

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN21LA213

MATERIALS LABORATORY

Factual Report 23-026

March 15, 2023

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A. ACCIDENT INFORMATION

Location: Merrill, Wisconsin
Date: October 19, 2021
Time: 15:00 central daylight time
20:00 coordinated universal time
Vehicle: Beech C23, N793Y
Investigator: Jennifer Rodi, AS-CEN

B. COMPONENTS EXAMINED

Remnants of tappets

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 May 11, 2021, a Beech C23 was substantially damaged when it was involved in an accident near Merrill, WI. The pilot and passenger had minor injuries. The pilot reported that during descent, the engine started to run rough and gradually lost power. The pilot then executed an off-field landing during which the landing gear collapsed, and the airplane slid to a stop on its belly. The airplane engine, a Lycoming O-360 series, was later torn down, and the tappets extracted from it were sent to the NTSB Materials Laboratory for additional examination.

Figure 1 shows the four tappets from the intake side of each of the four cylinder positions. They were annotated based on their cylinder position in the figure. Three of the four tappets had fractured on the flanged head, with only the #2 tappet remaining intact.

Figure 2 shows the #1 intake tappet from the head and side. The head exhibited three angled fractures, leaving a portion of the face that had been in contact with a camshaft lobe.

In contrast, the intact #2 tappet head face, shown in Figure 3, did not exhibit any chips or fractures. This tappet face did display small (approximately 1/8 inch long) radial features around the periphery. A closer examination of the face found small depressions near the center (see Figure 4 and Figure 5). These areas were consistent with pitting on the surface, as illustrated in Figure 6. In addition, the radial features were shown to be straight in morphology and tapered at each end—these

characteristics were consistent with scratches imparted to the surface. The false color image in Figure 5 demonstrates these qualities of the surface scratches.

Figure 7 shows the #3 tappet remnant, viewed from the head and side. About 1/3 of the tappet head had fractured and separated, leaving a jagged chord-oriented fracture surface coincident with the hollow tappet stem. The tappet from the #4 intake position was completely absent from the head, exhibiting two oblique fractures. This fractured remnant is depicted in Figure 8.

Figure 9 shows the four tappets and their remnants from the exhaust positions; each was annotated based on their positions from the engine. In this batch, the #1 and #3 tappets were intact, whereas the #2 and #4 tappets had fractured.

Figure 10 shows the head and side of the #1 exhaust tappet. The face of the head exhibited a radial streak from the center towards an edge. There were no other indications of damage on this part. The #3 exhaust tappet showed no visible features indicating damage, wear, or cracking.

Figure 11 shows the #2 tappet, which retained about 2/3 of the head area. However, unlike the other damaged tappets, most of the head face had been worn away, and the remainder of the head exhibited a depression most pronounced corresponding with the stem (see Figure 11b). The #4 tappet head was absent, leaving a flat, perpendicular fracture across the stem, deep enough to open to the interior cavity.

Some assorted but uncategorized fractured tappet remnants had been recovered and shipped together, as shown in Figure 12. Most of these had been fractured after separating from their tappet bodies, with the fracture surfaces smeared and worn.

The dimensions of the heads of the #1 and #2 exhaust tappets were measured using digital calipers for comparison. The thickness of the tappet heads increased towards the stem due to the radius at the corner transition. The outer head thickness of the #1 tappet was 0.179 inches, increasing to 0.223 inches near the stem.

The #2 exhaust tappet exhibited a thickness of 0.189 inches along the periphery of the head. However, this decreased to 0.088 inches at the fracture surface adjacent to the stem, consistent with wear and material spalling.

Several of the damaged and fractured tappets were examined further. Of note was the #2 exhaust tappet, the only one that underwent wear on the head significant enough to change its geometry. Figure 13 shows a montage of the head face, which was reflective and consistent with polishing from repeated contact with the mating camshaft lobe. The depression at the center of the tappet head corresponding to the stem exhibited circular wear marks. The fracture surface on the bottom of the figure was circular, conforming to the geometry of the stem radius. Figure 14 shows the

widespread spalling of the remaining surface, demonstrating the degree of material loss on this part. There were also smaller divots, consistent with the pitting observed in the #2 intake tappet face shown in Figure 6.

Figure 15 shows the fracture surface of the #2 exhaust tappet. The surface exhibited several ridges, separated by vertical angled edges. The fracture was rough in texture, with a general dull luster. Figure 16 shows a closer view of the part of the fracture surface near the stem radius. This area exhibited crescent-shaped morphologies adjacent to the edge with the worn head face. Radial marks and chevron marks were present on the surface consistent with fracture proceeding from the head face toward the underside.

This fracture surface was examined using a field-emission scanning electron microscope (SEM). Figure 17 shows a closer view of the boxed area in Figure 16, which was a portion of the fracture surface edge with the worn head face. The edge exhibited some rounding downward over the fracture surface, consistent with continued wear after fracture. The surface was mottled and rough, with radiating patterns emanating from the boxed area along the rounded surface edge.

The area near the edge shown in Figure 18 revealed faceted features with small steps and fanlike orientations. These features were consistent with cleavage fracture.¹ The area at the bottom of Figure 18 is highlighted in Figure 19. This area exhibited dimpled rupture on the facet. Both these types of features were consistent with overstress fracture.

Another area along the #2 exhaust tappet fracture surface edge is shown in Figure 20. The backscattered image demonstrates darker-contrasting dissimilar material on the surface, consistent with post-fracture contamination. The lighter gray areas that were smoother in contrast were consistent with localized smearing, indicative of post-fracture damage to and wear of the fracture surface features.

The boxed area is highlighted in Figure 21. Like in the previous region examined on this fracture surface, dimpled rupture was observed along with flatter facets and fan-shaped stems. These features, mixed dimpled rupture and cleavage, were consistent with overstress fracture of the tappet head. No other features consistent with other fracture modes were found.

The fractured head of the #1 intake tappet is illustrated in Figure 22, showing the trapezoidal remnant of the face and the angled fractures. Of note was the fracture facing the right in Figure 23, highlighted in Figure 24. The fracture surface exhibited

¹ Cleavage fracture is a type of overstress fracture occurring along low-index crystallographic planes of metallic grains, resulting in flat, reflective facets.

small pit-like or thumbnail-shaped features along the edge with the remnant of the face. This edge was examined using an SEM.

Figure 24 shows an area of the fracture surface on the edge of the #1 intake tappet face, as annotated in Figure 23. This fracture area exhibited a perpendicular crack to the fracture surface, shown on the left side of Figure 24. The surface exhibited darker-contrast nonconductive material, consistent with post-fracture contamination. The fracture surface exhibited downward-spreading radial marks, consistent with fracture from the head face toward the stem.

When examined closer, the fracture surface exhibited cleavage features—fan-shaped steps and ridge-like characteristics (typified in Figure 25). Isolated areas of dimpled rupture were also observed. These features were consistent with overstress fracture of the tappet head. No other features indicative of other fracture modes were observed.

Figure 26 shows the #3 intake tappet head fracture, exhibiting downward-radiating river patterns and chevron marks. This was most pronounced in the two rounded areas towards the left and right of the edge with the face. The left area is illustrated in Figure 27, showing radiating lines emanating from this feature along the edge.

This area of the fracture surface annotated in Figure 27 was examined using an SEM, as illustrated in Figure 28. Like the other tappet fractures, the #3 intake tappet surface exhibited a rough texture with a faceted undulating morphology. A closer view in Figure 29 showed many of the microscopic features had been obliterated, consistent with post-fracture smearing damage. The areas that were undamaged exhibited characteristics consistent with overstress fracture. As illustrated in Figure 30, this surface displayed cleavage facets and steps, along with areas of ductile tear ridges.

The chemical compositions of the #2 exhaust tappet and the #1 exhaust tappet were examined using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The composition was consistent with alloy steel, such as 300M or 4340. The hardness of both tappet stems was examined per ASTM E18.² The hardness for the #1 exhaust tappet averaged 26 HRC, and the hardness of the #2 exhaust tappet was 25 HRC.

² ASTM E18 - *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA. The Rockwell B (HRBW) scale is an indentation method of determining the hardness of soft metals and uses a 1/16-inch diameter tungsten ball indenter at a load of 100 kilograms.

Submitted by:

Erik M. Mueller
Materials Research Engineer



Figure 1. The intake tappets, as received, annotated by cylinder position.



Figure 2. The #1 intake tappet with the remnant recovered viewed from (a) the fractured head and (b) the side.



Figure 3. View of the #2 intake tappet head, as received.

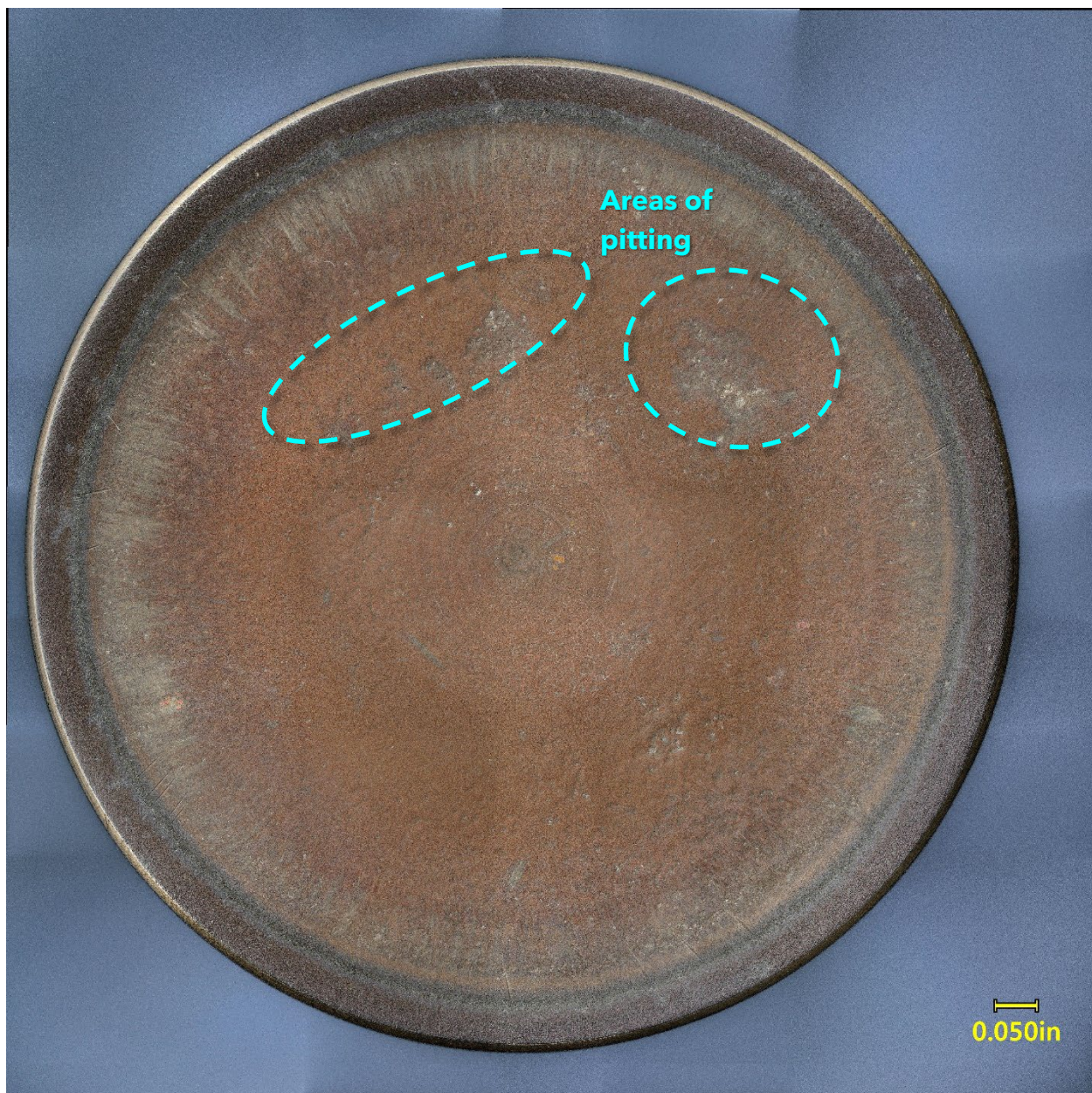


Figure 4. Closer view of the face of the #2 intake tappet head, using optical shadowing to show a band of pitting in the upper part of the figure.

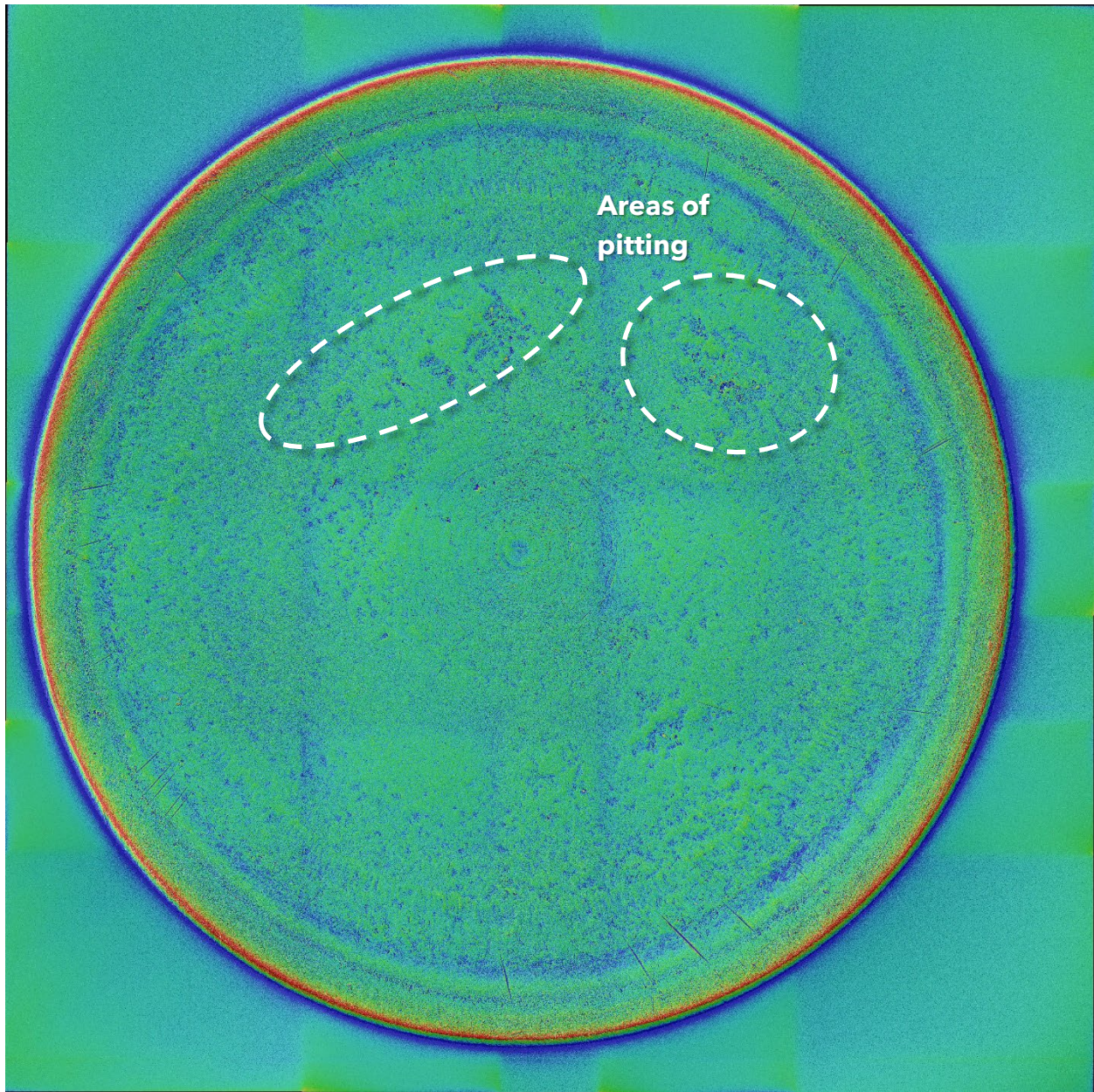


Figure 5. False color overlay of the #2 tappet head face in **Figure 4**, showing the depressed areas (blue) corresponding with pitting and radial scratches. The red areas around the edge are the highest relative elevation.



Figure 6. Closer view of the pitting on the surface of the tappet in **Figure 4**.



Figure 7. View of (a) the fractured head and (b) the side of the #3 intake tappet.

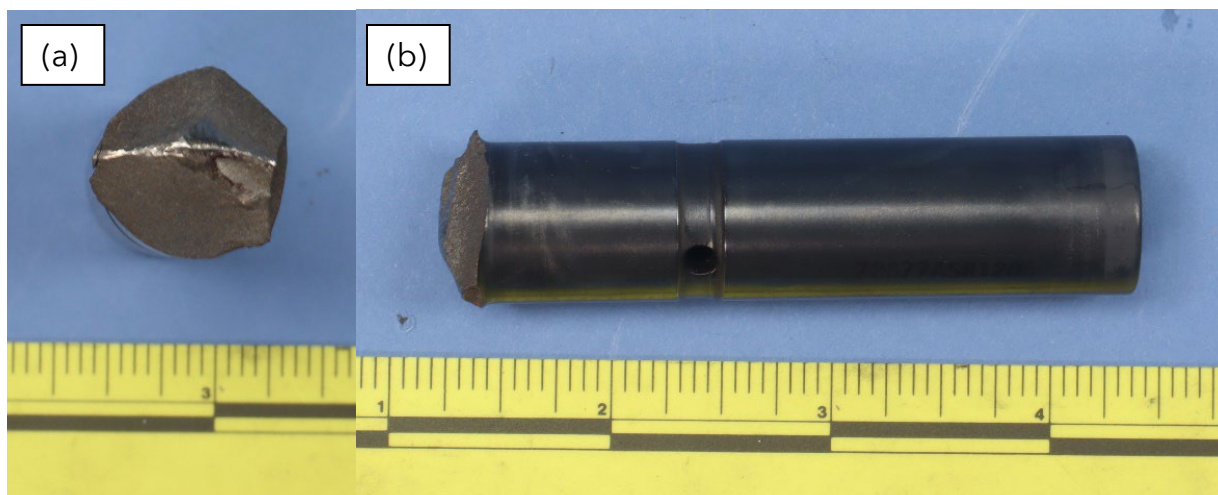


Figure 8. View of (a) the fractured head and (b) the side of the #4 intake tappet.



Figure 9. The exhaust tappets and #1 plunger piston as received, annotated by cylinder position.

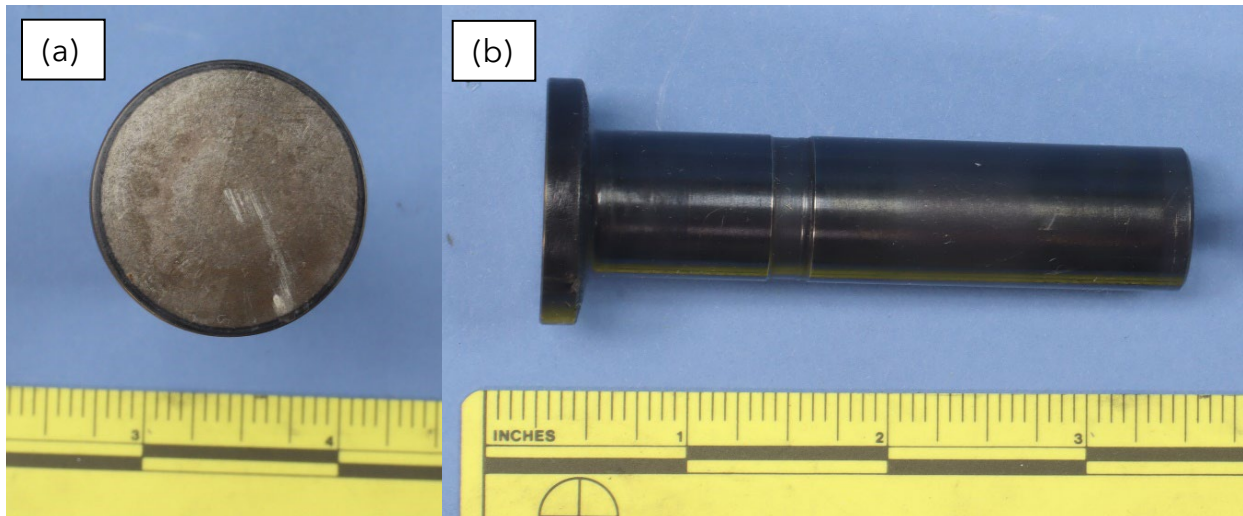


Figure 10. View of (a) the head and (b) the side of the #1 exhaust tappet.

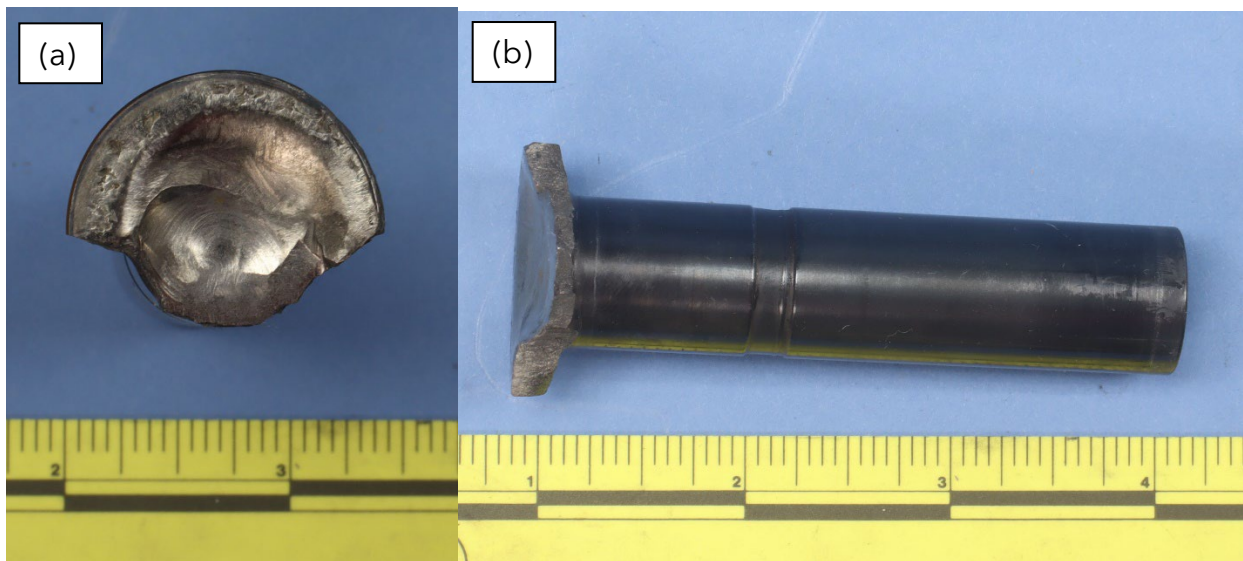


Figure 11. The #2 exhaust tappet shown from (a) the head and (b) the side.



Figure 12. Loose debris recovered from the engine.



Figure 13. View of the #2 exhaust tappet head.



Figure 14. Worn areas of the #2 exhaust tappet head, showing spalling and pitting.



Figure 15. View of the fracture surface on the #2 exhaust tappet head.

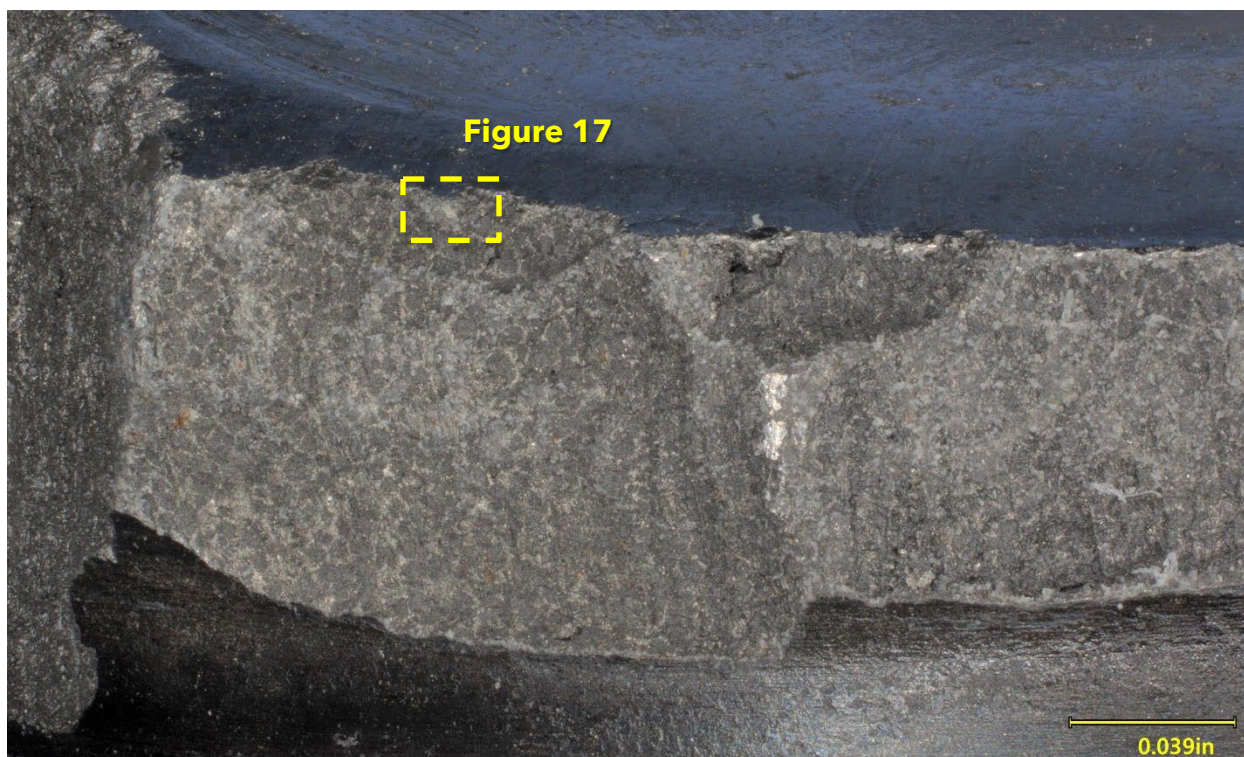


Figure 16. Closer view of initial fracture areas of the #2 exhaust tappet head.

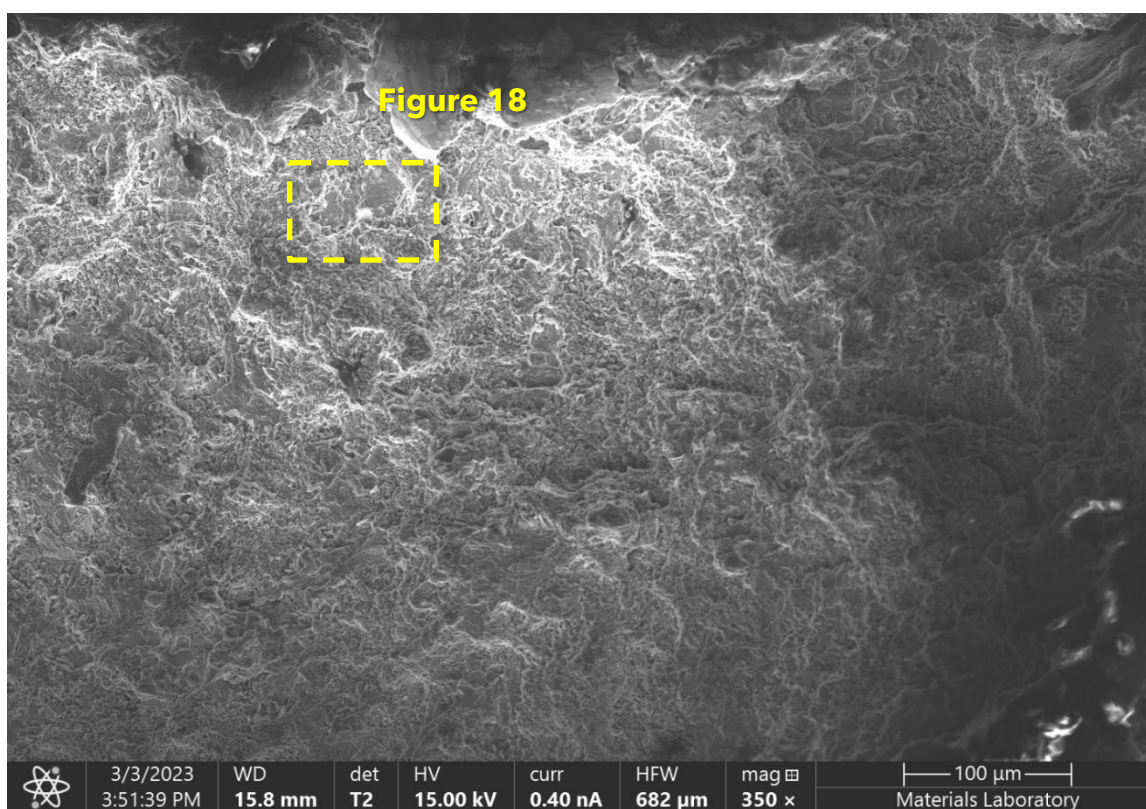


Figure 17. Secondary electron (SE) micrograph of the #2 exhaust tappet fracture edge from **Figure 16**.

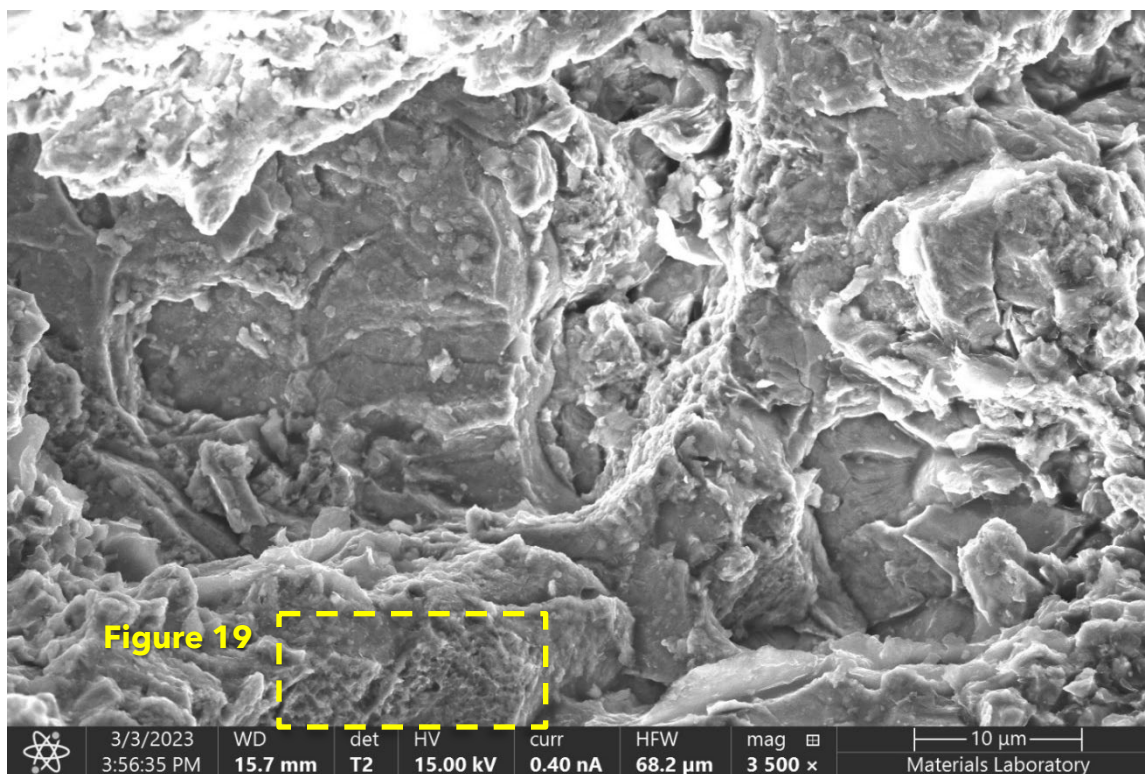


Figure 18. SE micrograph of the boxed area in **Figure 17**, showing cleavage.

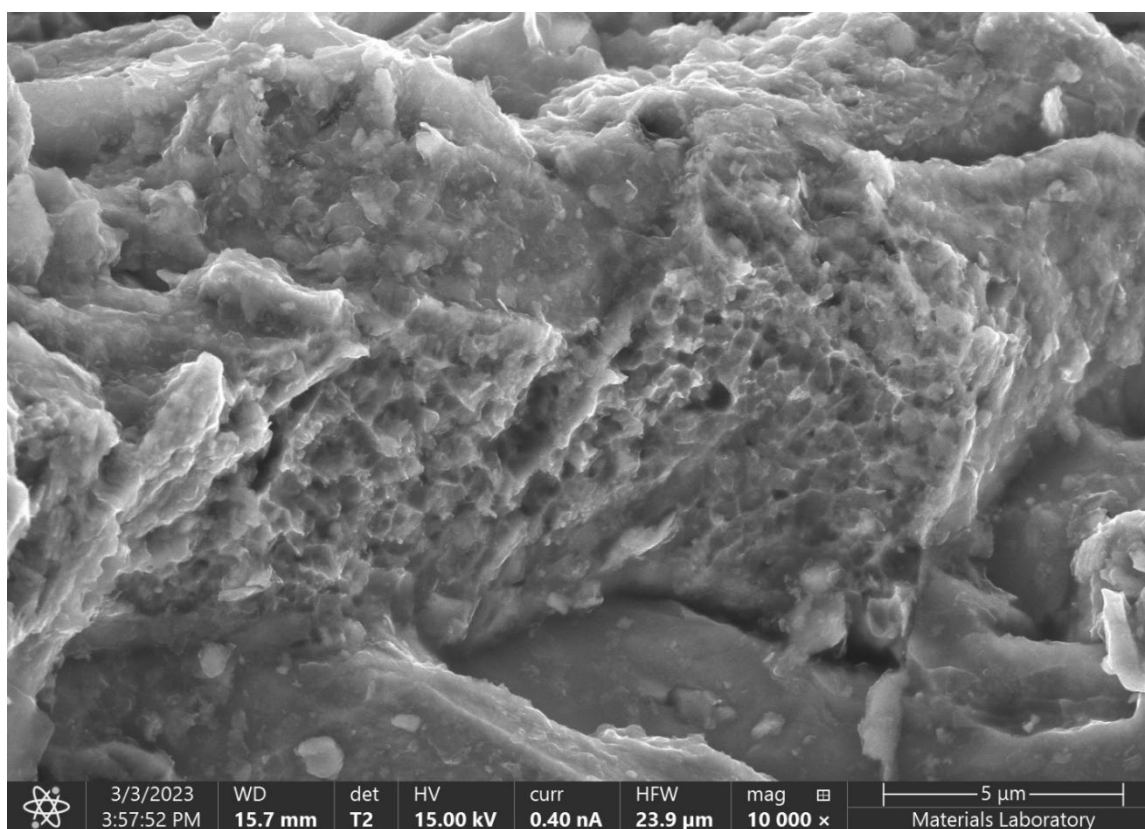


Figure 19. SE micrograph of dimpled rupture from the bottom of **Figure 18**.

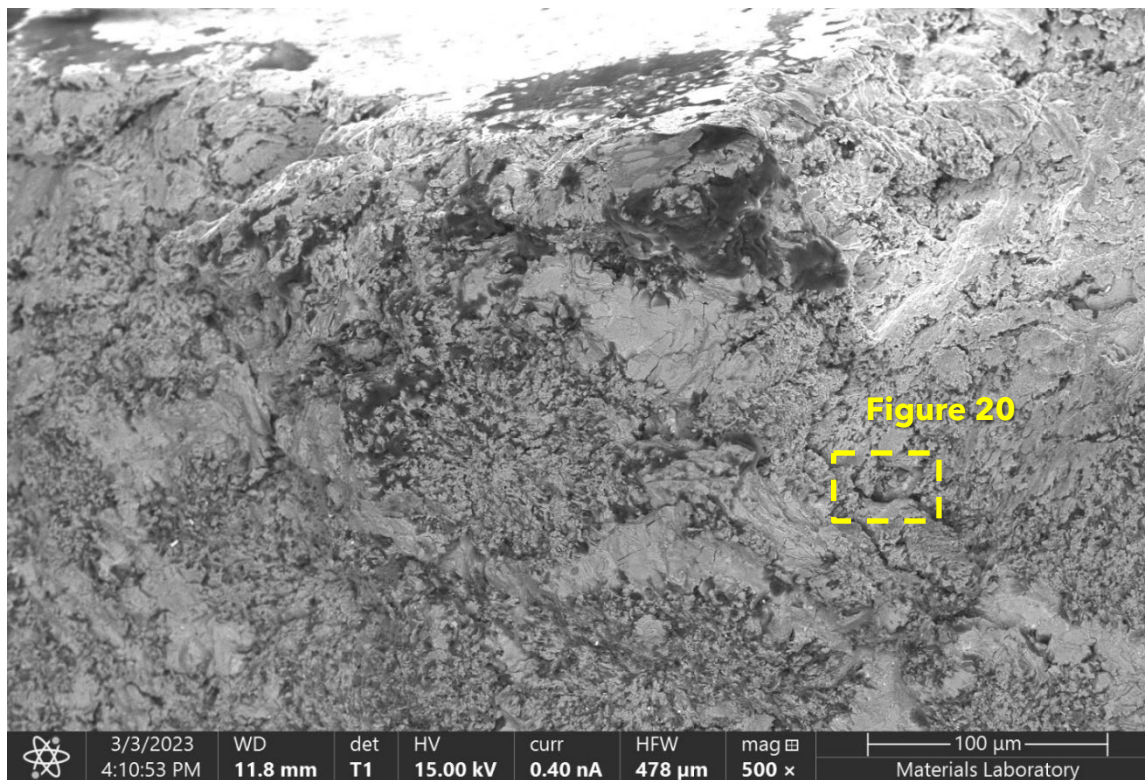


Figure 20. Backscattered electron (BE) micrograph of an edge of the #2 exhaust tappet fracture, towards the right of **Figure 17**.

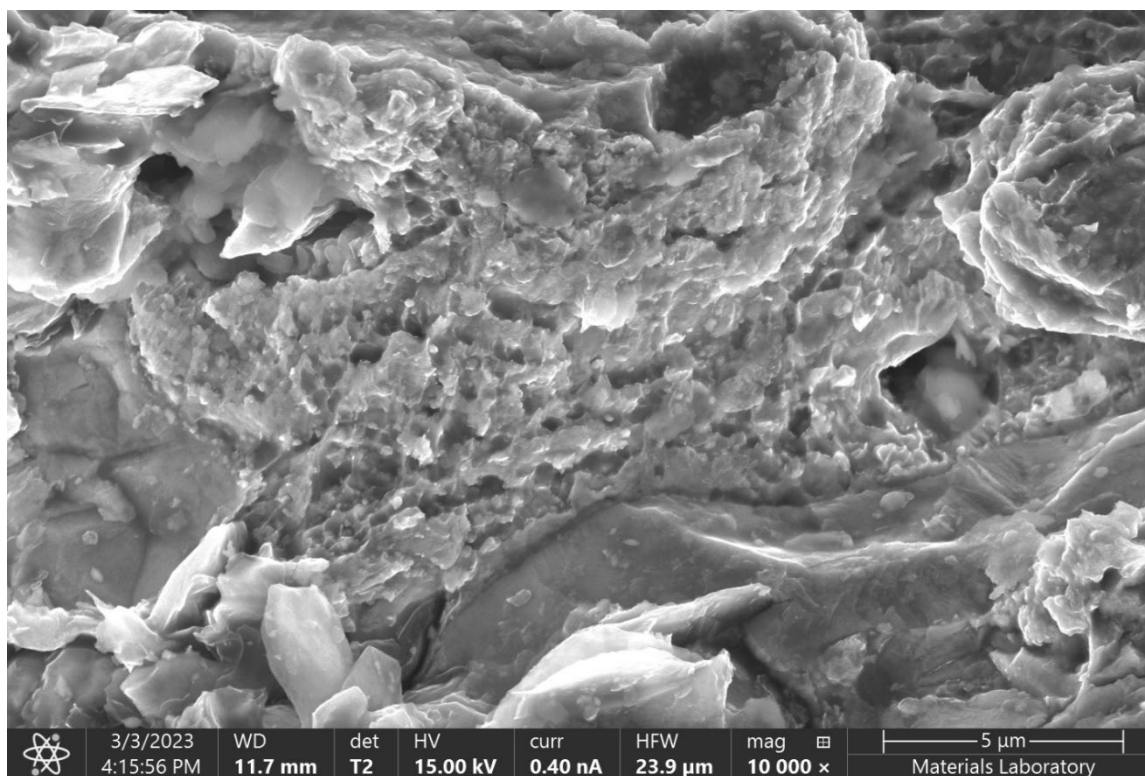


Figure 21. SE micrograph of dimpled rupture in an area in **Figure 20**.



Figure 22. Planar view of the #1 intake tappet fractures.

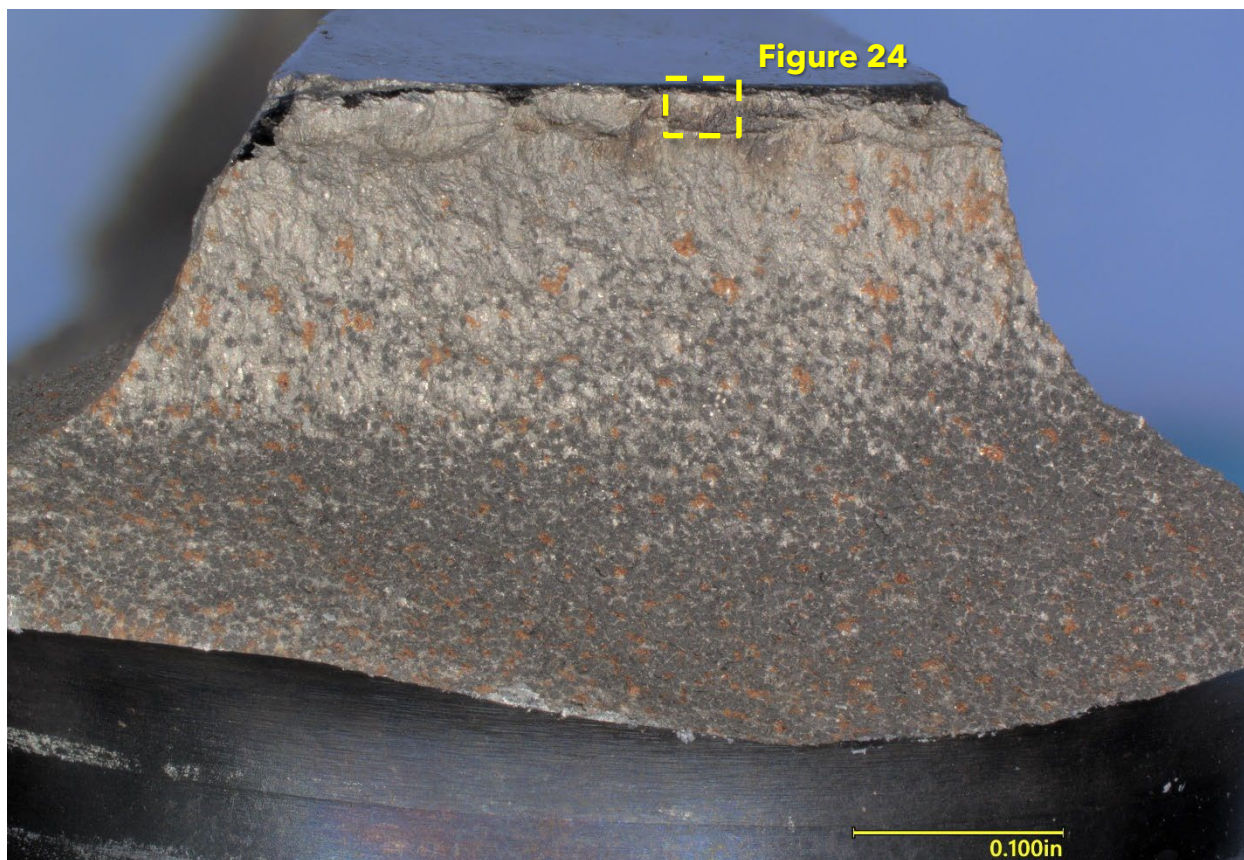


Figure 23. The right fracture surface edge of the #1 intake tappet in **Figure 22**.

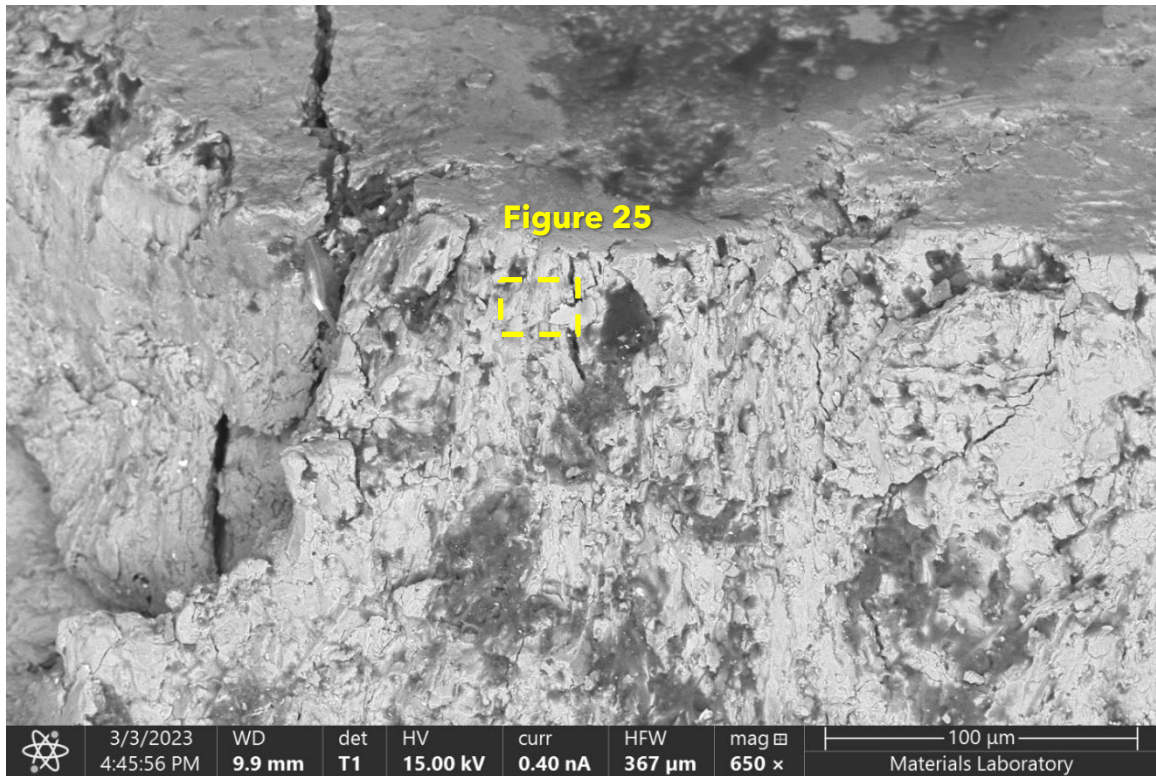


Figure 24. BE micrograph of the fracture edge of the #1 intake tappet in **Figure 23**.

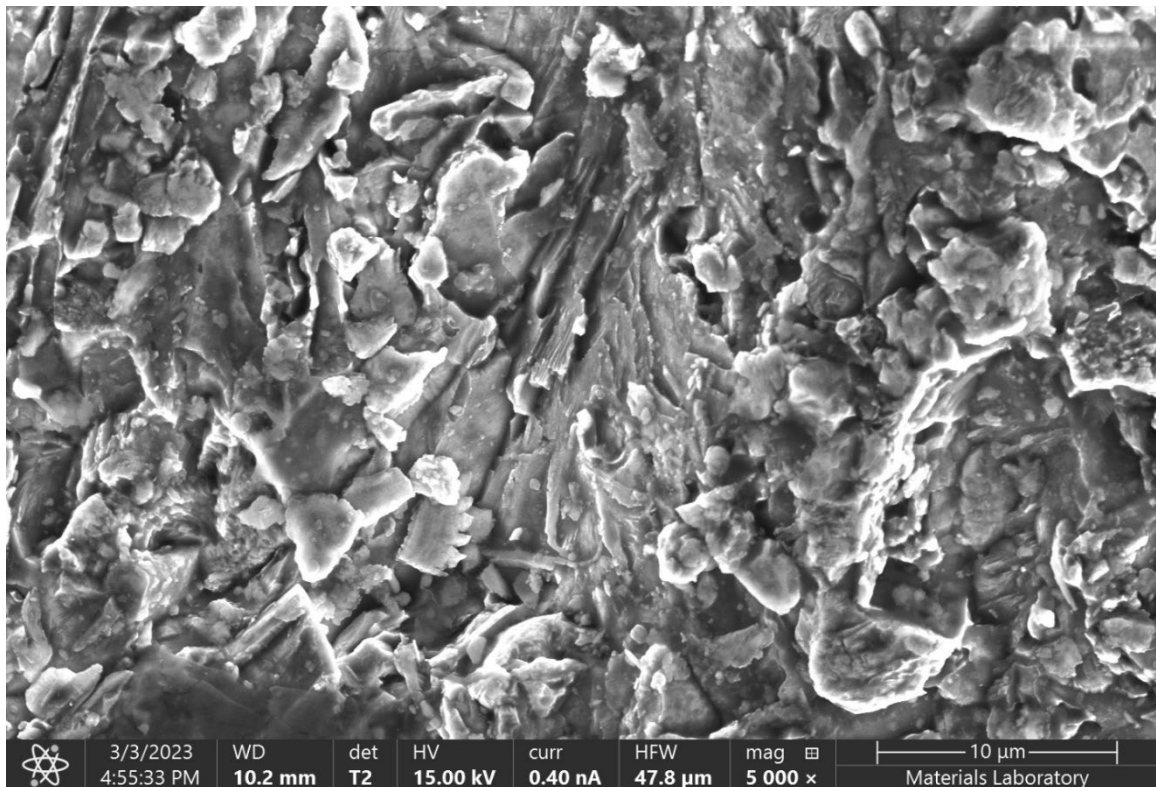


Figure 25. SE micrograph of cleavage facets on the #1 intake tappet fracture.

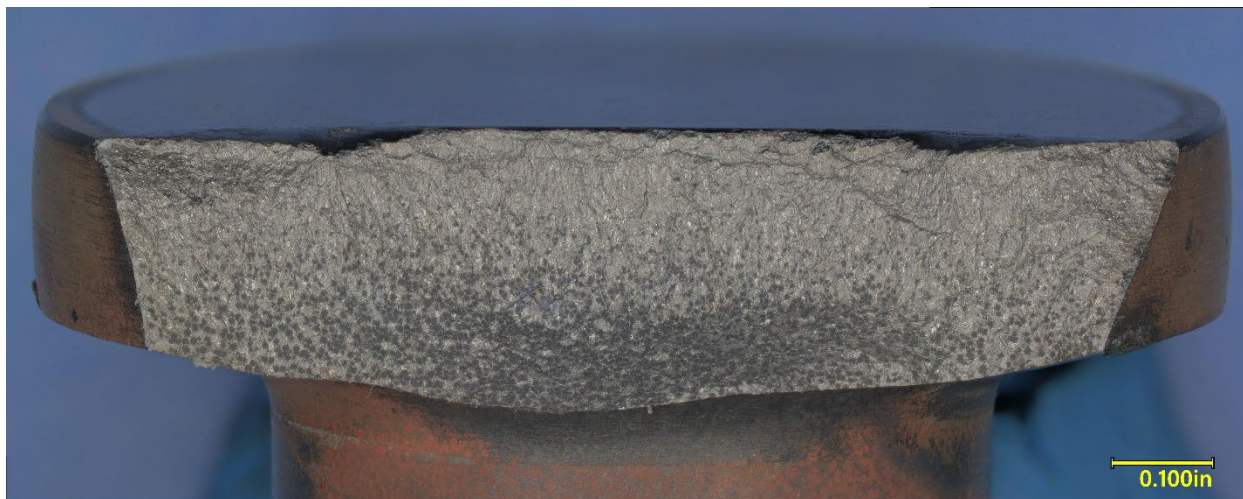


Figure 26. View of the #3 tappet head fracture surface.

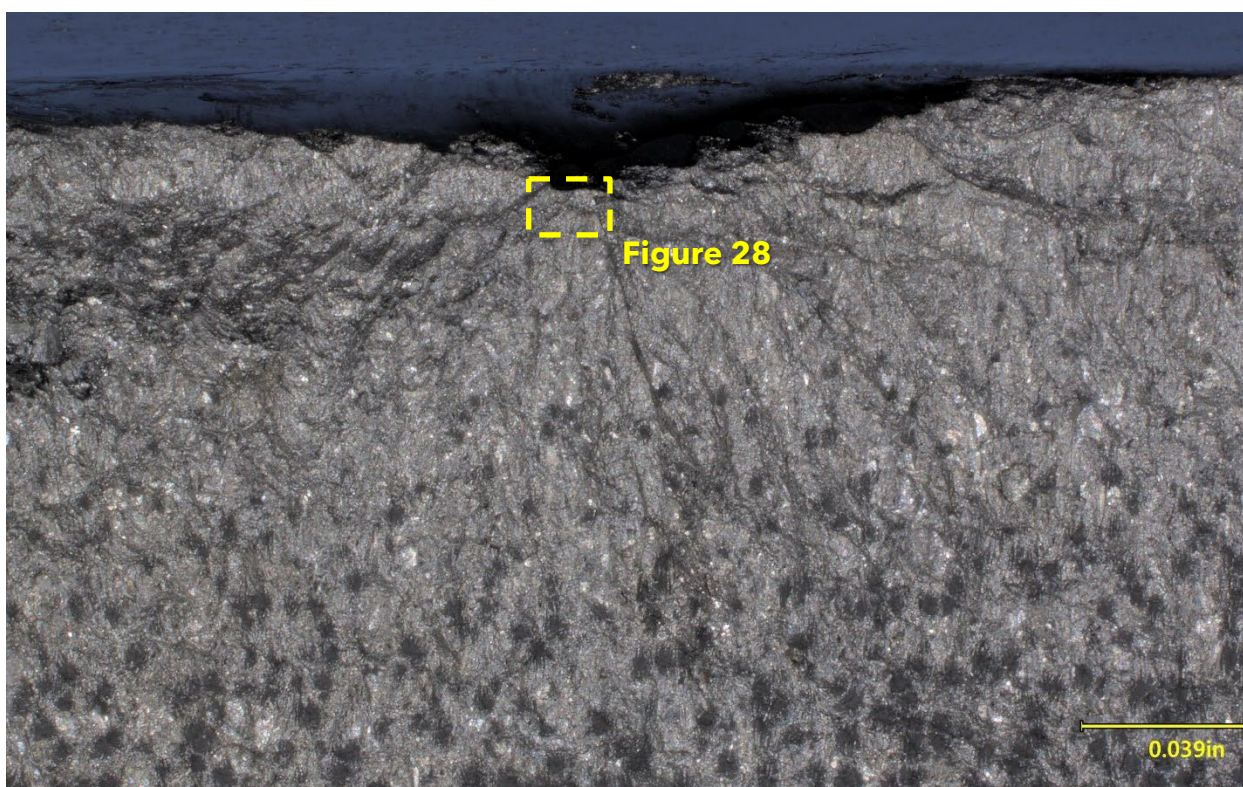


Figure 27. Initial areas of the #3 intake tappet fracture surface.

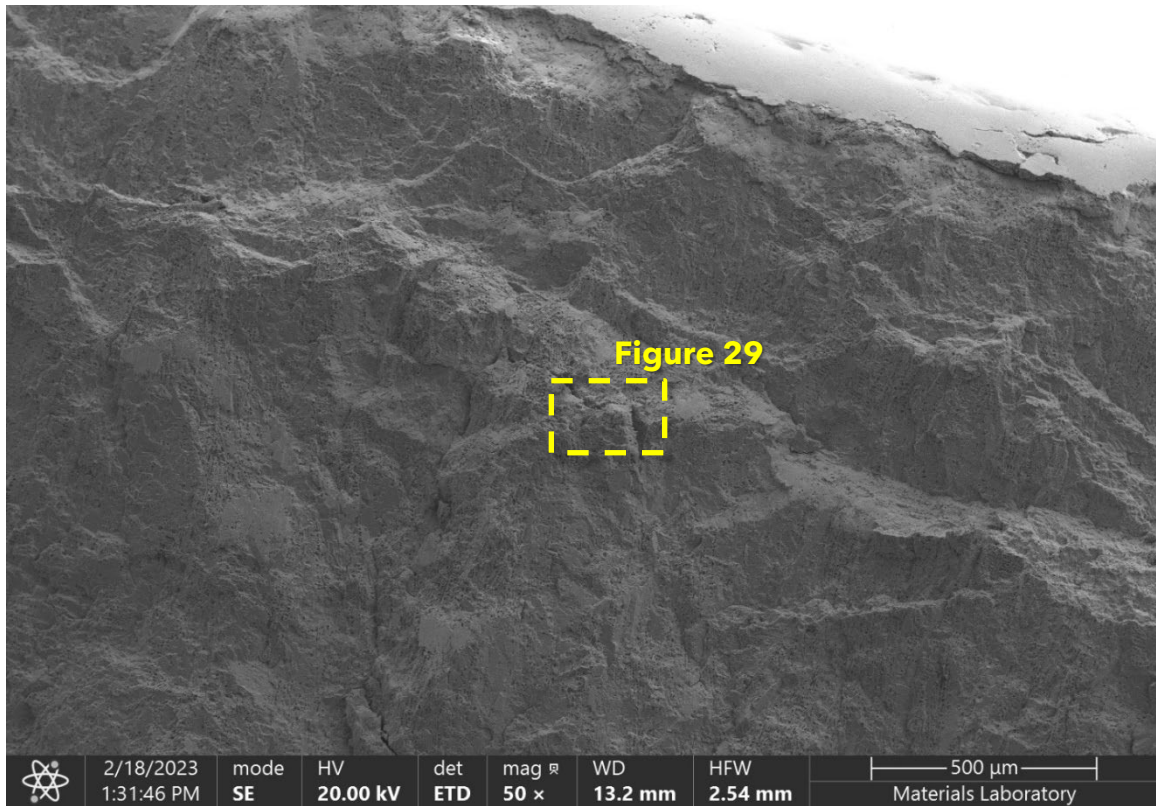


Figure 28. SE micrograph of the edge of the fracture surface of #3 intake tappet.

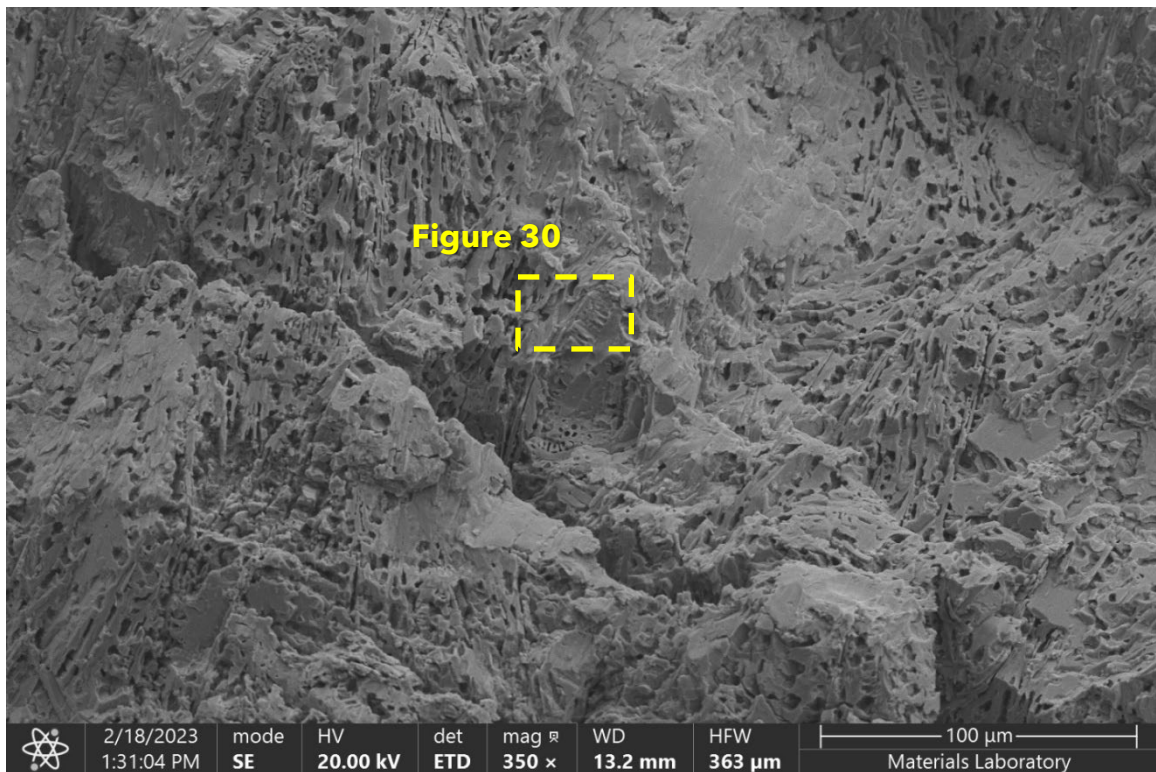


Figure 29. SE of the fracture surface of the #3 intake tappet, showing smearing damage.

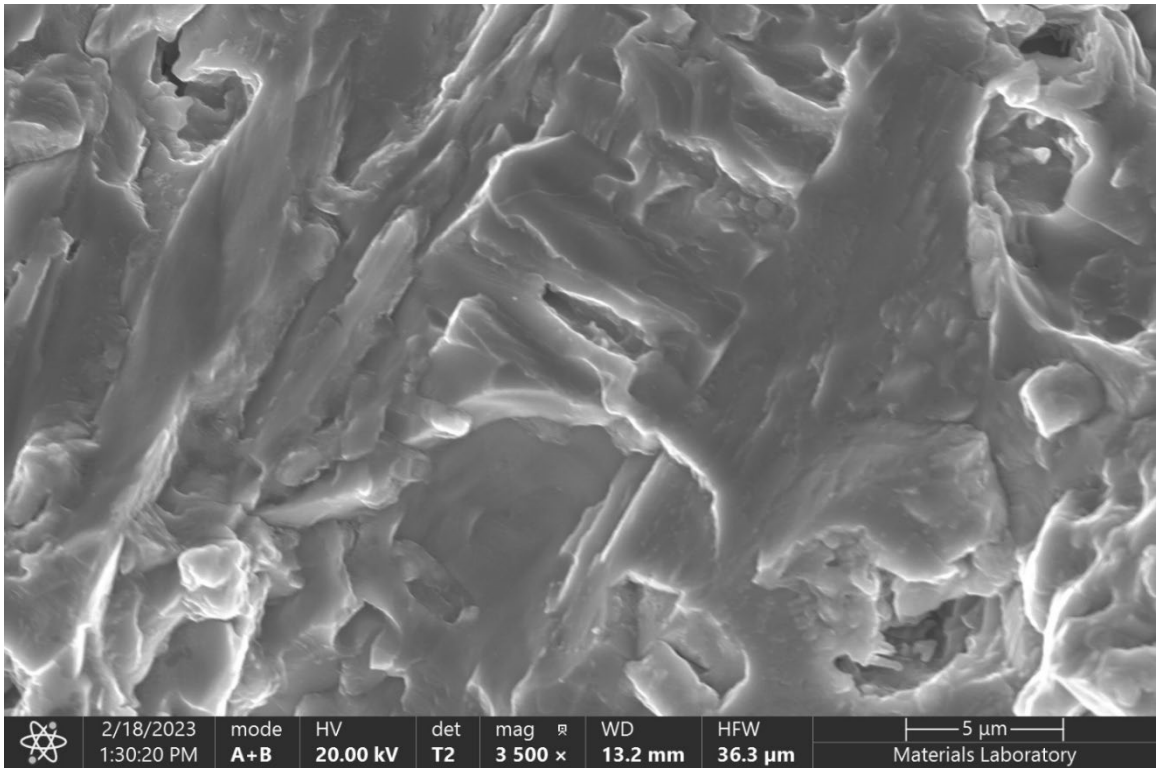


Figure 30. SE micrograph of the boxed area in **Figure 29**, showing cleavage steps and ductile tearing.