

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN22LA378

MATERIALS LABORATORY

Factual Report 23-016

March 20, 2023

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A. ACCIDENT INFORMATION

Location: Clinton, Arkansas
Date: August 9, 2022
Time: 10:57 central daylight time
15:57 coordinated universal time
Vehicle: Cessna 210B, N9637X
Investigator: Shaun Williams, AS-CEN

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 August 9, 2022, a Cessna 210B airplane sustained substantial damage when it was involved in an accident near Clinton, AR. The pilot was uninjured. The pilot reported that the main landing gear did not fully extend while attempting to land. The pilot elected to land with just the nose wheel extended. After the touchdown, the airplane rolled to the left, resulting in substantial damage when the left elevator and horizontal stabilizer contacted the runway. A post-accident examination revealed a fracture of the hydraulic actuator, which allowed the hydraulic fluid to escape the system. 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 plate and embossed markings for the actuator. The embossed markings on the barrel stated:

12693R

The metallic placard affixed to the barrel stated:

COX AIRPARTS, WICHITA, KANSAS
PART NO. EA161402
SERIAL NO. 190
ASSY DATE. 06/2021

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 to a longitudinal crack along the housing barrel (Figure 6)—the longitudinal section of the crack extended for 2.60 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). Though cracked, the end flange was still attached by a small filament near the transition with the longitudinal crack.

The barrel of the housing was sectioned at a 45° angle to separate the cracked area from the rest of the assembly. Figure 8 illustrates the sectioned cracked area positioned next to the actuator body, with the retaining ring and endcap towards the right.

The mating fracture surfaces of the opened circumferential crack are shown in Figure 9. This fracture surface exhibited one thumbnail-shaped crack. 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.

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).

The length of the fatigue portion of the crack was 2.64 inches or 131° of the part circumference. The depth was 1.7 inches from the retaining ring at its maximum, with the remaining 1.03 being subsequent fracture features. The thumbnail crack initiated at a corner in the retainer clip groove. 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 region, displaying 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 15). 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 16.

The thumbnail-shaped fatigue cracks exhibited ratchet marks, consistent with multiple fatigue crack initiation. One such crack initiation site is illustrated in Figure 17. Along this initiation site, fine striations were observed (Figure 18). A backscattered examination of this site revealed an area of high atomic number contrast along the retaining ring groove surface at the site (white area in Figure 19).¹ Examination of the material using energy dispersive x-ray spectroscopy (EDS) found it to be consistent with cadmium, consistent with remnants from a cadmium coating. Similar cadmium material was found at other crack initiation sites along the groove, such as in Figure 20.

Figure 20 also demonstrates the layer of nonconductive material present along the groove, manifesting as brighter contrast charging areas. A closer view at the crack initiation sites revealed a darker contrast surface layer with a small pit-like valley (Figure 21). EDS examination of this layer 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.

The opened longitudinal crack face was also examined using an SEM. The fracture features exhibited dimple rupture, consistent with tensile overstress fracture.

A portion of the actuator housing was cross-sectioned through the retaining ring for metallographic examination. Figure 22 shows this cross-section after mounting and polishing. Overall, the microstructure exhibited grain flow consistent with wrought material processing. As shown in Figure 22, an angled crack approximately 0.02 inches long had propagated out of an upward-facing corner of the retaining ring groove (lower left in the figure). Figures 23 and 24 show closer views of this crack at the groove corner, revealing additional smaller cracks. One of these smaller cracks exhibited a corrosion pit present along the surface of the retaining ring groove (see Figure 19).

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

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.

retaining ring was also examined using XRF, and it was found to consist of alloy steel with a cadmium coating.

The mounted cross section was hardness tested per ASTM E18.² The hardness averaged 93 HRBW. The electrical conductivity of a portion of the actuator housing was tested per ASTM E1004 after removing the surface paint and primer.³ The conductivity averaged 30.7 %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.

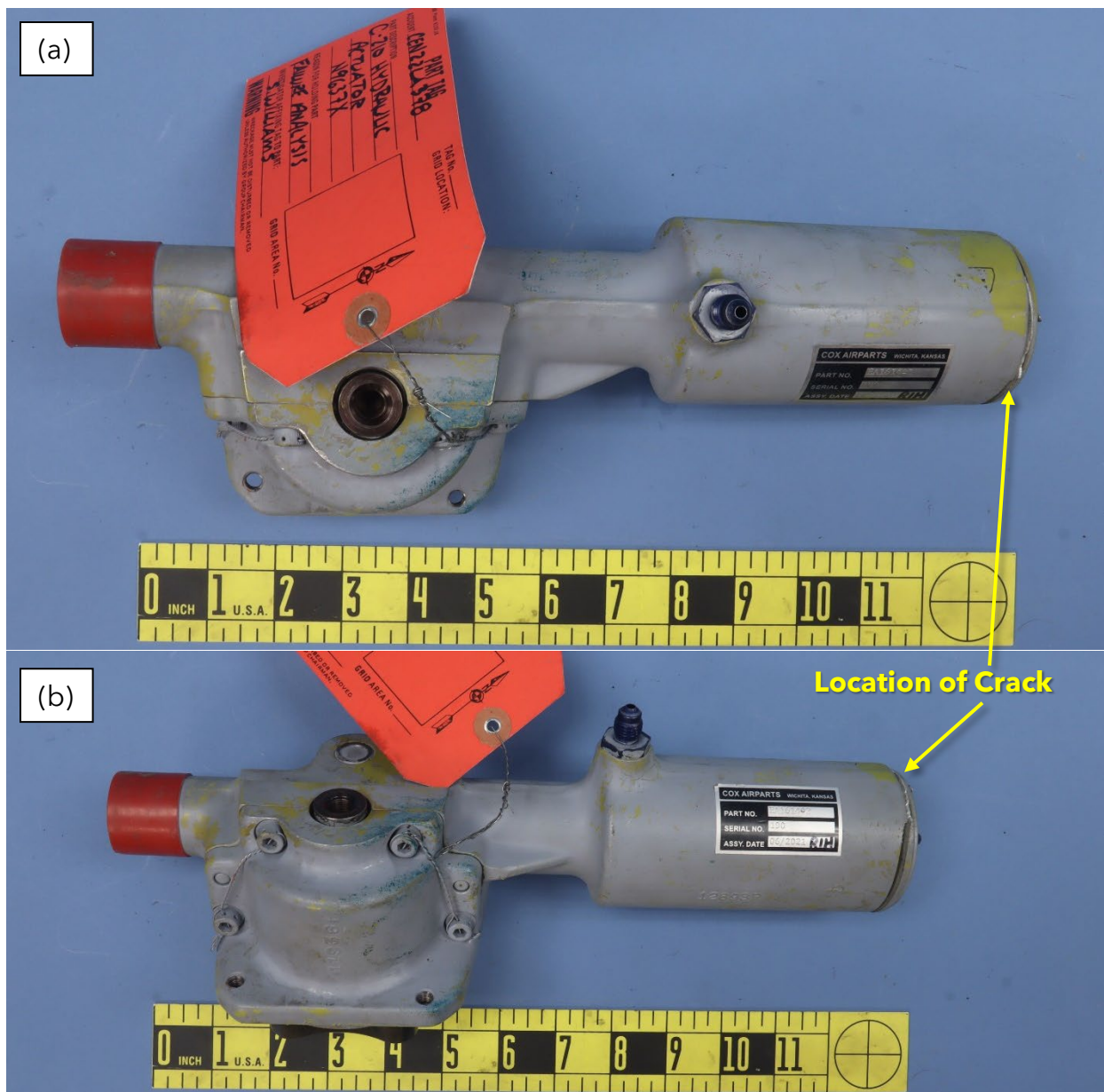


Figure 1. The hydraulic actuator, as received.

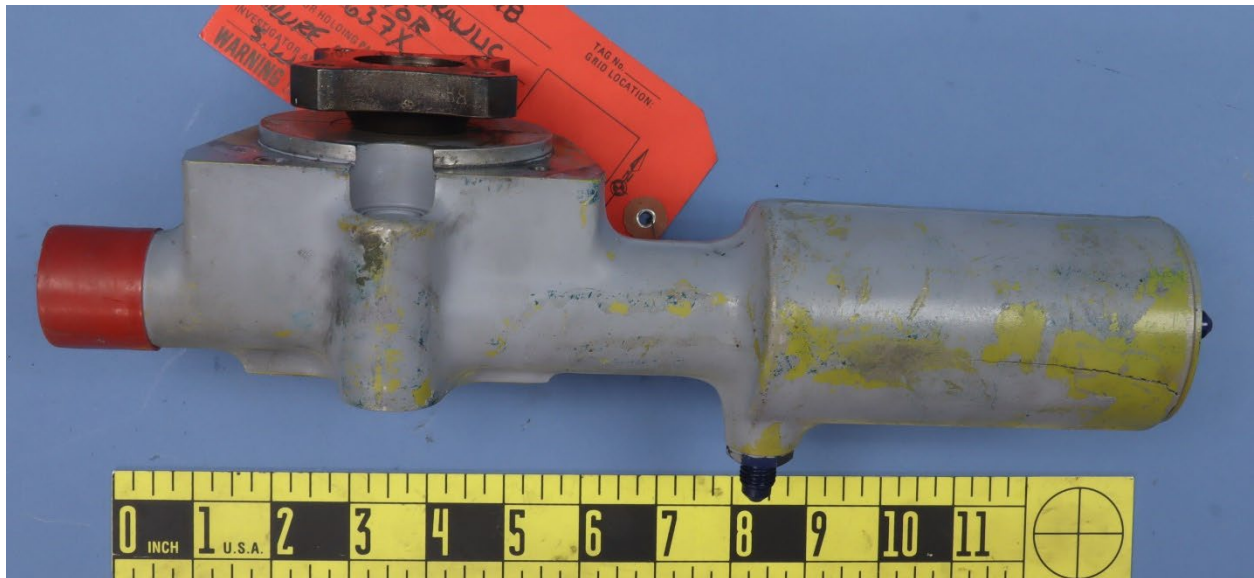


Figure 2. View of the hydraulic actuator, viewed opposite that in Figure 1b. This shows the longitudinal crack on the housing barrel.



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

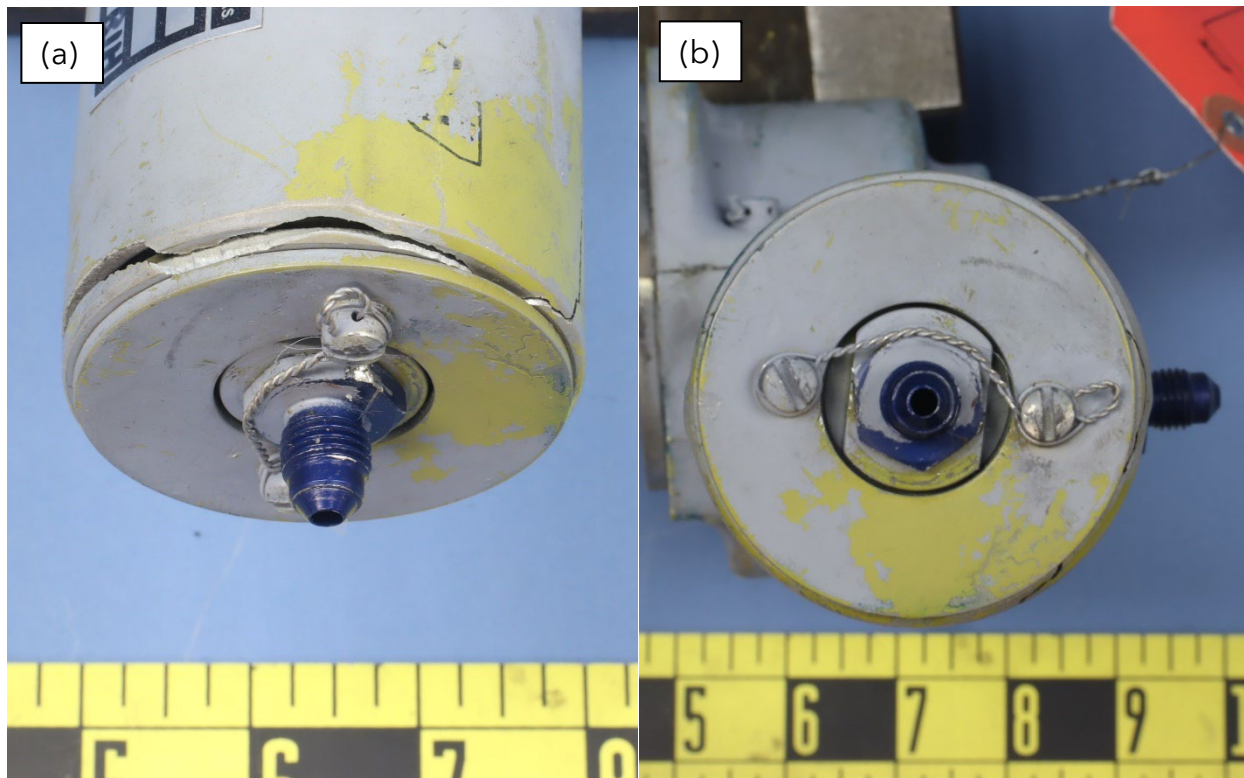


Figure 4. The end of the hydraulic actuator, showing the circumferential portion of the crack.



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

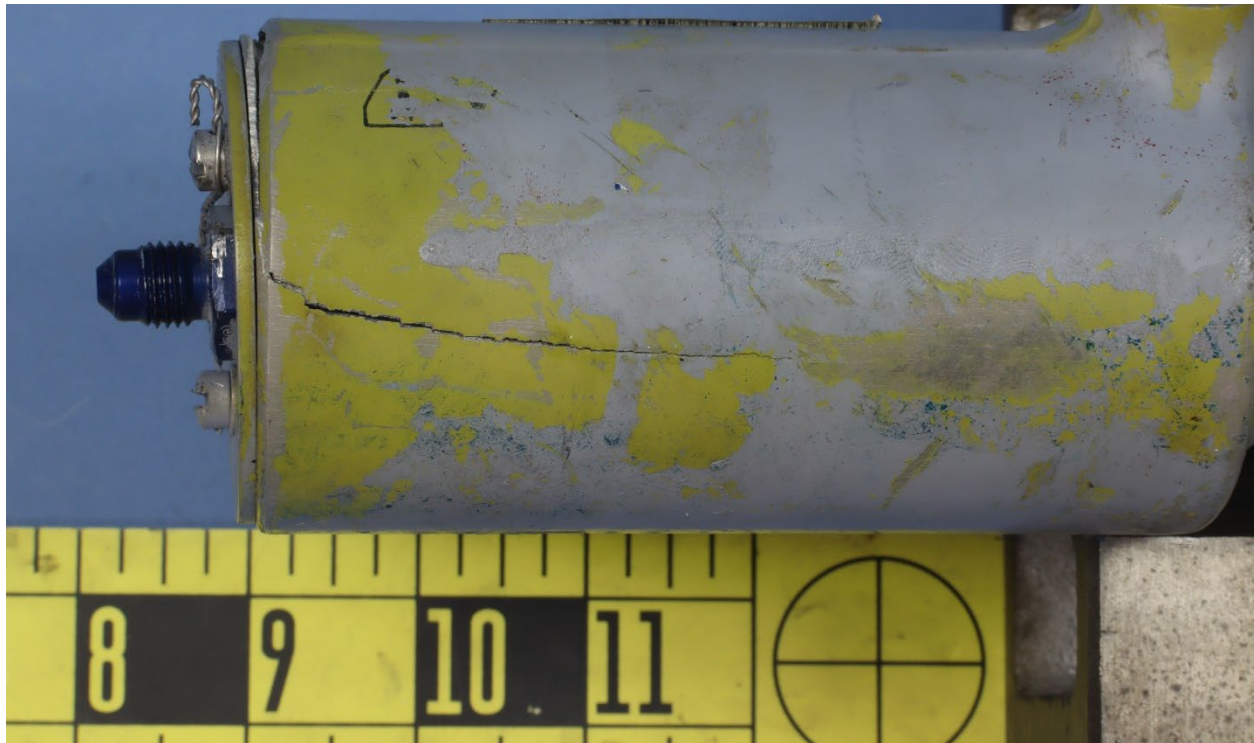


Figure 6. The longitudinal crack along the actuator housing barrel.

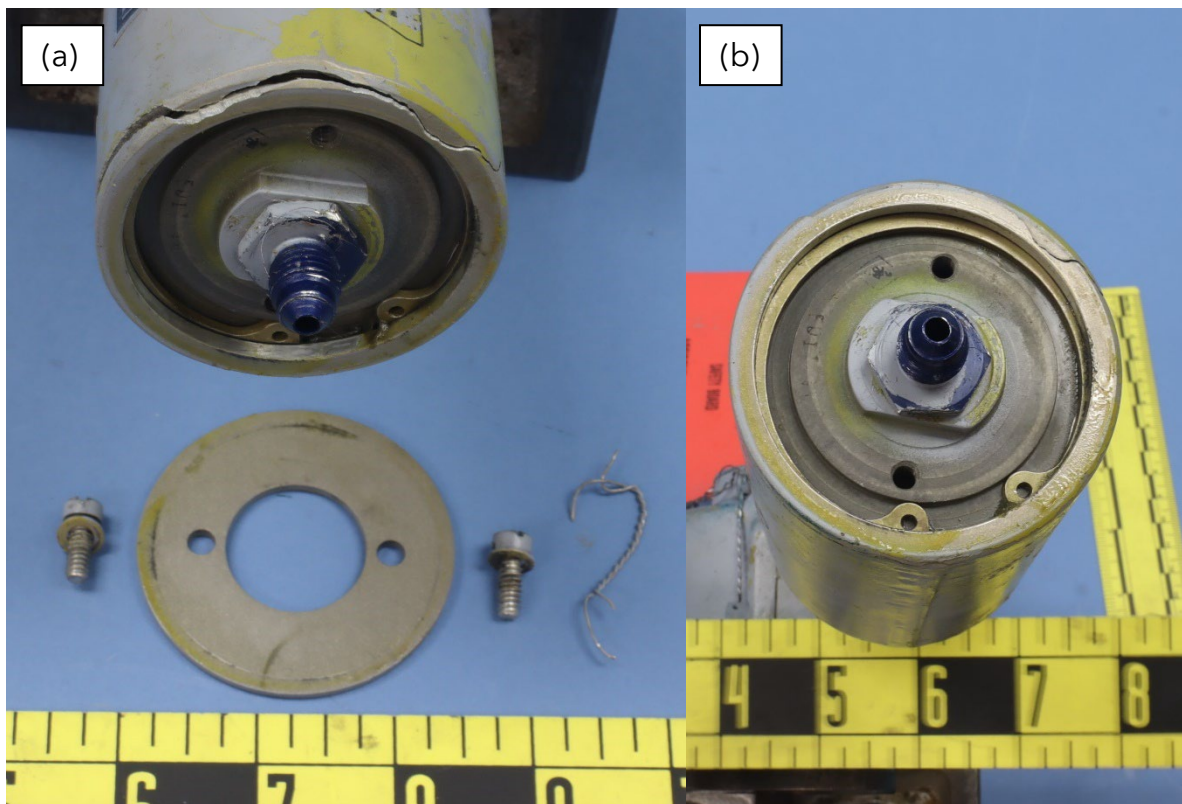


Figure 7. The cracked end of the actuator pictured in Figure 4, after removal of the screws and the end cap.



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

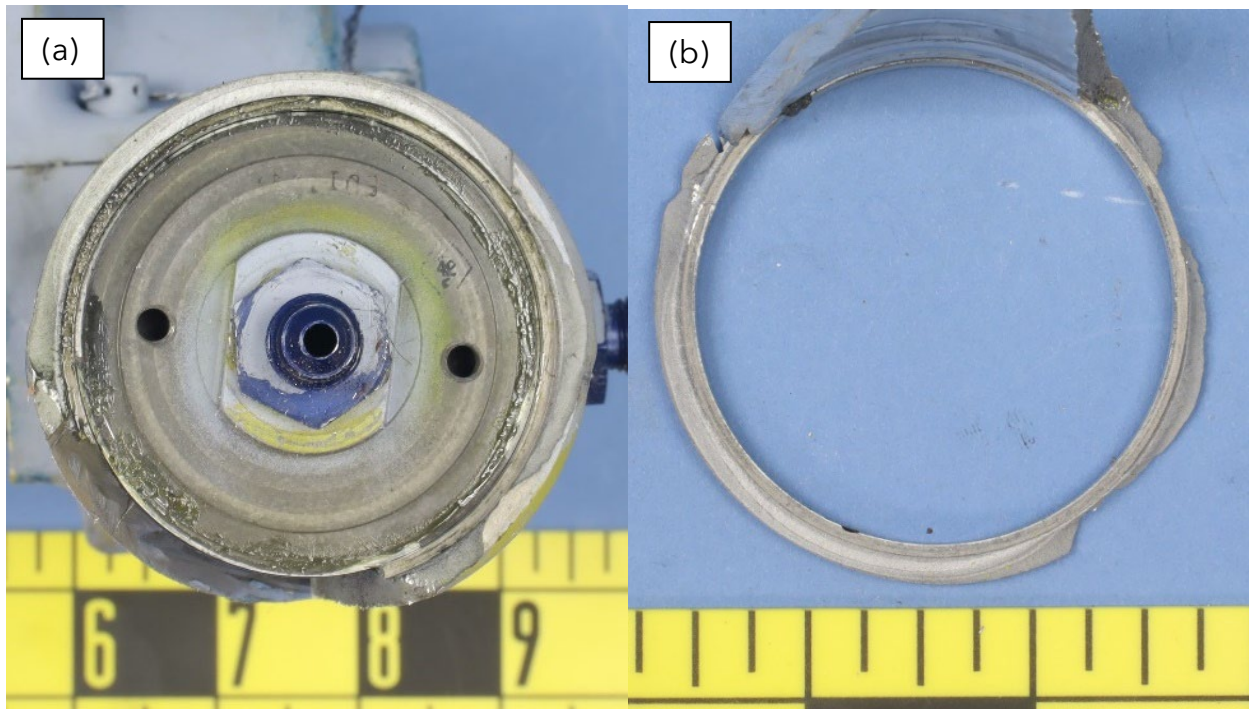


Figure 9. The mating faces of the fractured end of the actuator, after sectioning and disassembly.



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.

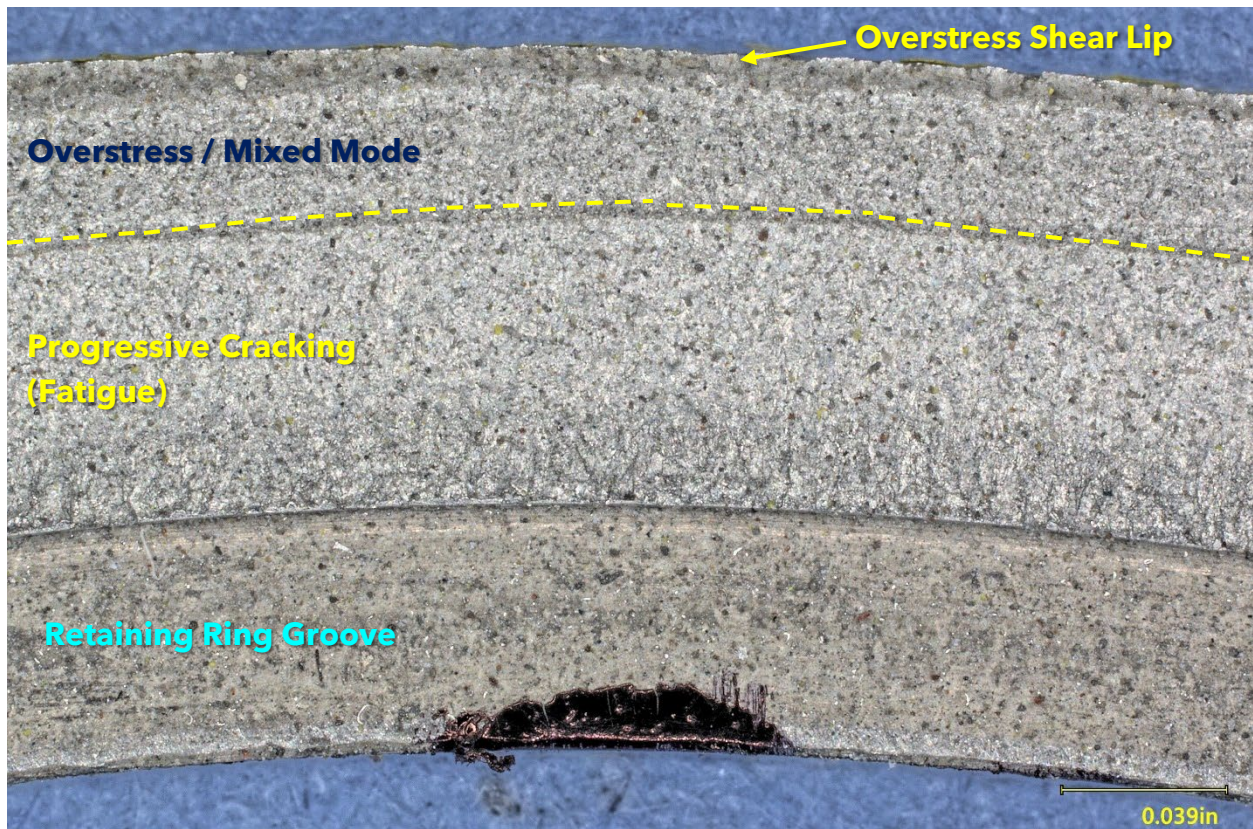


Figure 12. The progressive crack in Figure 11, showing the area of crack initiation.

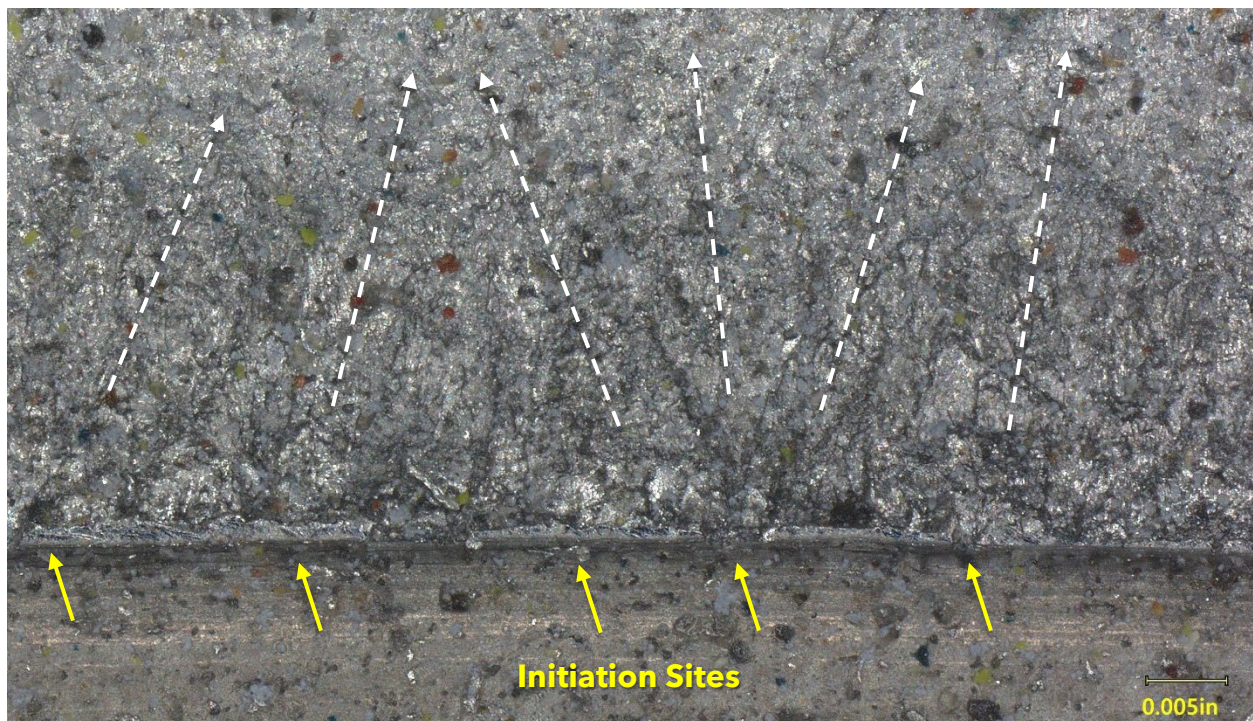


Figure 13. Closer view of the crack initiation area, with some initiation sites identified (yellow arrows) and the local crack growth directions annotated (white arrows).

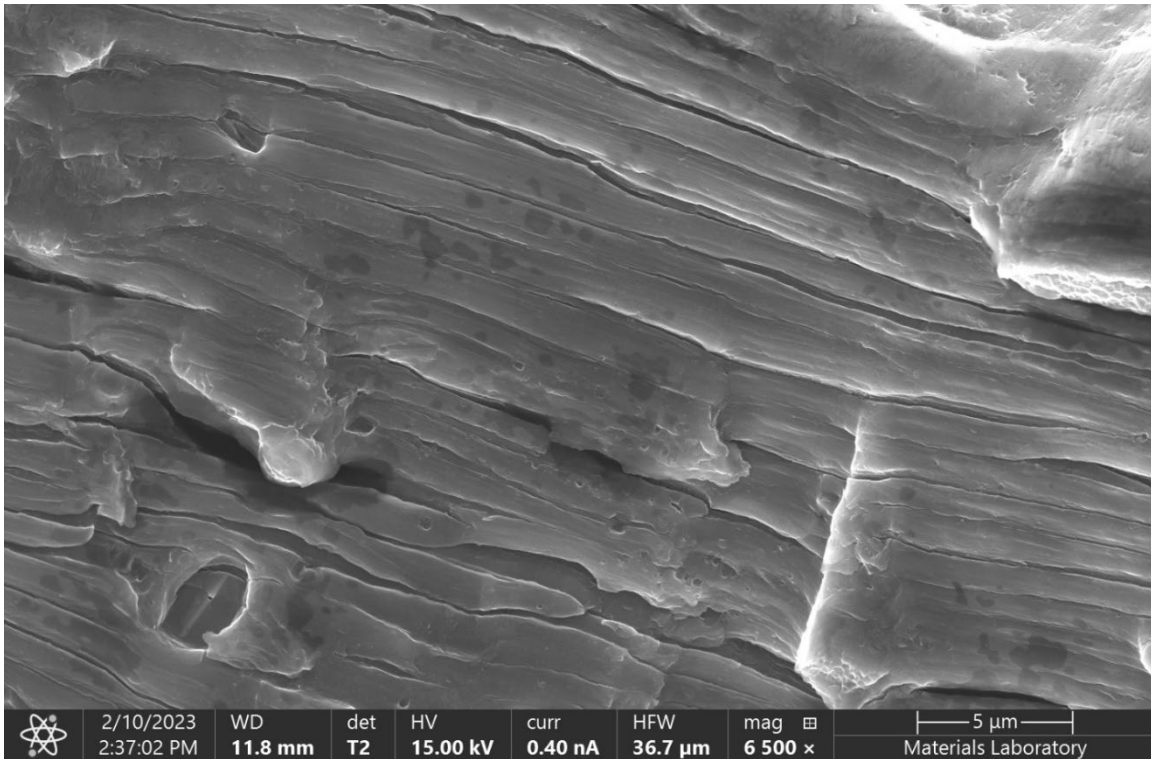


Figure 14. Secondary electron (SE) micrograph showing fatigue striations in the progressive cracking portion of the fracture surface.

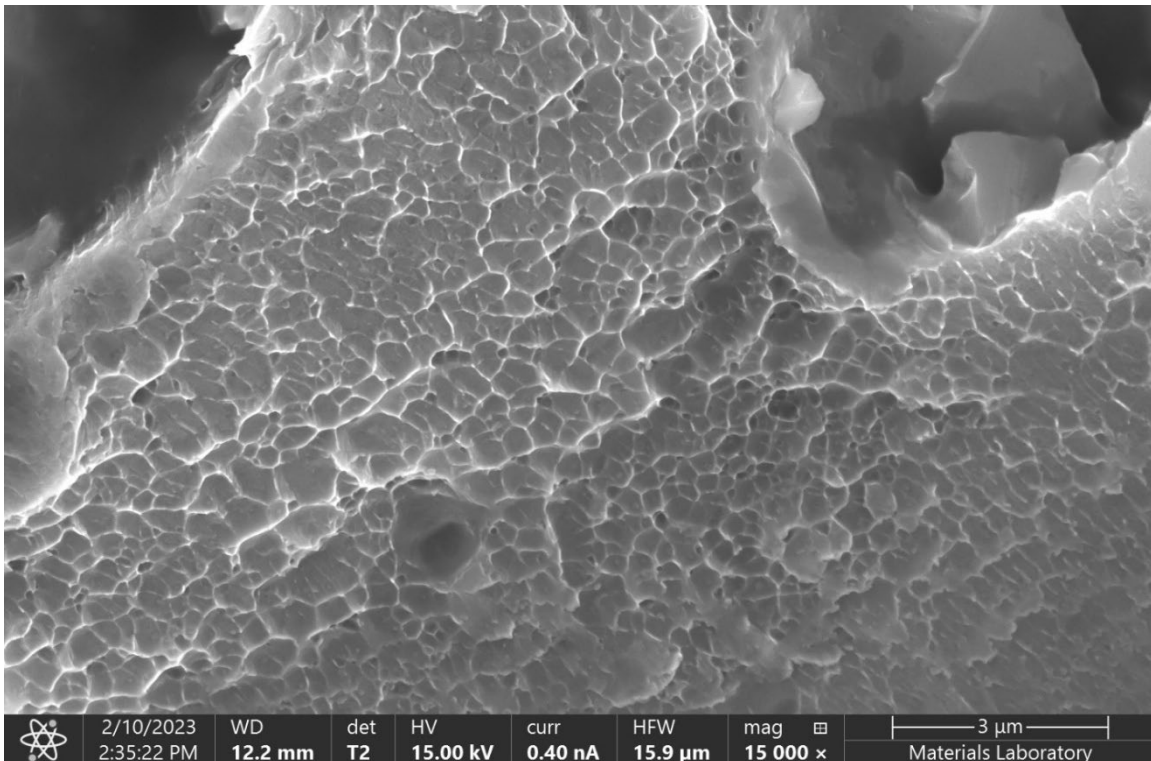


Figure 15. SE micrograph of dimpled rupture in the area outside the primary fatigue crack.

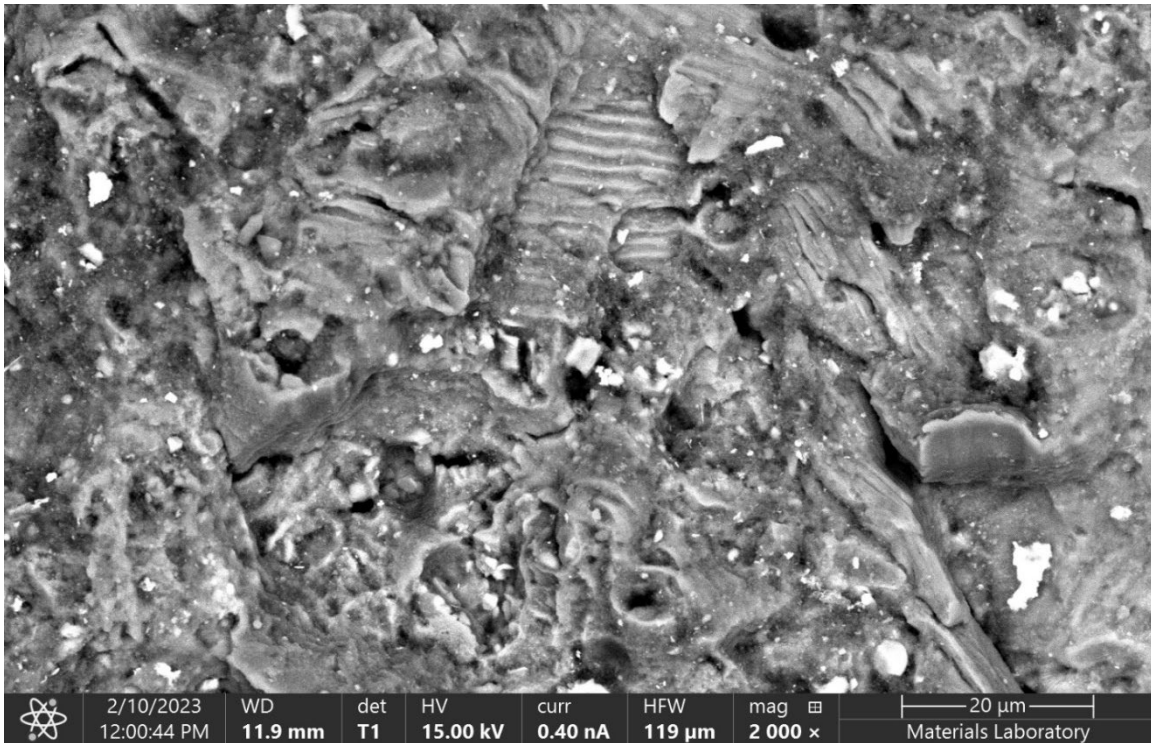


Figure 16. Backscattered electron (BE) micrograph of the mixed mode area outside of the primary fatigue crack, showing dimpled rupture and striations.

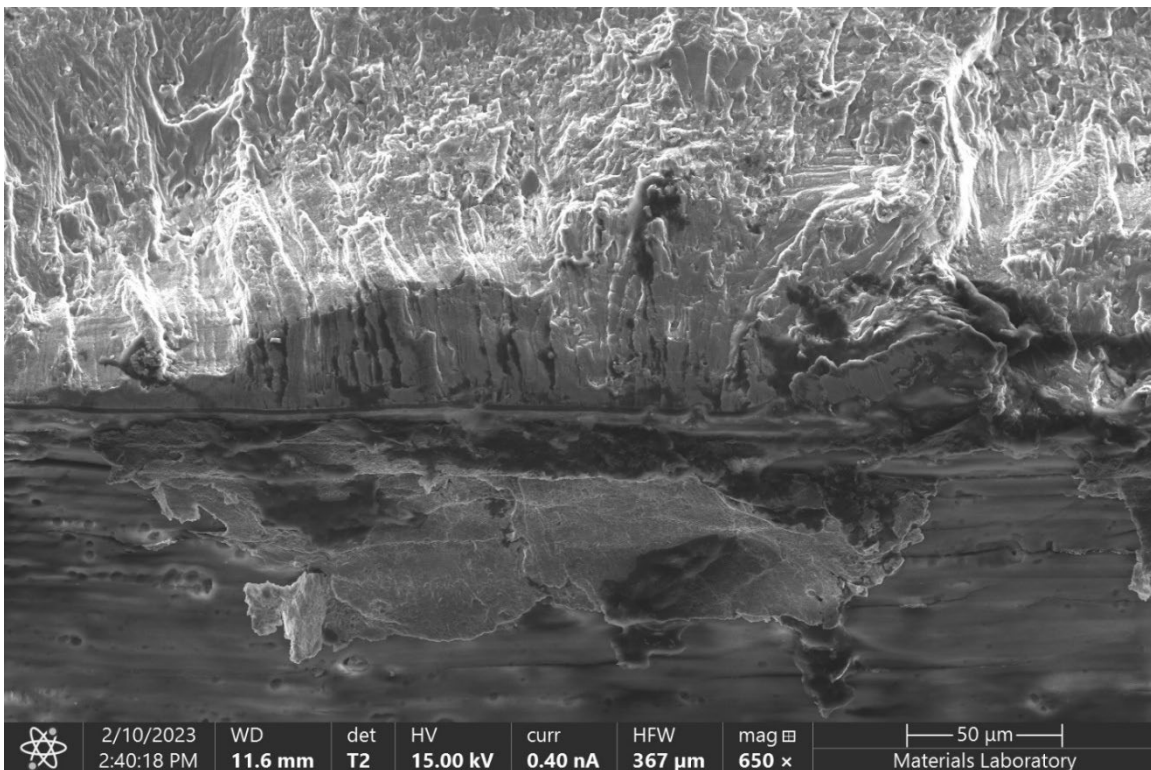


Figure 17. SE micrograph of one of the fatigue crack initiation sites on the cylinder groove.

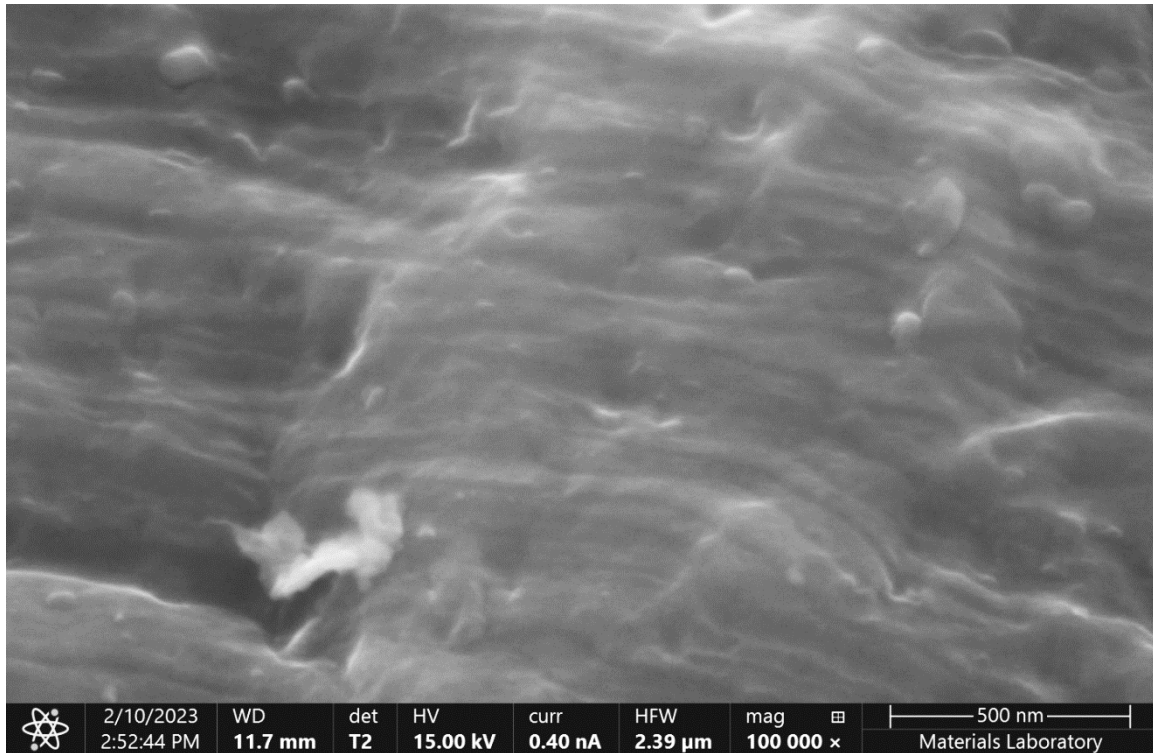


Figure 18. SE micrograph of fine striations near the initiation site in **Figure 17**.

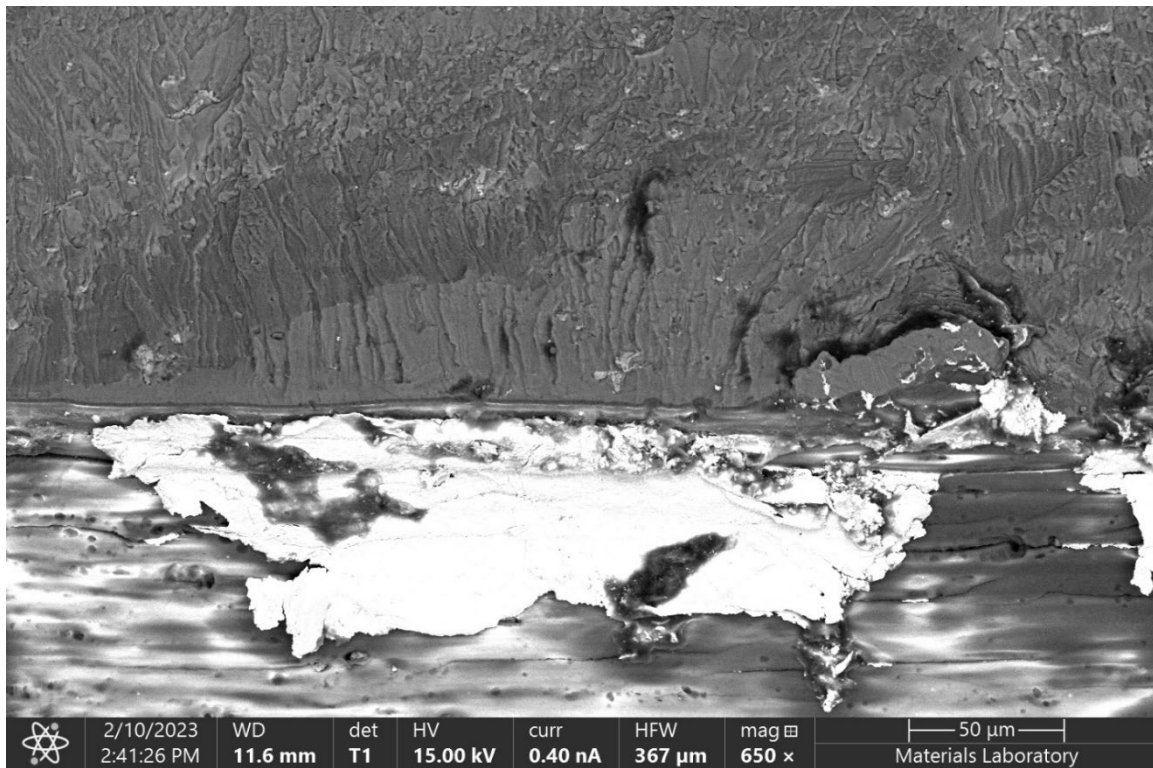


Figure 19. BE micrograph of the initiation site in **Figure 17**, showing a large cadmium-rich (white-colored) area adjacent to the initiation site.

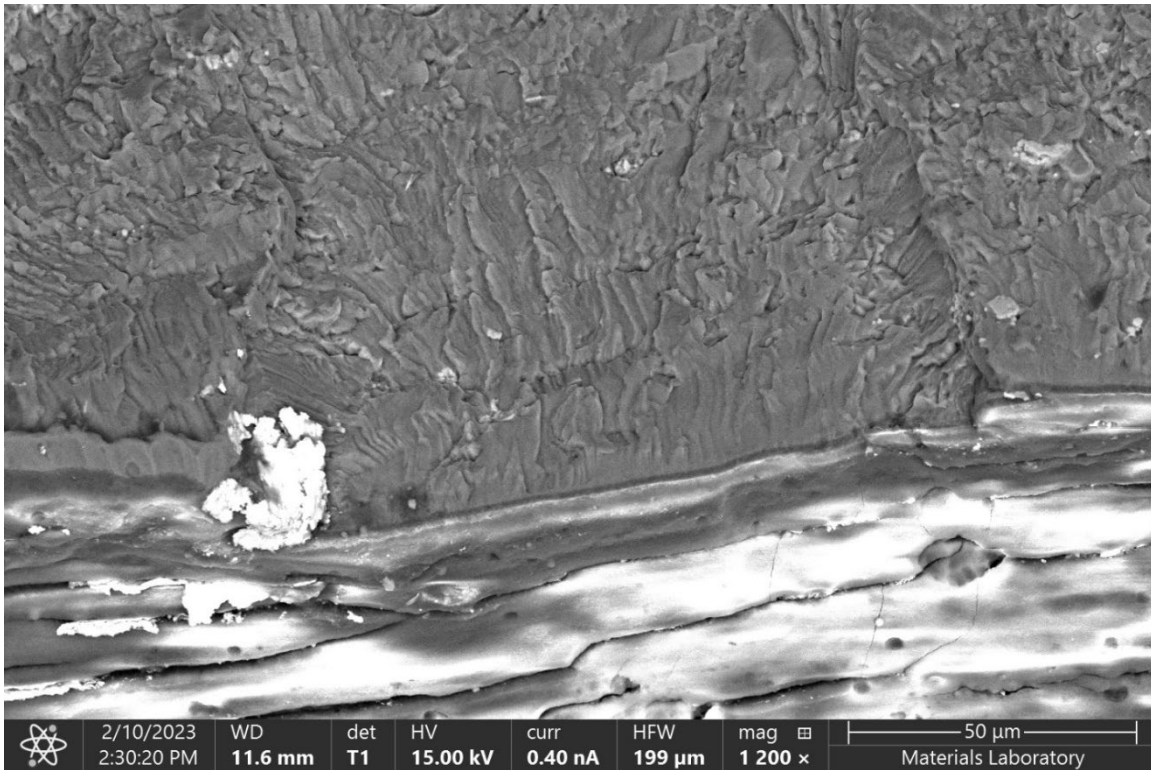


Figure 20. BE micrograph of a second crack initiation site, showing charging (nonconductive) compounds along the groove.

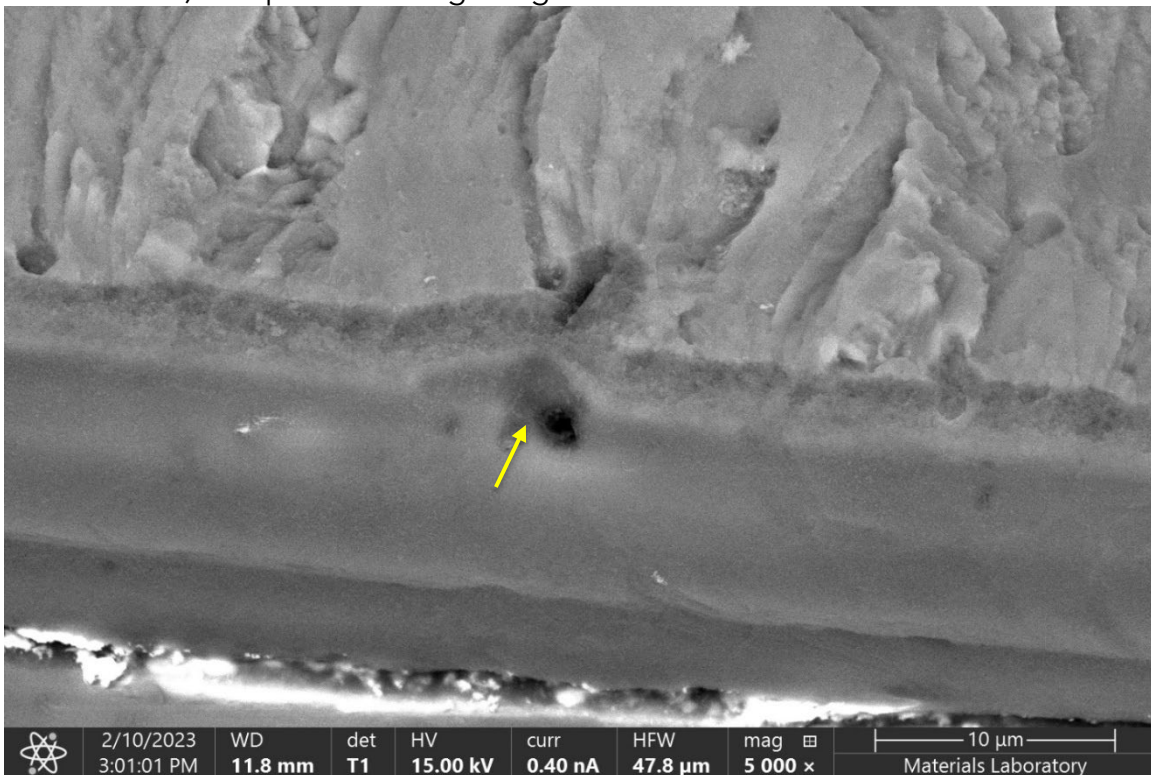


Figure 21. BE micrograph of the initiation site edge, showing a small groove with lower Z-contrast (arrow).

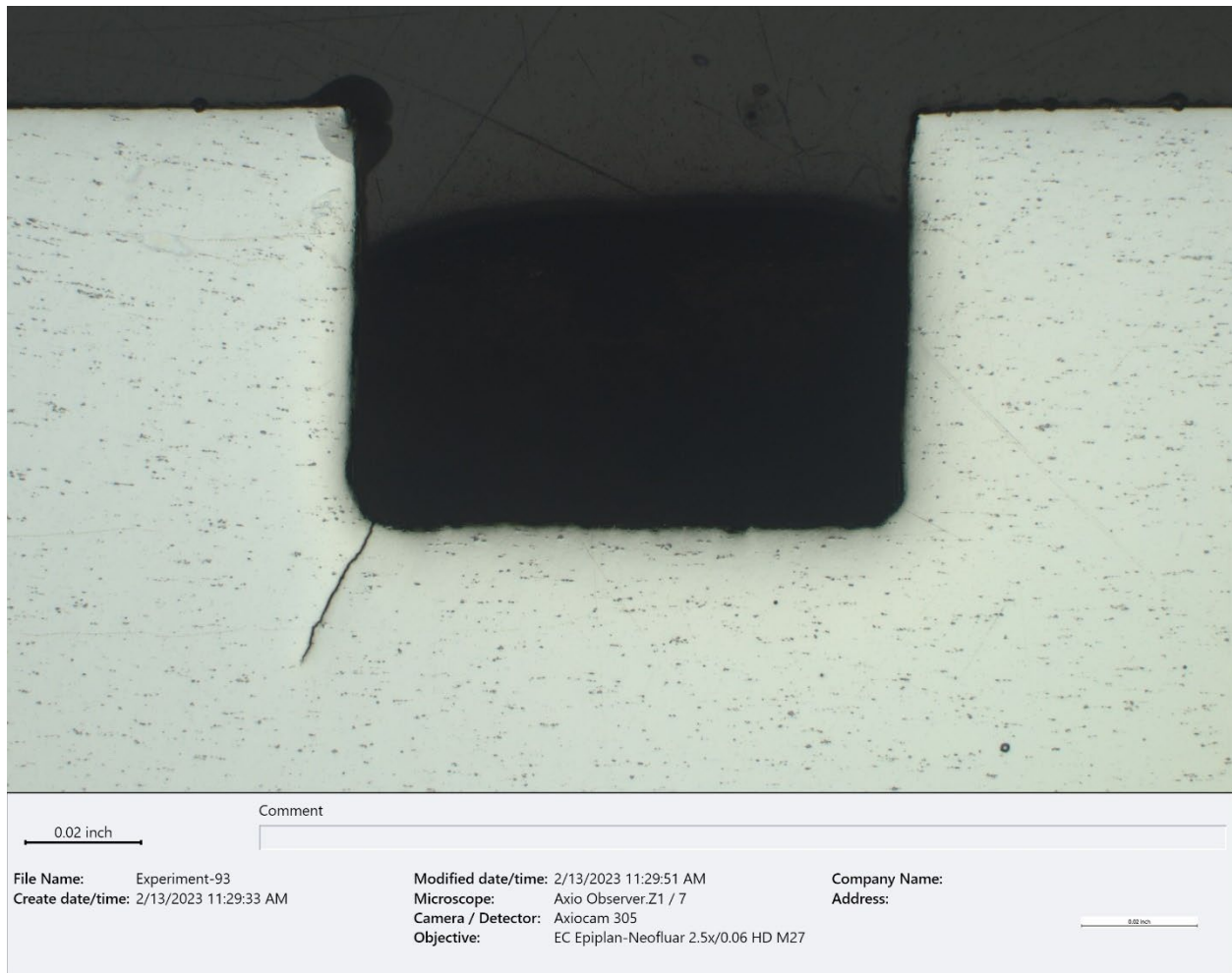


Figure 22. Bright-field (BF) optical metallograph cross-section of the actuator retaining ring showing an angled crack propagating from the left groove radius (~25X, as polished).



Figure 23. BF optical metallograph showing a closer view of the left corner crack from **Figure 22** (~100X, as polished).

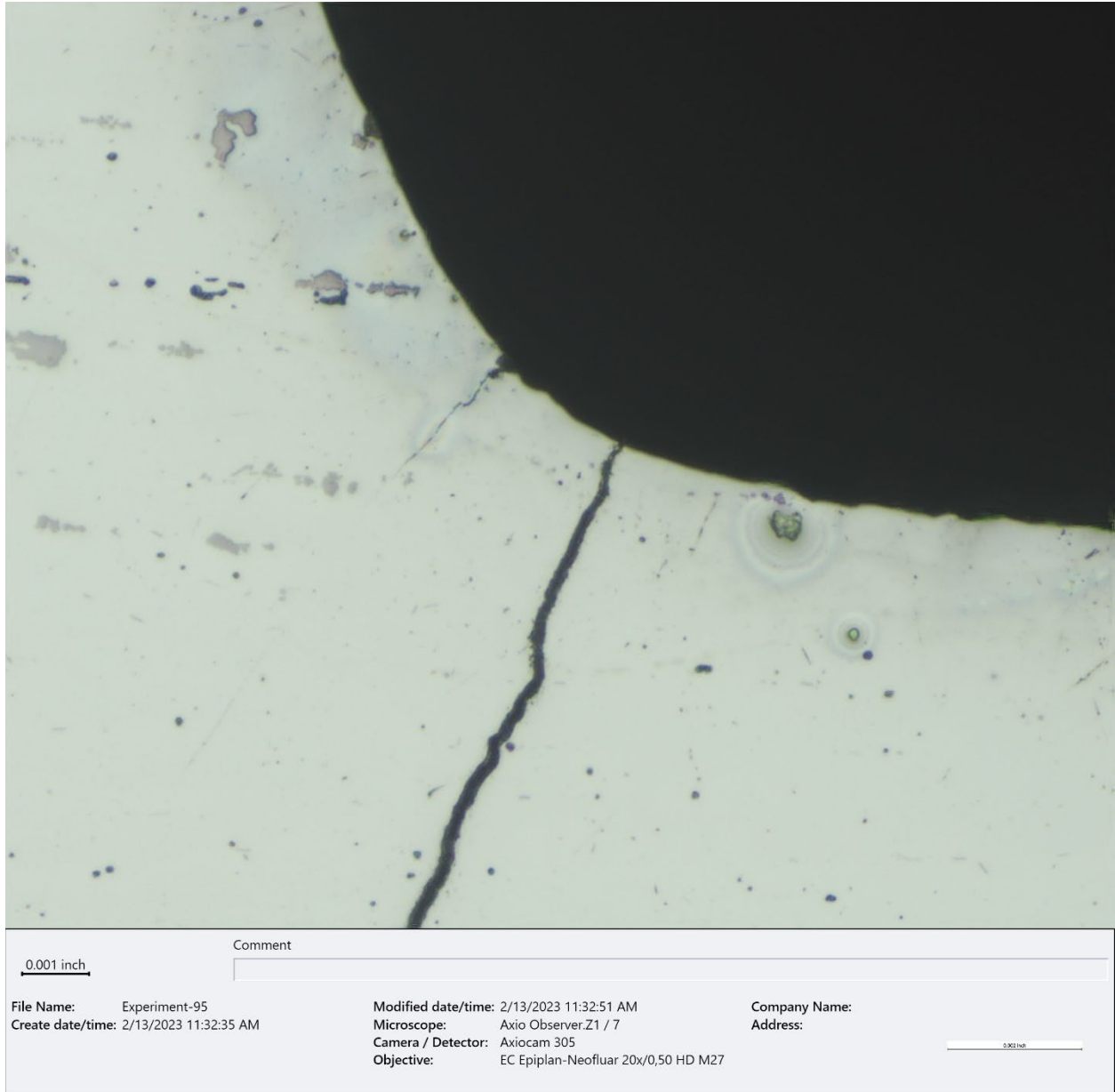


Figure 24. BF optical metallograph showing a closer view of the left corner crack from **Figure 22** (~320X, as polished).