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May 28, 2008

Patricia Van Gerpen
500 E. Capitol Ave
Pierre, SD 57501

VIA ELECTRONIC FILING ONLY

Re: PS07-002

Dear Ms. Van Gerpen:

Enclosed for filing please find the report created by South Dakota Pipeline Safety Staff's expert, Dr. Kiefner. The report presents detailed findings of the investigation of the natural gas pipeline incident of March 8, 2007.

Sincerely,

Kara Semmler

South Dakota Public Utilities Commission

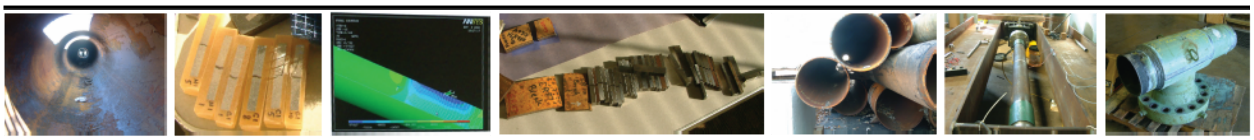
Final Report No. 08-016

Final Report

Investigation of the Natural Gas Pipeline Incident of March 8, 2007, in Mitchell South Dakota

John F. Kiefner, Ph. D., PE.

February 22, 2008



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0474-0701

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Investigation of the Natural Gas Pipeline Incident of March 8, 2007 in Mitchell South Dakota

John F. Kiefner, Ph. D., PE.

EXECUTIVE SUMMARY

This report presents the findings of an investigation of the natural gas pipeline incident of March 8, 2007 in Mitchell, South Dakota (Commission Docket: PS07-002). The incident involved release of gas from a partial-circumference crack on the bottom of a 2-3/8 inch diameter gas pipeline. The author was retained by the South Dakota Public Utilities Commission to arrange for appropriate testing and examination of the piece of pipe involved in the incident, to monitor such testing and examination, and to prepare this report of the findings. The goals of the investigation were:

a. Identification of any pipe defects.
b. Identify whether corrosion was an issue.
c. Determine whether there was any pre-cracking.
d. Identify the type of pipe.
e. Determine cause of failure.

The incident involved a failure of the pipe in the form of a circumferential crack. The crack was found to have propagated through the lower three-quarters of the circumference of the pipe before arresting.

The only defects found on the subject pipe were the result of mechanical impacts on the pipe. The circumferentially oriented crack initiated within a circumferentially oriented mechanically created gouge located on the bottom of the pipe. The crack appears to have occurred in one stage as a brittle fracture. There was no evidence of any pre-existing crack.

No evidence of external corrosion-caused metal loss was found on the pipe, and other evidence points to the high probability that the pipe was adequately protected from external corrosion. The pipe appears to be furnace butt-welded pipe, a type of pipe that could have been manufactured in accord with the API Specification 5L prior to 1963. The tensile and chemical

properties of the pipe met or exceeded those required by the API specification for line pipe in effect at the time the pipe was manufactured (mid-1950s). The cause of failure is mechanical damage inflicted on the pipe at some time in the past by an unknown piece of equipment.

The author is grateful for the diligent work of Mr. Dick Kielty of Stork Twin City Testing Corporation. His willingness to accommodate the requests of the author and the stakeholders made possible the achievement of the objectives in a short space of time. Dick provided many of the photographs that are contained in this report. The stand-alone Stork report, compiled by Dick, was made available to all stakeholders, and the author relied heavily on it to prepare the within report. The author is also indebted to Mr. Martin Bettmann and Mr. Nathan Solem, both staff employees of the South Dakota Public Utilities Commission, who provided photographs taken during various stages of the investigation of the incident.

INTRODUCTION

This report presents the findings of the investigation of the natural gas pipeline incident of March 8, 2007 in Mitchell, South Dakota (Commission Docket: PS07-002). The author was retained by the South Dakota Public Utilities Commission to arrange for appropriate testing and examination of the piece of pipe involved in the incident, to monitor such testing and examination, and to prepare this report of the findings. The goals of the investigation were:

f. Identification of any pipe defects.
g. Identify whether corrosion was an issue.
h. Determine whether there was any pre-cracking.
i. Identify the type of pipe.
j. Determine cause of failure.

The subject pipe involved in the investigation was a 51-inch-long length of 2-3/8” OD natural gas main containing a circumferential crack. According to factual information provided by the South Dakota Public Utilities Commission, the pipe was removed from Northwestern Energy’s distribution system in front of the house at 1612 Bridle Drive, Mitchell, South Dakota. The section of main was removed from that location on March 8, 2007 following an explosion and fire resulting in damages estimated to be less than $500,000.00.

EXAMINATION OF THE PIPE

On-site Investigation

Although the author did not see the pipe as it existed in the ditch after the incident, photographs of the pipe were provided that had been taken by a staff employee of the South Dakota PUC. The pipe as it appeared upon being exposed after the incident is shown in Figure 1.

Figure 1. Pipe as initially exposed after the incident

The dark-colored area in the center corresponds to the location of the leak. Upon removal of the piece containing the leak, it was found that the pipe contained a circumferentially oriented crack as shown in Figure 2. The crack is not visible in Figure 1 because it was located on the bottom portion of the pipe.

The piece containing the crack was held in storage until various stakeholders were able to agree on a protocol for examining and testing the pipe. Stakeholders included Northwestern Energy (the owner of the gas main facility), the South Dakota Public Utilities Commission, and other parties that have an interest in determining the cause of the incident.

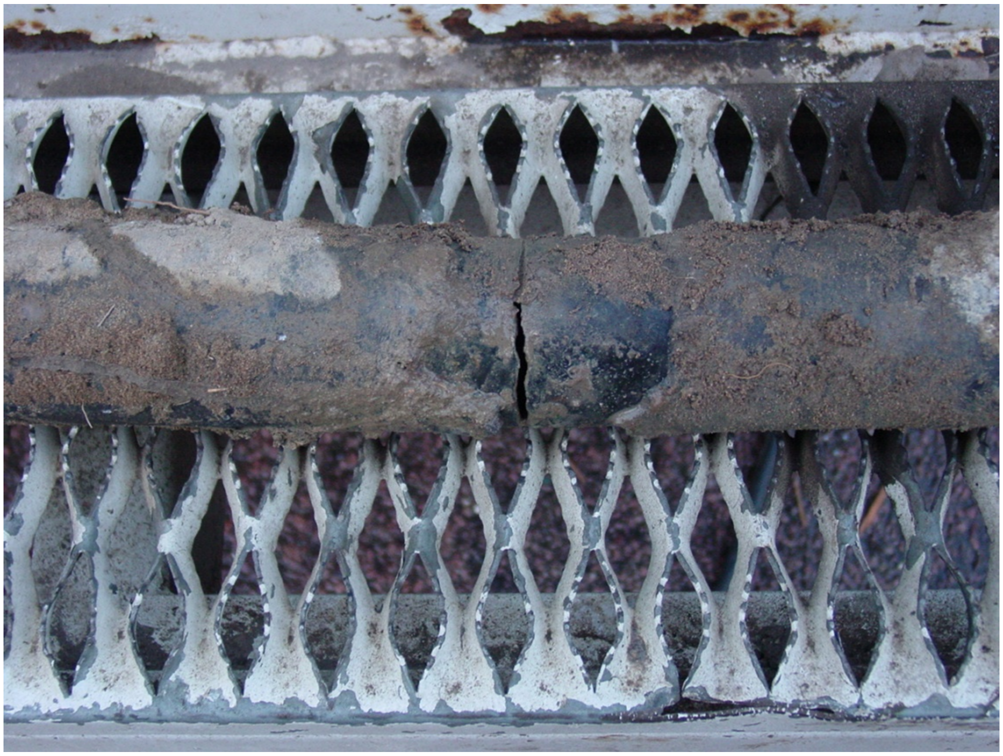

Figure 2. Circumferentially oriented crack in the pipe

Protocol for Examining and Testing the Pipe

The "Test Protocol" agreed upon by the stakeholders is presented in Appendix A. The stakeholders agreed to have the examination and testing conducted at Stork Twin City Testing Corporation (Stork) in St. Paul, MN. Representatives of the various stakeholders (see list in Appendix B) met at Stork on January 16 and 17, 2008 to observe the testing and examination of the pipe.

Visual Examination and Sample Collection

According the test protocol, the pipe was photographed and given a coordinate system for the purpose of locating important features. As shown in Figures 3 and 4, the piece arrived at Stork in the condition that it had existed upon its removal from the pipeline. Except for the immediate region of the circumferential crack, the pipe is coated with its original anti-corrosion coating and a fair amount of soil. Prior to the start of any alterations of the pipe, samples of soil, coating, and deposits were obtained by means of scrapings as illustrated in Figure 5.

Figure 3. Pipe as received at Stork oriented bottom-side up

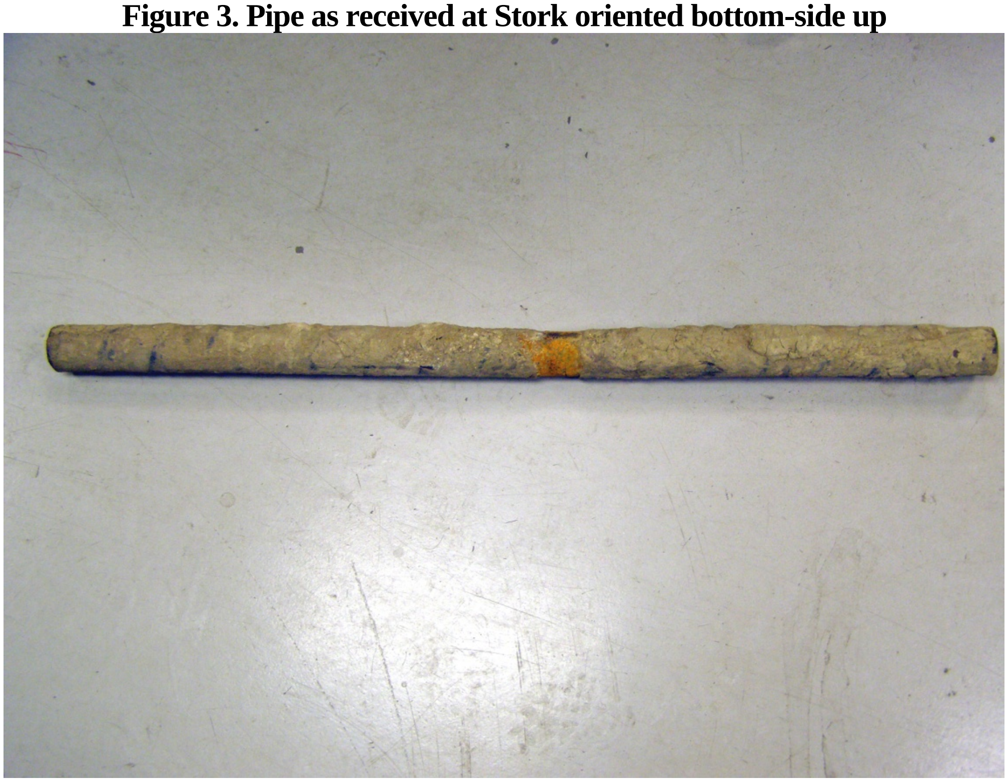

Figure 4. Pipe as received at Stork oriented top-side up

Figure 5. Illustration of sampling of coating and deposits that was done at eight locations along the pipe

The samples were removed from the side of the pipe in most cases as shown in Figure 5, and the samples and locations are as shown below. Qualitative analyses of these samples were carried out with energy dispersive spectrometry (EDS) in conjunction with a scanning electron microscope (SEM). The results of the EDS analyses are presented in Appendix C.

Table 1. Description of the samples of soil, deposits, and coating

Sample Number	**Distance from End A, inches**	**Nature of Sample**	Clock Position
1	1	Soil and coating	Side
2	13	White deposit	Side
3	25	Soil	Side
4	31	Soil	Side
5	43	Soil	Side
6	27.5	Deposit captured on adhesive tape	bottom
7	20 to 22	White deposit (large sample)	side
8	-	coating	-

After the samples had been collected, most of the soil was removed from the pipe by means of water and a soft brush. The pipe at this stage is shown in Figure 6 and the crack is shown in Figure 7. The maximum crack opening was determined to be about 0.12 inch (at the 6 o'clock position). The total circumferential extent of the crack was found to be 5-3/4 inches leaving an uncracked ligament of 1-3/4 inch. Assuming that the opening would be diamond-shaped if the pipe were to be laid out flat, one calculates a total crack-opening area of 0.345 square inches.

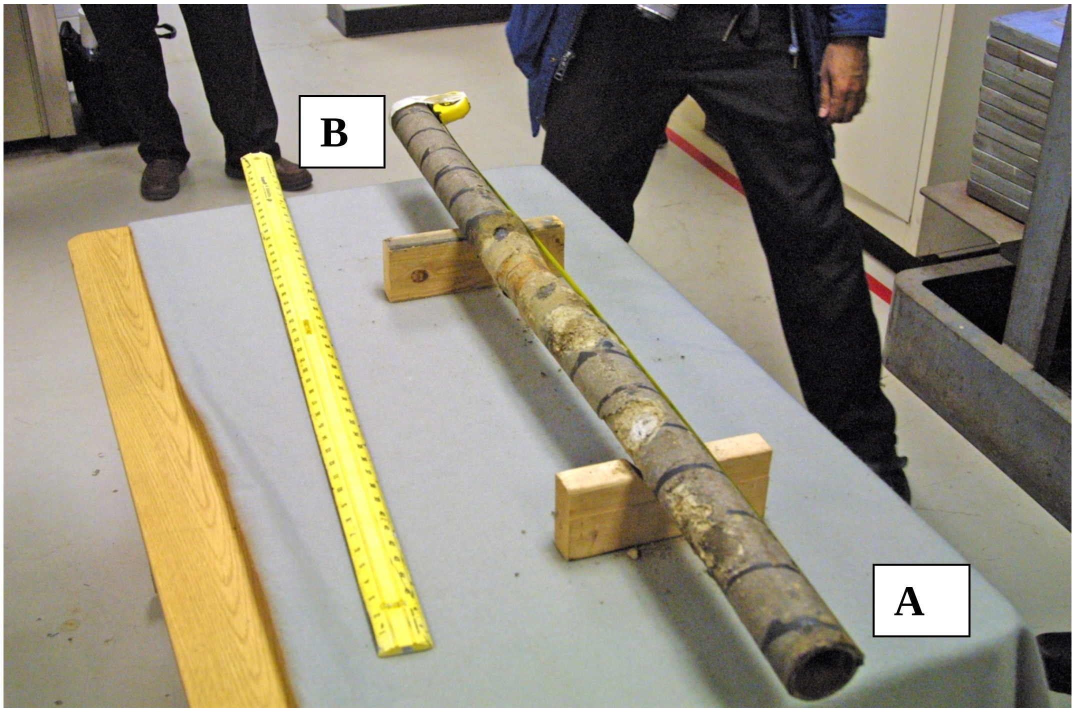

Figure 6. Piece of pipe after removal of most of the soil. Note that ends are labeled A and B and that the measuring tape is aligned with the top (12 o'clock position) of the pipe in service.

Figure 7. Circumferentially oriented crack located 28 inches from End A. The measuring tape in this photo is aligned with the bottom (6 o'clock position) of the pipe in service.

As seen in Figure 6 the coating was applied in a helical pattern highlighted by the black strip of coal tar enamel. The gray-colored portion of the coating is a fiber-wrap material that was impregnated with coal tar enamel. The coating was found to be in good condition except in the immediate area of the crack where the coating was missing and except for three other areas where disbonding of the coating had occurred. These three areas were located at roughly the 7 o'clock to 9 o'clock position when the pipe was in service looking from End A, and they were spaced roughly at distances of 7, 13, and 21 inches from End A. These three areas are shown in Figures 8 through 10.

Figure 8. Disbonded area, side of pipe, located about 7 inches from End A

Figure 9. Disbonded area, side of pipe, located about 13 inches from End A

Figure 10. Disbonded area, side to bottom of pipe, located about 21 inches from End A

As seen in the photographs these areas were mostly covered with a hard white deposit the removal of which required scraping with a screwdriver blade. As shown in Figure 11, additional coating disbondment had occurred in the vicinity of the crack, although the some of the coating was still intact. The boundary of the intact but disbonded coating is characterized by a hard white deposit as well.

Figure 11. Disbonded area near crack where coating remained intact. The boundary of the disbonded area is characterized by a white deposit (denoted by arrows).

A sample of the white deposit was moistened with dilute hydrochloric acid. As shown in Figure 12, the acid caused effervescence indicating the probable release of carbon dioxide from the deposit.

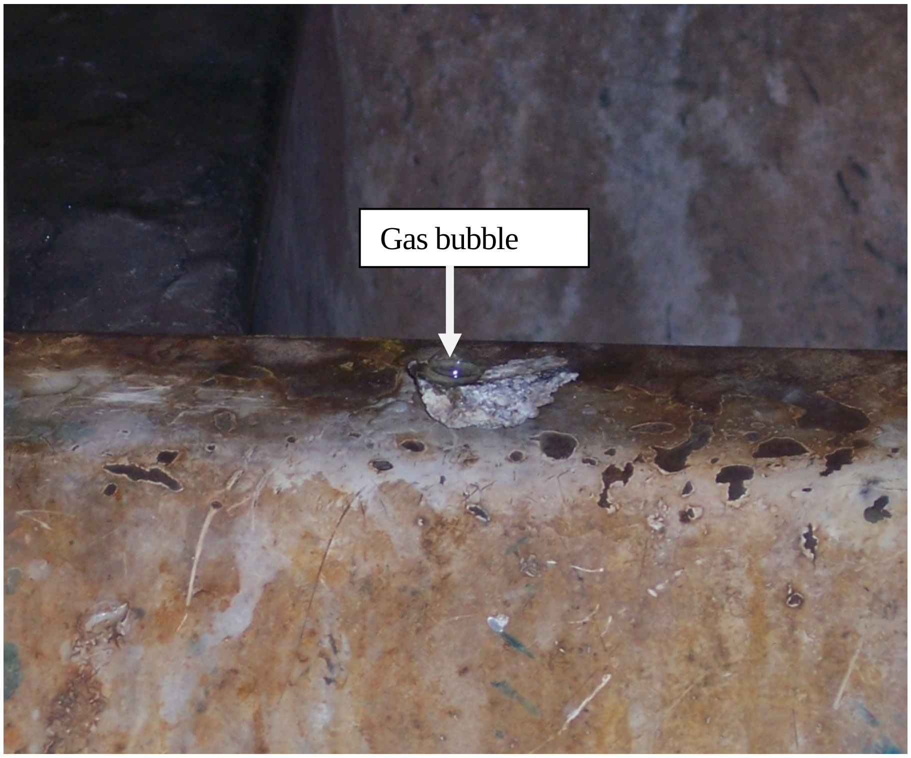

Figure 12. Effervescence of white deposit when treated with dilute HCl.

The fifty-one inch piece of pipe was clearly not straight. The deviation from straightness is somewhat evident in Figures 3 and 4, but it became obvious when the pipe was compared to a straight-edge as illustrated in Figures 13 and 14.

Figure 13. Deviation from straightness looking toward End A

Figure 14. Maximum deviation from straight-edge bearing on coated portions of the pipe

As these photographs indicate, the pipe appears to have the greatest deflection at the region of the crack. It is deflected downward relative to a straight-line position in service. Subtracting the thickness of the coating (0.15 inch) from the measured maximum deflection of 0.44 inch one finds that the deflection from straight is 0.29 inch. Note that the pipe appears to be straight between the region of the crack and End B though deflected downward from End B. In contrast, the pipe appears to be rather abruptly curved just beyond the cracked region looking toward End A in Figure 13.

The above-described observations and sampling activities constituted all of the preliminary visual examination of the pipe. The test for pH under disbonded coating was omitted.

Removal of Coating and Samples for Mechanical Tests and Chemical Analysis

Upon removal of intact coating the pipe metal was observed to be in like-new condition as seen in Figure 15.

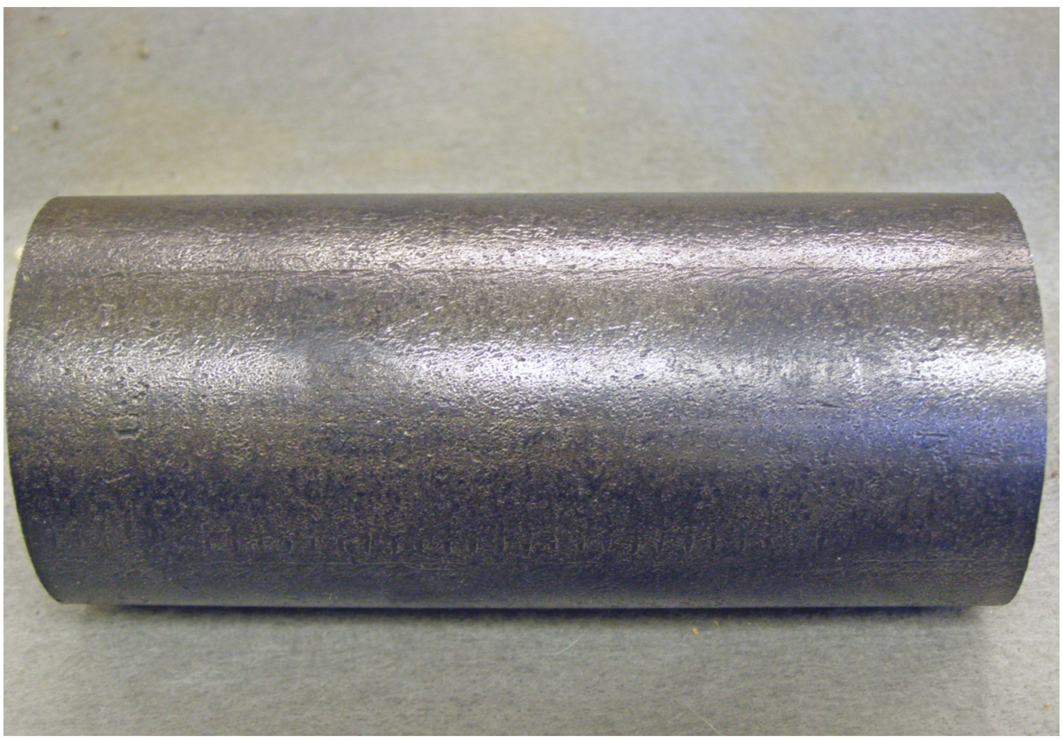

Figure 15. Representative appearance of pipe in areas where coating was intact before being removed.

A 1-inch long complete circumferential ring, a longitudinally-oriented tensile specimen, and a chemical analysis specimen were removed from End B of the pipe. The ring sample was used to determine whether or not a seam weld was present in the pipe. As shown in Figure 16, a longitudinally oriented score mark was visible on the inside surface of the pipe.

Figure 16. Score mark visible at ID surface that corresponded to butt-welded seam

It was thought that this score mark might correspond to the location of a seam weld. Indeed that turned out to be the case. At that location in the ring, a distinct difference in microstructure characterized by reduced pearlite relative to the parent metal was evident. The appearance of the microstructure suggests that the pipe is furnace butt-weld pipe. Furnace butt-welded pipe, a now obsolete product, was made by heating a 20-foot-long flat strip of pipe “skelp” to welding temperature and pulling the skelp through a circular die called a “welding bell”. The weld is formed by mechanical pressure between the forced-together edges of the skelp. No filler metal was required. A similar product called continuous welded pipe is still made today though the process has been modernized to allow the use of coil stock rather than flat individual pieces. It should be noted that the butt weld in the subject pipe was of excellent quality and contained no defects.

The tensile test revealed the material to have a yield strength of 42,488 psi, an ultimate tensile strength of 63,635 psi and an elongation of 28.5 percent. For comparison, the API Specification 5L for line pipe in 1955 required Class II open-hearth butt-welded pipe to have a minimum yield strength of 28,000 psi, a minimum ultimate tensile strength of 48,000 psi, and a minimum elongation of 20 percent. The tensile properties of the subject pipe material exceeded the minimum requirements for Class II open-hearth butt-welded pipe.

The chemical analysis of the subject pipe was determined by means of optical emission spectrometry, and the analysis revealed the following elements in percent by weight: carbon, 0.08; manganese, 0.45; phosphorus, 0.048; and sulfur, 0.02. For comparison the API Specification 5L for line pipe in 1955 required Class II open-hearth butt-welded pipe to have a minimum manganese content of 0.3, a maximum manganese content of 0.6, a minimum phosphorus content of 0.045, a maximum phosphorus content of 0.08, and a maximum sulfur content of 0.06, all in percents by weight. The specification does not provide limits for carbon content for Class II open-hearth butt-welded pipe. From this comparison it is seen that the chemical content of the subject pipe material meets the requirements for Class II open-hearth butt-welded pipe.

A number of measurements were made on the pipe after removal of coating. Two orthogonal measurements of diameter made at a circumferential plane well away from the cracked region showed the pipe to be slightly ovalized but both diameters were within the manufacturing tolerance. One was 2.370 inches and the other was 2.385 inches. Adjacent to the crack the side-to-side diameter measurement was 2.385 inches, almost the same as at the location away from the crack. The top-to-bottom measurement was 2.355 inches, and initially it was thought that the pipe had been flattened some at the point of the crack. However, as will be seen, this reduced-diameter measurement arises because of the mechanical damage anomaly that is present at the crack.

The average wall thickness as determined by several measurements appears to be about 0.164 inch. Standard full-size wall nominal pipe size (NPS 2) 2-inch pipe has specified dimensions of 2.375-inch outside diameter and 0.154-inch wall thickness. The dimensions of the subject pipe strongly suggest that it is standard NPS 2-inch pipe.

While the test protocol included a provision for Charpy V-notch impact testing, such testing was omitted for valid reasons. First, the diameter and wall thickness of the pipe are well below the minimum levels required to obtain standard full-sized or even standard sub-sized specimens. The testing of specimens with dimensions well outside the range normally employed would leave the results open to question. Secondly, and most importantly, there is no doubt that the pipe failed in a brittle (cleavage) fracture mode, so it is known that at the time it failed, its actual service temperature was below its ductile-to-brittle impact transition temperature. Since this is already apparent, and a major purpose of conducting Charpy impact tests is to establish the ductile-to-brittle fracture transition temperature, it is not clear what additional useful information could be obtained from Charpy impact tests.

Examination of the Fracture Surface

The remaining ligament of material holding the two portions of the piece together was severed by saw cutting to expose the two surfaces of the crack for visual examination. The surface chosen for examination is shown in Figures 17 and 18.

Figure 17. Fracture surface (one side)

Figure 18. Fracture surface showing locations of metallographic samples

Examination of the fracture surface revealed a brittle fracture, the origin of which was not absolutely clear. The nature of the partial circumferential fracture and the fact that the pipe appears in Figures 13 and 14 to have been flexed downward indicate that the fracture was created by bending stress. Because the crack was symmetrical about a vertical axis, one can reasonably believe that the bending stress would have been at its maximum tensile value at the bottom of the pipe. Moreover, the crack opening was maximum at the bottom of the pipe, and the location coincided with a gouge as can be seen in Figure 19.

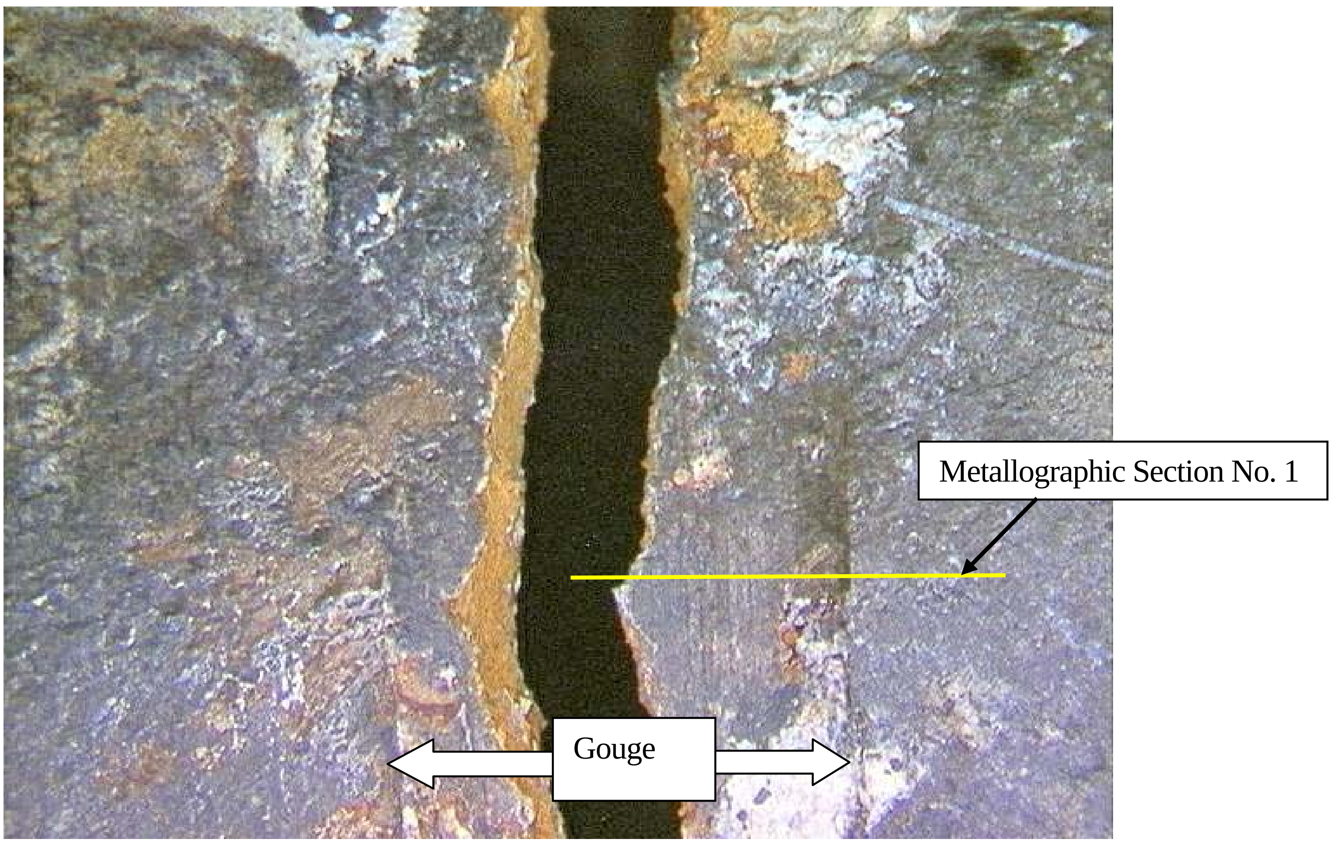

Figure 19. Gouge that coincided with the crack at the bottom of the pipe

The presence of the gouge made this region an area of primary interest as the likely origin of the crack. Accordingly, a longitudinally oriented metallographic section was taken at the location shown in Figure 19. For comparison a second metallographic section was taken across the fracture near one end of the crack as shown in Figure 18.

Metallographic Examination

A macro photograph of Metallographic Section No. 1 is shown in Figure 20.

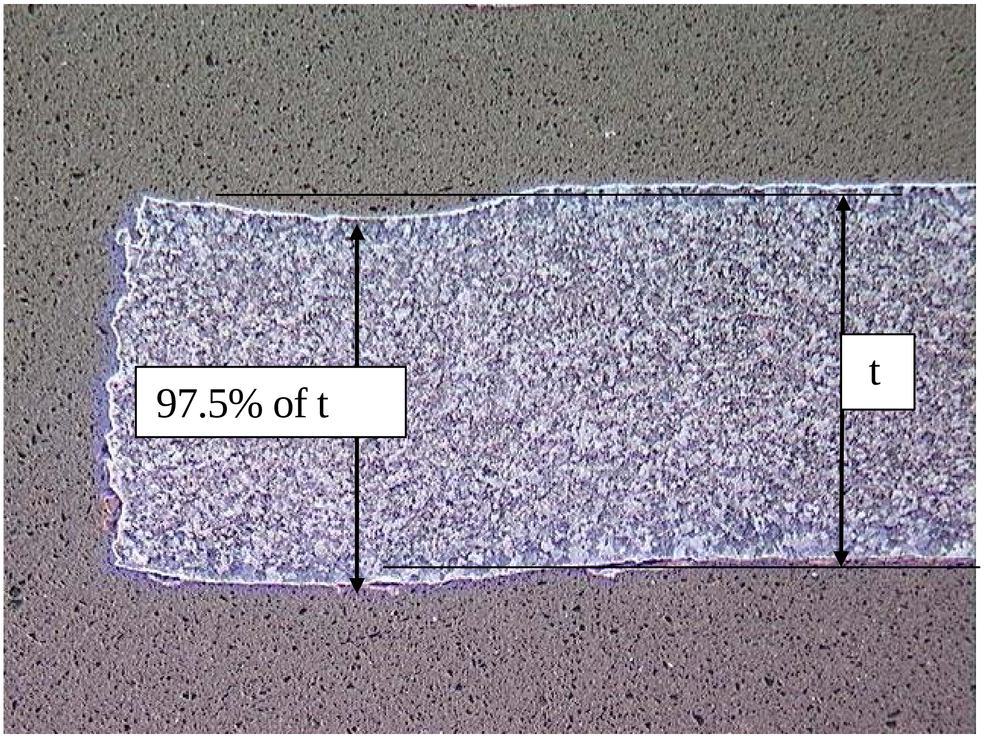

Figure 20. Metallographic Section No. 1, cross section of gouge at 12X

This photograph shows that whatever hit the pipe, bent the pipe wall thickness as well as gouged it. The groove visible at the outside surface of the pipe was found to be about 0.012 inch deep relative to the original surface of the pipe. However, the pipe is about 2.5 % thinner at the gouge than it is away from the gouge. Two and one-half percent of the average wall thickness (0.164 inch) is 0.004 inch. The bulge at the inside surface is two-thirds as high as the apparent depth of the groove. The reduction in thickness of 0.004 inch is the result either of compression of the material at the contact surface or the physical removal of material or a combination of the two. The microstructure at the base of the gouge is shown in Figures 21 through 23, and a comparative picture of the microstructure at the non-gouged section is shown in Figure 24.

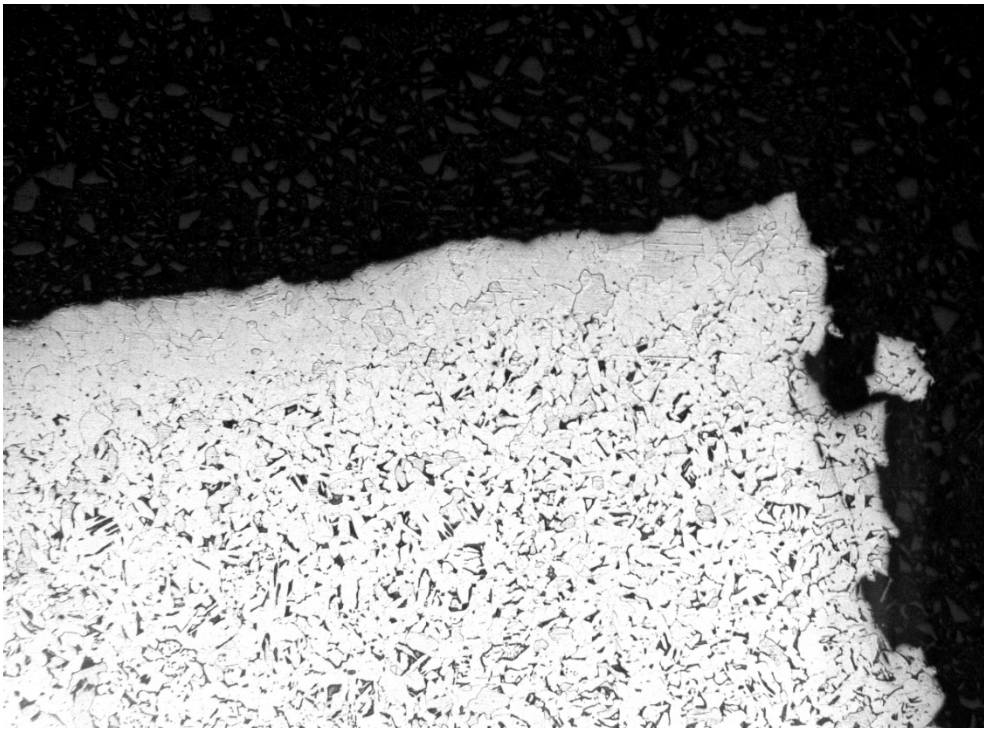

Figure 21. Gouged surface adjacent to crack at 50X

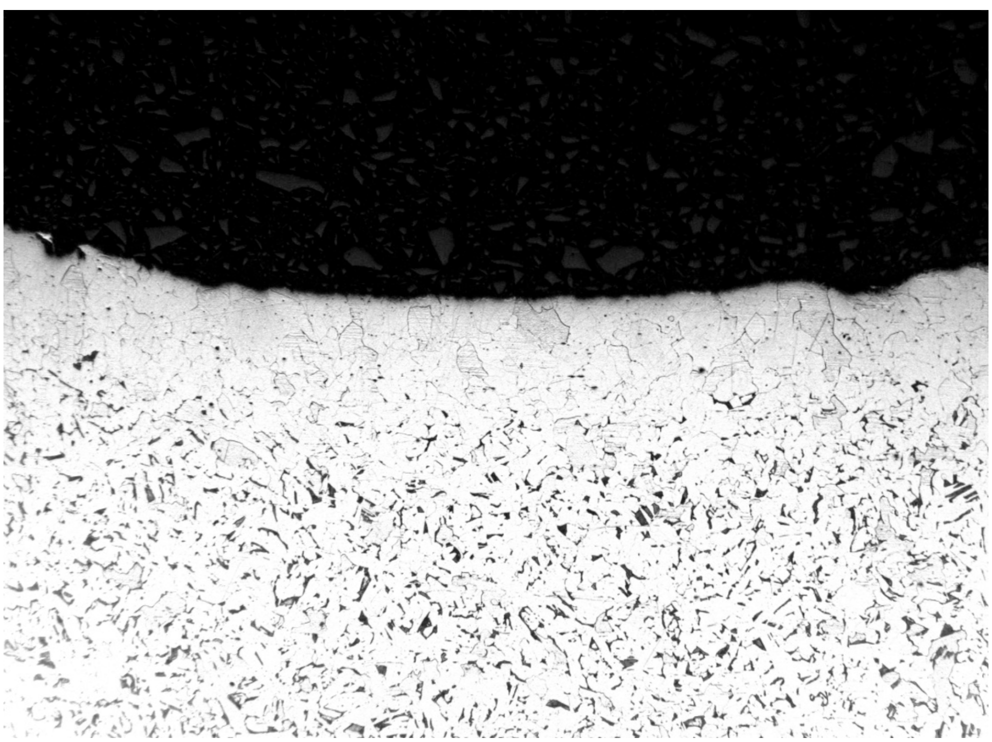

Figure 22. Gouged surface in center of groove at 50X

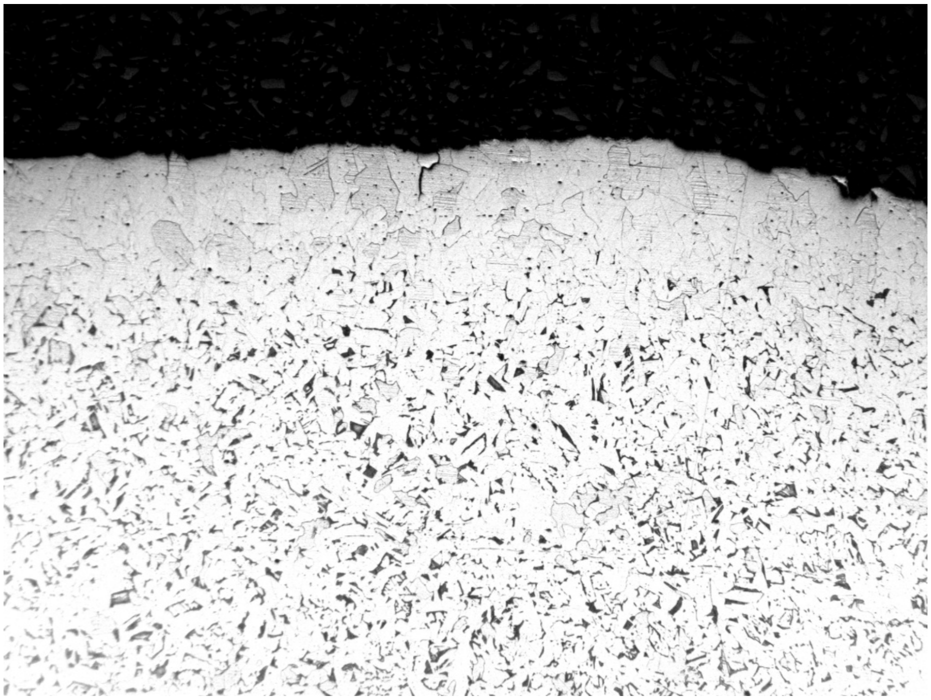

Figure 23. Gouged surface at edge opposite crack at 50X

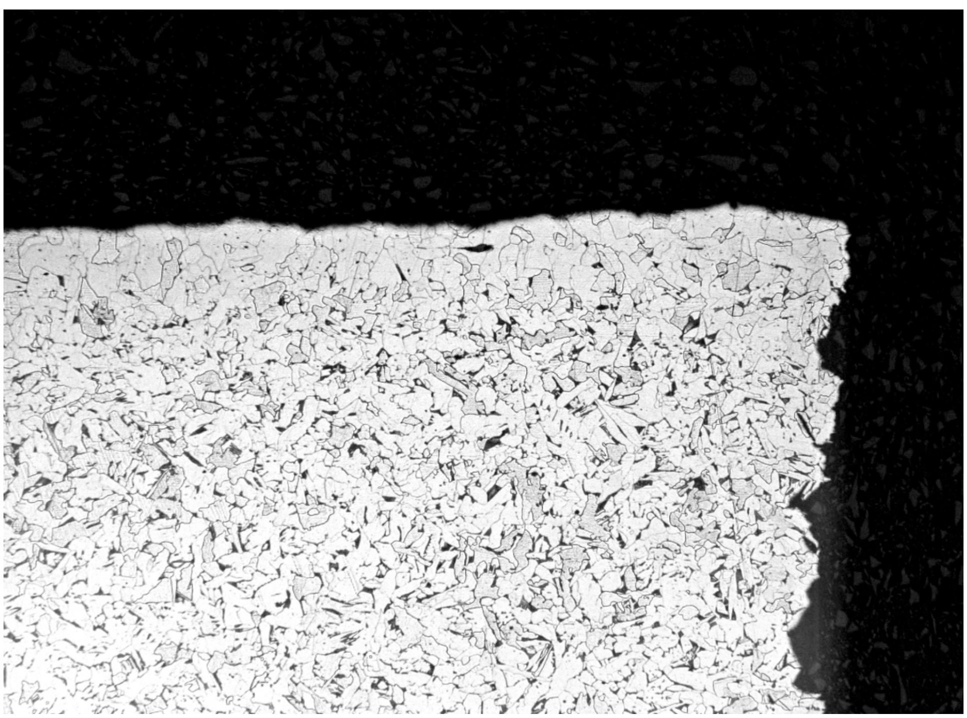

Figure 24. Non-gouged surface at crack at 50X

The micro photos of the gouged surface reveal a layer at the OD surface that is lighter in color than the material in the underlying substrate. The lighter-colored layer extends beyond the edge of the gouge as shown in Figure 23, so it is not possible to attribute its appearance to the gouging action. The non-gouged section shown in Figure 24 exhibits no similar layer.

Elements Present in the Various Samples of Soil, Deposits, and Coating

The elements present in the various samples listed in Table 1 of soil, deposits, and coating were identified via energy dispersive spectroscopy (EDS) in conjunction with a scanning electron microscope (SEM). The results are presented in Appendix C in terms of plots showing characteristic peaks of the elements based on the dispersive energy associated with the particular atomic weights. Samples 1, 3, 4, and 5 were purported to be mostly soil, with perhaps some of the pipe coating included, taken from various locations along the side of the pipe. As can be seen in Figures C1, C3, C4, and C5, these samples exhibited strong silicon (Si) and oxygen (O) peaks. This is not surprising in view of the fact that the soil appeared to be quite sandy. Other smaller peaks corresponding to aluminum (Al), magnesium (Mg) sodium (Na), calcium (CA), iron (Fe) and potassium (K) would be consistent with small amounts of clay mixed with the sandy soil and the common metal ions found in ground water. The small carbon (C) peak likely results from the capture of some of the coal tar enamel coating within the samples.

Samples 2 and 7 were taken primarily from the hard, white-colored deposits associated with areas of coating disbondment. Along with the characteristic peaks of the previously discussed samples, these two samples show strong peaks for calcium which would be consistent with the calcareous deposits (mostly calcium carbonate, $CaCO_3$) often associated with cathodically protected metal surfaces exposed to soil-ground water environments. These deposits charactistically effervesce CO_2 when treated with dilute hydrochloric acid. Such effervescence was demonstrated as shown previously in Figure 12.

Sample 6 was taken by an adhesive pick-up of material on the exposed metal surface adjacent to the crack. Not surprisingly it shows the peaks previously shown for soil and coating. The stronger iron peak in this case is likely the result of iron oxide on the surface of the metal.

Sample 8 was taken from freshly cut coal tar enamel on the pipe. Hence, the large carbon peak is as one might expect.

ANALYSIS

As the photographic evidence reveals, the incident at Mitchell SD on March 8, 2007 was associated with a circumferential crack developing and nearly severing the pipe. Given the large open size and the statement by the operator that the operating pressure at the time was 18 psig, one can reasonably assume that this crack developed suddenly and shortly before the incident. The presence of a natural gas leak of such a size would not go unnoticed for long (i.e., Using the orifice equation presented in Appendix D, one can calculate that the flow rate from the crack would have been about 277 cubic feet per hour). The brittle nature of the crack is consistent with a sudden, one-stage event as well.

The crack was caused by mechanical damage to the pipe. The apparent origin of the crack coincides with a mechanically-created gouge that was inflicted on the bottom of the pipe. One would expect that an upward deformation of the pipe would have been created at the same time. On the contrary, the pipe has been permanently deformed downward. Moreover, within two feet of the location of the crack, three other areas of damage were found that appear to have been caused by mechanical equipment impacts. These three areas are located at clock positions ranging from 7 to 9 o'clock. In the area located 20 to 22 inches from End A, the gouge can be seen in Figure 25.

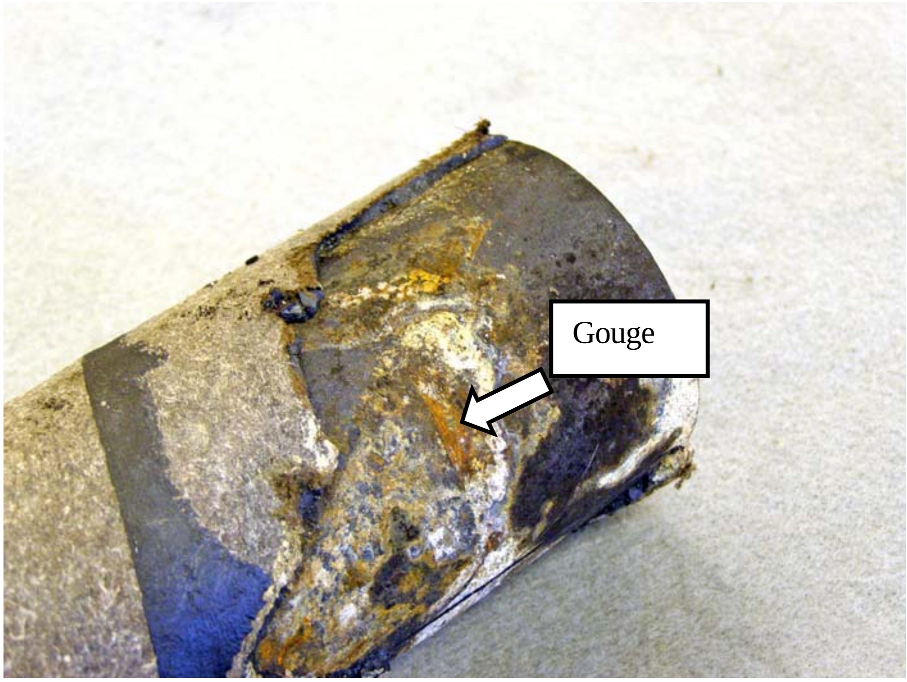

Figure 25. Gouge within the disbonded area located 20”-22” from End A

Thus, while the gouge that coincided with the crack was inflicted by an impact to the bottom of the pipe, the gouge shown in Figure 25 was inflicted on the side of the pipe. It does not seem likely that both of these gouges could have been inflicted by a single motion of a piece of mechanical excavating equipment. Moreover, it is hard to visualize how the downward deformation of the pipe could have resulted from the same motion that created either of the two gouges. It appears likely that multiple contacts with the pipe occurred. Whether or not the multiple contacts occurred as the result of a single excavation activity or more than one excavation activity could not be determined. The calcareous deposits on the gouged surface adjacent to the crack and at other areas where the coating was damaged indicate that none of the damage is new, but the evidence does not suggest when the damage was inflicted. Why the failure occurred after a delay rather than when the damage was inflicted is not known. A change in the status of the stress acting on the pipe and/or a change in the status of the gouge could explain the delay. The status of the gouge appears to have remained constant as there was no evidence of any time-dependent enlargement of the gouge. With regard to a possible change in stress, this investigation did not reveal whether any such change may have occurred.

The examination of the pipe indicated that no external corrosion-caused metal loss had taken place. Except for the areas that had been mechanically impacted, the original coal tar enamel coating and wrap were intact and well bonded to the pipe. The facts that no metal loss was observed at the areas exposed by mechanical damage and that the exposed areas were coated with a hard, white deposit strongly suggest that the cathodic protection of this area was adequate to protect the pipe from corrosion. Thus, external corrosion was not a factor in this incident.

The examination showed that the pipe material was a furnace-butt welded material. Its mechanical and chemical properties met or exceeded the requirements for an API 5L Class II furnace butt-welded line pipe material at the time of its manufacture. No manufacturing defects of any kind were found.

CONCLUSIONS

As a result of this investigation it can be concluded that:

- The cause of the incident was mechanical damage.
- A mechanically created gouge caused the pipe to fail.
- The mode of failure was a circumferentially oriented brittle crack that severed the bottom three quarters of the pipe.
- No evidence of time-dependent enlargement of the gouge was found.
- External corrosion played no role in the incident.
- The pipe was adequately protected from external corrosion.
- The pipe was furnace butt-welded pipe.
- The pipe contained no manufacturing defects.
- The damage that caused the failure is not new, but it was not possible to establish when it occurred.

- Whether or not the multiple impacts, noted at locations that would have required more than one motion of a single piece of excavating equipment, were created during a single excavation or during more than one excavation could not be determined.

APPENDIX A TEST PROTOCOL

PS07-002 - In the Matter of the Filing of the Investigation of the Natural Gas Incident of March 8, 2007 on NorthWestern Energy's System in Mitchell, South Dakota.

TEST PROTOCOL

II. TRANSPORTATION

a. The pipe sample shall be transported via courier whereby a chain of custody can be established to assure it reached the testing location in the same condition in which it was sent.

b. The pipe sample shall be shipped in a wooden crate after being wrapped in appropriate packaging to prevent any damage to the sample.

III. NON-DESTRUCTIVE TESTS

a. Identify orientation of the sample in terms of compass and clock position as it was in service and use these as coordinates for subsequent observations.

b. Photograph the sample from various angles in the as-received condition.

c. Measure crack length and the amount of crack opening at several points along the crack, and then calculate the crack-opening area.

d. Note and locate areas of coating disbondment and determine whether or not some patch recoating had been done.

e. Examine nature of white deposits at various locations most likely by seeing if dilute hydrochloric acid causes the release of bubbles indicating a calcareous deposit.

f. Measure pH at locations of coating disbondment including at origin of failure.

g. Remove all coating to examine surface of pipe for anomalies or discontinuities and to verify that there are no girth welds in the piece.

h. Measure ovality of pipe at the location of the crack with an outside caliper before separating the fracture and with a measuring tape across the exposed cracked ends.

i. Determine longitudinal curvature and measure vertical deflection of pipe with particular attention to angle change in vicinity of the crack.

j. Measure wall thickness at 12, 3, 6, and 9 o'clock positions at both ends of the piece.

k. Photos shall be taken throughout the process of non-destructive examination particularly to document the nature and location of anomalies or discontinuities defects revealed.

IV. DESTRUCTIVE TESTS

a. Examine the fracture surfaces of the crack.

1. Circumferentially saw-cut the remaining ligament to separate the pipe halves and expose the surfaces of the crack.
2. Determine whether the fracture is ductile or brittle.
3. Both fracture surfaces shall be photographed prior to any cleaning.

4. One side of the fracture shall be cleaned with a mild detergent solution and then photographed again.
5. Examine the cleaned fracture surface at various optical magnifications to identify the origin of the crack including any pre-existing defects or stages of crack propagation.
6. Photograph any anomaly or discontinuity or distinctly different fracture stages.
7. Determine the wall thickness at various points along the crack.
8. Hold in reserve the need of scanning the surface by means of scanning electron microscopy.

b. Taking one side of the fracture only cut longitudinally-oriented section through wall at the location of the origin of fracture
c. On the same piece, cut longitudinally-oriented section through wall at a location where no fracture existed (i.e. in the saw-cut zone)
d. Mount and polish both sections, and examine them in the unetched condition at various magnifications.
e. Photograph relevant features.
f. Etch the sections to reveal the microstructure, and examine the sections again at various magnifications.
g. Photograph relevant features.
h. Cut a ring of the pipe away from the crack and rough polish one end to identify pipe type.
i. If necessary, continue to polish areas of the ring to examine the microstructure if it will help in identifying the type of pipe.
j. Extract an appropriate coupon from one part of the piece away from the fracture to make a longitudinal tensile test.
k. Machine and test the coupon as per API Specification 5L.
l. Extract an appropriate coupon from the piece for determination of chemical content via a spectrographic method.
m. Extract samples for Charpy V-notch impact tests. Samples should be longitudinally-oriented with notch through the thickness. Test temperatures should be selected to develop full transition curve or at a minimum tests should be conducted at room temperature, +32, 0, and -40 degrees F.

V. TEST GOALS

a. Identification of any pipe defects.
b. Identify whether corrosion was an issue.
c. Determine whether there was any pre-cracking.
d. Identify the type of pipe.
e. Determine cause of failure.

VI. TEST LOGISTICS

a. Stork Twin City Testing, 662 Cromwell Avenue, St. Paul, MN 55114-1776, Phone (651)645-3601

b. The SD Public Utilities Commission will contract directly with Stork Twin City Testing

c. Party Participation

   1. Dr. John Kiefner, PE of Kiefner & Associates, Inc. will direct the testing to be done at Stork Twin City Testing. A representative for each party may observe tests as they are done. No party other than Dr. Kiefner will direct the testing nor shall any other party interfere with the tests as they are performed.

d. Testing Date

   1. Dr. Kiefner shall contact Stork Twin City Testing for a list of available testing dates

APPENDIX B LIST OF OBSERVERS AT STORK ON JAN. 16, 2008

Stork Twin City Testing Corporation

PROJECT NUMBER: SOU263-01-15-91979

DATE: January 16 & 17, 2008
PAGE 1 of 1

LIST OF ATTENDEES

Name	Company / Firm	Dates Present
Kara Semmler, Staff Attorney	South Dakota Public Utilities Commission	January 16, 2008
Nathan Solem, Utility Analyst	South Dakota Public Utilities Commission	January 16, 2008
Daris Ormesher	South Dakota Public Utilities Commission	January 16, 2008
Dr. John F. Kiefner, P.E., Advisor	Kiefner & Associates Inc	January 16-17, 2008
Eugene Smith, P.E., Engineer	EN Engineering	January 16-17, 2008
David J. Kramer, P.E., Engineer	Crane Engineering	January 16, 2008
S. N. Bhatt, P. E., Engineer	MEM Engineering	January 16, 2008
Larry D. Hanke, P.E., Engineer	Materials Evaluation and Engineering Inc	January 16, 2008
Richard Kielty, P.E., Engineer	Stork Twin City Testing	January 16-17, 2008
Lawrence "Bud" Eastman, CFI	Fire Check Inc	January 16, 2008
Roy Wise	Richardson Law Firm	January 16, 2008
Paul Linde	Shaffer Law Office	January 16, 2008
Jeffrey M. Baill, Attorney	Yost & Baill LLP	January 16, 2008

Prepared By:

Richard Kielty

Richard Kielty, P.E.
Senior Metallurgical Engineer
Materials Testing & Analysis Group
Phone: (651) 659-7229

Reviewed By:

V. Krishnamoorthi

Viswanathan Krishnamoorthi, P.E.
Manager, Failure Analysis
Materials Testing & Analysis Group
Phone: (651) 659-7346

APPENDIX C SEM EDS PLOTS

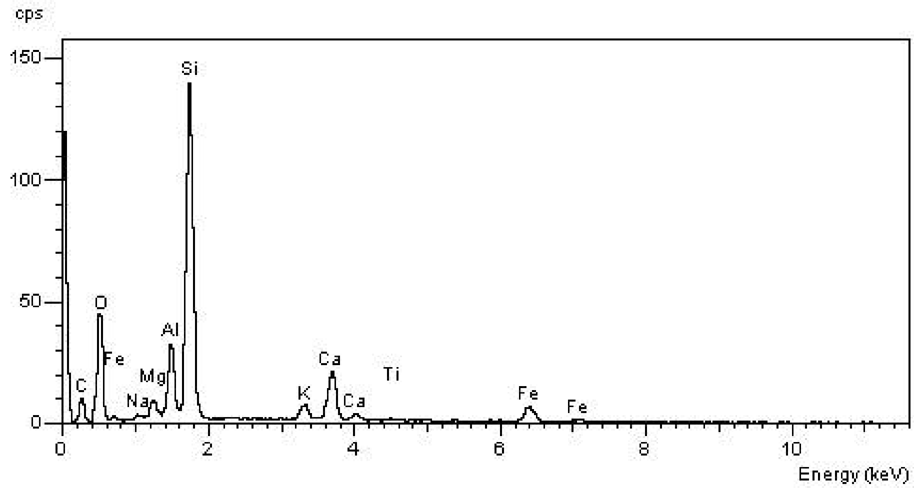

Figure C1 Sample 1, OD surface 1" from End A, side of pipe

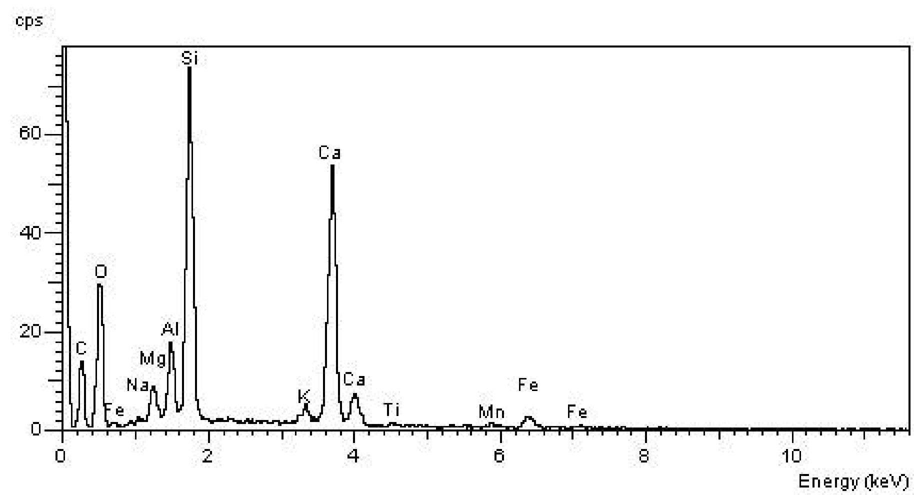

Figure C2 Sample 2, OD surface 13" from End A, side of pipe

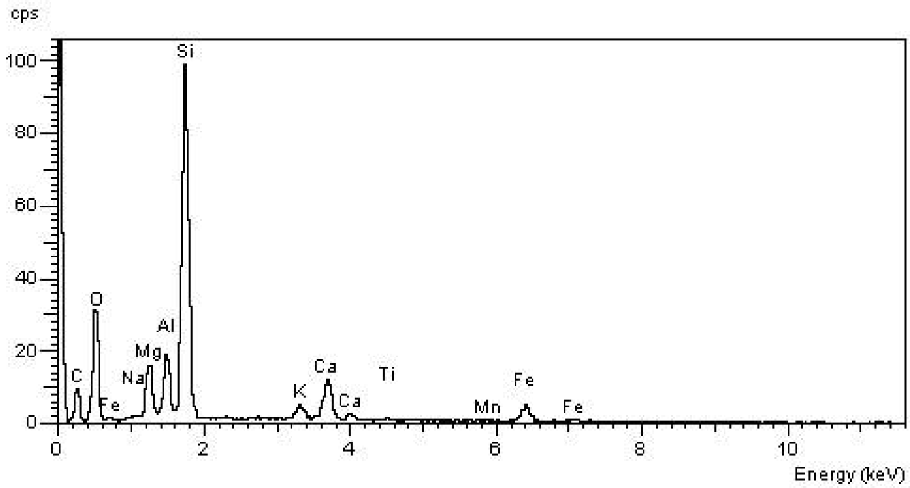

Figure C3 Sample 3, OD surface 25" from End A, side of pipe

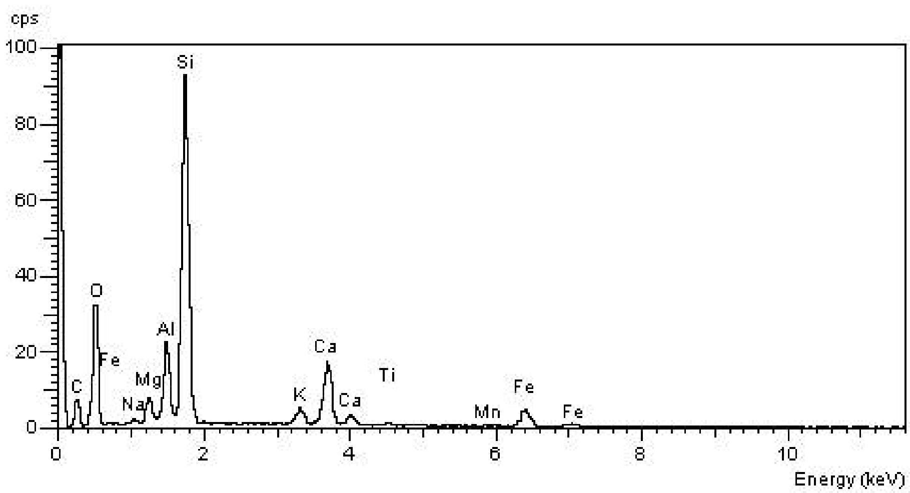

Figure C4 Sample 4, OD surface 31" from End A, side of pipe

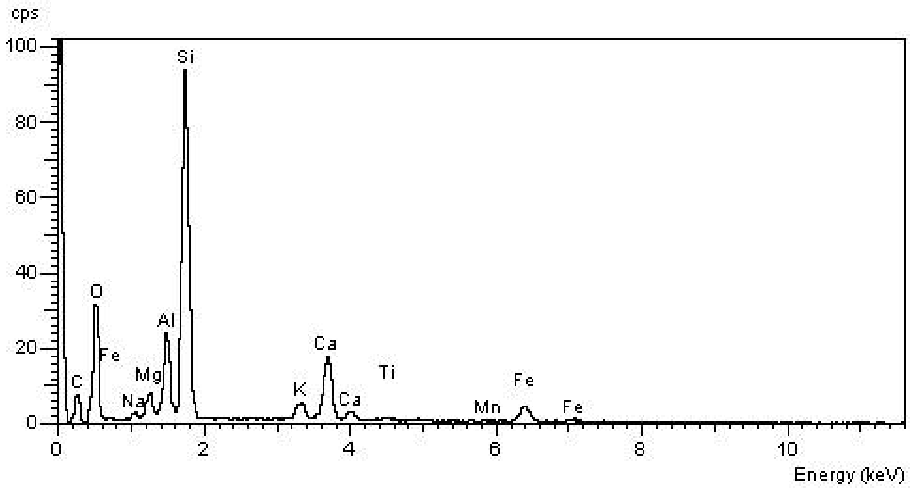

Figure C5 Sample 5, OD surface 43" from End A, side of pipe

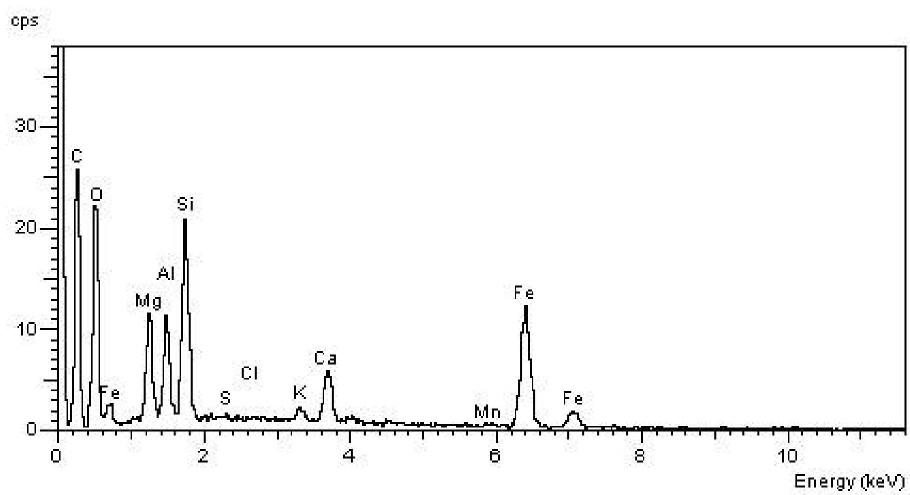

Figure C6 Sample 6, dabbed from exposed surface adjacent to crack

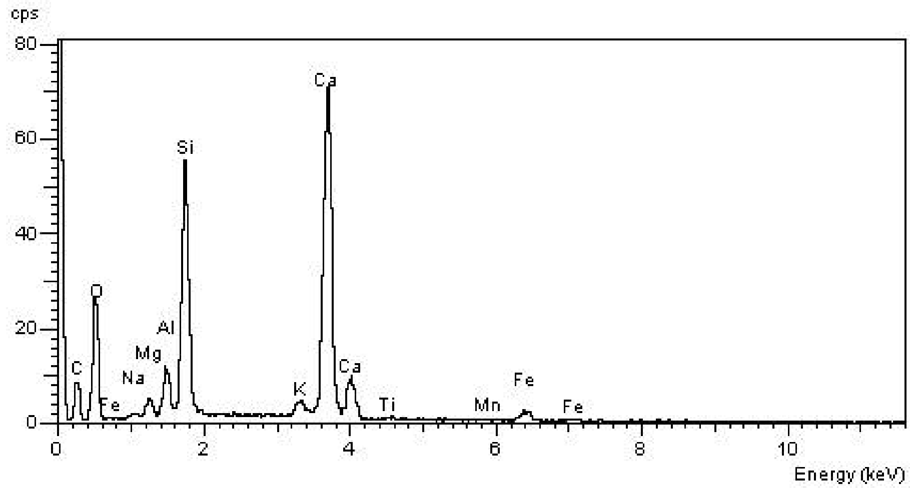

Figure C7 Sample 7, OD deposit 20”-22” from End A, side of pipe

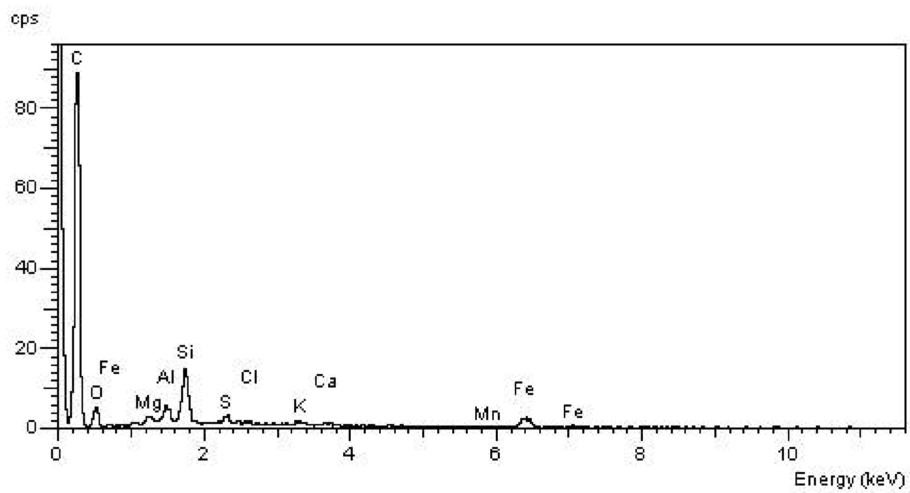

Figure C8 Sample 8, freshly cut surface of pipe coating

APPENDIX D FLOW RATE CALCULATION

ORIFICE EQUATION USED IN CALCULATION OF LEAK RATE

$$Q = 3600\frac{KAV}{144} = 3600\frac{KA\sqrt{\frac{2gp}{0.4333}}}{144}$$

Where:

- Q is the quantity of gas in cubic feet per hour
- V is the flow velocity through the orifice in feet per second
- A is the orifice area in square inches
- g is the gravitational constant, 32.2 ft/sec^2
- p is the pressure drop across the orifice in pounds per square inch
- K is an orifice constant equal to 0.62

$$Q = 3600\frac{KAV}{144} = 3600\frac{(0.62)(0.345)\sqrt{\frac{2(32.2)(18)}{0.4333}}}{144} = 277\frac{ft^3}{hr}$$