EXH. DJL-3r (Apdx. P)
DOCKETS UE-240004/UG-240005
2024 PSE GENERAL RATE CASE
WITNESS: DAVID J. LANDERS

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**Docket UE-240004** **Docket UG-240005**

APPENDIX P (NONCONFIDENTIAL) TO THE SECOND EXHIBIT TO THE PREFILED DIRECT TESTIMONY OF

DAVID J. LANDERS

ON BEHALF OF PUGET SOUND ENERGY

MARCH 4, 2024

the Energy to Lead

gti testing laboratories

GTI Project Number: 20835.1.32

Evaluation of Exhumed Aldyl-HD Gas Pipe Samples

Report Issued:
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Executive Summary

The aim of this project was to develop data, information, and predictions on the remaining useful life expectancy and the corresponding pressure-carrying capacity of a 2" SDR 11 Aldyl-HD pipe material installed in a gas distribution system operated by PSE.

Testing was performed on field-extracted Aldyl-HD pipe samples that were exhumed from various locations. There was a combination of straight pipe and pipe that had been subjected to squeeze-off. An indentation jig was developed and used to simulate rock impingement on the pipe specimens. The following tests were employed:

- Dimensioning
- Bend-back
- Rate Process Method (RPM)
- Dynamic Thermo-Mechanical Analysis (DTMA)

Based on the samples provided and the testing and analysis performed in this project the following conclusions are made:

1. None of the specimens evaluated by bend-back testing exhibited any signs of brittle cracking or crazing. The results do not indicate any abnormal deterioration of the field-extracted pipe samples.

2. The testing performed in this project demonstrates that it is possible to extract Bi-Directional Shift Factors (BDSF) from Dynamic Thermo-Mechanical Analysis (DTMA) test data and that the predictions are in excellent agreement to those obtained by the more traditional RPM analysis.

3. The squeeze-off pipe samples predominately failed at the squeezed location, however the failure times are comparable to the Control samples when tested at the same stress and temperature.

4. Due to the limited number of data points generated for the Squeeze-off and Indent pipes it was not possible to establish RPM models for these samples, however, the obtained test results were shifted to a reference temperature of 68°F (20°C) using BDSF developed from DTMA testing. The bi-directionally shifted points are in good agreement with RPM model of the Control pipe indicating that there does not appear to be a discernable difference in performance of these pipes to that of the Control pipe.

5. Based on the RPM model the 97.5% Lower Prediction Limit (LPL) expected lifetime in years, for a SDR 11 Aldyl-HD pipe at various end-use ground temperatures and operating pressures, are shown in the table below.

Temperature [°F]	Operating Pressure [psig]			Expected Lifetime Prediction - LPL (year)
	No Stress Riser	Allowable Stress Riser (Safety Factor = 3)	Extreme Stress Riser (Safety Factor = 6)	
40	180	60	30	> 100
42	180	60	30	> 100
45	180	60	30	> 100
47	180	60	30	73
50	180	60	30	56
52	180	60	30	47
55	180	60	30	36
57	180	60	30	30
60	180	60	30	23
62	180	60	30	19
65	180	60	30	15
67	180	60	30	13
70	180	60	30	10
72	180	60	30	8
75	180	60	30	6

At an average ground temperature of 57°F a pipe at a system operating pressure of 180 psig is expected to last 30 years. This calculated pressure reflects the material's 97.5% lower prediction limit capability. If the allowable system operating pressure is 60 psig we can say that the system has a safety factor of 180/60 = 3, with respect to a 60 psig operating pressure, 73°F and an expected lifetime of 30 years. From this we can infer that a typical segment of pipe should last about 30 years at 57°F if the operating pressure is 60 psig and there are not any extreme stress risers greater than 3 impacting the system. Squeeze-offs and impingement usually introduce stress risers above 3, possibly as high as 6. Reducing the operating pressure from 180 psig to 30 psig would increase the factor of safety to 6 and allow the operator to include squeeze-offs and some impingements in the lifetime expectancy of 30 years.

Additional calculations were made based on average ground temperatures ranging from 40-75°F and 5 psig pressure increments at each temperature. These are provided in a supplementary document.

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Background

The aim of this project was to develop data, information, and predictions on the remaining useful life expectancy and the corresponding pressure-carrying capacity of a 2" SDR 11 Aldyl-HD pipe material installed in a gas distribution system operated by PSE.

The following samples, as detailed in **Table 1**, were provided by the client. No further details of the samples were provided.

Table 1: Samples Submitted by PSE

Pipe Condition	Sample Description
Straight Pipe	10 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 03 80 PE3406 AF BE CD **P0316Q21** GAS *Manufactured at Pencader, DE on March 16, 1980*
	19 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 03 80 PE3406 AF BE CD **P0316Q31** GAS *Manufactured at Pencader, DE on March 16, 1980*
	25 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 03 80 PE3406 AF BE CD **P0318Q21** GAS *Manufactured at Pencader, DE on March 18, 1980*
	2 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 08 79 PE3406 AF BE CD **P0806P13** GAS *Manufactured at Pencader, DE on August 6, 1979*
	4 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 12 80 PE3406 AF BE CD **P1221Q11** GAS *Manufactured at Pencader, DE on December 21, 1980*
Squeeze-off Pipe	18 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 03 80 PE3406 AF BE CD **P0316Q21** GAS *Manufactured at Pencader, DE on March 16, 1980*
	7 pcs = ASTM D2513 2" IPS SDR11 DUPONT ALDYL®HD ROTA-SONIC INSPECTED 03 80 PE3406 AF BE CD **P0318Q21** GAS *Manufactured at Pencader, DE on March 18, 1980*

Discussion of Analytical Approach and Techniques

The submitted samples were assessed using the test method shown in **Table 2**.

Table 2. Test Methods Used

Test Method	Revision	Title
ASTM D2122	2008 (2010)	Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
ASTM D2513	2014e1	Standard Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings
PPI TN-16	2008	Rate Process Method for Projecting Performance of Polyethylene Piping Components
ASTM D1598	2002(2009)	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
DTMA	N/A	Dynamic Thermo-Mechanical Analysis

This laboratory maintains A2LA accreditation to ISO/IEC 17025 for specific tests listed in A2LA Certificates 2139-01 and 2139-04, and meets the relevant quality system requirements of ISO 9000:2008.

Description of Tests Employed

Dimensioning

Pipe specimens were conditioned and dimensioned in accordance with ASTM D2122. The pipe wall thickness at eight locations around each specimen and at both ends was measured. The outside diameter of each pipe specimen was measured by means of a circumferential wrap (Pi) tape.

Bend-back

Prior to initiation of hydrostatic pressure testing, bend-back testing was performed on five (5) specimens in accordance with ASTM D2513. Bend-back testing is used to qualitatively determine the presence of low inner pipe wall ductility and is most effective at detecting relatively large and relatively severe areas of the affected pipe wall. It is considered a macro material property test and is often employed in the field.

A ring of pipe with a minimum width of 1¼" was cut from a pipe specimen. The ring specimen was bent inside-out so that the pipe ID surface was on the outside surface of the bent specimen. The protruding reverse-bent ID surface was examined with unaided eye for signs of brittle cracking or crazing. Any indication of brittle cracking or crazing indicates failure.

Rate Process Method (RPM)

The RPM is a technique for forecasting the long term performance of polyethylene (PE) piping materials. The method requires hydrostatic pressure testing of pipe specimens at various pressures and temperatures. The hydrostatic pressure testing is carried in accordance with ASTM D1598. The pipe specimens are capped with free end type end closures, filled with deionized water, conditioned and tested in a water bath at various pressures (hoop stress levels). The failure data obtained at all temperatures are used to predict the performance of a pipe material at end-use temperature and pressure conditions.

RPM analysis was carried out by performing sustained hydrostatic pressure testing, at three different temperatures (73°F, 140°F, & 176°F), using the method described in ASTM D1598. Three pipe configurations were tested as follows:

1. As-Received (Control Pipe)
   A total of 40 specimens were tested at various stress levels and at three temperatures.

2. Indent Pipe
   An indentation jig was developed and used to simulate rock impingement on the pipe specimens. A total of 18 specimens were tested at various stress levels and at three temperatures. The indentation jig, as shown in **Figure 1**, was attached to each pipe specimen for the duration of testing.

3. Squeeze-off Pipe
   A total of 18 specimens that had been subjected to squeeze-off by PSE were tested at various stress levels and at three temperatures.

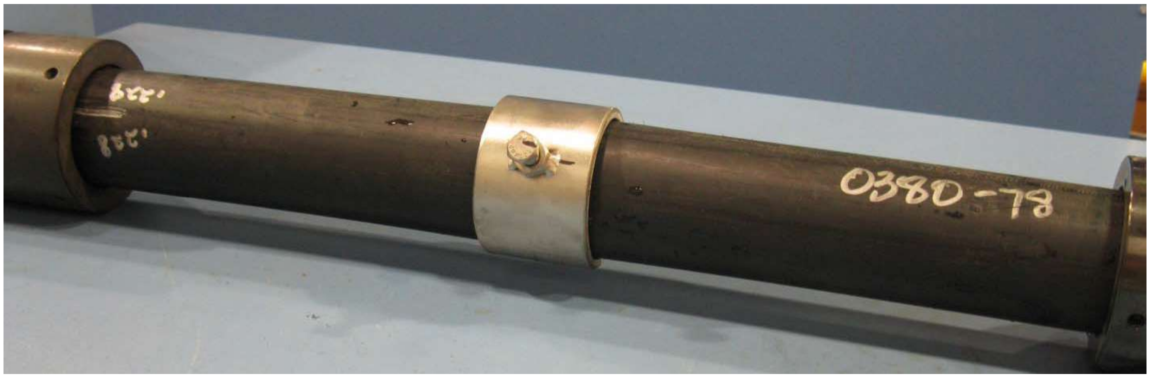

Figure 1. Indentation Jig attached to Pipe Specimen

Dynamic Thermo-Mechanical Analysis (DTMA)

DTMA utilizes a dynamic loading condition. It typically applies a sinusoidally oscillating load to the sample and measures the sample's response. This technique is very useful for measuring Storage Modulus (E'), Loss Modulus (E"), Loss Tangent (tan δ), or transitions that are hard to detect by other means. The vertical and horizontal activation energies for the Aldyl HD material were determined using the DTMA method. ASTM D638 Type V tensile bars were punched out of the pipe samples and tested at four temperatures (73°F, 104°F, 140°F, 176°F).

Test Results

Dimensioning

The dimensioning test results are incorporated in the hydrostatic pressure test results and are provided in **Appendix A**.

Bend-back Test

None of the specimens tested exhibited any signs of brittle cracking or crazing. Photographs of the tested specimens are provided in **Appendix A**.

RPM Analysis (Control Pipe)

The hydrostatic pressure test results are shown in **Figure 2**. Detailed test results together with selected photographs of tested specimens are provided in **Appendix A**.

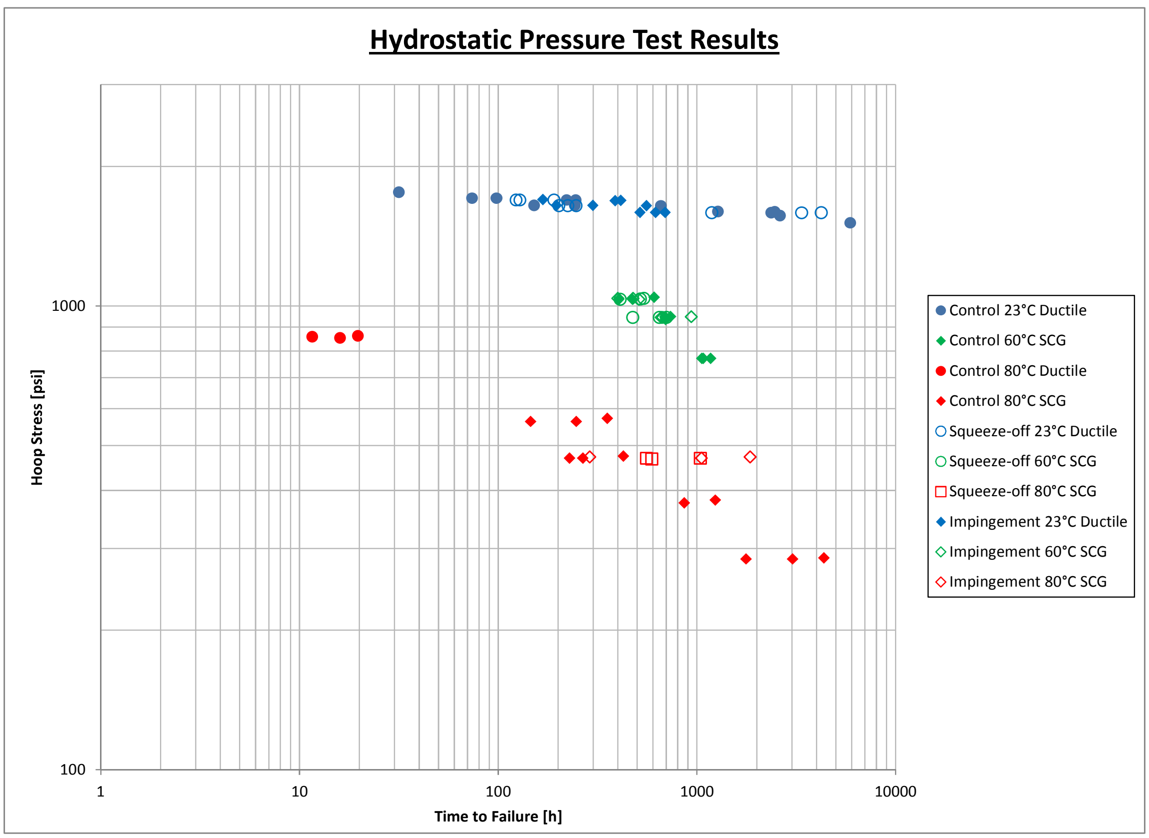

Figure 2. Hydrostatic Pressure Test Results

Using the hydrostatic pressure test results obtained for the Control samples, the three parameters for the following three-parameter RPM extrapolation equation were calculated:

$$\text{Log } t_f = C_1 + C_2/T + C4*\text{Log } S/T \qquad \textbf{Equation 1}$$

Where:

t_f = Time to failure (hours)
T = Absolute temperature (k)
S = Hoop stress (psi)
C_1 to C_4 = Regression parameters

The calculated model parameters and errors for the Ductile and Slow Crack Growth (SCG) failure modes are provided in **Table 3** and **Table 4**, respectively.

Table 3. Regression Model Parameters and Errors (Control Pipe - Ductile)

Parameters	C1	C2	C4	R^2	Adjusted R^2	Projected LPL HDB (psi)	Projected HDB (psi)
Value	-36.20	29,718	-5,667	0.89	0.87	1,048	1,233
Standard Error	3.62	3,203	682				

LPL: Lower Prediction Limit; HDB: Hydrostatic Design Basis

Table 4. Regression Model Parameters and Errors (Control Pipe - SCG)

Parameters	C1	C2	C4	R^2	Adjusted R^2	Projected LPL HDB (psi)	Projected HDB (psi)
Value	-16.55	9,737	-1,097	0.83	0.82	792	1,144
Standard Error	1.51	699	77				

LPL: Lower Prediction Limit; HDB: Hydrostatic Design Basis

Based on the regressions and models parameters the behavior of the material is consistent across the stress and temperature ranges tested, and the models are reasonable predictors of the average behavior of the material.

<u>RPM Analysis (Squeeze-off Pipe)</u>

The following numbers of specimens were tested:

- 9 at 73°F (23°C)
- 6 at 140°F (60°C)
- 3 at 176°F (80°C)

For all the nine (9) specimens that were tested at 73°F the failure location was at the squeeze-off point. The nine (9) specimens tested at 140°F and 176°F were all SCG failures of which only two failures were at the squeeze-off point.

The Squeeze-off pipe samples predominately failed at the squeezed location, however the failure times are comparable to the Control samples when tested at the same stress and temperature combination. This is unexpected. Our experience with Aldyl-A type materials indicate shorter failure times for both Squeeze-off and Indent pipes. It is puzzling that the squeezed pipes are failing how they are. Ductile failures were observed at a single temperature (73°F), therefore it was not possible to establish a RPM model for the ductile failure mode. Also, due to the limited number of SCG data points generated at 140°F and 176°F it was not possible to establish a RPM model for the SCG failure mode. However, the obtained test results were shifted to a reference temperature of 68°F (20°C) using Bi-Directional Shift Factors (BDSF) developed from DTMA testing. See next section for an explanation of the BDSF.

RPM Analysis (Indent Pipe)

The following numbers of specimens were tested:

- 9 at 73°F (23°C)
- 6 at 140°F (60°C)
- 3 at 176°F (80°C)

For all the nine (9) specimens that were tested at 73°F the failure location was not at the indentation point. The nine (9) specimens tested at 140°F and 176°F were all SCG failures of which only one failure, observed at 176°F, was at the indentation point.

Similar to the squeeze-off specimens, ductile failures were observed at a single temperature (73°F), therefore it was not possible to establish a RPM model for the ductile failure mode. Also, due to the limited number of SCG data points generated at 140°F and 176°F it was not possible to establish a RPM model for the SCG failure mode of the indent specimens. However, the obtained test results were shifted to a reference temperature of 68°F (20°C) using Bi-Directional Shift Factors (BDSF) developed from DTMA testing. See next section for an explanation of the BDSF.

Bi-Directional Shift Factors (BDSF)

Mavridis[1] provides a methodology to develop BDSF based on rheological principles. The test methodology employed is Dynamic Thermo-Mechanical Analysis (DTMA). Horizontal activation energies are calculated by fitting an Arrhenius type model to the tangent of the loss modulus as a function of excitation frequency and test temperature. The vertical activation energy is extracted from a model fitting the tangent of the loss modulus to the complex modulus as a function of excitation frequency and temperature. This method is very convenient as results can be generated in a few hours. The simplicity and low cost of the method enables us to test a sufficient number of replicates to generate statistical confidence limits on the calculated activation energies.

The Mavridis methodology fits an Arrhenius form yielding:

$$\textbf{Shift Factor} = \exp\left(\frac{\textbf{Activation Energy}}{R} * \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \qquad \textbf{Equation 2}$$

R – Boltzmann's Constant
T – Test Temperature [K]
T_{ref} – Reference Temperature [K]

Equation 2 is dependent on the difference between the inverse of the test temperature and the inverse of the reference temperature in degrees Kelvin.

The vertical and horizontal activation energies for the Aldyl-HD material were determined by means of performing DTMA testing. ASTM D638 Type V tensile bars were punched out of the pipe samples and tested at four temperatures (73°F, 104°F, 140°F, 176°F) and at multiple frequency sweeps.

The RPM test data for the Control pipe was shifted to 68°F (20°C) using the BDSF developed from DTMA testing, as shown in **Figure 3**.

1 Mavridis, H. and R. Shroff, Temperature dependence of polyolefin melt rheology. Polymer Engineering & Science, 1992. 32(23): p. 1778-1791.

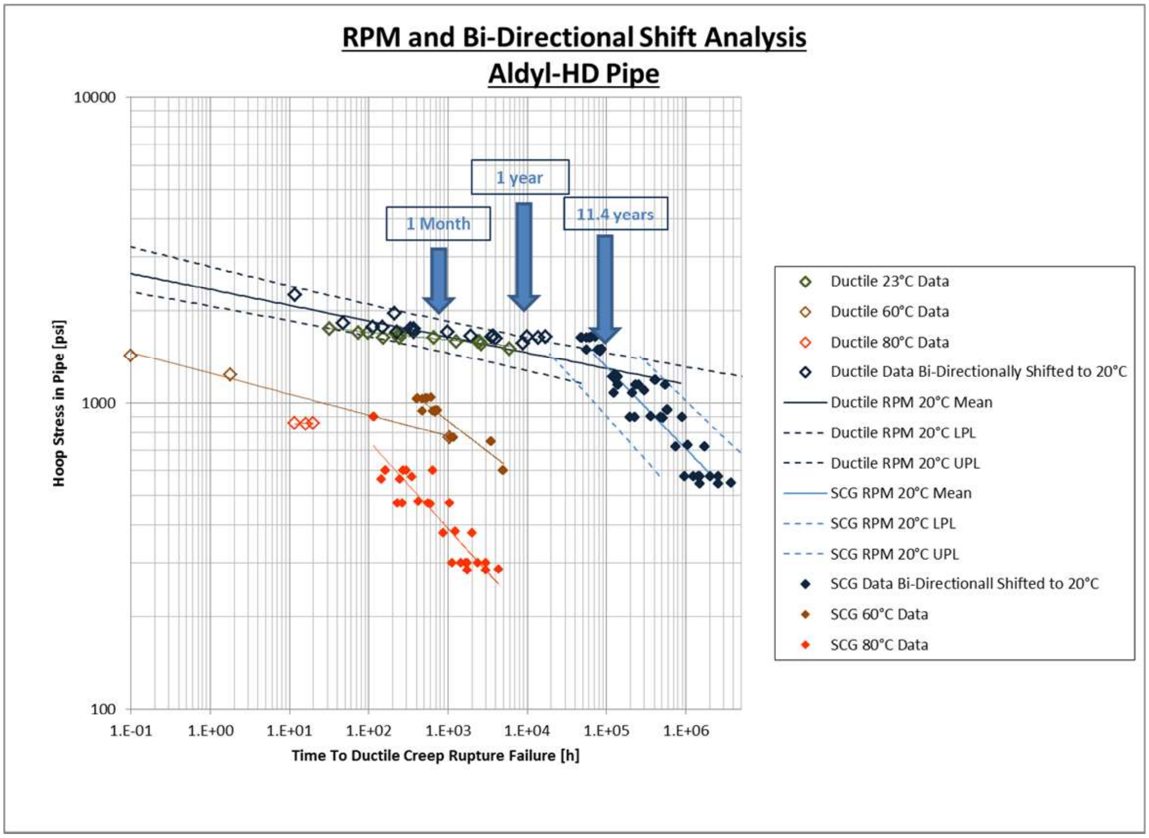

Figure 3. Control RPM Test Data Shifted to 68°F (20°C) using Bi-Directional Shift Factors

It can be seen that the bi-directionally shifted points are in excellent agreement with the RPM model, further strengthening our belief in the model as a reasonable predictor of average (mean) behavior of the material.

The RPM test data for the Squeeze-off and Indent pipes were also shifted to 68°F (20°C) using the BDSF developed from DTMA testing, as shown in **Figure 4**.

It can be seen that the bi-directionally shifted points are in good agreement with RPM model of the Control pipe indicating that there does not appear to be a discernable difference in performance of these pipes to that of the Control pipe. The open red circle shown in **Figure 4** is a shifted indent failure point that lies on top of a shifted squeeze-off failure point. This could be significant in that it indicates the stress intensification factors in the Squeeze-off and Indent pipe specimens are potentially of the same magnitude.

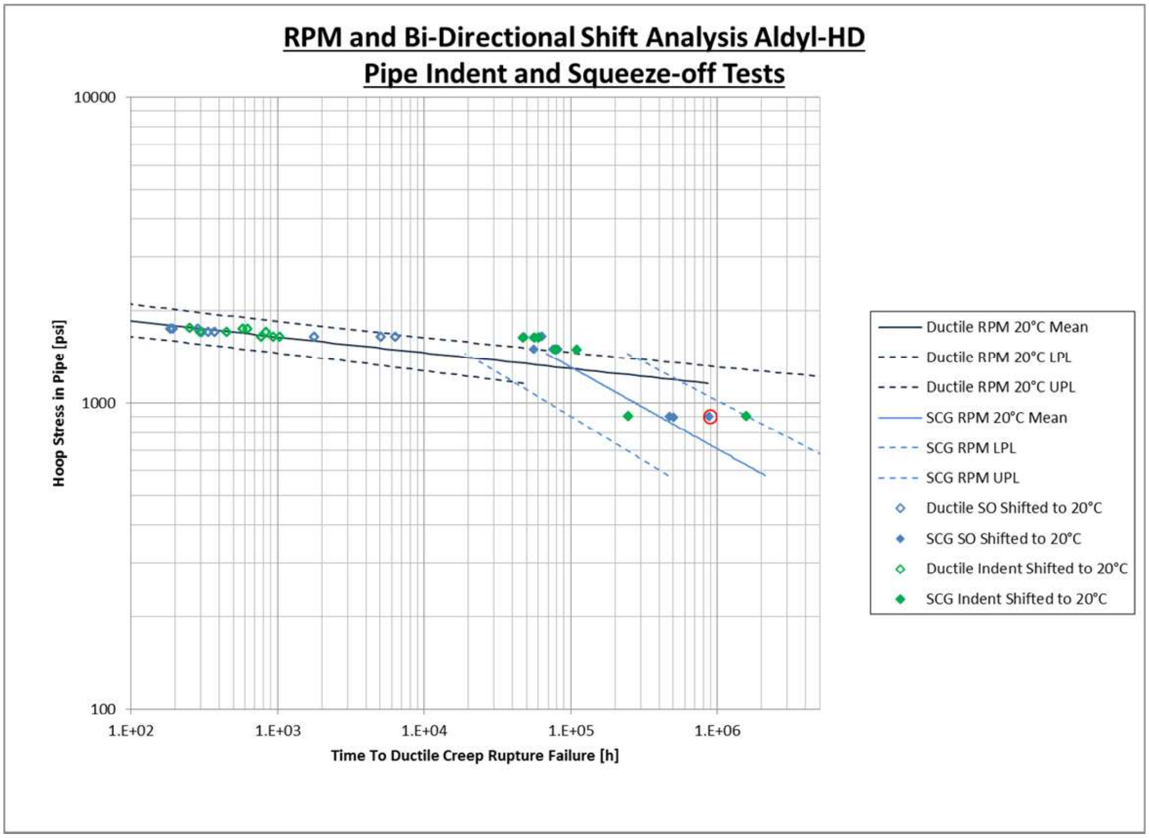

Figure 4. Squeeze-off & Indent RPM Test Data Shifted to 68°F (20°C) Using Bi-Directional Shift Factors

Lifetime Prediction

The BDSF can be used to set test pressures and temperatures to validate a specified service life expectancy or to shift an accelerated test result to the application temperature. For example a test conducted at 176°F (80°C) and a hoop stress of 470 psi fails in a brittle manner at 229 hours, shifts to an expected failure time of 22 years at a hoop stress of 903 psi at 68°F (20°C). In more meaningful terms; if a SDR 11 pipe were to be operating at 180 psig internal pressure it would have an average lifetime expectancy of 22 years. If the actual system operating pressure is 60 psig the implied factor of safety with respect to operating pressure and an expected lifetime of 22 years is 180/60 = 3. The typical stress risers encountered in a piping system are on average about 3. From this we can infer that a typical segment of pipe should last about 22 years at 68°F if the operating pressure is 60 psig and there are not any extreme stress risers impacting the system. The allowable stress risers include typical bend radii for installed pipe, typical fittings and typical butt-fusion joints. Squeeze-offs and impingement usually introduce stress risers above 3, possibly as high as 6. Reducing the operating pressure to 30 psig would increase the factor of safety to 6 and allow the operator to include squeeze-offs and some impingements in the lifetime expectancy of 22 years.

The RPM model can be used to predict the material behavior at any combination of pressure and temperature.

Based on the RPM model the 97.5% Lower Prediction Limit (LPL) expected lifetime in years, for a SDR 11 Aldyl-HD pipe at various end-use ground temperatures and operating pressures, are shown in the table below in **Table 5.**

Table 5. Lifetime Prediction at End-use Conditions

Temperature [°F]	Operating Pressure [psig]			Expected Lifetime Prediction - LPL (year)
	No Stress Riser	Allowable Stress Riser (Safety Factor = 3)	Extreme Stress Riser (Safety Factor = 6)	
40	180	60	30	> 100
42	180	60	30	> 100
45	180	60	30	> 100
47	180	60	30	73
50	180	60	30	56
52	180	60	30	47
55	180	60	30	36
57	180	60	30	30
60	180	60	30	23
62	180	60	30	19
65	180	60	30	15
67	180	60	30	13
70	180	60	30	10
72	180	60	30	8
75	180	60	30	6

At an average ground temperature of 57°F a pipe at a system operating pressure of 180 psig is expected to last 30 years. This calculated pressure reflects the material's 97.5% lower prediction limit capability. If the allowable system operating pressure is 60 psig we can say that the system has a safety factor of 180/60 = 3, with respect to a 60 psig operating pressure, 73°F and an expected lifetime of 30 years. From this we can infer that a typical segment of pipe should last about 30 years at 57°F if the operating pressure is 60 psig and there are not any extreme stress risers greater than 3 impacting the system. Squeeze-offs and impingement usually introduce stress risers above 3, possibly as high as 6. Reducing the operating pressure from 180 psig to 30 psig would increase the factor of safety to 6 and allow the operator to include squeeze-offs and some impingements in the lifetime expectancy of 30 years.

Additional calculations were made based on average ground temperatures ranging from 40-75°F and 5 psig pressure increments at each temperature. These are provided in a supplementary document.

Conclusions

Based on the samples provided and the testing and analysis performed in this project the following conclusions are made:

1. None of the specimens evaluated by bend-back testing exhibited any signs of brittle cracking or crazing. The results do not indicate any abnormal deterioration of the field-extracted pipe samples.

2. The testing performed in this project demonstrates that it is possible to extract Bi-Directional Shift Factors (BDSF) from Dynamic Thermo-Mechanical Analysis (DTMA) test data and that the predictions are in excellent agreement to those obtained by the more traditional RPM analysis.

3. The squeeze-off pipe samples predominately failed at the squeezed location, however the failure times are comparable to the Control samples when tested at the same stress and temperature.

4. Due to the limited number of data points generated for the Squeeze-off and Indent pipes it was not possible to establish RPM models for these samples, however, the obtained test results were shifted to a reference temperature of 68°F (20°C) using BDSF developed from DTMA testing. The bi-directionally shifted points are in good agreement with RPM model of the Control pipe indicating that there does not appear to be a discernable difference in performance of these pipes to that of the Control pipe.

5. Based on the RPM model the 97.5% Lower Prediction Limit (LPL) expected lifetime in years, for a SDR 11 Aldyl-HD pipe at various end-use ground temperatures and operating pressures, are shown in the table below.

Temperature [°F]	Operating Pressure [psig]			Expected Lifetime Prediction - LPL (year)
	No Stress Riser	Allowable Stress Riser (Safety Factor = 3)	Extreme Stress Riser (Safety Factor = 6)	
40	180	60	30	> 100
42	180	60	30	> 100
45	180	60	30	> 100
47	180	60	30	73
50	180	60	30	56
52	180	60	30	47
55	180	60	30	36
57	180	60	30	30
60	180	60	30	23
62	180	60	30	19
65	180	60	30	15
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Appendix A – Detailed Test Results and Selected Photographs of Tested Specimens

As-Received (Control Pipe)

1. Pipe Print Line: ASTM D2513 2" IPS SDR 11 DUPONT ALDYL HD ROTA-SONIC INSPECTED
2. Temperature of Test: 73°F ± 3.6°F (23°C ± 2°C)
3. The test environment inside/outside the specimen: Water/Water
4. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-011	0380-31	320	2.380	0.228	14.01.06	14.09.09	1510	5914.0	Ductile
131837-007	0380-67	330	2.381	0.227	14.01.06	14.04.25	1566	2622.0	Ductile
131837-049	0380-59	335	2.378	0.226	14.02.04	14.05.18	1595	2469.5	Ductile
131837-013	0380-33	340	2.380	0.230	14.01.24	14.05.03	1589	2367.7	Ductile
131837-042	0380-52	335	2.381	0.226	14.02.04	14.03.29	1597	1277.0	Ductile
131837-014	0380-34	350	2.380	0.229	14.01.07	14.02.03	1644	658.7	Ductile
131837-025	0380-76	355	2.379	0.226	14.02.11	14.02.21	1692	245.7	Ductile
131837-024	0380-75	349	2.379	0.228	14.02.21	14.03.03	1646	243.0	Ductile
131837-026	0380-77	355	2.380	0.226	14.02.11	14.02.20	1692	221.4	Ductile
131837-045	0380-55	349	2.379	0.228	14.02.21	14.02.27	1646	151.7	Ductile
131837-047	0380-57	360	2.380	0.227	14.02.03	14.02.07	1707	98.0	Ductile
131837-040	0380-50	360	2.379	0.227	14.02.03	14.02.06	1706	74.0	Ductile
131837-059	1280-3	360	2.380	0.221	13.20.30	13.12.31	1758	31.7	Ductile

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness

5. Temperature of Test: 140°F ± 3.6°F (60°C ± 2°C)
6. The test environment inside/outside the specimen: Water/Water

7. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-029	0380-80	161	2.379	0.225	14.02.17	14.04.07	771	1170.8	Slit
131837-044	0380-54	161	2.379	0.225	14.02.17	14.04.03	771	1074.4	Slit
131837-001	0380-26	160	2.381	0.227	13.12.20	14.02.02	770	1057.4	Ductile
131837-038	0380-48	200	2.380	0.227	14.02.03	14.03.06	949	736.7	Slit
131837-012	0380-32	200	2.380	0.230	13.12.23	14.01.21	935	696.1	Slit
131837-037	0380-47	200	2.379	0.227	14.01.30	14.02.28	948	691.6	Slit
131837-036	0380-46	220	2.380	0.227	14.01.30	14.02.25	1043	609.2	Slit
131837-018	0380-44	220	2.380	0.229	14.02.03	14.02.23	1033	473.2	Slit
131837-019	0380-45	220	2.380	0.229	14.01.30	14.02.16	1033	404.5	Slit
131837-008	0380-69	260	2.380	0.226	14.01.07	14.01.07	1239	1.8	Ductile
131837-003	0380-28	300	2.380	0.226	13.12.23	13.12.23	1430	0.1	Ductile
131837-002	0380-27	360	2.381	0.228	13.12.20	13.12.20	1700	0.03	Slit

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness

8. Temperature of Test: 176°F ± 3.6°F (80°C ± 2°C)
9. The test environment inside/outside the specimen: Water/Water

10. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-006	0380-64	60	2.381	0.226	14.01.06	14.07.06	286	4347.7	Slit
131837-016	0380-36	60	2.380	0.227	14.02.03	14.06.09	285	3024.7	Slit
131837-020	0380-65	80	2.380	0.229	14.01.07	14.04.01	376	2017.7	Slit
131837-015	0380-35	60	2.380	0.227	14.02.03	14.04.18	285	1770.7	Slit
131837-039	0380-49	80	2.380	0.226	14.02.03	14.03.26	381	1237.5	Slit
131837-017	0380-37	80	2.381	0.229	14.02.03	14.03.11	376	864.7	Slit
131837-023	0380-74	100	2.380	0.227	14.02.05	14.02.23	474	425.7	Slit
131837-005	0380-30	120	2.381	0.226	14.01.08	14.01.23	572	353.6	Slit
131837-050	0380-60	100	2.380	0.229	14.02.05	14.02.16	470	266.3	Slit
131837-048	0380-58	120	2.380	0.229	14.02.06	14.02.16	564	247.0	Slit
131837-046	0380-56	100	2.380	0.229	14.01.07	14.01.17	470	228.8	Slit
131837-053	0380-63	120	2.380	0.229	14.02.06	14.02.12	564	145.4	Slit
131837-022	0380-73	180	2.379	0.225	14.02.10	14.02.11	862	19.7	Ductile
131837-021	0380-72	180	2.379	0.227	14.02.10	14.02.11	853	16.0	Ductile
131837-009	0380-70	180	2.381	0.226	14.01.06	14.01.06	858	11.6	Ductile

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness

Ductile Failure in Specimen 131837-025 (0380-76) Tested at 73°F/355 psig

Slit Failure in Specimen 131837-036 (0380-46) Tested at 140°F/220 psig

Slit Failure in Specimen 131837-005 (0380-30) Tested at 176°F/120 psig

Squeeze-off Pipe

1. Pipe Print Line: ASTM D2513 2" IPS SDR 11 DUPONT ALDYL HD ROTA-SONIC INSPECTED
2. Temperature of Test: 73°F ± 3.6°F (23°C ± 2°C)
3. The test environment inside/outside the specimen: Water/Water
4. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-075	0380-22SQ	335	2.380	0.227	14.02.25	14.08.20	1589	4221.5	Ductile*
131837-074	0380-20SQ	335	2.379	0.227	14.02.25	14.07.15	1588	3370.1	Ductile*
131837-084	0380-19SQ	335	2.380	0.227	14.02.25	14.04.16	1589	1188.8	Ductile*
131837-076	0380-23SQ	345	2.381	0.226	14.03.04	14.03.14	1645	246.6	Ductile*
131837-078	0380-25SQ	345	2.381	0.226	14.03.04	14.03.13	1645	224.1	Ductile*
131837-067	0380-11SQ	345	2.381	0.226	14.03.04	14.03.12	1645	202.0	Ductile*
131837-066	0380-06SQ	355	2.380	0.226	14.03.15	14.03.23	1692	190.9	Ductile*
131837-085	0380-21SQ	355	2.380	0.226	14.03.15	14.03.20	1692	128.8	Ductile*
131837-083	0380-14SQ	355	2.380	0.226	14.03.15	14.03.20	1692	123.0	Ductile*

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is at the squeeze-off point

5. Temperature of Test: 140°F ± 3.6°F (60°C ± 2°C)
6. The test environment inside/outside the specimen: Water/Water

7. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-080	0380-8SQ	200	2.380	0.228	14.02.21	14.03.22	944	702.4	Slit
131837-072	0380-17SQ	200	2.380	0.228	14.02.21	14.03.20	944	647.3	Slit
131837-079	0380-7SQ	219	2.380	0.227	14.02.21	14.03.16	1039	540.7	Slit
131837-081	0380-18SQ	219	2.381	0.228	14.02.21	14.03.15	1034	519.8	Slit
131837-065	0380-5SQ	200	2.381	0.228	14.02.21	14.03.13	944	475.6	Slit
131837-073	0380-9SQ	219	2.380	0.228	14.02.26	14.03.15	1034	411.5	Slit*

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is at the squeeze-off point

8. Temperature of Test: 176°F ± 3.6°F (80°C ± 2°C)
9. The test environment inside/outside the specimen: Water/Water
10. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-082	0380-10SQ	98	2.381	0.225	14.02.19	14.04.03	470	1040.6	Slit*
131837-061	0380-1SQ	98	2.381	0.226	14.02.26	14.03.23	467	593.4	Slit
131837-062	0380-2SQ	98	2.381	0.225	14.02.19	14.03.14	470	556.3	Slit

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is at the squeeze-off point

Ductile Failure in Specimen 131837-066 (0380-6SQ) Tested at 73°F/355 psig

Slit Failure in Specimen 131837-080 (0380-8SQ) Tested at 140°F/200 psig

Slit Failure in Specimen 131837-061 (0380-1SQ) Tested at 176°F/98 psig

Indent Pipe

1. Pipe Print Line: ASTM D2513 2" IPS SDR 11 DUPONT ALDYL HD ROTA-SONIC INSPECTED
2. Temperature of Test: 73°F ± 3.6°F (23°C ± 2°C)
3. The test environment inside/outside the specimen: Water/Water
4. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-054	0380-81	337	2.380	0.228	14.07.02	14.07.31	1590	691.2	Ductile*
131837-041	0380-51	337	2.380	0.228	14.07.02	14.07.28	1590	619.8	Ductile*
131837-004	0380-29	347	2.380	0.227	14.07.29	14.08.21	1646	556.7	Ductile*
131837-052	0380-62	337	2.380	0.228	14.07.02	14.07.24	1590	516.8	Ductile*
131837-055	0879-1	349	2.380	0.223	14.07.29	14.08.15	1688	413.7	Ductile*
131837-057	1280-1	352	2.380	0.225	14.07.29	14.08.14	1686	387.1	Ductile*
131837-058	1280-2	344	2.380	0.225	14.07.29	14.08.11	1647	299.4	Ductile*
131837-010	0380-71	347	2.381	0.227	14.07.29	14.08.06	1646	196.1	Ductile*
131837-056	0879-2	347	2.380	0.221	14.07.29	14.08.05	1695	167.9	Ductile*

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is not at the impinged point

5. Temperature of Test: 140°F ± 3.6°F (60°C ± 2°C)
6. The test environment inside/outside the specimen: Water/Water

7. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-031	0380-39	201	2.379	0.228	14.06.25	14.08.03	948	938.2	Slit*
131837-033	0380-41	201	2.380	0.229	14.06.25	14.07.23	944	672.4	Slit*
131837-032	0380-40	201	2.379	0.229	14.06.25	14.07.23	944	661.8	Slit*
131837-035	0380-43	220	2.380	0.229	14.06.25	14.07.16	1033	510.3	Slit*
131837-027	0380-78	220	2.380	0.228	14.06.25	14.07.15	1038	476.0	Slit*
131837-028	0380-79	220	2.380	0.228	14.06.25	14.07.12	1038	399.6	Slit*

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is not at the impinged point

8. Temperature of Test: 176°F ± 3.6°F (80°C ± 2°C)
9. The test environment inside/outside the specimen: Water/Water
10. Time-to-Failure/Stress Data:

GTI Specimen ID	PSE Specimen ID	Test Pressure (psig)	OD_{Avg} (inch)	t_{Min} (inch)	Start YY.MM.DD	End YY.MM.DD	Hoop Stress (psi)	Total Hours	Failure Mode
131837-034	0380-42	100	2.380	0.228	14.07.02	14.09.17	472	1854.4	Slit*
131837-030	0380-38	100	2.380	0.229	14.07.02	14.08.15	470	1054.0	Slit†
131837-051	0380-61	100	2.380	0.228	14.07.02	14.07.14	472	288.8	Slit*

Legend: OD_{Avg} = Average Outside Diameter; t_{Min} = Minimum Wall Thickness, * Failure location is not at the impinged point
† Failure location is at the impinged point

Ductile Failure in Specimen 131837-054 (0380-81) Tested at 73°F/337 psig

Slit Failure in Specimen 131837-027 (0380-78) Tested at 140°F/220 psig

Slit Failure in Specimen 131837-051 (0380-61) Tested at 176°F/100 psig

Appendix B – Photographs of Specimens undergone Bend-back Testing


PSE Specimen 0380-35


PSE Specimen 0380-71


PSE Specimen 0380-81


PSE Specimen 0879-2


PSE Specimen 1280-1

End of Report