

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



WPR23LA213

MATERIALS LABORATORY

Factual Report 23-060

August 29, 2023

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A. ACCIDENT INFORMATION

Location: Tacoma, Washington
Date: May 30, 2023
Time: 11:15 Pacific daylight time
18:15 coordinated universal time
Vehicle: Cessna 210B, N9574X
Investigator: Zoë Keliher, AS-WPR

B. COMPONENTS EXAMINED

Remnants of a hydraulic actuator assembly

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 May 30, 2023, a Cessna 210 was substantially damaged when it was involved in an accident near Tacoma, WA. The flight instructor and student pilot were not injured. During landing, the pilot noted that the landing gear did not fully extend and appeared to be stuck in a transitional position. The flight instructor was unable to move the landing gear position, including emergency hand pumping. Landing with the gear partially extended, the airplane touched down on the runway centerline, coming to rest in the grass off the left side. A post-accident examination of the landing gear, performed by an airframe and powerplant mechanic, revealed that the left main-gear rotary actuator was cracked and was leaking hydraulic fluid. The actuator was sent to the NTSB Materials Laboratory for additional examination.

The cracked hydraulic actuator is illustrated in Figure 1 and Figure 2, as received from different sides. The part had cracked around the barrel, with circumferential components. Figure 3 shows the identification markings for the actuator. The embossed markings on the barrel stated:

12693L

The stamped labeling on the barrel stated:

*CURE 1061
ASSEM 4061
1280501-1*

The part was cracked about the barrel section adjacent to the endcap, as illustrated in Figure 4. The circumferential portion of the crack was 5.75 in long (in circumference). Figure 5 shows the transition from circumferential to a longitudinal crack along the housing barrel (Figure 6)—the longitudinal section of the crack extended for 3.33 inches.

The end cap of the actuator was separated by sectioning the safety wire and removing the retaining screws. Once the endcap was removed, the extent of the circumferential cracking was revealed (Figure 7). The end flange had completely separated from the rest of the barrel, and the clip was still positioned inside a remnant of the groove seat.

The barrel of the housing was sectioned at a 45° angle to separate the longitudinal crack face. Figure 8 illustrates the sectioned cracked area positioned next to the actuator body, with the retaining ring and endcap and other fractured pieces.

The mating fracture surfaces of the opened circumferential crack are shown in Figure 9. This fracture surface exhibited one thumbnail-shaped crack, shown in Figure 11. In contrast, the longitudinal crack exhibited a rough surface texture and a dull luster. The surface revealed V-shaped chevron marks pointing toward the circumferential crack at the endcap, consistent with fracture from that location. The mating sides of the longitudinal crack portion are depicted in Figure 10.

The length of the fatigue portion of the crack was 3.63 inches or 184° of the part circumference. The depth was 1.8 inches from the retaining ring at its maximum, with the remaining 1.0 inch exhibiting subsequent fracture features. The thumbnail crack initiated at a corner in the retainer clip groove.

Figure 12 shows a closer view of the deepest area of the thumbnail crack on the outer circumferential fracture face. The middle part of this fracture surface exhibited crack arrest marks, consistent with progressive cracking, later determined to be fatigue. The fatigue cracks originated from the retaining ring groove, progressing through more than half of the actuator barrel thickness at the largest portion (see Figure 12). Figure 13 shows a closer view of the groove, with multiple initiation sites identified by yellow arrows. The crack propagation direction is annotated with dashed white arrows.

This fracture surface was examined using a scanning electron microscope (SEM). Figure 14 shows a typical area of the thumbnail crack near the initiation region in Figure 13. As shown in this figure and Figure 15, the thumbnail crack exhibited striations consistent with fatigue crack propagation. Portions of the fracture surface outside the fatigue crack revealed mostly dimple rupture, consistent with subsequent

overstress fracture (Figure 16). However, there were also isolated fatigue striations, indicating an area of mixed-mode fracture. One such region was typified in the location shown in the backscattered micrograph of Figure 17.

The thumbnail-shaped fatigue cracks exhibited ratchet marks, consistent with multiple fatigue crack initiation. One such crack initiation site is illustrated in Figure 18. Along this initiation site, a small corrosion pit was observed (Figure 19). Similar examination along the retaining ring groove edge found pits at other crack initiation sites, as shown in Figure 20. Figure 20 also demonstrates the layer of nonconductive material present along the groove, manifesting as brighter contrast charging areas. A backscattered examination of the corrosion pit at this site revealed a darker contrast surface layer with a small pit-like valley (Figure 21).¹

Examination of the material using energy dispersive x-ray spectroscopy (EDS) found it to be consistent with aluminum oxide. This surface layer of oxide and inward depressions were typical of the other fatigue crack initiation sites along the retaining ring groove. These sites also contained cadmium, consistent with cadmium plating remnants from the clip that sat in the groove.

The opened longitudinal crack face was also examined, and Figure 22 shows the fracture surface along the clip groove. This figure demonstrates the rough, fibrous texture and dull luster of the longitudinal fracture. The figure also shows a crack along the outboard corner of the groove, which had propagated into the area of the longitudinal crack (yellow arrows in Figure 22). When examined using SEM, the longitudinal fracture exhibited dimple rupture, consistent with tensile overstress fracture.

A portion of the actuator housing was cross-sectioned through the clip groove. Figure 23 shows this cross-section after mounting and polishing (this figure is oriented opposite that in Figure 22). Overall, the microstructure exhibited grain flow consistent with wrought material processing. As shown in Figure 23, an angled crack approximately 0.025 inches long had propagated out this corner of the groove (lower left in the figure). Figure 24 shows closer views of this crack at the groove corner. Examination of the opposite corner revealed an additional smaller crack (Figure 25). There were also corrosion pits present along the flat of the clip groove (see Figure 26). This pit exhibited nonmetallic compounds, which contrasted darker against the cross sectioned housing metal alloy.

These features were consistent with fatigue cracking having initiated along the retaining ring groove of the actuator. Propagating outward in a circumferential

¹ Backscattered electrons: SEM micrographs produced using backscattered electrons display contrast associated with the elements' atomic numbers in the micrograph. Materials containing elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

direction, once the fatigue crack grew to its terminal size, the remainder of the cross-section fractured from mixed overstress and fatigue. This cracking led to part of the housing barrel fracturing in overstress, allowing the release of the internal pressurized hydraulic fluid.

The mounted and polished cross section was examined using energy dispersive x-ray spectroscopy and x-ray fluorescence (XRF) to verify the chemical composition of the actuator housing. The composition was consistent with AA 7075 aluminum alloy. The retaining clip was also examined using XRF, and it was found to consist of alloy steel with a cadmium coating.

The actuator housing was hardness tested per ASTM E18.² The hardness averaged 88 HRBW. The electrical conductivity of the housing was tested per ASTM E1004.³ The conductivity averaged 32.9 %IACS. Per AMS 2658, the conductivity and hardness were consistent with a T6 temper for a 7075 aluminum alloy.⁴ The prescribed material and temper for the actuator housing was AA 7075-T6 aluminum alloy.

Submitted by:

Erik M. Mueller
Materials Research Engineer

² ASTM E18 - *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA. The Rockwell B (HRBW) scale is an indentation method of determining the hardness of soft metals and uses a 1/16-inch diameter tungsten ball indenter at a load of 100 kilograms.

³ ASTM E1004 - *Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*. ASTM International, West Conshohocken, PA

⁴ AMS 2658 - *Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts*. SAE International, Warrendale, PA.

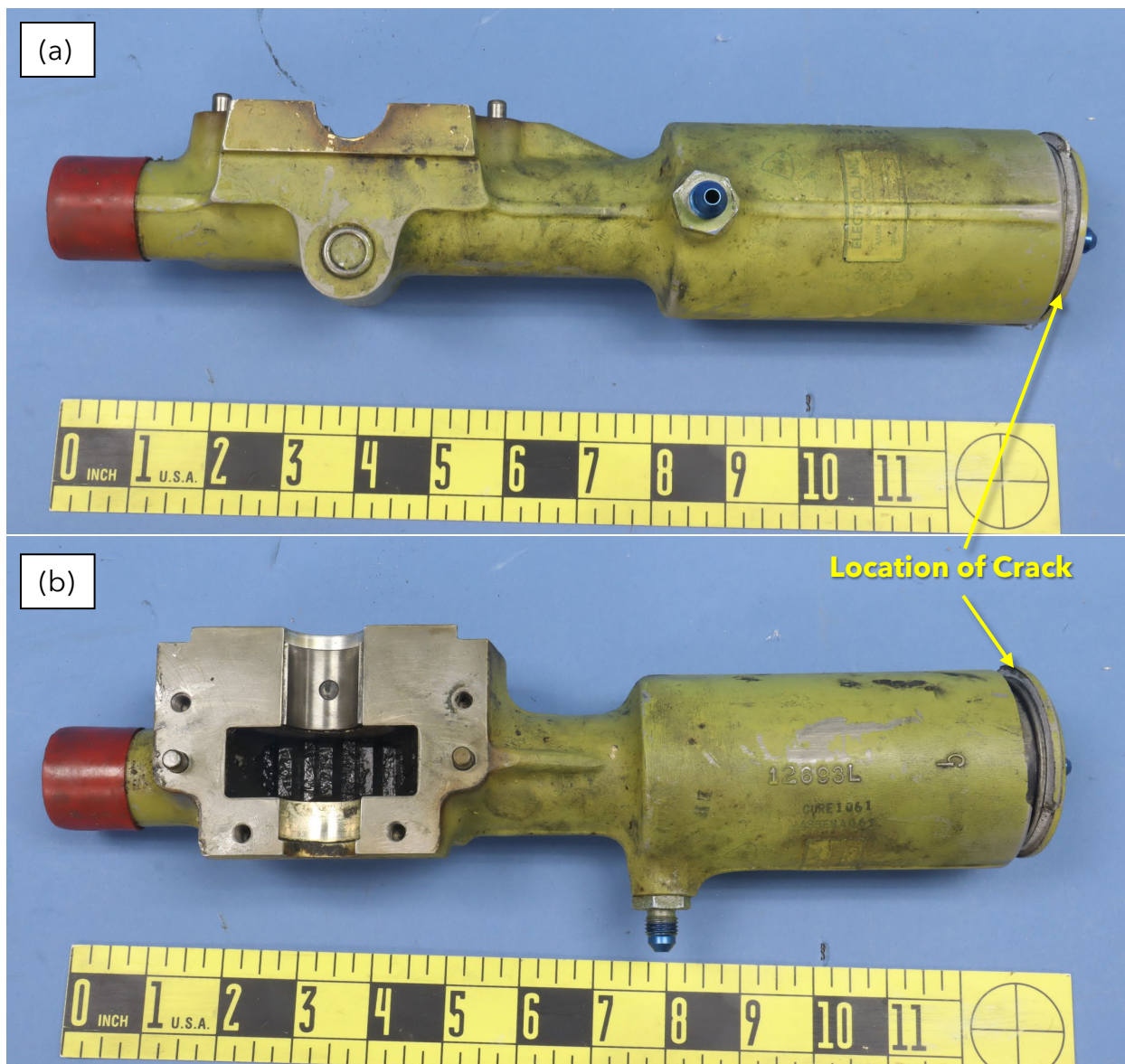


Figure 1. The hydraulic actuator, as received.



Figure 2. View of the hydraulic actuator, viewed opposite that in Figure 1b. This shows the longitudinal crack on the housing barrel.



Figure 3. View of the markings on the housing barrel of the actuator, with the circumferential crack on the right.

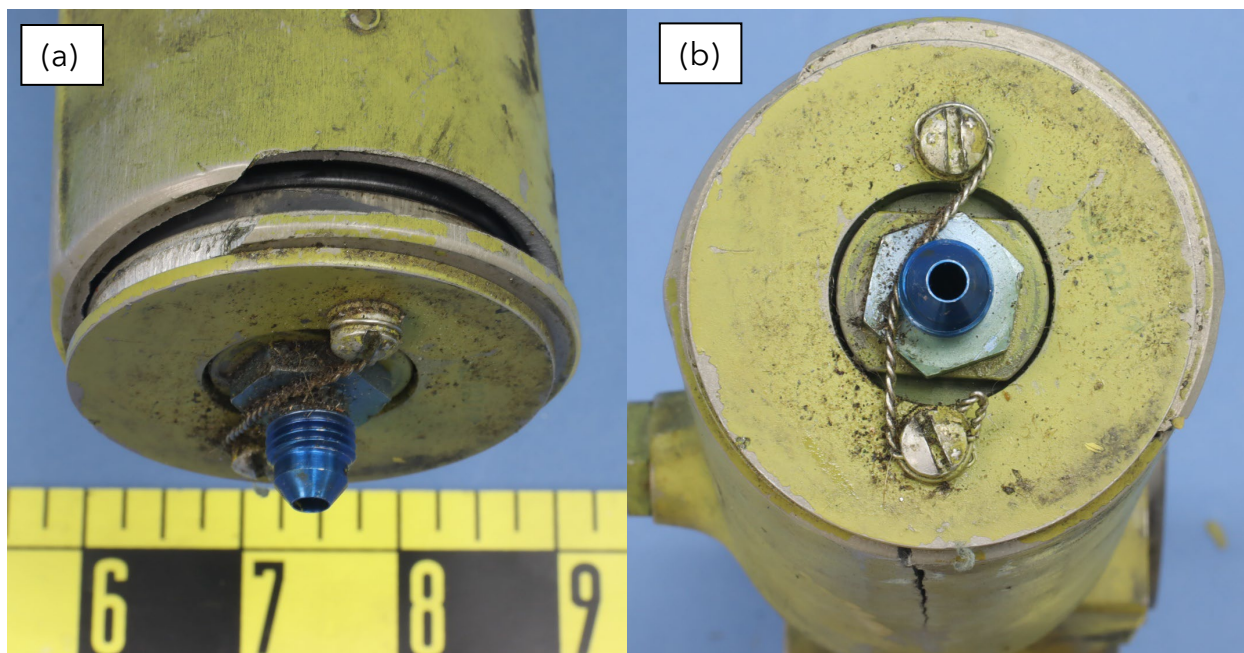


Figure 4. The end of the hydraulic actuator, showing the circumferential portion of the crack.



Figure 5. The longitudinal crack on the actuator housing, emanating from the circumferential crack (opposite the view in Figure 4a).



Figure 6. The longitudinal crack along the actuator housing barrel.

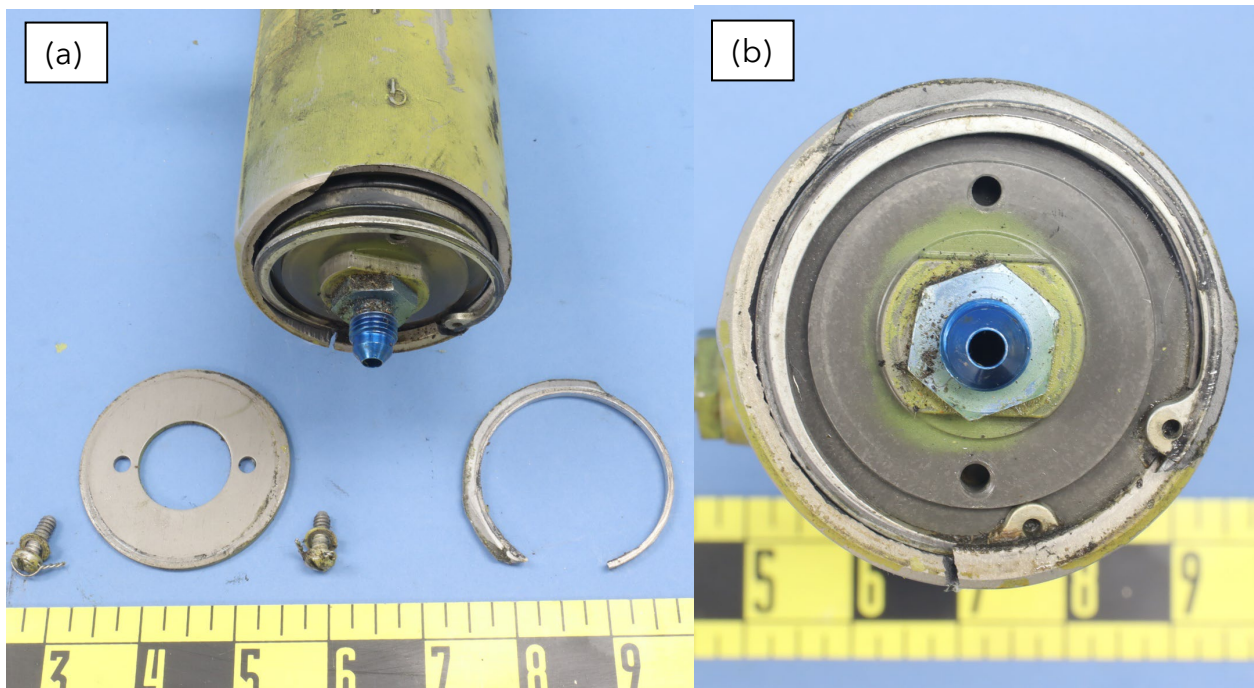


Figure 7. The cracked end of the actuator pictured in Figure 4, after removal of the screws and the end cap.



Figure 8. The cracked end of the actuator pictured in Figure 7a, after sectioning and removal of the cracked regions of the housing barrel.

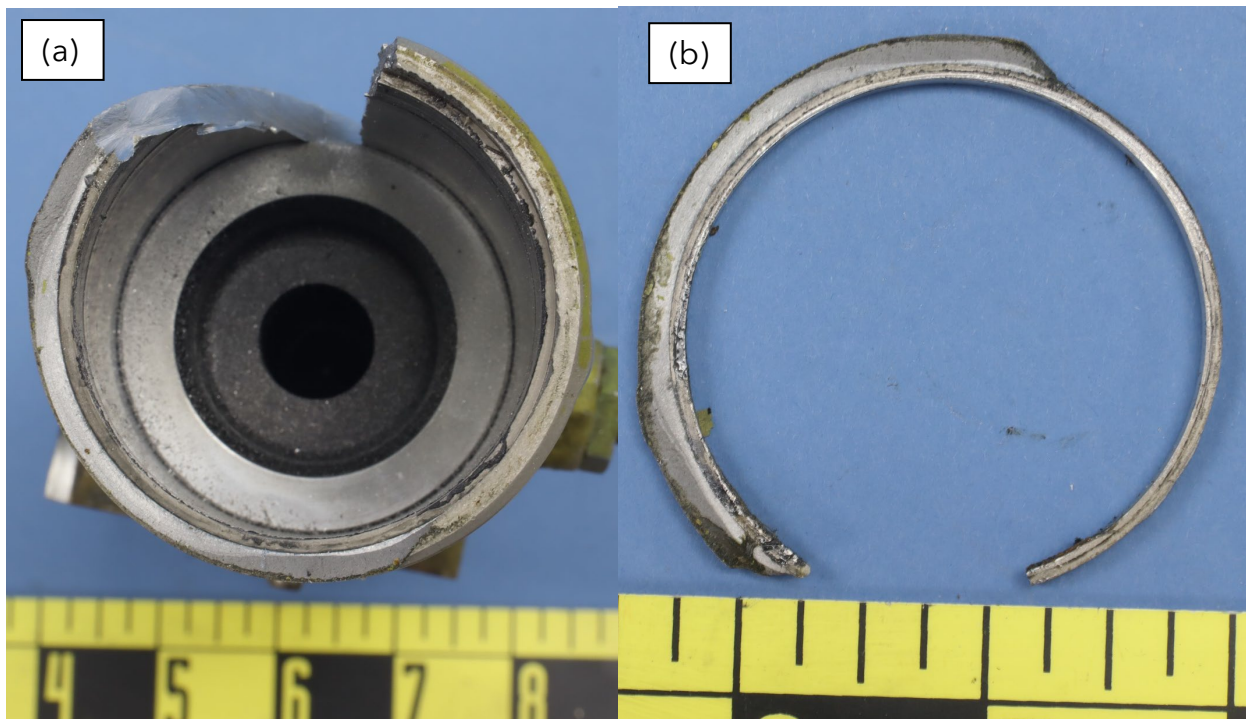


Figure 9. The mating faces of the fractured end of the actuator, after sectioning and disassembly.



Figure 10. Mating faces of the longitudinal crack, after sectioning to open the crack faces.



Figure 11. Montage of magnified images of the crack face of the circumferential crack, showing indications of progressive cracking.

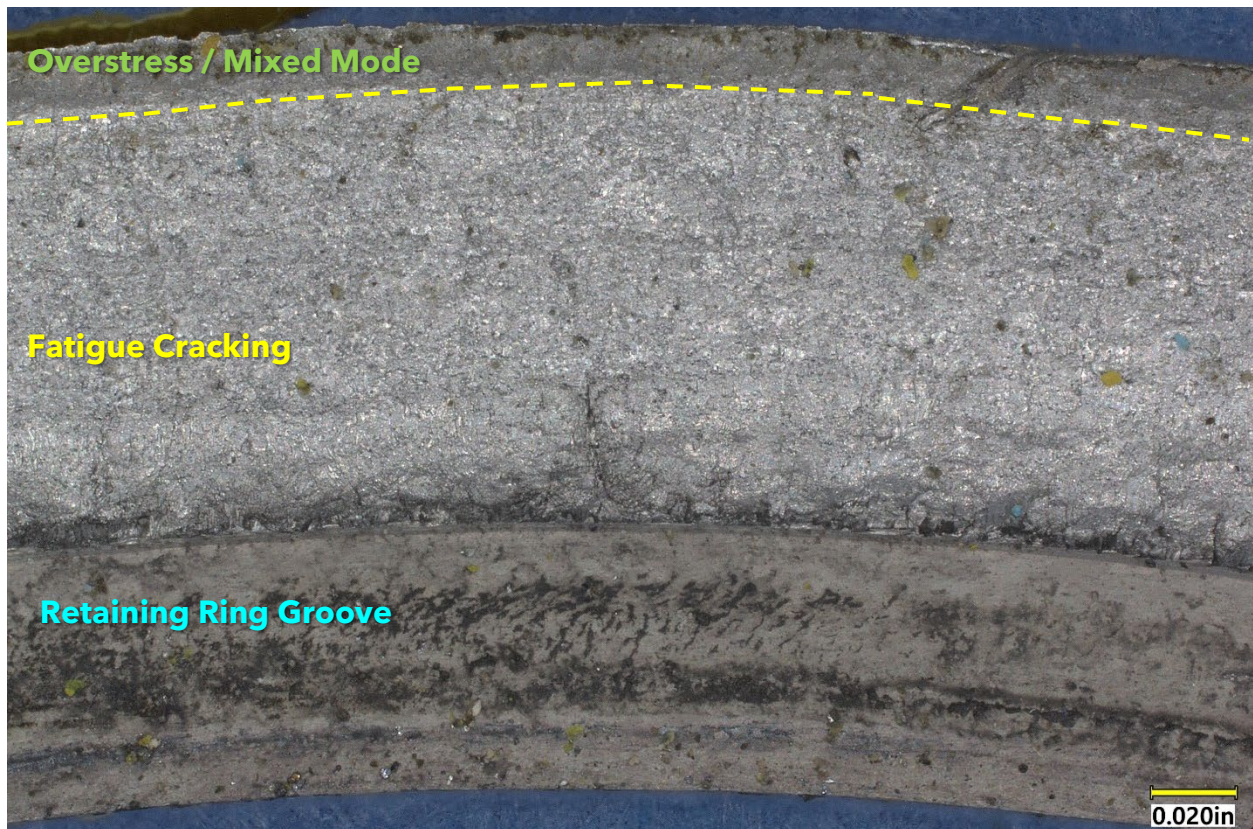


Figure 12. The progressive crack in Figure 11, showing the area of crack initiation.

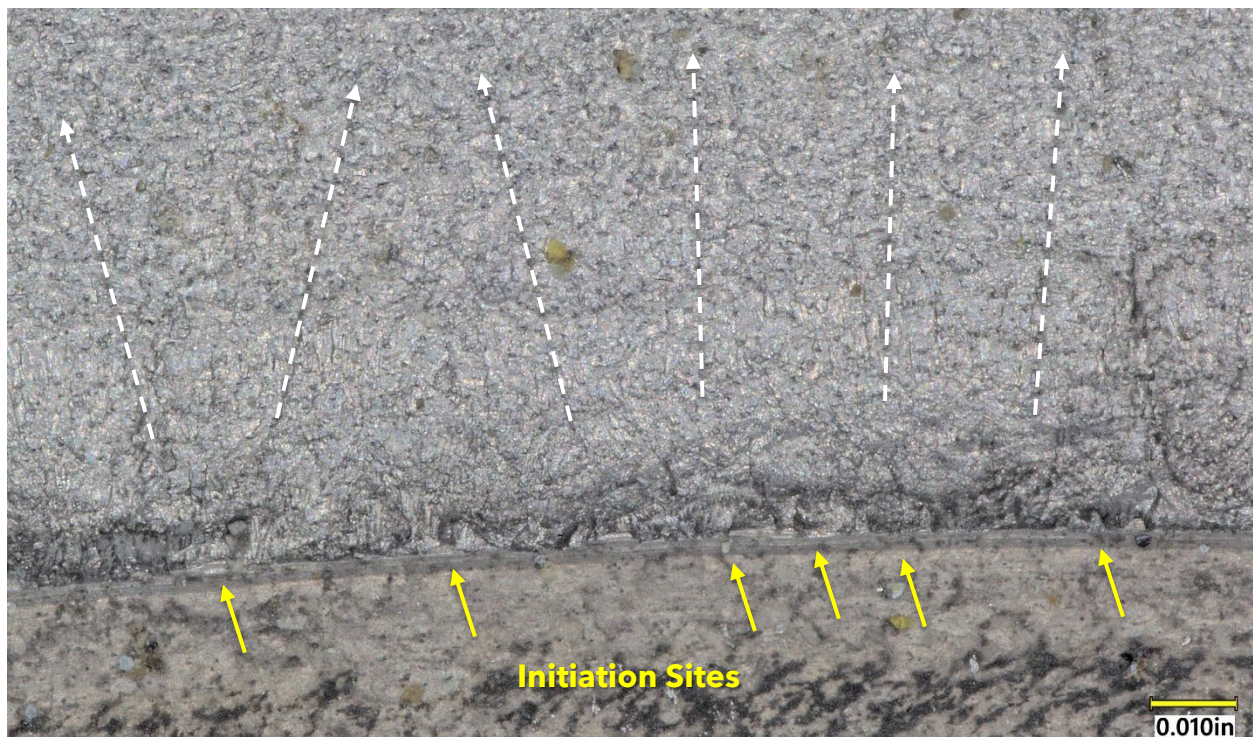


Figure 13. Closer view of the crack initiation area, with some initiation sites identified (yellow arrows) and the local crack growth directions annotated (white arrows).

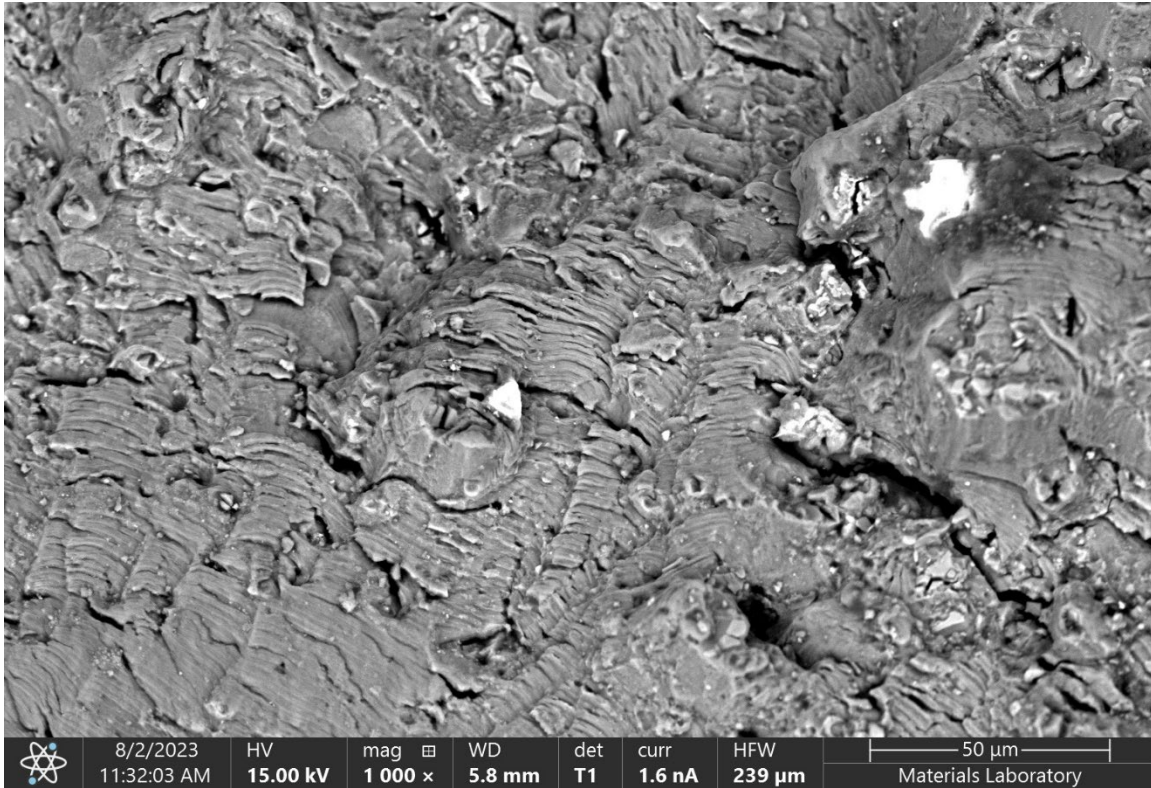


Figure 14. Backscattered electron (BE) micrograph of a typical area of the fatigue crack in Figure 13, showing multiple areas of fatigue striations.

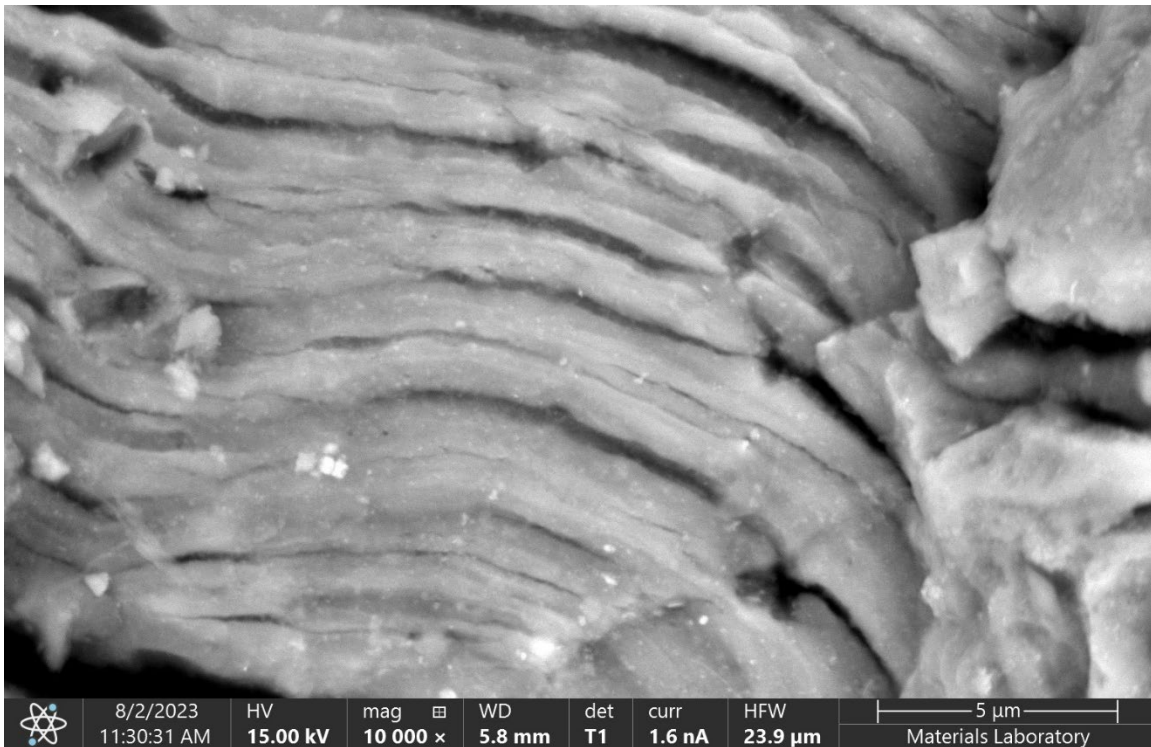


Figure 15. BE micrograph of a closer view of the fatigue striations in Figure 14.

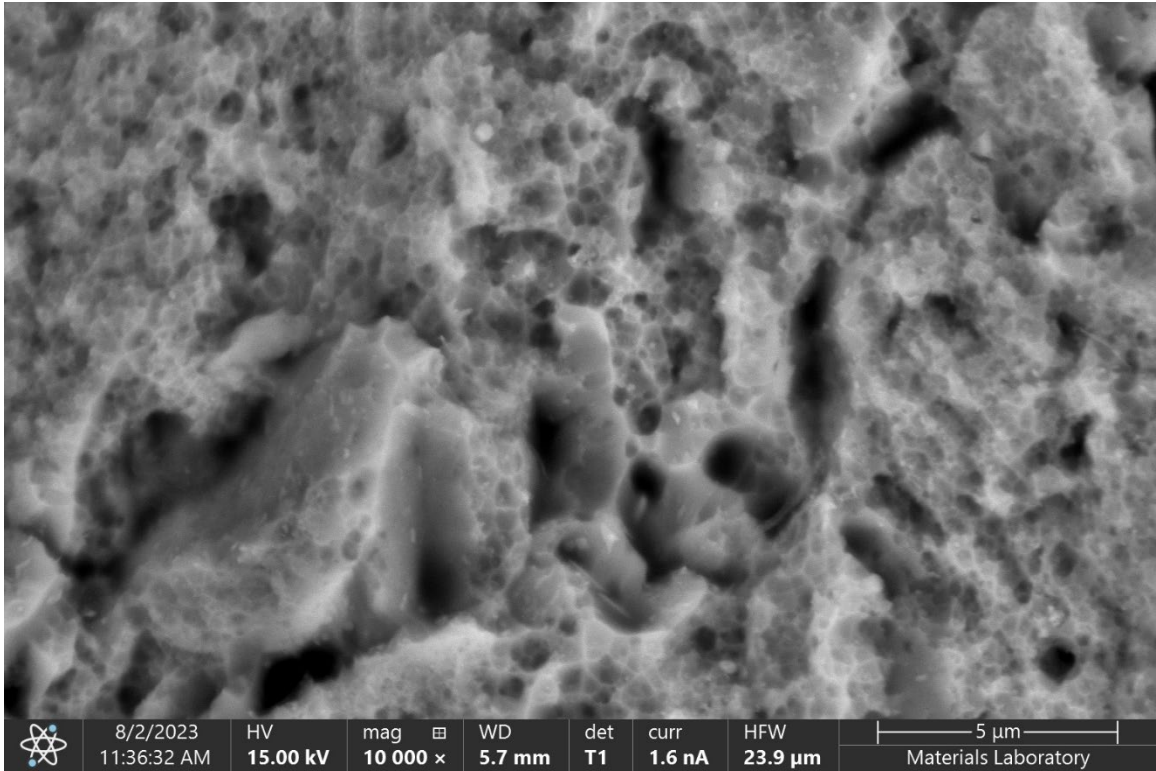


Figure 16. BE micrograph of dimpled rupture in the area outside the primary fatigue crack.

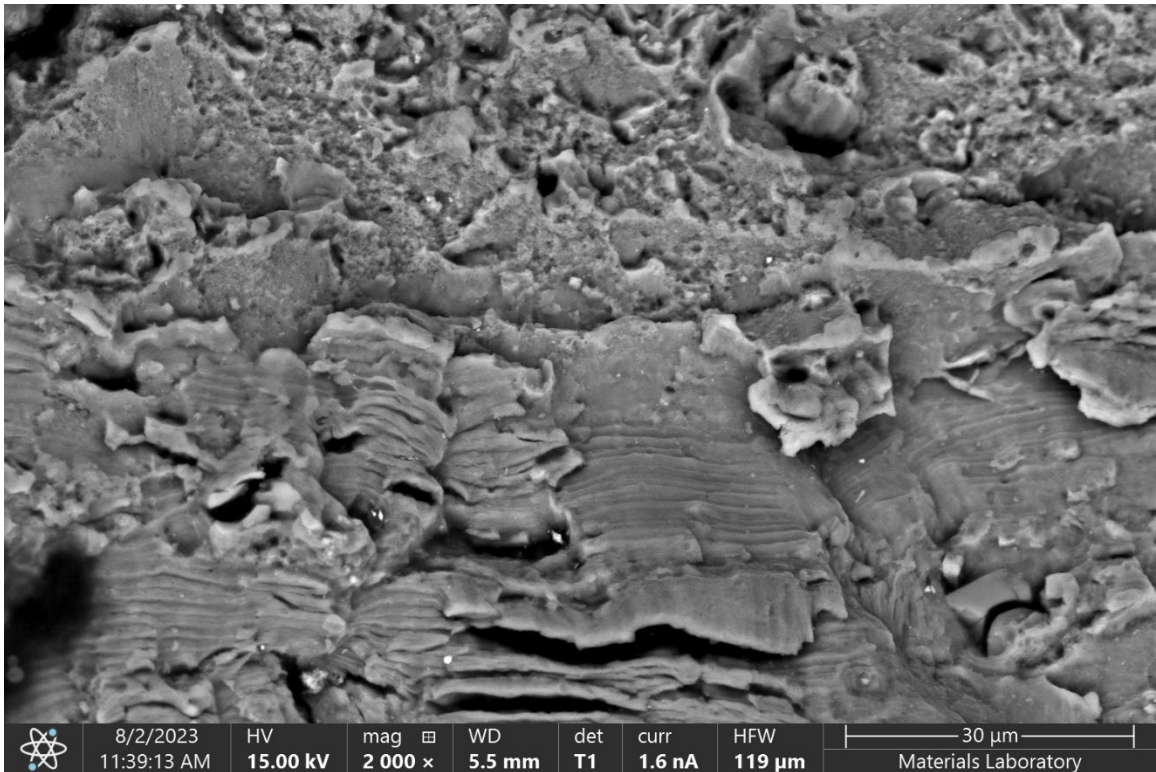


Figure 17. BE micrograph of the mixed mode area outside of the primary fatigue crack, showing dimpled rupture and striations.

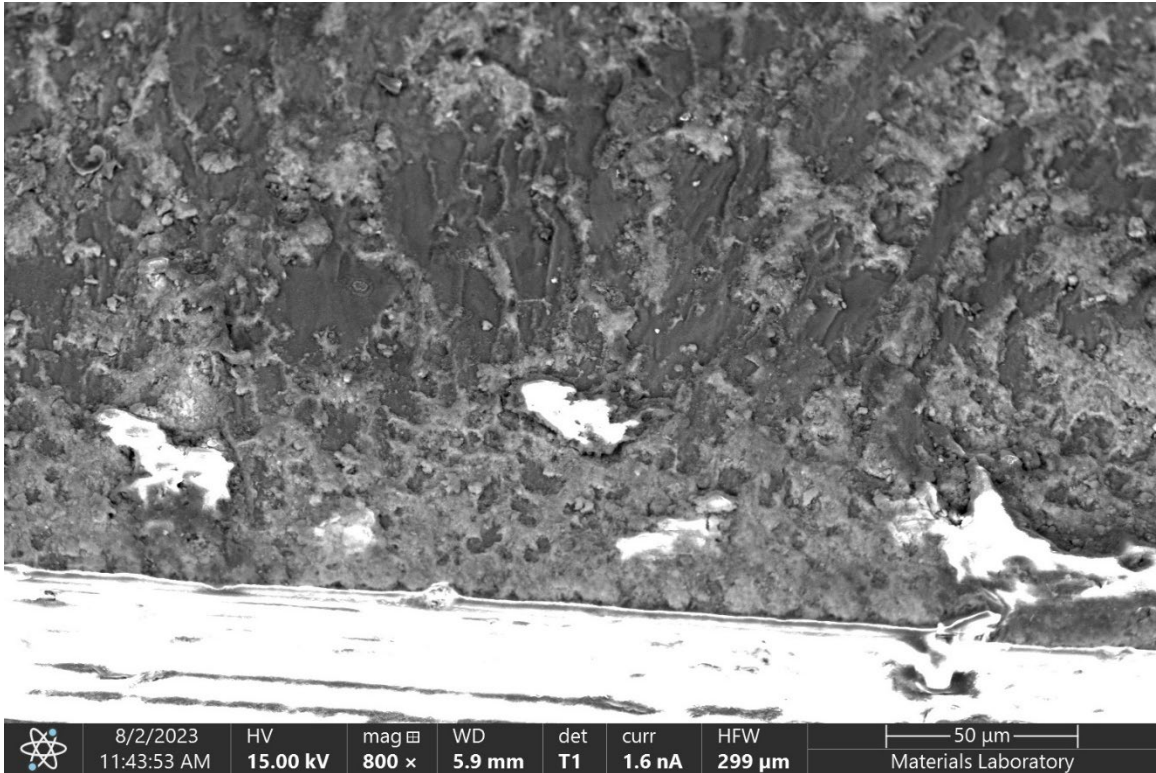


Figure 18. BE micrograph of one of the fatigue crack initiation sites on the cylinder groove.

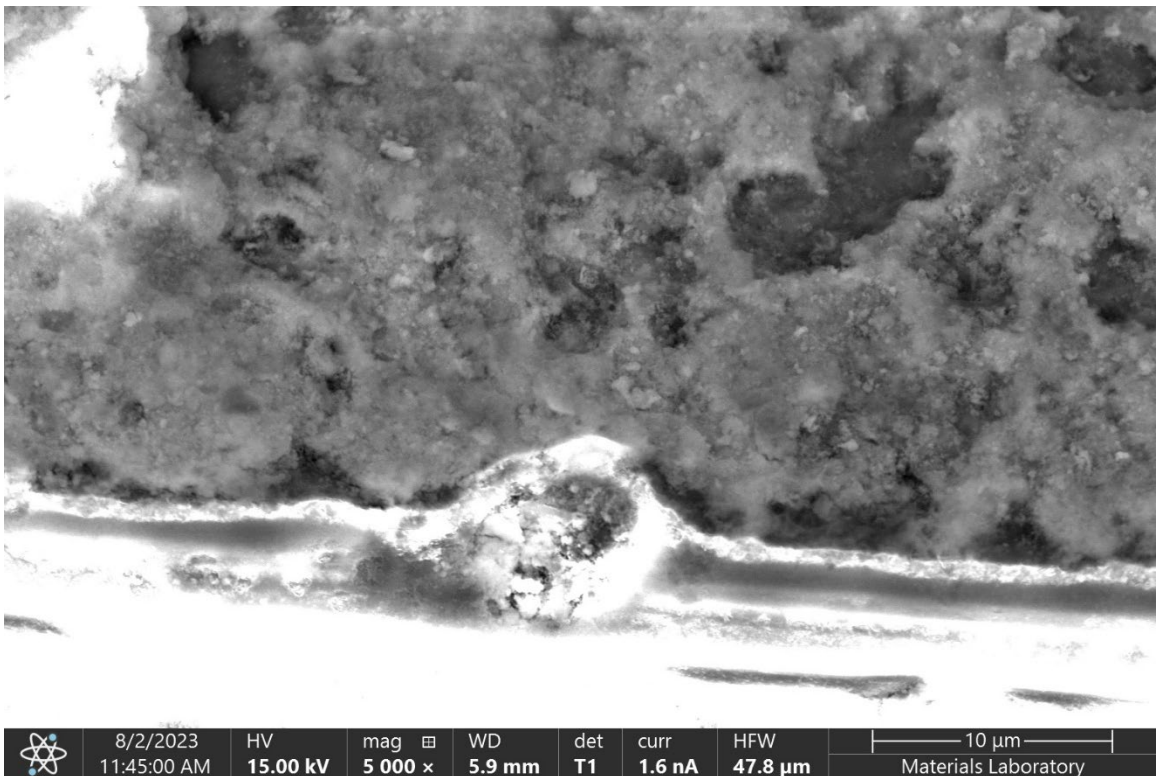


Figure 19. BE micrograph of the corrosion pit at the initiation site in **Figure 17**.

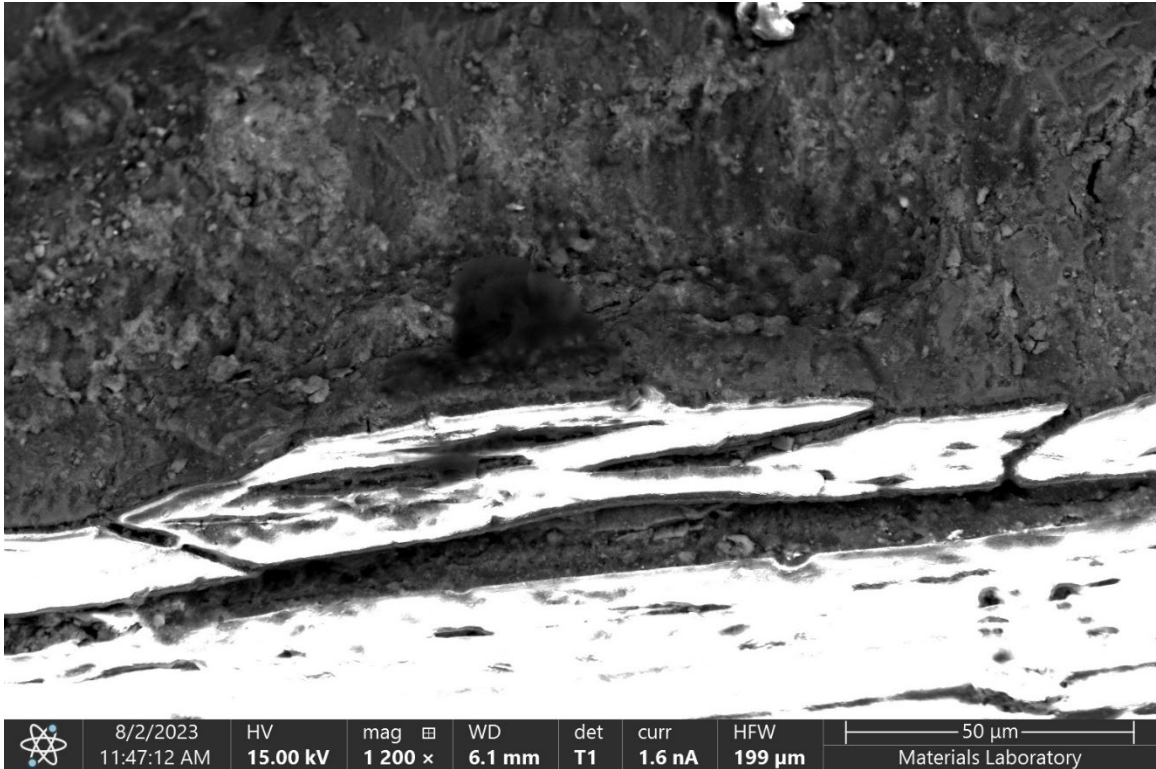


Figure 20. BE micrograph of a second crack initiation site, showing charging (nonconductive) compounds along the groove.

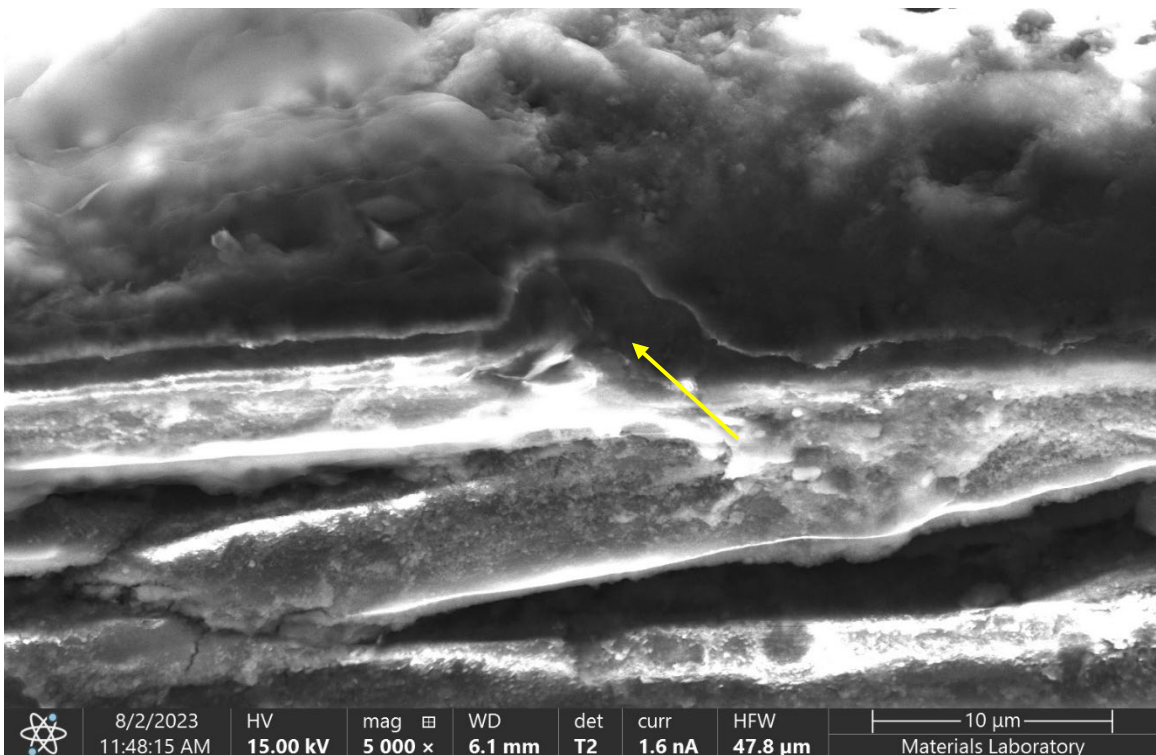


Figure 21. Secondary electron (SE) micrograph of the initiation site edge, showing a small groove (arrow).

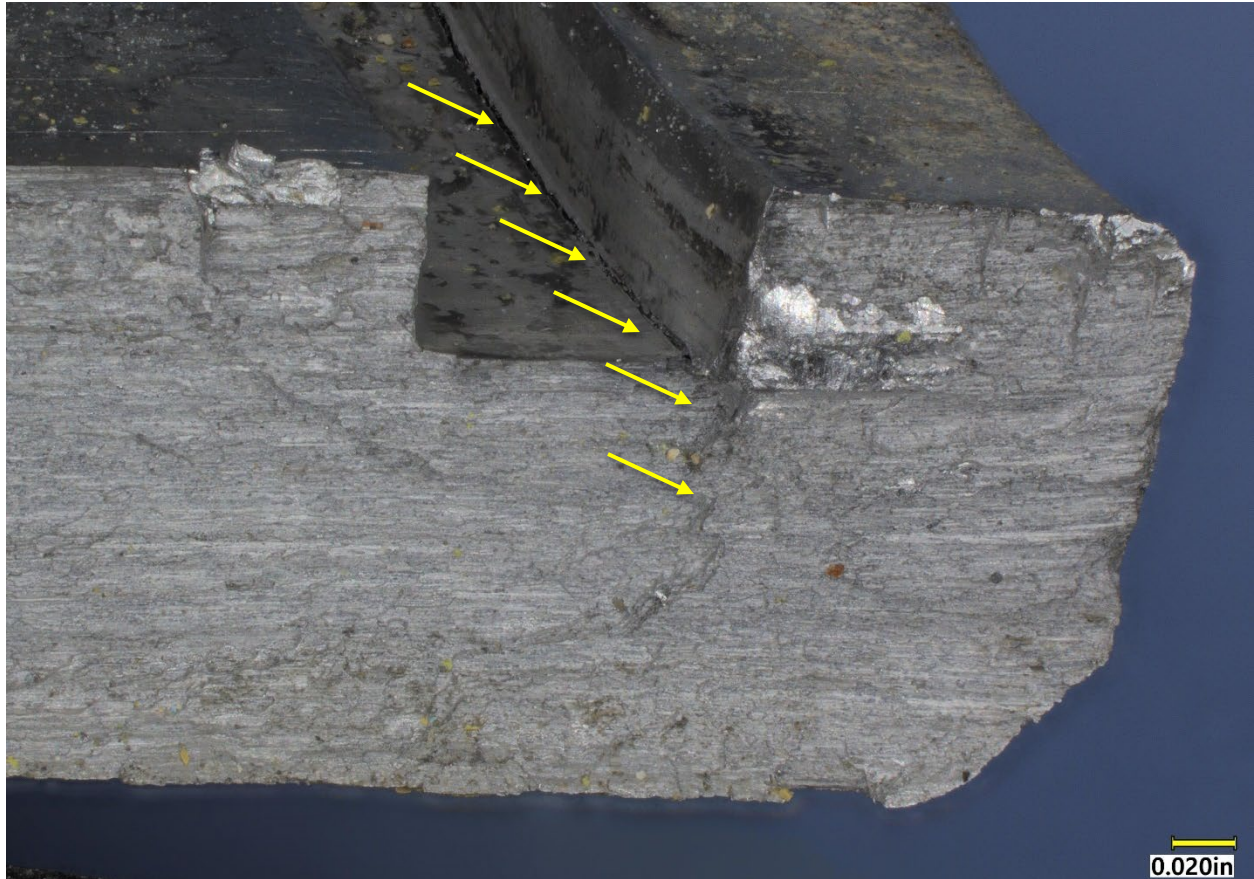


Figure 22. View of the longitudinal fracture at the clip groove, showing cracking along the outside corner that had progressed into the material exposed on the fracture surface (arrows).

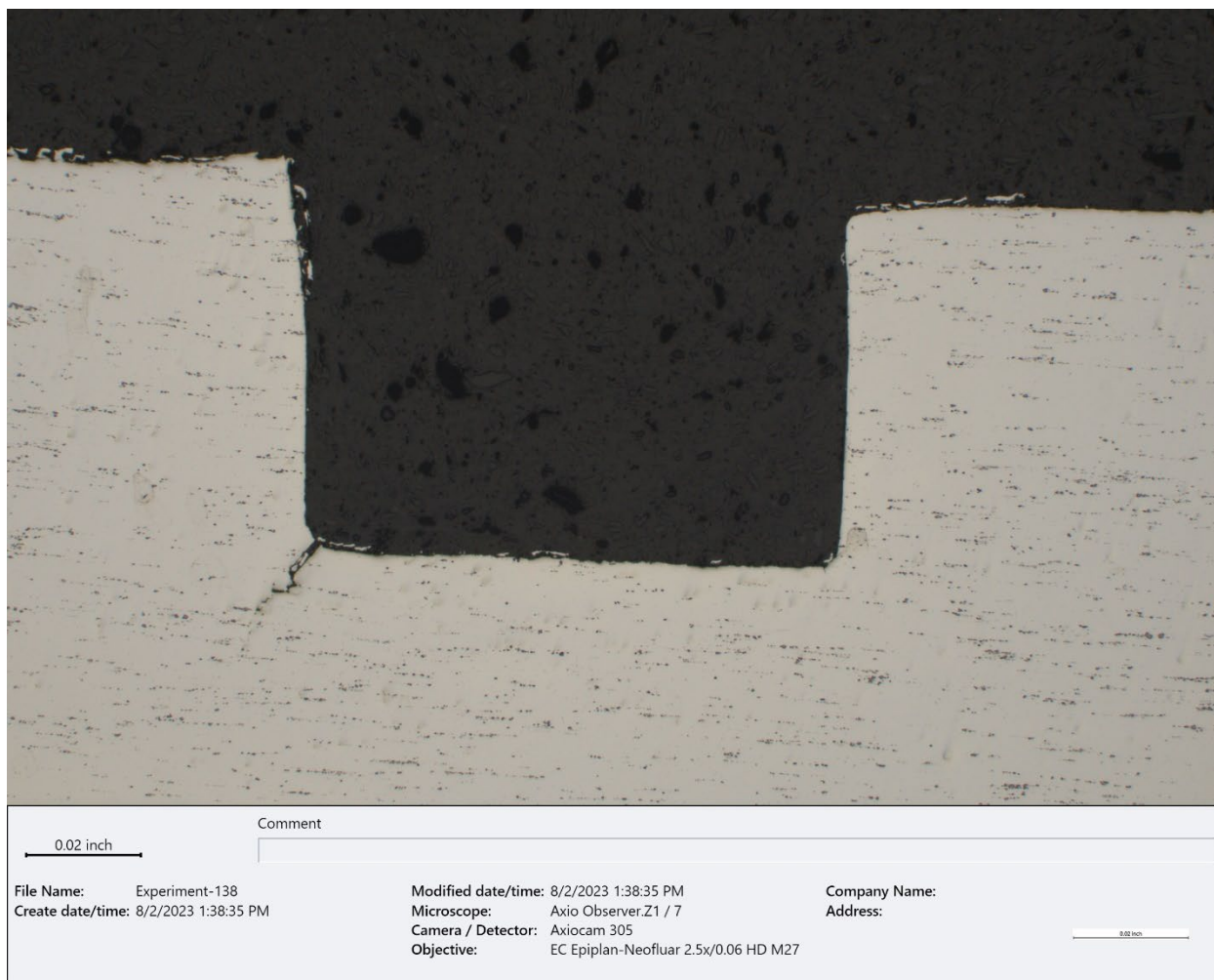


Figure 23. Bright-field (BF) optical metallograph cross-section of the actuator retaining ring showing an angled crack propagating from the left groove radius (~25X, as polished).

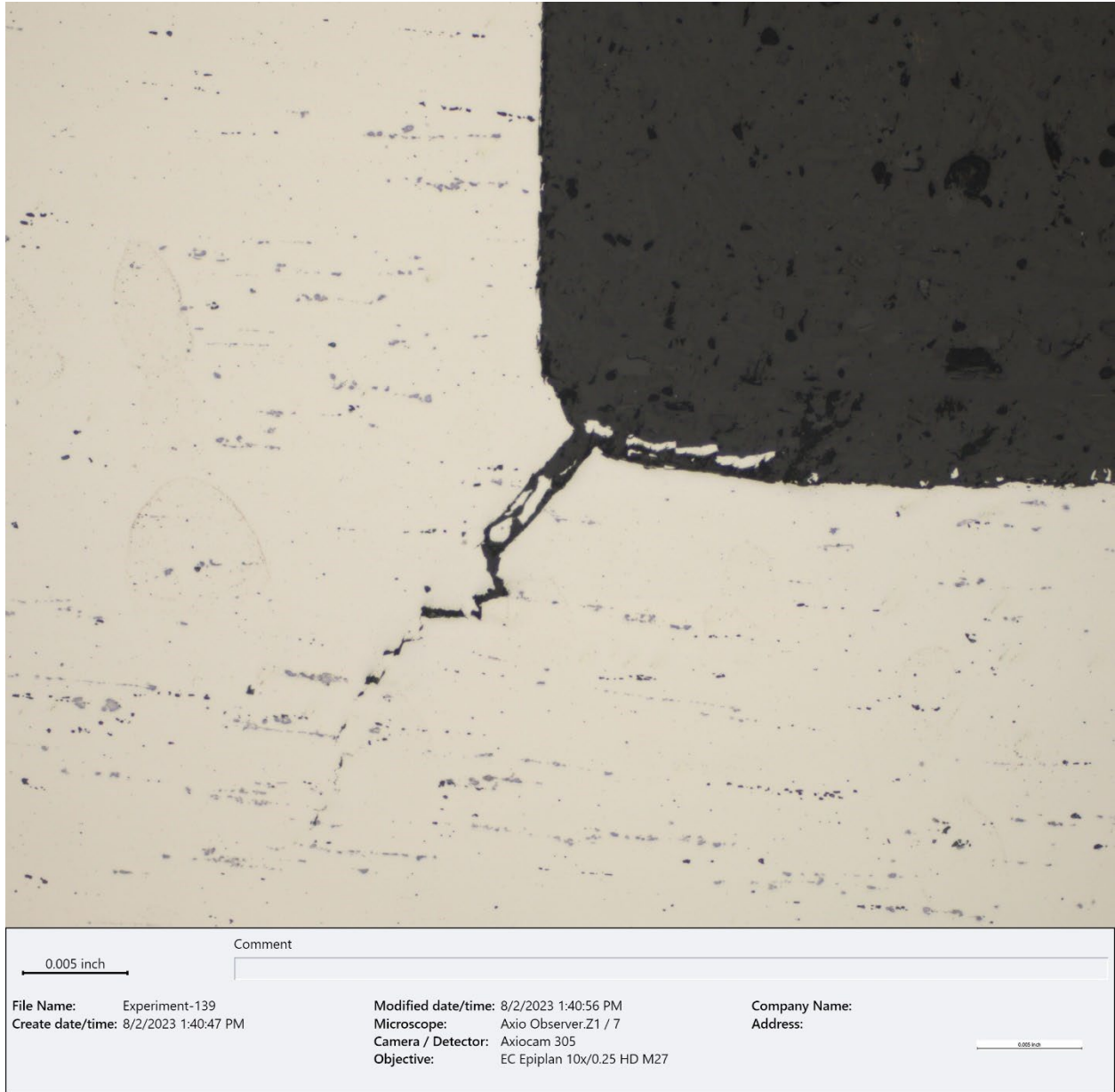


Figure 24. BF optical metallograph showing a closer view of the left corner crack from **Figure 22** (~100X, as polished).

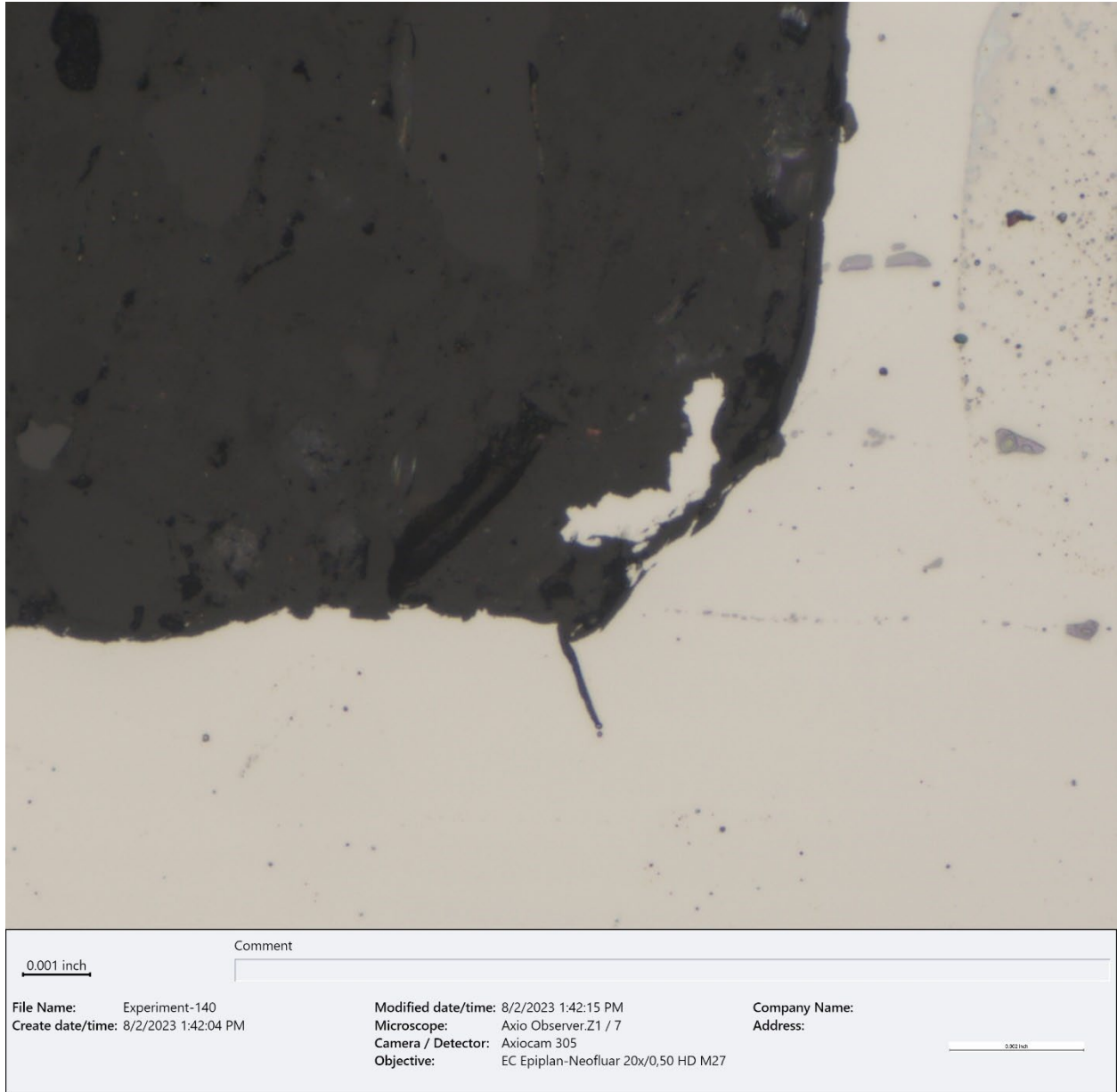


Figure 25. BF optical metallograph showing a closer view of the opposite right (inboard) corner crack from **Figure 22** (~320X, as polished).



Figure 26. View of a corrosion pit (arrow) along the bottom surface of the groove shown in **Figure 22** (~320X, as-polished).