

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN24LA018

MATERIALS LABORATORY

Factual Report 24-006

April 1, 2024

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A. ACCIDENT INFORMATION

Location: Pueblo, Colorado
Date: October 18, 2023
Time: 17:36 mountain daylight time
23:36 coordinated universal time
Vehicle: Cessna 210B, N9597X
Investigator: John Brannen, 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 October 18, 2023, a Cessna 210B airplane was substantially damaged when it was involved in an accident while landing at the Pueblo Municipal Airport (PUB), Pueblo, CO. The pilot was not injured. The pilot reported being unable to retract the landing gear after takeoff. The pilot also reported hearing a pop noise from the rear of the cockpit. Unable to fully extend the landing gear, the pilot eventually attempted an emergency landing at the airport. During the landing, as the main landing gear were in a partially extended position, the airplane skidded to a stop and incurred substantial damage to the left horizontal stabilizer and elevator. The hydraulic actuator from the main landing gear 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:

12693R

The metallic label affixed to the barrel stated:

ELECTROL INC., Kingston, N.Y.
ASSEM. NO. EA1614-2
SERIAL NO. 56

In addition, there were additional stamped markings on the barrel stating the part number was 1280501-2 with 'CODE J0021[]5'—the brackets representing a missing digit due to paint spalling.

The part was cracked about the barrel section adjacent to the endcap, as illustrated in Figure 4. Figure 5 shows the transition from circumferential to a longitudinal crack along the housing barrel. Figure 6 demonstrates the longitudinal section of the crack, which extended along the barrel for 3.1 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. This circlip was removed and the separate pieces are laid out in Figure 7.

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 several thumbnail-shaped cracks, shown in Figure 10. As stated earlier, the length of the thumbnail cracking was 5.847 in long or 299° of the part circumference, illustrated in Figure 11a. The largest crack measured 2.85 inches or 145° of the circumference (Figure 11b). The crack depth was a maximum of 0.116 inches from the retaining ring, with the remaining cross section exhibiting subsequent fracture features. These thumbnail cracks initiated at a corner in the retainer clip groove.

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 shown in Figure 12.

Figure 13 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. Figure 14 shows a closer view of the crack along this groove, with multiple initiation sites identified by yellow arrows. The crack propagation directions are annotated with dashed white arrows.

This fracture surface was examined using a field emission scanning electron microscope (SEM). Figure 15 shows a typical area of the thumbnail crack near the

initiation region in Figure 13 and 14. As shown in this figure and Figure 16, 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 17). 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 18.

The thumbnail-shaped fatigue cracks exhibited ratchet marks, consistent with multiple fatigue crack initiation. Two of these initiation sites are illustrated in Figure 19. Along these initiation sites, small corrosion pits were observed, as exemplified best in Figure 20. Most of the fatigue crack initiation sites along retaining ring groove edge contained pits, such as shown in Figure 20. Figure 22 also revealed the corrosion pit at this site exhibited a darker contrast surface layer in backscattered mode with a small pit-like valley.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 mating fracture surface and circlip groove was also examined, and Figure 23 and 24 show additional cracks along the outboard corner of the groove, which had propagated into the area of the longitudinal crack (denoted by yellow arrows in both figures). These figures show the cracking emanating from the outboard corner of the groove. On the opposite inboard corner of the groove, intermittent cracking was also observed, as illustrated in Figure 25. This layered and discontinuous nature of these cracks were consistent with multiple crack initiation sites, like the fatigue cracking on the outboard fracture surface. Closer views of the inboard crack shows areas of darker, less reflective material (Figure 26). This material was consistent with area of localized corrosion and pitting.

A portion of the actuator housing was cross-sectioned through the clip groove. Figure 27 shows this cross-section after mounting and polishing. Overall, the microstructure exhibited grain flow consistent with wrought material processing. As shown in Figure 27, the angled fracture had propagated out of the lower right (outboard) corner of the groove. Figure 28 shows closer views of this cross section of the groove floor. Typical of the initiation sites on the fracture and inboard crack, there

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.

were small corrosion pits present, 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 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 90 HRBW. The electrical conductivity of the housing was tested per ASTM E1004.³ The conductivity averaged 34.0 %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.

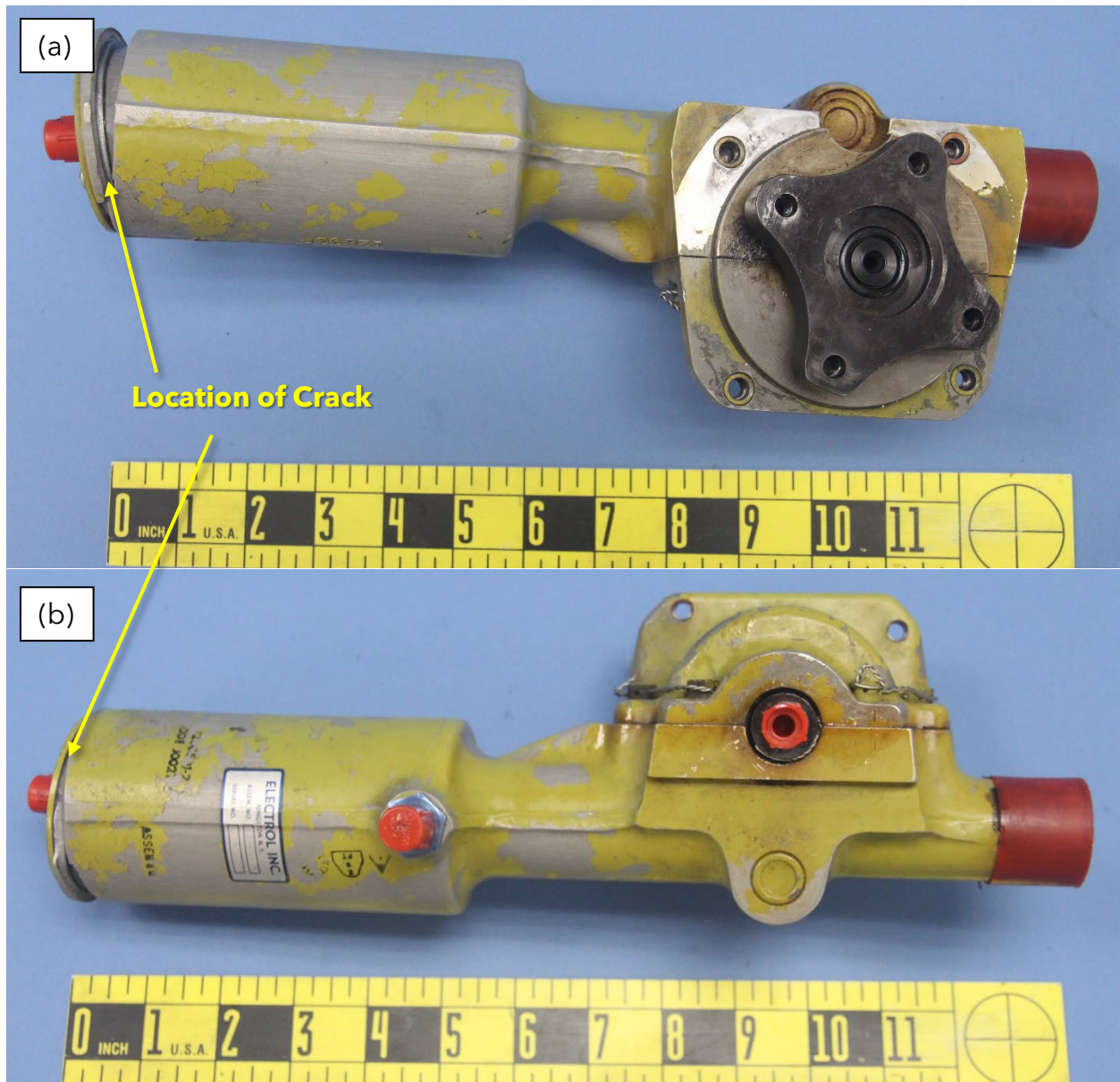


Figure 1. The hydraulic actuator, as received.

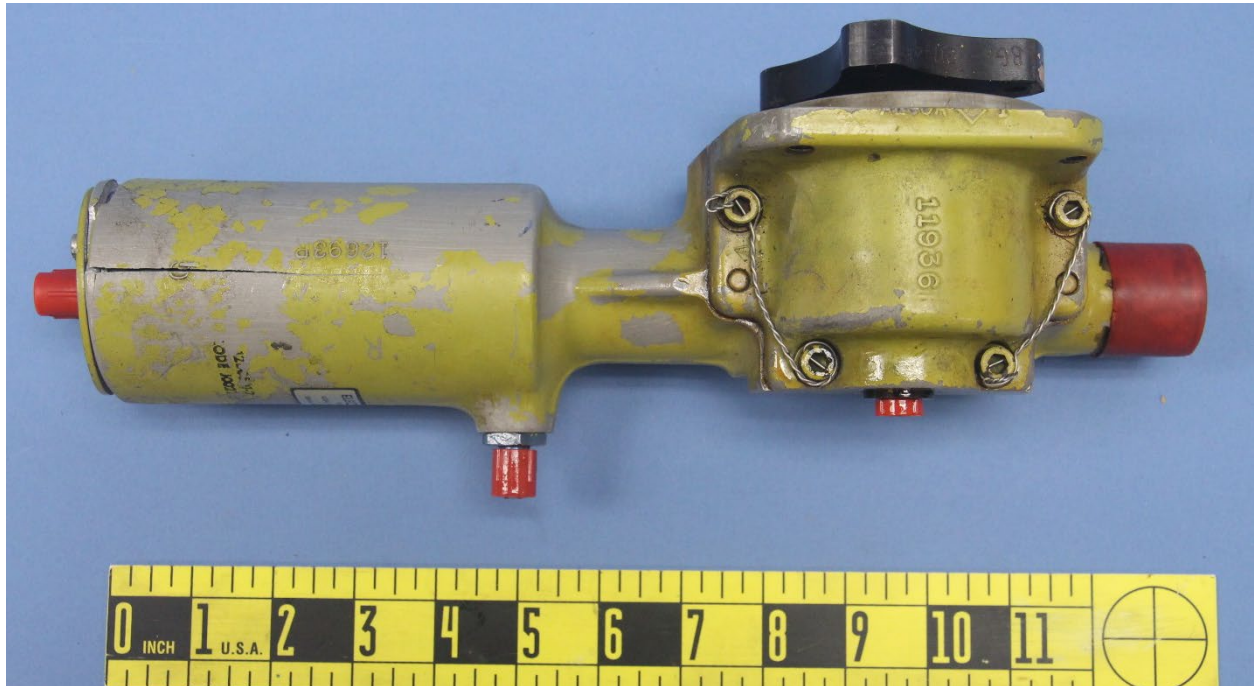


Figure 2. View of the hydraulic actuator, viewed opposite that in Figure 1b. This shows the longitudinal crack on the housing barrel.



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

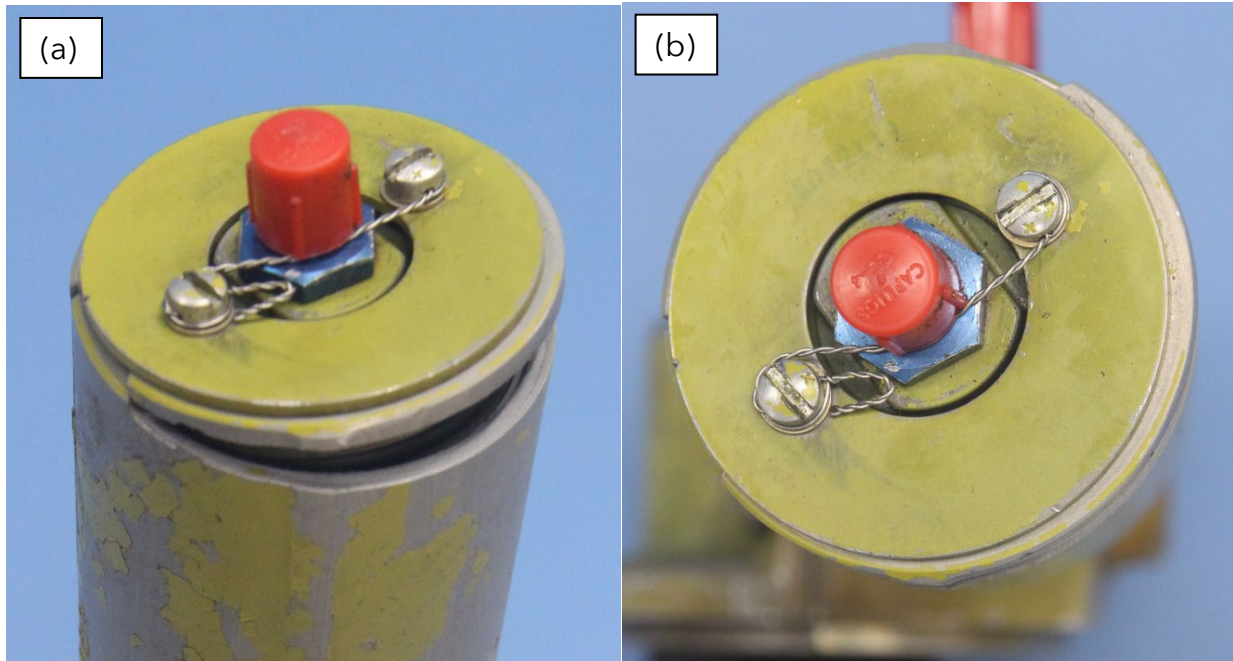


Figure 4. The end of the hydraulic actuator, showing the circumferential portion of the crack.

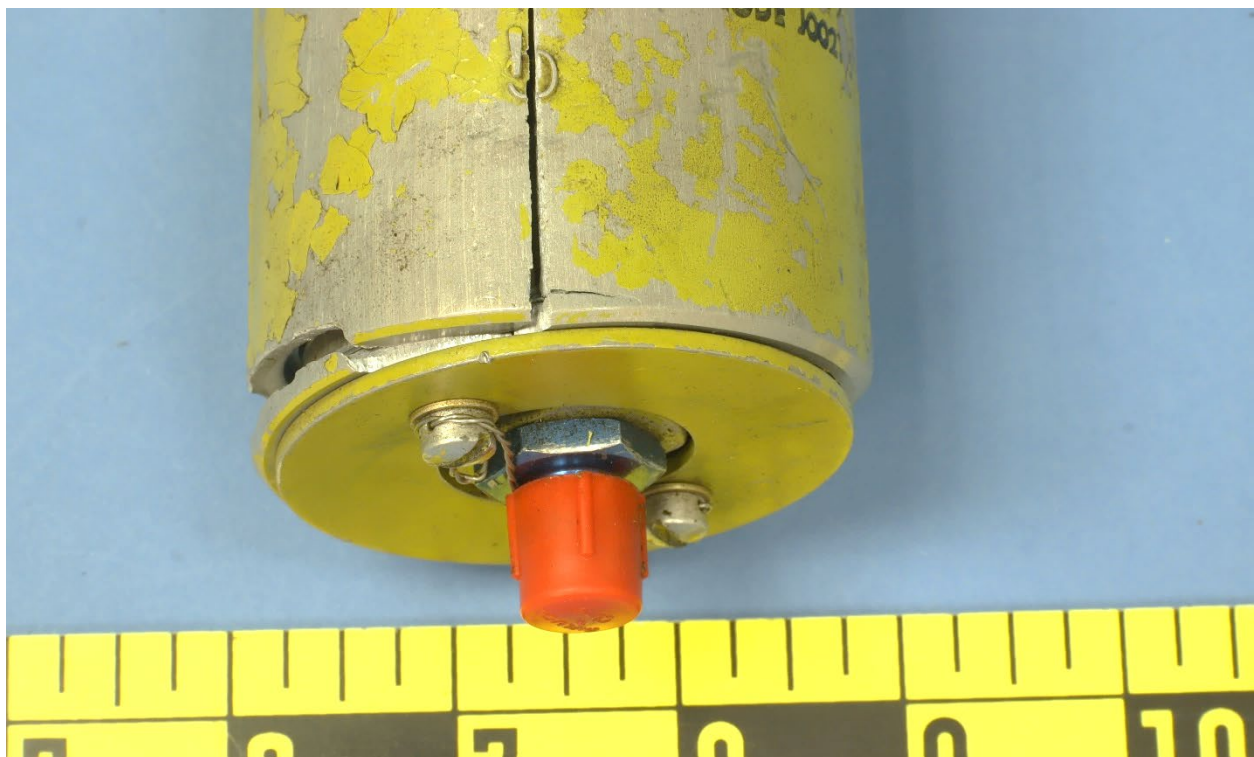


Figure 5. The longitudinal crack on the actuator housing, emanating from the circumferential crack (opposite the view in Figure 4a).

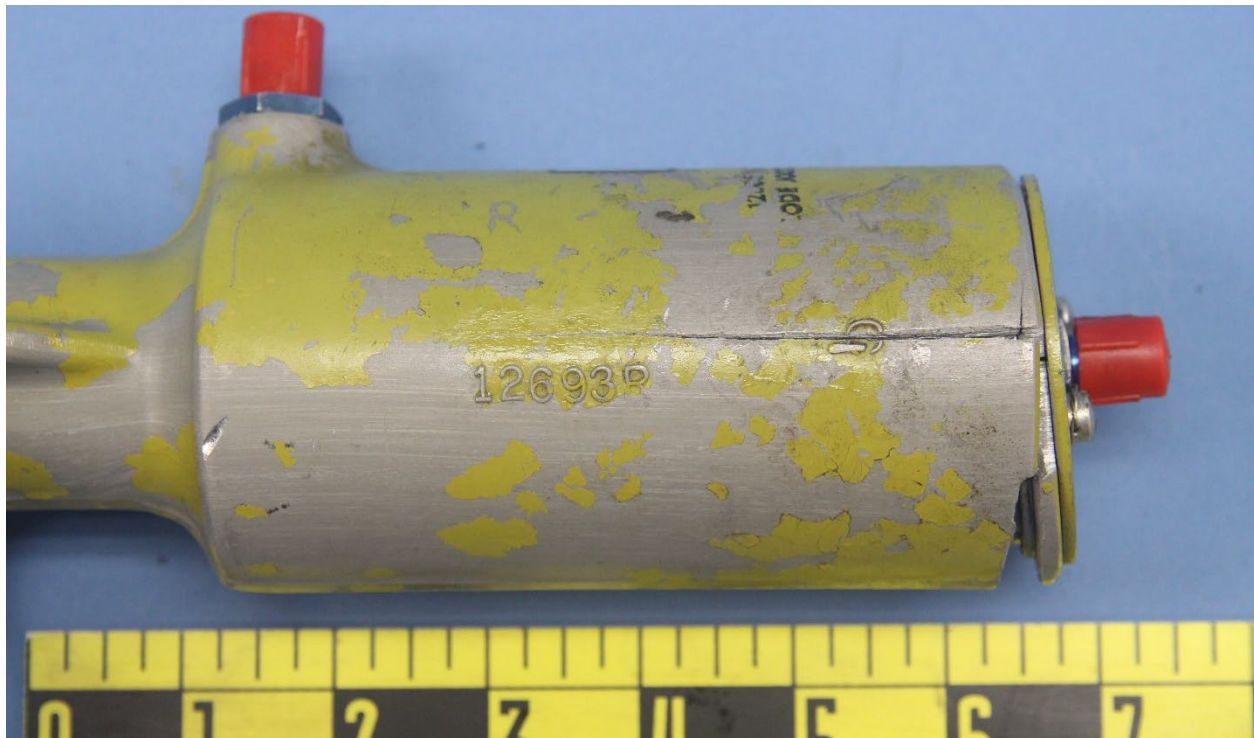


Figure 6. The longitudinal crack along the actuator housing barrel.



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.

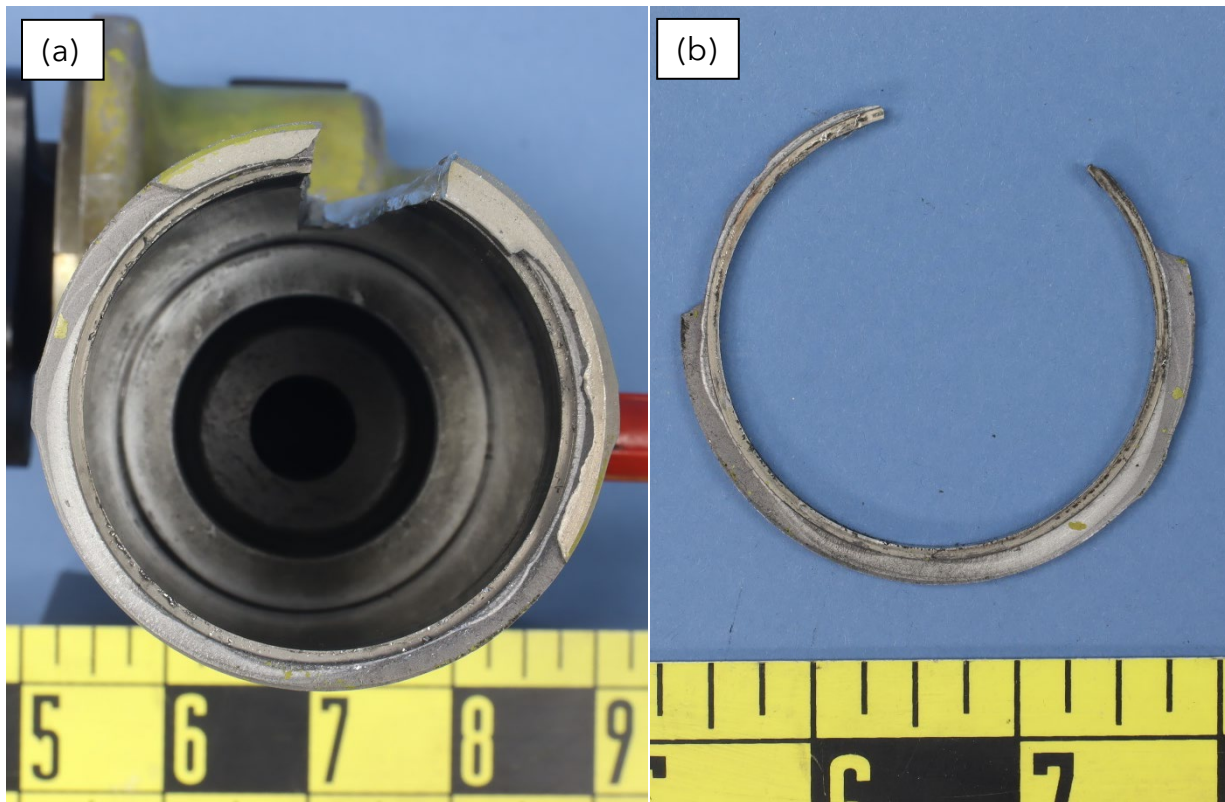


Figure 9. The mating faces of the fractured end of the actuator, after sectioning and disassembly.



Figure 10. Montage of magnified images of the crack face of the circumferential crack, showing indications of progressive cracking.

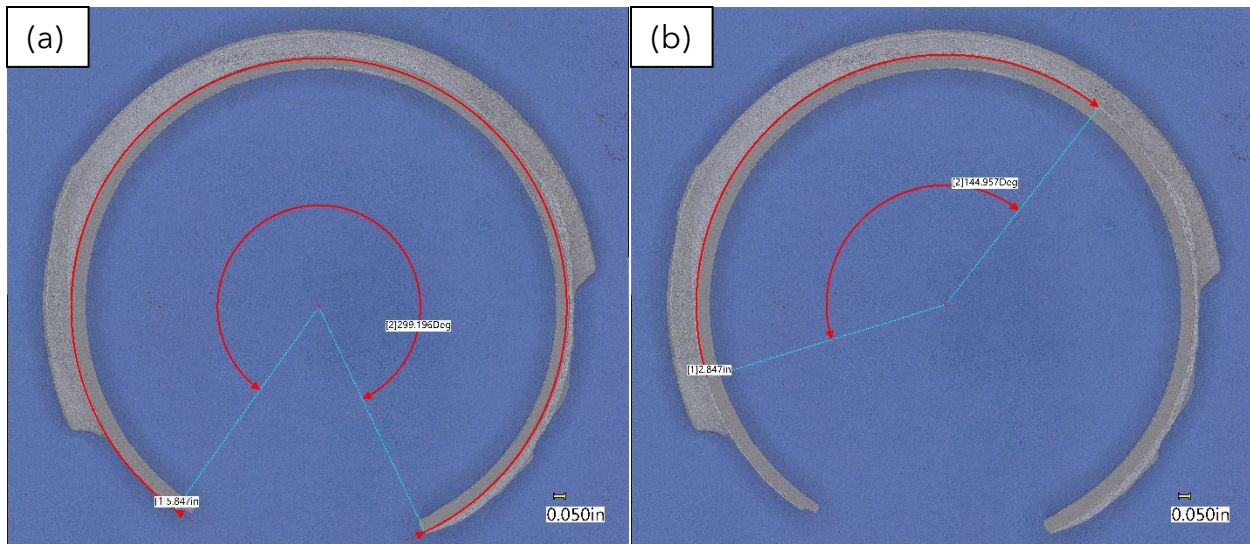


Figure 11. Measured regions of the fatigue cracking in Figure 11, showing (a) the total circumferential length exhibiting pre-existing cracks and (b) the largest crack.



Figure 12. Mating faces of the longitudinal crack, after sectioning to open the crack faces.

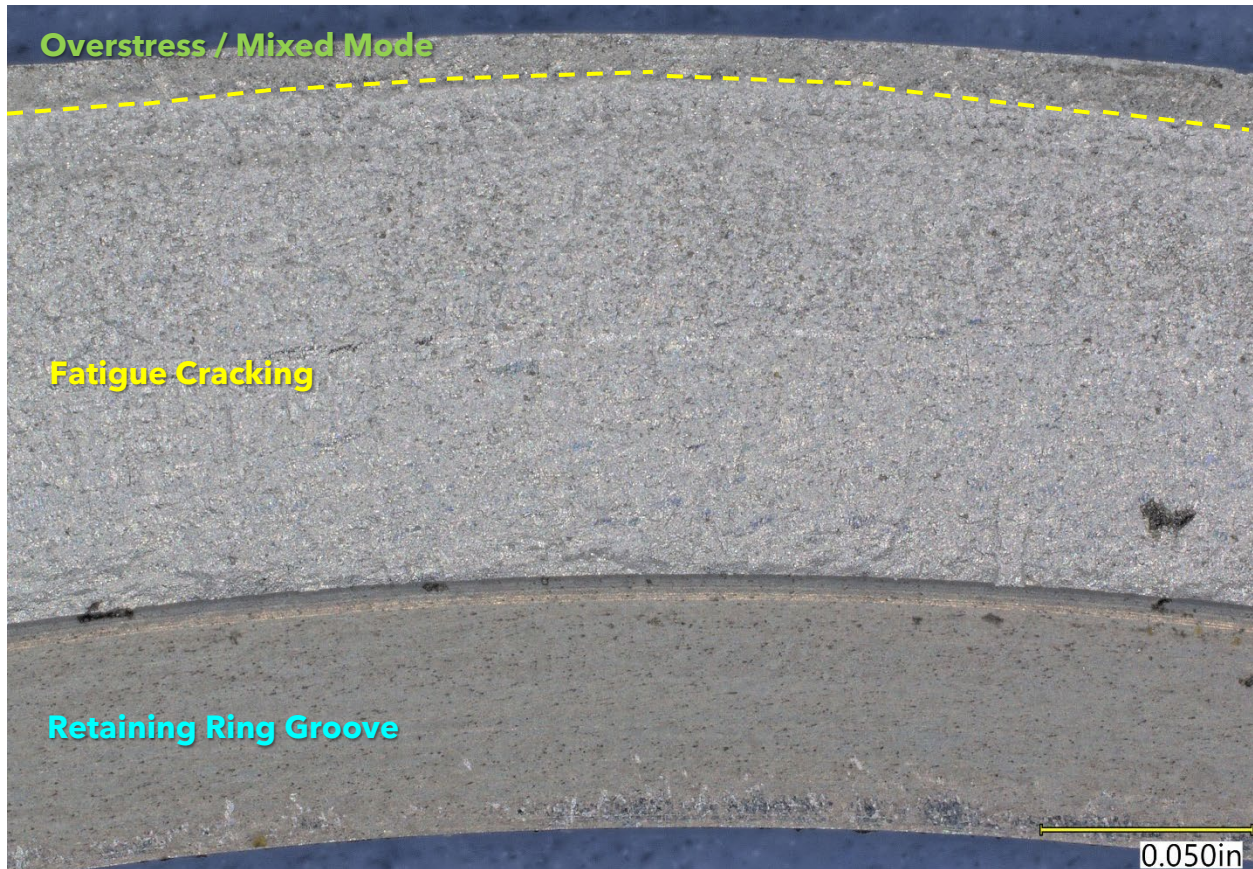


Figure 13. The fatigue crack in Figure 11, showing the area of crack initiation.

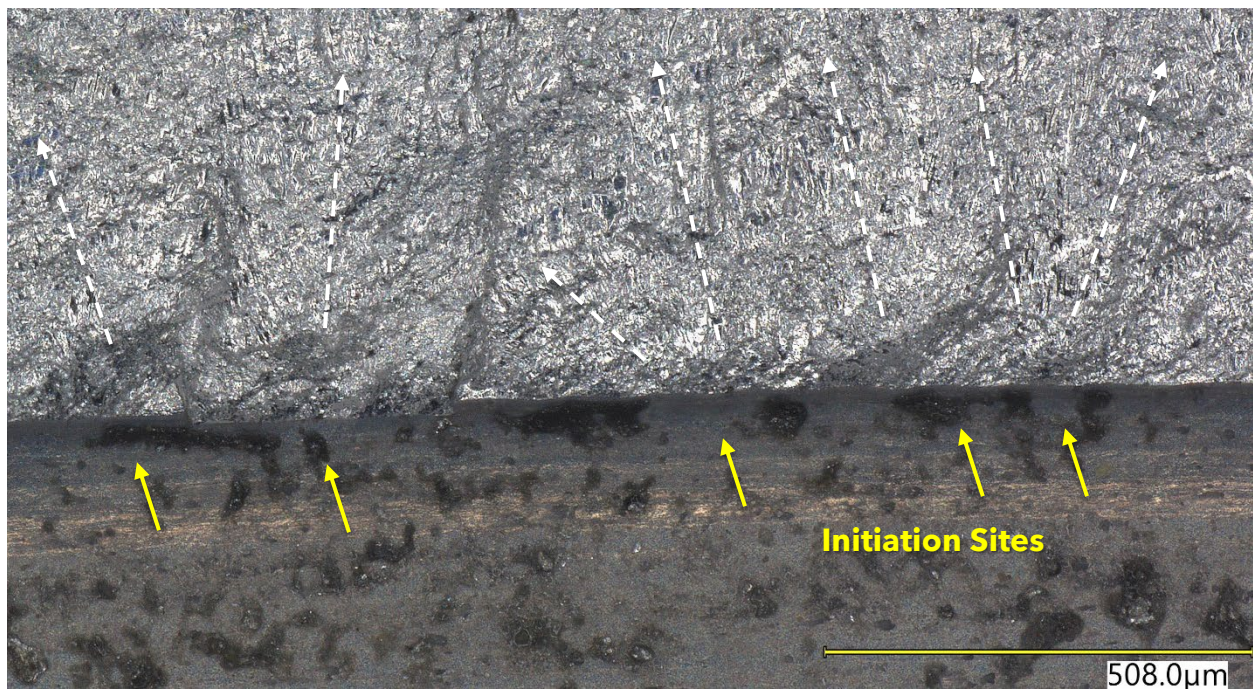


Figure 14. Closer view of the crack initiation area, with some initiation sites identified (yellow arrows) and the local crack growth directions annotated (white arrows).

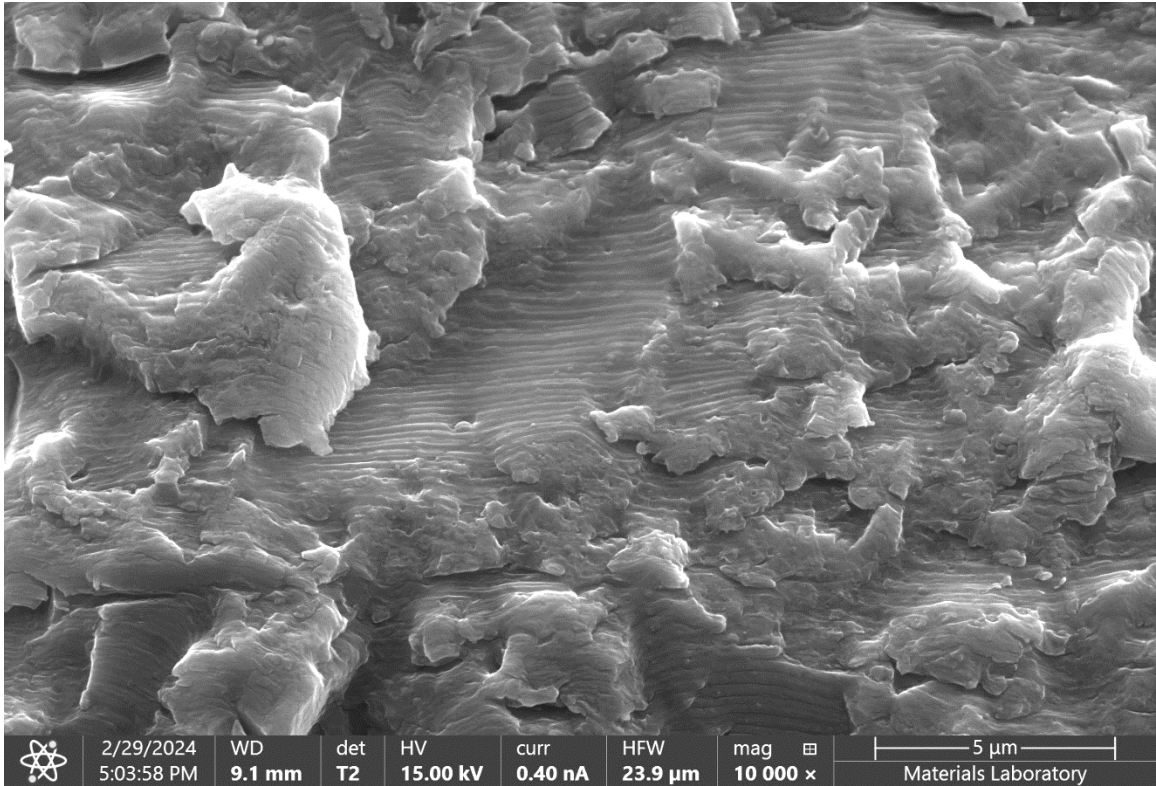


Figure 15. Secondary electron (SE) micrograph of a typical area of the fatigue crack in Figure 13, showing multiple areas of fatigue striations.

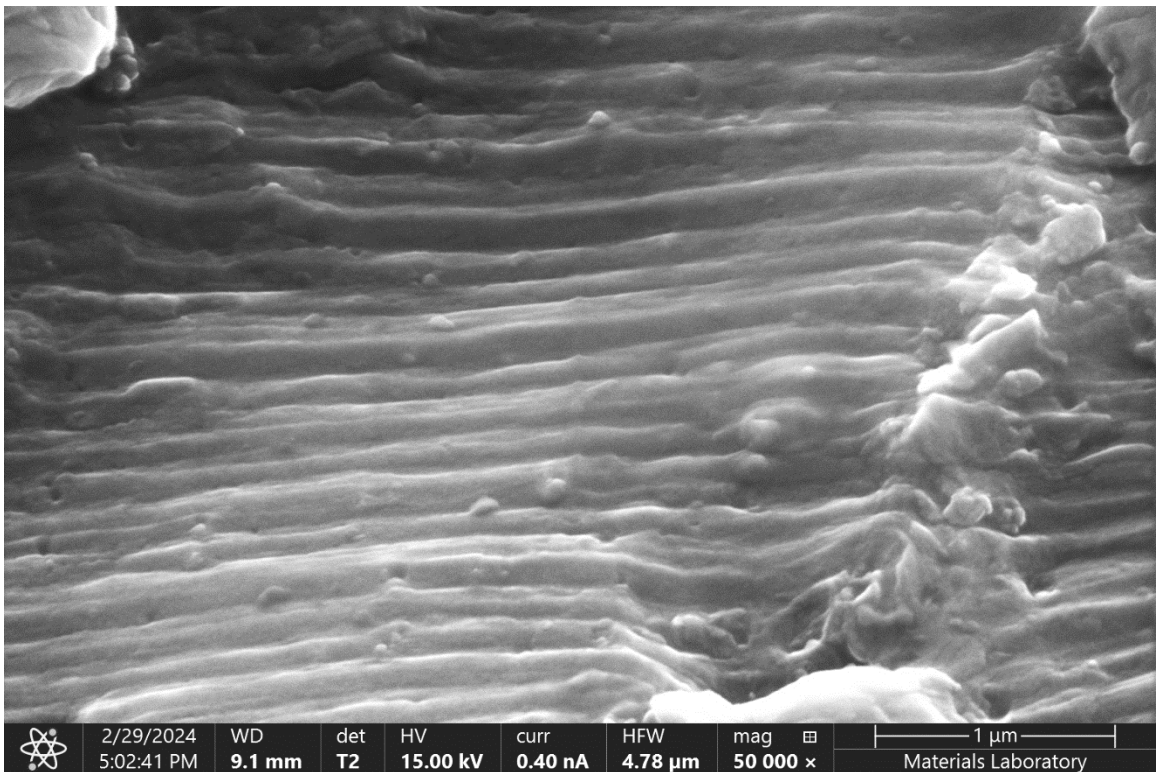


Figure 16. SE micrograph of a closer view of the fatigue striations in Figure 15.

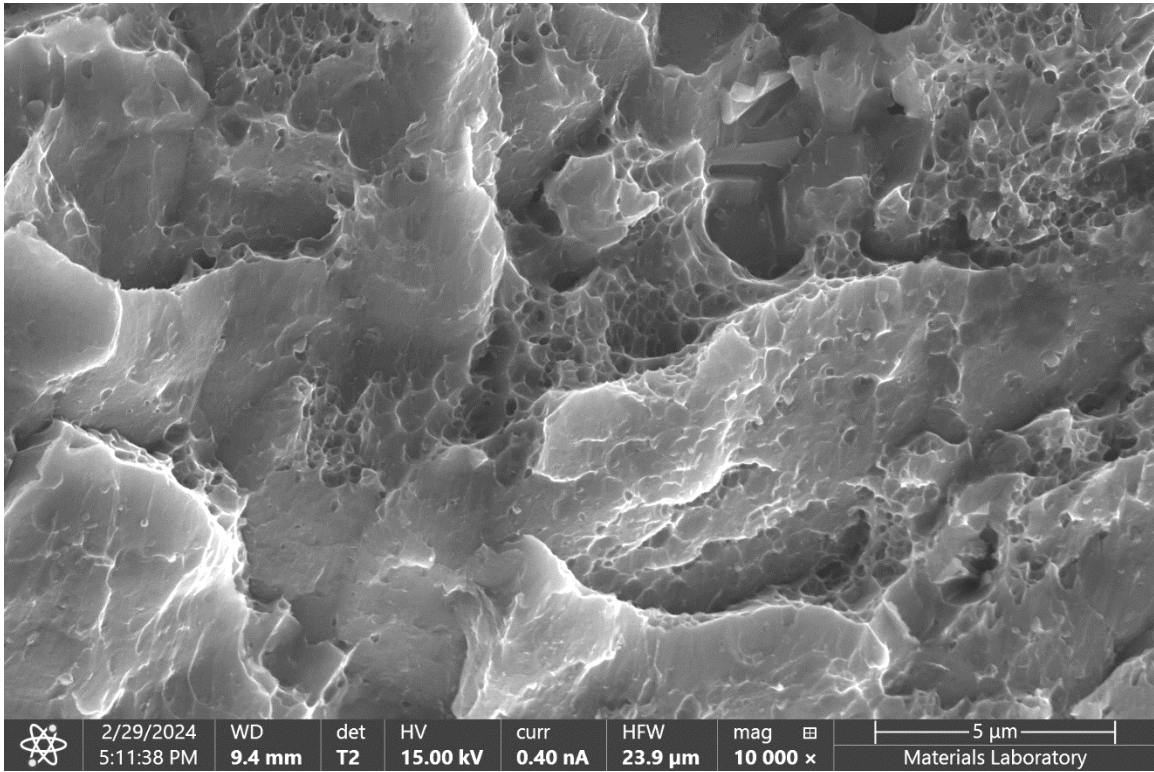


Figure 17. SE micrograph of dimpled rupture in the area outside the primary fatigue crack.

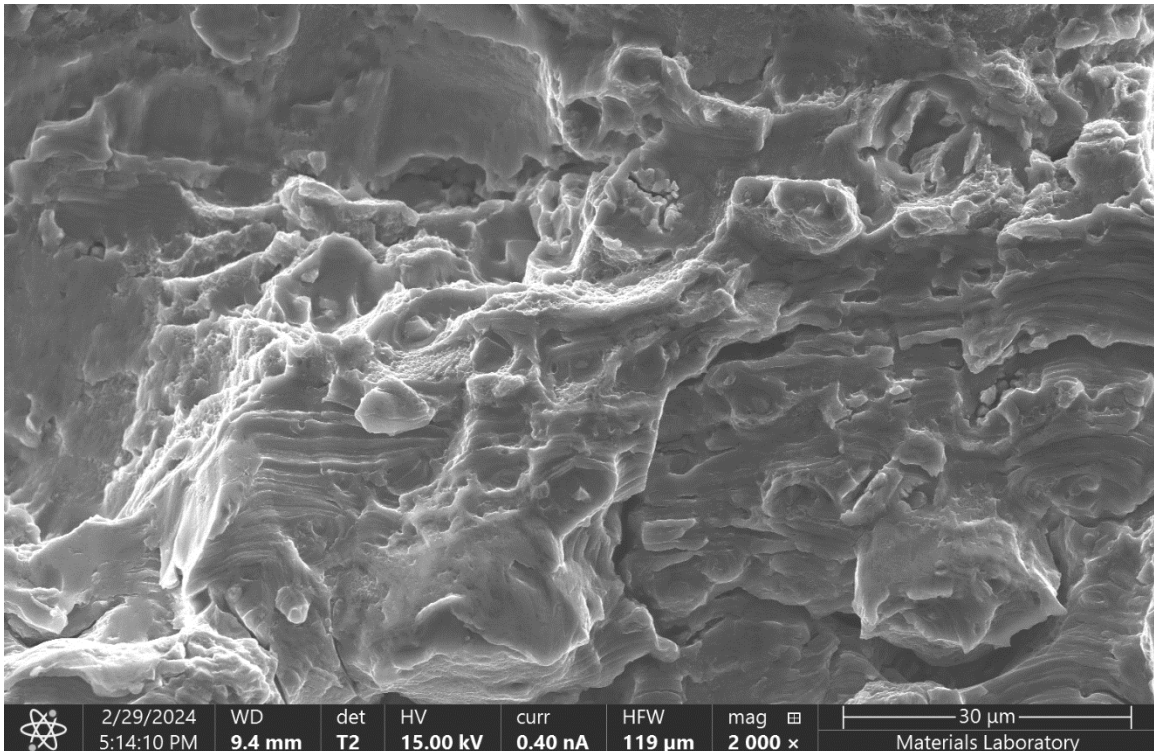


Figure 18. SE micrograph of the mixed mode area outside of the primary fatigue crack, showing dimpled rupture and striations.

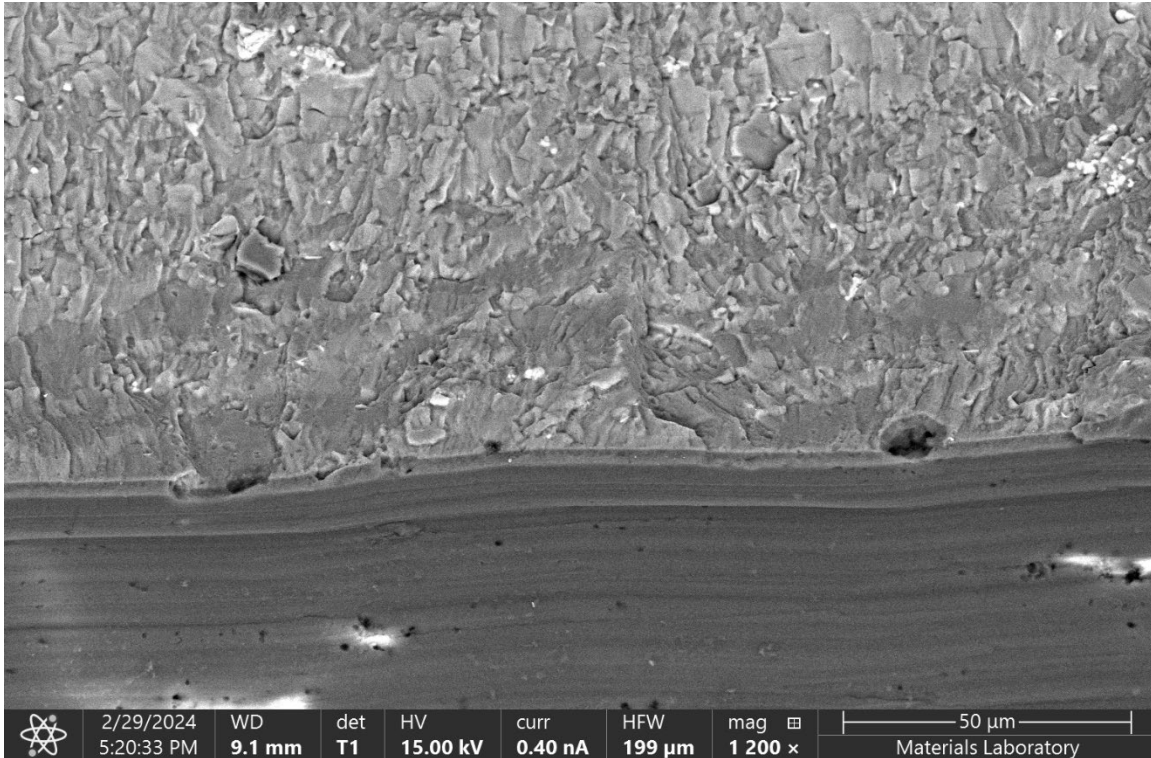


Figure 19. Backscattered electron (BE) micrograph of one of the fatigue crack initiation sites on the cylinder groove.

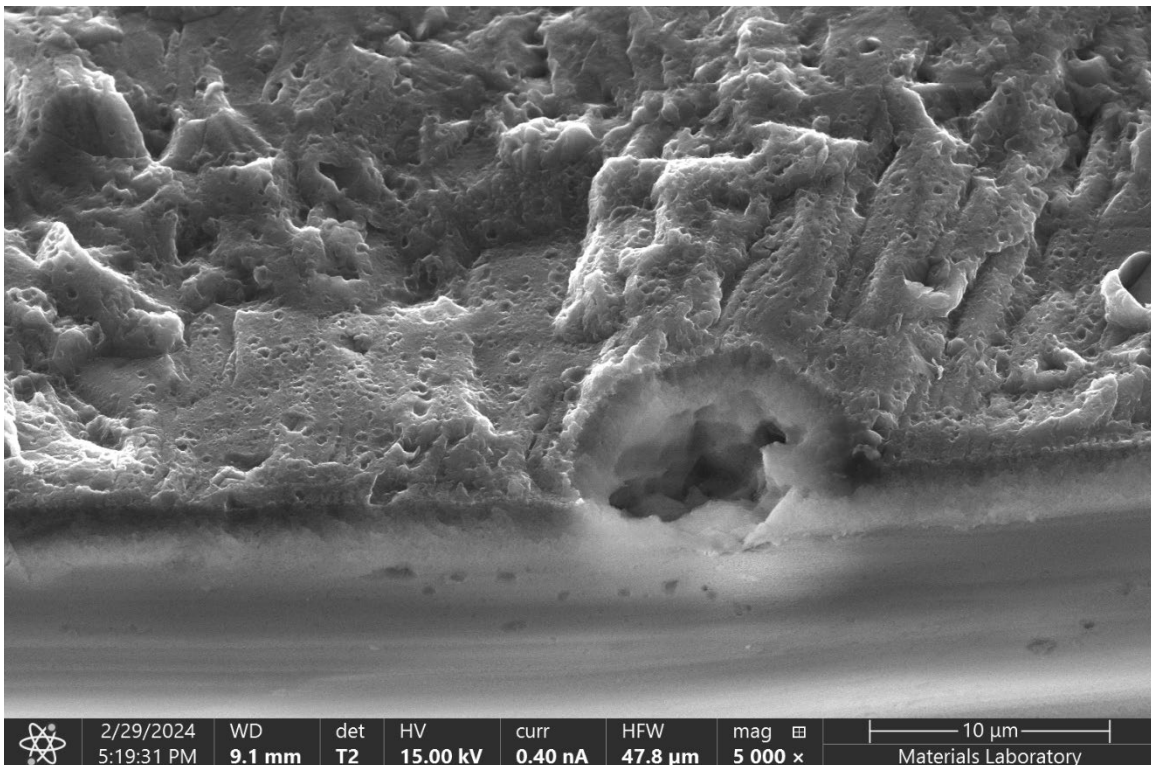


Figure 20. SE micrograph of the corrosion pit at the initiation site in **Figure 19**.

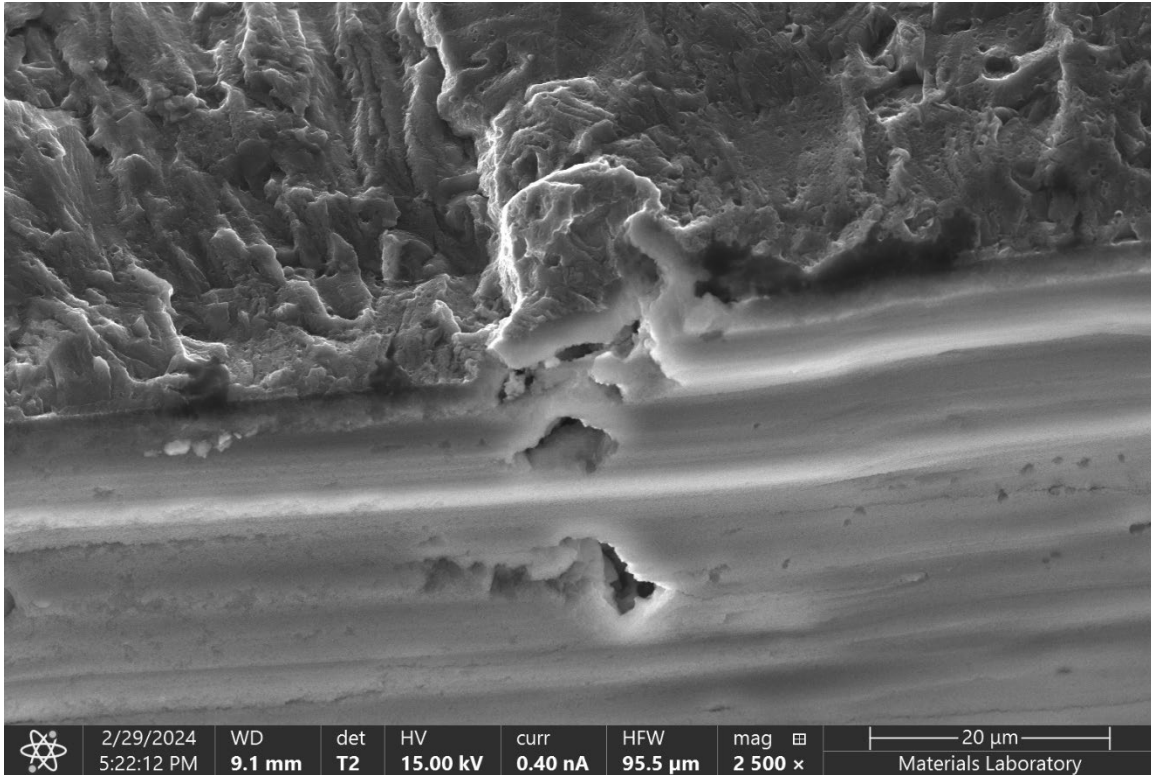


Figure 21. BE micrograph of a second crack initiation site, showing charging (nonconductive) compounds along the groove.

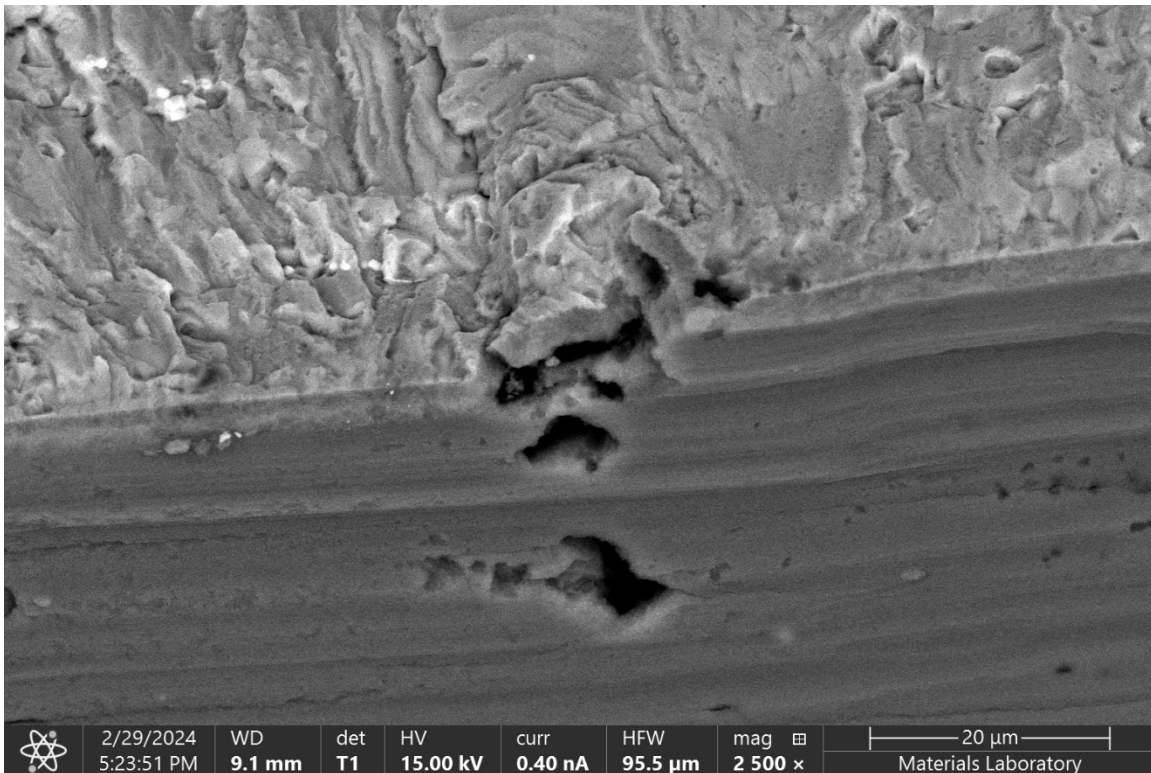


Figure 22. SE micrograph of the initiation site edge, showing a small groove (arrow).



Figure 23. View of the clip groove, showing cracking (arrow) along the corner with the separated mating fracture surface.



Figure 24. View of the secondary crack off the outboard groove corner, opposite angle showed in Figure 25. The crack is identified by the yellow arrow.



Figure 25. Additional cracking along the inboard corner of the groove opposite the fracture surface (lower portion).



Figure 26. Closer view of the inboard corner cracks, collocated with pitting (dark).



Figure 27. 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 28. BF optical metallograph showing a closer view of corrosion pits from the lower groove surface in Figure 27 (~200X, as polished).