Duke Energy®
Gas Transmission

METALLURGICAL ASSESMENT OF OWINGSVILLE LINE 15 FOR HARD SPOTS

NOVEMBER 10, 2004

PREPARED BY:
Gary Vervake
Sr. Metallurgical Engineer
Metallurgical Services & QA

APPROVED BY:
Steve Rapp, P.E.
Mgr. Metallurgical Services & QA

PLD19FR002 – Danville – NTSB009893

EXECUTIVE SUMMARY

On November 2, 2003 an in-service failure occurred in Duke Energy's Texas Eastern natural gas line 15. The failure occurred on the discharge side of the Danville compressor station at Mile Post (M.P.) 501.76. Metallurgical investigation determined that the incident was the result of hydrogen-induced cracking that initiated at the O.D. surface of the pipe in a hard spot that was coexistent with a lamination. As a result of the incident, in-line inspection for hard spots was scheduled for Line 15 from Owingsville to Wheelersburg.

In-line inspection with Tuboscope's hard spot detection tool was performed on June 29, 2004. However, due to sensor malfunction and data loss, a second ILI run was conducted on July 3, 2004 and 100% coverage was achieved. DEGT's Metallurgical Services specified to Tuboscope the following anomaly grading criteria based on Brinell hardness so that the ILI data could be ranked according to hard spot property severity:

- Grade 3 = Hardness of 301 Brinell and above
- Grade 2 = Hardness of 251 to 300 Brinell
- Grade 1 = Hardness of 200 to 250 Brinell

As a point of reference, hardness values greater than 327 Brinell exceed the acceptance limit for the current API 5L line pipe specification. The Tuboscope report indicated 11 hard spot anomalies in total, all with estimated hardness less than 260 Brinell. Upon physical hardness measurement, no values were measured to be greater than 260 Brinell. From the results of this ILI survey, there should be no integrity concern for hard spot defects. Even the hard spot anomalies removed as part of this investigation posed no structural integrity concern to the pipeline.

Tuboscope assessed the ILI data and determined that Owingsville Line 15 contained 11 hard spot anomalies, in 3 separate joints of pipe. One joint of pipe contained four Grade 2 hard spots anomalies and five Grade 1 hard spot anomalies. The other two joints of pipe each had one Grade 2 hard spot anomaly. The pipe sample containing the 9 hard spot anomalies, and one of the joints with a single anomaly were removed from service and submitted to DEGT's Metallurgical Lab in Houston for assessment.

Metallurgical assessment of the hard spot anomalies consisted of removal of the external coating, and blast cleaning of the pipe surface. The location of each hard spot anomaly was established based on Tuboscope's ILI report of distance and clock position data. A grid pattern was marked at each location, and Telebrinell hardness testing was performed to verify the presence of the hard spots. At each location, Telebrinell testing did detect regions of increased hardness with respect to the normal hardness of the pipe body. Microdur hardness testing, utilizing ultrasonic contact impedance principles, was performed at the Telebrineller test locations. The Microdur testing was performed in order to assess this technology for field hardness testing. Upon completion of the hardness testing, the hard spot regions of 200 Brinell or greater were marked for documentation. Three regions containing the highest hardness readings were sectioned from the pipe for metallographic and Vickers hardness testing.

Metallographic examination and Vickers testing of through thickness cross sections was performed in selected regions of three hard spot anomalies. Vickers testing was also performed on each metallographic cross section in order to reliably establishing the actual hardness properties of the material. Two hard spot anomalies had bainitic/martensitic microstructures indicative of a quenched and hardened steel material. At these two hard spot anomalies, the Vickers microhardness properties were relatively high (255 and 223 Brinell) with respect to the normal pipe body hardness (165 to 180 Brinell). At these two locations, the ILI hardness estimate data was found to be off by approximately 1% and 11% of from the Vickers hardness.

Based on the assessment of field hardness test data, and laboratory examination and test data, it was concluded that Tuboscope's ILI hard spot tool accurately and reliably detected the presence of hard spots. The tool accurately identified the location (distance and clock position), and accurately estimated the hardness properties of the hard spots. The hard spot hardness properties were below the current API 5L workmanship standard limit, and well below the level of hardness (300 Brinell) at which the steel would be at risk for hydrogen induced cracking.

The third hard spot metallographically examined had a pearlitic microstructure, consistent with the normal pipe body. The Vickers microhardness of this region was also consistent with the pipe body. It was concluded that the ILI tool provided a false positive hard spot indication for this anomaly.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on the results of this ILI survey, it was concluded that there should be no integrity concern for hard spot defects in Owingsville Line 15.
2. Hardness testing and metallographic examination confirmed that the Tuboscope ILI hard spot tool data was reasonably accurate in identifying the location and hardness of hard spots in DEGT's Owingsville Line 15.
3. Telebrineller and Microdur field hardness testing in accordance with recognized standards are reliable methods for assessing the hardness properties of line pipe steel. This conclusion was based on comparison of the field hardness data with Vickers microhardness test results.
4. All 10 of the hard spots that were located and examined had hardness properties less than 327 BHN, and therefore, have properties that are acceptable in accordance with current API 5L workmanship and defect requirements.
5. No evidence of cracking was detected during MT inspection of the hard spot with the highest hardness. As a result, it was concluded that hydrogen induced cracking was not an integrity threat at each of the hard spot locations.
6. It was concluded that the ILI hard spot tool data was reliable in detecting hard spots, and accurate in measuring the hardness and location of the hard spots that were detected. This conclusion is based on a comparison of dimensional measurements, the

actual Vickers hardness properties of the hard spots, the Telebrineller and Microdur data, and the Tuboscope Hard Spot tool data,

7. Based on these findings, no direct examination is required of the hard spot at 57185.70 ft. near MP 513.4208, and the hard spot may be considered to be acceptable in accordance to current API 5L workmanship standards. ILI data indicated that the hard spot at that location had a maximum hardness of 258 BHN. The confidence level in this data is high based on the findings in this report.

BACKGROUND

On November 2, 2003 an in-service failure occurred in Duke Energy's Texas Eastern natural gas line 15. The failure occurred on the discharge side of the Danville compressor station at Mile Post (M.P.) 501.76. This section of the line was constructed of 30" O.D. x 0.375" W.T., API Grade X52 line pipe manufactured by A.O. Smith. Metallurgical investigation determined that the incident was the result of hydrogen-induced cracking that initiated at the O.D. surface of the pipe in a hard spot that was coexistent with a lamination. According to industry research, a hard spot anomaly or defect can be created in one of two ways: either by locally quenching the skelp immediately following the hot-rolling operation or by reheating a small area of the skelp or pipe during the manufacturing or installation of the pipe.[1] As a result of the incident, DEGT scheduled in-line inspection of Line 15 from Danville to Wheelersburg.

On June 29, 2004 DEGT conducted in-line inspection of Line 15 with Tuboscope's hard spot inspection tool. See Figures 1 and 2. During the ILI run, above ground markers were placed at 1 mile intervals and the progress of the tool was closely monitored to assure that the speed remained within vendor specified limits. Upon completion of the ILI run on June 29, vendor personnel determined that 3 sensors had failed, resulting in a loss of loss of signal. In order to obtain complete coverage around the entire circumference of the pipeline, a second ILI run was performed on July 3, 2004 and preliminary assessment of the tool condition and data indicated that the ILI run was successful.

The Tuboscope hard spot tool is based on magnetic flux leakage detection technology. The inspection tool operated by inducing a magnetic field into the pipe wall to the point of saturation, immediately introducing a demagnetizing force, and then scanning the pipe wall for active and residual magnetic fields. Hard spots that were present retained a higher level of magnetism with respect to the standard pipe steel. The residual field detectors in the tool were used to measure the residual magnetic fields, and document the location (distance and clock position) and magnitude of the localized regions of high residual magnetism. The vendor then performed further assessment of the data to convert the residual magnetism to an estimated Brinell hardness value. The vendor reported an accuracy of +/-50 Brinell for the hardness estimation.

Prior to the ILI data assessment, DEGT Metallurgical Services Section developed a preliminary Hard Spot Assessment Plan. See Appendix 1. Based on industry documentation of hard spot behavior, a reporting criteria based on Brinell hardness properties was established. The hard spots were to be graded in the following manner:

- Grade 3 = Hardness of 301 Brinell and above
- Grade 2 = Hardness of 251 to 300 Brinell
- Grade 1 = Hardness of 200 to 250 Brinell

Furthermore, magnetic particle inspection was to be performed on hard spots greater than 300 Brinell, and further classified of the hard spot integrity was to be based on the presence or absence of cracks.

Assessment of the ILI data was performed by the vendor, and 11 hard spots in 3 separate joints of pipe were found to meet the reporting criteria. The ILI data indicated that all of the hard spots had hardness properties between 244 and 258 Brinell. One joint located at MP 530.12 contained 9 hard spot indications, and the other two joints located at MP 513.42 and MP532.89 each joint contained one hard spot indication. Comparison of the data with historical records revealed that 2 of the joints with hard spots were manufactured by A.O. Smith in 1957, and the other joint with a single hard spot was manufactured by National Tube. The two pipe joint samples manufactured by A.O. Smith were removed from service from MP 530.12 and MP 532.89, and were submitted to DEGT's Metallurgical Lab for assessment. The data from the physical testing of the samples was used to determine if examination of the remaining hard spot samples was required.

DISCUSSION

Metallurgical examination of the hard spot samples revealed that the Tuboscope data was reasonably accurate in identifying the spatial location of the hard spots, and in predicting their hardness properties. Microhardness testing and metallography confirmed the presence of two of the hard spots. These tests also revealed that one of the hard spots identified by ILI was a false positive. The maximum hardness as determined by Vickers testing was found to be 255 Brinell. This is well below the estimated maximum achievable hardness for this steel based on composition. This low level of hardness for the hard spots can be attributed to the relatively low cooling rates that each hard spot may have encountered when they were formed. All of the hardness testing confirmed that the hardness properties of each hard spot was less than 327 BHN, which is the current workmanship standard limit for hard spots in API 5L. As a result, all of the hard spots that were examined would be considered to be acceptable by modern industry standards. Based on these findings, direct examination of the remaining hard spot at 57185.70 feet is not required, and there should be no integrity concern for hard spot defects in Owingsville Line 15.

ANALYSIS

Visual Examination

The two pipe samples removed from Owingsville Line 15 are shown in Figure 3. Field personnel had identified each sample by paint marking the mile post, station number, and footage information on the I.D. surface of each sample. The flow direction and 12 o'clock position were labeled with flame cut arrows on each sample. One sample was approximately 25' long, and had been removed from M.P. 530.12 (SS 27990+26.7). The other sample was approximately 15' long, and had been removed from M.P. 532.89 (SS 28136+77.5) Upon removal of the pipe coating, the pipe surface was examined and found to have a normal rounded contour with no visible regions of distortion (i.e. flattened areas). The ILI hard spot tool data provided by Tuboscope was used to identify the location of the hard spot regions. Each location was marked, and a grid pattern was transferred to the pipe for general guidance during the initial phase of the hardness testing. For the convenience of discussion within this report, each hard spot anomaly identified by Tuboscope was labeled as follows:

A. Distance = 145533.55 ft., 10:15 o'clock position, 8.26 ft. from upstream girth weld.
B. Distance = 145535.43 ft., 02:00 o'clock position, 10.13 ft. from upstream girth weld.
C. Distance = 145536.09 ft., 11:45 o'clock position, 10.80 ft. from upstream girth weld.
D. Distance = 145536.10 ft., 03:05 o'clock position, 10.81 ft. from upstream girth weld.
E. Distance = 145537.02 ft., 07:00 o'clock position, 11.73 ft. from upstream girth weld.
F. Distance = 145537.03 ft., 02:50 o'clock position, 11.74 ft. from upstream girth weld.
G. Distance = 145537.64 ft., 07:50 o'clock position, 12.55 ft. from upstream girth weld.
H. Distance = 145540.83 ft., 06:15 o'clock position, 15.54 ft. from upstream girth weld.
I. Distance = 145542.73 ft., 02:50 o'clock position, 17.44 ft. from upstream girth weld.
J. Distance = 160230.41 ft., 02:50 o'clock position, 0.81 ft. from upstream girth weld.

Hardness testing of the pipe surface was first performed using the Telebrineller method, ultrasonic contact impedance (UCI) testing was then performed at the Telebrineller test locations, and finally Vickers microhardness testing was performed on selected regions on three hard spots.

Hardness Testing

Hardness can be defined as the steel's resistance to penetration. The hardness properties of the pipe samples were evaluated by two indention types of tests (Brinell and Vickers). The Brinell hardness measurements were achieved by using the Telebrineller method. See Figure 4. The Vickers tests were performed with the Microdur ultrasonic contact impedance (UCI) and standard microhardness testing methods performed on metallographic samples. Microdur testing represents field hardness tests using ultrasonic principles. See Figure 5. Vickers tests performed on the metallographic samples represent the most accurate method for assessing the actual steel hardness properties. The ILI data and field hardness test data were compared to the Vickers hardness results to determine the accuracy of each method. Table 1 provides a side by side comparison of the data. The results of the hardness tests performed at each hard spot are presented in Tables 2 through 11. Each of the hardness test methods are described below:

- Telebrineller – Telebrineller hardness testing was performed in accordance with ASTM A833 requirements. The Telebrineller test instrument was comprised of a test bar of known hardness, the anvil, rubber head and resting block, impression ball and hammer. The hardness test was performed by sharply striking the anvil with a hammer. As a result simultaneously creating an impression in the test bar and pipe surface. The Brinell hardness of the pipe was determined by measurement and comparison of the diameters of the impressions on the pipe and test bar.

At each location that Tuboscope identified, the Telebrineller method did locate a region with greater relative hardness when compared to the normal hardness of the pipe. See Figures 6 through 11. The Telebrineller test method reliably determined the hardness properties at each test location, and this test data was the primary means for identifying the boundaries of the hard spot at each location. Regions of hardness greater than 200 Brinell were classified as “hard spot” regions. The agreement between the ILI data and the Telebrineller data was found to vary between approximately 1% and 13%.

- Ultrasonic Contact Impedance (UCI) – Brinell hardness properties were further evaluated at each of the 10 hard spot locations using a MICRODUR instrument. The Microdur tester is based on ultrasonic contact impedance (UCI) principals, which are based on the relationship between the ultrasonic frequency and the size of the Vickers micro-indention. The instrument consists of a Vickers diamond attached to the end of a metal rod. The rod is excited into a longitudinal oscillation (approximately 70 kHz) by piezoelectric transducers. During the hardness test the frequency shift is measured and correlated to a Vickers hardness value. The frequency shift is proportional to the size of the test indention produced by the Vickers diamond. A lower hardness steel results in a larger impression and a larger shift in frequency. In the case of a hard spot, the impression is smaller, and the frequency shift is not as large.

  The Microdur instrument generated hardness readings that were significantly lower than the Telebrineller method. However, the Microdur results appeared to agree reasonably well with the actual Vickers hardness data.

- Vickers Microhardness Testing - Vickers microhardness testing was performed in accordance with ASTM E92 requirements. Vickers tests involved a small diamond penetrator that relied on optical evaluation of the indention were also performed on metallographic cross sections of selected areas in three hard spots. Vickers microhardness data provided the most reliable method for assessing the actual hardness properties of the steel at the selected locations. The testing was performed on metallographic cross sections from hard spots “A”, “C” and “H”. The Vickers hardness, or actual steel, properties for hard spots “C” and “H” were found to be in close agreement with the Telebrineller, ILI and Microdur data. Hard spot “A” properties as established by Vickers testing was in close agreement with the Microdur data, but not with the ILI and Telebrineller data. This indicated that hard spot “A” was a false positive indication.

Metallographic Examination

Metallographic examination was performed on selected regions of the hard spots “A”, “C”, and “H”. Each hard spot region will be discussed below:

- Hard Spot “A”– Seven metallographic cross sections from the region were prepared for metallographic examination. Four of the sections were removed from Telebrineller test locations indicating the presence of a hard spot, and the remaining three were removed from outside the hard spot region. All of the metallographic cross sections had a pearlitic microstructure, indicative of typical pipeline steel. See Figure 12. The microstructure was free of features that would indicate the presence of a hard spot. The Vickers hardness properties for each of these mounts were consistent with the pipe body properties.

- Hard Spot at “C” – Nine metallographic cross sections from the region were prepared for metallographic examination. Six of the sections were removed from Telebrineller test locations indicating the presence of a hard spot, and the remaining three were removed from outside the hard spot region. The metallographic cross sections from within the hard spot region had a bainitic/martinsitic microstructure indicative of quenched and hardened steel. See Figure 13. The cross sections outside of the hard spot region had pearlitic microstructure, indicative of typical pipeline steel. In each case, the microstructure was consistent with the Vickers properties for each of the mounts.
- Hard Spot at “H” – Six metallographic cross sections were removed from Telebrineller test locations indicating the presence of a hard spot. These metallographic cross sections had bainitic/martinsitic microstructures indicative of quenched and hardened steel. See Figure 14. The Vickers hardness properties for each of these mounts were found to be relatively high when compared to the normal pipe body hardness.

Ultrasonic Wall Thickness Measurement

The wall thickness was measured at each hard spot location using a UT thickness gauge. The actual wall thicknesses were in close agreement with the nominal wall thickness for the pipe. No evidence of lamination was observed during the UT wall thickness measurements.

Magnetic Particle Inspection

Dry magnetic particle inspection was performed on the hard spot “C”. MT was performed at this location because the ILI and field hardness testing had determined that this region had the highest hardness properties (252 to 260 BHN). Although the hardness properties were well below the 300 BHN criteria in the assessment protocol, the inspection was performed in order to verify that cracking was not present. No evidence of cracking was detected during MT inspection, and as a result, it was concluded that hydrogen induced cracking was not an integrity threat at each of the hard spot locations.

Mechanical Testing

Tensile testing was performed on a sample of a transverse sample removed from the sample identified as MP 530.12. See Table 12. The pipe met the mechanical property requirements for API 5LX (6^{th} ed., 1956) Grade X52 requirements.

Composition Characterization

Optical emission spectroscopy (OES) analysis revealed that the composition of the pipe sample from MP 530.12 met API Grade X52 requirements. See Table 13. Based on the composition, the pipe steel was found to have a carbon equivalent of 0.45 (IIW formula). Carbon steel with this composition can be estimated to have a maximum achievable hardness of approximately 514 to 650 Brinell (Rockwell 53 to 60 HRC).

[1.] NG-18 Report 131, “Summary of Field Failure Investigations”, Field Failure Investigation No. 29, “Failure in 30” Diameter Pipeline Due to Hard Spot”, page 2-27.

APPENDIX 1

OWINGSVILLE LINE15 HARD SPOT ASSESSMENT PLAN

Owingsville Line 15 Hard Spot Assessment Plan

June 28, 2004

Outline

1. Overview
2. Specific Requirements to Tool Vendor
3. Any Special Needs for ILI Execution
4. Log Interpretation
    a. Description of data provided by ILI tool
        i. Site Data
        ii. Hard Spot data
        iii. Criteria for Assessing Severity of Hard Spot
            1. Hardness, Distribution (Cluster or Isolated) and Location (Inside Waiver Area, Outside Waiver Area).
5. Selection and Prioritization of Dig Sites
    a. Ranking Criteria
6. Bell Hole Examination Procedures for Hard Spots
    a. Prior to Excavation
        i. Reduce Operating Pressure 80% of past 90 day MOP.
        ii. Pipe-to-Soil Potential Measurements
    b. Hard Spot Evaluation Procedure After Excavation
        i. Excavate
        ii. Record Field Site Data
        iii. Coating Removal
        iv. Visual Inspection
        v. Magnetic Particle (MT) Inspection
        vi. Ultrasonic Wall Thickness Survey
        vii. Hardness Testing and Dimensional Documentation
    c. Hard Spot Repair Recommendations
        i. Pipe with Hardness Properties Less Than 300 HB
            1. Carefully Re-Coat
        ii. Hard Spots with Hardness Between 301 and 400 HB (No Cracking)
            1. Replacement
            2. Pressure Containing Sleeve
            3. Reinforcing Sleeve
        iii. Hard Spots with Evidence of Cracking (301 and greater)
            1. Replacement
            2. Pressure Containing Sleeve
        iv. Hard Spots with Hardness Greater than 401 HB with No Cracking Present
            1. Replacement
            2. Pressure Containing Sleeve
7. Technical Support

1. Overview

   An in-line inspection (ILI) of Line 15 will be performed with the Tuboscope ILI Hard Spot (HS) tool as part of the remediation following the in-service break at MP 501.76 on November 1, 2003. The following assessment plan has been developed in order to methodically assess the data generated by the tool, and perform bell hole inspections of those sites that the ILI tool identifies as possibly having hard spots that could impair the serviceability of the pipeline.

2. Specific Requirements to Tool Vendor

   Tuboscope will perform in-line inspection of the 30" O.D. x 0.375" W.T., API Grade X52, Owingsville Line 15 owned by Duke Energy Gas Transmission. The ILI is to be performed using the High Resolution MFL inspection tool modified with the Hard Spot (HS) Tool package. Specific requirements for performing the ILI tool run have been incorporated in the current contract (98-H-005) with Tuboscope.

3. Special Needs for ILI Execution

   There are no special needs that need to be addressed prior to running the inspection tool.

4. Log Interpretation

   The inspection log shall reference the following:

   - Pipeline Section Surveyed
   - Line Size and Number
   - Survey Date
   - Tuboscope Job Number
   - Run Number
   - Tuboscope Pipeline Inspector
   - Tuboscope Survey Analyst

   The inspection log shall identify each anomaly by wheel count (feet) and clock position. It shall also note the distance to the upstream and downstream girth welds.

The ILI HS tool log will provide pipe hardness values using the Brinell scale (HB). According to the vendor, all hard spots with hardness equal to or greater than 235 HB, with an accuracy tolerance of +/-50 HB will be reported. The hardness data will then be graded by the ILI contractor and reviewed by DEGT personnel according to the scale shown below:

a. Grade 3 = Hardness of 301 Brinell (HB) and above
b. Grade 2 = Hardness of 251 to 300 HB
c. Grade 1 = Hardness of 235 to 250 HB (24HRC)

Metallurgical Services personnel will then evaluate grading assessment and determine if the proposed criteria appropriately discriminates the data, and if further refinement of the criteria may be needed.

The grading criteria shown above is based on API 5L requirements and PRCI research. API 5L states that any hard spot greater than 2" in any direction and a hardness greater than or equal to Rockwell 35 HRC (327 Brinell) shall be rejected.[1] Also, the PRCI Repair Manual states that hardness properties less than Brinell 327 (Rockwell 35 HRC) can be recoated and backfilled.[2] Hardness properties of 150 to 200 HB are consistent with the normal hardness properties that are to be expected for the API Grade X52 line pipe. API 5L specifies a minimum tensile strength of 66,000 psi (131 HB) for API Grade X52. Hardness properties of Rockwell 93 (207 HB) have been documented for the pipe body, in regions away from hard spots, for A.O. Smith, API 5L Grade X52 line pipe of similar vintage.[3] This information indicates that the grading criteria shown is a conservative assessment of the ILI data. The highest grade will be associated with regions that have hardness properties, as detected by the ILI tool, that exceed API 5L requirements and industry research limits.

5. Selection and Prioritization of Dig Sites

Experience using the Tuboscope Linalog ILI HS tool in Duke's BC Pipeline system indicated that there was a high degree of correlation between ILI data for clusters of hard spots that were detected and the physical presence of a hard spot at the specified location. In comparison, the ILI data that indicated the presence of isolated hard spots were found to be less reliable based on bell hole examination results. Based on the criteria shown in Section 4, the following criteria is proposed, in the order shown, to prioritize suspected hard spot sites for bell hole inspection:

1) Waiver Site, Cluster, Grade 3
2) Waiver Site, Cluster, Grade 2
3) Waiver Site, Individual, Grade 3
4) Outside Waiver Site, Cluster, Grade 3
5) Outside Waiver Site, Cluster, Grade 2
6) Outside Waiver Site, Individual, Grade 3

The results of bell hole examinations of the hard spot anomalies will be compared to the log from the ILI HS tool run. At any time, the bell hole examination results may be assessed to determine if continued bell hole investigation of hard spot anomalies is warranted.

6. Bell hole Examination Procedures for Hard Spots

   Excavation and bell hole examination of the pipeline will be performed in accordance with company SOP and safety policy. Each task will be performed by personnel qualified for the specific tasks discussed below.

   a. Prior to Excavation
      i. Pressure Reduction – The operating pressure shall be reduced to 80% of past 90 day MOP when the bell hole inspection is for the purposes of hard spot anomalies detected by ILI. If cracks or other types of defects are detected in a suspected hard spot region, Metallurgical Services shall be consulted to determine pressure reduction requirements.
      ii. Pipe-to-Soil (electrolyte) Potential Measurements – Pipe to electrolyte potential measurements are to be performed at the suspect hard spot location in accordance with SOP #2-2010 "Structure-to-Electrolyte Potential Measurements".
   b. Hard Spot Evaluation Procedure After Excavation – Pipe that is exposed for the purposes of investigating ILI hard spot data should be inspected using the procedure described in this section. Inspection results are to be recorded on the appropriate company forms listed in SOP section 1-7.
      i. Excavate - Excavation shall be performed using safe digging practices in accordance with SOP 1-4010, "Excavation and Backfill".
      ii. Record Field Site Data – Record the site features in accordance with the appropriate Company forms listed in SOP section 1-7.
      iii. Coating Removal – Remove coating for a distance of 5 feet either side of the hard spot using standard company practices. Grit blasting of the surface to a commercial finish is recommended. The surface should be free of material that might interfere with the application and movement of the MT suspension or powder during inspection.
      iv. Visual Inspection – Visually inspect the pipe external surface for evidence of flat spots or any other unique features in accordance to company SOP 1-3010. Features such as a relatively flat region with rounded edges may indicate the presence of a hard spot. All relevant anomalies and defects must be documented.
      v. Magnetic Particle (MT) Inspection – Personnel performing the inspection must have current ASNT Level II qualification for MT. NDT contractors shall have the materials for performing wet MT (fluorescent and contrast) inspection prior to arrival at the inspection site. These methods are the preferred methods for MT inspection, and either method shall be

acceptable. NDT contractors shall perform the specific MT method that is specified by DEGT representatives.

1. General Instructions - Perform MT inspection over the entire exposed pipe surface in accordance with generally accepted industry standards such as ASTM E1444-01. Metallurgical Services shall be consulted if any linear indications are detected.
2. Magnetizing Procedure – For MT inspection of the pipeline using a magnetic hand yoke, a magnetic field is produced that is oriented longitudinal between the two poles. Magnetizing current can be either A.C. or half-wave rectified D.C. For detecting surface cracks, the A.C. method is preferred. Linear defects oriented transverse to the magnetic field can be detected. In order to detect defects oriented in either direction on the pipe surface, MT inspection must be performed in both the circumferential and longitudinal directions with the hand yoke. Full coverage of a region larger than the pole spread is achieved by performing MT inspection using multiple passes, with each pass overlapping the other by approximately 1" or more.
3. MT Methods – The following methods are preferred for performing MT inspection of the pipe surface for the purposes of finding surface breaking defects such as cracks, seams, and laminations open to the O.D. surface.
    a. Wet Fluorescent MT – This method uses finely divided magnetic particles suspended in a liquid medium that is applied by spraying. Water based medium is recommended. The particles fluoresce when inspected under black light. Excessive background fluorescence during inspection shall require additional surface cleaning or a change to a different medium or method. This method is preferred except in bright light conditions.
    b. Wet Non-Fluorescent MT - This method uses finely divided magnetic particles suspended in a liquid medium (water or non-oil based medium is recommended) that is applied by spraying. White contrast paint is applied to the pipe surface and the applied particles (red or black) are visible under normal lighting conditions.

    The following method is acceptable for performing MT inspection, if the preferred methods are deemed not suitable due to operational and environmental conditions:

    a. Visible Dry MT – This method uses a colored powder that is selected to achieve maximum contrast to the pipe surface. A bubble blower is typically used to apply a light dust of powder to the pipe surface in the area being inspected while the current is being applied. Excessive application of the powder should be avoided because this may mask any indication present. Excess powder can often be removed by lightly blowing the surface while performing the inspection with current being applied.

vi. Ultrasonic Wall Thickness Survey – Perform an ultrasonic wall thickness measurement survey of the suspected hard spot region. Ultrasonic measurements shall be made by personnel with previous experience taking UT measurements. For the purpose of wall-thickness measurement using ultrasonic techniques, an ASNT certification is not required. Metallurgical Services shall be consulted if lamination or wall loss is detected.

vii. Hardness Testing and Dimensional Documentation – Prior to testing, the pipe surface should be thoroughly cleaned of surface deposits and debris. Test locations should be ground to a depth of 0.010" and finish ground using a 240 grit flapper wheel. Perform hardness testing over a 2" grid using a Microdur hardness tester that has current calibration documentation. Where areas of high hardness are detected a ½" or smaller grid shall be used to determine the shape of the hard spot. Isolated high hardness readings must be verified. Further investigation of elevated hardness locations may require additional grinding to depths of approximately 0.015" to 0.020". The contractor performing the hardness testing must have a process for addressing scatter in the hardness test results. The hardness test data should be reported as an attachment to the "Pipe and Coating Inspection Report" (7T-33).

a. Hard Spot Repair Recommendations - Repair of hard spots, and other defects located during bell hole examination, will be performed in accordance with SOP 1-3010 "Pipeline Repair". **Grinding removal of cracks in hard spots is not an acceptable or approved repair process.** The available repair options are provided for each type of hard spot that would require repair.

   i. Pipe with Hardness Properties Less Than 300 HB
      1. Carefully Re-Coat and Backfill.

   ii. Hard Spots with Hardness between 301 and 400 HB with No Cracking Present.
      1. Replacement
      2. Pressure Containing Sleeve (Type "B" Welded Ends)
      3. Reinforcing Sleeve with Filler (Type "A" or Type "B" Non-Welded Ends)

   iii. Hard Spots with Evidence of Cracking (301 and greater)
      1. Replacement
      2. Pressure Containing Sleeve (Type "B" Welded Ends)

   iv. Hard Spots with Hardness Greater than 401 HB (No Cracking)
      1. Replacement
      2. Pressure Containing Sleeve (Type "B" Welded Ends)

7. Technical Support

Contact the Metallurgical Services Section if additional detail or technical assistance is needed.

[1.] API 5L, "Specification for Line Pipe", 41st Ed., April 1, 1995.

[2.] PRCI Report PR-218-9307, "Pipeline Repair Manual" by J.F. Kiefner, W.A. Bruce, D.R. Stephens. Page 57 and Figure 20.

[3.] PRCI NG-18, Report 131, "Summary of Field Failure Investigations", Field Failure No. 6, "Hydrogen Cracking in 30" x 0.375" , X52 Pipeline".

APPENDIX 2

HARD SPOT ANOMALIES REMOVED FROM SERVICE FROM
OWINGSVILLE LINE15

PLD19FR002 – Danville – NTSB009910

Hard Spot	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller Hardness Test – Maximum Hardness (BHN)	Microdur – Ultrasonic Contact Impedance – Maximum Hardness (BHN)	Microhardness Test (BHN converted from Vickers) – Maximum Hardness (BHN)
A	248	255	156	167
B	248	255	162	---
C	252	255	260	255
D	244	218	149	---
E	256	213	200	---
F	252	225	160	---
G	252	229	208	---
H	248	229	236	223
I	248	229	179	---
J	252	215	155	---

BHN = Brinell Hardness Number

Table 1. Comparison of maximum hardness properties as determined by ILI and the three hardness testing methods (Telebrineller, Microdur, and Vickers).

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)	Microhardness (BHN)*
Outside of Hard Spot	N/A	---	---	167
Outside of Hard spot	N/A	186	156	---
Outside of Hard spot	N/A	195	135	---
Outside of Hard spot	N/A	186	151	---
Outside of Hard spot	N/A	196	174	---
Outside of Hard spot	N/A	186	153	---
Hard Spot Region	248	202	146	156
Hard Spot Region	248	255	146	158
Hard Spot Region	248	247	142	156
Hard Spot Region	248	225	148	156
Outside of Hard spot	N/A	184	156	159
Outside of Hard spot	N/A	191	143	159
Outside of Hard spot	N/A	181	154	---
Outside of Hard spot	N/A	196	138	---
Outside of Hard spot	N/A	194	151	---
Outside of Hard spot	N/A	195	146	---
Outside of Hard spot	N/A	181	---	---

* Brinell Hardness Number (BHN) converted from Vickers microhardness data.

Table 2. Hardness test data for hard spot "A". The hard spot region was located at approximately the 10:15 o'clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	197	---
Outside of Hard spot	N/A	196	---
Outside of Hard spot	N/A	194	155
Hard Spot Region	248	200	137
Hard Spot Region	248	232	152
Hard Spot Region	248	255	142
Hard Spot Region	248	204	140
Outside of Hard spot	N/A	186	142
Outside of Hard spot	N/A	170	---
Outside of Hard spot	N/A	194	162
Outside of Hard spot	N/A	179	143
Outside of Hard spot	N/A	195	154
Outside of Hard spot	N/A	195	150
Outside of Hard spot	N/A	179	139
Hard Spot Region	N/A	210	135
Hard Spot Region	N/A	204	140
Outside of Hard spot	N/A	192	144

BHN = Brinell Hardness Number

Table 3. Hardness test data for hard spot “B”. The hard spot region was located at approximately the 02:00 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)	Microhardness (BHN)*
Outside of Hard Spot	N/A	---	---	156
Outside of Hard spot	N/A	192	177	---
Outside of Hard spot	N/A	194	156	---
Outside of Hard spot	N/A	186	151	---
Outside of Hard spot	N/A	180	153	---
Outside of Hard spot	N/A	196	152	---
Outside of Hard spot	N/A	186	143	---
Outside of Hard spot	N/A	189	149	---
Outside of Hard spot	N/A	180	147	---
Outside of Hard spot	N/A	195	148	---
Outside of Hard spot	N/A	186	155	---
Outside of Hard spot	N/A	192	152	---
Outside of Hard spot	N/A	178	149	---
Hard Spot Region	252	206	155	---
Hard Spot Region	252	223	194	179
Hard Spot Region	252	207	218	---
Hard Spot Region	252	246	215	229
Hard Spot Region	252	255	260	255
Hard Spot Region	252	255	253	255
Hard Spot Region	252	206	177	---
Hard Spot Region	252	206	---	---
Hard Spot Region	252	239	212	197
Hard Spot Region	252	209	208	187
Outside of Hard spot	N/A	193	166	163
Outside of Hard spot	N/A	196	151	---
Outside of Hard spot	N/A	193	---	---
Outside of Hard spot	N/A	186	---	159

* Brinell Hardness Number (BHN) converted from Vickers microhardness data.

Table 4. Hardness test data for hard spot “C”. The hard spot region was located at approximately the 11:45 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	192	144
Outside of Hard spot	N/A	194	149
Outside of Hard spot	N/A	182	142
Hard Spot Region	244	218	138
Hard Spot Region	244	204	132
Hard Spot Region	244	210	---
Hard Spot Region	244	206	132
Hard Spot Region	244	207	124
Hard Spot Region	244	209	138
Outside of Hard spot	N/A	184	---
Outside of Hard spot	N/A	194	132
Outside of Hard spot	N/A	189	128
Outside of Hard spot	N/A	190	147
Outside of Hard spot	N/A	185	---
Outside of Hard spot	N/A	196	146
Outside of Hard spot	N/A	182	133
Outside of Hard spot	N/A	186	139
Hard Spot Region	244	206	147
Hard Spot Region	244	204	143
Hard Spot Region	244	203	148
Outside of Hard spot	N/A	184	142
Outside of Hard spot	N/A	174	133

BHN = Brinell Hardness Number

Table 5. Hardness test data for hard spot “D”. The hard spot region was located at approximately the 3:05 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Hard Spot Region	256	203	150
Outside of Hard spot	N/A	194	200
Outside of Hard spot	N/A	178	140
Outside of Hard spot	N/A	173	147
Outside of Hard spot	N/A	187	123
Hard Spot Region	256	206	151
Hard Spot Region	256	213	174
Hard Spot Region	256	200	168
Hard Spot Region	256	206	145
Outside of Hard spot	N/A	187	133
Outside of Hard spot	N/A	194	143
Outside of Hard spot	N/A	197	181
Outside of Hard spot	N/A	174	140
Outside of Hard spot	N/A	187	132
Outside of Hard spot	N/A	190	135
Outside of Hard spot	N/A	182	148
Outside of Hard spot	N/A	186	149

BHN = Brinell Hardness Number

Table 6. Hardness test data for hard spot “E”. The hard spot region was located at approximately the 7:00 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	194	162
Outside of Hard spot	N/A	184	132
Outside of Hard spot	N/A	186	138
Outside of Hard spot	252	204	135
Hard Spot Region	252	225	147
Hard Spot Region	252	210	154
Hard Spot Region	252	204	140
Hard Spot Region	252	206	127
Hard Spot Region	252	221	160
Hard Spot Region	N/A	181	142
Hard Spot Region	N/A	195	130
Hard Spot Region	N/A	181	104
Outside of Hard spot	N/A	186	125
Outside of Hard spot	N/A	197	132
Outside of Hard spot	N/A	196	145
Outside of Hard spot	N/A	182	143

BHN = Brinell Hardness Number

Table 7. Hardness test data for hard spot "F". The hard spot region was located at approximately the 02:50 o'clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	197	148
Outside of Hard spot	N/A	172	147
Outside of Hard spot	N/A	194	153
Outside of Hard spot	N/A	197	160
Outside of Hard spot	N/A	199	160
Hard Spot Region	252	214	164
Hard Spot Region	252	229	188
Hard Spot Region	252	214	208
Outside of Hard spot	N/A	174	148
Outside of Hard spot	N/A	187	130
Outside of Hard spot	N/A	187	139
Outside of Hard spot	N/A	172	140
Outside of Hard spot	N/A	187	137

BHN = Brinell Hardness Number

Table 8. Hardness test data for hard spot “G”. The hard spot region was located at approximately the 07:50 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)	Microhardness* (BHN)
Outside of Hard spot	N/A	185	121	---
Outside of Hard spot	N/A	196	134	---
Outside of Hard spot	N/A	174	145	---
Outside of Hard spot	N/A	187	140	---
Hard Spot Region	248	229	236	223
Hard Spot Region	248	212	197	192
Hard Spot Region	248	201	150	---
Hard Spot Region	N/A	199	162	170
Hard Spot Region	N/A	190	183	179
Hard Spot Region	N/A	186	150	---
Outside of Hard spot	N/A	175	146	---
Outside of Hard spot	N/A	183	163	---
Outside of Hard spot	N/A	183	148	---

* Brinell Hardness Number (BHN) converted from Vickers microhardness data.

Table 9. Hardness test data for hard spot “H”. The hard spot region was located at approximately the 06:15 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	195	156
Outside of Hard spot	N/A	187	152
Outside of Hard spot	N/A	187	134
Outside of Hard spot	N/A	181	132
Hard Spot Region	N/A	187	139
Hard Spot Region	248	229	179
Hard Spot Region	248	214	148
Hard Spot Region	248	187	132
Hard Spot Region	248	229	172
Hard Spot Region	248	202	131
Hard Spot Region	248	207	118
Hard Spot Region	248	214	137
Hard Spot Region	248	201	155
Hard Spot Region	248	201	145
Outside of Hard spot	N/A	187	141
Outside of Hard spot	N/A	194	132
Outside of Hard spot	N/A	187	136
Outside of Hard spot	N/A	182	143
Outside of Hard spot	N/A	186	137
Outside of Hard spot	N/A	194	132

BHN = Brinell Hardness Number

Table 10. Hardness test data for hard spot “I”. The hard spot region was located at approximately the 02:50 o’clock position.

Location	Tuboscope ILI Hardness Estimate (BHN)	Telebrineller (BHN)	Microdur (BHN)
Outside of Hard spot	N/A	194	134
Outside of Hard spot	N/A	195	138
Outside of Hard spot	N/A	187	137
Outside of Hard spot	252	200	135
Outside of Hard spot	252	200	147
Hard Spot Region	252	206	137
Hard Spot Region	252	202	145
Hard Spot Region	252	215	150
Outside of Hard spot	252	201	153
Outside of Hard spot	252	200	155
Outside of Hard spot	N/A	186	125
Outside of Hard spot	N/A	198	151
Outside of Hard spot	N/A	195	146

BHN = Brinell Hardness Number

Table 11. Hardness test data for hard spot "J". The hard spot region was located at approximately the 07:50 o'clock position.

Identification	Yield Strength (0.50%)	Ultimate Tensile Strength	Elongation
Sample MP 530.12 (Transverse Orientation)	53,800 psi.	75,500 psi.	34%
Grade X52 per API 5LX, 6th ed., February 1956	52,000 psi. min.	66,000 Psi. min.	22.00 % min.

Table 12. Tensile test results. Tests were performed in accordance with ASTM E8 requirements.

Identification	Sample MP 530.12 (Transverse Orientation) (wt.%))	Grade X52, per API 5LX, 6th ed. 1956
Carbon	0.24	0.24% max.
Manganese	1.02	1.25% max.
Phosphorous	0.013	0.10% max.
Sulfur	0.035	0.05% max.
Silicon	0.02	---
Nickel	0.03	---
Chromium	0.06	---
Molybdenum	0.01	---
Copper	0.06	---
Aluminum	<0.01	---
Vanadium	<0.01	---
Niobium	<0.01	---
Titanium	<0.01	---

Table 13. Optical emission spectroscopy (OES) results.

APPENDIX 3

PHOTOGRAPH FIGURES

g

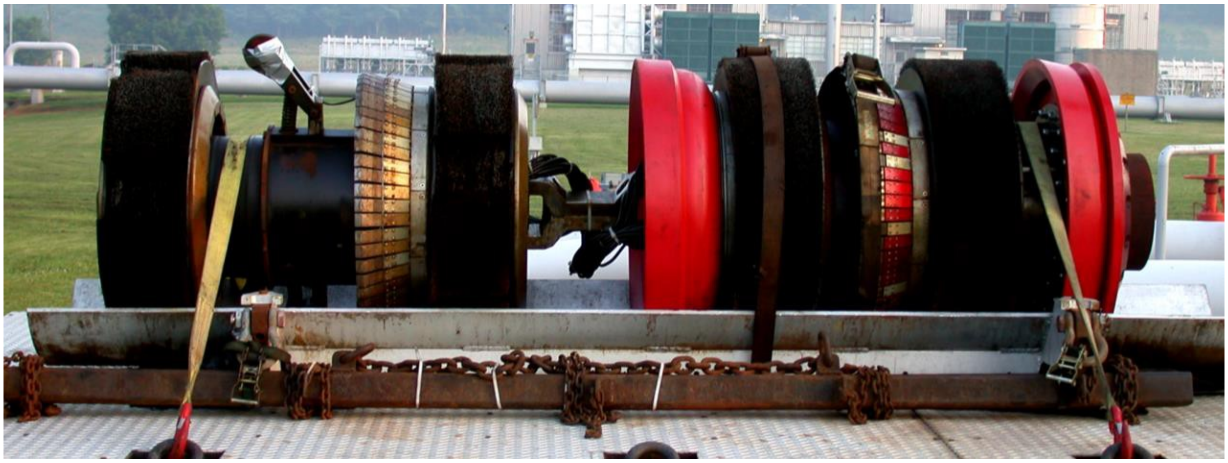


Figure 1. The Tuboscope hard spot tool prior to inspection.

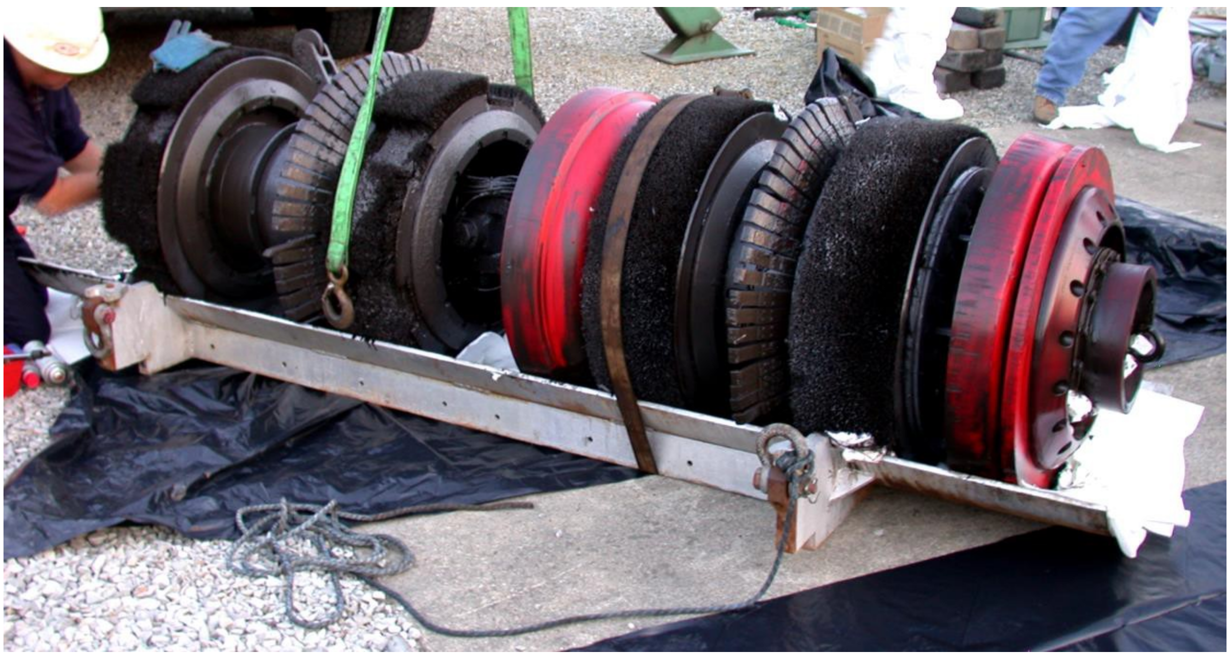


Figure 2. A view of the hard spot tool after the inspection operation.

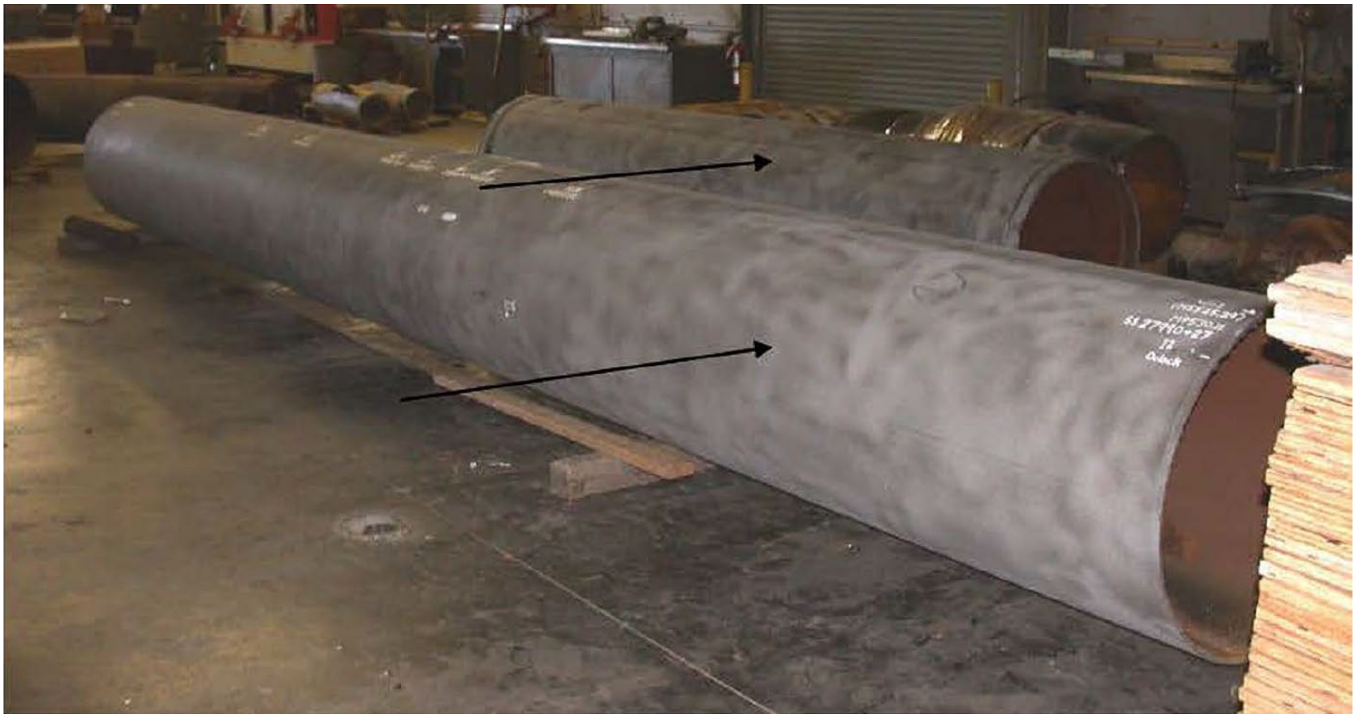


Figure 3. The sections of pipe removed from service from Owingsville Line 15 for assessment of hard spots.

Figure 4. A view of the Telebrineller hardness test equipment The image on the left shows the bru· holder which contains the steel bar of known hardness (280 Brinell), and hammer. The bar holder has a hardened steel ball that creates simultaneous impressions in the pipe and steel bar when the holder is struck with the hammer. The image on the right shows the optical viewer that is used to measure the diameter of the impressions in the bar and in the pipe surface. The calculator is also shown in this image.

Figure 5. Microdur hardness testing. This method involves ultrasonic contact impedance principles that related the shift in longitudinal oscillation frequency to a Vickers hardness which was converted to Brinell hardness.

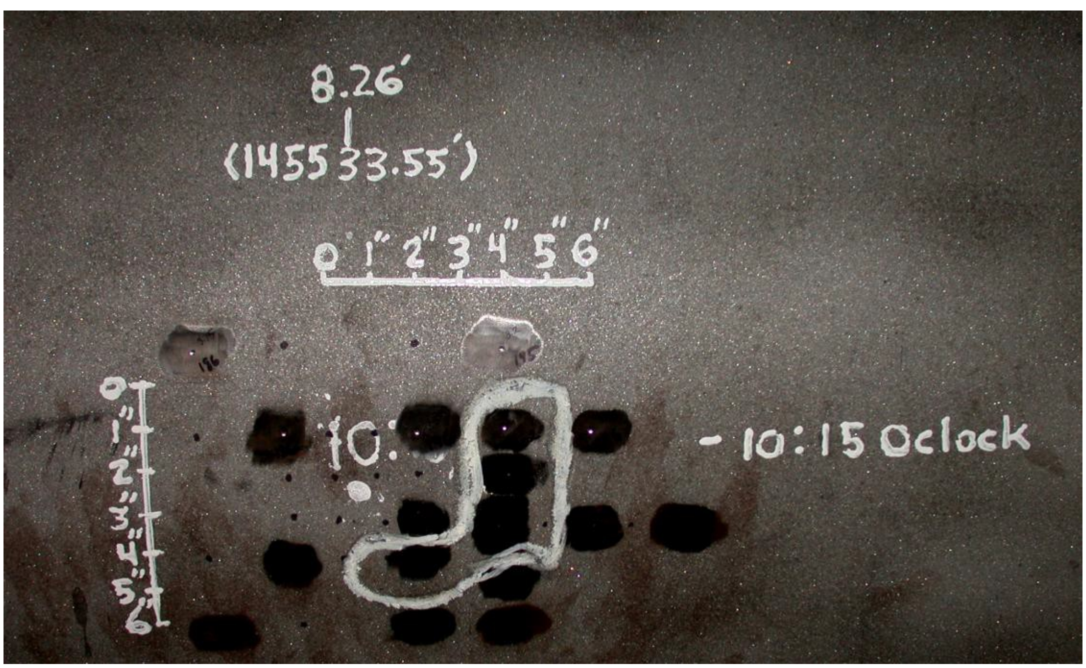


Figure 6. A view of hard spot region "A". The boundary of the hard spot indicates the region with hardness greater than 200 Brinell as determined by Telebrineller hardness testing.

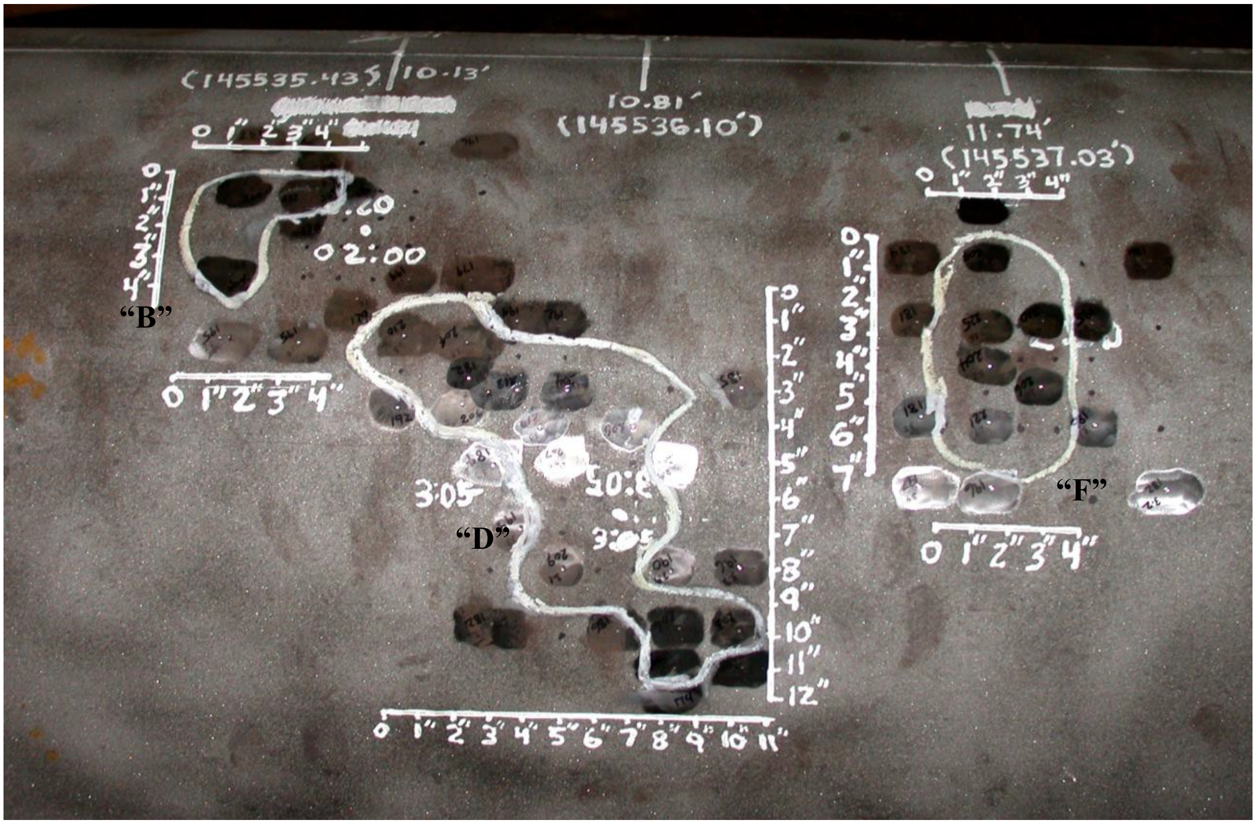


Figure 7. A view of hard spot regions "B", "D", and "F".

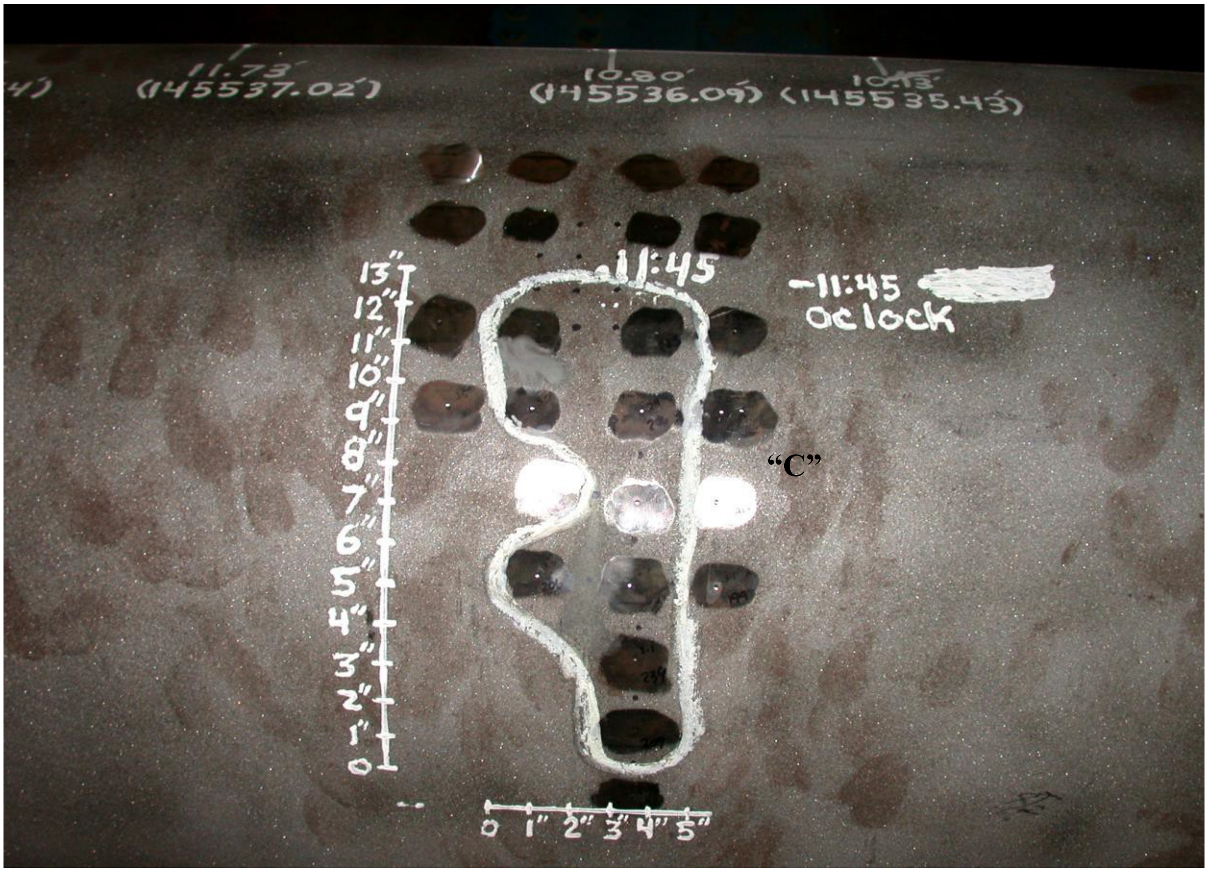


Figure 8. A view of hard spot region "C".

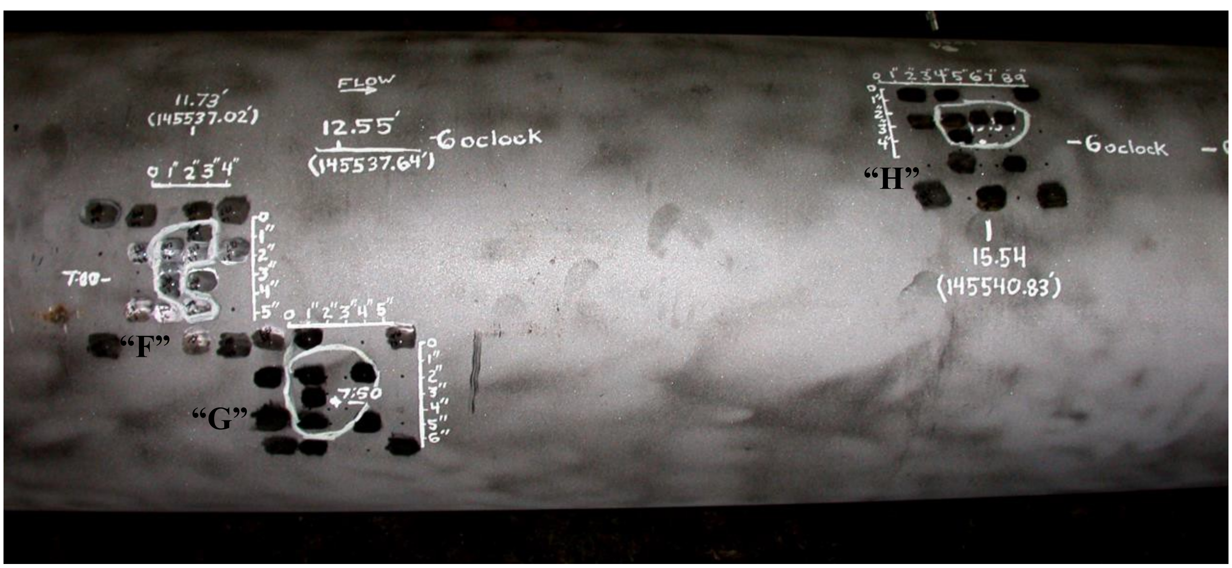


Figure 9. A view of hard spot regions "E", "G", and "H".

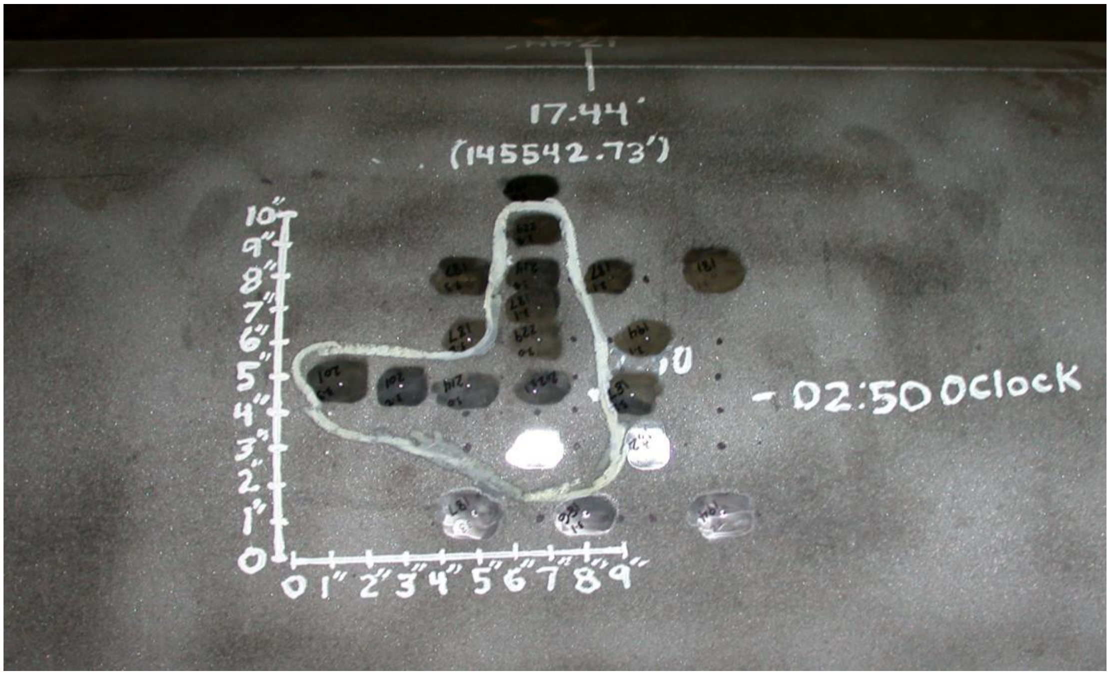


Figure 10. A view of hard spot region "I".

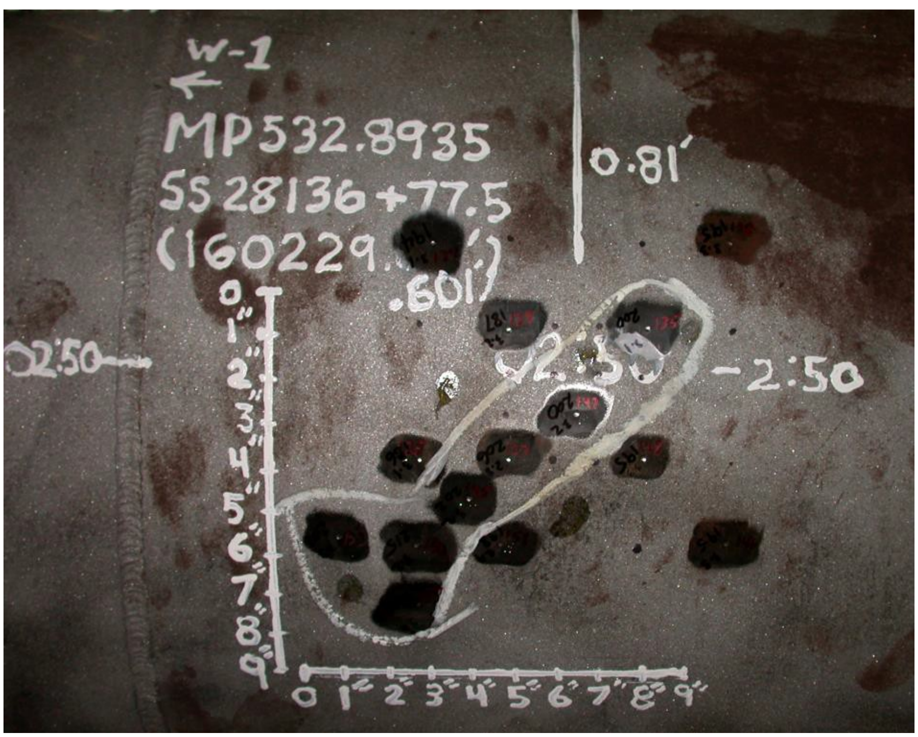
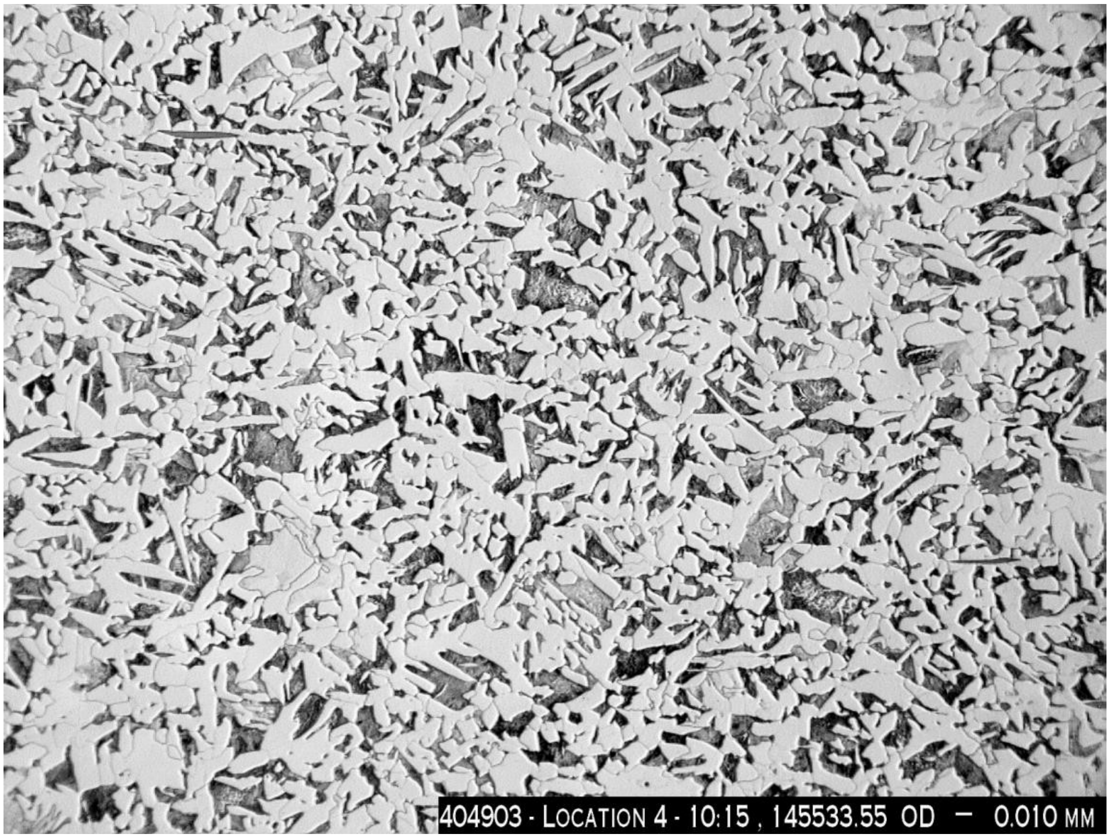


Figure 11. A view of hard spot region "J".



Magnification: 200X Etch: 2% Nital

Figure 12. A view of the microstructure at a location within the “hard spot” region of sample “A”. The microstructure consists of islands of pearlite (dark regions) in a ferrite matrix (light regions). This is typical for all of the samples from hard spot region “A”, and is consistent with a normal pipeline steel microstructure. This location had an ILI estimated hardness of 248 Brinell, a Telebrineller hardness reading of 247 Brinell, a Microdur reading of 142 Brinell, and an actual hardness value of 156 Brinell as determined by Vickers testing. The microstructure and microstructure indicate that this region was a false positive hard spot indication.

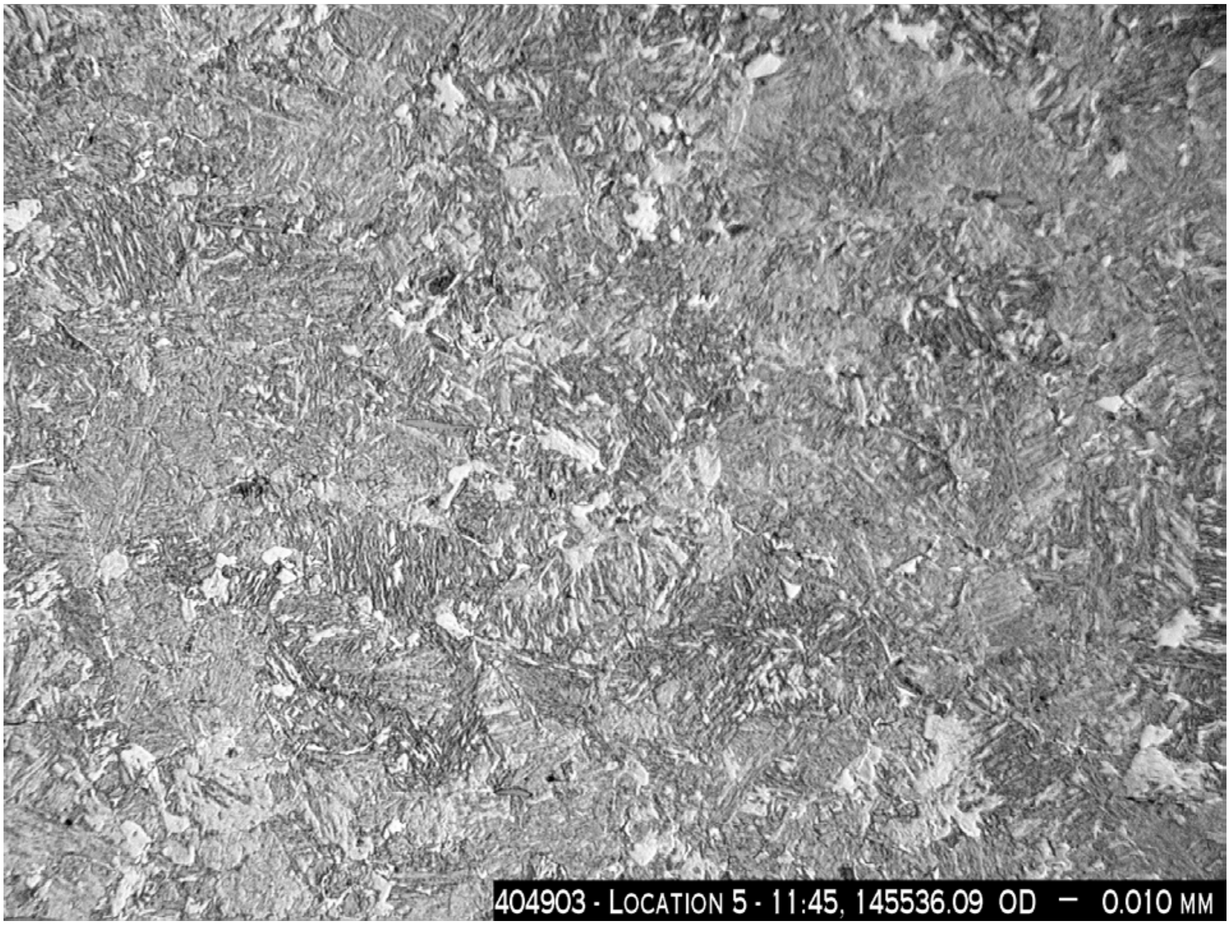


Figure 13. A view of the microstructure at a location within the hard spot “C”. This microstructure was classified as bainitic/martensitic, and is consistent with quenched and hardened steel. The microstructure shown was typical of the microstructures observed in the hard spot region. This location had an ILI estimated hardness of 252 Brinell, a Telebrineller hardness reading of 255 Brinell, a Microdur reading of 253 Brinell, and an actual hardness value of 255 Brinell as determined by Vickers testing.

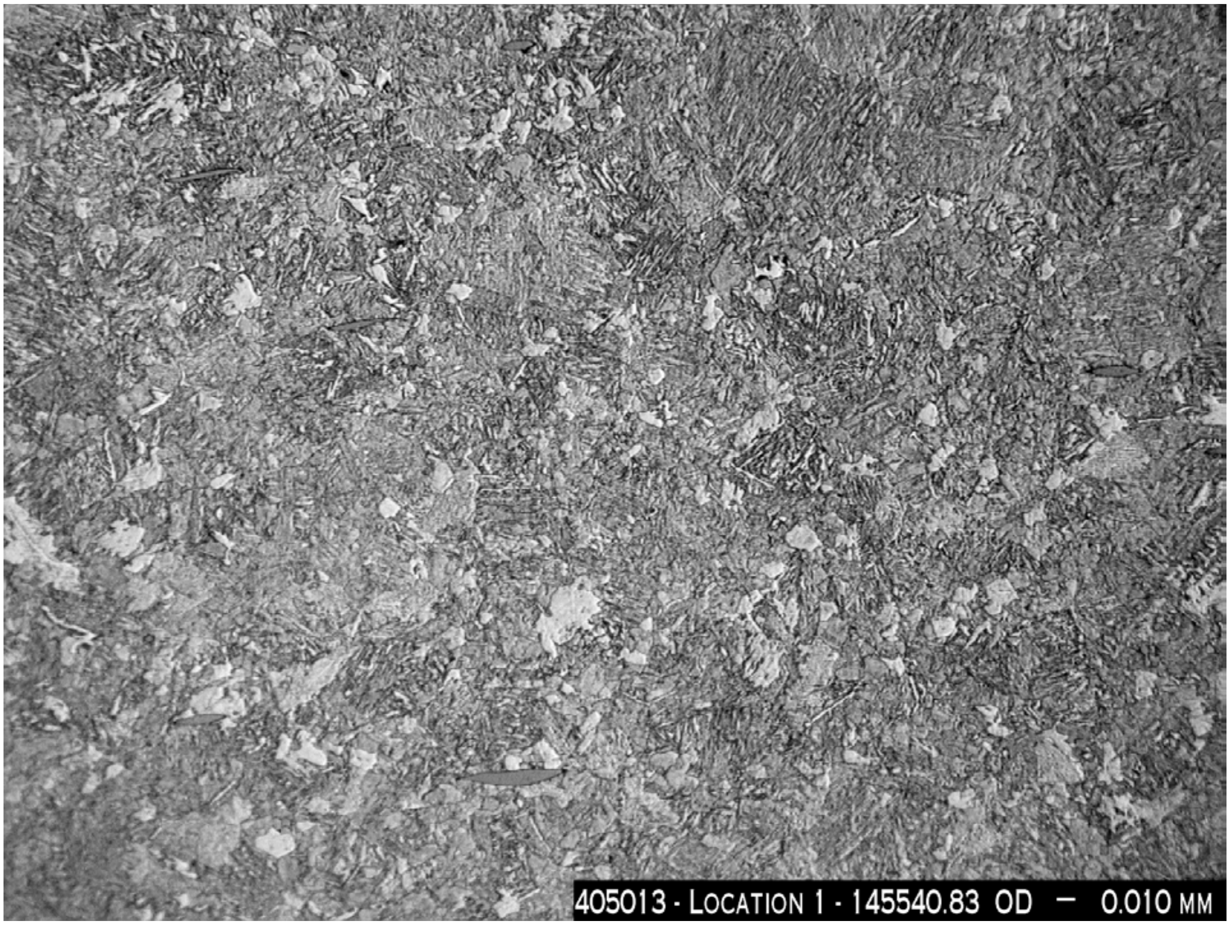


Figure 14. A view of the microstructure in hard spot "H". This microstructure was classified as bainitic/martensitic, and is consistent with quenched and hardened steel. The microstructure shown was typical of the microstructures observed in the hard spot region. This location had an ILI estimated hardness of 248 Brinell, a Telebrineller hardness reading of 229 Brinell, a Microdur reading of 236 Brinell, and an actual hardness value of 223 Brinell as determined by Vickers testing.