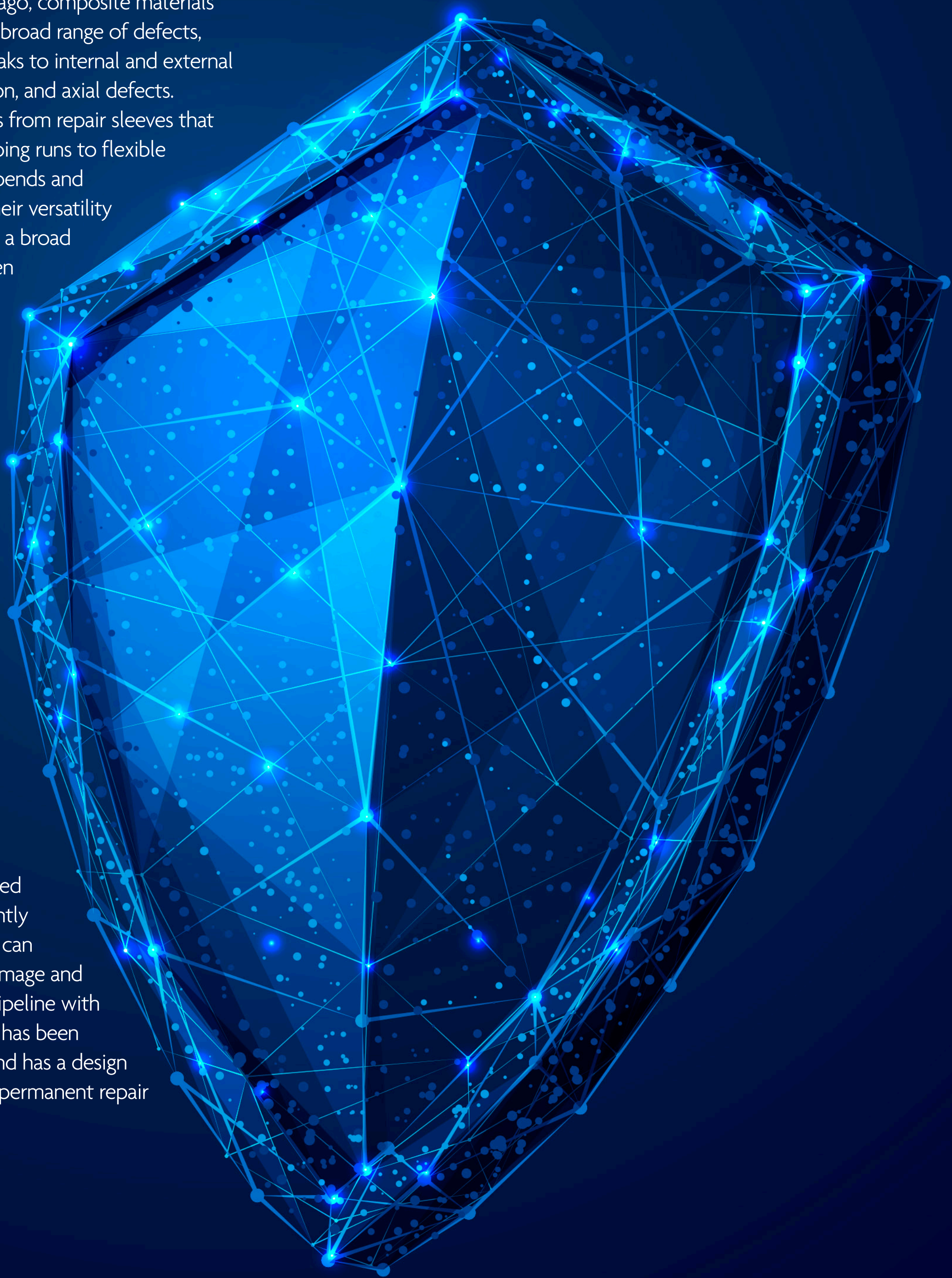
COMPOSITE REPAIR: STILL GOING STRONG

Matt Green and Tim Mally, CSNRI, USA, describe the testing of a 25 year old repair completed with composite repair sleeves, that left pipe sections even stronger than before.

Since the first composite repairs were introduced to the industry more than 30 years ago, composite materials have been used to address a broad range of defects, from cracks, fractures, and leaks to internal and external corrosion, mechanical damage, abrasion, and axial defects. Composites evolved over the decades from repair sleeves that could be used on standard straight piping runs to flexible wraps that can be applied to wrinkle bends and components with complex shapes. Their versatility has made them the go-to solution for a broad range of anomalies, and they have been installed around the world to resolve asset integrity and safety concerns. Although many have been in service for years, there have been few occasions when a repair has been recovered to allow designers to see how it has endured the test of time. A rare opportunity at the end of 2020 provided just such a chance, when a pipeline owner replaced a section of pipe that had been repaired using a Clock Spring® composite repair sleeve in 1995.



In the beginning

The Clock Spring coil is made up of eight layers of pretensioned unidirectional e-glass composite that is installed with a high-modulus filler material and a high lap-shear strength methyl methacrylate adhesive. Designed to structurally reinforce and permanently restore external anomalies, the sleeve can repair a broad range of mechanical damage and corrosion defects, and can restore a pipeline with up to 80% wall loss to full strength. It has been tested to 8000 psi internal pressure and has a design life beyond 50 years, qualifying it as a permanent repair by regulators around the world.

The repair sleeve was the subject of an extensive 10 year research and development programme, and was the pioneer for the approval of composite repairs across the industry. In 1987, the Gas Research Institute (GRI), assembled a team of pipeline professionals and research organisations to direct a comprehensive programme to verify the sleeve's effectiveness, durability, and performance characteristics. The decade-long testing programme, which assumed worst-case conditions, included extensive burst testing, stress rupture tests, field validations, cathodic shielding testing, and cathodic disbondment test. Technical evidence of the sleeve's performance was submitted to the United States Department of Transportation, which revised its code in the year 2000 to allow Clock Spring as a viable permanent repair. The GRI testing programme remains the most thorough and trusted composite testing programme ever conducted.

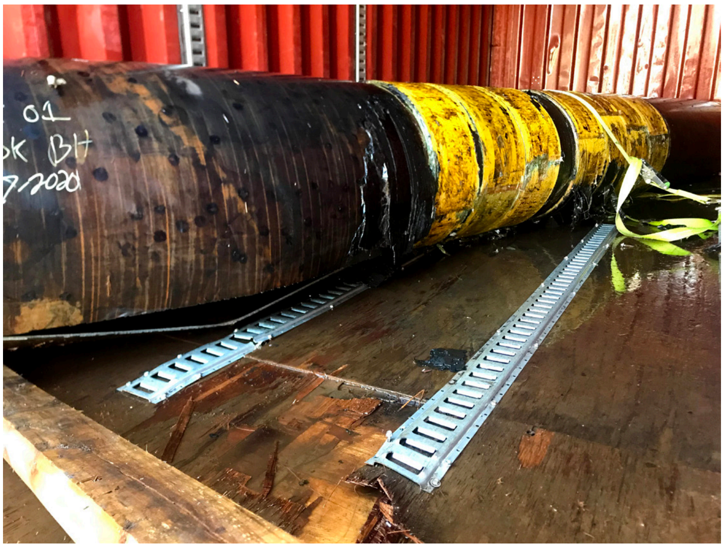


Figure 1. **The testing programme for the 25-year old Clock Spring® repair was designed to gradually increase pressure to 1455 psi (100.3 bar), which is 1.5 times the MAOP of the pipeline, where the MAOP was 970 psi (66.9 bar). The composite repair showed no damage when the repaired pipeline section was pressurised to the target value of 1455 psi (100.3 bar) and held at that pressure for five minutes. (Photo courtesy of CSNRI).**

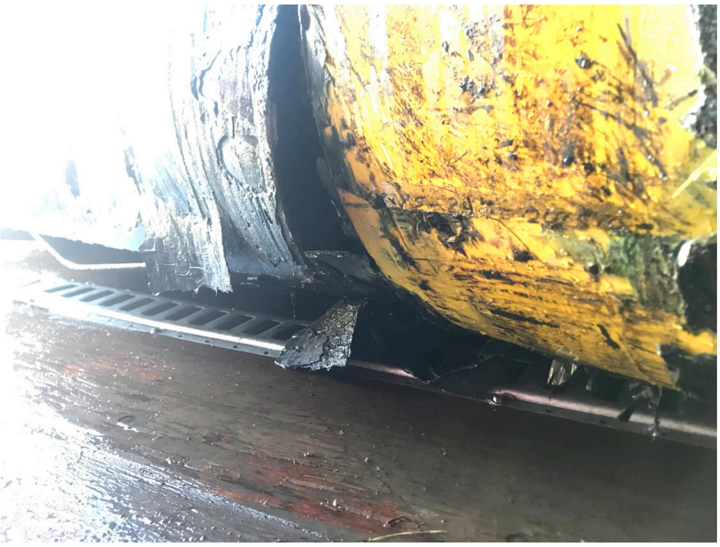


Figure 2. **The repaired pipeline section was pressurised to and then held at that pressure for five minutes. After successfully holding the repaired pipeline section at the target value of 1455 psi (100.3 bar) for five minutes, pressure was increased until the pipeline finally ruptured at 2180 psi (150.3 bar). Interestingly, the rupture was not on the Clock Spring repair but on a section of pipe outside of the repair area. (Photo courtesy of CSNRI).**

The original repair

In 1995, an owner, operator, and developer of an integrated portfolio of natural gas pipelines, found corrosion on a carbon steel pipeline operating at 750 psi (51.7 bar), with a maximum allowable operating pressure (MAOP) of 970 psi (66.9 bar). There were multiple corrosion defects in the pipeline, the worst of which was 12 in. (305 mm) long with 63% corrosion. The determination was made to repair the line using the Clock Spring composite repair sleeve.

With the pipeline in service, technicians cleaned and inspected the pipeline for any additional defects prior to molding filler into corroded areas. The filler acts as a load-transfer agent to transfer the stresses from the pipe to the composite sleeve. Following an inspection to ensure that the repair sleeve could be placed properly, technicians installed the sleeves and secured them to the damaged line. Within an hour, the composite repairs were fully cured, and the pipe was restored to safe service.

Withstanding the test of time

After 25 years of continuous service, the section of composite-repaired pipe was scheduled for inspection and replacement to conduct validation tests. The pipeline company contacted CSNRI late in 2020 and asked if there was any interest in inspecting the repaired segment of pipe that was being removed from service. Because there are few opportunities to examine composite repairs that have been in service for a quarter of a century, the company was eager to subject the repair sleeves to testing.

Once the pipe section was received, it was fitted with end caps and fittings to conduct a full-scale pressure test. The testing programme was designed to gradually increase pressure to a target value of 1455 psi (100.3 bar), which is 1.5 times the MAOP of the pipeline, where the MAOP was 970 psi (66.9 bar). The repaired pipeline section was pressurised to 1455 psi (100.3 bar) and then held at that pressure for five minutes. After a successful hold at the target value, pressure was increased until the pipeline finally ruptured at 2180 psi (150.3 bar). It is noteworthy that the pipe ruptured not on the repaired section of pipe, but on a section of pipe outside of the repair area.

Additionally, samples of the Clock Spring repair were removed from the tested sections, and coupon-level tensile testing was conducted. The results of the tensile testing on the samples removed from the tested pipeline, which had just successfully held up to the full-scale pressure test, showed that the tensile strength of the 25 year old repair sleeve was still 90 000 psi (6205.3 bar). This validates that no degradation occurred in the composite repair from the time of installation through continuous operation for 25 years.

This test programme validates the durability of the composite repair, underscoring the findings of the 10 year

Table 1. Third-party test results for the Atlas™ Carbon Fiber Repair System (data courtesty of CSNRI)								
Manufacturer	Corrosion Defect	Burst Pressure (psi) Year 0	Burst Pressure (psi) Year 1	Burst Pressure (psi) Year 2	Burst Pressure (psi) Year 3	Burst Pressure (psi) Year 5	Burst Pressure (psi) Year 7.5	Burst Pressure (psi) Year 10
CSNRI	40	4125	4040	4087	4123	4188	4177	4247
	60	4118	4089	4084	4191	4241	4089	4122
	75	4296	4263	4388	4397	4316	4328	4322

research and development programme led by GRI in 1987 that established the Clock Spring composite repair sleeve as a viable, permanent repair solution, and reinforcing the claims that the Clock Spring can last longer than 50 years in service.

More testing yields positive results

Although there are not a lot of opportunities to carry out testing on 25 year old repairs, there are many ways to develop and execute test programmes to provide performance data for composite repairs. Ten years ago, CSNRI participated in third-party testing in conjunction with the Pipeline Research Council International (PRCI) and Stress Engineering Services on another of its composite repair solutions, Atlas™, to determine its efficacy in addressing external corrosion.

Atlas is a high-strength, high-stiffness carbon fibre solution for repairing pipeline and piping structures. Designed for repairs that require strain reduction induced by dynamic loading conditions, this composite repair system includes a bi-directional carbon fibre system installed using a high-strength epoxy resin. Field saturated and applied, this carbon-fibre system contours to seam and girth welds and when combined with high-strength load transfer filler, helps minimise strain on complex pipeline anomalies. This solution is most commonly used for pipelines and piping systems that have suffered external corrosion and pitting or third-party damage such as dents, gouges, and scratches and is also appropriate for wrinkle bends, imperfect welds, manufacturing flaws, and cracks or crack-like features.

The third-party testing for this product simulated external corrosion at depths of 40%, 60% and 75% in depth on hundreds of 12 in. (0.3 m) diameter pipe spools to test the longevity of the composite repair. Each specimen was wrapped with an engineered carbon fibre and epoxy composite repair and then buried in wet Texas soil under a coating and cathodic protection to simulate how a composite repair would perform under similar conditions in the field. The pipe segments were pressure cycled 900 times per year over a 10 year period. At the conclusion of each year of the test programme, pipe segments were recovered and subjected to a burst test to determine their performance characteristics after exposure to wear. Testing from year zero to year 10 showed no degradation either in the appearance or the performance of the composite repair. In fact, the final burst pressures from each year of testing from one to 10 were within 3 - 5% of each other, showing remarkable consistency of results.

Many other studies have been undertaken – or are ongoing – to prove the value and longevity achievable with composite repair systems on high-pressure and highly cyclical pipelines. One such programme was carried out by the Gas Technology Institute (previously GRI) in 2013 in which a part of the study was dedicated to testing long-term tensile and adhesion strength of composite systems. The results further validate the durability of these types of repairs and illustrate why they are so valuable to asset owners.

Scores of testing programmes have been completed on composite repairs over the years by industry sponsors and third parties, as well as end users and composite system manufacturers. As more and more test results and data become available, there are additional reasons for industry confidence in the ability of composites to perform in the long term for a variety of defects to keep pipelines operating safely and efficiently.

Continuous improvement

Composite technologies are not only safe and relatively simple to install, they also deliver benefits that other repair solutions cannot, allowing installation on active lines, enabling repair on complex geometries and in areas with tight access, and providing reliable performance for decades of service.

Continuous testing and validation are important for quality assurance, meeting regulatory requirements, and verifying manufacturing process, but the biggest benefit of extensive testing is that it removes the grey areas, providing industry with products it can trust. This 25 year test demonstrates that composites can be counted on to perform to the levels that the laboratory tests initially indicated and can be trusted to be reliable for decades to come.

Over the years, successful composite repair installations have changed the way owners and operators extend the field life of their assets. Tested, validated, and field-proven composite solutions are readily available, and continuing R&D efforts are creating even more advanced products. As the superior performance of composite solutions becomes more well-known, more companies will look to composites to deliver long-lasting, reliable performance.