

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



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MATERIALS LABORATORY

Specialist's Factual Report 22-074

October 13, 2022

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A. ACCIDENT INFORMATION

Location: Merced, California
Date: June 24, 2022
Time: 09:05 Pacific daylight time
16:05 coordinated universal time
Vehicle: Bell 206B, N915B
Investigator: Zoë Keliher, AS-WPR

B. COMPONENTS EXAMINED

Remnant of a Kaflex coupling
Pieces of fractured links
Remnants of coupling bolts

C. EXAMINATION PARTICIPANTS

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

D. DETAILS OF THE EXAMINATION

On June 24, 2022, at 0905 Pacific daylight time, a Bell 206 helicopter sustained substantial damage when it was involved in an accident near Merced, CA. The pilot was not injured. The pilot reported feeling a vibration while in flight, followed by a “snap” whereupon the helicopter began to rotate left. The pilot initiated an autorotation and then performed a run-on landing in a corn field. Upon touchdown, the helicopter rolled up on its nose, and the main rotor blades severed the tail boom. The wreckage was examined by a Federal Aviation Administration (FAA) inspector, who found the Kaflex driveshaft had been separated, with remnants of bolts and flex plates located underneath the engine. The parts were sent to the NTSB Materials Laboratory for further examination.

Figure 1 shows all the components received by the NTSB Materials Laboratory, including the Kaflex coupling, fractured flex plate remnants, attachment bolt fragments, and a separated outer shaft end fitting. Figure 2 shows the positions of the outer shaft fitting and interconnect fitting components of the Kaflex coupling, as positioned when attached together, with the male end of the shaft end fitting facing the cylindrical tube body of the interconnect.

As the male end of the shaft end fitting had inserted into the body of the interconnect, the outer surfaces of the cylindrical walls of the shaft end fitting

exhibited areas with circumferential wear marks. Figure 2 shows these more reflective rotational wear marks on the wider shoulder surfaces and recessed surfaces of the fitting. These features were mirrored on the interior surfaces of the interconnect, which can be viewed on the left in Figure 3. These features were consistent with the interconnect and shaft fitting rotating against each other.

The main body of the Kaflex coupling, including the interconnect fitting and several flex plates joined with attachment bolts, is highlighted in Figure 4. The partially destroyed label on the interconnect body stated: "FAA-PMA, ...MATICS CORPORATION, P/N SKCP2348-101, ...GIBLE FOR INSTALLATION, BELL 206A & 206B MODEL",

The rectangular-shaped flex plates had been joined to the interconnect flanges, outer shaft fittings, and other flex plates by attachment bolts with washers and nuts. Each intact bolt assembly had a small amount of orange wax to denote the as-torqued position (see the bolt nuts on the right side of Figure 4). The plates and bolts on the left side of Figure 4, however, were not intact, with the bolts in those positions having fractured or separated entirely. Figure 1 shows three of the bolt remnants, with one of the remnants still in a bolt hole of a flex plate (left side of Figure 4).

Figure 5 shows both surfaces of the separated outer shaft end fitting. The flange surfaces on the exterior and the inward-facing surfaces all exhibited streaks, scrapes, and gouge marks. These marks were rotational or circumferential in orientation. In addition, there was a remnant of a bolt still within one of the fitting flanges, shown on the right in Figure 5a and the left in Figure 5b. The nut was still affixed to the threaded portion of the shank, and the bolt remnant was intact, but the head had experienced severe batter and deformation—enough to pull part of the head and shank out and over the fitting flange. The hole at this location and one on the opposite 180° location both experienced elongations, consistent with the circumferential orientation of the other wear and impact marks.

Figure 6 shows two mating sides of a fractured attachment bolt. Each face of the bolt fracture surface exhibited thumbnail-shaped crack features. Both sides of the bolt exhibited a smaller cross section at the location of the fracture surface. This area exhibited gouges and a more reflective luster, consistent with rubbing, impact, and wear. The shank diameter was measured with digital calipers as 0.295 inches wide, but only 0.234 inches wide at the fracture surface. Likewise, on the bolt head side, the shank remnant diameter was measured as 0.305 inches, but 0.236 inches at the fracture surface. The length of the head remnant was 0.207 to 0.268 inches, with the location of the fracture surface initiation location on the shanks being 0.058 inches from the bottom surface of the head. The shank and threaded remnant of the fractured bolt measured 0.753 inches long.

The remnants of the bolt were cleaned in an ultrasonic bath with acetone. Figure 7 shows the fracture surface from the shank and threaded side. The surface exhibited crack arrest marks, which were convex inward, consistent propagation from the worn area of the shank. Several distinct areas of this fracture surface exhibited oblong areas with a more reflective luster—these regions were consistent with smearing from post-fracture impact damage.

Figure 8 shows the mating fracture surface from the head of the bolt. This surface exhibited less damage and shows the crack arrest marks emanating from an initiation site along the worn area of the shank (bottom of the figure). Figure 9 shows the fractured head of the bolt viewed from the side. Figure 9a shows the initiation site along the edge with the worn area, with crack arrest marks oriented consistent with inward propagation (downward in the figure). When viewed rotated 90° (Figure 9b), the fracture surface was shown to exhibit an angled orientation relative to the direction of the shank.

The crack initiation site was depicted on the left in Figure 9b, in the area that had been worn away (approximately 0.07 inches of the shank diameter). A closer view of the crack initiation site and its location are shown in Figure 10. The mating fracture surfaces are shown from the side in Figure 11, demonstrating the degree of material loss on the shank diameter of the bolt.

The bolt head fracture surface was examined using a field-emission scanning electron microscope (SEM). The majority of the fracture surface exhibited fatigue striations, consistent with fatigue crack propagation, as illustrated in Figure 12 and Figure 13. Near the end of the fatigue crack terminus, the surface exhibited more acicular morphology consistent with the material microstructure (typical of hardened alloy steels), along with fatigue striations (Figure 14). Outside of the fatigue crack, located as shown near the top of Figure 8, the surface exhibited dimpled rupture, consistent with subsequent overstress fracture of the remaining cross section of the bolt (illustrated in Figure 15).

Figures 16 and 17 show a closer view of the fatigue crack initiation site on the bolt head. This location exhibited crack arrest marks and river patterns emanating from the edge of the fracture surface (upward crack propagation in the figures). The initiation site itself, shown in Figure 18, did not exhibit any material discontinuities, such as voids, pores, or inclusions. There were localized areas of smoothing and smearing, consistent with post-fracture impact damage. However, the location near the initiation site did exhibit some microscopic surface scratches and grooves, present throughout the worn region of the shank material.

The composition of the bolt was examined using energy dispersive x-ray spectroscopy (EDS). The chemical composition was consistent with an alloy steel.

The four fractured flex plate remnants are illustrated in Figure 19. The plate remnants were labeled 'A' through 'D' for the purposes of this report, as annotated on Figure 19a. The face of the bottom plate remnant (D) in Figure 19a exhibited damaged markings stating, "CP 2373-11". The faces of plates C and D exhibited discoloration and reflective smoothing towards and around their bolt holes. This was consistent with rubbing and impact against adjacent components. In addition, the bolt holes (left side in Figure 19b) of plate remnants C and D had deformed and elongated from their original circular shapes. With plate D, the intact hole exhibited a diameter of 0.314 inches, whereas the diameter of the fractured hole was 0.354 inches in diameter.

Except for two surfaces, annotated in Figure 19b, the plate remnant fracture surfaces exhibited rough texture with a dull luster. There were often features consistent with shear lips. All these features were consistent with overstress fracture of these plates. On the left surfaces of plate remnants B and D, annotated on the left in Figure 19b, repeating parallel concentric features consistent with crack arrest marks were present. The features of these surfaces are detailed further below.

The fractured surface of plate remnant D is shown from the top face in Figure 20 and the surface and opened hole in Figure 21. The top-down view in Figure 20 shows a smooth, reflective region with rotational wear marks. The depression was consistent with the size and shape of the washers shown in Figure 1. The depression on the plate remnant was inconsistent with a countersinking or chamfering machining operation, as the profile was uneven with sharp corners, and most of the other bolt holes of the other plate remnants did not exhibit such a feature (the elongated hole of plate C also exhibited a similar washer-shaped depression).

The plate thickness was measured as 0.150 inches. In the washer-shaped depression, the plate remnant thickness reduced to 0.136 inches.

The bolt hole in plate D had been elongated, in a direction parallel to the fracture surfaces. This elongation was consistent with wear on the material along the hole surface, not as gross plastic deformation was present on the left side of the remnant in Figure 20.

Figure 21 shows the plate D remnant fracture surface. On surfaces on either side, crack arrest marks were observed. Figure 22 shows a closer view of the fracture surface to the right of the bolt hole. The entire surface exhibited crack arrest marks, consistent with propagation from the bolt hole on the side with the washer-shaped depression. Further outward on the right-side fracture surface, crack arrest marks were seen continuing, as illustrated in Figure 23. Figure 24 shows a closer view of the left-side fracture surface, which also exhibited crack arrest marks.

The fracture surfaces of plate remnant D were examined using a SEM. Figure 25 shows a typical view of features of the fracture surface on the right-side fracture surface. While faceted in morphology, this region of the fracture surface exhibited fatigue striations, consistent with fatigue crack propagation.

Figures 26 and 27 show different views of the fatigue crack initiation site. The area was located along the corner of the fracture surface, bolt hole surface, and the washer-shaped depression. As shown in the figures, crack arrest marks present were oriented convex outward, consistent with propagation from the corner initiation site. This corner exhibited deformation, impact marks, and smearing, all consistent with post-fracture damage indicative of contact with adjacent metallic parts. This damage prevented further conclusive examination of the location.

The area near the initiation site on the right-side fracture did exhibit crack arrest marks and initiation sites, as shown in Figure 28. A closer view of the individual striations is shown in Figure 29. Outside the fatigue crack terminus, located to the rightmost side depicted in Figure 23, was an area exhibiting dimpled rupture. This location was consistent with overstress fracture of the remaining plate cross-section after the fatigue crack had propagated to that location.

The chemical composition of the plate remnant was examined in the overstress fracture region using EDS. This composition was consistent with a maraging steel.¹ This material is typical for flex plates in these couplings.

The fracture surface on the left side of the bolt hole in Figure 21 was also examined, and found to exhibit fatigue striations, as typified in Figure 31. The orientation of these striations was consistent with having propagated from an initiation site at the corner of the bolt hole surface (see Figure 32).

Unlike the right-side fracture surface, this initiation site was located on the corner of the face opposite that of the washer-shaped depression. The darker area was examined using EDS and was found to contain aluminum and minor amounts of copper, consistent with a 2000-series aluminum alloy. This initiation site also exhibited smearing and batter, consistent with post-fracture impact damage to the area.

One of the fracture surfaces of plate remnant B is shown in Figure 33. The bottom edge of the fractured plate remnant contained multiple thumbnail shaped cracks, which exhibited features distinct from the rough, dull remainder of the fracture surface. These thumbnail cracks exhibited arrest marks and ratchet marks, consistent with fatigue cracking at multiple initiation sites. The largest crack depth was 0.05

¹ Maraging steels are a class of high-strength steels that are hardened by the precipitation of intermetallic compounds, rather than by carbon.

inches, whereas the fatigue fracture on plate D was the entire thickness of the part, or 0.150 inches.

A view of the lower face of the plate remnant B, shown in Figure 34, found multiple parallel cracks along the face. These cracks were consistent in orientation with the fracture surface and the thumbnail crack that had initiated from that side.

Submitted by:

A handwritten signature in black ink, appearing to read 'E. Mueller', with a long horizontal stroke extending to the right.

Erik M. Mueller
Materials Research Engineer



Figure 1. The components from the Kaflex coupling assembly, as received



Figure 2. The shaft end fitting and interconnect fitting from the Kaflex coupling, as received.



Figure 3. Closer view of the connecting cylindrical surfaces of the outer shaft end fitting and interconnect, showing circumferential wear features.

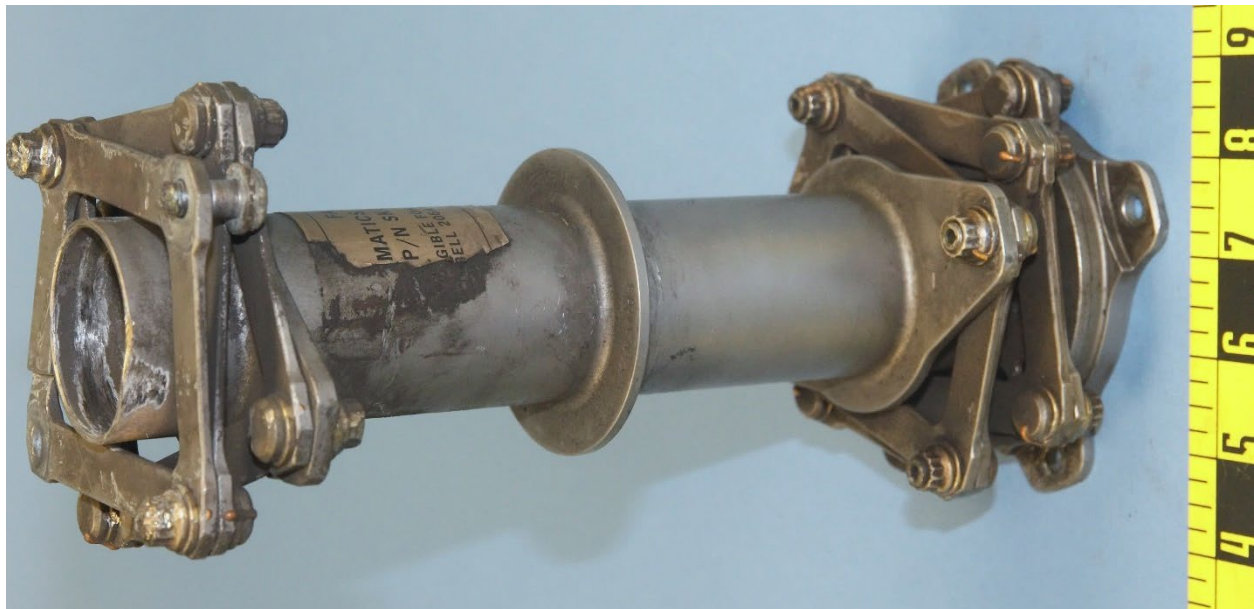


Figure 4. Angled view of the main body of the interconnect fitting and plate assembly, showing internal wear marks and deformation of the tube.



Figure 5. Views of (a) the interior and (b) exterior of the shaft end fitting.



Figure 6. Mating pieces of the fractured bolt from the coupling.



Figure 7. View of the bolt fracture surface from the shank remnant attached to the nut.

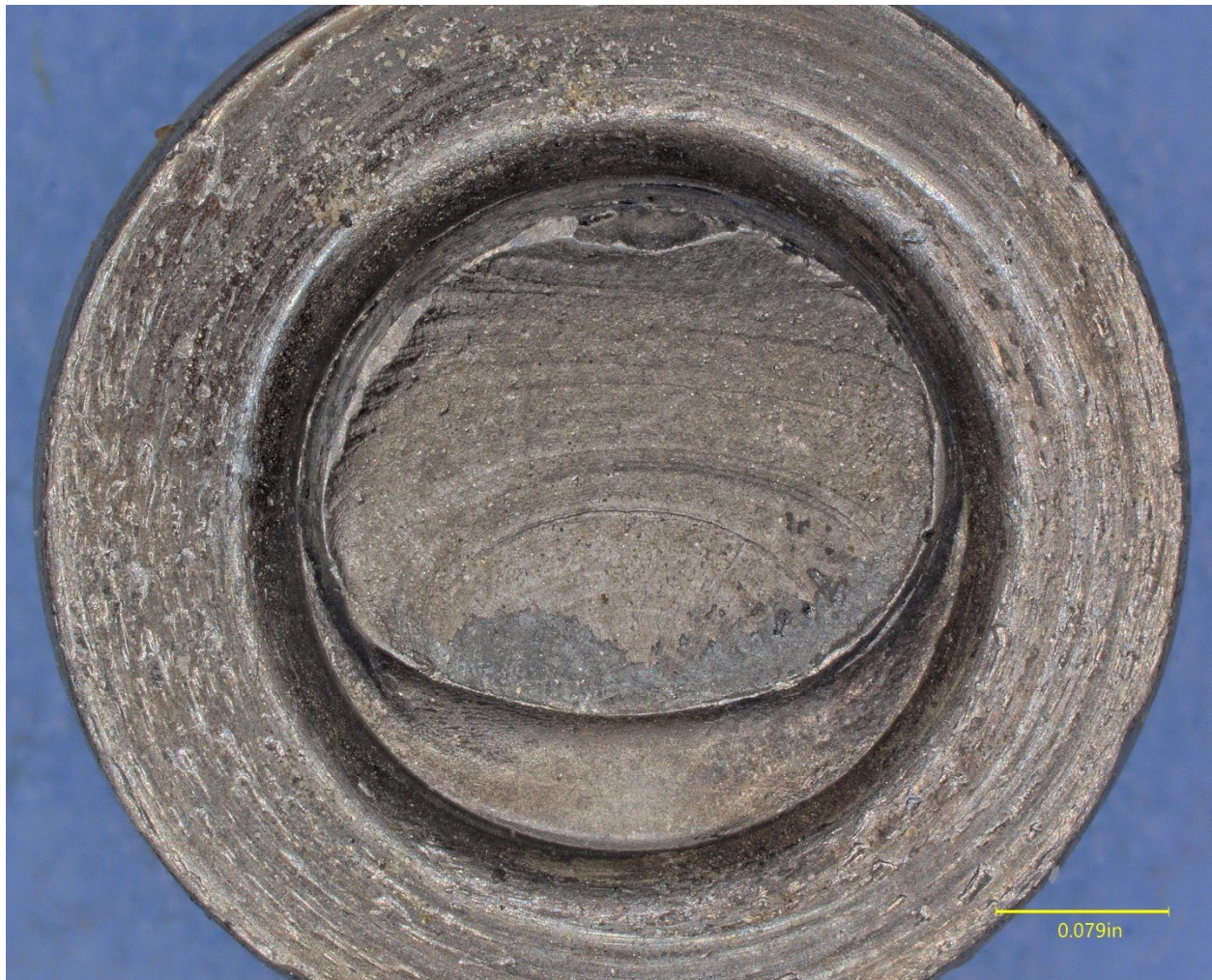


Figure 8. View of the bolt fracture surface from the head remnant of the bolt.

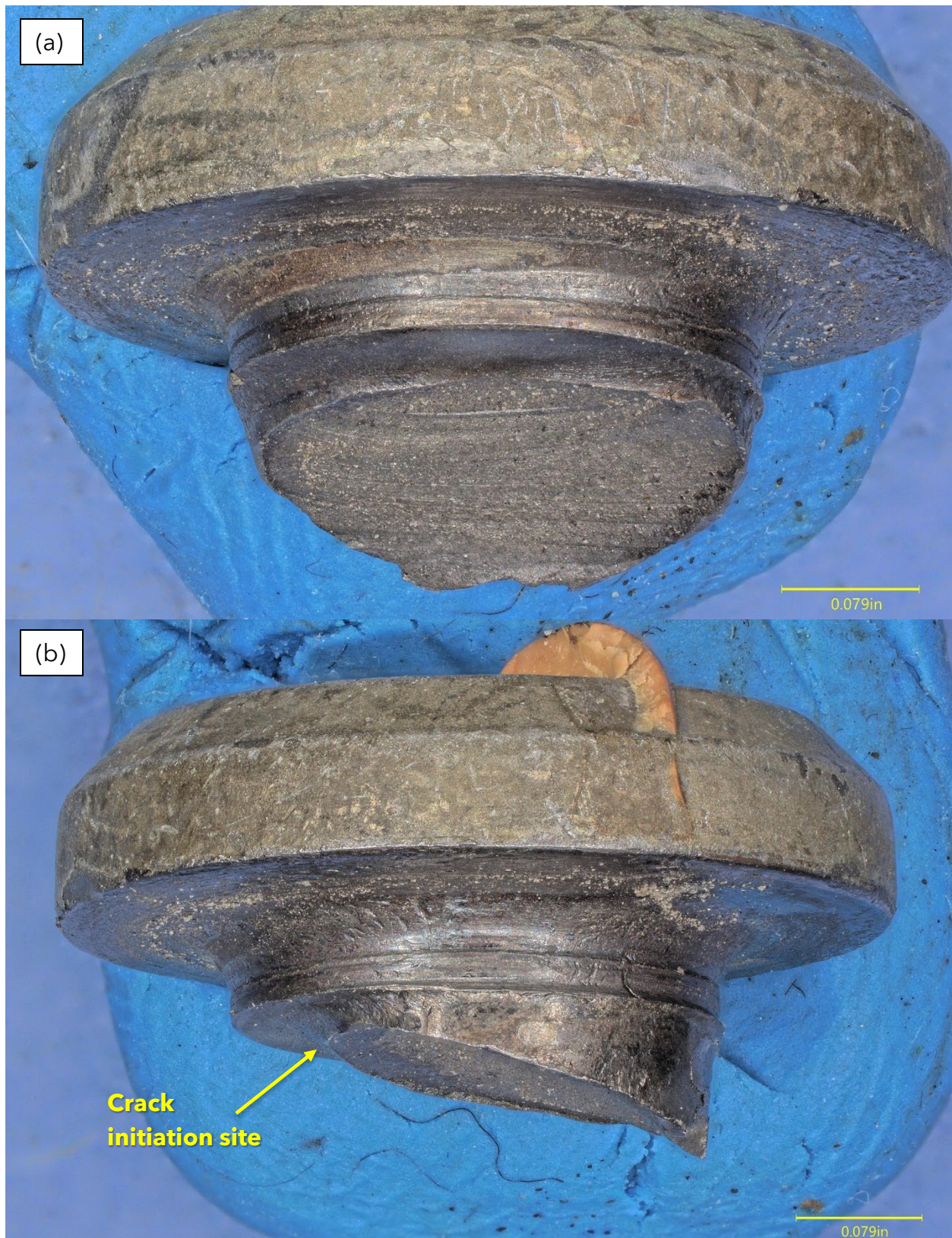


Figure 9. Side views of the head remnant of the bolt, showing (a) the crack initiation site and (b) rotated 90°, demonstrating the wear near and geometry of the fracture.

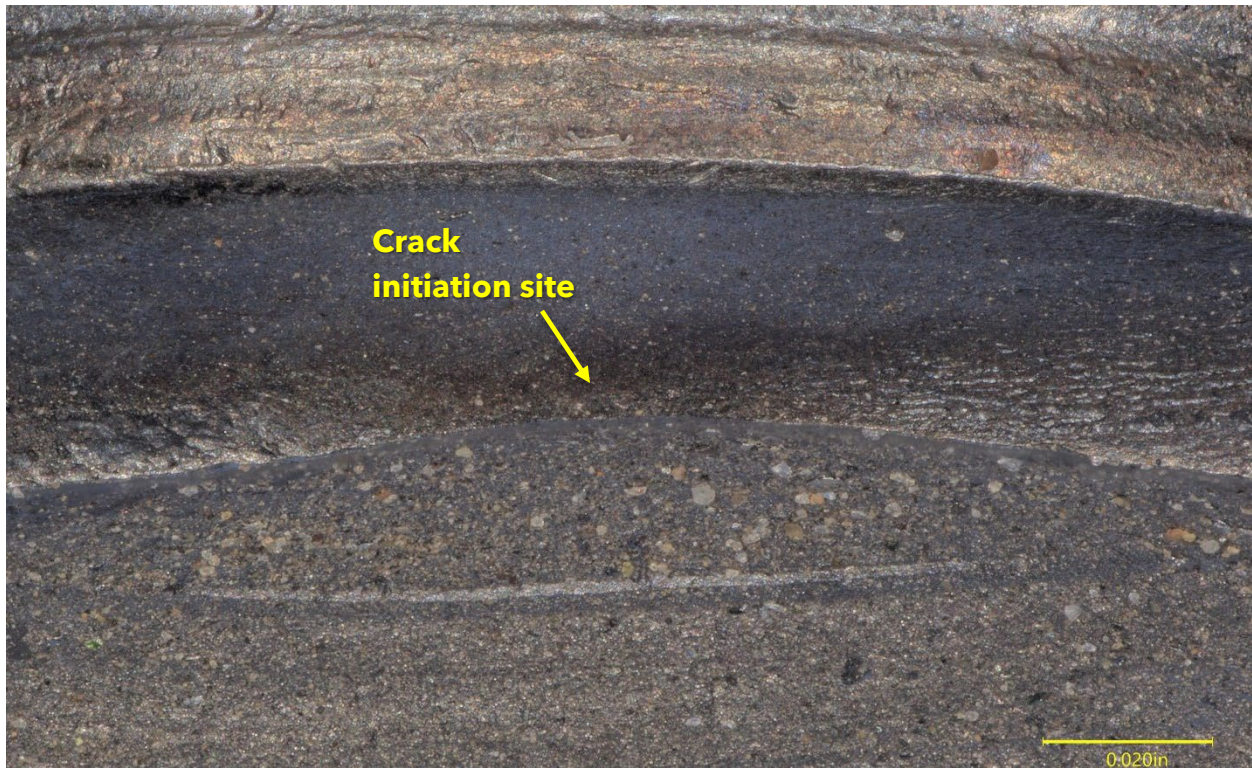


Figure 10. Closer view of the crack initiation site (arrow) of the bolt head remnant.

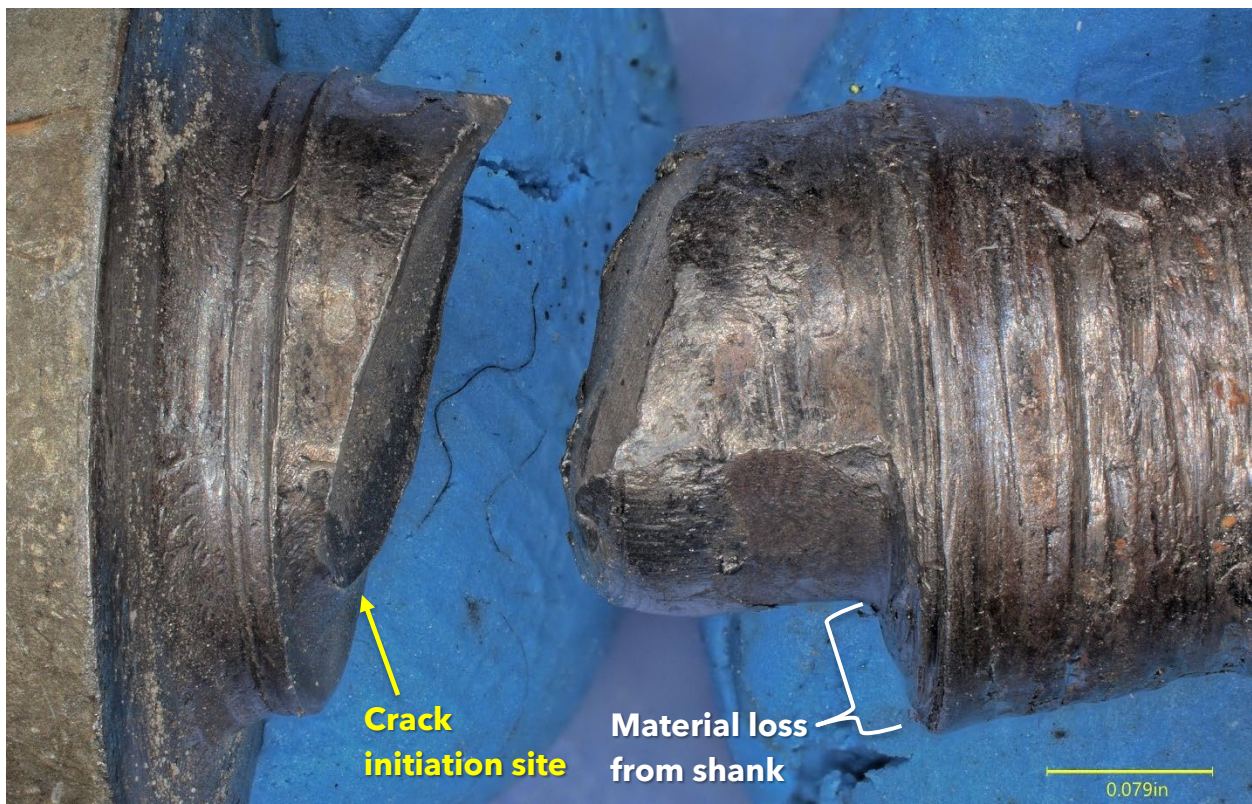


Figure 11. Closer view of the mating fracture surfaces of the bolt, positioned facing each other, with the degree of wear highlighted.

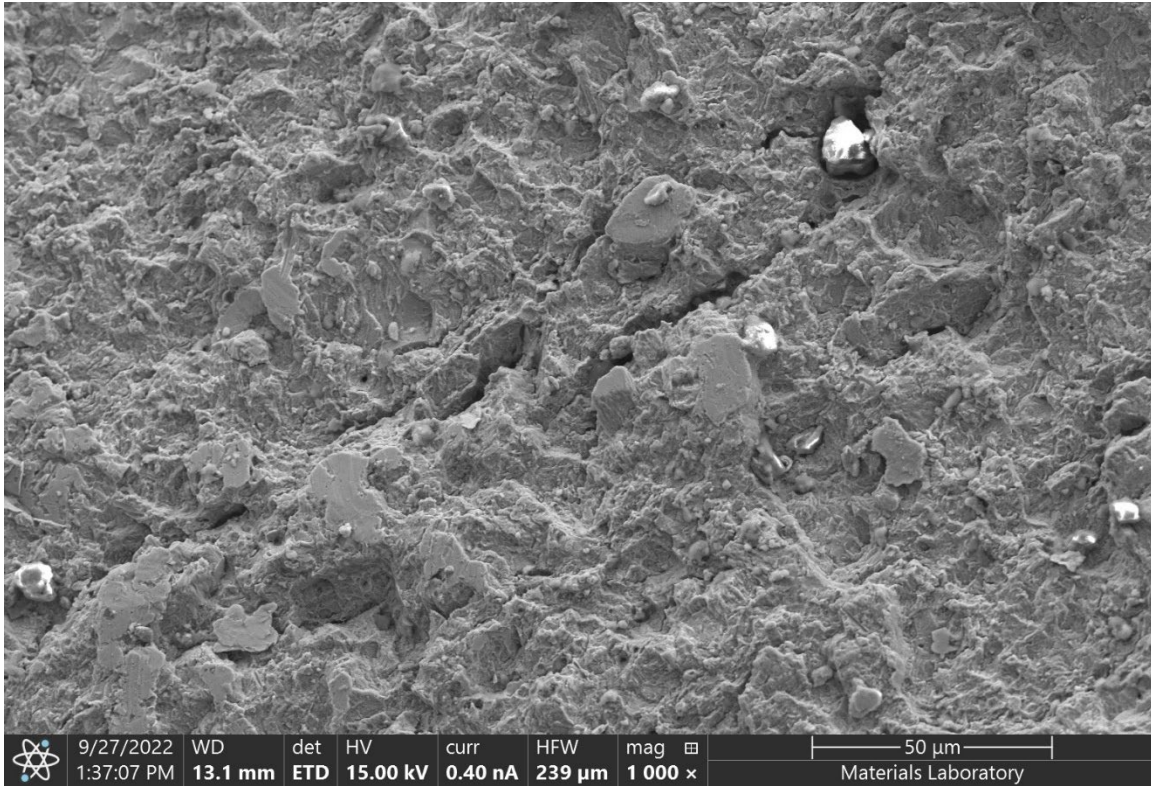


Figure 12. Secondary electron (SE) micrograph of a typical area of the bolt head fracture surface.

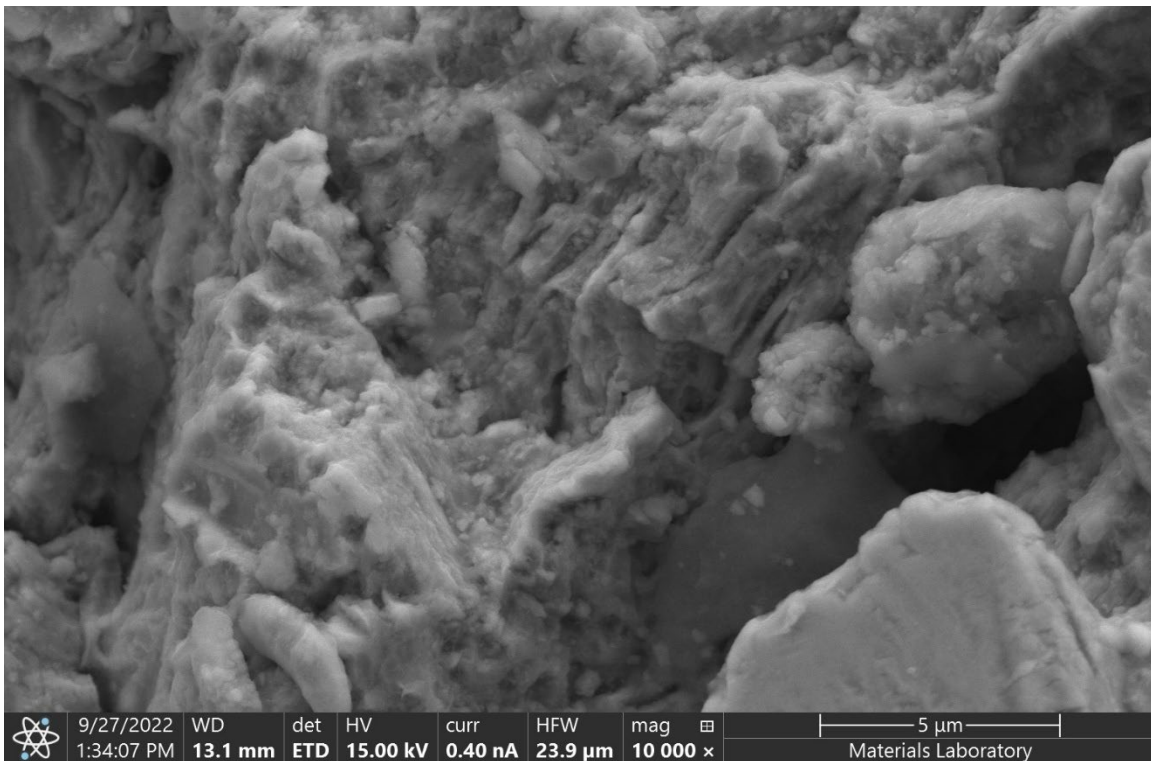


Figure 13. SE micrograph of a closer view of Figure 12, showing fatigue striations.

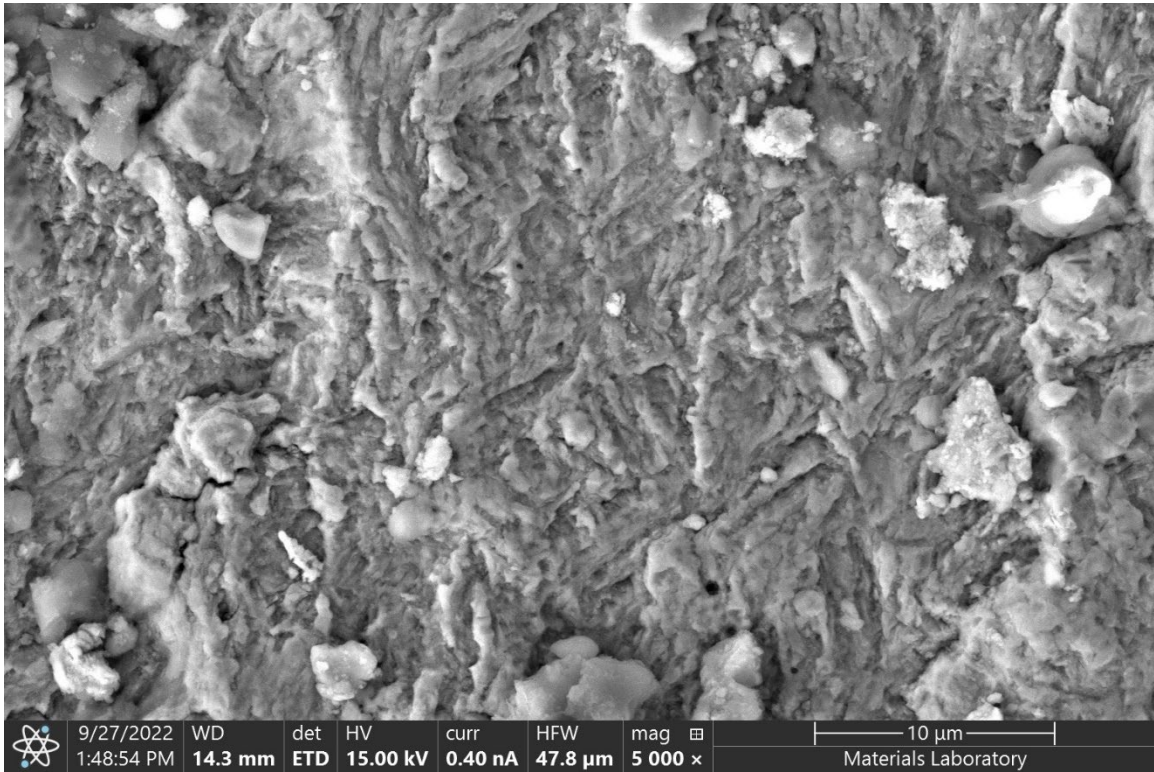


Figure 14. SE micrograph of striations near the end of the crack on the bolt fracture.

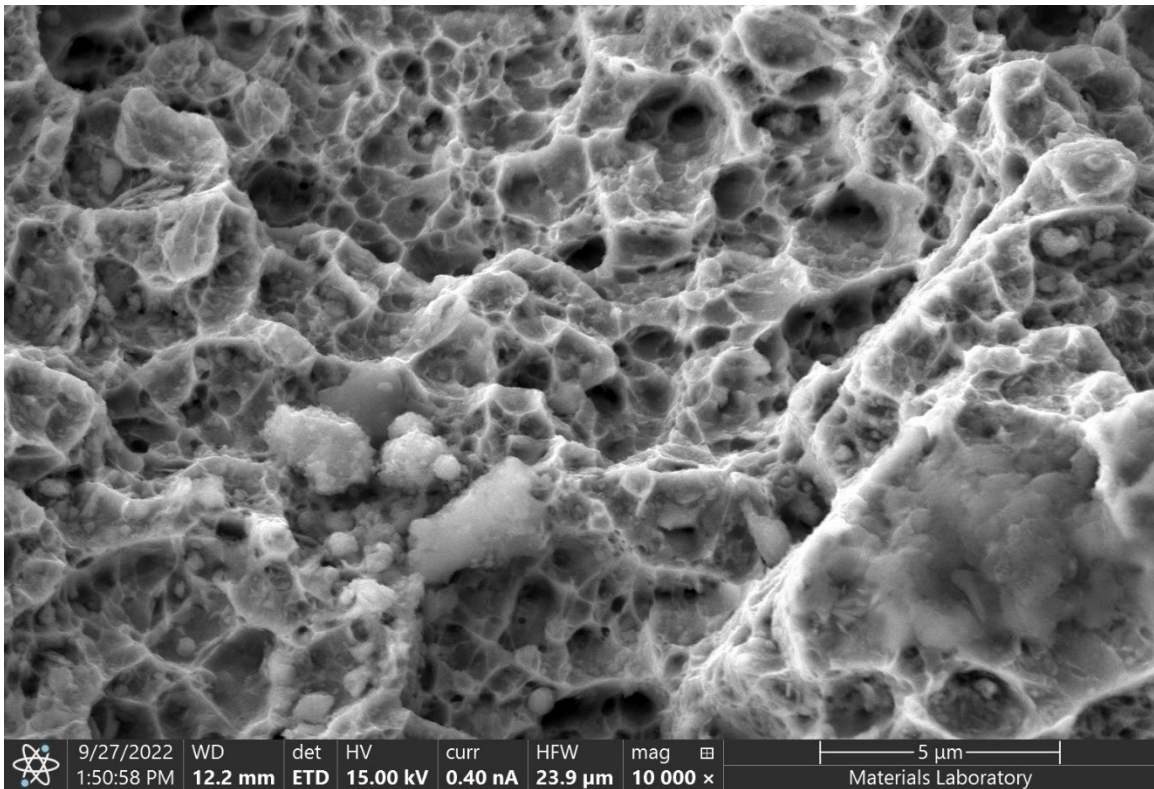


Figure 15. SE micrograph of dimpled rupture outside the fatigue crack on the bolt.

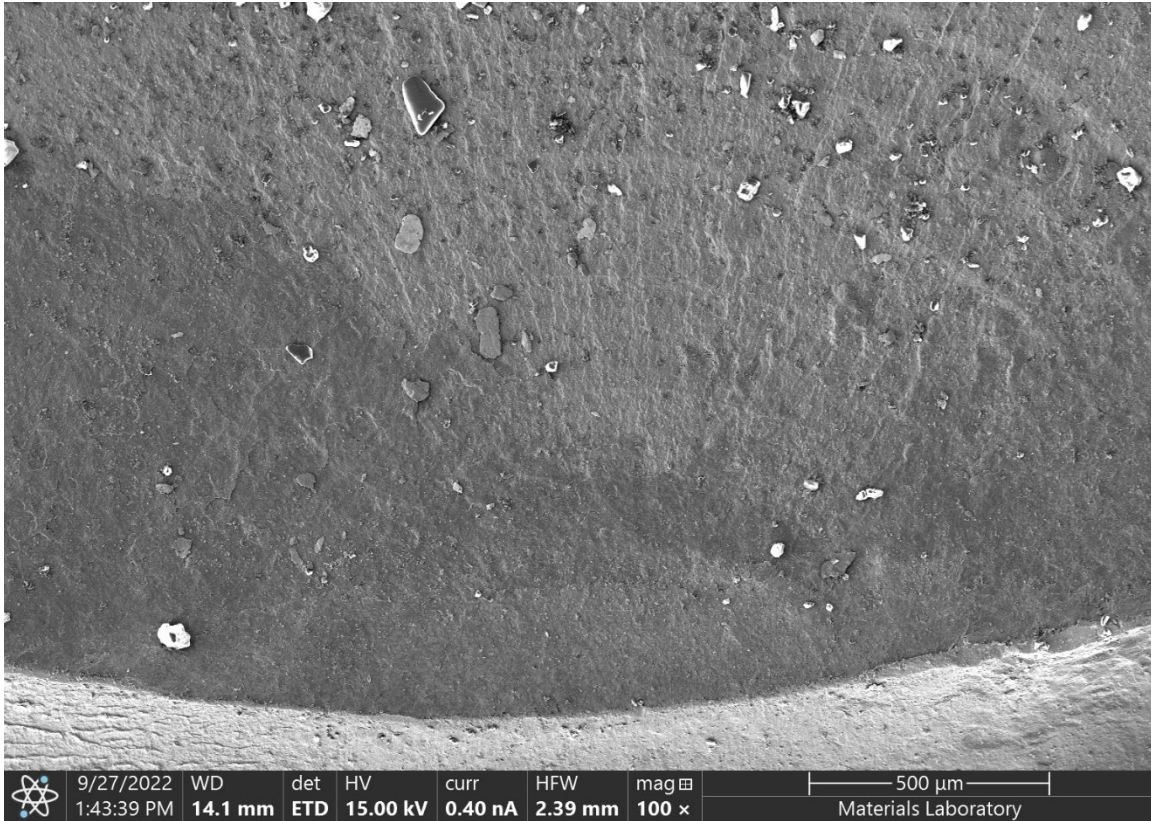


Figure 16. SE micrograph of the fatigue crack initiation site on the bolt fracture.

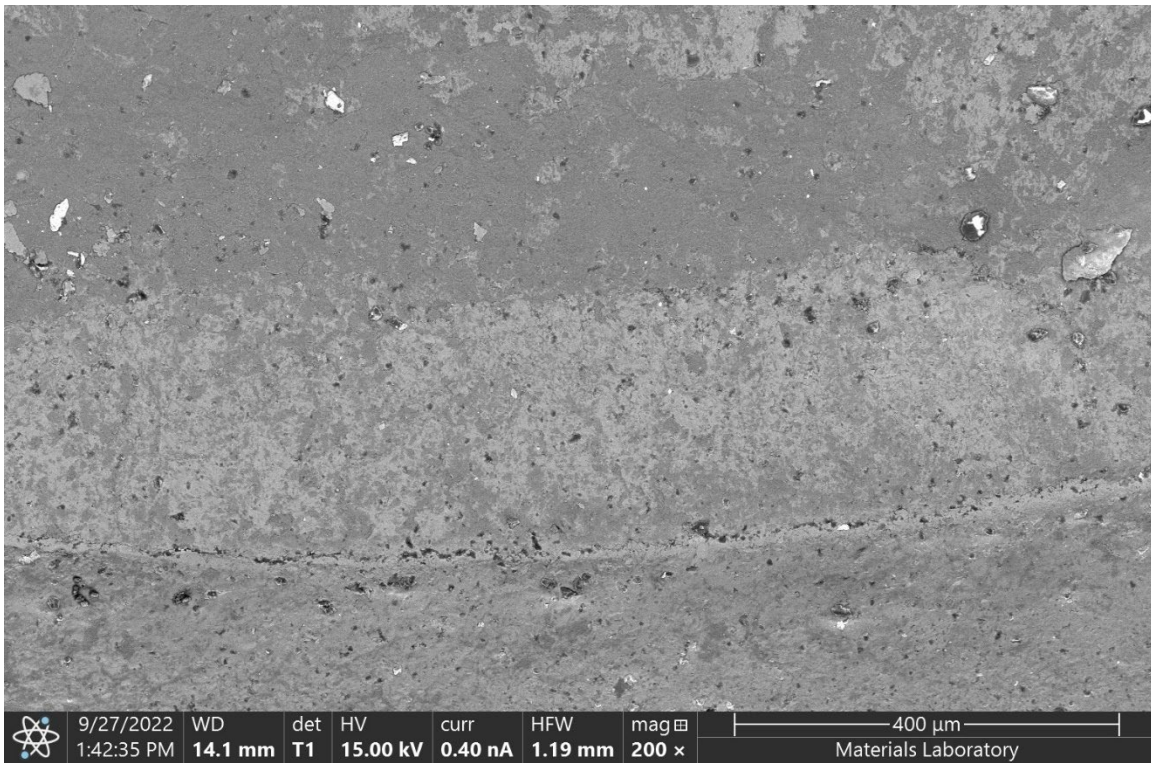


Figure 17. Backscattered electron (BE) of a closer view of the initiation site.

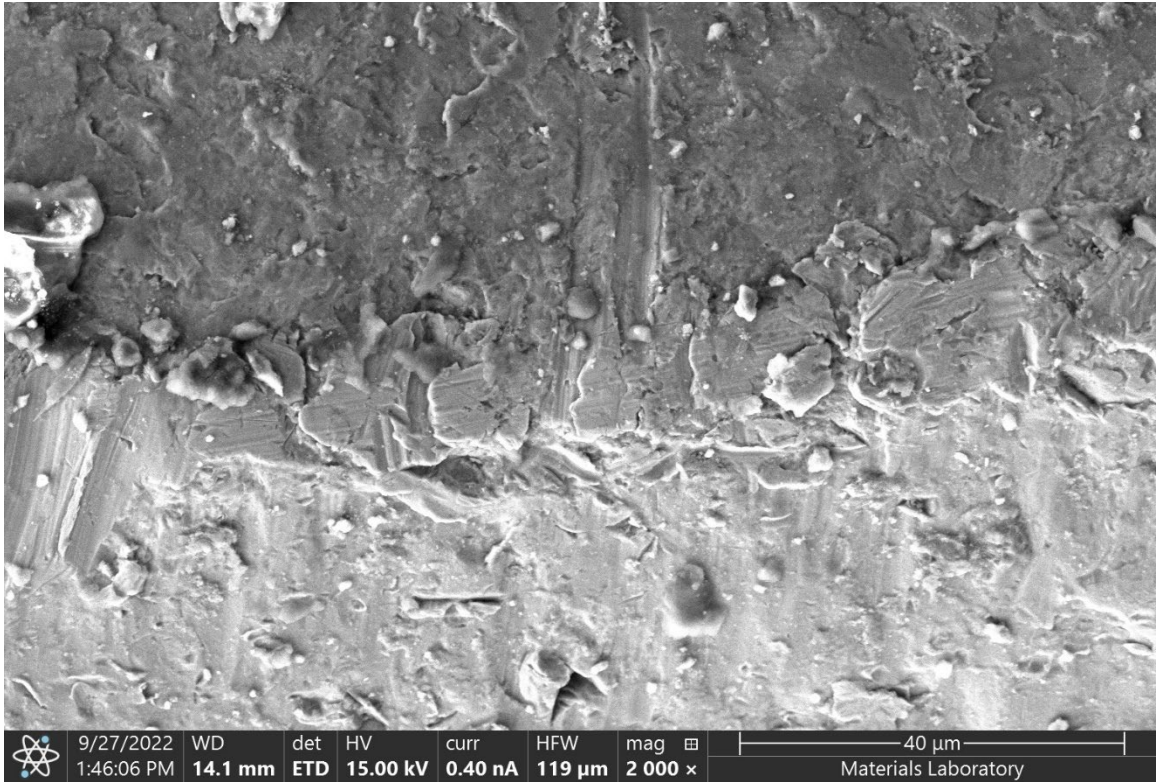


Figure 18. SE micrograph of the edge of the fatigue crack initiation site, showing smearing and edge deformation.

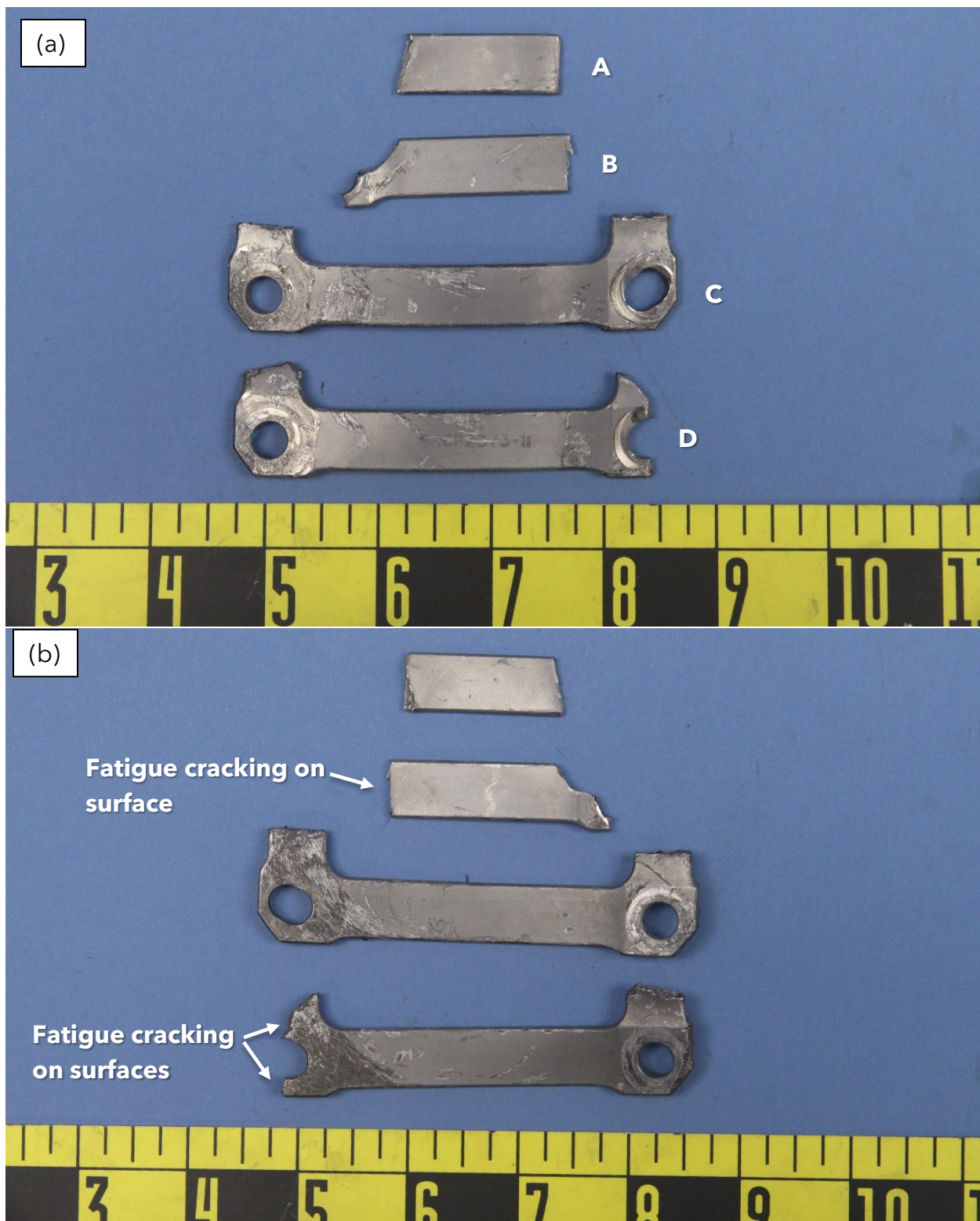


Figure 19. Opposite views of the fractured flex plates remnants. The annotated plate fracture surfaces were examined further.

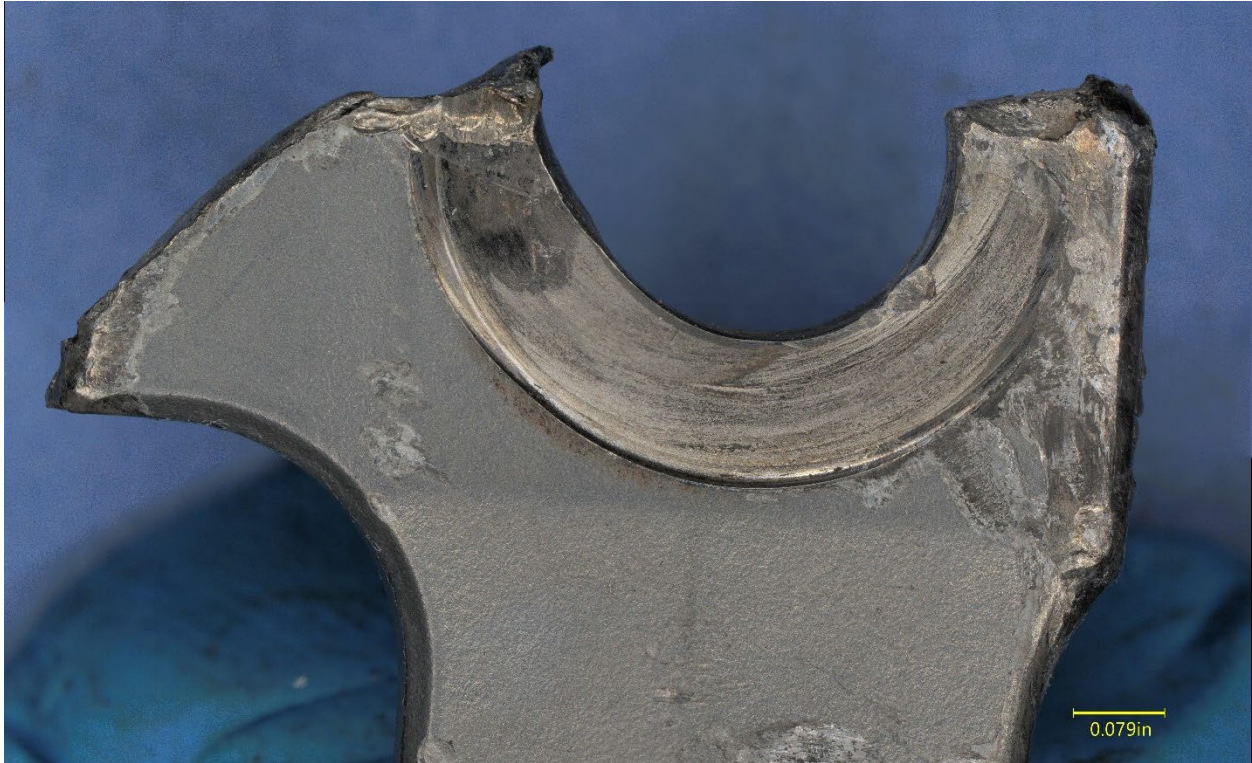


Figure 20. Top down view of the larger fractured flex plate remnant D, showing circular wear marks.



Figure 21. View of the fracture surface of the plate remnant D in Figure 20, showing crack arrest marks consistent with crack propagation from both sides of the bolt hole.



Figure 22. Closer view of the plate fracture surface on the right side of Figure 20.



Figure 23. The remainder of the right-side fracture surface, located to the right of Figure 22.

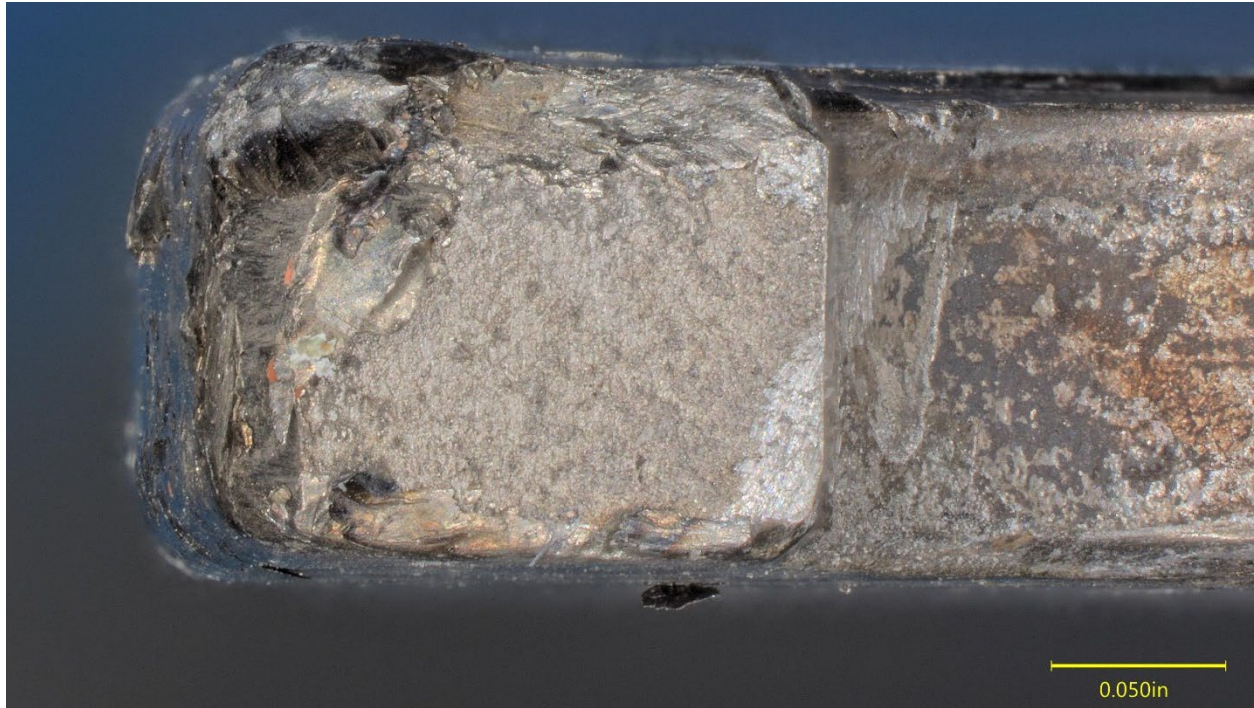


Figure 24. Closer view of the link fracture surface on the left side of Figure 20.

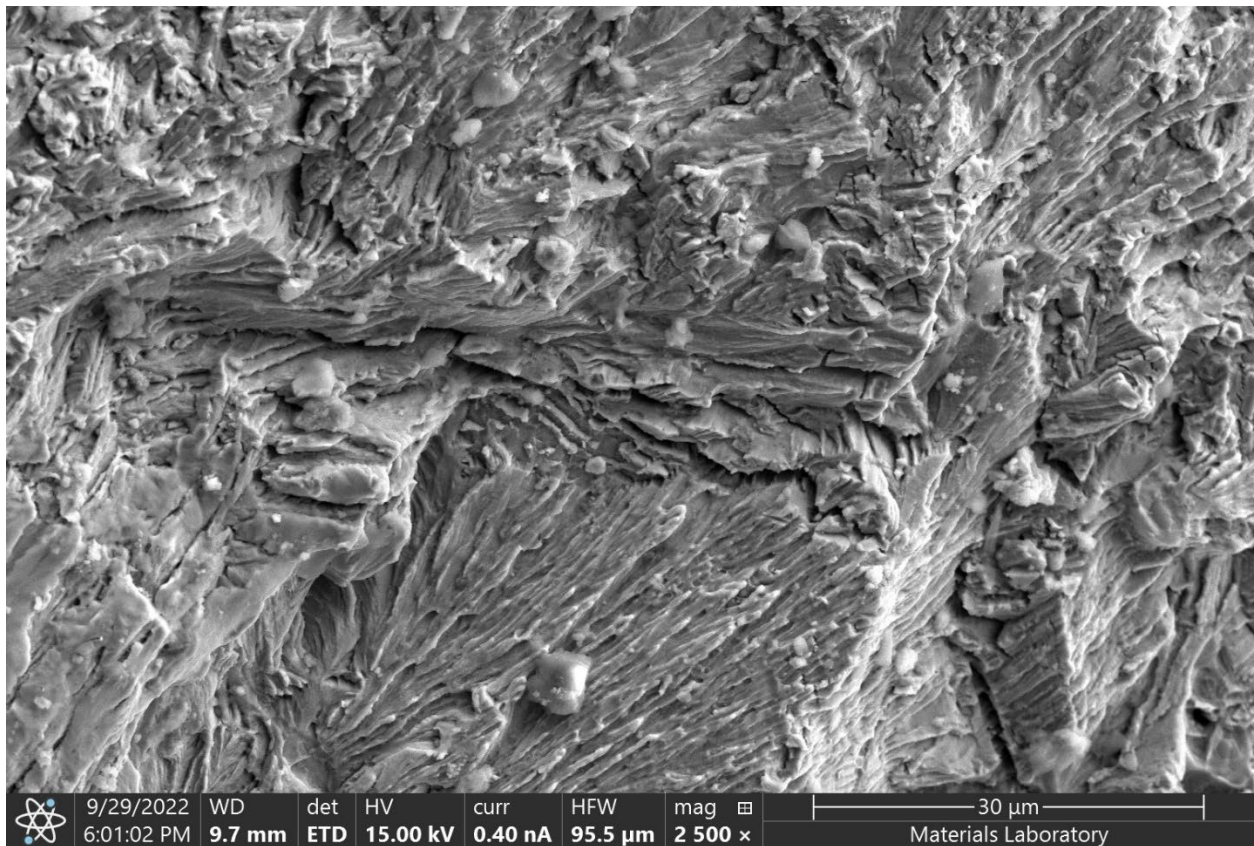


Figure 25. SE micrograph of a typical area of the right-side fracture surface.

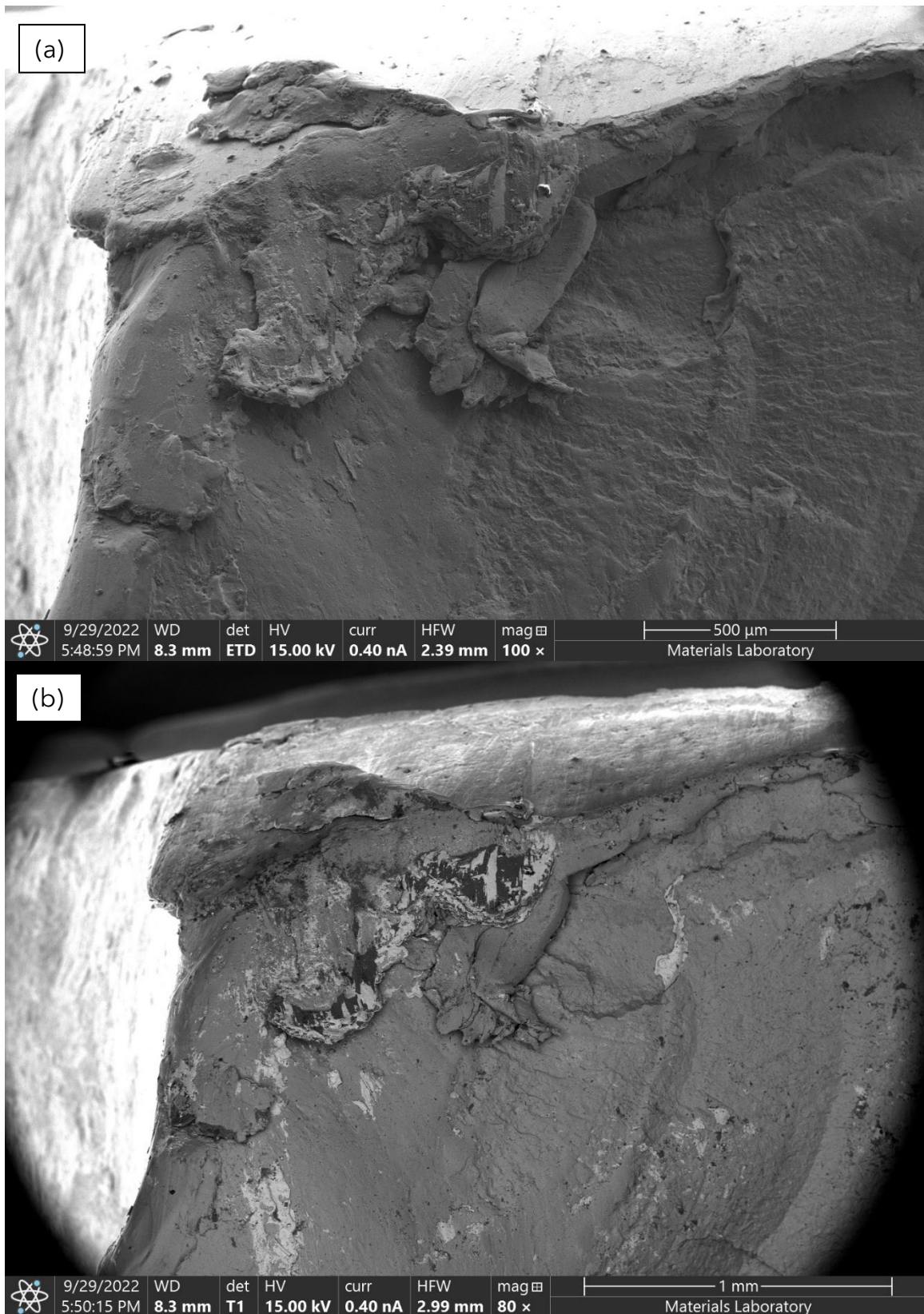


Figure 26. (a) SE and (b) BE micrographs of the fatigue crack initiation site of the right side fracture surface of the plate remnant D.

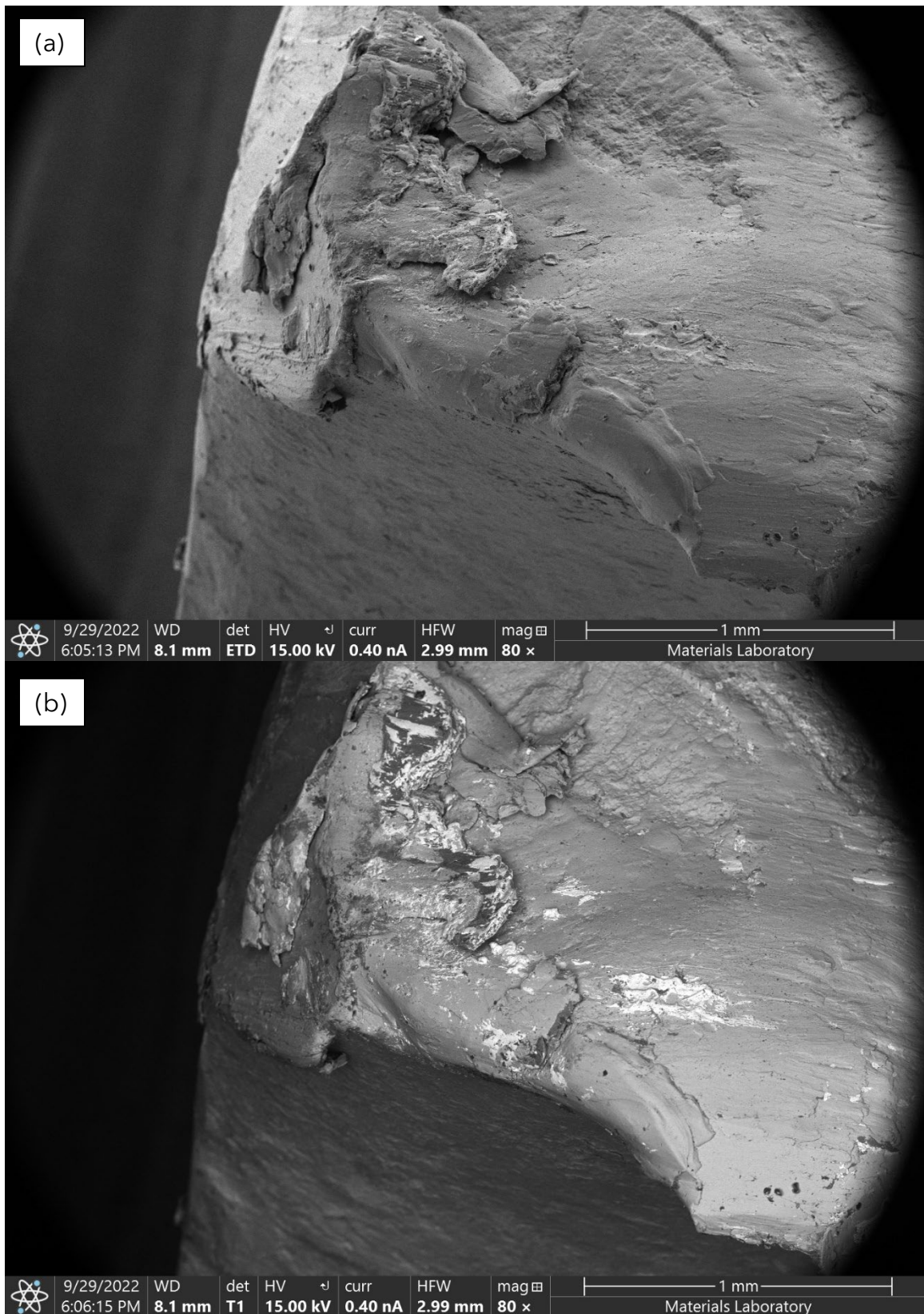
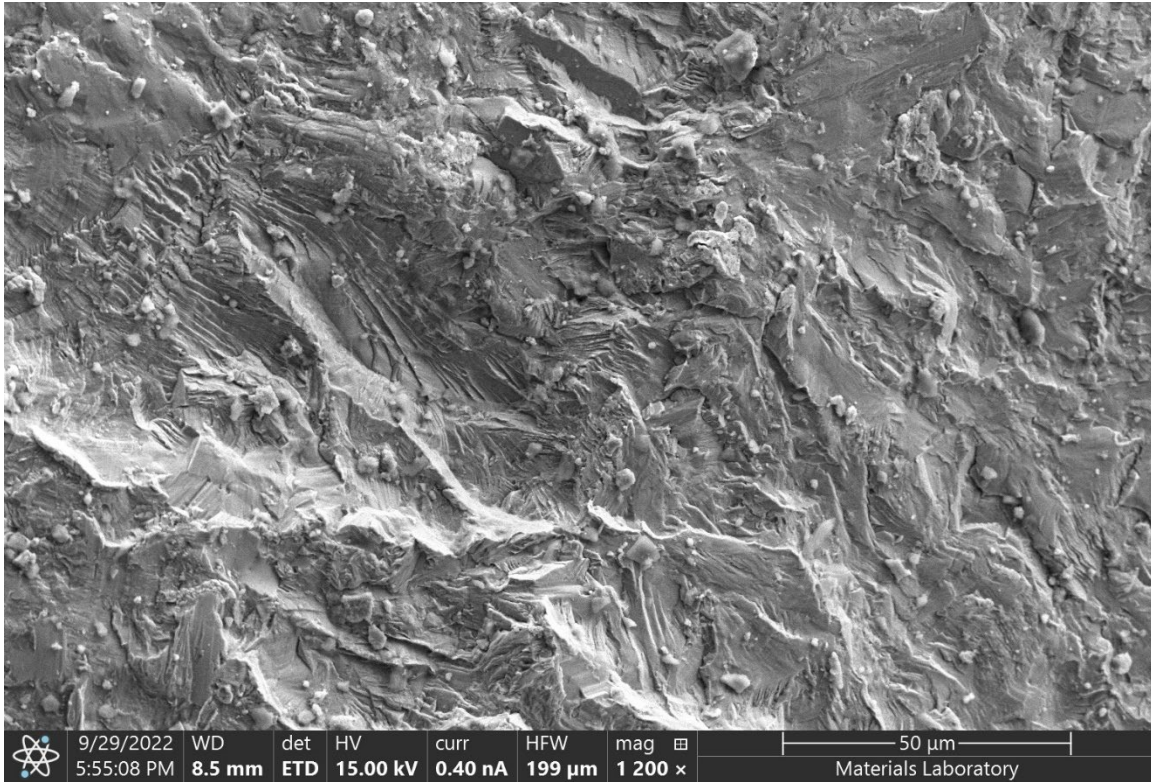


Figure 27. (a) SE and (b) BE micrographs of an angled view of the fatigue crack initiation site of the right side fracture surface of the plate remnant.



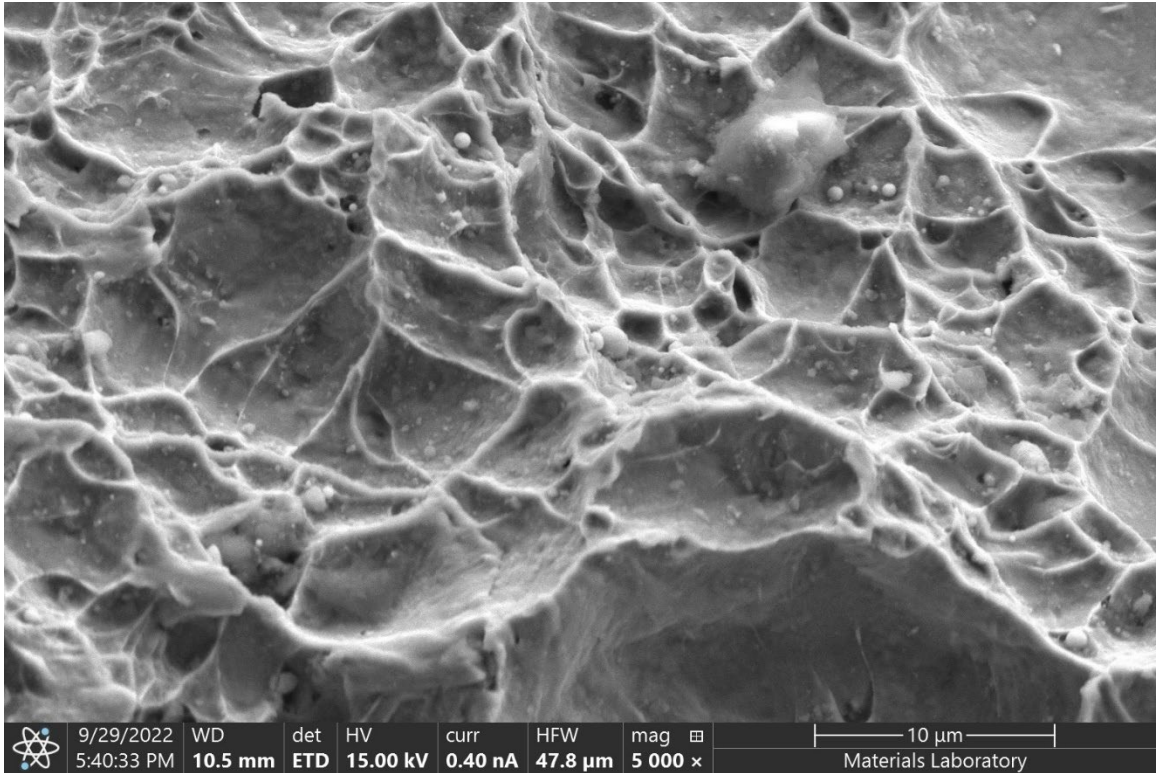


Figure 30. SE micrograph of dimpled rupture outside the right-side fatigue crack.

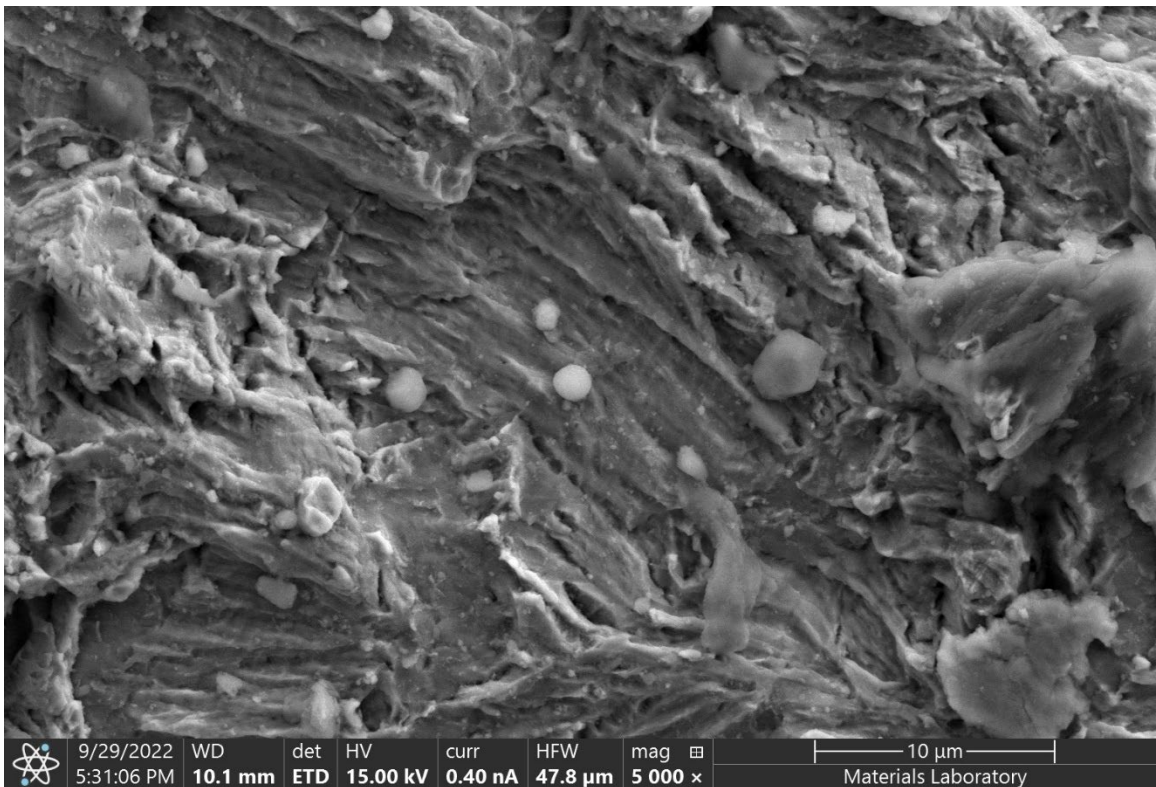


Figure 31. SE micrograph of striations near the left-side crack initiation site.

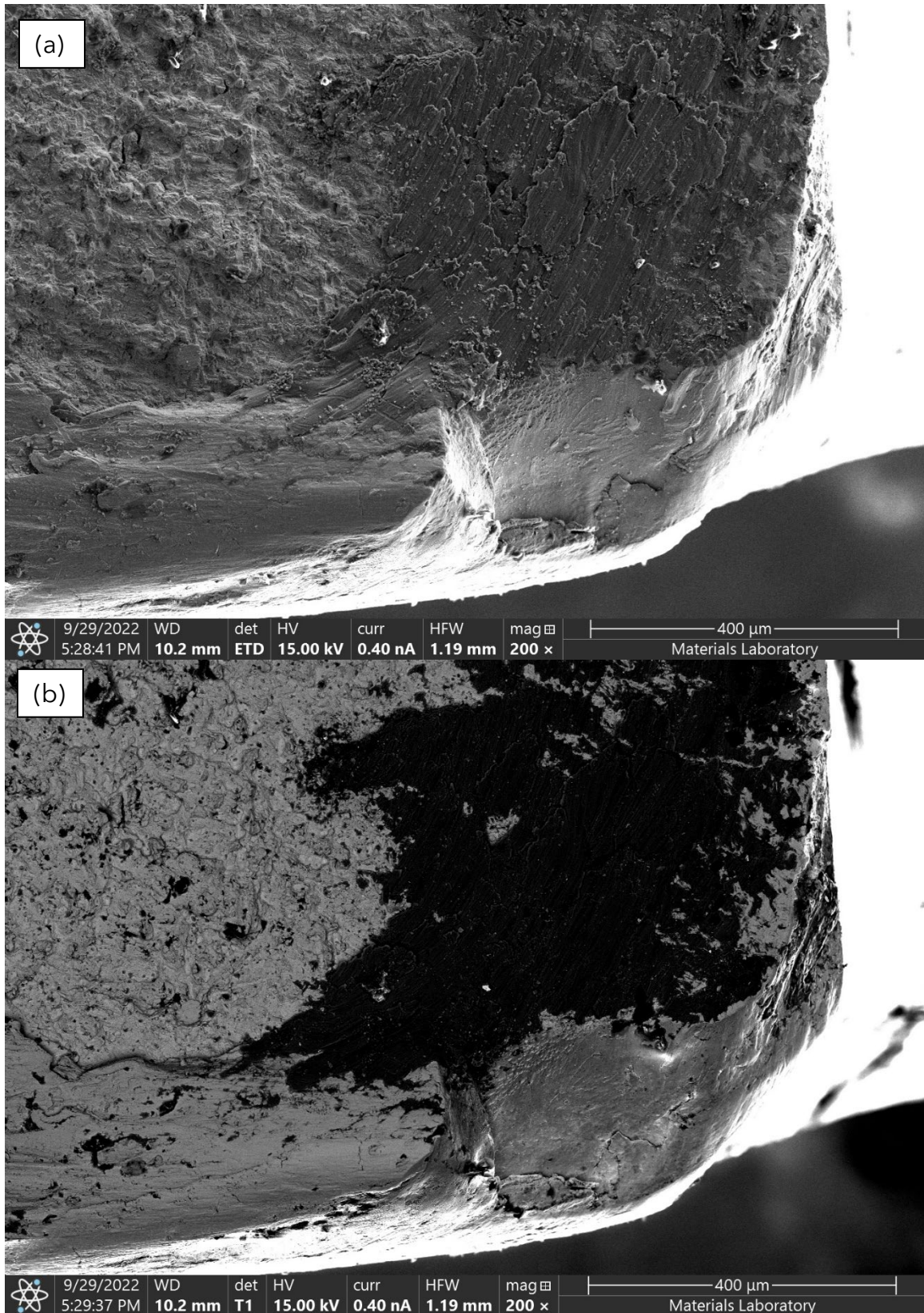


Figure 32. (a) SE and (b) BE micrographs of the fatigue crack initiation site of the left-side fracture surface of the plate remnant D.



Figure 33. The fracture surface of the flex plate remnant B, showing fatigue regions, as small thumbnail cracks along the bottom edge.



Figure 34. View of the bottom surface of the fractured plate remnant B in Figure 33, showing multiple parallel angled cracks.