

National Transportation Safety Board

Office of Research and Engineering

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MATERIALS LABORATORY

Factual Report 24-044

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A. ACCIDENT INFORMATION.....	3
B. COMPONENTS EXAMINED.....	3
C. EXAMINATION PARTICIPANTS.....	3
D. DETAILS OF THE EXAMINATION.....	3
E. FIGURES.....	9

A. ACCIDENT INFORMATION

Location: Attalla, Alabama
Date: November 27, 2023
Time: 17:48 central daylight time
23:48 coordinated universal time
Vehicle: Piper PA-32R-301T, N4187Q
Investigator: Timothy Monville, AS-ERA

B. COMPONENTS EXAMINED

Pieces of magneto gear assembly
Crankshaft idler gear assembly
Fuel pump idler gear assembly
Pieces of gears and crankcase
Remnants of a rivets
Metallic pieces extracted from an oil sump

C. EXAMINATION PARTICIPANTS

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NTSB, Washington, DC

D. SUMMARY

A crankshaft idler gear and fuel pump idler gear were received by the NTSB Materials Laboratory that each exhibited fractured of teeth at several locations. The fracture features exhibited dimpled rupture consistent with overstress fracture in bending of the gear teeth. The crankshaft idler gear exhibited features consistent with an overstress fracture typical of carburized or case-hardened steel. A magneto gear had fractured in half via overstress, with partial crack that also exhibited overstress features when opened.

Several remnants, determined to be from rivets from the left magneto, exhibited fracture and wear features. One of these remnants exhibited a fracture surface displaying features consistent with fatigue cracking that had initiated at multiple initiation sites along the outer surface, located at an area of wear.

E. DETAILS OF THE EXAMINATION

On November 27, 2023, a Piper PA-32R-301T was involved in an accident near Attalla, AL. The private pilot was fatally injured. During the flight, the pilot declared an emergency to air traffic control that the engine was losing RPM. Several witnesses reported the airplane impacting the ground, followed by a fireball and a loud bang.

The accident site was mountainous, wooded terrain about 11 nautical miles from the airport. A postaccident examination of the TIO-540-AH1A engine revealed the left gear retainer assembly (part number LW-19096) was fractured, with its pieces found in the oil sump.¹ Also, the left crankshaft idler gear assembly (part number 71668) and the fuel pump idler gear assembly (part number 71664) exhibited damaged or missing teeth. The fractured pieces of the left gear retainer assembly, damaged gears, and ferrous parts found in the engine oil sump were retained for further examination.

Figure 1 shows the gear and separated components, placed in individual bags, as received. The gears were labeled separately from the fractured remnants of gear teeth, flanges, and the rivet remnants. The remnants were submitted individually in separate plastic bags.

1.0 Left Crankshaft Idler Gear

The remainder of the left crankshaft idler gear is shown from the forward and aft faces in Figure 2 and Figure 3. This part was a combination gear, with a larger gear on the side facing the reader in Figure 2. From this view, there were three entirely fractured teeth—two at the 12 o'clock position and one entirely fractured tooth at the 4 o'clock position. There were also three partially missing teeth clockwise from the top fractured tooth. None of the teeth from the smaller gear had fractured.

Figure 3 and Figure 4 show the fractured teeth surfaces as received. In each of these, the fracture surfaces exhibited the same color and hue as the surrounding regions. There were three additional damaged or partially fractured teeth adjacent to the two fractured teeth along the clockwise direction (Figure 5). The degree of damage decreased in the clockwise direction. The teeth surrounding the lone fractured tooth from the 4 o'clock position exhibited small impact marks, evidenced by some plastic deformation. However, there was no missing material or partial fractures.

The fractured and liberated teeth were examined and were matched with their respective fracture locations on the gear. Figure 6 shows the locations of the fractured teeth near the gear viewed from the aft side. The mating fracture surfaces are shown closer in Figure 7 through Figure 9. As demonstrated in Figure 6, the gear fractures were oriented convex inboard. The fracture surfaces were generally rough and fibrous in texture, with a dull luster. The liberated teeth exhibited a lighter and more metallic hue than the gear, which was darker in color.

¹ The Lycoming TIO-540-AH1A is an air-cooled six-cylinder, horizontally opposed turbocharged, fuel-injected engine, manufactured by Lycoming Engines, headquartered in Williamsport, PA.

The fractured tooth, shown on the left in Figure 6, Figure 8, and Figure 9, was examined using a field emission scanning electron microscope (SEM). The overall view of the tooth is shown optically in Figure 9. This figure shows an area of smoother, more reflective material on the top, consistent with a corresponding area on the gear fracture. Figure 10 shows the lower edge of the left tooth fracture, revealing two distinct regions with separate fracture features. The center or core is shown closer in Figure 11 and Figure 12.

This region exhibited elongated features, consistent with the grain direction from the forging process. The fracture surface exhibited elongated phases, shown as white spots in Figure 11.² An EDS examination found these to be consistent with manganese sulfides, typically found in steel components.

Between these particles, the fracture surface exhibited dimpled rupture, as typified in Figure 12. The part of the tooth fracture surface closest to the edge exhibited mixed dimpled rupture and blocky intergranular facets (Figure 13). This fracture morphology was consistent with the hardened carburized surface layer. All these features were consistent with an overstress fracture of the tooth.

The smoother region of the tooth is shown in Figure 14. A closer view of this region revealed elongated dimpled rupture, consistent with overstress in a shear direction (Figure 15). These features were consistent with an overstress fracture of the tooth, with a bending and shear component at the end of the fracture sequence. There were no features present that were consistent with progressive cracking.

Figure 16 and Figure 17 show the mating fracture surfaces of the right gear tooth. These exhibited a similar pattern to the left tooth, exhibiting a core central area of elongated fibrous fracture features with a finer, blockier periphery. Examination of the tooth using an SEM found features consistent with the left tooth, exhibiting dimpled rupture with mixed dimpled rupture and intergranular facets along the edge. These features were consistent with an overstress fracture of the tooth.

Figure 18 shows the single tooth positioned as fractured. Like the other two separated teeth, the fracture surface exhibited a general concave appearance. Figure 19 and Figure 20 show the mating fracture surfaces of the tooth and the gear at this location. These exhibited the same pattern as the other two teeth, and examination of the fracture surface revealed nearly identical features to those of the other two fractured teeth, consistent with overstress fracture at this location.

² 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.

Figure 21 shows the fuel pump idler gear, viewed from opposite locations. This component exhibited two adjacent fractured teeth, as illustrated in Figure 22. The teeth on either side of the fractured ones were intact but exhibited batter and plastic deformation, as demonstrated with the two teeth in the counterclockwise direction in Figure 23. Figure 23 also shows the two liberated teeth, recovered from the engine teardown. These two teeth exhibited the same hue as the gear, and had a similar convex fracture shape. The curve of the fracture surfaces is shown in Figure 24.

Figure 25 illustrates the two tooth fractures on the fuel pump idler gear. Figure 26 and Figure 27 show the mating faces of the left tooth in Figure 25. This surface exhibited an elongated fracture morphology, with finer features along the edges. The tooth was examined using a SEM. A typical area of the center of the fracture surface is shown in Figure 28. This view demonstrates the elongated morphology of the fracture, consistent with the elongated grains of the forged part.

A closer view, shown in Figure 29, revealed areas of large elongated dimples. These longer dimples were interspersed with finer dimpled rupture, as typified in Figure 30. The smooth area along the edge also exhibited finer dimpled rupture features, as shown in Figure 31 and Figure 32. These features were consistent with an overstress fracture of the left fuel idler gear tooth.

Figure 33 and Figure 34 show the mating fracture surfaces of the other (right) tooth from the fuel pump idler gear. This fracture surface exhibited a similar morphology as the left fractured tooth. Examination in optical and electron microscopes revealed features consistent with an overstress fracture of this tooth.

2.0 Left Magneto Gear

The remnants of the left magneto gear are shown in Figure 35, as received. From the view in this figure, the fracture exhibited a Z-shaped orientation, with two parallel but nonaligned fractures between the center bore and the exterior surface. The fracture on the bottom left bisected a gear tooth, whereas the fracture in the upper right was located between two teeth. Several areas of the flange had fractured from the gear.

Figure 36 shows the mating faces of the magneto gear. These surfaces were generally rough and fibrous in texture, with a dull, dark hue consistent over all of the surfaces of the gear fragments. The fibrous direction was vertical in Figure 36, consistent with the grain direction from forging at manufacture.

A longitudinal crack was also present at the barrel portion of the larger gear remnant, shown in Figure 37. This crack was intentionally backcut and laboratory-opened to expose the crack faces. One of the opened faces is shown in Figure 38. The existing crack face was dark in color, and the area fractured in the laboratory is dull, light metallic gray. This color contrast shows the crack's edge, as illustrated in Figure 39.

This opened fracture was examined in the SEM. As illustrated in Figure 40, the opened crack exhibited dimpled rupture, consistent with an overstress fracture. These features were consistent in the crack face and the laboratory-opened areas of Figure 38.

The opposite interior region of the magneto gear fracture surface is displayed in Figure 41. This figure showed the directional and fibrous nature of most of the fracture surfaces. The material near the fracture surface, as exemplified in the right of the fracture in Figure 41, exhibited necking and material thinning. The bottom center left of the figure displays a small area with finer features.

Figure 42 shows an area with a geometrical transition, exhibiting finer fracture features and curved river patterns consistent with fracture direction outward from the upper surface. These areas were examined after cleaning with a solution designed to remove high-temperature surface contamination of metal alloys.³

Figure 43 shows a typical area of the cleaned fracture from Figure 41. This area exhibited a mixed region of elongated dimples adjacent to manganese sulfide particles and finer, more equiaxed dimpled rupture, as illustrated in Figure 44. The area from Figure 42, where the river patterns emanate, is highlighted in Figure 45. This region shows an angled ridge with flatter, finer features adjacent to vertically oriented blockier, prismatic features. Figure 46 shows a closer view of this transition—on the angled area at the bottom of the figure, the fracture exhibited dimpled rupture, angled toward the upper left. A closer view of the prismatic region is shown in Figure 47. This region exhibited fine dimpled rupture and smearing, oriented toward the upper left. These areas were consistent with overstress fractures in tension and shear.

3.0 Magneto Rivet Remnants

The remnants from magneto impulse hub assembly rivets are illustrated in Figure 48. The three remnants exhibited wear and impact damage as evidenced by plastic deformation, gouges, folds, and batter. As shown in Figure 48, each piece exhibited a fracture surface, with the middle remnant having two.

The width of the head or flange section of the left remnant in Figure 48 was 0.324 inches and the total combined length of all the three remnants was approximately 0.735 inches. The outer diameter of the shaft at the fracture location was 0.244 inches. This outer diameter width was consistent on all three remnants, ranging from 0.242 inches on the right remnant to 0.244 inches for the middle and left remnants.

³ The cleaning solution consisted of sodium hydroxide and potassium permanganate in water at 80°C. After soaking in the solution, a cellulose acetate replicating tape softened with acetone was applied to the surface and then peeled away to remove surface contamination

These fracture surfaces are shown in Figure 49 through Figure 51. Figure 49 shows the leftmost fracture near the flanged head. The bottom third of the remnant shown in Figure 49 was absent. This surface was entirely obliterated from wear damage. The remainder of the fracture surface exhibited a dull, fibrous appearance. This surface exhibited swirling river patterns, shear lips along the periphery, and outward bending on the top side surface. Examination in a SEM found dimpled rupture. These features were consistent with overstress fracture in multiple loading directions.

Figure 50 shows the different surfaces of the middle remnant. The bottom side, as positioned in Figure 48, had been entirely obliterated, as shown by Figure 50b. The opposite surface, shown in Figure 50a, exhibited a surface oxidation layer and features that were rough and fibrous. This surface was examined using an SEM, revealing dimpled rupture, both equiaxed and slanted. These features were consistent with overstress fracture.

The right remnant fracture surface is illustrated in Figure 51. Most of the sides of the remnant exhibited plastic deformation, gouges, and batter, consistent with post-fracture damage against other metallic components. The ovoid region to the figure's right exhibited features consistent with progressive cracking. Figure 52 shows a closer view of this part of the fracture surface, exhibiting crack arrest and ratchet marks.

Examination using a SEM shows these crack arrest and ratchet marks (Figure 53). The ratchet marks, indicative of multiple crack initiation sites, were located along the edge of the fracture surface. A closer view of the fracture surface revealed fatigue striations as shown in Figure 54 and Figure 55. These features were consistent with fatigue crack propagation.

Figure 56 shows ratchet marks separating individual crack initiation sites along the surface. Each of these initiation sites exhibited upward-facing areas of local plastic deformation. Figure 57 shows a closer view of the middle crack initiation site from Figure 56. This site contained the upward-oriented deformation (out of focus in Figure 57) and fatigue striations, propagating from the location. Figure 58 shows a different initiation site, absent a surface deformation feature. In this case, there was a small depression at the surface edge, with striations emanating from the location. A closer view in Figure 59 did not reveal any dissimilar material at the divot on the surface. Fine striations could be seen propagating from the rounded divot.

Submitted by:

Erik M. Mueller
Materials Research Engineer

F. FIGURES



Figure 1. The pieces submitted from the accident, including the fuel pump idler gear, left crankshaft idler gear, left magneto gear, and multiple loose gear teeth and debris in individual bags.



Figure 2. The marked face of the left crankshaft idler gear, as received.



Figure 3. The left crankshaft idler gear viewed opposite from **Figure 2**.



Figure 4. View of the two fractured teeth at the 12 o'clock position on the crankshaft idler gear as clocked in figure 2.

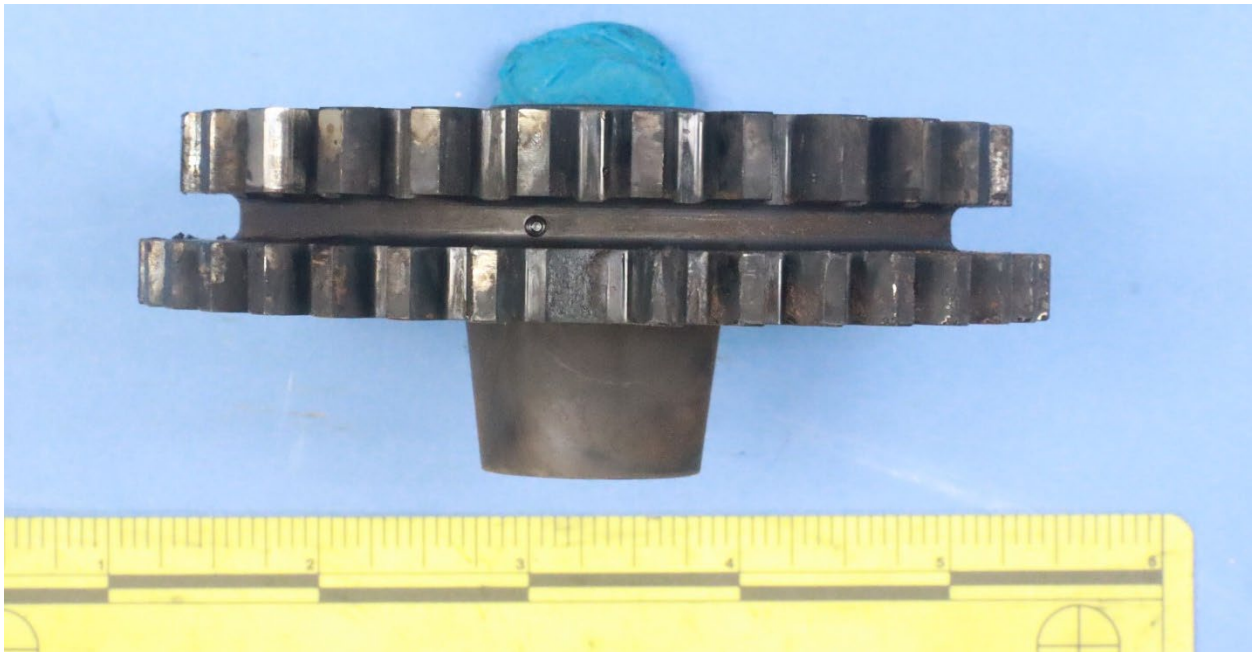


Figure 5. The fractured tooth on the crankshaft idler gear approximately 120° from the fractures in **Figure 4**.



Figure 6. View of the two fractured teeth from the idler gear, positioned near their respective fracture locations.



Figure 7. View of the fractured teeth surfaces in **Figure 6**, showing the adjacent damaged teeth remnants.



Figure 8. View of the left tooth fracture surface on the idler gear from Figure 7.



Figure 9. View of the left tooth fracture surface from the liberated tooth.

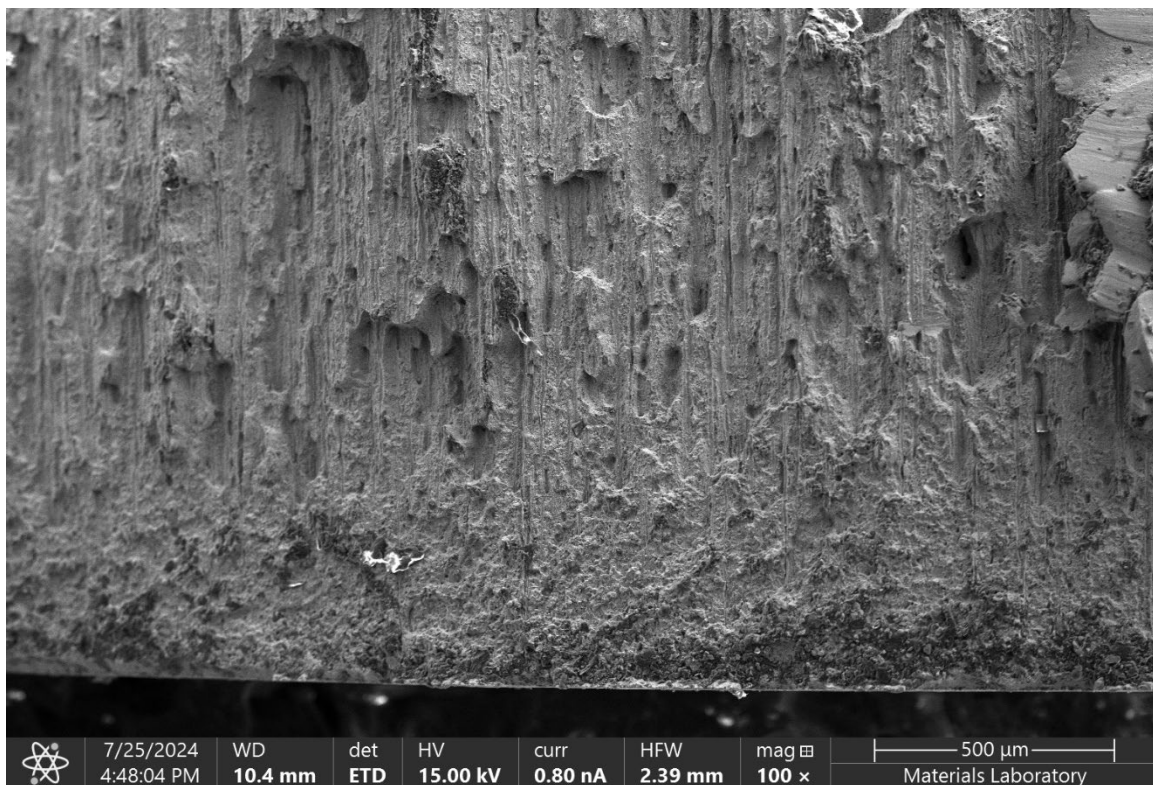


Figure 10. Secondary electron (SE) micrograph of the bottom edge of the tooth fracture surface in **Figure 9**, showing two distinct regions.

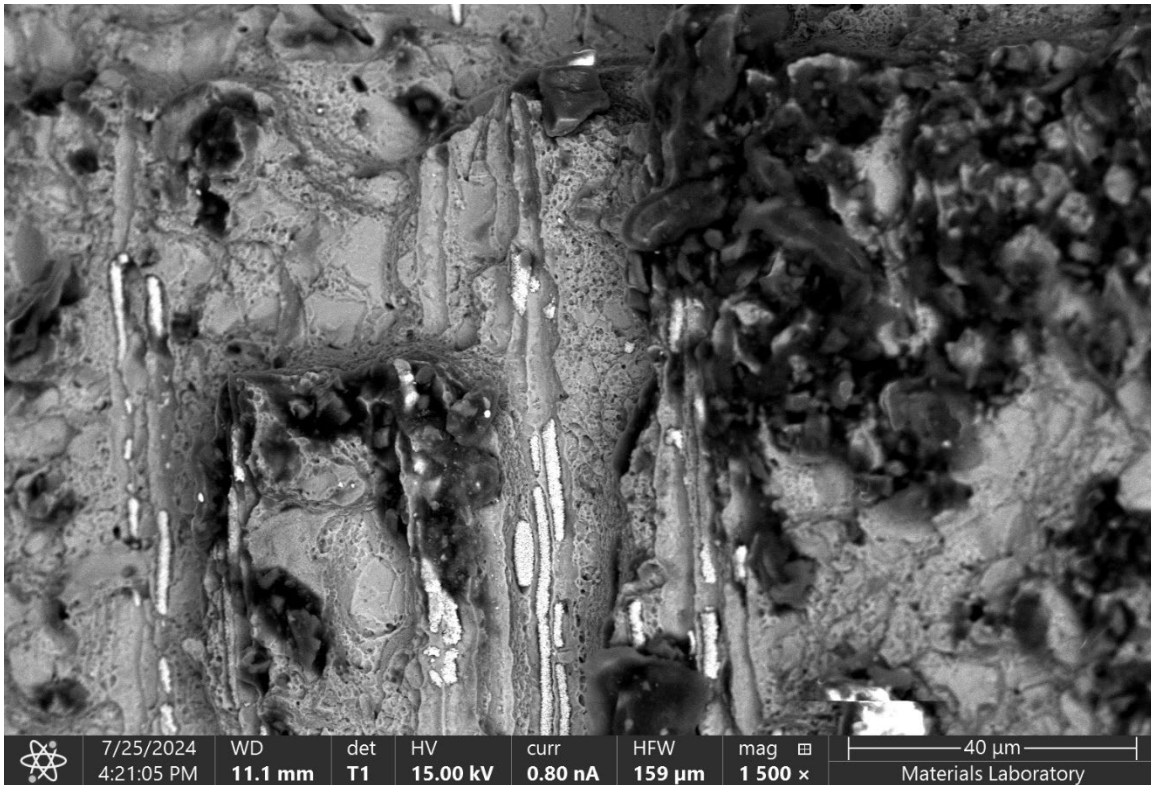


Figure 11. Backscattered electron (BE) micrograph of the core (center) of the fracture surface of the tooth in **Figure 9**.

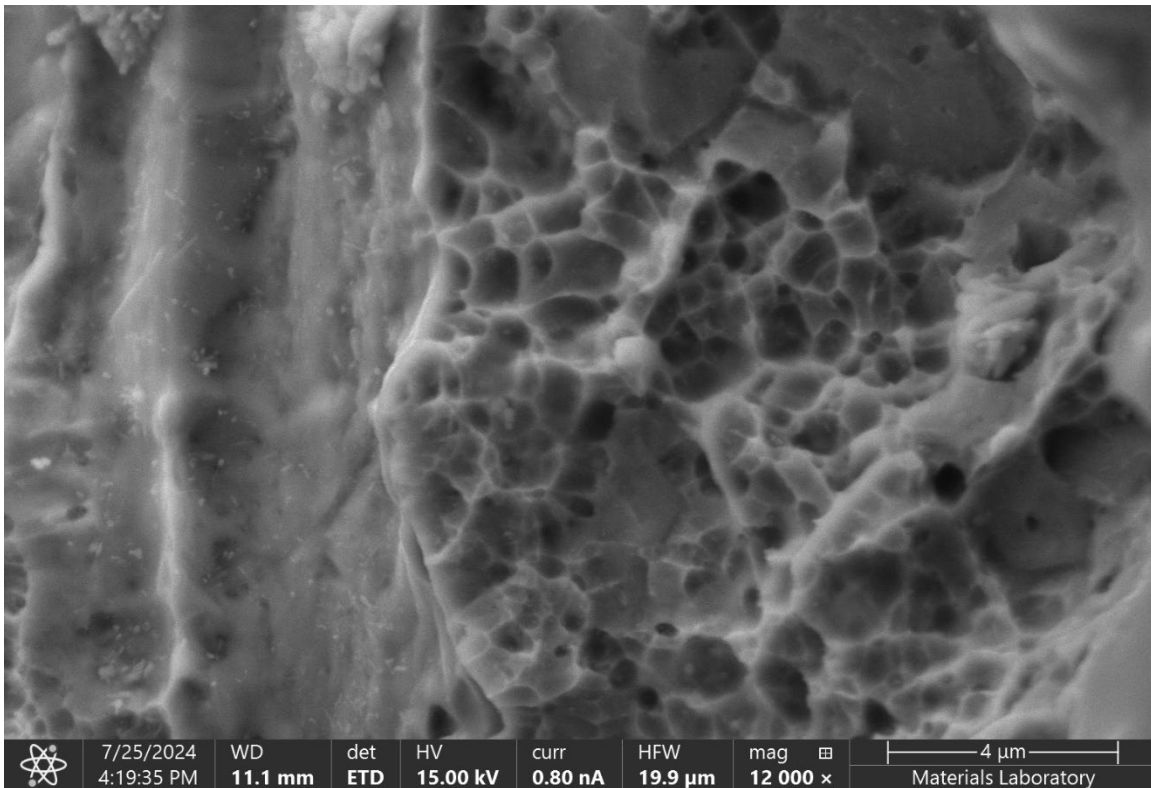


Figure 12. SE micrograph of dimpled rupture in the fracture surface in **Figure 11**.

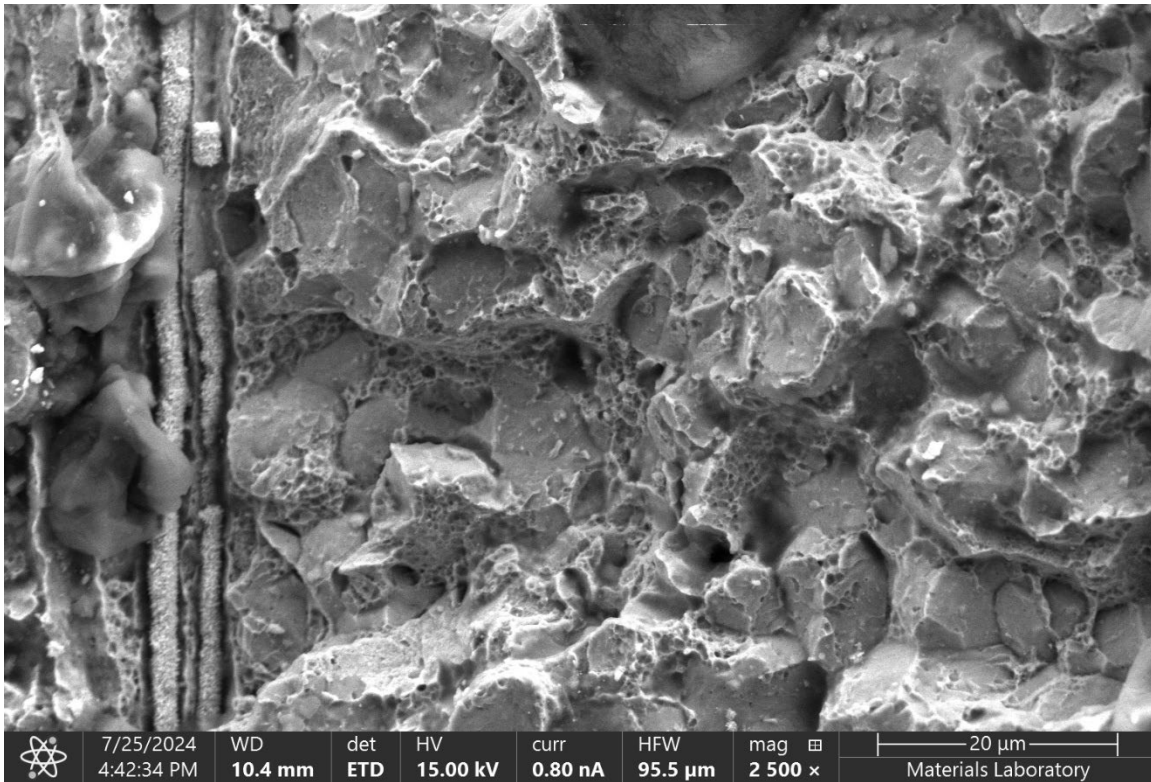


Figure 13. SE micrograph of mixed intergranular and dimpled rupture near the fractured tooth edge.

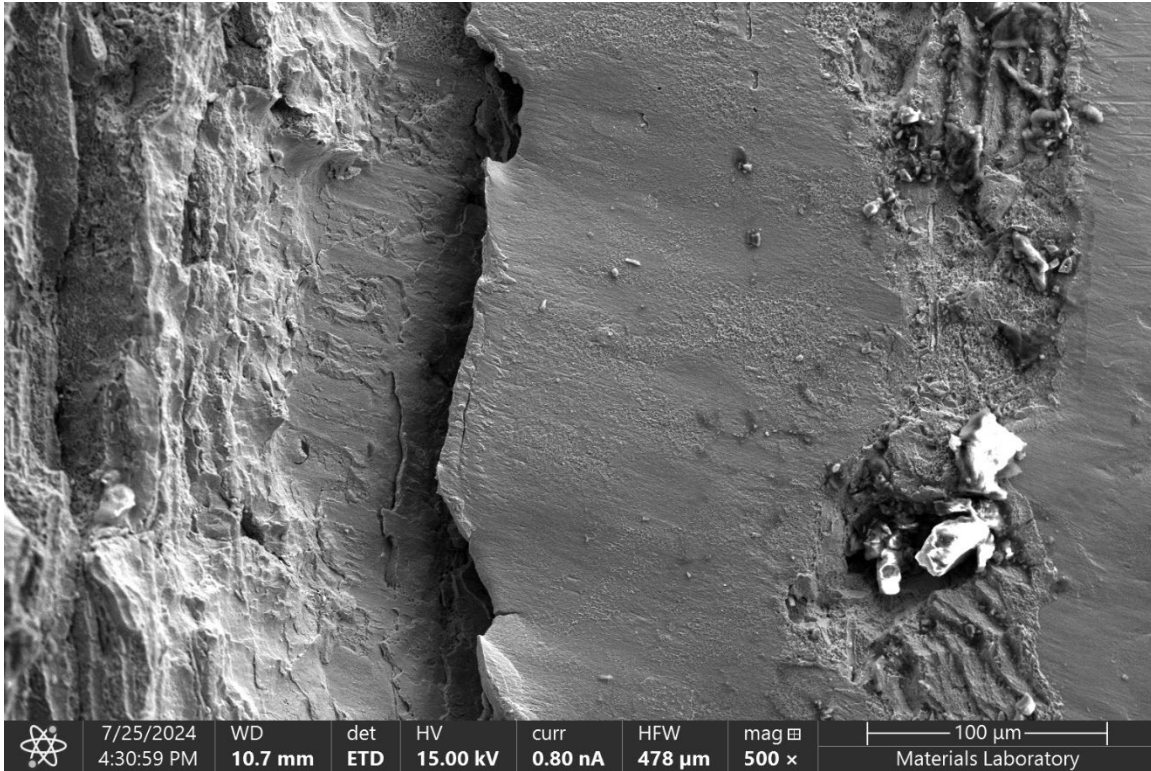


Figure 14. SE micrograph of the rounded area of the fractured tooth (upper part of **Figure 9**).

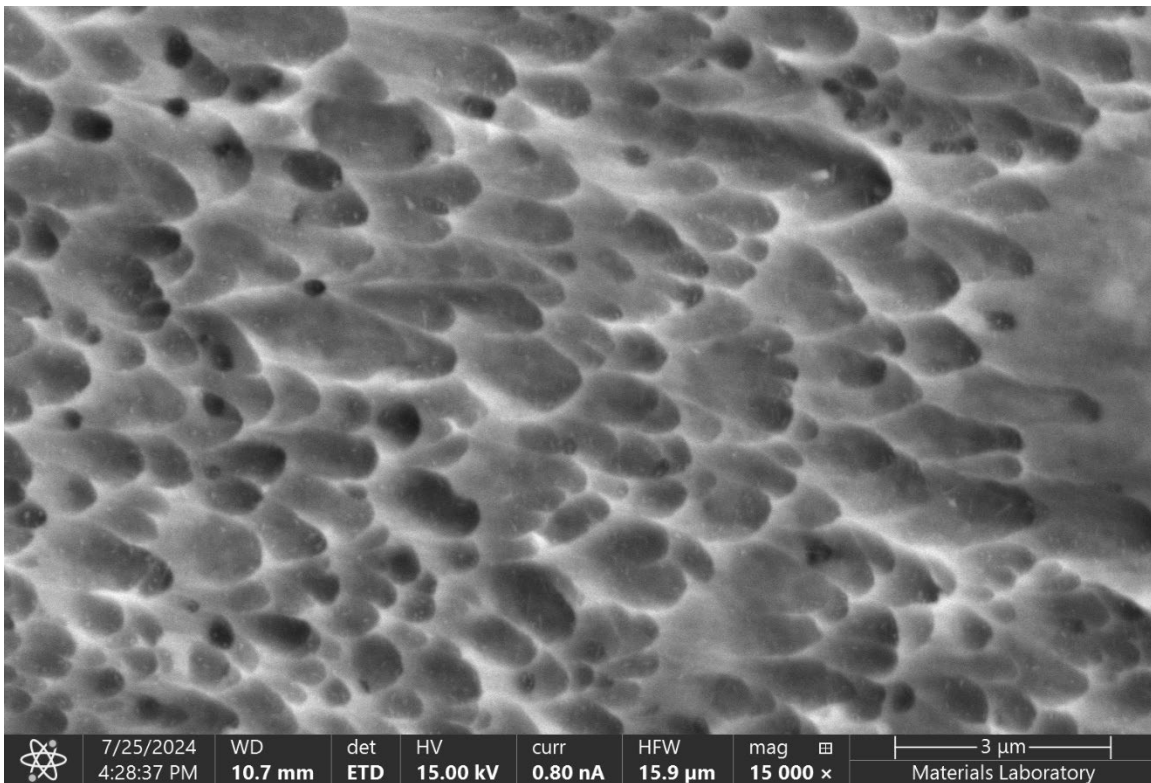


Figure 15. SE micrograph of dimpled rupture from the smoother area in **Figure 14**.



Figure 16. View of the right side crankshaft idler gear tooth fracture in **Figure 7**.

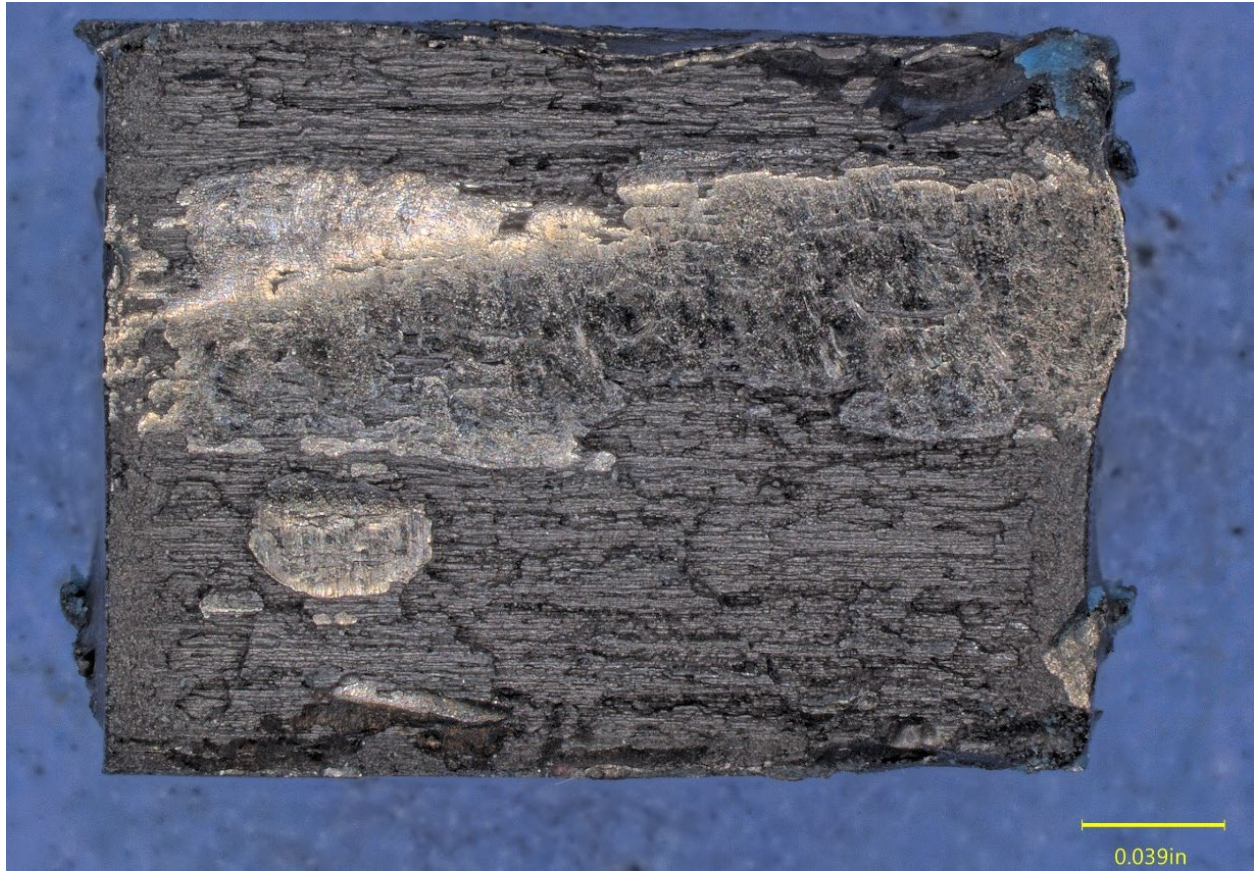


Figure 17. The mating right side tooth fracture of the idler gear, showing smearing along the centerline.



Figure 18. The opposite single tooth fracture of the crankshaft idler gear.



Figure 19. The single tooth fracture surface on the crankshaft idler gear.



Figure 20. The fractured tooth fracture surface opposite the gear surface in **Figure 19**.

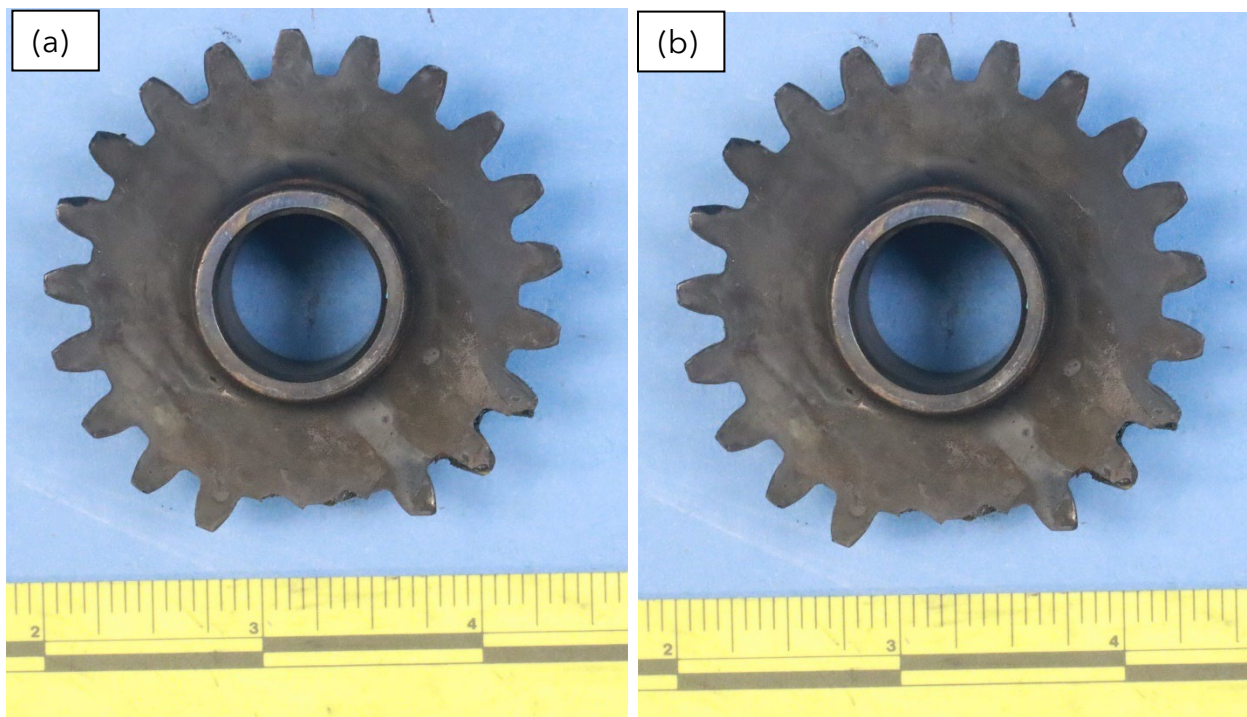


Figure 21. The fuel pump idler gear, viewed from opposite faces.



Figure 22. The fractured teeth locations of the fuel pump idler gear, as received.

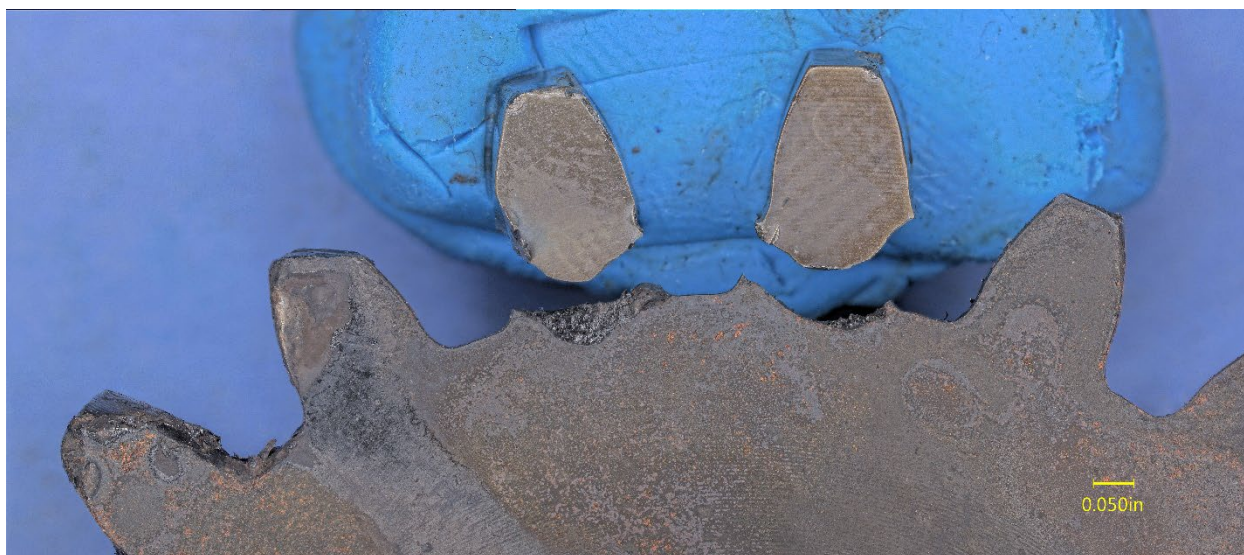


Figure 23. Side view of the fractured teeth of the fuel pump idler gear, positioned to show their locations prior to fracture.



Figure 24. Angled view of the fuel pump idler gear fracture surfaces.

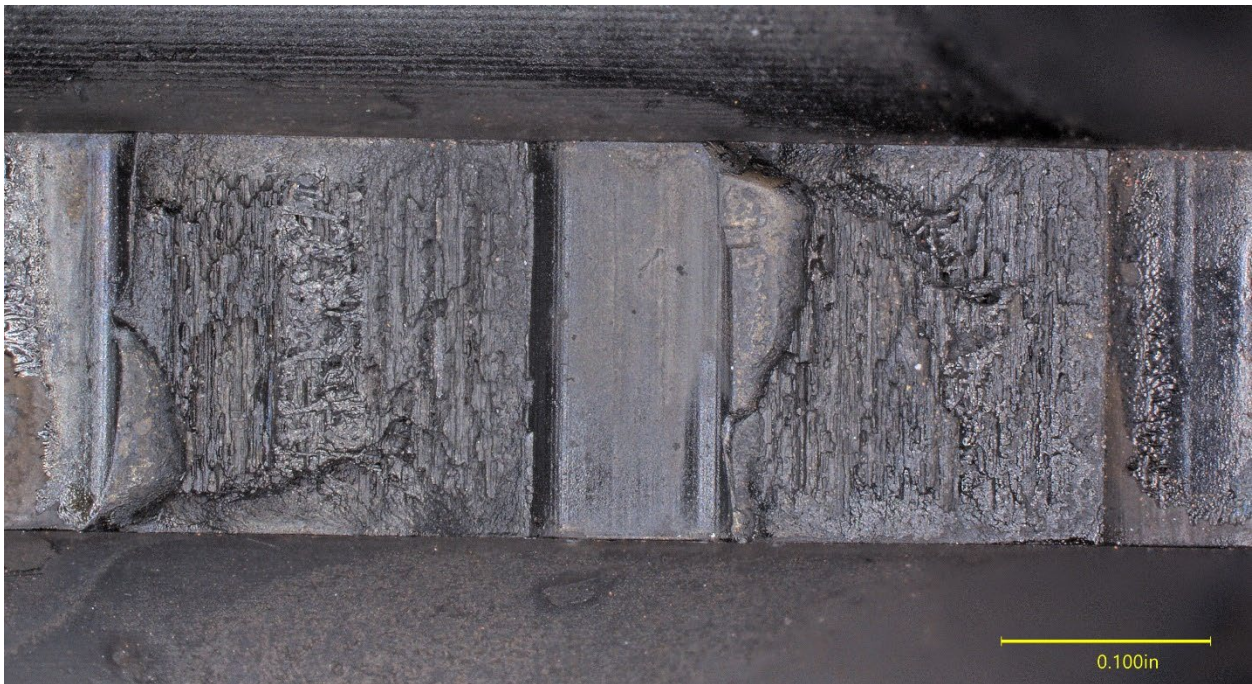


Figure 25. Straight view of the fractured teeth locations on the fuel pump idler gear.



Figure 26. View of the left tooth fracture on the fuel pump idler gear from **Figure 25**.

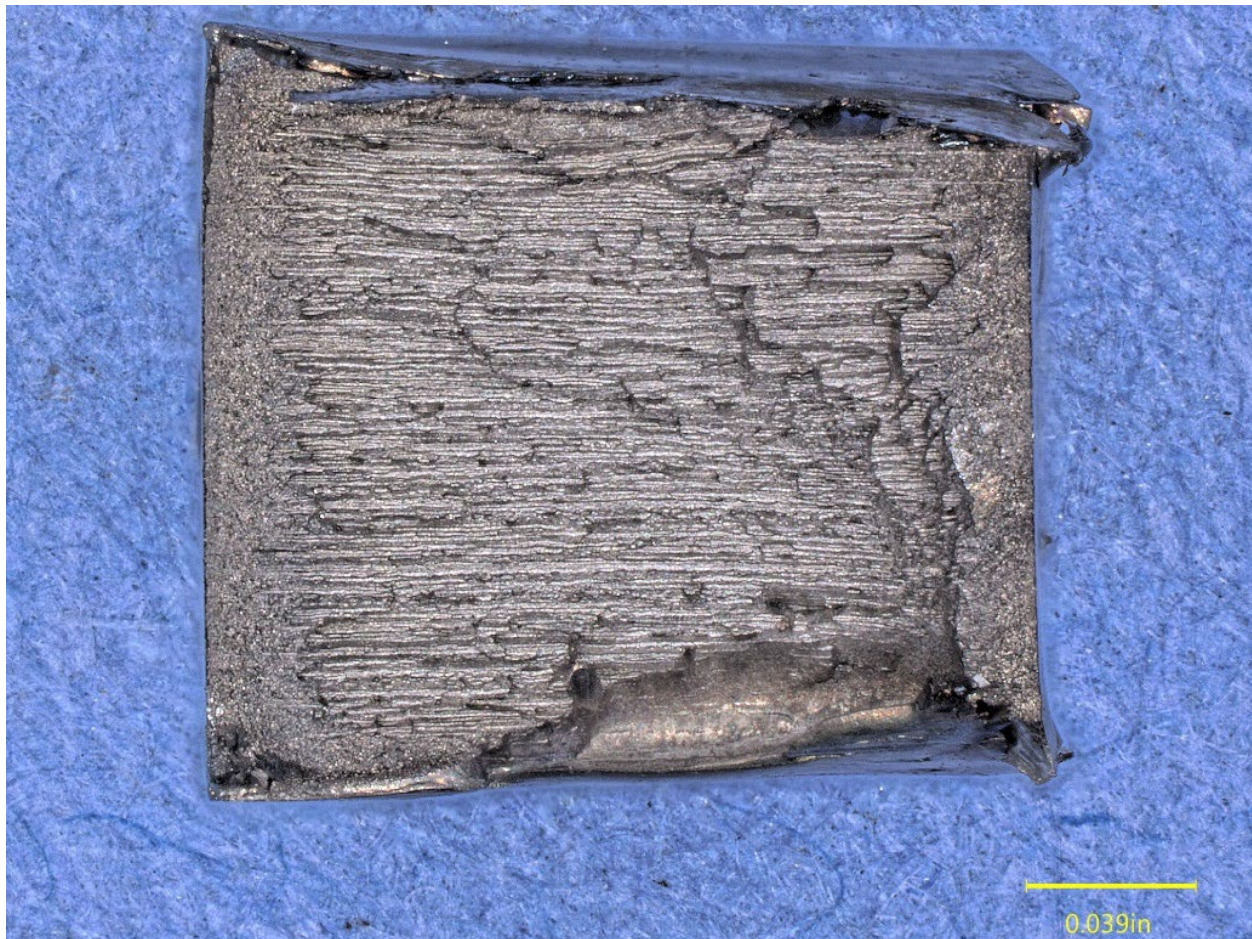


Figure 27. Fracture surface of the left liberated tooth from the fuel pump idler gear.

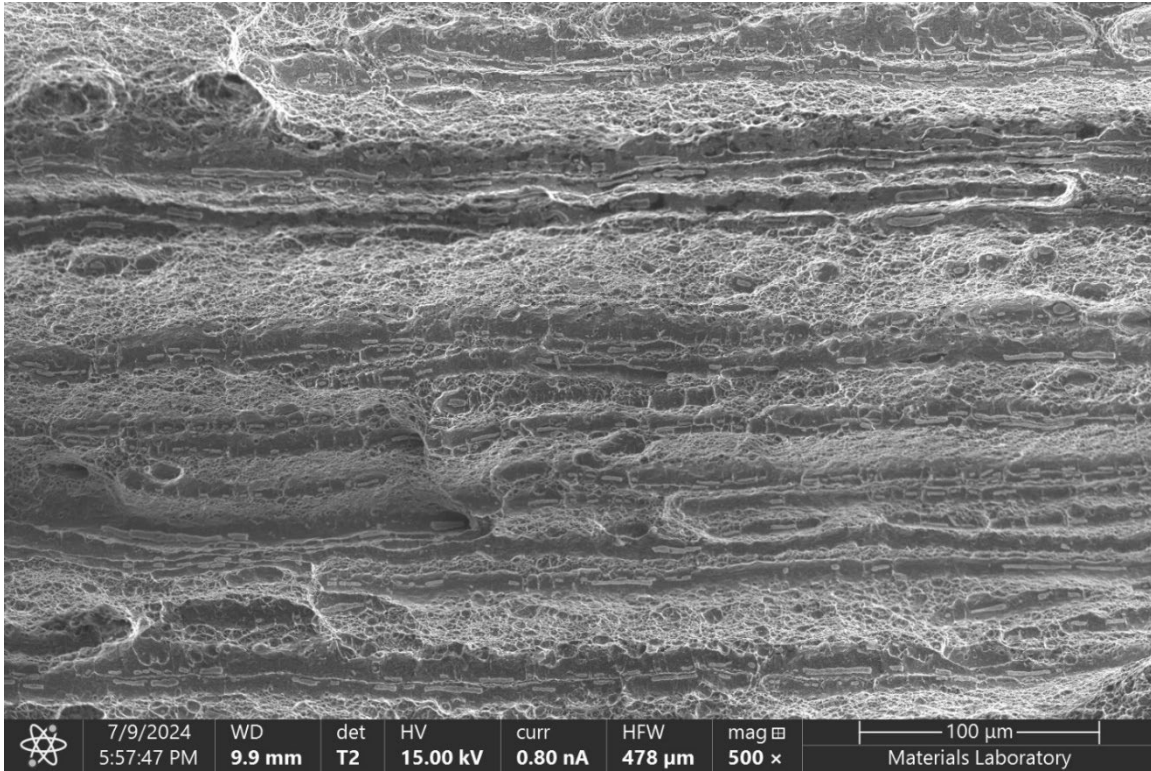


Figure 28. Secondary electron (SE) micrograph of a typical area of the center of the left tooth fracture surface from the fuel pump idler gear.

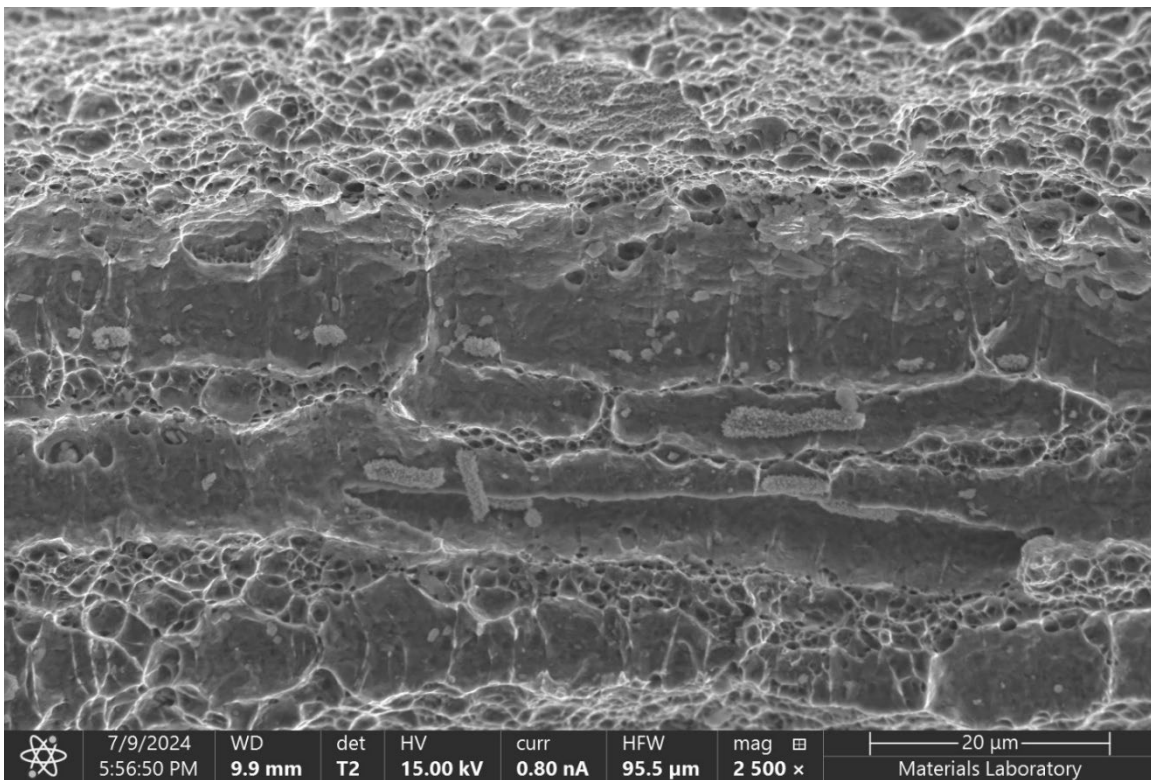


Figure 29. SE micrograph of a closer view of **Figure 28**, showing dimpled rupture.

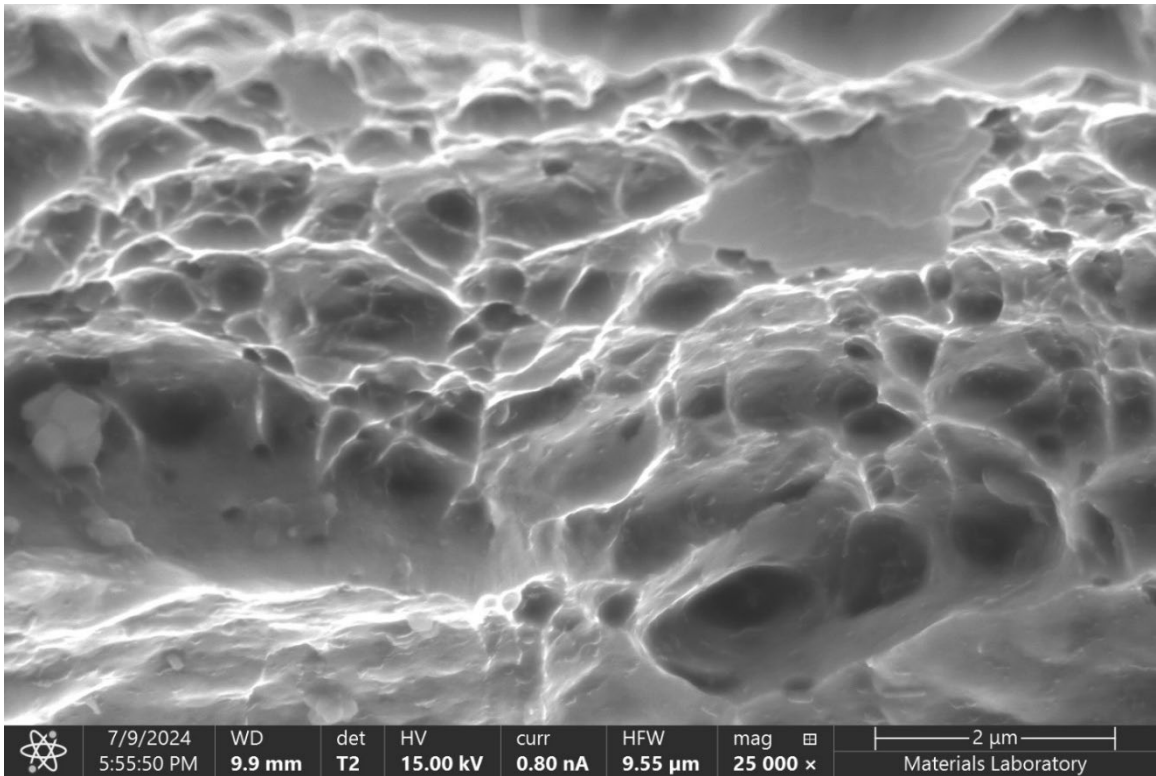


Figure 30. SE micrograph of the finer dimpled rupture features in **Figure 29**.

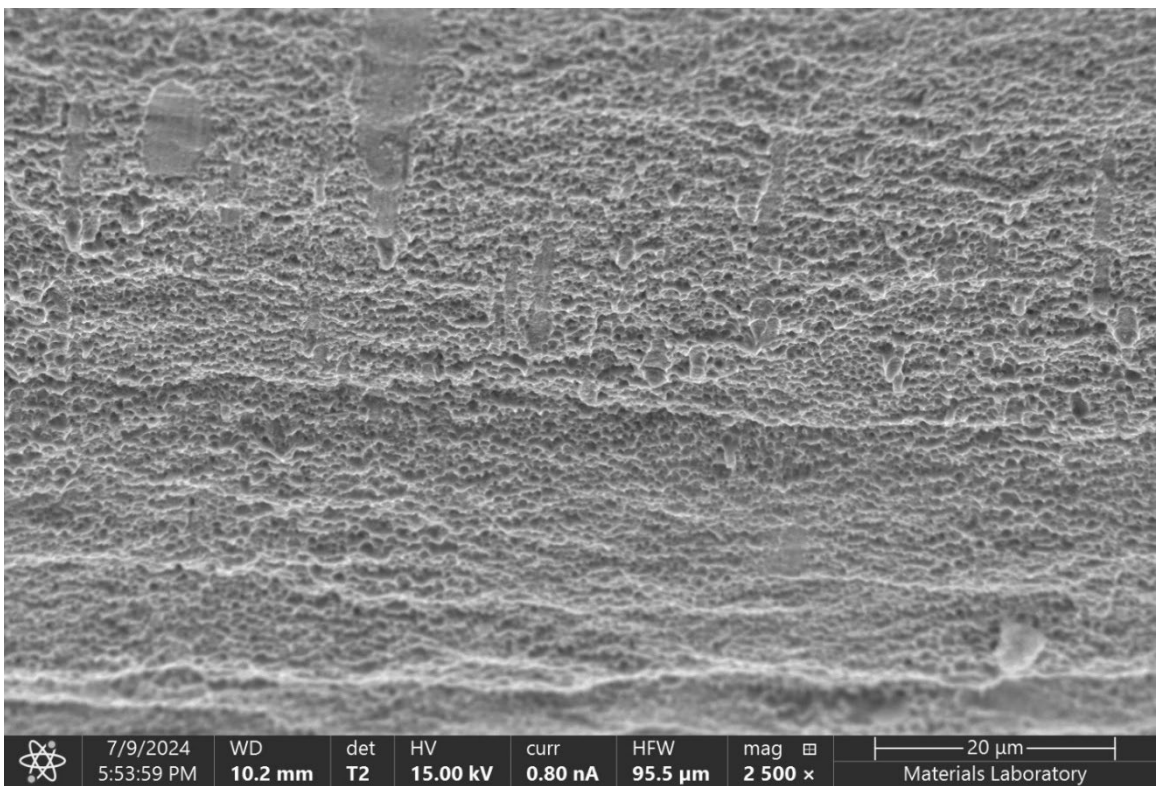


Figure 31. SE micrograph of the smoother area in **Figure 27**, showing dimpled rupture.

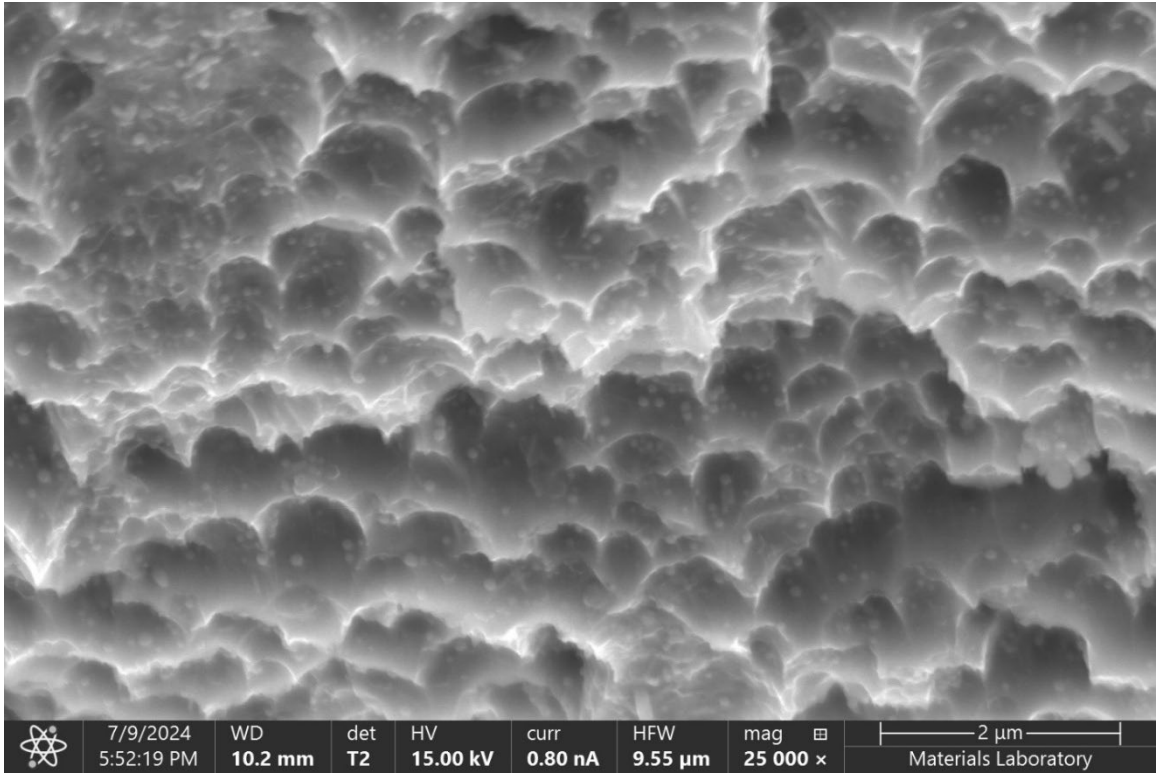


Figure 32. SE micrograph of a closer view of the dimpled rupture in **Figure 31**.



Figure 33. The right tooth fracture surface from the fuel pump idler gear in **Figure 25**.



Figure 34. Right liberated tooth fracture surface that mates with the surface in **Figure 33**.



Figure 35. The fragments of the fractured left magneto gear, as received.



Figure 36. The opposite-facing fracture surfaces of the left magneto gear, as received.



Figure 37. View of a crack on the boss of the larger magneto gear remnant.

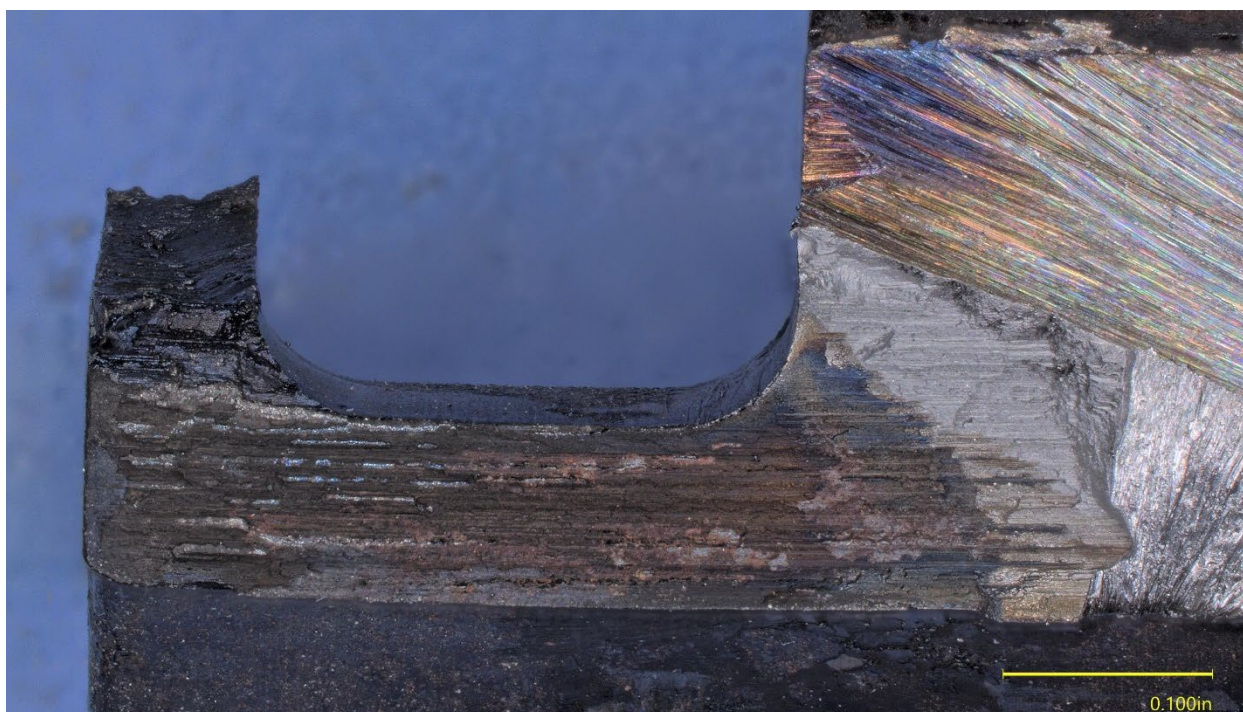


Figure 38. View of the opened crack in **Figure 37**, showing the crack (dark) and intentionally opened areas (lighter metallic gray).

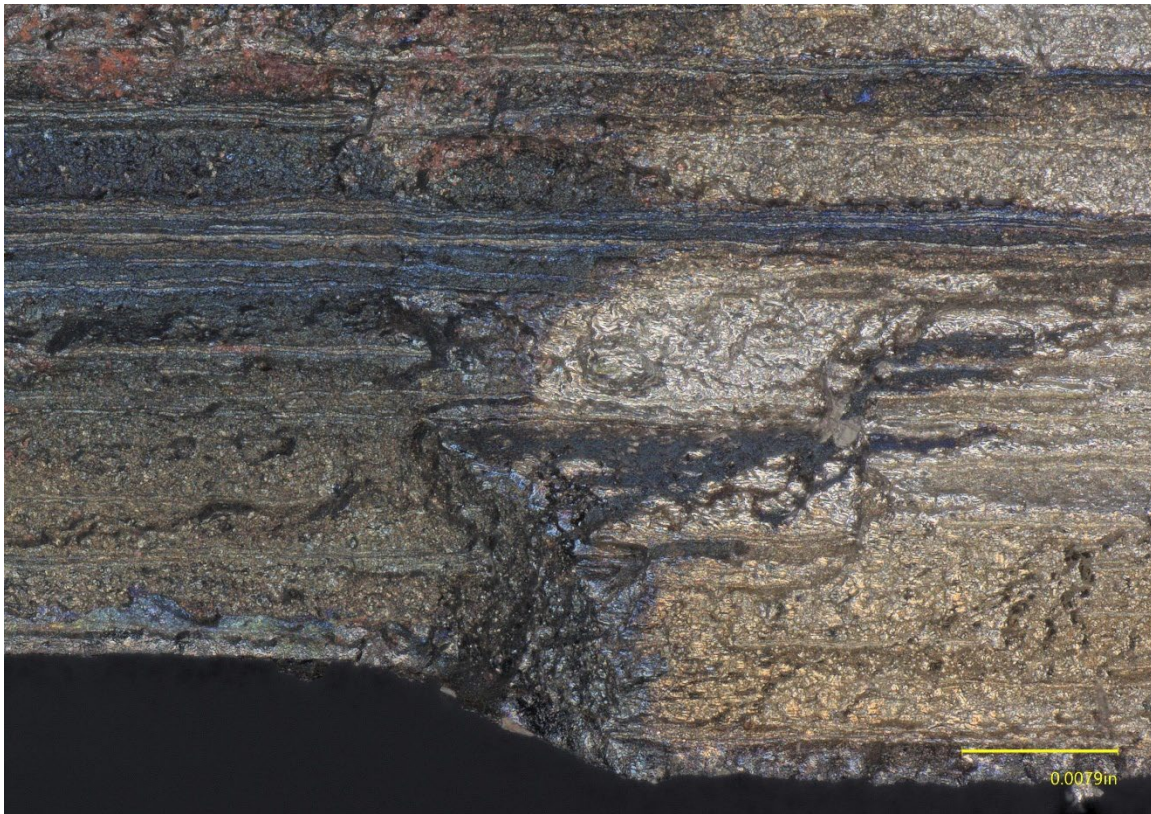


Figure 39. View of the end of the opened crack (right side in **Figure 38**).

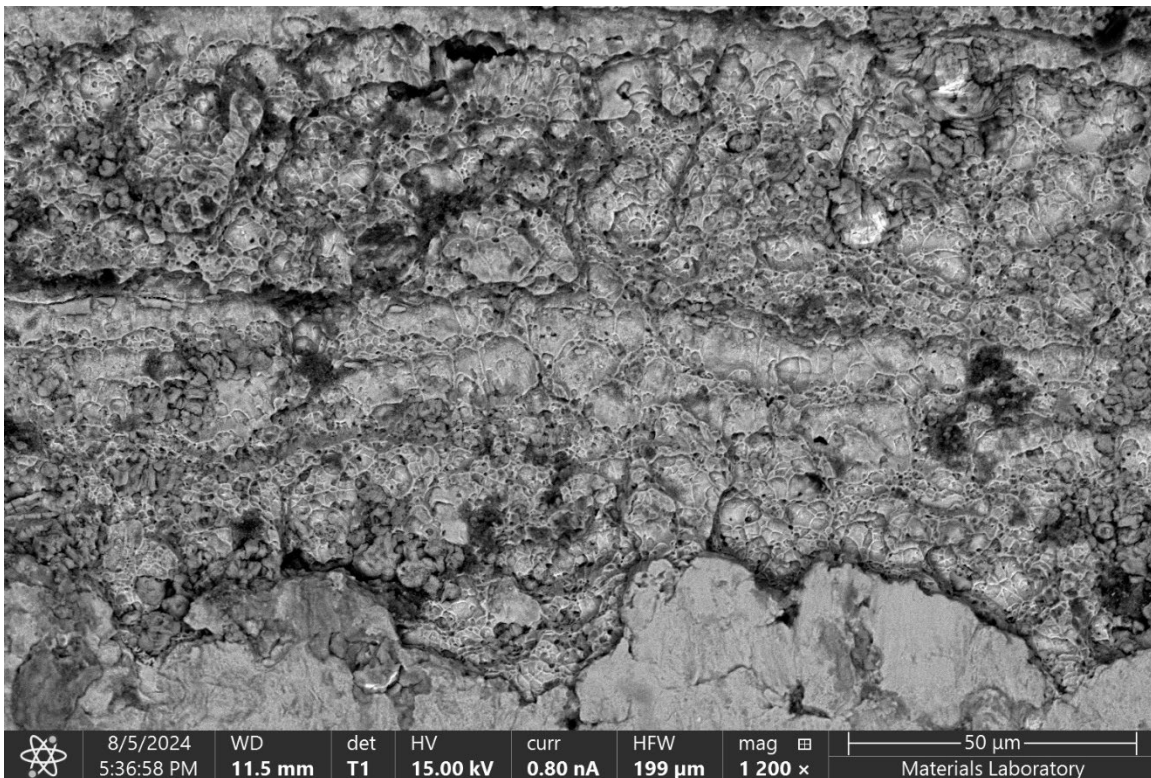


Figure 40. BE micrograph of a typical area of the opened crack of the magneto gear.

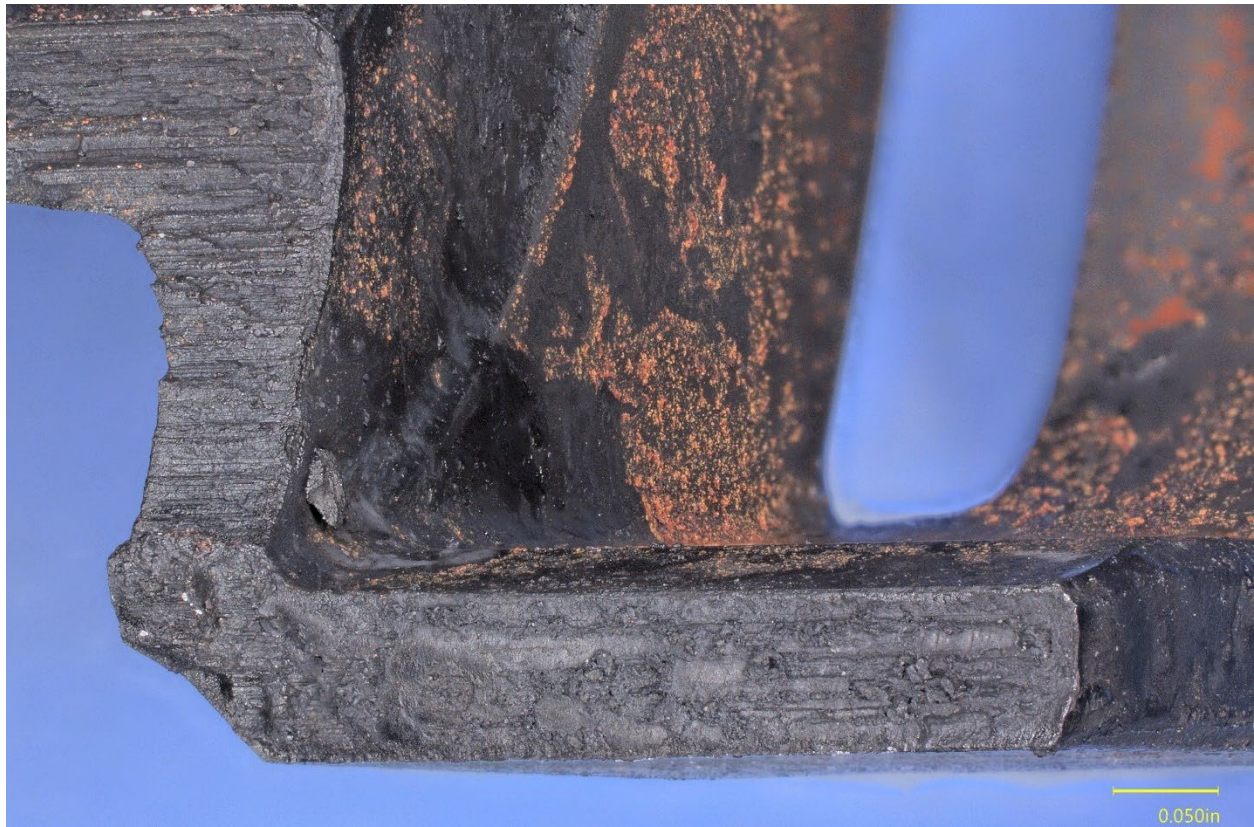


Figure 41. Closer view of the fracture surface from the interior side of the magneto gear.



Figure 42. View of the opposite edge of the fracture surface from **Figure 41**.

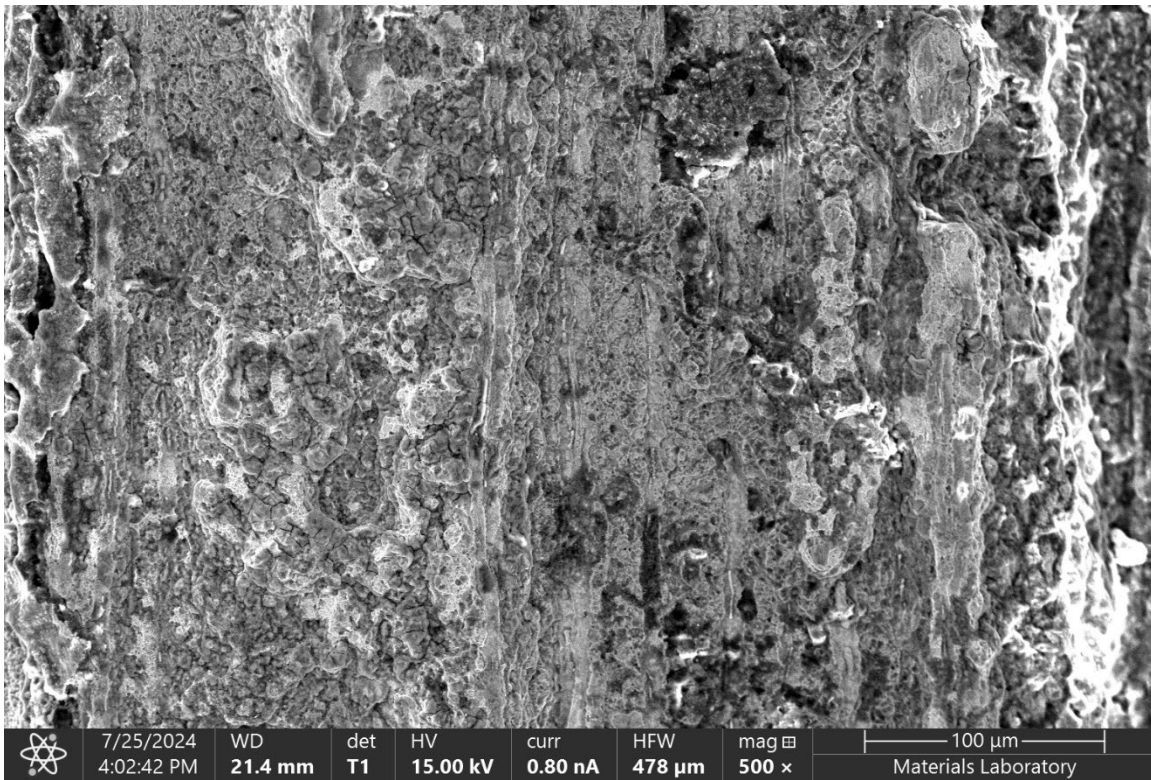


Figure 43. BE micrograph of the transition area in **Figure 42**.

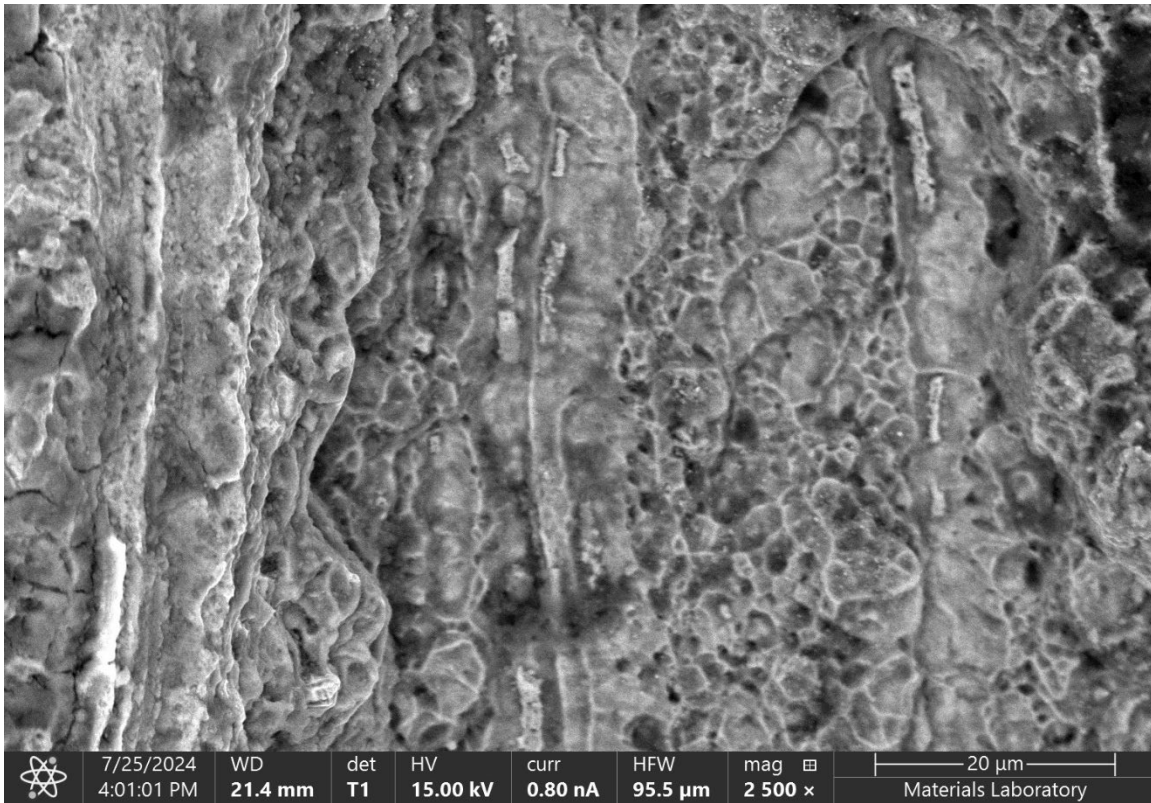


Figure 44. SE micrograph of dimpled rupture from the area in **Figure 43**.

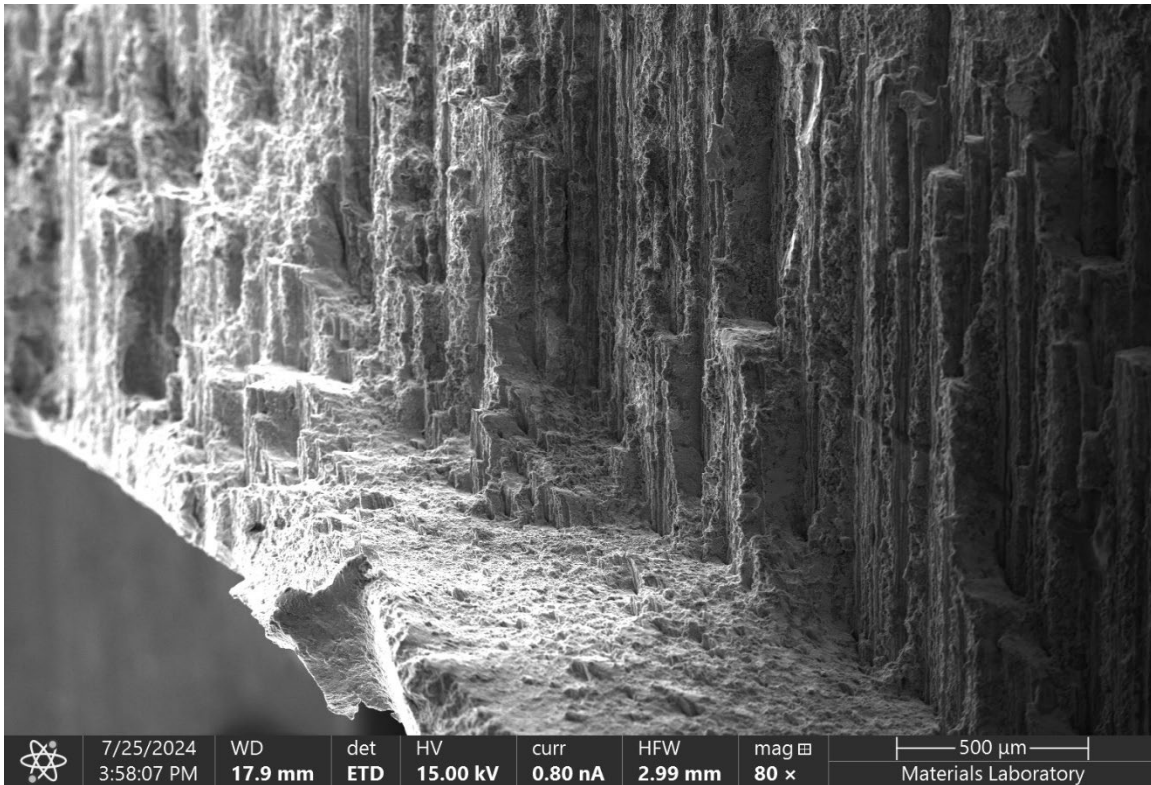


Figure 45. SE micrograph of the flat edge transition to the prismatic fracture features of the magneto gear fracture surface.

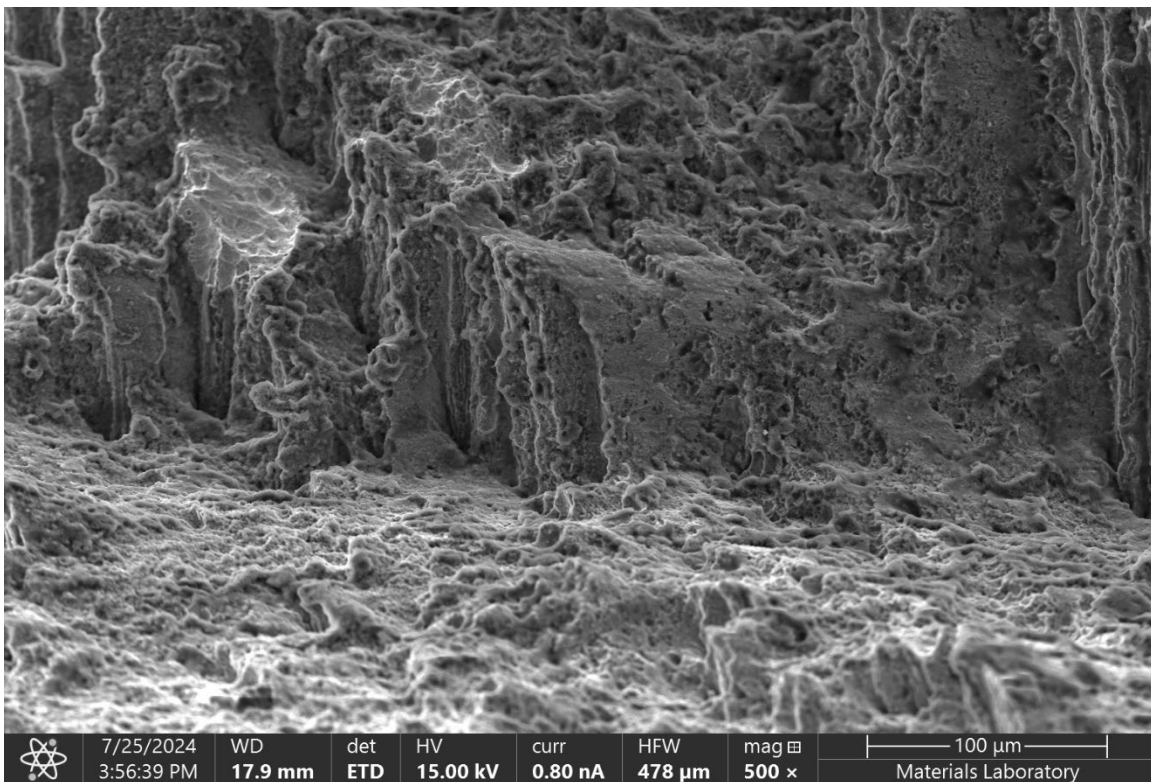


Figure 46. SE micrograph of the central area in the fracture surface in **Figure 45**.

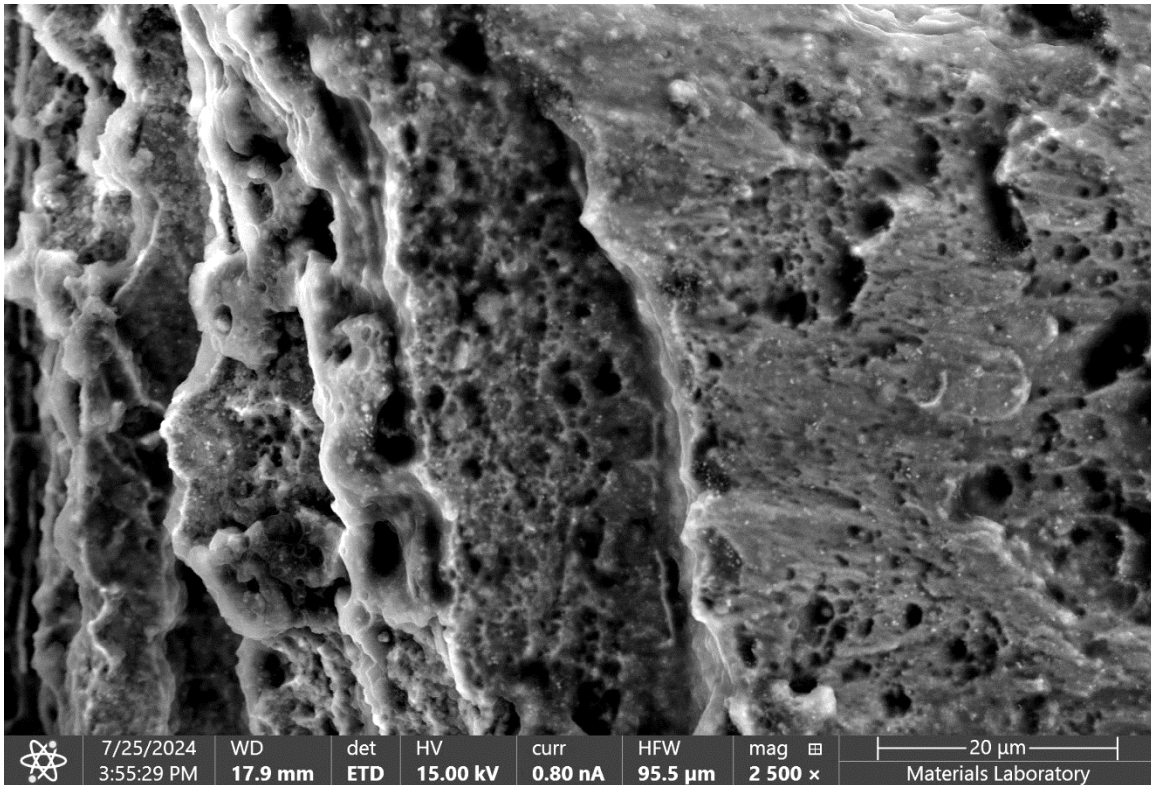


Figure 47. SE micrograph of dimpled rupture on the ridges on the center of **Figure 46**.



Figure 48. Side view of the three fractured rivet remnants. The arrow denotes the location of the fatigue cracking.

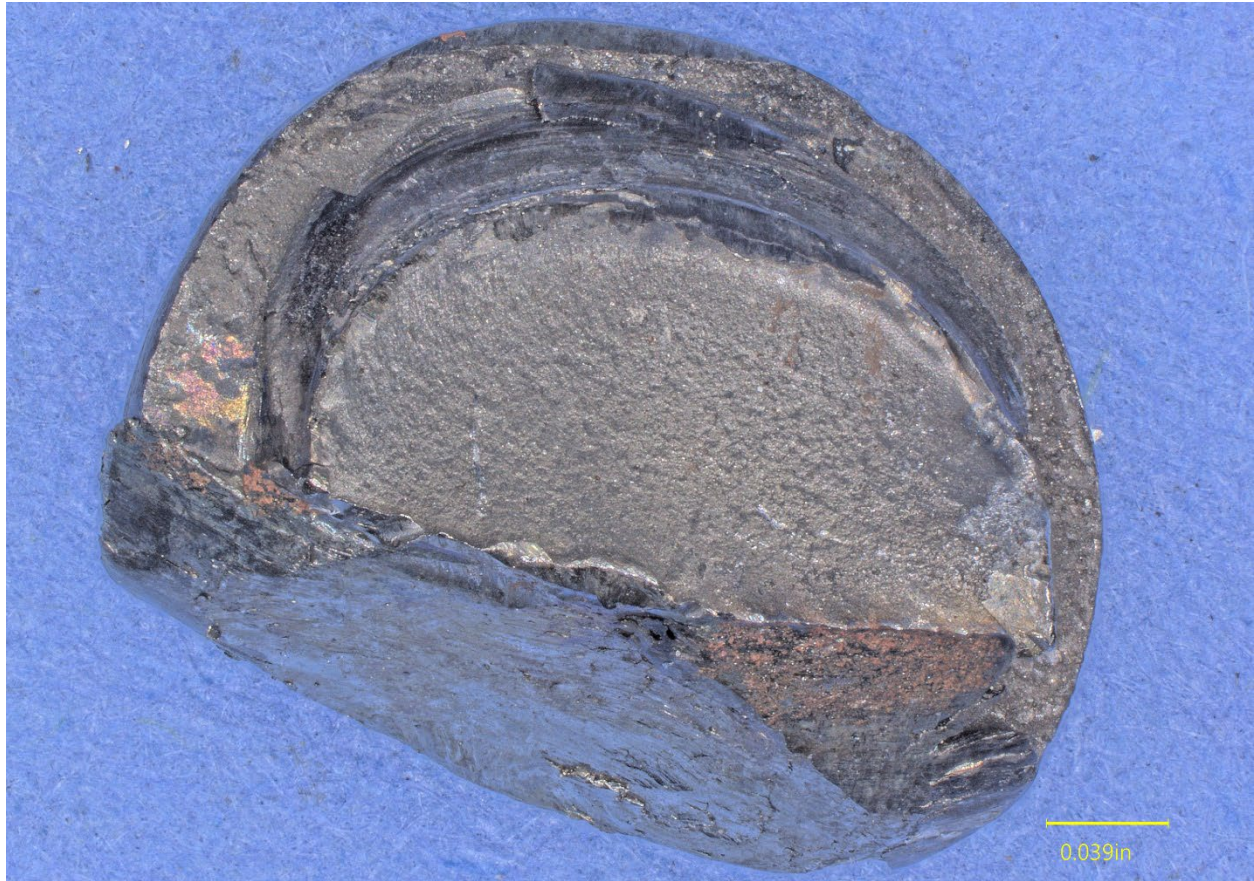


Figure 49. The fracture surface of the remnant near the rivet head (left in **Figure 48**).

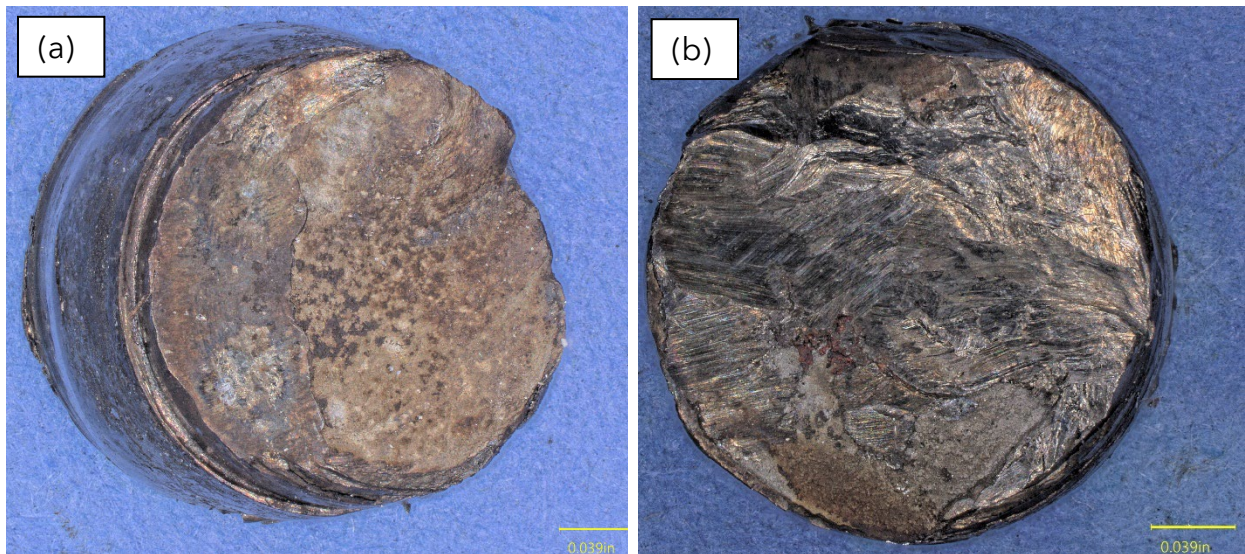


Figure 50. The (a) top and (b) bottom fractures of the middle remnant in **Figure 48**.

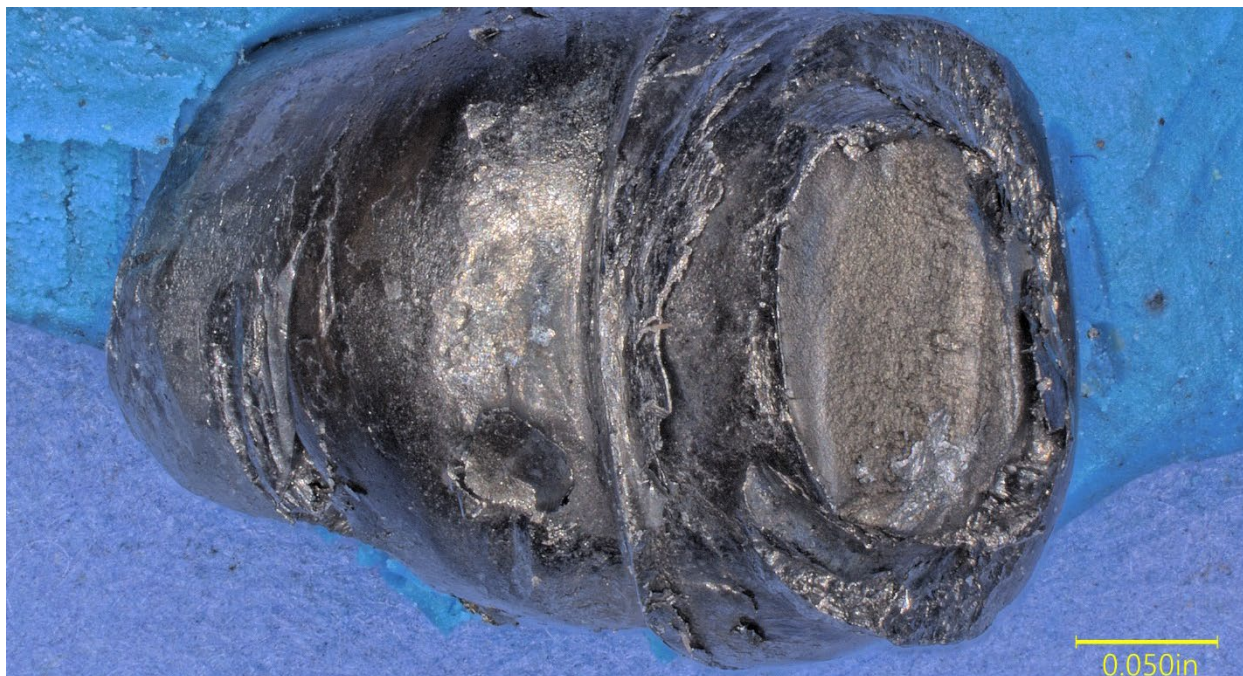


Figure 51. Angled view of the left fracture of the right remnant in **Figure 48**.

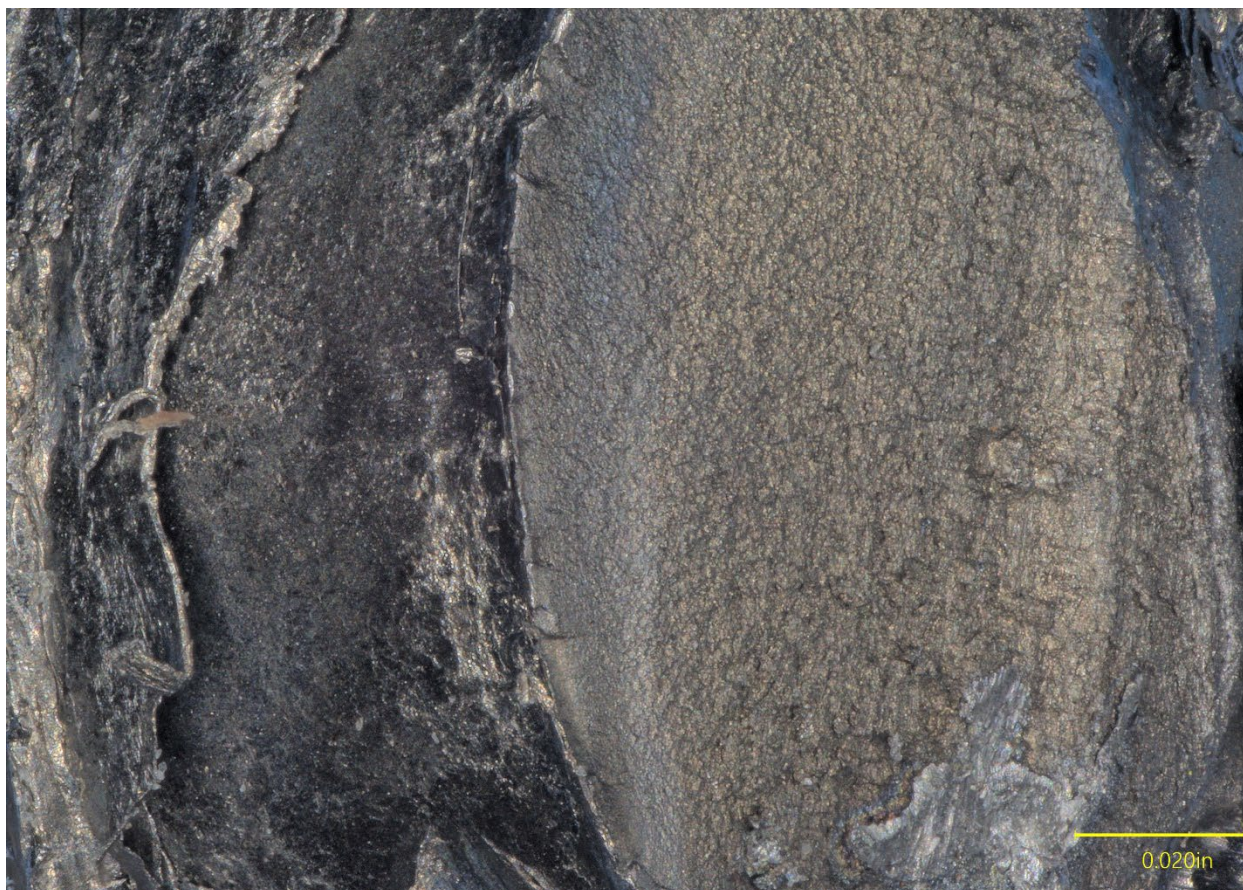


Figure 52. Closer view of the left edge of the fracture surface in **Figure 51**, showing ratchet marks and crack arrest marks.

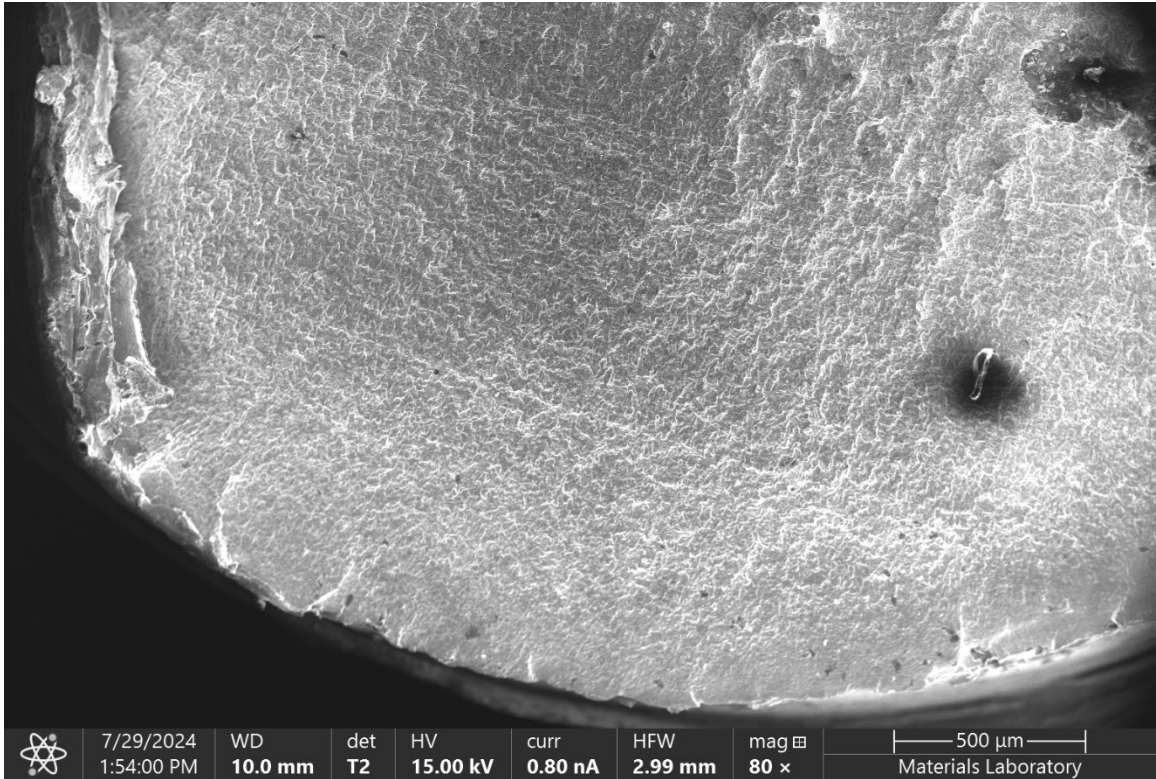


Figure 53. SE micrograph of the remnant fracture surface, from the edge.

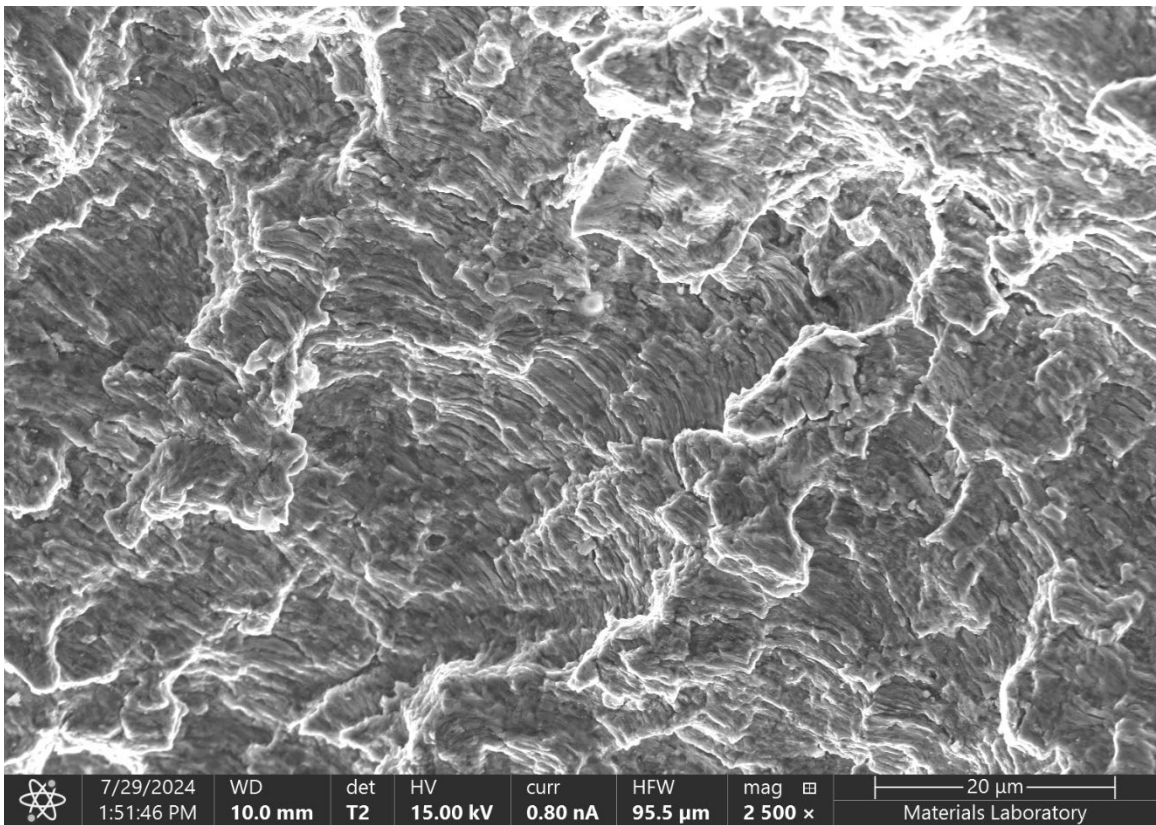


Figure 54. SE micrograph of fatigue striations on the remnant fracture surface.

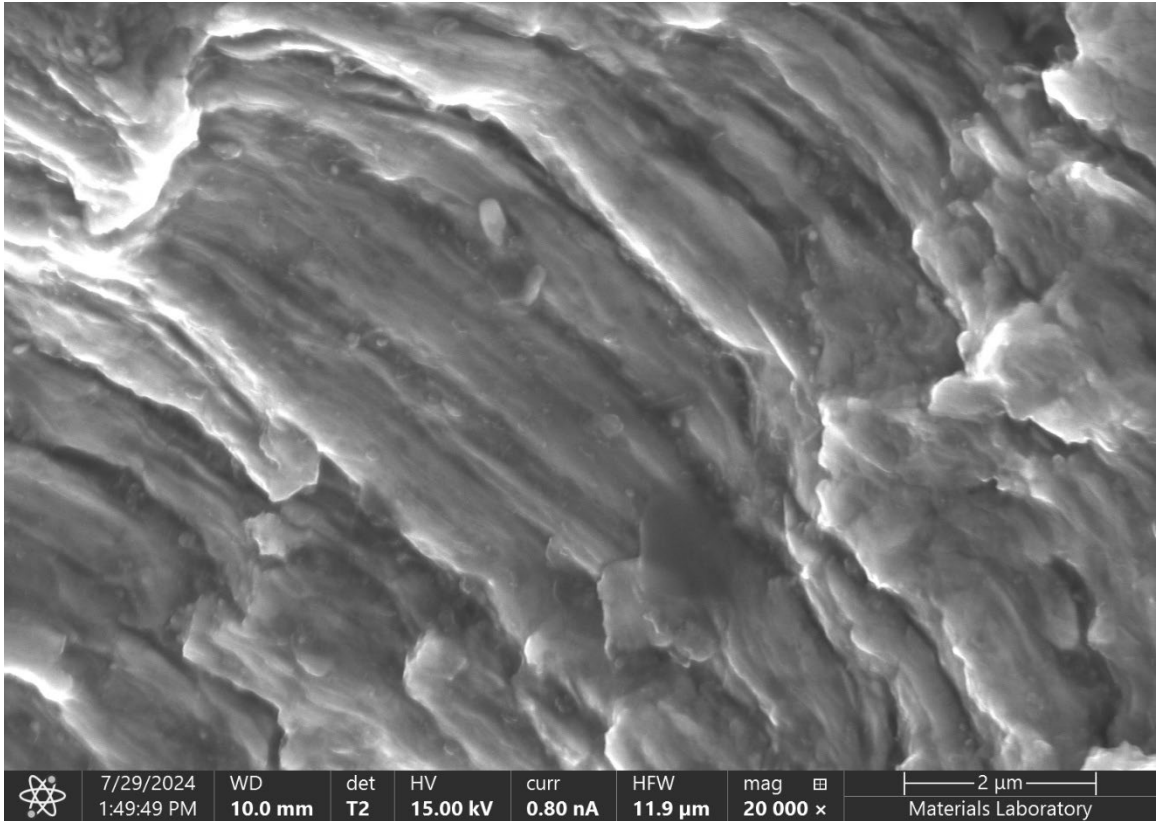


Figure 55. SE micrograph of a closer view of the striations in **Figure 54**.

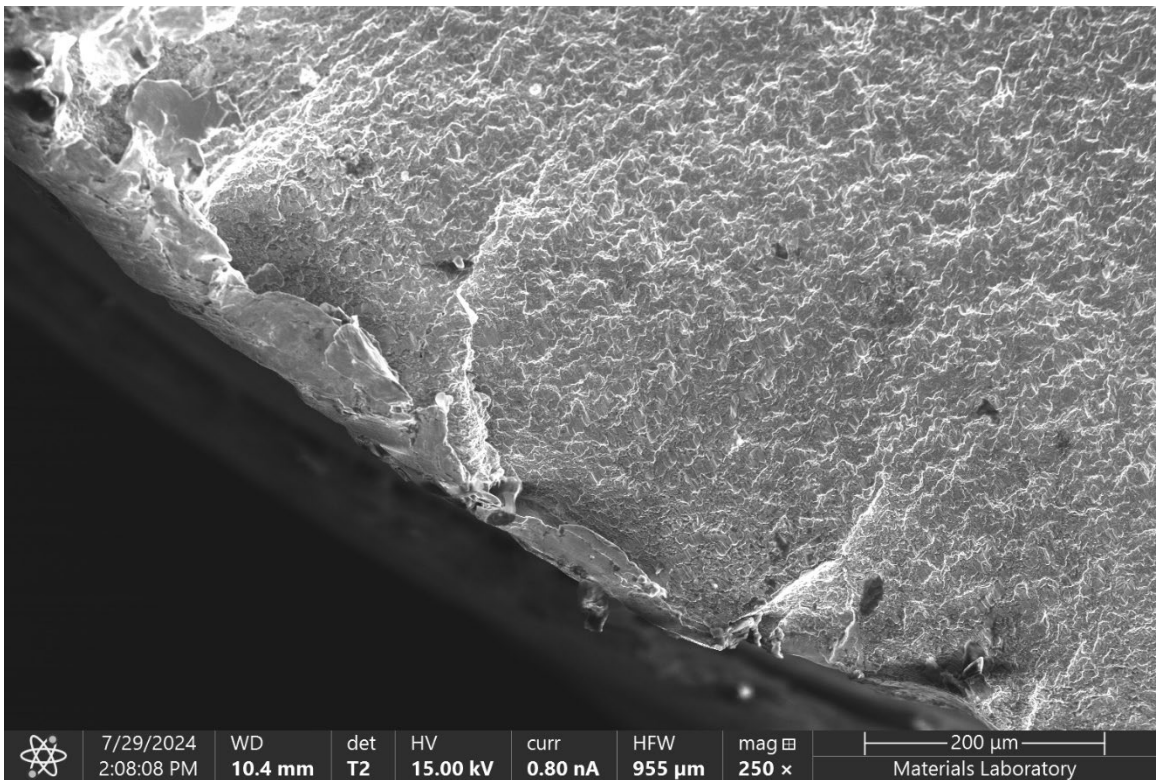


Figure 56. SE micrograph of several crack initiation sites on the remnant fracture edge.

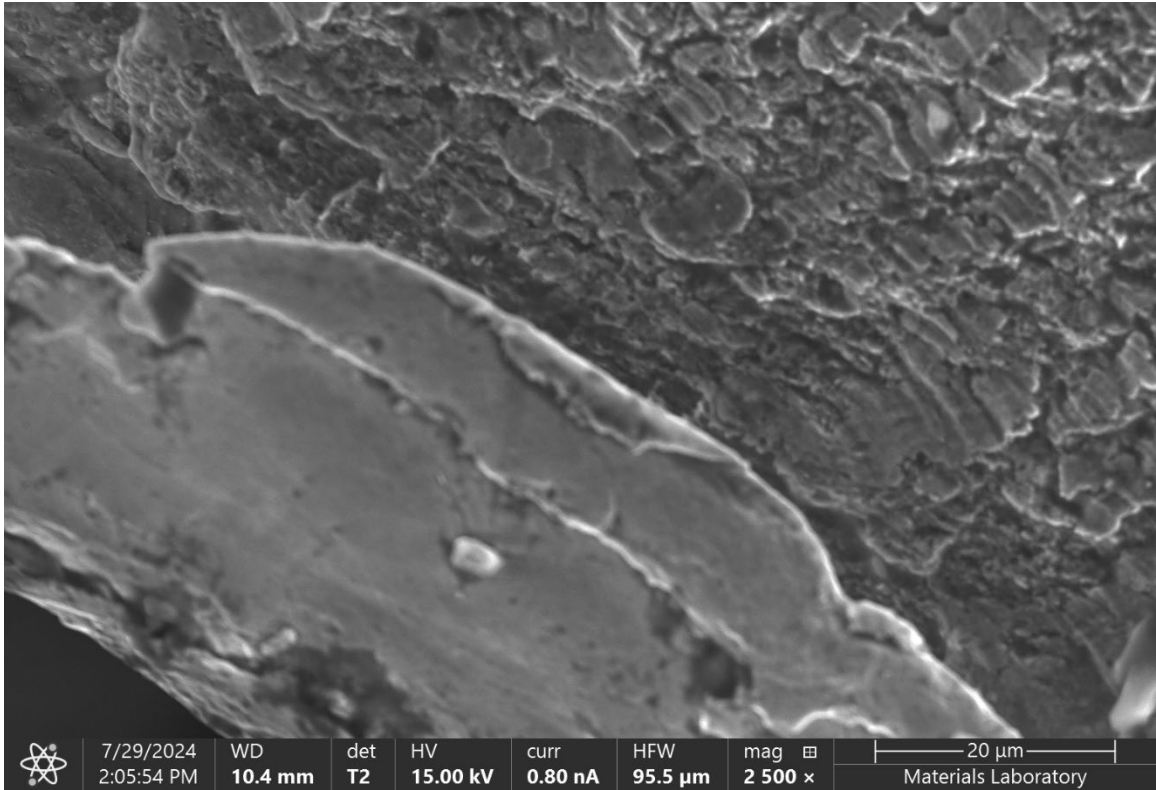


Figure 57. SE micrograph of the central initiation site at an area of plastic deformation in **Figure 56**.

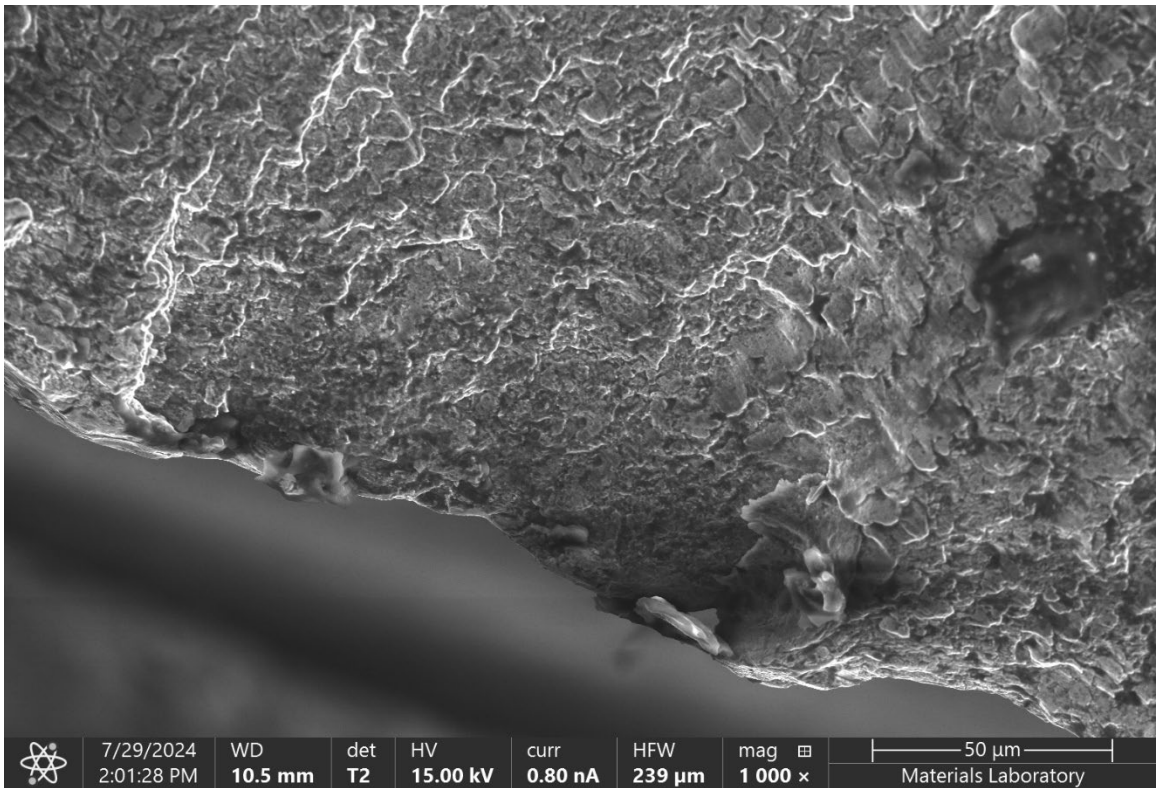


Figure 58. SE micrograph of the rightmost initiation site in **Figure 56**.

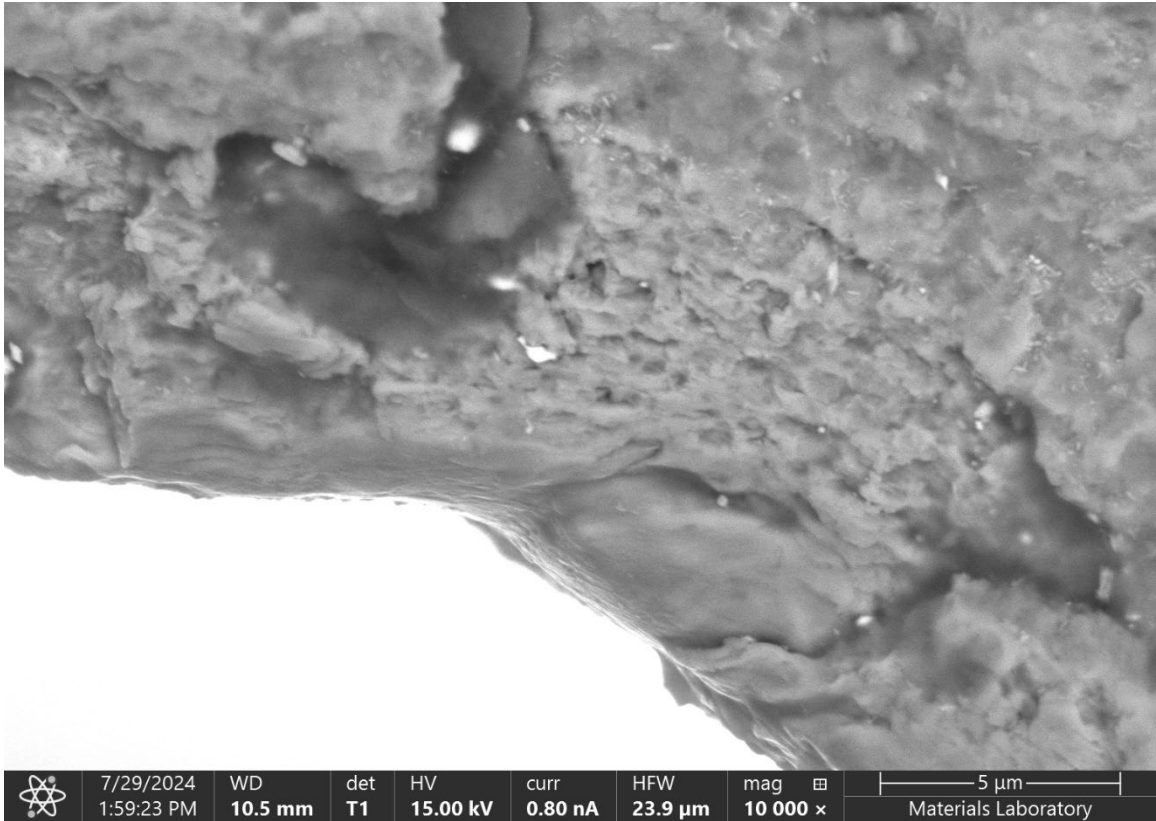


Figure 59. BE micrograph a closer view of the initiation site in **Figure 58**.