JANA

KNOWLEDGE • VALUES • SUCCESS

PROJECT 09-1176
FINAL REPORT

Failure Analysis of PE Gas Pipe

October 6, 2009

Executive Summary

The purpose of this project was to determine the root cause of an in-service fracture in a sample of Aldyl A Polyethylene (PE) gas pipe. The sample had been in service as natural gas distribution piping.

The physical properties of the pipe sample were consistent with expectations for this Aldyl A material. There was no indication that any measured property was unacceptable or unusual.

The pipe sample showed clear macroscopic evidence of external impingement from hard irregular objects (such as rocks) in two places. After opening the pipe to allow examination of the inside surfaces, it was apparent that each impingement location was also the site of a crack which had initiated at the inside surface of the pipe. One of these cracks had developed into a through-wall fracture and constituted in-service failure of the pipe. The other was a partial-wall fracture at the time the pipe was removed from service. If the pipe had not been removed from service due to the first leak, partial crack at the second impingement site would have eventually propagated through the remainder of the wall.

Examination of the fracture surface of the through-wall crack showed it to be consistent with Slow Crack Growth (SCG). There is some evidence of micro-ductility, there is clear wall deformation due to apparent impingement, and there is no macro-ductility evident except at the inside and outside surfaces. The fracture initiated at the inside surface where the outside of the pipe was indented. These are all features associated with SCG fracturing of PE pipe initiated by external rock impingement.

Therefore, the fracture of the sample was caused by impingement from bedding material such as rocks. The elevated local stress in this area from the impingement caused a crack to initiate at the inside surface. This crack then propagated by SCG from the inside surface outward. When this crack reached the outside surface leaking occurred.

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

Report No.: Project 09-1176 – Final Report

Distribution:

David Lykken & Al Jones
Washington Utilities and Transportation Commission
P.O. Box 47250
Olympia, WA 98504
U.S.A.

Don Stone
Paine Hamblen
Washington Trust Financial Centre
717 W. Sprague Suite 1200U
Spokane, WA 99201
U.S.A.

Mike Faulkenberry
Avista Utilities
P.O. Box 3727 MSC 24
Spokane, WA 99220
U.S.A.

Date of Issue: October 6, 2009

1.0 Purpose of Test

The purpose of this project was to determine the root cause of an in-service fracture in a sample of Aldyl A Polyethylene (PE) gas pipe.

2.0 Test Item Identification and Description

The sample listed in Table 1 was received from the Client. The sample had been in service as natural gas distribution piping.

Table 1: Sample Description

Jana Sample ID	Description	Print Line
09-504	Failed 2" diameter PE Aldyl A pipe, 60 inches long, with 3" axial crack circled	2" IPS SDR 11 DUPONT ALDYL A ROTA-SONIC INSPECTED 04 81 PE2306 AF(B or R) FCD TO410R12 ASTM D2513

3.0 Test Methods

- Dimensioning was performed in general accordance with ASTM D2122-98 (2004).
- Melt Index testing was performed in accordance with ASTM D1238-04c.
- Density was determined in accordance with ASTM D792-08.
- Resistance to Slow Crack Growth (SCG) was determined in accordance with ASTM F1473-07 at 80°C and 2.4 MPa load.
- Ash Content was determined in accordance with ASTM D5630-06 Procedure B.
- Surface Embrittlement was evaluated by the Bend Back test of ASTM D2513-09 Section A1.5.10.1.

The sample was visually examined by eye and optical microscopy, and was photographed macroscopically and microscopically.

Testing to ASTM D2122, ASTM F1473, and ASTM D2513 is covered by the scope of Jana's ISO 17025 accreditation (I.A.S. TL-256). Density, Ash Content, and Melt Index tests were performed at an approved subcontract laboratory.

4.0 Test Details

Dimensioning was performed in general accordance with ASTM D2122 to determine the average outside diameter and minimum wall thickness.

Density was determined in accordance with ASTM D792 Method A at 70.2°F.

Melt Index testing was performed in accordance with ASTM D1238-04c, Condition 190/2.16, in triplicate, on specimens taken from the mid-wall portion of the sample.

Resistance to Slow Crack Growth (SCG) was determined in accordance with ASTM F1473-07 at 80°C and 2.4 MPa load. Two specimens were tested, machined from a plaque compression-molded in accordance with the method.

Ash Content was determined in accordance with ASTM D5630-06 Procedure B.

Inside Surface Embrittlement was evaluated by the Bend Back test of ASTM D2513-09 Section A1.5.10.1 on two specimens. A similar test was performed to evaluate Outside Surface Embrittlement with the direction of bending reversed.

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

5.0 Results

Table 2: Sample 09-504 Test Results

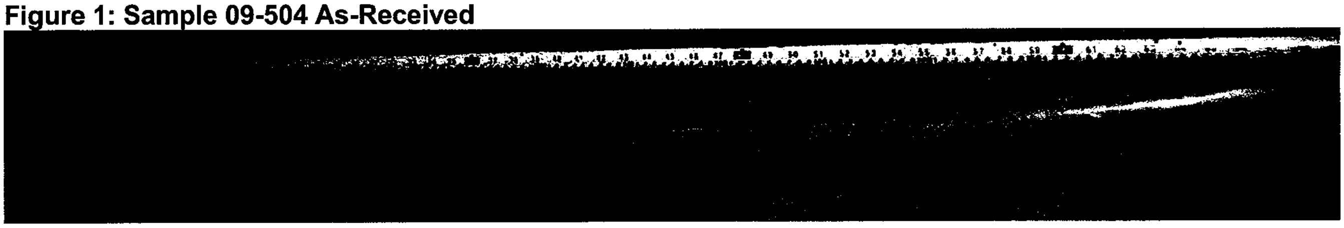
Property	ASTM Test Method	Units	Results		
			Average	Standard Deviation	Number of Specimens
Average Outside Diameter	D2122	inches	2.374*	0.001	4
Average Wall Thickness	D2122	inches	0.232*	0.003	4
Minimum Wall Thickness	D2122	inches	0.227*	Not Applicable	4
Density	D792	g/cm^3	0.944	0.001	2
SCG by PENT	D1473	Hour	0.4	0	2
Melt Index	D1238	g/10 min	1.137	0.040	3
Ash Content	D5630	% by weight	0.56	0.01	2
Inside Surface Ductility	D2513	Not Applicable	Pass	Not Applicable	2
Outside Surface Ductility	D2513	Not Applicable	Pass	Not Applicable	2

* The measured dimensions comply with the requirements of all editions of ASTM D2513

6.0 Observations

The sample was examined as-received. Figure 1 is a photograph of the sample as-received.

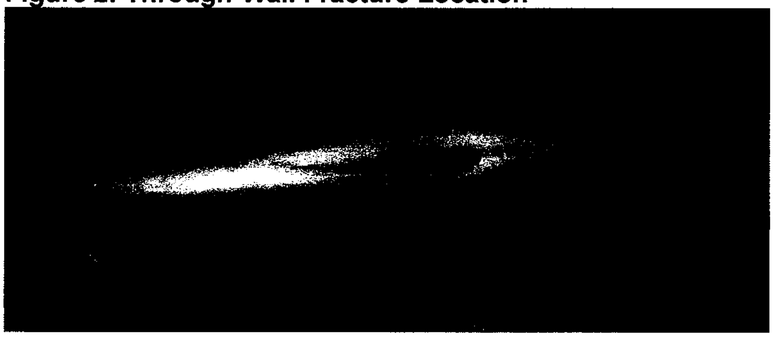
Figure 1: Sample 09-504 As-Received



Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

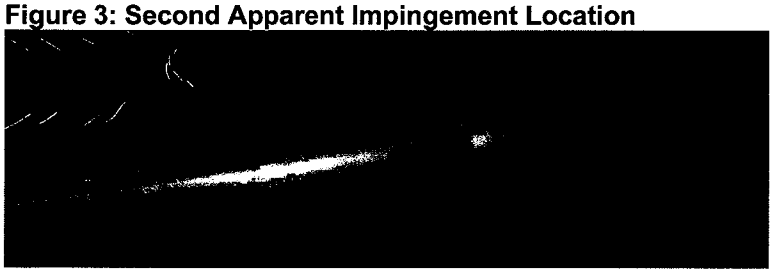
The sample had one through-wall slit-type fracture apparent when examined from the outside of the pipe (marked on pipe with black oval). The sample also displayed evidence of external impingement in two locations, one of which was generally coincident with the fracture. A closer view of the through-wall fracture as viewed external to the pipe is provided in Figure 2.

Figure 2: Through-Wall Fracture Location



A second area of apparent external impingement was visible as shown in Figure 3.

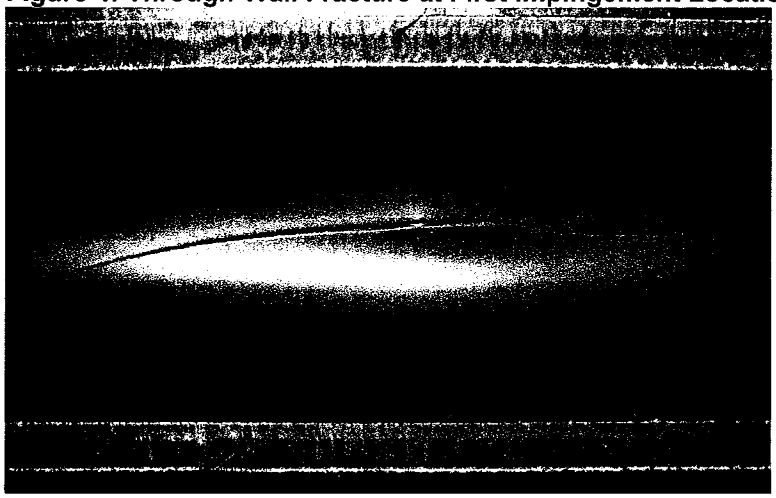
Figure 3: Second Apparent Impingement Location



The sample was examined further by bisecting the pipe into half-round sections and inspecting the inside surfaces. The appearance of the full-wall fracture coincident with the first impingement location is shown in Figure 4.

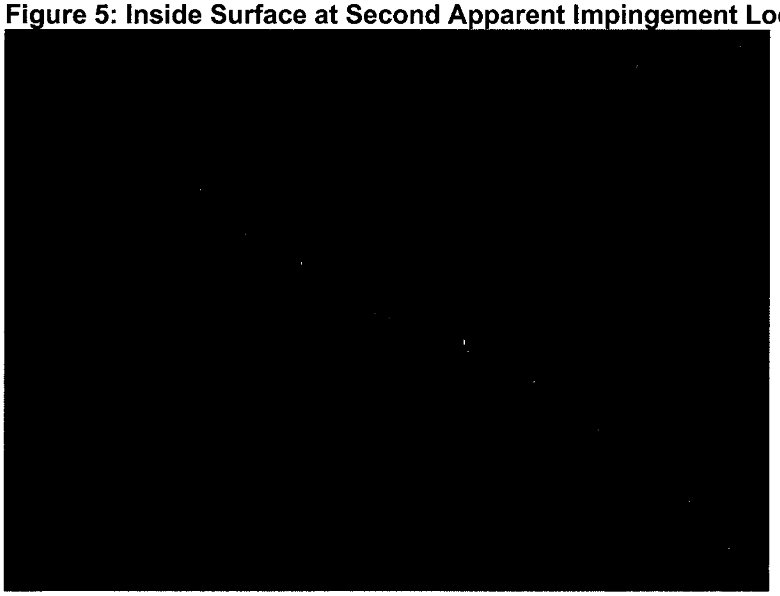
Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

Figure 4: Through-Wall Fracture at First Impingement Location



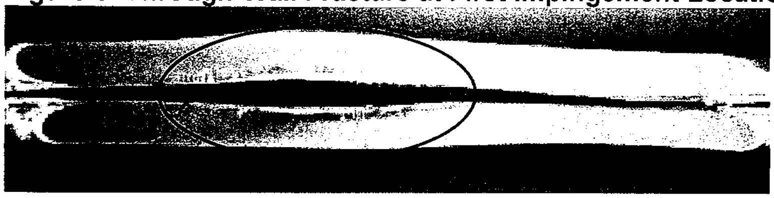
A partial fracture (not extending entirely through the wall thickness) was visible coincident with the second apparent impingement location. This partial fracture at the inside surface is shown in a 20X close-up obtained using optical microscopy as Figure 5.

Figure 5: Inside Surface at Second Apparent Impingement Location 20X



The through wall fracture (the leak) was opened for further examination by cutting out the fractured portion and bending the pipe to open the fracture from inside out. The full fracture surfaces are shown in Figure 6, with the inside surfaces of the pipe at the top and bottom, and the outside surfaces adjacent to one another at the center. The general area of external impingement as well as the area of crack initiation are shown by the black oval.

Figure 6: Through-Wall Fracture at First Impingement Location



One of the fracture surfaces is shown in detailed view in Figures 7 and 8. Figure 7 is a photograph of the full fracture surface taken by optical microscopy at 7X magnification. The inside surface is indicated by the arrows, with the center arrow indicating the area of fracture initiation.

Figure 7: Fracture Surface at Impingement Location - 7X

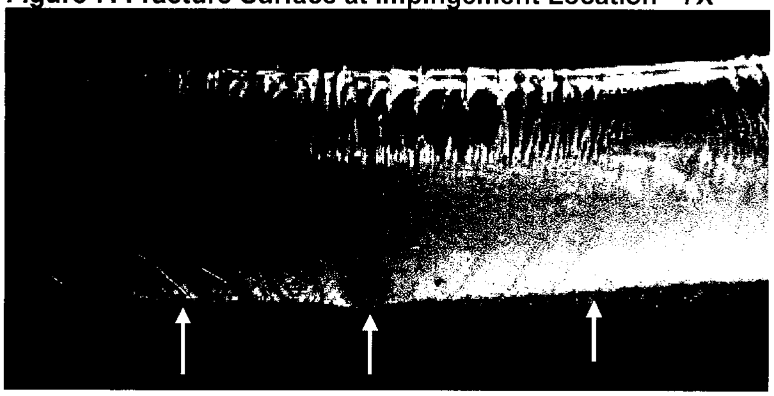
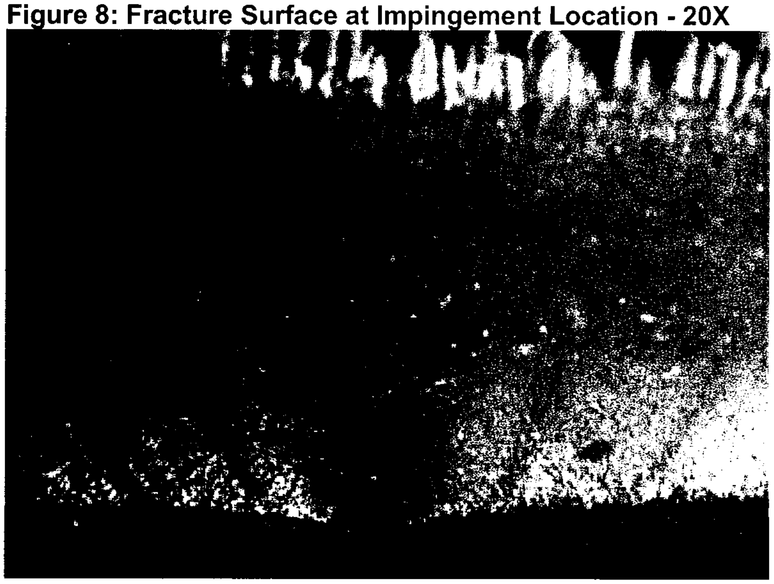


Figure 8 shows the area of fracture initiation at 20X magnification. The characteristics of the fracture surface are typical of SCG initiated at the inside surface due to external rock impingement.

Figure 8: Fracture Surface at Impingement Location - 20X



Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

7.0 Discussion and Conclusions

The physical properties of the pipe sample were consistent with expectations for this Aldyl A material. There was no indication that any measured property was unacceptable.

The pipe sample showed clear macroscopic evidence of external impingement from hard irregular objects (such as rocks) in two places. After opening the pipe to allow examination of the inside surfaces, it was apparent that each impingement location was also the site of a crack which had initiated at the inside surface of the pipe. One of these cracks had developed into a through-wall fracture and constituted in-service failure of the pipe. The other was a partial-wall fracture at the time the pipe was removed from service. If the pipe had not been removed from service due to the first leak, partial crack at the second impingement site would have eventually propagated through the remainder of the wall.

Examination of the fracture surface of the through-wall crack showed it to be consistent with SCG. There is some evidence of micro-ductility, there is clear wall deformation due to apparent impingement, and there is no macro-ductility evident except at the inside and outside surfaces. The fracture initiated at the inside surface where the outside of the pipe was indented. These are all features associated with SCG fracturing of PE pipe initiated by external rock impingement.

Therefore, the fracture of the sample was caused by impingement from bedding material such as rocks. The elevated local stress in this area from the impingement caused a crack to initiate at the inside surface. This crack then propagated by Slow Crack Growth (SCG) from the inside surface outward. When this crack reached the outside surface leaking occurred.

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

Issued by

David Woods, B.Sc.
Senior Project Leader

Reviewed by

Sarah Chung, M.A.Sc., P.Eng.
Senior Project Leader

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

Appendix A
Test Details

Density, PENT, Melt Index and Ash Test Results

Property	ASTM Test Method	Units	Results			
			Specimen 1	Specimen 2	Specimen 3	Average
Ash Content	D5630	% by weight	0.55	0.56	-	0.55
		ppm	5,540	5,560	-	5,550
PENT	F1473 2.4 MPa	hour	0.4	0.4	-	
Melt Index	D1238 A	g/10 minutes	1.130	1.100	1.180	1.137
Density	D792	g/cm^3	0.944	0.943	-	0.944

Dimensions

Specimen 09-504-01	Wall Thickness	OD	Out-of-Roundness
1	0.231	2.374	
2	0.227	2.374	
3	0.231	2.373	
4	0.235		
5	0.231		
6	0.232		
7	0.233		
8	0.234		
Average	**0.232**	**2.374**	**0.00**
Minimum	**0.227**		
Maximum	**0.235**		
09-504-01 Retest			
1	0.231	2.375	
2	0.234	2.374	
3	0.231	2.374	
4	0.233		
5	0.234		
6	0.235		
7	0.233		
8	0.228		
9	0.228		
Average	**0.232**	2.374	0.00
Minimum	**0.228**		
Maximum	**0.235**		

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com

Specimen 09-504-02	Wall Thickness	OD	Out-of-Roundness
1	0.229	2.374	
2	0.235	2.374	
3	0.236	2.374	
4	0.232		
5	0.230		
6	0.233		
7	0.233		
8	0.229		
9	0.227		
Average	**0.232**	**2.374**	**0.00**
Minimum	**0.227**		
Maximum	**0.236**		
09-504-02 Retest			
1	0.230	2.375	
2	0.230	2.374	
3	0.235	2.374	
4	0.236		
5	0.233		
6	0.230		
7	0.233		
8	0.233		
9	0.229		
Average	**0.232**	**2.374**	**0.00**
Minimum	**0.229**		
Maximum	**0.236**		

Jana Laboratories Inc. 280B Industrial Pkwy S. Aurora, Ontario L4G 3T9 Ph: 905-726-8550 Fax: 905-726-8609 www.janalab.com