

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



WPR24LA134

MATERIALS LABORATORY

Factual Report 25-011

March 19, 2025

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A. ACCIDENT INFORMATION

Location: Tracy, California
Date: April 4, 2024
Time: 10:50 Pacific daylight time
17:50 coordinated universal time
Vehicle: Bell Helicopters 206L-3, N17592
Investigator: Stephen Stein, AS-WPR

B. COMPONENTS EXAMINED

Parts from a collective servo
Cyclic servo

C. EXAMINATION PARTICIPANTS

Specialist	Erik Mueller Office of Research and Engineering – Materials Laboratory Division NTSB, Washington, DC
Party Rep	Henry Trabue Field Investigations Laboratory – MM&P Bell, Fort Worth, TX
Specialist	Peter Kaido Tactair, Liverpool, NY

D. DETAILS OF THE EXAMINATION

On April 23, 2024, a Bell 206 L-3 helicopter was substantially damaged when it was involved in an accident near Tracy, CA. The pilot and passenger were not injured. According to the pilot, during a pipeline inspection they heard a loud pop, followed by a shudder. The helicopter began an uncontrolled descent that the pilot was unable to correct with collective control inputs. At the time, engine power and rotor rpm were normal, and the pilot was able to use cyclic inputs to level the aircraft as it descended to the ground. The helicopter sustained substantial damage to the tailboom. Postaccident photographs of the wreckage revealed that the collective servo actuator assembly was fractured. These fractured collective, and intact cyclic, servo actuator units were sent to the NTSB Materials Laboratory for additional examination.

The collective and cyclic servos' examination by the Materials Group of NTSB investigation CEN23LA232 occurred at the 5th-floor materials laboratory at NTSB headquarters in Washington, DC, on Tuesday, September 17, and Wednesday, September 18, 2024.

Figure 1 and Figure 2 show the two servos from the accident helicopter, as received. The bottom servo in the figures is connected to the collective system and had fractured in two locations along the upper and lower legs of the arm (see Figure 3 through Figure 5). The top servo in Figure 1 was from the left cyclic control system and was used as an exemplar for the examination. The arm of this servo was intact.

Figure 3 and Figure 4 show the two fracture locations of the collective servo arm. Both fractures were relatively flat and oriented 90° relative to the longitudinal direction of each leg. The fractures were also located near the radii at each end of the opening in the middle of the arm. The bottom leg fracture surface was next to the side with the two aft fisheye bearings (on the left in the figures), whereas the fracture surface on the upper leg was towards the main servo body, approximately 0.5 inches from the arm end, or 0.25 inches from the radius.

In both cases, the cracks on the fracture surfaces had propagated from the interior surfaces outward, as denoted by the red dashed arrows in Figure 4. Figure 4 also illustrates the various thicknesses of the fractured legs of the arm (in yellow), as well as the widths (in white). The fractured surfaces, annotated in Figure 4, are shown in Figure 5. This figure depicts the fracture surfaces on the aft arm fragment. Figure 6 shows an angled view of the forward fragment of the collective servo arm.

Figure 7 and Figure 8 show the two servo arm fragments positioned in a way that demonstrates out-of-plane displacement or deformation. Figure 7 shows the displacements between the upper and lower legs of the aft arm fragment are also annotated in Figure 7. Figure 8a shows a top-down view of the forward collective arm fragment, showing a bend of approximately 1° or 0.050 inches (towards the up direction on the left in the figure). The side view in Figure 8b also exhibited an upward bend. Figure 8a also shows a vertically oriented linear witness mark located at the edge of the piston in Figure 8b.

Figure 9 shows the fractured collective servo arm after removal from the rest of the assembly and cleaning in an ultrasonic bath with acetone. Both legs exhibited out-of-plane bending in the upward direction, as shown on opposite sides in the figure. Both arms from the collective and cyclic servos were examined using fluorescent penetrant inspection (FPI). One indication was identified on the upper-facing surface of the lower leg from the collective servo. This indication corresponded with the witness mark shown in Figure 8a. No other indications were observed on the surfaces of either servo arm.

The forward fracture surfaces of the fractured collective servo arm legs were sectioned for microscopic inspection. Figure 10 shows the upper leg fracture surface, which exhibited two thumbnail cracks. These features exhibited crack arrest marks and ratchet marks between each crack. Figure 11 shows the initiation site of the

larger of the two cracks. This area exhibited a darker contrast and concave crack arrest marks emanating from the initiation site at the edge corner. The thumbnail cracks comprised approximately 40% of the fracture surface area, whereas the rest of the fracture surface exhibited a rough, fibrous surface texture with a dull luster.

Figure 12 illustrates the lower leg fracture surface. Much of this surface had been damaged by smearing and streaks, consistent with post-fracture damage to the surface. The fracture surface was not entirely destroyed, and it exhibited a larger area (approximately 80%) of features consistent with crack propagation features than the upper leg surface. Figure 12 shows the general crack propagation direction from the lower right corner toward the left and then back toward the upper right. This cracking initiated at the site shown in Figure 13 and Figure 14. This location contained a prominent corrosion pit, distinguishable by the darker color and lack of yellow-tan anodized layer on the surface.

The fracture surfaces were examined using a field emission scanning electron microscope (SEM). The surfaces were observed before and after cleaning with a chromic acid solution. Figure 15 and Figure 16 show typical features within the thumbnail cracks. These fatigue striations were consistent with fatigue crack propagation. Dimpled rupture was observed outside the fatigue cracking regions (Figure 17). These disparate features were consistent with subsequent overstress fractures of the leg following the end of fatigue crack propagation.

Of note was a partial horizontal ridge about mid-height on the lower leg fracture surface, as seen in Figure 12. Figure 18 shows a closer view of the ridge imaged using an SEM. The area near the ridge, shown in Figure 19, exhibited fine fatigue striations, consistent with crack propagation upward, as depicted by the white dashed arrows in the figure. This propagation direction was consistent with that of the fatigue crack from the primary crack initiation site. The area above the ridge, as illustrated in Figure 20, exhibited more widely spaced fatigue striations, propagating from left to right in the figure. This was consistent with the later crack propagation direction annotated in Figure 12.

Figure 21 shows the primary crack initiation site on the lower leg fracture surface after subsequently more aggressive cleaning steps. Both figures show the extent to which lower atomic number (Z) compounds were present in this region.¹ Figure 22 shows an angled view, illustrating the darker gray surface anodized layer and a depression at the initiation site, consistent with a corrosion pit. Figure 23 illustrates a closer look at the corrosion pit at the crack initiation site, which exhibited darker-contrasting

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

compounds, which were typically blocky in shape with multiple cracks. The corrosion pit measured 1.1 mm wide by 0.34 mm deep (0.043 by 0.013 inches).

As illustrated in Figure 24 and Figure 25, the blocky features at the edge of the corrosion pit served as individual initiation sites for multiple fatigue cracks, separated by small ratchet marks. These cracks coalesced during the initial propagation stage, exemplified by the striations and termination of the ratchet marks.

Figure 26 highlights the darker-contrasting blocky compounds at the tip of the corrosion pit in Figure 23. These compounds were examined using energy dispersive x-ray spectroscopy (EDS). As typified in Figure 27, the compounds were consistent with aluminum oxide. There were also elements consistent with corrosion products in a marine environment, namely sodium, potassium, calcium, chlorine, and sulfur. There was an elevated amount of chlorine in the deepest regions of the pit, located in the upper part of the pit depicted in Figure 26.

The base material of the servo arm was also examined using EDS, as well as x-ray fluorescence (XRF). Figure 28 shows a typical EDS spectrum of the alloy, which was consistent with a 7075 aluminum alloy composition. Electrical conductivity was examined per ASTM E1004.² The conductivity averaged 39.2% IACS. The hardness was inspected per ASTM E18.³ The hardness averaged 84 HRBW. These data were consistent with a T73 temper for this alloy, per AMS 2658.⁴ A 7075-T73 aluminum alloy was the prescribed material for the servo arm.

The fracture surface of the upper leg was also examined using an SEM. The two thumbnail cracks exhibited three major initiation regions. Figure 29 and Figure 30 show the crack initiation site for the smaller of the two thumbnail cracks. This site contained a corrosion pit, and fatigue striations were observed emanating from the location (Figure 30).

The larger thumbnail crack on the upper leg fracture surface exhibited a wider corrosion pit at the initiation site (Figure 31). This pit measured 0.30 mm wide by 0.14 mm deep (0.012 inch by 0.0055 inch). The pit exhibited blocky compounds that had crack in multiple places, consistent with localized brittle fracture. Fatigue striations were present near the corrosion pit, showing propagation into the leg cross section away from the surface corrosion pit (Figure 32).

² ASTM E1004 – *Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*. ASTM International, West Conshohocken, PA

³ ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

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

Figure 33 to Figure 35 show the middle crack initiation sites, which consisted of two elongated corrosion pits. This blocky aluminum oxide compound had fractured, as evidenced by multiple cracks. Similar to the initiation site of the lower leg fracture surface, multiple fatigue cracks on the upper leg had initiated along the edges of the blocky corrosion pit tips, creating striations consistent with crack propagation away from the pit on the interior surface (Figure 35).

Examination of the interior surfaces of both servo arm legs away from the fracture surface found areas with numerous corrosion pits, as exemplified in Figure 36. These pits appeared as rough depressions within the surface anodizing coating, as shown in Figure 37. Being non-conductive, the anodizing coating generated charging artifacts during SEM examination, except within the pits, which were absent the coating. The chemical composition was consistent with those near the fatigue crack initiation sites, primarily aluminum oxide with elements associated with salt compounds, similar to those shown in Figure 27.

Submitted by:

Erik M. Mueller
Materials Research Engineer

E. FIGURES

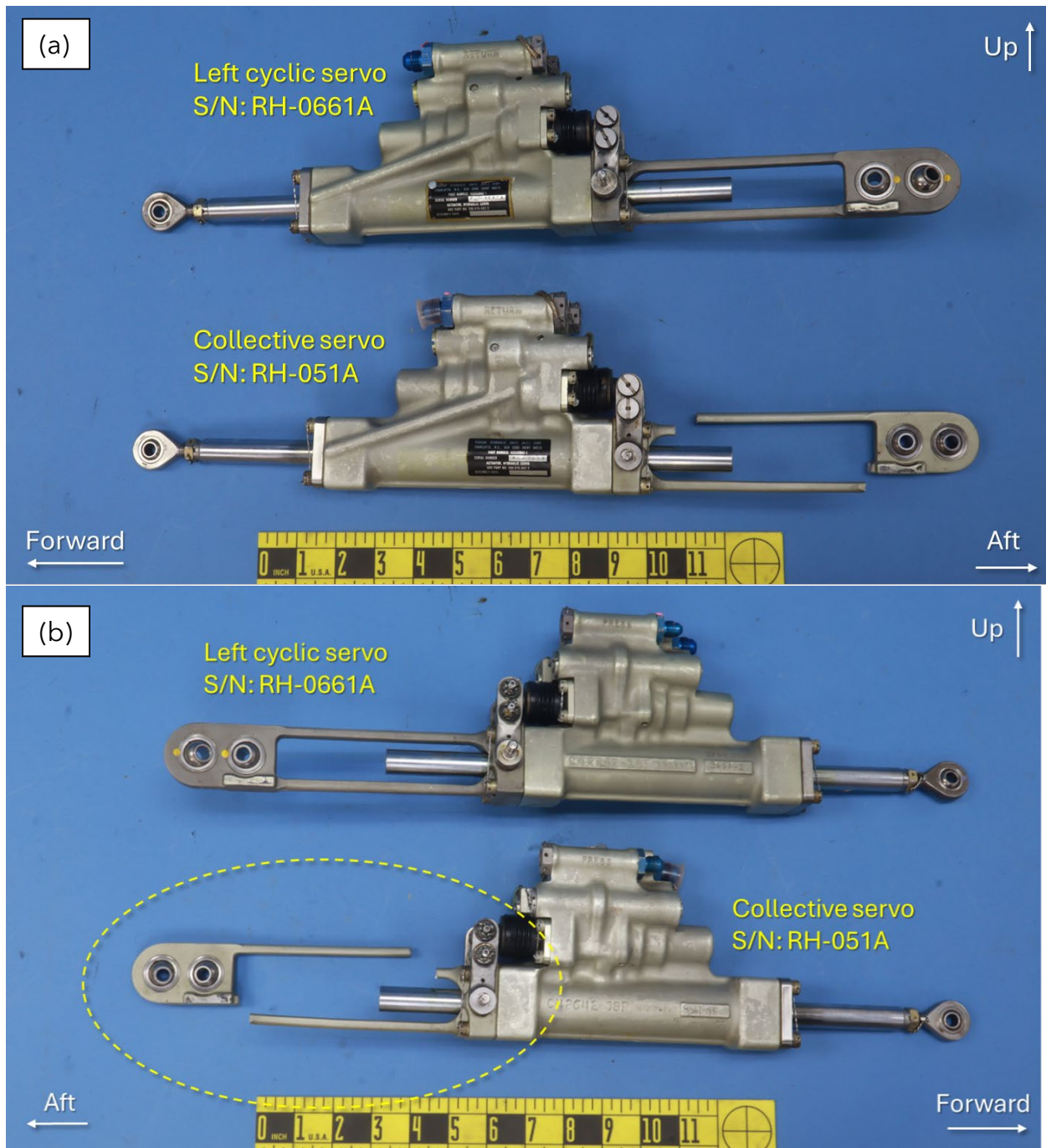


Figure 1. The two servos from the accident helicopter, as received. The circled area in (b) corresponds to the fractured arm legs from the collective servo.

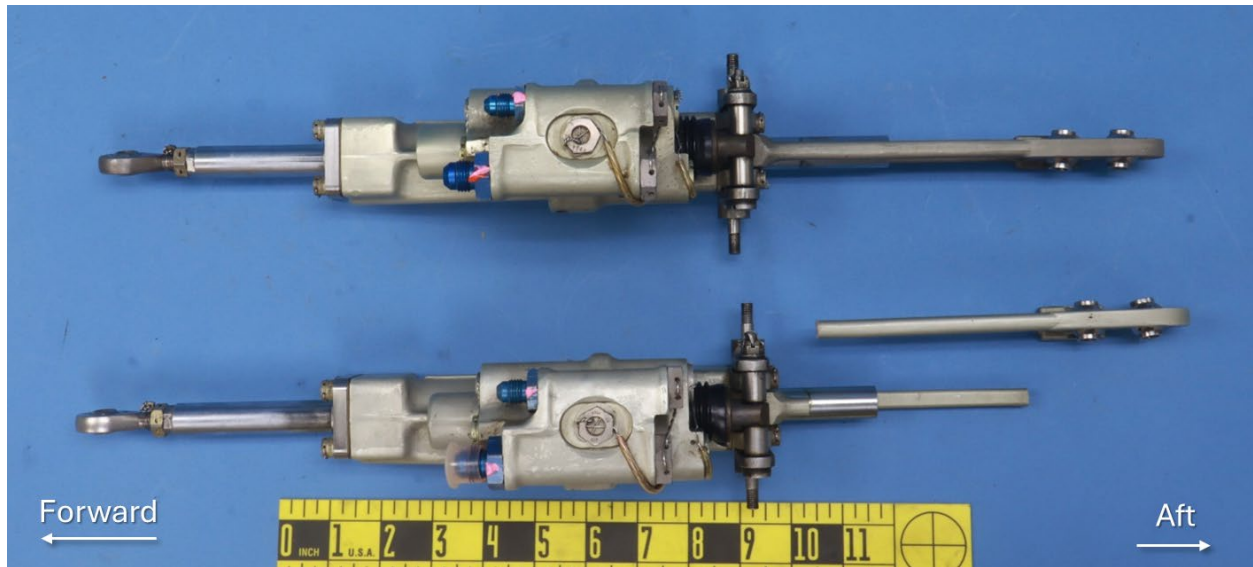


Figure 2. Views of the servos from the upward-facing surfaces, showing the locations of the fractures on the collective servo.

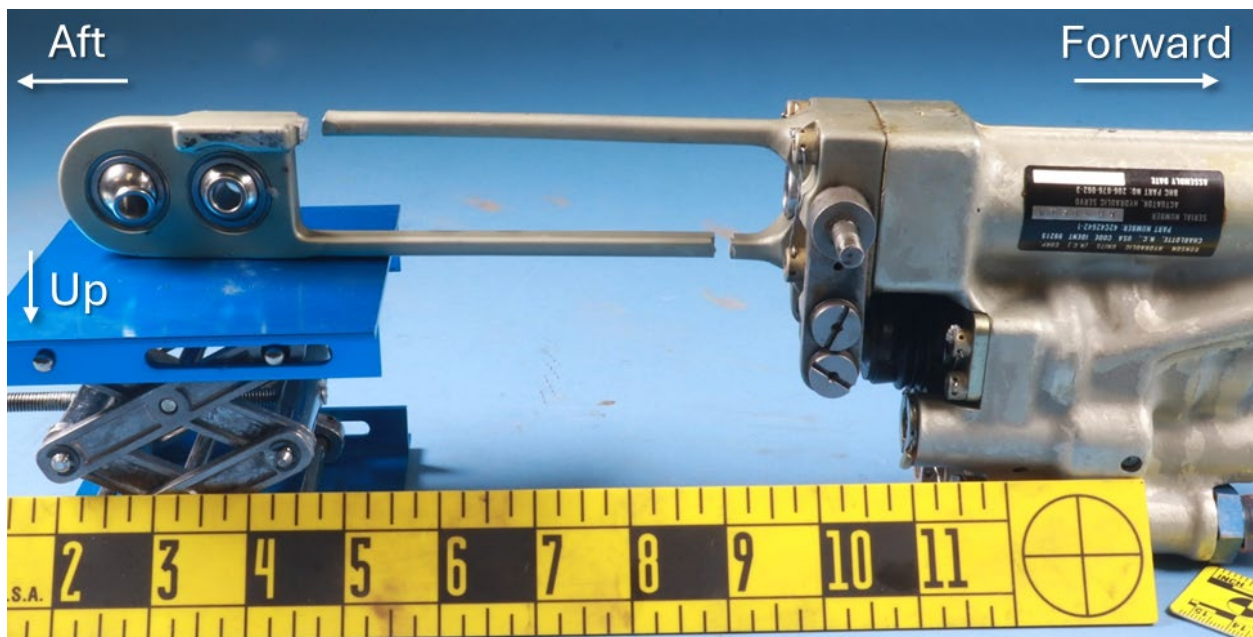


Figure 3. The collective servo arm, positioned to show the locations of the fractured remnants at the time of fracture.

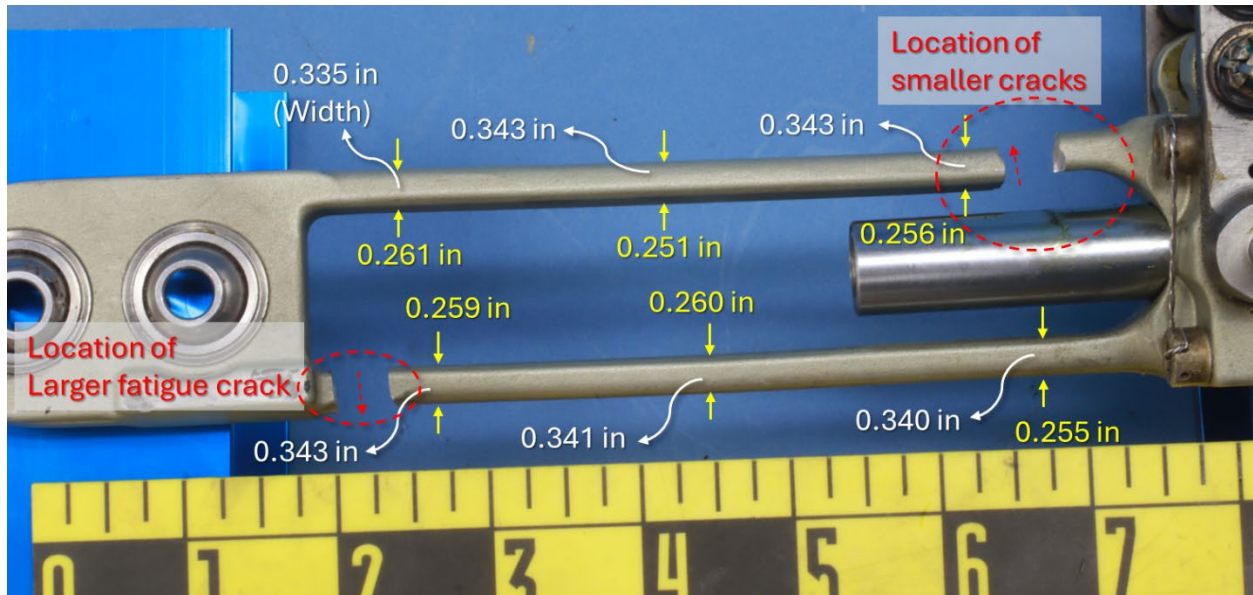


Figure 4. Closer view of the collective servo arm fractures.



Figure 5. View of the two fracture surfaces of the servo arm, from the forward-looking aft view.

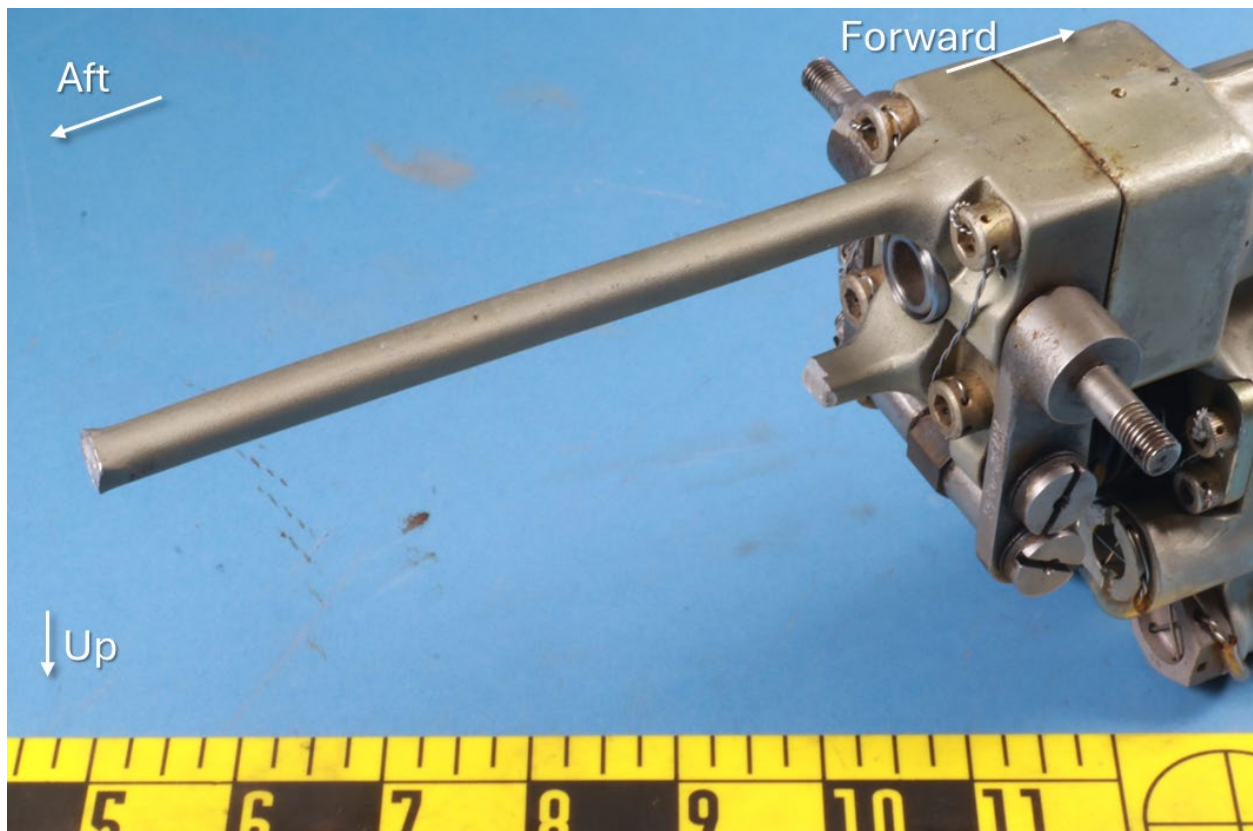


Figure 6. Angled view of the two inboard side fractures of the collective servo arm.

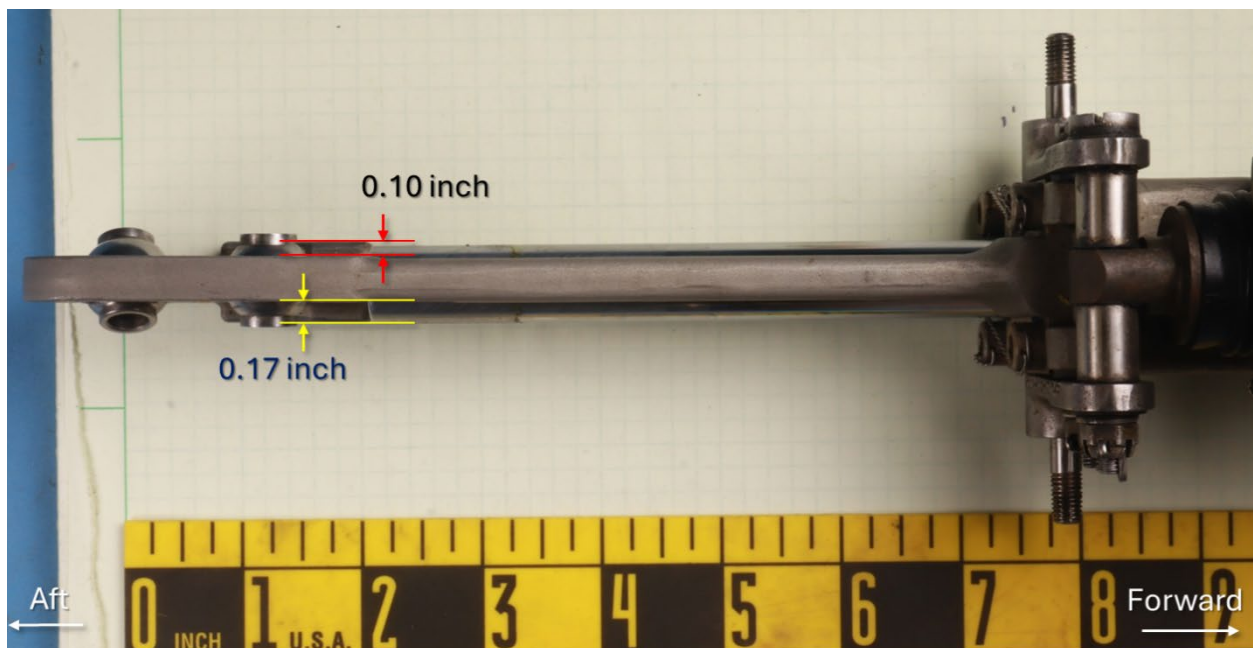


Figure 7. Top-down view of the cyclic (exemplar) servo arm.

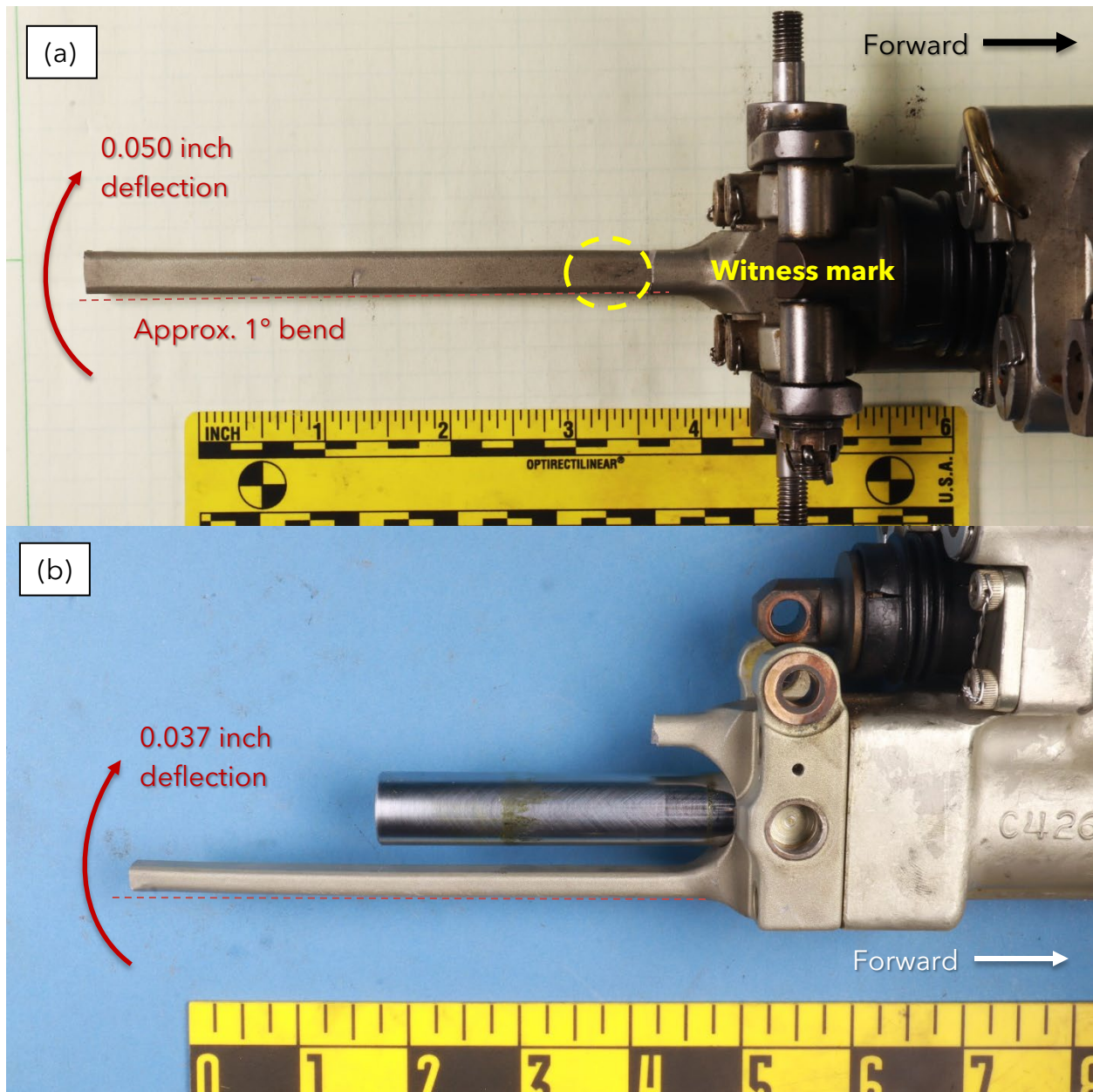


Figure 8. Views of the inboard side of the fractured arm from (a) the top-down view and (b) the side view from the right.

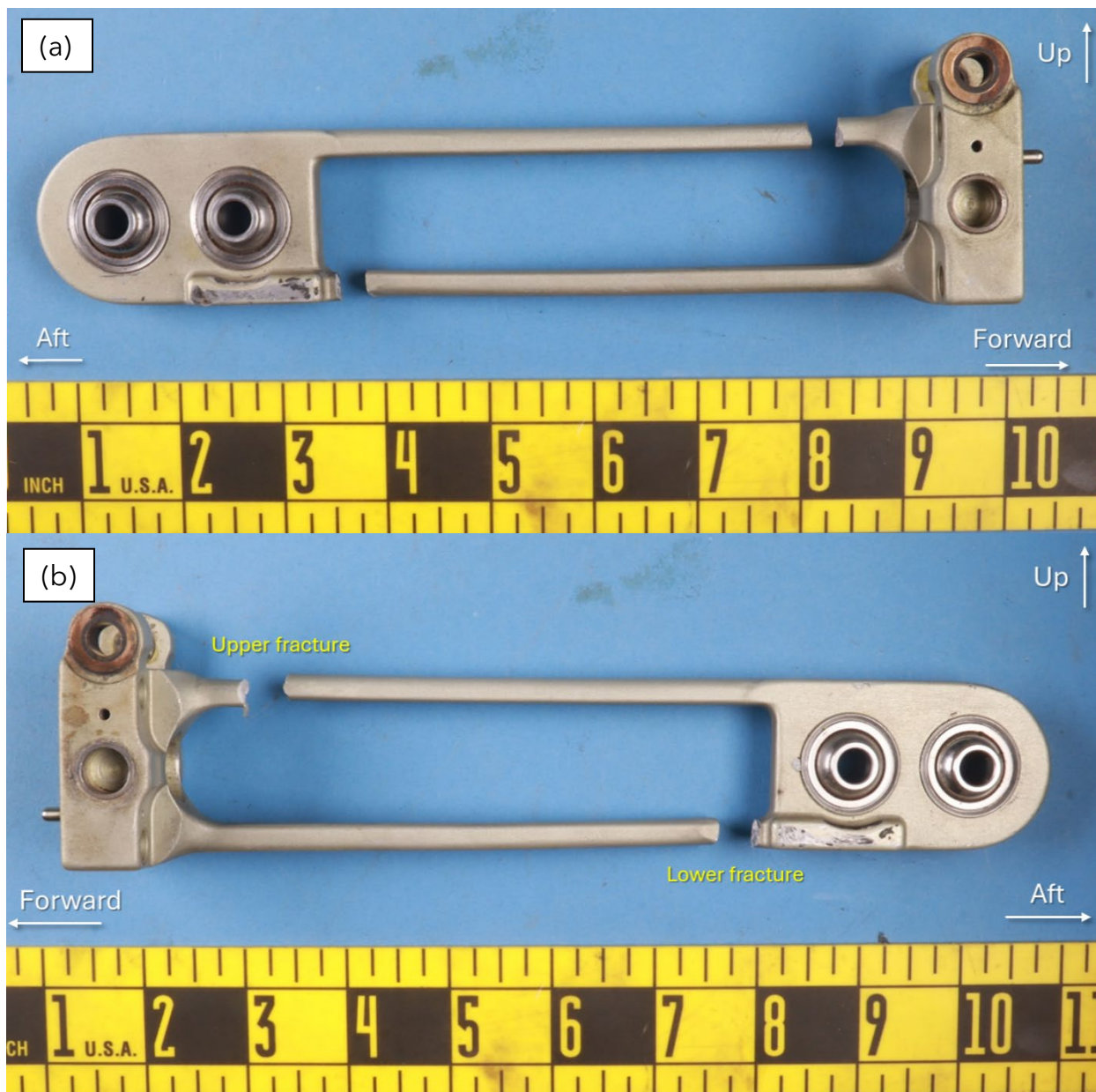


Figure 9. Opposite side views of the fractured servo arm, after disassembly and cleaning with acetone.



Figure 10. Upper leg fracture surface from the forward face.



Figure 11. Primary crack initiation site of the larger crack in Figure 10.

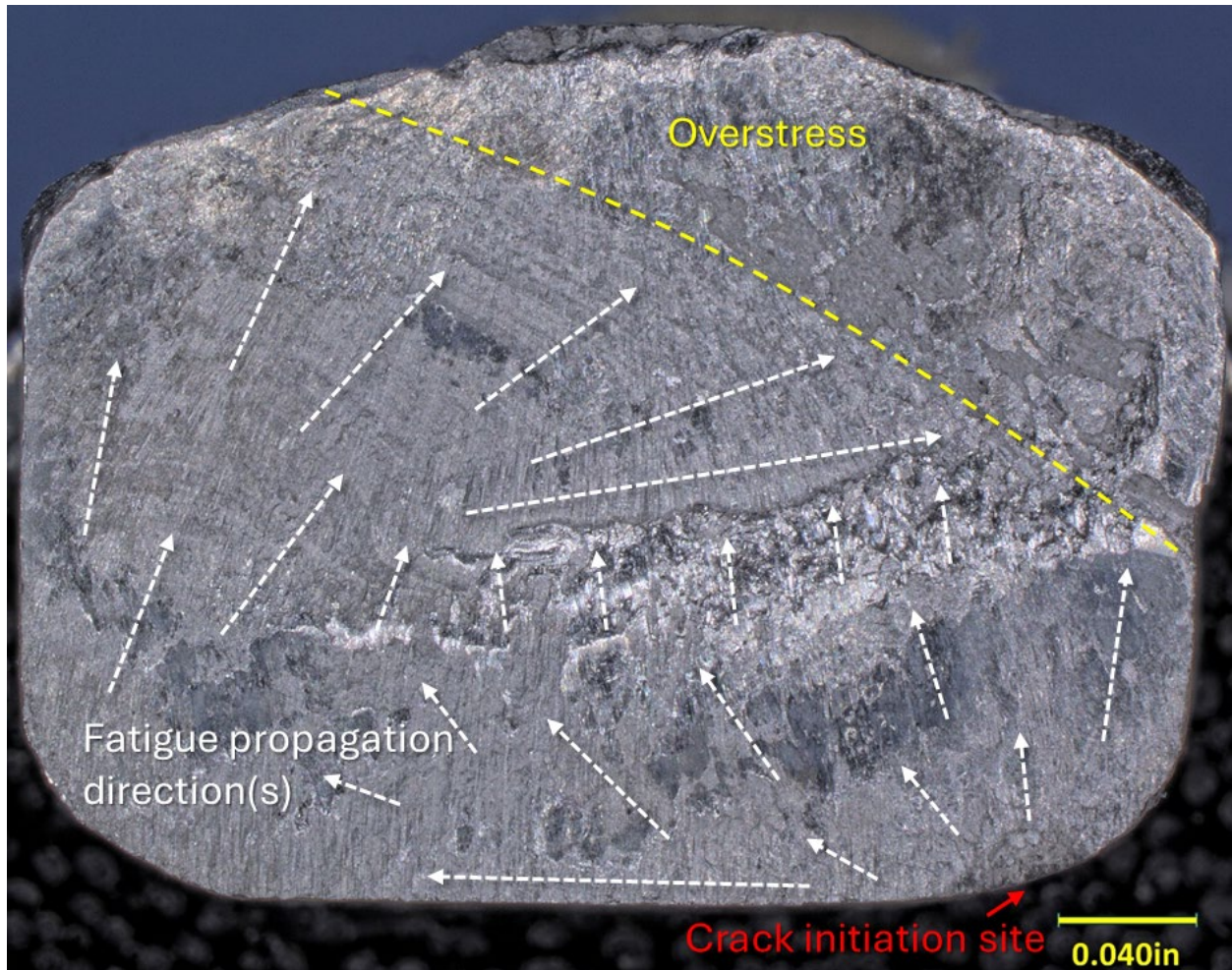


Figure 12. View the lower servo arm leg fracture surface from the forward face. The dashed lines represent the general crack propagation direction, with the red arrow showing the primary crack initiation site.

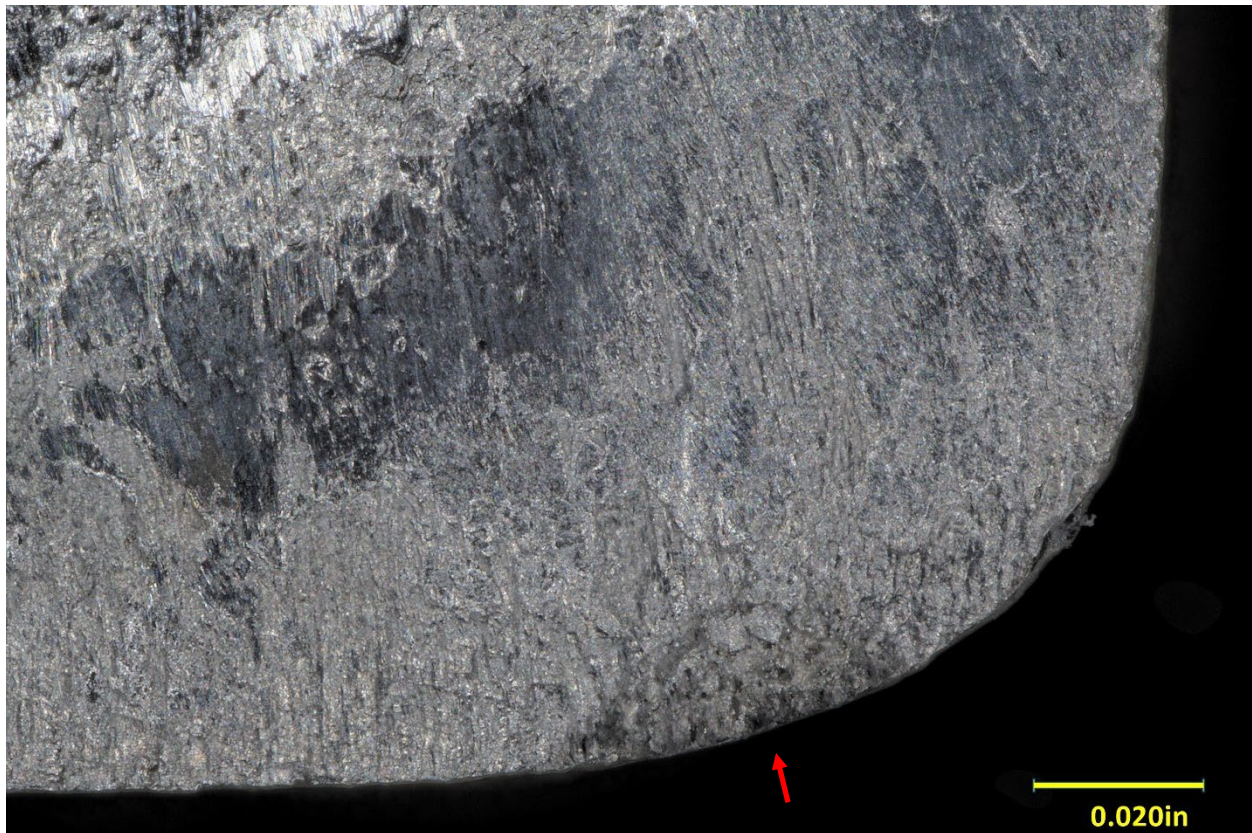


Figure 13. The crack initiation site (red arrow) of the lower leg fracture surface.

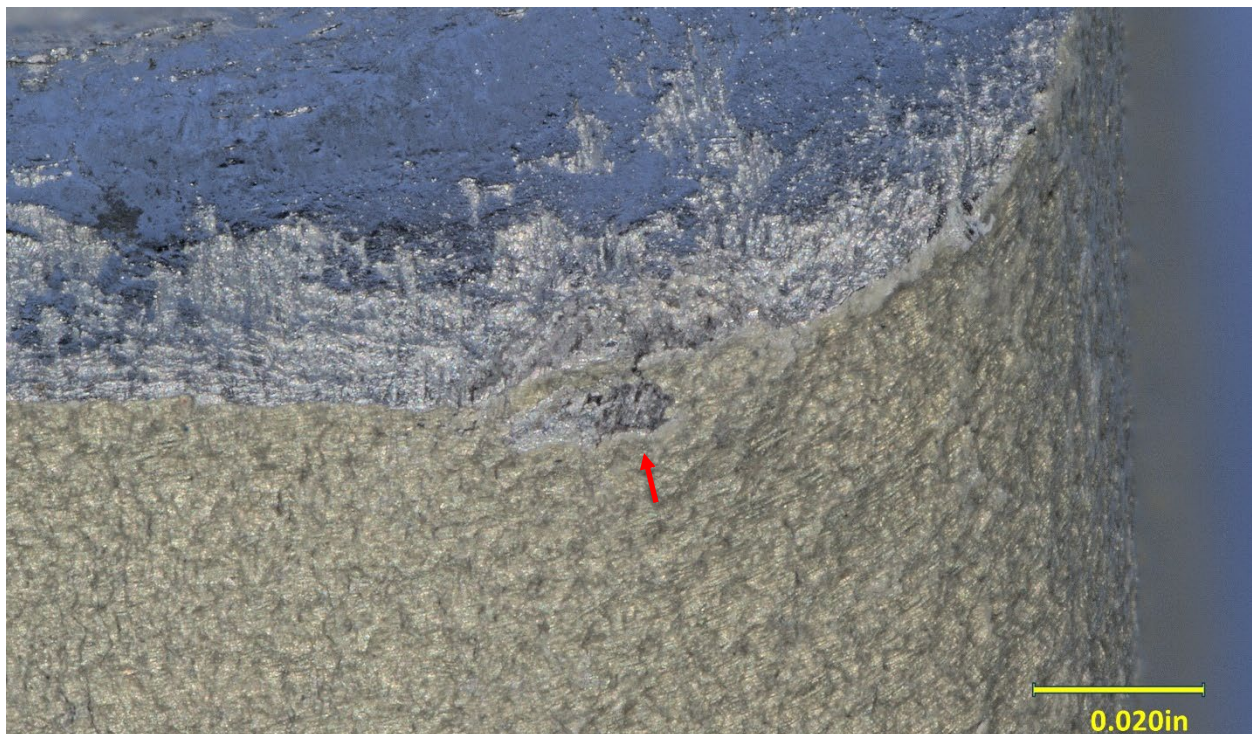


Figure 14. Angled view of the initiation site (red arrow) in Figure 13.

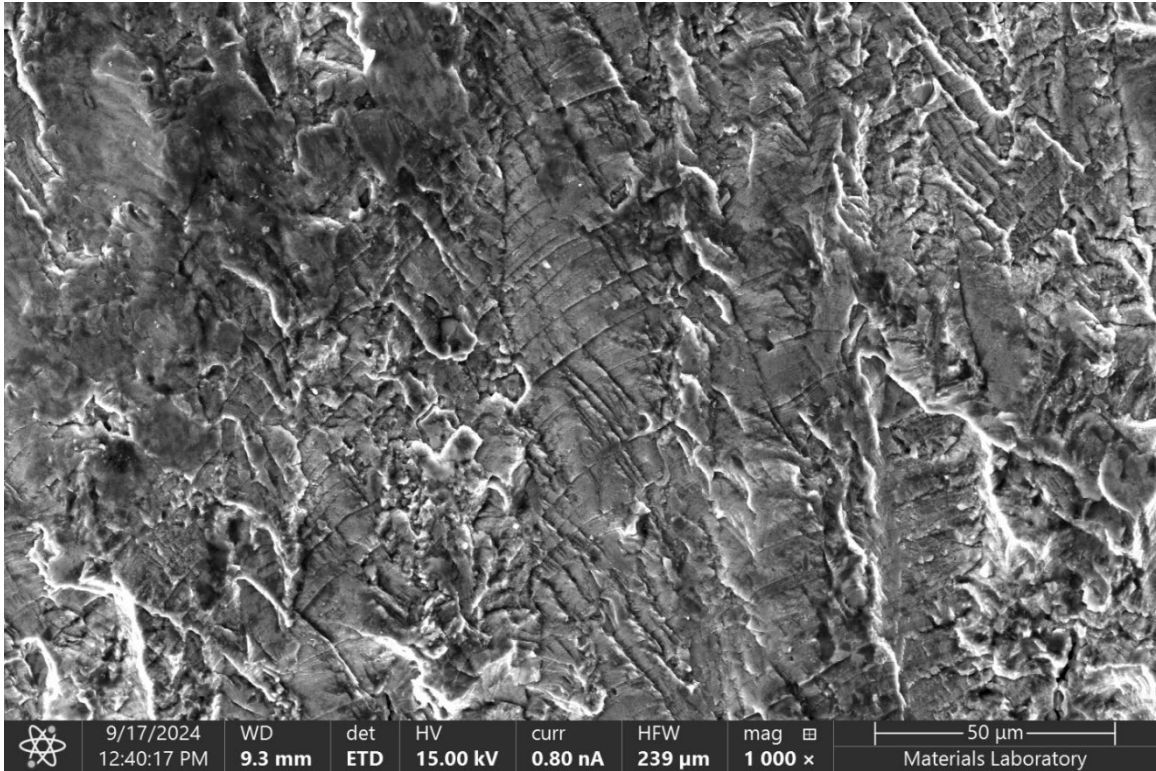


Figure 15. Secondary electron (SE) micrograph of fatigue striations on the lower leg fracture surface.

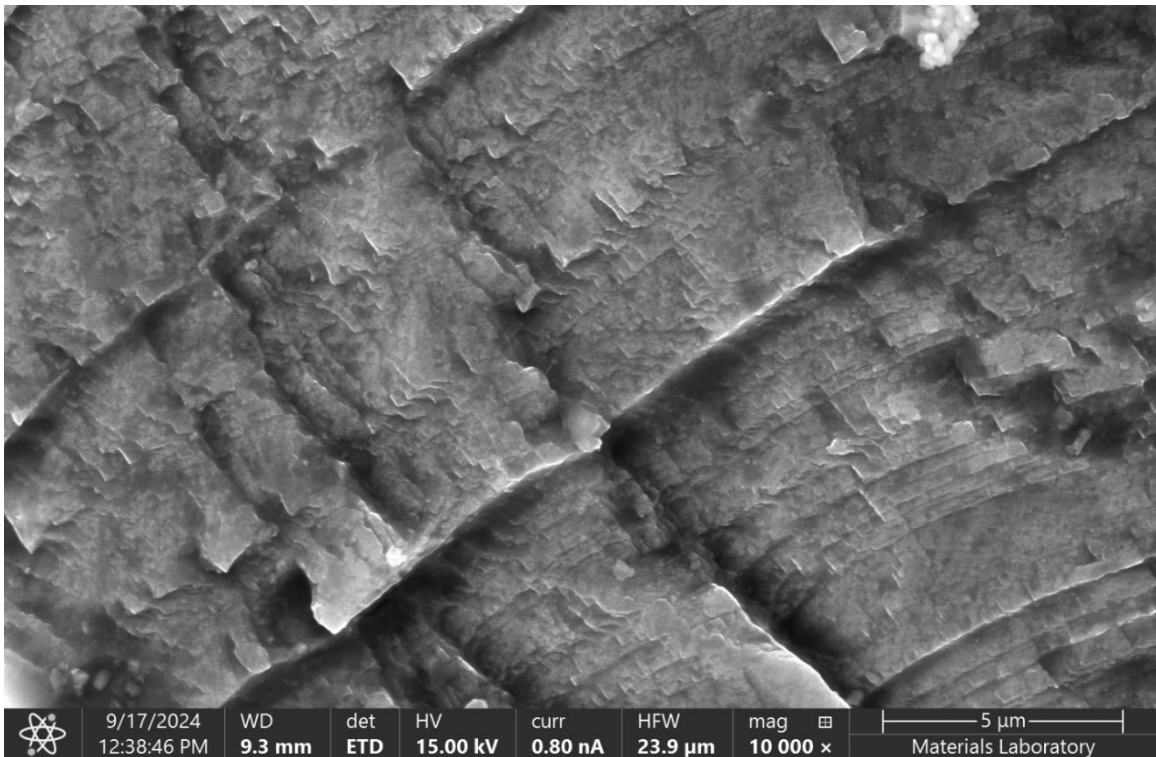


Figure 16. SE micrograph of fatigue striations and larger bands in Figure 15.

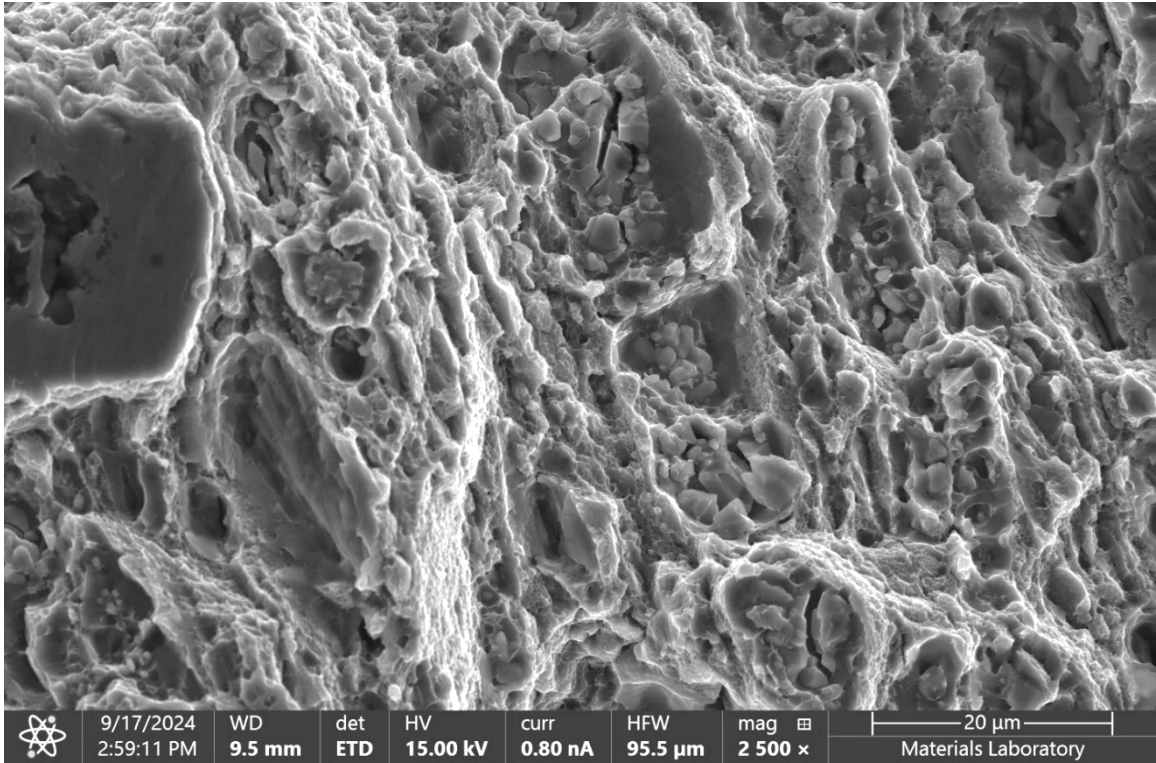


Figure 17. SE micrograph of dimpled rupture outside of the fatigue cracking areas.

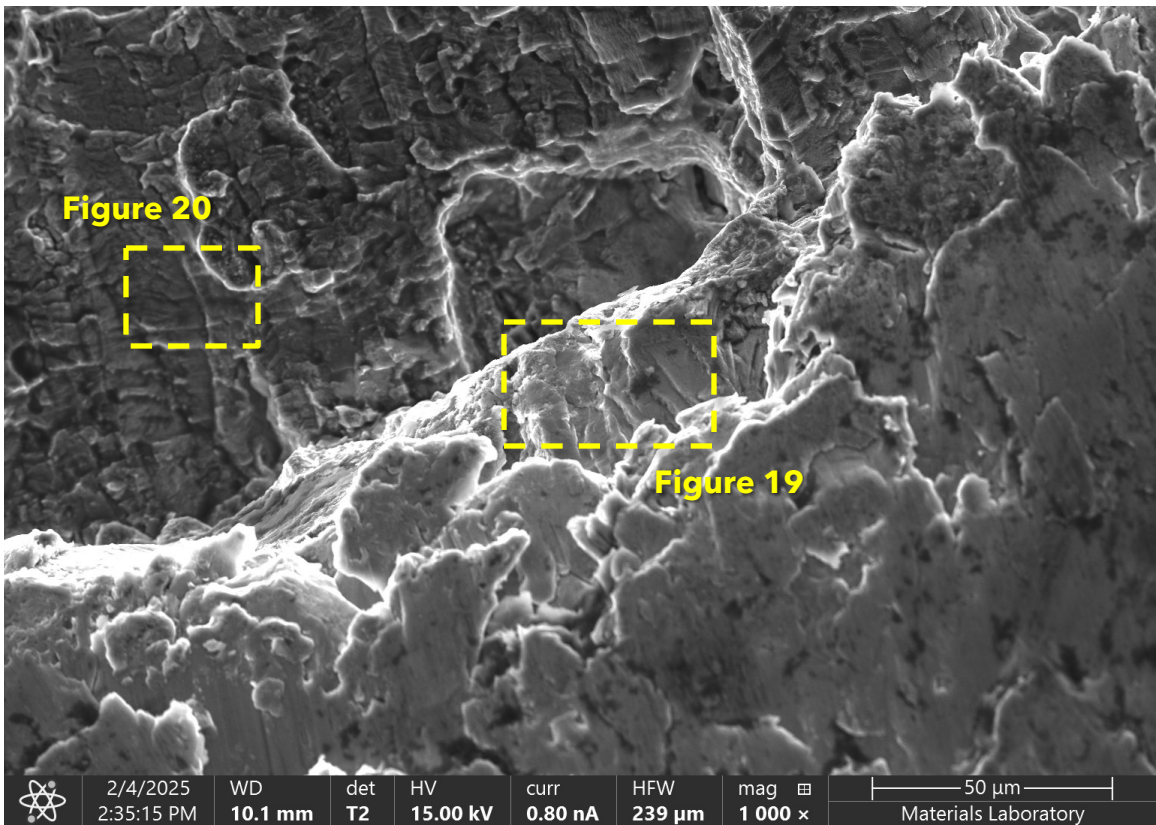


Figure 18. SE micrograph of the ridge in the center of the lower leg fracture surface.

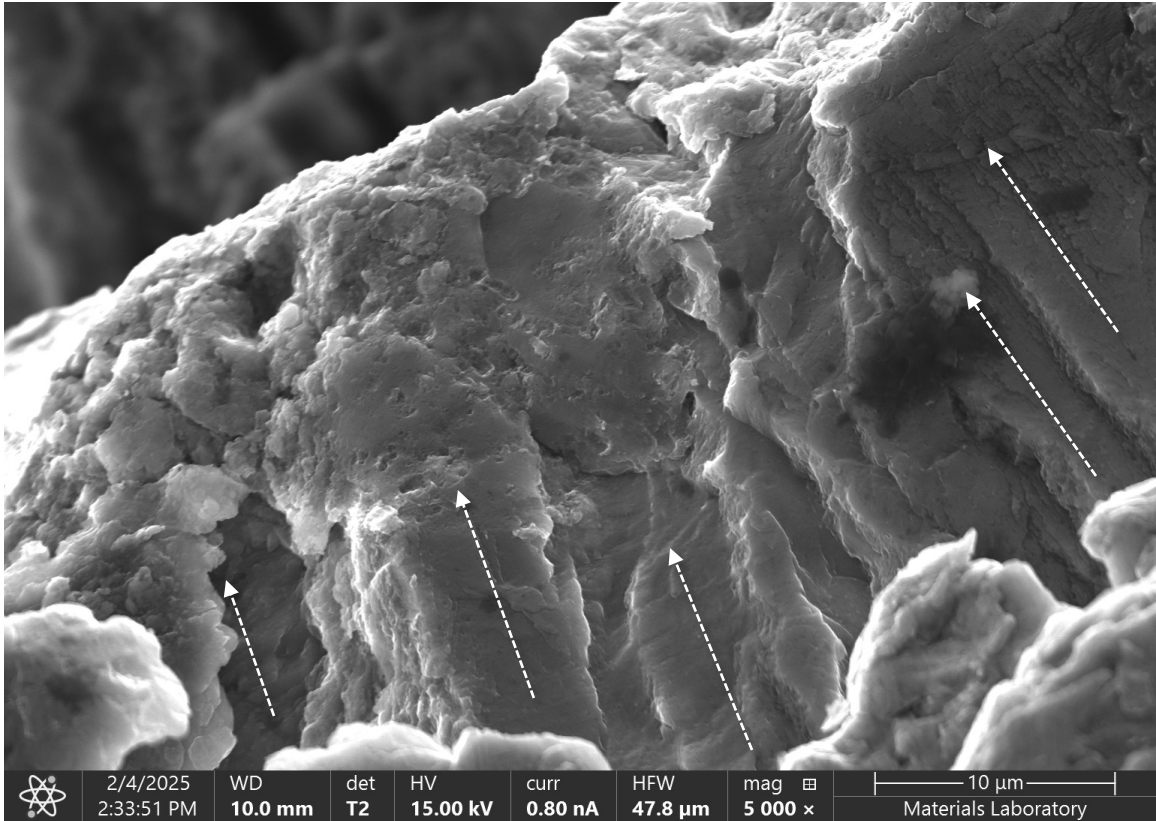


Figure 19. SE micrograph of fine striations near the ridge on the fracture surface.

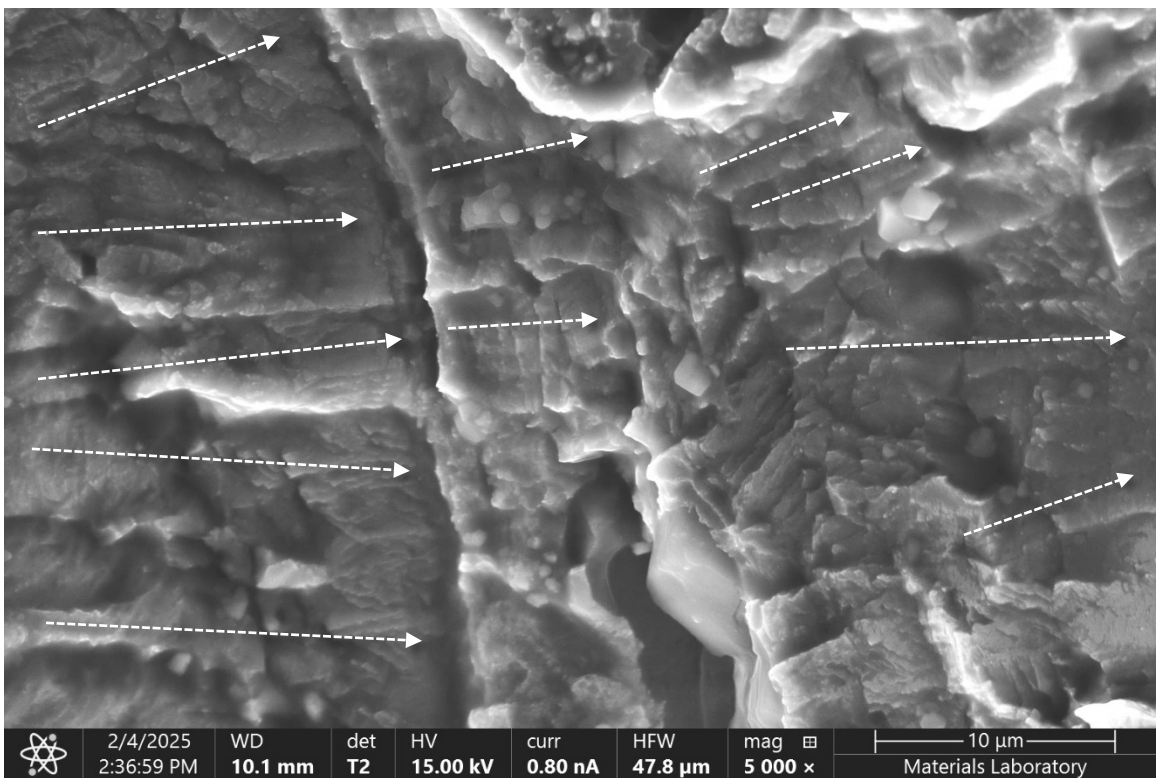


Figure 20. SE micrograph of striations on the upper portion of Figure 18.

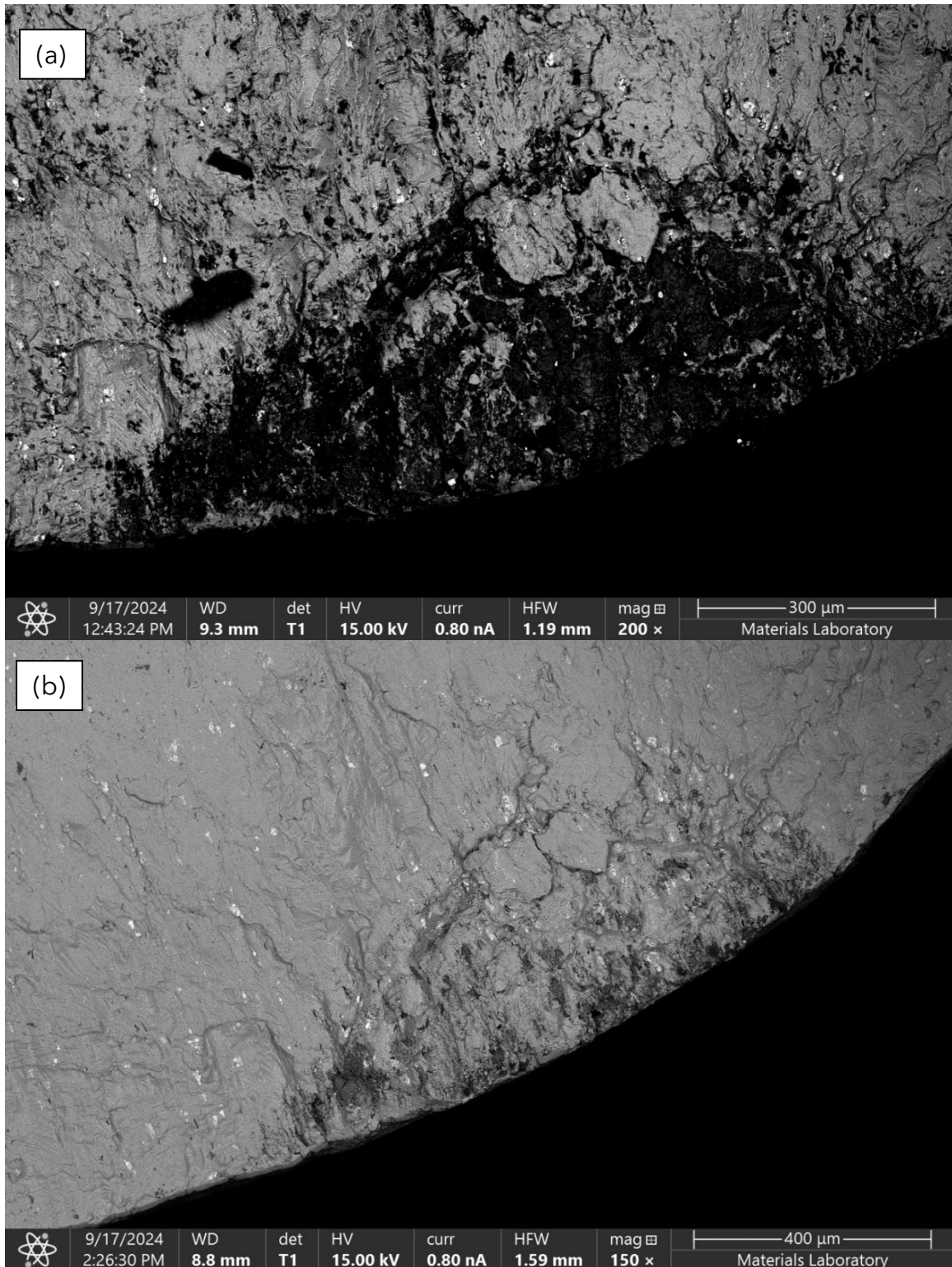


Figure 21. Backscattered electron (BE) micrographs of the lower leg crack initiation site (a) after cleaning with acetone and (b) after cleaning with a chromic acid solution.

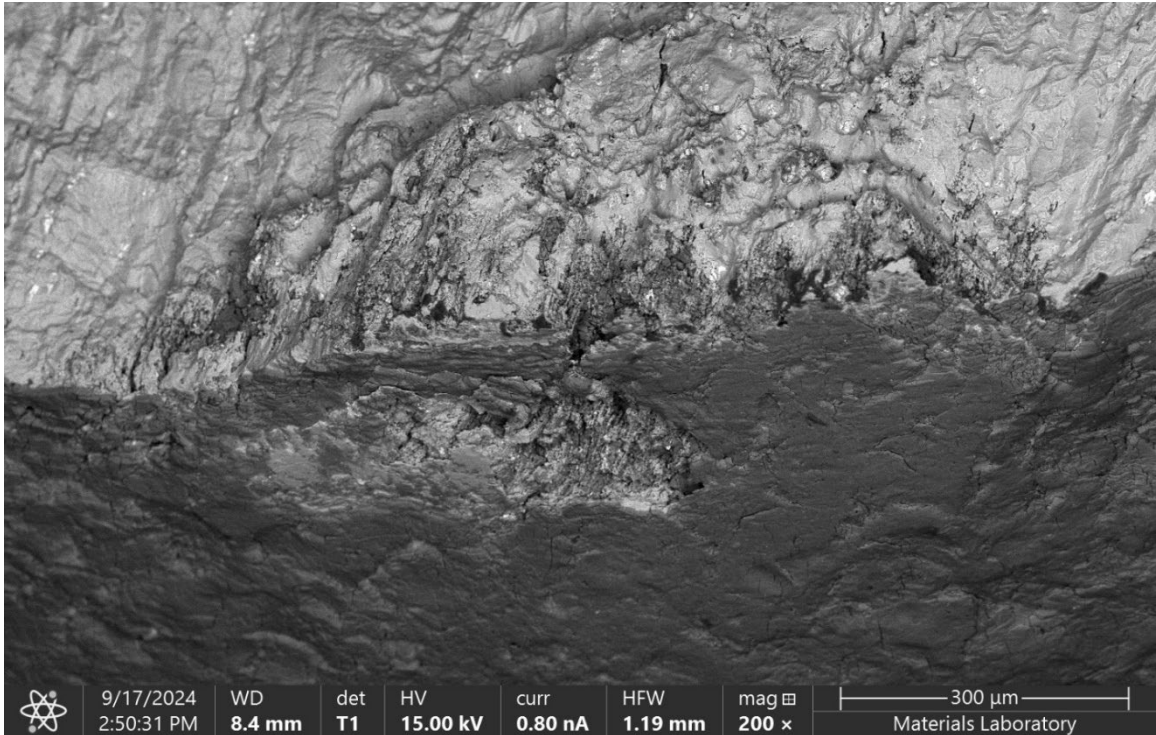


Figure 22. BE micrograph of an angled view of the initiation site, showing pitting.

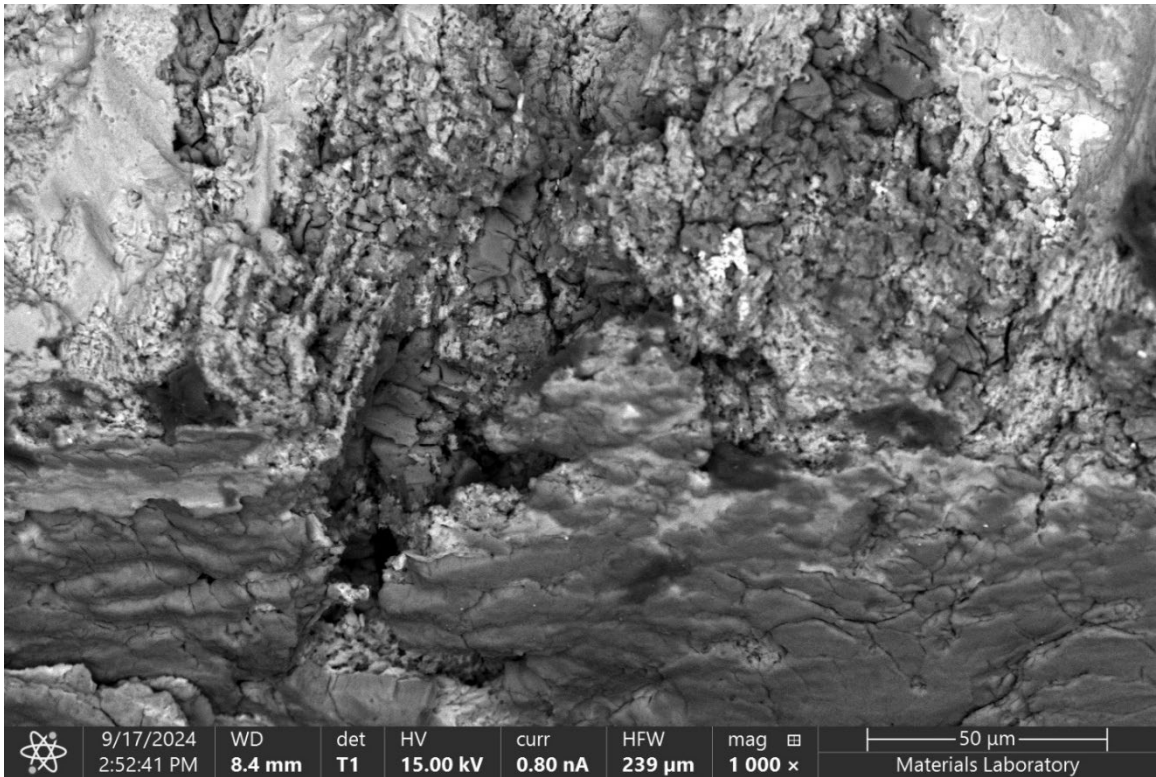


Figure 23. BE micrograph showing the fractured brittle compounds within the corrosion pit.

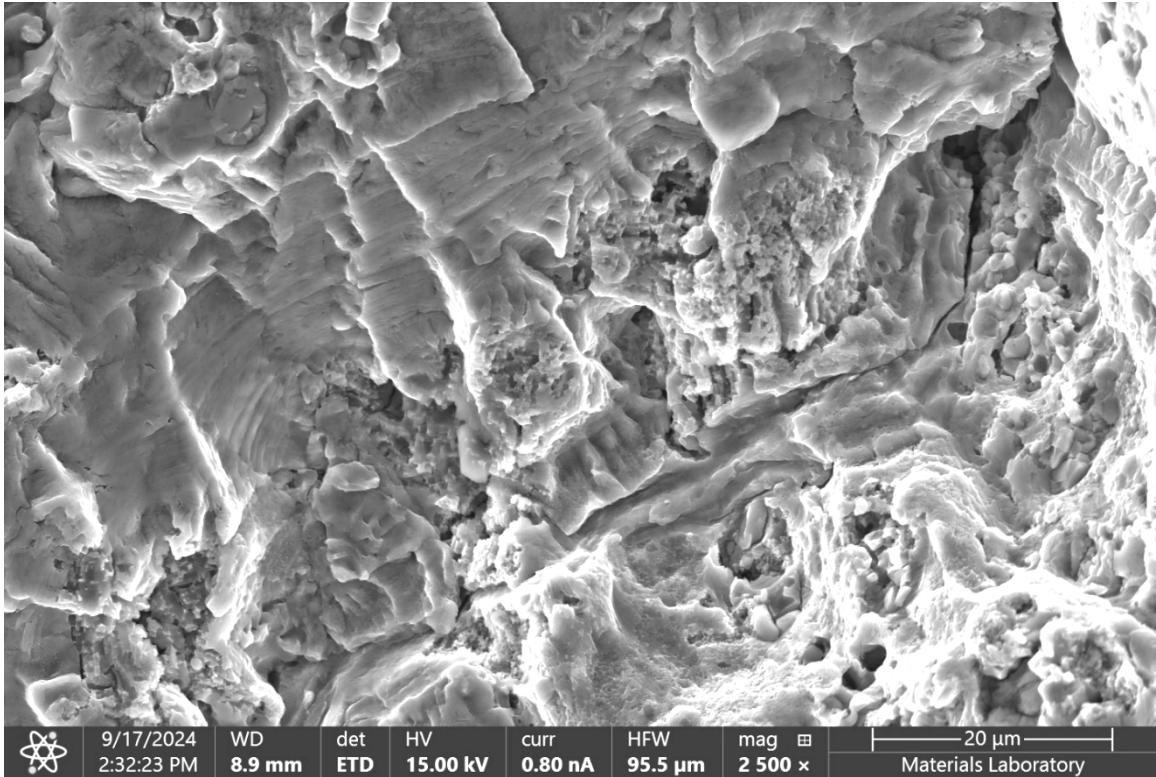


Figure 24. SE micrograph of fatigue striations propagating from the edge of the pit tip.

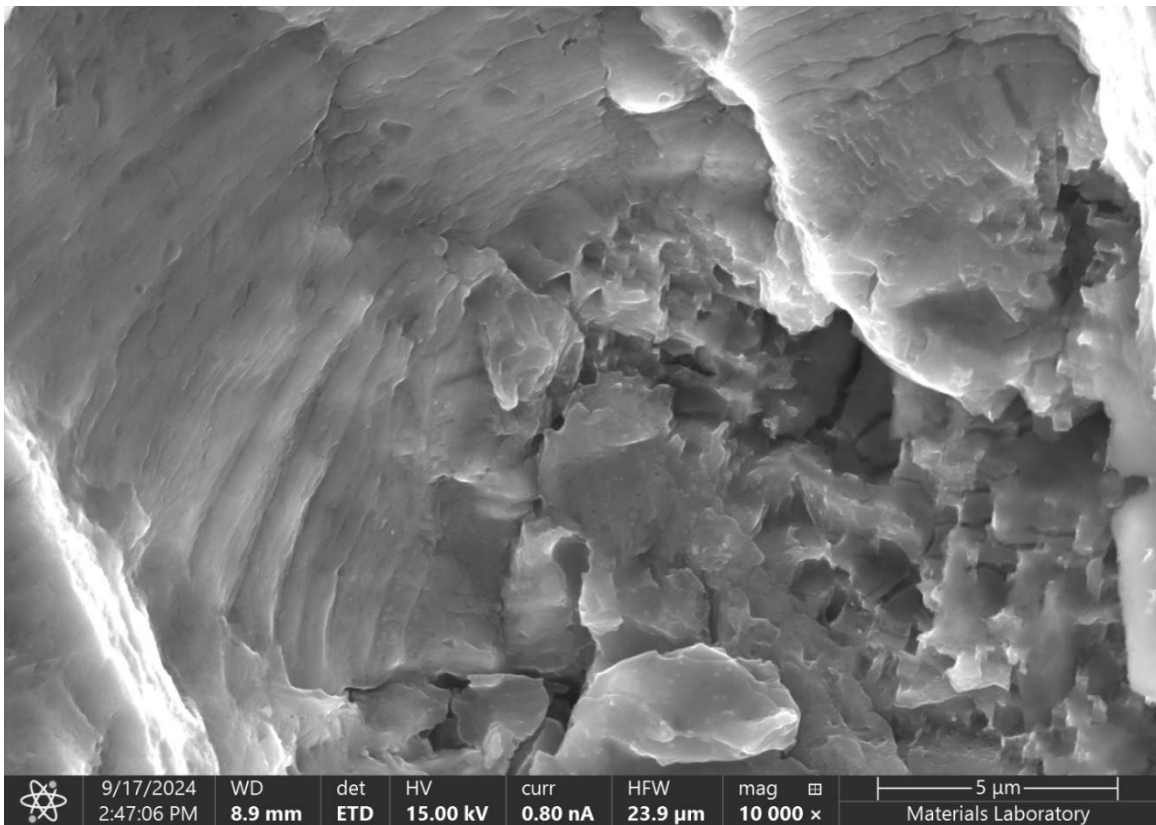


Figure 25. SE micrograph of several initiation sites along the pit tip in Figure 21.

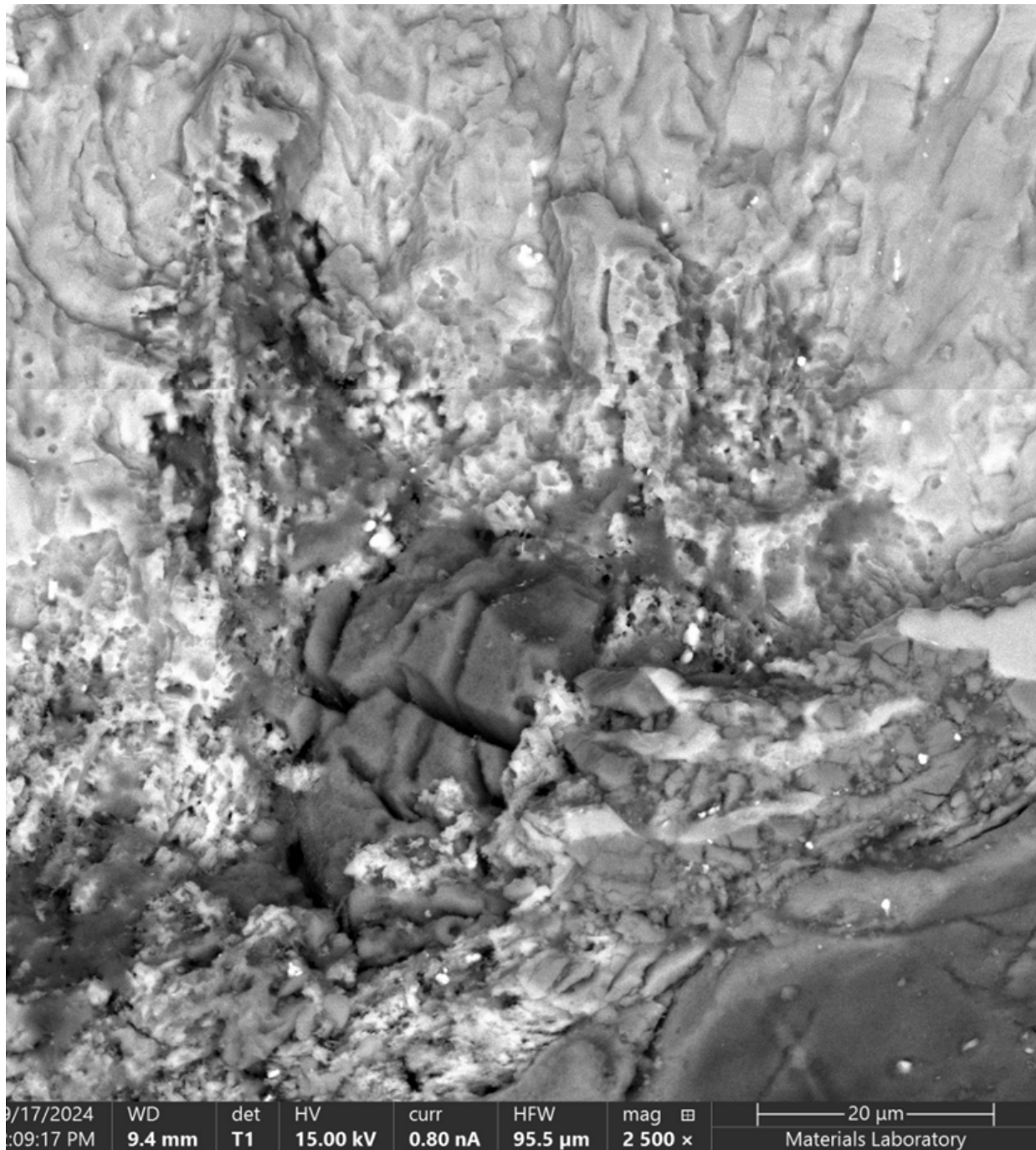


Figure 26. Montage of BE micrographs of the pit tip, showing contrast between the fatigue crack propagation regions and the pit, which contained lower Z-compounds.

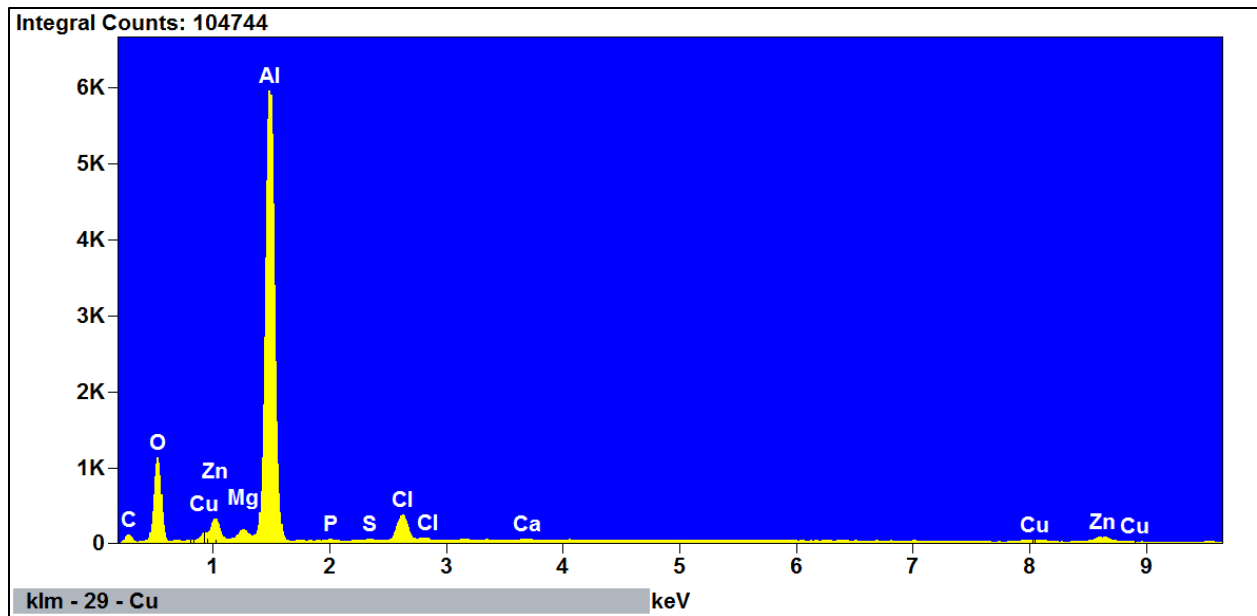


Figure 27. EDS spectrum of the dark area in Figure 23b, showing peaks consistent with aluminum oxide and an elevated chlorine peak.

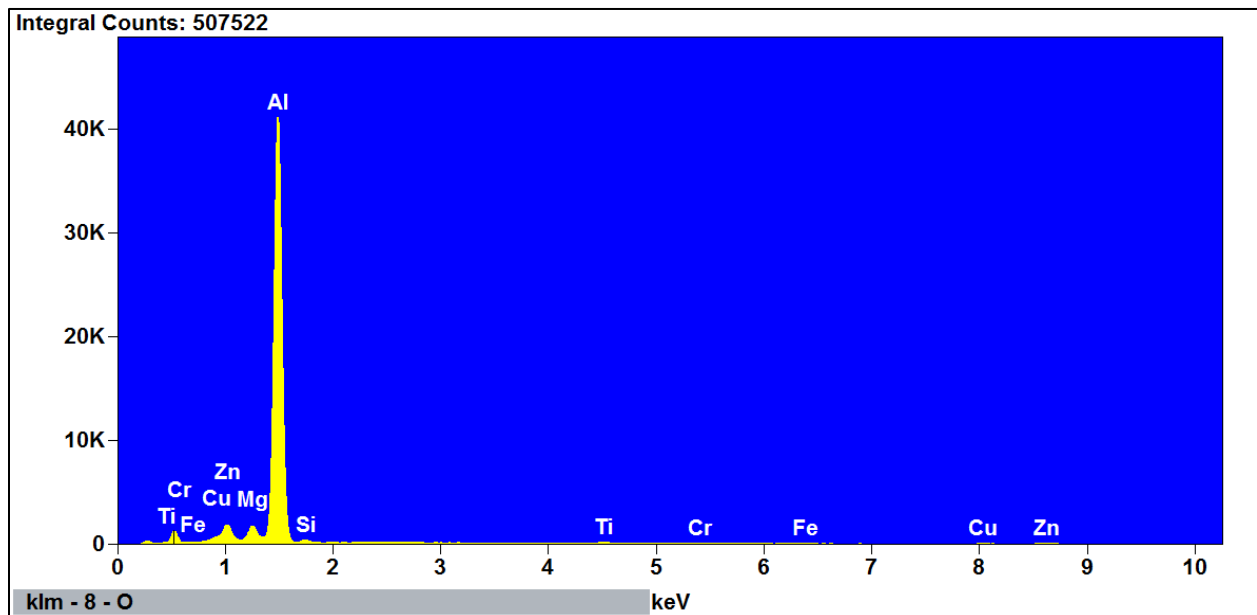


Figure 28. EDS spectrum of a typical area of the servo arm material from Figure 17, consistent with a 7000-series aluminum composition.

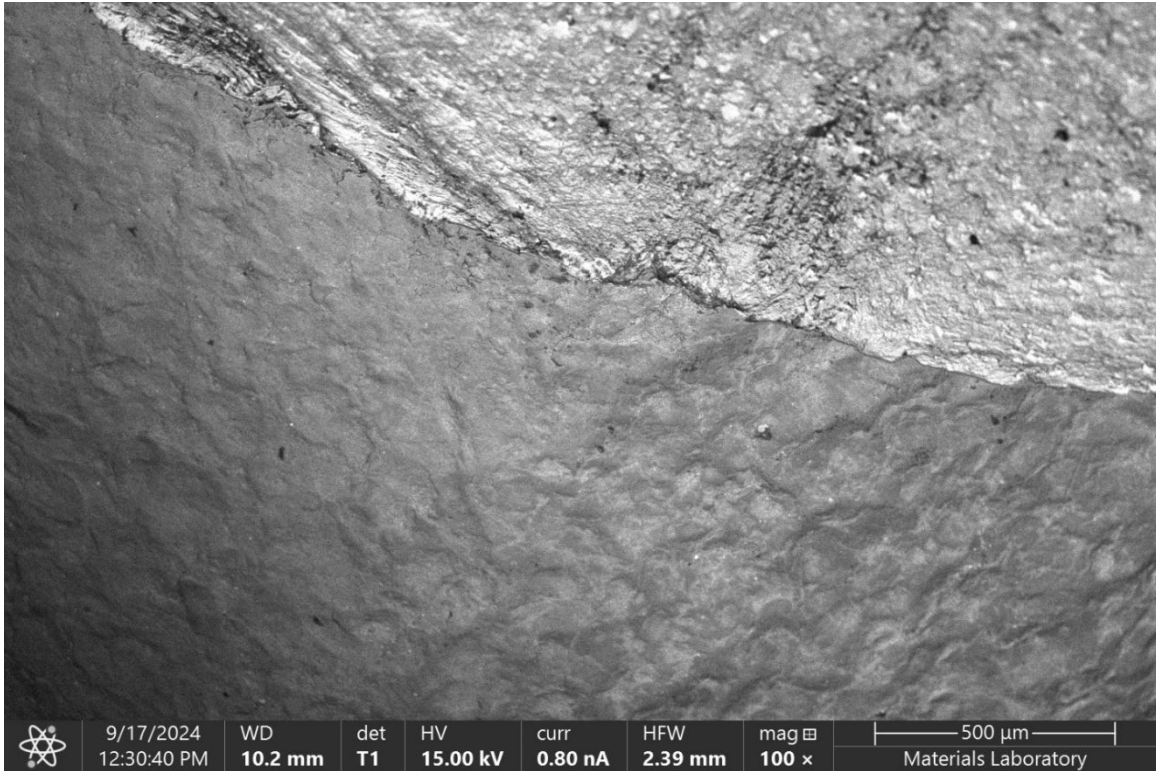


Figure 29. BE micrograph of an angled view of the initiation site of the smaller fatigue crack on the upper leg fracture surface.

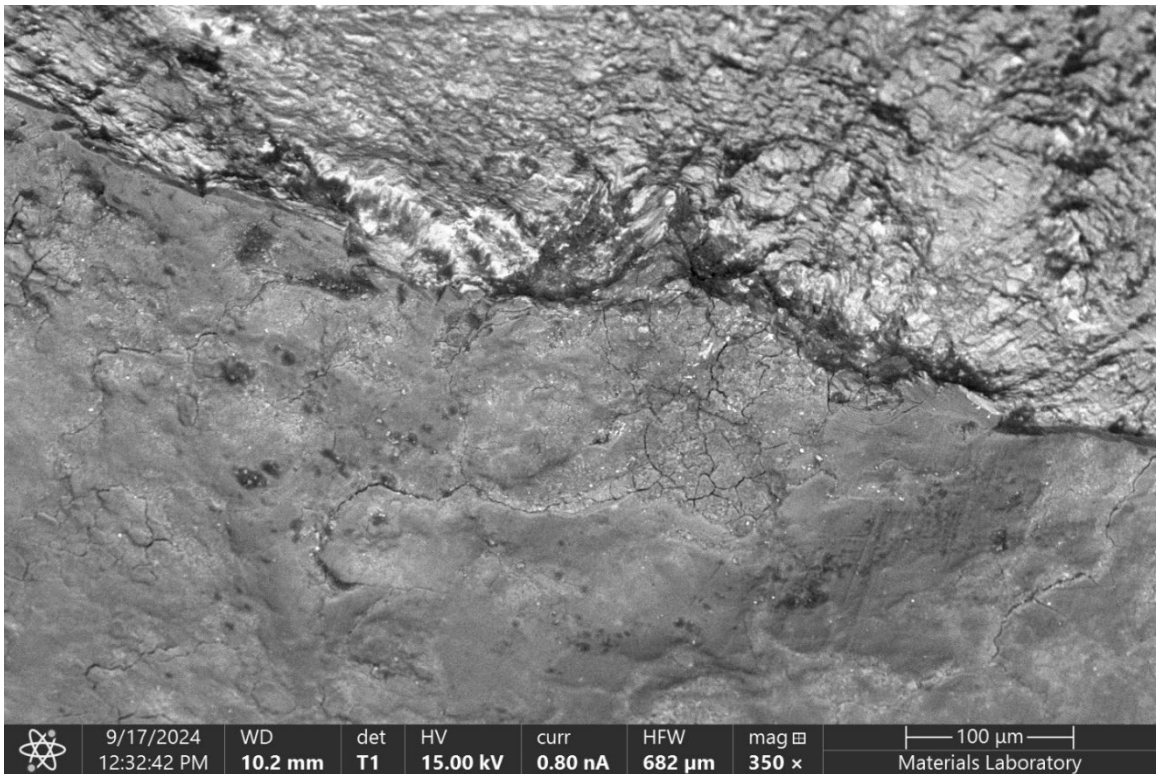


Figure 30. BE micrograph of the pit at the initiation site in Figure 26.

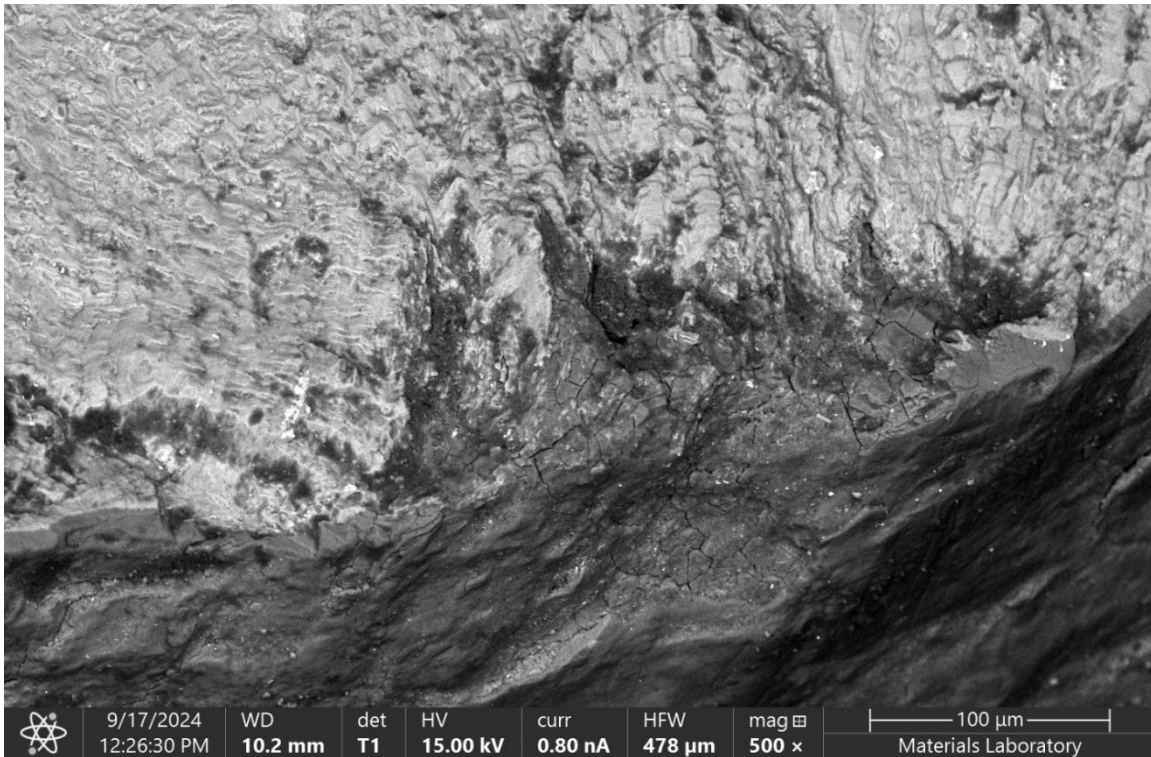


Figure 31. BE micrograph of the larger fatigue crack initiation site on the upper leg fracture.

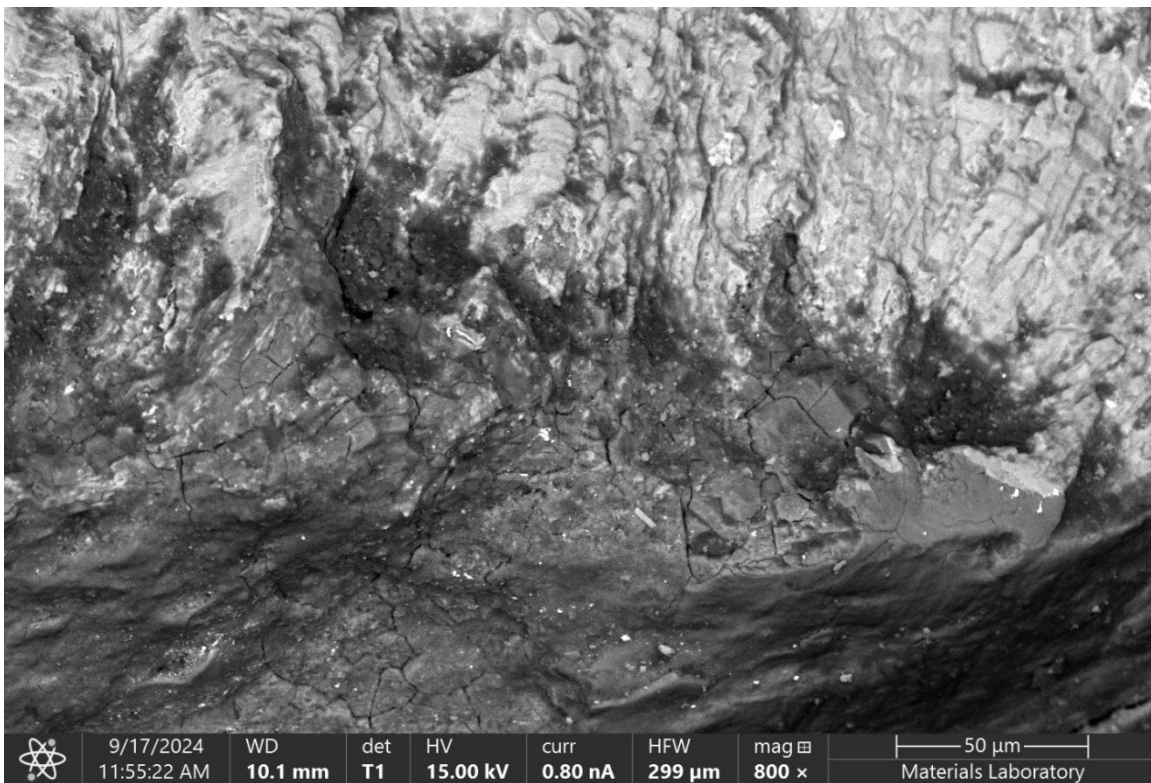


Figure 32. BE micrograph of the pit creating multiple initiation sites in Figure 28.

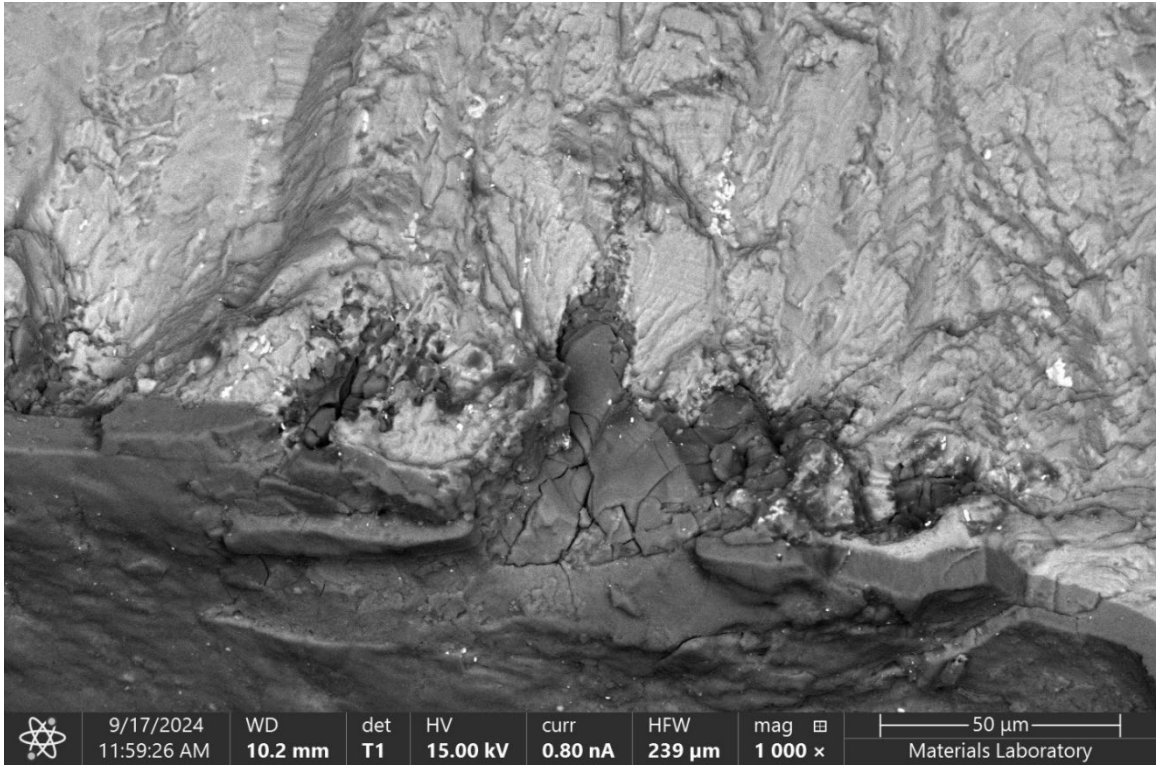


Figure 33. BE micrograph of two pits at the middle initiation sites of the upper leg fracture surface.

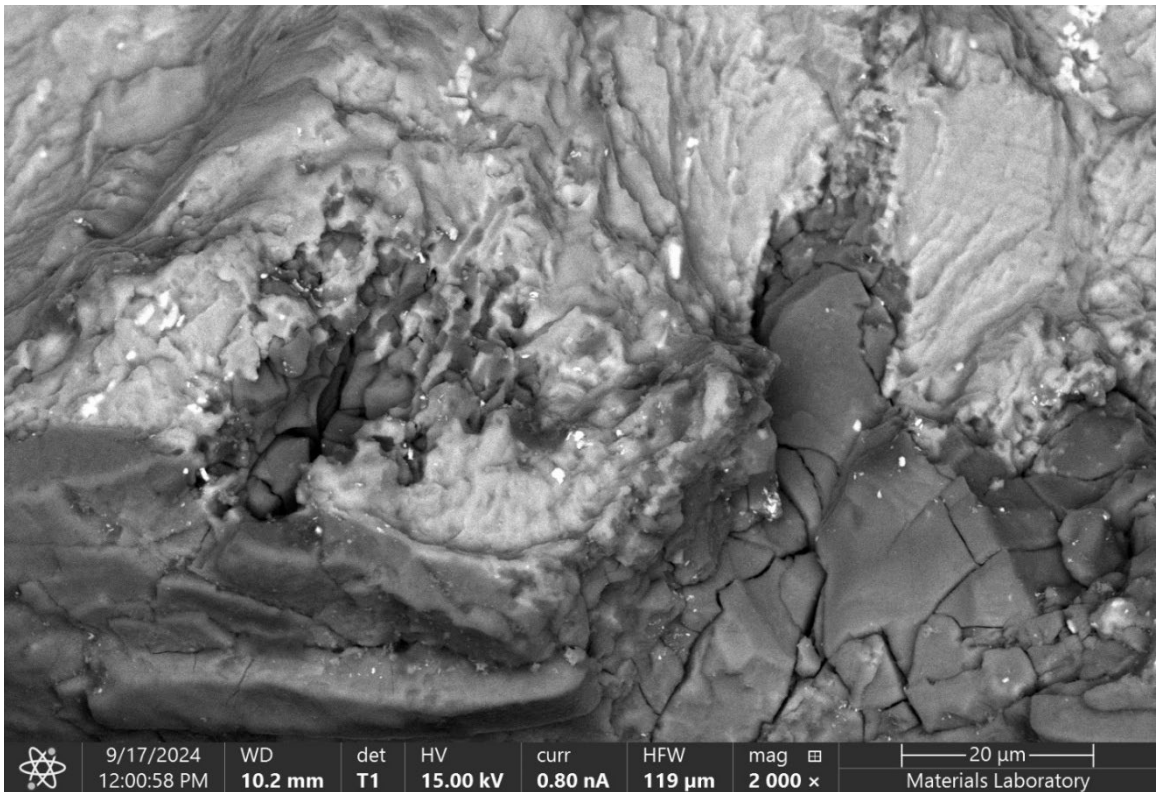


Figure 34. BE micrograph of the pits in Figure 30.

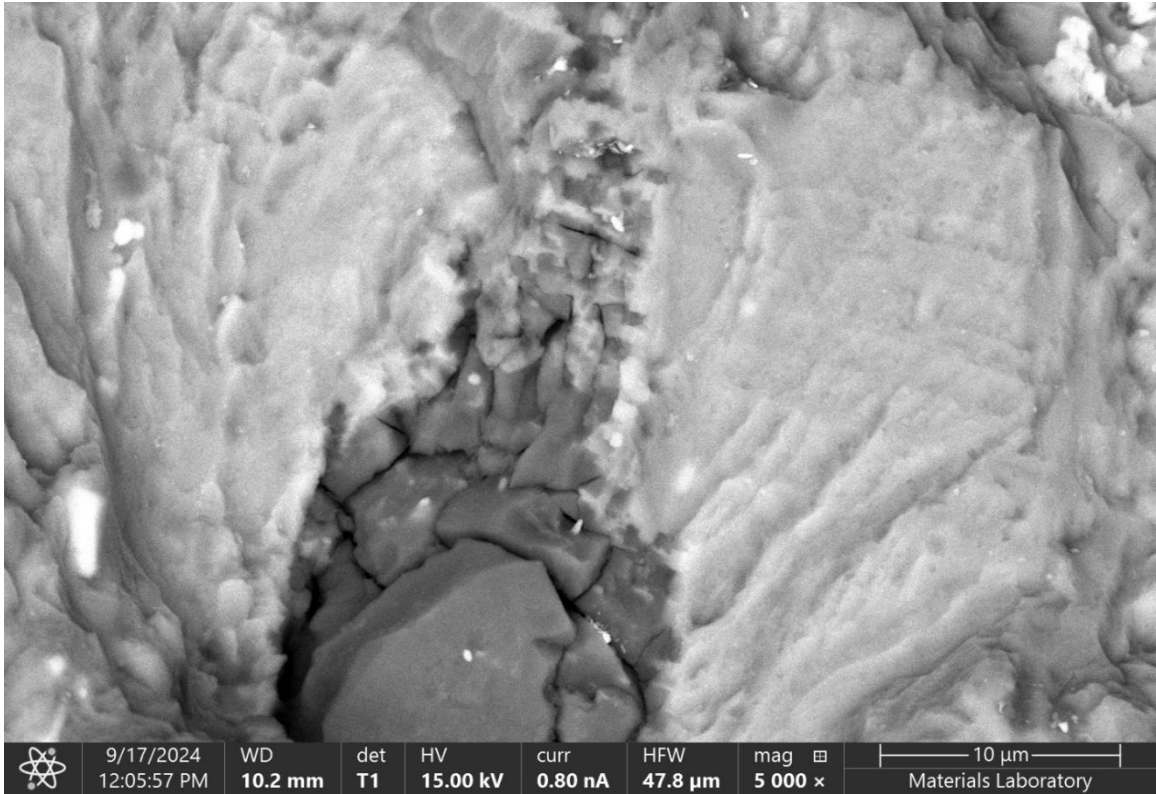


Figure 35. BE micrograph of fatigue crack initiation along the facets of the tip of the corrosion pit to the right in Figure 31, showing striations along the propagation direction.

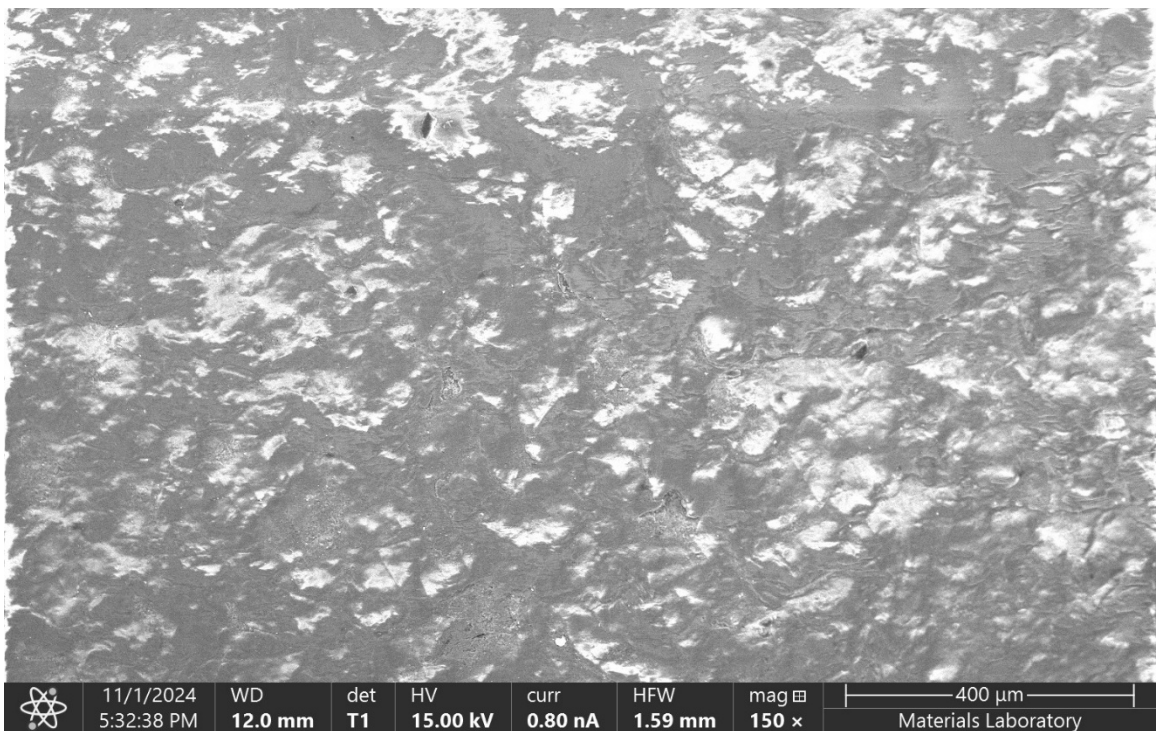


Figure 36. BE micrograph of the surface along the interior collective servo arm surface, showing multiple divots and pock marks.

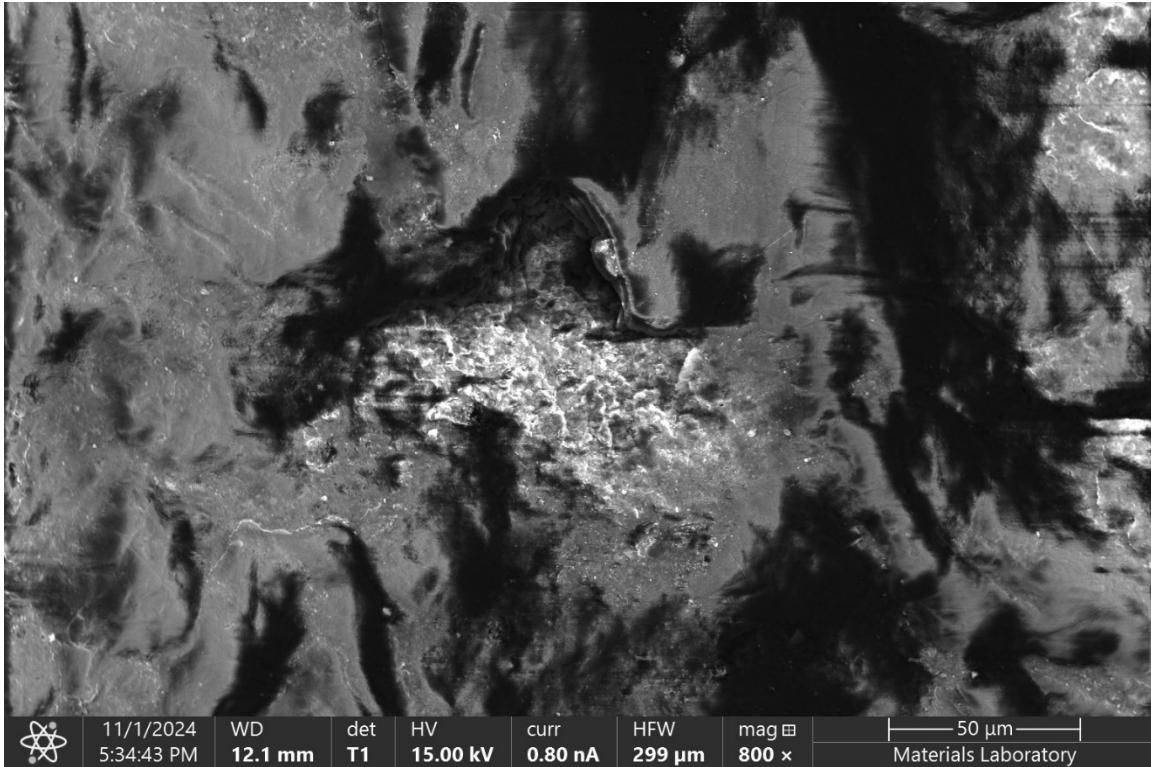


Figure 37. BE micrograph of a closer view of one of the corrosion pits from the surface in Figure 36.