

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



WPR22LA351

MATERIALS LABORATORY

Factual Report 23-044

July 18, 2023

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A. ACCIDENT INFORMATION

Location: Ventura, California
Date: September 16, 2022
Time: 16:30 Pacific daylight time
23:30 coordinated universal time
Vehicle: Cessna 172L, N7917G
Investigator: Eric Gutierrez, AS-WPR

B. COMPONENTS EXAMINED

Remnants of an engine cylinder assembly
Remnants of an exhaust valve

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., P.E.
Office of Research and Engineering – Materials Laboratory Division
NTSB, Washington, DC

D. DETAILS OF THE EXAMINATION

On September 16, 2022, a Cessna 172L was substantially damaged when it was involved in an accident near Ventura, CA. The pilot and one passenger were not injured; another sustained a minor injury. The pilot reported hearing a “pop” followed by a partial loss of engine power. The pilot stated that the airframe started shaking, so the engine was idled, and the pilot initiated a forced landing to a clearing on the beach. Post accident examination of the airplane revealed that the left wing and forward fuselage were substantially damaged. The wreckage was recovered for further study, and parts from the Lycoming O-320-E2D were sent to the NTSB Materials Laboratory for additional examination.¹

Figure 1 shows the #4 cylinder from the engine, as received. The cylinder had been disassembled, with the piston assembly removed and the valve housing detached along with the valves and rockers. The intake and exhaust ports are shown in the figure, with the nonmetallic deposits present, particularly along the interior surfaces of the exhaust port.

Figure 2 shows the cylinder interior from the rocker and upper valve stem area—these components had been removed prior to receipt. The cylinder surfaces located near the stem and rocker positions exhibited a darker contrast, consistent with exposure to

¹ The Lycoming O-320-E2D is an air-cooled, four-cylinder, horizontally opposed, direct-drive engine with 150 hp (112 kW) at 2700 rpm, produced by Lycoming Engines, headquartered in Williamsport, PA.

oil lubrication during engine service. The intake valve stem opening (right in Figure 2a) revealed a brighter metallic luster than the darker exhaust valve side, consistent with lower temperature exposure.

While there were no indications of physical damage on the stem and rocker side of the cylinder assembly (Figure 2a), the interior combustion side had been gouged and battered, as illustrated in Figure 2b and Figure 3. The damage was more concentrated on the exhaust valve side (right side of Figure 3), as the impact damage was present on the corner of the valve seat and the face of the valve stem bore.

Figure 4 shows the exhaust valve as received. The exhaust valve had fractured at the shoulder transition of the stem and the head, identified in Figure 4b. The head fragment exhibited a rounded, globule shape, consistent with plastic deformation from repeated batter against adjacent metallic components. The stem fragment showed less damage, with the stem fracture illustrated in Figure 4a.

The stem fragment measured 3.164 inches long, with an outer diameter of 0.498 to 0.506 inches. The stem was hollow, and the inner diameter ranged between 0.281 and 0.307 inches.

Figures 5 and 6 show closer views of the valve stem fracture surface after degreasing and then after cleaning with an aqueous solution of Alconox.² A side view of the stem's lower (fractured) end is illustrated in Figure 7 after cleaning. The innermost 0.75 inches of the valve stem surface contained surface deposits, which exhibited a variety of colors, from brighter white to dull brown, orange, and gray. These deposits were consistent with combustion products typical of reciprocating engines expending avgas fuel.

Measurements of the fractured valve stem's outer diameter revealed that the valve's thickness increased closer to the fracture surface. Near the face of the stem, the outer diameter was 0.4980 inches wide, but it increased to 0.5060 near the fracture surface. The increase was consistent with layering of combustion deposits on the valve stem exterior.

The fracture surface, shown in Figures 5 and 6, exhibited a rough but flat orientation with a dull luster. The surface was alternately light black and orange-brown, consistent with post-fracture oxidation.

The fracture surface was examined using a field emission scanning electron microscope (SEM). Figure 8 depicts a typical area of the stem fracture surface near the exterior edge. The surface was partially concealed by nonconductive material,

² Alconox is a powdered cleaning detergent, containing primarily sodium bicarbonate and sodium alkylbenzene sulfonate, manufactured by Alconox, Inc., White Plains, NY.

consistent with the post-fracture oxide seen visually. Figure 9 and Figure 10 show closer views of the surface compounds, which exhibited either a rounded blocky morphology or more platelike structures. The cleaning processes removed some surface compounds, revealing even parallel features.

As demonstrated in Figure 11, these features were consistent with fatigue striations. Striations were observed on other parts of the valve stem fracture surface, as illustrated in Figure 12. While still covered in enough oxide to obscure much of the underlying features (Figure 13), selected areas did display striations, as shown in Figure 14 and Figure 15. The orientation of these fatigue striations was consistent with propagation from the outside surfaces inward and across the stem cross-section. Due to the amount of post-fracture surface oxidation and batter on the edges of the fractured valve stem, no features could be discerned on the edges of the fracture surface along the exterior. Streaking, plastic deformation, and batter were prevalent, consistent with impact against an adjacent metallic component. Therefore, no initiation sites were observed on this fracture. The liberated valve head was so damaged that no fracture features were present.

A portion of the valve stem fracture surface was excised, cross-sectioned, mounted, polished, and etched using a 2% Nital solution. Figure 16 shows a valve stem cross-section, with the fracture surface facing toward the right. The metallographic examination revealed external surface oxides and corrosion compounds, as typified by the darker gray material in Figure 17.

Also present were internal oxidation and subsurface attack, most prevalent towards the fracture surface, as shown in Figures 18 and 19. These features manifest as clusters of small needlelike phases beneath the exterior oxidation layer located within the stem metal (Figure 19).

The cross-section through the fracture surface did not reveal subsurface oxidation but rather a more uniform layer approximately 50 μm (0.002 inches) thick. Much of this layer was cracked. Due to the uniformity in thickness, the layer was consistent with post-fracture oxidation rather than corrosion occurring during crack growth.

Figure 21 shows an area with rounded triple-point-shaped voids near the fracture surface. These features were consistent with void formation at high-temperature exposure, where diffusion and deformation occur along grain boundaries. These features were associated with small, shallow cracks that branched off from the main fracture surface in this location. Other small secondary cracks parallel to the fracture surface are depicted in Figures 22 and 23.

The chemical composition of the valve stem fragment was examined using energy-dispersive x-ray spectroscopy (EDS). The composition was consistent with alloy steel. The oxide of the fracture surface was also examined. Areas that appeared white or

bright in Figure 9 were consistent with high lead and bromine content, consistent with combustion deposits from tetraethyl lead additives in avgas fuel. The darker areas in Figure 9, as well as in Figure 13, were consistent mainly with iron oxide. This oxide also contained minor amounts of sodium, calcium, and chlorine—elements typical of exposure to salt or marine atmospheres.

These features were consistent with fatigue cracking in the exhaust valve at the radius between the head and the stem. Once the fatigue crack had propagated through enough of the valve stem cross-section, the head separated and became battered by the reciprocating piston, leading to a loss of engine power and proper timing in the #5 cylinder.

Submitted by:

Erik M. Mueller
Materials Research Engineer



Figure 1. View of the cylinder from the side with the intake and exhaust ports.

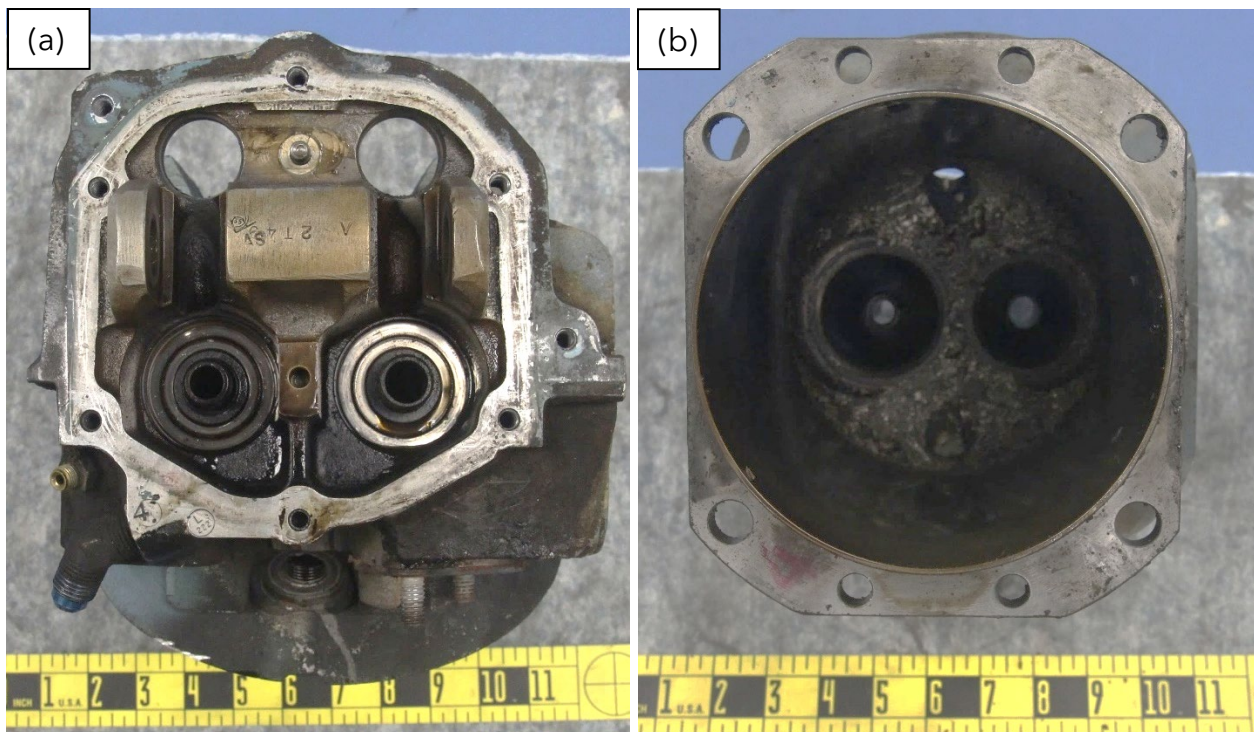


Figure 2. Views of the cylinder from (a) the rocker and valve stem area with housing removed and (b) the piston end, as received.



Figure 3. Closer view of the interior of the cylinder, showing impact damage to the cylinder and valve seat surfaces.



Figure 4. View of the fractured exhaust valve from (a) the stem fracture and (b) side showing the stem side and liberated valve head remnant.



Figure 5. View of the exhaust valve stem fracture surface after degreasing.



Figure 6. View of the exhaust valve stem fracture surface after cleaning with Evaporust.



Figure 7. Side view of the exhaust valve stem remnant, after cleaning.

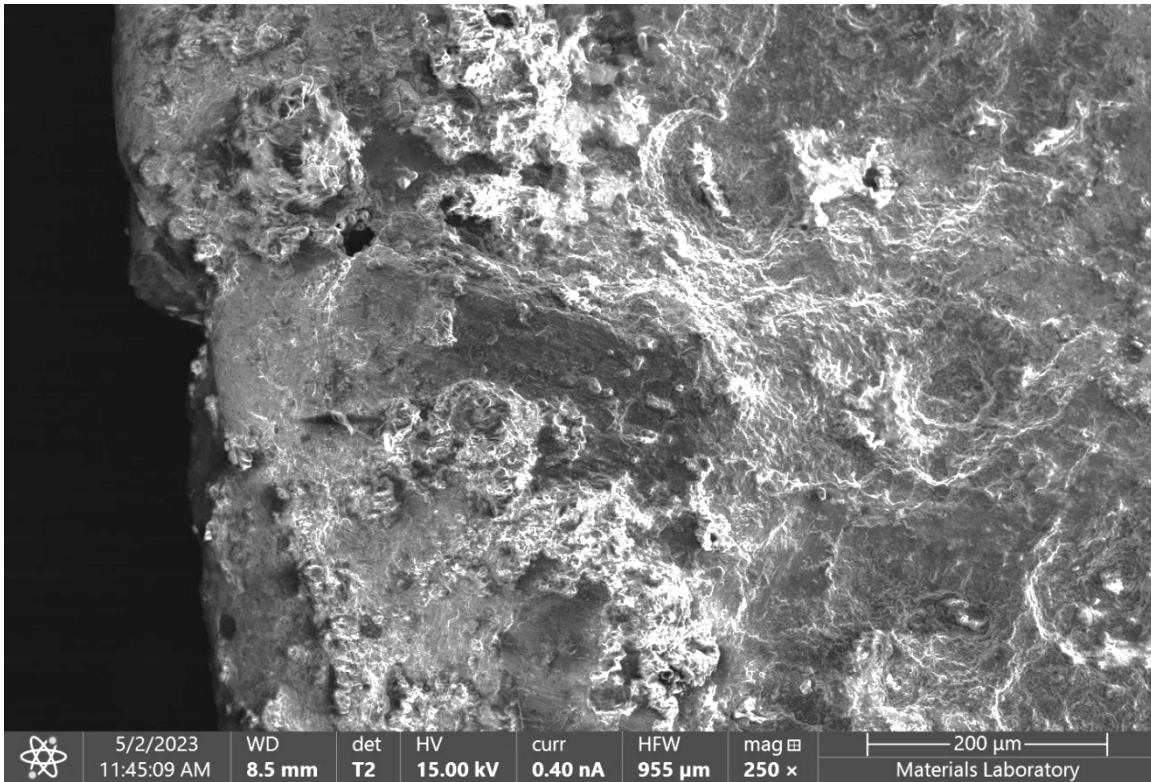


Figure 8. Secondary electron (SE) micrograph of an edge of the exhaust valve stem fracture surface.

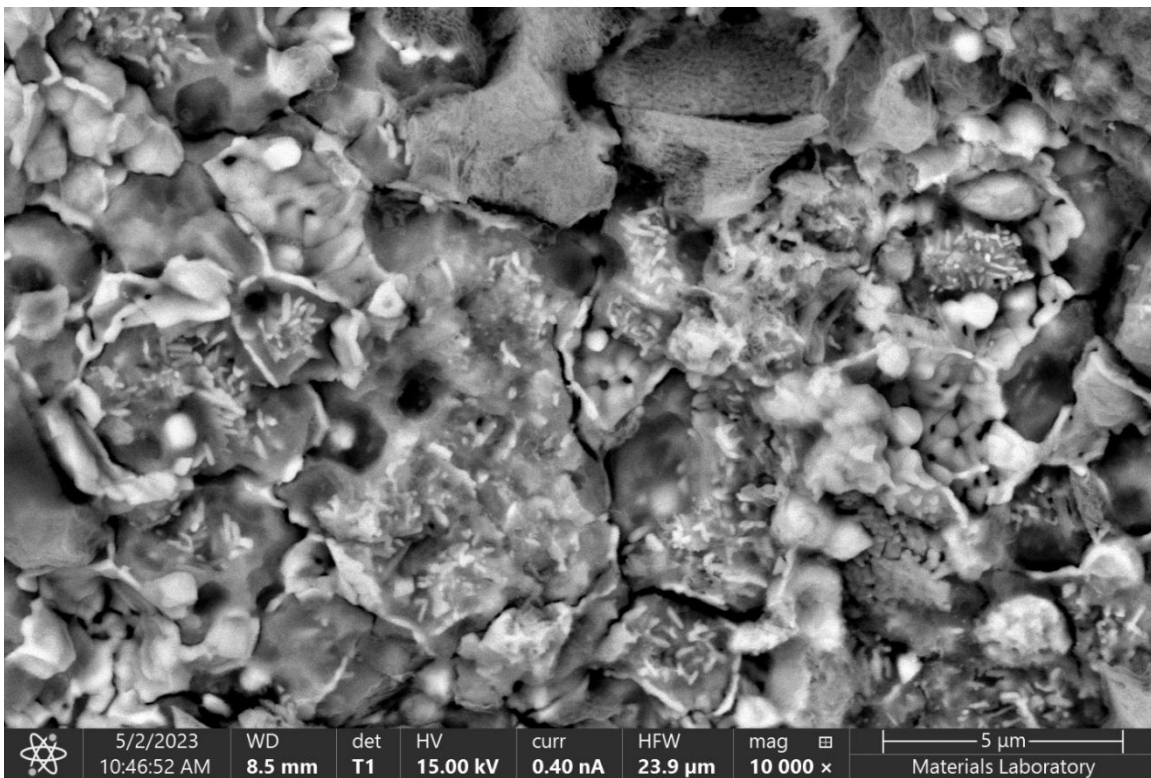


Figure 9. BE micrograph of an area of thicker surface oxide on the fracture.

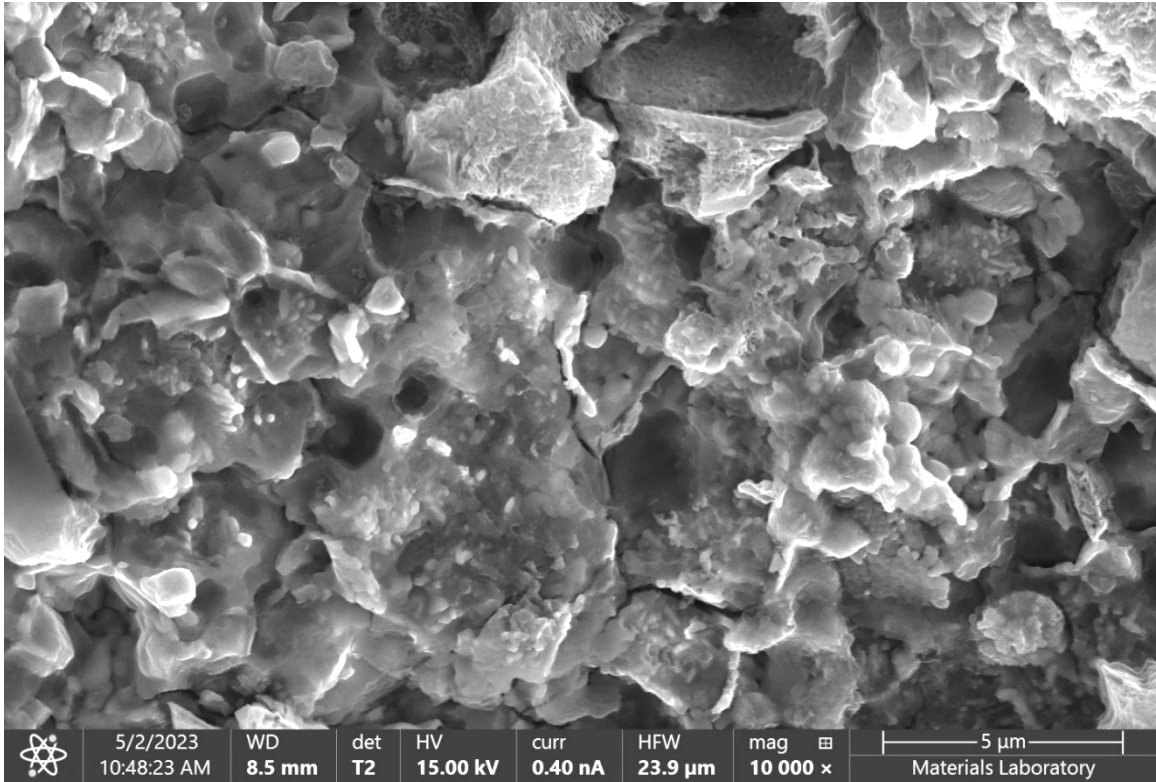


Figure 10. SE micrograph of an area of surface oxide in **Figure 9**.

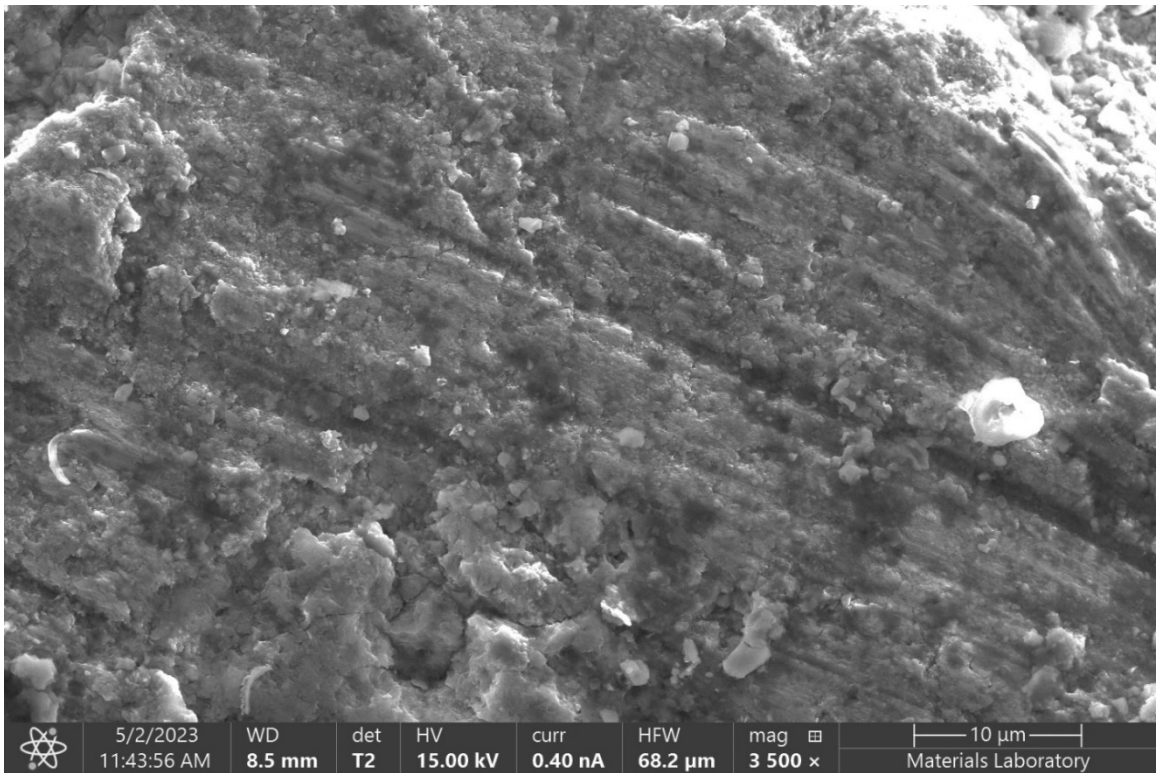


Figure 11. SE micrograph of the boxed area in **Figure 8**, showing fatigue striations.

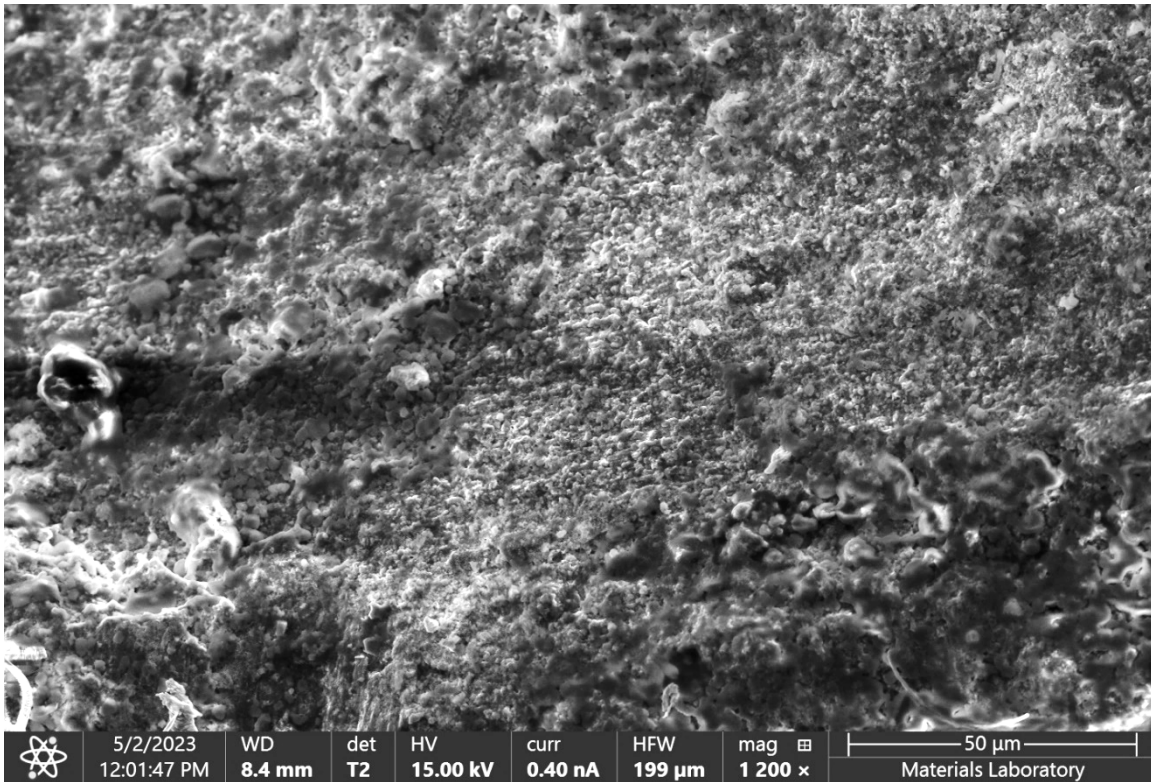


Figure 12. SE micrograph of a central area of the stem fracture.

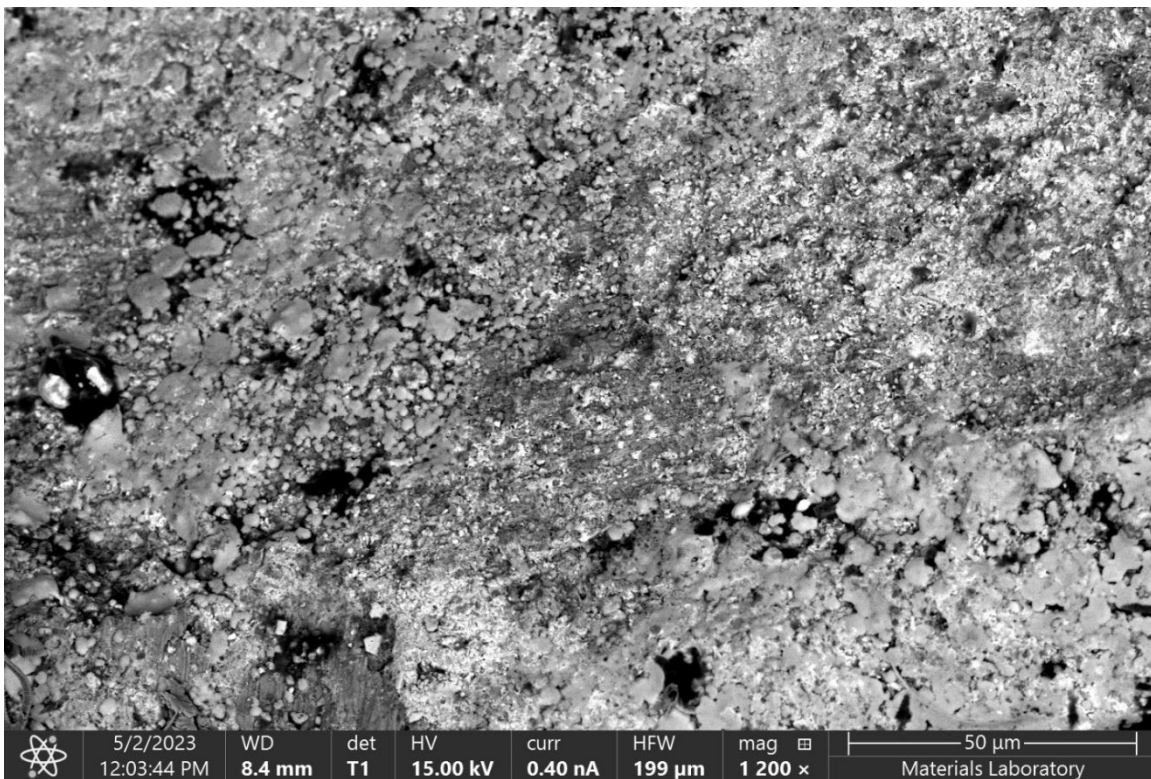


Figure 13. Backscattered electron (BE) micrograph of the central stem fracture area in **Figure 12**.

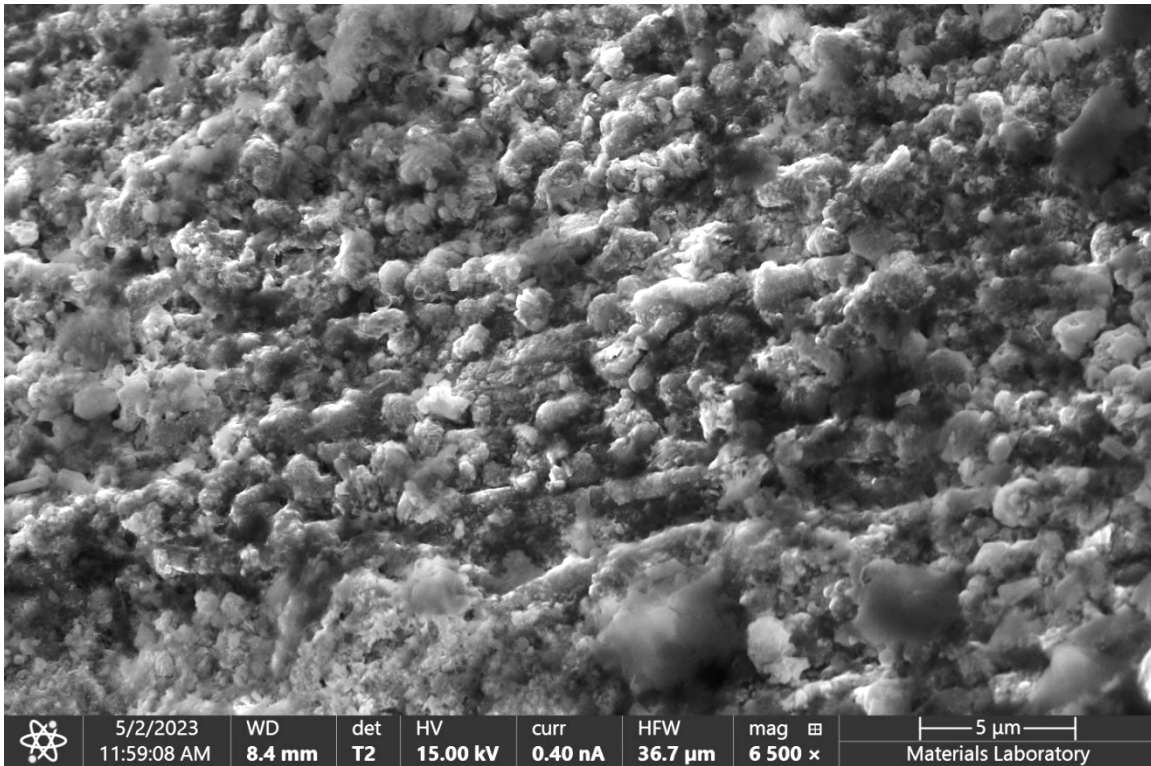


Figure 14. SE micrograph of a closer view of the area in **Figure 12**, showing striations underneath surface oxide globules and films.

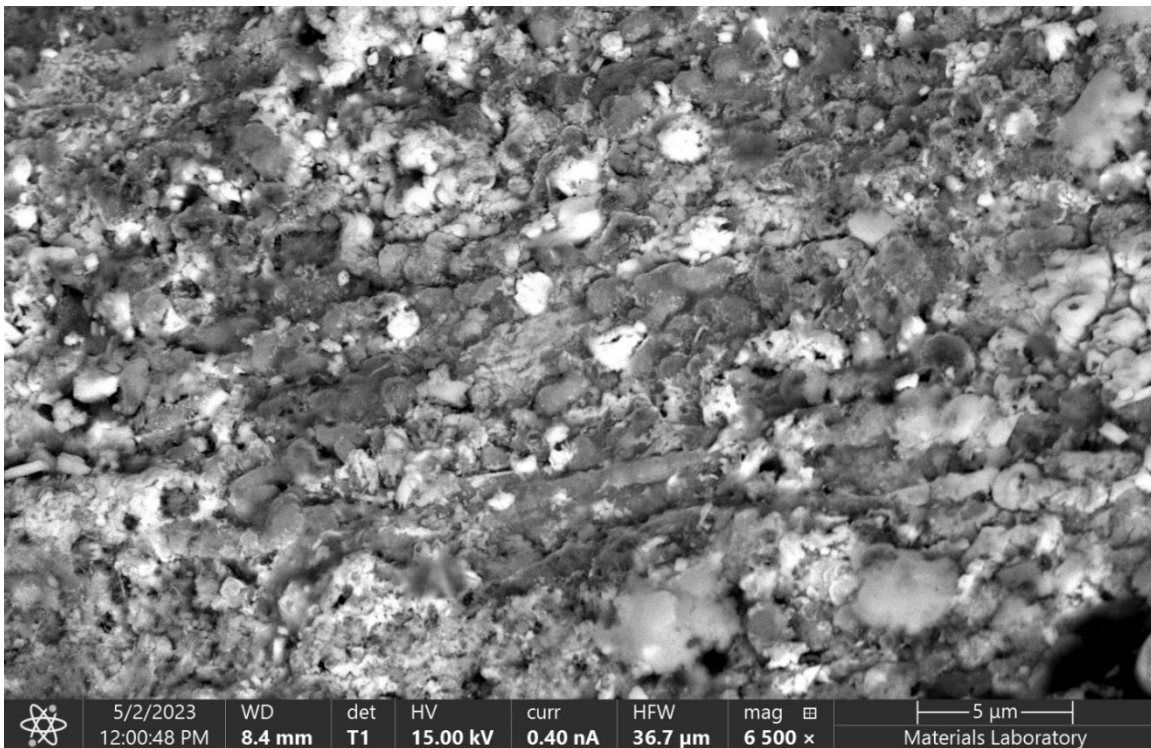


Figure 15. BE micrograph of a closer view of the area in **Figure 14**, showing striations underneath surface oxide globules and films.

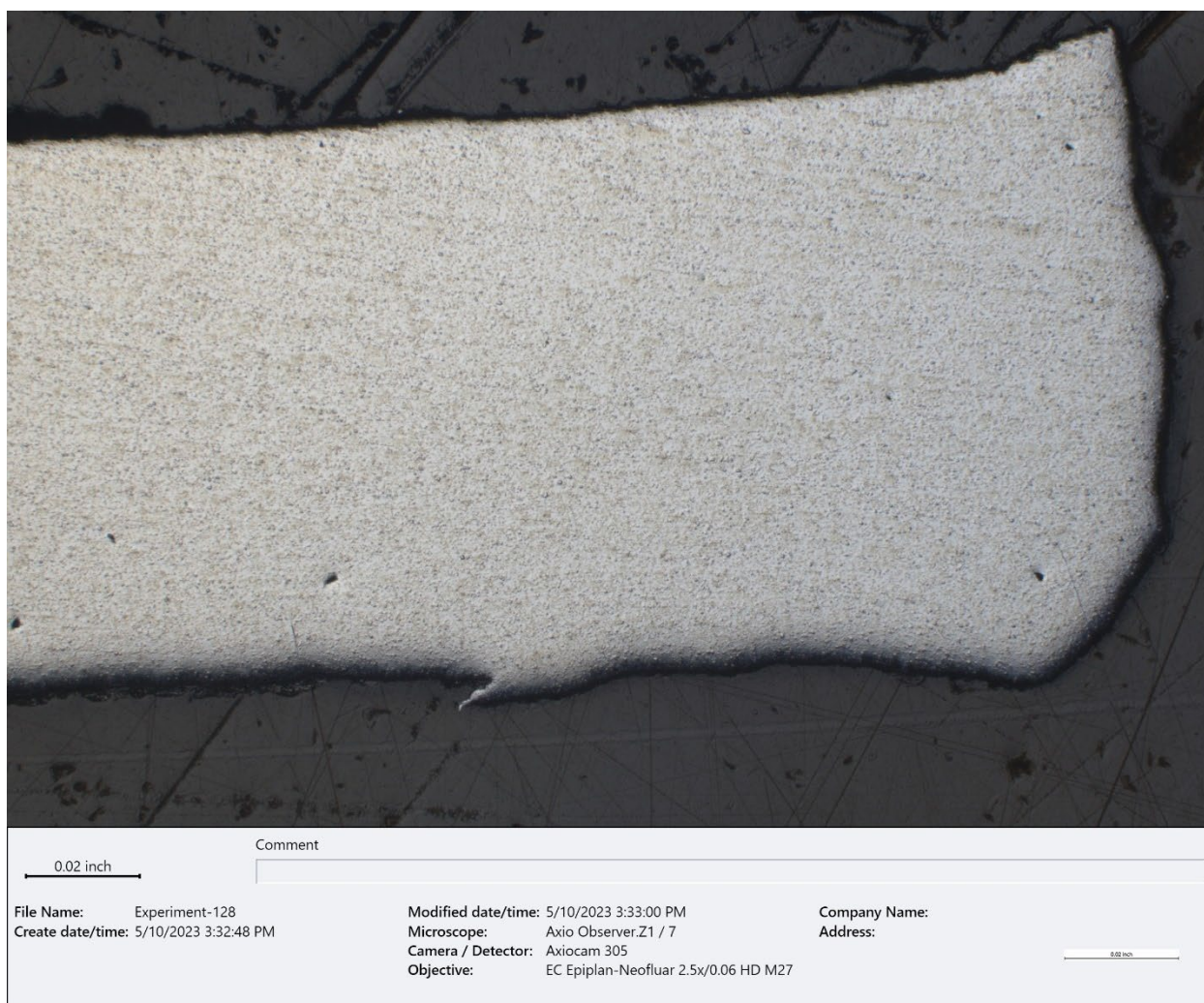


Figure 16. Bright-field (BF) optical micrograph of a cross section of part of the exhaust valve stem fracture surface (towards the right) (~25X, as polished)..

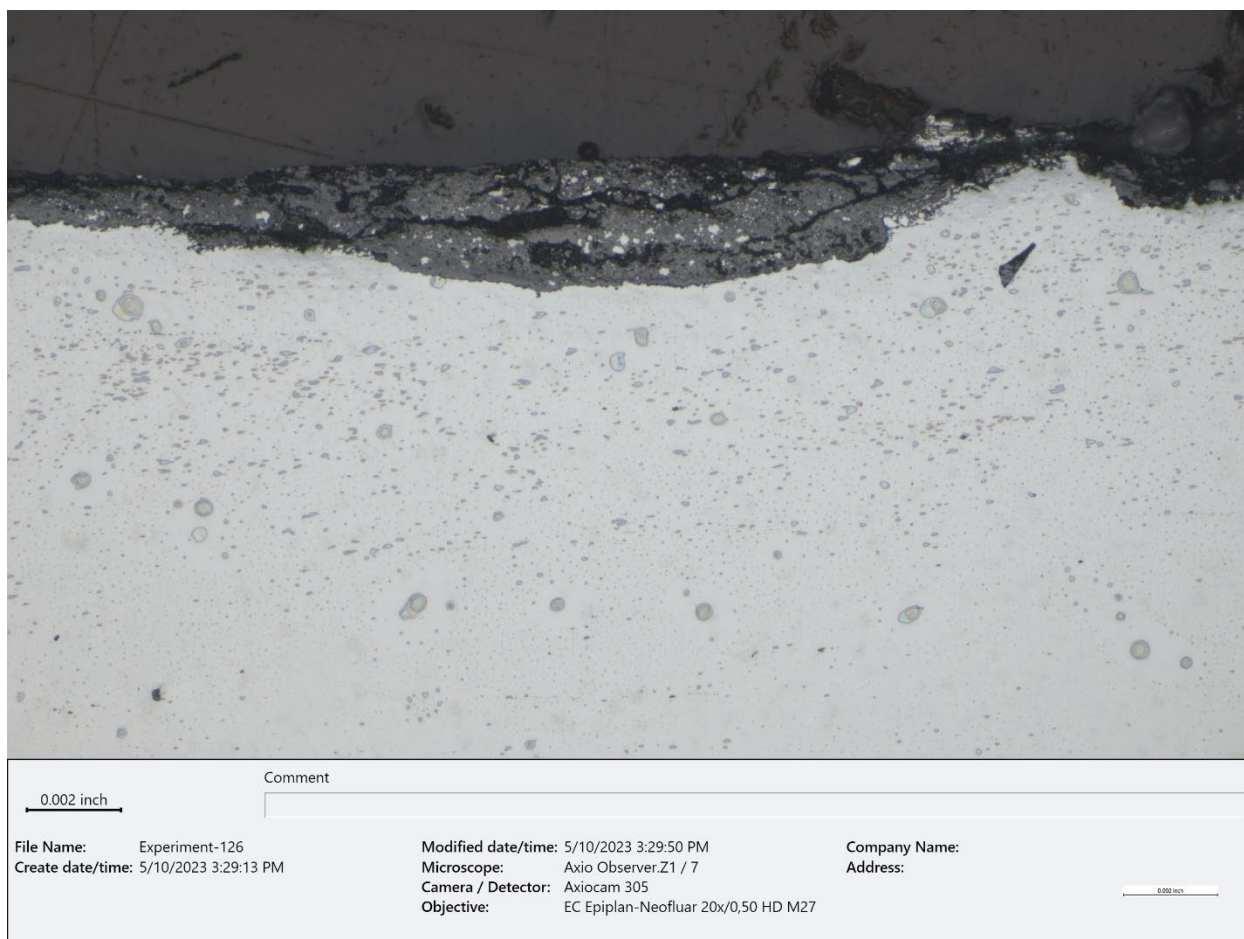


Figure 17. BF optical micrograph of nonmetallic surface compounds on the exterior of the stem fragment (~100X, as polished)..

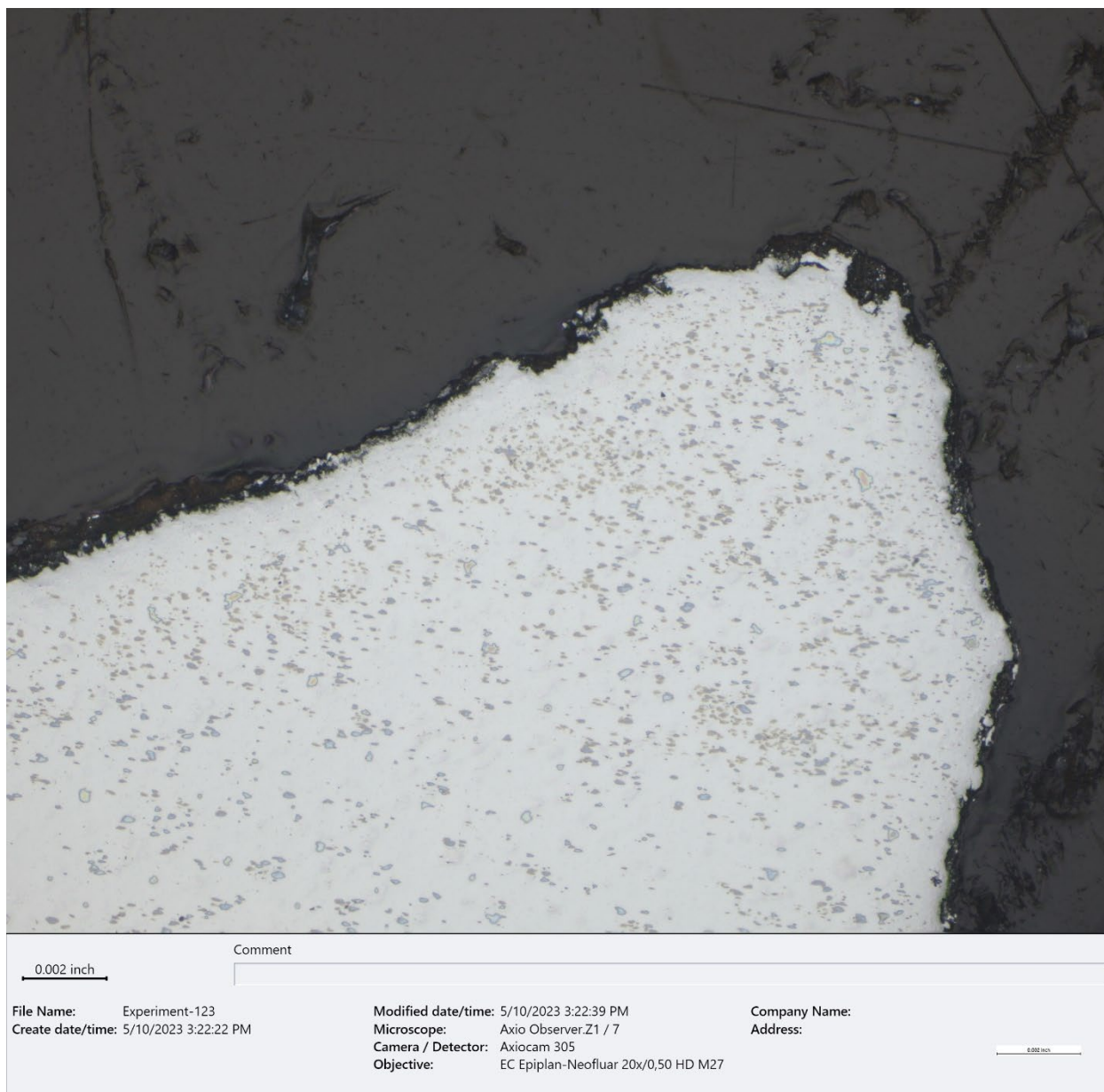


Figure 18. BF optical micrograph of the outer corner of the exhaust valve surface and fracture surface. The boxed area is shown in Figure 19 (~100X, as polished).

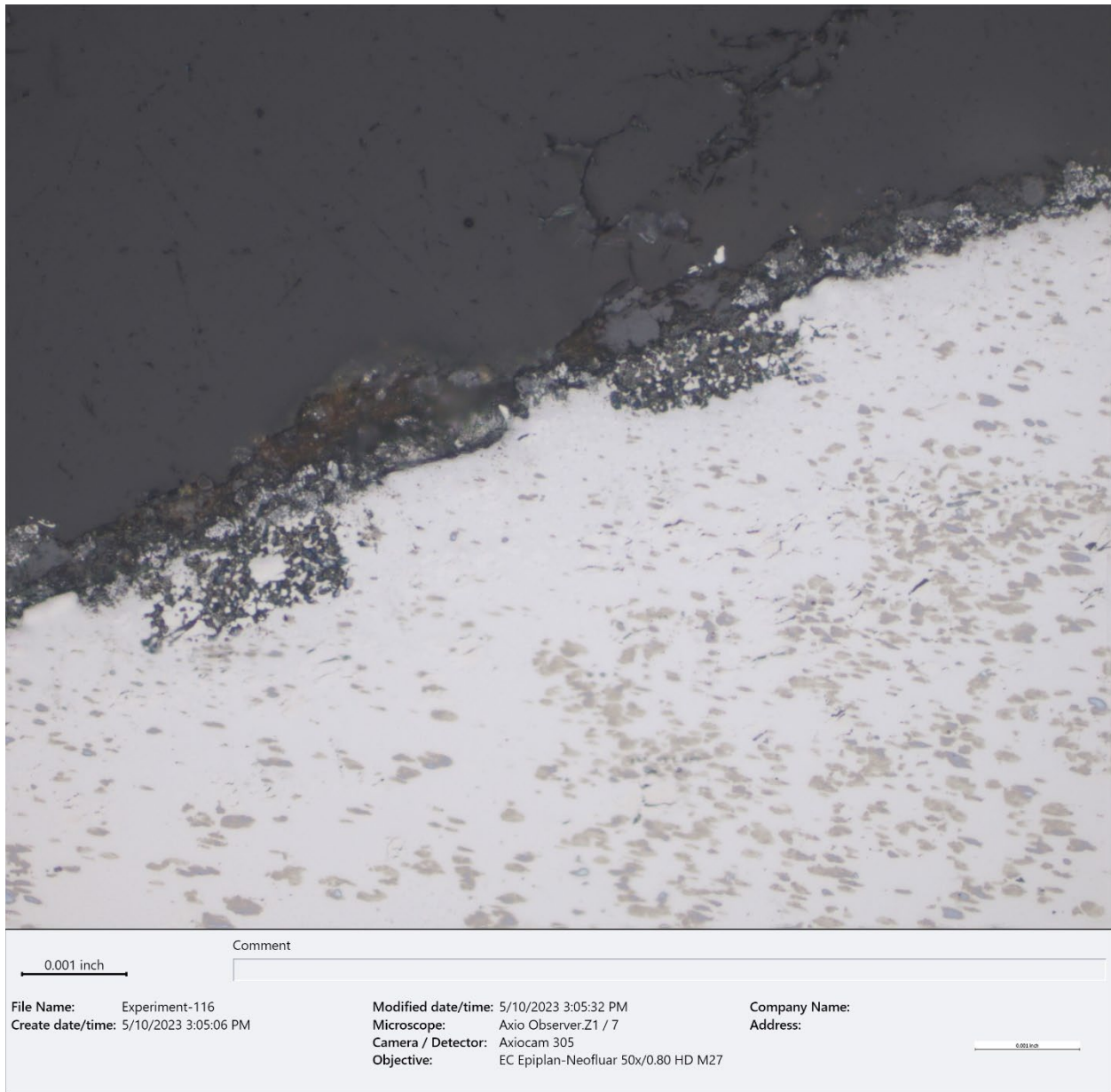


Figure 19. BF optical micrograph of the boxed area in Figure 18, showing areas of internal oxidation below the exterior surface (~200X, as polished).



Figure 20. BF optical micrograph of nonmetallic deposits on the fracture surface of the fractured valve stem (~500X, as polished).

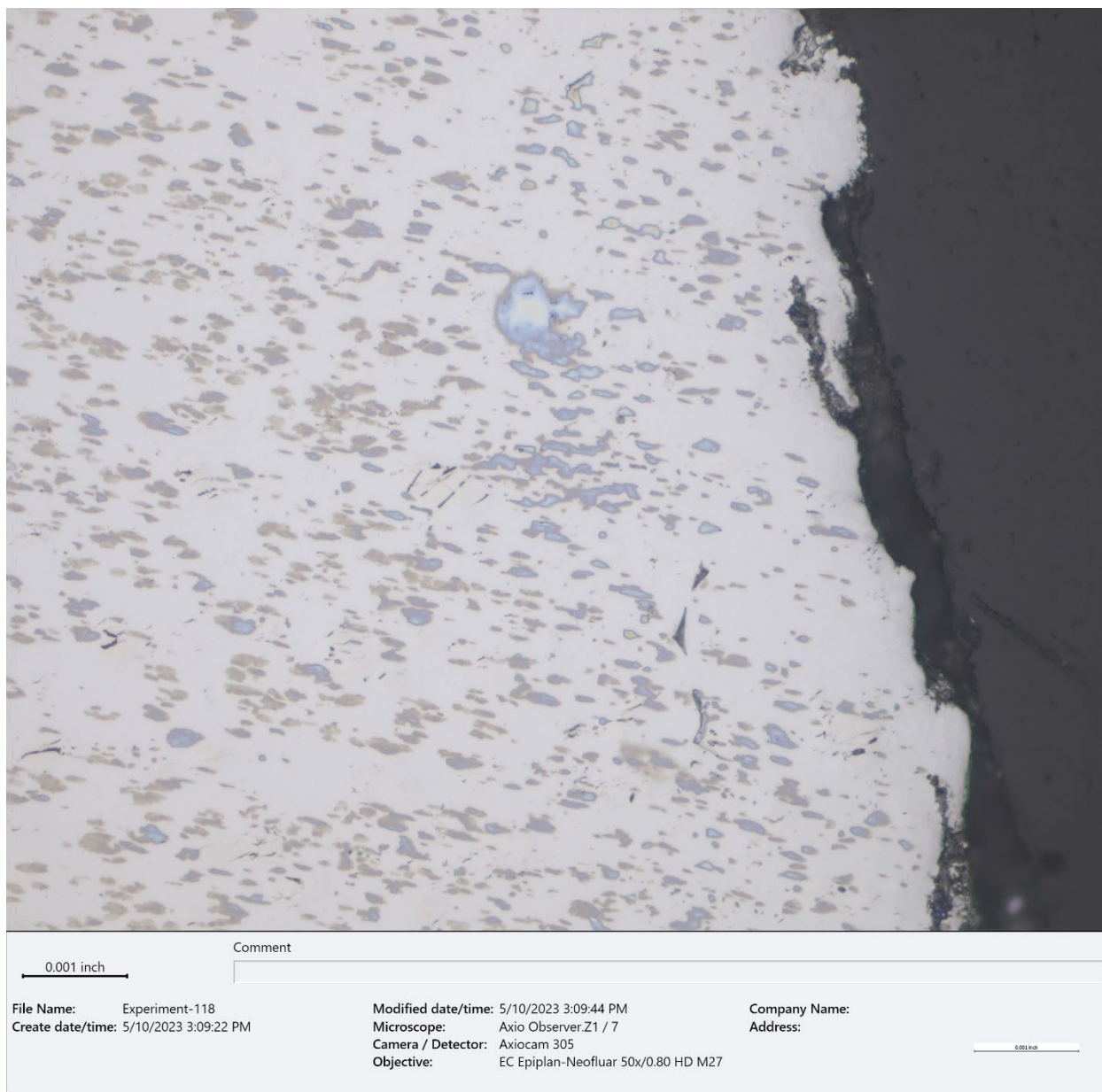


Figure 21. Closer view of an cross section of the fracture surface, showing sub surface cracks, and areas of internal intergranular porosity (~500X, as polished).



Figure 22. BF optical micrograph of small internal secondary cracks along the fracture surface (~200X, as polished).

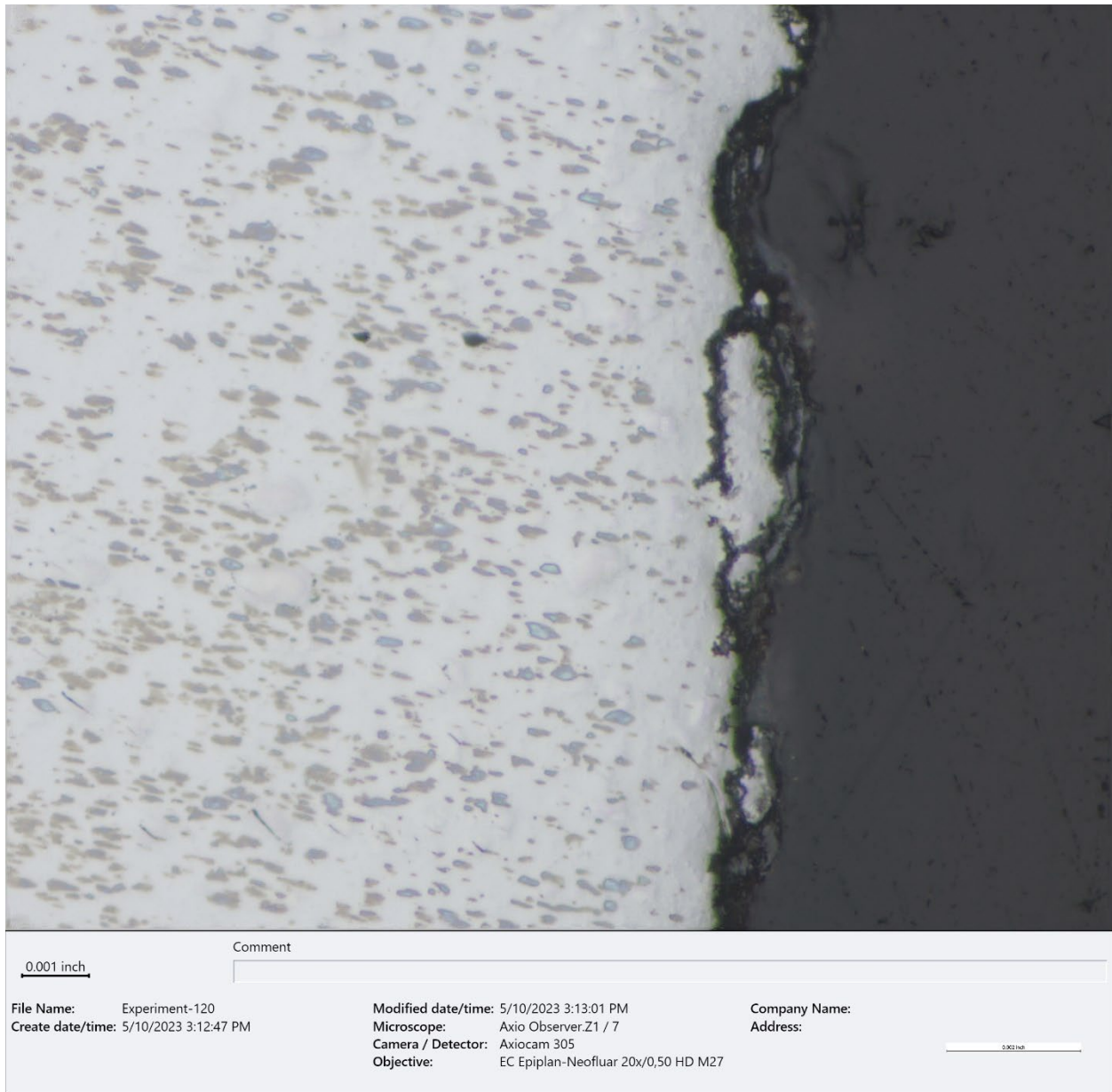


Figure 23. BF optical micrograph of secondary cracks in Figure 22, showing oxidation along the crack interior (~500X, as polished).