminate, adhesive, and application method.

The documentation and qualification data related to repair system should be provided by suppliers as shown in the below table:
2.2 Material Technical Data
The material technical data should include:

- The technical datasheets of the resin and reinforcements used
- Basic data on material compatibility with the working environment
- The resin and curing agent effect on the substrate to confirm they will not cause further degradation of the substrate
- Potential galvanic corrosion of the substrate by the repair

2.3 Surface Preparation
As an important element of the repair system, surface preparation quality determines the durability of the bonded repair under an applied working load, which includes surface cleanliness and roughness achieved after the surface preparation. The specific method of surface preparation should be an integral part of the repair system and its qualification tests. Any change in the surface preparation method calls for requalification of the repair system.

Details of the surface preparation procedure and standards used in the qualification tests should be provided. Refer to 1-5/3 for details.

2.4 Qualification Test Data for Short-term or Long-term Repairs
These test data should include tensile strength and modulus in the circumferential (hoop) direction and the axial direction of the pipe repair. These also include the adhesion strength between the repair laminate and the substrate. 2-2/Table 2 below provides the items to be tested for all repair classes, except for Class A.

<table>
<thead>
<tr>
<th>Documentation</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material documentation and data</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Surface preparation documentation</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Short-term test data</td>
<td>Applicable</td>
<td>Applicable</td>
<td>Applicable</td>
</tr>
<tr>
<td>Long-term test data</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4.1 Short-term Repairs
For short-term repairs, the test data should include the following:

- Tensile strength
- Ultimate tensile strain and modulus, in both the hoop and axial directions
- Strength of the adhesive bond layer between the repair laminate and the substrate material
- Energy release rate (optional)

2.4.2 Long-term Repairs
For long-term repairs, the test sample should have at least 1,000 hours in a water/oil environment with a temperature no less than the design temperature or in a dry environment with a temperature greater than 100°C (212°F). The test data for long-term repairs should include the following:

- Strength of the adhesive bond layer between the repair laminate, substrate, and filler material
- Optionally, the long-term tensile strain of the repair laminate

Performance testing may be done to determine design allowable in accordance ISO 24817 Annex E. The long-term strain to failure allowable is determined by any of the following:

- 1000 hours of survival testing
- Regression testing
- Representative repair laminate coupon regression testing
2.4.3 Hydrostatic Test
When needed, internal hydrostatic pressure short term Prototype Test should be done based on the Sections 4-6-2 and 4-6-3 of the ABS Marine Vessel Rules:

- For non-through-wall defects (Type I Defect), internal pressure testing should have $1.5 \times \text{Design Pressure}$.
- For through-Wall Defect (Type II Defect), internal pressure testing should have $4.0 \times \text{Design Pressure}$.

**TABLE 2**
Qualification Tests

<table>
<thead>
<tr>
<th>Material Property of Laminate or Laminate/Substrate Interface</th>
<th>Minimum Values</th>
<th>Recommended Test Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus and Poisson’s ratio</td>
<td>Strain to failure &gt; 1%</td>
<td>ISO 527, ASTM D3039</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>None</td>
<td>ASTM D5379 or ASME PCC-2 – Article 4.1 – Mandatory Appendix II – Section II – item (f)</td>
</tr>
<tr>
<td>Compressive modulus</td>
<td>None</td>
<td>ASTM D695, ASTM D6641, ISO 604, ISO 14126</td>
</tr>
<tr>
<td>Barcol or Shore hardness</td>
<td>None</td>
<td>ISO 868, ASTM D2583, ASTM D2240</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>None</td>
<td>ISO 11359-2 or ASTM D696 or ASTM E831</td>
</tr>
<tr>
<td>Glass transition temperature of the resin$^{(1)}$</td>
<td>None</td>
<td>ISO 11357-2, ASTM D6604, ASTM D7426, ASTM E1356, ASTM E1545, ASTM E1640, ASTM E831</td>
</tr>
<tr>
<td>Heat distortion temperature (HDT)$^{(2)}$</td>
<td>None</td>
<td>ISO 75, ASTM D648</td>
</tr>
<tr>
<td>Adhesion strength – lap shear$^{(3)}$</td>
<td>4 MPa (580 psi)</td>
<td>EN 1465 or ASTM D3165, ASTM D5868</td>
</tr>
<tr>
<td>Long-term lap shear performance (optional)</td>
<td>30% of 4 MPa (580 psi)</td>
<td>ASME PCC-2 Part 4/Mandatory Appendix II-2</td>
</tr>
<tr>
<td>Impact performance</td>
<td>Per standard</td>
<td>ISO 24817 Annex F Impact survival test, ASME PCC-2 Part 4/Mandatory Appendix VI</td>
</tr>
<tr>
<td>Energy release rate (optional)</td>
<td>None</td>
<td>ISO 24817 Annex D Energy release rate, ASME PCC-2 Part 4/Mandatory Appendix IV</td>
</tr>
<tr>
<td>Structural strengthening</td>
<td>Wrap not fail</td>
<td>ISO 24817 Annex C Short-term pipe spool survival test, ASME PCC-2 Part 4/Mandatory Appendix III</td>
</tr>
<tr>
<td>Cathodic disbondment</td>
<td>None</td>
<td>ASTM G8, ASTM G42, ASTM G95</td>
</tr>
<tr>
<td>Cyclic loading (optional)</td>
<td>None</td>
<td>ISO 14692, ISO 24817</td>
</tr>
<tr>
<td>Electrical conductivity (as required by the applicable ABS Rules)</td>
<td>None</td>
<td>ISO 14692, ASTM D149</td>
</tr>
<tr>
<td>Chemical compatibility (as required by the applicable ABS Rules)</td>
<td>None</td>
<td>ASTM D543, ASTM C581, ASTM D3681, ISO 10952</td>
</tr>
</tbody>
</table>

**Notes:**

1. Please note that the glass transition temperature, $T_g$, is determined for a range of relevant cure times and temperatures. The installed repair is subject to the same cure schedule as the $T_g$ value tested for the design.

2. For the matrix polymer (without reinforcing fibers), use ASTM D648 to measure HDT under a load of 1.82 MPa (264 psi). As an alternative, when measuring HDT for reinforced polymers, the minimum load should be 18 MPa (2,640 psi).

3. The shear strength should be determined by the average shear strength > 5 MPa, or adhesive failure between the substrate and the laminate should not be greater than 70%.
2.5 Substrate Defect Repairs

2.5.1 Type I Defect Repairs
Type I Defect repairs are repairs to substrates with non-through-wall defects. The short-term pipe spool survival test (ISO 24817 Annex C) data should be used to determine the maximum percentage wall loss allowed for the repairs.

2.5.2 Type II Defect Repairs
Type II Defect repairs are repairs to substrates with through-wall defects.
For all repair classes, the following test data should be used for repairs to substrates with through-wall defects:
- Fracture toughness parameter (ISO 24817 Annex D)
- Impact test for determination of the minimum acceptable laminate repair thickness (ISO 24817 Annex F)
- Degradation factor (optional) (ISO 24817 Annex G)

2.6 Repair System Requalification
If the repair system is changed or modified, the testing specified in ISO 24817/7.6.2 (Type I defect repairs) or ASME PCC-2/3.6.1 (Type I defect repairs) or ISO 24817/7.6.3 (Type II defect repairs) or ASME PCC-2/3.6.2 (Type II defect repairs) should be completed.

3 ABS Certification
Materials and components tested in accordance with this Section may be certified by ABS with ABS Product Design Assessment certificate or Product Type Approval certificate.
CHAPTER 2 Composite Repairs of Piping

SECTION 4 Repair Installation and Quality Assurance

1 General

The detailed repair specification and procedures should be provided for the process of the piping system repair installation and inspection. The repair design, installation, or inspection should be done by personnel qualified and certified for the job and the repair technology in accordance with approved/agreed installation procedures (see 1-1/2). The attending ABS Surveyor should verify that the quality assurance and documentation are done appropriately, as recommended in 2-4/6.

2 Repair Specification

2.1 General

Prior to the application of the repair system, specifications on repair method selection and installation procedures for surface preparation and repair application, hold point inspection, and installer and inspector qualification should be agreed between the parties and reviewed by ABS.

2.2 Scope of Work

The details of status and condition of the piping component for repair and the repair design condition should be provided.

2.3 Piping Repair Design Details

The piping design details should include drawings of the planned repair, thickness and dimensions of the repair, and cure schedule.

2.4 Installer and Inspector Qualifications

Installation personnel and inspectors should obtain the required level of training and certification for the specific repair method.

2.5 Repair Method and Repair Procedures

The repair method and installation procedures/instructions should be provided by the repair system supplier. The installation procedure should include specific installation instructions for the repair method. See 2-4/3 for details.

2.6 Health, Safety and Environmental

The repair system supplier should provide a list of materials used and their Material Safety Data Sheets (MSDS). The supplier also should provide a list of hazards associated during the repair and information for complying with national regulations (e.g., EPA, OSHA). Details of personal protective measures should also be provided.
3 Installation Procedure

3.1 General
Installation procedures should be provided by the repair system supplier and implemented by a qualified installer. The inspection should be done by a qualified inspector during after the repair system is installed. The installation procedures should include the following (2-4/3.2 through 2-4/3.9) for all repair classes. Additional requirements are indicated for repair Class C.

3.2 Materials Used for Repair
The repair system supplier should provide the material safety datasheets and the technical data sheets for the materials used in the repair, including instructions for materials storage and handling. The materials used for the repair should be stored and handled in accordance with the material supplier's recommendations/instructions. See 1-5/6.

3.3 Environment for Repair Installation
Acceptable environmental conditions for surface preparation, repair system application, and curing, such as relative humidity, dew point, air temperature, substrate surface temperature during the repair and curing should be specified in the procedures.

The repair system supplier should provide information and procedures for the disposal of unused chemicals, resins, and waste with consideration of local city and state regulations. Refer to 1-3/2.6 for information on repair consideration.

The installer should check for compliance with related regulations, and the installation supervisor should monitor the compliance.

3.4 Repair Detail
Repair details should include location, dimensions, and extent of repair. The installer should check the repair details.

3.5 Surface Preparation
The piping substrate should be inspected before the repair system is installed.

The repair area should be free of sharp changes. Sharp edges/changes should be at least 2 mm (0.8 in.) in radius. The substrate surface preparation (cleanliness and roughness), surface temperature, and defect treatment should be in accordance with the design.

Surface preparation should include specifications of defect treatment and surface preparation grades for the surface area specified. The surface area to be prepared should extend at least over the whole surface onto which the repair laminate is to be applied and be in accordance with the specific repair system specifications.

Prepared surfaces should be assessed for roughness and cleanliness (visible and non-visible) immediately before the application of the repair laminate by using SSPC or ISO standards. The time period between surface preparation and initial coating/laminate application should be as short as possible to avoid contamination and corrosion. Prepared surfaces should be protected from contamination prior to the application of the repair laminate. Prepared surfaces that have deteriorated should be rejected.

Any chemicals used for surface preparation should be agreed upon by the repair system supplier.

The surface preparation method should be recommended from the repair system supplier. Refer to 1-5/3 for details.

Class C repairs should have inspection specification and inspection testing data on surface cleanliness and roughness profile. Class C repairs also should have a soluble salt limit and inspection testing data.

An installer and the inspector should check the surface preparation. The installation supervisor should monitor the surface preparation.
3.6 Laminate Lay-up

The laminate ply should be applied with correct fiber orientation relative to the substrate geometry as specified. An acceptable alignment tolerance should be specified in the installation procedure.

Information provided in 1-5/5.3 can be referred to for on-site lamination. Laminate application information should include the following:

- Details of in-fill to achieve a smooth outer profile prior to the application of the repair laminate
- Primer preparation and application
- Details of resin mixing, laminate lay-up and wetting, number of wraps, and orientation and sequence of individual layers of reinforcement.
- Details of overlap, taper, and taper length
- Finishing layer/coating (top coat)

Class C repairs should have lamination specification, inspection/verification, and documentation.

The installer/inspector should check each step of the laminate lay-up process. The installation supervisor should monitor the laminate installation.

3.7 Cure and Post-cure

The cure temperature and cure time of the repair system should be controlled to obtain sufficient bonding strength in accordance with the resin technical datasheets. This information should be specified in the fabrication procedure.

The cure schedule should be specified and demonstrated to meet the necessary $T_g$ value. Shore or Barcol hardness tests may be used as a field measure of cure and should be $\geq 90\%$ of the minimum value from the repair system qualification tests.

The cure of a repair laminate depends on the curing temperature and the correct mixing of resin components. The curing temperature (including a post-cure heating when specified) and time should adhere to the repair system supplier’s guidance. The limits in the installation instructions provided by the repair system supplier should not be exceeded without approval from the repair system supplier.

If the piping system pressure has been reduced during repair, the repaired system should not be returned to its normal operating pressure until a satisfactory cure has been achieved.

The installer and inspector should check the curing process. The installation supervisor should monitor the curing process and verify the hardness test results.

3.8 Inspection, Testing, and Quality Assurance of the Repair

A quality assurance (QA) plan and details of hold points for inspection and testing should be specified. QA inspection should be performed by qualified personnel (installer, inspector, and supervisor).

Quality assurance should include details of hold/inspection points during the repair system application, details of any materials tests specified by the owner or the repair system supplier, and details of any pressure system tests.

The results of the tests on the repair laminate should be compared with the qualification data. Acceptance values of the test results should be provided by the repair system supplier prior to repair system installation.

3.9 Live Repair

Repairs to non-leaking, live process systems are possible, provided that the associated hazards are fully considered in the risk assessment for the operation. This should include any hazards to and from surrounding equipment, in addition to the component being repaired.
4 Inspection and Testing after Installation

4.1 General
This Section provides guidance on the testing and inspection during and after the repair system is installed, including:
- Inspection of the repair materials, including the repair laminate
- Inspection of the bond between the repair laminate and piping substrate
- Inspection of the substrate underneath the repair laminate
- Schedule of examination
- Pressure testing

Refer to 2-5/2 for inspection methods and 2-5/3 for in-service maintenance of the repair system.

4.2 Recommended Maximum Defects
After installation, the repair system should be inspected in accordance with the recommended acceptance limits given in 2-4/Table 1. Defects that exceed the limits should be removed and a new repair system should be applied, unless the remedial repair of the repair system can demonstrate full performance restoration of the repair system in accordance with 2-5/3.4 below.

### TABLE 1
Recommended Limits for the Repair after Installation and In Service

<table>
<thead>
<tr>
<th>Inspection Part</th>
<th>Defect</th>
<th>Acceptance Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface pipe and repair laminate</td>
<td>Delamination</td>
<td>Not allowed</td>
</tr>
<tr>
<td>Repair laminate</td>
<td>Fiber orientation</td>
<td>As specified</td>
</tr>
<tr>
<td></td>
<td>Thickness of the repair laminate</td>
<td>As specified</td>
</tr>
<tr>
<td></td>
<td>Delamination within laminate layer</td>
<td>Not allowed</td>
</tr>
<tr>
<td></td>
<td>Positioning the repair laminate</td>
<td>As specified and not to extend beyond the prepared surface</td>
</tr>
<tr>
<td>Prepared surface after the first resin layer applied</td>
<td>Crack, pin holes</td>
<td>Non-through layer penetration is allowed</td>
</tr>
<tr>
<td></td>
<td>Resin color</td>
<td>Uniform</td>
</tr>
<tr>
<td></td>
<td>Foreign mater and blisters</td>
<td>Maximum 10 mm (0.4 in.) in width and 1.5 mm (0.6 in.) in height</td>
</tr>
<tr>
<td></td>
<td>Pits</td>
<td>Maximum 25 mm (1 in.) in diameter and 1.5 mm (0.6 in.) in height. No limit for depths less than 1 mm (0.4 in.)</td>
</tr>
</tbody>
</table>

4.3 System Testing
When needed, system pressure testing should be specified by the owner. System pressure testing should be to Maximum Allowable Working Pressure (MAWP). A service test (hydrostatic or pneumatic test in accordance with the system) of not less than 1.0 times the Maximum Allowable Working Pressure (or the maximum pressure indicated on the set point of the relief/safety valves) should be performed on board for a period of at least 60 minutes over which any changes in pressure and temperature should be recorded.

System pressure testing should be completed if necessary or as recommended based on the relevant pipe design standard, such as 4 6 2/7.3 of the Marine Vessel Rules may be referenced.

Before commencement of pressure testing, all repairs should be fully cured in accordance with their repair system supplier instructions.
5 Repair Documentation (Technical File)

A record for each repair, with a unique identifier assigned, should be made and retained for the repair life.

Repair documentation after completion of the repair should include:

- Installation Specification as described in 2-4/2 above
- Installation Procedure and Instructions as described in 2-4/3 above
- Design records, such as design data and calculations, location of repair, layers and orientation of reinforcement, number of layers, axial extent of repair, preparation procedure, cure procedure, and post cure
- Material records, such as repair system supplier, polymer resin type and quantity, reinforcement type and quantity, and batch numbers for materials
- Quality control records, such as visual inspection report, thickness measurement, repair dimensions, installer, Barcol or Shore hardness measurement (if specified), and $T_g$ measurement (if specified)
- The details of future service inspection intervals

6 Installation Inspection

The installation procedure should cover surface preparation, environmental conditions, curing conditions, and testing after installation with associated allowable limits for installations/lamination. Inspection and documentation should be carried out by a qualified and certified inspector. A QA/QC system is in place and covers each step documented and signed off by qualified and responsible personnel.

The attending ABS Surveyor should:

- Verify installer’s qualification and certification for the repair technology
- Verify Inspector’s qualification and certification for the repair technology
- Verify repair material storage condition and materials certification
- Monitor surface preparation for meeting cleanliness and roughness requirement before installation
- Monitor during lamination installation process, and curing condition
- Verify NDT inspection after installation, see 1-5/2
- Verify inspection documentation
Chapter 2  Composite Repairs of Piping

Section 5  Inspection, Survey, Monitoring and Maintenance

1 General

ABS survey includes the piping repair system certification survey, the repair installation survey, and the in-service survey.

ABS survey in certification of the piping repair system is a part of the ABS Type Approval program and verifies that the repair system and the materials used for repairs are tested by a nationally or internationally accredited test laboratory in accordance with recognized industry standards, as recommended in Chapter 2, Section 3.

The repair installation survey verifies and monitors that the repair installation and inspection are carried out in accordance with the approved installation specification and procedures. The repair installation and inspection should be carried out by qualified and trained personnel. The composite repair QA/QC system should be in place and cover each step documented and signed off by qualified and responsible personnel, as recommended in Chapter 2, Section 4.

The in-service survey should be included in the Class survey plan. An in-service inspection strategy and inspection procedure, which may include a remote monitoring/inspection system and guidance on defect investigation and control, should be prepared for the repair. The inspection strategy and inspection interval should be reported to ABS or other relevant authorities and entered into the unit’s survey plans. The survey plan should have the location and extent of the repair available during subsequent surveys.

The information on the inspection strategy and inspection interval should be included in the unit’s In-Service Inspection Plan (ISIP).

2 Inspection Methods

Defects or damage are not always visible to the naked eye and are best detected by suitable nondestructive inspection (NDI) methods.

The repair system supplier should provide guidance on inspection methods for the repair system installed. The inspection technology company may also provide guidance on the methods used. The inspection methods may be used after completion of the repair system installation or in service.

A tapping test may be utilized to identify delamination and voids in the cured laminate that sound hollow in comparison with a solid area. In the tapping test, the surface of the structure is tapped by hand using a hard, blunt object such as a tapping hammer [less than 60 g (2 oz)], sounding wand, or a coin. This method is often used as the first inspection method, which may be followed by other NDI techniques.

An advanced ultrasonic technique is the Dynamic Response Spectroscopy (DRS) method, which can be used for corrosion mapping through composite repairs. DRS uses a probe to excite the steel with a range of low ultrasonic frequencies and to determine the steel thickness profile from the steel responses. Where delamination-type flaws exist in the repair, the signals cannot travel into the steel. DRS detects these flaws by loss of response from the steel.
3 Repair System Maintenance

3.1 General
The maintenance plan of the repairs and the frequency of inspection should be determined by the risk assessment of the repair system installed. The risk assessment includes the repair system selected, installer qualification, QA on material and installation process, nature of the defects repaired and post-installation inspection/testing.

Defect repair of the repair system in 2-4/4.2 above is recommended.

When a coating covers the ends of the repair, the coating should be in good condition. If there is no coating over the ends of the repair, the pipe substrate should be in good condition. If corrosion is visible at the ends of the repair, re-assessment for service fitness should be considered.

3.2 External Defects
Good integrity of the repair system can stop further deterioration of the external defects repaired. Periodic inspection and appropriate maintenance should be performed to maintain the laminate and adhesion to the substrate intact during the designed service life.

With the additional consideration of internal corrosion for Class C repairs, inspection of the pipe beneath the repair system by using inspection techniques recommended by the repair system supplier and inspection companies may be necessary. See 2-5/2 for inspection methods.

3.3 Internal or Through-wall Defects
In addition to 2-5/3.2, the inspection and maintenance plan should be provided to make sure that the internal defect is within the limit of the repair design. Again, inspection of the pipe beneath the repair system as recommended in 2-5/3.2 may be necessary for Class C repairs.

3.4 Maintenance and Repair Options
If the repair system will be replaced, the following options are recommended:

i) Completely remove and replace the repair system. The removal of the repair system may be achieved by mechanical means, such as abrasive blasting or high pressure waterjetting.

ii) Repair the damaged laminate only for a new repair design.

iii) Local repair of repair system defects, such as delamination at the end of the repair, as listed in 2-4/Table 1.

3.5 Schedule of Examination
The repairs should be examined on a regular basis as laid out in the Technical File for each repair. When each repair is examined or tested, the results of the examination should be recorded in the Technical File for future reference. The list of items repaired should be maintained for reference during Class surveys. The Owner should consider including the repairs in the unit’s maintenance system for ease of tracking of scheduled examinations and results of examinations.

3.6 Life Extension of the Repair System
3.6.1 Class A and Class B Repairs
If failure of the Class A or Class B repairs could cause a leak of the carried fluid but would not be harmful, the repairs can be examined in situ to determine if they are suitable to be left in place. If leakage of the carried fluid is harmful, a Class C repair (see 2-5/3.5.2) should be used.
3.6.2 Class C Repairs
It is recommended that the original Class C repair be re-validated for any life extension up to a maximum of 20 years. Re-validation of the repair system is performed by re-designing the repair based on the necessary lifetime and the current inspection/assessment data of the original repaired area/defect. The re-design may specify the need for extra layers of repair material over the existing repair.

3.6.3 Modification of the Repair System
An existing repair system may be modified or upgraded by adding additional repair length or thickness with a compatible system to offset additional corrosion. This modification should only be done after a design reassessment is performed.

4 System Testing
When piping pressure testing is specified by the owner after maintenance or repair of the piping repair system, refer to 2-4/4.3.