Proceedings of IPC2010
8th International Pipeline Conference
September 27 – October 1, 2010, Calgary, Alberta, Canada

IPC2010-31595

AN OPERATOR'S PERSPECTIVE IN EVALUATING COMPOSITE REPAIRS

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ABSTRACT

For more than a decade composite materials have been used by pipeline operators to repair damaged pipelines. To validate the performance of composite repair materials, numerous research programs have been conducted. The recent introduction of standards such as ASME PCC-2 and ISO 24817 have provided industry with guidance in using composite materials concerning factors such as the minimum required repair thickness, recommended performance tests, and qualification guidance. Up until now, operators have developed individual requirements for how composite materials can be used and under what circumstances their use is deemed acceptable. To compliment these internal guidance standards, several operators have elected to conduct independent investigations to evaluate the benefits derived in using composite materials for reinforcing specific anomalies such as gouges, dents, girth welds, and wrinkle bends. This paper provides insights that can be used by operators in evaluating the use of composite materials in repairing damaged pipelines with an emphasis on incorporating the current industry standards.

INTRODUCTION

A challenge that exists for the pipeline industry is determining what constitutes an acceptable repair. The recent development of composite repair standards, such as ISO 24817 and ASME PCC-2 [1], provide guidance for operators; however, not all composite repair systems have demonstrated their ability to meet the requirements of these standards. As a result, there continue to be challenges for pipeline operators in knowing what capabilities exist in the current composite repair technology and what specifically these repair systems should be able to accomplish.

The purpose of this paper is to provide an operator's perspective in how to evaluate composite repair technology. Central to this effort is identifying what specific tests and analyses are required to ensure that an adequate level of evaluation takes place. What is presented are specific tests designated in ASME PCC-2. In addition to these particular tests, there are additional tests that have been performed to perform specific assessments. These tests have demonstrated a range of performance with the composite repair systems currently on the market. For certain applications these differences are significant; namely conditions involving cyclic pressure and conditions where large strains are expected (e.g. such as significant levels of corrosion, dents, and wrinkle bends). Generalized results from several of these test programs are presented. Additionally, an industry-wide survey was conducted to determine the pipeline industry's perspective on composite materials and their usage. Results from this survey are included in this paper.

The sections that follow provide a brief history on the composite repair standards and results from the composite repair survey. Select data are presented from tests involving composite repair systems in repairing severely corroded pipes subjected to both static and cyclic pressures, as well as recent data from a testing program focused on evaluating the repair of dents using composite materials. Also included in this paper is a list of specific tests that should be considered as part of the composite repair assessment process.

BACKGROUND

Because of the wider acceptance of composite materials in recent years, industry's overall knowledge of this repair technology has increased significantly over the past 5 years. Most transmission pipeline companies use composite materials and many are actively involved in evaluating composite repair technology through member-driven research organizations such as the Pipeline Research Council International, Inc. (PRCI). At the current time PRCI has several ongoing research programs evaluating composite materials with several more being planned for 2011. Ongoing programs include MATR-3-4 (assessment of composite repair long-term performance), MATR-3-5 (repair of dents), and MATV-1-2 (wrinkle bends).

To provide the reader with background on how industry is evaluating the current technology and what critical issues are worthy of attention, the following sections have been prepared. The first section concerns background information on *Industry Standards*; the second section, *Operator Perspectives*, provides background on how El Paso is evaluating the current composite technology and how these materials are used as part of El Paso's ongoing integrity management program.

Industry Standards

For much of the time period during which composite materials have been used to repair pipelines, industry has been without a unified standard for evaluating the design of composite repair systems. Under the technical leadership of engineers from around the world, several industry standards have been developed that include ASME PCC-2 and ISO 24817 (hereafter referred to as the *Composite Standards*). Interested readers are encouraged to consult these standards for specific details; however, listed below are some of the more noteworthy contributions these standards are providing to the pipeline industry.

- The Composite Standards provide a unifying set of design equations based on strength of materials. Using these equations, a manufacturer can design a repair system so that a minimum laminate thickness is applied for a given defect. The standards dictate that for more severe defects, greater reinforcement from the composite material is required.
- The most fundamental characteristic of the composite material is the strength of the composite itself. The Composite Standards specify minimum tensile strength for the material of choice based on maximum acceptable stress or strain levels.

- Long-term performance of the composite material is central to the design of the repair systems based on the requirements set forth in the Composite Standards. To account for long-term degradation safety factors are imposed on the composite material that essentially requires a thicker repair laminate than if no degradation was assumed..
- One of the most important features of the Composite Standards is the organization and listing of ASTM tests required for material qualification of the composite material (i.e. matrix and fibers), filler materials, and adhesive. Listed below are several of the ASTM tests listed in ASME PCC-2 (note that there are also equivalent ISO material qualification tests not listed here).
  - Tensile Strength: ASTM D 3039
  - Hardness (Barcol or Shore hardness): ASTM D 2583
  - Coefficient of thermal expansion: ASTM E 831
  - Glass transition temperature: ASTM D 831, ASTM E 1640, ASTM E 6604
  - Adhesion strength: ASTM D 3165
  - Long term strength (optional): ASTM D 2922
  - Cathodic disbondment: ASTM-G 8

With the development of standards for composite repairs, industry can evaluate the performance of competing repair systems based on a set of known conditions. It is anticipated that the Composite Standards will either be accepted in-part or in-whole by the transmission pipeline design codes such as ASME B31.4 (liquid) and ASME B31.8 (gas).

Operator's Perspective

The El Paso Pipeline Group has taken a focused interest in using composite materials and determined that when properly designed, evaluated, installed, they are well-suited for repairing many pipeline defects. As shown in Figure 1, 31 percent of El Paso's 2008 repairs involved the use of composite materials. El Paso has used composite materials to repair a range of pipeline anomalies that include corrosion, dents, and wrinkle bends.

In order for composite materials to effectively meet the pipeline regulations and restore integrity of damaged pipelines, there are certain requirements and expectations associated with composite repair systems that include the following:

- Repair system expectation:
- Easy to procure & design
- Reliable & permanent – test results
- Easy to install
- Training and Qualification records (OQ Covered Task)
- Installation training for Company or representatives
- Economic advantages over conventional repair methods

As noted in the last bullet, economics is an important consideration when evaluating the use of composite materials. The authors have prepared Table 1 that lists several points of considerations when comparing the use of steel sleeves to composite materials. As a point of reference, for an equivalent repair the cost of a steel sleeve is $34,000, while for the composite material the cost is $23,000. Obviously, the costs will vary for each particular situation; however, the point is that composite materials can provide an economic and safe alternative to steel sleeves.

One of the challenges presented to each operator is evaluating the composite technology itself. There are more than 15 different composite repair systems on the market with manufacturing headquarters in both the United States and Europe. There exists confusion in what is required of each system according to standards such as ASME PCC-2. The authors have also observed composite repair companies purporting to be compliant with ASME PCC-2, yet when questioned about requirements for compliance, some manufacturers do not have a complete understanding of the requirements. On the other side there are several composite repair systems that have performed very well in all testing programs and have demonstrated their capabilities to repair a wide range and class of pipeline defects. Table 2 is presented and can be used by operators to distinguish those manufacturers who truly have systems worthy of recognition and possess the requirements necessary to repair high pressure gas and liquid transmission pipelines. Much of the contents in this table are taken from the requirements set forth in ASME PCC-2. The general observation is that if a particular manufacturer meets the requirements of ASME PCC-2, this particular system is adequately designed to repair most pipeline anomalies.

The section that follows provides information on several specific test programs that evaluated the repair of corrosion subjected to both static and cyclic pressures. Also provided is a discussion on a recent program where composite materials were used to repair dents subjected to cyclic pressure conditions. It should be noted that the information provided in these tests are not explicitly defined in ASME PCC-2, but are extremely important in evaluating the true limit state condition of composite repair technology in an effort to satisfy the intent of both the pipeline codes and regulations stating that *reliable engineering tests and analyses* must be used to demonstrate the worthiness of composite materials for long-term performance.

PERFORMANCE TESTING

While performing tests to meet the minimum requirements of ASME PCC-2 is a starting point for any composite repair system, ultimate performance cannot be established without evaluating performance relative to more aggressive testing regimes. This section of the paper presents details and results associated with three specific test programs that include the following:

- Repair of 75% corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe subjected to static burst testing
- Repair of 75% corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe subjected to cyclic pressures
- Repair of dents in 12.75-inch x 0.375-inch, Grade X42 pipe subjected to cyclic pressures

  What has been observed in the test results is that not all composite materials perform equally. The authors have presented contrasting test results to make this point clear. Operators and industry at large are encouraged to use composite materials that can exceed the minimum requirements set forth in the existing standards.

Burst Pressure Testing on 75% Corrosion Samples

Burst test samples were fabricated by machining a 6-inch wide by 8-inch long corrosion section in a 12.75-inch x 0.375-inch, Grade X42 pipe as shown in Figure 2. After the machining was completed the sample was sandblasted to near white metal. Prior to installing the composite repair material, four strain gages were installed in the following regions and shown in Figure 3.

- Gage #1: Gage installed in the center of the corrosion region
- Gage #2: Gage installed 2 inches from the center of the corrosion region
- Gage #3: Gage installed on the base pipe

- Gage #4: Gage installed on the outside surface of the repair

Results are presented in this paper for a sample that was repaired using an E-glass material that was 0.625 inches thick.. The sample was pressurized to failure and burst outside of the repair at 3,936 psi. Figure 4 shows the strain gage results that were monitored during testing. Also included in Figure 4 are the average strain readings from the PRCI long-term study beneath the composite repairs of 12 different composite repair systems. At the MAOP (72% SMYS or 1,778 psi) the hoop strain was approximately 3,000 microstrain, compared to the average PRCI value of 3,410 microstrain at this same pressure level. Additionally, at 100% SMYS (2,470 psi) the strain beneath the repair was recorded to be 5,200 microstrain, whereas the average PRCI strain at this pressure level was 5,170 microstrain. It should be noted that the PRCI data set comprises a range of composite materials that including E-glass, carbon, and Kevlar. Also included in Figure 4 are data for a composite repair system that did not perform adequately in reinforcing the corroded section of the pipe. This data is provided to demonstrate that not all composite repair system perform the same or provide the same level of reinforcement.

The failure in the test sample occurred outside of the repair. The significance in the failure having occurred outside of the repair is that these results indicate that the repair is at least as strong as the base pipe. Additionally, at the failure pressure the hoop strain in the reinforced corroded region was less than 1.2 percent, whereas the measured strains in the base pipe outside of the repair were in excess of 10 percent (based on the final measured circumference at the failure location).

Cyclic Pressure Testing on 75% Corrosion Samples

Most of the experimental research associated with the composite repair of corroded pipelines has focused on burst tests. The general philosophy has been that in the absence of cyclic pressures during actual operation, there are few reasons to be concerned with qualifying composite repairs for cyclic conditions. One could argue that only liquid transmission pipelines need to be concerned about cyclic pressures. However, recent studies have indicated that for severe corrosion levels (on the order of 75%) there is a need to take a closer look at the ability of the composite to provide reinforcement. The case study presented herein was actually preceded by a series of tests using E-glass materials that evaluated the number of pressure cycles to failure in reinforcing 75% corrosion in a 12.75-inch x 0.375-inch, Grade X42 pipeline (sample as the geometry shown in Figure 2 with Figure 3 shows the strain gage positions). The test samples were pressure cycled at a pressure range of 36% SMYS (i.e. differential of 894 psi for this pipe size and geometry).

Tests were performed on six different composite systems that included the following cycles to failure.

- E-glass system: 19,411 cycles to failure
- E-glass system: 32,848 cycles to failure
- E-glass system: 140,164 cycles to failure
- E-glass system: 165,127 cycles to failure
- E-glass system: 259,357 cycles to failure
- Carbon system: 532,776 cycles to failure

Minimal information is provided with the above data (e.g. no information provided on thickness, composite modulus, filler materials, fiber orientation, etc.). However, one can definitely conclude that all composite repair systems are not equal. The study on the carbon composite system having four different pipe samples was specifically conducted by a manufacturer to determine the optimum design conditions for reinforcing the severely corroded pipe. Figure 5 shows the strains recorded in the four carbon-reinforced test samples. What is noted in this plot is that the lowest recorded mean strains occur in Pipe #4, which also corresponds to the test sample that had the largest number of cycles to failure.

Cyclic Pressure Testing on Dented Pipe Samples

In response to past successes a Joint Industry Program (JIP) was organized to experimentally evaluate the repair of dents using composite materials. This program was co-sponsored by the Pipeline Research Council International, Inc. and six manufacturers testing a total of seven different repair systems. Additionally, a set of unrepaired dent samples was also prepared to serve as the reference data set for the program. The dent configurations included plain dents, dents in girth welds, and dents in ERW seams. Testing involved installing 15% deep dents (as a percentage of the pipe's outside diameter) where the dents were cycled to failure or 250,000 cycles, whichever came first. The dents were created using a 4-inch diameter end cap that was held in place during pressurization. The test samples were made using 12.75-inch x 0.188-inch, Grade X42 pipe with a pressure cycle range equal to 72% SMYS. Strain gages were also placed in the dented region of each sample and monitored periodically during the pressure cycle testing. Figure 6 provides a schematic of the test samples, while Figure 7 is a bar chart showing graphically the cycles to failure.

The following general observations are made in reviewing the pressure cycle data.

- The average cycles to failure for the unrepaired dent samples were 10,957 cycles. The target *cycles to failure* for the unrepaired dents was 10,000 cycles.
- Two of the seven systems had 250,000 cycles with no failures that included a carbon/epoxy system and a pre-cured E-glass system.
- The minimum cycles to failure was recorded for System E that had average fatigue life of 34,254 cycles.

To be effective in repairing dents subjected to cyclic pressures, a composite repair system should demonstrate an ability to increase fatigue life by a factor of at least 10 times that of the unreinforced dent samples, and a factor of 20 for high cycle applications. For the program presented herein this implies fatigue lives of at least 100,000 cycles, or 200,000.cycles for high pressure applications.

INDUSTRY SURVEY

To determine industry's perspective on the use of composite materials, an on-line survey was conducted of PRCI members and readers of Hart's Pipeline & Gas Technology. The survey was completed in October 2009 and included input from 18 pipeline companies. Figure 8 shows the front page of the www.compositerepairstudy.com website used to both collect data and post the results. Interested readers are encouraged to visit the website for additional details and results, including postings from the composite manufacturers themselves.

The questions that were developed for the survey were based on input received from pipeline companies and specifically PRCI members. Topics of interest ranged from what type of repair materials to the range of repaired pipeline anomalies. Provided below are responses to 5 of the 11 questions posed to operators. The details provided include the statistical data, as well as pie charts showing the distribution of responses.

Number of Composite Repairs

Question: Estimate the total number of composite repairs that will be used in the next 12 months. Figure 9 graphical shows the responses for this question.

- None [3 votes]
- 1 - 10 repairs [11 votes]
- 11 - 25 repairs [6 votes]
- 26 - 50 repairs [7 votes]
- 51 - 75 repairs
- 76 - 100 repairs [1 vote]
- More than 100 repair [4 votes]

Types of Geometries Repaired Using Composites

Question: Do your composite repair procedures allow for the repair of the following pipe geometries? Figure 10 graphical shows the responses for this question.

- Straight pipe [30 votes]
- Elbows [19 votes]
- Tees [16 votes]
- Field bends [18 votes]
- Others [2 votes]

Types of Anomalies Repaired Using Composites

Question: Which of the following anomaly type repairs are not permitted by your company using composite materials? Figure 11 graphical shows the responses for this question.

- Corrosion [4 votes]
- Corrosion in girth or seam welds [14 votes]
- Metal loss [4 votes]
- Dents [5 votes]
- Corrosion in dents [11 votes]
- Gouges [8 votes]
- Dents with gouges [11 votes]
- Longitudinal weld seams [14 votes]
- Girth weld seams [15 votes]
- Wrinkle bends [12 votes]
- Hard spots [8 votes]
- Others [3 votes]

Number of Composite Repairs

Question: How many total composite repairs have been removed by your company? Figure 12 graphical shows the responses for this question.

- None [16 votes]
- 1 - 5 repairs [12 votes]
- 6 - 19 repairs
- 11 - 25 repairs [1 vote]
- More than 25 repairs [2 votes]

Reasons for Composite Repair Removal

Question: For what reasons were the composite repair materials removed? Figure 13 graphical shows the responses for this question.

- Considered temporary [11 votes]
- Failed in service due to disbonding of composite material [3 votes]
- Others [4 votes]

CONCLUSIONS

This paper has provided insights on how composite materials can be used by pipeline operators to repair damaged pipelines with an emphasis on incorporating the current industry standards. Over the past decade several industry-sponsored programs have focused on looking at the available composite repair technology and determining if any pertinent limitations exist. Additionally, what is earned from the survey data presented in this paper is that the pipeline industry is using composite materials and that for many of these companies, composite repair systems are an important part of their integrity management programs. It was the intent of the authors to provide for industry with a systematic means for assessing repair technology and how standards such as ASME PCC-2 can be integrated into this process.

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Table 1 – Comparison of welded versus composite sleeves

Welded Sleeve	Composite Sleeve
Could be used for Pressure Containment	Not for Pressure Containment
Repair Leaks	Cannot Repair Leaks
Weld Requirements ▪ Hot Work Permit ▪ NDE Pipe Body & Seam ▪ Welding Parameters ▪ Flow-Press. Control ▪ Typically Company Welding Crew	▪ No Welding – No Hot work ▪ No Flow-Press. Control ▪ Trained installation crew
Cost – Approx - $34,000 Typically 2 days installation (Logistics Risks)	Cost – Approx - $23,000 Typically 2 days of installation
Can Use for Repairing ▪ Leaks Corrosion ▪ Plain dents Mech. Damage ▪ Long Seam & Girth Weld defects	Can Use for Repairing ▪ Corrosion ▪ Plain dents ▪ Potential for reinforcement, not as a repair
Repairs to include ▪ Defective Girth welds ▪ Defective Long Seam	▪ Not tested for Defective Girth welds ▪ Not tested Defective Long Seam

Table 2 – Suggested operator assessment criteria based on ASME PCC-2

ASME PCC-2 (2006) - Part 4 - Nonmetallic and Bonded Repairs	
Provide additional information where necessary to support the data	
Material	
Fiber	
Resin	
Primer if any	
Filler Material	
Fabric Orientation	
Thickness	
Laminate or fabric width	
Application	
Types of Repair Made	
Can you repair Leak	
Compliance	
ASME PCC-2 or Others	
Installation	
Pipe Surface Requirements in terms of NACE	
Do you use primer? If so state the time between application of primier & installation of the fabric	
How is resin prepared on site	
How is resin applied to fabric	
Time to cure after installation	
Time before backfill	
Recommended pressure reduction during installation	
Storage Life	
Primer	
Resin	
Properties (Indicate testing methods used to determine the property)	
Min & Max temperature	
Tensile Modulus in hoop & axial direction	
Lap Shear Strength (Adhesion to Steel)	
Tensile Strength in Hoop & Axial direction	
Shear Modulus	
Moisture sensibility. Humidity levels recommended during installation	
Allowable strain in the laminate (Circumferential & Axial)	
Repair Thickness Determination	
Do you use PCC-2 equations? If yes identify which equations	
If no, how is thickness calculated.	
Have you done performance testing per PCC-2 Appendix V(1000 hrs survival test)	
If yes, what is the longterm composite stress.	
Calculate no. of layers & thickness for the two repairs:	
1) 12.75" OD, 0.375" WT, X-42, with 75% metal loss for 1000 psi MOP	
2) 24" OD, 0.250" WT, X-52, with 75% metal loss for 750 psi MAOP	
Testing Program	
Have you preformed cyclic pressure tests? If yes, indicate the sample spec., pressure cylces & cyclic press.	
Have you preformed bending or pull test? If yes, indicate the sample spec., max loading.	
Have you performed tests to repair leaks?	
Are you participating in PRCI Project - "Program to Evaluate the Long-term Performance of Composite Repair Systems".	

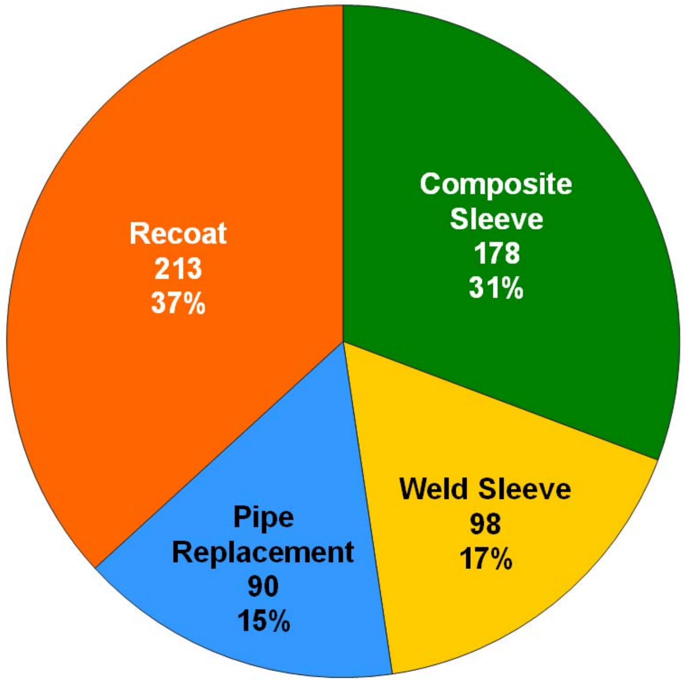


Figure 1 – Statistical data on El Paso's 2008 repairs

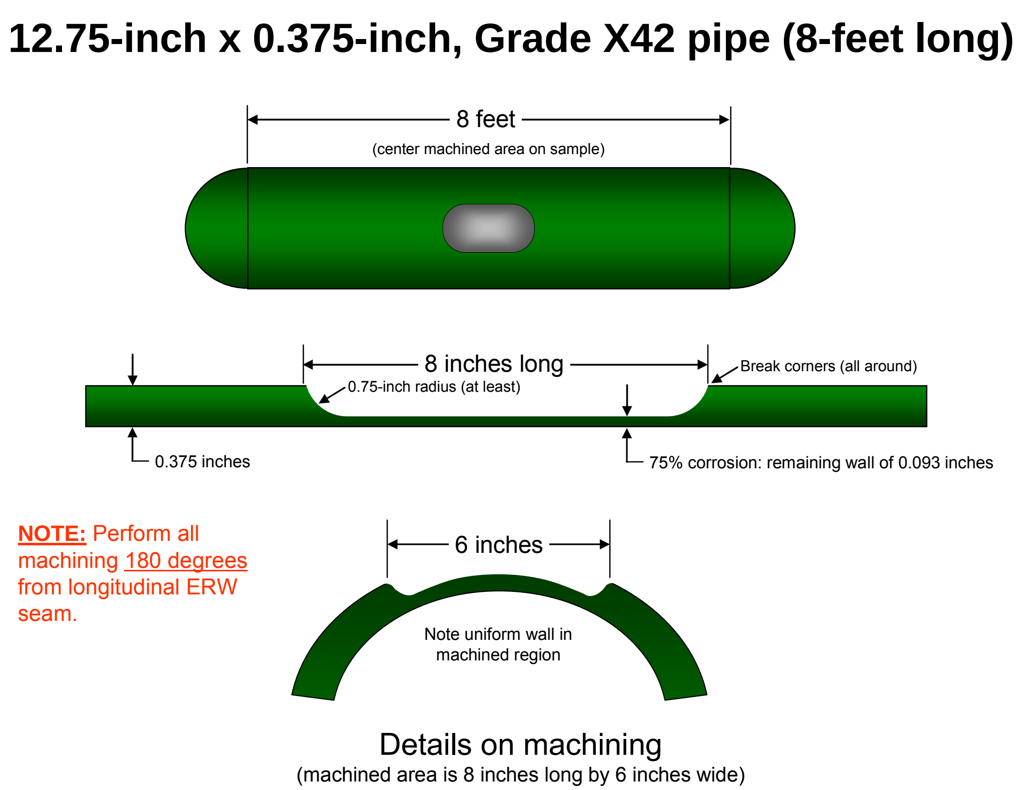
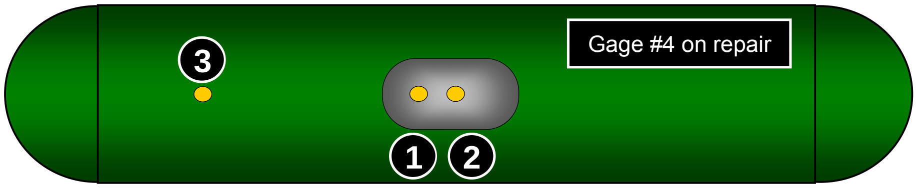
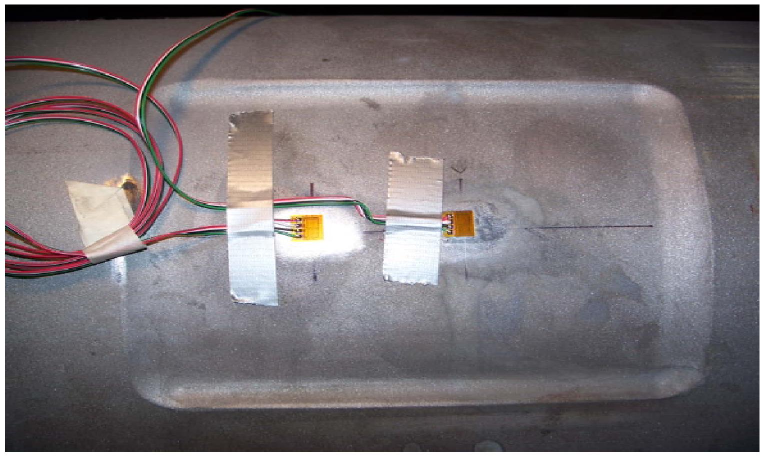


Figure 2 – Schematic diagram of composite repair pipe test sample



Location of strain gages installed on the test sample



Photograph of strain gages installed in the machined corrosion region

Figure 3 – Schematic showing location of strain gages of photo of machined region

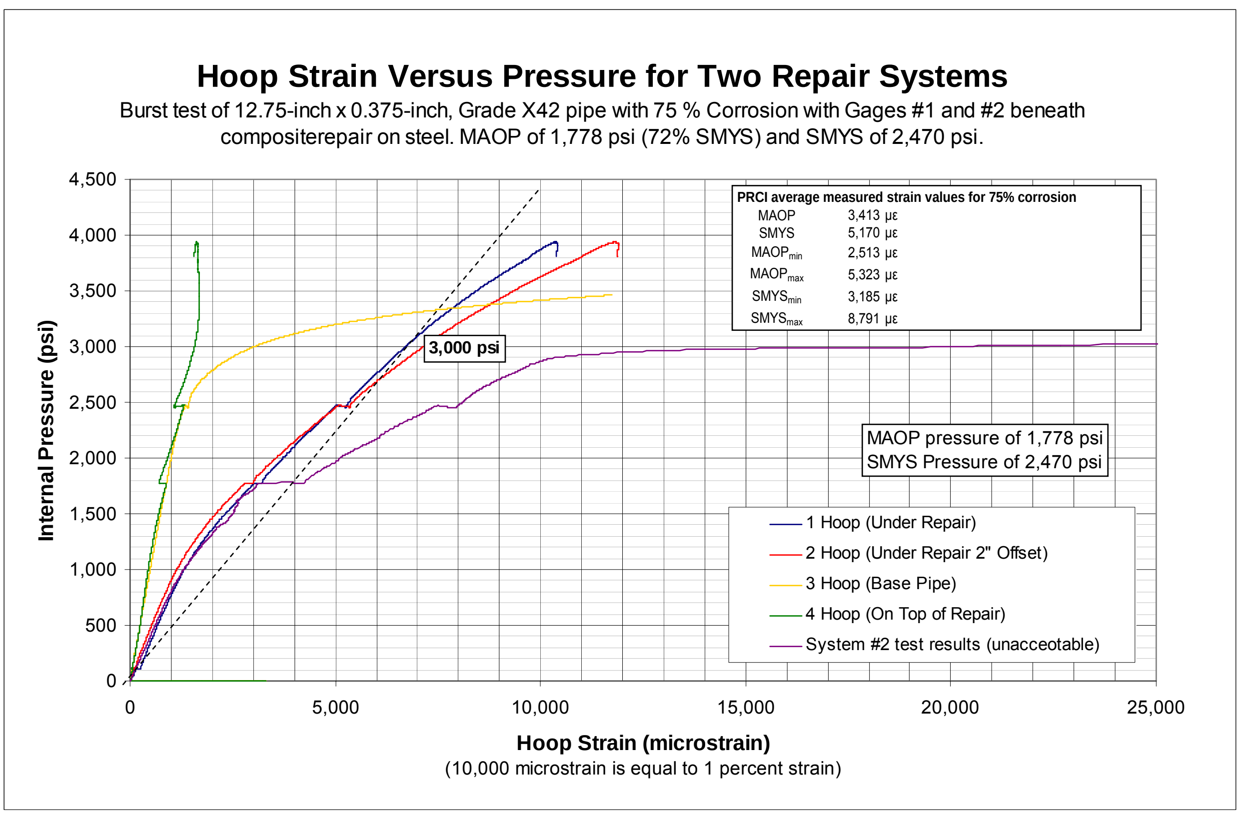


Figure 4 – Strains measured in composite reinforced corroded pipe sample
(12.75-in x 0.375-in, Grade X42 pipe with 75% corrosion)

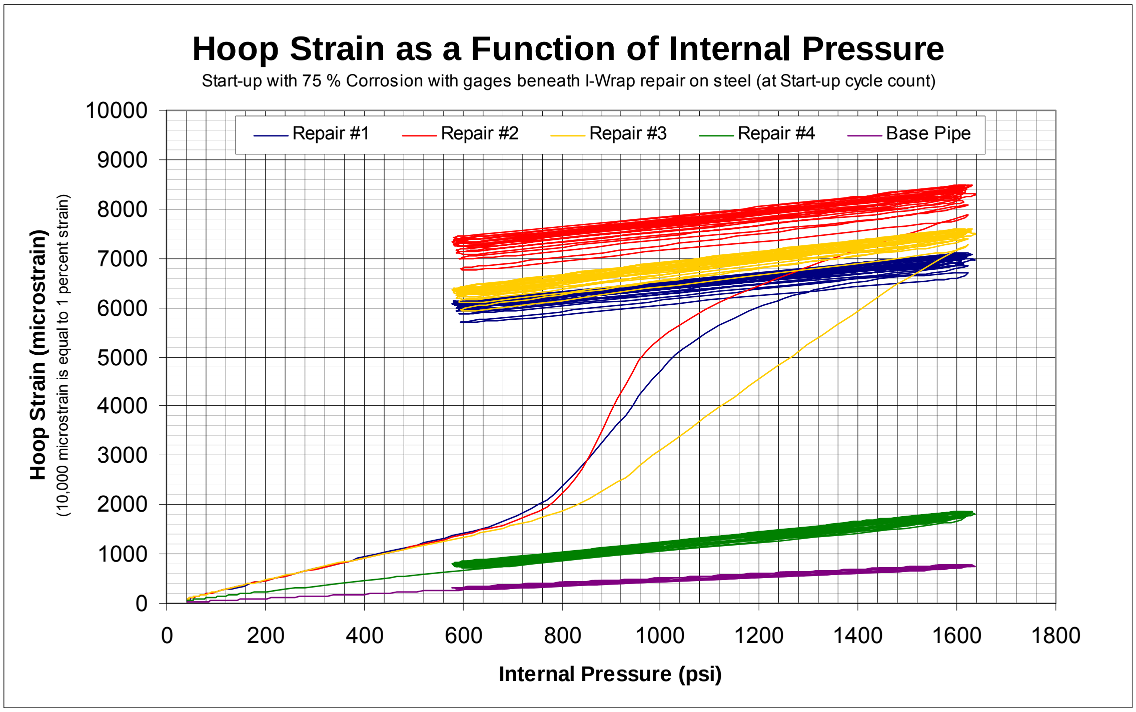


Figure 5 – Measured strain range in 75% corroded test sample
(test sample cycled at ΔP = 36% SMYS, data plotted at start-up)

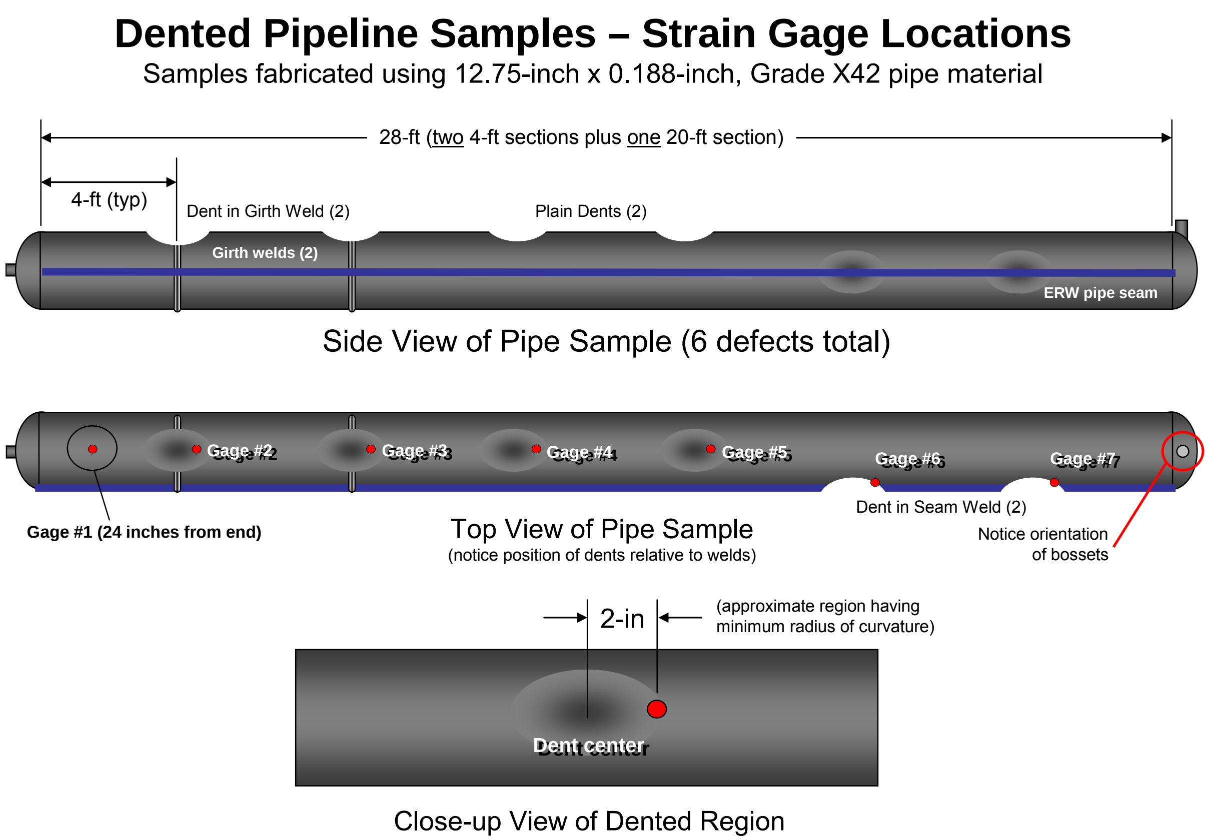


Figure 6 – Layout for pipe samples with 6 defects per sample
(the off-axis orientation of the dents interacting with the seam weld alleviates the need for an additional girth weld)

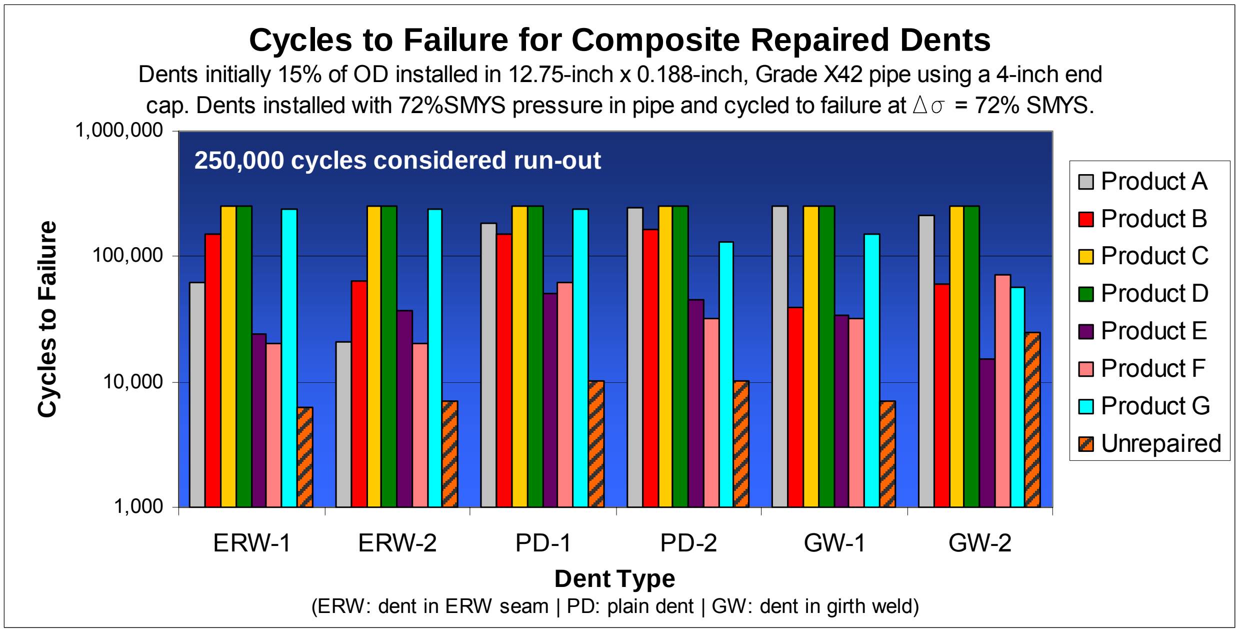


Figure 7 – Pressure cycle results for all dented test samples

Figure 8 – Composite survey website for industry and manufacturers

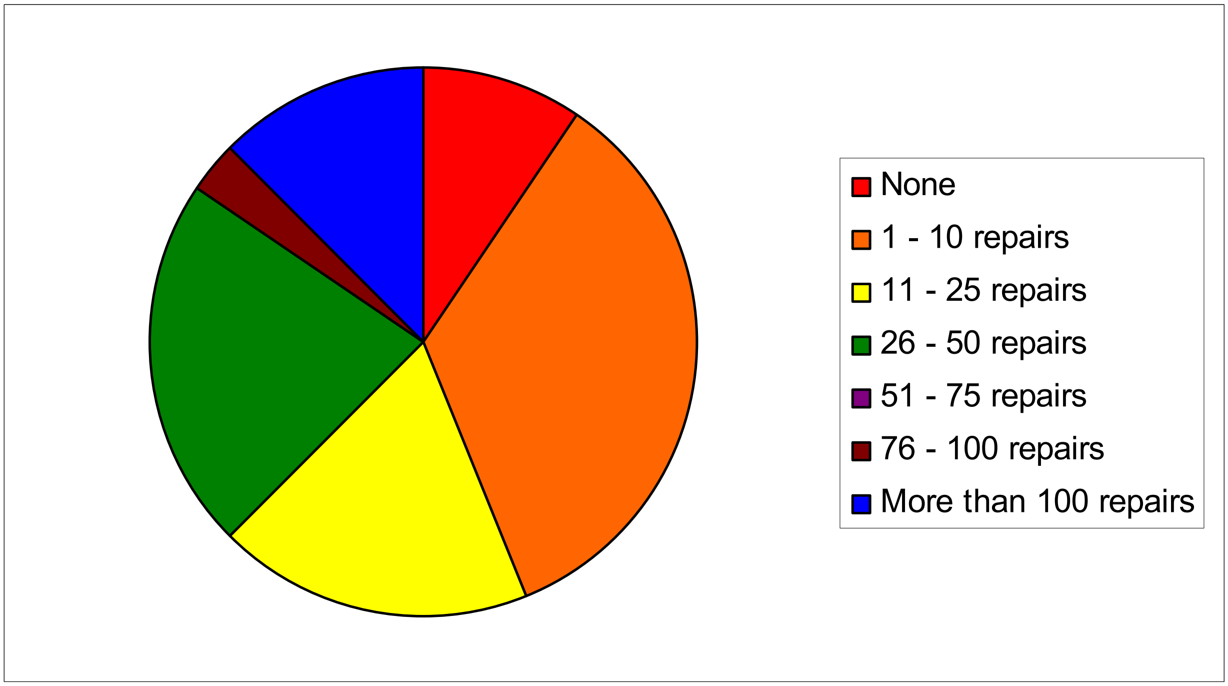


Figure 9 – Number of composite repairs to be used in the next 12 months

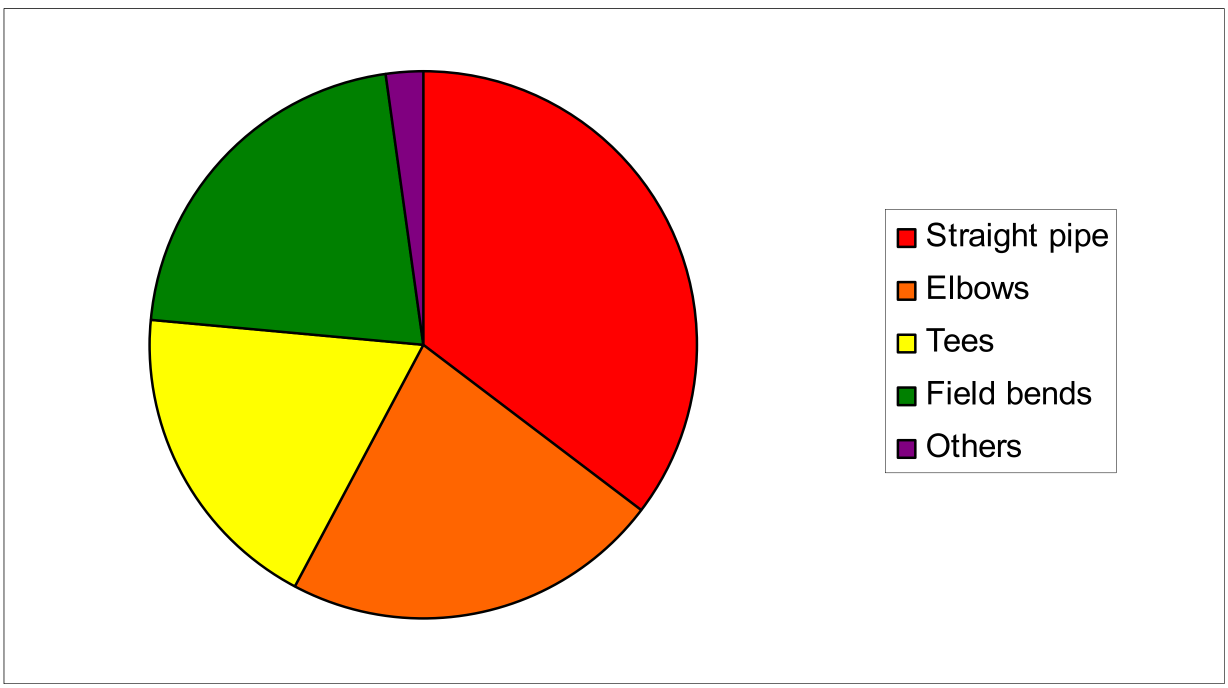


Figure 10 – Composite repairs allowed for the repair of the following pipe geometries

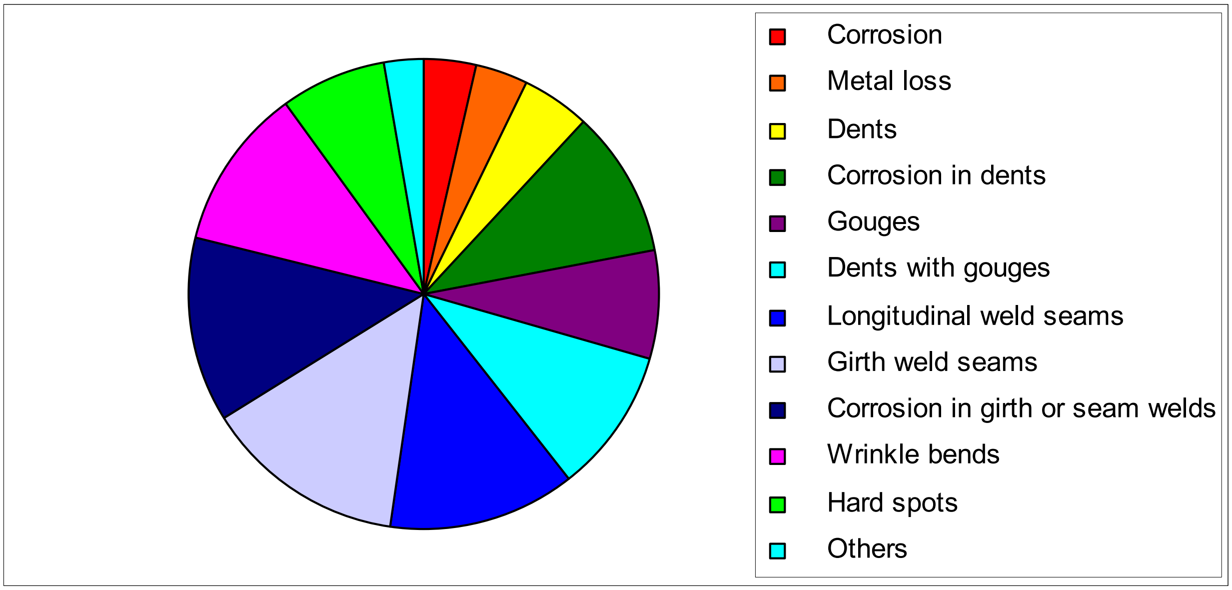


Figure 11 – Anomaly type repairs not permitted using composite materials

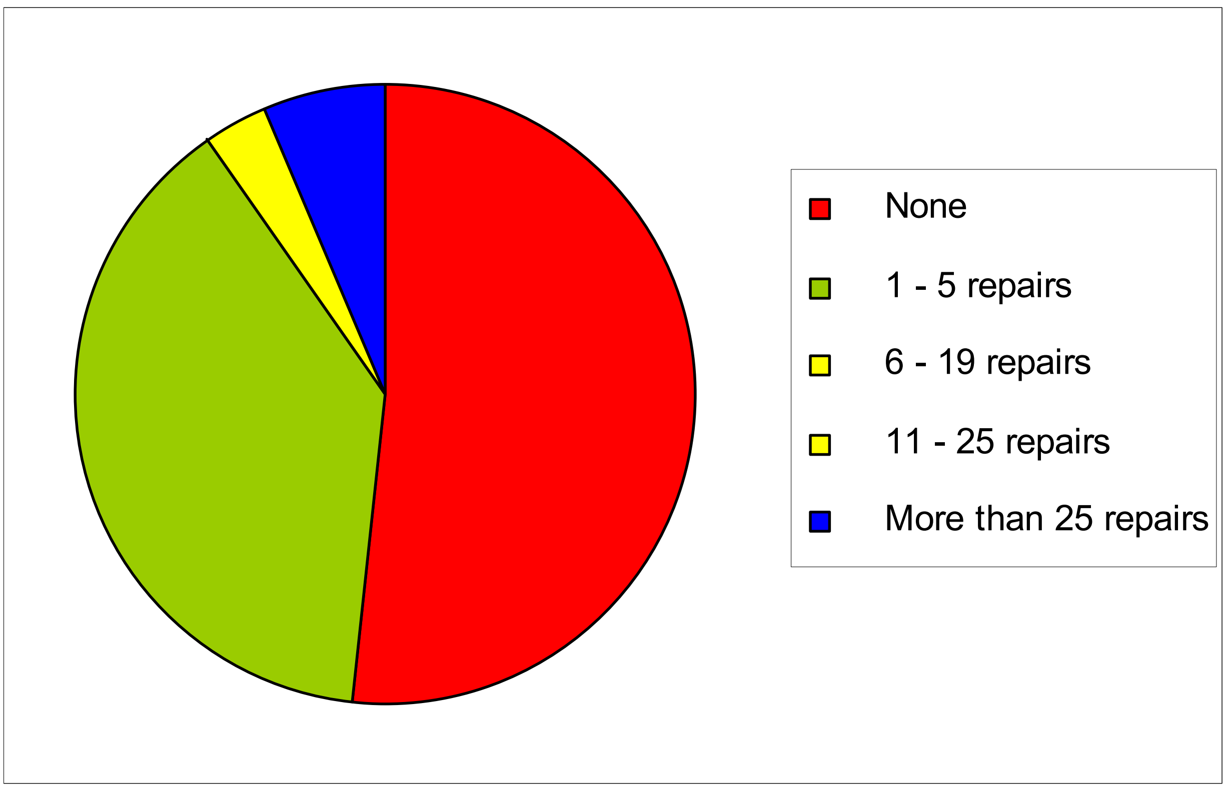


Figure 12 – Number of total composite repairs that have been removed

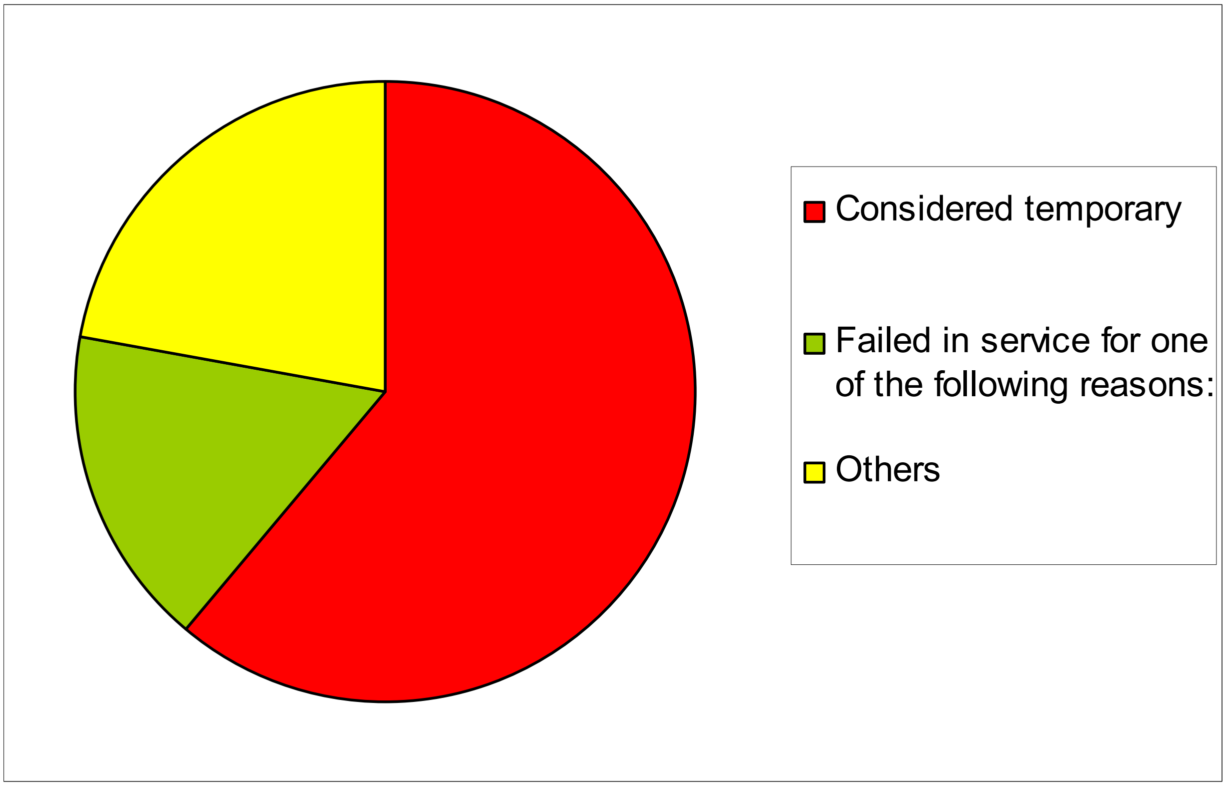


Figure 13 – Reasons that composite repair materials were removed