

AN EXPERIMENTAL STUDY TO EVALUATE THE PERFORMANCE OF COMPETING FILLER MATERIALS USED WITH TYPE B AND STAND-OFF STEEL SLEEVES

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ABSTRACT

An experimental study was conducted to evaluate the performance of various filler materials used in Type B tight-fit and stand-off steel sleeve designs. Full-scale testing was performed to examine the performance of three filler materials and two sleeve types reinforcing four separate dents subjected to cyclic internal pressure. All filler materials were installed with the test pipe at 55°F and allowed to cure for 7 days. The metric for comparing filler material performance was stress concentration factors (SCFs) measured in the dents in the unrepaired and repaired configurations. The filler materials included a two-component epoxy, an epoxy-based grout, and a cement-based grout. The average SCF for the unreinforced dents was 5.64, while after reinforcement the average SCF was 1.2 (an average reduction of 79%).

The results of this study generated two important findings. First, the stand-off sleeve design was able to provide reinforcement similar to what was measured for the tight-fit sleeve. Second, the study determined that the cement-based grout actually slightly outperformed the epoxy-based grout, the latter being the filler material of choice prior to this study. This paper provides readers with practical information and data on the performance of competing filler material types, while also presenting a systematic method for evaluating different methods of reinforcement.

INTRODUCTION

Stress Engineering Services, Inc. (SES) was contracted by Alyeska Pipeline Service Company in the fall of 2014 to provide full-scale testing services to evaluate the performance of filler materials for use in stand-off type repair sleeves. The particular stand-off sleeves considered in this test program are used for reinforcing dents, buckles, ripples, and wrinkles in liquid pipelines where a Type B tight-fit sleeve is inappropriate. In addition to stand-off sleeves, a Type B tight-fit sleeve was evaluated in the test program. The filler materials included a high strength, thermosetting, polymer-based, two-component (resin and catalyst) epoxy; a three-component (resin, catalyst, and inert aggregate) epoxy grout; and a non-shrink cement-based grout.

The test program was conducted using a NPS 12 (12.75-inch OD, 0.188-inch WT, Grade X42) API 5L pipe section. Four similar dents were formed along the length of the test pipe and pre-cycled to determine their relative severity using strain gages installed in the vicinity of each dent. After pre-cycling, stand-off sleeves were installed over three of the dents and a Type B tight-fit sleeve was

installed over the fourth dent. The Type B tight-fit sleeve was filled with a two-component epoxy. The three stand-off sleeves were filled with the following materials: (1) Epoxy grout, (2) a modified mix ratio epoxy grout (half of the component Part C inert aggregate material to epoxy), and (3) Non-shrink cement grout. All filler materials filled the sleeves and cured with the test pipe at a temperature of 55°F. The filler material suppliers and products used in the tests were:

- Wil-Cor, Inc.; Armor Plate 999 (AP-999) Epoxy (Part A Resin and Part B Catalyst)
- Wil-Cor, Inc.; Armor Plate 999 (AP-999) Epoxy Grout (Part A Resin, Part B Catalyst, and Part C Inert Aggregate)
- Five Star; FLUID GROUT 100

Once the sleeves were filled, the filler materials were allowed to cure for 7 days at a temperature of 55°F using chilled water circulated in the test pipe section. After the designated cure time was completed, the test pipe was pressurized to 100% SMYS and subjected to pressure cycles to evaluate the performance of the filler materials. The primary means for evaluating the filler material performance was a comparison of the SCFs in the dents reinforced by the filler materials and steel sleeves using strain-gage measurements. The SCF is defined as the ratio of the maximum stress calculated from the strain gages to the nominal hoop stress in the test pipe. The SCF is directly proportional to the severity of the dent and inversely proportional to its remaining life. After all phases of testing were completed, circumferential cross-sections of the sleeves were removed at each of the reinforced dents to visually examine the filler materials in the annular space between the pipe and the sleeves.

This paper is divided into five sections that include the Elements of the Test Plan section, which provides details for forming dents and installing strain gages; the steps used to test the sleeve reinforced dented pipe section; and the steps executed in the full-scale testing work to complete this test program. The Sample Fabrication section documents the detailed process and steps used to create the dents, the initial unreinforced SCFs, and fabrication and installation of the sleeves and filler materials. The Results section presents the SCFs measured during the post-repair cycling and observations made in reviewing the cross-sections removed after testing was complete. The Discussion section provides some commentary on the results and provides points for Alyeska to consider based on the results of the full-scale testing. The Conclusions section provides a summary of the findings from this work.

ELEMENTS OF THE TEST PROGRAM

All testing was performed using 12.75-inch OD, 0.188-inch WT, Grade X42, API 5L pipe material. The test pipe section was 25 ft. long. Four dents were placed in the pipe at equally-spaced 5-ft. intervals as shown in Figure 1. The dents were installed according to the following steps:

1. Prepare the dent frame with a 2-inch diameter hemispherical indenter.
2. Drive the indenter to an initial depth of 1.91 inches (15% OD) with no internal pressure in the pipe. Hold indenter in place during first pressure cycle.
3. Increase the pressure to 890 psi (72% SMYS) and hold for 1 minute.
4. Remove internal pressure.
5. Remove indenter.
6. Repeat steps 2–5 to generate three more dents.
7. Install one strain gage on each dent periphery as shown in Figure 2; this is the high stress location.
8. Perform 1,000 pressure cycles on all dents with a range from 100–890 psi (8–72% SMYS).
9. Install additional strain gages on dents as shown in Figure 2.
10. Install Type B tight-fit and stand-off sleeves. The geometry of the stand-off sleeve is shown in Figure 3.
11. Circulate water to ensure pipe at 55°F through test pipe overnight (temperature designated by Alyeska).
12. Fill sleeve annulus with filler materials while continuing water circulation at 55°F in the test pipe.
13. Allow filler materials to cure for seven days, while continuing water circulation at 55°F within the test pipe. The selection of the 55°F temperature was to evaluate the ability of the filler materials to cure under these conditions.
14. Pressurize the test pipe to the following pressures with 5 minute holds at each pressure (cold temperature not maintained during pressure testing):
 - a. 890 psi (72% SMYS)
 - b. 1,116 psi (90% SMYS)
 - c. 1,240 psi (100% SMYS)
15. Apply 25,000 pressure cycles with a pressure range from 100–890 psi (8–72% SMYS).
16. Drain test pipe and cut cross-sections of the sleeves through the center of each dent.

SAMPLE FABRICATION

This section of the paper documents fabrication of the dents and the steel reinforcement sleeve for each dent.

Dent Fabrication

A photograph of the indenter set-up used to create the dents is shown on the left in Figure 4. An example of a dent prior to re-pressurization (end of Step 5) is shown on the right in Figure 4. During the initial pressure cycling (Step 8), the SCF was measured for each dent using strain gages installed in the dented regions. A summary of the particulars for each dent is presented in Table 1. All dents were similar in terms of depth and SCF. All dents were located at the 12 o'clock position of the test pipe in relation to the sleeve's fill and vent ports.

Sleeve Fabrication

After completion of the initial 1,000 pressure cycles, the sleeves to reinforce each dent were installed. Photographs of a typical stand-off sleeve installation are shown in Figure 5. In the case of the stand-off sleeves, the sleeve fabrication followed the design with no

variation. For the Type B tight-fit sleeve, SES engineers worked with the sleeve fabricator to ensure that a small annular space was maintained between the pipe and the sleeve around the circumference of the pipe. A small gap was needed to permit full coverage of the epoxy within the sleeve and was created by using welding rods to position the sleeve off the pipe surface while it was welded into place. Photographs of the installation are shown in Figure 6. When the sleeve's longitudinal weld seam backing strips were positioned, intermittent small weld beads oriented in the circumferential direction were placed on the pipe side of the strips to preserve the annular space around the entire circumference of the pipe.

Filler Material Installation

This section of the paper presents the processes and temperatures observed during installation of the filler materials. The filler materials were installed over 2 days. Table 2 provides information on the filler materials and sleeve type used to reinforce each dent. Each sleeve was prepared and filled based on guidance from Alyeska. Two fill/vent lines with clear plastic tubes were placed at the top of each sleeve. At the bottom of each sleeve, a fill line was prepared with a ball valve to stop back flow as needed.

The filler material for Dent #1 was Armor Plate 999 2-component epoxy mixed and pumped into the sleeve annulus by representatives from Wil-Cor, Inc. A small pump was used to pump the pre-mixed epoxy through an approximately ½-inch diameter clear hose. Initially, the epoxy was pumped into the top of the sleeve. The outlet at the bottom of the sleeve was closed using the ball valve. After the sleeve annulus was initially filled, the pumping configuration was modified at the request of Alyeska such that the epoxy was pumped into the bottom of the sleeve with the top fill/vents open. The epoxy was pumped through the bottom until it was forced out of the vent tubes as shown in Figure 7. As can be seen in Figure 7, some settlement of the epoxy was noted during curing throughout the day as the epoxy level in the top of sleeve vent tubes decreased.

The filler material for Dent #2 was installed by pouring pre-mixed Armor Plate 999 epoxy grout into the stand-off sleeve through the fill/vent tubes at the top as shown in Figure 8. The mixing of the three components and pouring of the epoxy grout was performed by Wil-Cor representatives. After the filling process was completed, the valve at the bottom of the sleeve was opened. When the valve was opened, the epoxy grout was observed to readily flow out of the sleeve. In addition, the level of epoxy grout between the two vent lines was observed to equalize over time as shown in Figure 8. Similar to Dent #1, some settlement of the epoxy grout during curing was noted in Dent #2 throughout the day. Approximately 2 in³ of contraction of the filler material was observed in the vent tubes in Figure 8, which corresponds to approximately 0.14% of the total sleeve annulus volume.

The stand-off sleeve for Dent #3 was filled with Five Star FLUID GROUT 100. The usage instructions for the non-shrink cement-based grout recommended water contents between 4 and 6 quarts per 55 lb. bag. Higher water contents increase the flowability of the grout, but decrease the compressive strength. After discussions with Alyeska, it was decided to prepare the grout with 6 quarts of water. The grout was installed by SES technicians using a pump and a 1.25-inch diameter hose as shown in Figure 9. The fluid grout was pumped through the bottom port of the sleeve until it was pushed out through the vent lines at the top of the sleeve.

The stand-off sleeve for Dent #4 was initially attempted to be filled with a two-component epoxy filler material provided by another pipeline repair products supplier. However, the epoxy was found to be too viscous and cured too quickly to be pumped into the sleeve, and the filling attempt was unsuccessful. Consequently, the stand-off sleeve for Dent #4 was filled with a modified mix ratio of Armor Plate 999 epoxy grout, which consisted of a standard mix ratio of components Part A (resin) and Part B (catalyst) along with a reduced mix ratio of component Part C (inert aggregate filler, i.e., Cabosil¹). The modified epoxy grout mixture used approximately one-half of the Part C component material recommended for a typical application of 1-part mixed epoxy to 1-part inert aggregate. Initially, the modified epoxy grout was pumped into the bottom fill port of the sleeve by the same pump used for the cement-based grout as shown in Figure 10. However, the higher exothermic heat generated from the modified mix ratio epoxy grout destroyed the pump; the filling had to be completed by pouring the epoxy grout into the sleeve through the top fill/vent port lines as shown in Figure 10. The pumping and pouring of the epoxy grout for Dent #4 was completed by Wil-Cor representatives with some assistance from SES technicians.

Prior to filling the sleeves with filler materials, chilled water at a temperature of 55°F was circulated through the NPS 12 test pipe section overnight. Eight thermocouples were placed on the test pipe in the following locations and monitored throughout the filler material installation process:

- One thermocouple was placed on the pipe body of the test pipe.
- Four thermocouples were placed on the outside surface of each sleeve.
- Three thermocouples were placed inside each of the three stand-off sleeves on the test pipe surface.

A plot of the cooling-water temperature and pipe temperature for the duration of the chilling, filler material filling, and curing processes is shown in Figure 11. It can be seen that the pipe temperature was maintained below 55°F for the duration of filling all the sleeves. The intent was to achieve a pipe temperature 55°F, so a lower temperature was required in the water. The filler materials were installed on two days, and these time periods are noted in Figure 11. The filler materials in Dents #1–#3 were installed near the end of the first day, while the filler material for Dent #4 was installed near the end of the second day.

RESULTS

After the epoxy, epoxy grout, and cement grout filler materials were allowed to cure for 7 days, the test pipe section was pressure tested to 100% SMYS (1,240 psi) and the strain readings for the dents were compared. Once this static hold was completed, the test pipe section was subjected to 25,000 pressure cycles at a range of 790 psi (8–72% SMYS). The SCF in each of the dents was compared to the original SCF associated with testing the unreinforced condition. This combination of tests provided a quantitative assessment of each filler material's performance.

Post-Sleeve Static Pressure Data

The stresses in the test pipe were compared for each of the dents during the static pressure hold. The hoop strains from Gage #1 on each dent (refer to Figure 2 for gage locations) were compared to strains in the test pipe. A plot of hoop strain vs. internal pressure is shown in Figure 12 for the regions near the dents and in the test pipe. It can be seen that the reinforced dents all showed lower hoop strains at higher pressures as a result of the reinforcement provided by the epoxy, epoxy grout, and cement grout filled sleeves.

Tabular results for the stresses in the test pipe are shown in Table 3. Tabular results for the stresses in the test pipe adjacent to each dent are shown in Table 4, which also includes the ratio between the von Mises stresses adjacent to the dent and the test pipe away from the dents. It can be seen that this ratio is lower at higher pressures. This trend is expected because the effectiveness of the filler and sleeve materials is more evident at higher pressures when the expansion of the test pipe causes engagement of the reinforcing filler and steel sleeve materials. The Type B tight-fit sleeve (Dent #1) had the lowest ratios due to the fact that the annular space was the smallest, resulting in more engagement of the reinforcing steel sleeve at lower pressures.

Post-Sleeve Cyclic Pressure Data

After the static test, the test pipe was pressure cycled for 25,000 cycles with a pressure range of approximately 790 psi. The pressure range was chosen to be as large as possible within expected operating conditions of the test pipe. The lower-bound pressure of 100 psi is the minimum the pressure pump can achieve, while the upper-bound pressure of 890 psi corresponds to 72% SMYS, a Maximum Operating Pressure (MOP) typical for liquid pipelines based on an ASME B31.4 design.

At set intervals during cycling, the strain-gage readings were recorded. The results were used to calculate SCFs for the reinforced dents. The SCFs calculated from the unreinforced dents can be compared to the SCFs after the repairs to determine the effectiveness of the steel sleeve reinforcements. The results for the post-repaired SCFs are shown in Table 5. The results show that all of the repair sleeves produced SCFs that were stable across 25,000 cycles.

Post-Test Cross-Sections

After all phases of testing were completed, 1-inch wide circumferential cross-sections of the sleeves were cut from each of the dented regions. The purpose of the cross-sections was to evaluate how well each filler material filled the annular space between the sleeve and the pipe, as well as look for any degradation or anomalies within the filler materials.

A photograph of the cross-section from Dent #1 is shown in Figure 13. The epoxy appeared to completely fill the annular space between the pipe and the Type B tight-fit sleeve around the entire circumference of the test pipe (despite the small annular space). One small air pocket was observed in the cross-section at the 12 o'clock position where the dent was located.

A photograph of the cross-section from Dent #2 is shown in Figure 14. The epoxy grout filled the total annular space between the stand-off sleeve and the pipe. However, one air pocket was observed in the grout at the 12 o'clock position where the dent was located. This air pocket ran through the cross-section. The epoxy grout

¹ Cabosil (manufactured by the Cabot Corporation), also called colloidal or fumed silica, can be mixed with epoxy on its own or added into a blend of epoxy fillers. It is a fine, high-density epoxy filler often used to control the viscosity of epoxy and commonly used on structural bonding, filling, and filletting applications.

material did not appear to be compromised near the region of the dent.

A photograph of the cross-section from Dent #3 is shown in Figure 15. The cement grout filled the annular space between the stand-off sleeve and the pipe. A few small air pockets were observed near the top of the sleeve where the dent was located, although they were minimal in size when compared to the air pockets observed in the other three sleeves. It should be pointed out that the cement grout adjacent to the dent was damaged during the saw cutting process to remove the cross-section ring from the sleeve. This damage, which can be seen in Figure 15, was not believed to be a result of the pressure-cycling process. The cement grout material in the other regions of the annular space was in good condition without any observed separations.

A photograph of the cross-section from Dent #4 is shown in Figure 16. The modified mix ratio epoxy grout filled the annular space between the stand-off sleeve and the pipe. However, one air pocket was observed in the grout at the 12 o'clock position where the dent was located. This air pocket ran through the cross-section, and was similar to the air pocket observed in the Dent #2. It was also observed that the inert aggregate material in Dent #4 appeared to segregate and settle more toward the bottom of the sleeve. Photographs showing this segregation are provided in Figure 17. The photographs show the separation that appears at the 3 and 9 o'clock positions in Dent #4.

DISCUSSION

The testing results documented in this paper demonstrate that all of the filler materials used within the steel sleeves did an excellent job in reducing SCFs in the dents. Prior to reinforcement, the SCFs in the dents ranged from 5.24 to 5.88. Typical SCFs in plain dents examined in the field range from 2 to 4.5. Therefore, the dents considered in this test program represent fairly severe dents. The SCFs calculated after reinforcement and pressure-cycling ranged from 1.12 to 1.28. This represents a 75–80% reduction in the peak stresses observed in each dent.

This significant reduction in stresses corresponds to an even larger increase in fatigue life. Typical fatigue exponents are 3.5 for plain steel². Therefore, a 75% reduction in stress would result in a reinforced fatigue life that is over 100 times greater than the unreinforced fatigue life. In fact, the reduced SCFs associated with the reinforced dents are lower than SCFs associated with typical line pipe longitudinal seam weld profiles.

Some observations can be made regarding the installation of the epoxy, epoxy grout, and cement grout filler materials. First, the 55°F installation and curing temperature did not appear to have any deleterious effects on the installation and curing of the filler materials. Secondly, the modified mix ratio epoxy grout (Dent #4) showed noticeably higher curing temperatures when compared to the standard epoxy grout (Dent #2). The temperatures measured on the outside of the sleeve reached 110°F. The higher curing temperature is attributed to the fact that only half of the component Part C inert aggregate was used. While this temperature does not pose a concern to the materials, it should be considered in light of the annular space tested and the resulting volume of epoxy grout materials. A larger

annular space with increased volume will likely result in higher temperature increases than were observed in this test stand-off sleeve.

With regard to the cement grout (Dent #3), the test was conducted using the maximum recommended water content of 6 quarts per 55 pound bag. Using the maximum recommended water content will produce lower-bound compressive strengths in the grout material. Since the material performed well in this test with the maximum recommended water content, it is reasonable to conclude that it would perform equally well, if not better, at lower water contents.

As described previously, once cycling was complete, circumferential cross-sections were cut from the sleeves at the dent locations and examined to determine how well the filler materials filled the annular space and whether any degradation of the filler materials had occurred. The examination of the cross-sections did not appear to show any degradation of the filler materials after being subjected to 25,000 pressure cycles. The epoxy was able to fill the tight annulus within the Type B tight-fit sleeve. Some air pockets were observed in the stand-off sleeves filled with the epoxy grout, but these air pockets did not appear to affect the performance of the epoxy grout materials. In addition, the modified mix ratio epoxy grout also appeared to show some settlement of the aggregates into the lower half of the sleeve annulus.

CONCLUSIONS

The testing work completed to evaluate the performance of filler materials for Type B tight-fit and stand-off steel sleeves has provided valuable information on the performance of repair sleeves. Measuring strains in dents subjected to pressure cycles before and after installation of the repair sleeves provided a direct means for assessing the performance of epoxy-based and cement-based filler materials.

The conclusions developed from this testing program are summarized below:

1. All of the filler materials and sleeve designs were effective at significantly reducing SCFs in the dented regions.
2. All of the filler materials exhibited stable performance over 25,000 pressure cycles with no visible degradation or significant anomalies.
3. The modified mix ratio epoxy grout showed higher installation and curing temperatures than the standard epoxy grout, but did not provide any appreciable difference in performance.
4. The non-shrink cement-based grout performed well with the maximum recommended water content.

REFERENCES

1. ANSI/ASME PCC-2-2011, Repair of Pressure Equipment and Piping, Repair Standard, Article 4.1, Non-metallic Composite Repair Systems for Pipelines and Pipework: High Risk Applications, American Society of Mechanical Engineers, New York, 2011.
2. Alexander, C., and Bedoya, J., Repair of Dents Subjected to Cyclic Pressure Service Using Composite Materials, Proceedings of IPC2010 (Paper No. IPC2010-31524), 8th International Pipeline Conference, September 27–October 1, 2010, Calgary, Alberta, Canada.

² Department of Energy, 1984, *Offshore Installations; Guidance on Design and Construction*.

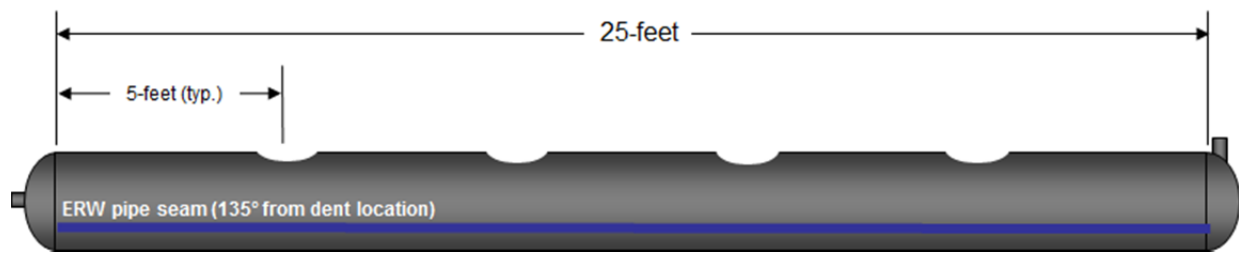
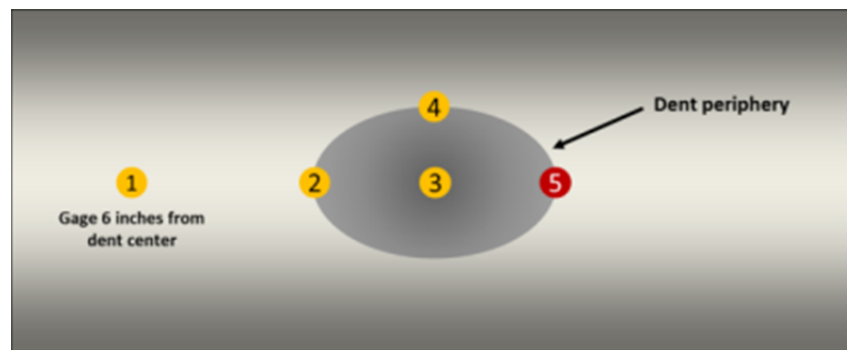


Figure 1: Sample Dent Locations



- Original strain gage location (used to measure pre-repair dent strains)
- Additional strain gage locations

Figure 2: Strain Gage Locations for each Dent

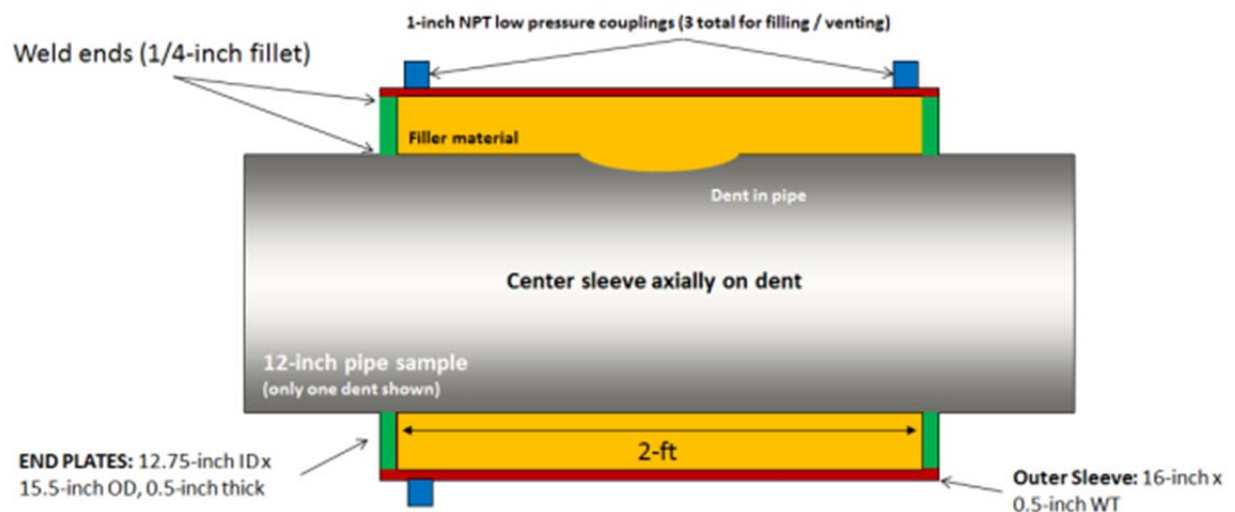


Figure 3: Stand-off Sleeve Dimensions

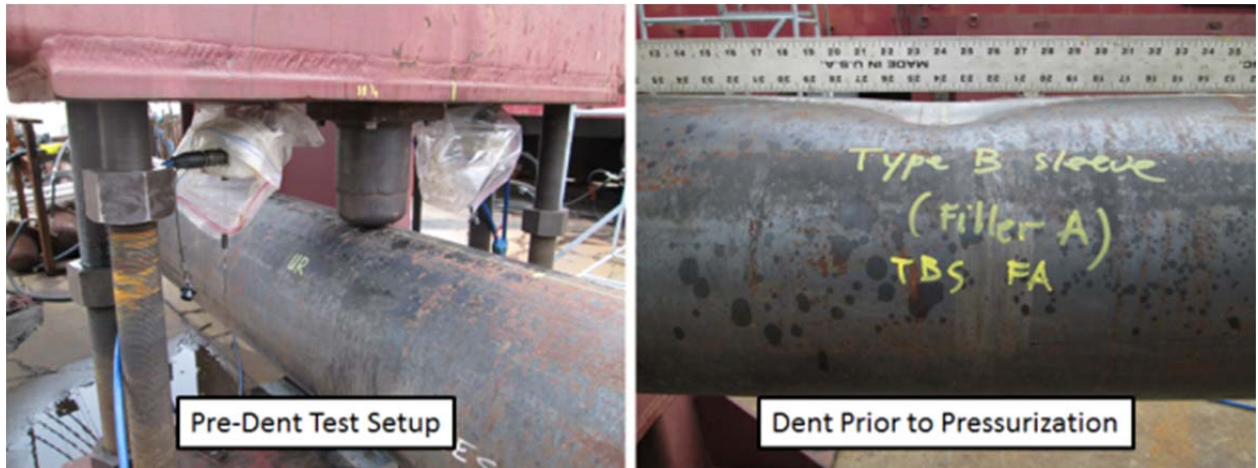


Figure 4: Dent Creation



Figure 5: Stand-Off Sleeve Installation



Figure 6: Type B Sleeve Installation

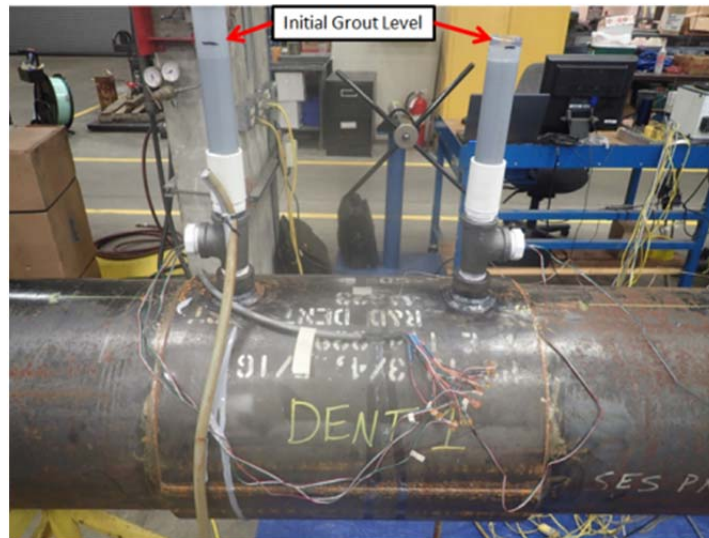


Figure 7: Dent #1, Armor Plate Epoxy Vent Lines



Figure 8: Dent #2, Armor Plate Epoxy Grout Installation

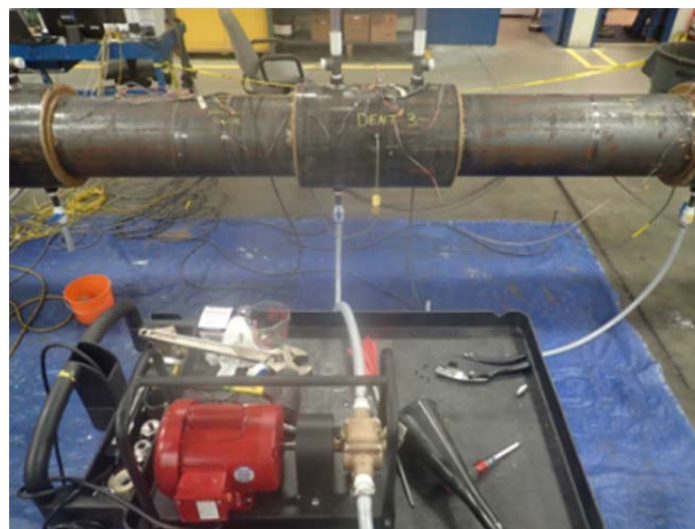


Figure 9: Dent #3, Five Star FLUID GROUT 100 Installation



Figure 10: Dent #4, Armor Plate Modified Mix Ratio Epoxy Grout Installation

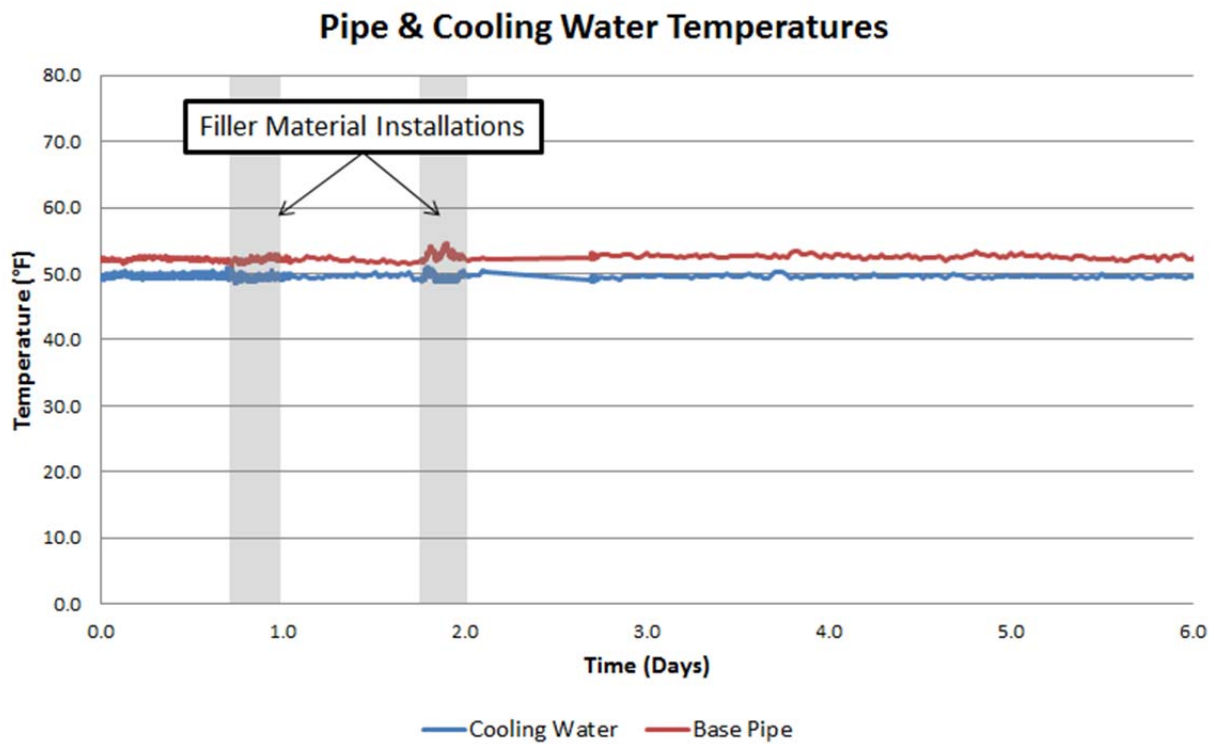


Figure 11: Cooling Water and Base Pipe Temperatures

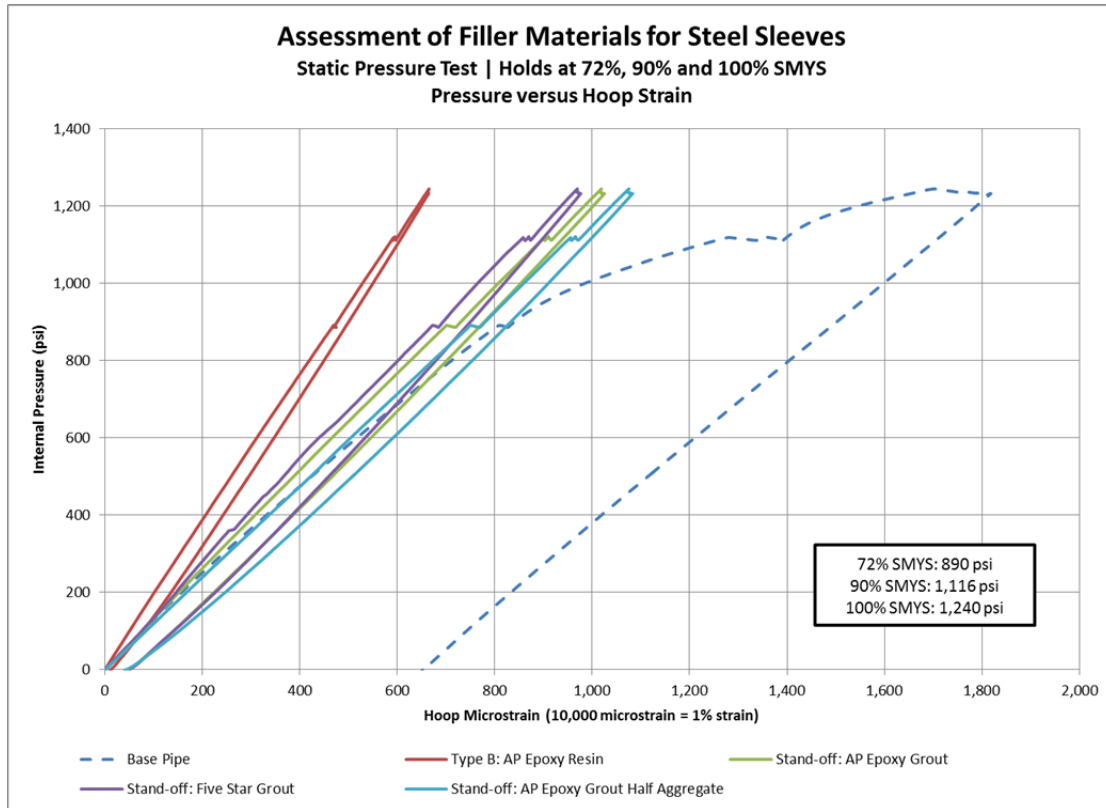


Figure 12: Hoop Strains during Post-Sleeve Static Pressure Test

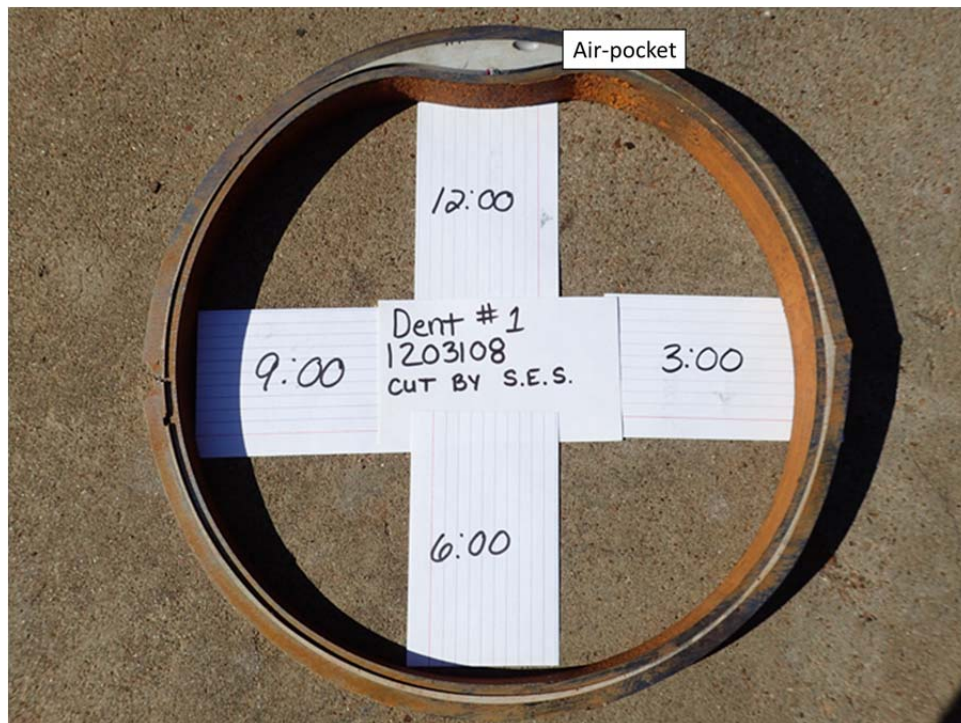


Figure 13: Dent #1 Cross-Section (Type B, AP Epoxy)

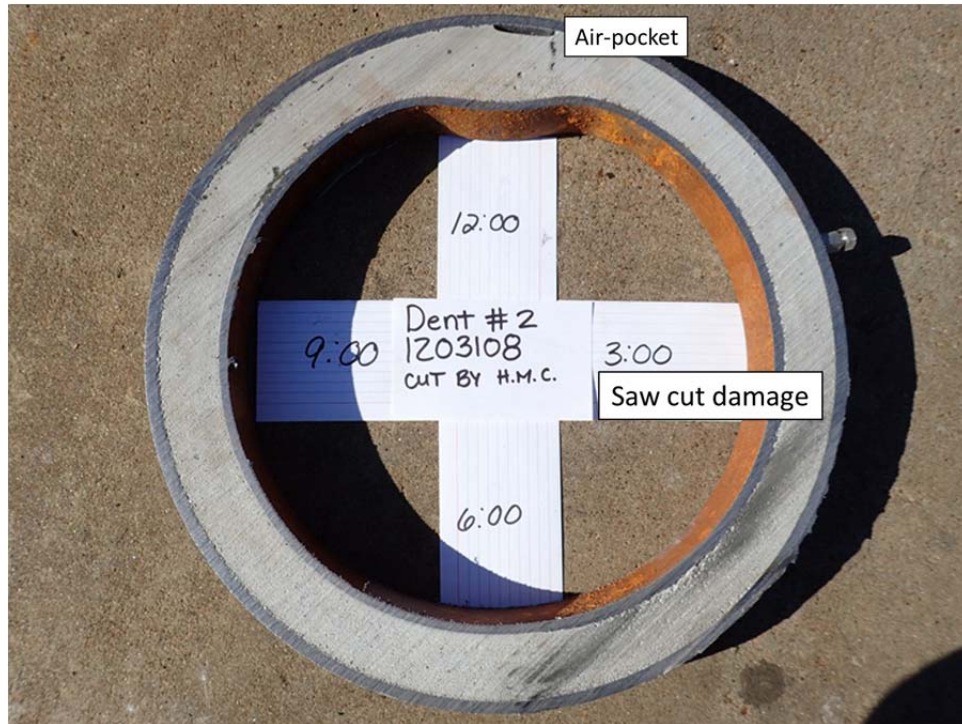


Figure 14: Dent #2 Cross-Section (Stand-off, AP Epoxy Grout)

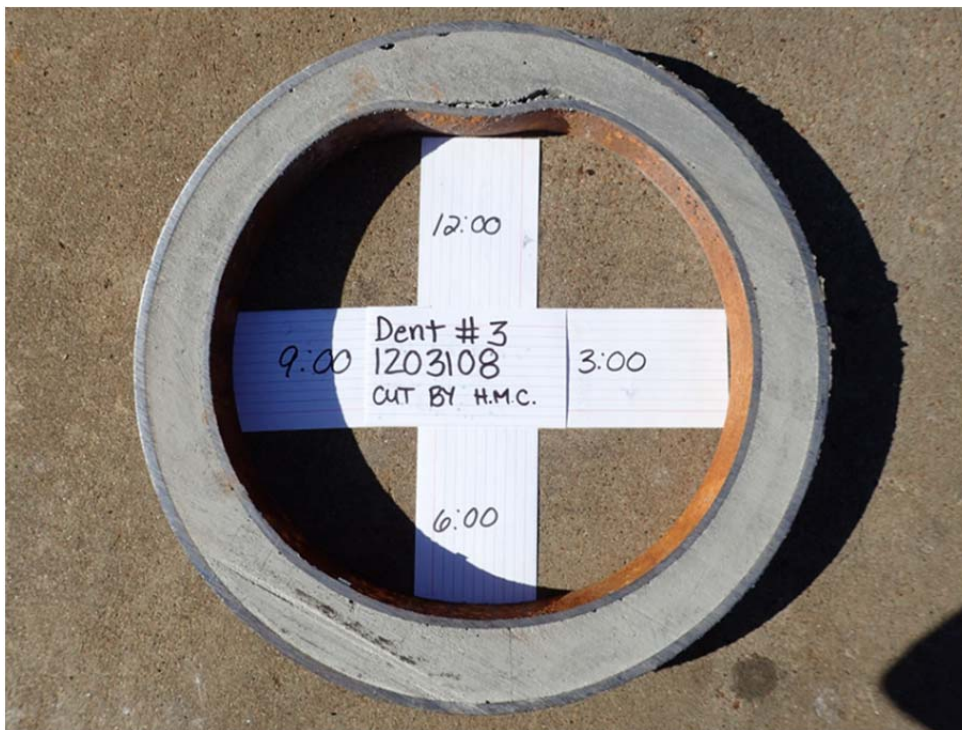


Figure 15: Dent #3 Cross-Section (Five Star FLUID GROUT 100)

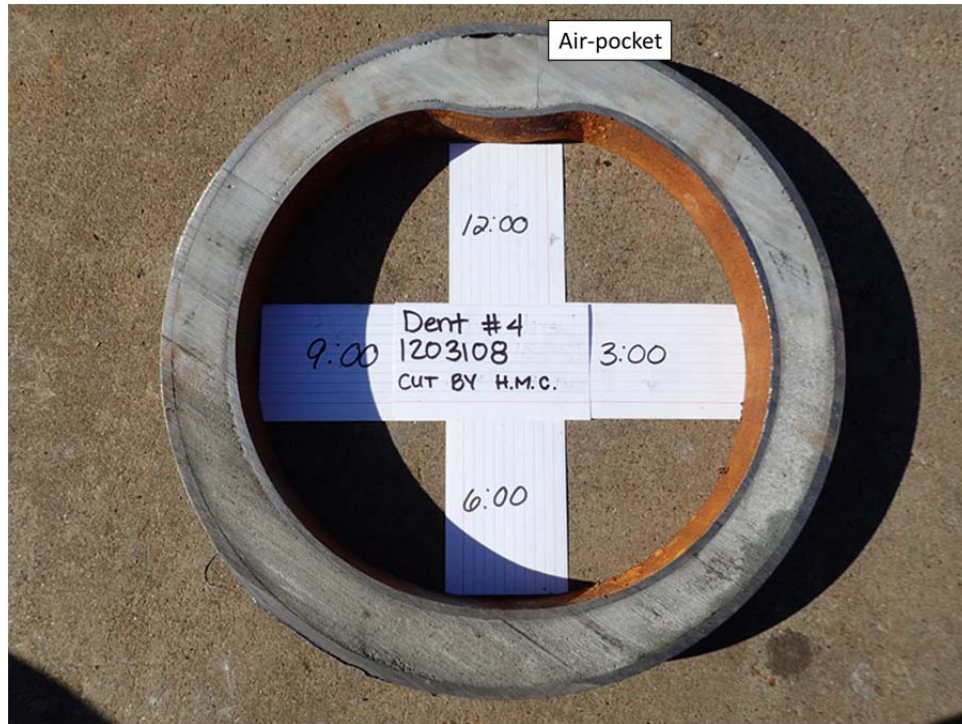


Figure 16: Dent #4 Cross-Section (AP Modified Mix Ratio Epoxy Grout)

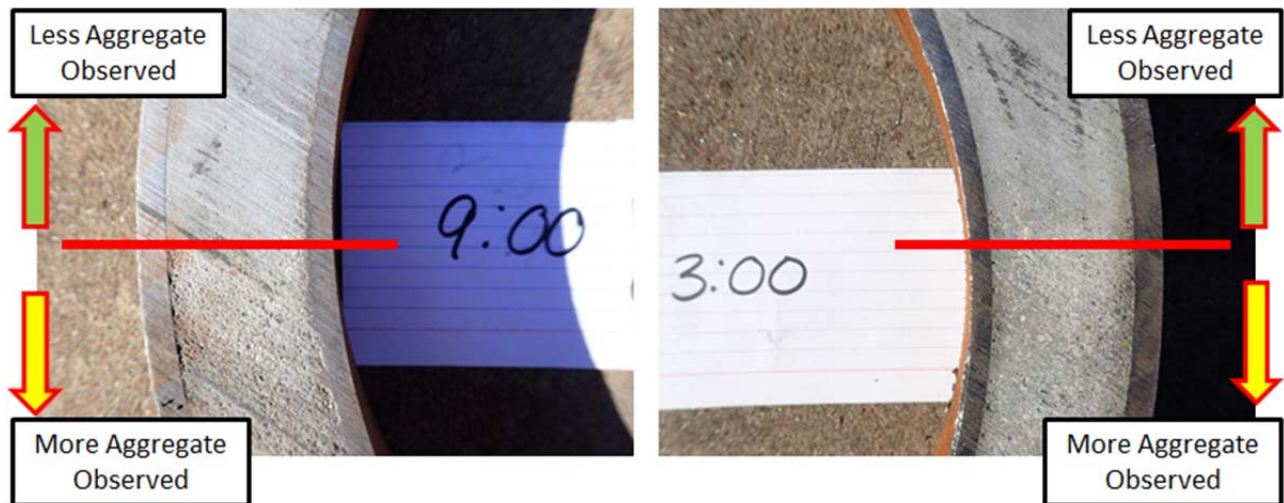


Figure 17: Aggregate Settlement in Dent #4 (AP Modified Mix Ratio Epoxy Grout)

Table 1: Dent Particulars

Dent ID	Initial Depth (inches)	Depth after 1,000 cycles (inch)	SCF
Dent 1 (Type B, AP Epoxy)	1.206	0.629	5.88
Dent 2 (AP Grout)	1.189	0.624	5.78
Dent 3 (Five Star)	1.208	0.613	5.24
Dent 4 (Modified AP Grout, ½ Part C)	1.215	0.617	5.69

Table 2: Dent Filler Materials

Dent ID	Sleeve Type	Filler Material
1	Snug, Type-B	Armor Plate Epoxy (Parts A & B)
2	Stand-Off	Armor Plate Epoxy Grout (Parts A, B, & C)
3	Stand-Off	Five Star FLUID GROUT 100
4	Stand-Off	Armor Plate Modified Epoxy Grout (Parts A, B, and ½ C)

Table 3: Base Pipe Stresses Adjacent to Dents in Post-Sleeve Static Pressure Test

Pressure	Hoop Stress (psi)	Axial Stress (psi)	von Mises Stress (psi)
892	29789	16034	25823
1114	49135	24353	42552
1233	63325	29283	54893

Table 4: Base Pipe Stresses in Post-Sleeve Static Pressure Test

Pressure	Dent ID	Description	Hoop Stress (psi)	Axial Stress (psi)	von Mises Stress (psi)	Ratio Relative to Base Pipe
892	1	Type B Sleeve: Armor Plate Epoxy	17988	12703	16013	0.62
1114	1		22689	15845	20158	0.47
1233	1		25152	17436	22318	0.41
892	2	Stand-Off Sleeve: Armor Plate Epoxy Grout	27639	19703	24649	0.95
1114	2		35007	24847	31193	0.73
1233	2		39029	27586	34751	0.63
892	3	Stand-Off Sleeve: Five Star Grout	26612	19853	23958	0.93
1114	3		33749	24947	30322	0.71
1233	3		37584	27638	33730	0.61
892	4	Stand-Off Sleeve: Armor Plate Modified Epoxy	29478	20835	26246	1.02
1114	4		37121	26371	33083	0.78
1233	4		41265	29261	36764	0.67

Table 5: Post-Repair SCFs

Dent ID	Description	Base SCF	SCFs Calculated at Cycle Counts†								
			100	200	500	1,000	2,000	5,000	10,000	20,000	25,000
1	Type B: AP Epoxy	5.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.08	1.12
2	Stand-Off: AP Epoxy Grout	5.78	1.17	1.20	1.19	1.19	1.20	1.20	1.19	1.22	1.26
3	Stand-Off: Five Star Grout	5.24	1.09	1.13	1.12	1.11	1.12	1.13	1.13	1.16	1.14
4	Stand-Off: AP Modified Epoxy Grout	5.69	1.24	1.24	1.23	1.23	1.23	1.22	1.22	1.22	1.28

† The SCFs from the cycle counts were calculated as the highest SCF from either gage 2 or 5