

Extreme makeover: PIPELINE EDITION

Aleese Post and Casey Whalen, CSNRI, USA, outline the fundamental design considerations necessary for corroded pipe composite repairs.

The use of composite material to repair corroded pipelines continues to be a standard for many pipeline operators. While composite repair manufacturers and designers explore more advanced repair possibilities, the knowledge around general corrosion repair also has changed over time, and the questions have evolved from 'Will composites work?' to 'What do the regulations allow?' and 'How long will a composite work?' While some owners

may want to just 'bury and forget' the repair, many issues and questions need to be addressed before the repair is considered to be permanent.

- ▶ Was the composite properly designed for its specific application and in accordance with PHMSA and the ASME B31 standards?
- ▶ Was it tested to withstand the current defect and operating conditions?
- ▶ How did the manufacturer determine the design life?
- ▶ Is the design to code and backed by sound engineering logic?



These are just a few questions that need to be answered before moving forward with any repair. Composite repairs should not be designed for today; they need to be predictably designed for safety in the future.

What are the written requirements?

The first rule of any repair is based on compliance, so the initial focus should be on what the regulations allow. The regulation of most transmission pipelines falls under PHMSA 49 CFR 192 and 49 CFR 195 for gas and hazardous liquids lines, respectively. Within these regulations, composite repairs are not specifically mentioned. The only actual notation of permanent repairs for general corrosion or imperfections of the pipe are mentioned in PHMSA 49 CFR Part 192.713 (a)(2) and 49 CFR Part 195.585 (a)(2), which state that a permanent field repair must be repaired by a “method that reliable engineering tests and analyses show can permanently restore the serviceability of the pipe.”

Both PHMSA 49 CFR 192 and 49 CFR 195 incorporate by reference other regulations, including ASME B31.4 and ASME B31.8.

ASME B31.4 - 2016 provides a list of permanent repairs and their allowable defects, listing “Composite Sleeve” as an option with a reference to ASME PCC-2 for further information. Allowable defects include external corrosion with



Figure 1. Transmission pipeline suffering from general external corrosion.



Figure 2. Pipeline repaired with the A+ Wrap™ repair system.

80% or less wall loss, with limitations on internal corrosion, gouges, cracks and dents.

ASME B31.8 - 2016 states that composites cannot be used on dents or mechanical damage “unless proven through reliable engineering tests and analysis.” No mention of composites is made with regard to general corrosion.

The 2018 ASME PCC-2 standard provides guidance for the design and application of composite repairs. However, ASME PCC-2 does not provide any guidance on how long a repair should last. Therefore, without any other considerations or safety factors, a designed composite repair using only ASME PCC-2 for guidance can claim two or 200 years for the design life and still be compliant. Compliance with ASME PCC-2 guidance alone does not explicitly show permanent restoration to the pipe. Additional understanding, design, and documentation are needed.

How do we get to ‘permanent?’

If a design life is not specifically stated in any standard or regulation used in the industry, what does ‘permanent’ really mean? For external corrosion, the obvious answer is that the repair will stop the corrosion from growing and not degrade over time. Perhaps a better way of phrasing this is to state that for a composite repair to show permanency, it must restore safe serviceability, prevent or minimise further damage, demonstrate long-term durability, and be properly documented.

To restore serviceability, the current repair standards utilise basic principles which consider current pipe conditions. These equations work well; however, they may not adequately take long-term or external considerations fully into account. In addition to defect rehabilitation, a composite repair needs to act as an appropriate coating to prevent future damage when possible. Potential issues such as soil movement, soil type, weather or climate patterns should be considered when designing the repair. Ultimately, the success in restoration and continued protection rely on the quality and repeatability of installation.

While external corrosion repairs are relatively straightforward, that is not the case with internal corrosion. Pipes with internal wall loss typically cannot be permanently repaired with composites, since the composite cannot stop the corrosion growth. Complete wall loss will eventually occur. For permanent repairs, ASME B31.4-2016 is straightforward regarding what can be repaired. It states, “Composite sleeves shall not be used to repair leaks, metal loss with a depth greater than 80% nominal thickness, crack, or circumferentially oriented defects.”

This is not to say, however, that composite repairs can never be used to strengthen a pipe with internal wall loss. If the wall loss is slow and predictable, a composite repair can be designed for an agreed-upon end-of-life condition. In cases where the rate of internal wall loss can be calculated, the time to reach this end-of-life condition can be reasonably estimated. By taking the appropriate safety factors into account, a temporary repair can be designed, installed and monitored. Once these conditions are met, a cut-out or other permanent repair method must be utilised.

How do we demonstrate long-term durability?

Although the standards do not provide lifetime estimates, they do provide reputable guidance for initial material testing. All systems used should have basic properties such as tensile strength and thermal properties available. The standards provide two long-term tests that measure material creep. The first test – long-term lap shear values – evaluates the adhesive primer's bond to a specified substrate in hot-wet conditions for 1000 hours. The lap-shear value of these coupons after exposure needs to be at least 30% of pristine samples.

The second, but optional, test is long-term performance testing. There are multiple approaches to this test with each providing different outputs, even though the same property is being tested: material creep. Completion of this test and proper implementation allow for safety factor reductions based on an understanding of the system's long-term creep fatigue failure limitations.

Following this testing, a condition is tested that demonstrates a maximum stress or strain value that is allowed for design purposes. This value can change based on the designated design life. When using this value, it can be safely said that the properly designed composite repair is seeing a stress value low enough to prevent long-term material creep failure.

The consideration of material creep is extremely important in conditions where the composite is likely to see a large amount of continuous stress. However, for situations where the composite repair is installed near maximum operating pressures, material creep is unlikely to play a major role in a composite failure as the stress seen is inherently well below the creep rupture envelope.

Lastly, this test only demonstrates the creep resistance of the composite material and does not consider the life of the underlying pipe. Simply performing these tests, but not considering these additional concerns, does not guarantee that the repair is going to last for 50 years. As in all cases, the composite repair must be properly designed using sound and reliable engineering.

Cyclic fatigue

The other primary mode of time-based failure is cyclic fatigue. Unlike the assumed static stress condition of material creep, cyclic fatigue is based on continuous change in stress loads. The most common type of cyclic fatigue examined is pressure cycling, which is caused by pressure fluctuations during normal operating conditions. The severity of fatigue is dependent on frequency and amplitude and may be a non-issue for many pipelines in operation, such as natural gas lines. For lines with moderate or aggressive cyclic fatigue, the introduction of damage to the pipeline can cause serious concerns. In severe defects, the pipe can be at risk of fatigue failure, which is much harder to predict.

The construction codes provide no guidance for composite repairs with regard to combatting cyclic fatigue. The composite repair standards provide a misleading section on cyclic fatigue that provides only a superficial increased safety factor and does not consider the actual stress loads



Figure 3. A+ Wrap system repair utilising the offset method.

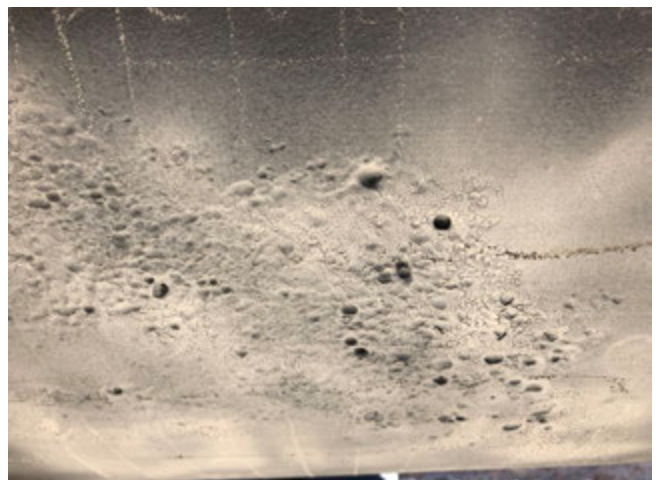


Figure 4. Close-up of a pipeline with severe external corrosion.

in the composite. Additionally, the standards provide no guidance with regard to the substrate. In one equation in ASME PCC-2, the only concern is number of cycles and the ratio between minimum and maximum pressure. It does not consider how the stress is shared between the components.

Composite repairs can provide protection against pipe fatigue failure, and should be considered in lines with aggressive cycling and severe defects. When designed and installed correctly, composite repairs can reduce the stress amplitude in the defect seen in each cycle, thus reducing the accumulated fatigue damage rate and increasing the life of the piping system.

Key factors for consideration include composite modulus, low installation pressure, known or estimated cyclic values, and a good estimate of the stress intensification factor for certain defects. The key for addressing cyclic fatigue is to realise that the defect, pipe, and composite are acting as an intertwined system that is only as strong as its weakest link.

Documentation

A conservative permanent composite repair can only exist if the proper documentation is in place. A composite repair design documentation intended for permanent use should:

- Provide all inputs and design considerations.
- List all assumptions made.
- Show material properties of the pipe and composite.
- Have verifiable and repeatable outputs.
- Display appropriate design equations for the defect or condition.
- Show intended service life and/or design life.
- Specify the safety factor used.

Additionally, for defects or repair scenarios outside the scope of relevant standards, specific testing should be on file or provided that can demonstrate reliable, predictable engineering. All designs should follow a correct and proven standard or explain in detail why a custom solution is being used. They should be easily explained to any interested third party and need to be clearly understood by the operator.


Providing and maintaining proper documentation throughout the installation process also is important. These documents can include the installation procedure, a quality verification guide, a record of batch numbers, ambient conditions, installer names and certification numbers, and post inspection results. If the composite repair ever fails, the information recorded can help to determine the potential

cause. Without proper documentation, there is no proof of a composite repair's capabilities.

Every defect is unique

The most important thing to remember when using a composite repair is that composites are designed, not a one-size-fits-all solution. Every defect has unique challenges with regard to short-term or long-term failure mechanisms, and each case should be addressed accordingly with supportive testing and design documentation. Even simple defects such as external corrosion can yield varying results based on operating conditions and local environments.

All long-term repairs assume that the product is installed correctly and according to the final design. For this reason, work should be performed by trained individuals who understand the composite being used, as well as the defect-specific or geometric-specific installation procedure.

When designing a composite repair, it is important to remember that there are certain situations when a composite should not be used. As composite repairs are used in more advanced applications, the standard safety factors may not be enough. In these cases, the design and documentation are even more important. When composites are used correctly, properly designed in accordance with the standards and properly supported, they can be extremely valuable tools for permanent repairs. 

Note

Portions of this article were presented at the 2019 PPIM Conference by secondary author, Casey Whalen.