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**Hydraulic Pressure Cycling and Performance Evaluation of five DOT-3AL 2015
Cylinders**

FINAL REPORT

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Packer Project # 501856

**Prepared for
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Office of Hazardous Materials Technology
Pipeline and Hazardous
Materials Safety Administration
U.S. Department of Transportation**

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Hydraulic Pressure Cyclic and Evaluation of DOT-3AL 2015 Cylinders

1.0 INTRODUCTION

Objective: - The purpose of this solicitation is to determine the fatigue performance and fatigue failure initiation location of five DOT-3AL 2015 cylinders.

1.1 Technical Approach

In this project three DOT – 3AL cylinder with serial number AR0119582, AR0118046 and AR0116501 were pressure cycled up to 12,000 cycles. The remaining two cylinders with serial number AR0119572 and AR0118110 were pressure cycled until failure occurred. The cylinder with serial number AR0119582 was hydraulically burst tested after pressure cycling up to 12,000 cycles. Before testing an external and internal visual observation was performed on all cylinders to document any markings or surface defects.

2.0 GENERAL DOCUMENTATION OF THE CYLINDER

2.1 Visual Documentation and Cylinder Specifications

Based on visual inspection of all the five cylinders submitted to Packer Engineering for evaluation, the cylinders were produced by Airgas Puritan medical at Airgas S inc, Kennesaw GA 30144. These cylinders were used by Miami Dade Fire department. During their service live, these cylinders contained compressed oxygen compliant with USP (United States Pharmacopoeia). It is a medical gas. The shipping ID of these cylinders is UN1072. The received five cylinders are shown in Figure 1.

1) DOT-3AL AR0119582

The external and internal examination photos of DOT – 3AL Cylinder with serial number AR0119582 are shown in Figure 2 to 10.

- The cylinder is identified as DOT- XXX AR0119582 O2 CLIFF DIV 12 @ 03 TC – 3AL M139.
- It is marked as MDFR
- Lot # invisible
Capacity: 4.25 liters
Expiration date: 2013
- There were no visible cracks observed on the outer surface of the cylinder.
The paint on the cylinder was scratched at several locations.



- Internal observation of the cylinder showed cracks in the shoulder area showed by Figures 11 to 13. The location of cracks is identified in Figures 14 and 15. The cylinder showed no major signs of corrosion on the inside.

2) DOT-3AL AR0118046

The external and internal examination photos of DOT – 3AL Cylinder with serial number AR0118046 are shown in Figure 16 to 27.

- The cylinder is identified as DOT –XXXAR0118046 O2 Cliff Div 12@O3 TC- 3ALM139.
- Lot # invisible
Capacity: 4.25 liters
Expiration date: 12- 2013
- There were no visible cracks observed on the outer surface of the cylinder. The paint on the cylinder was scratched at several locations.
- Internal observation of the cylinder showed cracks in the shoulder area showed by Figures 28 to 30. The location of cracks is identified in Figures 31 and 32. The cylinder showed no major signs of corrosion on the inside.

3) DOT-3AL AR0116501

The external and internal examination photos of DOT – 3AL Cylinder with serial number AR0119582 are shown in Figure 33 to 43.

- The cylinder is identified as DOT- XXX AR0116501 O2 CLIFF DIV12 @O3 TC-3ALM139
- It is marked as MDFR
- Lot # TV04V343B
Capacity: 4.25 liters
Expiration date: 12-2013
- There were no visible cracks observed on the outer surface of the cylinder. The paint on the cylinder was scratched at several locations.
- Internal observation of the cylinder showed cracks in the shoulder area showed by Figures 44 to 46. The location of cracks is identified in Figures 47 and 48. The cylinder showed no major signs of corrosion on the inside.

4) DOT-3AL AR0118110

The external and internal examination photos of DOT – 3AL Cylinder with serial number AR0118110 are shown in Figure 49 to 59.

- The cylinder is identified as DOT-XXX AR0118110- O2 CLIFFDIV 12@O3 TC – 3AL M139.



- It is marked as MDFR
- Lot # TV01V309A
Capacity: 4.25 liters
Expiration date: 11-2013
- There were no visible cracks observed on the outer surface of the cylinder. The paint on the cylinder was scratched at several locations.
- Internal observation of the cylinder showed cracks in the shoulder area showed by Figures 60 to 62. The location of cracks is identified in Figures 63 and 64. The cylinder showed no major signs of corrosion on the inside.

5) DOT-3AL AR0119572

The external and internal examination photos of DOT – 3AL Cylinder with serial number AR0119572 are shown in Figure 65 to 75.

- The cylinder is identified as DOT AR0119572 O2 CLIFF DIV 12 @ 03 TC – 3AL M139.
- It is marked as MDFR
- Lot # TC05V
Capacity: 4.25 liters
Expiration date: 12-2013
- There were no visible cracks observed on the outer surface of the cylinder. The paint on the cylinder was scratched at several locations.
- Internal observation of the cylinder showed cracks in the shoulder area showed by Figures 76 to 79. The location of cracks is identified in Figures 80 and 81. The cylinder showed no major signs of corrosion on the inside.

3.0 PRESSURE CYCLING TEST:

The cylinder was filled with hydraulic fluid and was subjected to sinusoidal pressure cycles from a minimum pressure of less than or equal to 300 psi to a maximum pressure of approximately 3,023 psi. The rate of pressure cycling was 0.25 Hz (15 cycles/min). The test set up is shown in Figures 82 and 85. The cyclic pressure testing was controlled with a Moog Model 76-262C servo-valve run by an MTS Model 407 controller. Pressure was supplied by a Flodyne/Hydradyne 5000 psi hydraulic pump. The pressure was measured using was a CEC Model 4-325-0001 pressure transducer.

3.1 Pressure Cycling up to 12,000 cycles:

The cylinders AR0119582, AR0118046 and AR0116501 successfully completed 12,000 cycles without leaking. Figures 86 to 88 shows the maximum and the minimum pressure observed during the 12,000 cycle test of the AR0119582, AR0118046 and AR0116501 cylinders respectively.



3.2 Pressure Cycling continued until failure:

The cylinders AR0119572 and AR0118110 were pressure cycled until failure occurred. The cylinder AR0119572 failed after 56,474 cycles as shown in Figure 89. The failure occurred at the bottom of the cylinder as seen in Figures 90 and 91. The cylinder AR0118110 failed after 53,507 cycles as shown in Figure 92. The failure occurred on the wall of the cylinder near the bottom as shown in Figures 93 and 94.

4.0 HYDRAULIC BURSTING TEST:

After completing 12,000 cycles of pressure cycling test, the cylinder AR0115982 was filled with water and hydrostatically tested to failure. The hydrostatic burst test was performed using a SC Hydraulic Engineering Model 10-60005402 air-powered fluid pump. The pressure was measured using an Omegadyne PX35 pressure transducer (0-30,000 psi) and recorded with an IOTech Wavebook 516E at a rate of 100 samples per second. Care was taken to avoid air entrapment in the circuit. The test setup is as shown in Figures 95 to 96. The pressure data is shown in Figure 97. The cylinder reached a maximum pressure of 5,534 psi in about 5.23 min (5 min 13 sec) and failed after 5.52 min (5 min and 31 sec). The cylinder burst along the length of the cylinder. The failure location is as shown in Figures 98 to 100.

5.0 RESULTS & DISCUSSION

In this project three DOT – 3AL cylinder with serial number AR0119582, AR0118046 and AR0116501 were pressure cycled up to 12,000 cycles. The remaining two cylinders with serial number AR0119572 and AR0118110 were pressure cycled until failure occurred. The cylinder with serial number AR0119582 was hydraulically burst tested after pressure cycling up to 12,000 cycles.

External observation of the five received DOT – 3AL cylinders showed no signs of leaks or cracks. The paint had come off from all the cylinders at some locations and there were some scratches on the cylinders. Internal observation of all the cylinders was done using a borescope prior to testing. In all the cylinders cracks were found in the neck and shoulder area. The cylinder showed no signs of corrosion on the inside.

The DOT- 3AL cylinders with serial number AR0119582, AR0118046 and AR0116501 successfully completed 12,000 cycles without leaking. The maximum test pressure for AR0119582 cylinder was 3036.2 psi and minimum was 289.7 psi. The maximum test pressure for AR0118046 cylinder was 3047 psi and minimum was 27.6 psi. The maximum test pressure for AR0116501 cylinder was 3043.6 psi and minimum was 65.1 psi. The frequency of reversals was 0.25 Hz (15 cycles/min).

The cylinders AR0119572 and AR0118110 were pressure cycled until failure occurred.



The cylinder AR0119572 leaked at the bottom after 56,474 cycles. The cylinder AR0118110 failed on the wall of the cylinder near the bottom after 53,507 cycles.

During the hydraulic burst test the cylinder AR0119582 reached a maximum pressure of 5,534 psi in about 5.23 min (5 min 13 sec) and failed after 5.52 min (5 min and 31 sec). The cylinder burst along the length of the cylinder.

This concludes the hydraulic pressure cycling and performance evaluation of the five DOT 3AL 2015 cylinders with serial no. AR0119582, AR0118046, AR0116501, AR0119572 and AR0118110. If you have questions or need additional information, please email us at mpareek@packereng.com or call at 630-577-1930.

Sincerely,

PACKER ENGINEERING, INC.

Mridula L Pareek
Engineering Technologist

John E Myers, Ph.D., P.E.*
Technical Vice President

* Registered professional
Engineer in the state of
Wisconsin



6.0 FIGURES



Figure 1: Shows the five received DOT-3AL 2015 cylinders.



Figure 2: Shows the as received DOT-3AL cylinder # AR0119582



Figure 3: Indented marking on the DOT-3AL cylinder # AR0119582



Figure 4: Indented marking on the DOT-3AL cylinder # AR0119582



Figure 5: Indented marking on the DOT-3AL cylinder # AR0119582



Figure 6: Indented marking on the DOT-3AL cylinder # AR0119582



Figure 7: Labels on the DOT-3AL cylinder # AR0119582

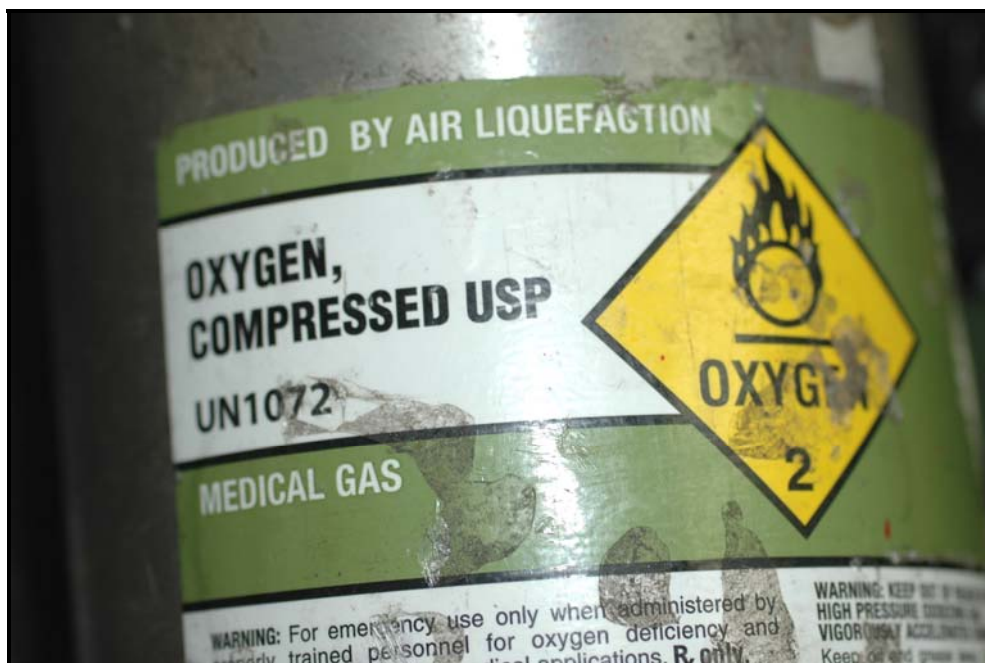


Figure 8: Labels on the DOT-3AL cylinder # AR0119582



Figure 9: Labels on the DOT-3AL cylinder # AR0119582



Figure 10: Shows neck and shoulder of DOT-3AL cylinder # AR0119582

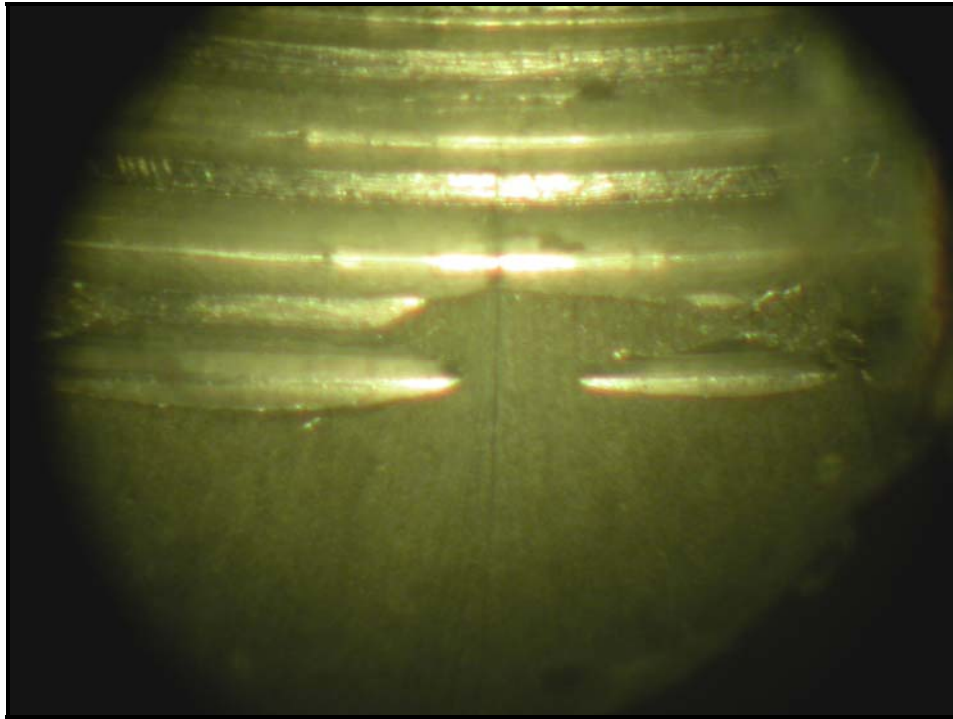


Figure 11: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119582 at 0° location identified in Figure 15.

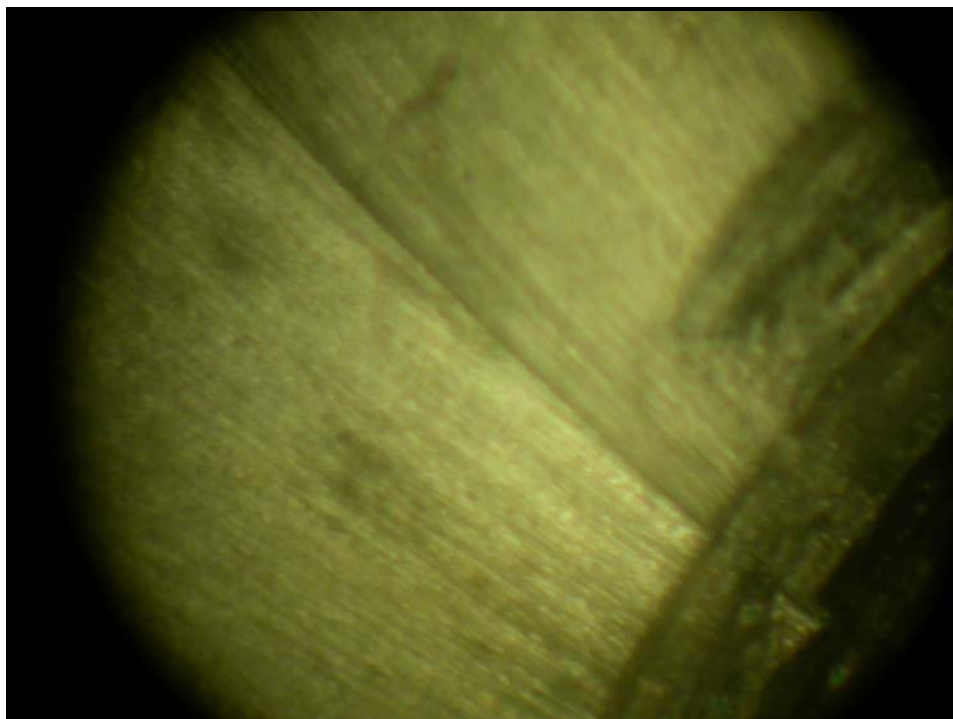


Figure 12: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119582 at 100° location identified in Figure 15.

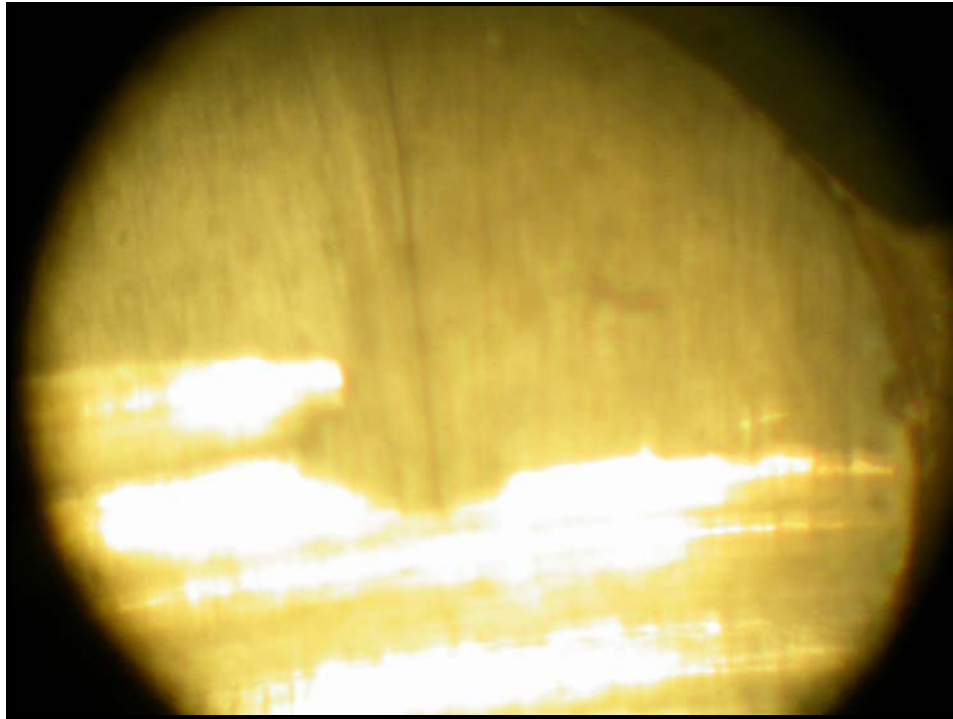


Figure 13: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119582 at 110° location identified in Figure 15.



Figure 14: Shows the orientation of the crack in the shoulder area of DOT-3AL cylinder # AR0119582 at 0° location with respect to the indented markings.

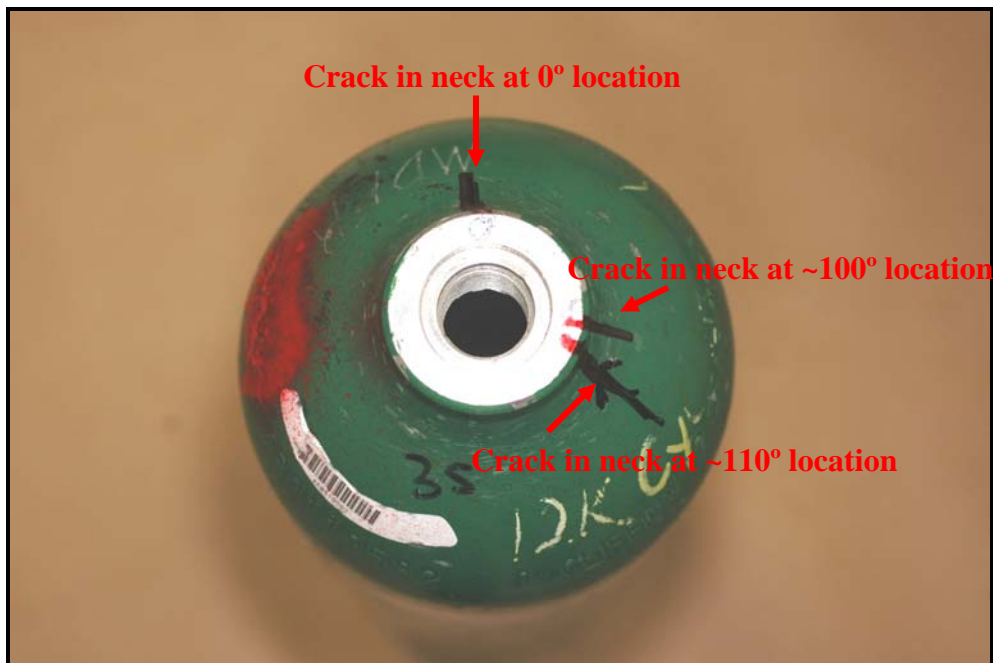


Figure 15: Shows the orientation of the cracks in the shoulder area of DOT-3AL cylinder # AR0119582 with respect to the 0° crack location.



Figure 16: Shows the as received DOT-3AL cylinder # AR0118046



Figure 17: Indented marking on the DOT-3AL cylinder # AR0118046



Figure 18: Indented marking on the DOT-3AL cylinder # AR0118046



Figure 19: Indented marking on the DOT-3AL cylinder # AR0118046



Figure 20: Indented marking on the DOT-3AL cylinder # AR0118046

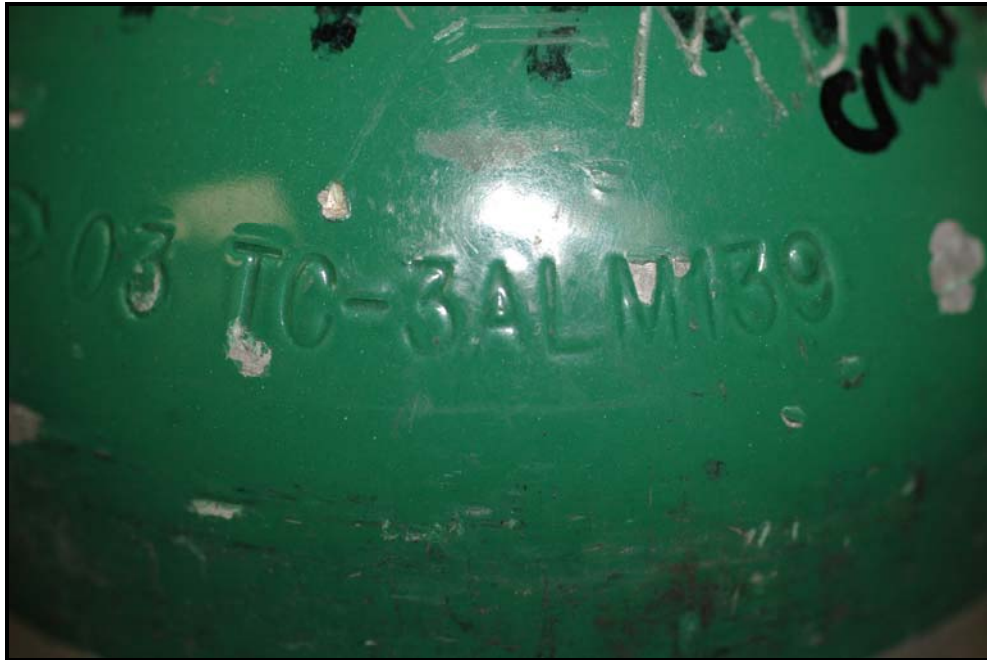


Figure 21: Indented marking on the DOT-3AL cylinder # AR0118046

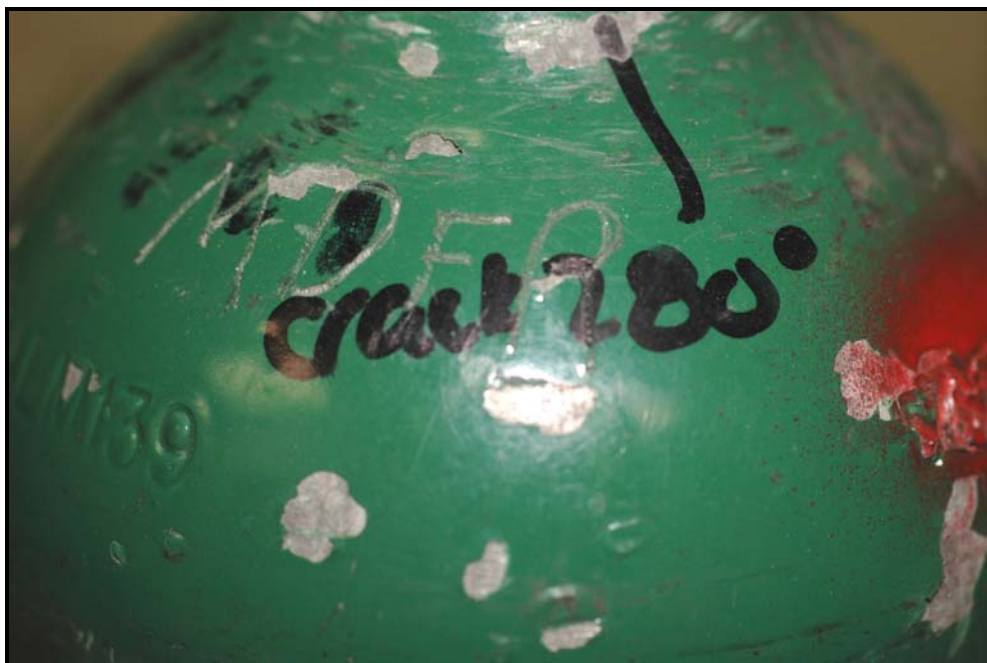


Figure 22: Indented marking on the DOT-3AL cylinder # AR0118046



Figure23: Labels on the DOT-3AL cylinder # AR0118046

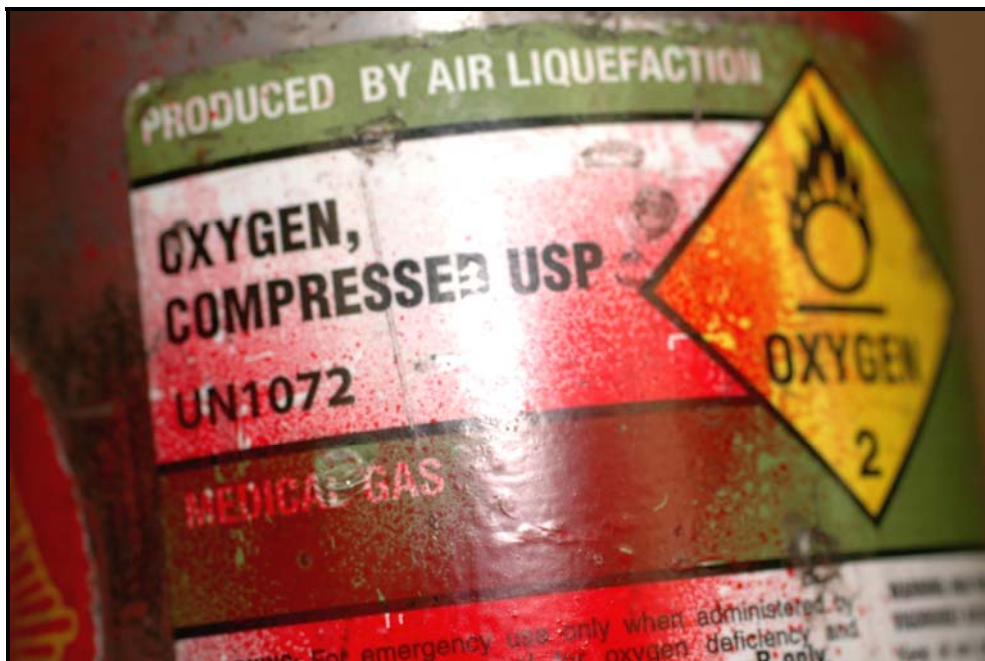


Figure 24: Labels on the DOT-3AL cylinder # AR0118046

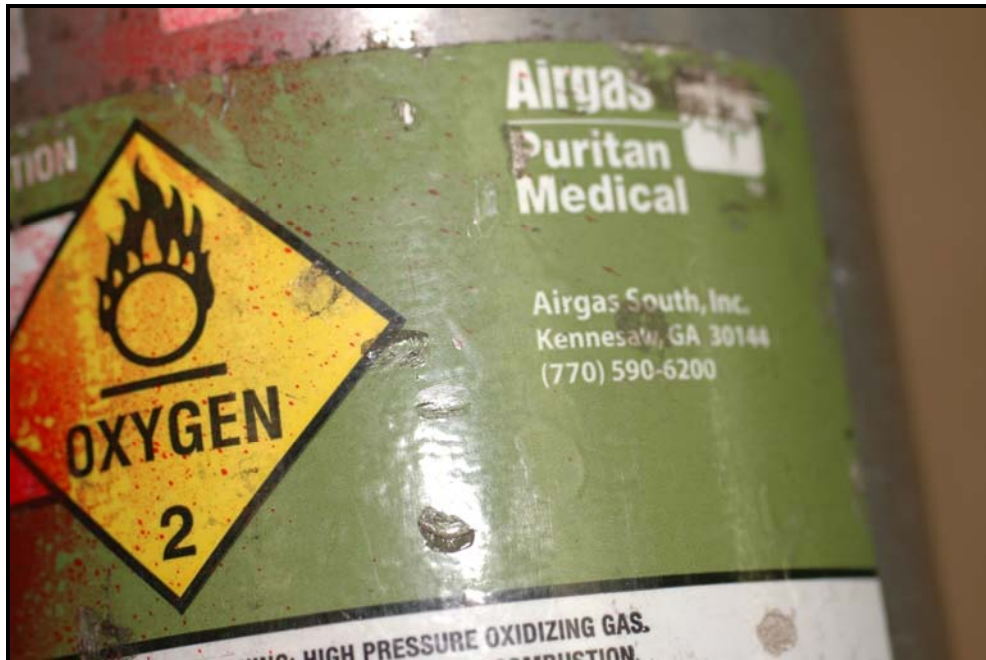


Figure 25: Labels on the DOT-3AL cylinder # AR0118046

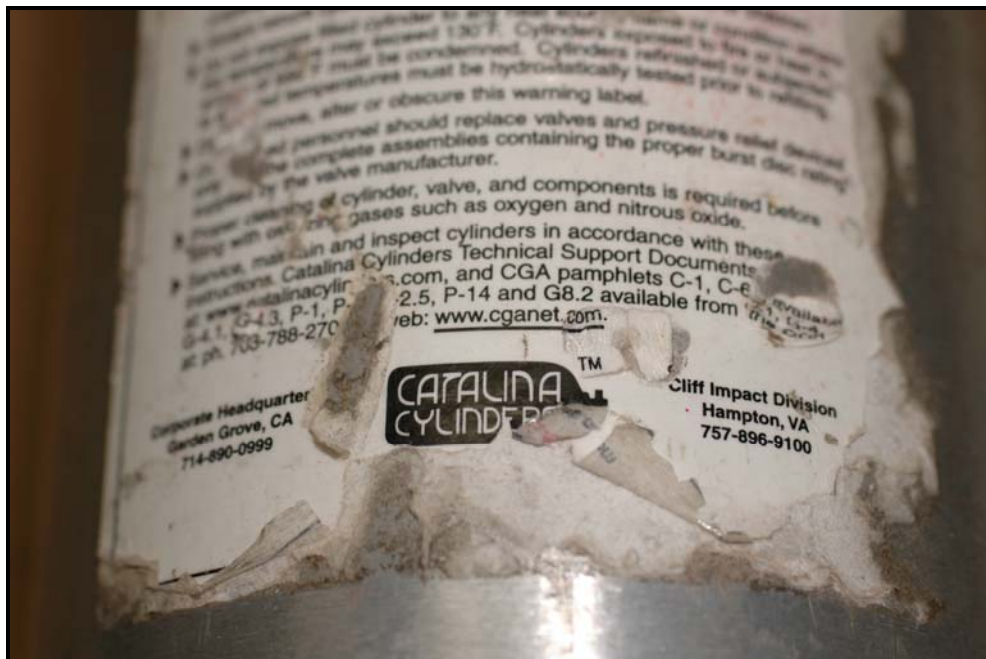


Figure 26: Labels on the DOT-3AL cylinder # AR0118046



Figure 27: Labels on the DOT-3AL cylinder # AR0118046

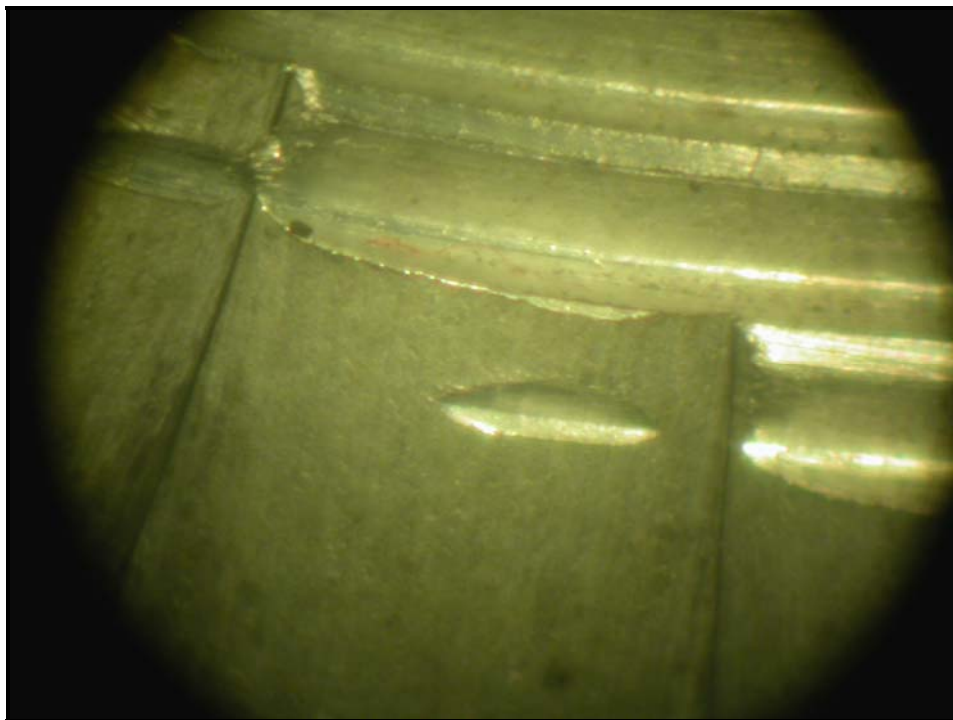


Figure 28: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118046 at 0° location identified in Figure 32.

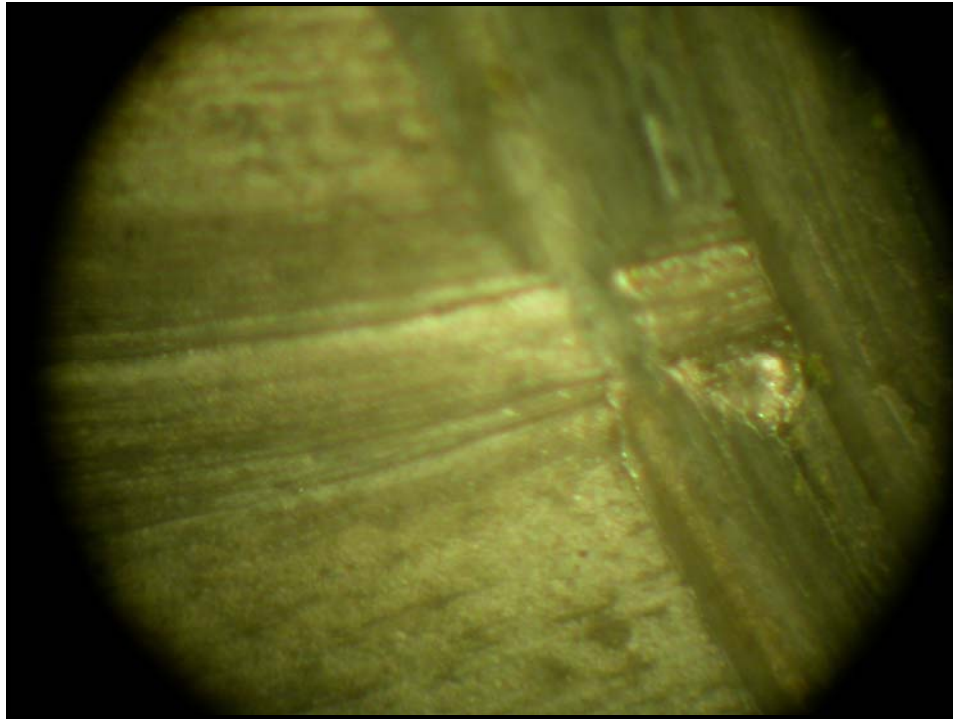


Figure 29: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118046 at 90° location identified in Figure 32.

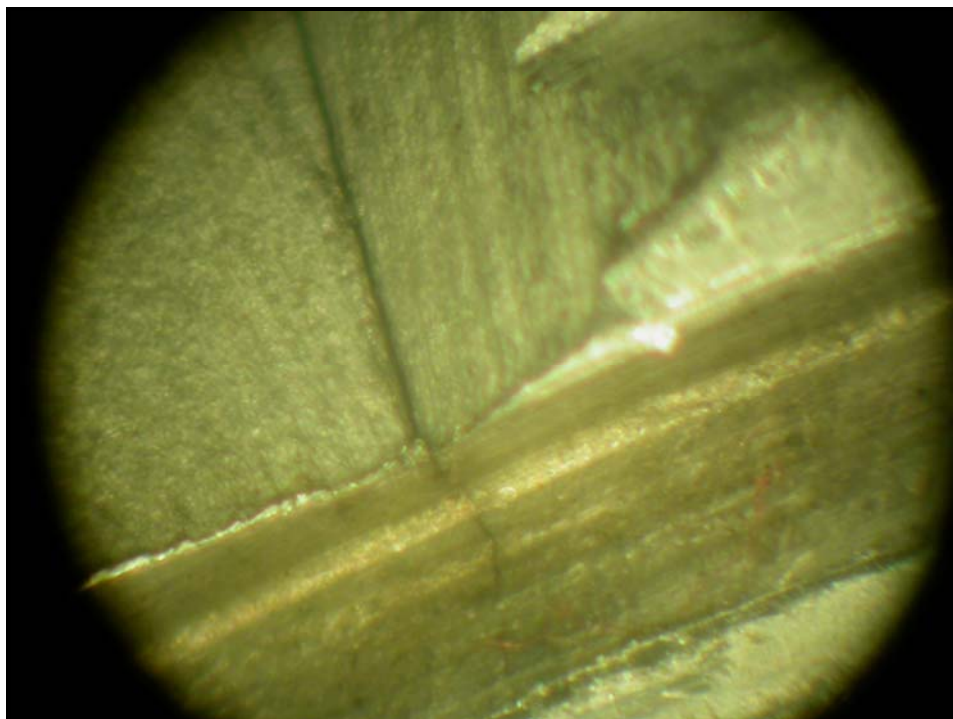


Figure 30: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118046 at 175° location identified in Figure 32.



Figure 31: Shows the orientation of the crack in the shoulder area of DOT-3AL cylinder # AR0118046 at 0° location with respect to the indented markings.

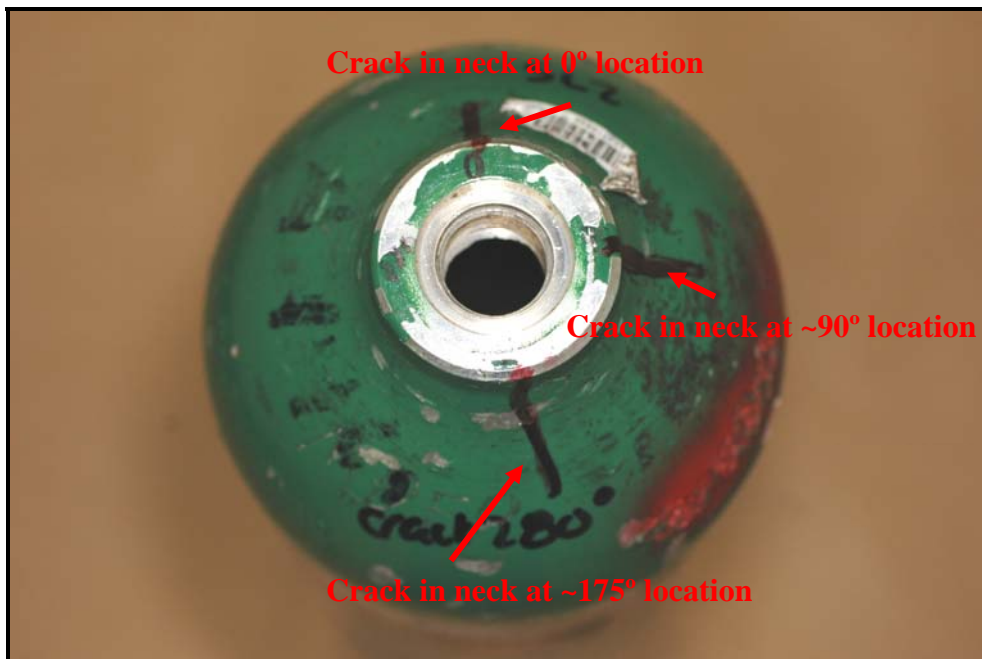


Figure 32: Shows the orientation of the cracks in the shoulder area of DOT-3AL cylinder # AR0118046 with respect to the 0° crack location.



Figure 33: Shows the as received DOT-3AL cylinder # AR0116501



Figure 34: Indented marking on the DOT-3AL cylinder # AR0116501

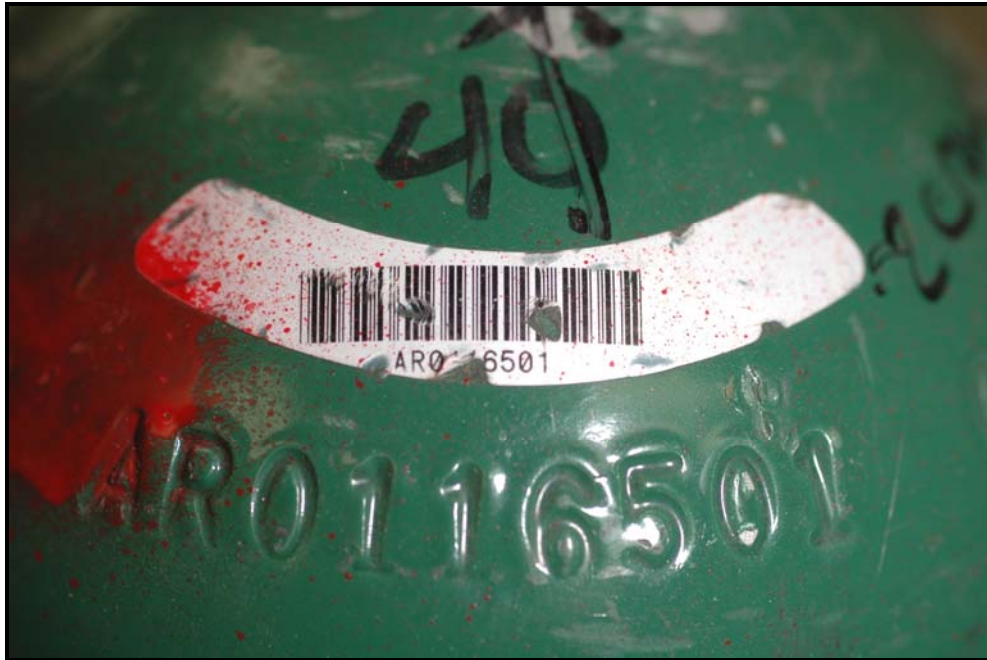


Figure 35: Indented marking on the DOT-3AL cylinder # AR0116501



Figure 36: Indented marking on the DOT-3AL cylinder # AR0116501



Figure 37: Indented marking on the DOT-3AL cylinder # AR0116501



Figure 38: Indented marking on the DOT-3AL cylinder # AR0116501



Figure 39: Indented marking on the DOT-3AL cylinder # AR0116501

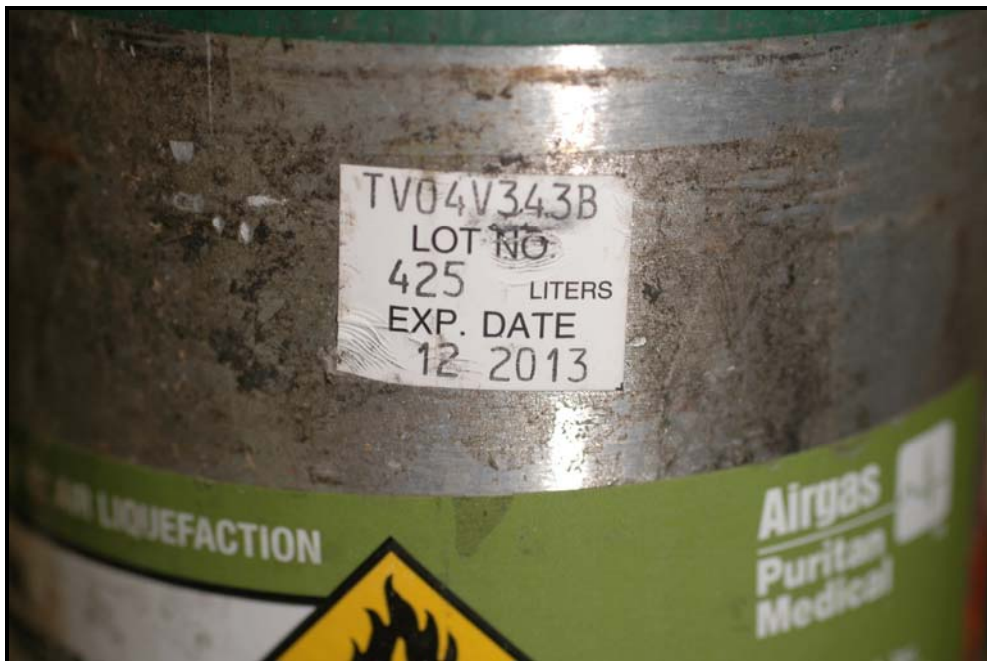


Figure 40: Labels on the DOT-3AL cylinder # AR0116501

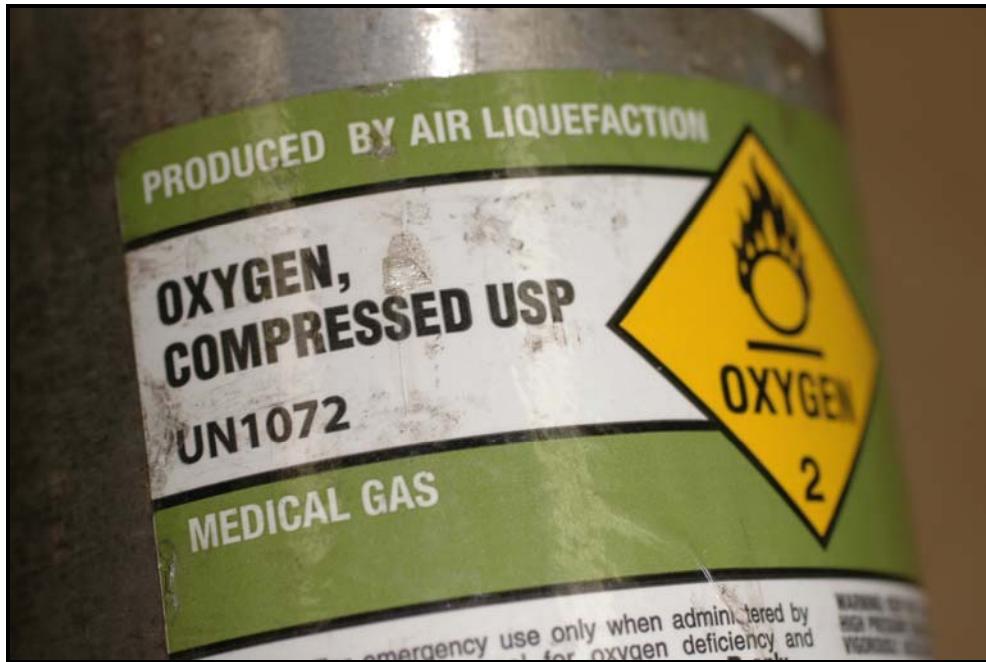


Figure 41: Labels on the DOT-3AL cylinder # AR0116501



Figure 42: Labels on the DOT-3AL cylinder # AR0116501



Figure 43: Labels on the DOT-3AL cylinder # AR0116501

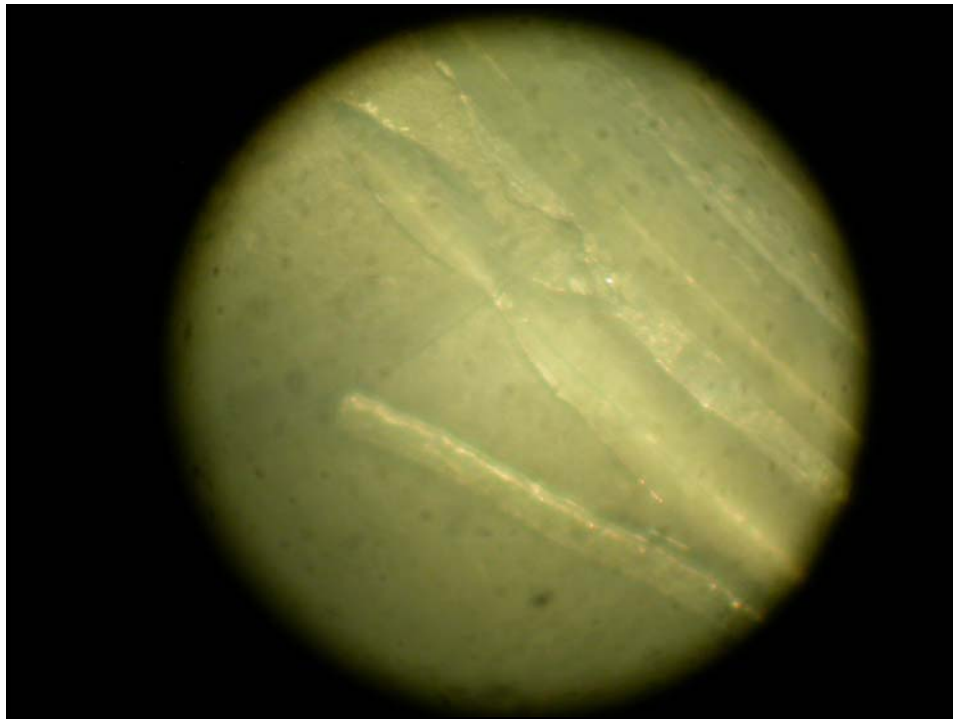


Figure 44: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0116501 at 0° location identified in Figure 48.

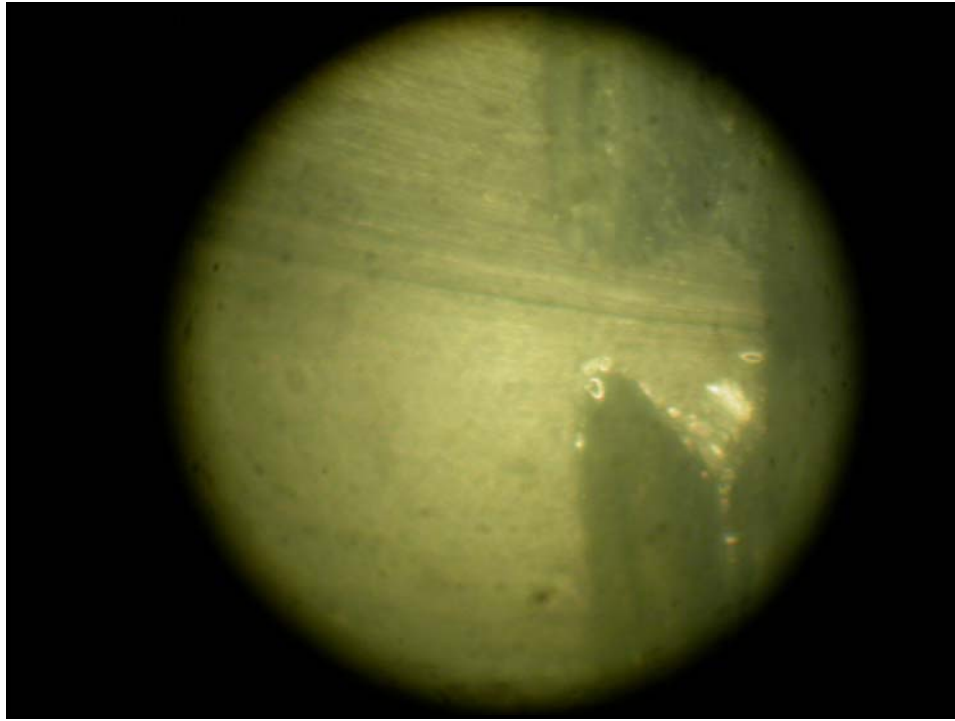


Figure 45: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0116501 at 90° location identified in Figure 48.

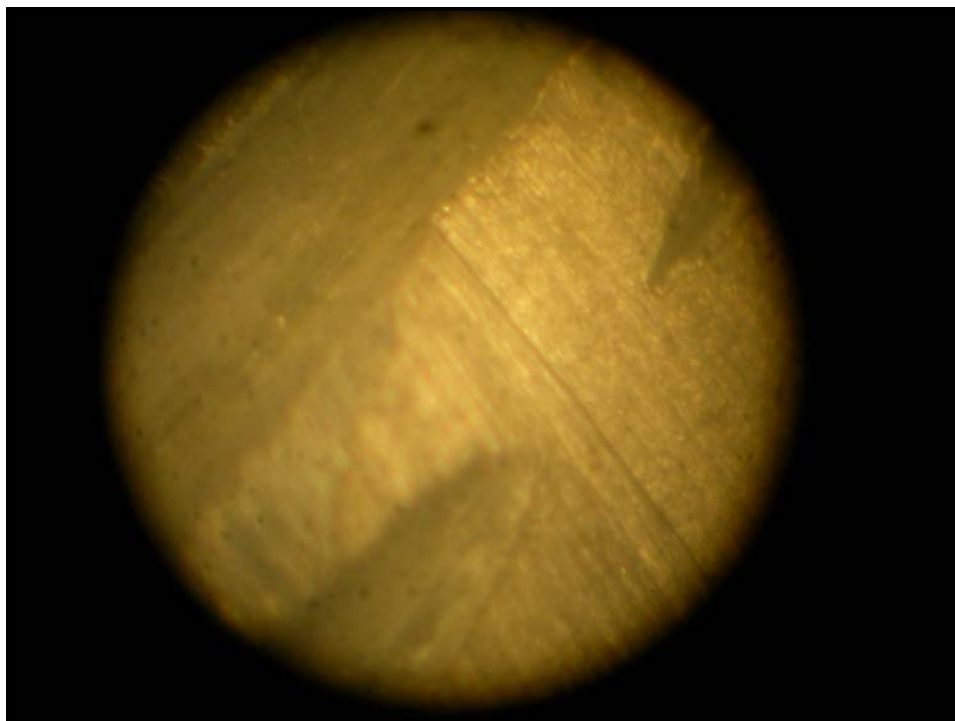


Figure 46: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0116501 at 180° location identified in Figure 48.



Figure 47: Shows the orientation of the crack in the shoulder area of DOT-3AL cylinder # AR0116501 at 0° location with respect to the indented markings.



Figure 48: Shows the orientation of the cracks in the shoulder area of DOT-3AL cylinder # AR0116501 with respect to the 0° crack location.



Figure 49: Shows the as received DOT-3AL cylinder # AR0118110



Figure 50: Indented marking on the DOT-3AL cylinder # AR0118110



Figure 51: Indented marking on the DOT-3AL cylinder # AR0118110

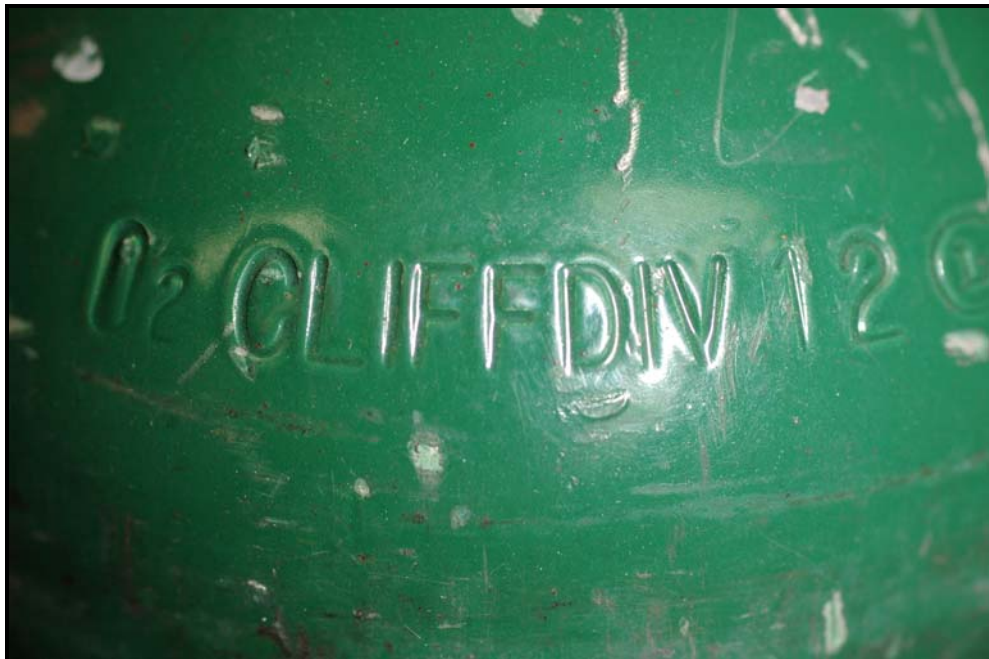


Figure 52: Indented marking on the DOT-3AL cylinder # AR0118110



Figure 53: Indented marking on the DOT-3AL cylinder # AR0118110



Figure 54: Indented marking on the DOT-3AL cylinder # AR0118110



Figure 55: Labels on the DOT-3AL cylinder # AR0118110

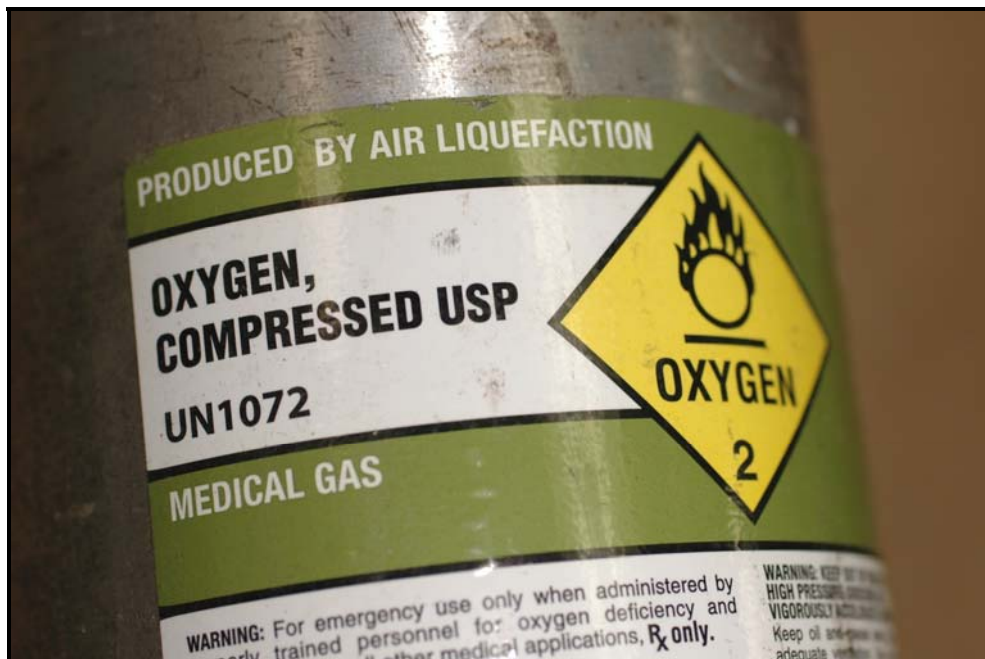


Figure 56: Labels on the DOT-3AL cylinder # AR0118110



Figure 57: Labels on the DOT-3AL cylinder # AR0118110



Figure 58: Labels on the DOT-3AL cylinder # AR0118110



Figure 59: Labels on the DOT-3AL cylinder # AR0118110

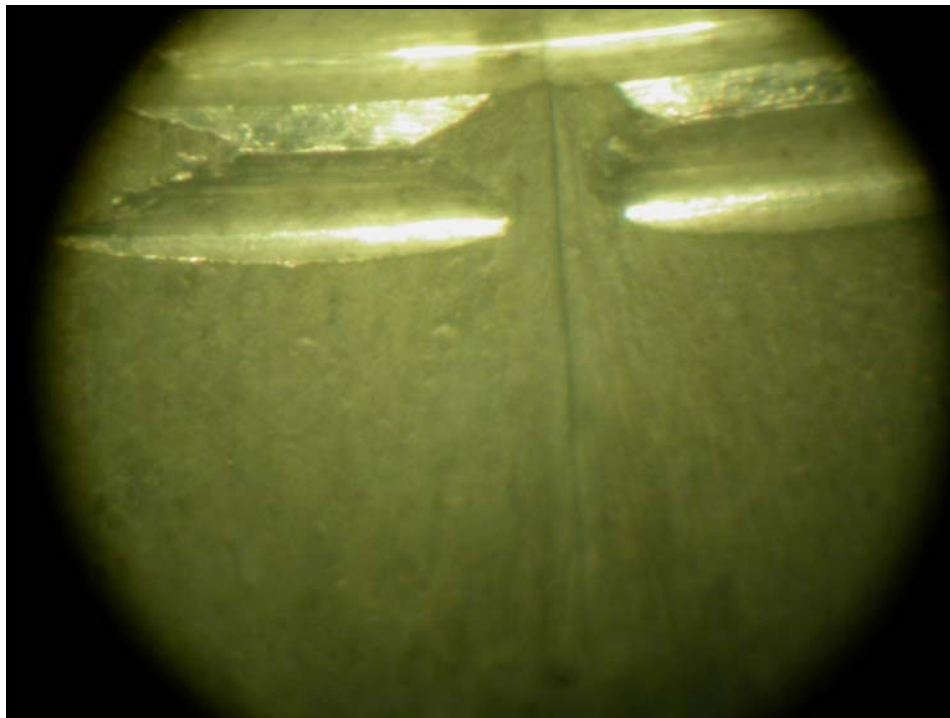


Figure 60: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118110 at 0° location identified in Figure 64.

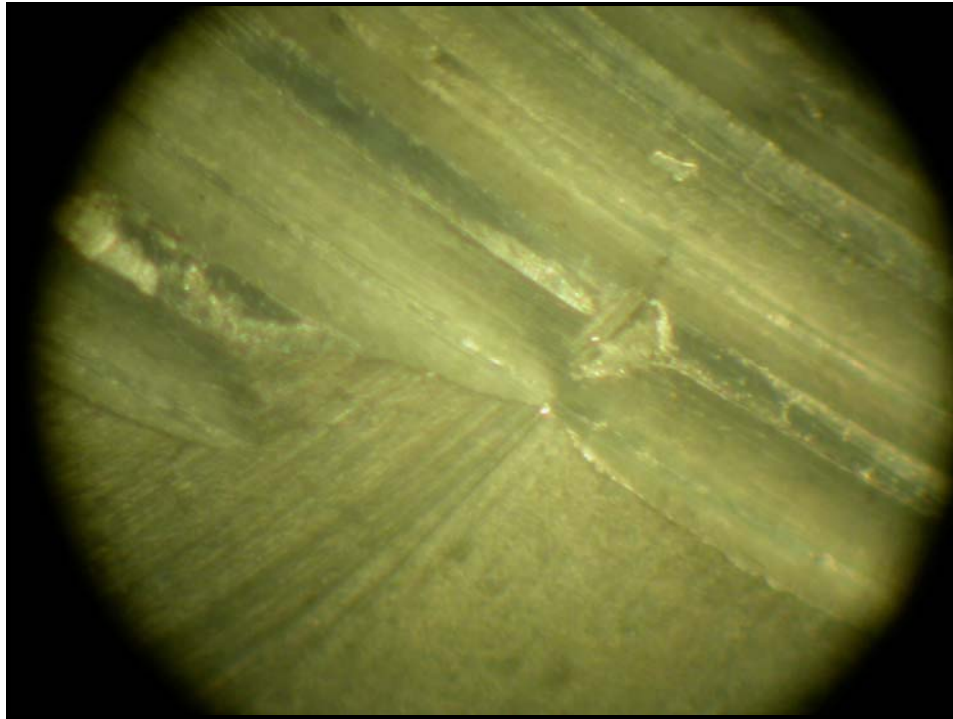


Figure 61: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118110 at 45° location identified in Figure 64.

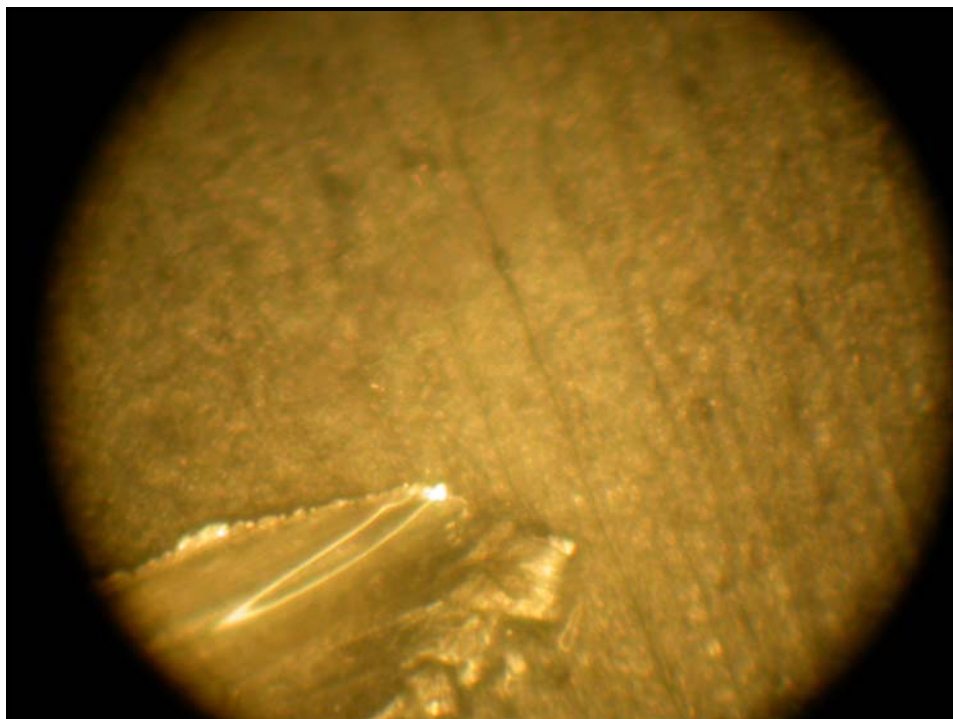


Figure 62: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0118110 at 165° location identified in Figure 64.



Figure 63: Shows the orientation of the crack in the shoulder area of DOT-3AL cylinder # AR0118110 at 0° location with respect to the indented markings.



Figure 64: Shows the orientation of the cracks in the shoulder area of DOT-3AL cylinder # AR0118110 with respect to the 0° crack location.



Figure 65: Shows the as received DOT-3AL cylinder # AR0119572



Figure 66: Indented marking on the DOT-3AL cylinder # AR0119572



Figure 67: Indented marking on the DOT-3AL cylinder # AR0119572



Figure 68: Indented marking on the DOT-3AL cylinder # AR0119572



Figure 69: Indented marking on the DOT-3AL cylinder # AR0119572

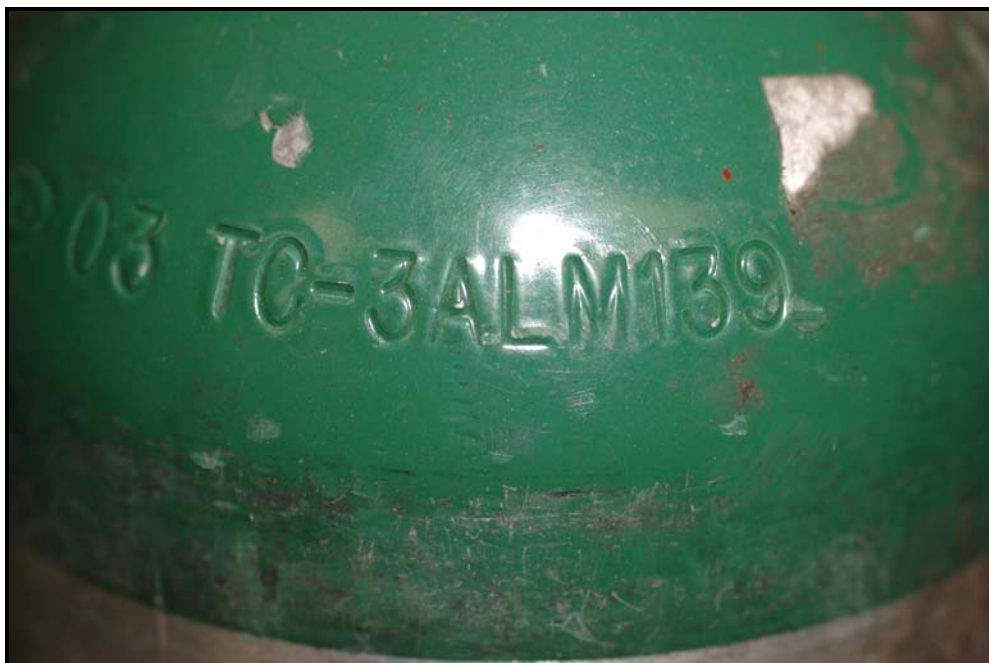


Figure 70: Indented marking on the DOT-3AL cylinder # AR0119572



Figure 71: Indented marking on the DOT-3AL cylinder # AR0119572

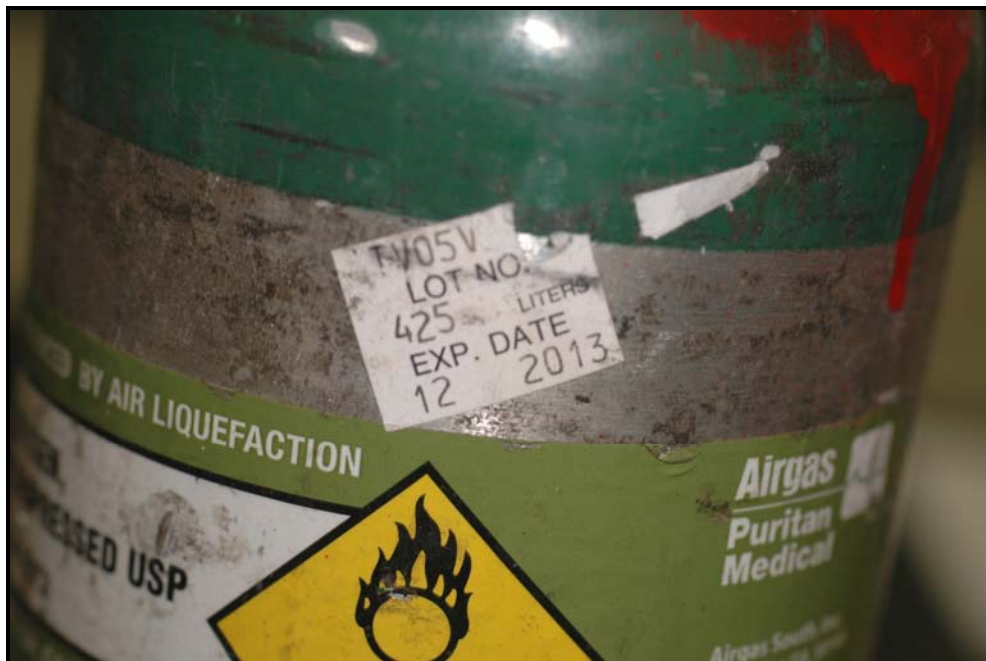


Figure 72: Labels on the DOT-3AL cylinder # AR0119572

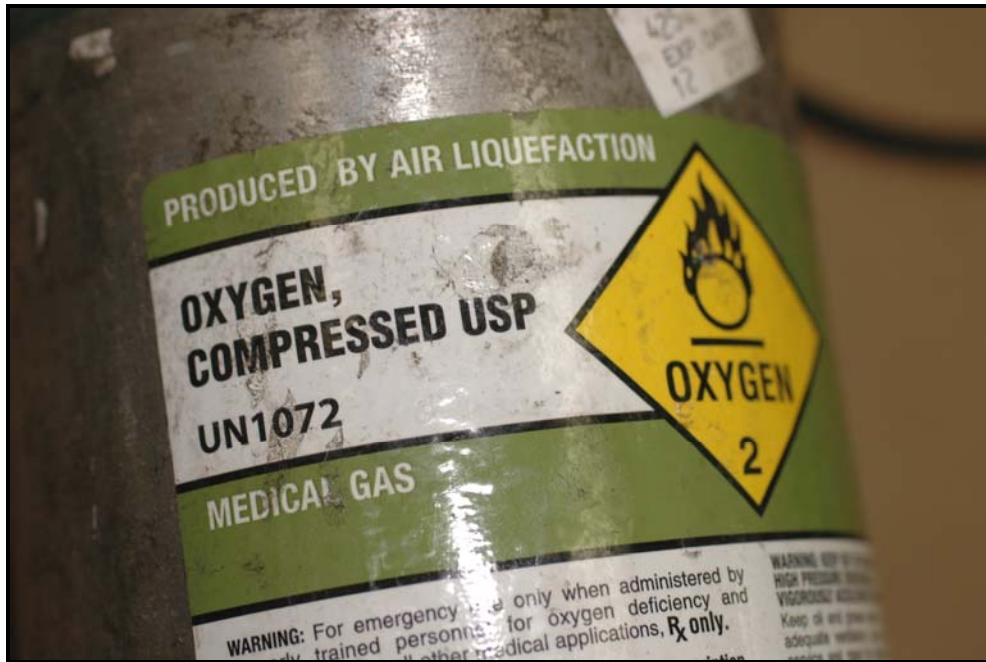


Figure 73: Labels on the DOT-3AL cylinder # AR0119572

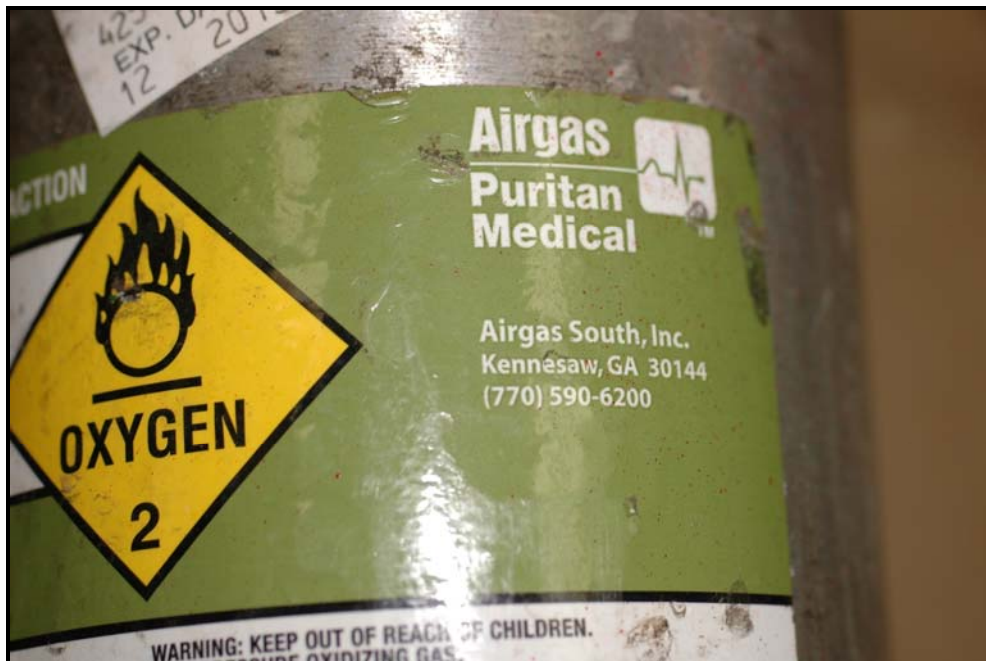
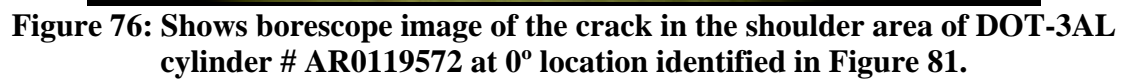


Figure 74: Labels on the DOT-3AL cylinder # AR0119572



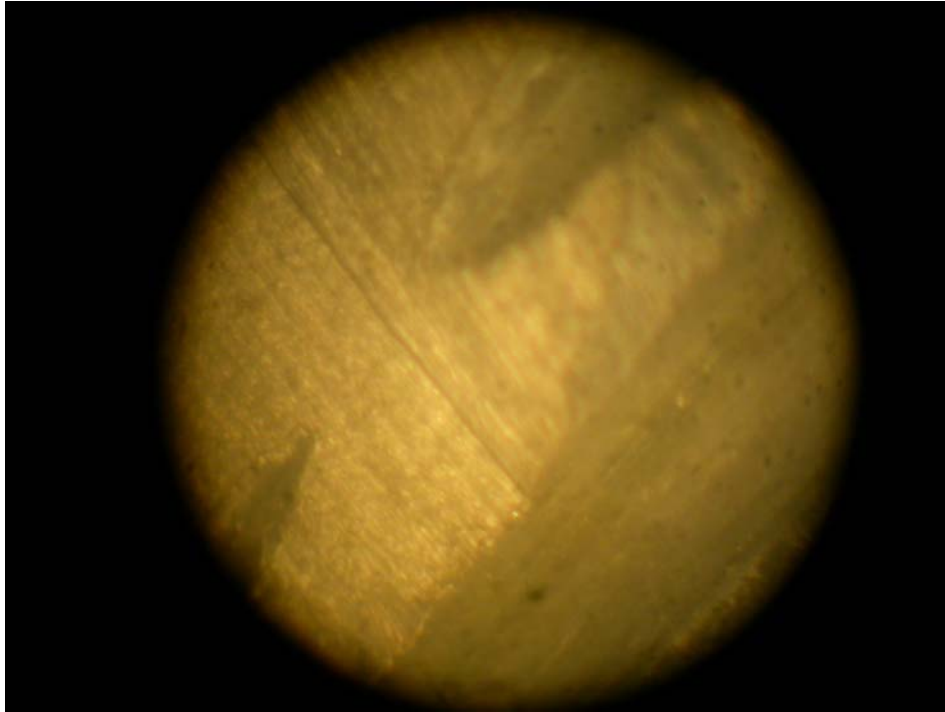


Figure 77: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119572 at 90° location identified in Figure 81.

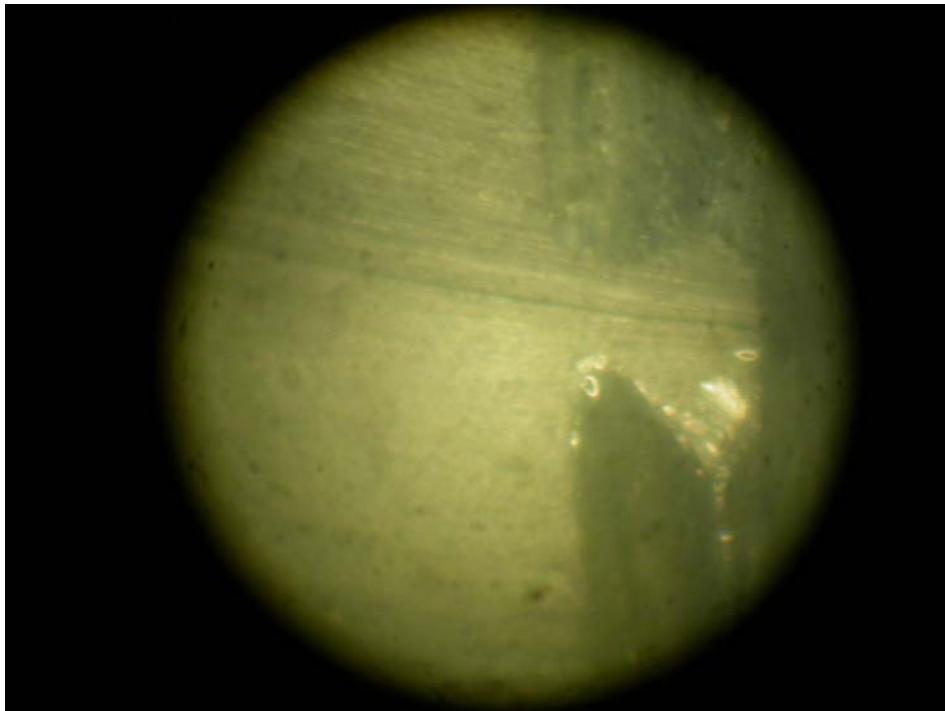


Figure 78: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119572 at 180° location identified in Figure 81.

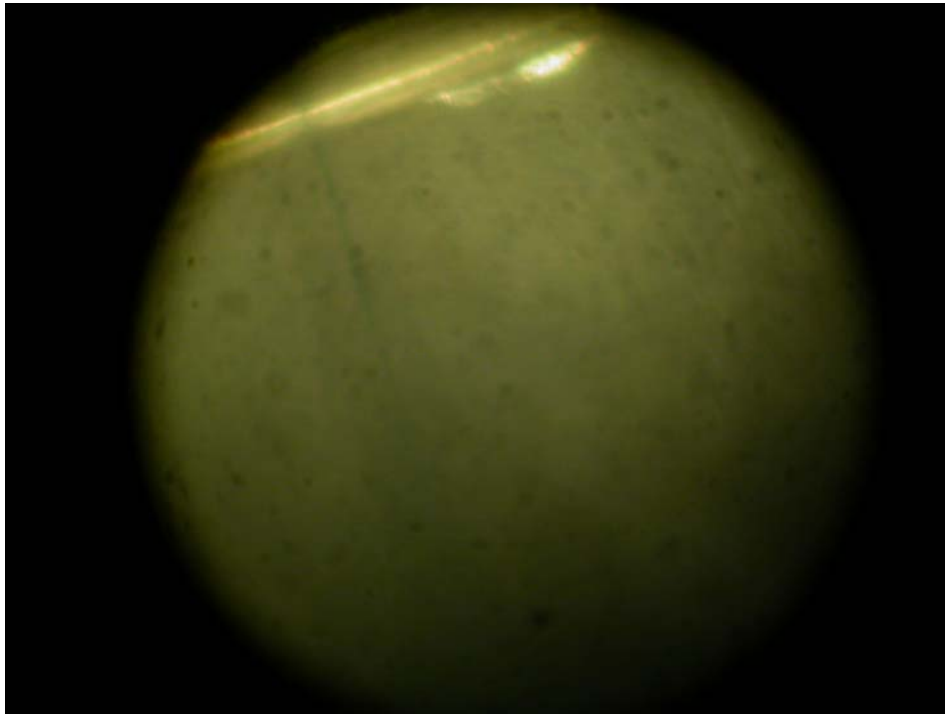


Figure 79: Shows borescope image of the crack in the shoulder area of DOT-3AL cylinder # AR0119572 at 280° location identified in Figure 81.



Figure 80: Shows the orientation of the crack in the shoulder area of DOT-3AL cylinder # AR0119572 at 0° location with respect to the indented markings.



Figure 81: Shows the orientation of the cracks in the shoulder area of DOT-3AL cylinder AR0119572 with respect to the 0° crack location.



Figure 82: Test set up for pressure cycling DOT-3AL 2015 cylinders up to 12,000 cycles and until failure of the cylinder



Figure 83: Test set up for pressure cycling DOT-3AL 2015 cylinders up to 12,000 cycles and until failure of the cylinder



Figure 84: Test set up for pressure cycling DOT-3AL 2015 cylinders up to 12,000 cycles and until failure of the cylinder

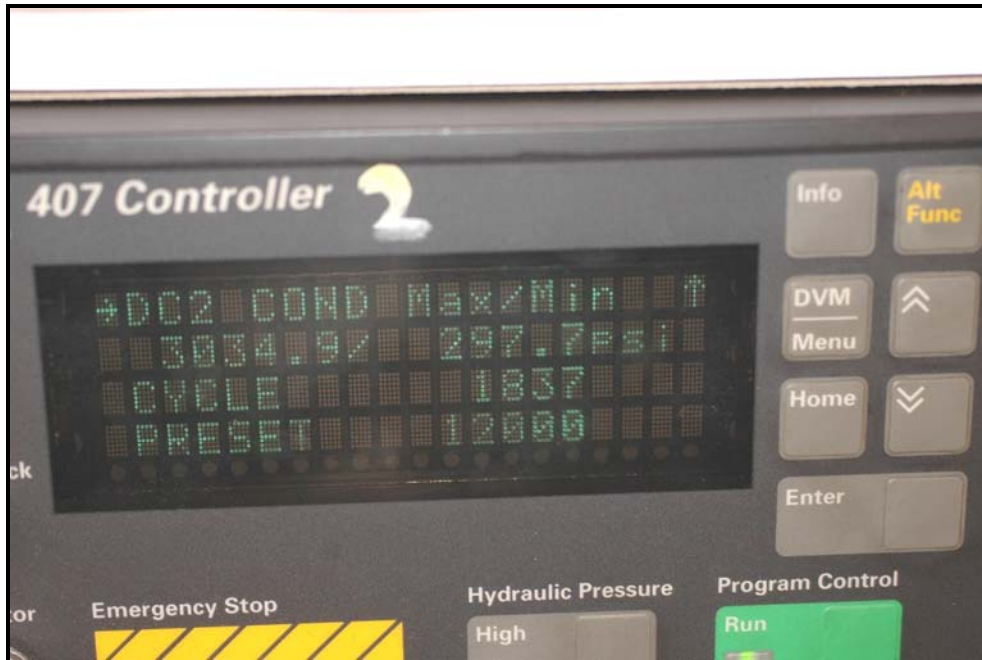


Figure 85: Shows the controller for pressure cycling DOT-3AL 2015 cylinders up to 12,000 cycles and until failure of the cylinder.

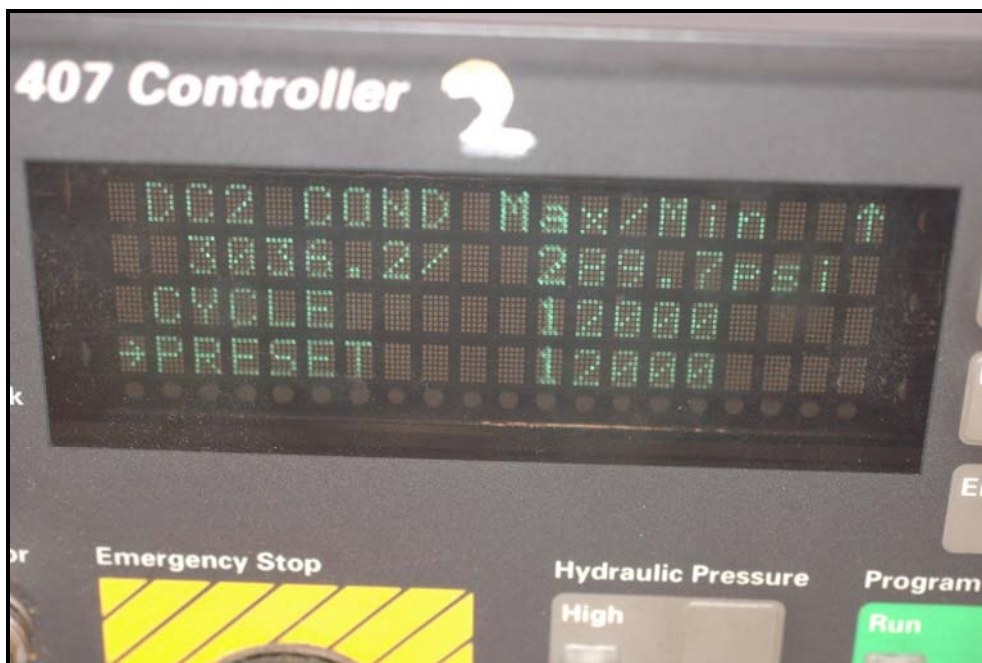


Figure 86: Shows the maximum/minimum pressure and the number of cycles completed during the pressure cyclic testing of the DOT – 3AA cylinder # AR0119582.



Figure 87: Shows the maximum/minimum pressure and the number of cycles completed during the pressure cyclic testing of the DOT – 3AA cylinder # AR0118046



Figure 88: Shows the maximum/minimum pressure and the number of cycles completed during the pressure cyclic testing of the DOT – 3AA cylinder # AR0116501



Figure 89: Shows the maximum/minimum pressure and the number of cycles until the failure of the DOT – 3AA cylinder # AR0119572. The cylinder leaked after 56,474 cycles.



Figure 90: Shows the location where the leak occurred as indicated by the arrow. The cylinder # AR0119572 leaked at the base of the cylinder.



Figure 91: Shows the leak at the base of the cylinder # AR0119572



Figure 92: Shows the maximum/minimum pressure and the number of cycles until the failure of the DOT – 3AA cylinder # AR0118110. The cylinder leaked after 53,507 cycles.



Figure 93: Shows the location where the leak occurred as indicated by the arrow. The cylinder # AR0118110 leaked on the wall of the cylinder near the bottom of the cylinder.



Figure 94: Shows the leak on the wall of the cylinder near the bottom of the cylinder # AR0118110



Figure 95: Test set up for hydraulic burst testing of cylinder #AR0119582



Figure 96: Test set up for hydraulic burst testing of cylinder #AR0119582

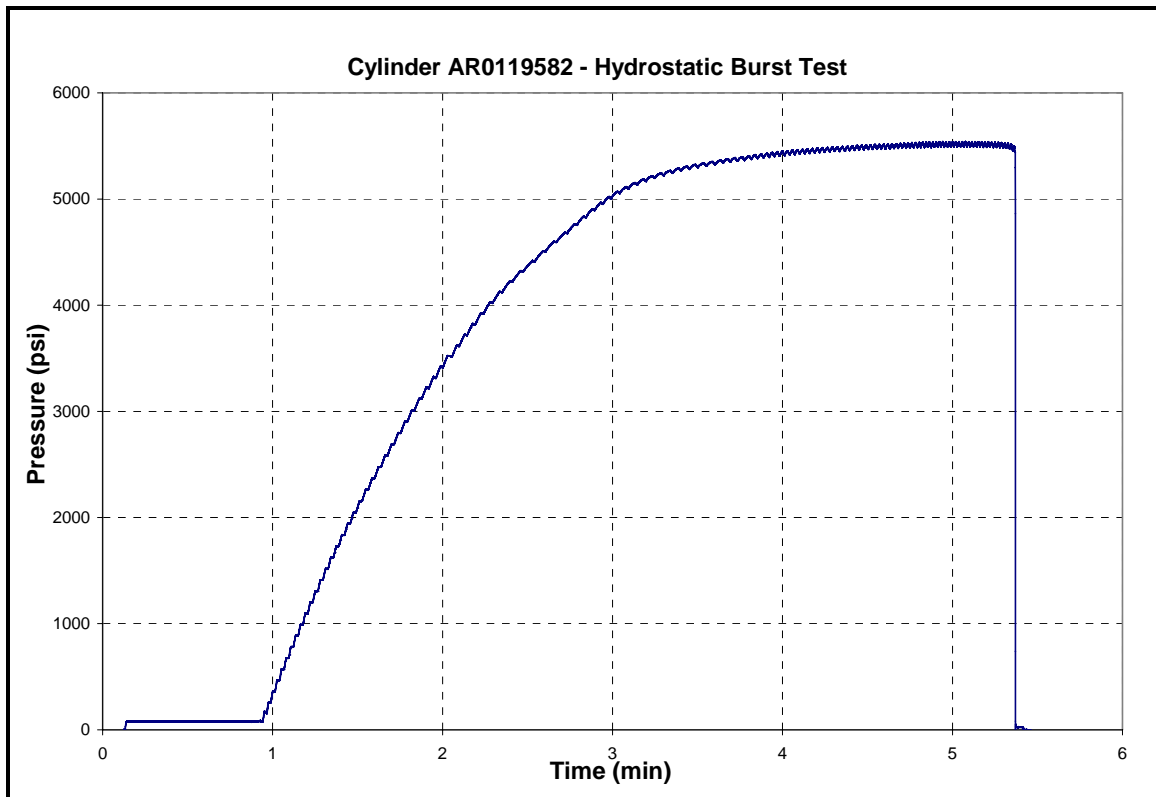


Figure 97: Pressure v Time data for Hydraulic burst test of cylinder # AR0119582.



Figure 98: Ruptured cylinder #AR0119582 after hydraulic burst testing



Figure 99: Ruptured cylinder #AR0119582 after hydraulic burst testing



Figure 100: Ruptured cylinder #AR0119582 after hydraulic burst testing