

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



WPR21FA340

MATERIALS LABORATORY

Factual Report 23-004

March 16, 2023

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A. ACCIDENT INFORMATION

Location: Lake Havasu City, Arizona
Date: September 12, 2021
Time: 16:09 mountain daylight time
23:09 coordinated universal time
Vehicle: Cessna 177RG, N2085Q
Investigator: Zoë Keliher, AS-WPR

B. COMPONENTS EXAMINED

Remnants of a piston rings

C. EXAMINATION PARTICIPANTS

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

D. DETAILS OF THE EXAMINATION

On September 12, 2021, a Cessna 177RG was substantially damaged when it was involved in an accident near Lake Havasu Airport. The pilot was fatally injured. Witnesses observed the airplane takeoff at a slow groundspeed, noting the engine sounded rough. During takeoff, the airplane pitched up and made an aggressive left bank. Witnesses observed the airplane stall with the left wing dropping toward the terrain. The main wreckage consisted of the airframe and engine, most of which had been consumed by fire except the right wing.

As part of the post-accident examination, the remainder of the Lycoming IO-360-A1B6 engine was completely disassembled.¹ According to the engine teardown report, the #1 and #4 top compression piston rings were fragmented (see Figure 1). The report stated evidence of corrosion and wear on all the piston skirts, with light scuffs and grooves from the base to the crowns oriented in the direction of actuation. There was additional evidence of blow-by with heat signatures on the piston skirts on all cylinders. Separation of the crankcase halves revealed severe spalling on the faces of all the intake lifters and the #3 exhaust lifter with evidence of galling. The camshaft showed excessive wear on the cam lobes, including rounding of the lobes, pitting, and material deformation.

The fractured piston rings from the #1 and #4 positions were forwarded to the NTSB Materials Laboratory for further examination. Figure 1 shows the piston assemblies

¹ The Lycoming IO-360 is a fuel-injected, four-cylinder, direct-drive, horizontally opposed, air-cooled, piston aircraft engine, manufactured by Lycoming Engines, headquartered in Williamsport, PA.

and respective piston rings, photographed on-scene at the engine teardown before receipt of the parts. The figure illustrates the fractured upper compression rings from the #1 and #4 pistons, positioned near their respective piston assemblies.

Figure 2 shows the opposite faces of the larger piston ring fragments from the #1 piston. The pieces exhibited a rounded, smooth face on the side in Figure 2a and a dull luster and rougher surface on the opposite (Figure 2b). The four small fragments from the #1 position are depicted from both faces in Figure 3. These fragments were labeled 1 through 4 for this report, from longest to shortest length.

The upper compression rings from the #4 piston are shown in Figure 4. Similar to the larger ring pieces from the #1 piston, these also exhibited one face with a smoother, more reflective surface (Figure 4b) than that on the opposite face.

Various dimensions of the larger ring remnants and the four smaller fragments were measured using digital calipers. The data are tabulated in Table I. Of note were the thicknesses differences between the #1 and #4 ring remnants and the smaller fragments found in the #1 position. These smaller pieces exhibited a thickness of 15-31% less than the average for the larger ring remnants (0.0644 inches).

The ends of each piston ring fragment were examined using a Keyence digital optical microscope, using the high dynamic range (HDR) function to record the features present better. For the purposes of this report, each end was labeled 'A' or 'B,' with an attempt to mate ends with consistent features (e.g., the two 'A' ends of the #1 rings in Figure 2).

Figures 5 through 9 show the ends of the ring remnants from the #1 piston position. These were described by the larger and shorter remnant circumferential length, as depicted in Figure 2. These surfaces exhibited a combination of vertically-oriented streaks and dark, flaky divots. Figure 6 shows a closer view of one of the surfaces, highlighting the pock-marked dark depressions on the surface. The area surrounding the dark depression was reflective, exhibiting linear features that were not parallel. There were also indications of gouge marks on the surface. These reflective features were consistent with wear marks on the surface. The vertical direction (transverse to the ring cross sections) was consistent with the vertical movement of the piston during engine operation.

Figures 10 through 18 show the cross-sectional surface of the four fractured ring fragments. As documented in Table I, these fragments exhibited a smaller thickness and widths than the larger ring remnants. Most of the fragment cross sections showed rounded protrusions facing outward, located on the left side of the figures for these parts. As with the #1 ring remnant ends, these fragments exhibited vertical streaks, wear marks, and darker mottled depressions. The smallest piece, illustrated

in Figures 16 and 17, revealed the most severe surface damage, with most surface areas reflecting light consistent with smoothing from wear.

Figures 18 through 21 show the ends of the ring remnants from the #4 piston position. Like the ends of the #1 rings and the smaller fragments, the #4 ring remnants displayed a combination of vertically-oriented streaks and dark, depressed areas.

Several fragments and the shorter #1 ring remnant were examined using a field emission scanning electron microscope (SEM). Figure 22 shows a typical area along the inner edge of the #1 ring, side 'A,' shown visually in Figure 8. The rough and darker area contrasted with the surrounding smoother regions of the surface (toward the left and bottom in Figure 22).² The pock-marked area exhibited peripheral areas of light contrast. Closer views in Figure 23 showed these regions displayed electrical noise, consistent with the charging effects of nonconductive materials in an electron microscope. This region also exhibited a rounded intergranular appearance, with secondary cracks present normal to the surface.

A smoother area of the #1 ring surface 'A' was also examined, showing more minor depressions along the surface (see Figure 24). The smoother regions exhibited a layered appearance, consistent with deformation and exuding of the ring material over gaps and valleys. As shown in the backscattered micrograph in Figure 25, the surface depressions exhibited some contrast, consistent with dissimilar material present. Figure 26 shows a closer view of the central depression in Figure 24. The feature exhibited a rounded intergranular appearance, with smaller protrusions on the surface indicative of oxidation or corrosion deposits.

The lower edge of this #1 ring remnant surface was also examined, showing a wider area of depressed features and absent material (Figure 27). As illustrated in Figure 8, this region exhibited characteristics consistent with the other rough depressions, showing intergranular interstices, rounded facets, and dissimilar nonconductive material. These areas were examined using energy dispersive x-ray spectroscopy (EDS). The composition was consistent with iron oxide and high amounts of carbon, lead, bromine, and phosphorus. These later elements were consistent with combustion products from tetraethyl lead additives in avgas. This chemistry was consistent in all rough areas containing dissimilar, non-conductive material.

One of the ring remnants from the #1 piston was intentionally fractured in bending overstress to examine how such a fracture surface would appear. Figure 29 shows a typical area of the intentionally overstressed fracture surface. The surface exhibited a

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.

blocky, faceted appearance. Imaging with backscattered mode revealed randomly alternating areas of light gray and dark features, consistent with dissimilar constituents on the fracture.

Figure 31 shows a closer view of one of the faceted features on the fracture surface. This feature exhibited a 'rosette' of faceted river patterns emanating from a central acicular feature. When imaged in backscattered mode, this constituent displayed darker contrast (lower atomic number), found to be consistent with nearly all carbon when examined by EDS (Figure 32). The surrounding iron-rich material exhibited cleavage facets and some areas of fine-dimpled rupture (as exemplified in Figure 33).

This laboratory fractured surface was examined by EDS. The composition, along with the morphology of the fractured carbon-rich phases on the surface, were consistent with malleable iron.

Submitted by:

Erik M. Mueller
Materials Research Engineer

Table I. Measurements of the four upper compression ring remnants and the smaller ring fragments.

Part Name	Circumference (in)	Inner diameter segment length (in)	Outer diameter segment length (in)	Width (in)	Thickness (in)
#1 Ring – Larger	7.5625	4.8125	5.1875	0.1915	0.0640
#1 Ring – Smaller	7.2500	4.6875	5.1250	0.1920	0.0660
#4 Ring – Larger	9.0000	4.8125	5.1875	0.1860	0.0650
#4 Ring – Smaller	6.2500	4.5000	4.8750	0.1865	0.0625
Fragment – Piece 1	0.6600	0.6445		0.1865	0.0520
Fragment – Piece 2	0.4315	0.3945		0.1875	0.0525
Fragment – Piece 3	0.2670	0.2495		0.1865	0.0445
Fragment – Piece 4	0.2060	0.1880		0.1850	0.0545



Figure 1. Images of the pistons and fracture rings from the engine teardown.

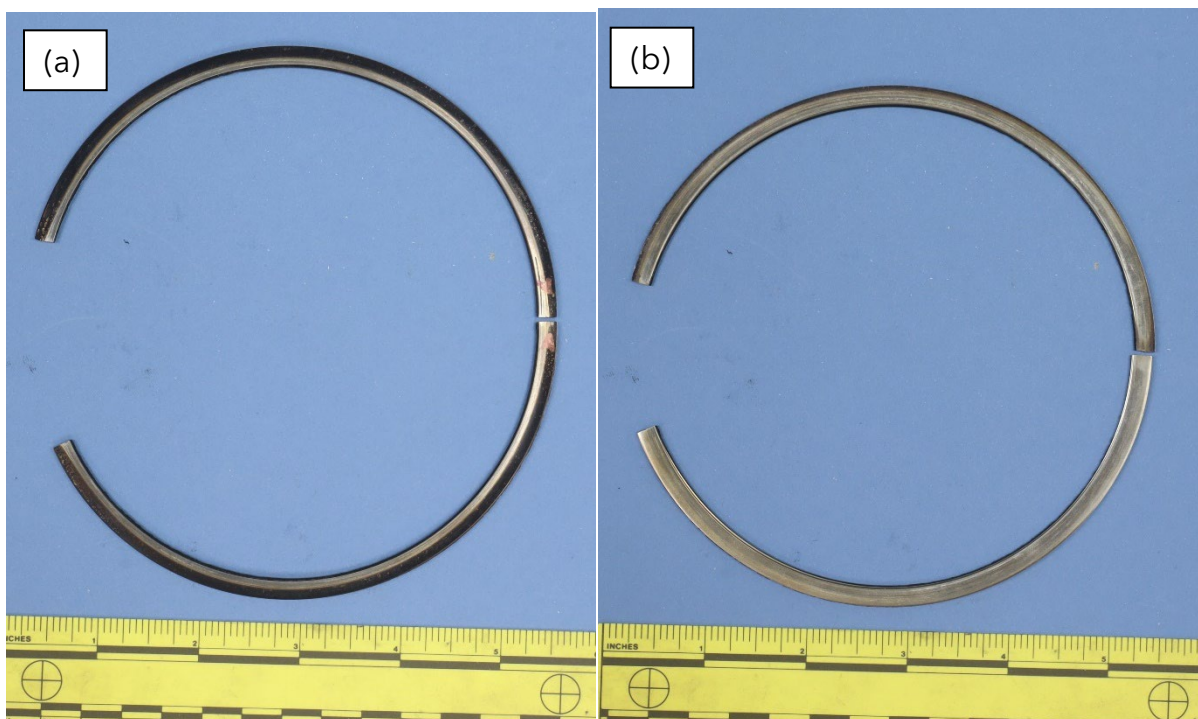


Figure 2. The ring remnants from the #1 piston assembly, viewed from opposite sides..

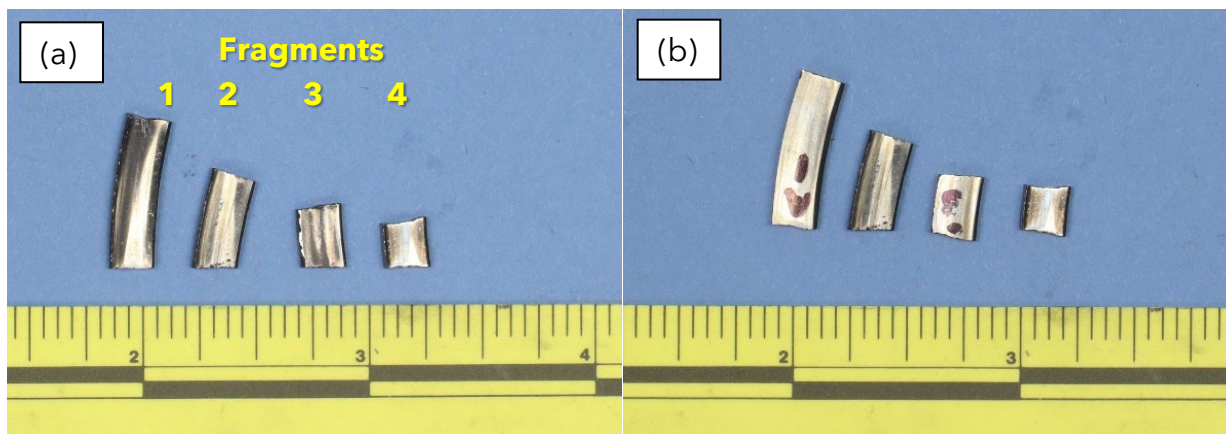


Figure 3. Smaller fragments of the ring retrieved from the #1 piston assembly.

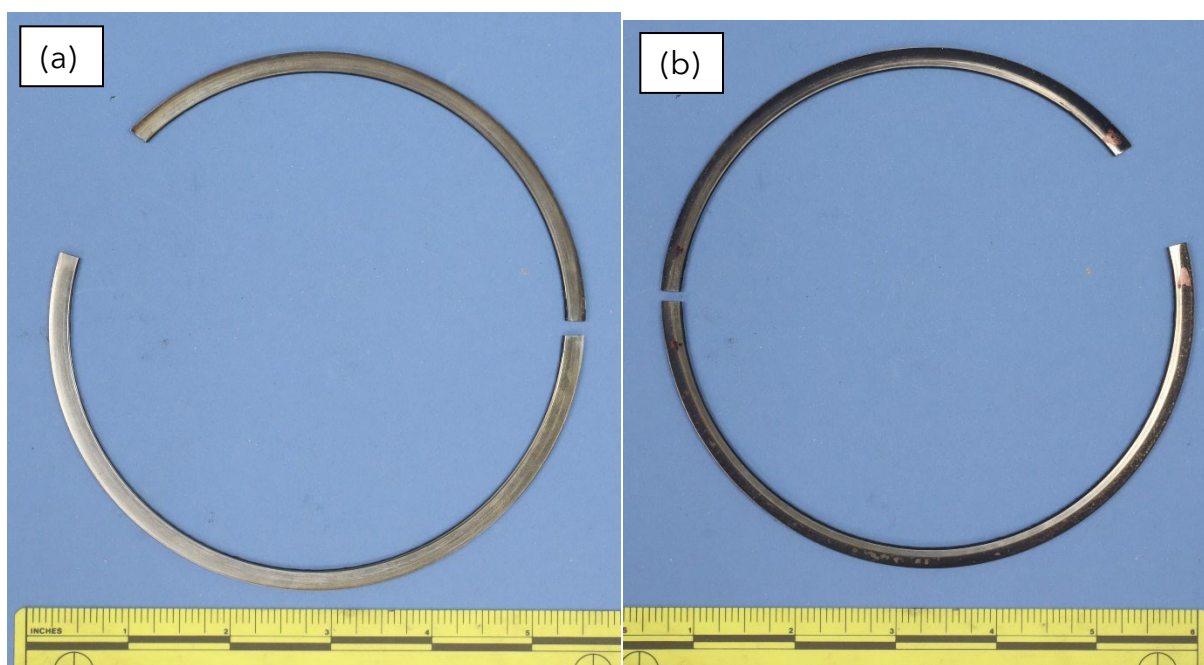


Figure 4. The ring remnants from the #4 piston assembly.



Figure 5. Surface 'A' from the larger #1 ring remnant.

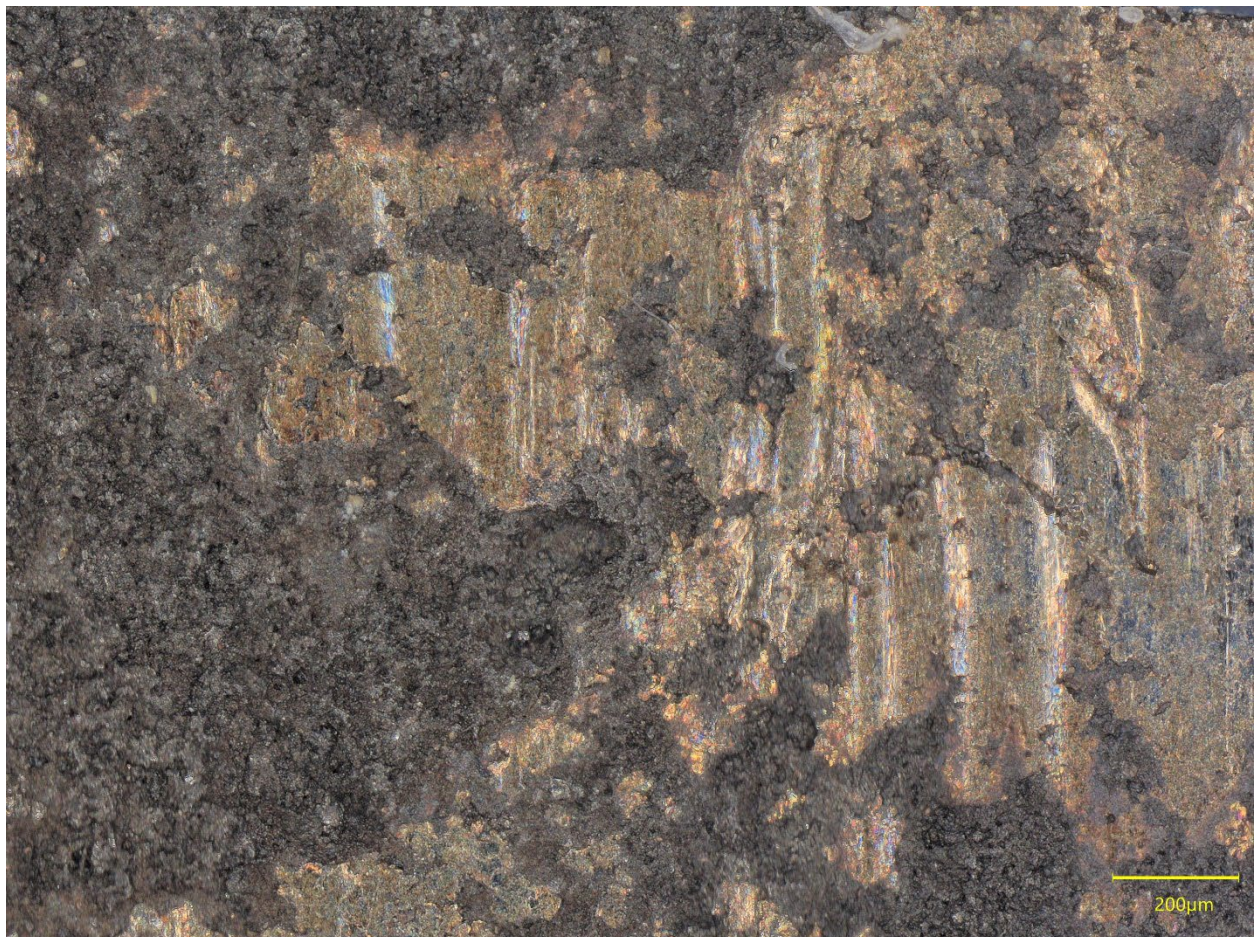


Figure 6. Closer view of depressions, foreign material, and vertically-oriented wear marks on the surface in **Figure 5**.



Figure 7. Surface 'B' from the larger #1 ring remnant.



Figure 8. Surface 'A' from the shorter #1 ring remnant.

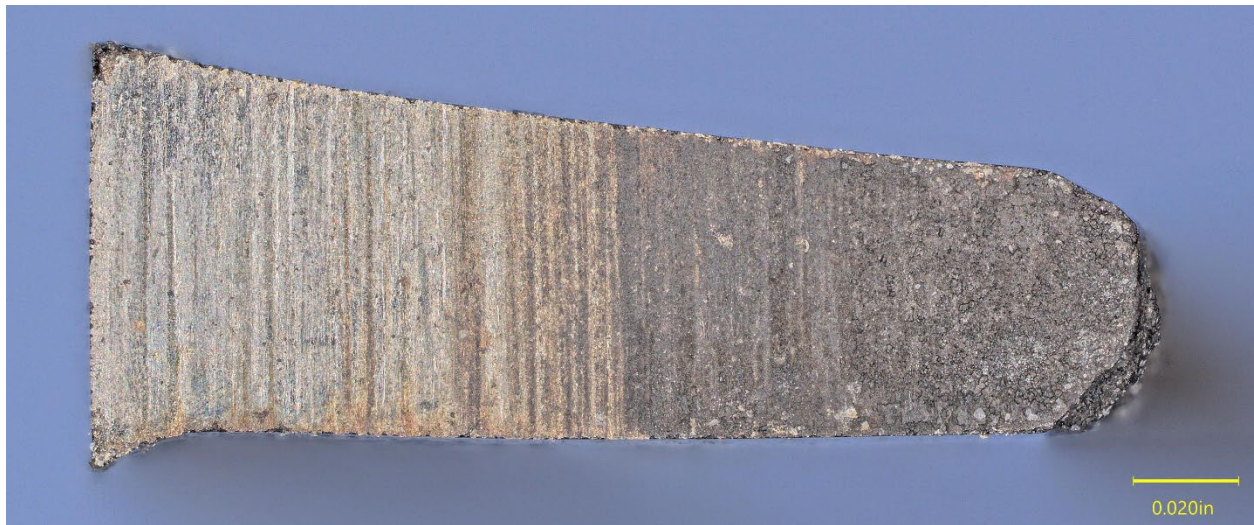


Figure 9. Surface 'B' from the shorter #1 ring remnant.



Figure 10. Surface 'A' from the ring fragment #1.



Figure 11. Surface 'B' from the ring fragment #1.



Figure 12. Surface 'A' from the ring fragment #2.



Figure 13. Surface 'B' from the ring fragment #2.



Figure 14. Surface 'A' from the ring fragment #3.

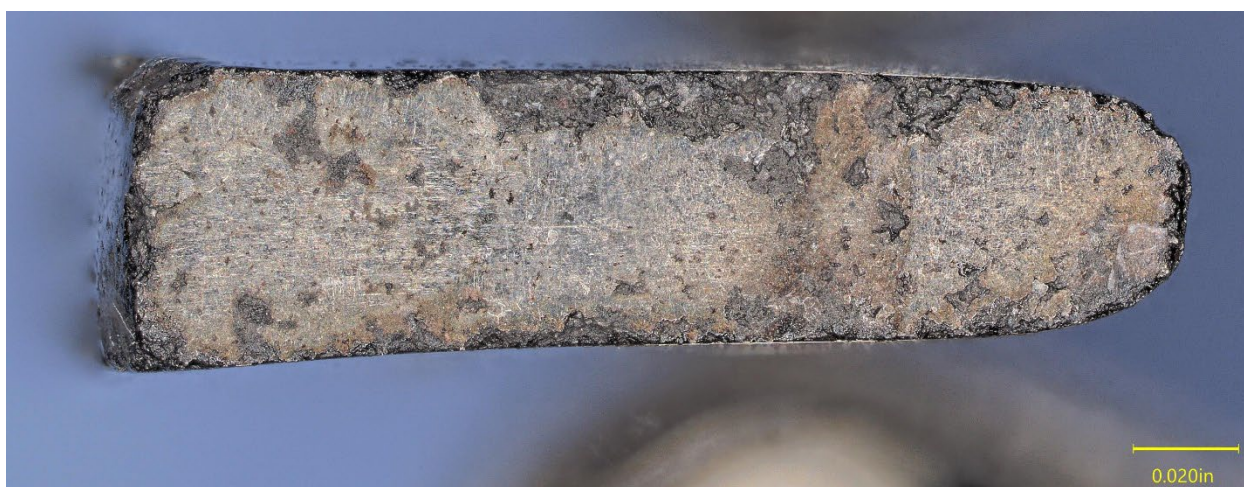


Figure 15. Surface 'B' from the ring fragment #3.



Figure 16. Surface 'A' from the ring fragment #4.



Figure 17. Surface 'B' from the ring fragment #4.

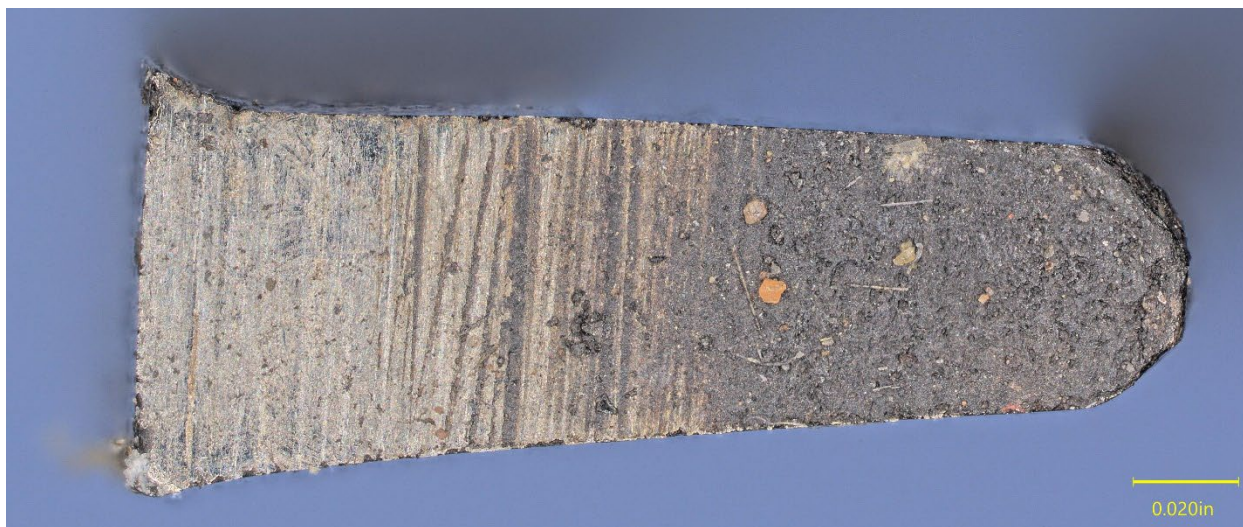


Figure 18. Surface 'A' from the longer #4 ring remnant.



Figure 19. Surface 'B' from the longer #4 ring remnant.



Figure 20. Surface 'A' from the shorter #4 ring remnant.



Figure 21. Surface 'B' from the shorter #4 ring remnant.

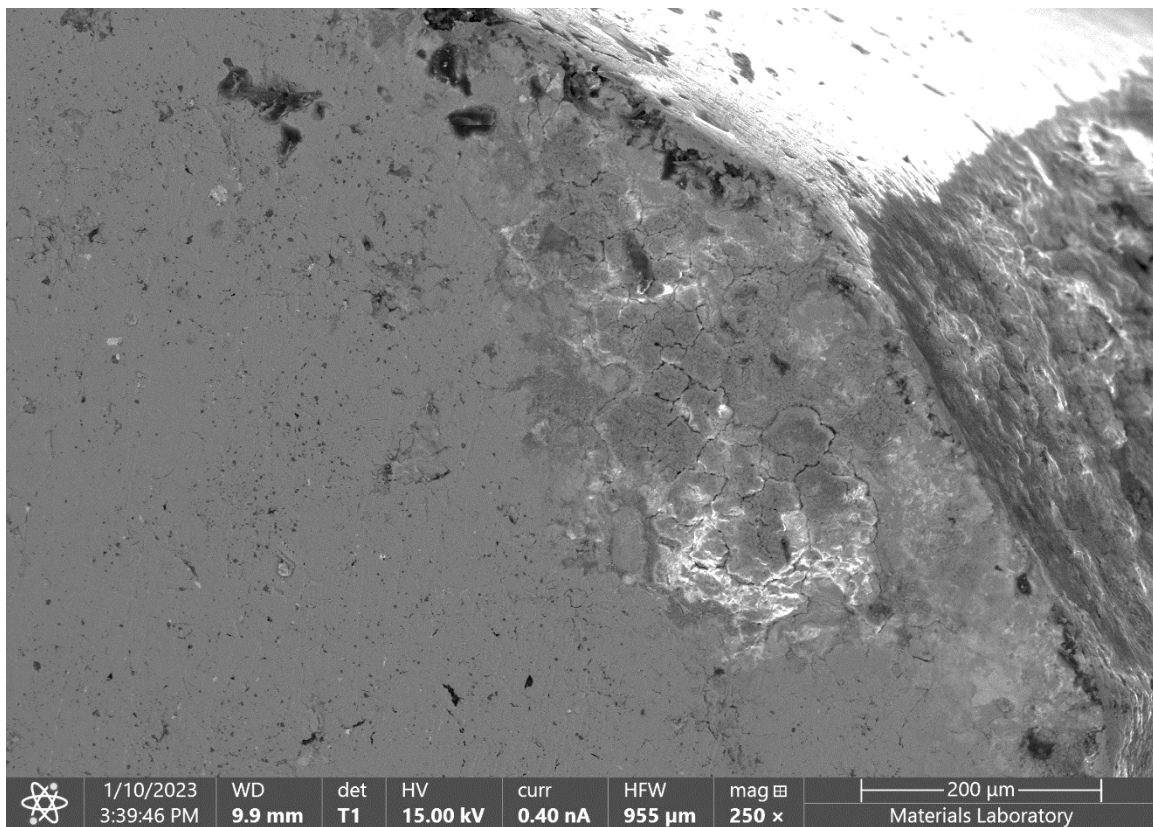


Figure 22. Backscattered electron (BE) micrograph of the inside corner of the shorter #1 ring surface A.

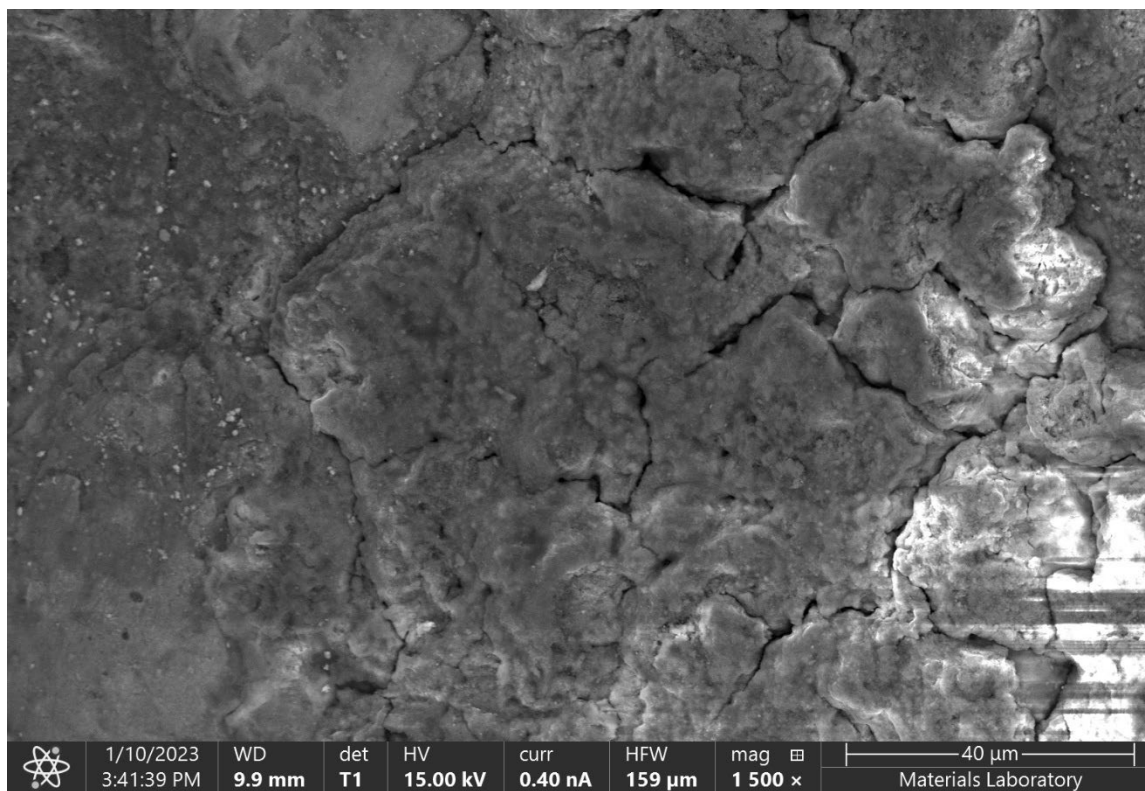


Figure 23. BE micrograph of the rumpled area in the upper right of **Figure 22**.

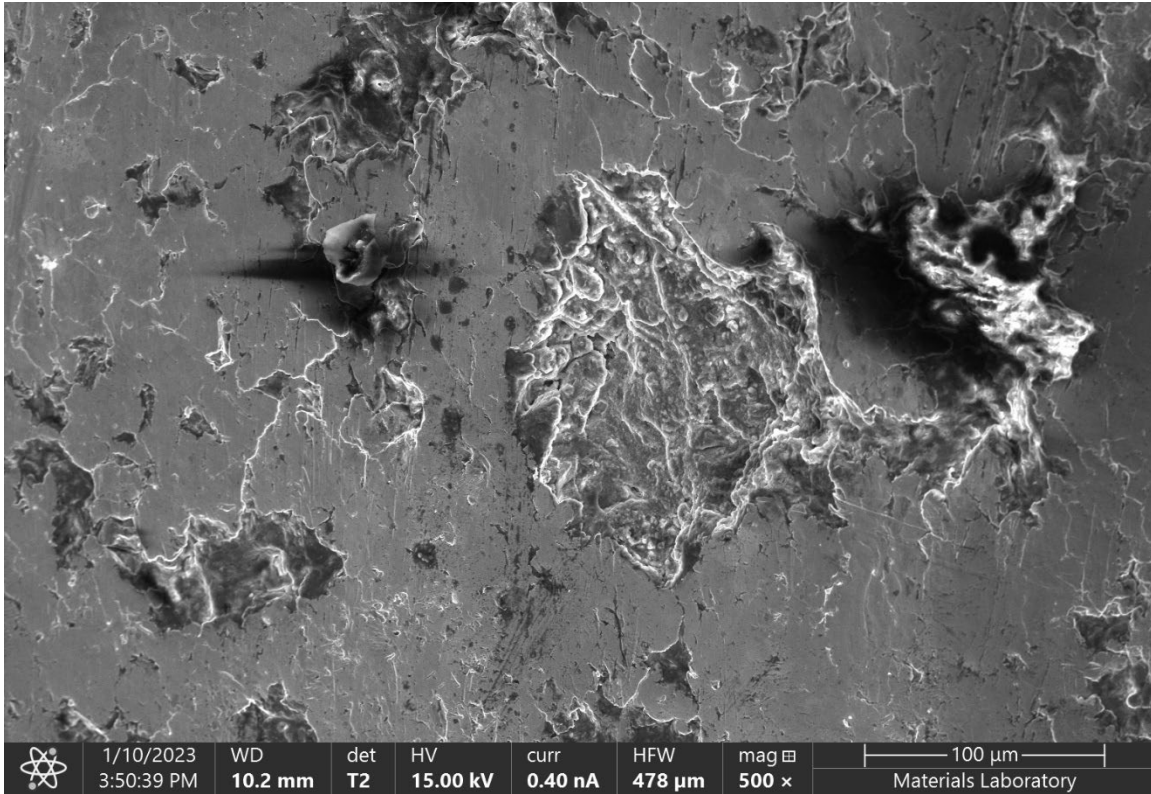


Figure 24. Secondary electron (SE) micrograph of a depression on the worn area of #1 ring surface A.

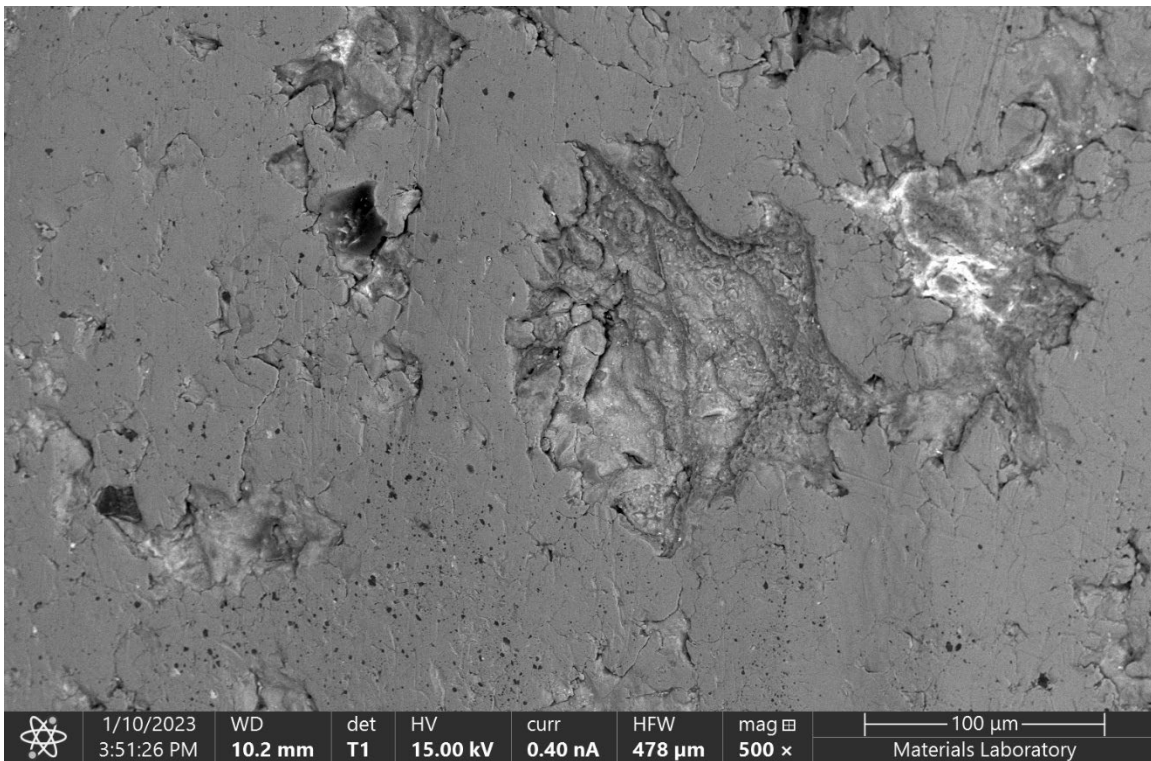


Figure 25. BE micrograph of the area in **Figure 24**.

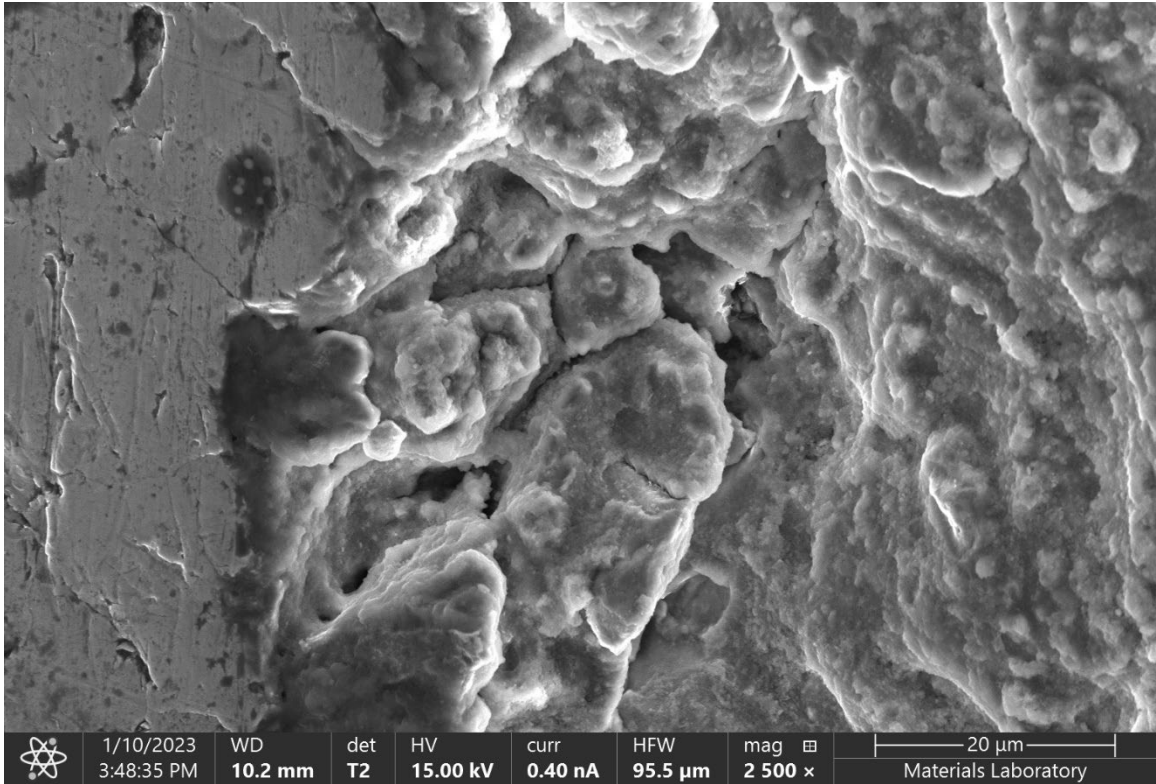


Figure 26. SE micrograph of a closer view of a corner of the depression in **Figure 24**.

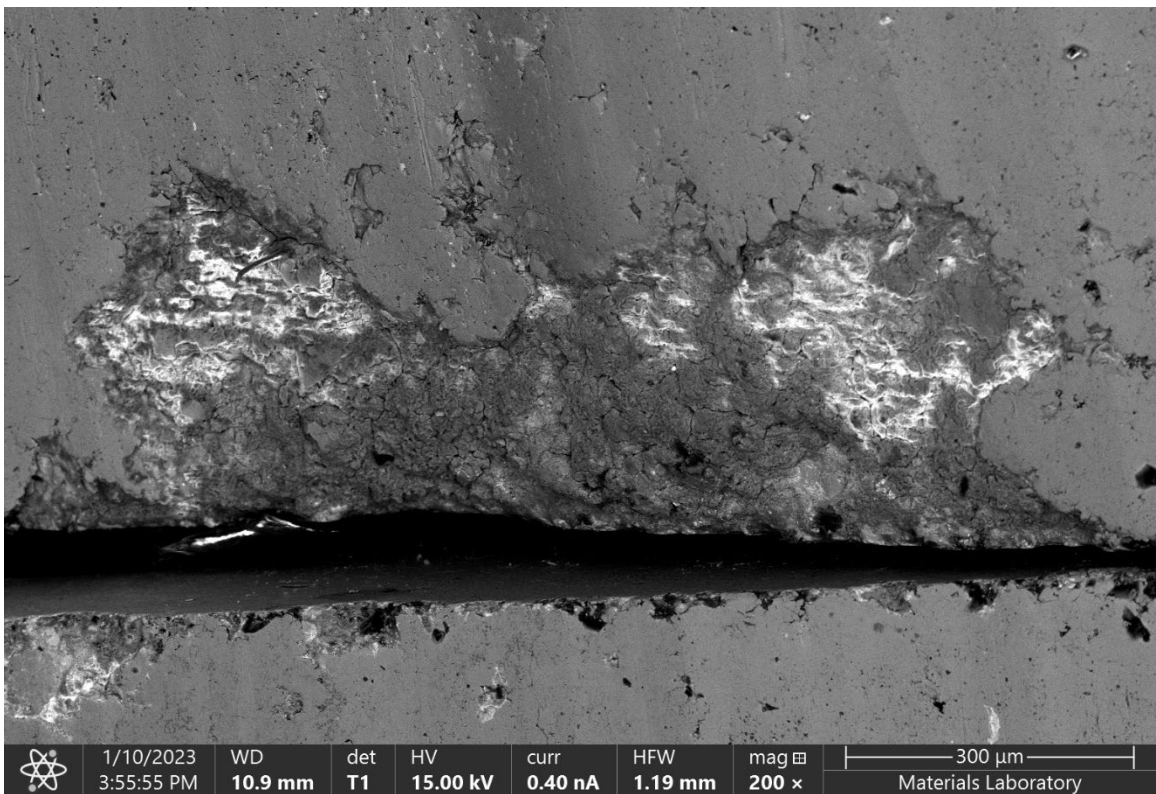


Figure 27. BE micrograph of wear and corrosion on the middle of the lower edge of the shorter #1 ring.

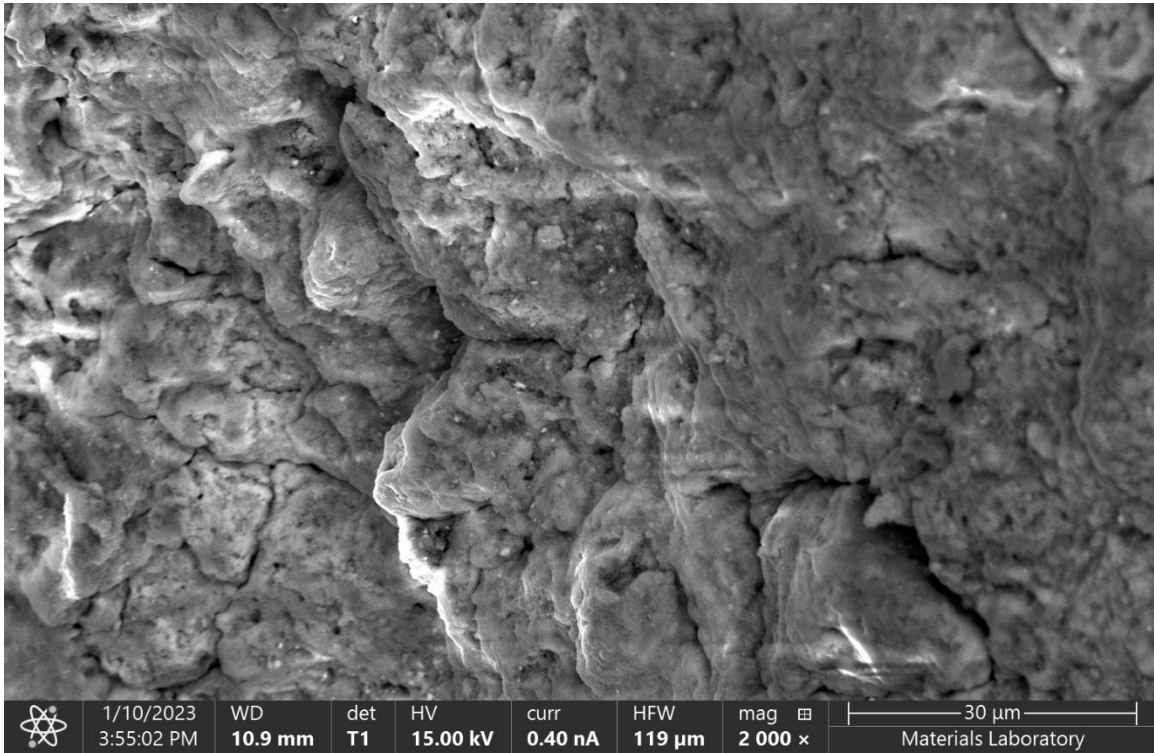


Figure 28. BE micrograph showing a closer view of the corroded, intergranular portion of the fracture (lower middle of **Figure 27**).

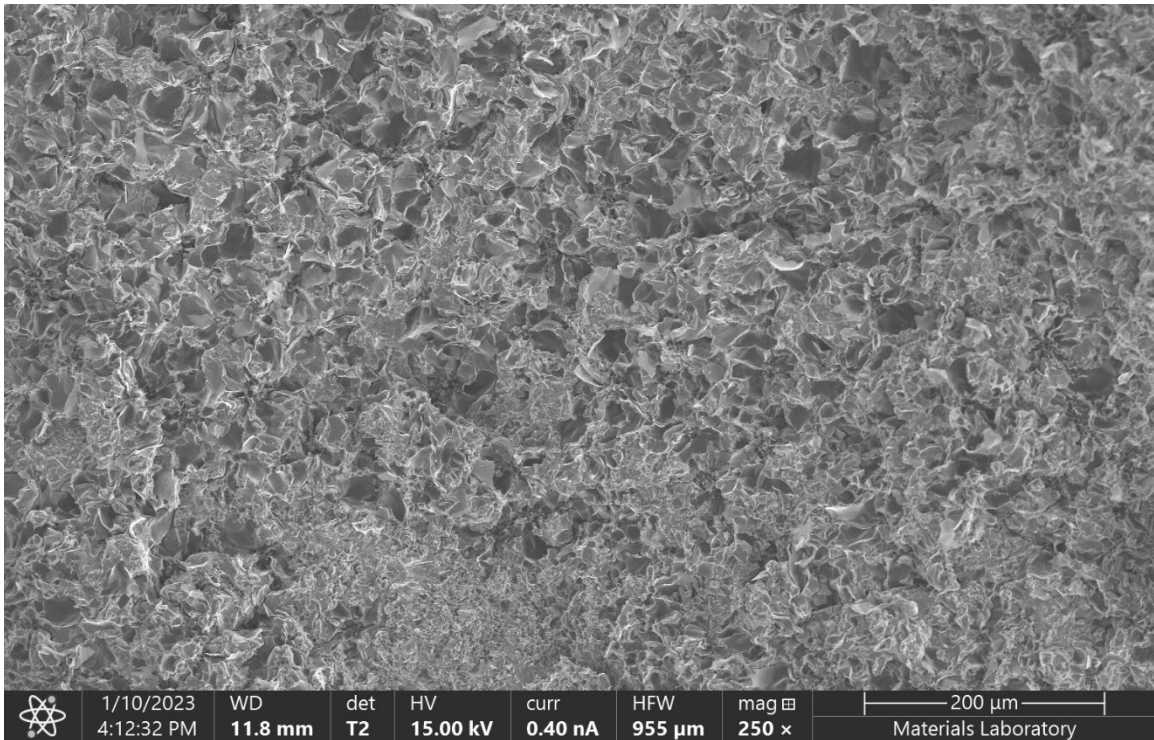


Figure 29. SE micrograph of the laboratory opened fracture surface of the #1 shorter ring, showing an intergranular morphology.

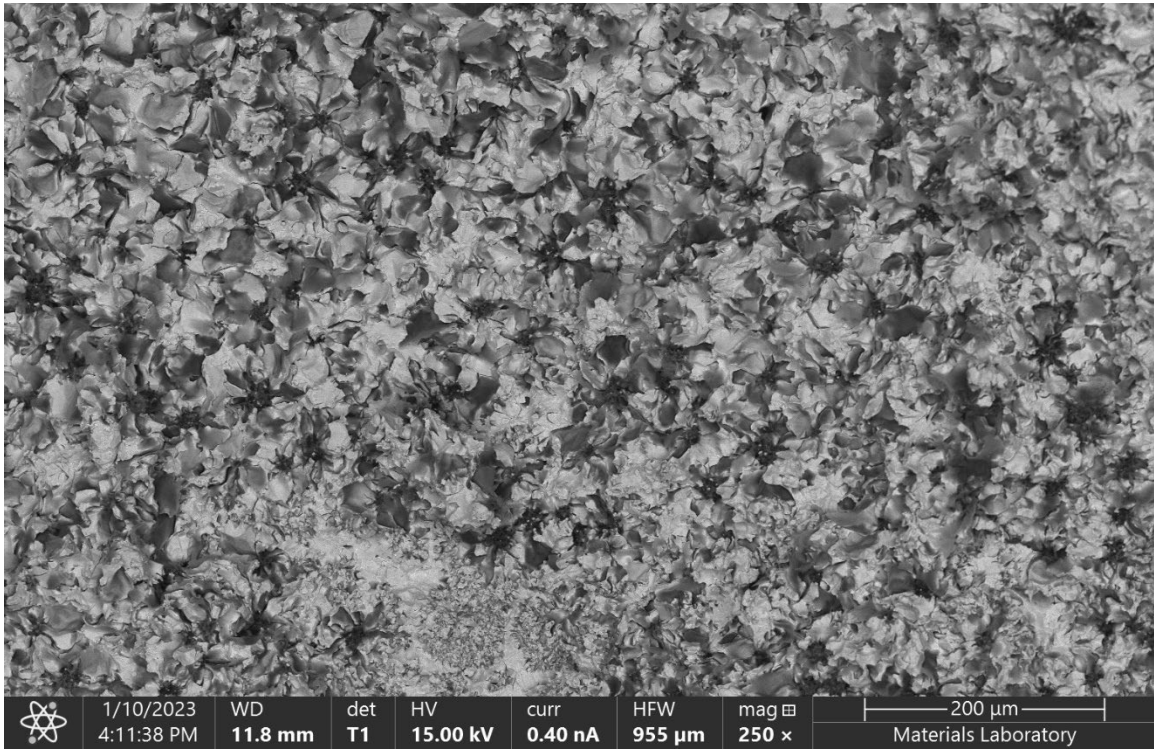


Figure 30. BE micrograph of the laboratory opened fracture surface of the #1 ring.

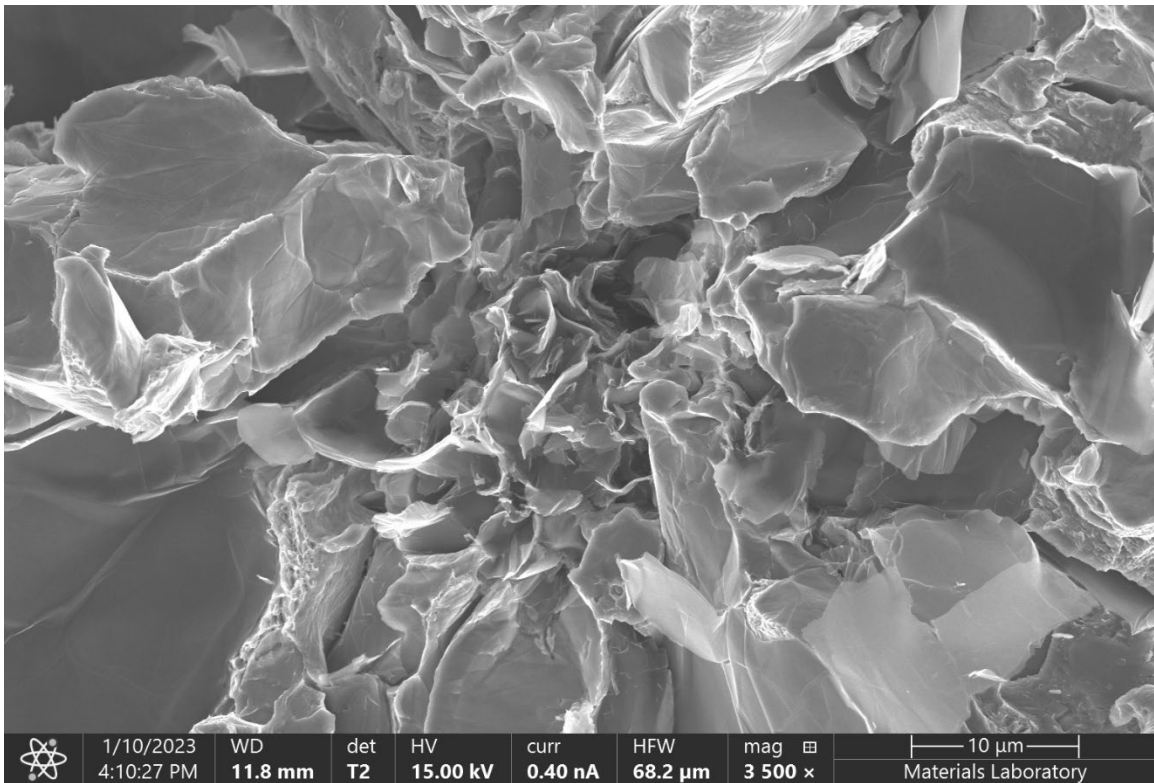


Figure 31. SE micrograph of the 'rosette' shaped features on the laboratory opened fracture surface.

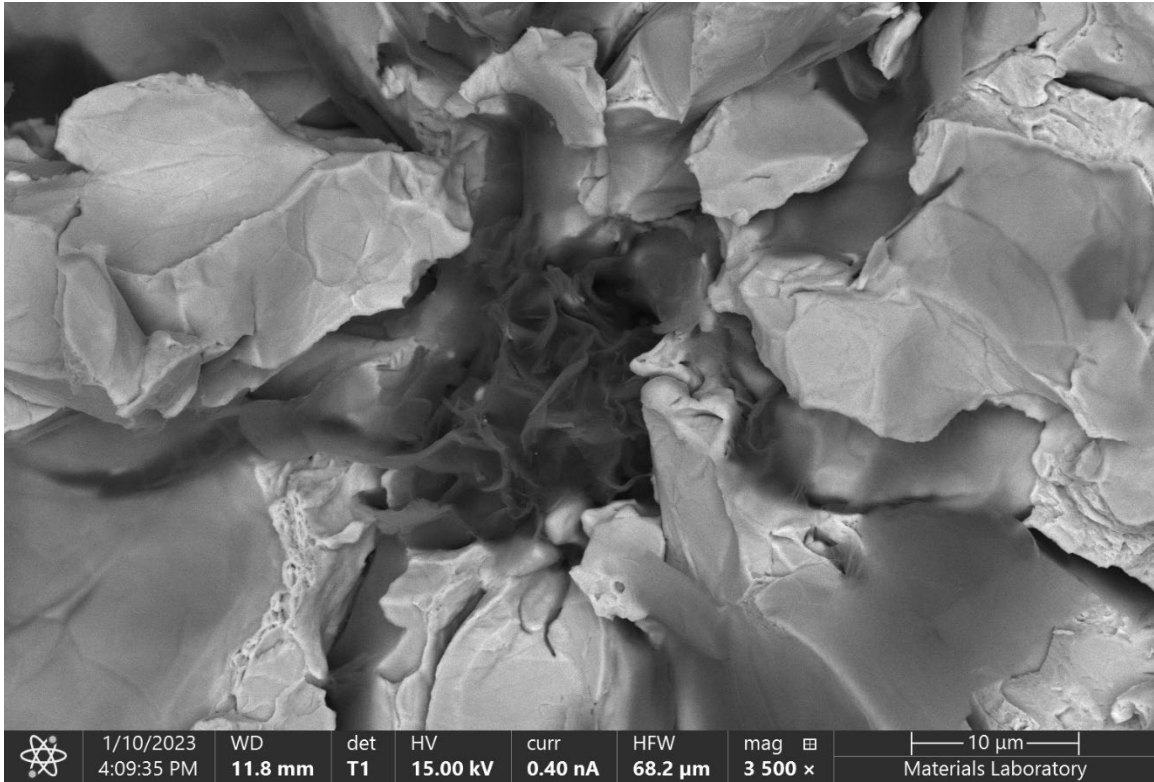


Figure 32. BE micrograph of **Figure 30**, showing a central C-rich area.

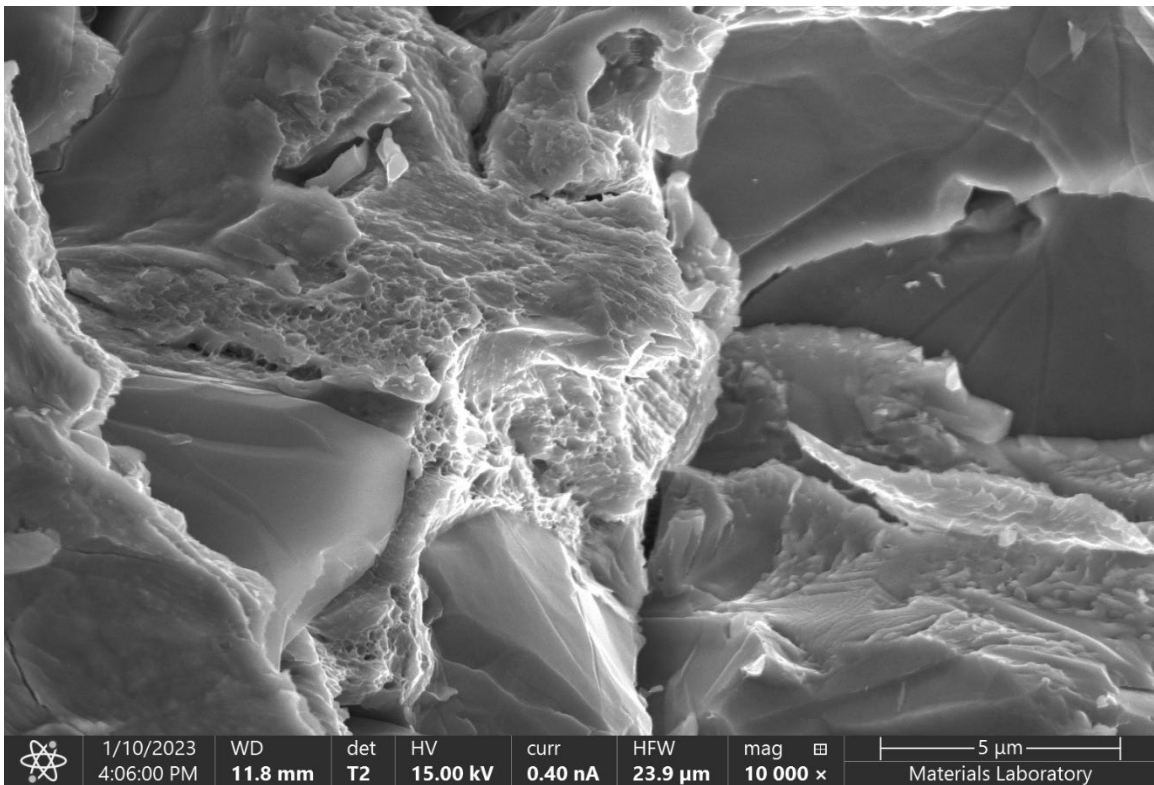


Figure 33. SE micrograph of fine dimpled rupture on facets in the laboratory opened fracture surface.