What are The Key Criteria to Have A Safe and Reliable Installation of Composite Repair System?

Non-metallic composite repair technology has proven to be an effective and efficient means of repairing corroded or otherwise damaged pipelines and piping systems across a variety of industries due to its lightweight, high strength, and corrosion-resistant properties. The two main codes and standards for composite repair system are:

1. ASME PCC-2-2022, Article 401 – Nonmetallic Composite Repair Systems: High-Risk Applications.
2. ISO 24817- 2017 - Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection.

However, is there a thorough understanding and implementation of the right "Controlled Processes" to achieve the ultimate goals of safe and reliable installation of Composite Repair Systems? This article discusses the crucial roles of the "Controlled Processes", highlighting the Key Criteria during the implementation of Selection, Design, Training, Installation/ Inspection and Documentation phases.

Many studies have demonstrated that when composite repair systems are correctly selected, designed, installed, inspected and documented, they can restore a piping and pipeline's structural integrity and pressure containment capability for a wide range of anomalies and applications—even to an extent that the performance level of the damaged pipe is equal to that of the original pipe. Of course, there are cases where poorly selected and designed, improperly installed, inspected and documented composite system will provide little to no benefit. This means that safe and reliable performance of a composite repair system is critically dependent on five 'Controlled Processes': (1) Selection of Materials that have been tested to meet qualification requirements according to the standards, (2) Repair Design, (3) Installer Training, (4) Repair Installation and (5) Repair Documentation.

(1) Selection of Materials that have been tested to meet qualification requirement

In general, the following are types of composite repair systems in the market.

(a) Pre-cured - Provided in pre-cured sheets that are bonded layer-upon-layer in the field utilizing adhesive between each layer.

Figure 1: Pre-cured composite repair systems

(b) Pre-saturated, field-cured - Typically provided in rolls with resin impregnated into the fiber at the factory that are applied and cured in place in the field.

Figure 2: Pre-saturated, field-cured composite repair system

(c) Field-saturated, field-cured - Typically provided in rolls of dry fiber and resin separate, then mixed and combined in the field, then cured in place.

Figure 3: Field-saturated, field-cured composite repair system

Each system, regardless of type, has specific properties and parameters that affect all aspects of the system from start to finish. For example, pre-cured systems generally offer fast turnaround installations for simple straight pipe geometry only, but they are not capable of repairing leaking defects. Moisture Cured Urethane (MCU) systems are a good example of a pre-saturated, field-cured composite system offering simple and fast application, but they are not suitable for higher risk defects (dents for example) and high pressure leaking defect repairs due to lower bond strength adhesion resulting from the polymer type in combination with the curing process (MCU uses water to initiate curing and produces gases of carbon dioxide during curing). The excess water and gases of carbon dioxide are the main culprits for the potential porosity and voids within the laminate of MCU composite repair.

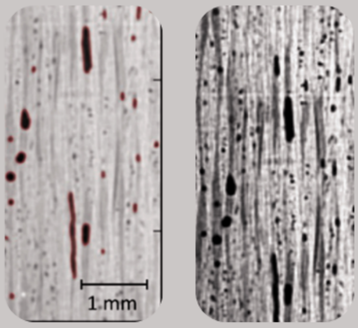

Figure 4: Microscopic view of cross section of the defective composite repair system with voids and porosity

In general, factors that affect the overall performance of the composite repair system, such as elastic modulus, tensile strength and adhesion strength, can be traced to the fiber type, matrix material (i.e., resin), and fiber orientation. For example, HJ3's CarbonSeal system, which is a high layer thickness (1.3 mm per layer), bi-directional carbon fiber with ambient cured novalac epoxy resin, offers faster application and a more cost-effective repair for any demanding defect requiring restoration of strength in both hoop and axial directions due to its high strength per layer and carbon fiber-based fabric structure. In contrast, a carbon fiber system with similar strength properties but with uni-directional iber architecture and a low layer thickness (typically 0.4 mm to 0.8 mm) will likely require more layers resulting in longer installation time to achieve the same result in terms of hoop reinforcement and offer little axial reinforcement. For a uni-directional architecture, the axial reinforcement will largely be driven by the matrix (resin) which can be an order of magnitude lower in strength than the hoop strength. Additionally, some novalac epoxy systems require post curing (controlled application of high temperature beyond ambient or installation conditions) to complete the curing process and achieve the strength determined in qualification testing and hence the level of reinforcement that the calculation is based upon. This leads to additional cost and extensive curing time.

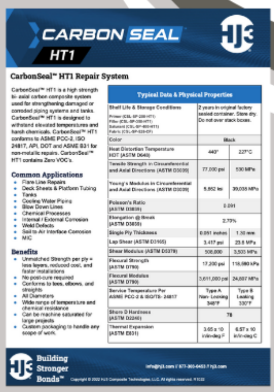

Figure 5: Technical Data Sheet of HJ3's CarbonSeal Repair System

All the technical data and testing results should be documented in the manufacturer's Technical Binder, Testing Report or Accredited Third Party Testing report which has outlined all full-scale testing for both Type A and Type B repair in accordance with Table 401-3.2-1 in ASME PCC-2 and Table 4 in ISO 24817.

Figure 6: Technical Binder of CarbonSeal Repair Systems

(2) Repair Design

ASME PCC-2 Article 401 Appendix 401-I, contains a two-page "Component Repair Data Sheet" that is an ideal reference for ensuring that all parameters required for the repair design have been completed. ASME PCC-2 addresses this by including a list of important questions to be resolved in the "assessment" process. It is paramount to collect the above data before designing and installing a composite repair in order to form the basis for determining the repair requirements. An anomaly targeted for repair must be characterized in terms of extent and severity to determine its impact on the integrity of the piping. For example, essential data to assess a corrosion defect include the pipe diameter, nominal and remaining wall thickness, and material grade, as well as the length and width of the corrosion. Standards and guidance documents such as API 579/ASME FFS-1, ASME B31G, or BS7910 are typically used to perform the required calculations for corrosion assessment. As part of this assessment, the decision is made as to whether the anomaly is in need of repair.

Once the severity of the defect has been assessed, the composite repair requirements can be determined using Design Methodology in ASME PCC-2 Article 401 Section 401-3.4 or ISO 24817 Section 7.5. The inputs to the composite repair design must consider all facets of operation which are captured in the Design Data Sheet of ASME PCC-2, for example, expected loads, including external bending moments and axial loads, expected maximum operating temperature of the piping, or the ambient temperature of the soil/water/atmosphere in the vicinity of the repair.

The end user must review and approve the Repair Design by confirming the inputs to the assessment and ensuring the design methodology addresses those inputs and is valid to match the risk and expectation of each specific repair.

(3) Installer Training

Personnel involved in the installation of a Composite Repair System shall be trained and qualified according to Installer Qualifications in ASME PCC-2 Article 401 Mandatory Appendix 401-VII or ISO 24817 Annex I. The installers are taught the full installation instructions, and the training qualifications must include the definition and terminology of the composite repair system, health and safety, surface preparation, material preparation, material application, control of repair conditions, QA/QC methods and QA/QC documentation. Typically, each new installer must attend 2 days of theoretical classroom training and practical training of installing a composite repair on one (1) straight pipe, one (1) elbow and one (1) tee. After successful inspection of the composite repair, the straight pipe with a through wall hole will be subjected to a hydrostatic pressure test. The new installer will be awarded with installer qualification certificate once he/she has passed the examination and tests for both theoretical and physical application.

Figure 7: Installer qualification hand on installation training

(4) Repair Installation

During repair installation, the qualified installer is required to follow full installation instructions from the manufacturer and conduct all required quality assurance methods in accordance with Hold Points in ASME PCC-2 Table 401-4.6-1 or ISO 24817 Table 14. Listed below are several key criteria that should be adhered to when composite repair systems are installed on piping:

- Surface been prepared to the manufacturer’s requirements.
- Proper materials on hand that match the repair design and installed according to the installation procedure.
- Service temperature limitations during the installation.
- Cure fully completed before the line is placed back in service.
- Measurements taken during and after curing time has elapsed to ensure that all materials (fillers, primers and resins) were properly mixed and have cured properly (e.g., hardness tests, etc.).

If the incorrect composite repair system or the installation is not properly completed, then the premature failure of the composite may happen in service which may eventually lead to safety issues, risk to personnel and/or fire.

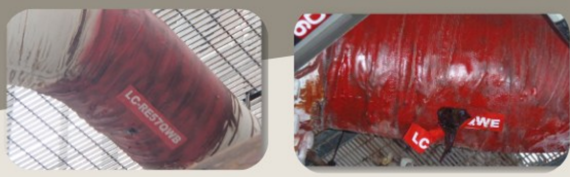

Figure 8: Composite repair failures

Figure 9: Collapse of offshore platform due to fire and explosion

(5) Repair Documentation

The final step of the primary key “Controlled Processes” will be the Repair Documentation. The information and data from all the above controlled process will be recorded and documented into one final report for traceability and tracking to ensure that what has been designed is delivered to the end user.

Final Thoughts

In summary, a good rule for any end user is to make sure that all the above controlled processes are strictly followed to ensure a high level of confidence in any composite repair system being used on assets. A composite repair system must demonstrate that it meets the requirements of ASME PCC-2 and/or ISO 24817 industry standards before being used to repair a piping anomaly. Composite repair system manufacturers should be able to produce official documentation demonstrating their compliance with these standards and the required material and performance properties. The repair system sent should also be controlled under a documented quality control program (e.g. ISO 9001) to ensure the materials sent to the field are of equal quality and strength to the materials used in the qualification testing. For anomalies more complex than standard external corrosion, it is essential that testing be conducted on the composite repair system to demonstrate that adequate performance levels can be achieved, for example reinforcement of a pipeline dent or crack. HJ3 has worked with various accredited third parties to ensure HJ3's CarbonSeal is capable of reinforcing pipe material having corrosion, crack or dent features subject to the pressure loading conditions considered in these testing program. The program involved testing defects repair on 12.75-inch x 0.375-inch Grade X42 pipe samples with 75% corrosion wall loss features, as well as repair on 12.75-inch x 0.188-inch Grade X42 pipe samples with dents. Defects were filled with load transfer filler material prior to installing the carbon-epoxy repair system. Several noteworthy observations are made in reviewing the results of this testing program.

- The composite thickness designed and used by HJ3 in repairing the pressure cycle fatigue and inter-layer strain burst tests was validated as an optimized repair configuration for several reasons. First, the hoop strain in the reinforced region was low enough to permit a 100,000-cycles runout condition to be achieved. Secondly, the average hoop strain range in the composite material was measured to be less than the ASME PCC-2 design strain limit.

- The dent sample achieved the 250,000-cycle runout condition. During pressure cycling, the hoop strain measurements in the reinforced dents at 20,000 cycles are significantly less than the unreinforced dents for the dent magnitude considered in this study.

Figure 10: Composite Repair System Validation Program

In another testing program which involved a combination of unreinforced and reinforced 12.75-in x 0.25-in, Grade X52, LF ERW pipe samples with 3-in x 50% deep (approximate) crack geometries in their seam welds. ADV worked with HJ3 to determine an effective repair thickness of HJ3's CarbonSeal, carbon-epoxy repair system. One of the samples of repaired pipeline which has been cycled with a "moderately aggressive" condition, the failure was at the 20,376 cycles (this is the one of lowest of three repaired samples of pipelines in this test program) corresponds to 122 years of service assuming a fatigue safety factor of 5 (i.e., 20,376 cycles / 5 (fatigue safety factor) / 33.4 cycles per year @ ΔP = 67% SMYS). For a "light" pressure cycle condition (12.7 cycles per year @ ΔP = 67% SMYS) typical for gas transmission pipelines, the 20,376 cycles represent 320 years of service.

Figure 11: Composite Reinforcement of Cracks Study

Overall, HJ3's CarbonSeal composite technology is an effective repair method for reinforcing severe corrosion, crack and dent features. The validation efforts and results provided in these reports can be used to support the repair of corrosion, crack and dent features in high pressure transmission pipelines.

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A quarterly magazine PP18691/01/2018(034114)/ISSN2289-9030

MATERIALS MIND

Issue 41

October 2024

www.iomm.org.my Institute of Materials, Malaysia

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ISSN 2289-9030

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