Southern Natural Gas
an El Paso company

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety
Southern Region Office
233 Peachtree Street
Suite 600
Atlanta, GA 30303

May 27, 2008

Attention: Mr. Dallas Rea

Re: CPF No. 2-2007-1004H
Proposed Amendment No. 1 to the 1/26/07 Corrective Action Order (CAO)
Mechanical and Metallurgical Testing and Failure Analysis

Dear Mr. Rea:

In our telephone conversation this morning, you requested a letter from Southern Natural Gas Company (SNG) on its letterhead to confirm that the mechanical and metallurgical testing and failure analysis your office received as an email attachment May 22, 2008, is the final report and intended to satisfy Item 11 of the captioned CAO. This is the letter you requested and affirms both issues relative to SNG's 18" South Main Pipeline near York, Alabama that incurred a leak on March 14, 2008.

The May 22, 2008 email attachment was accompanied by Stress Engineering Services (SES) letterhead to comply with Item 11(D) of the captioned CAO, insuring that PHMSA would receive the report at the same time it was made available to SNG. Furthermore, this is the report for which SNG had requested an extension of time until May 30, 2008, in a letter to PHMSA's Mr. Michael Khayata dated May 19, 2008.

Once again, thank you for your cooperation.

Sincerely,

Kenneth C. Peters

Kenneth C. Peters
Manager – DOT Compliance Services
Field Support

cc: Mr. Michael Khayata
Mr. Mike Schwarzkopf

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May 22, 2008 PN 117869RWS

Todd D. Kedzie
Laboratory Services Manager
El Paso Corporation
16951 JFK Boulevard
Houston, TX 77032

Subject: Evaluation of 18-inch Girth-Weld Failure

Todd,

We appreciate the opportunity to be of service to you and El Paso Corporation. This letter report presents the findings from our analysis of the failure of an 18-inch x 0.312-inch, Grade X52 pipeline segment that leaked at the girth weld and was provided to Stress Engineering Services, Inc.

Our results indicate that the girth-weld failure was most likely the result of longitudinal forces, and that the fracture initiated at a group of imperfections in the girth weld that were present in the pipeline since its construction. The loading the pipeline experienced following weld completion (including subsequent construction activities, gas testing, and operations) caused the crack to propagate through the wall, which resulted in the leak identified by pipeline operations.

Please contact me if you have any questions.

Regards,

Ron Scrivner
ron.scrivner@stress.com
281-897-6501 (direct phone)
713-449-2789 (cell phone)

BACKGROUND

Stress Engineering Services, Inc. (SES) received three pipeline samples from Southern Natural Gas's (SNG) 18-inch South Main Line. The line was operating at 1,075 psig on March 14, 2008 when a leak was discovered in a girth weld. The maximum allowable operating pressure of the line is 1,200 psig. El Paso Corporation's Metallurgical Laboratory Services personnel visually examined, photographed, and collected the failed girth weld and two upstream girth welds from the incident site for subsequent metallurgical evaluation. This failure analysis by SES focused on the failed girth weld.

The pipe (18-inch OD by 0.312-inch nominal wall thickness) was installed in 1951. The pipe manufacturer was A.O. Smith and the pipe was flash butt-welded in accordance with American Petroleum Institute (API) 5LX, grade X52 specifications. The external surface was reportedly coated with coal tar enamel, but the coating had been removed from the samples prior to their shipment to SES. A protocol for the failure analysis of the subject girth welds was developed and accepted by El Paso.

The material received by SES included Sample 1 (8 ft long) and Samples 2 and 3 (4 ft long each) (Figures 1 through 3). Each sample consists of two pipe segments connected by a girth weld, with Sample 1 including the failed girth weld. One package of X-ray films of the three girth welds was also received by SES. Chain-of-custody papers for the pipeline samples and X-ray films were signed by SES and a copy provided via email to El Paso.

VISUAL EXAMINATION

Sample 1 was examined closely for overall condition and the presence of any irregularities (Figure 1). A square-shaped protrusion ¼ inch wide by ⅛ inch high was present for the full length of each joint, which is typical for an A.O. Smith flash butt weld. The surface of the pipe was covered with a black primer with the exception of a triangular area 3 by 3 inch on one side of the girth weld (Figure 4). Along the edge of the weld cap was a band of what appears to be erosion that reduced the wall thickness. There were no signs of corrosion or mechanical damage on the OD of the pipe.

The girth-weld cap area was visually examined for welding imperfections. The following imperfections were observed (Figures 5 and 6):

- Arc-strike (arc-burn)
- Undercut
- Misalignment of the pipe ends (1/16 inch maximum)

During examination of the ID of the pipe before it was cut, SES found the pipe to be free of corrosion and coated with a thin layer of what appeared to be condensate or engine oil. It was also noted that there was a line of small gouges parallel to the long seam (Figure 7).

Following release from El Paso personnel, SES cut an 8-inch long ring containing the girth weld from Sample 1. The root region of the girth weld was then examined, which revealed the following imperfections (Figures 8 through 10):

- Cracking was visible on the ID of the pipe near the root of the weld
- Unrepaired burn-through
- Lack of penetration
- "Suck-back"

Sample 2 (Figure 2) was next examined closely for overall condition and for any irregularities. A flash butt weld typical of A.O. Smith pipe was observed running the length of both pipe segments. The outer surface of the pipe was covered with a black primer, and there were no signs of corrosion or mechanical damage on the OD of the pipe.

The girth-weld cap area of Sample 2 was visually examined for welding imperfections. The following imperfections were observed (Figures 11 through 13):

- Arc-strike (arc-burn)
- Undercut
- Hammer strike marks
- Misalignment of the pipe ends (1/16 inch maximum)

The outer surface of Sample 3 (Figure 3) was also examined closely for overall condition and any irregularities. As in the other samples, the long seam was an A.O. Smith flash butt weld. The OD surface of the pipe was also covered with a black primer, and there were no signs of corrosion or mechanical damage.

The girth weld cap area of Sample 3 was visual examined for welding imperfections, with the following observed (Figures 14 and 15):

- Arc-strike (arc-burn)
- Undercut
- Misalignment of the pipe ends (1/16 inch maximum)

The number and severity of visual imperfections on Samples 2 and 3 were less than on Sample 1. The root regions of the girth welds on Samples 2 and 3 were not examined.

NONDESTRUCTIVE INSPECTION

The girth weld in the ring cut from Sample 1 was inspected via magnetic-particle inspection (MPI) for indications of imperfections (Figures 16 and 17). MPI revealed a crack-like indication on the OD and ID at the same circumferential location as the erosion on the OD. The shape and angle of the cap pass with respect to the pipe made it difficult to discern indications of cracking from the tight corner created by the weld cap and OD of the pipe. Similarly, the root shape at some locations made it difficult to define the length of the crack. It was clear that indications of cracking were present both on the ID and OD of the weld, but the precise extent was difficult to discern.

The X-ray films provided by El Paso were also examined and found to confirm SES's visual findings and MPI results. There were indications of unrepaired burn-through, incomplete penetration, lack of fusion, "suck-back", metal loss due to the erosion, and a crack visible on the X-ray films.

DIMENSIONS

Dimensions of Sample 1 were also measured and recorded:

- Diameter (measured 4 inches from the girth weld using a Pi tape):
  - Up-stream pipe – 18.03 inches
  - Down-stream pipe – 18.02 inches
- Ovality
  - Up-stream
    - Maximum diameter – 18.09 inches
    - Minimum diameter – 17.95 inches
  - Down-stream
    - Maximum diameter – 18.05 inches
    - Minimum diameter – 17.97 inches
- Wall thickness
  - Up-stream – 0.325 to 0.338 inches
  - Down-stream – 0.319 to 0.324 inches
- Maximum high-low at girth weld – 1/16 inch @ 8:00 to 9:00 o'clock position

MECHANICAL TESTING

A section of pipe material from both joints in Sample 1 was sent out for destructive testing. Results showed that the yield and tensile strengths of the up-stream pipe are 57,600 psi and 81,100 psi, respectively (Table 1). For the down-stream material, the yield and tensile strengths are 65,900 psi and 94,100 psi, respectively. These values were within limits specified by API 5L at the time the pipe was manufactured.

Material chemistry and toughness at 50°F were also obtained and are summarized in Tables 2 and 3, respectively. The chemical analysis results were also within limits specified by API 5L at the time of manufacture. Toughness testing was not required by API 5L.

METALLOGRAPHIC EXAMINATION

Macroscopic Examination

SES examined the fracture first with low-power magnification (less than 5X) using a stereoscope (Figures 18 and 19). Much of the fracture surface was smooth with very few fracture features.

Fracture features that were present suggested that the weld contained slag and gas pockets before the fracture occurred (Figures 20 and 21).

There were also signs that the fracture propagated through the weld in stages. The fracture appeared to initiate at the ID. There were then one or two extensions of the crack, as well as an apparently recent crack extension, near the OD surface(Figure 21 and 22).

Metallographic Examination
A metallographic cross-section was prepared at the apparent crack origin (Figure 23). The most notable feature seen in the metallographic section was a lamination in the plate material on one side of the girth weld (Figure 24). The cross section also showed good alignment of the cap weld and several points along the fracture. There were also wide gaps where the fracture did not fit together as well.

The grain structure seen in the cross-section is typical of pearlite ferrite steel. The welds had a typical structure for a shielded metal arc weld process.

SCANNING ELECTRON MICROSCOPIC EXAMINATION

The fracture was examined using a scanning electron microscope (SEM) to confirm the mode of fracture. Much of the fracture was corroded or eroded over time. The fracture appears to have initiated as a ductile fracture (dimpled), but now has a smooth appearance (Figure 25). The recent fracture surface, which covers a relatively small percentage of the area, has a typical ductile, dimpled rupture appearance (Figure 26).

DISCUSSION

Visual examination of the girth weld clearly showed that the root pass has several imperfections. The most significant was the unrepaired burn-through. The short segments of lack of fusion were also significant. However, only the lack of penetration was associated with the crack and it is unlikely this imperfection alone would have resulted in a through-wall failure.

Laminations are considered defects by API when they are present in the weld bevel because they are a source of welding imperfections. When the weld pool contacts a lamination, the liquid metal picks up impurities and gases which are often deposited in the weld when it solidifies. This is believed to have occurred in this girth weld. The hot pass and first fill pass imperfections were created by the lamination, and further reduced the integrity of the girth weld. The compromised weld likely cracked during laying of the pipeline into the open ditch, at which time large bending stresses are often created. The gas test following construction, which is the highest hoop stress the pipeline likely experienced, could have contributed to or caused additional crack extension.

Once the pipeline was in place and back-filled, residual stresses in the pipeline would have depended on all the prior activities and how well the pipe fits the ditch and how the ditch is back-filled. After back-filling, the soil would have consolidated around the pipeline, which would likely change the stresses in the girth weld once more. Each of these phases of construction could have created or lengthened the crack.

It is not possible to determine exactly when each phase of the cracking occurred. The erosion of the pipe adjacent to the cap is unusual and suggests that a leak had been present for some time. Hydrostatic testing before placing a pipeline in service is effective in finding leaks resulting from construction. The gas test used in this case would not be as effective and is not effective at finding small leaks. There is also a narrow band of what appears to be recent crack extension. This crack extension allowed additional gas to leak, apparently allowing sufficient gas to migrate to the surface to be detectable. This most recent crack extension occurred following record drought for several months followed by a short period of heavy rain which was reported in the region. Changes in moisture content in the soil are known to increase stresses on pipelines, and may have caused the recent crack extension.

The SEM examination confirmed that the cracking occurred in at least two phases. The first phase occurred several years ago. This conclusion is supported by the smooth fracture appearance seen on the fracture surface and confirmed in the SEM. The second phase of cracking occurred very recently. This is again confirmed by SEM examination.

The failure examined here is typical of most in-service girth-weld failures. Girth welds fail as a result of longitudinal forces that are most often caused by bending. These welds then leak in service and are found during operation. The length of time before they are detected is primarily a function of the size of the leak. It seems likely that this leak was initially very small and difficult to detect. Later, environmental conditions changed the stresses on the girth weld and extended the crack, creating the leak that was detected.

CONCLUSIONS

The following conclusions are offered based on SES's investigation of the girth-weld failure:

1. The leak in the girth weld was a result of imperfections created during welding at the time the pipeline was constructed.
    a. The most significant imperfections were those found in the hot pass and first fill pass.
    b. Imperfections in the root bead may also have contributed to the failure.
2. The majority of the crack was formed many years ago. This conclusion is supported by the following observations:
    a. The observed erosion of the pipe surface would likely require many years of flow.
    b. The fracture surface examined both visually and with the SEM showed extensive time-dependent degradation.

Figure 1. Photograph of pipe Sample 1 as received, containing the girth weld that leaked. Scale shown is in inches.

Figure 2. Photograph of pipe Sample 2 as received. Scale shown is in inches.

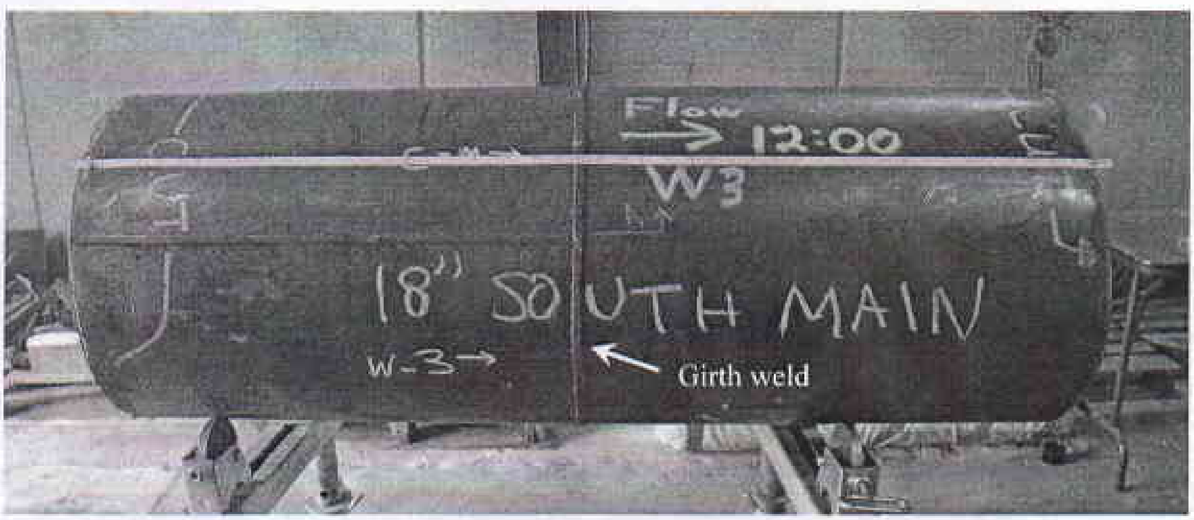

Figure 3. Photograph of pipe Sample 3 as received. Scale shown is in inches.

Figure 4. Photograph of area that appears to be eroded adjacent to the girth weld. Scale shown is in inches.

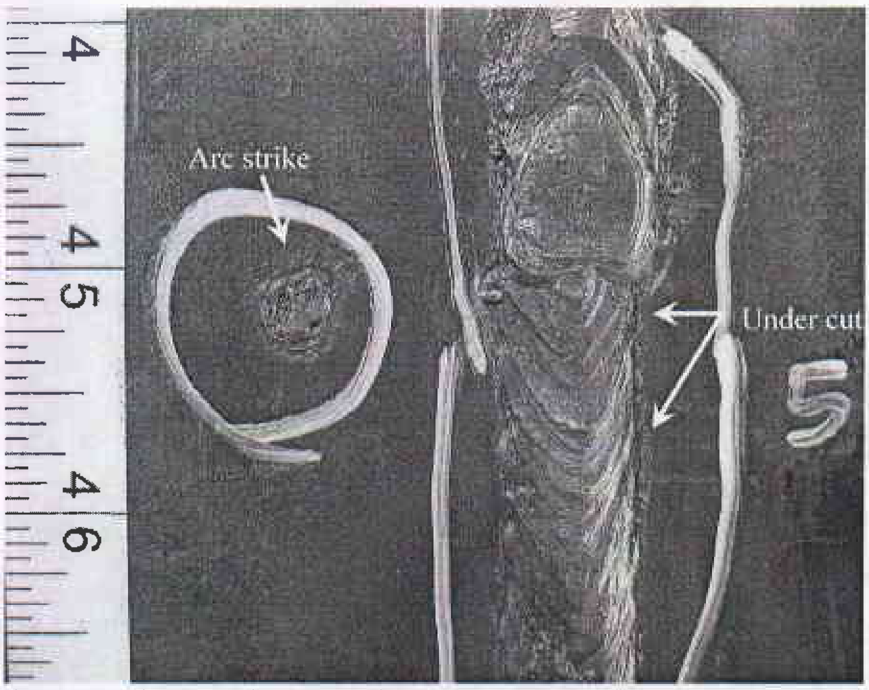

Figure 5. Photograph of Sample 1 showing workmanship imperfections (under-cut and arc-strike of weld). Scale shown is in inches.

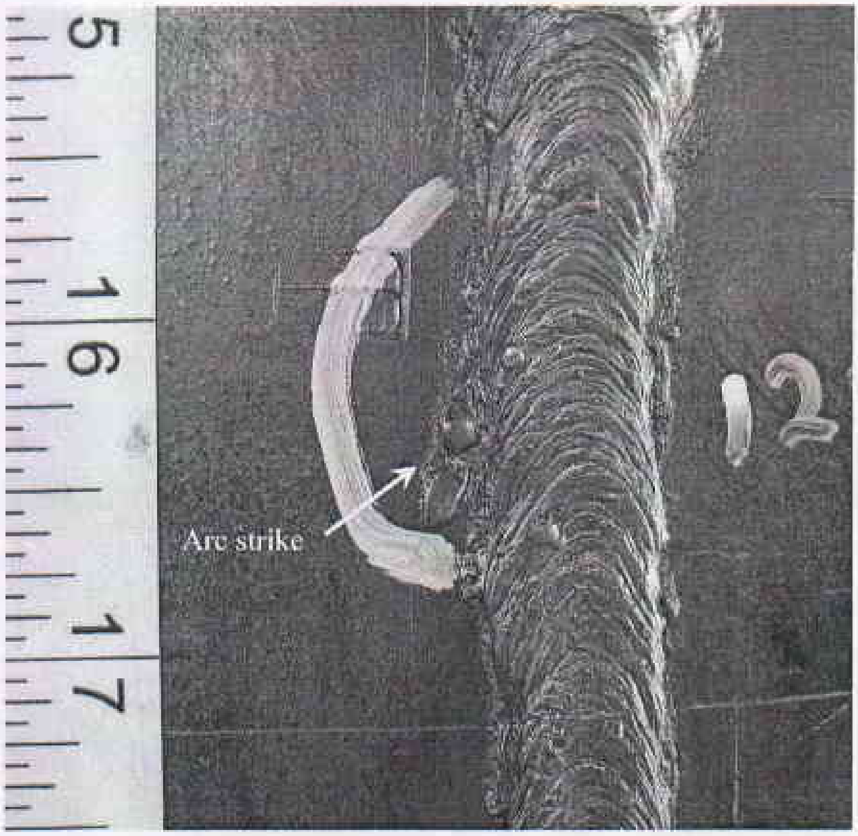

Figure 6. Photograph of Sample 1 showing workmanship imperfection (arc-strike of weld). Scale shown is in inches.

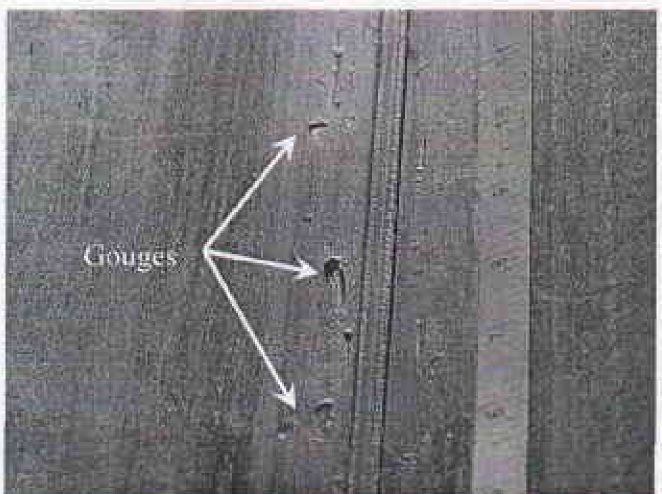

Figure 7. Photograph of Sample 1 imperfections in pipe adjacent to long seam weld. Scale shown is in inches.

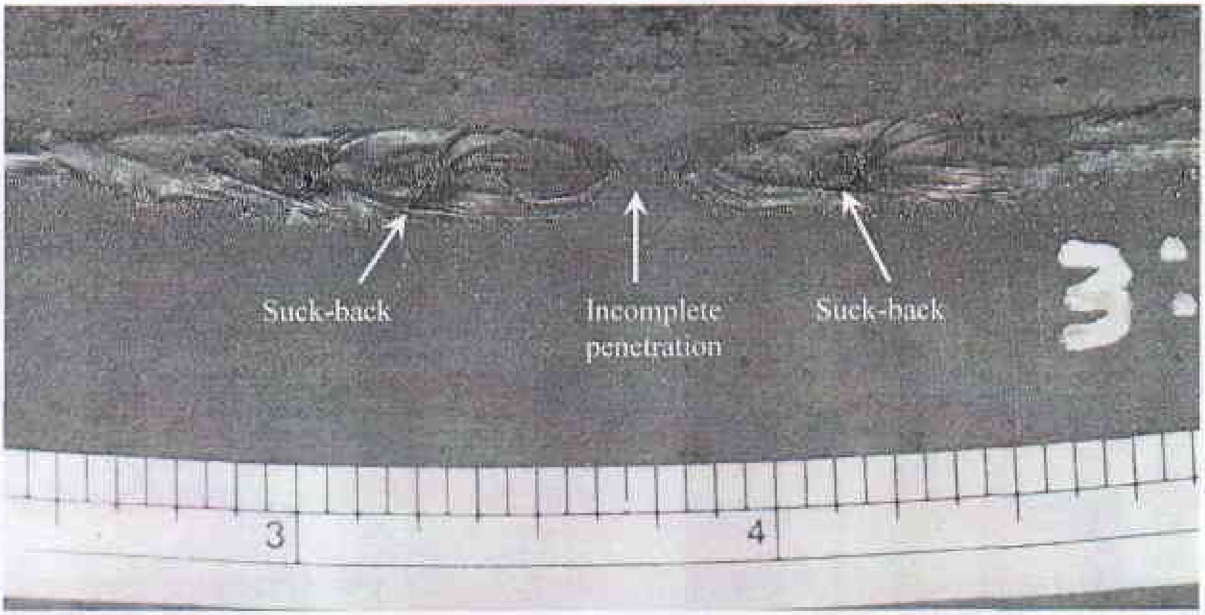

Figure 8. Photograph of root of girth weld in Sample 1. Lack of penetration is clearly visible. Scale divisions are 1/16th inch.

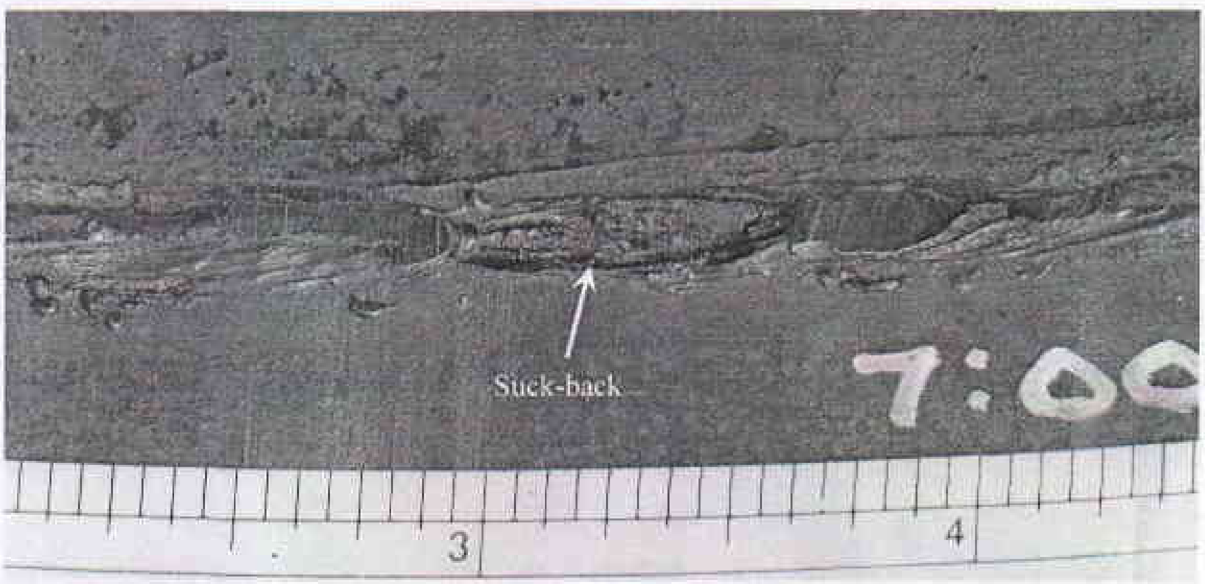

Figure 9. Photograph of root of girth weld in Sample 1. "Suck-back" is clearly visible. Scale divisions are 1/16th inch.

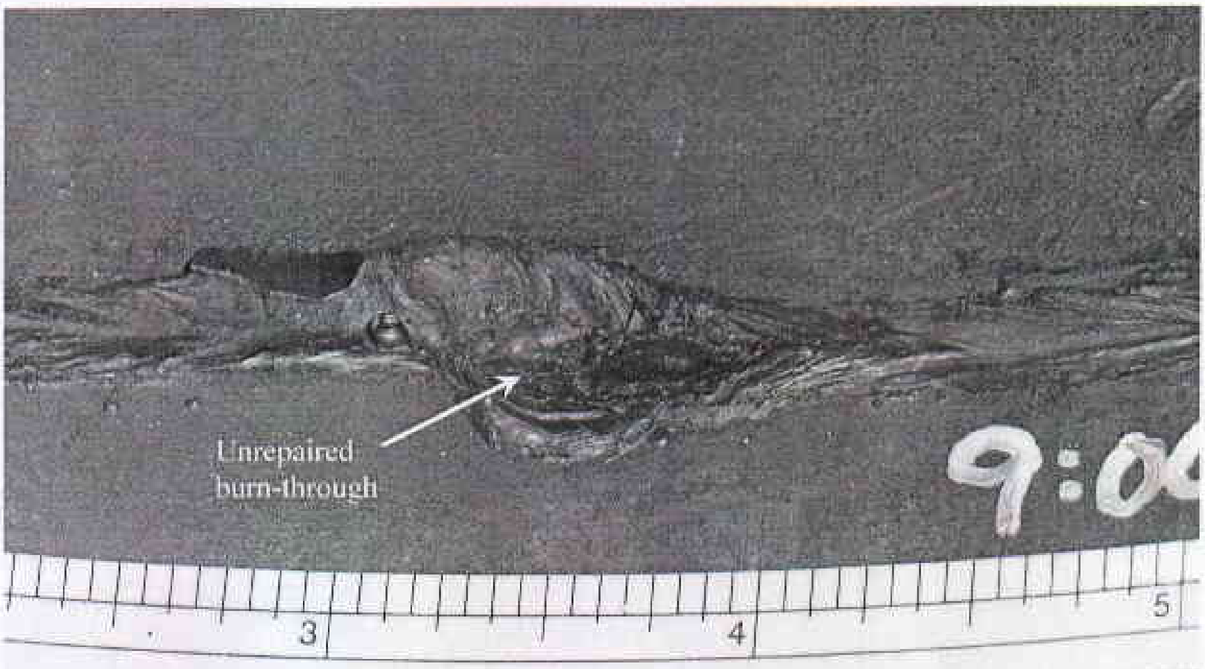

Figure 10. Photograph of root of girth weld in Sample 1. Unrepaired burn-through is clearly visible. Scale divisions are 1/16th inch.

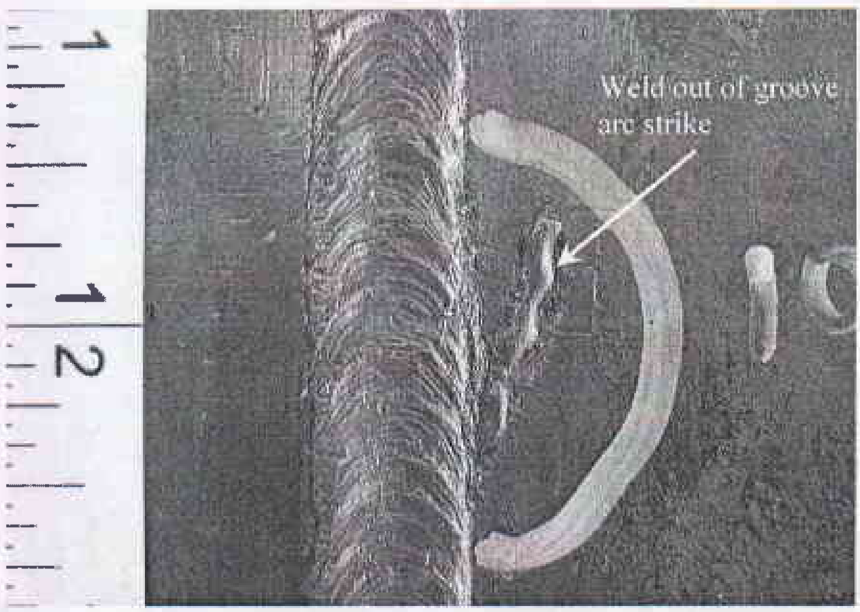

Figure 11. Photograph of root of girth weld in Sample 2. Arc-strike or out of groove weld is clearly visible. Scale divisions are 1/16th inch.

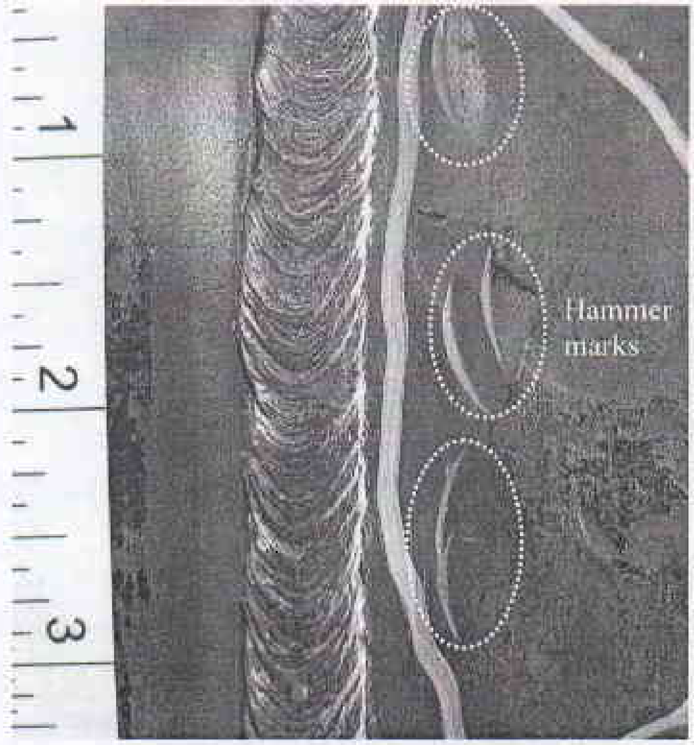

Figure 12. Photograph of root of girth weld in Sample 2. Hammer marks are clearly visible. Scale divisions are 1/16th inch.

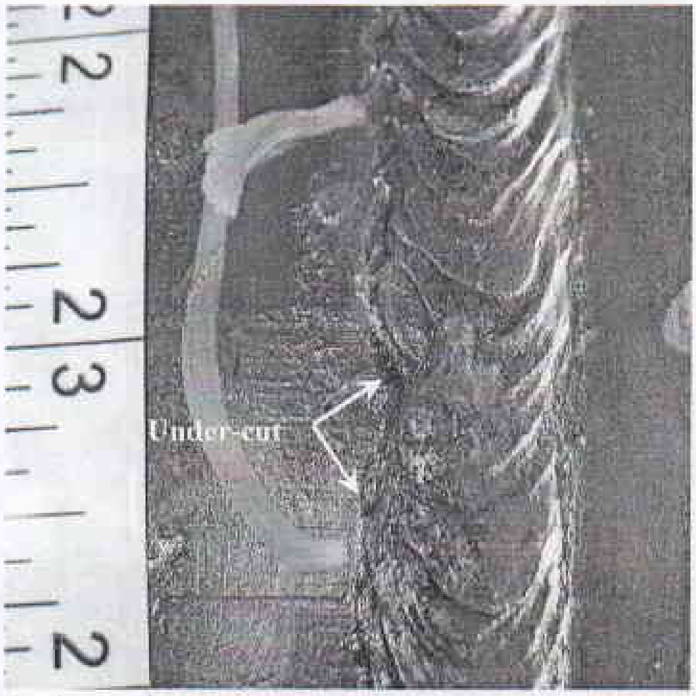

Figure 13. Photograph of root of girth weld in Sample 2. Under-cut is clearly visible. Scale divisions are 1/16th inch.

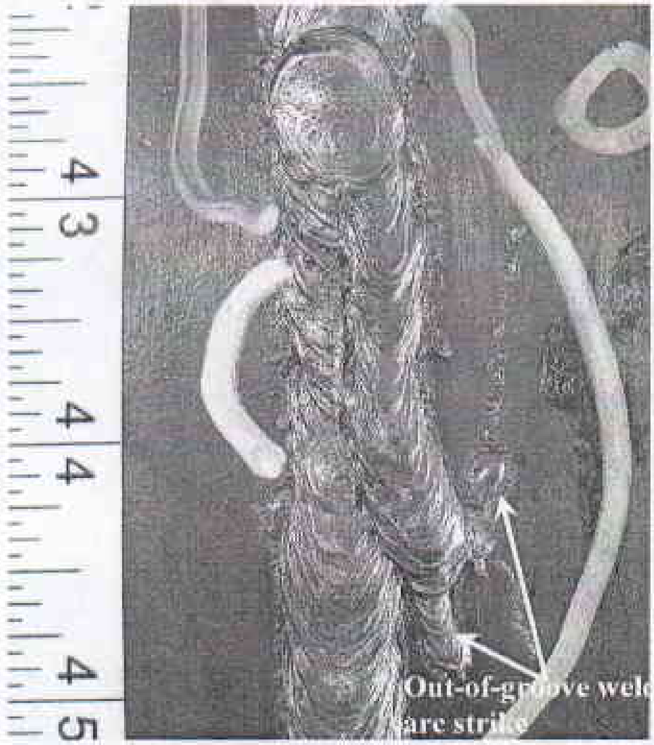

Figure 14. Photograph of root of girth weld in Sample 3. Arc strike and out-of-groove weld are clearly visible. Scale divisions are 1/16th inch.

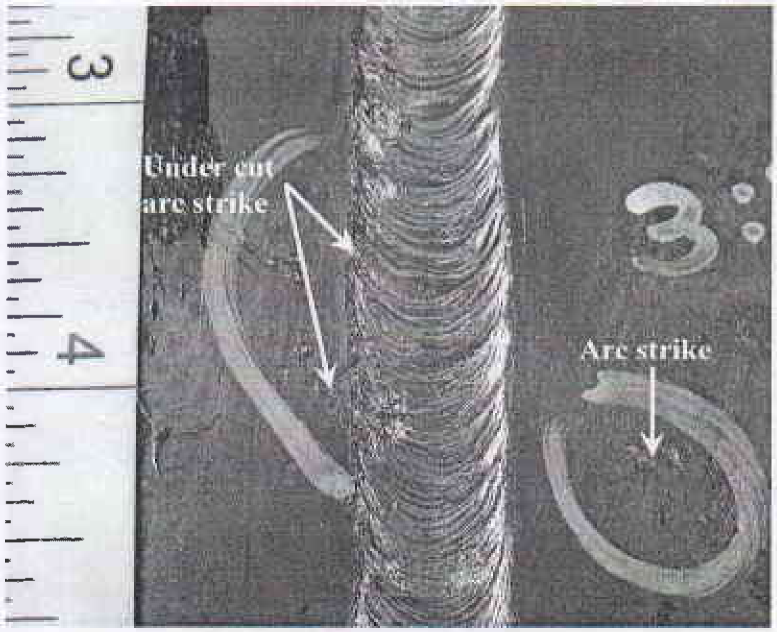

Figure 15. Photograph of root of girth weld in Sample 3. Arc strike and under-cut are clearly visible. Scale divisions are 1/16th inch.

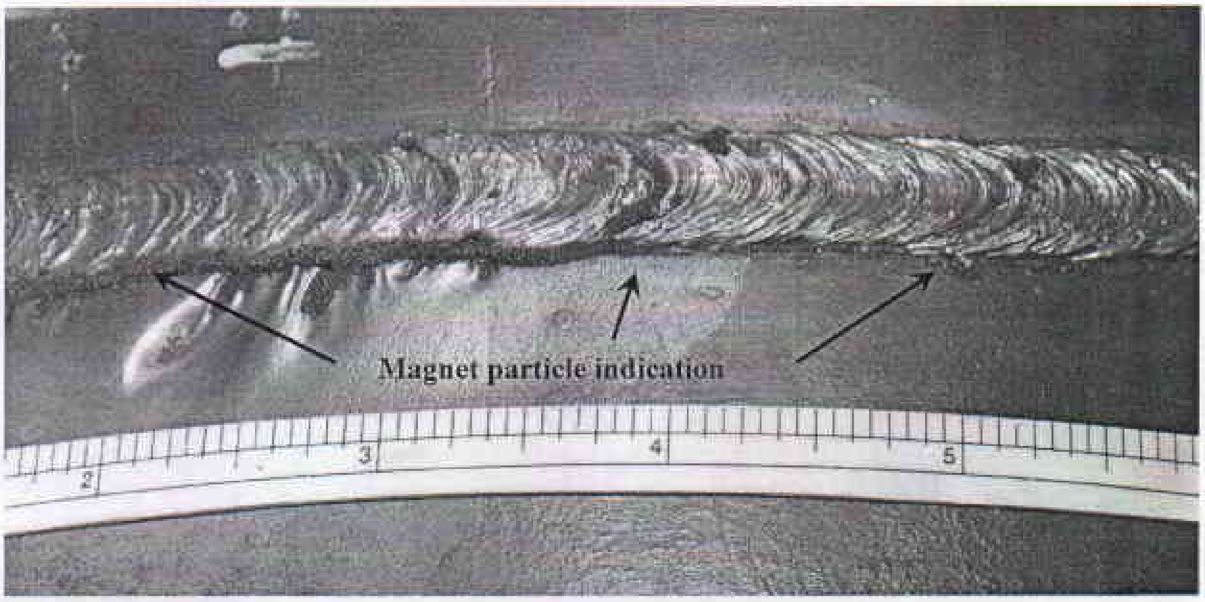

Figure 16. Photograph showing magnetic particle indication of crack-like indication on OD of Sample 1. Scale divisions are 1/16th inch.

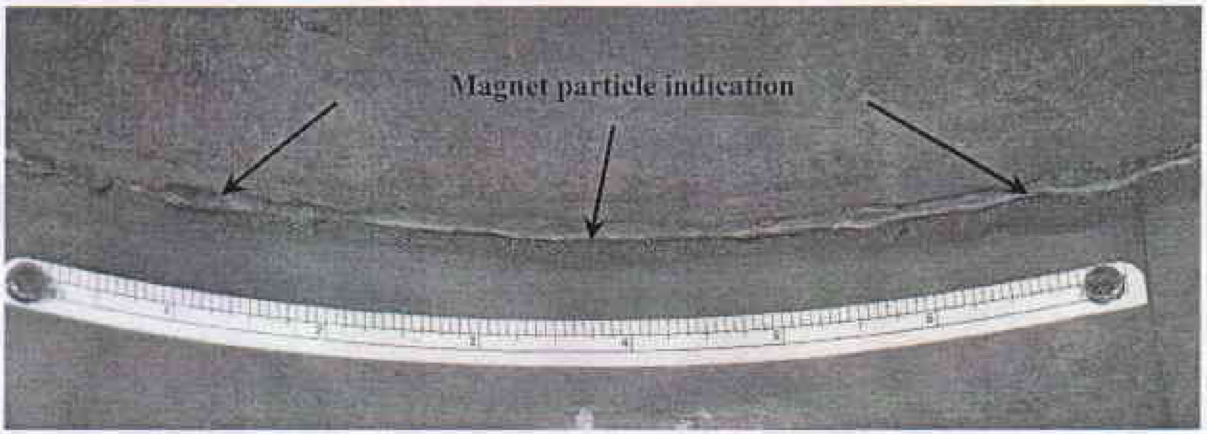

Figure 17. Photograph showing magnetic particle indication of crack-like indication on ID of Sample 1. Scale divisions are 1/16th inch.

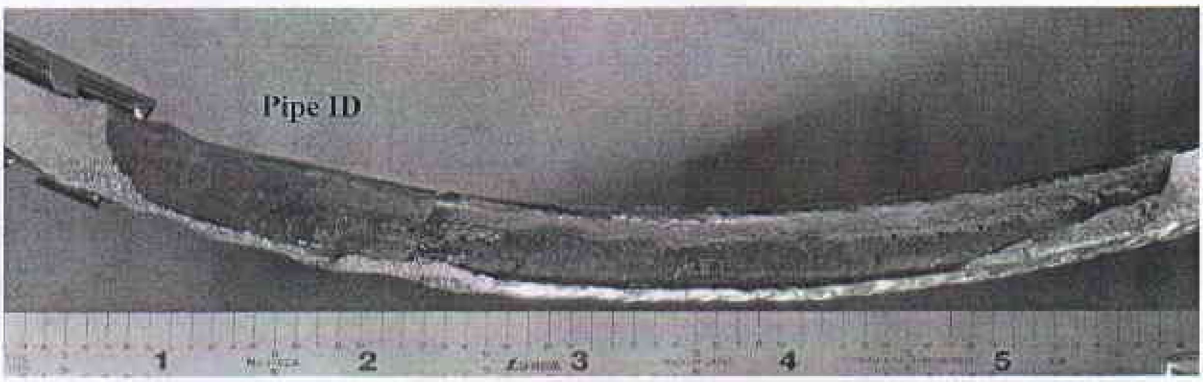

Figure 18. Photomacrograph showing fracture after crack was broken open. Scale divisions are 1/10th inch.

Figure 19. Photomacrograph showing fracture after crack was broken open. Scale divisions are 1/10th inch.

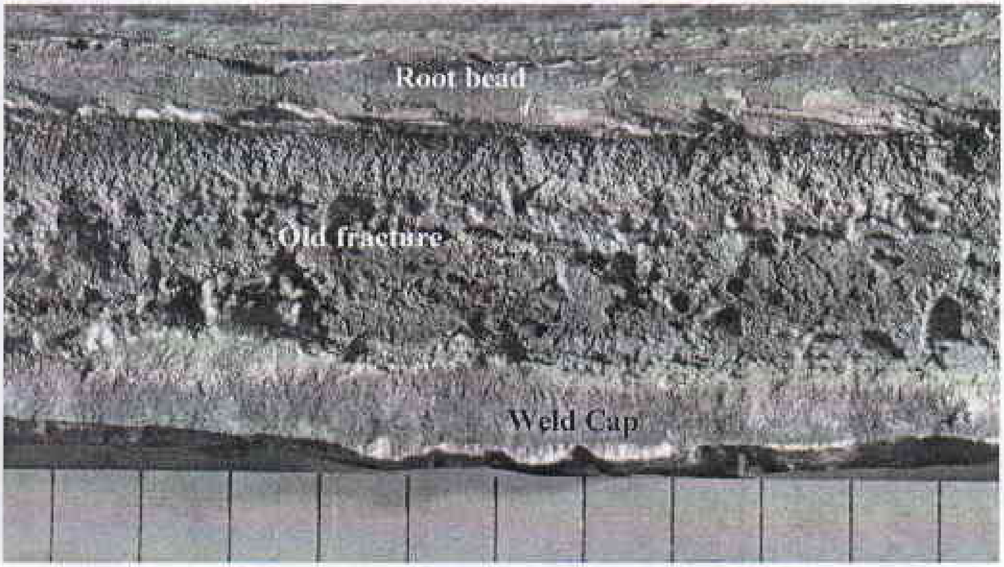

Figure 20. Photomacrograph showing fracture after crack was broken open and before cleaning. Scale divisions are 1/10th inch.