OOC Guidelines for the Installation of Bonded Composite Repairs of Plate on FPS and Fixed Leg Topsides Structures

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OFFSHORE OPERATORS COMMITTEE

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1 General

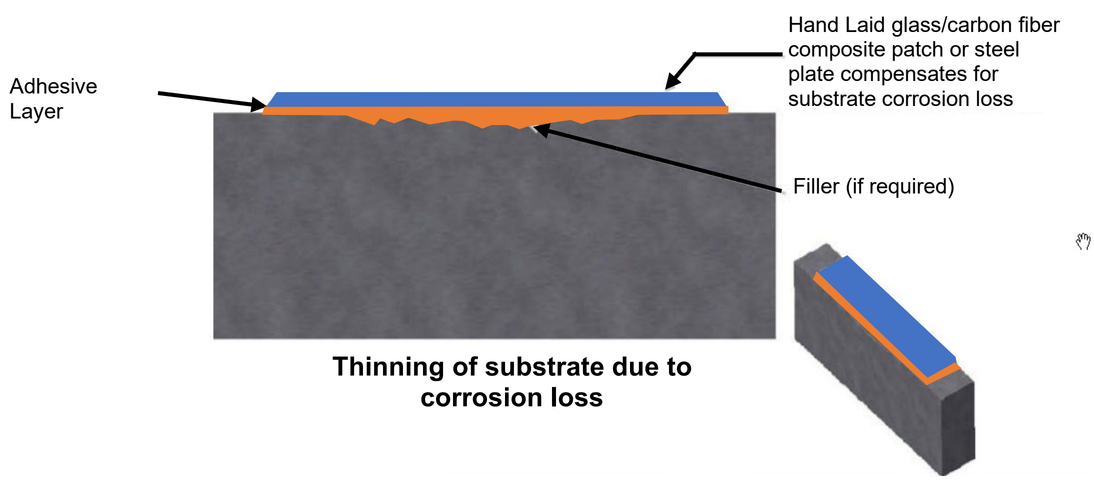
1.1 Overview

This paper provides guidelines for the use of bonded composite systems to temporarily or to permanently repair existing corroded steel plates on the topsides of FPS and fixed leg structures in the US Gulf of Mexico (GoM). The scope of this document covers the assessment, design, qualification, installation, and inspection of bonded repairs.

A bonded composite repair is a commonly used technology outside of the US GoM in both international offshore and US onshore applications. There is interest to implementing the methods in the GoM. BSEE (and previously MMS) have funded research into the technology including a research project performed by Stress Engineering in 2017 for long term subsea serviceability. While the research has typically been directed towards use in pipe repairs, many of the attributes of the materials and mechanics are similar, if not simpler in plate structures. The research used for pipes is applicable to plates as well to analyze a plate repair such that it meets or exceeds the service requirements.

The principal of a bonded repair is shown in Figure 1[1] below. Section loss due to corrosion of the existing steel deck has reduced the functional performance of the deck (i.e. load rating, containment). As an alternative to hot work repairs, a bonded composite repair can restore the functional requirements of the deck. The advantages of this type of repair include lower costs, POB requirements, HSE exposure and weight for floating installations.

Figure 1: Bonded Composite Repair



1.2 Scope

The scope of this document is limited to structural steel plate welded to structural steel framing, including building floors, walls, and roofs that has lost section due to corrosion. Plate that contributes to the lateral stability of the topsides (i.e. membrane and lateral bracing) and plate that is local area support only

[1] Figure from "Composites Part A: Repair of floating offshore units using bonded fiber composite materials" (McGeorge, et al., 2009) with amended notation.

(distributes gravity load to beams) are both considered. The function of the element being repaired should be assessed on an individual basis.

Structural damage due to fatigue cracking in plate or welds is excluded from the scope of this document. All composite repairs replacing lost structural capacity require the review and approval BSEE, USCG (as required), and ABS (as required). Repairs that only provide secondary containment or sealing do not require regulatory review. This guidance does not apply to pressure containing equipment or piping.

For applicable repairs, advance approval from the governing regulatory bodies is required. Until the CFRs include language pertaining to the use of composite repairs, this will involve the process for obtaining alternative compliance.

1.3 Acronyms

ABS	American Bureau of Shipping
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
BSEE	Bureau of Safety and Environmental Enforcement
DNV	Det Norske Veritas
NDE	Non-Destructive Examination
OEM	Original Equipment Manufacturer
PFP	Passive Fire Protection
USCG	United States Coast Guard
UV	Ultraviolet

1.4 Definitions

Composite Repair – A repair consisting of more than one type of material intended to act in concert to perform the function of the element being repaired.

Bondline – the interface plane between the substrate and the repair material.

Substrate – The original element being repaired that the repair is bonded to.

Delamination – When layers in an element detach from one another.

Temporary Repair – A short term repair with a permanent repair planned for implementation.

Permanent Repair – A repair with an intent of lasting until the end of the asset's life.

1.5 Reference Documents

At present, there are no US standards in place for carrying out composite repairs on offshore topsides oil and gas structures. Neither the CFRs nor the traditional offshore design standards provided by API publications cover the three references below. While both the ABS and DNV documents were written for classed, vessel structures, the concepts applied for bonded composite repairs remain similar. The applicable information contained within these documents has been amended for use on non-classed, offshore topsides structures. The workgroup discussed the contents of the documents referenced below and included the requirements from each determined to be most applicable to the scope of the guidance. The standards are referenced in the body of the guidance to indicate where criteria came from.

- ABS "Guidance Notes on Composite Repairs of Steel Structures and Piping", September 2019. [1]
- DNVGL-RP-C301 "Design, fabrication, operation and qualification of bonded repair of steel structures", July 2015. [2]
- ASME PCC-2-2018 "Repair of Pressure Equipment and Piping", 2018 [3]

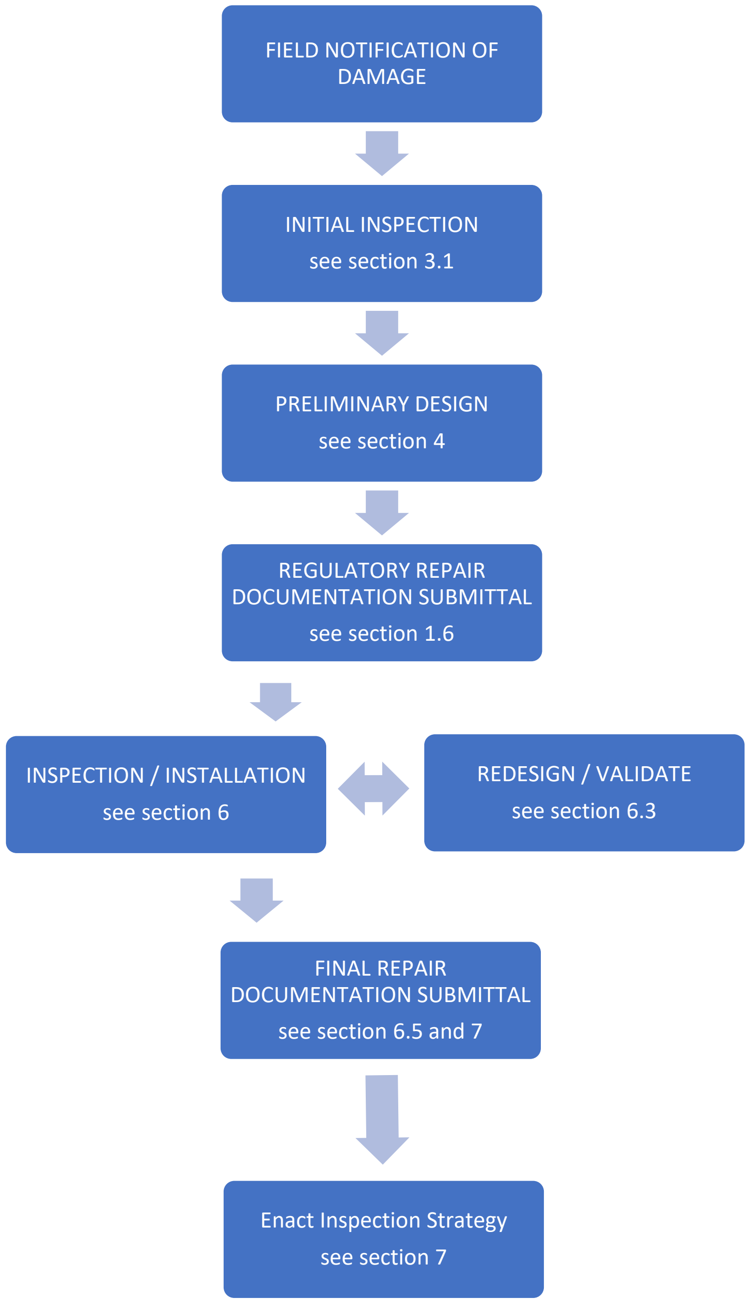
1.6 Documentation Requirement

The documentation required for all composite repairs include:

1. Inspection report
2. Design report with qualification including previous testing and design calculations. May be generic if the repair is within established off-the-shelf parameters.
3. Installation Report
4. In-service inspection Plan

Guidelines for the preparation of these documents are included in the subsequent sections.

Process Flowchart



2 Assessment for Repair

This section provides the guidelines for assessing the severity of the corrosion and determining the criticality of the structural element. The combination of these factors determines whether a bonded composite repair is acceptable.

2.1 Inspection Report

The first step of the repair assessment is to conduct an inspection of the existing plate to determine the extent and severity of the material loss. The inspection report serves as input to the repair design.

It may also be beneficial to investigate the cause of the corrosion to help determine the best method by which to perform the repair and to potentially arrest further degradation of similarly affected areas.

Corrosion can be divided into the following categories as defined by ABS[2]:

1. General Corrosion – Uniform corrosion over an entire surface.
2. Pitting Corrosion – Localized corrosion, consisting of small holes or pits.
3. Grooving Corrosion – Localized corrosion, typically along a weld line
4. Edge Corrosion – Corrosion along the free edge of plates.

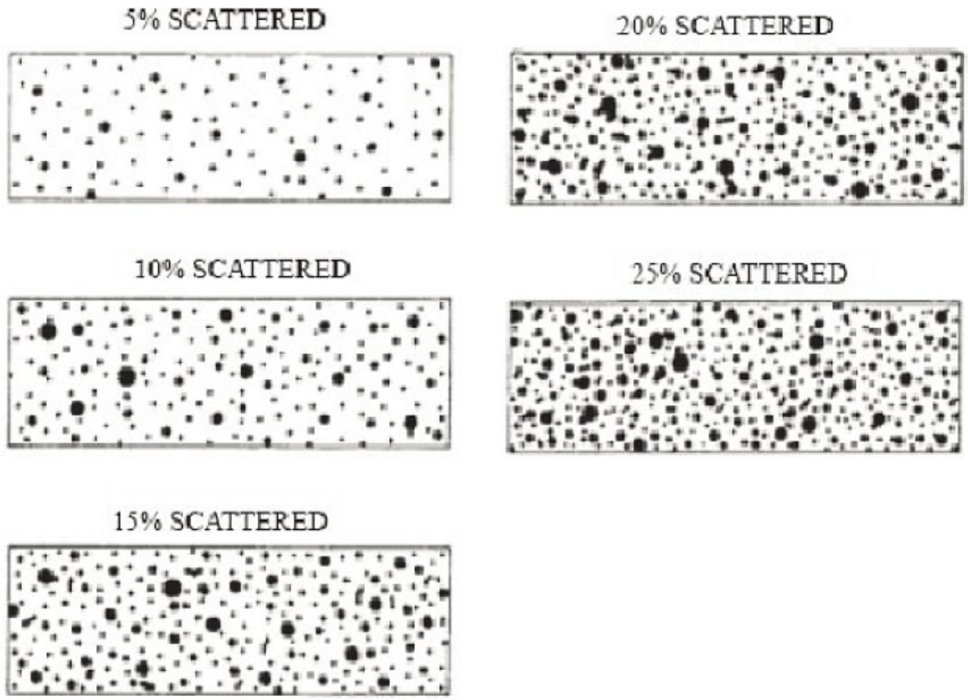
General corrosion and pitting corrosion are the most prevalent types on offshore plated structures and are the primary focus of this document. However, all detectable types of corrosion should be noted in the inspection report and considered when developing a bonded composite repair design.

The inspection procedure of plated decks exhibiting signs of corrosion should consist of the following[3]:

1. Clean surface in accordance with NACE No. 1 / SSPC-SP 5-2006 White Metal Blast Cleaning to a surface cleanliness of SA 2 ½.
2. UT thickness reading to establish nominal remaining plate thickness, t_{plate}.
    a. Where the corrosion allowance is exceeded, a minimum 5 thickness check points over a 1 square meter is required to determine loss.
4. Pit gauge readings to establish pit depth, d_{pit}, relative to the adjacent plate nominal thickness, t_{plate}.
    a. A minimum of the five deepest pits in the area should be measured. Use readings to determine the average remaining thickness at pitting, t_{pit}.
    b. The pitting intensity as defined in **Figure 2**[4] should be recorded.
    c. The following equation should be used to estimate the average remaining thickness in pitted areas
    d. $t_{ave} = t_{plate} \times (1 - Intensity) + t_{pit} \times Intensity$
5. Record the size and locations of through thickness holes

[2] The information contained below is compiled from Section 1.2.4 of "Guidance Notes on Composite Repairs of Steel Structures and Piping" (American Bureau of Shipping, 2019).
[3] Procedure is an amended version of the one provided in Chapter 1, Section 2.4 of the ABS Guidance Notes (American Bureau of Shipping, 2019). The requirements were made more stringent to align better with DNV requirements.
[4] Figure from page 363 of "ABS Rules for Survey after Construction" (American Bureau of Shipping, 2019).

Figure 2: Pitting Intensity Diagram



Following the inspection, it is recommended that the plate be either be re-coated, or the composite repair applied in a timely manner to prevent further corrosion. This may be achieved by performing repair design calculations prior to mobilizing the inspection and repair crew. Multiple repair options can be developed assuming different ranges of average remaining thickness, t_{ave}. Once the t_{ave} of an area is established during repair preparation, the appropriate repair design for that range of thickness can be selected and applied. This catalogue of potential repair geometries can be used to optimize the repairs such that only the required thickness of repair material is added in a given zone of the repair area. If the t_{ave} falls outside the bounds of those ranges, or other anomalies are found, the repair design shall be re-evaluated. If the repair design at hand cannot be re-evaluated in a timely manner such that further corrosion cannot be avoided, mitigations against further corrosion are required. The deck should be re-coated to prevent further corrosion; allowing time for an appropriate repair design to be developed.

The above inspection data along with the following additional information should be included in an inspection report.

- Date and Inspector name
- Pictures of each inspection area
- Location, type, size, and extent of corrosion overlaid onto a structural framing/plating drawing.

This report serves as the basis for which the composite repair design is based or for the selection of one of the pre-determined design

2.2 Repair Criticality

When the plate section loss exceeds the allowable corrosion over a substantial area, a repair should be performed. The allowable corrosion may be an explicit corrosion allowance stated in applicable standards, a margin based on an engineering assessment of the structural utilization based on actual / expected loading or determined using engineering judgement in simple cases.

When evaluating whether a composite repair is suitable, the structural element's criticality should be assessed. This can be determined based on the applicable class rules from a classification society (ABS, DNV)[5]. Class rules may not be directly applicable, but the concept of structural criticality is still relevant and can be applied here. Critical structural elements may be either of the following:

1. Structural elements that would result in progressive collapse or an otherwise un-acceptable event if failure were to occur.
2. Structural elements subjected to significant loading and are approaching their design limits (i.e. strength, fatigue life).

Repairs to plate that is not considered in the global structural analysis of the topsides structure, or if the remaining plate is still adequate for the anticipated global loading, shall be classified as non-critical.

Plate which serves as the in-plane lateral force resisting system for a deck level or wall is critical to the stability of the overall structure. However, due to the small demand on the plate, there is potentially significant redundancy available for the load to redistribute and still provide the lateral strength and stability required. To assess the criticality of an area of plate, either of the following sensitivity analyses may be performed.

1. Perform an analysis where complete areas of the plate are removed. If the resulting load redistribution does not overstress the existing structural framing or the adjacent plate, the plate may be deemed non-critical.
2. Perform an analysis with areas of plate reduced to the average remaining plate thickness defined in Section 3.1. If the remaining plate has in-plane utilization ratios within design limits, the plate area may be deemed non-critical. This analysis should include reassessment of the buckling strength of the reduced plate section.

If the plate is deemed non-critical, the composite repair may also be considered non-critical. The repair design, while considered local only, should account for the transfer of the in-plane membrane stresses at the bond line between the steel substrate and the composite material.

This approach ensures that the repair installed will not compromise overall asset integrity is case of failure through fire or other means.

Critical repairs shall be considered Class B or C as defined in section 4.3. Non-critical repairs can be considered either class A or B as defined in section 4.3.

[5] Structural element criticality is defined in Section 1.5 of the DNV Recommended Practice (DNV GL Group, 2015) and Chapter 1, Section 2.3 of the ABS Guidance Notes (American Bureau of Shipping, 2019).

For applications where fire resistance is required for the overall stability of the structure or the protection of personnel in refuge areas, intumescent passive fireproofing may protect the composite repair from the effects of fires. PFP installation is most effective on vertical elements and is not typically used on horizontal elements such as on floors and roofs. Some areas of a structure may not be appropriate for the installation of a composite repair.

Analysis or testing should be performed to determine the effects of impact resistance which may degrade the strength of the composite repair, both for laminate and plate type repairs.

2.3 Design Basis

A bonded composite repair consists of a composite laminate, an adhesive bond layer and existing steel plate. A cold bonded plate repair consists of three components, i.e., the bonded plate, an adhesive bond layer, and the existing steel plate. The design of the repair should cover all three components and their interfaces, with the following considerations:

1. Functional requirements
2. Relevant failure mechanisms
3. Repair Class
4. Material Safety Factors
5. Structural Analysis

2.4 Functional Requirements [6]

A bonded composite repair should typically restore the functional requirements of the original design. For repairs where the functional requirements are not intended to be retained from the initial design, proper Management of Change should be applied. The relevant functional requirements for plate repairs are listed in in *Table 1*.

[6] The functional requirements table is an amended version of Table 402 from DNV Recommended Practice (DNV GL Group, 2015).

Table 1: Functional Requirements

Functional Requirement	Comments
Design Life	Define service life. Repair should be managed by an inspection plan over this period and removed or repaired when it no longer can be shown to be functioning as designed. An inspection interval should be established if long term testing is unavailable.
Load Capacity	Typically to restore original capacity. Includes area loads, point loads, in-plane membrane stresses and any other expected load conditions throughout its planned service life.
Stiffness	Achieve stiffness per serviceability requirements
Impact resistance	Specify the required impact resistance
Containment	Where specified, repair shall maintain or restore fluid containment
Temperature resistance	Specify the expected operating, minimum, maximum and assumed installation temperature.
UV Resistance	Specify UV exposure (e.g. top deck, interior, etc.…)
Environmental Conditions	Specify the expected range and installation humidity. Indicate exposure to salt or fresh water.
Chemical Resistance	Specify type and concentration levels of chemical exposure
Abrasion/ Wear resistance	Specify functional use of the deck (e.g. drilling deck). Indicate levels of abrasion
Electrical Chemical Properties	Patches made from conductive materials shall be electrically isolated from the steel substrate to prevent galvanic corrosion
Fire resistance	No specified fire resistance required. Materials used for the repair should not be accelerants or emit toxic gases if they may be exposed to fire during their planned service life. Egress and emergency fire requirements should be applied per ABS, USCG and ASTM 3059. (ASTM, 2018)
Electrical Conductivity	Repair shall ensure static electricity is not developed.

2.5 Failure Mechanisms

The relevant failure modes of bonded composite repairs of corroded steel decks shall be identified in the manufacturer's specification. Depending on the proposed repair, a HAZID may be necessary to investigate the consequences of a repair failure to better understand the criticality of the repair. The failure modes include:

1. Patch Debonding from steel substrate
   a. Bonding Layer Fatigue and Debonding Propagation – Debonding resulting from a crack initiated and propagated in the bond layer when exposed to cyclic loading.
   b. Free Edge Cracking – Debonding crack initiated and propagated from the free edge of the repair
   c. Bonding Layer Fracture – Debonding initiated when capacity of the bonding layer is exceeded and fracture occurs
   d. Blistering - Fluid build-up between the bonding layer and the patch or substrate. When pressure exceeds adhesion, blistering and delamination occurs
   e. Creep Rupture – Under permanent loads, creep and subsequent creep rupture may result in separation of the path from the substrate

   f. Bonding Layer Property Changes Due to the Service Environment – Reduction of bonding layer capacity due to temperature or chemical environmental changes
   g. Substrate Corrosion – Debonding resulting from corrosion of the substrate at the bonding layer
2. Laminate Patch Failure – If the stress or strain in the patch exceeds a critical level, cracks initiate and propagate until failure
3. Repair efficiency – Ability of the repair to fully or partially restore the strength and stiffness of the original design. Assessed both initially and long term.

2.6 Repair Class

There are three repair classes defined by the amount of qualifications required. The level of repair class required is determined based on criticality and repair reliability as provided by the OEM.

2.6.1 Class A Repairs

Repairs where the integrity and efficiency of the repair are not qualified and where load carrying capability is not intended to be restored. These repairs are typically to restore containment or as sealant. The repair installation is based on rules of thumb included in procedures provided by the OEM with applicable boundary conditions for use.

2.6.2 Class B Repairs

Repair which has been specifically engineered for the expected loading and where the system's qualification is based upon small-scale test results assessing the static bond-line capacity, patch capacity, and repair efficiency. The qualification would be based on coupon level and short-term load testing. This testing may be comprised of non-repair specific material tests. In lieu of testing the long-term effects of cyclic (fatigue) or permanent (creep) loads, a larger safety factor is required to reduce the likelihood of these long-term failure modes.

2.6.3 Class C Repairs

In addition to the requirements for Class B, the system's qualification is based upon project specific accelerated long-term and large-scale tests used in combination with long term capacity models to assess the effects of cyclic and permanent loads. The testing can be performed by the OEM or an independent testing laboratory. The additional documentation quantifies with confidence the reliability of the repair for the intended design life.

2.7 Material Safety Factors

The material safety factors used in the design repair are provided in *Table 2.*

Table 2: Material Safety Factors

Component	Repair Class	Short Term (static loading)	Long Term (fatigue loading)	Comment
Bond-line[7]	B	1.35	1.64	Representative of typical degradation with time
	C	1.35	1.00	Long-term behavior explicitly accounted for
Patch Laminate[8]	B & C	1.22	1.00	Reduced factor due smaller variability
Steel Substrate	B & C	1.25		Per API-RP-2A (WSD)

The material factor of safety for the Bond-line and Patch Laminate are pulled from the ABS Guidance Notes and DNV Recommended Practices and are identical in both. In the absence of an American regulatory standard, each of these documents serves as a relevant third-party standard of practice addressing composite repairs of steel structures. Both documents are applying the industry standards provided in ISO 24817 for composite pipe repairs out to structural. The original whitepaper had the below footnote for this table.

Whether the short term or long-term column can be used is dependent on the qualification testing referenced for the repair.

2.8 Structural Analysis

A structural analysis must consider all three components (substrate, bond layer, and composite laminate) of the bonded repair and their interfaces. As mentioned in Section 2.2, the analysis of the repair is only required for local strength and stiffness verification as the bonded composite plate repair does not contribute to the global strength of the structure for non-critical repairs. A global analysis may be required to prove an element is non-critical. For critical repairs, a global analysis is required to assure the repair can provide the required capability.

The repair design should incorporate the material properties defined in Section 5.2,including time-dependent degradation into the design calculations. The calculations should reflect all pertinent functional requirements and factors of safety defined by the repair class of the composite. The design calculations should identify the controlling failure mode for each component and interface. They should also document that all limit states are within their allowable or design strength or stiffness.

For bonded composite plate repairs, the design calculations shall determine the required composite thickness and axial length beyond the damaged area. In addition, the allowable or design impact resistance should be provided when required.

Analysis is not required for Class A repairs. They can be designed and implemented using typical details and OEM guidance concerning repair boundary conditions. A set of typical repair details for simple repairs can be developed by the operator or OEM and the application of these details be controlled by a responsible party.

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[7] These values referenced directly from DNV GL Group. (2015). *DNVGL-RP-C301* and American Bureau of Shipping. (2019). *Guidance Notes on Composite Repairs of Steel Structurand and Piping*.

[8] These values referenced directly from DNV GL Group. (2015). *DNVGL-RP-C301* and American Bureau of Shipping. (2019). *Guidance Notes on Composite Repairs of Steel Structurand and Piping*.

2.9 Design Report

A design report covering the design basis and all relevant information for the design input, analysis, fabrication, and qualification shall be prepared for all class B and C bonded composite repairs to plated structures. The design report forms the basis for acceptance of the repair by the owner and relevant regulatory authorities.

The design report should contain the following at a minimum:

1. Description and drawings of the corroded plate areas to be repaired.
2. Description and drawings of the entire repair.
3. Identification of all raw materials with general material type (e.g. carbon fiber, resin) and trade name including specification of all material and accompanying design documentation.
4. Design assumptions used in the design basis, including design life, loading conditions, environmental conditions, and other relevant conditions impacting the repair design.
5. Design analysis including evaluation of corroded plate areas and their criticality for compliance with governing technical requirements.
6. Installation and fabrication procedures/specification, including acceptable surface preparation, temperature and humidity, acceptable qualification level of the installer and the inspector, references to specifications, and drawings.
7. Description and evaluation of the identified failure modes and mechanisms.
8. Inspection procedure and inspection schedule for verifying effectiveness after installation.
9. Qualification testing protocol and test results consistent with the repair materials, repair design, and installation type.

3 Material Qualification[9]

This section describes testing required to qualify a bonded composite repair system. The material properties derived from testing are used as input data in the repair design calculations. The four main types of properties required are:

1. Static properties
2. Properties under constant permanent static loads or deformations
3. Properties under cyclic loads or deformations
4. Functional properties
5. Properties under thermal considerations

The extent of testing required to obtain material properties is determined by the repair class defined in Section 4.3, and by the material properties required in the design calculations. Under certain conditions, typical values from existing references may be used in lieu of testing.

3.1 Testing Requirements

Testing shall be performed under conditions to mimic the in-service environment specified in the design basis. The test specimen should be representative of the actual repair and should be manufactured and applied in the same way. The existing substrate original condition and post surface preparation condition should be, to the extent possible, identical. All the raw material shall be the same as the actual repair.

3.2 Material Properties

Table 3 provides the material properties required depending on repair class and functional requirement. All properties should be obtained directly by measurement or traced back to measurements. All samples shall be prepared using the same surface preparation and curing schedules as intended for use in the field. Changes to curing schedule or surface preparation method shall require re-testing of material properties.

[9] The material qualifications are based upon the guidance contained in Chapter 1, Section 3.4 and Chapter 2, Section 3.2.4 of the ABS Guidance Notes (American Bureau of Shipping, 2019).

Table 3: Material Properties

Material Property of Laminate or Laminate/Substrate Interface	*Class A/B*	*Class C*
Young's modulus	X	X
Poisson's ratio	X	X
Shear modulus	X	X
Ultimate Tensile Strain	X	X
Ultimate Tensile Strength (1)	X	X
Barcol or Shore hardness	X	X
Thermal expansion coefficient	X	X
Glass transition temperature of the resin	X	X
Adhesion strength – lap shear	X	X
Long-term lap shear performance	-	X
Energy release rate	X	X
Long-term strength	-	X
Cyclic loading	-	X
Cathodic disbondment	X	X
Electrical conductivity	X	X
Chemical compatibility	X	X

4 Repair Installation and Quality Assurance

This section provides general recommendations on the installation requirements and procedures for a hand-laid bonded composite repair. A detailed, step by step installation procedure, which will allow the repair to meet the minimum requirements to achieve design conditions shall be provided by the manufacturer.

A QA/QC system should be in place that covers each step and that requires each step to be signed off on by qualified and responsible personnel. At a minimum, the QA system should include checks for the parameters in the following sub sections.

The quality and reliability of the repair is directly dependent upon the skill and experience of the personnel carrying out the repair. Therefore, all installation and inspection personnel should be recognized as competent by the composite manufacturer for installing the repair.

4.1 Surface Preparation

The surface preparation is a key factor in achieving a satisfactory bond to the existing substrate and is essential to the long-term performance of the bonded composite repair. The manufacturer's installation procedure should include level of surface cleanliness and surface roughness required to achieve the necessary bonding strength.

At a minimum, the surface preparations should consist of the following (NACE, 2006)[10]:

1. Prior to blasting operations, any grease, oil and other contaminations shall be removed in accordance with SSPC-SP-1 or ISO 8501-1:2007
2. A surface cleanliness of Sa 2 ½ shall be achieved by grit-blasting the deck. The surface profile shall be in the range 60 to 100 µm. The roughness shall be: 7 mm ≤ Ra ≤ 15 mm on all measurement points as per (EN ISO 4287/4288 lc = 2, 5 mm)
3. Dust, blast abrasives and other loose particles shall be removed from the deck. Per ISO 8502-3: Dimension ≤ 2; Quantity ≤ 2
4. Surface salinity (ISO 8502-6 & 9) < 40 mg/m2

Priming of the cleaned surface with a primer shown to be compatible with the selected composite may be performed if explicitly allowed by the composite manufacturer's installation procedure to avoid the formation of rust blooms, to reduce the sensitivity of contamination to the surface, and to enhance the bond strength between the steel substrate and the patch. The bond strength of the primed surface should be demonstrated by testing.

4.2 Adhesive Bonding

Bonding of patches onto an existing substrate requires the control of several key process parameters to obtain a sufficient bond quality. In addition to achieving the manufacturer required surface preparation, the following controls should be followed.

[10] NACE. (2006). *No. 1/SSPC-SP 5-2006 White Metal Blast Cleaning.* NACE.

4.2.1 Control of Bondline Thickness

The bondline thickness may influence the peel strength of the repair and should be controlled within the limits specified by the manufacturer. For on-site lamination directly to a substrate, proper wet-out of the first reinforcement or insulating layer should be verified. Dry spots or excessively resin rich areas are not allowed and should be corrected by the laminator before the subsequent reinforcement layers are applied per the OEM installation procedure.

4.2.2 Control of Alignment

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

4.2.3 Control of Cure Parameters

The cure temperature and cure time of the adhesive should be controlled to obtain sufficient bonding strength in accordance with the manufacturer's installation procedures. The contact pressure should be controlled as specified.

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

4.2.4 Pull-off Strength of the Repair

To control the quality of surface treatment and bonding, pull-tabs pull-tabs may be installed on test areas at the same time as the repair using the same materials and procedures. The pull-off strength can then be used to compare with the specified values. The test repair areas shall be removed or pull-off damage repaired and recoated after performing the test.

4.3 Repair Installation

On-site lamination of patches onto an existing substrate requires control of several key process parameters in order to obtain sufficient bonding and patch laminate strength. In addition to achieving the manufacturer required surface preparation, the following controls shall be followed.

1. <u>Handling and Preparation of Materials.</u> All precursor materials should be stored and handled appropriately according to the manufacturer's instructions.
2. <u>Control of Lay-up.</u> The lay-up sequence, orientation and length of fiber reinforcement layers should be done according to repair design documentation.
3. <u>Control of Wet-out.</u> When using hand wet lay-up processes, appropriate wet-out may be needed for each applied reinforcement layer.
4. <u>Control of Cure Parameters</u>. The correct temperature and time for curing the laminate should be followed.

4.4 Design Rejection

If the design does not adequately or accurately reflect the initial condition of the substrate, installation should be halted while the design can be updated and validated against the actual condition of the corroded steel.

4.5 Installation Report

The repair installation report, prepared by the repair installer, shall document that the bonded repair was installed in accordance with the design specification and installation procedures. In cases where multiple repair options were developed, the applicable repair option should be noted with the supporting evidence that the found condition of the substrate matched that of the applied repair design criteria.

The qualified repair inspector shall document compliance with QA/QC procedures including documentation of the installer's qualifications consistent with the recommendations in PCC2[11].

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

[11] ASME. (2011). *PCC-2-2011, Repair of Pressure and Piping.* ASME.

5 In-Service Inspection

An inspection strategy that accounts for the likely failure modes of the bonded composite repair shall be established. The inspection strategy should include inspection schedules, instructions to surveyors regarding inspection techniques and parameters to be recorded. Acceptance criteria should be given for all inspection parameters. A single In-Service Inspection plan may be used across multiple repairs provided the limit states and failure mechanisms are addressed.

5.1 Composite Laminate

Delamination, resin erosion and impact damage in the patch laminates are all possible failure mechanisms that reduce the strength of the repair. Visual inspection is expected to be the primary mode of inspection. For detection of possible delamination, other NDE methods including ultrasonic and tap testing (light impact audial testing) may be used, provided they are qualified for the relevant application through testing.

5.2 Bondline

Through proper design of the composite bonded repairs, the highest peel stress should occur at the edge of the repair. The most likely bondline failure would therefore occur around the perimeter of the repaired edges allowing for visible inspection of the defect. For bondline defects not at the edge, no reliable technology for inspection currently exists. New inspection methods may be employed for monitoring of the bondline integrity provided they are qualified for the relevant application through testing.

5.3 Steel Substrate

For plate composite repairs, the steel substrate is completely covered by the composite patch making detection of corrosion a challenge. NDE procedures such as Ultrasonic, Radiography or Electromagnetic may be used provided they are qualified for the relevant application through testing. Visual inspections focused around the perimeters of the repair area and (where accessible) the back side of the repair area may be useful in detecting continuing corrosion damage to the steel substrate.

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