Requirements for

Bonded and Composite Repairs of Steel Structures and Piping

November 2022

REQUIREMENTS FOR

BONDED AND COMPOSITE REPAIRS OF STEEL STRUCTURES AND PIPING
NOVEMBER 2022

American Bureau of Shipping
Incorporated by Act of Legislature of the State of New York 1862

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Foreword

These *Requirements for Bonded and Composite Repairs of Steel Structures and Piping* provide classification requirements for marine vessels and offshore units where bonded and composite repair methods provide a suitable repair solution for deteriorated steel structures or piping at construction, conversion, or renewal. It is based on and replaces the previous ABS *Guidance Notes on Composite Repairs of Steel Structures and Piping*. In this document, reference to “bonded and composite repair” encompasses bonded steel plate repair and FRP laminate repair.

For repairs to steel structures, this document covers bonded and composite repair systems: the adhesively bonded steel plate systems and the fiber reinforced plastics (FRP) laminate systems. The adhesively bonded steel plate system installs a reinforced steel plate as reinforcement over a damaged substrate. The adhesively bonded composite system attaches the FRP laminate as reinforcement to the damaged substrate.

This document is not a substitute of the renewal requirements of ABS *Rules for Survey After Construction (Part 7)* or other applicable ABS Rules. The repair for steel structures exceeding the wastage limit is to comply with the survey requirements in the aforementioned Rules. The additional requirements for bonded and composite repair are defined in this document.

This document becomes 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 is the most current.

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

REQUIREMENTS FOR

BONDED AND COMPOSITE REPAIRS OF STEEL STRUCTURES AND PIPING

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Bonded and Composite Repairs of Steel Structures

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CHAPTER 1

Bonded and Composite Repairs of Steel Structures

SECTION 1

General

1 Scope and Applicability

The bonded and composite repairs in this Chapter include using adhesively bonded steel plate or fiber reinforced plastics (FRP laminate) to reinstate the strength of degraded structural members. In general, the degraded structure suitable for bonded or composite repair in accordance with this document includes general corrosion, or local pitting and grooving. The structural repair with bonded or composite material is to be considered only for local repairs of base material. If the hull-girder strength is to be restored, the effective longitudinal continuity of the bonded or composite repair throughout main supporting members and transverse bulkheads is to be provided. Therefore, the overall wastage of the structure caused by corrosion is analyzed to confirm that the required structural intervention can be considered as local.

Bonded or composite repairs are generally not to be used for crack repairs. Repairs for cracks are limited to noncritical structural members and limited to repair products with sufficient bonding layer stiffness. In addition, repairs for cracks may be considered if the repair reinforcement is extended over the span of the stiffeners in the longitudinal direction or the spacing of the web frame in the transverse direction. The procedure to determine if the damage is eligible for repair using the bonded or composite patches method is given in 1-2/2.

Bonded or composite repairs are not to be considered to increase remaining fatigue life.

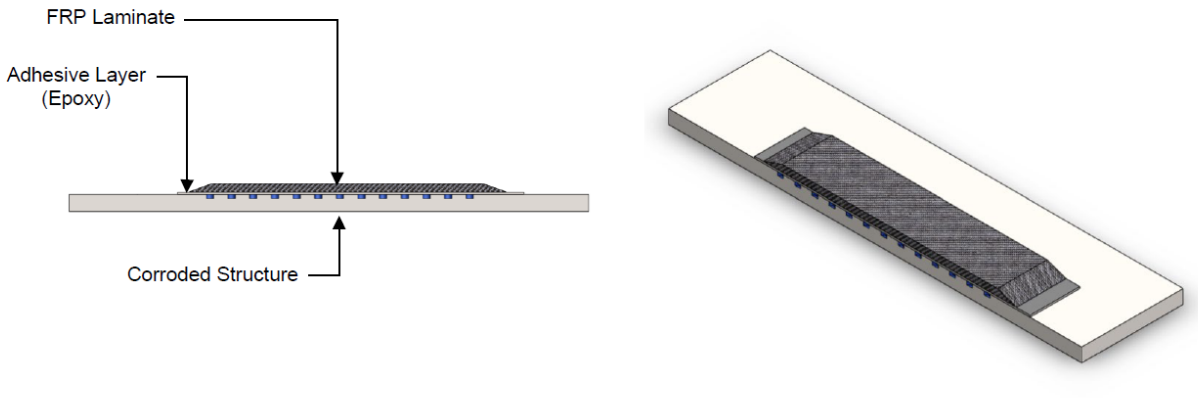
This document provides an alternative to traditional renewal, where hot work or other factors may have a negative impact on the safety of an offshore unit or a vessel. Instead of using traditional hot welding, an existing degraded steel structure can be repaired to restore the capacity of the structure by utilizing patches of steel plates or FRP laminates that are adhesively bonded to the degraded steel structure. See 1-2/5.

This Chapter provides requirements on adhesively bonded or composite repairs of steel structures. It covers assessment, design, qualification, installation, and inspection of a bonded repair.

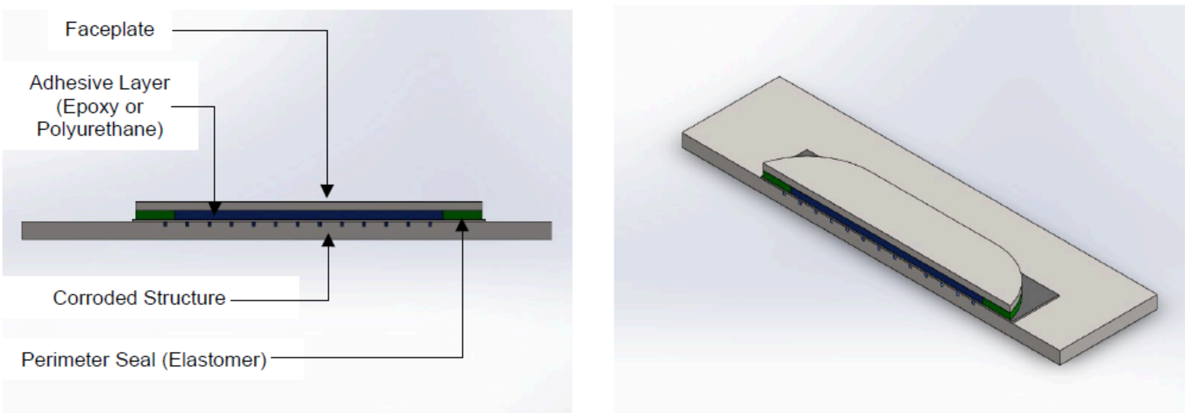
This Chapter refers to the ABS *Rules for Building and Classing Floating Production Installations (FPI Rules)*. However, for other vessel/unit types, reference may be made to similar sections of other applicable Rules (i.e., *Marine Vessel Rules*, *MOU Rules*, etc.).

1-1/Figure 1 represents the configuration of a bonded patch repair. This repair technique can also be used for modification or reinstatement of existing structures by reinforcing structural elements to provide additional strength or arrest wastage by corrosion. 1-1/Figure 1a represents a repair system including corroded structure, adhesive layer (epoxy) and FRP laminate as reinforcement. 1-1/Figure 1b represents a repair system including corroded structure, perimeter seal/elastomer, adhesive layer (epoxy/polyurethane), and steel plate as reinforcement. 1-1/Figure 1c represents a repair system including corroded structure, perimeter member (bar), bonding layer (elastomer), and steel plate as reinforcement, which is described in AMPP SP21507. Note that there are additional requirements for this the type of repair in the AMPP document.

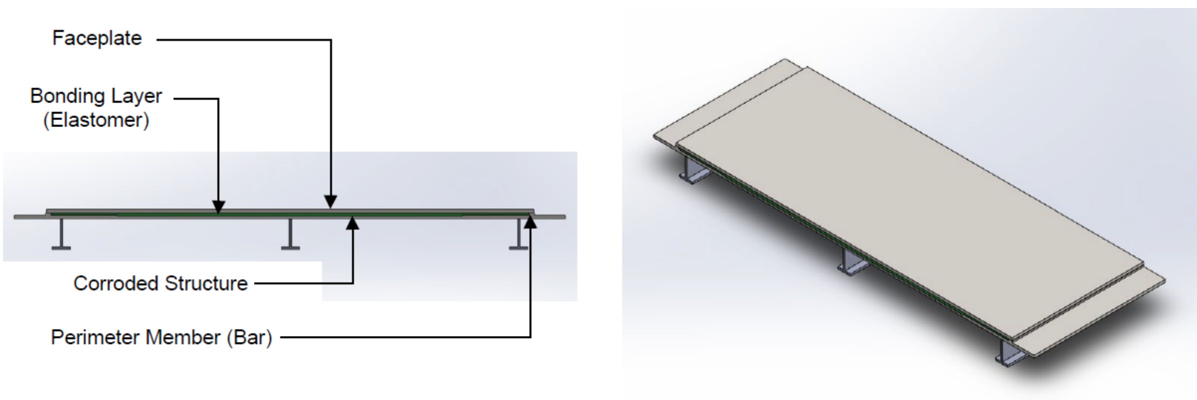
FIGURE 1
Examples of Bonded and Composite Repair for Corroded Substrate Structure



(a): Repair System – Corroded Structure, Adhesive Layer (Epoxy), FRP Laminate



(b): Repair System – Corroded Structure, Perimeter Seal (Elastomer), Adhesive Layer (Epoxy or Polyurethane) and Faceplate



(c): Repair System – Corroded Structure, Perimeter Member (Bar), Bonding Layer (Elastomer) and Faceplate

2 Personnel Qualification

Personnel engaged in the installation of the repairs are to be qualified by the manufacturer and documented showing practical experience by a quality management system. The Surveyor is to be satisfied that personnel responsible for conducting bonded or composite repairs are thoroughly familiar with the equipment and materials being used and that the technique and equipment used are suitable for the intended application. For each bonded or composite repair method, personnel are to be qualified by training, with appropriate experience, and documented to perform the necessary inspections and tests and to interpret and evaluate repairs in accordance with the terms of the specification.

The FRP laminate installer is to receive relevant training to possess appropriate competence in the lamination process.

The personnel responsible for conducting inspection or test (such as tap testing for adhesive injection) are to comply with the recognized standards or practices, as applicable.

The bonded and composite repair installation process can be manual. Thus, the quality of the adhesively bonded steel plate or FRP laminate repair is directly dependent upon the skill and experience of the personnel performing the repair. The repair procedure documentation is to be provided, including personnel certificates and other relevant information, to verify that the personnel performing the repair and inspection are qualified for the job and the repair technology.

If welding to the hull is required, welding procedures and welders are to be qualified by ABS in accordance with Appendix 2-A9 and 2-A11 respectively, of the ABS *Rules for Materials and Welding (Part 2)*.

3 Risk Assessment

Risk assessment is required for repair of critical structural members defined in 1-1/6, where failure of the repair may lead to pollution, flooding, fire, or explosion, or may compromise the global strength of the vessel/unit. Considerations to be included in risk assessments for bonded or composite repair are provided below for critical structures and long-term repairs. Refer to the ABS *Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries* for other applicable considerations.

i) The nature and location of the damage or wastage

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, environmental conditions such as temperature, and exposure to chemicals and water)

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

v) Hazards associated with repair installation and in-service operation

vi) Repair installer skills, surface preparation quality, and repair environment such as temperature and relative humidity

vii) Repair system materials selected

viii) Repair life expected (refer to 1-2/2)

ix) In-service inspectability and inspection interval (refer to 1-6/6.2)

x) Failure modes of bonded or composite repairs as introduced in 1-1/3.1.

3.1 Failure Modes of the Bonded and Composite Repairs

3.1.1 General

Failure modes are dependent upon the type of repair. The relevant failure modes of bonded and composite repairs are to be considered in the repair design. The primary failure modes are debonding, laminate patch, and substrate failures.

3.1.2 Debonding

3.1.2(a) Bonding Layer Cracking

When a crack of the substrate is repaired, a crack can initiate and develop very quickly through the thickness of the bonding layer, just above the crack to be repaired. This crack of the bonding layer is arrested when it reaches the reinforced patch.

3.1.2(b) Bonding Layer Fatigue and Debonding Propagation

When the repaired component experiences a cyclic load, a debonding crack may initiate and propagate in the bonding layer, thus partially separating the patch from the substrate.

3.1.2(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.

3.1.2(d) Bonding Layer Shear Fracture

If shear loading transmitted to the patch exceeds the shear capacity of the bonding layer, the bonding layer may fracture, resulting in failure of the repair.

3.1.2(e) Blistering

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.

3.1.2(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 is close to the adhesive's glass transition temperature, T_g.

3.1.2(g) Bonding Layer Property Changes Due to the Service Environments

Temperature, UV exposure, 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.

3.1.2(h) Substrate Corrosion

When the bonding layer is exposed to a corrosive environment, corrosion on the substrate behind the patch repair can occur and can cause premature failure of the bonding layer.

3.1.3 Laminate Patch Failure

3.1.3(a) Laminate Matrix Cracking

If the strain or stress in the patch exceeds a critical level, cracks in the laminate matrix may initiate and propagate, which can cause failure of the repair.

3.1.3(b) Laminate Patch Fracture

If the load transmitted by the laminate patch exceeds the capacity of the patch, it may cause fracture and failure of the repair.

3.1.4 Substrate Failure

The load reduction produced by the reinforcement may be insufficient to prevent the unacceptable spread of damage in the substrate (e.g., where continued cumulative corrosion, reduces the substrate thickness, and consequently, loads exceed allowable limits).

4 Bonded Composite Repair Procedure

A typical bonded or composite repair procedure and the documentation required for each implementation stage are illustrated in 1-1/Figure 2.

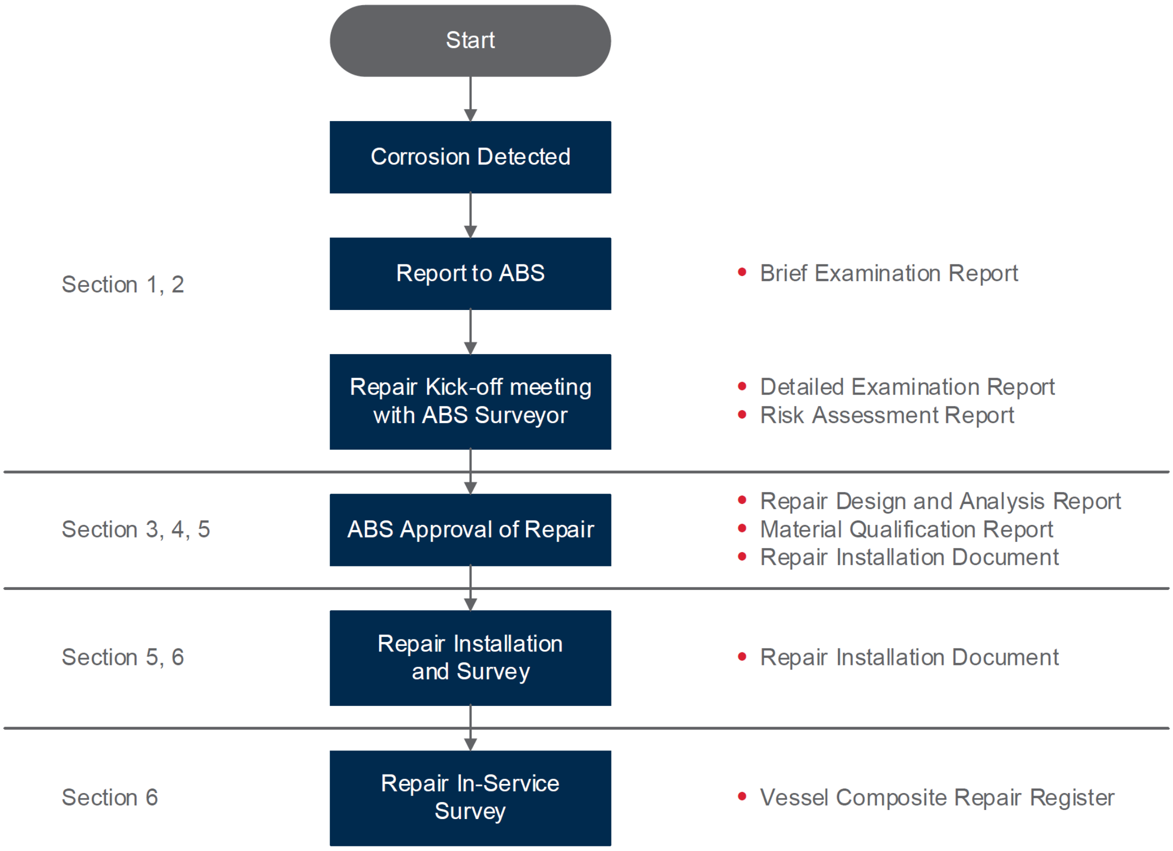
Should the owner or operator wish to utilize a bonded or composite repair, the damage is to be detailed in an inspection report, and this report is to be reviewed by ABS Engineering to determine whether the bonded or composite repair or traditional repair method is appropriate. The decision-making process on bonded or composite repair is to be followed in accordance with 1-2/2. For long-term and critical structural member repair, the risk assessment report is to be documented, submitted by the manufacturer/owner, and approved by ABS Engineering. Then, the manufacturer/owner is to initiate a bonded or composite repair kick-off meeting with the ABS Surveyor for the detailed damage repair.

ABS approval of the use of bonded or composite repair is granted provided that the repair design can sufficiently reinstate damaged structure such that the integrity and service capacities of bonded or composite repair will comply with Class requirements. The documents required for ABS review and approval include, in addition to the Risk Assessment if applicable, a Repair Design and Analysis Report, Material Qualification Report, and Repair Installation Document.

The ABS Surveyor is to witness the bonded or composite repair installation process and subsequent quality testing in accordance with the ABS approved repair installation document, which contains the Repair Specification and Installation Plan to instruct installation procedures and the Repair Completion Quality Report to record the quality testing results at the completion of the repair installation.

In-service surveys are to be conducted periodically to verify the integrity and service capacities of the bonded or composite repair are still in compliance with the Class requirements. A Vessel Composite Repair Register is to be used for tracking the conditions of the composite repair throughout its lifetime.

FIGURE 2
Bonded and Composite Repair for Corroded Substrate Structure



5 Documentation for Review

A bonded or composite repair booklet is to be developed to collect a series of documents required by ABS for review prior to, during, and after the installation of the composite repair. The booklet is to include:

i) *Inspection Report*, covering the examination results of a damaged structure with respect to corrosion, erosion, and/or fatigue cracking and providing corresponding information as specified in 1-2/3. The inspection report is to be submitted by the owner to the ABS Survey Department for their verification that the inspection report duly represents the on-board conditions during survey. The inspection report, including the references to the survey report and details of the inspected areas, is to be kept on board and submitted to ABS Engineering for review.

ii) *Risk Assessment Report*, covering the risk assessment results for potential failure modes such as de-bonding, patch or substrate failure, and materials degradation, whenever applicable. Details are provided in 1-1/3.

iii) *Repair Design and Analysis Report,* covering the design basis, qualification results and design calculations. The report is to document all relevant information collected and all identified issues addressed in the design input, strength analysis, and fabrication. Details are provided in 1-3/6.

iv) *Material Qualification Records*, covering the material testing records for the required components and/or assembly of repair system. Details are provided in 1-4/7.

v) *Repair Installation Documentation*, consisting of Repair Specification and Installation Plan, fabrication procedure, and Repair Completion Quality Report to cover the detailed installation and inspection specifications, including the fabrication/installation procedures, QA/QC manual, installer qualification and inspector qualification. Details are provided in 1-5/2 and 1-6/5.

vi) *Vessel Composite Repair Register (VCRR),* documenting the identification of the repair, location, repair lifetime, associated maturation year, survey intervals, maintenance record, inspection method, and inspection result records. Details are provided in 1-6/6.

6 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 measurement of the hardness of a laminate and thereby the degree of completion of the cure.

Bond Layer. The adhesive layer between the patch surface and the substrate surface. It may be primer layers, if any.

Bonded Repair. A repair system encompassing bonded steel repair or bonded FRP laminate repair.

Critical Structural Member. For application of this document, a structural member or an area within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. Refer to *FPI Rules* 3-3-A1/7 for all installations, 5A-3-4/13 for ship-type installations, and 7-2-3/3.5 for non-ship-type installations.

Cure/Curing. The transition of resin from a liquid to a solid.

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

Curing Time. The time required for resin to change from a liquid to a solid after a catalyst has been added.

Debonding. Separation along the bond layer.

Delamination. The separation of the layers of material in a laminate.

Elastomer Core. A material that 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 is achieved.

Fiber Reinforced Plastic (FRP). 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 FRP composite materials for bonded repairs 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.

Filler. A material added to resin to modify its working properties or other qualities, or to lower densities.

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 soft and ductile material to a hard and brittle material. T_g of a material characterizes the range of temperatures over which this glass transition occurs. Unless otherwise agreed, T_g is specified by the onset temperature of the endothermal transition of the Differential Scanning Calorimetry (DSC) curve in accordance with ASTM D3418, D1356 or equivalent.

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. A material composed of successive bonded layers, or plies, of resin and fiber or other reinforcing substances.

Localized Corrosion. Relatively concentrated or spot-wise corrosion attacks on a 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 steel structures. It can be made of steel plate or fiber reinforced plastic.

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. The act of placing a laminate in an autoclave and raising the temperature to assist in the cure cycle of the resin.

Pot Life. The length of time that a catalyzed resin remains workable.

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 length of time that an uncatalyzed resin maintains its working properties while stored in a tightly sealed, opaque container.

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

Substantial Corrosion. An extent of corrosion such that assessment of corrosion pattern indicates wastage in excess of 75% of the allowable margins, but within the acceptable corrosion limits.

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.

7 Abbreviations

CFRP:	Carbon Fiber Reinforced Plastics
CIP:	Coating Inspection Program
COV:	Coefficient of Variation
DEC:	Design Environmental Condition
DSC:	Differential Scanning Calorimetry
EPA:	The Environmental Protection Agency
FEA:	Finite Element Analysis
FOI:	Floating Offshore Installations
FPI:	Floating Production Installations
GFRP:	Glass Fiber Reinforced Plastics
HDT:	Heat Distortion Temperature
IDLH:	Immediately Dangerous to Life or Health
IMO FTP Code:	IMO Fire Test Procedures Code
MODU:	Mobile Offshore Drilling Units
MSDS:	Materials Safety Data Sheet
NACE:	National Association of Corrosion Engineers
NDCV:	Nominal Design Corrosion Values
NDI:	Nondestructive Inspection
OSHA:	The Occupational Safety and Health Administration of the United States Department of Labor
OSV:	Offshore Support Vessels
QA:	Quality Assurance
QC:	Quality Control
RFL:	Remaining Fatigue Life
RIFT:	Resin Infusion under Flexible Tools
RTM:	Resin Transfer Molding
SDS:	Safety Data Sheet
SHE:	Safety, Health, and 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
VARTM:	Vacuum-Assisted Resin Transfer Molding
VCRR:	Vessel Composite Repair Register

CHAPTER 1
Bonded and Composite Repairs of Steel Structures

SECTION 2
Assessment for Repair

1 General

This Section provides the procedure for assessing the criticality of corrosion and/or fatigue cracking of steel structures to determine a viable bonded or composite repair method covered in this document. The assessment for repair is to be in accordance with the applicable ABS Rules.

The allowable corrosion or wastage limit for renewal requirements is given in the ABS *Rules for Survey After Construction (Part 7)*. The adhesively bonded or composite repair is generally not to be used on structural elements contributing to hull-girder strength if the actual hull-girder section modulus (before repair) is less than 90% of the original section modulus at new construction or conversion (refer to 7-A1-4/33 of the ABS *Rules for Survey After Construction (Part 7)*).

Commentary:

The section modulus check may be specially considered in cases where the corroded area is small (such as where the corroded area does not extend to the span of the stiffener in the longitudinal direction or the spacing of the web frames in the transverse direction) and it can be obviously discerned that the remaining hull girder section modulus exceeds 90% of the original section modulus.

End of Commentary

The actual hull-girder section modulus is to be determined by the gauged thickness. The repair plan is to be defined for each tank. The gauged thickness is to be updated and applied only for the tank that needs repair. The latest available data for other tanks that do not need repair are to be adjusted, if older than 15 months. However, reinstatement of the hull-girder strength may be specially considered, with the structural analysis report if the FE model already reflects the actual condition of the hull structure.

In addition, for restoring hull-girder strength, effective longitudinal continuity of the bonded or composite repair throughout main supporting members and transverse bulkheads is to be provided. Otherwise, the repair will be considered to restore local strength only.

The bonded or composite repairs covered in this Chapter are intended for repairs of the structural deterioration caused by corrosion (see 1-2/4) and fatigue cracking of non-critical members (limited to repair products with sufficient bonding layer stiffness, see 1-2/5). Repairs for fatigue cracks may be considered if the repair reinforcement extends over the span of the stiffeners in the longitudinal direction or the spacing of the web frames in the transverse direction. The repair of mechanical damage to steel structures caused by, for instance, grounding, explosion, and contact/collision is not covered.

It is important that any repair implemented does not accelerate the structural deterioration. This can be achieved by using best practices for design (avoiding stress risers), qualification, fabrication, inspection, and maintenance of the repair. The potential effect on the areas immediately adjacent to the repair is to be considered in case of repair failure. The repair is not to create new issues such as creating significant new loads or preventing future inspection.

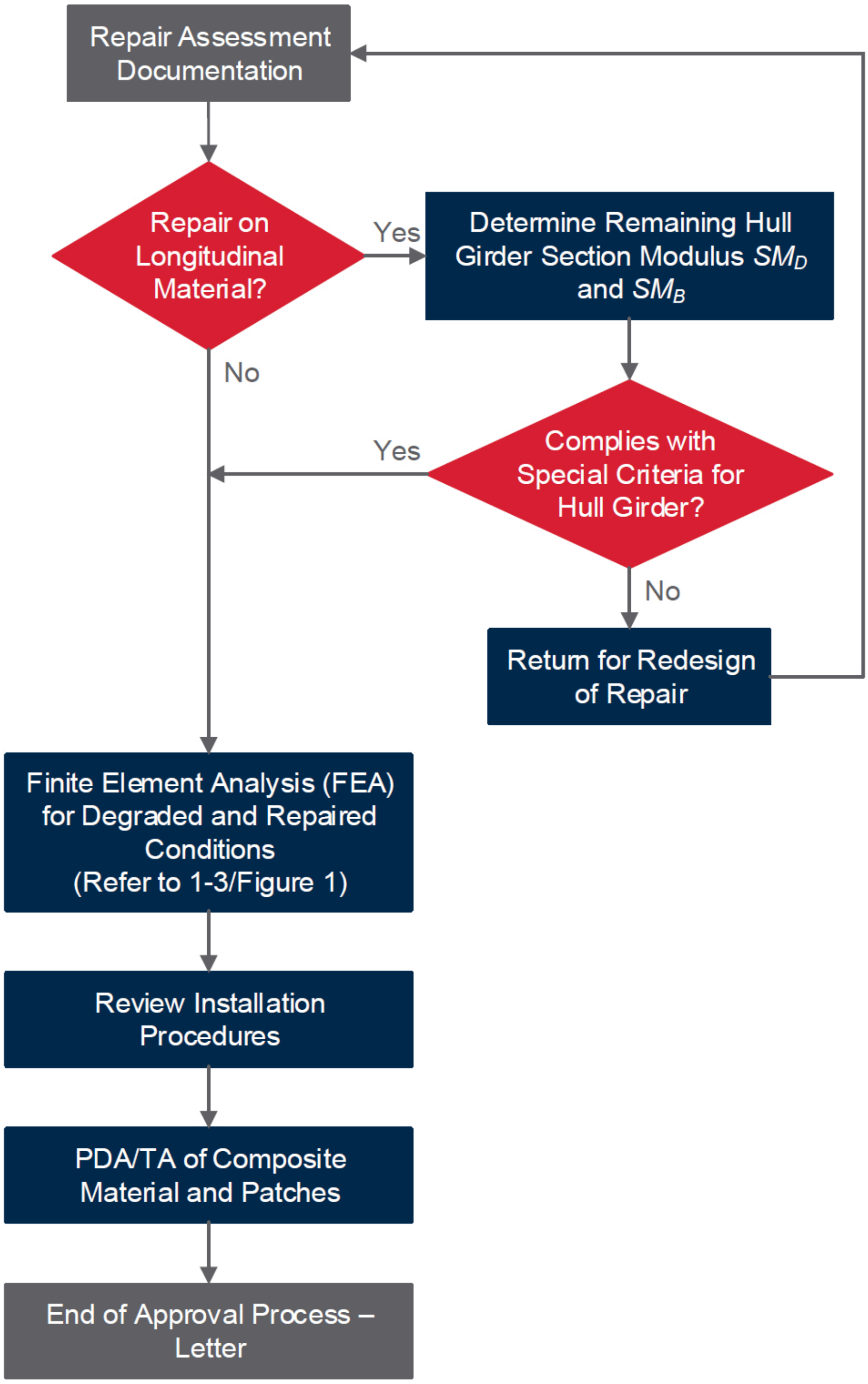
2 Decision-Making Process for Bonded and Composite Repair

When substantial corrosion or fatigue cracking has been detected and documented, the decision-making process for the selection of repair method is to follow the procedure outlined in 1-2/Figure 1, risk assessment, and the inspection report, when required. The repair assessment is to be used to determine if the composite repair system is feasible for the structural damage and to decide the repair critical/class level (see 1-1/3). The repair design life is to be defined in the Risk Assessment and supported by PDA or TA, if applicable. The repair design life (in years) is the maximum service lifetime of the repair (emergency, short term, or long term), which is to be defined by the owner in the repair design with consideration of the repair risk level, defect type, and service condition.

The repair decision-making process is to consider the criticality of degraded structural members in the asset. The criticality assessment and the measures to determine critical and non-critical members are provided in 1-2/2.iii) and iv), respectively.

- *Critical Members* are structural members or areas within the structure that may have a higher probability of failure during the life of the vessel compared to the surrounding areas, even though they may have been modified in the interest of reducing such probability. Refer to *FPI Rules* 3-3-A1/7 for all installations, 5A-3-4/13 for ship-type installations, and 7-2-3/3.5 for non-ship-type installations. Structural strength evaluation is required for critical members to verify the bonded or composite repair design for the deteriorated area satisfies the classification requirements for the original scantling design. Refer to 1-2/3.5 for structural strength evaluation. Critical members can be identified using Rule-based, experience-based, or analysis-based approaches. The methodology is applicable to both marine vessels and offshore units. Examples of critical areas include:
  - Bottom structure and bottom plating
  - Side structure and side plating
  - Deck structure and deck plating
  - Watertight or tank bulkheads
- *Non-Critical Members* are structural members excluded by critical members and typically not subject to significant loads, and the structural integrity of the original structure will not be compromised by their structural deterioration. The failure of non-critical members will not generate the risk of progressive collapse of the overall structure. Structural strength evaluation for non-critical member repairs is not required. All other requirements in this document are to be followed when bonded or composite repair products are applied to non-critical structural members. Examples of non-critical areas include:
  - Brackets
  - Stiffeners

FIGURE 1
Decision-making Process on Bonded or Composite Repair



The bonded or composite repair decision is to be made based on the structural member criticality and the structural deterioration criticality:

i) This decision-making process is solely intended for substantial corrosion (general corrosion or scattered pitting) found in steel structures, refer to the ABS *Rules for Building and Classing Floating Production Installations (FPI Rules)*.

ii) Refer to 7-A1-4/33 of the ABS *Rules for Survey After Construction (Part 7)*. If the repair comprises structures contributing to hull-girder strength, the actual hull girder section modulus (*SM*) before repair is to be not less than 90% of the original as-built section modulus at construction or the conversion approved section modulus, whichever is less. If the actual section modulus is not at least the 90% of the as-built/conversion value, a traditional weld repair is to be made, such as cutting a damaged plate and welding a new plate.

iii) A criticality assessment is to be submitted to ABS to verify the criticality of deterioration and repair priority. An inspection report is to be included to provide deterioration conditions and propose an extent of repair. See 1-2/3 for the details of the inspection report. Identification of the type of critical or non-critical members is to be made in accordance with item *iv)* below. Repair classes are to be determined to specify which qualification requirements for composite repair are to be met. See 1-2/4 for details on the repair classes.

iv) For critical members with fatigue cracking defects, traditional weld repair is to be implemented.

v) For repair of degraded structures, where the average wastage of the local structural panel exceeds the allowable limit, progressive collapses are to be avoided by controlling the non-linear elastic and plastic deformations of the structure for the most critical load case (generally design environmental condition (DEC) cases). The primary structures containing degraded parts are to withstand the critical load cases without permanent deformations by any failure mechanism or mode, away from degraded locations. If necessary, local FEA is to be developed to demonstrate that the degraded area will not induce progressive failure of adjacent structures.

vi) For non-critical members with appearance of fatigue cracking (limited to repair products with sufficient bonding layer stiffness) or corrosion that exceeds the wastage limits, the implementation of composite repair may be considered.

- It may be possible or desirable to arrest or remove fatigue cracks prior to bonded or composite repair of damaged structures found with fatigue cracking. After repair, a monitoring and inspection plan is to be established.
- For corrosion extent which has exceeded the wastage limit or may develop to such within the next inspection interval, the bonded or composite repair may be considered.

vii) Repair area for fatigue cracking of non-critical members may be considered if the repair reinforcement is extended over the span of the stiffeners in the longitudinal direction or the spacing of web frames in the transverse direction.

viii) The wastage limits for different forms of corrosion are included in 1-2/6.

ix) Whenever a bonded or composite repair is ineligible to be used, a traditional repair method is to be applied.

The location of the bonded or composite repair is to be assessed regarding the safety of the work environment. It is not to be applied in way of transit/escape routes without adequate protection for personnel. Additionally, refer to 1-3/2.4 and 1-3/2.5 for requirements of fire and electrical safety.

3 Inspection Report

The inspection report is to include the following information:

i) Unit name and ABS class number

ii) Date of the most recent inspection, which is to have been completed within 15 months of the application of the bonded or composite repair

iii) Description of corrosion, erosion and fatigue cracking and a list of the following 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

iv) ABS report including the condition of class or Additional Requirement identifying the area requiring repairs.

4 Repair Classes

Three (3) repair classes are defined by the repair qualification. The repair class is determined based on the structural member criticality, deterioration criticality, failure mechanism (see 1-1/3.1) and the repair reliability.

Class A is for non-critical member repairs. Class B and C are both for critical member repairs where the Class C repair involves the use of less conservative safety factors if sufficient material testing and load data can be provided. The repair class is to be identified, documented, and submitted for ABS review for each installation.

4.1 Class A Repairs

Class A repairs are for non-critical structural member repairs in which the design approval does not require structural analysis as indicated in 1-3/4. In the case where several non-critical structural members (refer to 1-2/2), supporting the same structure are considered to be repaired, a structural analysis is required for design approval.

Commentary:

Generic design considerations are provided below for Class A Repairs:

- If applicable, the repair patch should be balanced, and the patch edges extended and tapered to reduce stress raising at edges.
- The repair extent should be determined by corrosion information and calculation report.
- The calculated shear strength of the adhesive used for shear load transferring should not exceed that of the reinforcement patch.

End of Commentary

4.2 Class B Repairs

Class B repairs are for critical structural member repairs in which design approval is based on structural analysis with small-scale testing or component testing in absence of long-term material properties.

4.3 Class C Repairs

Class C repairs are for critical structural member repairs in which design approval is based on detailed structural analysis with sufficient information and data provided to quantify the reliability of the repair for the intended service life of the structure. The failure modes (see 1-1/3.1) during and at the end of the design life are to be estimated.

5 Bonded and Composite Repair System Types

The typical types of composite repair systems are provided in this section. However, ABS will also consider other types of repair systems provided that they can effectively reinstate the damaged steel structure and meet all Class requirements.

5.1 Bonded Steel Plate Repairs

A bonded steel plate repair system consists of a reinforcement plate and an adhesive layer used to bond the reinforcement plate with the corroded substrate structure. The reinforcement plate can be a single steel plate (see 1-1/Figure 1c) or pre-fabricated steel assembly (see 1-1/Figure 1b). It is common that certain constraint members around the repair system are installed to provide temporary or permanent support for the reinforcement plate and to form an injection cavity. A polymer adhesive layer is provided to achieve adhesive bonding and load transferring functions.

Although a reinforcement steel plate is connected to a substrate using a bonding material, the installation process may involve either hot welding, cold bonding, or bolting techniques when installing perimeter members. The selection of the installation method depends on restrictions at the repair site due to the presence of hazardous risks (e.g., flammable or explosive media).

In case of the hybrid load transfer by hot welding or bolting, a proper assessment is to be performed to evaluate the allocation of loads taken by different paths, depending on actual stiffnesses of the bonding layer materials and service environment.

5.2 FRP Laminate Repairs

The FRP laminate repair system includes an FRP laminate bonded to a corroded substrate structure where a primer may be used to fill any cavities and level surfaces (See 1-1/Figure 1a). The FRP laminate can be prefabricated, laminated ply-by-ply manually in-situ or fabricated using Vacuum-Assisted Resin Transfer Molding (VARTM) method.

The factors affecting an FRP laminate repair include:

- The characteristics of laminate (selection of constituent materials (reinforcement and matrix), fiber orientation, thickness)
- The design of the laminate (number of lamina lay-ups, orientation of each lamina, taper and size designs)
- The installation quality when bonded to the degraded substrate.

6 Temporary Repairs for Emergency

Temporary repairs are repairs made in an event of incidents or emergency conditions to maintain the functionality of structures. Such repairs, if performed beforehand without ABS approval, are to be well documented and submitted to ABS for record afterwards. Unless otherwise agreed, the repairs are to be removed within a maximum of six (6) months after installation if they do not meet the requirements of composite repairs in Chapter 1, Sections 2 to 4 or if they do not meet the satisfaction of the attending ABS Surveyor.

7 Corrosion

7.1 General

This Subsection defines the forms of corrosion and the alternatives for bonded or composite repair. As described in 1-2/2 for repair decision, a bonded or composite repair can be used for any non-critical structural member with different corrosion extents. For critical members, a bonded or composite repair is permitted when the extent of corrosion may develop to the maximum of the allowable wastage within the next inspection interval. The wastage due to corrosion is to be estimated considering the different defect growth rates before and after repair. If the maximum of the allowable wastage is to be reached before the next inspection, additional inspection or special survey is required. The composite repair of corroded structural members is to restore the capacity and/or stiffness.

Corrosion can be divided into the following categories:

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 may be accepted subject to special consideration.

ii) *Pitting Corrosion*. A form of localized corrosion, which is an attack with localized pits on the steel surface. The intensity of the pitting is to be estimated. Typically, pitting repairs include renewal of plates, building up pits by welding, or application of filler compounds such as epoxy or epoxy with glass-flake. The requirements for pitting corrosion repair of structures are equivalent to the pitting corrosion repair of machinery components, such as shaft in accordance with Appendix 7-A1-11 of the ABS Rules for Survey After Construction (Part 7).

iii) *Grooving Corrosion*. Another form of localized corrosion, which is localized material loss normally adjacent to welding joints. Special consideration of the corrosion repair may be needed as such corrosion could affect the structural strength.

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.

7.2 Corrosion Limits

For particular types of vessels and specific structures not covered in the ABS Rules, such as 5A-2-1/9.5 of the *FPI Rules* or 7-A1-4/35 of the ABS *Rules for Survey After Construction (Part 7)*, the following renewal criteria for corrosion are to be used.

7.2.1 General Corrosion – Extensive Areas of Corrosion

An *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 to be taken to confirm the extent of substantial corrosion. Where extensive areas of wastage exceed allowable margins, renewals or repairs are typically required.

Where the bonded or composite repair in lieu of steel replacement is intended to be applied to a critical structural member, special consideration is needed in accordance with 7-A1-4/35 of the ABS *Rules for Survey After Construction (Part 7)* to verify that the average remaining thickness of the degraded element is generally not to be less than 30% of the as-built thickness or reassessed ABS required scantling, if applicable, or 6 mm (0.25 in.), whichever is greater. For watertight plating, the area to be repaired by bonded or composite repair is not to have average wastage above 50% of the as-built thickness or reassessed ABS required scantling, if applicable. For non-tight structures (e.g., plate between stiffeners, stiffener webs between stiffener supports, etc.), use of bonded or composite repair for minimum scantlings less than 30% of the as-built thickness or 6 mm (0.25 in.), whichever is greater may be accepted on a case-by-case basis and subject to provision of adequate protection of the substrate steel to avoid any wastage during the remaining service life.

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

7.2.2 Acceptance Criteria for 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-A1-4/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.

i) For plates with a pitting intensity less than 20%, the minimum remaining thickness in pits is to be at least 70% of the original as-built thickness (without voluntary addition) or 1 mm (0.04 in.) less than renewal thickness, whichever is less.

ii) 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 is not to be less than the minimum thickness for general corrosion in given 1-2/6.2.1.

iii) 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 is 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-A1-4/Figure 5 of the ABS *Rules for Survey After Construction (Part 7)*

If applicable, for widely scattered pitting where the remaining thickness in pitting is not less than the value calculated above, a plastic compound filler material such as epoxy resin with glass flake or FRP composite patch may be used. When the overall wastage is sufficient to warrant renewal of the affected plate, the pitting repair using filler material is not to be used but a bonded composite repair may be considered.

7.2.3 Acceptance Criteria for Localized Corrosion – Grooving

Grooving Corrosion is typically local material loss adjacent to weld joints along abutting stiffeners or plating 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 to be 15% of the web height or 30 mm (1.18 in.), whichever is less. The allowable remaining thickness in the grooved area is to 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 grooving length is greater than 15% of the web height or 30 mm (1.18 in.), the renewal thickness due to general corrosion, t_{ren}, in 1-2/7.2.1 above, can be applied.

The accumulated length of transverse grooves in deck, bottom, longitudinal bulkhead, or side plating within the cargo area is not to be greater than 20% of the breadth of the unit. For special units with large deck openings, the accumulated length of transverse grooves in the passageway is not to be greater than 10% of the breadth. The allowable remaining thickness in the grooved area is to be taken as 75% of as-built thickness or 6 mm (0.25 in.), whichever is greater.

A bonded composite repair can be used for grooving corrosion provided the structural integrity is maintained.

7.2.4 Acceptance Criteria for 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-A1-4/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 is to be less than 25% of the flange's breath or the flat bar height, and the remaining edge thickness is not to be less than 70% of the as-built thickness or t_{ren} – 1.0 mm (0.04 in.), whichever is less, refer to 7-A1-4/35.1.3(b) of the ABS *Rules for Survey After Construction (Part 7)*. The average thickness of the breadth or the web height uses the minimum thickness due to general corrosion from 1-2/7.2.1.

A bonded composite repair can be used for the repair or reinforcement of corroded edges provided the structural integrity is maintained.

8 Fatigue Cracking of Non-Critical Structural Members

A bonded or composite repair of fatigue cracking is acceptable only for non-critical structural members using repair products with sufficient bonding layer stiffness and is to be supported by PDA or TA, if applicable. Fatigue cracks are to be arrested prior to composite repair of damaged structures found with fatigue cracking. The FRP composite patch repairs may be used to improve fatigue cracking resistance by:

- Reducing stresses to a level where the crack propagation is stopped.
- Reducing crack growth rate to an acceptable level with consideration of the intended lifetime of the repair.
- Arresting the crack where the crack size is acceptable by fracture mechanics and inspected to verify no crack growth has occurred at a later date.
- Protecting damaged structures from exposure to hazardous environments such as moisture, water, chemistry, which may assist crack growth.

The configuration and placement of the FRP composite patch relative to the crack are important, and efficient crack monitoring is to be feasible.

Commentary:

Repair area for fatigue cracking of non-critical members may be considered if the repair reinforcement is extended over the span of the stiffeners in the longitudinal direction or the spacing of web frames in the transverse direction.

End of Commentary

CHAPTER 1
Bonded and Composite Repairs of Steel Structures

SECTION 3
Bonded and Composite Repair Design

1 General

The bonded or composite repair system as covered in this document consists of a patch (a steel plate or a FRP laminate), a metallic substrate with defects, and an adhesive layer used to bond the patch and the substrate together, as shown in 1-1/Figure 1. The repair design is to address all three components and their interfaces, and the following items are to be considered:

- The reliability of the repair which is assessed by its capacity to resist the effects of design loads (see 1-3/2.2) and environment (see 1-3/2.3).
- Repair classes in accordance with criticality of structural member (see 1-2/4).
- Repair design, considering the repair life associated with each phase: i) during the installation and ii) during the operation.
- Loading condition of the structure for application of the repair (see 1-3/2.2).
- The allowable strength and applicable safety factors (see 1-3/3).
- Specified material strength/properties (see Chapter 1, Section 4).

This section provides design requirements concerning design objectives, allowable stress criteria, structural analysis, strength checks, and the analysis reports required to be submitted to ABS.

2 Bonded or Composite Repair Service Capacities

2.1 Service Life

The purpose of a bonded or composite repair is to restore and maintain the service capacities of the original structural component over its remaining service life. As applicable, the service capacity requirements may include:

- Load carrying capacity
- Cyclic load endurance
- Stiffness requirements
- Resistance to chemicals and fluids
- UV resistance

- Temperature properties
- Fire endurance, if applicable
- Explosion and blast capacity, if applicable
- Corrosion, erosion, and wear resistance, if applicable
- Vibration stability, if applicable
- Dimensional stability
- Fluid/cargo containment and tightness
- Electric continuity
- Overall service life from the combined effects

Other factors related to arrangement are to be considered for bonded and composite repair design including:

- Tripping hazards in access way or egress route
- Blockage of drain path, cargo or tank washing liquid flow
- Accessibility for inspection

If applicable, the design life of the repair is to be at least the same as the remaining design life of the structure to be treated for long-term repairs and maximum 2 years for short-term repairs. A shorter life, maximum 2 months, may be used for temporary or emergency repairs that are to be replaced by a permanent repair as agreed to by ABS.

The achievable repair life is affected by the environment, corrosion/erosion mechanisms, and external mechanical influences. The corrosion/erosion rate of the opposite side of the repaired area is also to be estimated during the repair design.

2.2 Loads

The bonded or composite repair is to withstand the static, dynamic, and fatigue loads in the design of the repair, including but not limited to:

- Loads from dead weights
- Loads from mechanical equipment
- Loads from loading and unloading from ballast water and storage tanks
- Loading condition of the structure for application of the repair
- Weight of bonded or composite repair patch and other parts of the structure
- Environmental loads (wind, waves, current, tidal, ice, snow, and temperature variation)
- Global loads, if applicable

The sequence of the loads is to be identified. When possible, a simplified approach using a permissible stress range towards design for fatigue capacity may be adopted. In addition, loads due to the expected maximum or minimum strain of the substrate are to be considered where the bonded or composite material is attached.

The design assessment of the repair is to consider the loading condition of the structure during application of the repair, which is to be carried out at unloaded condition wherever possible. For repairs to loaded structures, the initial strain at the substrate steel prior to application of the repair is to be clearly considered in the design assessment.

2.3 Environment

Polymeric materials are sensitive to environmental conditions that can change their structural behaviors and lead to accelerated degradation on the bonding interface, in the adhesive layer, or in the FRP laminate matrix. The design is to verify that the repair is suitable for the intended operating environment. The following applicable environmental effects are to be 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 are to be protected by a suitable coating or other protection system to avoid adverse effects or mitigate them to a safe level.

ii) The extreme design temperatures are to be determined from the maximum and minimum service temperatures of the repair. Temperature gradients over the length and thickness of the composite repair are to be evaluated. The lowest temperature and the short-term loads (such as waves, inertia, wind, dynamic loads etc.) are to be used for the evaluation of the fracture toughness of the steel substrate as well as the strength of the repair. In addition, the high temperature and sustained loads acting permanently (such as gravity, cargo loading or offloading etc.) are to be applied for evaluation of the efficiency of the repair for equivalent steel thickness.

iii) The repair design temperature and operating temperature for polymer materials, if used, are generally to be lower than T_g - 20°C (T_g - 36°F).

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

v) The effects of exposure to water/oil are to be considered in the material selection for the bonded or composite patch, adhesive, and primers, if any.

2.4 Fire

A risk-based approach is to be used to assess the criticality of a fire scenario, the likelihood of fire in the subject area, and the consequences of failures of composite repair during and after a fire. Generally, the following measures are to be considered to mitigate fire exposure:

i) Isolation from fire or excessive heat sources

ii) Protective coating and insulation

iii) Automatic sprinkler or deluge system

iv) Blow down venting

Polymeric materials used in composite repairs are often combustible and temperature sensitive. The fire performance of the composite repair with fire protection is to be evaluated. The relevance of fire safety codes to composite materials is to be checked. Appropriate strategy to achieve fire endurance for composite repair is to be established. Effective measures include:

i) Application of additional coating of repair laminate material such that enough basic composite will remain intact for the duration of the fire event.

ii) Applications of intumescent external coating.

iii) Applications of intumescent and other energy absorbent materials within the repair laminate.

iv) Use of polymer formulations with specific fire-retardant properties.

If a FRP laminate is used for the repair, the fire safety requirements are to 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 to be used in accommodation, service areas, control spaces, and areas where smoke and toxicity are a concern.

In cases such as the repair of small holes on the main deck due to localized pitting, where the FRP composite material will be the sole boundary to provide watertightness, the FRP composite material/repair is to be qualified for fire resistance at least equivalent to “A” Class boundary.

When a steel plate is used for the repair, such restriction may not be required if the adhesive materials and elastomer fillers are sealed by the steel faceplates and perimeter steel members.

See 1-4/5 for material qualifications for fire properties of bonded or composite repairs, including fire reaction and fire resistance.

2.5 Electric Shock

Nonconductive polymer materials may develop static electricity which can potentially cause an electric discharge and, thus, a fire or explosion hazard. Metallic parts of the bonded patch repair are to be effectively grounded to the hull to prevent possible electric discharge. Electrical continuity of the metallic structure is to be provided. Electrical conductivity requirements for the bonded steel plate repairs are to be provided in the design. Specified conductivity requirements and mitigation solutions are to be established to eliminate such risk. If no specific requirements are given, the requirements on the electrical conductivity and electrostatic dissipative properties denoted in ISO 14692-2 are to be applied to bonded or composite patch repairs.

3 Allowable Stress

The design allowable stress is to be derived and defined by the manufacturer with documented design methodology, qualification test plan, and test results.

3.1 Design Allowable Stress by Structural Analysis

The design allowable stress is to be derived by the structural analysis coupled with the full-scale component/panel tests using the following procedures:

i) Load test of full-scale component/panel until failure occurs to obtain the maximum load.

ii) Apply the load history to the maximum load for Finite Element Analysis (FEA).

iii) Test mesh convergence until the calculated stress trends to be flat as the mesh size decreases.

iv) Extract the maximum tensile, shear, and peel stress of FEA analysis results.

v) Derive the allowable tensile, shear, and peel stress with sufficient safety factor, which may be adjusted to a smaller safety factor than f_s in 1-3/3.2.

3.2 Design Allowable Stress by Material Properties

The design allowable stress may be derived by material properties coupled with the sufficient safety factor f_s, which can be considered by the manufacturer. However, the bond-line shear or peel strength (σ_f) may not be well captured from standard tests using small coupons, due to: (1) the different stress states between standard tests and full-scale geometry and (2) the different ways the shear and peel stresses are derived. If manufacturer applies the design allowable stress using material properties issued from standard tests, design methodology is to be verified and validated using FEA structural analysis and full-scale component testing.

The design allowable stress, σ_{da}, is to be calculated as:

$$\sigma_{da} = \frac{\sigma_{ma}}{f_s}$$

where

σ_{ma} = material allowable stress.

= $\sigma_f k_s k_w k_t$

σ_f = specified material strength corresponding to a specific failure mode. Unless otherwise agreed, the specified strength is taken as 0.5 of the ultimate strength of the considered failure mode such as pulling, peeling or shearing failure.

k_s = material reduction factor due to statistical variation.

= 0.85, unless otherwise agreed. Coefficient of Variation (COV) of 15% is recommended to use 0.85, otherwise, k_s is to be appropriately adjusted

k_w = material reduction factor due to moisture or wetness.

= 0.85, unless otherwise agreed.

k_t = material reduction factor due to temperature.

= 1.0 for room temperature.

= For temperatures different than room temperature, an appropriate reduction factor is to be proposed and documented (refer to 1-3/2.3). If other material reduction factor value is provided, it may be specially considered and approved by ABS with support of the material degradation test data.

f_s = safety factor.

= $f_s^1 f_s^2 f_s^3$

f_s^1 = partial safety factor due to the location of structure members. Unless otherwise agreed, 1-3/Table 1 is to be used.

f_s^2 = partial safety factor due to the load case. Unless otherwise agreed, 1-3/Table 2 is to be used.

f_s^3 = partial safety factor due to the failure mode and load scenario. Unless otherwise agreed, 1-3/Table 3 is to be used.

TABLE 1
Location Partial Safety Factor, f_s^1

Location	*Safety Factor*
Non-Strength Decks, Hatches, Stacks, Vents, Main supporting members	1.05
Decks, Transverse Bulkheads	1.10
Hull Girders, Watertight Bulkheads	1.15

TABLE 2
Load Case Partial Safety Factor, f_s^2

Load Case	*Safety Factor*
Hydrostatic Loads, Tank, Dead Loads	1.05
Hull Girder, Live Loads, Cargo Loads	1.15
Wave Slap	1.25
Interior Pressure	1.00

TABLE 3
Failure Mode Partial Safety Factor, f_s^3

	Bondline		*In-Plane Stress*	*Core Prop, Bearing, Pull-Through, Pull Out*	*Laminate Through Thickness, Fracture*
Static Loading	Short-term	1.35	1.20	1.30	1.50
	Long-term*	1.35/2.20			
Fatigue Loading	5		1.30	1.40	N/A

Note: If long term material properties for bondline capacity are available, the safety factor of 1.35 is to be used; otherwise, 2.20.

4 Structural Analysis

4.1 General

Structural analysis is to verify that a bonded or composite repair design can adequately reinstate a degraded structure to withstand static, fatigue, and buckling loads in its remaining service life. Finite Element Analysis (FEA) is to be used to verify structural responses under required load conditions.

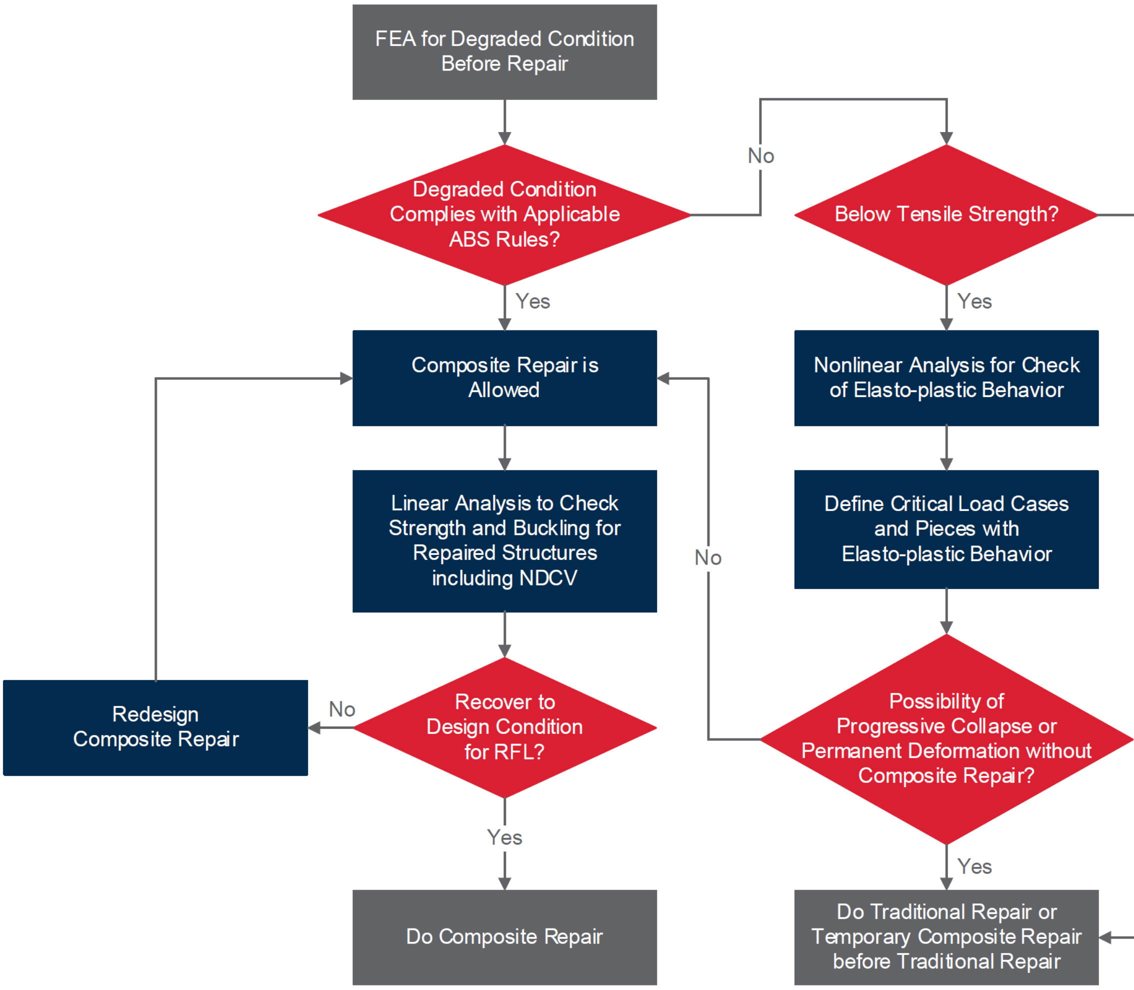
The necessity to perform a structural analysis is to comply with Repair Classes in 1-2/4.

Continuing from 1-2/Figure 1 for the decision-making process for bonded or composite repair, the decision-making process for FEA of the repair strength checks is provided in 1-3/Figure 1 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 1) where the average wastage of the local structural member exceeds the allowable limit. This is to replicate the case where the patch becomes delaminated. Progressive collapse is to 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 scantlings are to withstand the critical load cases without permanent deformations by any failure mechanism, away from degraded locations. If necessary, local FEA may be developed to demonstrate that the degraded area will not induce progressive failure of adjacent structures.

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.

FIGURE 1
Linear or Nonlinear FEA for Decision-making of Bonded or Composite Repair



4.2 Finite Element Analysis (FEA)

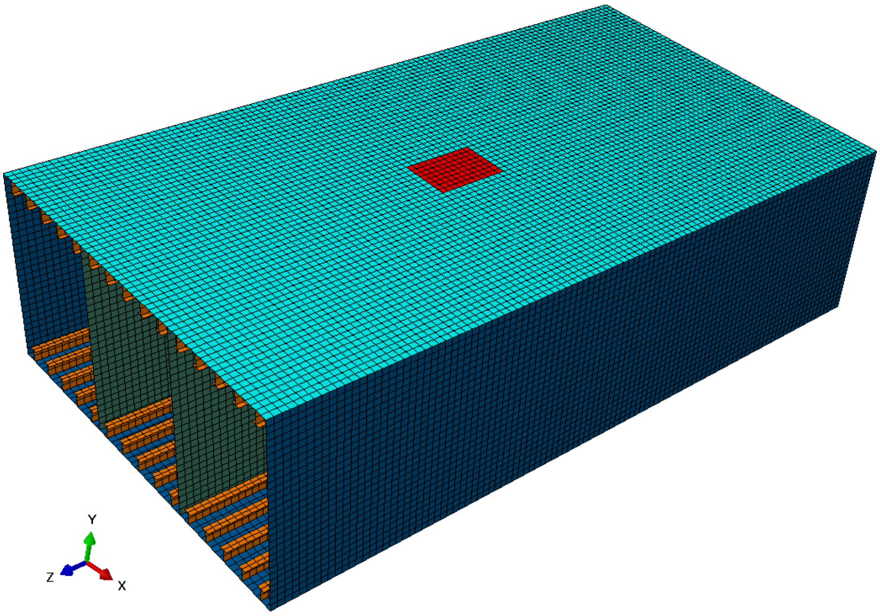
4.2.1 Global FE Analysis

Global FE analysis is to be used to obtain the loads around a degraded structure subjected to a bonded or composite repair (See 1-3/Figure 2). The internal loads in the global FEA result are to be transferred to the local FE model for performing the detailed structural analysis to verify the strength and fatigue strength for the composite repair system.

In the global FE model, typically shell, beam, and bar elements with coarse mesh sizes are to be used, and the repair system may be properly simplified by using equivalent thickness and material stiffness without modeling each reinforcement plate, bonding layer, or any small features. For FE modeling concerning the mesh size, refer to ABS *Guidance Notes on SafeHull Finite Element Analysis for Hull Structures*. For the equivalent thickness of the composite repair patch, refer to 1-3/5.3. The equivalent elastic modulus and Poisson's ratio are determined based on the "Rule of Mixture".

The global load cases are to be established in accordance with 1-3/4.3.

FIGURE 2
Bonded or Composite Repair Global FEA Model



4.2.2 Local FE Analysis

In a local FE model, a sub-area covering the repair system and degraded features is to be used. A reasonable modeling simplification, such as an averaged corrosion depth derived from multi-point measurements, is permitted. Refined mesh is to be applied to the local model for accessing structural responses due to degraded features and the repair being made.

The distance from the boundary of the local model to the repaired structure region is to be sufficient to avoid any local effects due to application of boundary conditions or loads on the boundary that could distort structural responses. The calculated displacements in the global FE model are to be mapped to the boundary of the local FE model as the driving variables. The displacements (translations and rotations) from the global model are to be transferred to the local model boundaries so that the model can represent the adequate stress distribution with and without repair stiffness.

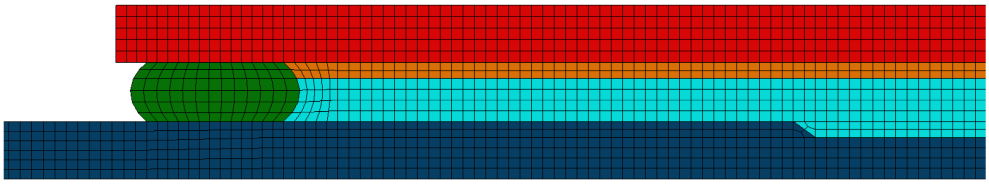
Refer to 3-1-3/9 of the ABS *Rules for Building and Classing Light Warships, Patrol and High-Speed Naval Vessels (LHSNV Rules)*, Section 3-2-20 of the *Marine Vessel Rules*, or Appendix 5A-3-A4 of the *FPI Rules* for general guidance on FEA modeling. The specific considerations to construct local FEA models for bonded steel plate and FRP laminate are provided below, respectively.

4.2.2(a) Bonded Steel Plate

3D solid elements may be used to model each component of bonded steel plate, including steel substrate, bonding layer, perimeter members, and reinforcement plate. The selection of element type is to be appropriate to reflect the material behavior and loading condition of each component. In general, brick (hexahedron) elements are to be used in most regions to achieve accurate results. Tetrahedron and wedge elements may be used in transition areas where the use of regular brick elements is not feasible. The mesh size is to be fine enough to yield accurate FEA results and a mesh sensitivity study is to be used to determine a sufficient value.

In addition, 2D planar analysis can be used to evaluate debonding stresses such as peel and shear stresses at the interface of any cold bonding layers (See 1-3/Figure 3). This type of analysis can also be used to verify interface strengths of other connection mechanisms used within composite repair systems such as hot welding connections or bolting connections. For 2D planar analysis, proper stress convergence is to be demonstrated by decreasing mesh size, usually down to ultra-fine mesh. In cases where non-linear material behavior is used, strain convergence may also be required.

FIGURE 3
2D Local FE Model for Bonded Steel Plate Repair



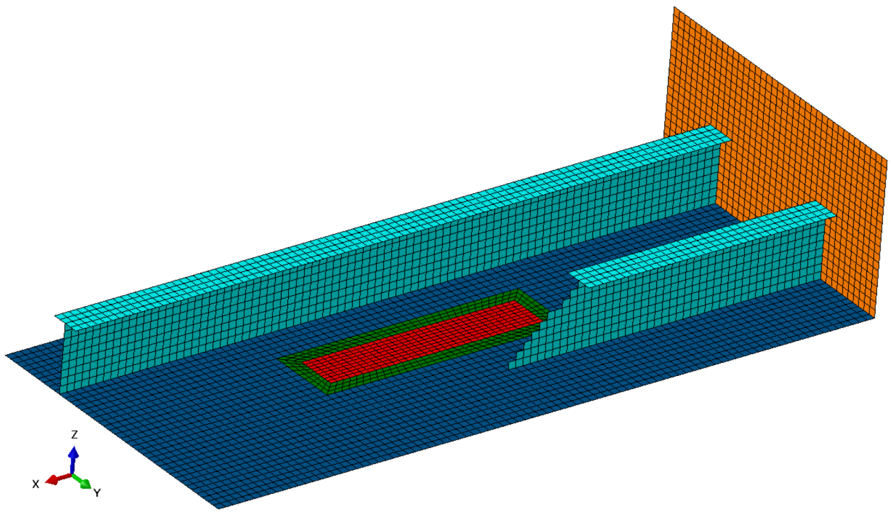
4.2.2(b) FRP Laminate

3D shell elements can be used to model a FRP laminate system consisting of a FRP laminate, a primer layer (if applicable), and a steel substrate (See 1-3/ Figure 4). Quadrilateral elements are to be used in most areas while the use of triangular elements is to be limited to transitional areas. A value of shell surface offset is to be specified to account for the difference between the real geometry and the shell model. The mesh size is to be fine enough to yield accurate FEA results, and a mesh sensitivity study is to be used to determine a sufficient value.

The FRP laminate layup is to consist of a number of laminae where each one has an individual material configuration, fiber orientation, and thickness. See 1-3/4.4.2 and 1-3/Figure 5.

Refer to 3-1-3/11 of the *LHSNV Rules*, Section 3-2-20 of the *Marine Vessel Rules*, or Appendix 5A-3-A4 of the *FPI Rules* for assessing the FEA results for the failure modes of laminate and adhesive materials.

FIGURE 4
Local FE Model for FRP Laminate Repair



4.3 Load Cases

Loads defined in 1-3/2.2, which include hull girder loads, cargo pressure, ballast pressure, wave-induced cyclic/extreme/impact loads, loading/offloading induced cyclic loads, and sloshing loads are to be applied for strength and fatigue evaluations. The load cases are dependent on the vessel type and location of the repair. All load cases for static loading and buckling check, as well as fatigue check, refer to the applicable Rules (i.e., *FPI Rules*, *Marine Vessel Rules*, *MOU Rules*, etc.).

4.4 Material Properties

Refer to Chapter 1, Section 4 for general information on material tests and qualifications.

4.4.1 Bonded Steel Plate

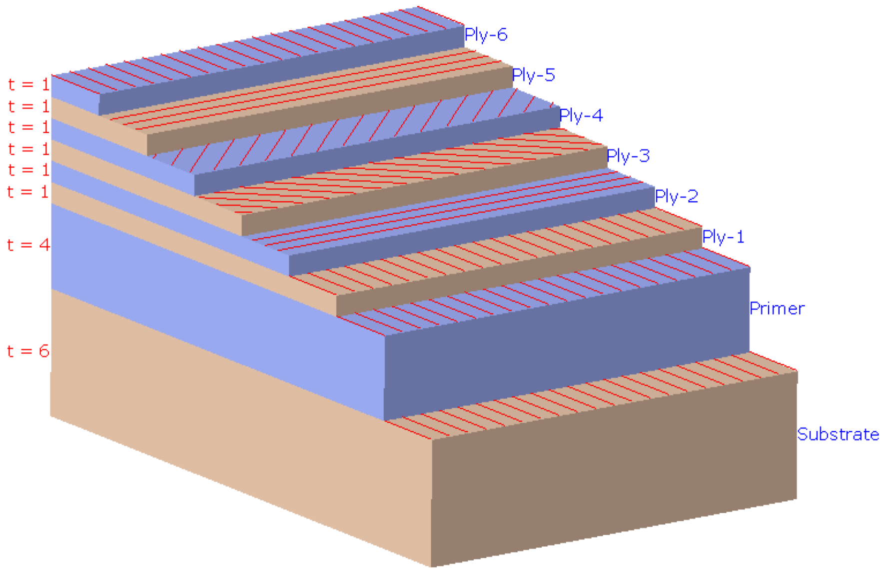
Steel plates demonstrate isotropic mechanical behaviors which are governed by the manufacturing process and material properties of elastic modulus and Poisson's ratio. These material properties vary with temperature and are to be considered when performing an FE analysis.

If the thickness of bonding layer is sufficient, polymer used for the adhesive bonding and filling can be considered as an isotropic material and be described by elastic modulus and Poisson's ratio under the specified service temperatures. Alternatively, hyper-elastic material can be used provided that testing data is available. If the thickness of bonding layer is not sufficient, the failure mode due to the load direction is to be considered.

4.4.2 FRP Laminate

An FRP laminate is laid up by a number of laminae consisting of reinforcement fibers and matrix. Each lamina can be regarded as homogeneous material and presents an orthogonal mechanical behavior (see 1-3/Figure 6). The minimum material properties required for a lamina include elastic moduli, shear moduli, and Poisson's ratios corresponding to its material orientation and thickness. The material values are to be provided with consideration for the application conditions, such as specified extreme service temperature.

FIGURE 5
FRP Laminate Layup



5 Strength, Thickness and Section Modulus Checks

5.1 General

The acceptance of a repair design made to a degraded steel plate is granted upon the satisfactory completion of:

- Strength check
- Equivalent thickness check
- Section modulus check
- Other checks for FRP laminates

The efficiency of the load transfer from substrate to the reinforcement is to be analyzed and demonstrated through FEA. Conservatively, the low modulus at highest temperature is to be applied considering the longest load duration. High modulus at low temperature and short loading duration is to be applied to exhibit the highest stress level at the bondline.

5.2 Strength Check

The calculated stress, σ, obtained from FE analysis is not to exceed the design allowable strength, σ_{da}, in 1-3/3.

$$\sigma < \sigma_{da}$$

Axial compression, tension, bending, and shear stresses are to be verified.

5.3 Equivalent Thickness Check

For repair for corrosion, the equivalent thicknesses, $t_{m,eq}$ and $t_{b,eq}$ after repair are not to be less than the original design thickness, t_s, of a steel plate.

$$t_{m,\,eq} \geq t_s$$

$$t_{b,\,eq} \geq t_s$$

The equivalent thicknesses are to be defined as:

$$t_{m,eq} = \left(E_sA_s + E_cA_c\right)/\ E_sA_s \times \alpha_E t'_s \quad \text{for membrane stress}$$
$$t_{b,eq} = \sqrt{(E_sI_s + E_cI_c)/\ E_sI_s} \times \alpha_E t'_s \quad \text{for bending stress}$$

where

E_s	=	elastic modulus of existing steel
E_c	=	elastic modulus of composite repair
A_s	=	cross-section area of existing steel
A_c	=	cross-section area of composite repair
I_s	=	area moment of inertia of existing steel
I_c	=	area moment of inertia of composite repair

t'_s = thickness of existing steel plate

α_E = efficiency factor, calculated from FEA by comparing the effectiveness of the analyzed configuration and the ideal case $\alpha_E = 1$ for 100% of development length. The efficiency factor is to be adjusted based on the temperature effects on the modulus of the material (refer to 1-3/2.3).

5.4 Section Modulus Check

The local section modulus after the bonded steel plate repair is to be verified in accordance with the strength requirements given in the *Marine Vessel Rules* or *FPI Rules*. When calculating the hull girder section modulus, the degraded parts and their shadow areas are to be deducted. All continuous longitudinal strength members contributing to the global strength are to be taken into account. The calculation of section modulus is to be provided by the repair manufacturer.

5.5 Other Checks for FRP Laminates

For the FRP laminate repair of steel plating, the acceptable equivalent thickness, refer to 3-2-3/5.5 of the LHSNV Rules. For the FRP laminate repair made to internals such as longitudinals, stiffeners, transverse webs and girders, the acceptance values for section modulus, moment of inertia, and shear area, refer to 3-2-4/3 of the LHSNV Rules.

6 Repair Design and Analysis Report

A Repair Design and Analysis Report is to address the design basis and all relevant information for the design input, and structure analysis of the bonded or composite repair.

The Repair Design and Analysis Report is to contain the following items 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 patches to be used for the repair.

iii) Description and evaluation of the identified failure modes and mechanisms.

iv) Identification, trade name, datasheets (technical datasheets and materials' Safety Data Sheets), and certifications of all raw materials used for the repair, with a bill of materials planned by the designer and made available to the repair installer.

v) Design basis, including drawings of bonded or composite repair assemblies, material properties, rationales, principles, assumptions, objectives, constraints, loading conditions of the vessel/unit, loading condition of the repaired structure, other environmental conditions, design life, and other relevant conditions including applicable limitations.

vi) Analysis report, including analysis method description, standards/codes applied, technical assumptions, evaluation of corroded areas and their criticality, accepted calculations for strength, stiffness and thickness checks, acceptance criteria, and other documents for compliance with governing technical requirements.

vii) Reference to documentation for repair and modification.

SECTION 4
Materials and Qualification

1 General

This Section covers the material requirements for bonded or composite repair. Repair strength and performance are affected by both properties of each material and the interface bonding properties of the repair system.

The materials of bonded or composite repair system include bonding materials and steel patch/FRP laminate. The required properties of each material denoted in 1-4/2 are to be defined in the material specification and qualified by the manufacturer. Material properties are to be obtained directly by measurements or traced back to measurements, which are to be documented with full traceability and submitted for ABS review.

The required interface bonding properties are to be specified and demonstrated by the manufacturer. Assembled coupons/components are to be tested and witnessed by the ABS attending Surveyor. Qualification records are to be documented with full traceability and submitted for ABS review.

Alternative test methods, test standards and acceptance criteria for each material or interface bonding strength may be specially considered by ABS.

The following factors are to be considered for material properties and interface bonding properties:

i) Short term and long term (optional) static properties

ii) Fatigue properties under cyclic loads

iii) Compatibility for intended service environment such as service temperature and chemical environment

2 Material Requirements

2.1 Steel Structure and Steel Plate Patch

The steel grade of the structure is to be verified. If available, a material test report of the steel structure, documented by an ABS approved steel mill, is to be submitted.

The steel grade of the steel plate patch is to comply with the applicable ABS Rules or recognized industry standards.

If the steel plate patch material is not ABS grade procured from an ABS approved mill, the material certificate is to be submitted to ABS for review. The steel plate patch is to be specified and qualified by the manufacturer in accordance with recognized industry standards. The material properties of the steel plate patch are to be obtained directly through material properties testing or traced back to the original mill certificates, which are to be documented with full traceability and submitted for ABS review, and are to include the following items:

- Specified minimum yield strength and yield strength test results
- Specified minimum ultimate strength (UTS) and UTS test results
- Specified minimum elongation and elongation test results
- If applicable, specified minimum absorbed energy of Charpy V-Notch test at the applicable test temperature and Charpy value test results
- Young's modulus and shear modulus

For complicated or highly specialized designs, additional information may be specially considered, documented, and reviewed by ABS, on a case-by-case basis.

2.2 Bonding Materials

A bonding material such as elastomer, epoxy, or polyester is used to bond the steel plate patch/FRP laminate to the corroded surface of steel structure. If applicable, FRP composite patches can be directly laminated to the steel structure. In this case, the first layer of resin is considered as the bonding layer.

The material properties for adhesive/core elastomer are to be specified and qualified by the manufacturer. Material properties are to be obtained directly by measurements or traced back to measurements, which are to be documented with full traceability and submitted for ABS review, and are to include the following items:

- Tensile strength, Young's modulus, Poisson's ratio test results in accordance with ISO 527, ASTM D638
- Compressive strength, modulus test results in accordance with ASTM D695, ISO 604.
- Shear strength, modulus test results in accordance with ISO 11003-2, ASTM D1002, ASTM D3983. ASTM D429, ISO 11003-1, ASTM D3165 are to be referred for higher shear strength values.
- Shear modulus in accordance with ISO 6721-2 for determination of dynamic mechanical properties.
- Barcol, Shore or other applicable hardness test results in accordance with ISO 868, ISO 48-4, ASTM D2583, ASTM D2240.
- Chemical compatibility test results in accordance with ASTM D543, ASTM C581, ASTM D3681, ISO 10952.
- Coefficient of thermal expansion (CTE) test results in accordance with ISO 11359-2, ASTM E831.
- Glass transition temperature (Tg) test results in accordance with ISO 11357-2, ASTM E1640, ASTM D3418, ASTM D1356.
- If specified or required, viscosity test results at room temperature in accordance with ASTM D1652.
- If specified or required, softening temperature in accordance with ASTM 3104.

In addition, the following characteristics of the adhesive/core elastomer is to be provided:

i) Constituent adhesive material(s)

ii) Generic adhesive type (e.g., epoxy, polyester, polyurethane)

iii) Specific adhesive type (trade name and batch number) *iv)* Catalyst (trade name and batch number)

v) Accelerator (trade name and batch number)

vi) Fillers (trade name and batch number)

vii) Additives (trade name and batch number)

viii) Processing: method, temperature, pressure

ix) Curing temperature and time

x) Post curing (temperature and time)

xi) Density of core material

xii) Maximum and minimum allowable service temperatures

Other details of the adhesive/core elastomer, including the handling, mixing, and application of adhesives are to be in accordance with the documented and qualified manufacture's procedure, which are to be submitted in the repair plans.

Adhesive/core elastomer properties are to be obtained from test results that represent the adhesive/core elastomer used in the bonded patch repair as closely as possible. The number of material tests for design required properties depends on the theoretical models used and safety factors applied. Generally, the required material properties are to include those required for structural analysis such as shear modulus, critical shear and peel stress, and fracture toughness under the intended service environment. For fatigue and fracture modeling, fatigue properties and stress rupture performance (with consideration of the effect of environmental degradation) may be additionally required in the design basis.

2.3 FRP Laminates

2.3.1 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 prefabricated or manually laid out onsite.

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

Through-thickness properties can be critical for composites. Through- thickness shear properties of laminates are 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. Under certain conditions, typical values from existing databases can be used.

Laminates test results are to comply with the applicable requirements in 2-6-1/7 of the ABS *Rules for Materials and Welding (Part 2)*.

2.3.2 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 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.

2.3.3 Fiber

For most FRP composite patch repairs designed to perform as a structural part of the hull structure, the required 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 are in contact with the steel. They are to be separated from the steel structure/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.

2.3.4 Laminate Material Properties

The material properties for an FRP laminate are to be specified and qualified by the manufacturer. For the laminate on-site lay-out, it is to be witnessed by the ABS attending Surveyor. If required, material properties are to be obtained directly by measurements or traced back to measurements, which are to be documented with full traceability and submitted for ABS review including the following items:

i) In-plane shear modulus in accordance with ASTM D3518

ii) In-plane shear strength in accordance with ASTM D3518

iii) Longitudinal modulus, along the primary stress

iv) Transverse modulus, the perpendicular direction to the primary stress

v) Tensile strength, along the primary stress in accordance with ASTM D3039

vi) Tensile strength, the perpendicular direction to the primary stress in accordance with ASTM D3039

vii) Compressive strength, along the primary stress in accordance with ASTM D3410

viii) Compressive strength, the perpendicular direction to the primary stress in accordance with ASTM D3410

ix) Bending fatigue properties in accordance with ASTM D7264

x) Poisson's ratio, negative of the strain transverse to the primary stress divided by the strain along the primary stress

In addition, the following characteristics for an FRP laminate are to be provided:

i) Generic fiber type and volume percentage

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, refer to ASTM D3171

viii) Void content

3 Fabrication Procedure

The fabrication procedure for assembled coupons/components is to be documented, qualified by manufacturer with verification by ABS attending Surveyor and submitted for ABS review. The fabrication procedure is to comply with the following:

i) The fabrication procedure and testing condition are to be representative of the service environment as specified in Chapter 1, Section 3.

ii) The fabrication procedure of the test specimen is to be prepared using the same process as the actual bonded repair.

iii) The FRP laminate/steel plate patch used in the test specimen is to be representative of that specified for the actual repair.

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

v) The surface treatment is to be identical to the one used in the application in the field, under simulated atmospheric conditions (e.g., humidity and temperature).

vi) If applicable, the FRP laminate is to be produced in the same way as in the actual application.

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

viii) If applicable, the lay-up is to be representative of the actual repair. Relative humidity is to be equal to or higher than the limitation stated for application in the field.

ix) The adhesive/core elastomer is to be the same as in the actual application and is to be applied in the same manner.

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

xi) If applicable, before testing a FRP laminate, the sample is to be fully cured or post-cured at a specified temperature for a given period. For other reinforcement and resin combinations, the time and temperature for accelerated aging are to be determined.

xii) The qualified fabrication procedure is to be controlled and maintained through the on-site installation process.

4 Qualification Tests

4.1 General

The interface bonding properties, such as short-term or long-term static properties, fatigue properties under cyclic loads, and environment compatibility for intended service, are to be considered in the design and controlled through the installation process. All properties relevant for the analysis are to be specified and validated by experimental data. The specified values are to be applied to verify design.

The required interface bonding strength between the steel structure/substrate and the adhesive/core is to be specified and demonstrated by the manufacturer. Assembled coupons (refer to 1-4/4.2.1 through 1-4/4.2.5) and/or components (refer to 1-4/4.2.6) are to be tested and witnessed by ABS attending Surveyor. Qualification records are to be documented with full traceability and submitted for ABS review.

4.2 Qualification Tests using Assembled Coupons

4.2.1 Shear Strength

Lap shear strength is to be determined by an adhesively bonded lap joint test. The interface bonding shear strength for the bonded or composite repair is to be specified, tested, and reported in accordance with ISO 11003-2, ASTM D1002, ASTM D3983, ASTM 3165 by tensile test method.

Short-term performance is required for all bonded or composite repair systems and is to be carried out by a lap shear strength test at room temperature.

Commentary:

1 The short-term performance test at room temperature could be used for the average shear strength or failure defined at the minimum of 30% the remaining bonded area.

2 For metal substrate, the minimum average shear strength should be 4 MPa (580 psi).

3 The bonding shear strength could be 15 MPa (2175 psi) - 45 MPa (6526 psi) for epoxy-based adhesive layer or 4 MPa (580 psi) -15 MPa (2175 psi) for Polyurethane-based adhesive layer.

End of Commentary

If specified or required, the long-term performance is to be determined by a lap shear strength test for the intended service environment.

Commentary:

1 The long-term test could be considered as an accelerated aging test, following immersion in water or potential sea water, oil, or other chemical environment for 1000 hours at the design temperature or 40 ^{o}C (104 ^{o}F), whichever is higher.

2 The average lap shear strength for long-term test should be at least 30% of the average lap strength for short-term test at room temperature.

End of Commentary

The stress-strain curve is to be provided for shear strength test, which could be applied to the design analysis by strain/stiffness such as the stress/modulus values at the defined strain or elongation.

4.2.2 Peel Strength

If required or specified, the interface bonding peel strength is to be specified, tested, and reported in accordance with ISO 4578, ASTM D1876, ASTM D1781, ASTM D903.

4.2.3 Pull-Off Strength

Unless otherwise agreed, the interface pull-off strength is to be specified, tested, and reported in accordance with ASTM D4541 or ISO 4624.

4.2.4 Fatigue Property

If specified or required, the interface bonding fatigue property is to be tested and reported in accordance with ASTM D3166.

Commentary:

1 Test substrates may be metal substrate or FRP laminate.

2 The test should be conducted at 50% of the ultimate tensile strength and should last for a minimum of one million cycles at 30 Hz.

3 Tests of alternative fatigue properties may be carried out, documented, and submitted for ABS review.

End of Commentary

4.2.5 Other Characterization

The interface bonding may be additionally characterized considering fracture toughness, debonding, stress rupture, creep, degradation, which is specially considered, documented, and reviewed by ABS, on a case-by-case basis, depending upon the structural member being repaired and in-service conditions.

4.3 Qualification Tests using Assembled Components

4.3.1 General

If specified or required according to the critical level (refer to 1-2/4), prototype tests of assembled components are to be carried out in accordance with recognized industry standards, manufacturer's procedures, or best practices.

The component panel is to 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 is to be provided before conducting the test.

The prototype component panel is to 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, such as acceleration corrosion or fatigue tests. The test data under such different conditions are to be evaluated based on appropriate theoretical knowledge, experience in testing, and sound engineering judgement.

The adhesive bond is to be tested on substrates that represent the actual metal substrate conditions. This is to consider the surface preparation for repair. In addition, corrosion may occur on the steel below the bonding line, which is to be considered and addressed in manufacturer's procedure.

4.3.2 Design Qualification

i) *Design Qualification Based on Component Testing Only*

A sufficient number of tests are to be carried out to define the characteristic strength of the bonded patch repair with a defined confidence level using statistics analysis method for the test data (refer to 1-4/4.4). Historic test data may be provided by the manufacturer and specially considered by ABS for acceptance on a case-by-case basis.

ii) *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.

iii) *Testing Crack Growth in Steel*

When a bonded steel or FRP composite patch is used for crack repairs, the most severe load direction for crack growth in the metal is to be tested. If multiple load directions are critical, more testing may be necessary when testing in one load direction is not considered sufficient.

One component test to failure is to be performed to obtain the static strength and failure mechanism. The experimentally observed failure mechanism is to be the same as the one predicted in calculations.

4.3.3 Prototype Tests of Assembled Components

A load test of the bonded or composite repair prototype is to be carried out by direct experimental assessment.

i) *Tensile Test.* A single strap tensile test is to be carried out (refer to ASTM C633).

ii) *Bend Test.* Composite/steel plate bend tests carried out in multiple planes. For example, steel in compression side, composite in compression side, composite and steel bent sideways.

iii) *Fatigue Test.* The fatigue test is to include the taper of the composite patch, if applicable. The loading to be imposed is to be detailed such as tensile-tensile, compressive-tensile, flexing, or bending.

If applicable, the material, including the adhesive bonds, is to be characterized under static and cyclic loading by immersion tests for compatibility of the composite repair system with the intended service environment such as seawater and/or cargo oil.

4.4 Statistical Approach for Test Data

The number of samples is to be sufficient (such as 18 FRP test coupons) to provide a statistically adequate number of specimens to test each combination of material and fabrication procedure.

The material testing program is to account for the statistical variability in actual FRP composite material properties and interface bonding strength, both as manufactured and at the end of service life.

Material strength and interface bonding strength test results are to be reported in accordance with a recognized statistical approach such as lower-bound 95% confidence interval, Coefficient of Variance (COV) of 15% for reference, or B-Basis value per MIL-HDBK-17-1F.

5 Properties under Fire

5.1 General

Bonded or FRP laminate repairs are to meet the same fire endurance as required for the substrate steel material.

FRP materials are not accepted in accommodation, service, and control spaces, and areas where smoke and toxicity are a concern.

However, if a steel patch is used for bonded repair and all adhesive materials used for bonding are sealed by the steel faceplates and not exposed to the surrounding area, such restriction may not be valid and may be specially considered on a case-by-case basis.

5.2 Fire Reaction

The reaction of a bonded or FRP laminate repair to fire is described in terms of flammability and flame spread, refer to IMO FTP Code Part 5, smoke development and emission of toxic gases, refer to IMO FTP Code Part 2. 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 is to be evaluated. Delamination and chemical reactions due to fire are to be evaluated.

The average surface flammability value of the repair material is not to exceed the criteria listed in IMO Resolution A.653(16). Flame spread testing can be referred to IMO A.653(16) or ASTM D635.

5.3 Fire Resistance

The remaining strength of a bonded or composite structure under a fire is described by fire resistance. If bonded and composite repairs are applied for fire rated divisions, fire resistance testing is required. Fire resistance testing can be referred to relevant flag Administration regulations, standards (i.e., ISO 14692, ASTM E84) and codes (i.e., IMO FTP Code).

5.4 Insulation

The properties of the insulation related to fire reaction and fire resistance are to be evaluated.

5.5 Properties after Fire

If applicable, the material properties after the fire are to be evaluated to confirm that structural integrity is maintained

6 ABS Approval

Design review is required in accordance with this Chapter for on-site bonded or composite repair of damaged structure.

Properties of materials and components are to be tested by a nationally or internationally recognized independent testing facility in accordance with recognized industry standards. Qualification testing on coupons or components in 1-4/4 is to be performed in the presence and witnessed by an ABS Surveyor.

Commentary:

Repair products including materials and components tested in accordance with this Section can be certified by ABS with ABS Product Design Assessment certificate or Product Type Approval certificate.

End of Commentary

7 Qualification Tests Record

The manufacturer's specifications for design and materials, fabrication procedures for assembly, tests method, procedure/standards and qualification tests records are to be documented with full traceability and submitted for ABS for review.

Documentation of material qualification testing, including at least the following information, is to be submitted for ABS review.

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
Bonded and Composite Repairs of Steel Structures

SECTION 5
Repair Installation and Quality Assurance

1 General

This Section presents the requirements for the bonded or composite repair installation and quality assurance. An installation specification and repair procedure plan are to be developed and approved by ABS prior to the commencement of repair application in accordance with Chapter 1, Section 3 and Chapter 1, Section 4.

The installation procedure is to be divided into steps, covering installation considerations, methods, and check points, and is to indicate quality check measurements after installation is completed.

The attending ABS Surveyor is to verify and monitor that the bonded repair has been inspected and installed in accordance with the installation/fabrication specification and procedures.

A bonded or composite Repair Completion Quality Report is to be created and maintained by qualified and responsible personnel and is to include repair installation considerations and a procedure broken down into steps, indicate inspection method and procedure to be used, and document repair results with qualification check outcomes.

The installation/fabrication specification and procedures and the QA/QC manual are to be reviewed by ABS.

2 Repair Installation Documentation

The repair installation document, consisting of Repair Specification and Installation Plan (refer to 1-5/2.1) and Repair Completion Quality Report (refer to 1-5/2.2), is to be prepared and completed by the repair contractor/installer. A unique identifier is to be assigned to each repair. The report is to cover all repairs that are part of the installation. The report is to be retained on board for tracking for the life of the repair. The repair installation specification is to detail the repair installation procedure and relevant specifications during the bonded or composite repair.

2.1 Repair Specification and Installation Plan

The Repair Specification and Installation Plan is to include the following as a minimum, where applicable. The prepared document is to be agreed upon between the Owner and the repair manufacturer and submitted for ABS review.

i) Accessibility to the surface to be examined, prepared, repaired, inspected, verified, and monitored.

ii) The repair design drawing indicating the location and structural details (plate thickness, adhesive lay thickness), including surrounding structures.

iii) The qualification record for the repair installer in accordance with manufacturer's procedure and inspector agreed upon by manufacturer, ABS, and owner.

iv) Material specification, including repair patch and adhesive components, together with the material datasheets with information of storage method and specification.

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

vi) Material handling and preparation specifications. See 1-5/6.

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

viii) Ambient humidity and temperature specifications allowed for surface preparation, repair installation and curing.

ix) The time window specification allowed for repair application and curing.

x) Loading condition of the repaired structure.

xi) Specification and procedures for the surface preparation, including surface cleanliness and roughness. substrate temperatures, humidity, See 1-5/3.

xii) Specification and procedure instructions for adhesive injection or bonding applications. See 1-5/4.

xiii) Specification and procedure instructions for adhesive curing applications. See 1-5/4.

xiv) FRP laminate fabrication specification and installation procedure instruction. See 1-5/5.

xv) Quality check coupon specification and preparation instruction.

xvi) Quality check items at the completion of installation and the acceptance criteria. See 1-5/7

xvii) Inspection and survey plan during installation. See 1-6/1.

xviii) In-service inspection, monitoring, and survey plan. See 1-6/6.

2.2 Repair Completion Quality Report

The Repair Completion Quality Report is to be provided to verify that the repairs are established in accordance with the specifications and the approved criteria.

Repair quality is to be checked in accordance with the ABS approved test specifications and criteria (see 1-5/7). Service capacities required for the bonded or composite repair are to be established in accordance with Class requirements (See 1-3/2).

The report is required to be signed off by key personnel, including Owner's representative, repair contractor/installer, inspector, and other applicable contractors. The completed report is to be reviewed by ABS, and the approved report is to be retained on board for the life of the repair.

3 Surface Preparation

Before and during repair, surfaces are to be well prepared to meet surface cleanness and roughness requirements in accordance with the documented qualified procedure. Refer to Section 4 of the ABS *Guidance Notes on the Application and Inspection of Marine Coating Systems* for surface preparation techniques and standards.

The surface cleanliness is to be such that no substance or contaminant prevents adherence to the reinforcement patch and substrate. Harmful substances and contaminants at the repair installation stage include:

- Moisture, water, ice

- Oil, grease, sludge, mud, sediments
- Soluble salts
- Rusts, mill scale, rust scale
- Old, loose or blistered steel coating
- Dust/dirt, abrasive materials

Surface cleaning methods include dry abrasive blasting, power tools, and water blasting with or without abrasive. The correct sequence is to be followed in accordance with the cleaning technology used to meet the required surface cleanliness for bonded composite repairs. The presence of any pitting, corrosion products, cathodic protection products, aged coatings or trapped cargo residues is to be considered, particularly for localized surface preparation of the most severely affected areas.

Unless otherwise agreed, the measures for surface preparation as below are to be followed to achieve a good adhesion:

i) The surface pre-condition is to comply with SSPC-SP 1, if dry, water, or slurry blasting and/or grinding is to be used.

ii) Any visible oil and grease are to be removed in accordance with SSPC-SP 1, if water blasting or slurry blatting is to be used.

iii) Cleanliness of the surface is to be to Sa 2½ according to ISO 8501-1 for blast cleaning or equivalent for the use of other surface cleaning procedures such as SSPC SP 10 or NACE 2. A sufficient surface profile is to be met for the adhesive performance such as power tool bristle blaster (SP-11). The cleaning tool may affect the bondline strength even if the same surface roughness is met. Therefore, the type of cleaning tool is to be documented in the qualified manufacturing procedure and is not to be replaced by other types of tools during installation.

Commentary:

Abrasive blast cleaning during in-service maintenance could be challenging at a field location. Power tool cleaning and water-jetting could alternatively be applied for surface treatment.

End of Commentary

iv) Dust, blast abrasives and other loose particles are to be removed from the surface.

v) Oil or grease are to be removed from the surface.

vi) Steel temperature and air humidity are to be monitored for possible condensation on the steel surface during blasting and fabrication/installation. Normally, as a minimum, steel temperature is to be at least 3°C (5.4°F) higher than the air dew point. Relative humidity is not to be greater than 85% (refer to SSPC-SP10). The actual relative humidity may be documented and controlled by manufacturer for good bonding quality, such as 60%.

vii) If no other evidence is provided, a soluble salt concentration (Chloride, Cl^-) of no more than 50 mg/m^2 may be used.

viii) The surface profile of the surface is to be in the range of 75 to 115 μm (3 to 4.5 mils) according to ISO 8503 or specified in accordance with manufacturer's procedure.

ix) After surface preparation, the surface conditions are to be checked to confirm that they meet the above requirements.

Due to high humidity from wet cleaning methods, light rusting may occur immediately after the steel surface is cleaned. If rust is visible before application, the surface is to be re-cleaned to meet cleaning requirements. Dry air blowing, dehumidification, or other technique such as priming of the cleaned surface can be considered to prevent rust before the bonded patch is applied. When priming is used, the bond strength of the primed surface is to be tested.

Surface cleanliness before repair installation is to be carefully verified by qualified personnel in accordance with the agreed-upon specification. The surface condition requirement can be applied to the top steel plate surface.

4 Adhesive Bonding Application and Testing Procedure

When the adhesive bonding method is selected to connect the bonded or composite patch to the substrate for prefabricated patch installation or on-site FRP lamination process, the adhesive bonding procedure is to be provided in the composite Repair Installation Document and submitted for ABS review.

The adhesive bonding procedure is to establish control parameters to obtain sufficient bond quality. The key control parameters for adhesive bonding procedure are to include:

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

4.1 Control of Bonding Thickness

The bonding thickness is to be controlled within the limits specified in accordance with the manufacturer's procedure. Correct bonding thickness can 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 initiators of local delamination or cracks is to be accounted for in the design of the bonded repair.

The adhesive and patch are to 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.

4.2 Control of Patch Pressure

During curing, the pressure applied between the patch and the substrate metal surface is to be controlled so as not to influence the bonding thickness. A specific pressure range is to be maintained and controlled in accordance with the procedure specified.

4.3 Control of Alignment

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

4.4 Control of Cure Temperature and Cure Time

The cure temperature and cure time of the adhesive are to be specified and controlled to obtain sufficient bonding strength in accordance with the qualified procedure, refer to 1-4/4.

5 FRP Laminate Fabrication and Installation

5.1 General

The fabrication of an FRP patch is to be built with a consistent quality.

The two main patch fabrication methods are:

i) Prefabricated laminate (plate or strip), to be bonded onto the corroded substrate surface.

ii) On-site FRP lamination, which directly applies FRP sheets layer-by-layer onto the corroded substrate surface.

Prefabricated laminate is to be marked and documented, including abbreviation of resin, the quantity and type of fibers (such as glass or carbon), continuous fibers, and weight/volume percentage of fibers with sufficient traceability back to the original manufacturing lot. Quality of prefabricated laminate is to meet the same requirements as onsite laminate. Prefabricated laminate products complying with these requirements are to be marked in accordance with the manufacturer's requirement traceable by the manufacturer on each finished product to signify that the material has satisfactorily complied with the tests prescribed in this section and that certificates for the material will be furnished to the Surveyor.

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

Carbon fibers used in the composite patch may cause galvanic corrosion if the fibers contact the steel structures. Thus, care is to be taken when conducting the QA/QC for prefabricated FRPs and performing the installation procedure.

5.2 Prefabricated Laminate

Prefabricated laminates are to be produced in a shop with a good quality control measurement. Prefabricated laminates are to match the substrate geometry to minimize any pre-stress condition.

Appropriate fabrication methods include lay-up on mold, resin infusion, extrusion, and pultrusion. The selection of a method is to consider patch geometry, production quality, available facilities and tools, the available time, and experience/skill.

5.3 On-site FRP Lamination

For on-site lamination of patches onto substrate surfaces, careful control of process parameters to obtain both sufficient bonding strength and sufficient patch laminate strength is needed. Personnel performing the FRP lamination are to be qualified in accordance with a recognized standard; see 1-1/2.

The on-site FRP lamination process is to follow the applicable requirements for surface preparation in 1-5/3, handling and preparation of materials in 1-5/6, and adhesive bonding application in 1-5/4. The manual lay-up sequence, orientation, and length of fiber reinforcement layers are to be made in accordance with approved design specifications. When the wet-out technique is used, control of sufficient wet-out is to be checked.

6 Handling and Preparation of Materials

Correct handling and preparation of materials is necessary to obtain the required quality and mechanical properties of the bonded or composite repair in accordance with the documented and qualified procedure. Specific handling and fabrication instructions may be given by the material supplier. In general, the following instructions are to be included:

i) Mixing ratio and quality of a two-component resin

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

iii) Storage conditions of resin components such as temperature, relative humidity, and maximum shelf-life

iv) Allowable moisture range of fibers during storage and transport specified by the material supplier and verified by testing. Dry fiber materials are to be protected from contamination. Unacceptable contamination includes dust or debris containing abrasive particles (sand, and metal particles), and salts.

v) Storage conditions for pre-impregnated fiber mats or tape.

vi) Specified storage temperature and maximum shelf-life for pre-impregnated fiber mats.

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

7 Quality Check at Completion of Repair Installation

The Repair Completion Quality Report documenting the quality check results of a bonded or composite repair is required; refer to 1-5/2.2. Unless otherwise agreed upon by ABS, the quality check for the installed bonding material is to be validated through the tests listed below.

A hardness test is required as a quality check measurement 24 hours after installation and curing procedures. Barcol or Shore hardness test methods or other applicable methods are to be performed on all cured polymeric materials. Samples of adhesive material remaining in the injection funnel or prepared by coupons on site are to be used. The hardness test values are to be within the specified range obtained in the qualification testing. See 1-4/2.2.

Commentary:

Pull-off test and/or shear-off test are recommended to verify bonding strength in pull-off and/or shear-off directions. When owner chooses to conduct such tests, the corresponding test tabs should be installed at the same time as the repair using the same materials and procedures. After cure, pull-off and/or shear-off strengths can be tested on the tabs and verified with the specified values.

End of Commentary

CHAPTER 1
Bonded and Composite Repairs of Steel Structures

SECTION 6
Inspection, Monitoring and Survey

1 General

ABS survey of the bonded or composite repair is to verify that the design, material, fabrication, installation, and in-service condition of the patch repair comply with the associated procedures and specifications. ABS survey requirements for a bonded or composite repair include:

- Material/component qualification survey
- Repair installation and completion survey
- In-service survey

Class requirements such as watertightness and fire protection are to be maintained after repair installation.

A Repair Register is to be used to track each repair made on board and to be retained on marine vessels and offshore units for the ABS Surveyor. The Repair Register is to contain the pertinent information of a repair, such as unique identification numbers and locations of repairs, and is to indicate a list of documents and reports associated with the development, qualification, installation, and inspection of the bonded or composite repair. See 1-6/3.

The material/component qualification survey is to verify material qualifications using assembled coupons or assembled components in accordance with manufacture's specifications, or industry standards. The qualification records are to be documented with full traceability and submitted for ABS review. See 1-6/4.

The repair installation and completion survey is to verify that the bonded or composite repair is installed in accordance with the procedures and specification approved by ABS and the integrity and service capacities of the installed repair are in compliance with Class and applicable requirements.

The inspection, examination or test result for the installed repair is to be to the satisfaction of the ABS Surveyor and recorded in the Repair Completion Quality Report. See 1-6/5.

For in-service surveys, the bonded or composite repair is to be included in the Vessel Composite Repair Register (VCRR), which is to be addressed by the Class survey plan and retained on marine vessels or offshore units. In-service inspection strategy and procedures are to be established for the installed repair. The inspection interval is to be determined and agreed to by ABS and other relevant parties. The ABS Surveyor is to verify the integrity and applicable service capacities (see 1-3/2) of the bonded or composite repair and the substrate structure remain acceptable at the required intervals in the VCRR. See 1-6/6.

The failure mechanisms noted in 1-3/2.7 are to be identified and listed in the VCRR. The plan includes the inspection method to be used for the detection of the identified failure mechanisms.

2 Nondestructive Inspection and Monitoring

Proper NDI methods are required to detect any defects hidden behind the installed patch.

2.1 Visual Inspection

The failure modes and mechanisms of the repair are to be identified during the repair design. See Chapter 1, Section 3. The adhesive bonding layer between the substrate and the repair patch is a common 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.

Visual inspection can be used to detect complete separation or separation at an edge 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 detected by visual inspection.

2.2 Tap Testing

Tap testing can be used for a bonded structure to detect the existence of void space due to insufficient injection of bonding material or failure of bonding formation. Both steel tap hammers and digital tap hammers are appropriate for use.

Steel hammer inspection can be used for any bonded or composite repair systems. A check point being tapped rebounds a sound to indicate whether a void exists. A low pitch sound implies that a void exists behind the tapping point, and a high pitch sound indicates that no or minimal voids exist.

A digital tap hammer is usually used for FRP laminates. An accelerometer is mounted to the hammer to measure the force-time pulse response in each tapping. The response results showing on the connected oscilloscope indicate the occurrence of defect. The device needs a proper calibration before use.

2.3 Steel Substrate

Structural deterioration is to be described in terms of its initial size and development over time, which depends on the deterioration type and its location in the structure.

Examples of structural deterioration are corrosion and fatigue cracking. Corrosion (see 1-2/7) may be characterized by corroded areas, corrosion depths, and remaining thicknesses, and fatigue cracks (see 1-2/8) are characterized by crack depth and lengths.

Several NDI methods exist for metal inspection such as ultrasonic thickness gauging, thermography, and X-ray. Detection and monitoring of the crack beneath the patch can be challenging. Advanced NDI technologies such as advanced ultrasonic or 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 be performed from the other side of the steel, or a special NDI plan can be developed for the detection of a defect through the laminate patch and adhesives.

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

2.4 Bond Layer

Detecting and monitoring bond layer cracking/defects hidden behind the repair may be difficult. At present, no fully reliable methods for detection and monitoring of initial cracking/defect in the bond layer have been identified. However, tap testing is practical to detect an existence of a void in a structural bonding layer of the bonded steel plate repair system and is considered effective to detect delamination defects within an FRP laminate plate. See 1-6/2.2.

2.5 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 Repair Register

A Repair Register for all composite repairs is to be retained on board the vessel, unit, or installation.

The Repair Register is to include the following information:

i) Unique Identification Number

ii) Type of repair

iii) Location

iv) Installation date of repair

v) Expiry date of repair

vi) ABS approval of the Composite Repair Booklet (1-1/5), including:

- *a)* Inspection Report
- *b)* Risk Assessment Report
- *c)* Repair Design and Analysis Report
- *d)* Material and Component Qualification Certificates
- *e)* Repair Installation Document, consisting of:
  - Repair Specification and Installation Plan
  - Repair Completion Quality Report
- *f)* Vessel Composite Repair Register (VCRR)
  - Inspection intervals
  - Inspection criteria
  - Inspection results
  - Required mitigations

4 Material Certificate and Component Qualification

ABS survey of the certification of steel material and the qualification of assembled coupons/ components is to be in accordance with 1-4/4. The ABS Surveyor is to witness and verify the required qualification tests are conducted by a responsible party. The manufacturer's specifications for design and materials, fabrication procedures for assembly, test method, procedure/standards and qualification test records are to be documented with full traceability and submitted for ABS review.

5 Survey During and at Completion of Installation

It is recommended that a kick-off meeting 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.

The structure to be repaired is to be verified to be compliance with repair requirements in 1-2/2.

The survey during installation is to verify the surface preparation procedure and result, environmental conditions, curing conditions, and testing after installation are within the allowable limits for the installation. Inspection and documentation are to be carried out by an inspector qualified and certified by the manufacturer and agreed by ABS and the owner.

A Repair Specification and Installation Plan is to be established as a quality assurance (QA) measure, documenting a stepwise installation procedure and instructions. Upon the completion of installation, a Repair Completion Quality Report, as a Quality Check (QC) measure, is to be updated with the installation inspection or examination result and the report is to be signed off by all key responsible personnel.

The attending ABS Surveyor is to:

i) Verify Repair Specification and Installation Plan (see 1-5/2.1)

- Conditions prior to installation for non-emergency repair: pre-existing condition of parent material or damaged structure, ABS type approval products, qualification records for approval, suitability of the product for the repair (e.g., approved for Oil Service)
- Verify repair category: short term or long term
- Verify installer’s qualification and certification for the repair technology
- Verify the suitable existing conditions, (e.g., scantlings according to ABS approved plans and specifications as applicable)
- Verify correct installation of product in accordance with manufacturer’s procedure and range of approvals by ABS
- Verify the testing and NDI inspection plan, including procedure, equipment, and acceptance criteria
- Verify repair material storage condition and materials certification
- Monitor surface preparation for cleanliness and roughness requirements before installation
- Monitor lamination or patch installation process
- Monitor curing condition and process
- Monitor post repair activity such as removal of temporary constraint or installation auxiliaries.

ii) Verify Repair Completion Quality Report (see 1-5/2.2)

- Witness the required quality testing and verify the result in accordance with the procedure and criteria approved by ABS in Repair Installation Procedure and Specification
- Witness the required NDI inspection and verify the result in accordance with the procedure and criteria approved by ABS in Repair Installation Procedure and Specification
- Verify service capacities of the installed composite repair (see 1-5/8)

iii) Verify the Vessel Composite Repair Register with consideration of the achieved repair quality.

iv) Issue findings for Condition(s) of Class or Class or Class Additional Requirement(s), as appropriate.

6 Survey While In-Service

After the bonded or composite repair is installed to the degraded structure, ABS in-service surveys are to be made in accordance with the Vessel Composite Repair Register. The ABS Surveyor is to verify that the integrity/condition of the bonded or composite repair and the structure being repaired is acceptable at the time of the survey and will remain acceptable until the next survey.

6.1 Vessel Composite Repair Register (VCRR)

The VCRR is to be retained on board the vessel, unit, or installation.

The Vessel Composite Repair Register (VCRR) is to be established to cover all survey activities for the bonded or composite repair while in-service. The VCRR is to contain the unique identification number for the repair, the location, components and dimensions of the patch repair, inspection internals, survey activities, and inspection records for each repair that has been made.

As an alternative, appropriate thickness measurement of the repaired steel from inside the hull may be provided.

If substantial corrosion or failure associated with the patch repair occurs, additional actions are required to confirm the area is suitable for continuous service or if it requires another repair.

6.2 Inspection Interval

The repair is to be inspected in accordance with the mandated ABS Survey period for the repaired structural member. In addition to the mandated ABS Survey period, a separate inspection interval may be required if the previously observed degradation rate before the repair will exceed the critical defect limits before the next mandated survey. If such, the minimum inspection interval time is to be determined in accordance with estimated defect growth rates before and after any repair being made, and critical defect limits, which may be determined and agreed during risk assessment (refer to 1-1/3).

In all repair cases the defect growth rate and the corresponding time expected to reach a critical size/level, including from the opposite side of the repaired area, are to be established for the substrate. This information is to be available in the Repair Design and Analysis Report and Vessel Composite Repair Register (VCRR). The inspection interval can be determined based on experience from details under similar loading conditions, direct calculations, or a combination of these. Finite Element Analyses (FEA) may be used to provide critical information to determine the time interval such as stress distributions and stress concentrations.

6.3 In-service Survey Activity

The attending ABS Surveyor is to:

i) Review the registered Vessel Composite Repair Register and Repair Completion Quality Report prior to in-service inspection and examination.

- Verify that repair is eligible within the approved use period.
- Review inspection, examination, or monitoring procedure and criteria.
- Identify any mitigation being made without ABS approval.

ii) Verify the qualification of personnel performing the inspection or examination.

iii) Verify the suitability of composite repairs by applicable and effective inspection methods:

- Visual inspection
- NDI examination
- Proactive monitoring device in place

iv) Update the Vessel Composite Repair Register with the inspection and examination results.

CHAPTER 2

Composite Repairs of Piping

CONTENTS

CHAPTER 2
Composite Repairs of Piping

SECTION 1
General

1 Scope

This Chapter specifies requirements for composite repairs of steel piping (see 2-1/2) for offshore units and marine vessels. This Chapter provides simplified requirements that apply the industry standards ISO 24817 and ASME PCC-2.

This Chapter addresses composite repairs of steel piping. However, it also applies to repairs of nonmetallic substrate materials such as Glass Fiber Reinforced Plastics (GFRP) piping.

The key aspects considered herein are listed below:

- Design of the repair
- Repair system qualification, which typically considers qualification testing specific to a pipe material
- 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*. Piping refers to following components:

- Straight pipes
- Tubes
- Pipe fittings used to join together sections of pipe such as sleeves, elbows, tees, bends, flanges, and reducers.

Valves and pumps are not covered in this Chapter.

3 Repair Application

The following situations are to be considered for repair:

- External corrosion, where the corrosion may or may not be through-thickness (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-thickness (continuous internal corrosion/erosion is taken into account after the repair).
- Crack-like defects, which may or may not be through wall cracks.

The composite repairs can also provide local structural strengthening of piping. For other damage conditions not listed above such as rupture or burst piping, the use of composite repair will require ABS technical assessment and approval. Additional requirements to those in this Section may be applicable.

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*.

The original design pressure/temperature and the 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 to be 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 FRP
- 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 including fluid properties, operating conditions, internal corrosion/erosion mechanisms, and external mechanical influences.

7 Personnel Qualification

Designs of the repairs are to be undertaken by a technically competent person who has suitable knowledge, experience, and familiarity with ISO 24817 and ASME PCC-2 standards and repair system manufacturers' requirements.

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

The repair installation is to be inspected by a certified and qualified inspector. The inspector's documentation of certification and qualification is to be reviewed by the attending ABS Surveyor at the installation site.

8 Risk Assessment

A risk assessment is to be completed with the risk level and the repair life defined for long-term repairs. The repair system application to piping could typically change the piping failure mode and reduce the probability of failure.

- The following items are to be considered, as a minimum, 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
- Repair life expected
- In-service inspectability

9 Documentation for Review

9.1 Temporary Repairs

For temporary repairs, the following documentation for repair installation is to be registered and traceable during the lifetime of the repair:

i) Repair Design, if applicable

ii) Repair System Installer Warranty, if applicable

iii) Repair Installation and Inspection Procedure, if applicable

9.2 Short-term and Long-term Repairs

For short-term and long-term repairs, the documentation provided prior to installation of the repair is to 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) A Vessel Composite Repair Register (VCRR) deemed appropriate for maintaining the integrity of the repair system is to 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 is to be submitted to ABS for review and to be available for the attending ABS Surveyor to verify that the quality assurance and documentation for repair installation is performed appropriately.

The information of the repair, identification, location, date of installation, material used, repair lifetime, associated maturation year and survey intervals is to be included in the unit´s Vessel Composite Repair Register (VCRR).

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 1-1/5 of this document, 4-6-1/3 of the *Marine Vessel Rules* and 4-2-1/3 of the *MOU Rules*. For abbreviations, see 1-1/6.

CHAPTER 2
Composite Repairs of Piping

SECTION 2
Repair Design

1 General

Designs of repairs are to be undertaken by a technically competent person who has suitable knowledge, experience, and familiarity with ISO 24817and ASME PCC-2 standards and repair system manufacturer's requirements. The short-term and long-term repair design is to be documented and submitted for ABS review before the commencement of any repair work. Temporary repairs, if performed beforehand without ABS approval, are to be well documented and submitted to ABS for record afterwards.

2 Repair Assessment

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

The following information is to be provided in 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, as well as installer's qualification and skills.

Original piping system design data and maintenance/repair/operational histories are to be provided by the owner/ operator. The materials and qualifications are to be provided by the repair system supplier 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 are to be tapered if the repair thickness is governed by axial loads. A minimum taper of approximately 5:1 is to be used. The overlap length is to be designed to be sufficient in transferring the axial load.

3.2 Type I Defects

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

For short-term and long-term repairs, the repair laminate thickness, the number of wraps, and the axial length of the repair are to 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 to be considered as structural reinforcement only.

The short-term pipe spool survival test (ISO 24817 Annex C) data is to be used to determine the maximum percentage wall loss allowed for the repairs.

3.3 Type II Defects

Type II defects are for through-thickness defects including defects in which 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.

For short-term and long-term repairs, the repair laminate thickness or the number of wraps is to 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.

For short-term and long-term repairs, the repair impact performance is to be considered for repairs to leaking piping systems (see ASME PCC-2, Part 4/3.4.7).

For short-term and long-term repairs, the following test data is to 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)

For temporary repairs, manufacturer’s requirements are to be followed.

4 Repair Design Life

The repair design life (in years) is the maximum service lifetime of the repair, which is to 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 is also to be identified in the Risk Assessment.

A temporary repair is usually needed for emergency repairs to avoid shutdown and downtime. The temporary repair is to be removed at the first opportunity (not more than 2 months), unless the temporary repair is re-assessed and it meets the requirements of piping repairs in Chapter 2, Sections 2 through 4 for being qualified as a short-term or long-term repair.

A short design life (up to 2 years) is for situations in which the repair survives until the next scheduled shutdown/drydocking or 2 years, whichever is less.

A long design life (up to 20 years) is for situations in which 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 (see 2-5/3.6).

5 Repair Design Considerations

5.1 General

For temporary repairs, manufacturer's requirements are to be followed. Short-term and long-term repairs are to comply with this 2-2/5.

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 is to be considered in determining the suitability of the repair system application. The repair system supplier is to provide the following environmental compatibility data:

- Compatibility with fluid carried in the range of specified design operating 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 taken 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 is not to 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 is to be determined for the repair system design temperature (T_d).

T_g or HDT is not to be greater than T_d.

For all repair Classes, T_d is to 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 is to be at least 30°C (54°F) less than T_g (or at least 20°C (36°F) less than HDT).

The cure schedule is to be specified and demonstrated to meet the required T_g value. Hardness testing is to be used to test curing and 90% of the minimum value from the repair system qualification tests is acceptable.

5.4 Fire Endurance

The composite repair for piping is to meet the fire endurance requirements in 4-6-3/Table 1 of the *Marine Vessel Rules*, 4-2-2/Table 2 of the *MOU Rules* or A1-2/Table 3 of the *Facilities Rules.* An appropriate strategy to achieve fire endurance for composite repairs is to be established. Effective measures are to include application of additional wraps of repair laminate material such as enough basic composite remaining intact for the duration of the fire event, applications of intumescent external coating, applications of intumescent and other energy absorbent materials within the repair laminate, or usage of polymer formulations with specific fire-retardant properties or fire endurance jackets.

Fire endurance testing requirements can be referred to relevant flag Administration regulations, standards (i.e., ISO 14692, ASTM E84), codes (i.e., IMO FTP Code) and 4-6-3/5.11 of the *Marine Vessel Rules*.

For composite repairs in locations that, as per the above-mentioned Rules, do not require compliance with any fire endurance level, the PDA Certificate for the repair product is to clearly indicate that the product is only to be installed in locations and systems for which fire endurance is not required by the Rules. If applicable, safety studies are to be considered for the use of passive fire protection (PFP) in composite repairs and submitted to ABS for approval.

Flame spread and smoke generation for the composite repair are to be considered. The average surface flammability value of the repair material is not to exceed the criteria listed in IMO Resolution A.653(16). Flame spread testing can be referred to IMO Res. A.653(16) or ASTM D635.

One (1) sample of 150 mm (6 inch) pipe diameter for each defect type is to be tested and witnessed by the ABS Surveyor.

5.5 Cathodic Disbondment

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

5.6 Electrical Conductivity

If electrical conductivity is required by the original design specifications, the repair's electrical conductivity properties are to be tested in accordance with 4-6-2/9.15 of the *Marine Vessel Rules* for static electricity control, or other applicable standards.

5.7 Weight Change

The repair system installation may cause design weight/load changes. This is to 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 to be used for the repair installation:

i) Number of layers, n:

$$n = \frac{t_{repair}}{t_{layer}}$$

n is not to be less than 2 and is to be rounded up to the nearest integer number

where

t_{repair} = repair laminate thickness

t_{layer} = layer thickness

ii) Repair area.

iii) Total axial repair length.

iv) Details of laminate lay-up, 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.

TABLE 1
Repair Classes of the Piping

Repair Class	*Typical Service*	*Design Pressure*	*Design Temperature*
Class A	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.	< 1.6 MPa (232 psi)	>-20ºC (-4ºF) and < 45°C (113ºF)
Class B	Fire water(1)/deluge systems. This class is for systems that have specific safety-related functions.	≥ 1.6 MPa (232 psi) and < 2 MPa (290 psi)	≥ 45°C (113ºF) and < 100°C (212ºF)
Class C	Produced water and hydrocarbons(1), flammable fluids(1), gas systems. This class covers operating conditions more onerous than described in Class A and B.	Qualified upper limit(2)	Qualified upper limit

Notes:

1 Where non-metallic repair is used on steel piping for fire main, sea water service, or flammable fluids, the limitations regarding location as well as fire testing requirements are to be applied. Refer to the relevant ABS Rules such as 4-6-3/Table 1 of the *Marine Vessel Rules,* 4-2-2/Table 2 of *MOU 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-thickness), defect dimension (depth and extent), pipe diameter, design temperature, and repair design lifetime.

2 Repair System Qualification

2.1 General

For short-term and long-term repairs, the following repair system qualification data is to be provided:

- Material properties for all repair classes.
- Surface preparation data for all repair classes including 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 are to be carried out using the same substrate material, surface preparation, repair laminate, adhesive, and application method.

The documentation and qualification data related to the repair system are to be provided by suppliers as shown in the following table:

Documentation	*Class A*	*Class B*	*Class C*
Material documentation and data	Applicable	Applicable	Applicable
Surface preparation documentation	Applicable	Applicable	Applicable
Short-term test data	Applicable	Applicable	Applicable
Long-term test data	N/A	Applicable	Applicable

2.2 Material Technical Data

The material technical data is to 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
- Fire endurance

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 is to be an integral part of the repair system and its qualification tests. Any change in the surface preparation method will require requalification of the repair system.

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

2.4 Qualification Test Data for Short-term or Long-term Repairs

These test data are to include tensile strength and modulus in the circumferential (hoop) direction and the axial direction of the pipe repair. The data is also to include the adhesion strength between the repair laminate and the substrate. 2-3/Table 2 below provides the items to be tested for all repair classes, except for Class A. Patch repair is not permitted, unless a patch repair is particularly appropriate for the application, and the patch repair is qualified through satisfactory testing for all applicable patch configurations.

2.4.1 Short-term Repairs

For short-term repairs, the test data is to 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, applicable to leak repair only

2.4.2 Long-term Repairs

For long-term repairs, the test sample is to have at least 1,000 hours in a water/oil environment with a temperature not less than the design temperature or in a dry environment with a temperature greater than 100°C (212ºF). The test data for long-term repairs is to 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 is to 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 (based on a series of tests on the repair system over different time periods and extrapolation to design life for measurement of the long-term strength)
- Representative repair laminate coupon regression testing results

2.4.3 Hydrostatic Test

For long-term repairs, an internal hydrostatic pressure short term Prototype Test is to be performed based on Sections 4-6-2 and 4-6-3 of the *Marine Vessel Rules*:

- For non-through-thickness defects (Type I defect), the internal pressure testing is to be 1.5 times Design Pressure. Three (3) samples of 150 mm (6 inch) pipe diameter are to be hydrostatically tested. One (1) of the three samples is to be witnessed by the ABS Surveyor.
- For through-thickness Defect (Type II defect), the internal pressure testing is to be 4.0 times Design Pressure. Samples of 150 mm (6 inch) pipe diameter are to be hydrostatically tested; three (3) samples with hole of 10 mm (0.4 inch) diameter, three (3) samples with hole of 25 mm (1 inch) diameter, and three (3) samples with hole of 50 mm (2.0 inch) diameter. One (1) of the three samples for each hole diameter is to be witnessed by the ABS Surveyor.
- For short-term repairs requesting type approval (PDA and MA), prototype hydrostatic tests as per above are to be performed.

TABLE 2
Qualification Tests

Material Property of Laminate or Laminate/ Substrate Interface	*Applicable Test Standard*
Young's modulus and Poisson's ratio	ISO 527, ASTM D3039
Shear modulus	ASTM D5379 or ASME PCC-2 – Article 4.1 – Mandatory Appendix II – Section II – item (f)
Compressive modulus	ASTM D695, ASTM D6641, ISO 604, ISO 14126
Barcol or Shore hardness	ISO 868, ASTM D2583, ASTM D2240
Thermal expansion coefficient	ISO 11359-2 or ASTM D696 or ASTM E831
Glass transition temperature of the resin(1)	ISO 11357-2, ASTM D6604, ASTM D7426, ASTM E1356, ASTM E1545, ASTM E1640, ASTM E831
Heat distortion temperature (HDT)(2)	ISO 75, ASTM D648
Adhesion strength – lap shear(3)	EN 1465, ASTM D3165, ASTM D5868
Long-term lap shear performance (optional)	ASME PCC-2 Part 4/Mandatory Appendix II-2
Impact performance	ISO 24817 Annex F Impact survival test, ASME PCC-2 Part 4/ Mandatory Appendix VI
Material Property of Laminate or Laminate/ Substrate Interface	*Applicable Test Standard*
Energy release rate (optional)	ISO 24817 Annex D Energy release rate, ASME PCC-2 Part 4/ Mandatory Appendix IV
Long-term strength	ISO 24817 Annex E Long-term strength, ASME PCC-2 Part 4/ Mandatory Appendix V
Structural strengthening	ISO 24817 Annex C Short-term pipe spool survival test, ASME PCC-2 Part 4/ Mandatory Appendix III
Degradation factor (optional)	ISO 24817 Annex G Degradation factor, ASTM D2990, ASTM D2992
Cathodic disbondment	ASTM G8, ASTM G42, ASTM G95
Cyclic loading (optional)	ISO 14692, ISO 24817
Electrical conductivity (as required by the applicable ABS Rules)	ISO 14692, ASTM D149
Chemical compatibility (as required by the applicable ABS Rules)	ASTM D543, ASTM C581, ASTM D3681, ISO 10952
Fire Endurance, if required	4-6-3/5.11 of the ABS *Marine Vessel Rules*, ISO 14692, ASTM E84
Flame spread	ASTM D635, IMO A.653(16)

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 is to be 18 MPa (2,640 psi).

3 The shear strength is determined by the average shear strength > 5 MPa, or adhesive failure between the substrate and the laminate is not to be greater than 70%.

4 Qualification tests are to be carried out in accordance with the applicable ISO standard or the applicable ASME PCC-2 standard for each category. Mixing of test standards is to be justified and is subject to approval by ABS.

2.5 Repair System Requalification

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

3 ABS Approval

Design review is required in accordance with Chapter 2 for short-term and long-term piping repairs. Materials and components are to be tested in accordance with this Section.

Commentary:

Repair product including materials and components tested in accordance with this Section should be certified by ABS with ABS Product Design Assessment certificate or Product Type Approval certificate.

End of Commentary

CHAPTER 2
Composite Repairs of Piping

SECTION 4
Repair Installation and Quality Assurance

1 General

The detailed repair specification and procedures are to be provided for the process of the piping system repair installation and inspection. The repair design, installation, or inspection is to be performed by personnel qualified and certified for the job and the repair technology is to be in accordance with approved/agreed installation procedures (see 1-1/2).

The attending ABS Surveyor is to verify that the quality assurance and documentation are performed 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 are to 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 are to be provided.

2.3 Piping Repair Design Details

The piping design details are to 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 are to 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 are to be provided by the repair system supplier. The installation procedure is to include specific installation instructions for the repair method. See 2-4/3 for details.

2.6 Health, Safety and Environmental

The repair system supplier is to provide a list of materials used and their Safety Data Sheets (SDS). The supplier is also to 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 are also to be provided.

3 Installation Procedure

3.1 General

Installation procedures are to be provided by the repair system supplier and implemented by a qualified installer. The inspection is to be done by a qualified inspector during and after the repair system is installed.

The installation procedures are to include the following (2-4/3.2 through 2-4/3.9) for all repair classes. Additional requirements are to be indicated for repair Class C.

3.2 Materials Used for Repair

The repair system supplier is to provide the SDS 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 are to 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, and substrate surface temperature during the repair and curing are to be specified in the procedures.

Commentary:

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

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

End of Commentary

3.4 Repair Details

Repair details are to include location, dimensions, and extent of the repair. The installer is to check the repair details.

3.5 Surface Preparation

The piping substrate is to be inspected before the repair system is installed.

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

Surface preparation is to include specifications of defect treatment and surface preparation grades for the surface area specified. The surface preparation area is to extend no less than the area which the repair patch is applied to.

Prepared surfaces are to 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 between surface preparation and initial coating/laminate application is to be as short as possible to avoid contamination and oxidation/corrosion. Prepared surfaces are to be protected from contamination prior to the application of the repair laminate. Prepared surfaces that have deteriorated are to be rejected.

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

The surface preparation method is to be specified by the repair system supplier. Refer to 1-5/3 for details.

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

The installer and the inspector are to check the surface preparation. The installation supervisor is to monitor the surface preparation.

3.6 Laminate Lay-up

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

Information provided in 1-5/5.3 can be referred to for on-site lamination. Laminate application information is to 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 are required to have lamination specification, inspection/verification, and documentation.

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

3.7 Cure and Post-cure

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

The cure schedule is to be specified and demonstrated to meet the necessary T_g value. Shore or Barcol hardness tests are to be used as a field measure of cure and are to be ≥ 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 are to adhere to the repair system supplier's guidance. The limits in the installation instructions provided by the repair system supplier are not to be exceeded without the approval from the repair system supplier.

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

The installer and inspector are to check the curing process. The installation supervisor is to 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 are to be specified. The QA inspection is to be performed by qualified personnel (installer, inspector, and supervisor) in accordance with the manufacturer's procedure.

Quality assurance is to 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 are to be compared with the qualification data. Acceptance values of the test results are to 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, including any hazards to and from surrounding equipment, in addition to the component being repaired.

4 Inspection and Testing after Installation

4.1 General

The testing and inspection during and after the repair system is installed are to include:

- 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 Maximum Defect Limits

After installation, the repair system is to be inspected in accordance with acceptance limits given in 2-4/Table 1. Defects that exceed the limits are to be removed and a new repair system is to 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.

TABLE 1
Maximum Defect Limits for the Repair after Installation and In Service

Inspection Part	*Defect*	*Acceptance Limits*
Interface pipe and repair laminate	Delamination	Not allowed
Repair laminate	Fiber orientation	As specified
	Thickness of the repair laminate	As specified
	Delamination within laminate layer	Not allowed
	Positioning the repair laminate	As specified and not to extend beyond the prepared surface

Inspection Part	*Defect*	*Acceptance Limits*
Prepared surface after the first resin layer applied	Crack, pin holes	Non-through layer penetration is allowed
	Resin color	Uniform
	Foreign mater and blisters	Maximum 10 mm (0.4 in.) in width and 1.5 mm (0.6 in.) in height
	Pits	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.)

4.3 System Testing

The Maximum Allowable Working Pressure (MAWP) is to be used in system pressure testing. A service test (hydrostatic or pneumatic test in accordance with the system) of not less than the Maximum Allowable Working Pressure (or the maximum pressure indicated on the set point of the relief/safety valves) is to be performed on board for a period of at least 60 minutes over which any changes in pressure and temperature are to be recorded.

System pressure testing is to be specified by the owner and is to be completed based on the relevant pipe design standard such as 4-6-2/7.3 of the *Marine Vessel Rules*.

Before commencement of pressure testing, all repairs are to be fully cured in accordance with instructions provided by the repair system supplier.

5 Repair Documentation

A repair booklet is to be available for the Surveyor to verify. The booklet is to indicate all the composite piping repairs carried out, including temporary/emergency repairs. A record of each repair, with a unique identifier assigned, is to be made and retained for the life of the repair. Repair documentation after completion of the repair is to 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).
- Details of future service inspection intervals.

6 Installation Inspection

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

The attending ABS Surveyor is to:

- 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 NDI 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 qualification survey, the repair installation survey, and the in- service survey.

ABS survey in qualification of the piping repair system (refer to 2-3/2) 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 (see Chapter 2, Section 3). This qualification survey can be a part of the ABS Type Approval program.

The repair installation survey (refer to 2-4/6) monitors and verifies that the repair installation and inspection are carried out in accordance with the approved installation specification and procedures. The repair installation and inspection are to be carried out by qualified and trained personnel. The composite repair QA/QC system is to document each installation step and be signed off by qualified and responsible personnel (see Chapter 2, Section 4).

The in-service survey (refer to 2-5/3) is to 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, are to be prepared for the repair. The inspection strategy and inspection interval are to be reported to ABS or other relevant authorities and entered into the unit's survey plans. The survey plan is to document the location and extent of the repair available during subsequent surveys.

The information on the inspection strategy and inspection interval are to be included in the unit´s VCRR.

2 Inspection Methods

Defects or damage are not always detectable through visual inspection but are best detected by suitable nondestructive inspection (NDI) methods.

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

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

Other NDI methods may be accepted subject to special consideration.

3 Repair System Maintenance

3.1 General

Inspection intervals are to be agreed with ABS and are to generally follow manufacturers recommendations. The repairs are to be examined on a regular basis as laid out in the Repair Booklet for each repair. When each repair is examined or tested, the results of the examination are to be recorded in the Repair Booklet for future reference.

The maintenance plan of long-term repairs and the inspection interval are to be determined by the risk assessment for the installed repair system. 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 to be followed.

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

3.2 External Defects

Good integrity of the repair system can prevent further deterioration of the external defects being repaired. Periodic inspection and appropriate maintenance are to be performed to maintain the laminate and adhesion to the substrate during the designed service life.

3.3 Internal or Through-thickness Defects

Inspection of the pipe beneath the repair system by using inspection techniques recommended by the repair system supplier and inspection companies is required. This inspection is to confirm that the internal defect is within the limit of the repair design. See 2-5/2 for inspection methods.

3.4 Maintenance and Repair Options

If the repair system will be replaced, the following options are to be considered:

i) Complete removal and replacement of the repair system. The removal of the repair system may be achieved by mechanical means such as abrasive blasting or high-pressure water jetting.

ii) Repair of the damaged laminate. This option applies only to 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 are to be examined on a regular basis as denoted in the Repair Document for each repair. When each repair is examined or tested, the results of the examination are to be recorded in the Repair Document for future reference. The list of items repaired and documented with an appropriate Condition of Class or Class Additional Requirement, as appropriate, is to be maintained for reference during Class surveys. The Owner is to enter the repair data 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 the failure of Class A or Class B repairs causes a leak of the carried fluid but would not be harmful, the repairs are to 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) is to be used.

3.6.2 Class C Repairs

For an original Class C repair requesting a life extension up to a maximum of 20 years, re-validation of the repair system is required. Re-validation is to be performed by re-designing the repair based on the proposed lifetime and the current inspection/assessment data of the original repaired area/defect. The re-design is to 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 is to be modified or upgraded by adding additional repair length or thickness with a compatible system to offset additional corrosion. This modification is to 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, MAWP is to be used in System pressure testing. Refer to 2-4/4.3.