

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA23LA264

MATERIALS LABORATORY

Factual Report 24-029

June 3, 2024

(This page intentionally left blank)

A. ACCIDENT INFORMATION

Location: Lancaster, Tennessee
Date: May 21, 2023
Time: 14:35 central daylight time
19:35 coordinated universal time
Vehicle: Piper PA-28-180, N9139J
Investigator: Timothy Monville, AS-ERA

B. COMPONENTS EXAMINED

Remnants of an engine cylinder assembly
Remnants of a piston assembly
Remnants of an exhaust valve
Spring, retainer, rocker arm, keepers (pair)

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., PE, FASM
Office of Research and Engineering - Materials Laboratory Division
NTSB, Washington, DC

D. DETAILS OF THE EXAMINATION

On May 21, 2023, a Piper PA-28-180 was substantially damaged when it was involved in an accident near Lancaster, TN. The private pilot and one passenger sustained minor injuries. The pilot stated that during flight, the engine experienced a loss of power and began to run rough, with the airframe shaking while losing altitude. The pilot performed a forced landing in a field where the airplane nosed down and came to rest upright in a nose-low-tail high attitude.

The airplane was salvaged for further examination of the engine. The wreckage was recovered for further study, and parts from the Lycoming O-360-A3A engine were sent to the NTSB Materials Laboratory for additional examination.¹ The last inspection of the airplane was stated as April 4, 2023, at a total time of 3223 flight hours. The inspection had been performed 7 flight hours prior to the accident.

Figure 1 shows the received components from the #2 engine cylinder. The cylinder had been partially disassembled, with the springs, retainer, rocker arm, keepers, and valve stem remnant from the exhaust side removed. Figure 2 shows the side of the cylinder with the intake and exhaust ports. The exhaust port exhibited some flaky

¹ The Lycoming O-360-A3A four-cylinder, direct-drive, horizontally opposed, air-cooled, piston aircraft engine produced by Lycoming Engines, headquartered in Williamsport, PA.

deposits along the interior. However, there were no indications of impact or mechanical damage to the exterior of the cylinder.

Figure 3 shows the upper portion of the cylinder assembly, as received. The housing and pushrods had been removed, along with the components from the exhaust side. The rocker and retainer from the intake side remained intact and exhibited few indications of wear or damage. Dark and flaky deposits were visible along the valve stem bore on the exhaust side (left in Figure 3).

Figure 4 shows the interior of the cylinder, viewed from the crown side. The seat of the exhaust valve exhibited dark deposits built up along the interior surfaces, consistent with those seen on the exhaust side in Figure 3 and the fractured valve stem in Figure 1. The cylinder interior also exhibited elongated and randomly oriented impact marks. These marks were present throughout the cylinder crown and skirt interior surfaces.

Figure 5 shows the mating piston from the crown and skirt sides. The piston pin was still partially inserted into the piston, as received. As illustrated in Figure 5a, the piston crown surface exhibited multiple linear impact marks surrounded by localized upward deformation features. These randomly oriented impact marks were consistent with those on the cylinder interior. The piston crown also exhibited tan and dark, flaky compounds along the surface.

Figure 6 shows the components from the exhaust side of the cylinder assembly that had been removed before receipt. Except for the valve stem remnant, all other parts were intact. Many parts exhibited discoloration, indicating compounds deposited on their outer surfaces. These deposits were most prevalent on the left third of the springs in the figure, which showed white and tan flaky compounds, and the valve stem remnant, which exhibited progressively thicker deposits toward the fracture surface.

Figure 7 shows the remnant of the exhaust valve stem and the keepers. Figure 7 shows the dimensions of several regions along the stem. The total length of the remnant was 3.77 inches long, with 2.81 inches being the amount with combustion deposits. The region of thickest deposits was located in the nearest 0.53 inches of the stem remnant near the fracture surface. This was consistent with the diameter of the stem being thicker near the fracture surface than in areas away from it.

Figure 8 shows the face of the stem head. This face did not exhibit concentric or hourglass marks that would indicate uneven wear or contact with the rocker arm. No deformation or impact indications were observed on the upper part of the stem remnant.

Figure 9 shows the fracture surface of the valve stem, as received. Corrosion compounds entirely obscured the surface, manifest as dark and rust-colored material in the figure. The valve stem was progressively cleaned in an ultrasonic bath of acetone, aqueous Alconox solution, and aqueous Evapo-Rust solutions to remove as much of the surface oxide without damaging the underlying metal morphology.² Figure 10 shows the fracture surface after the final cleaning.

The upper left portion of the fracture surface exhibited an inward deformation at the edge, along with material deformed outward along the sides. This region was consistent with a post-fracture impact mark. Most of the rest of the fracture surface was relatively flat and oriented perpendicular to the stem direction. This portion of the fracture surface exhibited radial marks in the upper right, which only intersected with the external surface edge. A portion in the lower region exhibited a rougher surface morphology and appeared lighter than the rest of the darker areas of the fracture surface.

Figures 11 through 13 show side views of the stem near the fracture surface, with the rougher region at the bottom of Figure 10 being demarcated with a black permanent marker, as shown in Figure 11. The exterior of the stem near the fracture surface generally exhibited material loss and indications of impact region, particularly in Figure 13. This area corresponded to the impact in the upper left of Figure 10 on the fracture surface.

Figure 14 shows an angled view of the fracture surface along the area of rougher texture. Just below this region were parallel cracks, as demonstrated in Figure 15. Similar cracks were present on the opposite exterior surface, though smaller in size and quantity.

The fracture surface was examined using a field emission scanning electron microscope (SEM). Figure 16 shows a typical fracture surface area when examined at a magnification of 5000X. Even though the surface was cleaned of much of the oxide and corrosion product, a thick enough layer was still present over much of the surface, as typified in Figure 16. This figure shows a faceted surface texture with disparate material, as demonstrated by the contrast in backscattered electrons. This area was examined using energy dispersive x-ray spectroscopy (EDS), and was consistent with chromium and iron oxides (see Figure 17).

Some areas of the fracture surface exhibited bright contrast, as illustrated in Figure 18. When examined using EDS, the compounds exhibited high lead and bromine

² Alconox is a powdered cleaning detergent, containing primarily sodium bicarbonate and sodium alkylbenzene sulfonate, manufactured by Alconox, Inc., White Plains, NY. Evapo-Rust is a commercially-available chelating rust stripper currently manufactured CRC Industries, headquartered in Horsham Township, PA.

content, consistent with combustion deposits from tetraethyl lead additives in avgas fuel (see Figure 19).

Selected areas of the fracture surface exhibited oxide layers that were thin enough to reveal the underlying features of the fracture surface. One area was present along the edge in Figure 20, between two of the radial marks in Figure 10. A closer view of this area revealed parallel linear features consistent with fatigue striations (see Figures 21 and 22). These striations were oriented parallel to the edge and were consistent with crack propagation from the exterior inward.

The fracture surface was cross-sectioned parallel to the stem's longitudinal direction through the secondary cracking area shown in Figure 14. Figure 23 shows a cross-section through the crack region, with the exterior facing upward in the figure and the fracture surface facing the right. This figure shows one of the larger cracks on the upper surface. Figure 24 shows a closer view, demonstrating the wide gap of the outer part of the crack, with the branched quality of the crack towards the tip. The surface differential of the opposite sides of the cracks also illustrates the material loss closer to the fracture surface.

Figure 25 shows the opposite side of the stem cross-section across the hollow center cavity (in this figure, the exterior surface faces downward, and the fracture surface faces the right). Closer views of the edge near the fracture surface revealed shorter parallel cracks, consistent with having initiated at and propagated from the exterior surface (Figure 26).

As typified in Figures 27 and 28, the exterior surface exhibited areas of cavity formation and localized cracking. Much of this cracking was oriented parallel to the exterior surface rather than perpendicular. In addition, there were areas of cracking within the second phase precipitates near the surface (Figure 27). In some regions, these cracks had coalesced below the surface.

The core of the valve stem microstructure was examined after etching with Fry's Reagent. Figure 28 illustrates a typical view of the microstructure away from the surface. This microstructure showed multiple second phases consistent with chromium carbides typical of this composition.³ The larger carbides exhibited rounding and coarsening throughout the microstructure, both near the surface and in the core. This microstructure was consistent with that near the surface shown in previous figures. These features were consistent with excessive temperature exposure, which changed the valve microstructure at this location.⁴ The composition

³ G.F. Vander Voort, G.M. Lucas, E.P. Manilova. "Metallography and Microstructures of Stainless Steels and Maraging Steels." *ASM Handbook, Vol 9: Metallography and Microstructures*. ASM International: Materials Park, OH. (2004) pp. 670-700

⁴ B.A. Lindsley, A.R. Marder. "The Morphology and Coarsening Kinetics of Spheroidized Fe-C Binary Alloys." *Acta Mater.* Vol 46 (1997) pp. 341-351

was consistent with a martensitic or ferritic stainless steel, and the microstructure shown in these cross sections was inconsistent with typical as-manufactured conditions.⁵

The exhaust valve fractured from fatigue cracking, which initiated at multiple locations along the stem exterior surface. Once the cracking progressed through most of the valve stem cross-section, the head liberated, and this loose fragment was repeatedly battered against the cylinder and piston surfaces. This sequence of events led to leading to a loss of engine power and proper timing in the #2 cylinder.

The presence of thick lead oxide deposits, surface oxidation, and coarsened microstructure indicated elevated temperature exposure the valve experienced.

Submitted by:

Erik M. Mueller
Materials Research Engineer

⁵ D. Zhang, J. Shen, B. Li. "Investigation of Creep Properties and Fracture Mechanism of 430 Ferritic Stainless Steel at Elevated Temperature." *Journal of Materials Engineering and Performance*. Vol 33 (2004) pp. 1549-1559.

E. FIGURES



Figure 1. The components from the engine, as received.



Figure 2. View of the cylinder from the side with the intake and exhaust ports.

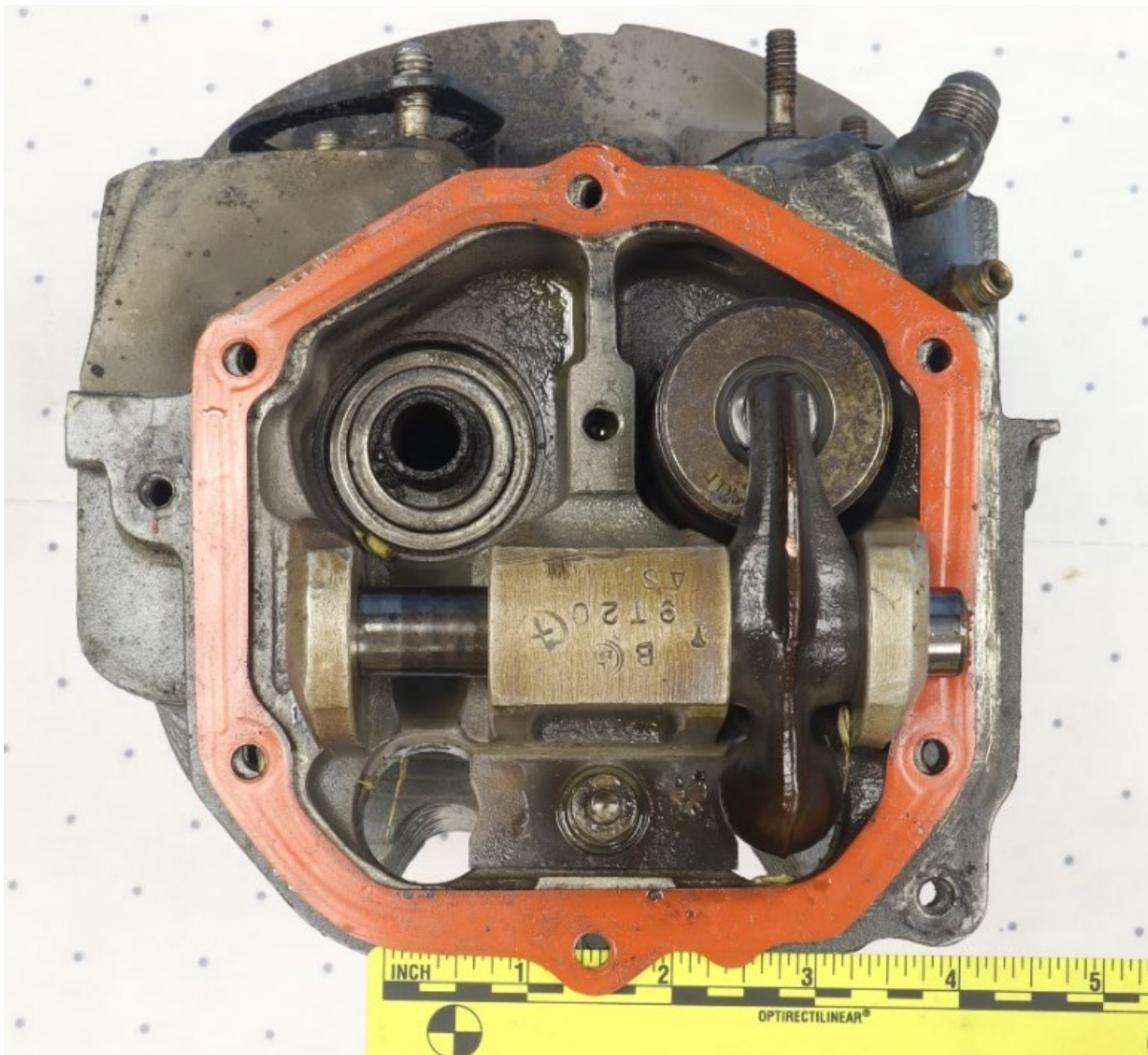


Figure 3. View of the cylinder from the rocker and valve stem area with housing removed.



Figure 4. Closer view of the interior of the cylinder, showing impact damage to the cylinder and valve seat surfaces.



Figure 5. Views of the piston and pin, as received, from (a) the crown and (b) the underside.



Figure 6. The disassembled rocker arm, retainer, keepers, springs, cap, and exhaust valve stem, from different sides.



Figure 7. Closer view of the exhaust valve stem remnant and keepers.

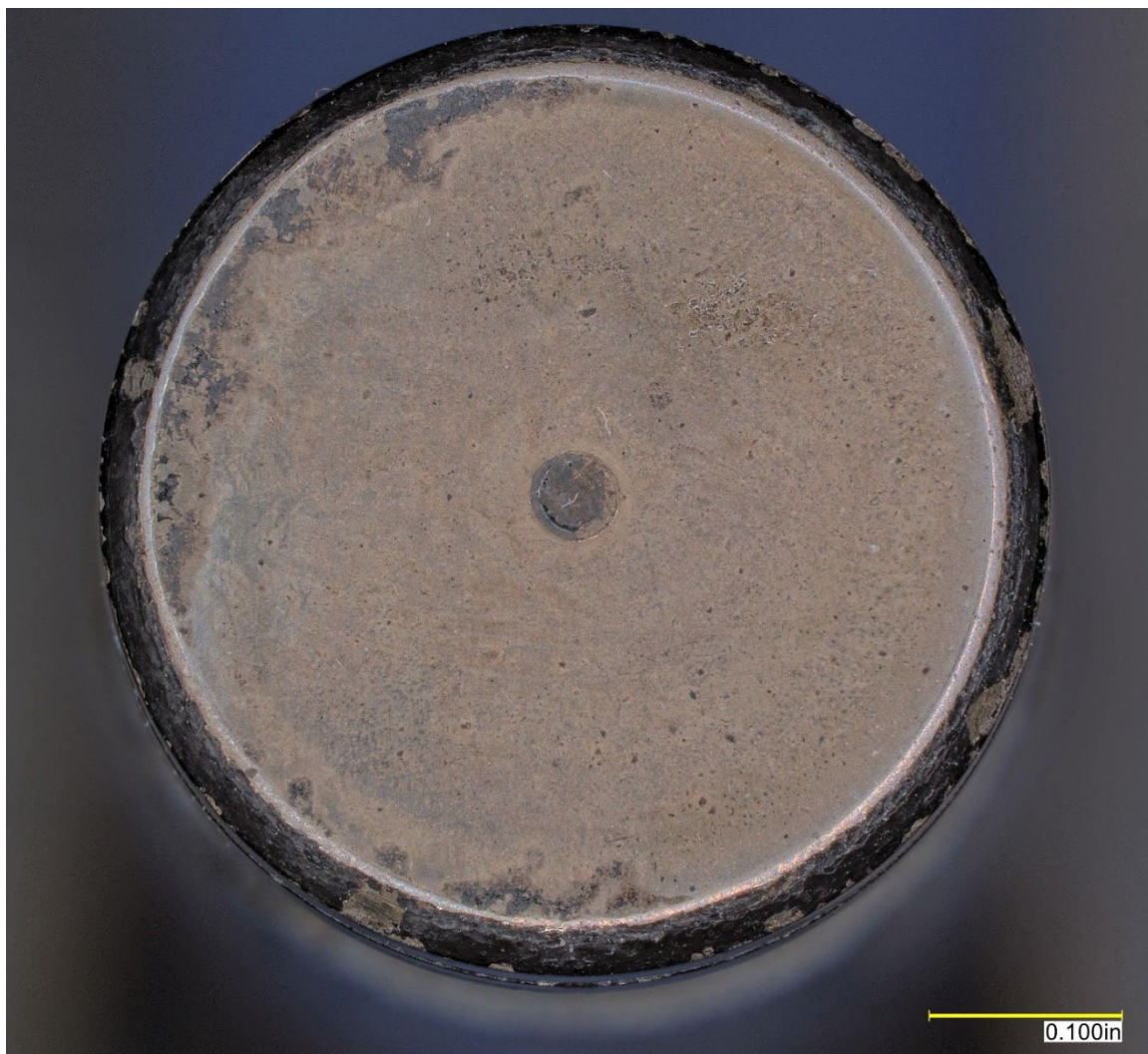


Figure 8. The stem head face of the exhaust valve.



Figure 9. The exhaust valve stem fracture surface, as received.

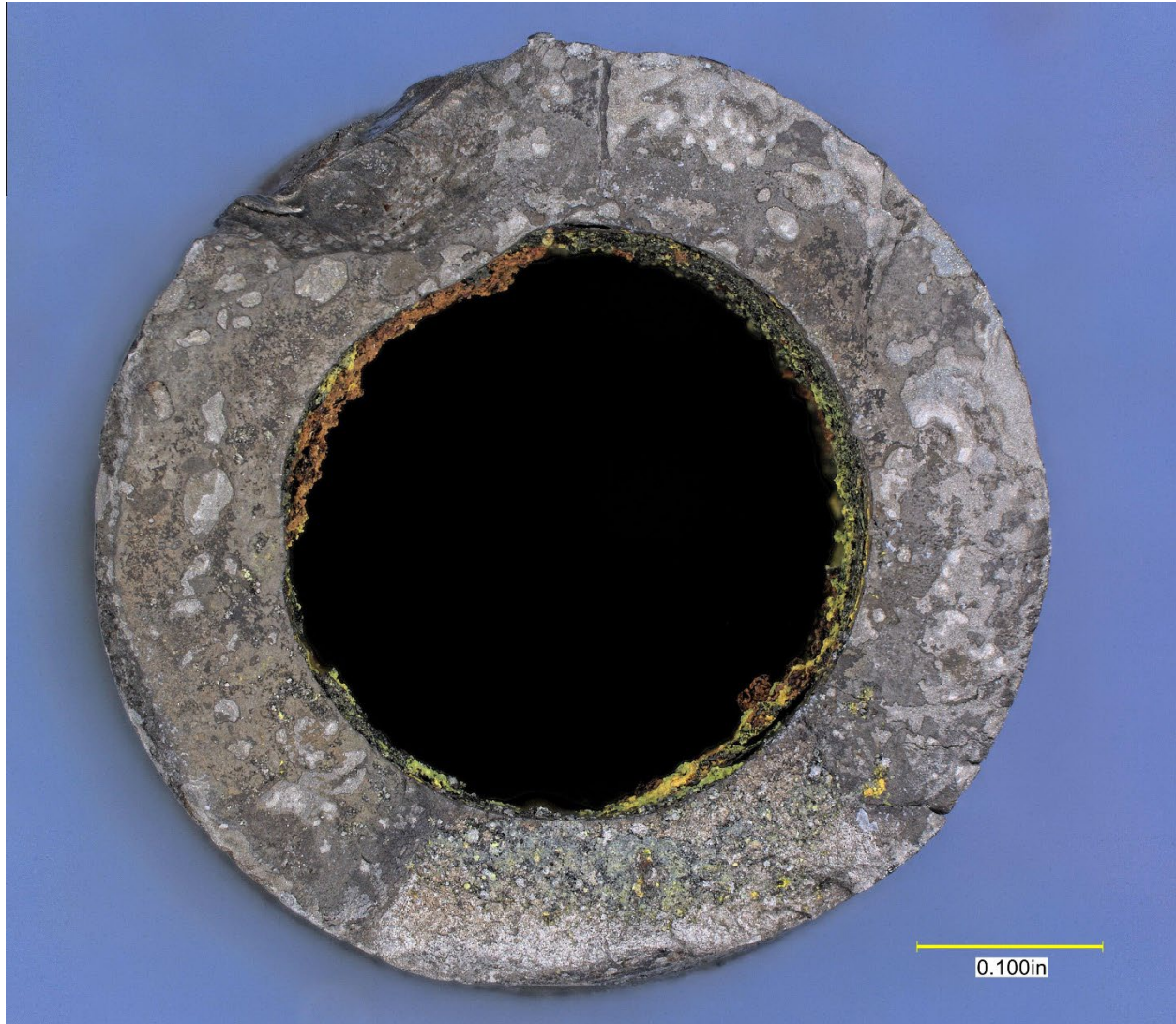


Figure 10. View of the exhaust valve stem fracture surface after multiple cleaning steps.

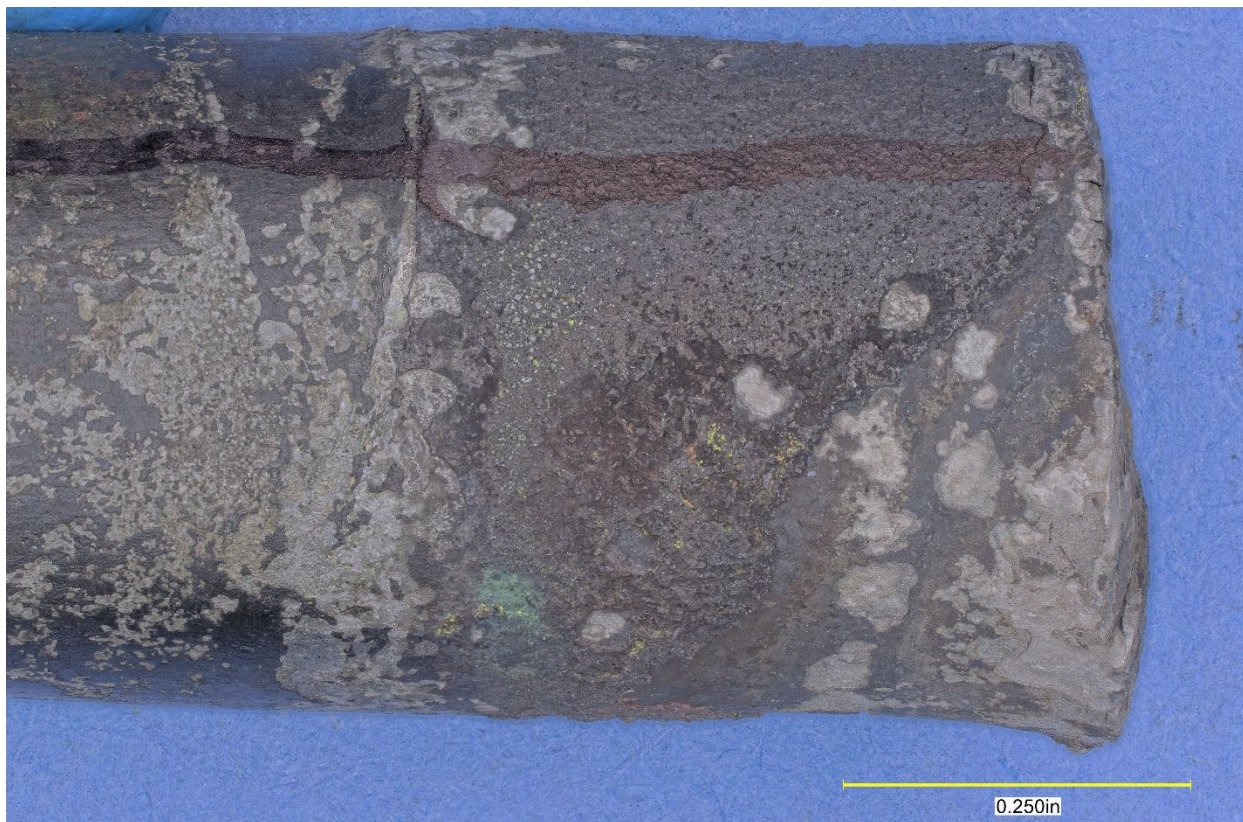


Figure 11. Side view of the valve fracture surface with the rougher region facing up.



Figure 12. Side view of the valve near the fracture, after cleaning, rotated 90° from Figure 11.

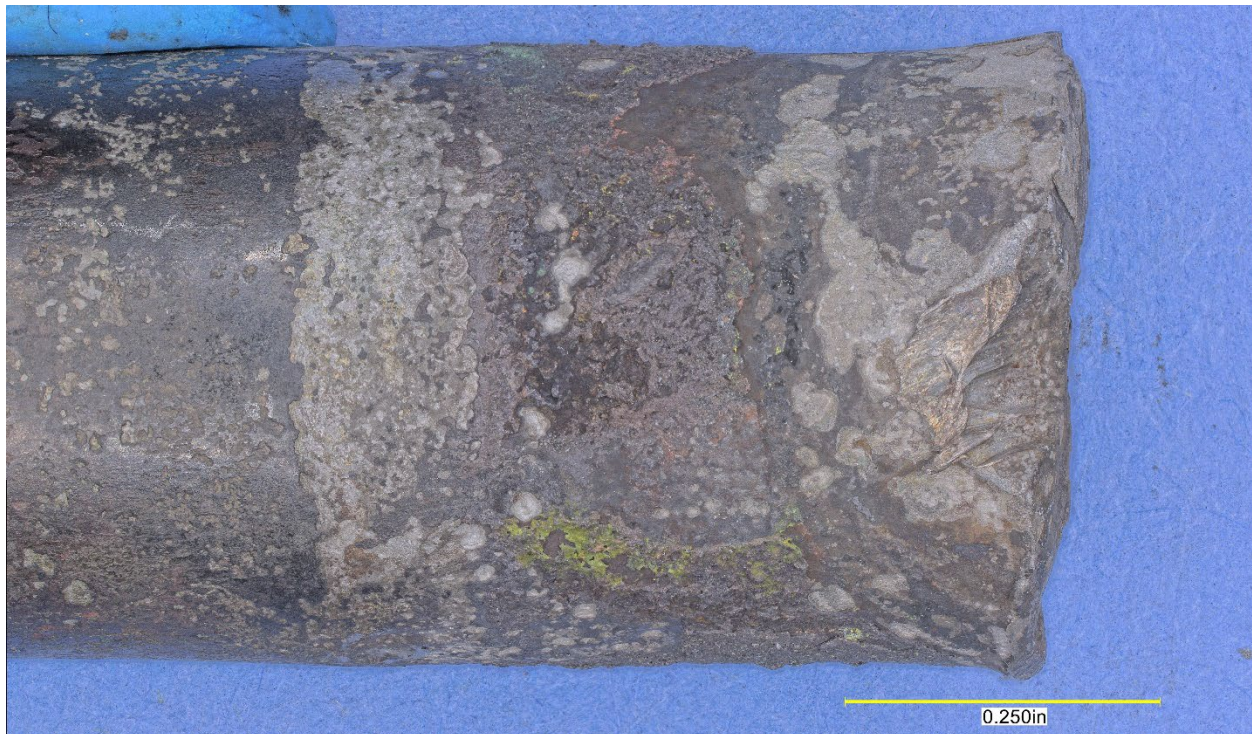


Figure 13. Side view of the valve near the fracture, after cleaning, rotated 90° from Figure 12.

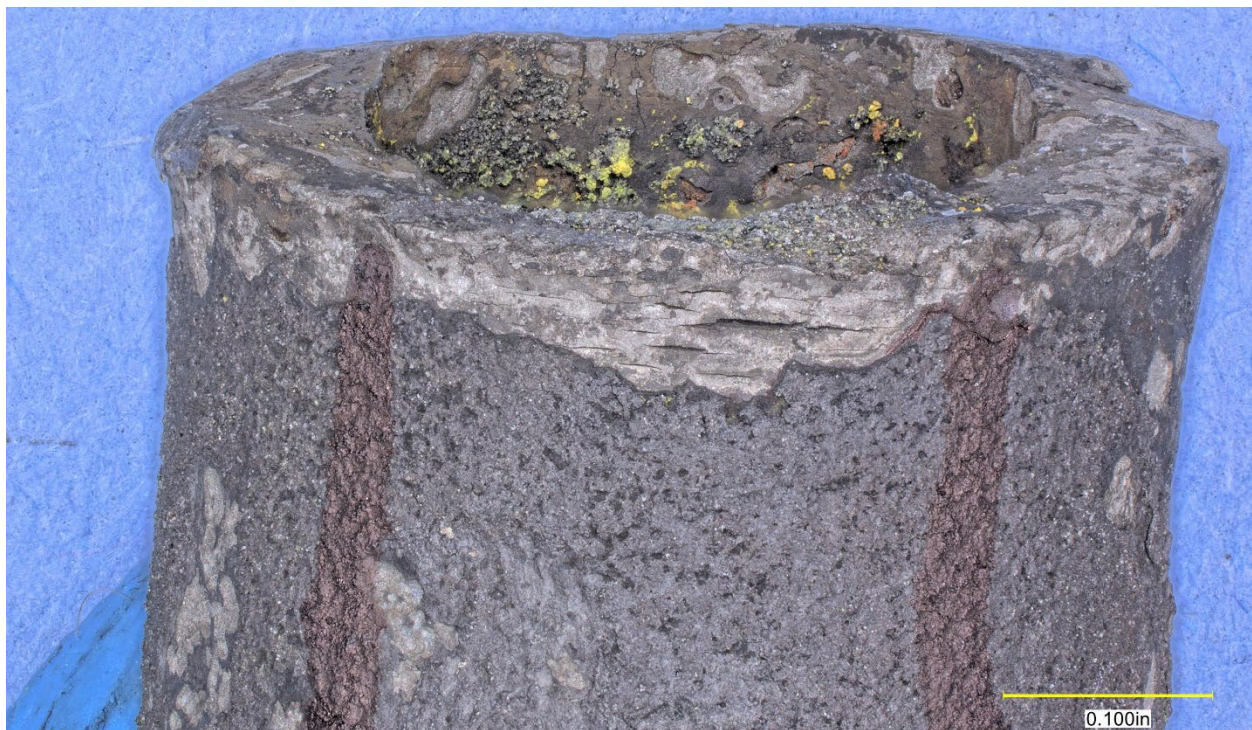


Figure 14. Angled view of the exhaust valve fracture surface, showing parallel cracks revealed after part cleaning.



Figure 15. Closer view of the parallel cracks in Figure 14.

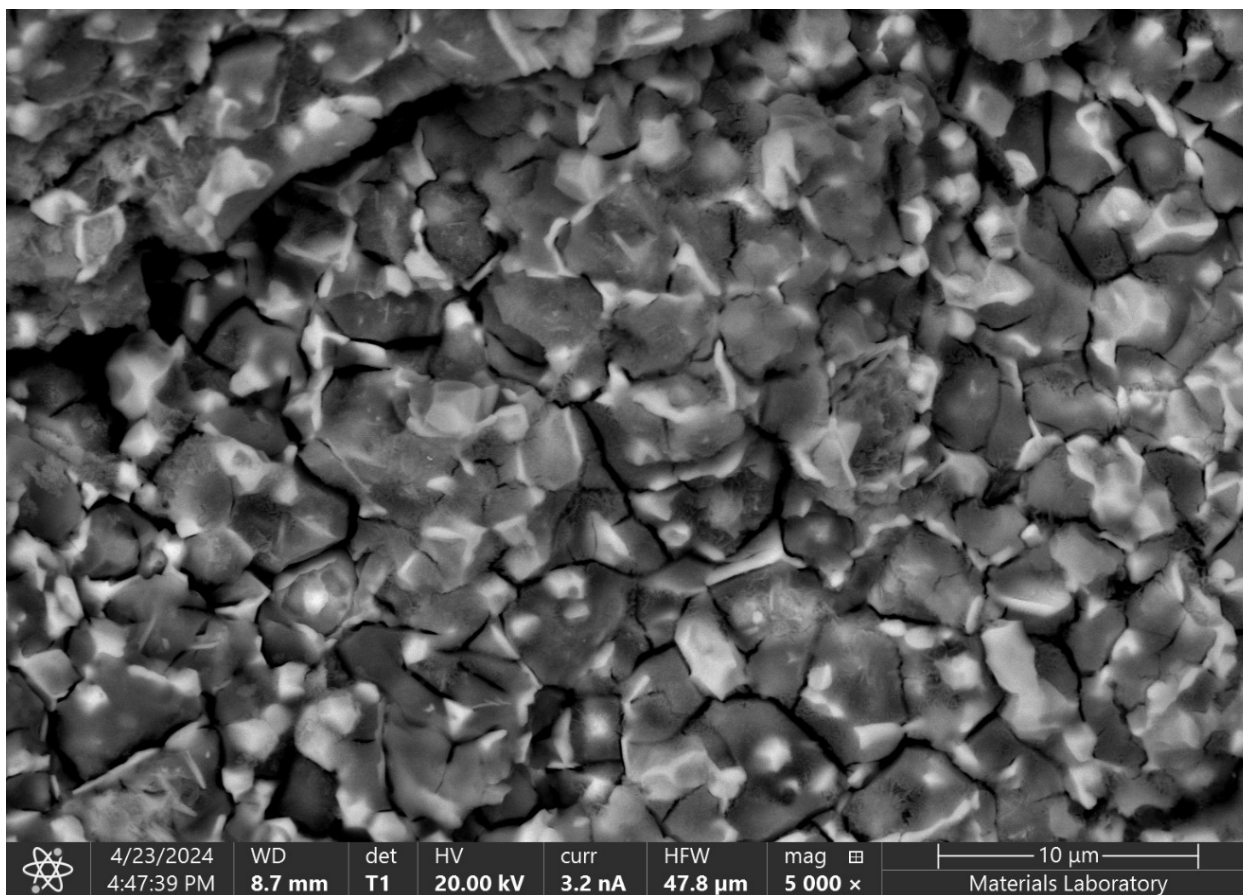


Figure 16. Backscattered electron (BE) micrograph of a typical area of oxide on the valve fracture surface.

Integral Counts: 427767

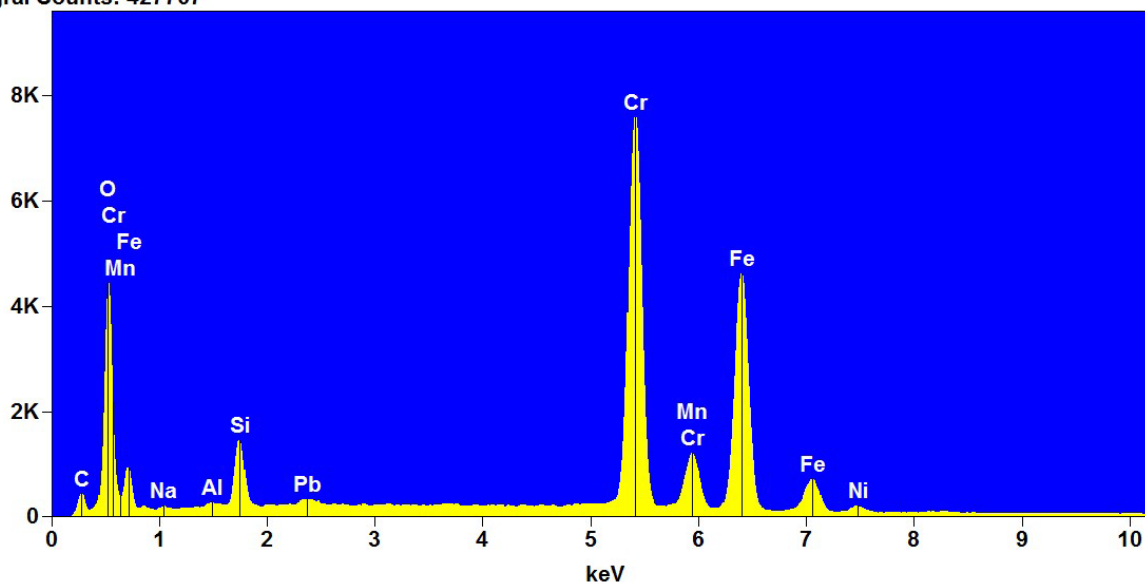


Figure 17. Typical EDS spectrum of the area in Figure 16, showing primarily Cr and Fe oxide.

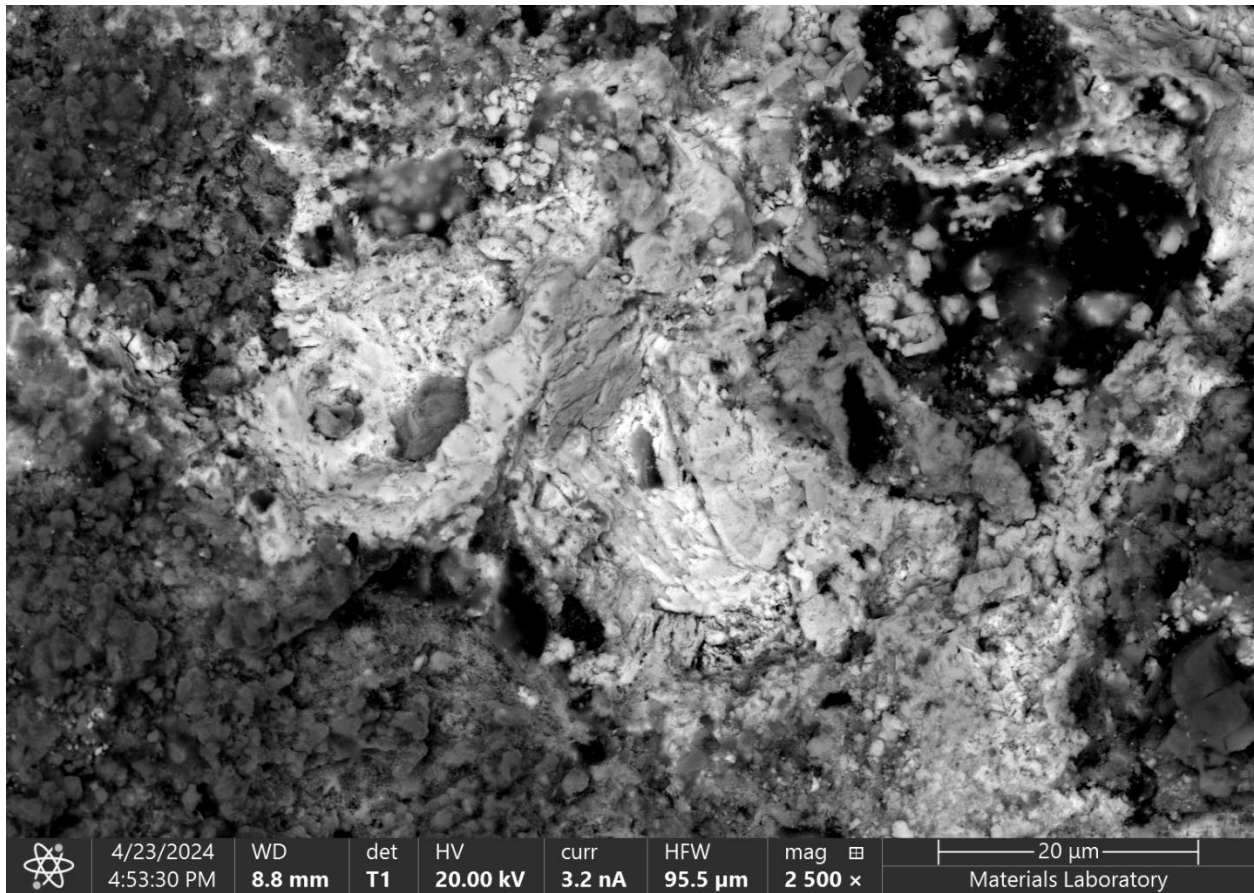


Figure 18. BE micrograph of an area with high atomic number contrast (white) on the exhaust valve fracture surface.

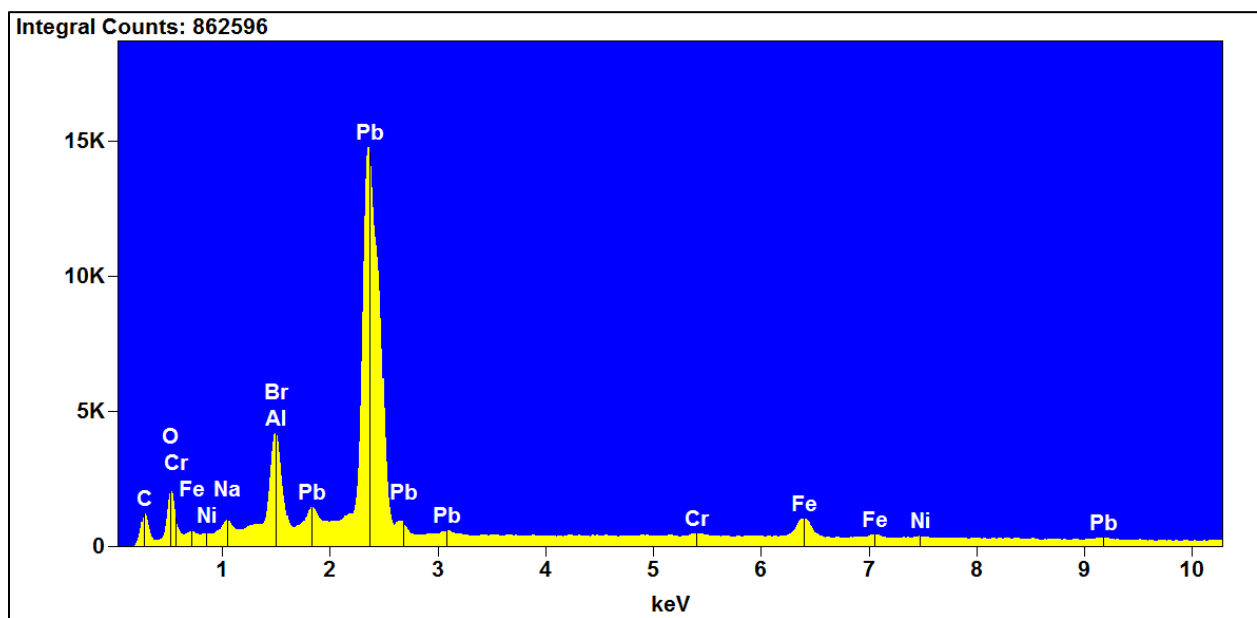


Figure 19. Typical EDS spectrum of the white area in Figure 18, showing compounds consistent with lead oxides.

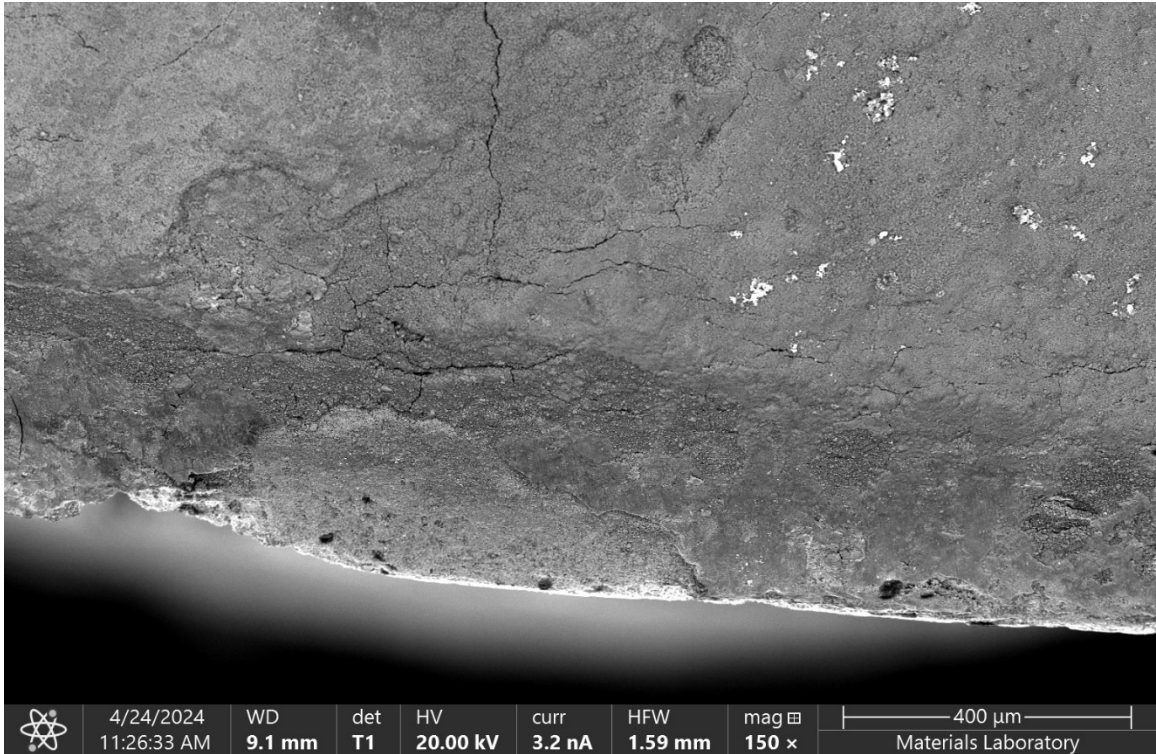


Figure 20. BE micrograph of an edge of the valve fracture surface.

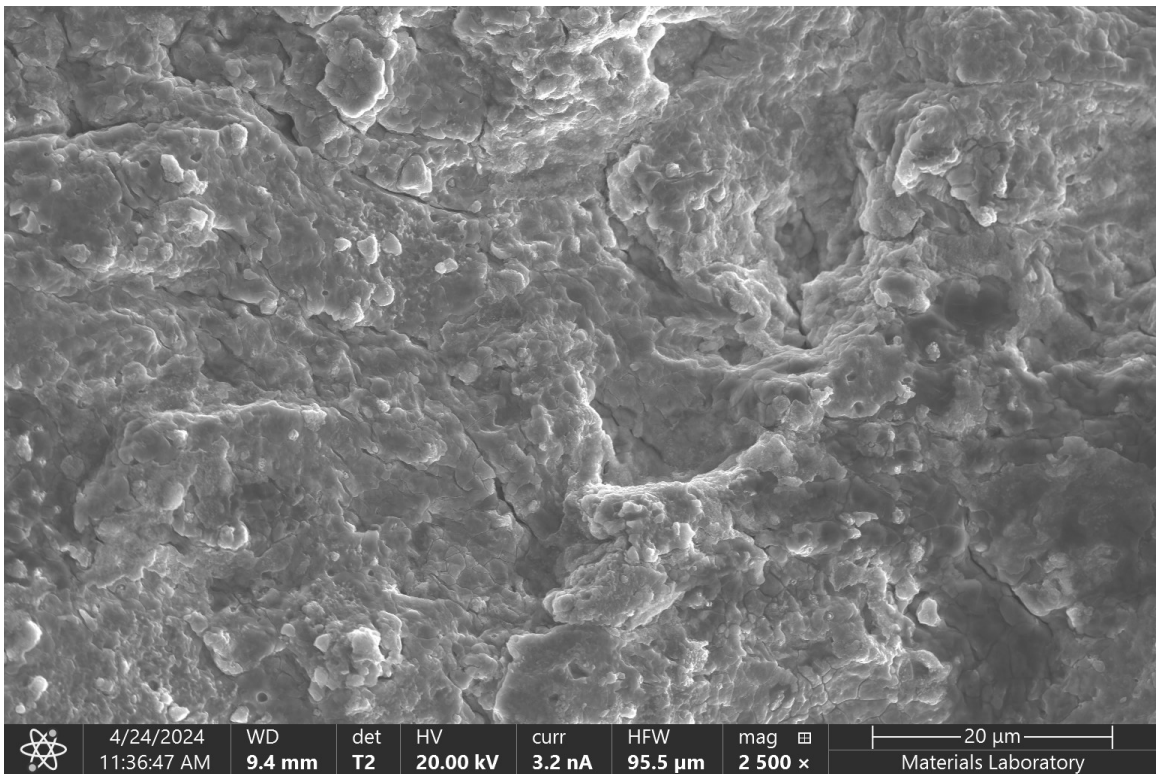


Figure 21. SE micrograph of an area of the fracture surface after oxide removal, showing parallel striation-like features.

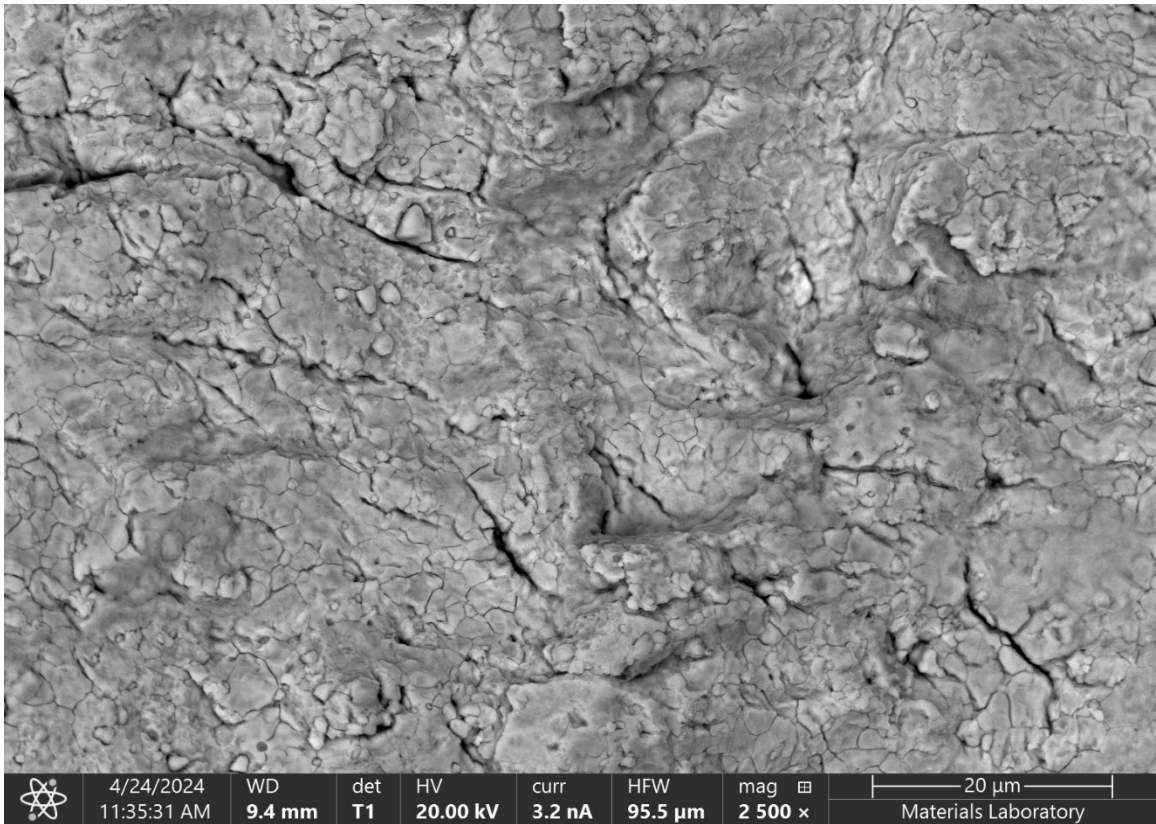


Figure 22. BE micrograph of the area in Figure 21, showing striation-like features.

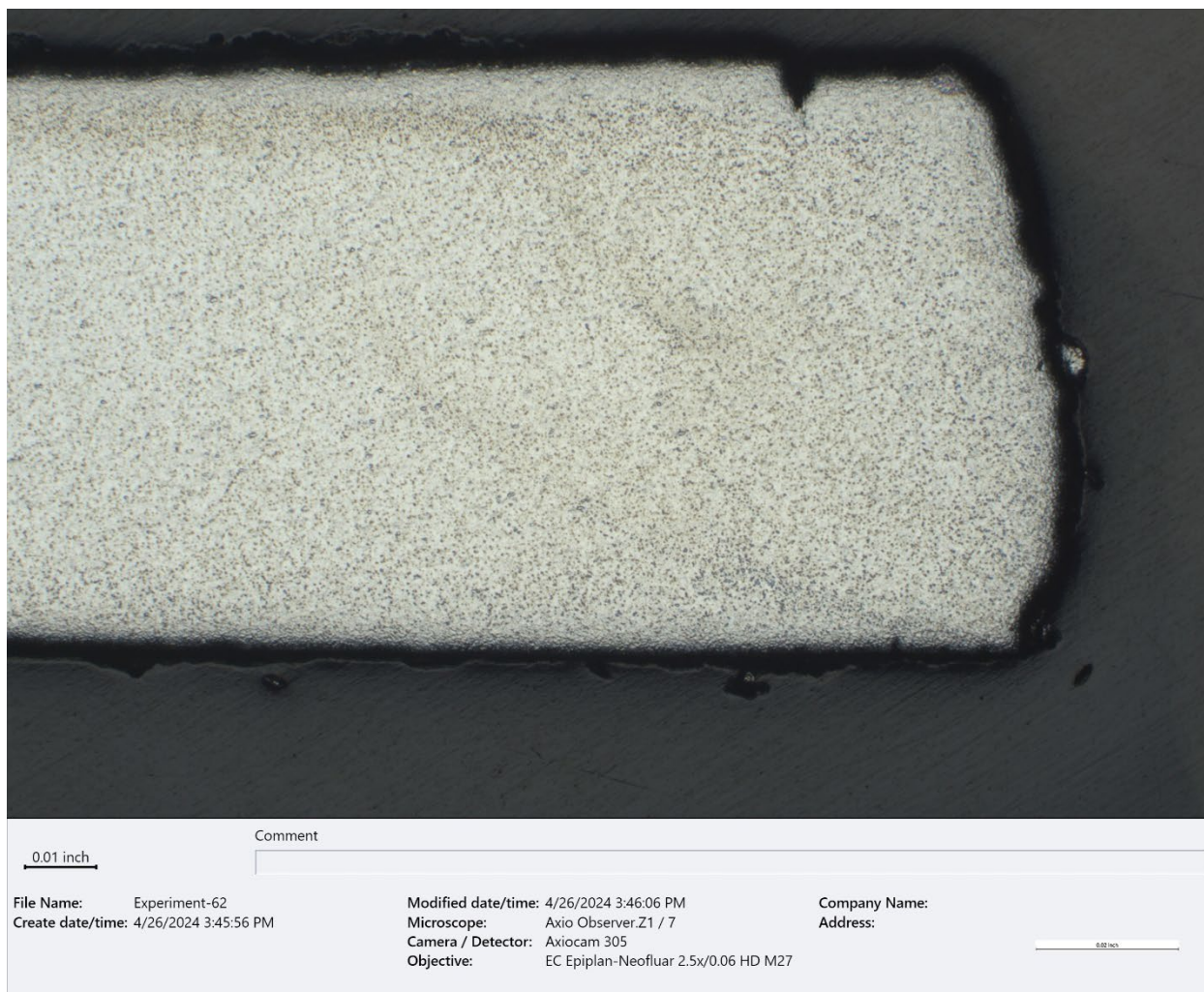


Figure 23. Bright-field (BF) optical micrograph of a cross section through the area in Figure 14, showing cracking near the fracture surface, on the right in the figure (~25X, as-polished).

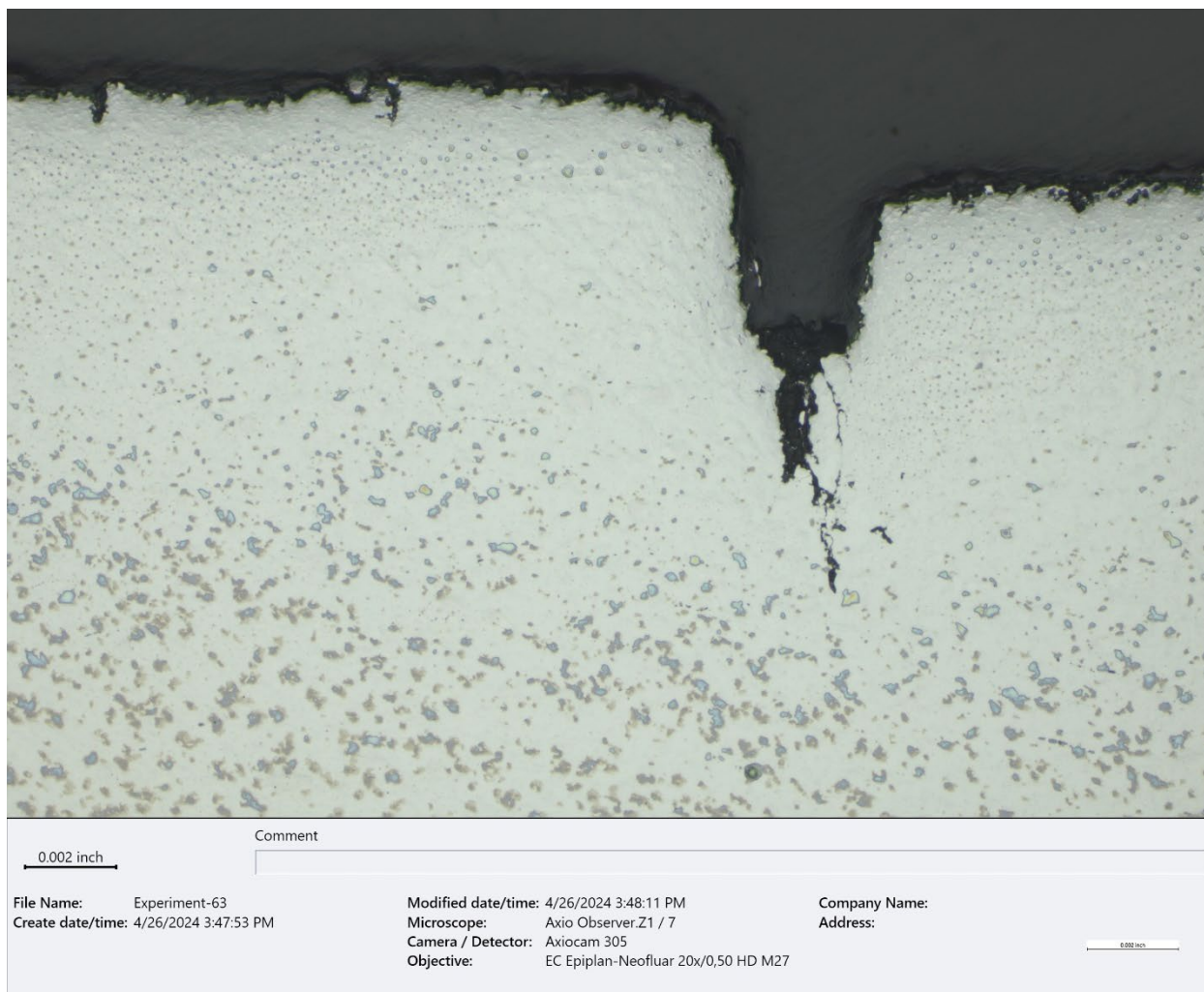


Figure 24. BF optical micrograph of a the surface crack in Figure 23 (~100X, as-polished).



Figure 25. BF optical micrograph of the opposite side of the valve, in cross-section (~25X, etched Fry's Reagent).



Figure 26. BF optical micrograph of a closer view of the exterior surface of the valve area in Figure 25, showing three surface cracks (~100X, etched Fry's Reagent)..

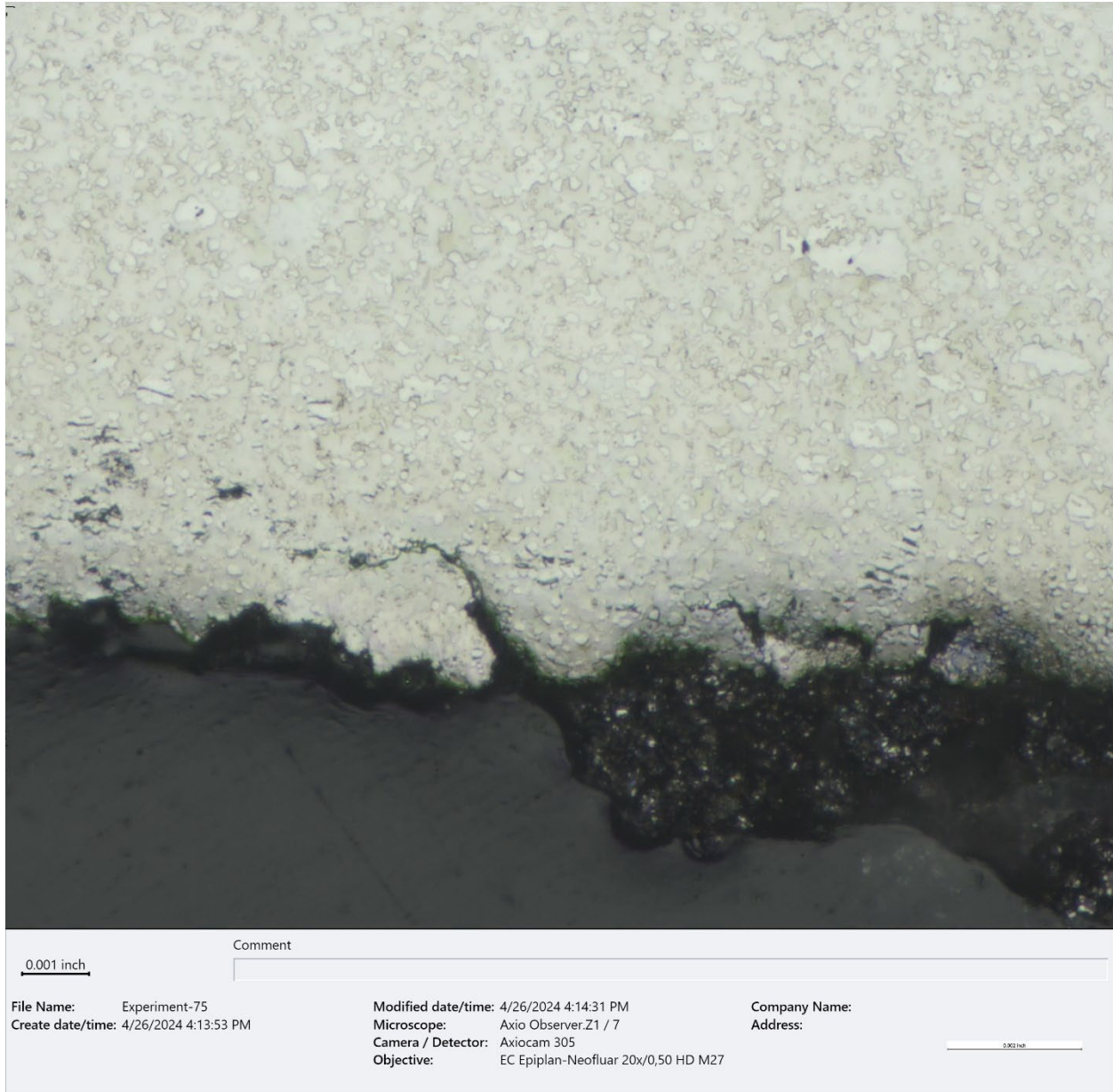


Figure 27. BF optical micrograph of surface cracks and cracking within precipitates near the surface (~200X, etched Fry's Reagent).

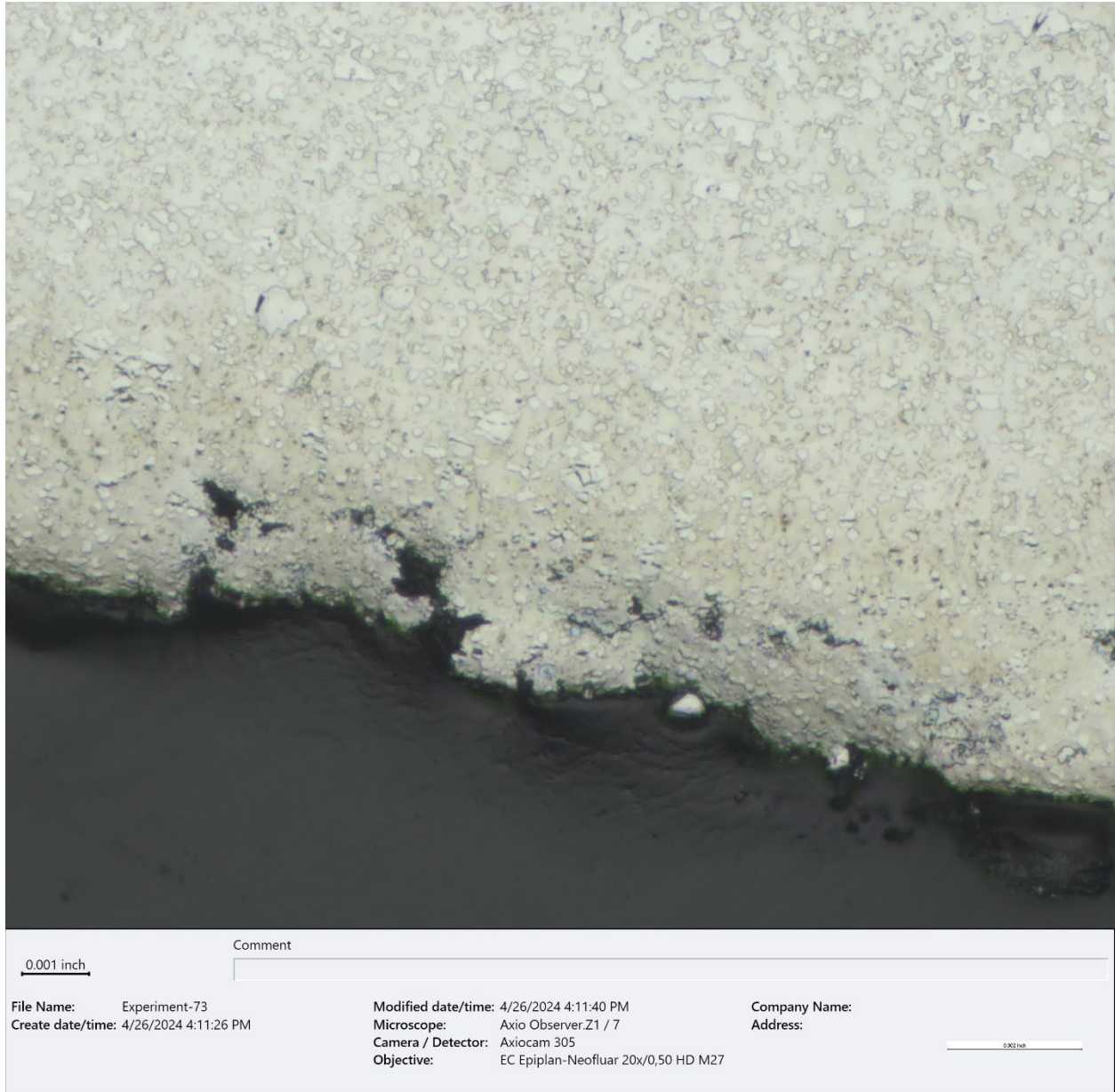


Figure 28. BF optical micrograph of additional cracking parallel to the surface to the left of Figure 27 (~200X, etched Fry's Reagent).

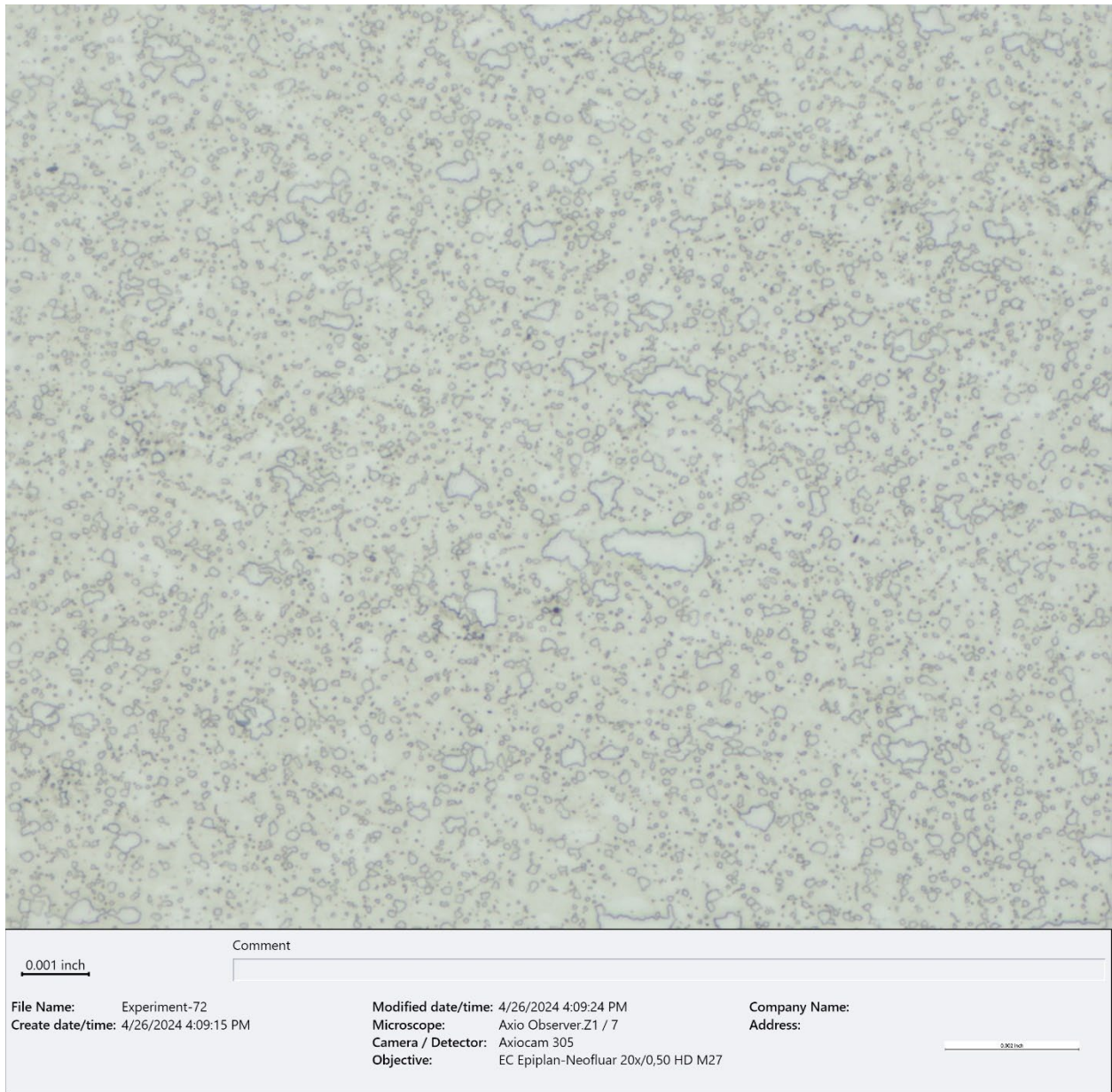


Figure 29. BF optical micrograph of a typical area of the core microstructure of the exhaust valve cross section (~320X, etched Fry's Reagent).