

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN23LA232

MATERIALS LABORATORY

Factual Report 24-022

May 20, 2024

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A. ACCIDENT INFORMATION

Location: Bloomfield, Nebraska
Date: June 7, 2023
Time: 13:30 central daylight time
18:30 coordinated universal time
Vehicle: Grumman G-164B, N48485
Investigator: Tim Sorenson, AS-CEN

B. COMPONENTS EXAMINED

Cam gear and shaft assembly
Loose metal debris

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., PE, FASM
Office of Research and Engineering – Materials Laboratory Division
NTSB, Washington, DC

D. DETAILS OF THE EXAMINATION

On June 7, 2023, a Grumman G-164B airplane was substantially damaged when it was involved in an accident near Bloomfield, NE. The pilot was not injured. The pilot reported a loss of engine power during takeoff and executed a forced landing to an agricultural field off the end of the runway. The airplane sustained damage to the upper and lower right wings. The airframe and engine were recovered from the accident site, and a camgear and camshaft assembly were sent to the NTSB Materials Laboratory for additional examination.

The examination of the pieces from a camgear and shaft for the Materials Group took place at the 5th floor materials laboratory at NTSB headquarters in Washington, DC, on Tuesday, March 19, and Wednesday, March 20, 2024. Additional examination was performed without the group members present following these dates.

1.0 Examination of the Assembly and Seized Camshaft

Figure 1 shows the received camgear, shaft, and bag of loose debris. Figure 2 shows the remnant of the assembly from two different rotations, and Figure 3 displays each end of the shaft. The assembly consisted of a slotted shaft, a camgear, a bearing, and a sectioned remnant of the surrounding housing. The surrounding housing, affixed to the outer race of the bearing, was stationary, but the bearing could be rotated about the shaft. Further, the inner race of the bearing could be slid a short distance longitudinally along the mating surface of the shaft up to the camgear. The camgear itself would not move in any direction.

The assembly was first examined by sectioning the housing remnant and removing the supporting washer. The components are displayed in Figure 4 after this sectioning, revealing the surface of the bearing outer race. As shown, the camgear could not be moved, consistent with having seized on the shaft.

The amount of the slot present towards the left side of Figure 5 was 0.22 inches. Different views of each face of the slot that faced the bearing and gear side of the shaft are shown in Figure 6 through Figure 9. Figure 10 shows an angled view of the slot visible from the opposite face of the camgear, which faced the straight shaft end. The amount of the slot present on this side was 0.03 inches longitudinally. The slot shown in Figure 7 was named Slot 1, and the slot in Figure 6 was named Slot 2 for the purposes of this examination.

The figures were taken as received and before any cleaning. In all the figures, mud-cracked compounds were present along the edge between the camgear and the shaft. These compounds were also present within the slots and the pinhole, as shown in Figure 8. The compounds exhibited both a dull black and yellowish-orange color. The compounds from each side and area were extracted and collected for later examination.

After removing the excess surface compounds, the camshaft assembly was cleaned in an ultrasonic bath with acetone. Figure 11 shows the slot visible from the shaft side, whereas Figure 12 through Figure 14 show areas of the slot on the pinion and bearing side of the camshaft. Of note was the condition of the bushing on the interior surface of the camgear—at two slot edge corners in contact with the inner bushing surface. Figure 12 and Figure 13 show the bushing deformation longitudinally against the shaft (upward in the figures) on slot 1.

A similar but less pronounced deformation was also visible on the bushing inner surface in contact with the clockwise edge corner of slot 2, shown in Figure 14. Two concentric damage marks were present near this contact and deformation.

2.0 Examination of the Disassembled Camshaft

The shaft was sectioned between the seat of the bearing and the seized camgear along the more prominent slot protrusions. Figure 15 and Figure 16 show different views of the shaft interface with the bushing from the pin and slot 2, respectively. Disassembly allowed the markings on the face of the camgear to be visible, which stated, "ASSY 3037-404."

Once sectioned, the camgear readily slid off of the shaft. The sectioned and separated subcomponents are illustrated in Figure 17. Figure 18 shows different rotations of the opposite sections of the camshaft, with the pinion and bearing seats

positioned on the left. The area on the shaft where the camgear had been seated still exhibited yellowish-brown compounds. This area of the sectioned shaft is shown at different angles in Figure 19.

The two areas of damage at the corners of the slot adjacent to the inner bushing surfaces were found to align, as illustrated in Figure 20 and Figure 21. The grease line in these figures indicated the seized camgear's position before separation. Figure 22 and Figure 23 show closer views of the concentric damage patterns on the corner of the slot 2 edge, previously shown in Figure 14.

The grease remnants were collected to better examine the damaged areas of the slots on the shaft, and the shaft was cleaned in an ultrasonic bath of acetone. Figure 24 and Figure 25 show the damaged areas of the slot corners, positioned to show their alignments with each other and the pinhole. Figure 24 shows the circular damaged area of slot 1, and Figure 25 shows the concentric damage pattern of slot 2.

Figure 26 and Figure 27 show direct views of the damaged area on the corner of slot 1 of the shaft. As illustrated in these figures, the damage pattern manifested as convex ovoid areas, exhibiting radiating cracking from an area consistent with inward deformation or indentation of the slot face. The degree of deformation is illustrated in Figure 27.

The shaft diameter was measured with digital calipers after the disassembly. The outer diameter away from the areas of deformation damage measured 0.3735 inches. When the outer diameter was taken in a plane incorporating both areas of outward deformation at the slot corners, the diameter was as wide as 0.3780 inches.

The shaft was examined using a field-emission scanning electron microscope (SEM), which confirmed the radiating cracking pattern shown in Figure 28 and Figure 29. A closer view of the cracking found the concurrent areas of localized fractured and spalled material (see Figure 30).

As shown in Figure 31 and Figure 32, these areas of spalled material exhibited forks and tongues consistent with cleavage fracture. This type of fracture on this material was consistent with the higher hardness and lower ductility properties typical of a nitride (surface-hardened material). As found from examination using energy-dispersive x-ray spectroscopy (EDS), the spalled areas exhibited a composition consistent with 17-4 precipitation-hardened stainless steel and nitrogen contents typical of nitriding processes.

As shown in Figure 33, some of the spalled areas in the cracking contained material with a higher atomic number (Z).¹ Rather than sharp, faceted cleavage features, this material was mottled and smoother in surface features, consistent with dissimilar material. Portions of the spalled surface also contained lower-Z material, indicated by the darker regions in Figure 30.

A reverse view of the slot 1 damaged area revealed a circular indentation pattern on the slot face. The diameter of a circle fitted to this indent was approximately 0.14 inches. Figure 34 and Figure 35 show the extent of this deformation, with Figure 36 highlighting the localized cracking along the corners of the region. Like the cracking on the surface, the cracks at the indented area radiated outward from a central location (Figure 37).

As illustrated in Figure 38, some of this cracking developed into localized surface material spalling (left in the figure). In some instances, the spalled regions were backfilled with dissimilar material. While the surface and fractured areas of the shaft exhibited compositions consistent with a ferrous material (exemplified by the spectrum in Figure 39), the higher-Z dissimilar material was consistent with a copper alloy (Figure 40).

Figure 41 and Figure 42 show closer views of the damaged area on the corner of slot 2 on the shaft. Like slot 1, this damaged area was next to an indentation at the slot face surface. Unlike slot 1, the impression pattern into the shaft was angled and flat rather than rounded (see Figure 43 and Figure 44). The interior distance between the angled indentation was 0.094 inches, and the exterior was 0.103 inches.

Multiple cracks were present at the corners of the impression (Figure 45). Where they intersected, the cracks had developed into fractured and spalled material, as shown in Figure 46 through Figure 48. Like the spalled regions on the exterior surface, these chipped areas at the slot 2 indentation corners exhibited features consistent with cleavage fracture.

Parallel cracks occurred along the surface with the indent (see Figure 49). In several locations, mainly where these cracks were closely spaced (less than 50 mm), regions of material had spalled. As shown in Figure 50, this spalling exhibited rounded regions, with some areas of cleavage fracture features and some areas of smearing, consistent with post-fracture wear.

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.

3.0 Examination of Materials Characteristics of Camshaft

As illustrated in Figure 39, the chemical composition of the camshaft was consistent with a 17-4 precipitation-hardened (PH) stainless steel. This composition was the prescribed material for the camshaft. The surface areas also exhibited elevated high nitrogen content, consistent with a surface nitriding treatment. The composition of the bushing material was consistent with that of Figure 40, consistent with a C660 copper alloy, as prescribed for the bushing.

The camshaft was cross-sectioned, mounted, polished, and etched with Fry's Reagent. Figure 51 shows a typical view of the cross-section, showing the exterior nitriding layers on both the exterior and internal surfaces. Figure 52 shows a typical area of the core microstructure, exhibiting a tempered martensitic structure with well-dispersed precipitates typical of the chemical composition. Figure 54 shows closer views of the nitriding layer. This layer was between 0.001 and 0.002 inches in thickness. Several areas of the nitride layer exhibited cracking, as illustrated in Figure 53 and Figure 54.

As measured using a microindentation hardness tester per ASTM E384, the hardness in the nitriding layer averaged 54 HRC (574 HK₅₀₀). The hardness in the core averaged 40 HRC (385 HK₅₀₀). These data were typical of a surface nitride layer and precipitation-hardened stainless steel, respectively.

The metal debris was examined using x-ray fluorescence (XRF). The debris was consistent with an aluminum casting alloy. This composition was consistent with that of the sectioned housing remnant when examined by EDS and XRF. This housing remnant had been attached to the bearing outer race when received (Figure 1).

All the compounds collected from the bearing, shaft, and bushing surfaces were examined using a Fourier-transform infrared detector (FTIR). The spectra generated from these specimens were consistent with Aeroshell 17 grease, irrespective of the collection location.²

4.0 Examination of the Camgear and Bushing

Figure 55 shows the two faces of the camgear, seen from the bearing/pinion and shaft sides. After cleaning the interior, the bushing was still affixed in the camgear bore, and its interior is illustrated in Figure 56. The bushing interior exhibited longitudinal witness marks consistent with the dimensions of the mating camshaft slots. These areas with the slots still exhibited cross-hatched markings consistent with those made by the original machining.

² Aeroshell 17 is a fully synthetic grease since replaced with Aeroshell 64, manufactured by Shell UK Oil Products Ltd., headquartered in London, United Kingdom.

In contrast, the surrounding areas exhibited more longitudinal wear marks, consistent with movement against the camshaft exterior. As shown in Figure 56, outward deformation of the interior edge of the bushing coincided with the most pronounced longitudinal wear marks, consistent with the corner of slot 1.

The camgear and bushing were bisected and cleaned with acetone to facilitate examination of the longitudinal wear marks. Montage images of the mating sides are shown in Figure 57. A closer examination of the corner deformation found it outward from the bushing face and depressed inward along the longitudinal witness mark (Figure 58 and Figure 59). The most pronounced damage was on the bottom of this side in Figure 58, but on the top in Figure 59. Also, both figures show wear and localized deformation of the shaft interior corner with the pinhole (center of Figure 58 and Figure 59).

Along with the camgear, the bushing was sectioned, with these surfaces shown in Figure 57. On both sides, the longitudinal wear regions coincide with the pin holes. Figure 58 shows a closer view of the bushing end interior near the mating damage of slot 1 of the shaft. Figure 59 shows the bushing interior edge near the slot 2 corner.

Both bushing interior surfaces exhibited deeply gouged areas with protruding plastic deformation on the edges. These areas were examined using a SEM. Figure 60 shows the outward deformation of the slot 1 area of the bushing interior. The edge exhibited foreign material, which manifest as the darker regions along the protrusion in the figure. Examination of this material found it to be consistent with carbon-based nonmetallic compounds.

Embedded materials were commonly found along the worn bushing areas as illustrated in Figure 61. These materials were often fractured in multiple locations, and their edge morphologies were mirrored in the surrounding bushing material. These features were consistent with harder material embedded in softer material. EDS probes of the embedded material in Figure 61 were consistent with the nitrided steel of the mating camshaft.

Other disparate material was observed, as shown in Figure 62. This material on the bushing exhibited a wrinkled and curled morphology. Examination with EDS found the material consistent with the mating PH stainless steel material of the camshaft, absent high nitrogen levels. Both the materials demonstrated in Figure 61 and Figure 62 were consistent with wear debris from the camshaft embedded or affixed to the mating bushing surface.

5.0 Examination of Bearing

The bearing removed from the camshaft is shown in Figure 63. The face of the inner bearing race bore the following markings: "ND SS R8 USA." There were no severe

gouges or other witness marks on the exterior faces of the bearing components, and the bearing could rotate freely when actuated without discernible noise or impingement.

The bearing balls were still in place with no loose debris, as shown in Figure 64. The race surfaces facing the balls did exhibit dark material buildup, as illustrated in Figure 65.

6.0 Examination of Camshaft Pinion Gear

Figure 66 shows some of the teeth of the pinion gear of the camshaft. While the teeth were intact, they exhibited cracking or material spalling areas. The most damaged tooth was the one illustrated in Figure 67. There were larger areas of discolored wear along the face of the tooth.

Along the flank of the tooth closer to the bottom land, there were areas of parallel cracking features, shown in Figure 68. While the wear on the face was similar in size and shape to the reverse face of the same tooth (Figure 69), there was an absence of the same kind of cracking along the flank, as demonstrated in Figure 70.

The gear end of the camshaft was examined using a SEM. The edges of the teeth were positioned as illustrated in Figure 71 to configure the teeth for imaging. This corner and that of the adjacent tooth to the left in the figure exhibited cracking along the flanks and the addendum and dedendum surfaces facing towards the lower right in Figure 71.

Figure 72 shows a closer view of the cracking. The cracks on both surfaces exhibit branching as the cracks move away from the corner—this was consistent with the cracking originating at the corner. Much of the cracks exhibited angular regions of missing material. As demonstrated in Figure 73, this was consistent with limited material spalling adjacent to the cracks.

Figure 74 and Figure 75 show closer views of the cracking along the flank and the nearby fillet radius. This area exhibited three parallel longitudinal cracks that had branched out just to the left of the corner, as shown in Figure 74. Secondary cracking was observed teeing off these cracks in a vertical direction. As shown in Figure 75, some spallation areas exhibited a clamshell shape. Figure 76 shows a closer view of the spalled regions. This figure exhibited cleavage fracture features, consistent with that observed in the nitriding layer on the shaft near the slot.

The opposite corner is shown in Figure 78. This corner also displays cracking on the flank and front face of the tooth. Of note is the corner in the figure, where cracking emanates from an area of spalled material. Figure 79 shows a closer view of the

spalled material at the corner. This spalled region also exhibited similar cleavage features, consistent with those observed along the nitrided surface of the camshaft.

The features on the gear were consistent with shallow cracking on several of the gear teeth, concentrated in the surface nitride region. Areas of wear were consistent with the interaction of the tooth face against the face of the mating teeth.

Submitted by:

Erik M. Mueller
Materials Research Engineer

7.0 Figures



Figure 1. The camgear/camshaft assembly and a bag of metallic debris, as received.

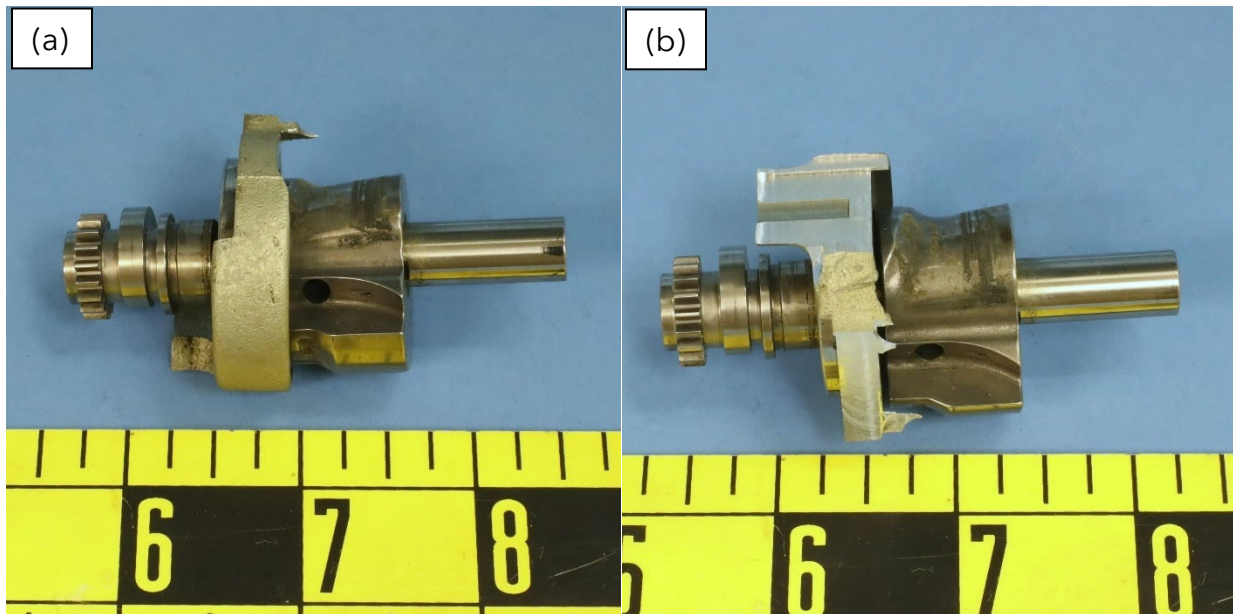


Figure 2. View of the camshaft/camgear assembly as received from opposite rotations of the seized camgear.

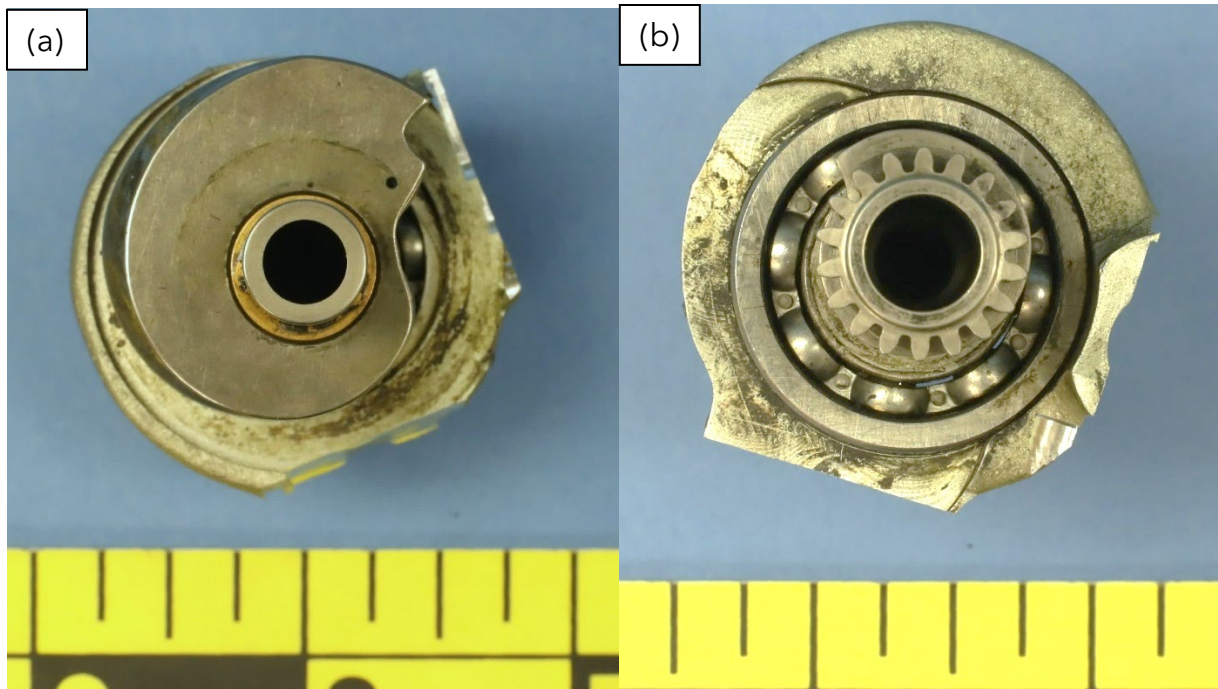


Figure 3. View of the assembly from (a) the shaft end and (b) the pinion gear end.

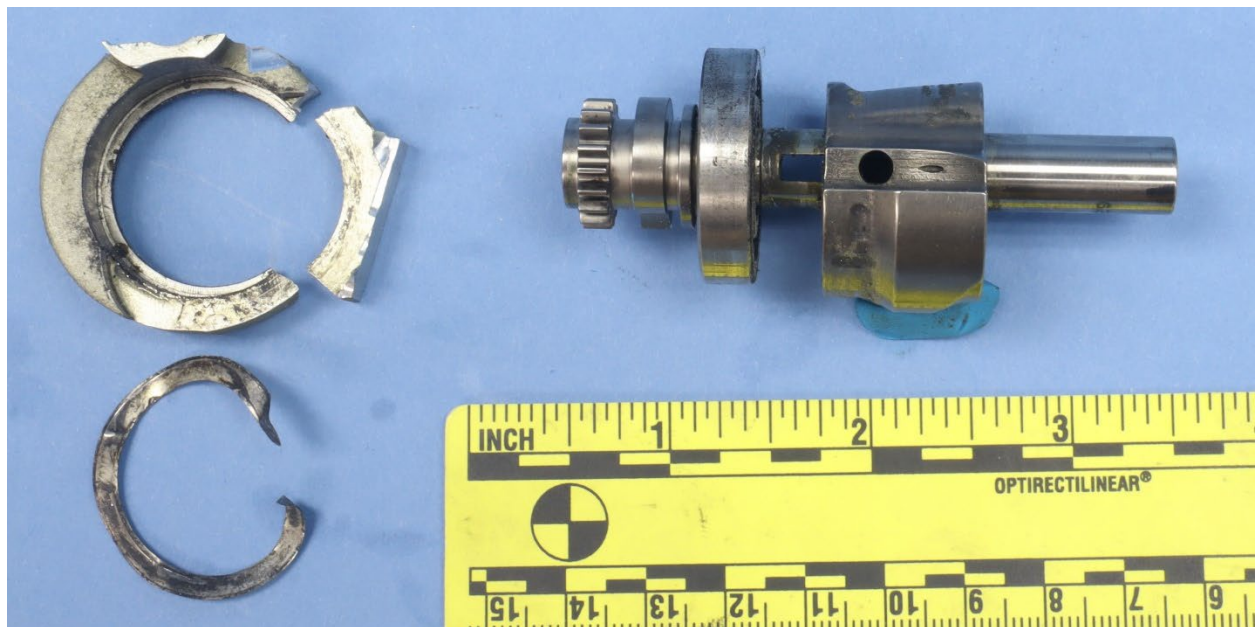


Figure 4. The camshaft assembly components after sectioning and removal of the housing remnant and washer.

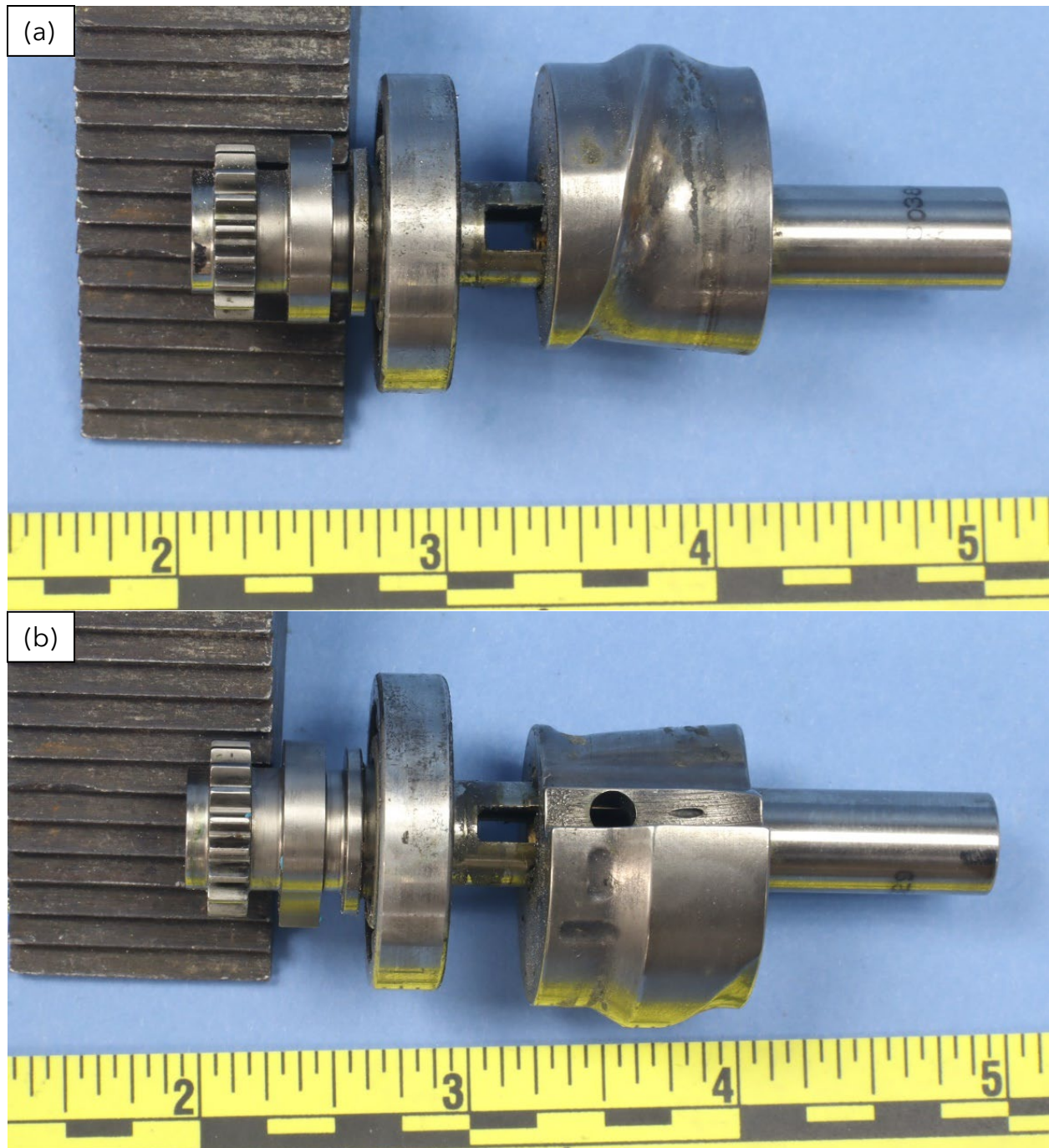


Figure 5. Isolated view of the camshaft assembly with the bearing on its seat, rotated 180° of the camgear.



Figure 6. Angled view of the shaft and camgear face from the pinion side of the shaft, showing slot 2.

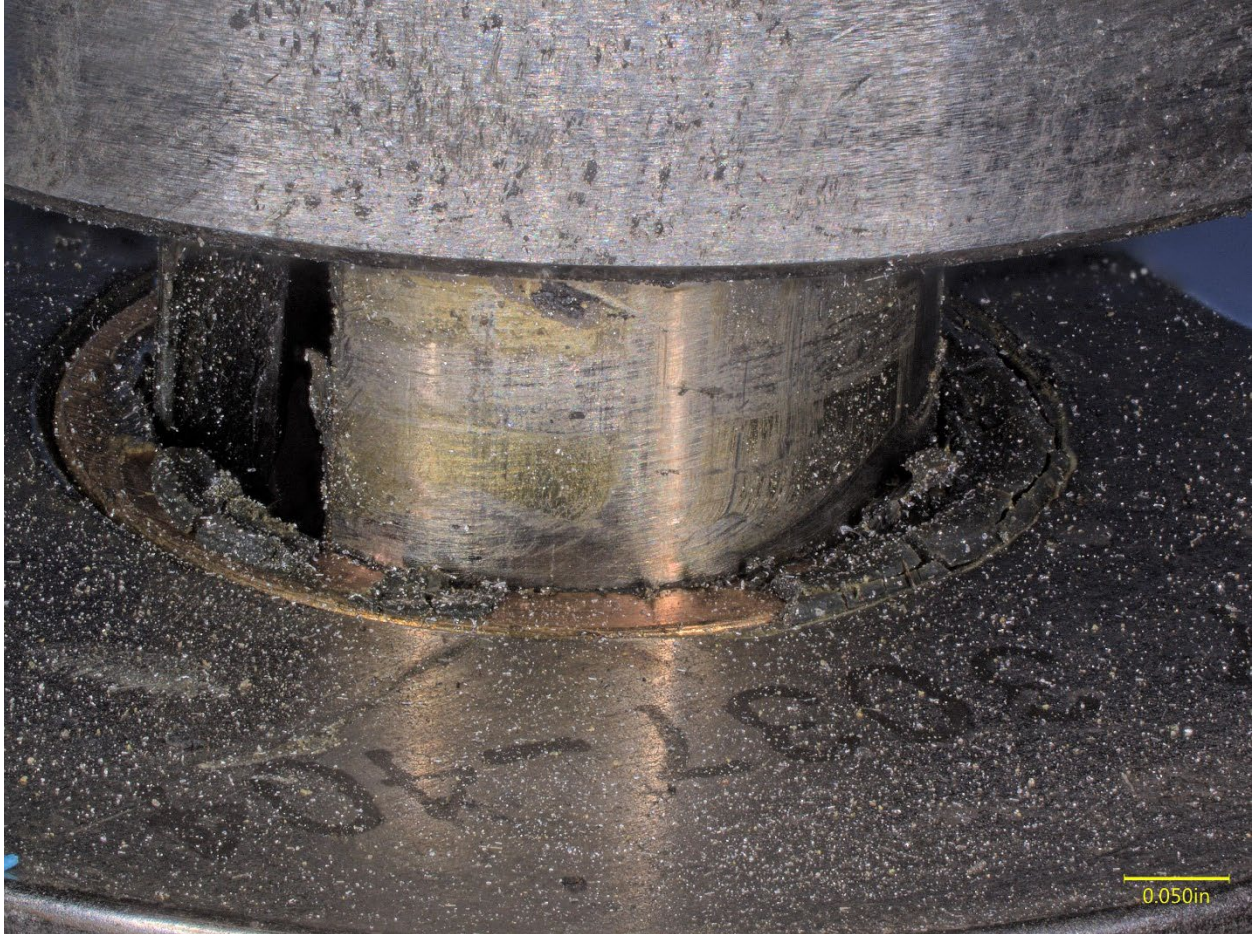


Figure 7. Angled view of the shaft and camgear face from the pinion side of the shaft, showing slot 1.



Figure 8. Angled view of the shaft and camgear face from the pinion side of the shaft, showing the pinhole.

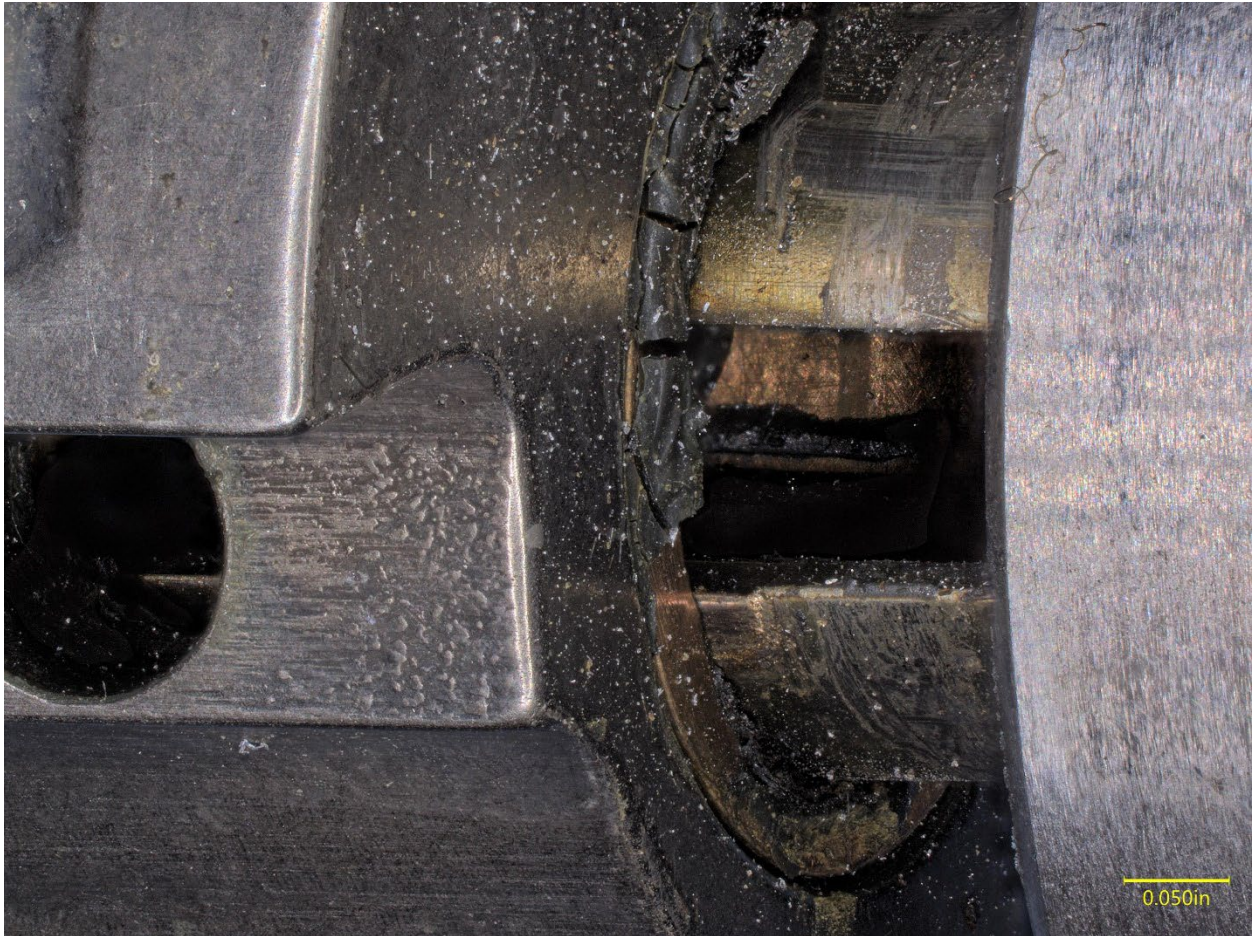


Figure 9. Angled view of the shaft and camgear face from the pinion side of the shaft, showing slot 2.

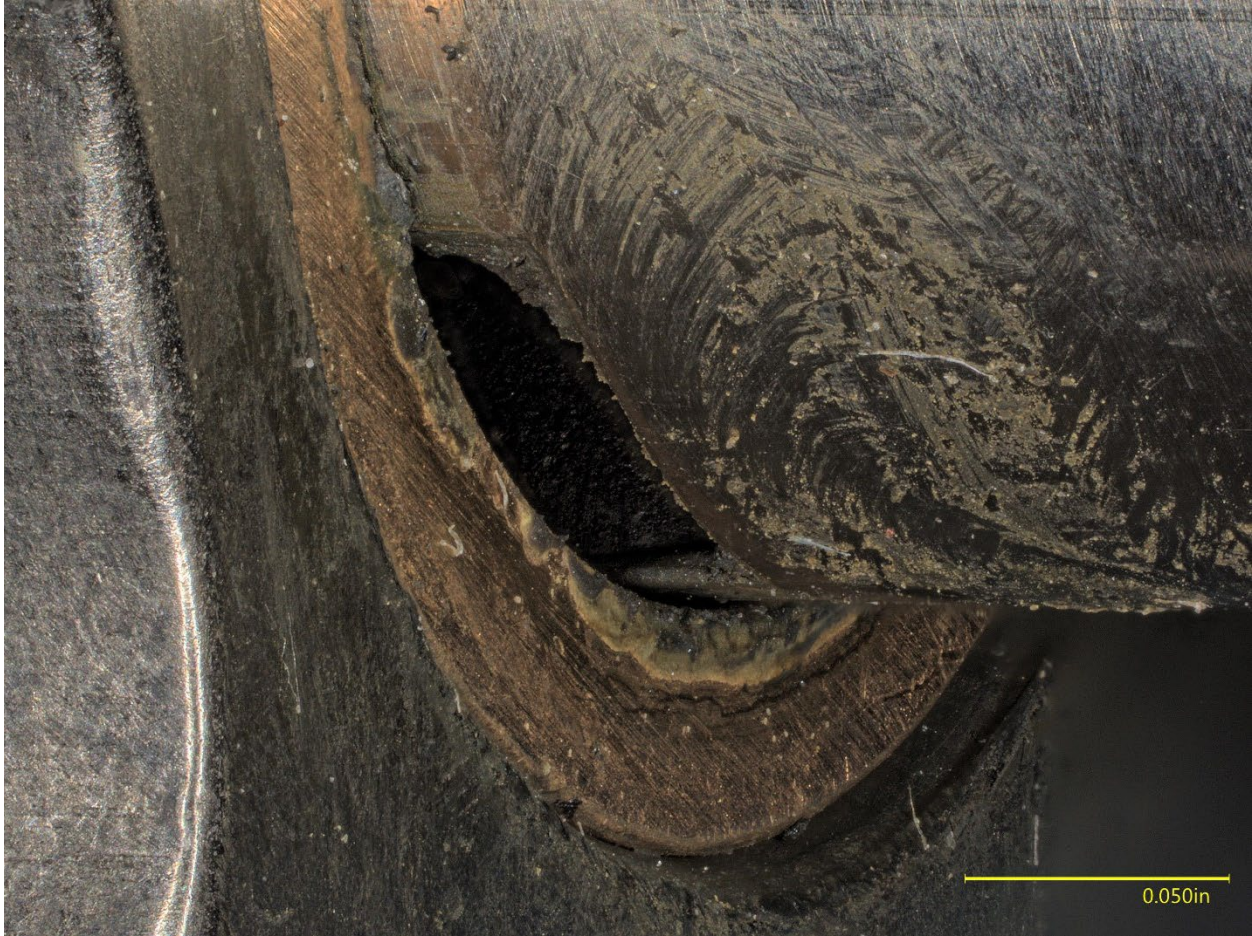


Figure 10. Angled view of the shaft and camgear face from the plain side of the shaft, showing slot 1.

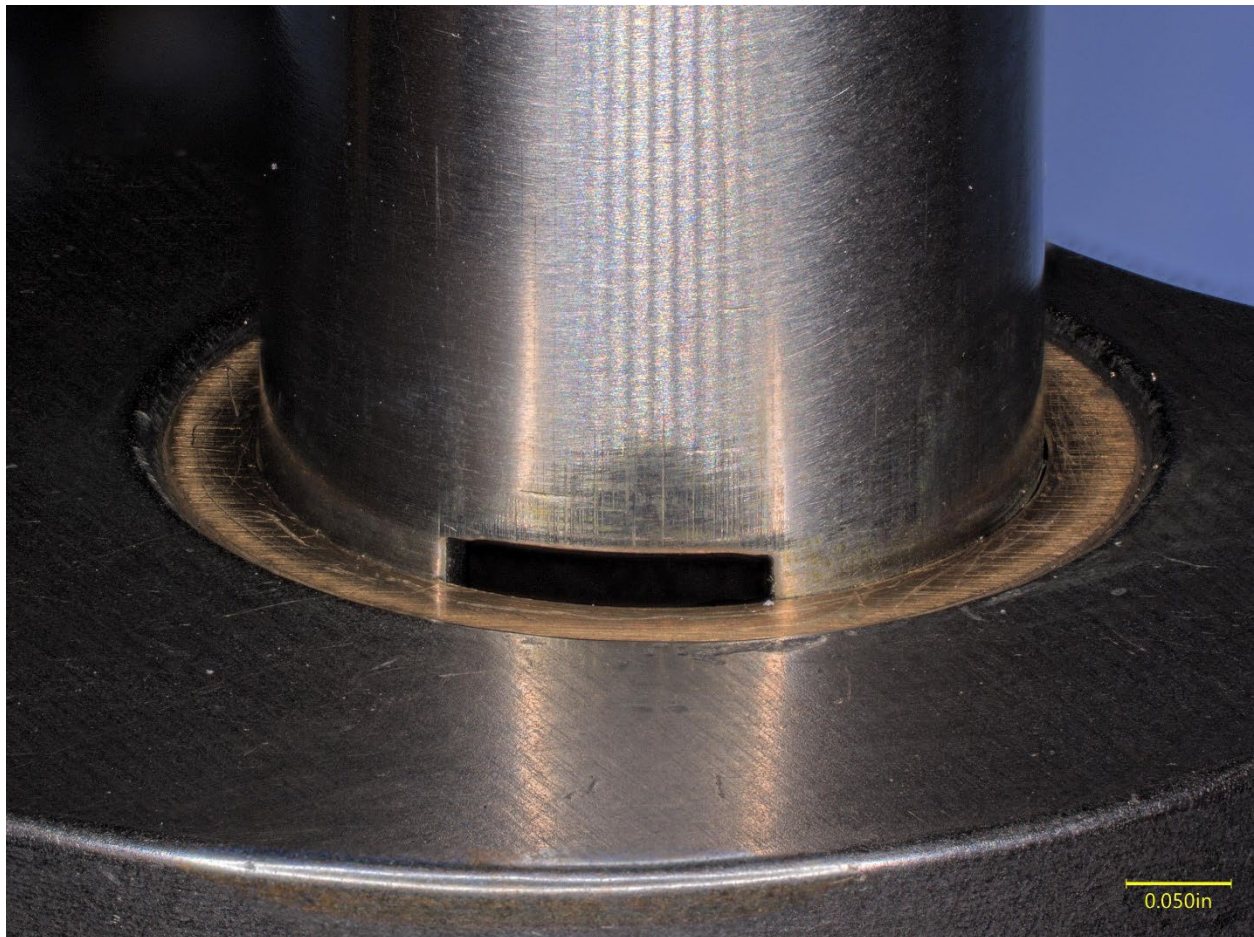


Figure 11. Angled view of the shaft and camgear face from the plain side of the shaft after cleaning, showing slot 1.

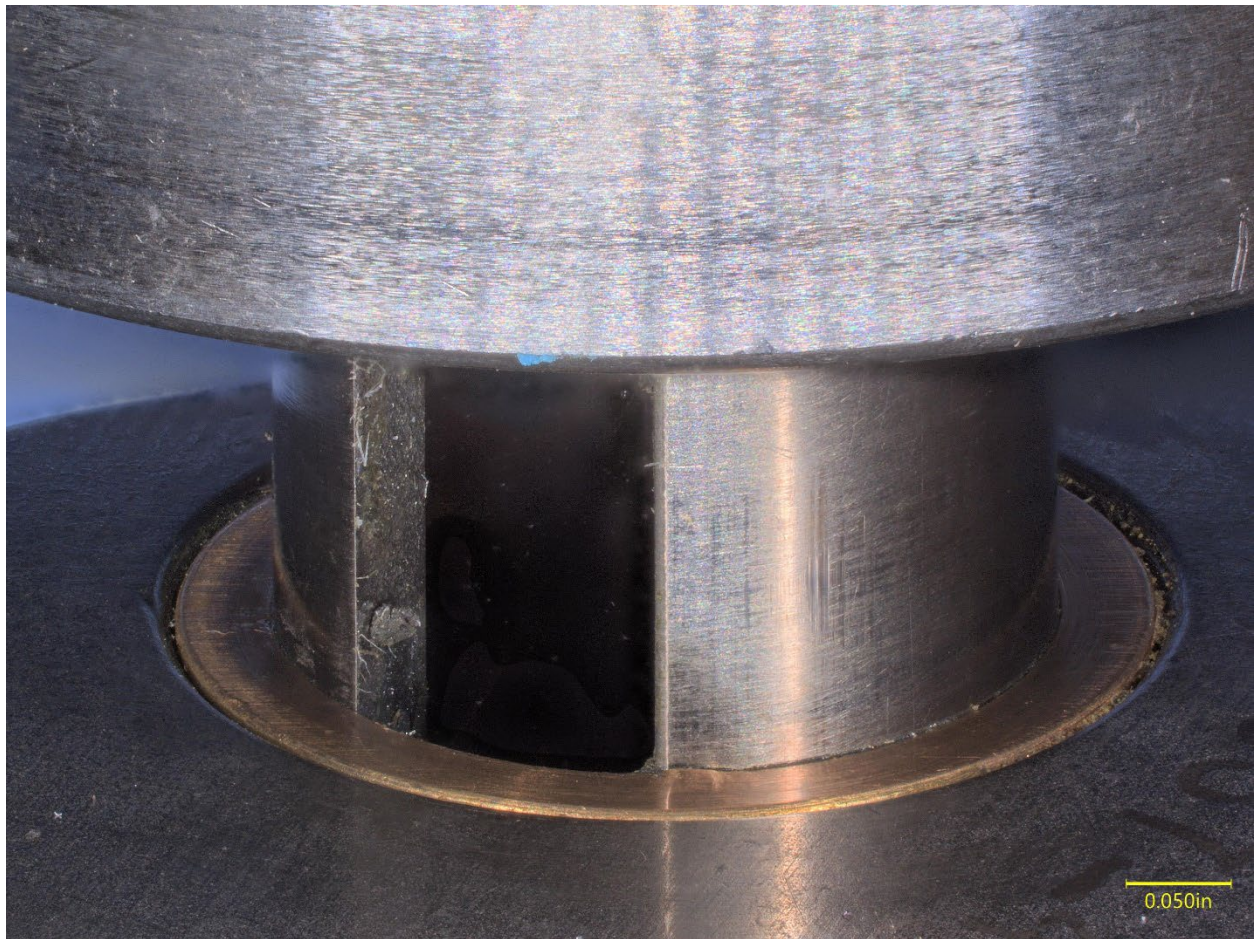


Figure 12. Angled view of the shaft and camgear face from the pinion side of the shaft after cleaning, showing slot 1.

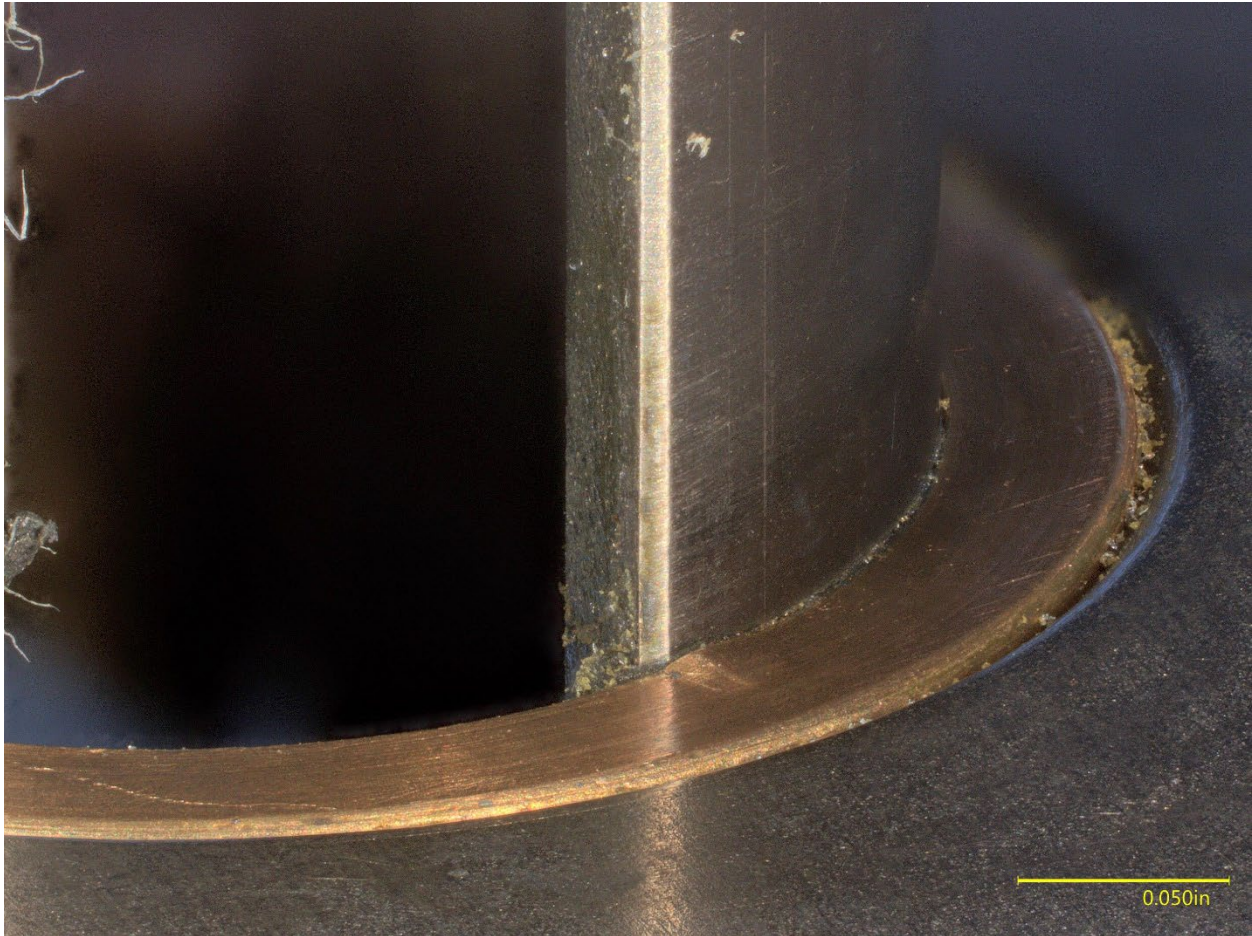


Figure 13. Closer view of the corner of slot 1 against the bushing, showing deformation.

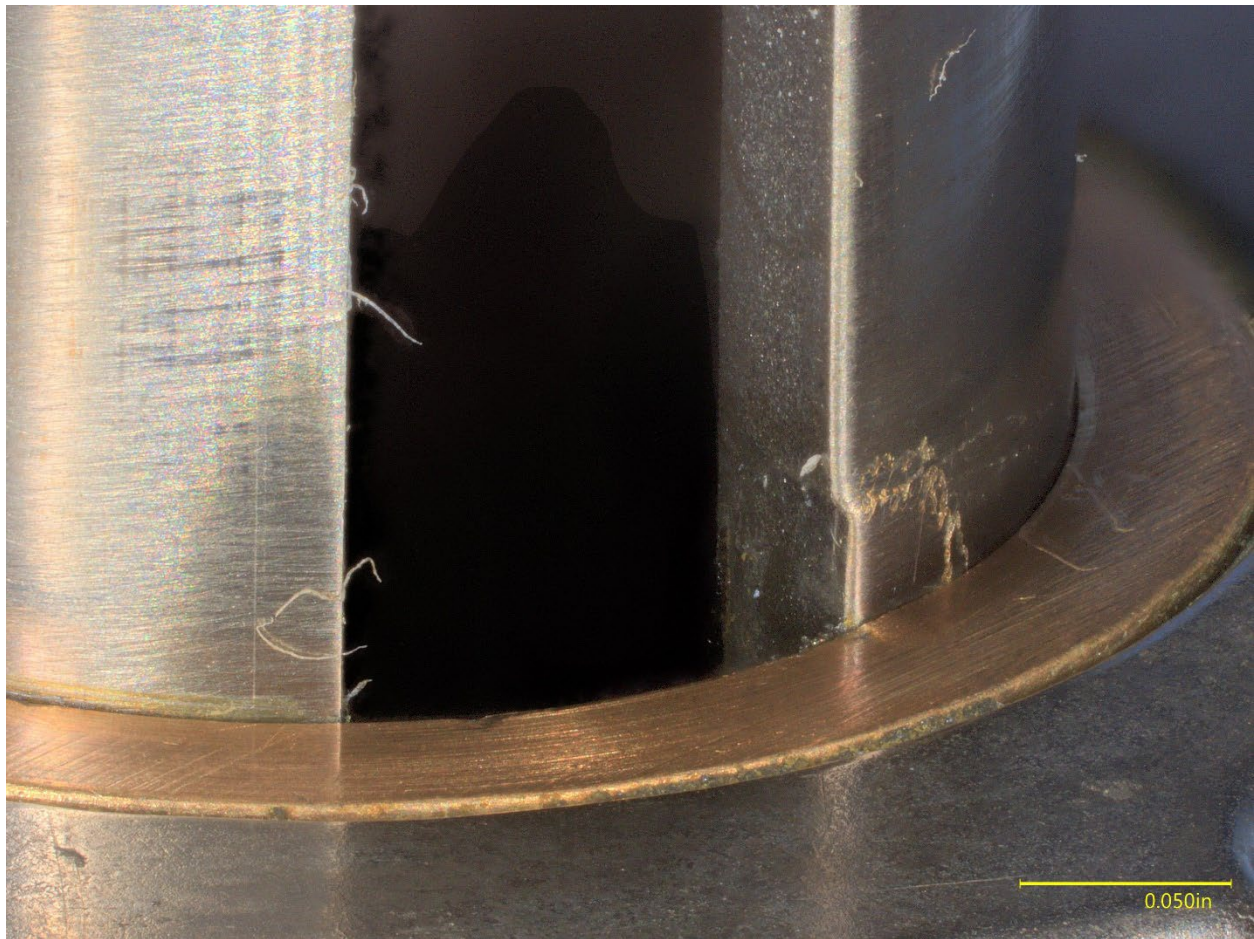


Figure 14. Closer view of the corner of slot 2 against the bushing, showing bushing deformation and cracking in the shaft surface.

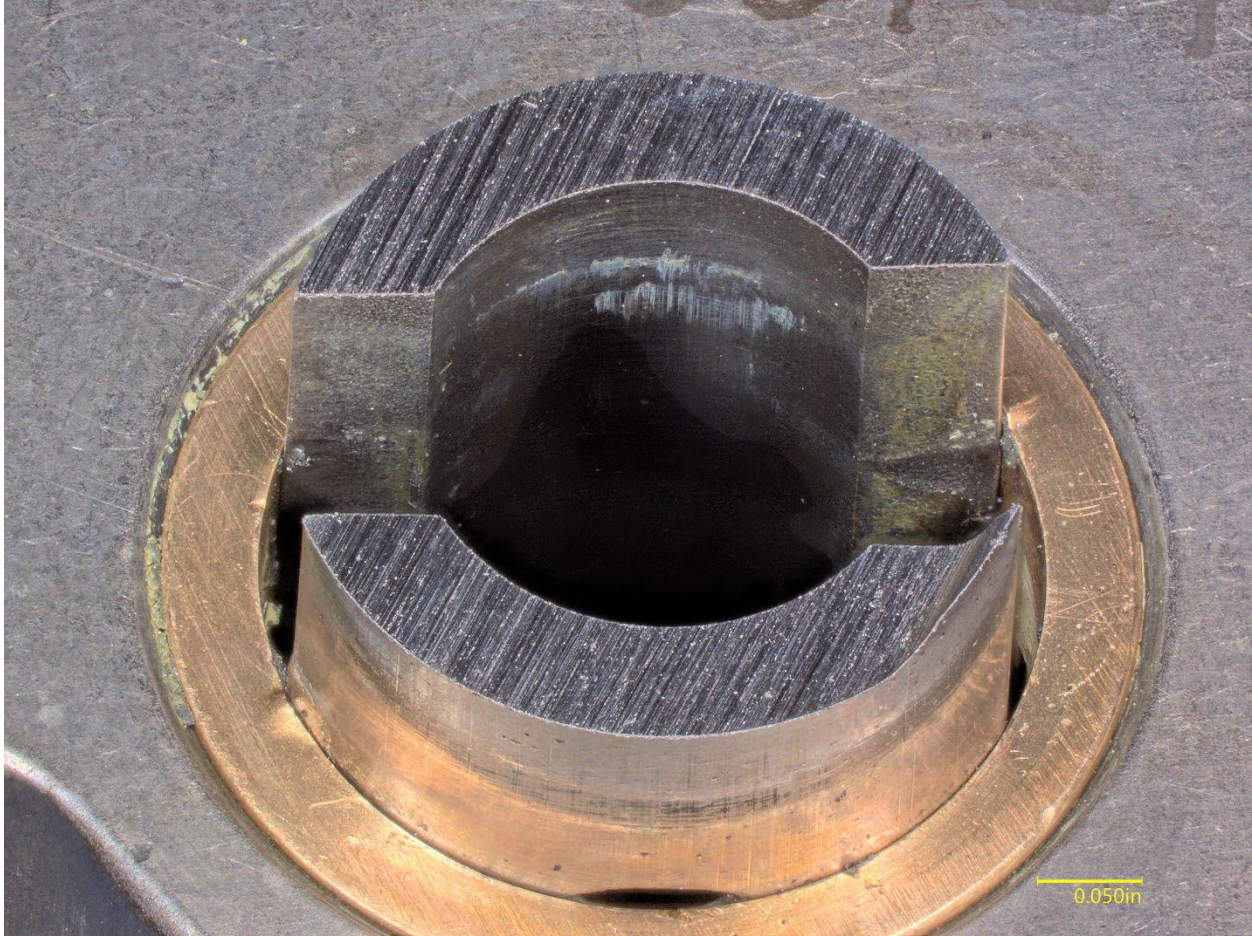


Figure 15. Angled view of the shaft remnant inside the bushing after sectioning the pinion and bearing seat, viewed from the pinhole side.

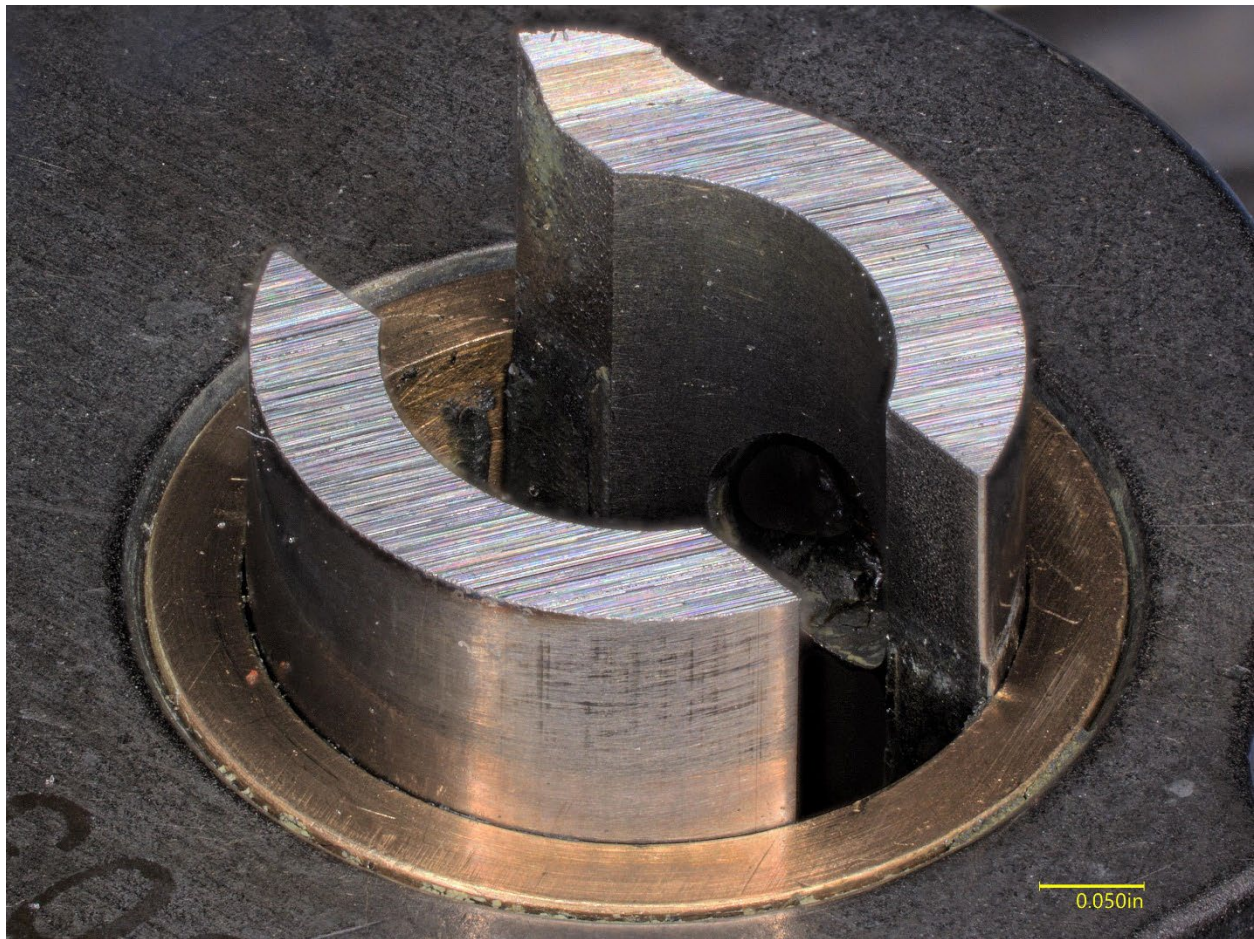


Figure 16. Angled view of the shaft remnant inside the bushing after sectioning the pinion and bearing seat, viewed from the slot 2.



Figure 17. View of the camshaft, camgear, and bearing after sectioning and disassembly.

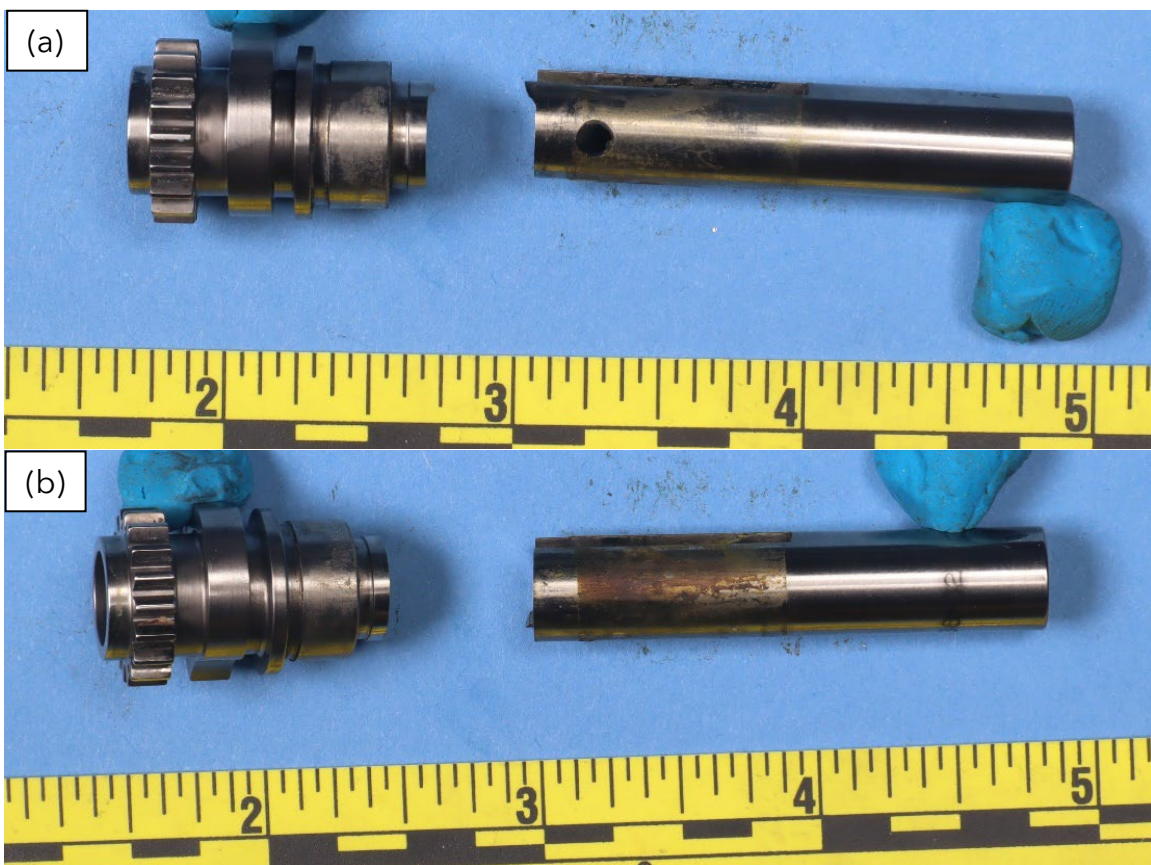


Figure 18. View of the sectioned camshaft from (a) the pinhole side and (b) the opposite side.

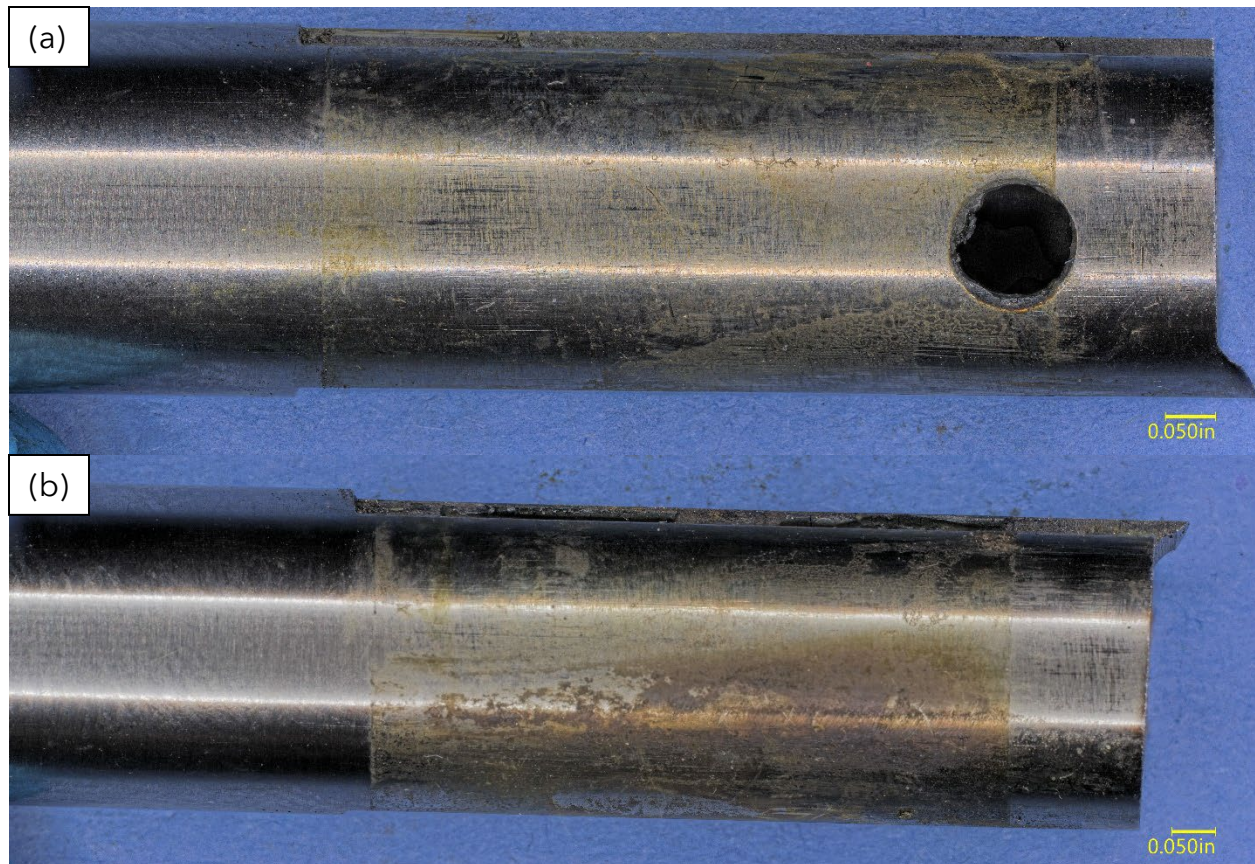


Figure 19. Views of the sides of the sectioned shaft where the camgear mated, showing grease remnants, viewed from (a) the pinhole side and (b) the opposite side.

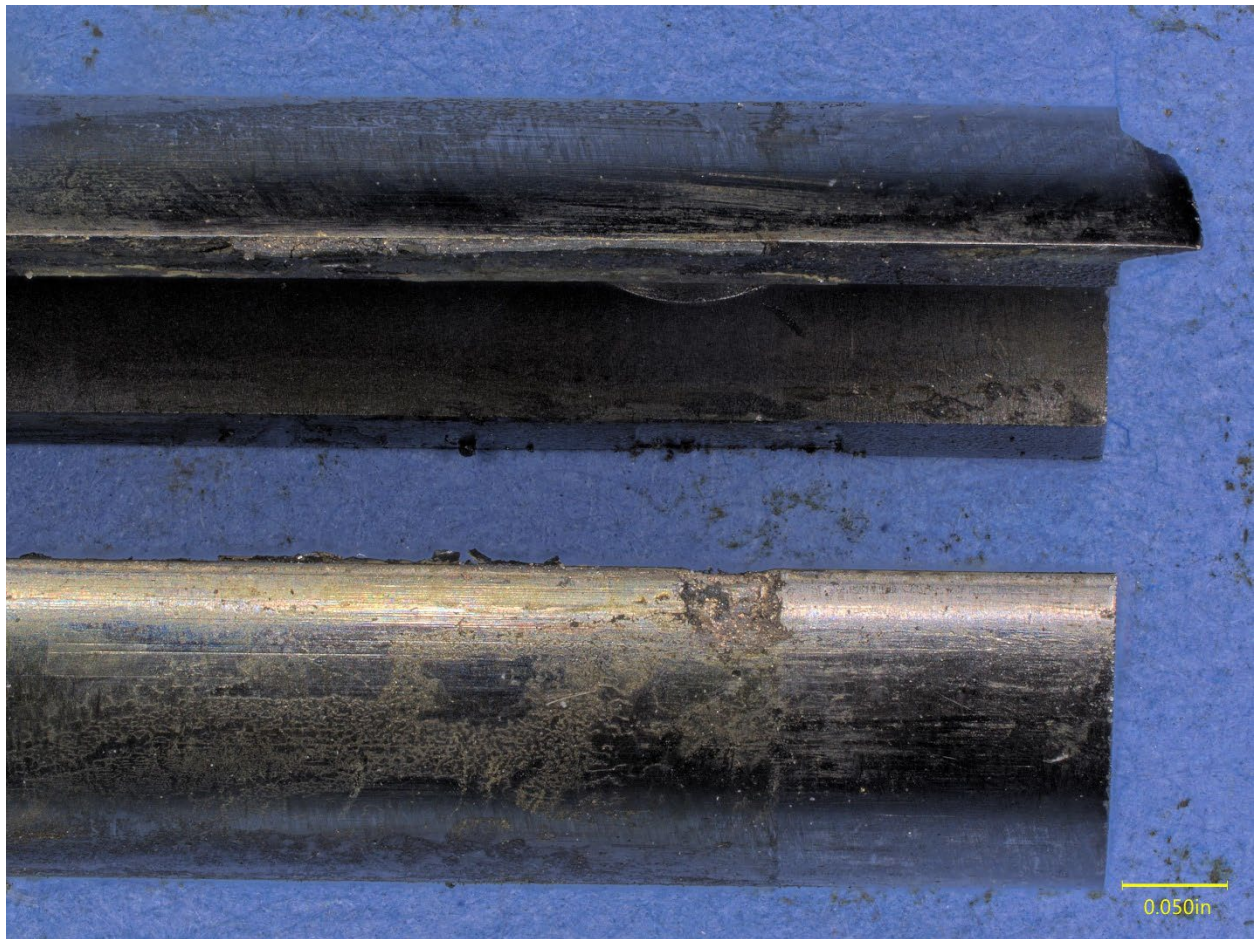


Figure 20. Angled view of the damage marks to the slot corners, viewed from slot 1.

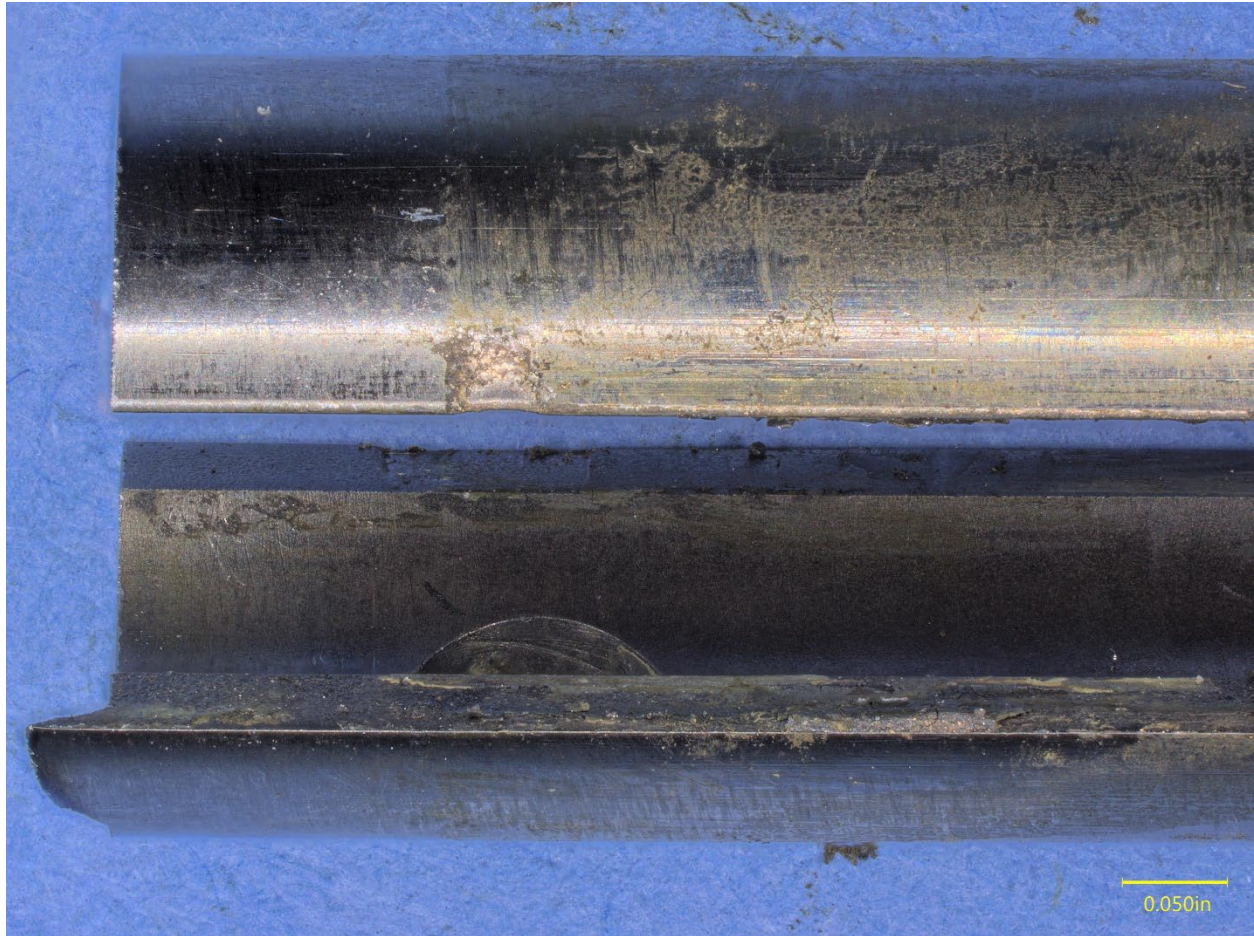


Figure 21. Angled view of the slot corner damaged areas, viewed from slot 2.

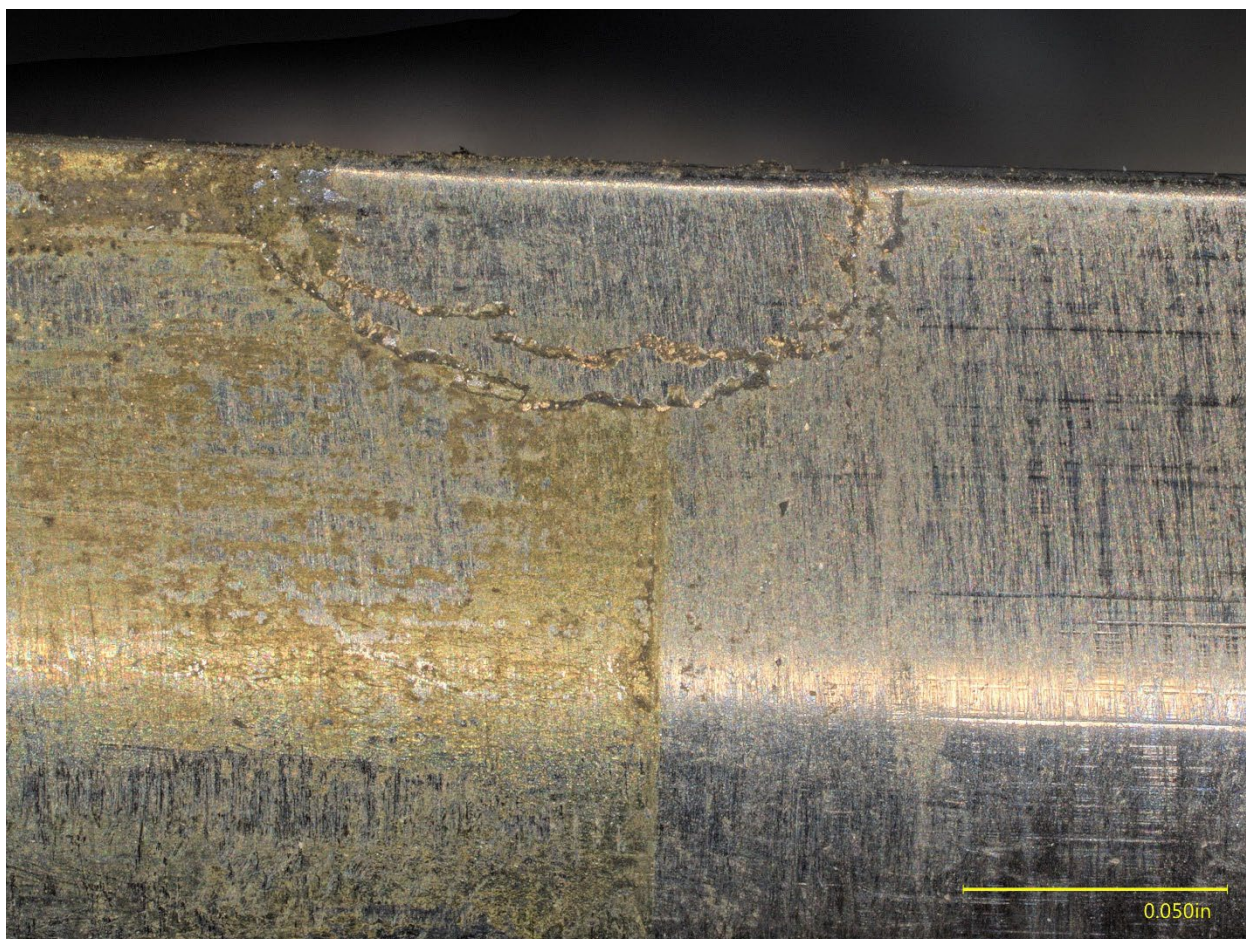


Figure 22. Closer view of the damaged area of slot 2.

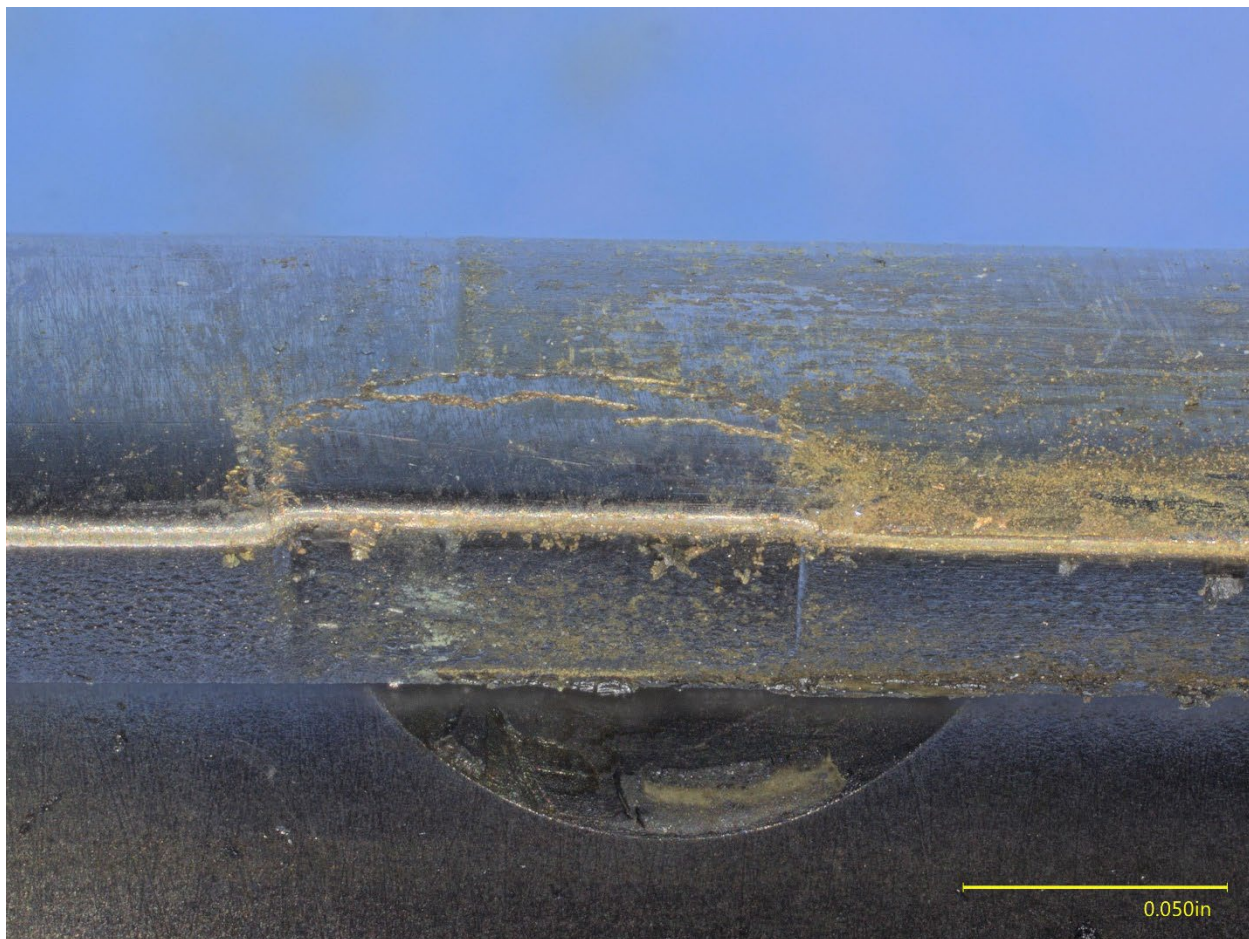


Figure 23. Viewed of the slot 2 corner damaged area, rotated 180* from Figure 22 and viewed from the slot face.

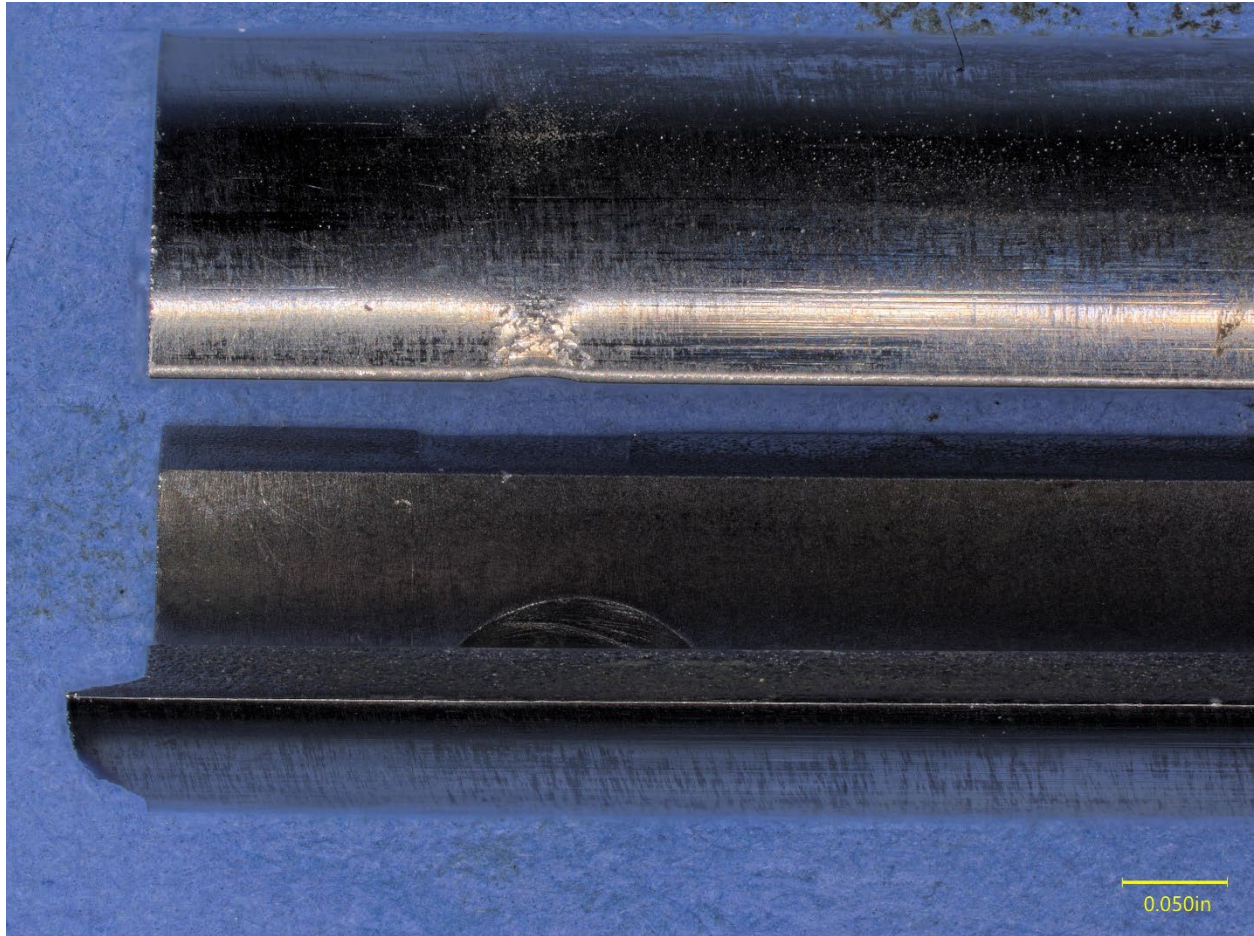


Figure 24. View of the damaged areas of the slot corners after cleaning and grease removal, viewed from slot 1.



Figure 25. View of the damaged areas of the slot corners after cleaning and grease removal, viewed from slot 2.

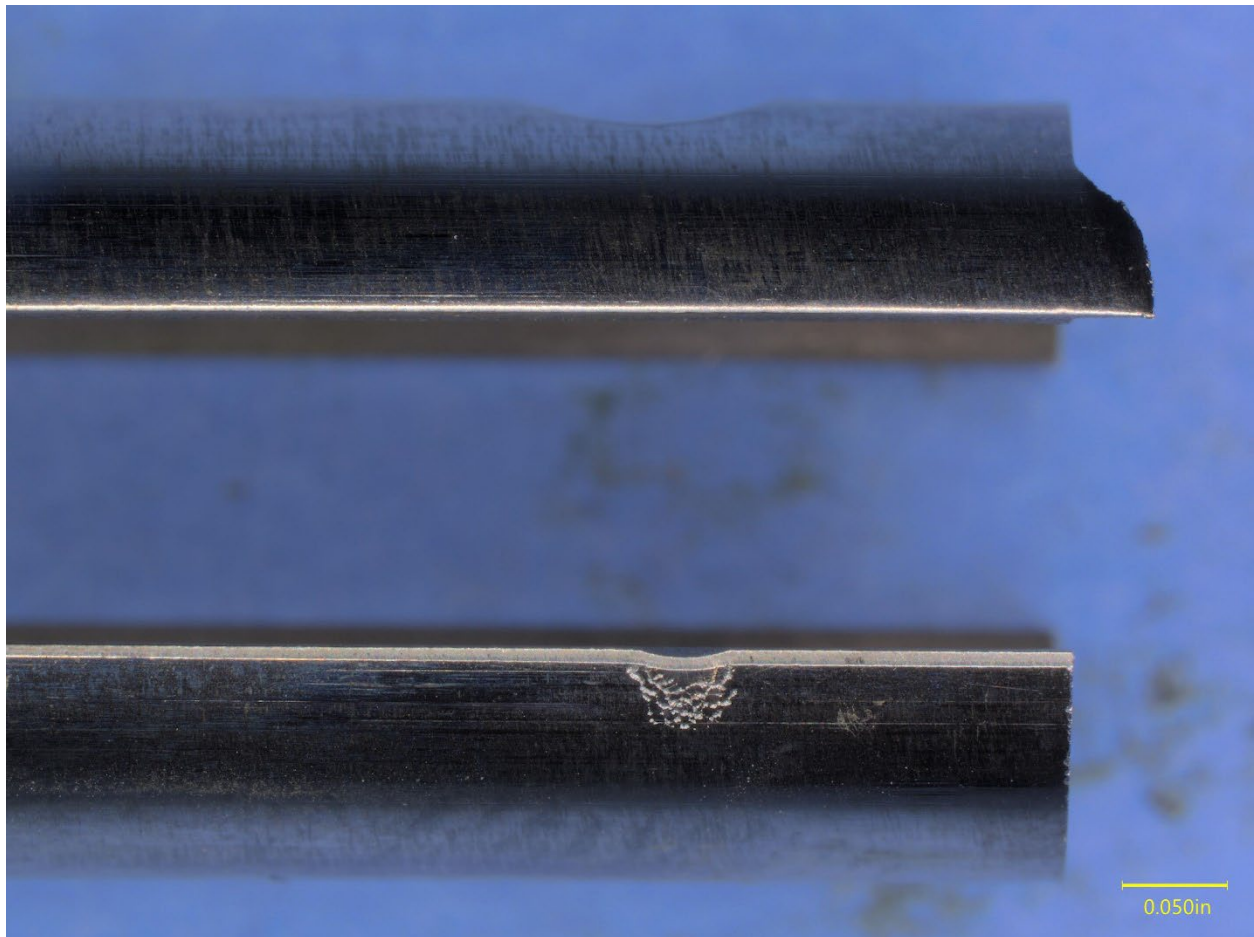


Figure 26. View of the damage to slot 1, after cleaning and removal of grease.

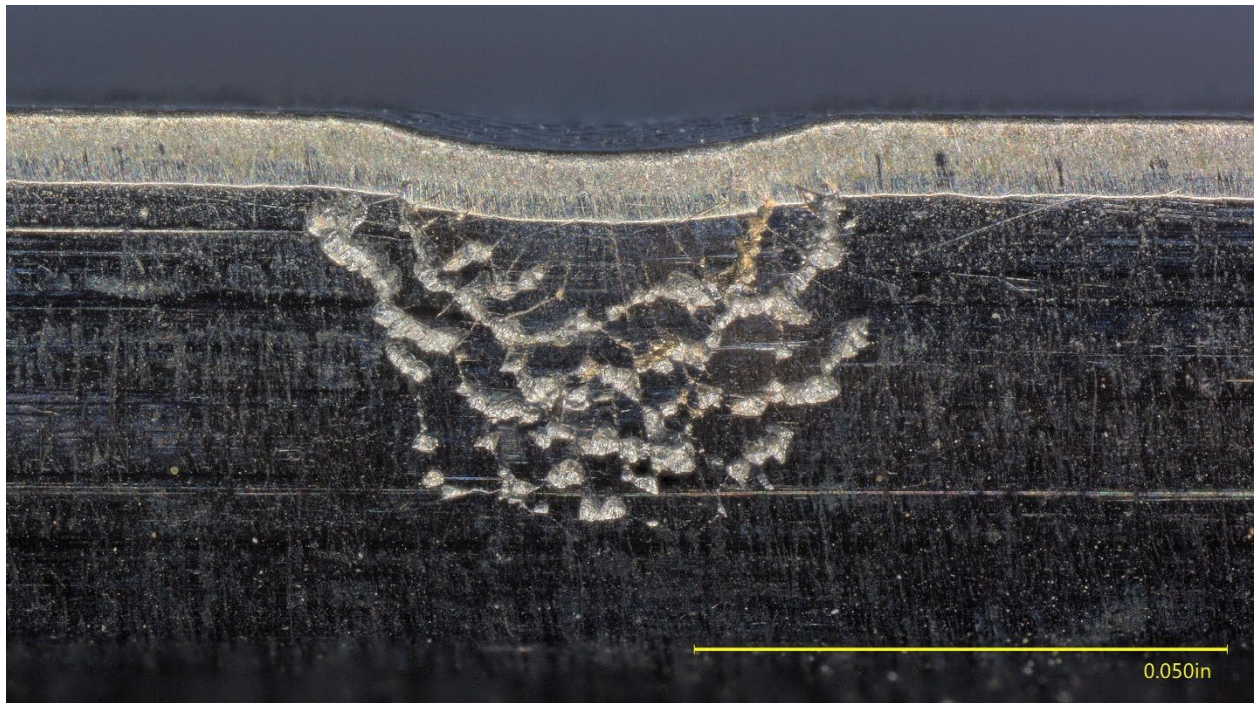


Figure 27. Closer view of the slot 1 damaged area in Figure 26.

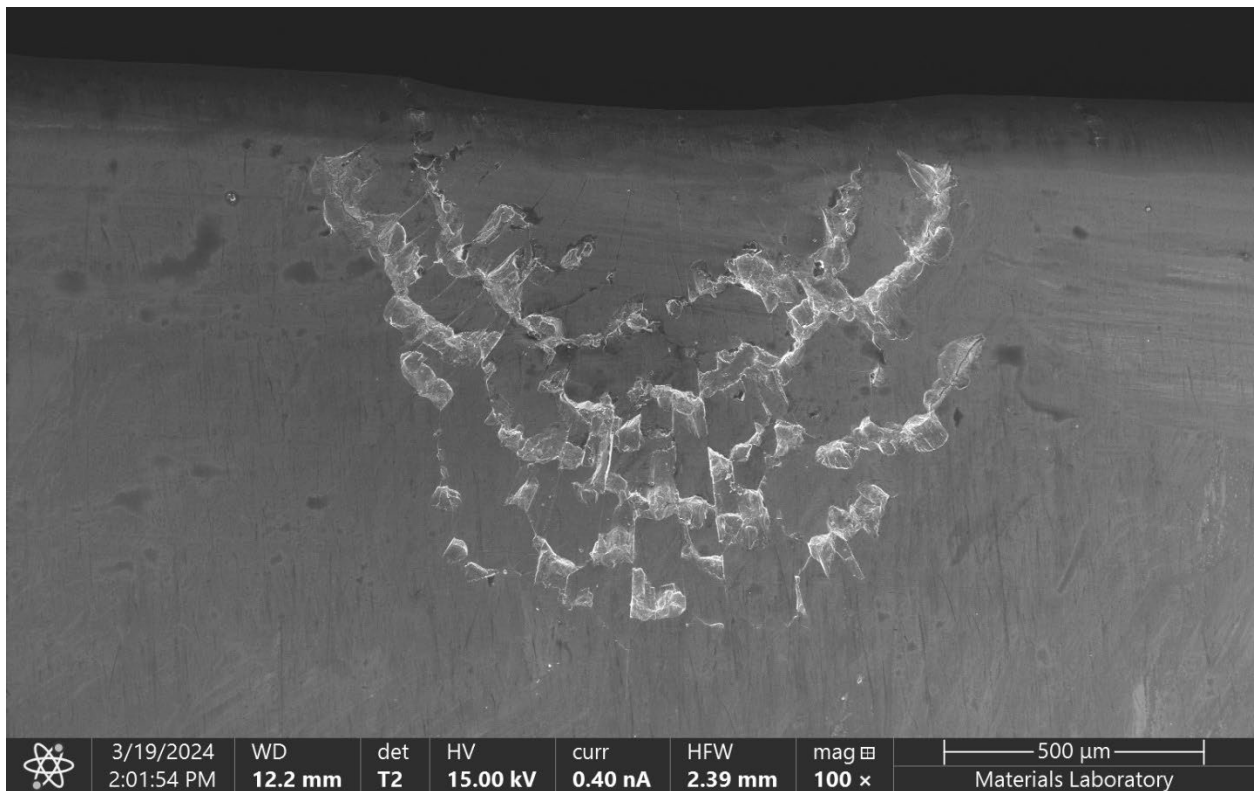


Figure 28. Secondary electron (SE) micrograph of the damaged area of slot 1.

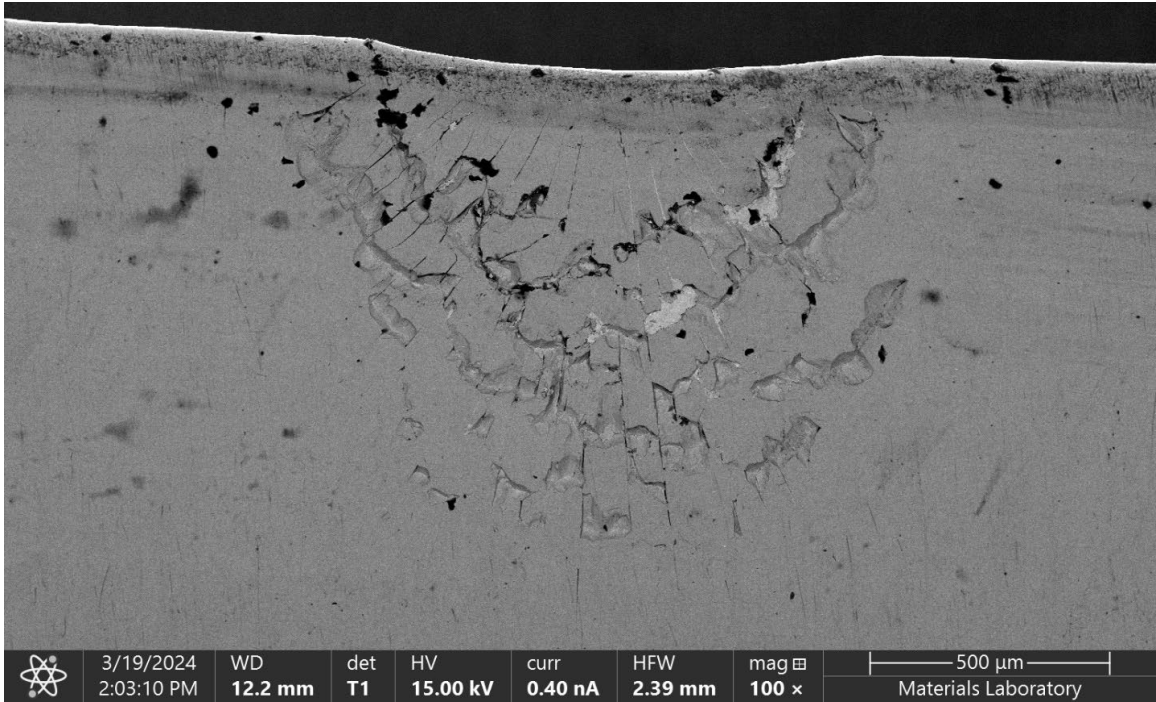


Figure 29. Backscattered electron (BE) micrograph of the damaged area of slot 1.

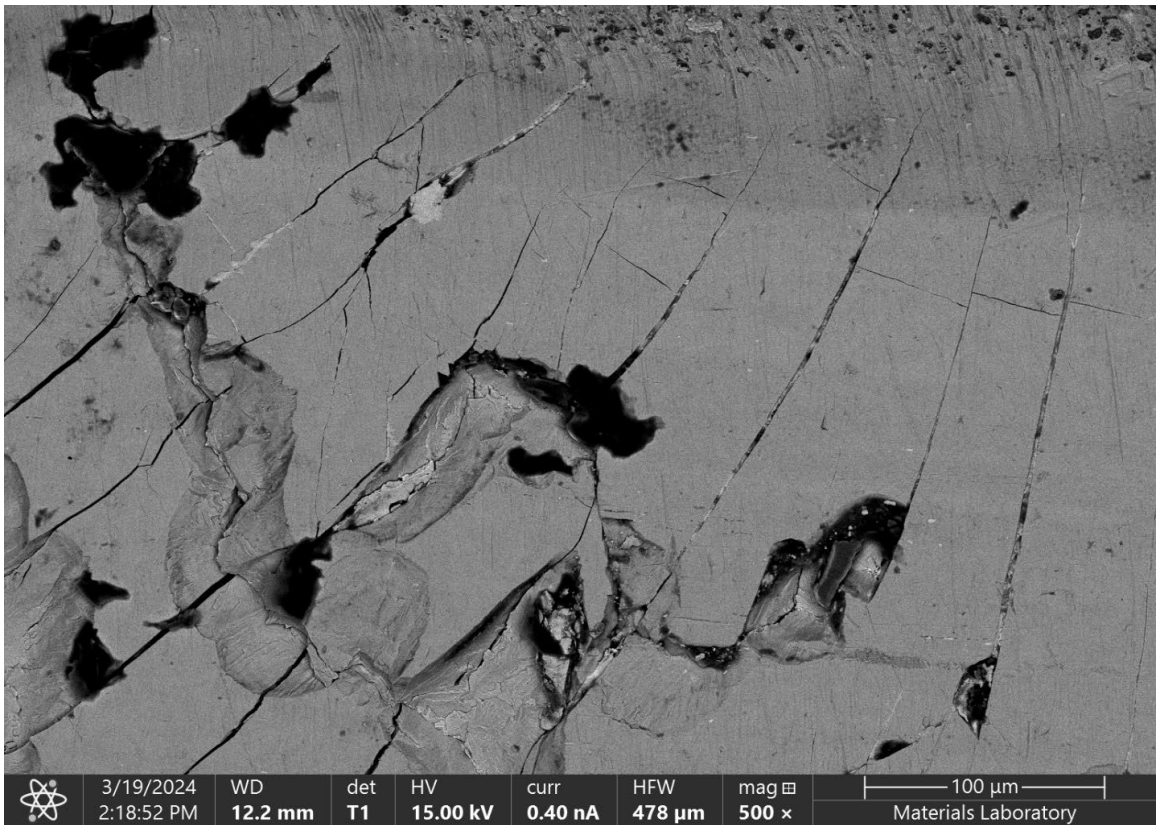


Figure 30. BE micrograph of cracked and spalled areas of the slot 1 damaged area containing no or lower-Z material (dark).

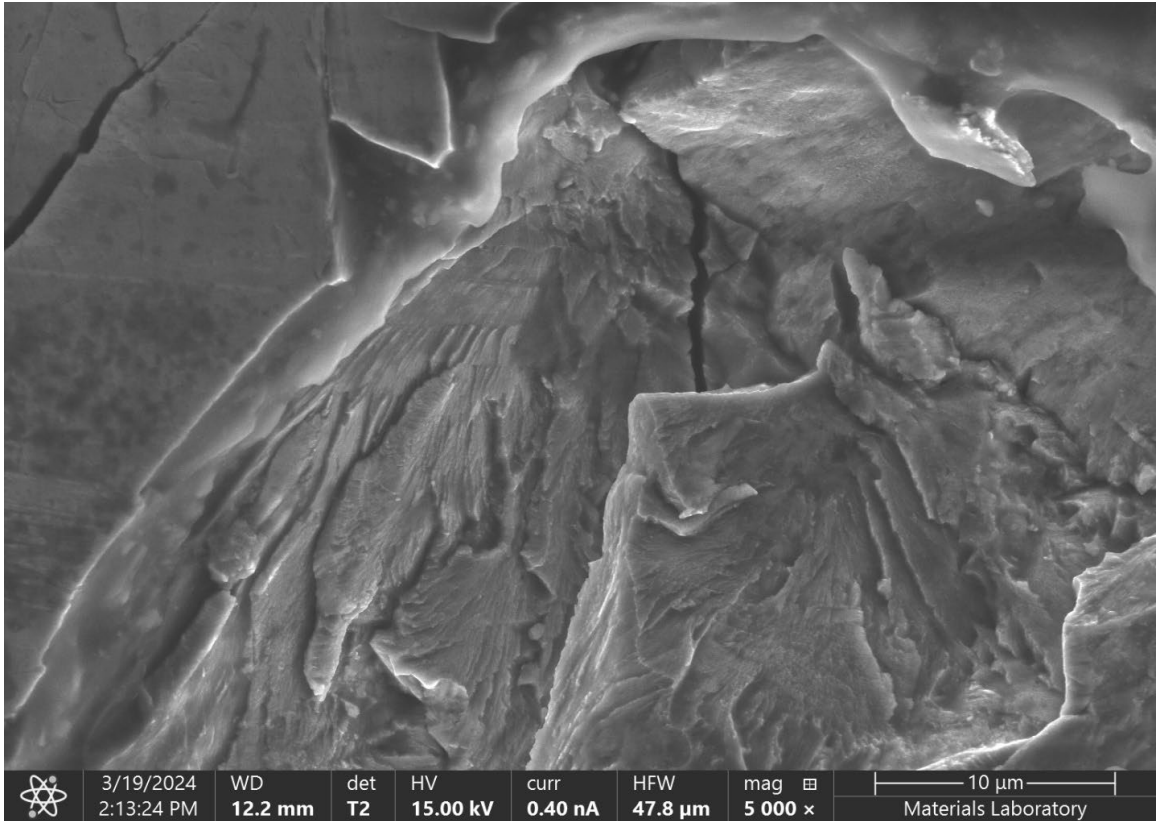


Figure 31. SE micrograph of a closer area of spalled surface material in Figure 30, exhibiting cleavage features.

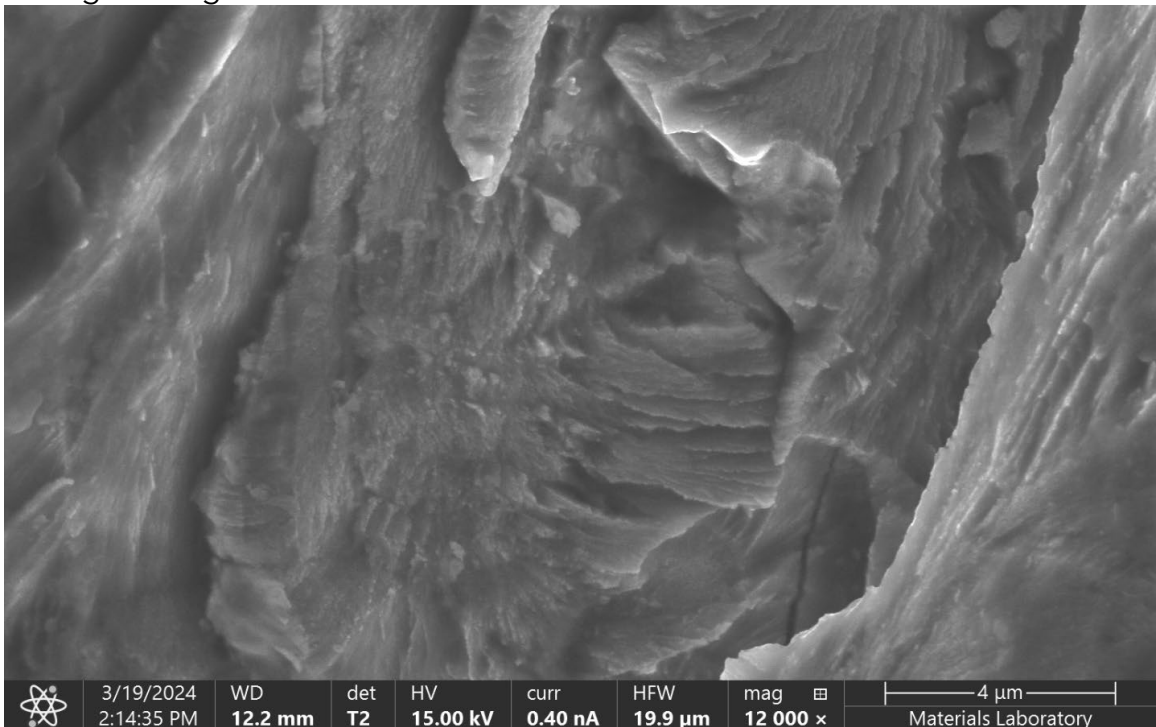


Figure 32. SE micrograph of a closer view of the tongues and river patterns in the cleavage fracture in Figure 31.

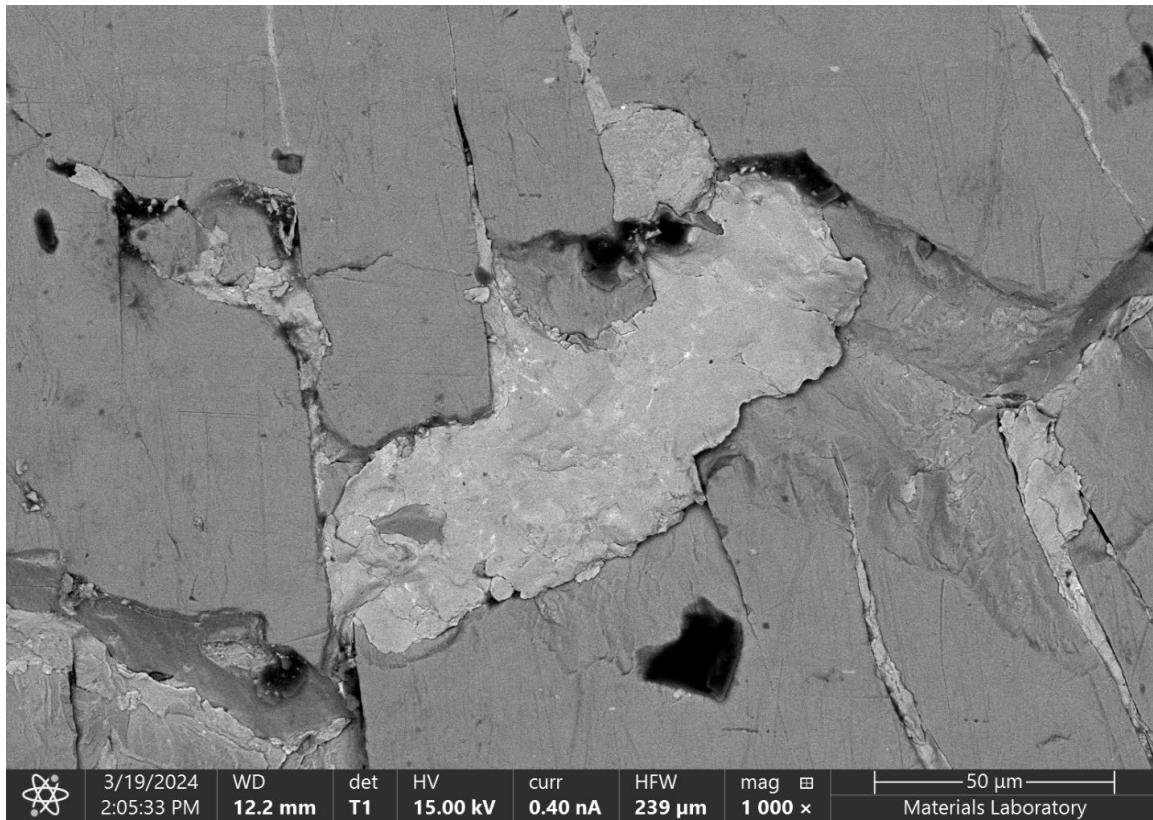


Figure 33. BE micrograph of a closer view of the damage and cracks in Figure 29, showing higher-Z material in the spalled areas.

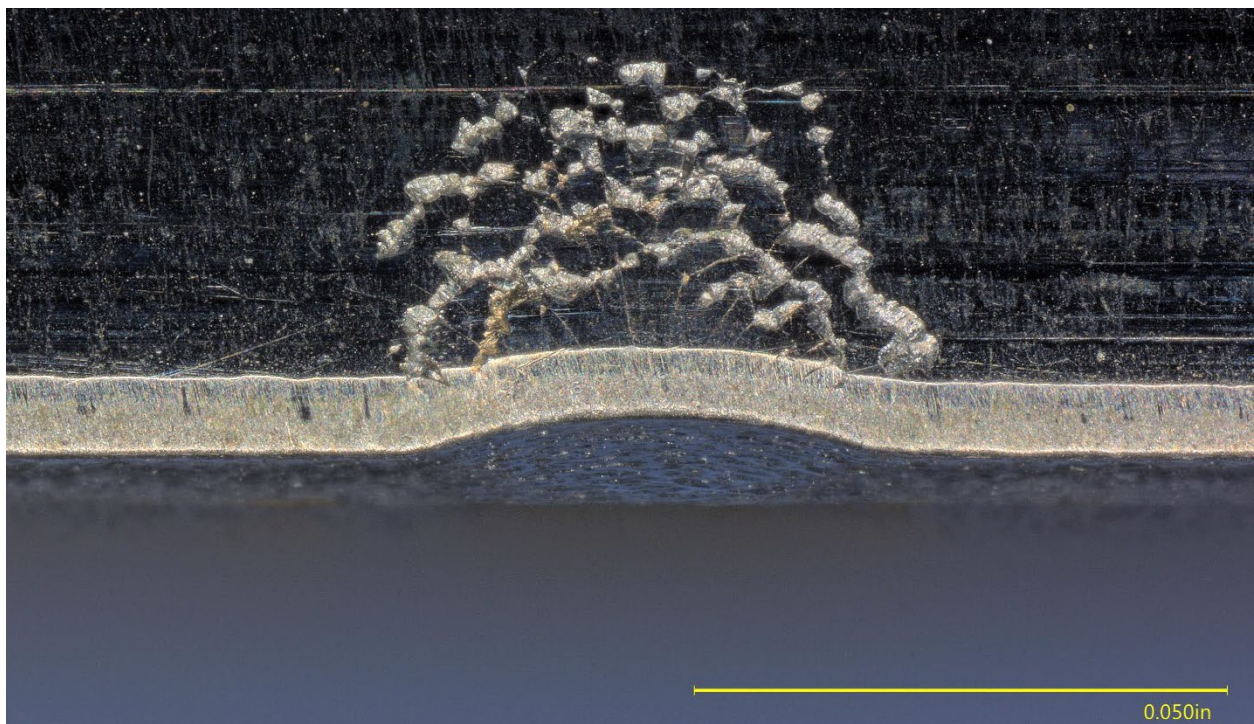


Figure 34. Reverse view of the damaged region of the slot 1 corner, showing inward indentation at the slot face below the corner.

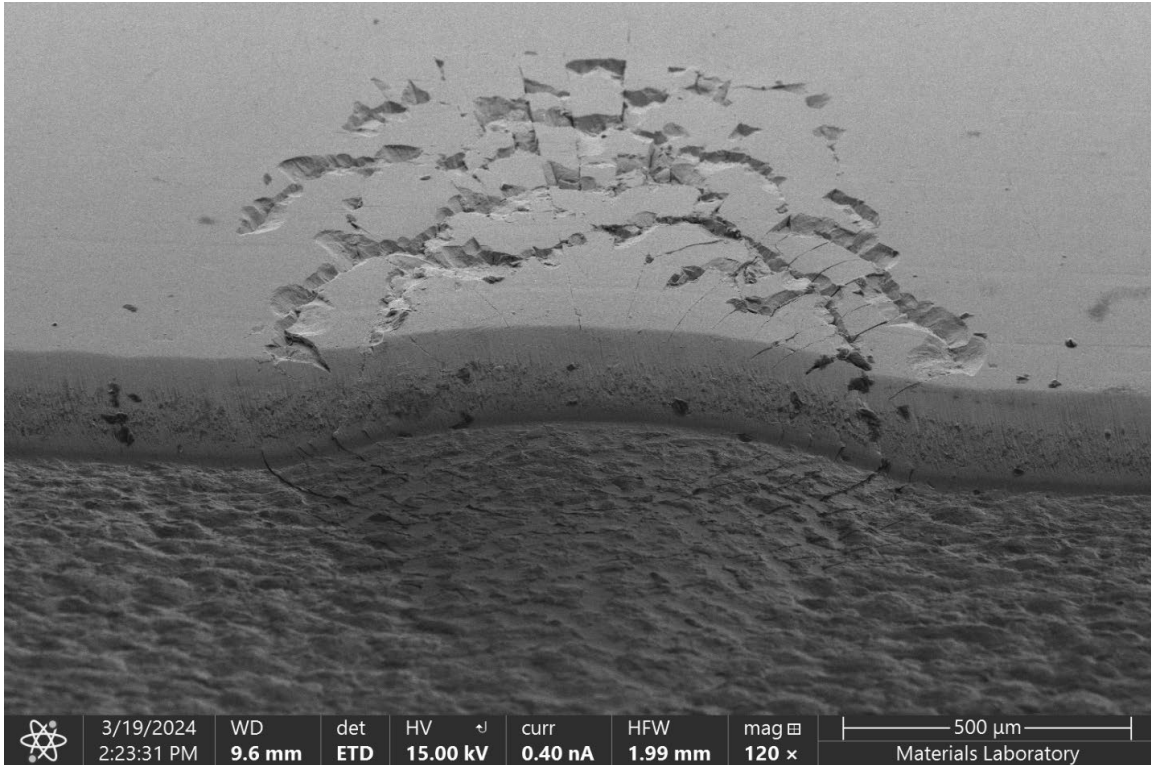


Figure 35. BE micrograph of the damaged slot 1 corner area.

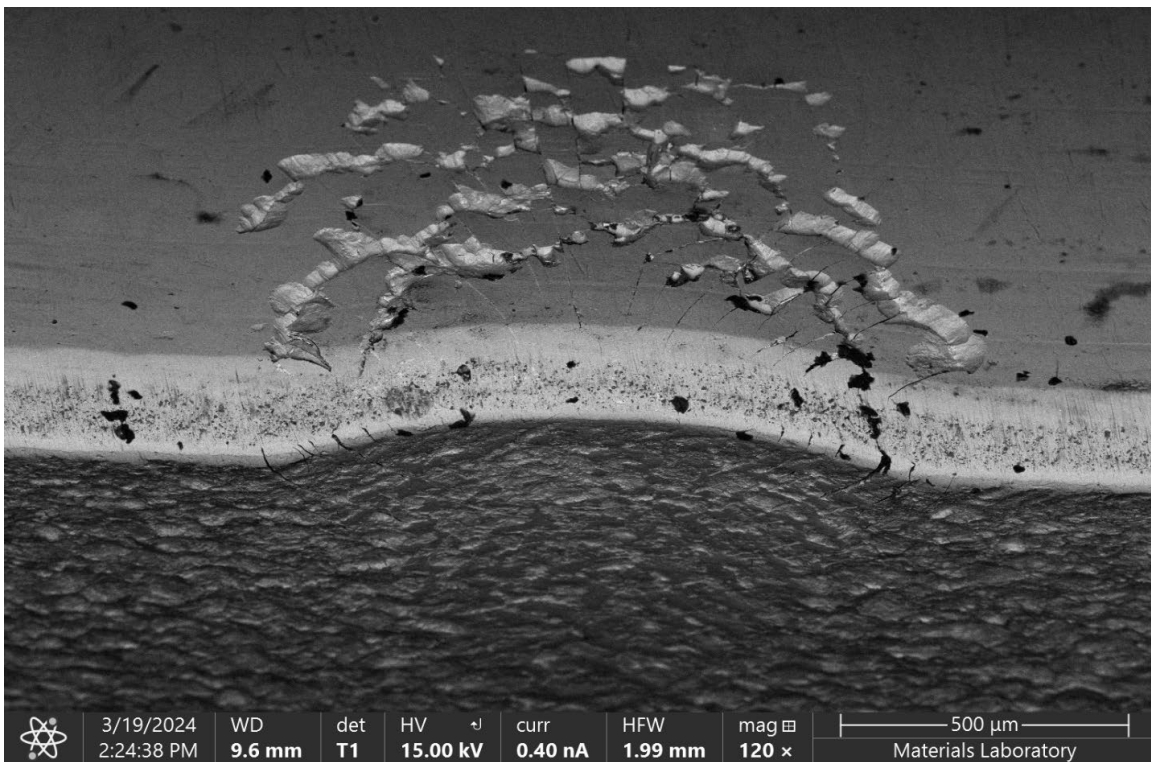


Figure 36. SE micrograph of the damaged area in the slot 1 corner.

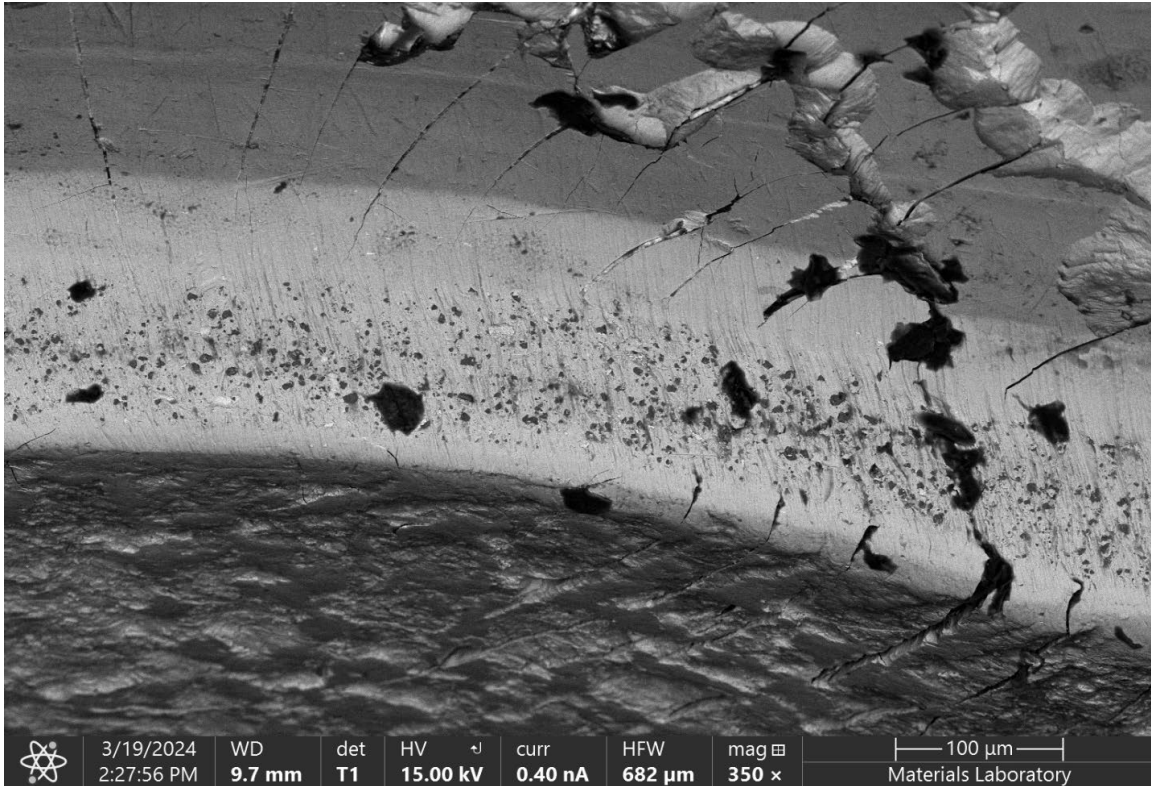


Figure 37. BE micrograph of a closer view of the slot 1 corner, showing surface cracking emanating from the indentation in a radial pattern.

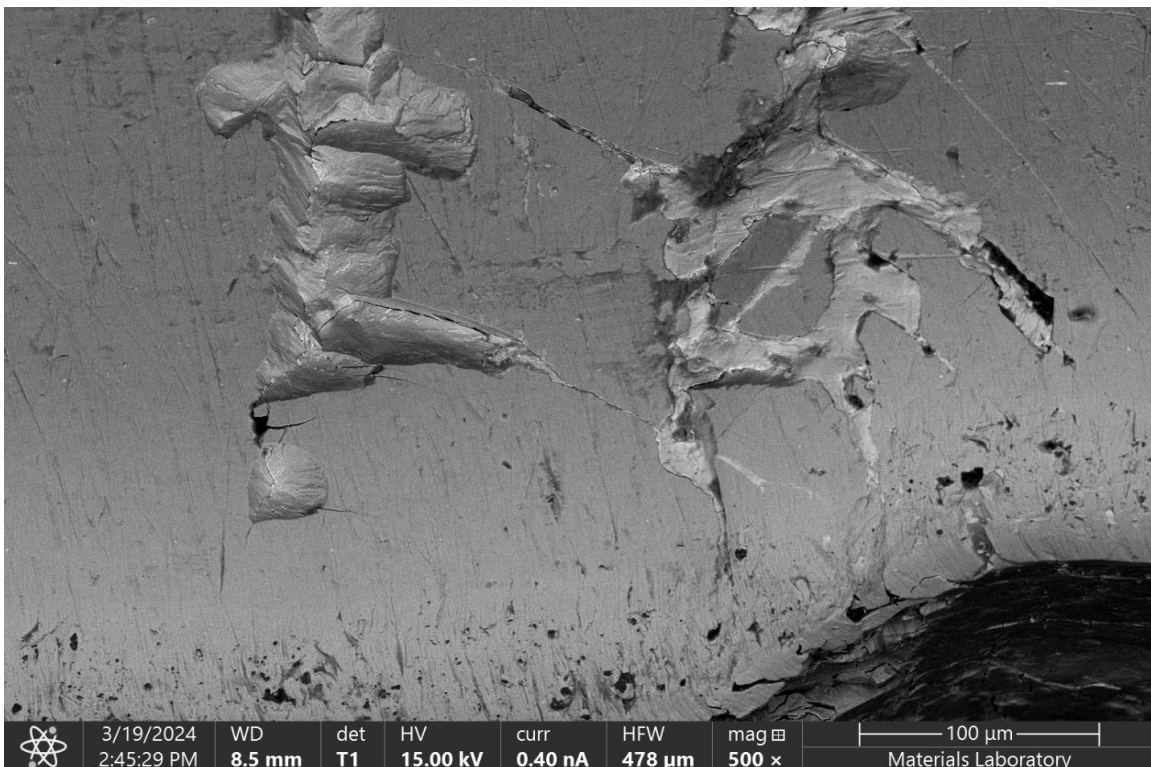


Figure 38. BE micrograph of spalled surface material along the cracks in Figure 38, with the left area absent of and the right area filled with higher-Z material.

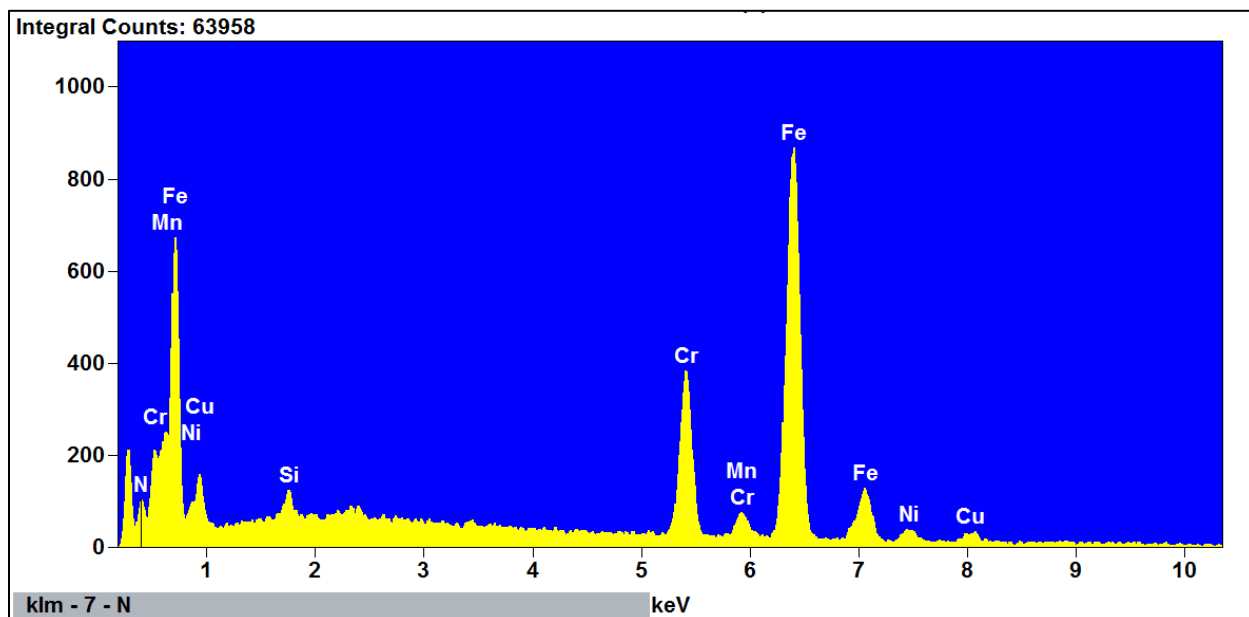


Figure 39. EDS spectrum of a typical area of fractured and spalled fracture surface.

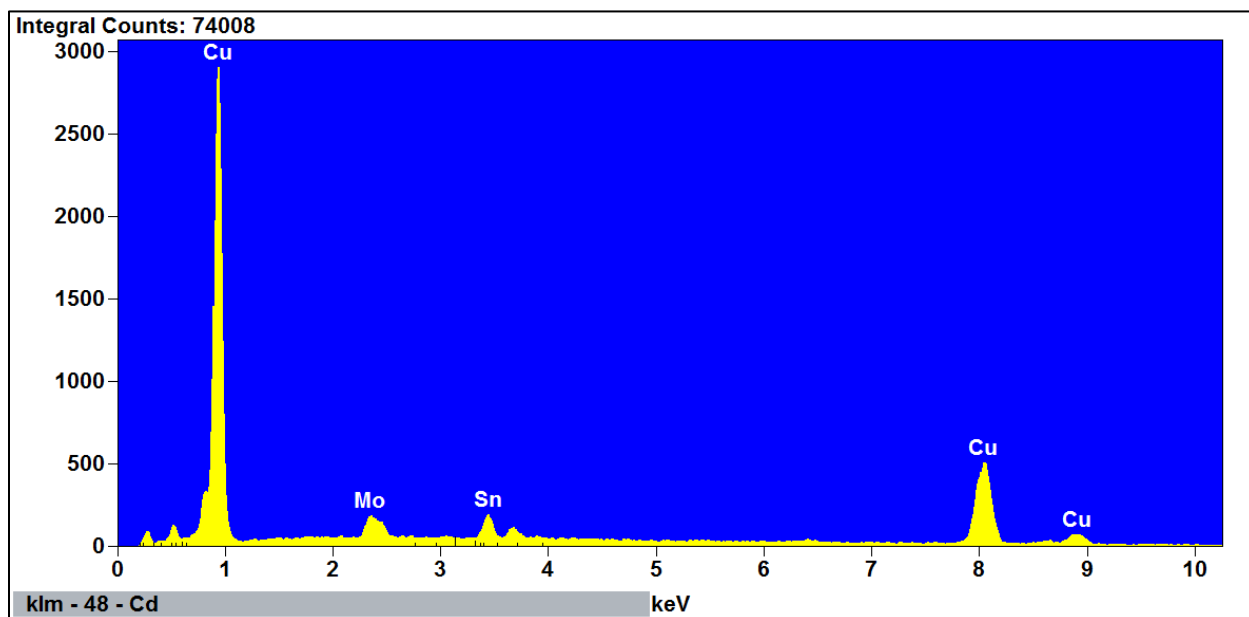


Figure 40. EDS spectrum of a typical area of the high-Z entrained material in Figure 39.



Figure 41. View of the damaged area in the corner of slot 2, after full cleaning.

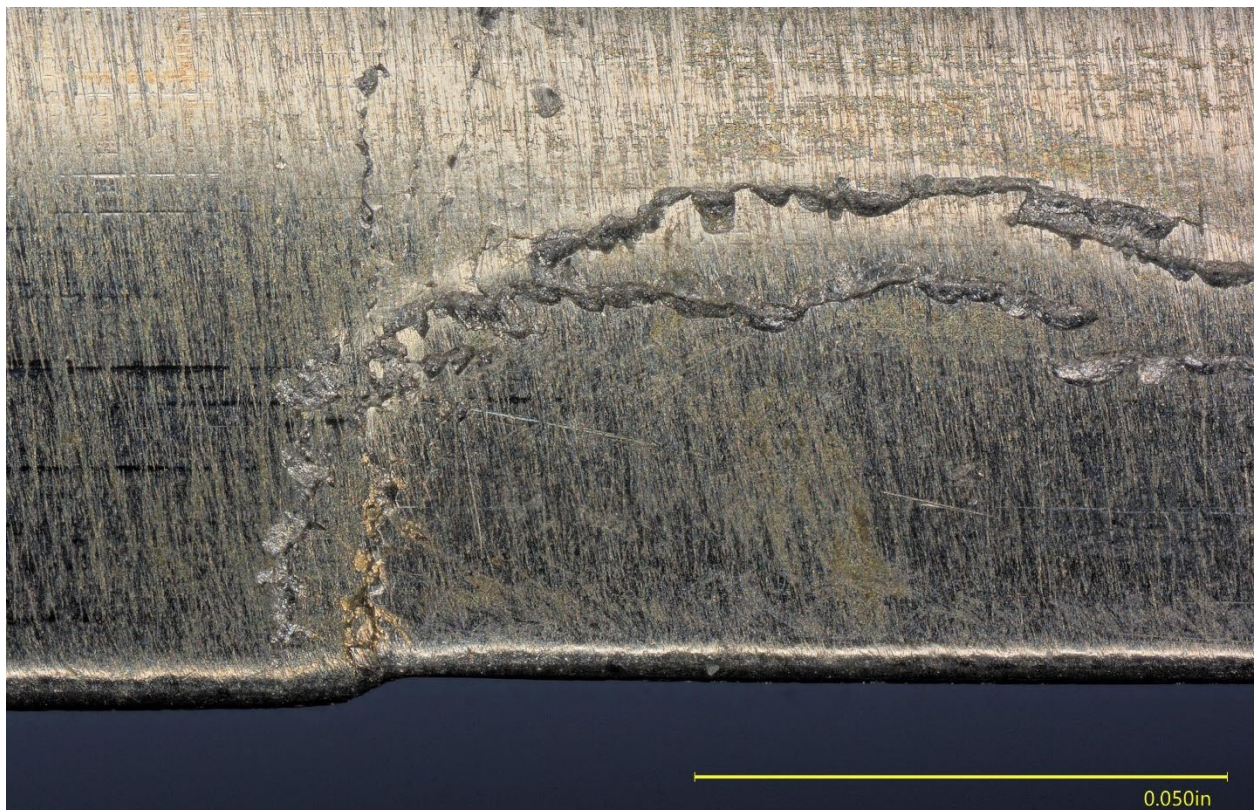


Figure 42. Closer view of the left side of the damaged area in Figure 45, showing the nature of the crack branching.

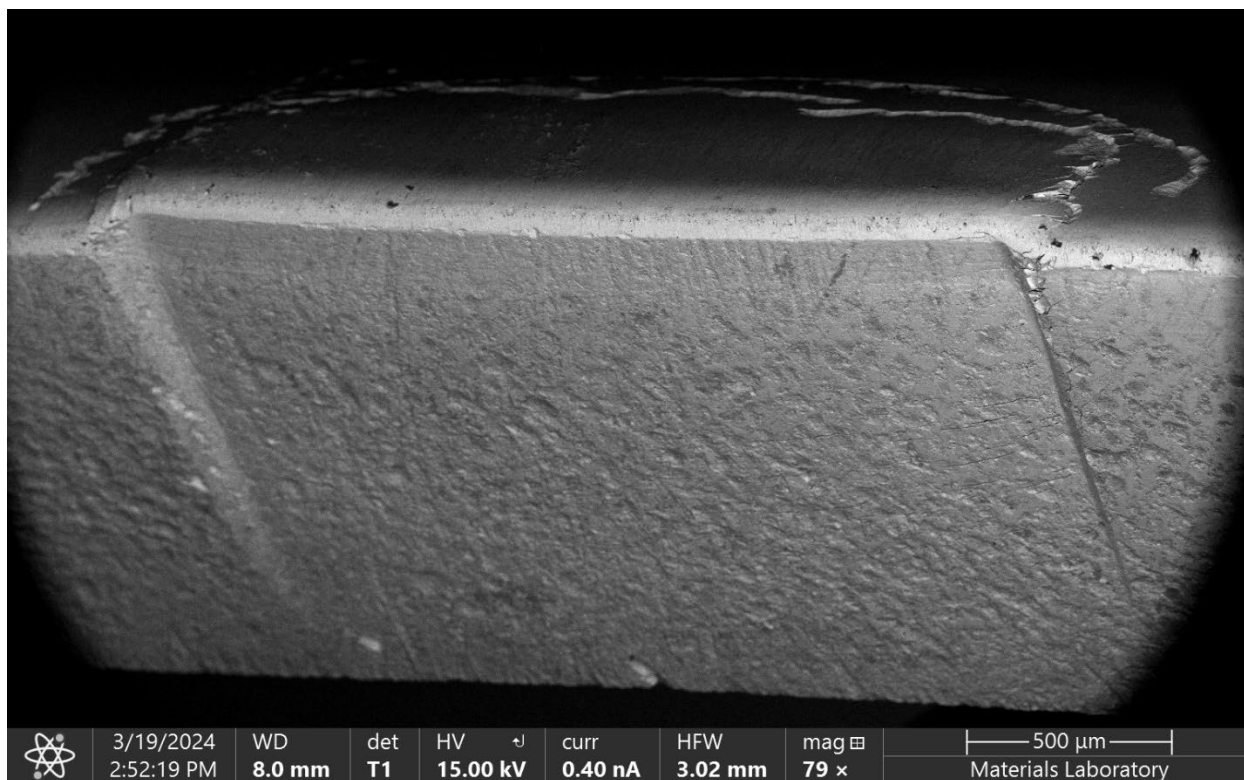


Figure 43. BE micrograph of the slot face at the slot 2 damaged corner.

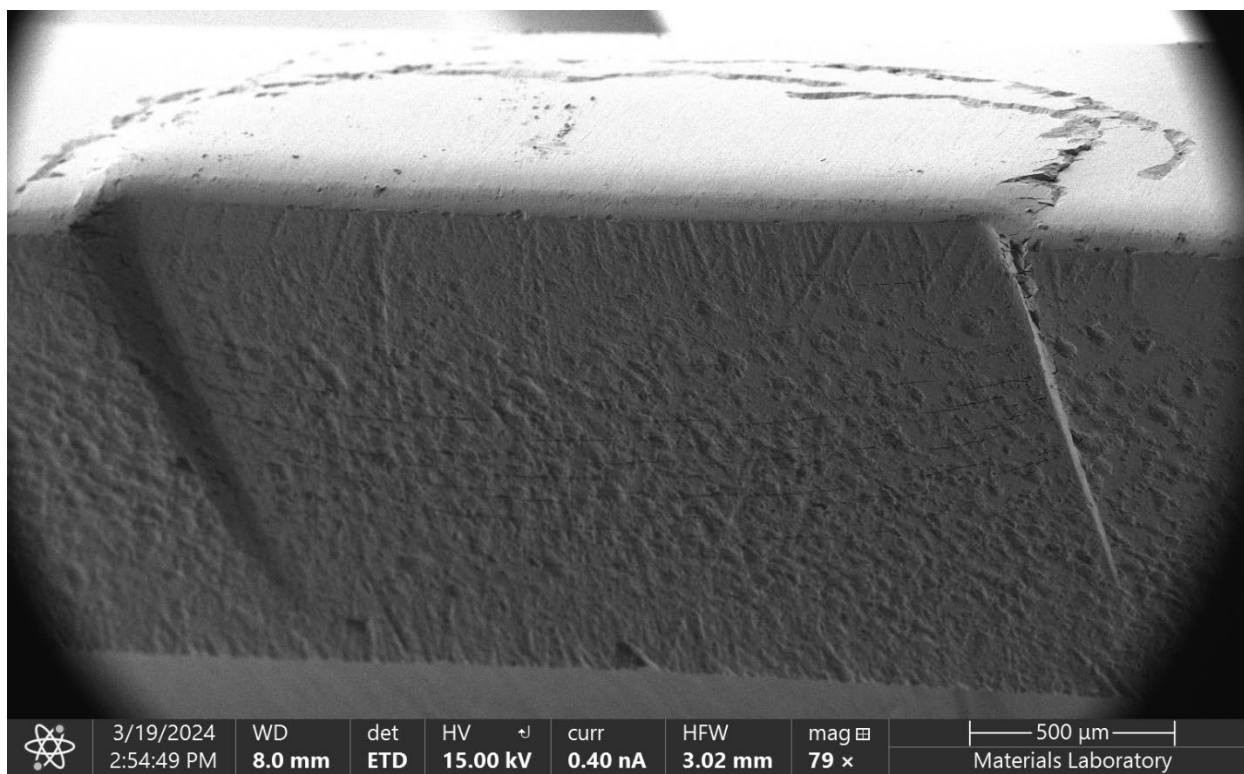


Figure 44. SE micrograph of the slot face at the slot 2 damaged corner.

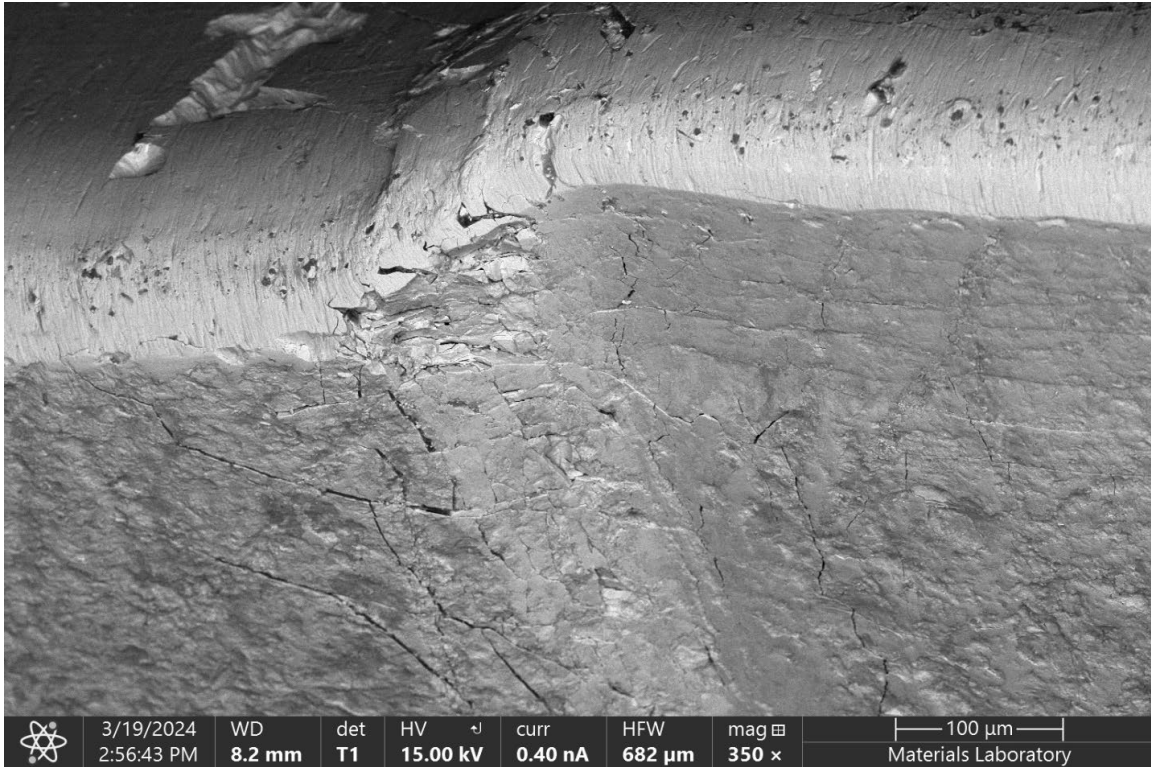


Figure 45. BE micrograph of a closer view of the left angled corner depression in Figure 44, showing parallel horizontal and cross-cracking in the area.

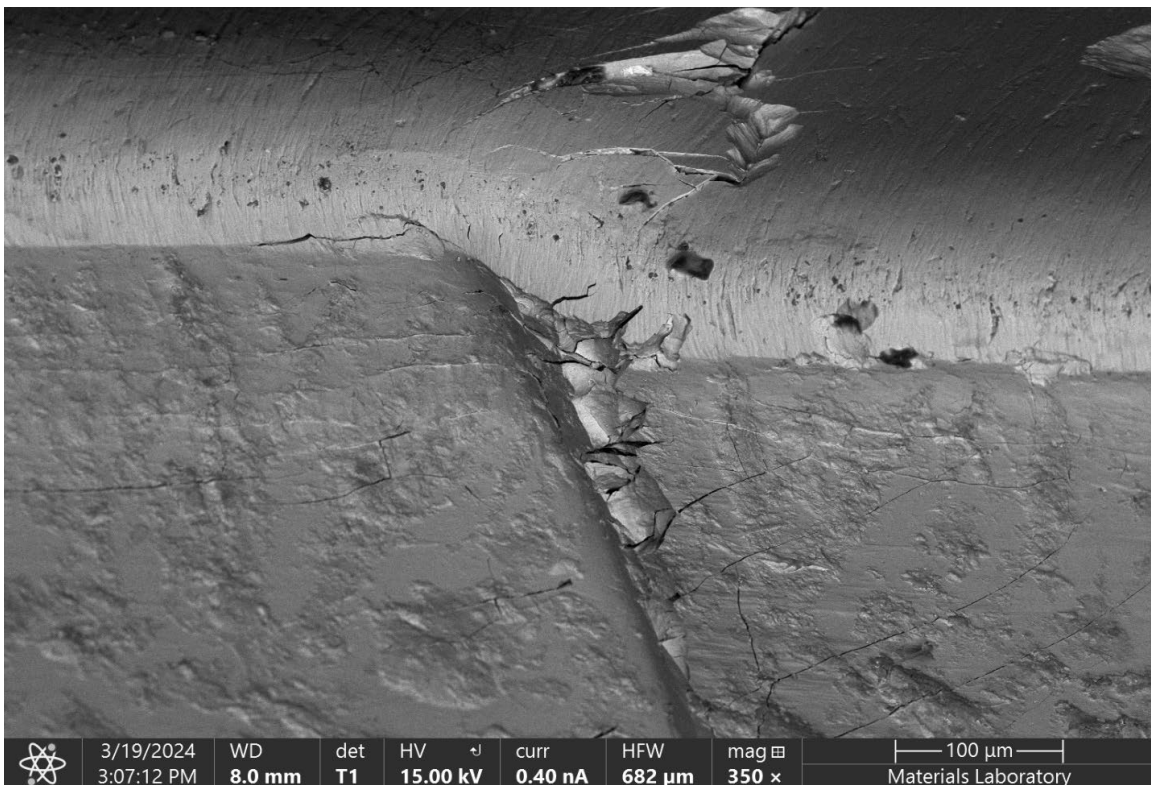


Figure 46. BE micrograph of a corner of the depression on the sides of the slot 1 damage, showing chipping and spalling, with cracking emanating outward.

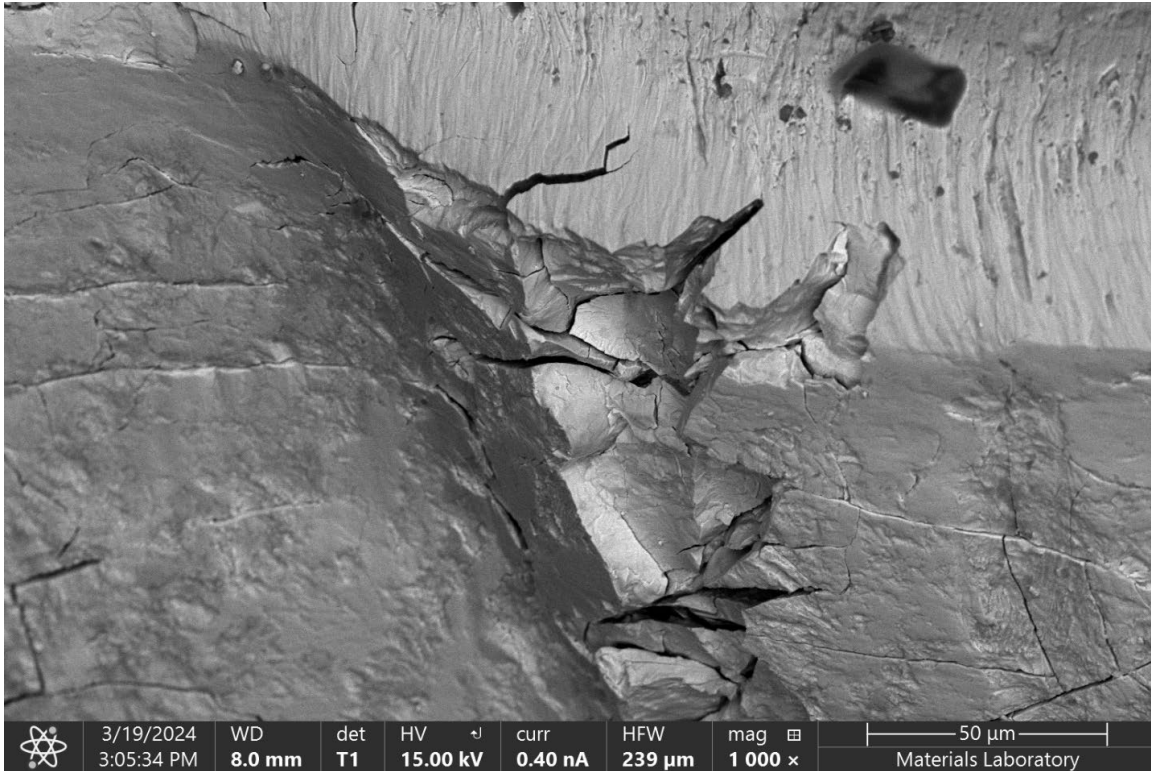


Figure 47. BE micrograph of a closer view of the spalled area of the depression corner in Figure 42, with cracks emanating outward.

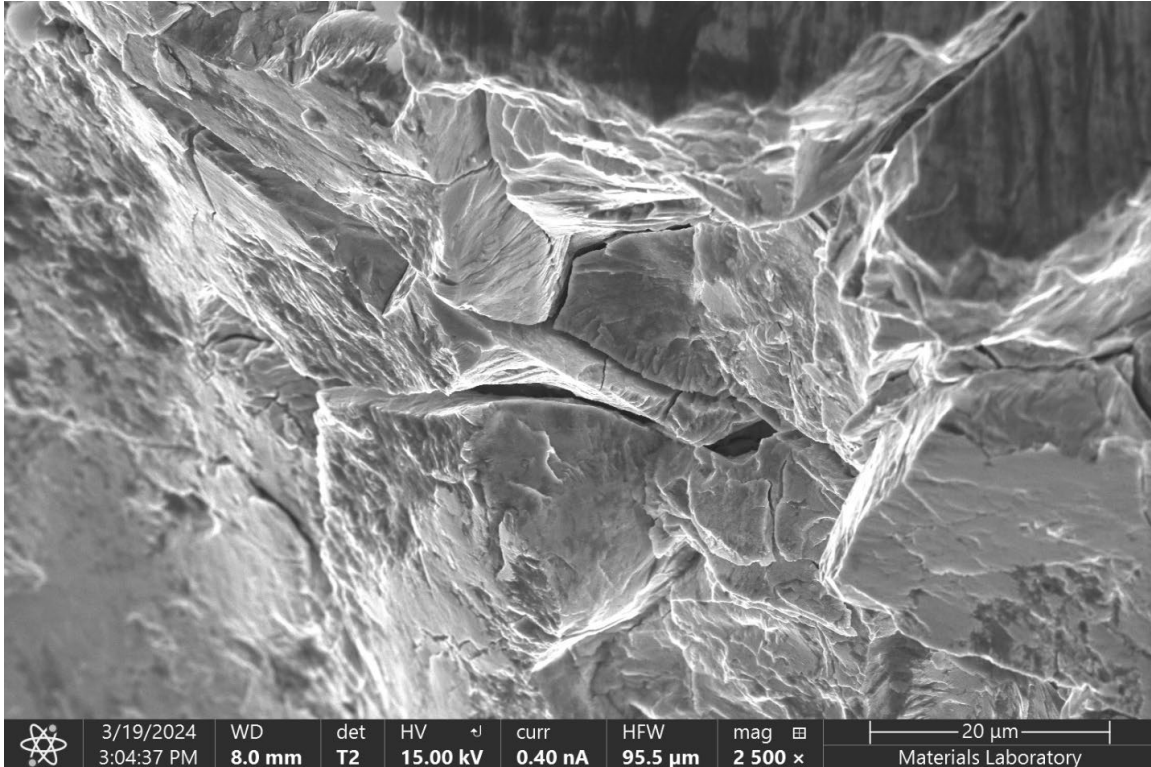


Figure 48. SE micrograph of the cleavage fracture patterns in the spalled area in Figure 43.

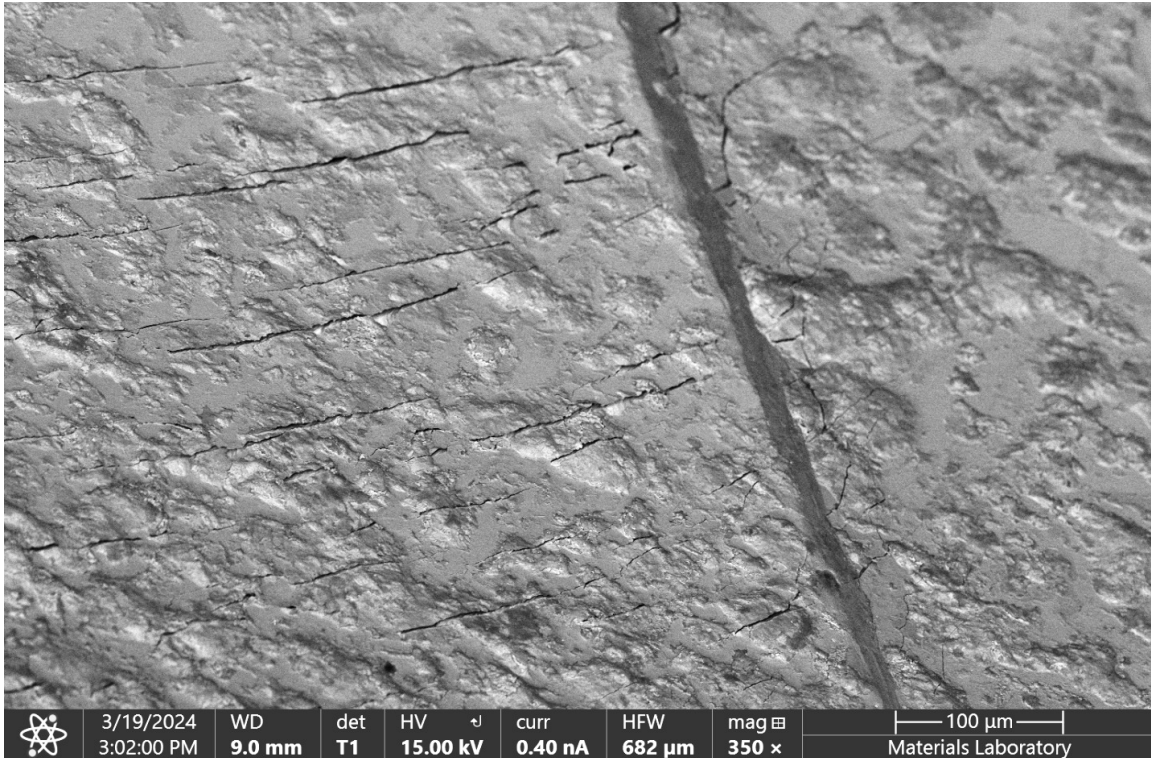


Figure 49. BE micrograph of parallel horizontal cracks in the depression area on the slot 2 face.

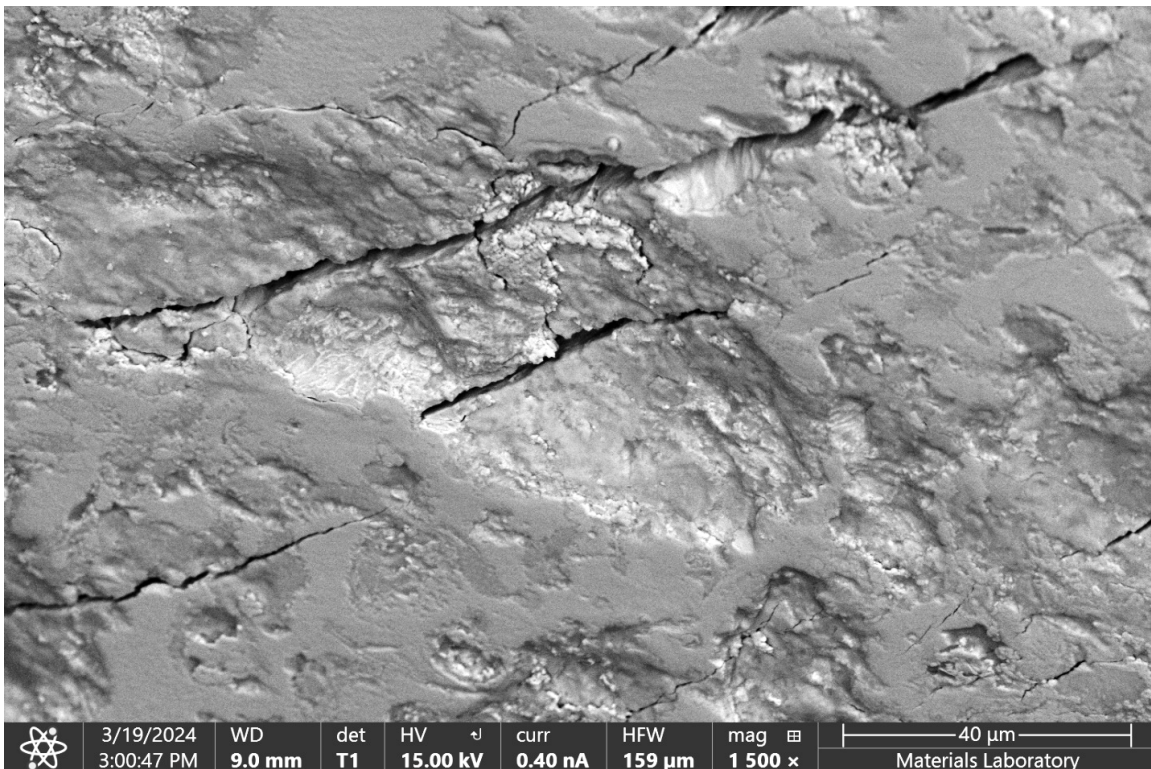


Figure 50. BE micrograph of a closer view of the cracks in Figure 50, showing material spalling.

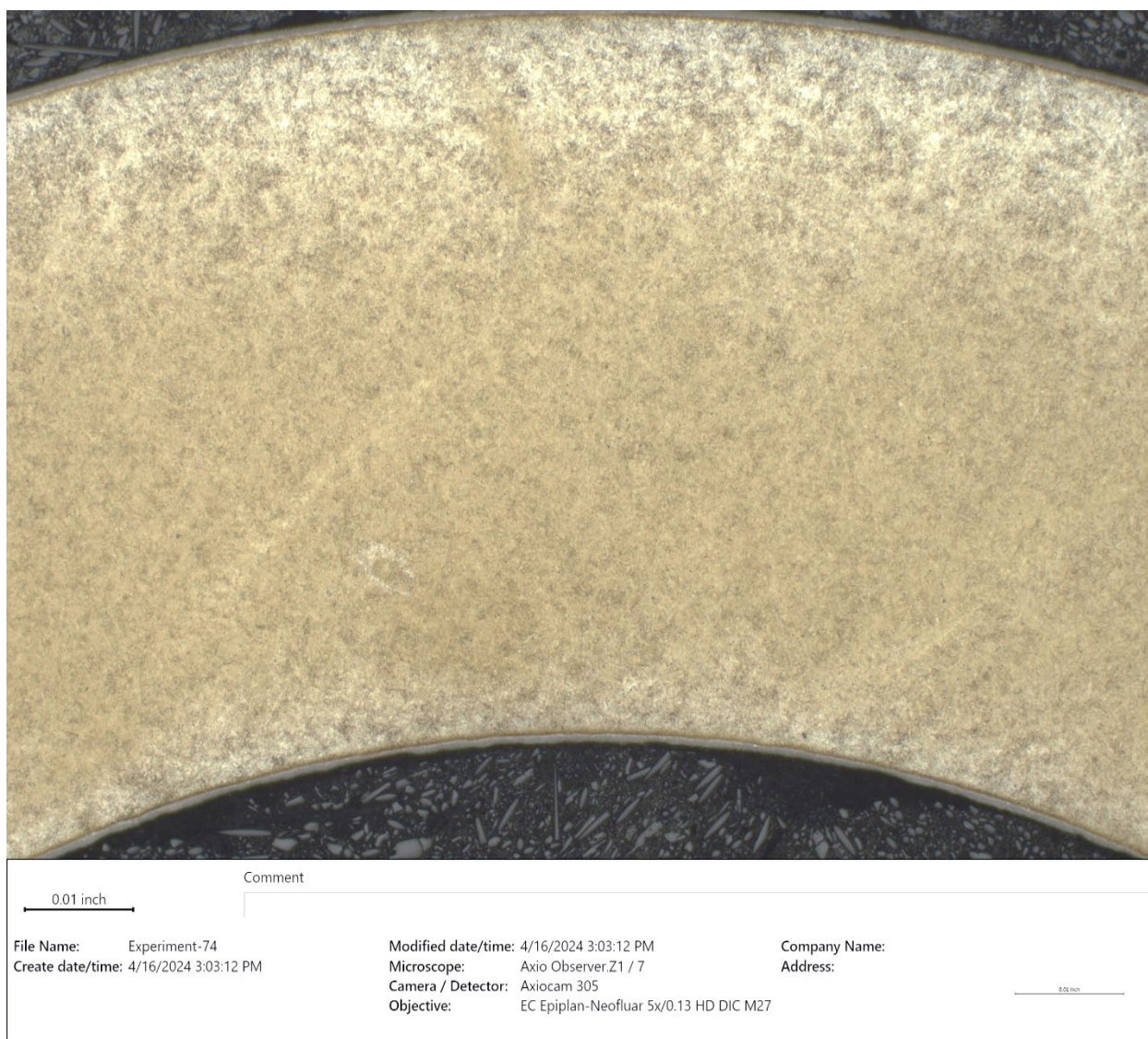


Figure 51. Bright-field (BF) optical micrograph of an etched cross section of the camshaft (~25X, etched Fry's Reagent).

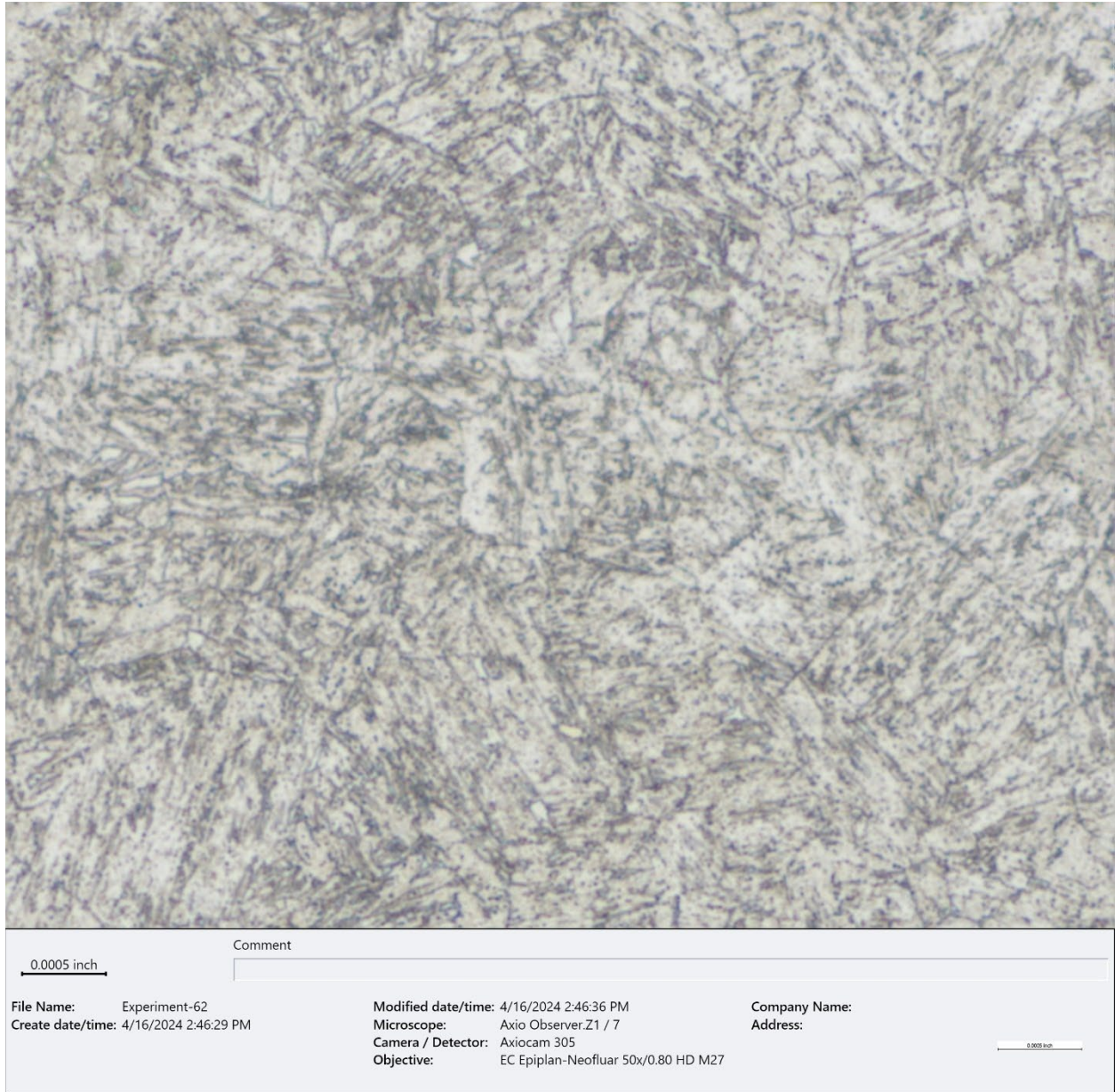


Figure 52. BF optical micrograph of a typical area of the core microstructure of the camshaft (~800X, etched Fry's Reagent).

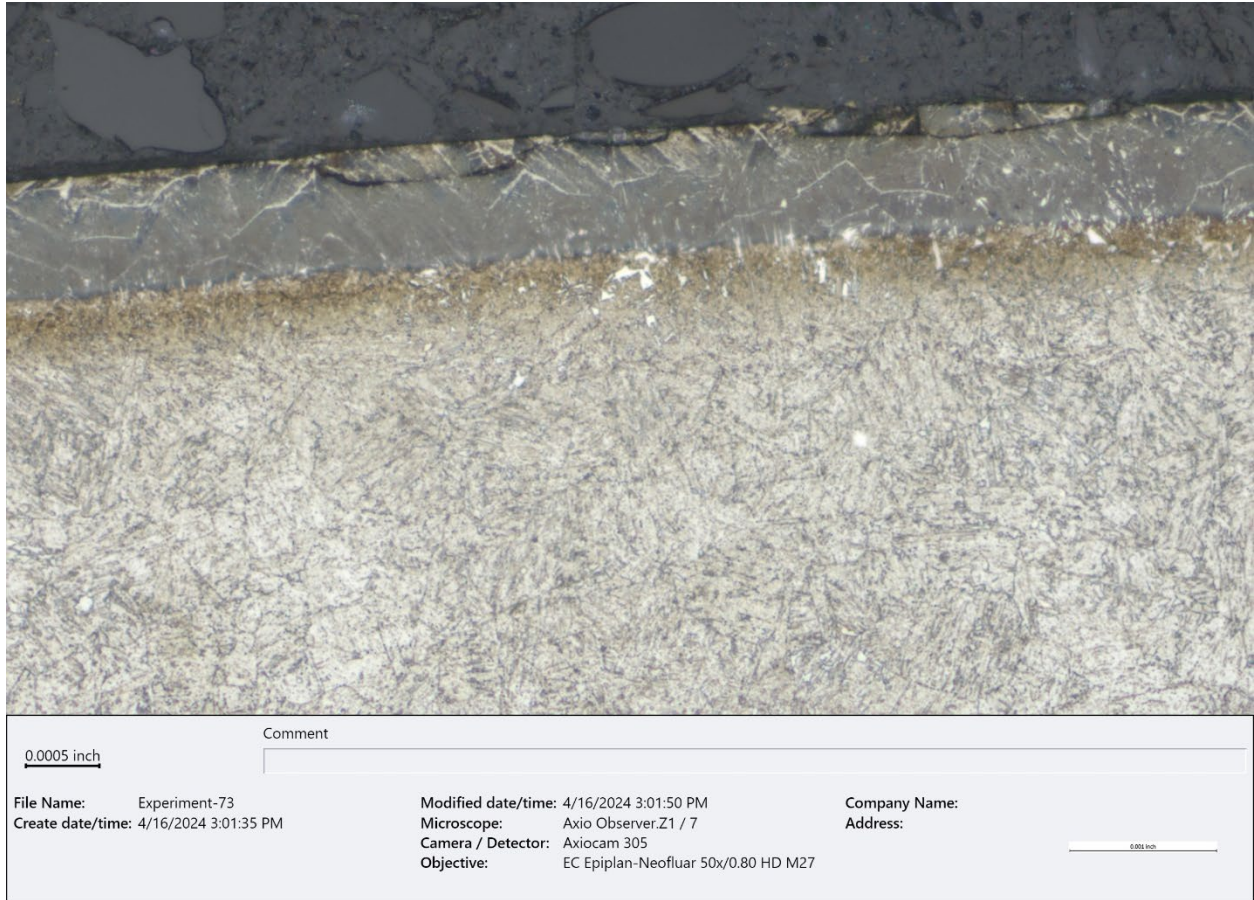


Figure 53. BF optical micrograph of a surface nitride layer of the camshaft, showing parallel cracking open to the surface (~320X, etched Fry's Reagent).

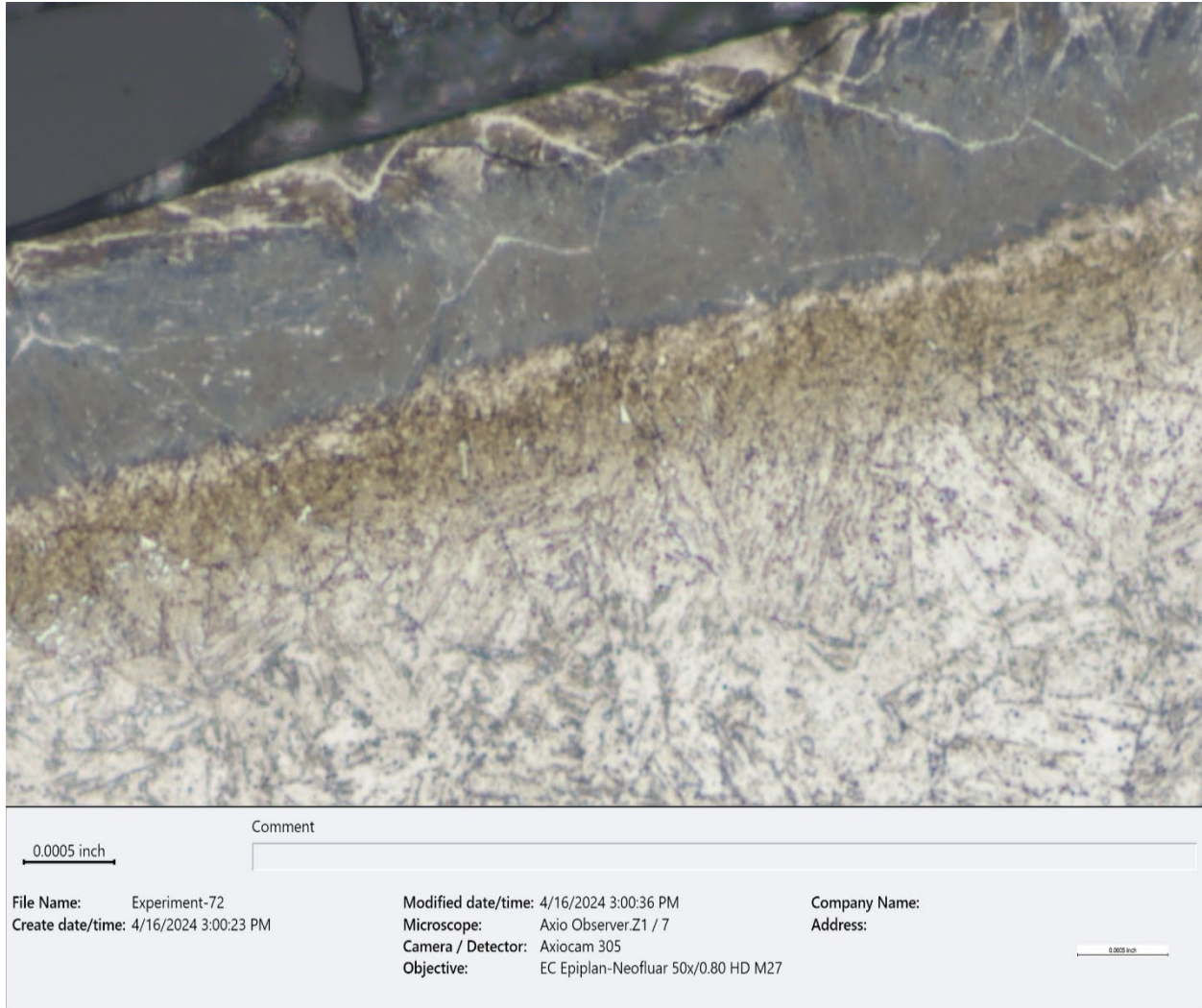


Figure 54. BF optical micrograph of a surface nitride layer of the camshaft, showing a subsurface crack (~500X, etched Fry's Reagent).

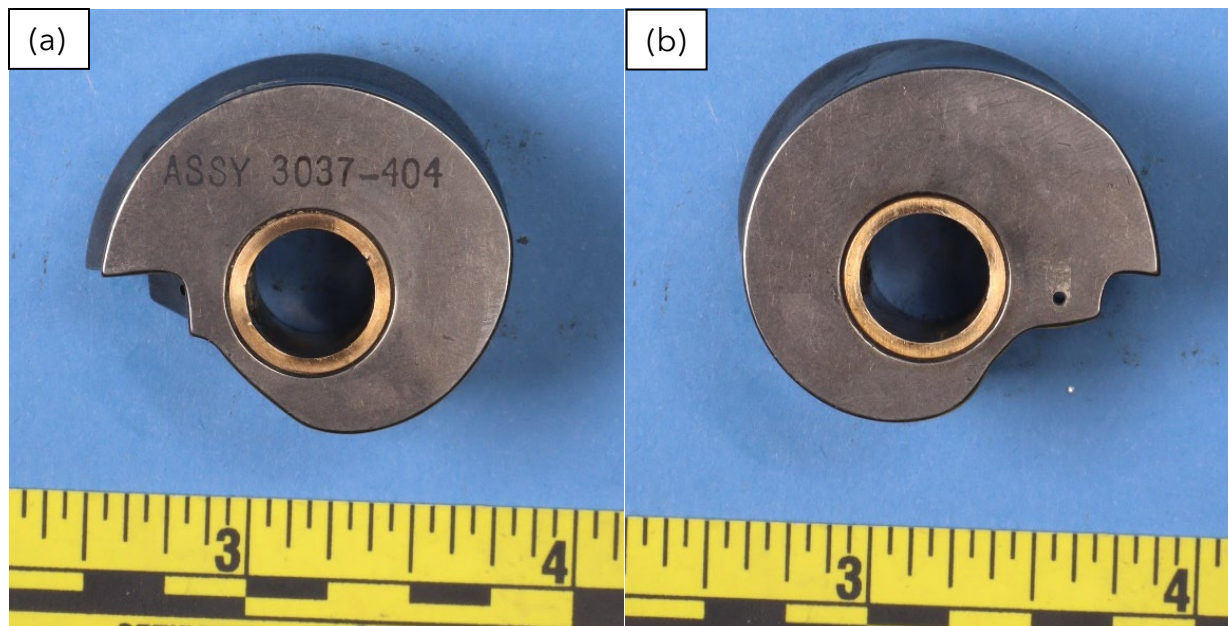


Figure 55. Opposite faces of the camgear, after removal from the camshaft.



Figure 56. Angled view of the bushing interior that mated with slot 1 of the shaft, after cleaning.

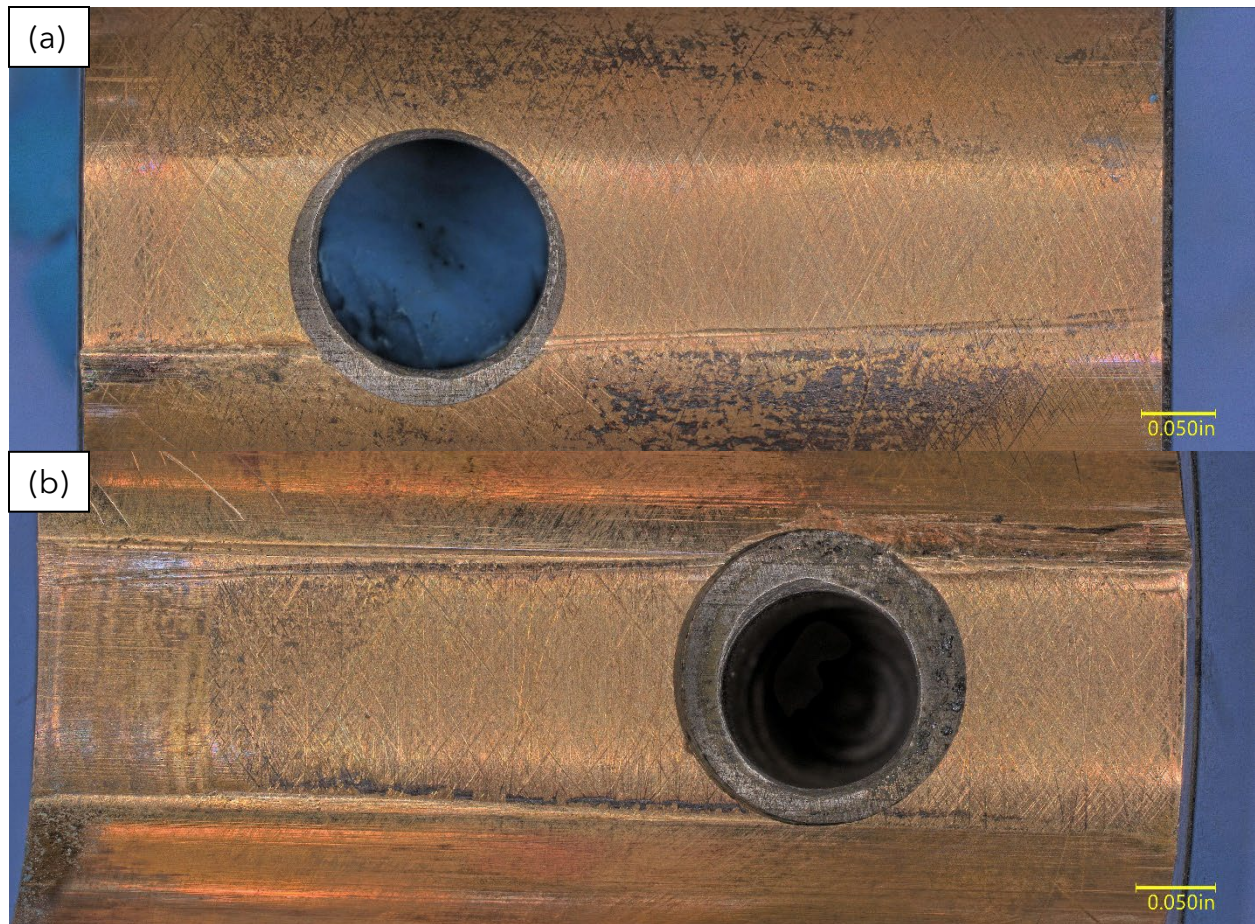


Figure 57. Mating views of the bushing interior, after sectioning.

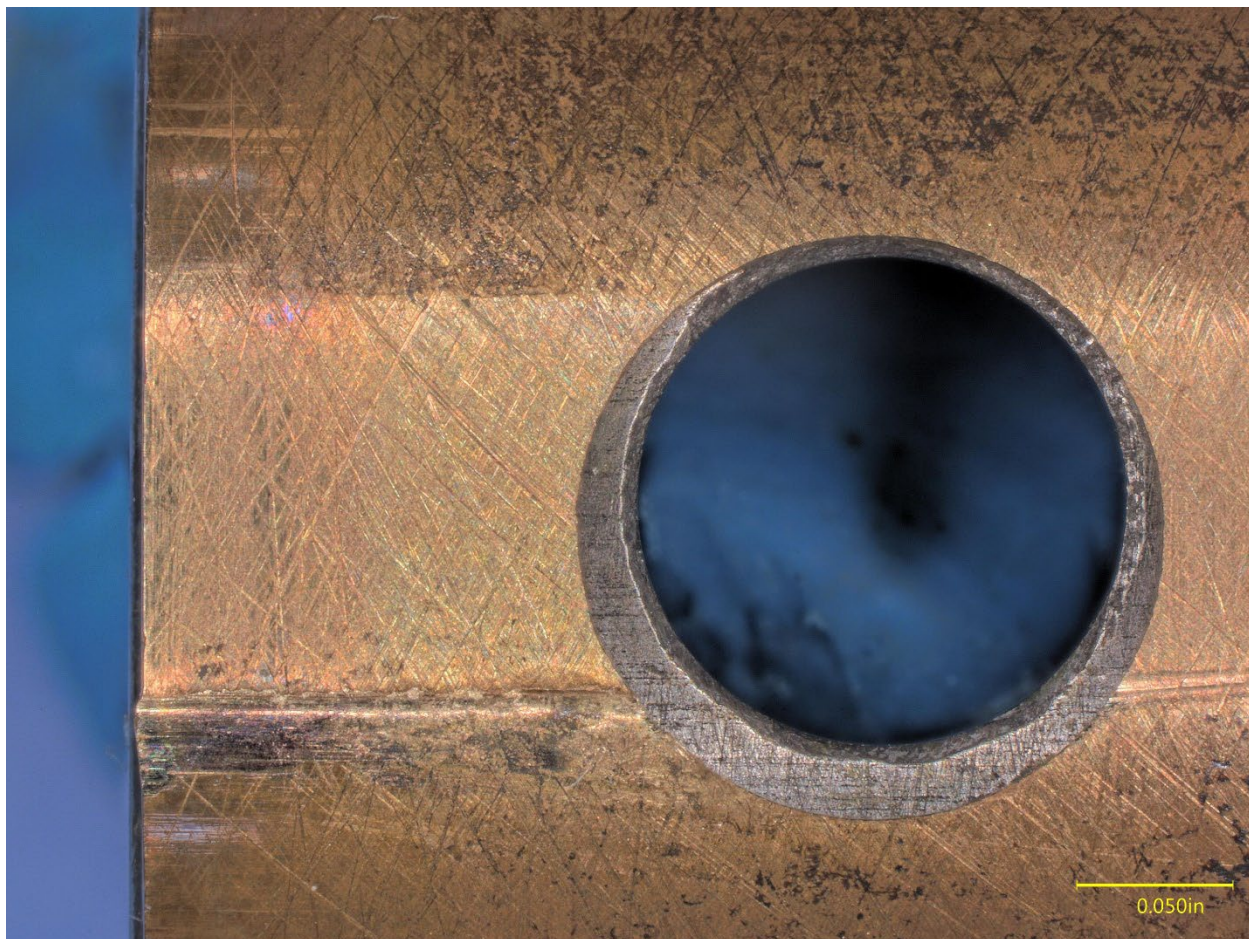


Figure 58. Closer view of the end of the bushing interior near the slot 1 damage.

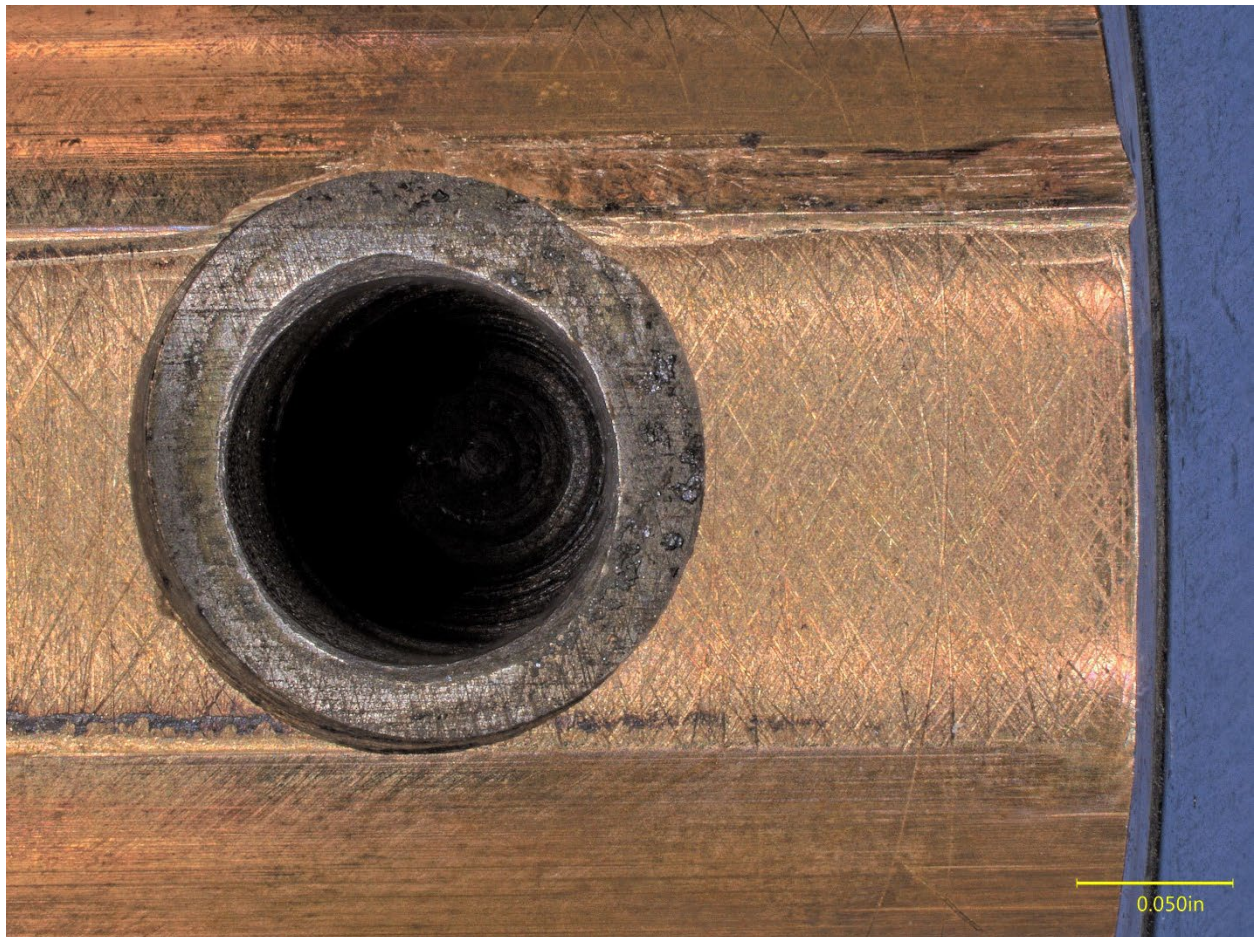


Figure 59. Closer view of the bushing interior near the edge with the slot 2 corner damage.

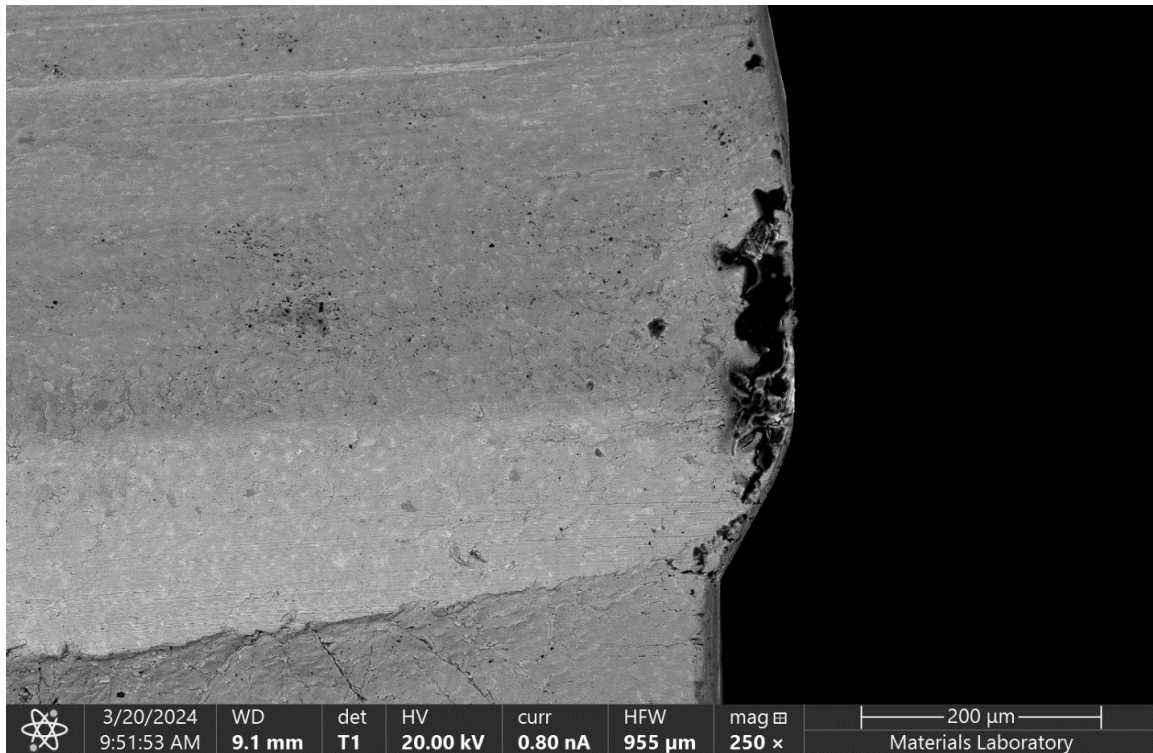


Figure 60. BE micrograph of the bushing protrusion deformation in **Figure 58**.

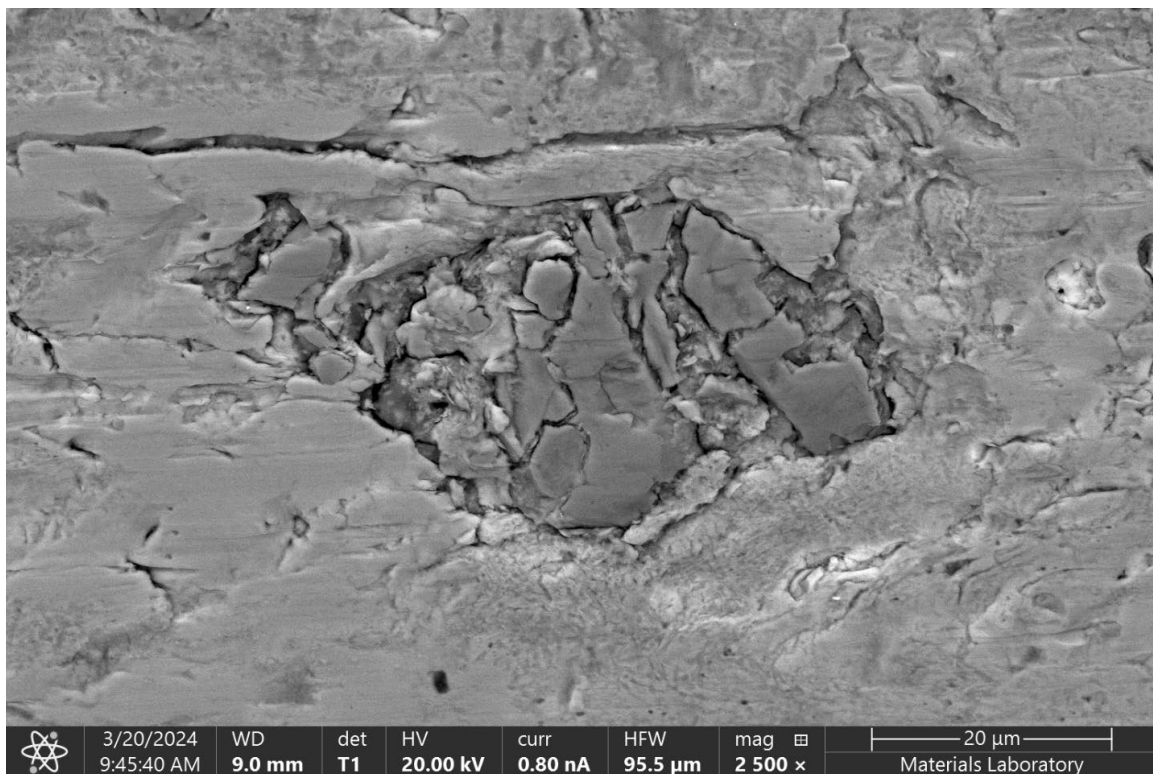


Figure 61. BE micrograph of the boxed area in **Figure 60**, showing dissimilar material embedded in the bushing.

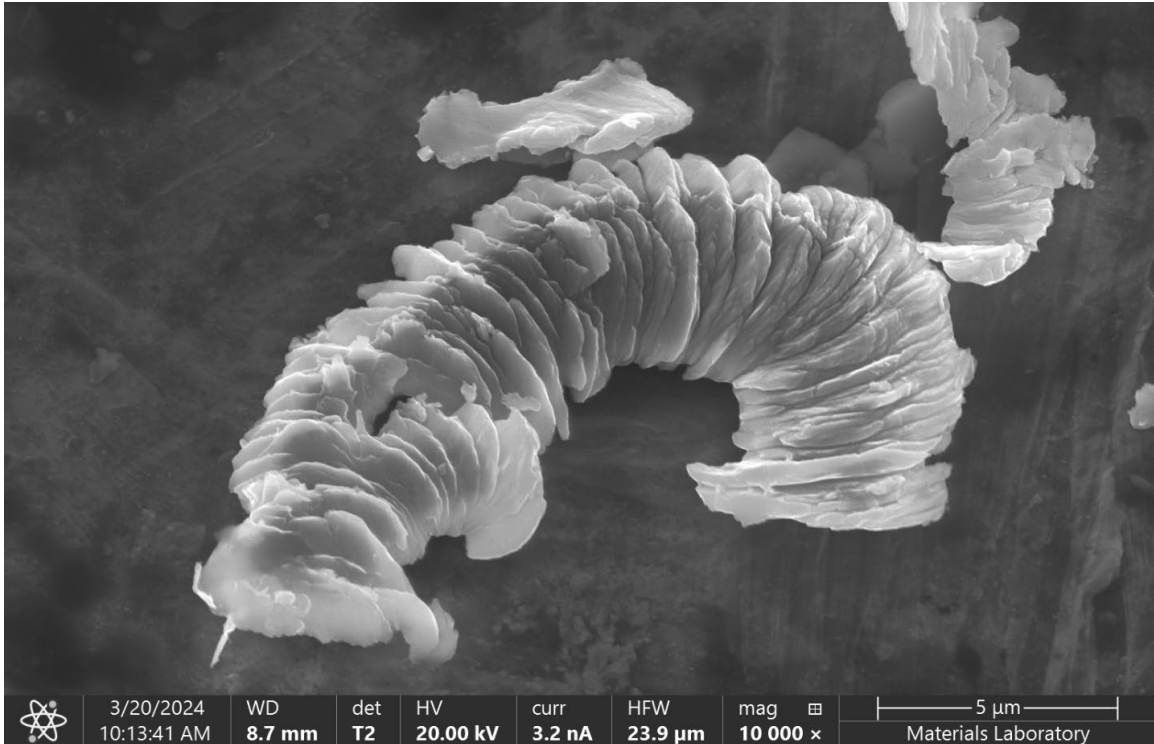


Figure 62. SE micrograph of a wrinkled metal shaving on the bushing surface, consistent with the shaft material.



Figure 63. View of the bearing after removal from the camshaft assembly.



Figure 64. Closer view of the cage and roller balls inside the bearing in Figure 56.



Figure 65. Angled view of the inner race outer surface with the cage, showing darker deposits between the surface.

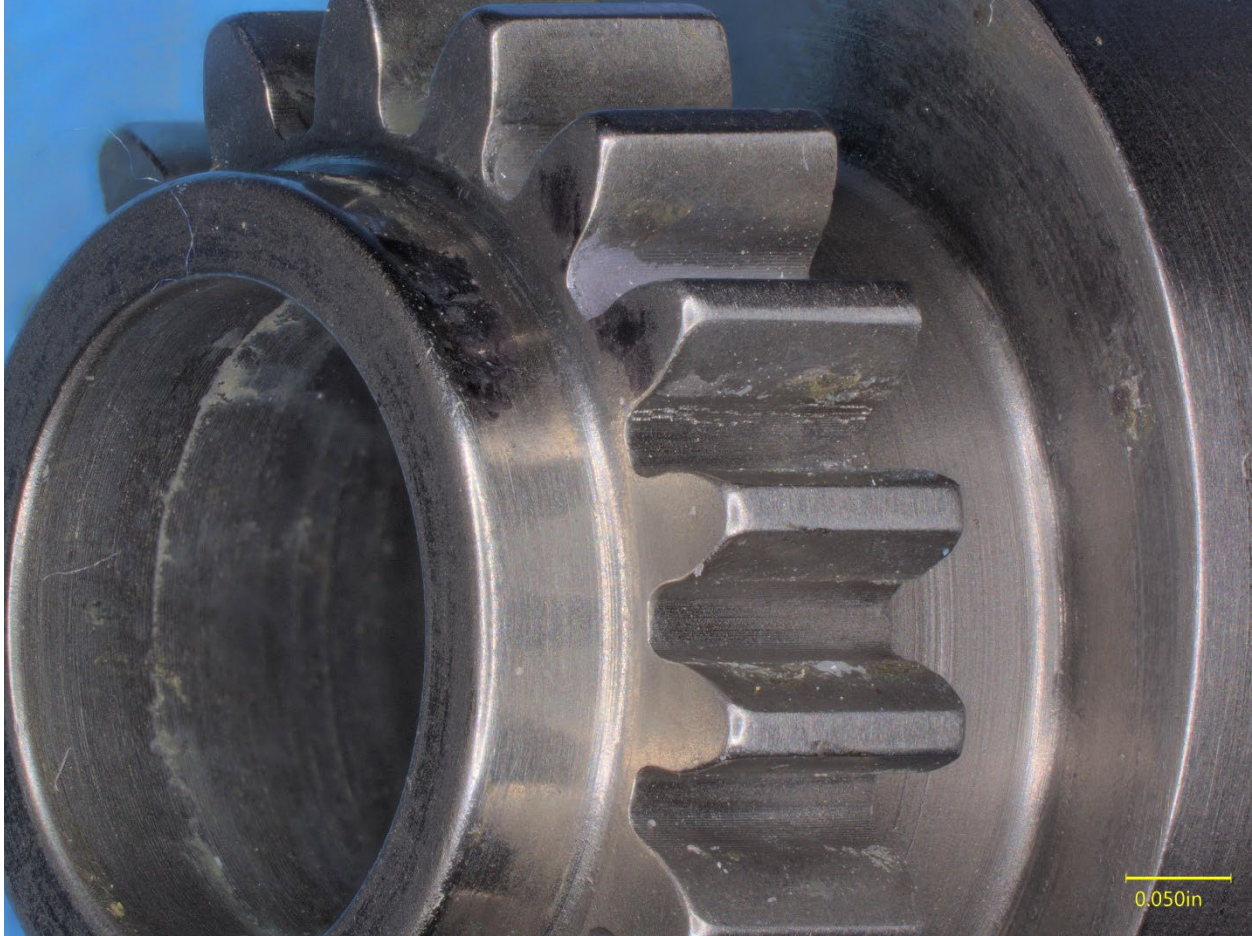


Figure 66. View of the teeth of the pinion gear portion of the camshaft.

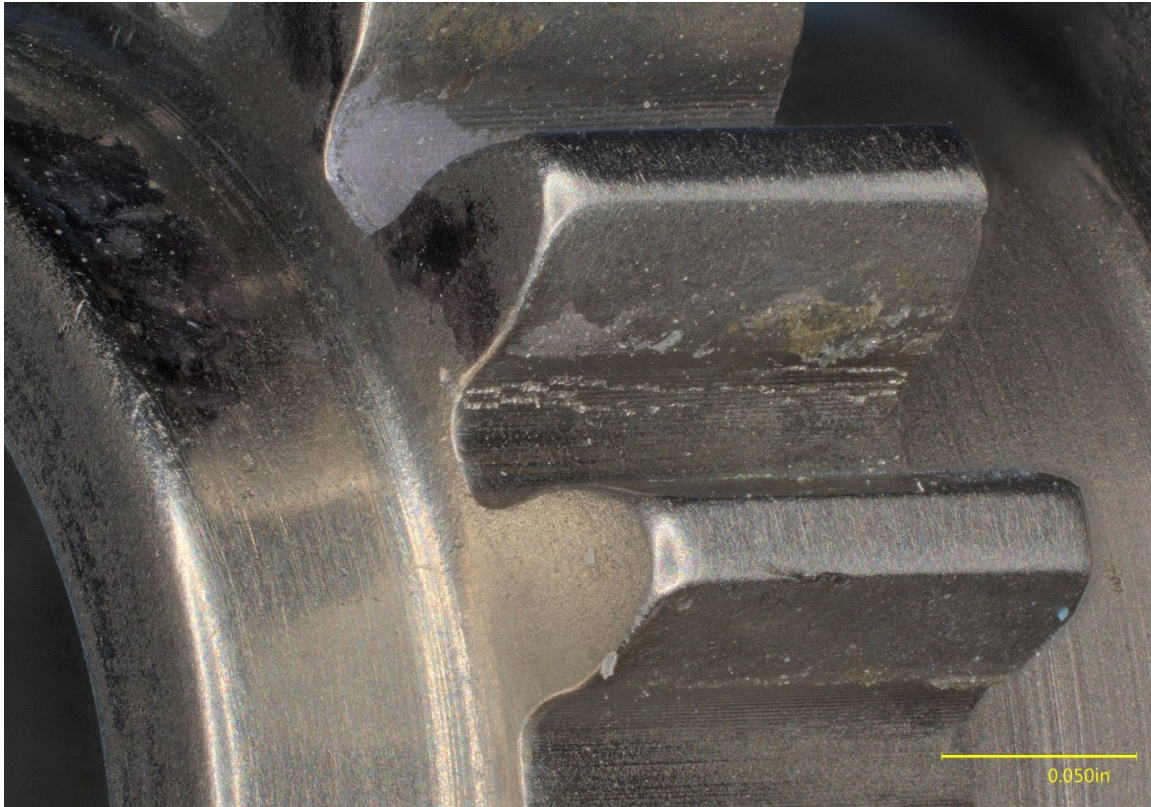


Figure 67. Closer view of the central teeth in **Figure 66**.

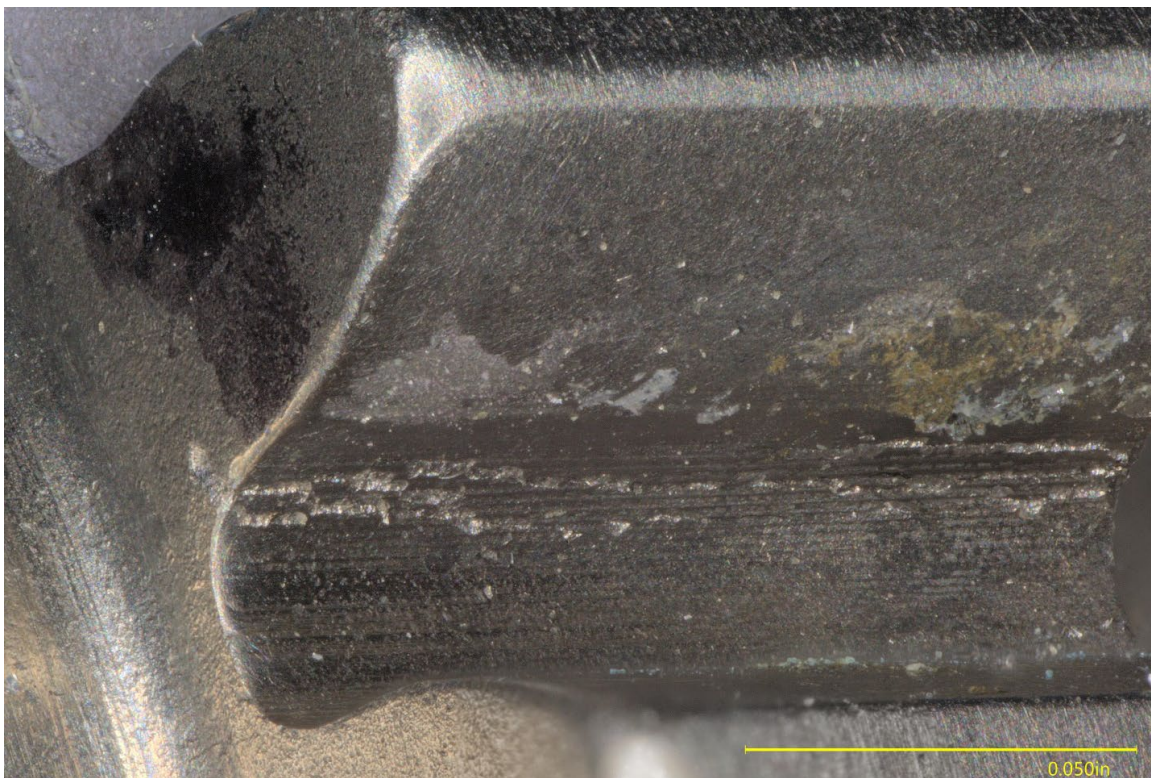


Figure 68. View of the center-positioned tooth in **Figure 67**.

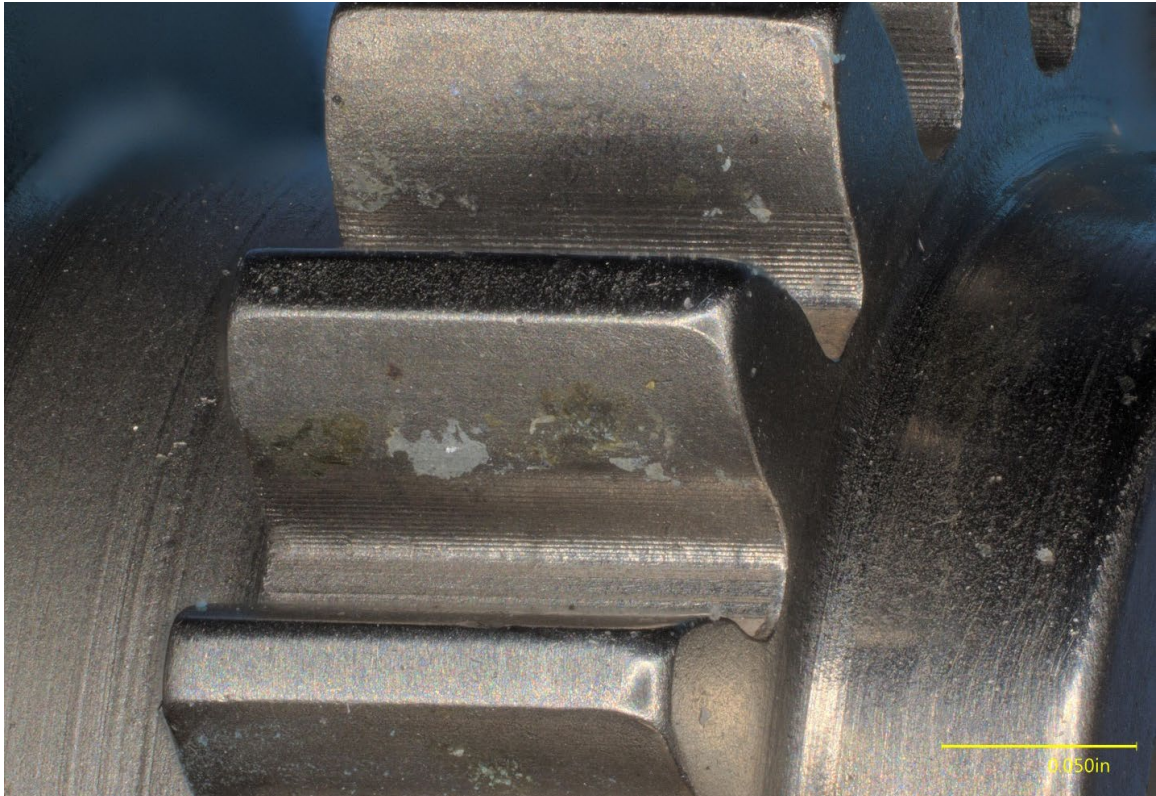


Figure 69. Opposite angled view of the tooth in **Figure 67** and **Figure 68**.

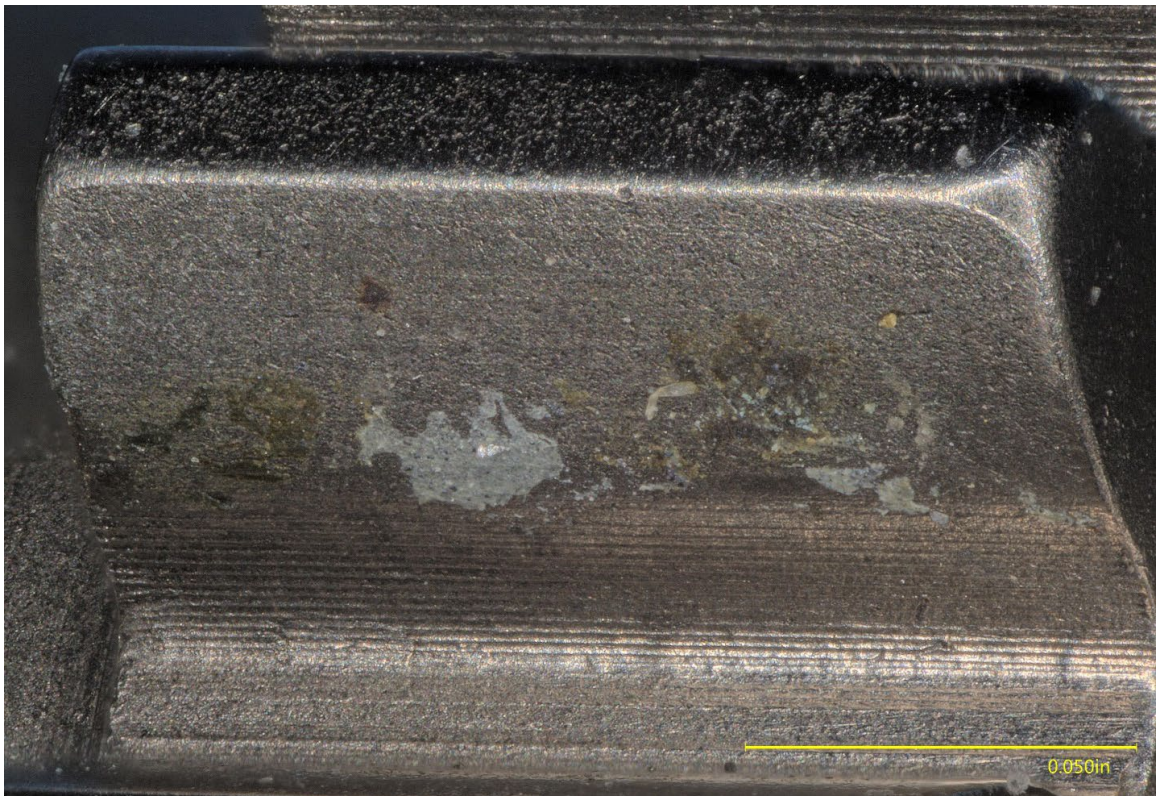


Figure 70. Closer view of the central positioned tooth in **Figure 69**.

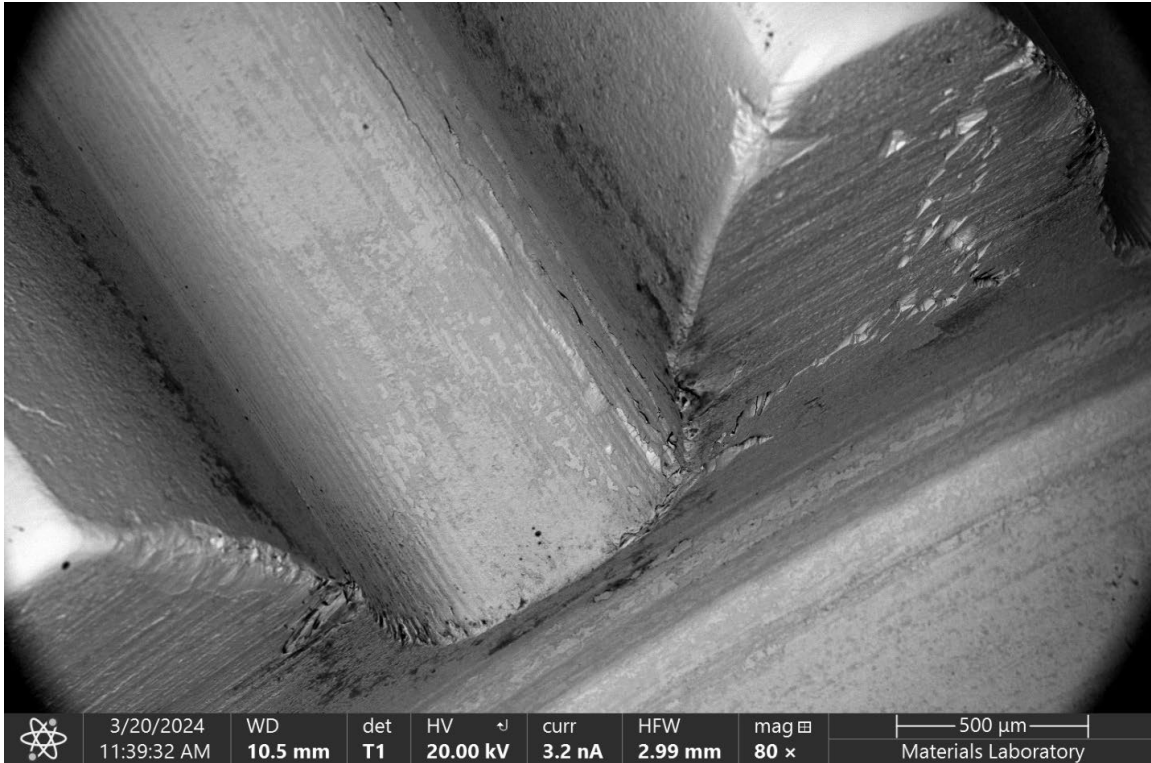


Figure 71. BE micrograph of the outer corner of the tooth in **Figure 70**.

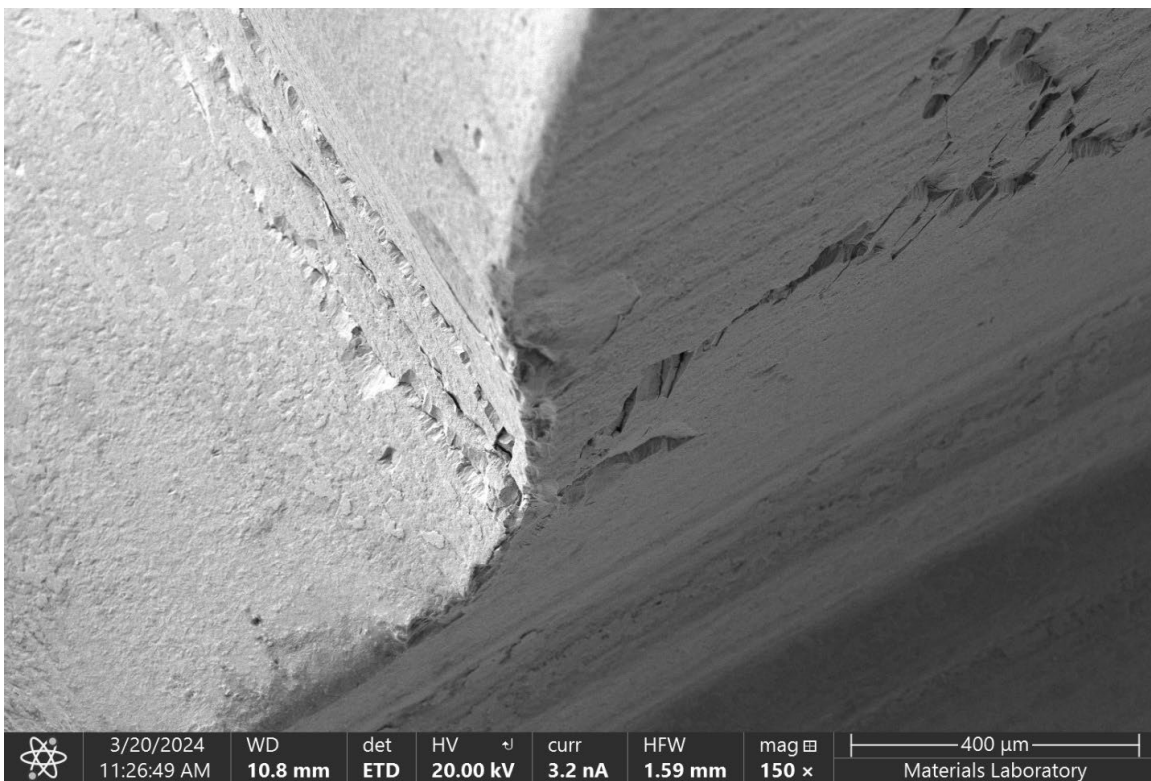


Figure 72. BE micrograph of the tooth corner in **Figure 71**, showing spalling and cracking.

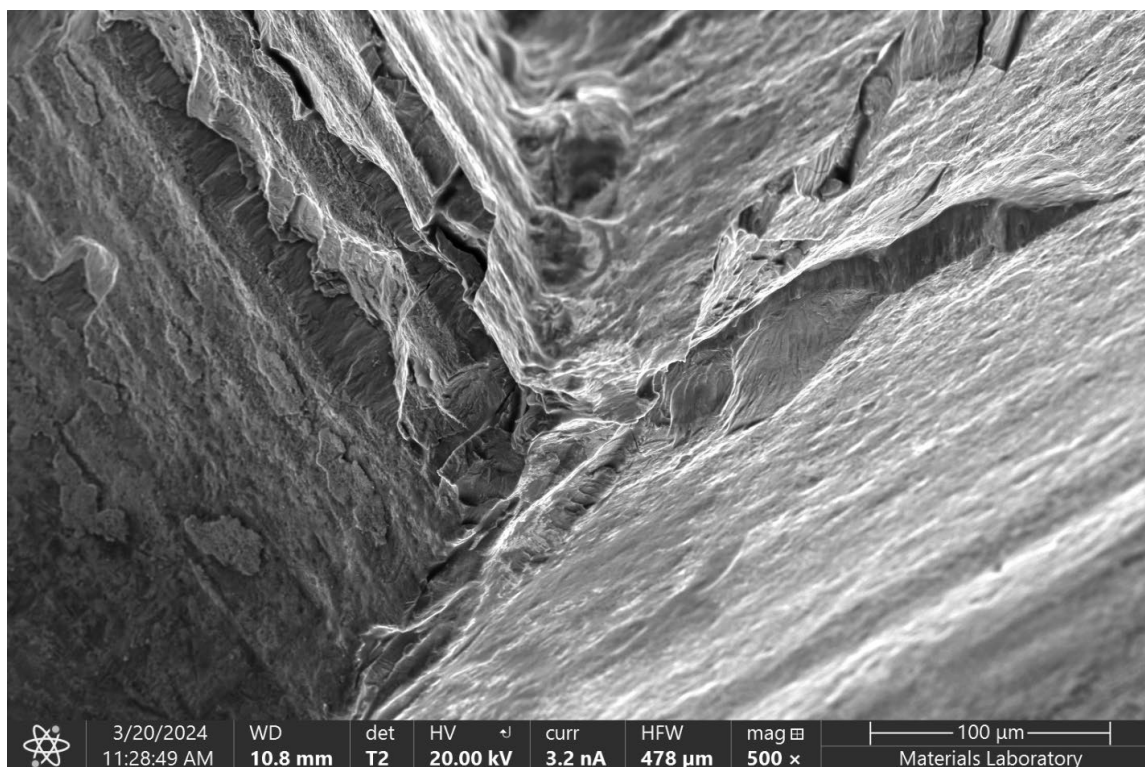


Figure 73. BE micrograph showing a closer view of the cracked edge in **Figure 72**.



Figure 74. BE micrograph of the fillet radius of the gear tooth, showing longitudinal cracking.

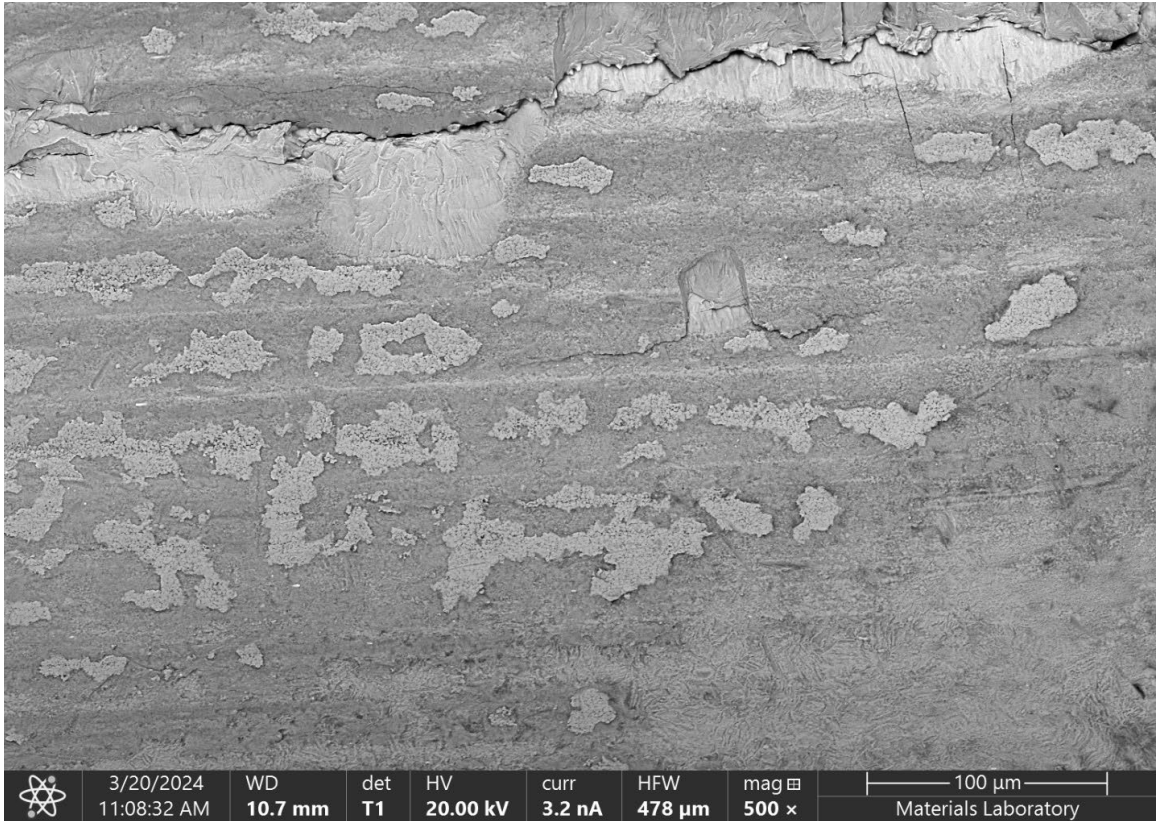


Figure 75. BE view of spalled material adjacent to cracking in **Figure 74**.

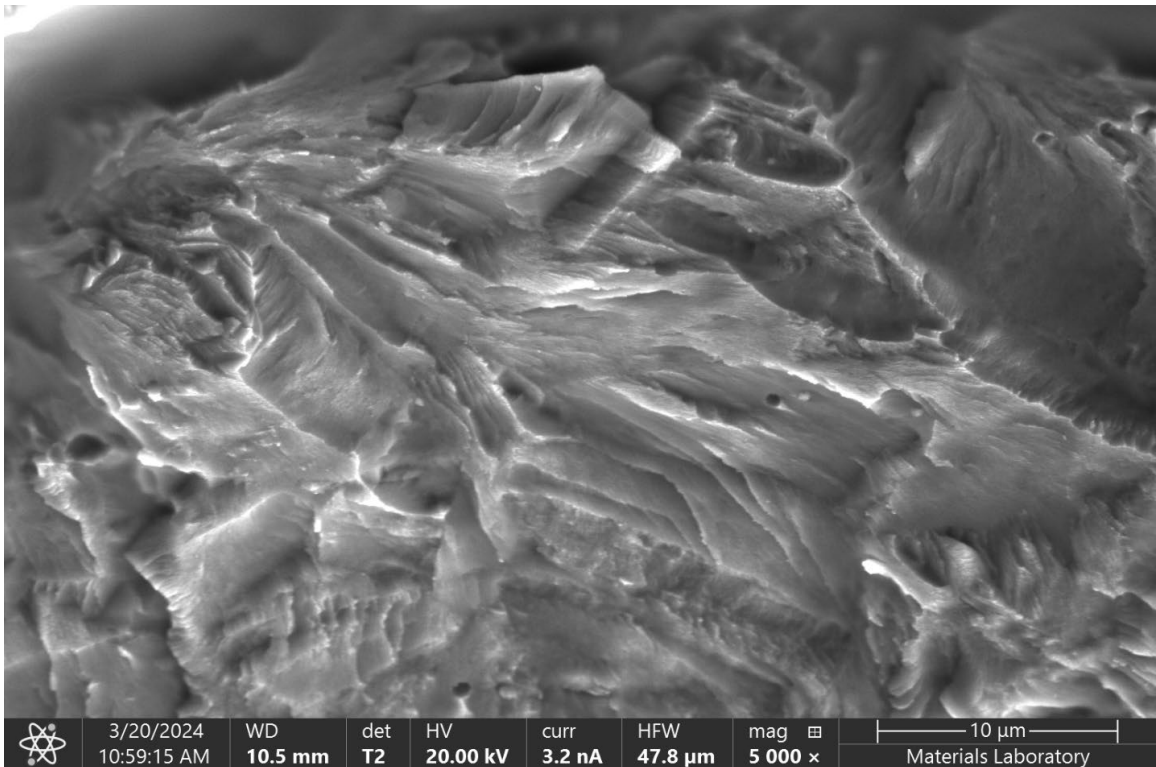


Figure 76. BE micrograph of cleavage facets on a spalled area of the tooth surface.

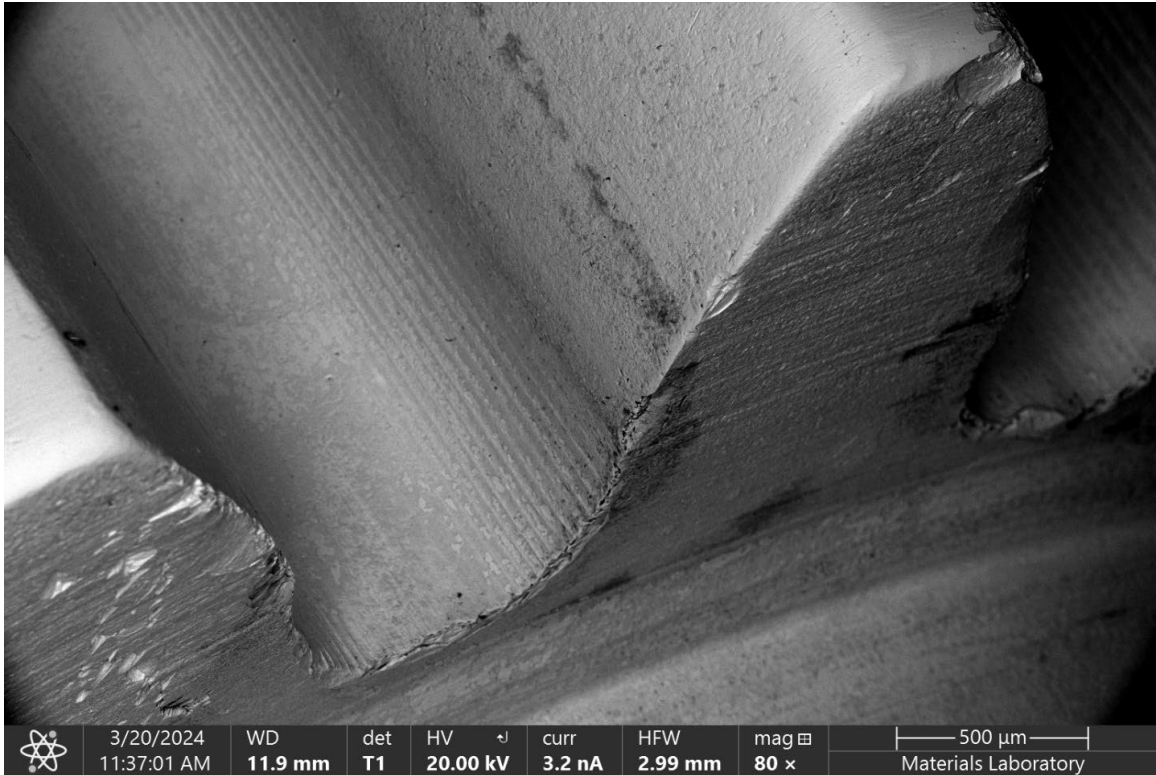


Figure 77. BE micrograph of the opposite edge of the tooth in **Figure 71**.

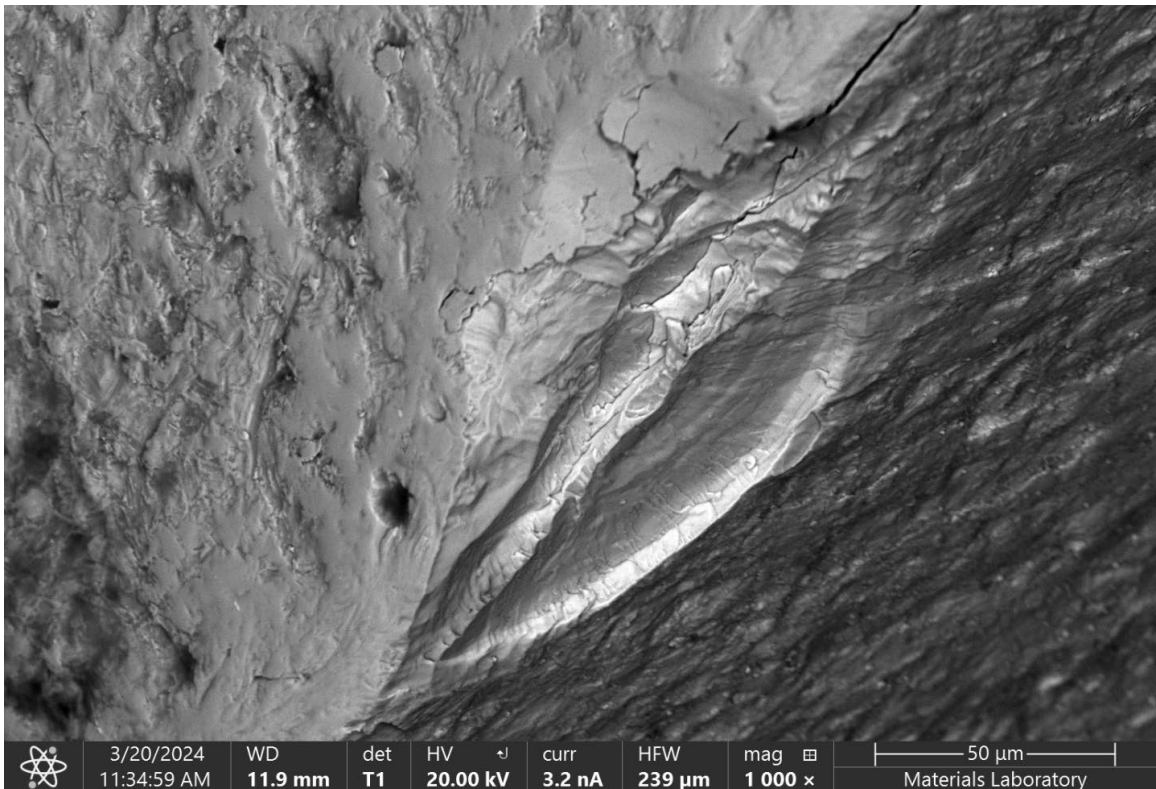


Figure 78. BE micrograph of the tooth corner in **Figure 78**, showing a spalled corner section.