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MATERIALS LABORATORY

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A. ACCIDENT INFORMATION

Location: Sullivan, Missouri
Date: April 11, 2024
Time: 0825 central daylight time
1325 universal coordinated time
Vehicle: Piper PA-32-301, N651ED
Investigator: Brian Rutt, AS-CEN

B. COMPONENTS EXAMINED

Pieces of a fractured crankshaft with attached pieces of one connecting rod assembly
Main bearing halves

C. EXAMINATION PARTICIPANTS

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D. SUMMARY

The crankshaft fractured in two locations from fatigue cracking that initiated at multiple sites along the radius between the bearing journals and the webs. The fatigue crack initiation sites were located near rotational wear bands. The inner diameter surfaces and edge faces of two sets of the main bearing journals exhibited severe gouging, cracking, and material spalling, consistent with rotational abrasive wear. In addition, the C4 connecting rod exhibited fracture from reverse-bending fatigue cracking that initiated at each flange face, and the associated bearing exhibited severe spalling and wear on the interior surface.

E. DETAILS OF THE EXAMINATION

On April 11, 2024, a Piper PA-32-301 was substantially damaged when it was involved in an accident near Sullivan, MO. The passenger sustained minor injuries, and the pilot was not injured. According to the pilot, several hours after takeoff, the engine's rpm decreased, and later, it surged and lost all power. The pilot forced a landing in a field where the airplane impacted trees, coming to rest upright. A postaccident review of the airplane's engine monitor data revealed an increase in oil temperature and a decrease in oil pressure before the total loss of engine rpm.

The initial examination of the Lycoming IO-540-KG15 engine found the case had cracked, and the crankshaft had fractured in two locations.¹ Metallic particles were

¹ The Lycoming IO-540 is a family of air-cooled, fuel-injected, six-cylinder, horizontally opposed fixed-

found throughout the oil filter and inside the case. The crankshaft from the engine was sent to the NTSB materials laboratory for further examination.

Figure 1 shows the crankshaft and several adjacent components, as received by the NTSB Materials Laboratory. The crankshaft, which had fractured through two of the webs, also included the remnants of a connecting rod and cap at the number 4 location. The counterweights on the web between the C5 and C6 journals were still attached.

All the main journal bearings were submitted with the crankshaft, but they were not labeled, so the shorter bearings corresponding to the M2 through M4 crankshaft positions could not be distinguished. The longer M1 bearings had been positioned in the forwardmost journal of the crankshaft.

1.0 Crankshaft Fracture Surfaces

The crankshaft had fractured through the webs between M2 and C3 journals, and between the C4 and M3 journal positions. Figure 2 shows the fracture surface of the web between M2 and C3, displaying crack arrest marks consistent with progressive crack growth from the radius between the web and M2 journal, propagating towards the aft direction. The other web fracture surface exhibited prominent crack arrest and ratchet marks consistent with crack growth from the radius along the C4 side, as shown in Figure 3 after removing the attached connecting rod.

The crack dimensions on the forward fracture surface (near M2) measured 4.64 inches wide by 0.84 inches deep (or 94% of the total web thickness of 0.89 inches), whereas the aft fracture surface crack in Figure 3 measured 3.99 inches by 0.89 (or 90% of the total web thickness of 0.98 inches).

Figure 4 shows the end of the crack on the web fracture between M2 and C3, showing distinct regions with disparate fracture features. When examined using a field emission scanning electron microscope (SEM), the crack revealed striations consistent with fatigue crack propagation (see Figure 5). Outside this area (as delineated in the upper portion of Figure 4), the fracture surface exhibited dimpled rupture, consistent with subsequent overstress fracture. The macroscopic fracture features were consistent with a compression curl from an overstress fracture in bending during final separation.

Figure 6 shows a closer view of the edge of this forward web fracture, highlighting the radius between the M2 journal and the web. Concentric crack arrest marks emanated from the area annotated by the yellow arrow, consistent with propagation

wing aircraft and helicopter engines, manufactured by Lycoming Engines, headquartered in Williamsport, PA.

from an initiation region along the surface edge. Though faint, ratchet marks were present near the edge, consistent with multiple crack initiation sites, as exemplified in Figure 7.² This figure identifies several initiation sites with yellow arrow annotations and indicates the general direction of early crack growth.

Gouge marks were observed along the fracture surface edge in Figure 7 and Figure 8, oriented parallel to the fracture surface edge. These features indicate that this fatigue cracking had initiated along the radius of the M2 journal, and propagated aftward through most of the web cross section before completely fracturing.

Circumferential wear bands were identified along the radius of the M2 journal bearing. As demonstrated in Figure 8, one of these bands was near the initiation sites of the fatigue crack that propagated through the web between the M2 and C3 journals. This wear band was measured at a width of 0.034 inches (0.86 mm).

The other web fracture surface, located aft between the M3 and C4 journals, exhibited more prominent crack arrest and ratchet marks, as demonstrated in Figure 3. The initiation area is illustrated in Figure 9, showing multiple crack initiation sites along different planes, exhibiting ratchet marks that developed between the sites during fatigue crack propagation. With this web fracture, the fatigue crack initiation sites were located along the edge of the C4 journal radius, and the crack propagated forward through the web cross-section before the remaining 10% subsequently fractured from overstress.

Similar to the forward web fracture, the fatigue cracking that initiated from the radius of the C4 journal was located near wear bands, shown in Figure 10. This band was approximately 0.051 inches (1.30 mm) wide, and several initiation sites were located along this circumferential feature. The radius surface along the initiation sites also exhibited folding and smoothing of material, consistent with adhesive wear in a rotational direction.

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

2.0 Crankshaft Journal Surfaces

Figure 11 through Figure 20 show the surfaces of the individual main and connecting rod journals. Each journal was measured along a full 360° rotation to determine the minimum and maximum outer diameters for each. These data are tabulated in Table II.

² Ratchet marks are vertical steps in the fracture that link smaller fatigue cracks on disparate offset planes at a fatigue origin area. Ratchet marks generally are aligned in the direction of cracking and taper during crack growth as multiple smaller fatigue cracks coalesce.

Table II and the figure set also highlight the wear and damage patterns present. The most damaged journal surfaces were those of the C1 and C2 positions, as shown in Figure 12. The C1 journal surfaces from opposite sides, as received, and Figure 13. These journals exhibited severe gouging and localized plastic deformation, consistent with abrasive wear typical of bearing disintegration and entrained debris. The nearby C1 position also exhibited circumferential gouge marks, consistent with entrained wear debris during rotation.

The C3 position in Figure 15 exhibited blue and tan discoloration, consistent with heat tinting from high temperature exposure to the lubricating oil. The C5 journal exhibited dark brown marks, consistent with burnt or decomposed oil. This position also showed a small area with spalled surface material.

The M2 and M3 journals did not exhibit severe wear marks, though the M2 did exhibit a duller reflection along the center. The major wear signatures on these two locations were along the radii with the webs, coinciding with the fatigue crack initiation sites.

3.0 Crankshaft Main Journal Bearings

Figure 21 shows the main journal bearings from the interior and exterior surfaces, which would have been in contact with the crankshaft journal and engine case surfaces, respectively. While the bearings from the M1 position could be distinguished because of their longer length and wider diameter, those from the M2 through M4 positions were not labeled upon receipt, and their locations could not be determined.

Of note, as illustrated in Figure 22 and Figure 23, were the part numbers on the main journal bearings. The M1 and M2 through M4 bearings each exhibited part numbers that have been superseded by upgraded bearing part numbers, per Lycoming Service Instruction No. 1512.³ These part numbers, along with those of the C4 connecting rod bearing that was disassembled, are detailed in Table I.

The bearings exhibited wear patterns consistent with rotational contact between the faying surfaces on both sides. On the M1 bearing interior were the hyperbola-shaped wear patterns along the centerline toward the forward and aft edges (see pair to the left in Figure 21a). All three of the smaller main bearings also exhibited similar, but broader, parabolic wear shapes along the ends on the forward and aft edges (see the two pairs towards the left in Figure 21a).

³ Service Instruction No. 1512, entitled, "Main and Connecting Rod Bearing Upgrade," requires upgrading specific superseded bearing part numbers in all Lycoming model engines whenever new bearings are installed. It was issued by Lycoming, headquartered in Williamsport, PA, on September 23, 2004.

All main bearing interior or inner diameter surfaces exhibited features consistent with prolonged rotational wear. Some of the most severe damage is highlighted in Figure 24 through Figure 26. Most of the inner surfaces exhibited indications of spalling and abrasion. Figure 24 illustrates an area of cracked and spalled material, with circumferential gouging from the entrained material dragging into the inner surface.

Two of the smaller main bearings exhibited gouging consistent with abrasive wear, material loss, and spalling along the edge (Figure 25). This damage coincided with a thinner bearing thickness on the edge, measured as 0.094 inches for all three sets of shorter main bearings. The edge faces of two of the main bearings exhibited deep gouging and were oriented parallel to the bearing and rotation direction. This gouging was severe enough to have developed into radial cracking, flaking, and material spalling (Figure 26). Along the left side of Figure 26, the babbitt material had spalled off the steel backing exposed the original chamfered edge.

4.0 Connecting Rod and Bearing

The C4 connecting rod remnants were still attached to the connecting rod at that journal position when received, as shown in Figure 1. These components were disassembled and removed from the crankshaft, as shown in Figure 27. The connecting rod embossed markings along the neck web stated "LW-13756 TW 2-13."

The connecting rod had fractured perpendicular to the neck, located approximately 4 inches from the interior rod bearing surface. This fracture surface was sectioned and cleaned with acetone. Figure 28 shows the fracture surface of the connecting rod, which displays multiple areas of battered, reflective regions, consistent with impacts from post-fracture impacts with adjacent components.

In the undamaged regions of the rod fracture surface, there were areas with visible crack arrest marks, as typified in Figure 29. Examination using a SEM revealed fatigue striations, as typified in Figure 30. The directionality of the crack arrest marks was consistent with crack initiation along the four exterior flange surfaces of the rod. These four fatigue cracks propagated inward before the remaining center of the web fractured from overstress. Due to the post-fracture damage to the surface edges, no observations could be made about any crack initiation sites. The connecting rod failed from reverse-bending fatigue.

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

Figure 31 shows the C4 connecting rod bearing from both surfaces, and the exterior markings are shown in Figure 32. The interior of this bearing exhibited an erratic, blotched surface pattern on one side, with a parabolic wear pattern on the other, showing a more reflective surface pattern on the outside and a darker hourglass

shape towards the center. Both surfaces exhibited a rough texture consistent with abrasive wear. The pattern on the inner diameter surface was severe material spallation, as demonstrated in Figure 33.

Submitted by:

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F. TABLES

Table I. Main and connecting rod journal bearing part numbers and build dates, with newer superseded upgraded bearing part numbers per Lycoming Service Instruction No. 1512. #

Main Bearing Position	Current Part Number	Build Date	Upgraded Part Number
M1	LW-13885-M06	2-96	18A19399
M2-M4	LW-13683-M06	4-97	LW-14830
C4	74309-M06	6-97	18N19391

Table II. Diameter measurements and selected characteristics of the main and connecting rod journals of the fractured crankshaft.

Bearing	Min. Diameter (in.)	Max. Diameter (in.)	Notes
M1	2.617	2.619	Two wide circumferential wear bands
C1	2.243	2.255	Gouge marks and spalling; rougher surface
C2	2.243	2.257	Wear marks and abrasion
M2	2.617	2.619	Fracture surface crack initiation from web radius
C3	2.242	2.252	Blue and tan discoloration
C4	2.245	2.253	Smooth surface with some chatter marks
M3	2.617	2.628	Fracture surface crack initiation from web radius
C5	2.245	2.246	Burnt oil and small area of spallation
C6	2.244	2.245	
M4	2.619	2.622	Single circumferential wear band

G. FIGURES



Figure 1. The fractured pieces of the crankshaft, positioned with the bearings, as received.



Figure 2. The fracture surface of the crankshaft web between the M2 and C3 locations, viewed from the M2 (forward) side.



Figure 3. The fracture surface of the crankshaft web between the M3 and C4 locations, viewed from the C4 (aft) side.



Figure 4. End of the fatigue crack on the M2 web fracture surface.

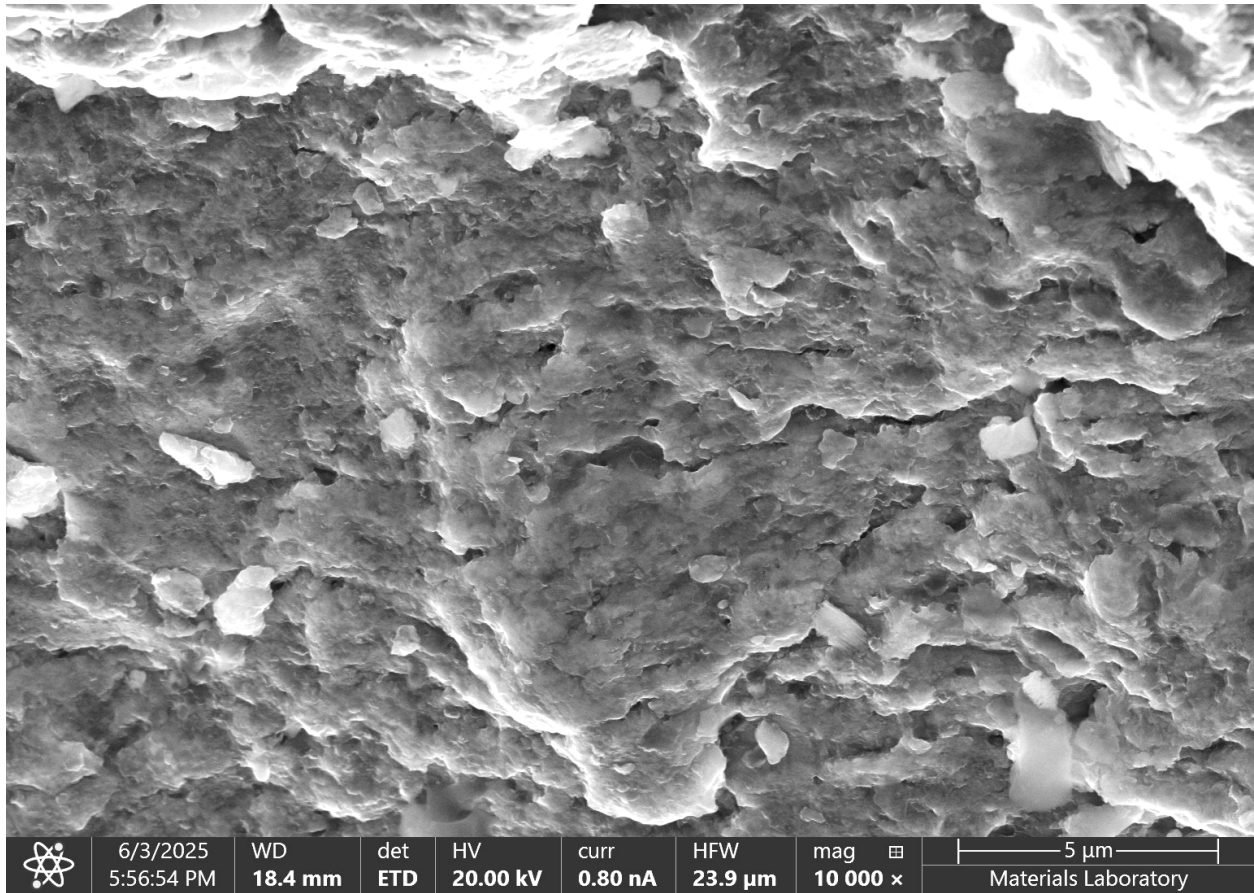


Figure 5. Secondary electron (SE) micrograph of fatigue striations on the fatigue region of the M2 fracture surface shown in Figure 4.



Figure 6. Montage image of the crack initiation site of the M2 fracture surface (yellow arrow).

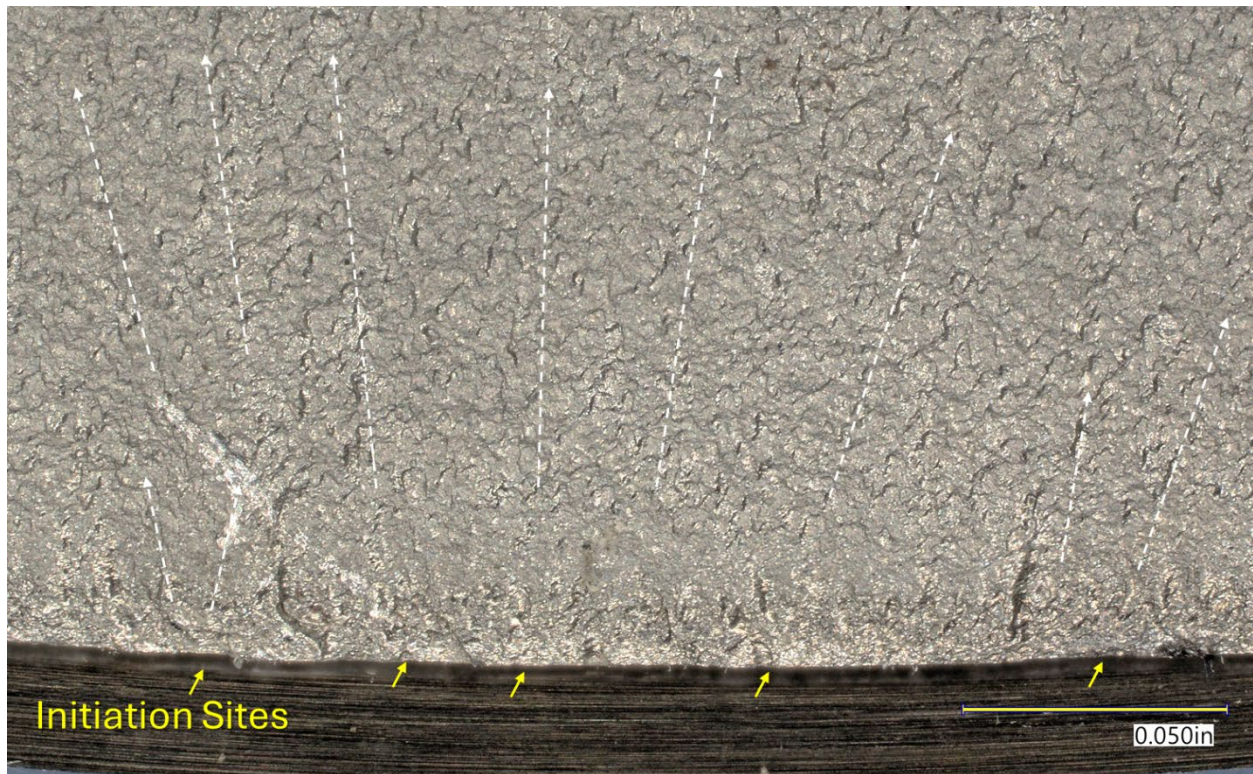


Figure 7. Closer view of the crack initiation site in Figure 6.

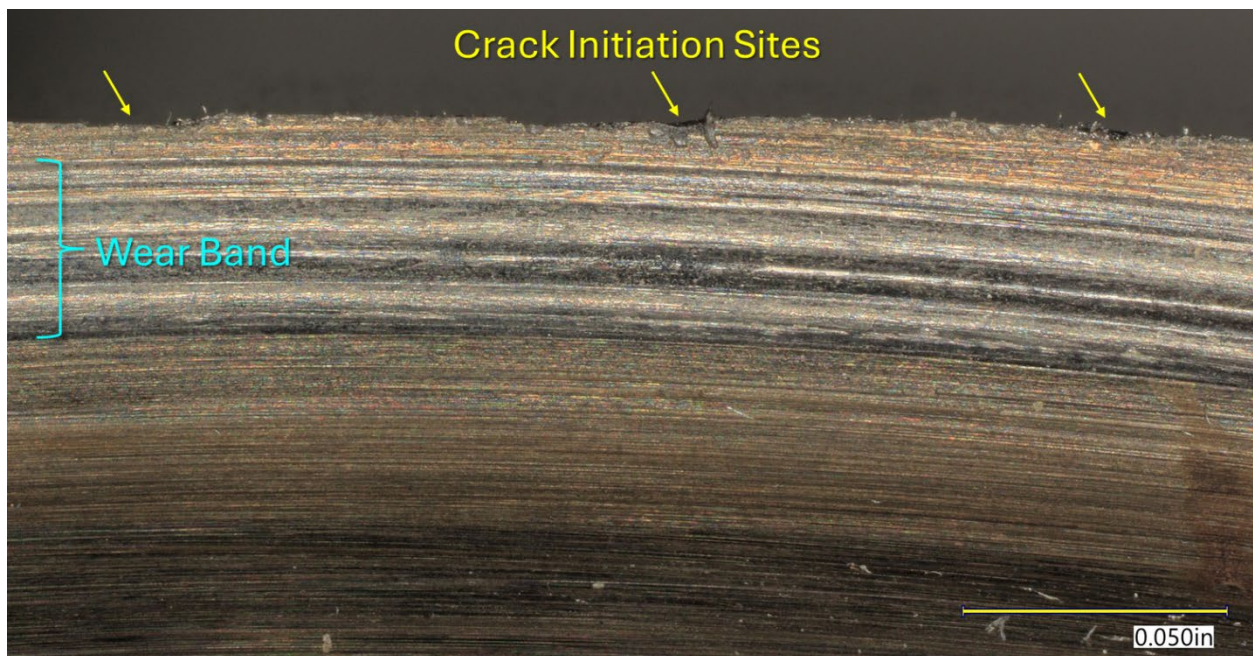


Figure 8. View of the radius surface under the web fracture surface edge in Figure 7, showing a circumferential wear band.



Figure 9. The initiation sites and ratchet marks on the edge of the crankshaft web fracture between the M3 and C4 journal, from the radius with the C4 journal (forward face).

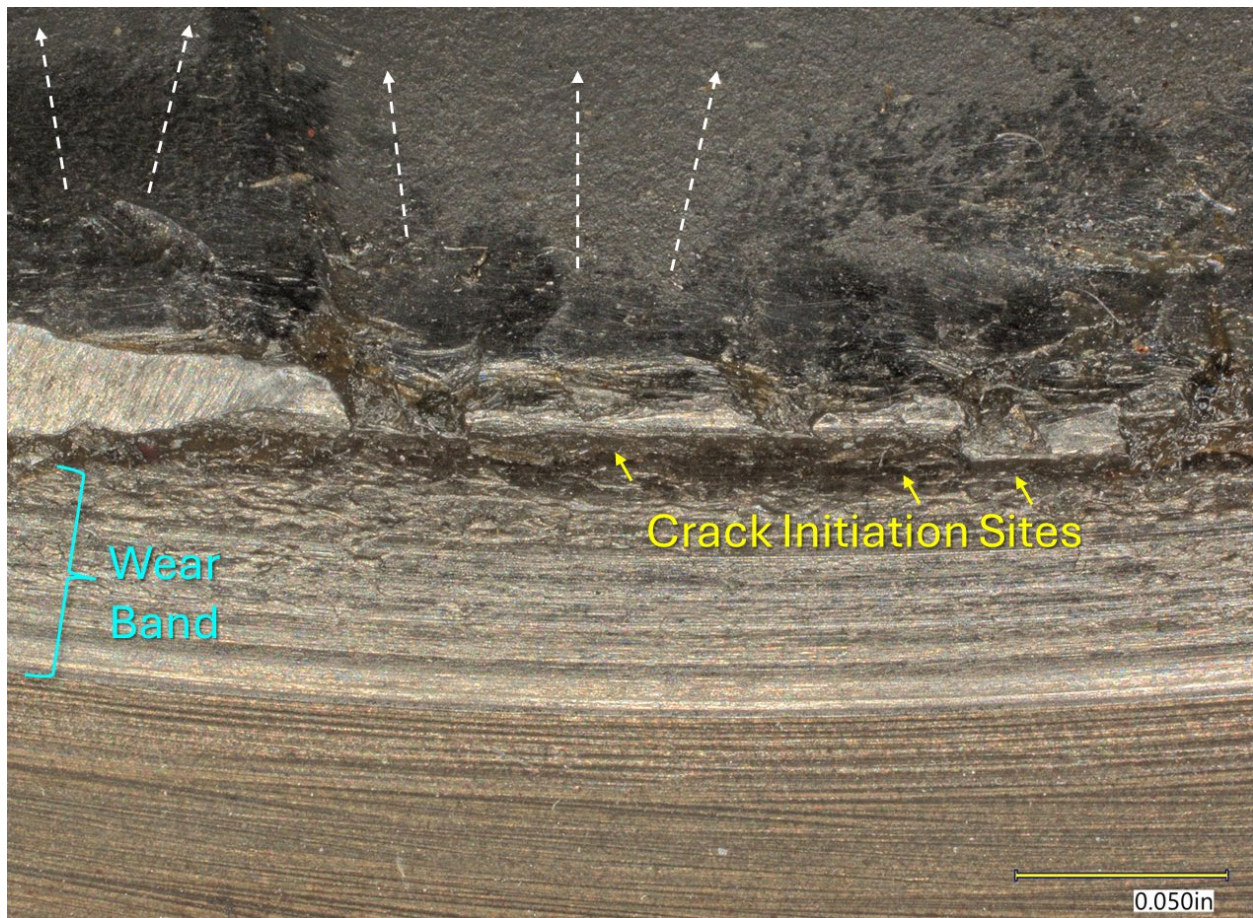


Figure 10. View of the radius surface under several fatigue crack initiation sites from the fracture surface edge in Figure 9, showing a circumferential wear band.

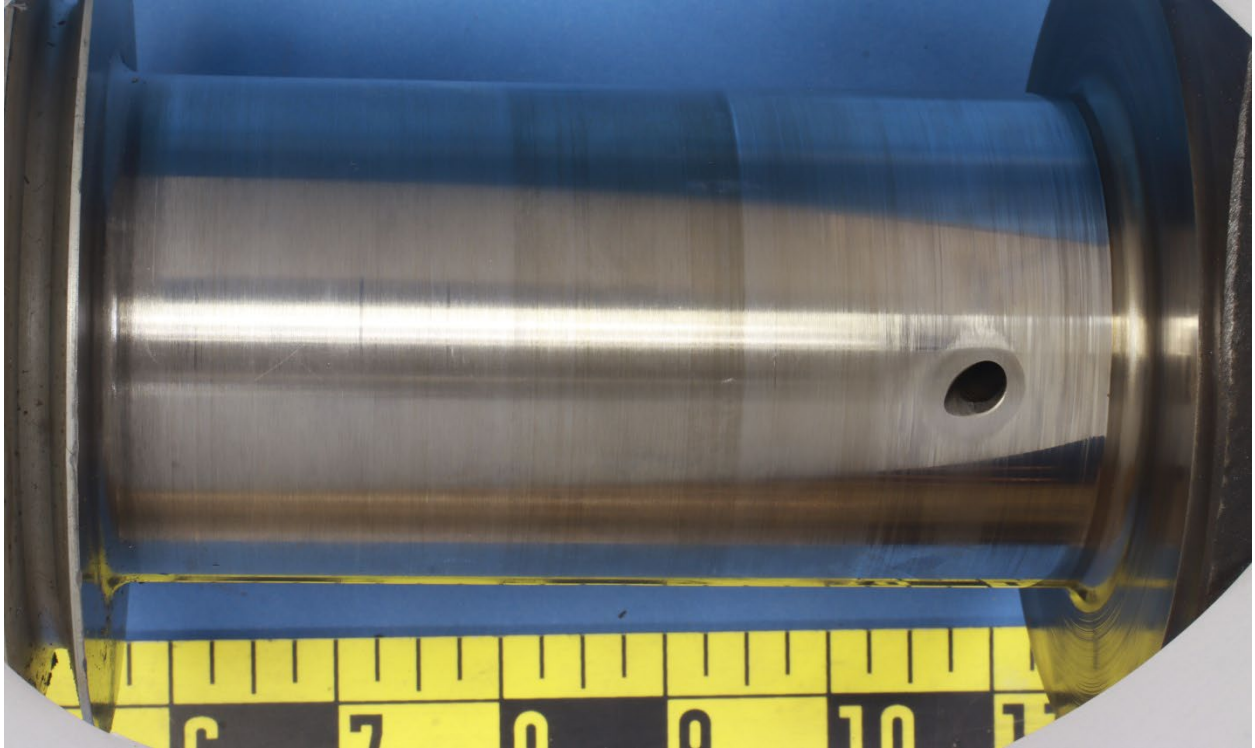


Figure 11. The M1 journal surface from the crankshaft.

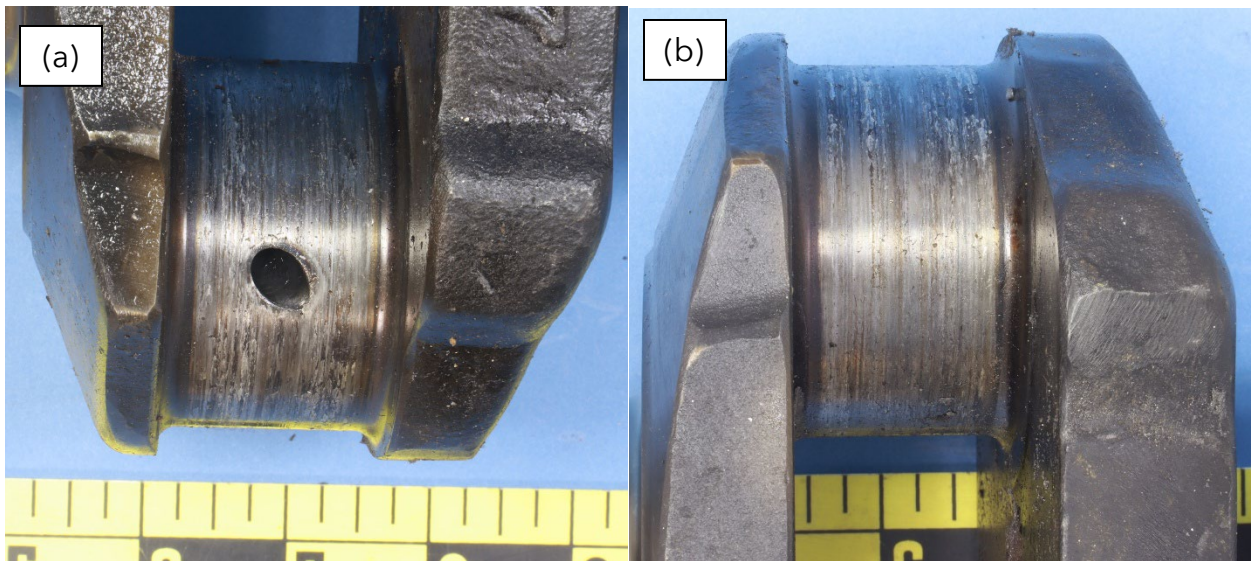


Figure 12. The C1 journal surfaces from opposite sides, as received.

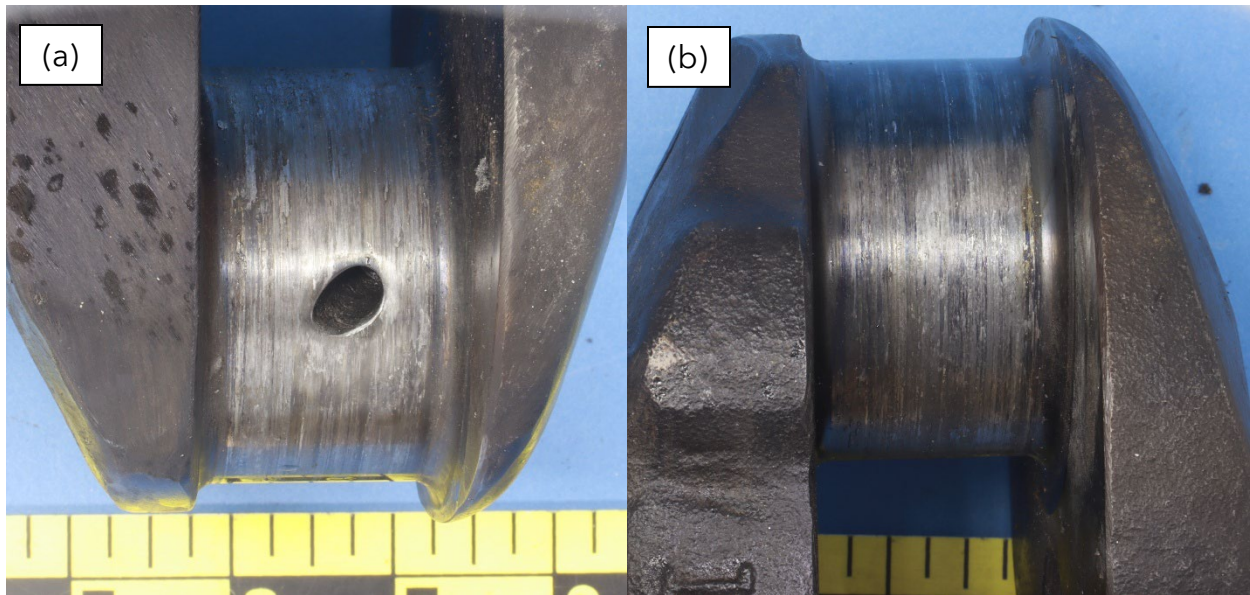


Figure 13. The C2 journal surface from opposite sides, as received.

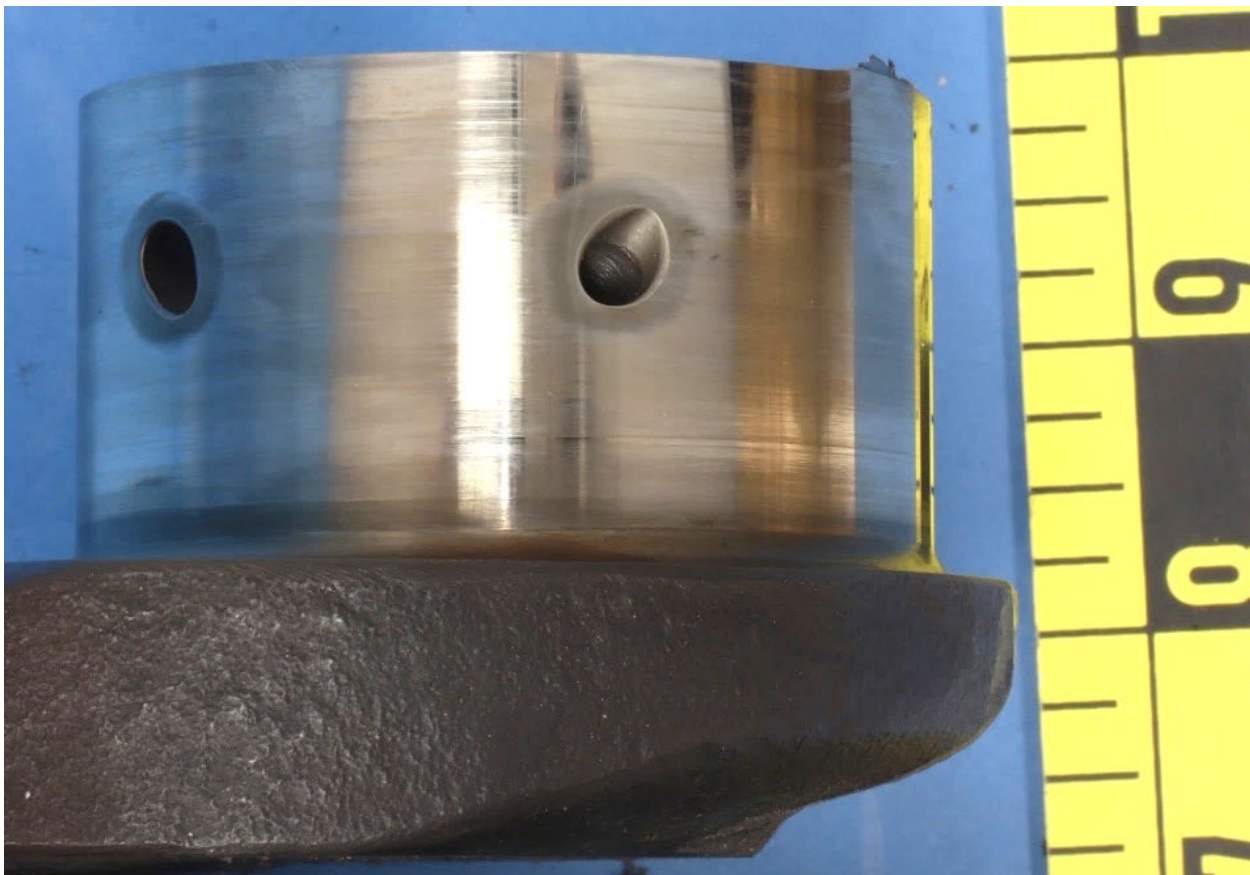


Figure 14. Side view of the M2 journal, after cleaning and sectioning of the web fracture surface.

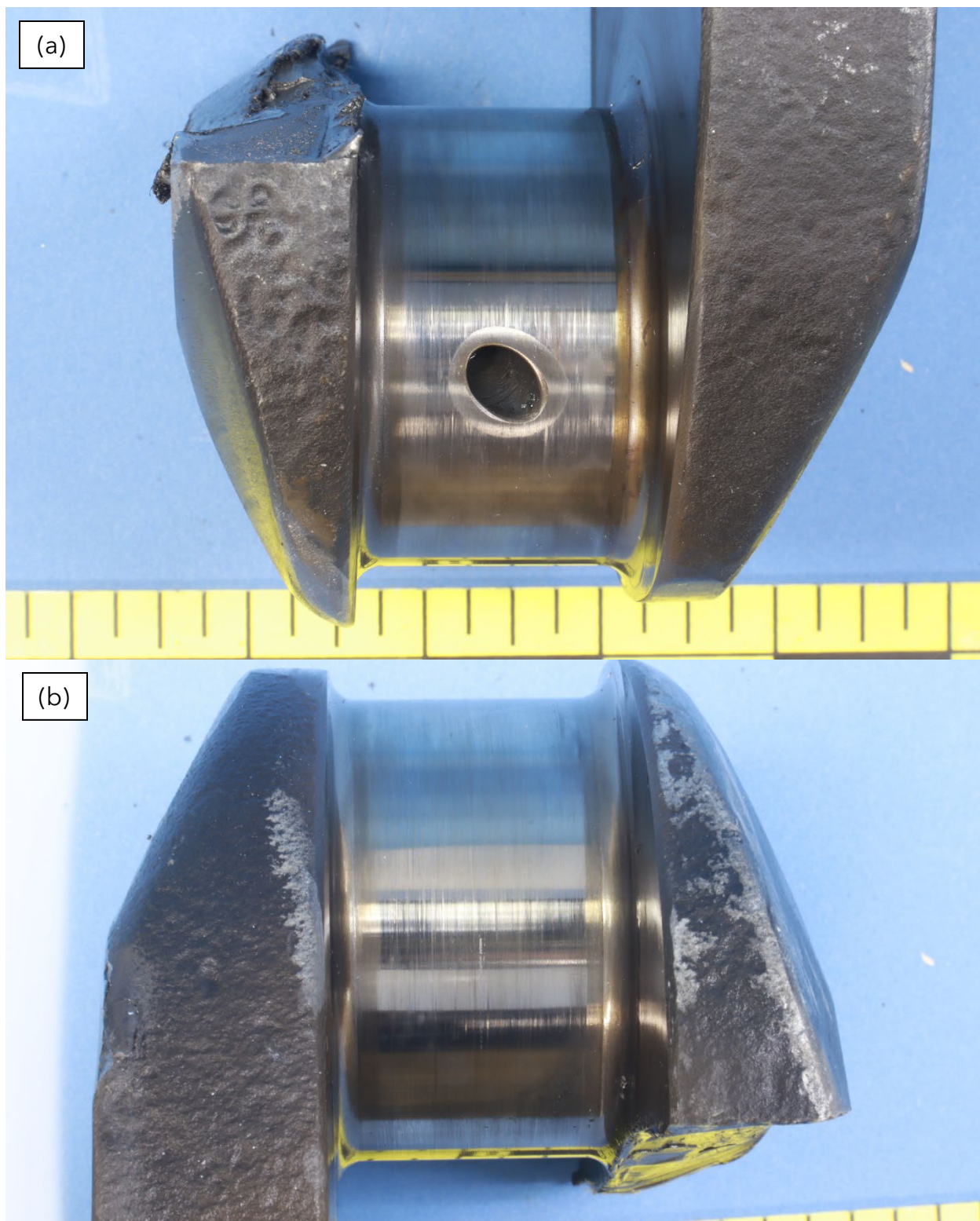


Figure 15. Opposite views of the C3 journal surfaces.

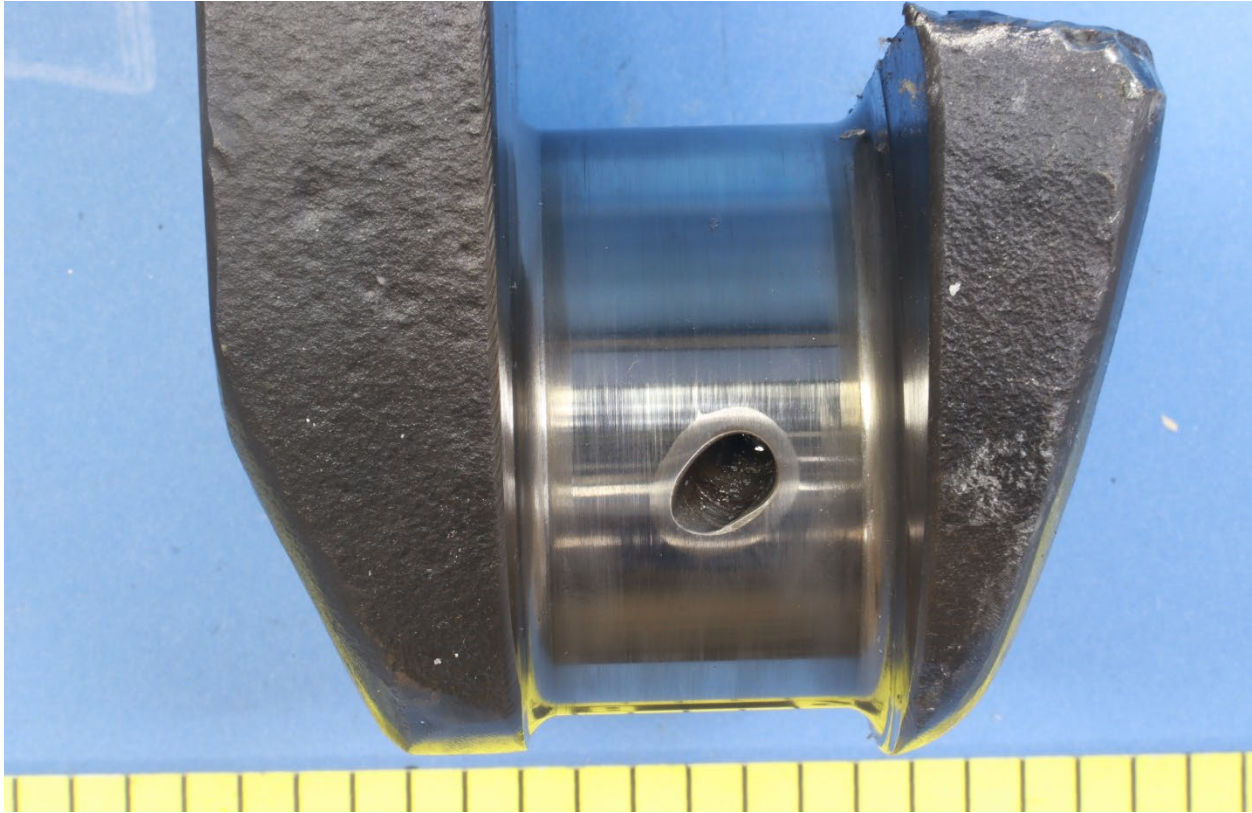


Figure 16. View of the C4 journal and associated fracture surface, after removal of the connecting rod remnant and cleaning.

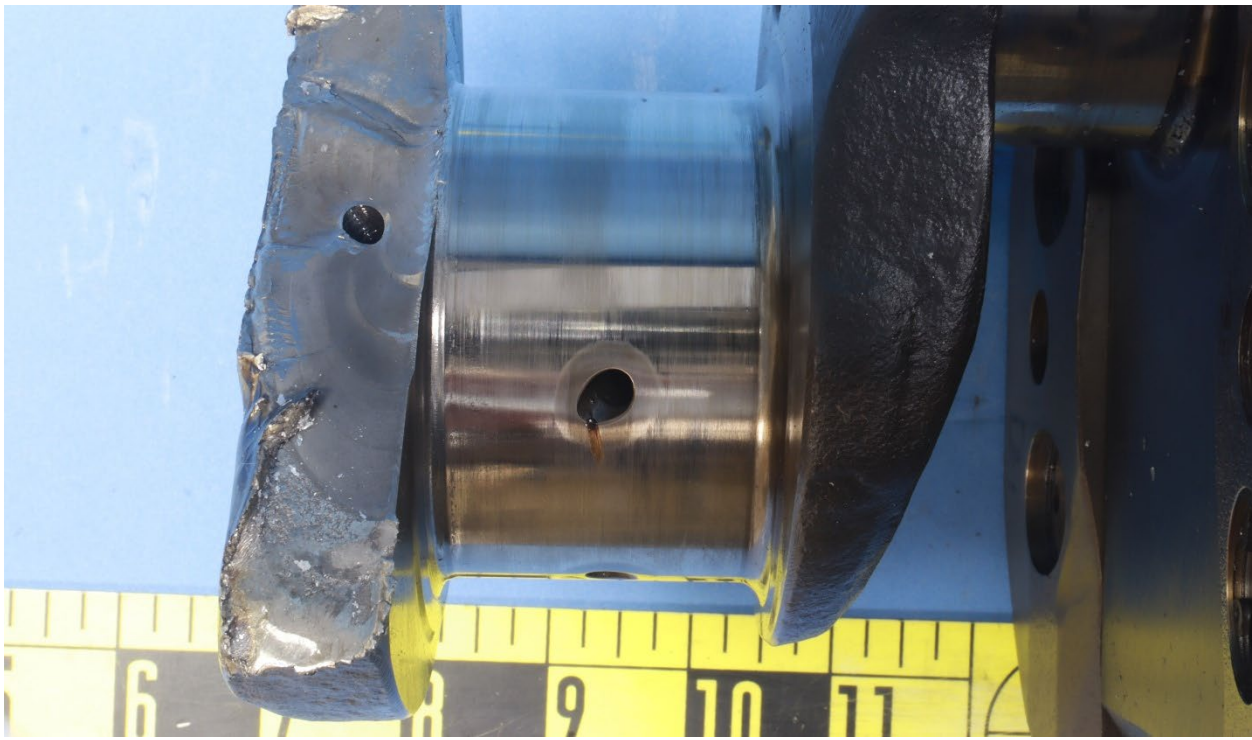


Figure 17. The M3 bearing surface, with the fractured web that mates to the one in Figure 16.

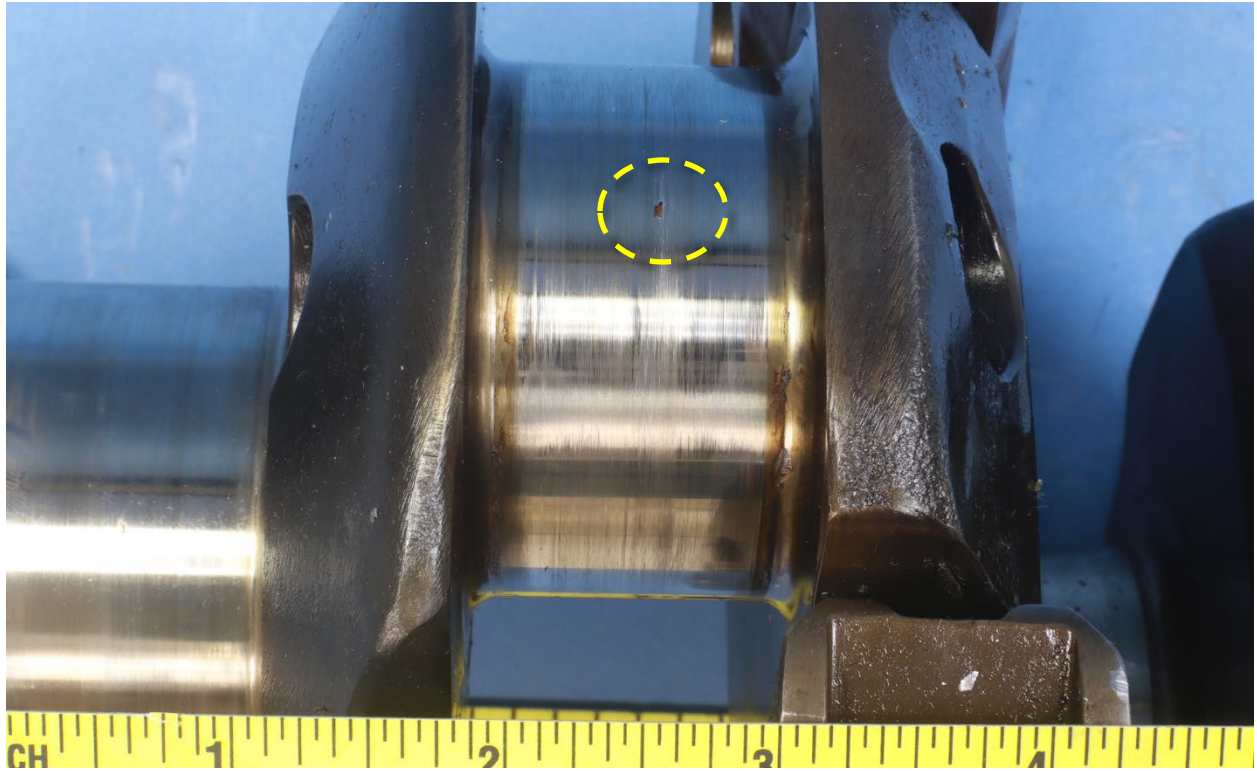


Figure 18. The C5 bearing surface on the crankshaft, with an area of material spalling circled.

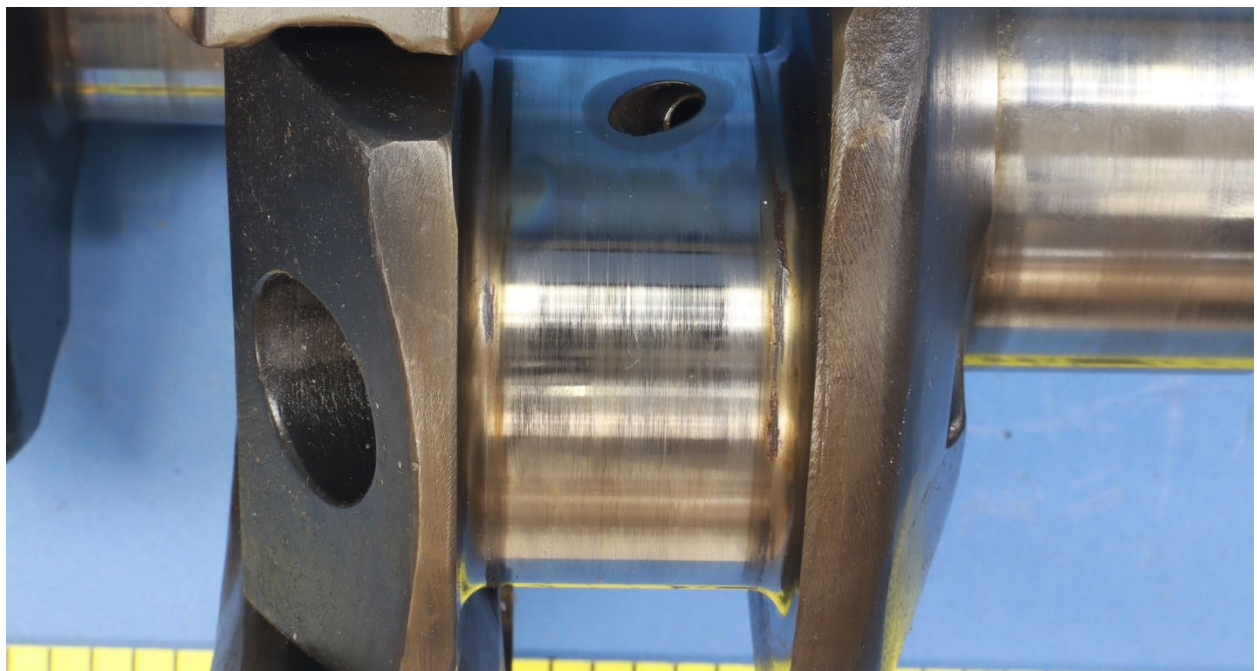


Figure 19. The C6 bearing surface on the crankshaft.



Figure 20. The aftmost main bearing journal, M4.



Figure 21. The main bearings, showing the (a) the interior and (b) the exterior surfaces.

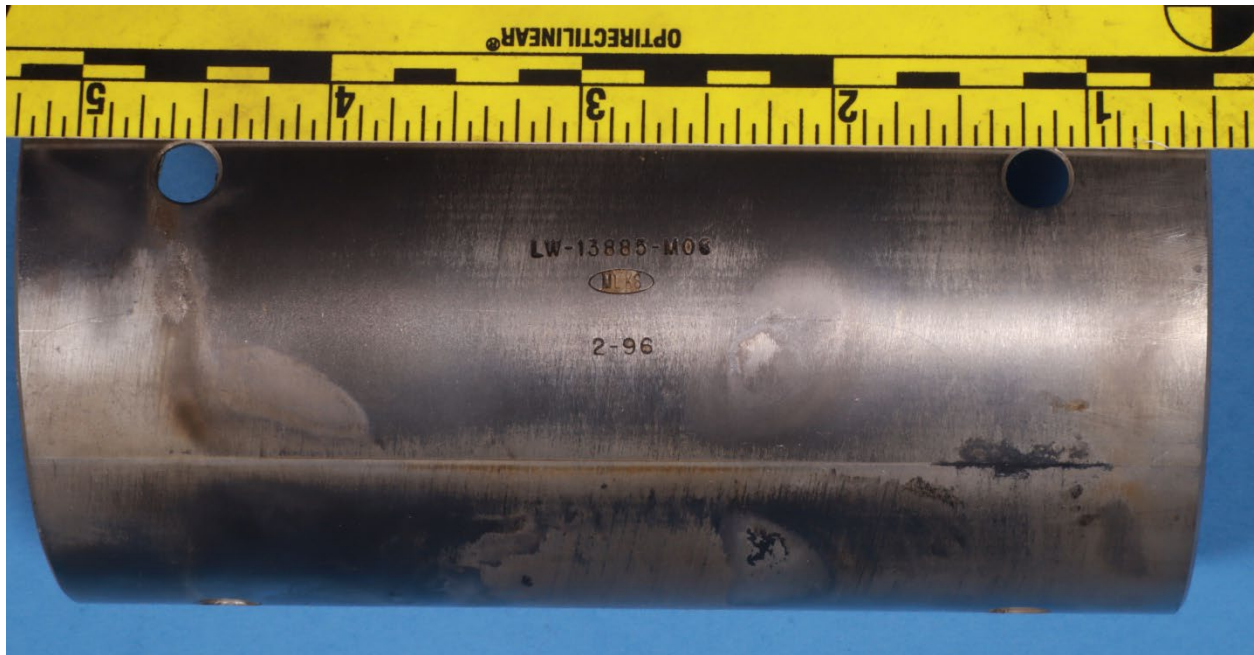


Figure 22. Closer view of the markings on the M1 bearing, stating "LW-13885-M06" and "2-96."



Figure 23. Outer surfaces of several of the other main journal bearings, showing markings stating "LW-136830-M06" and "4-97."



Figure 24. Spalling of the interior surface of one of the main bearings, with a gouge and abrasion marks in the direction of rotation.



Figure 25. Edge damage, abrasion, and localized spalling on the ID surface of one of the main journal bearings from Figure 23.

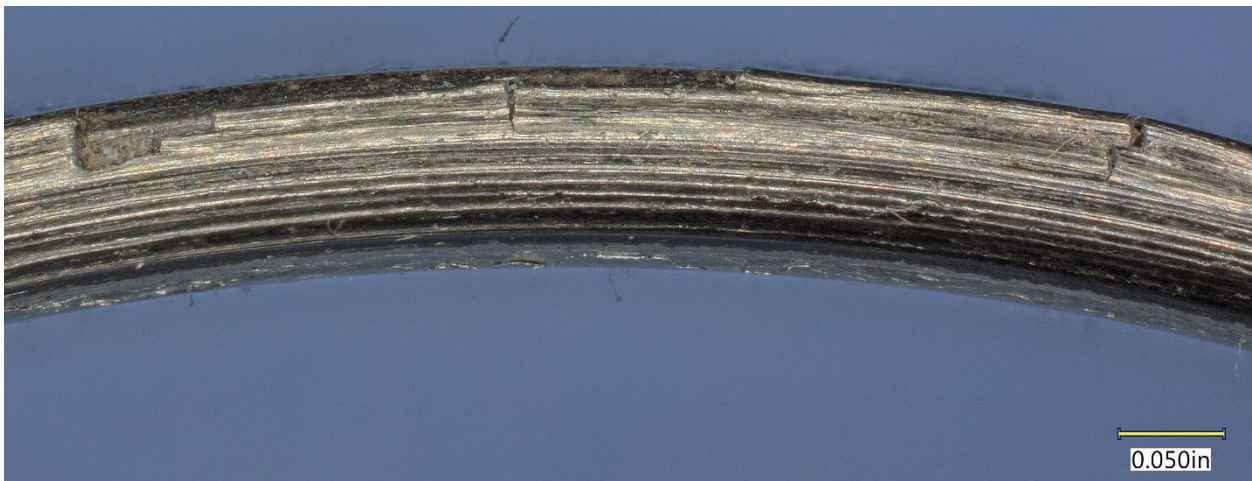


Figure 26. Rotational wear scars on the edge of one of the main bearings from Figure 23, showing cracking, material loss, and flaking.



Figure 27. The two halves of the #4 connecting rod, after removal from the crankshaft.

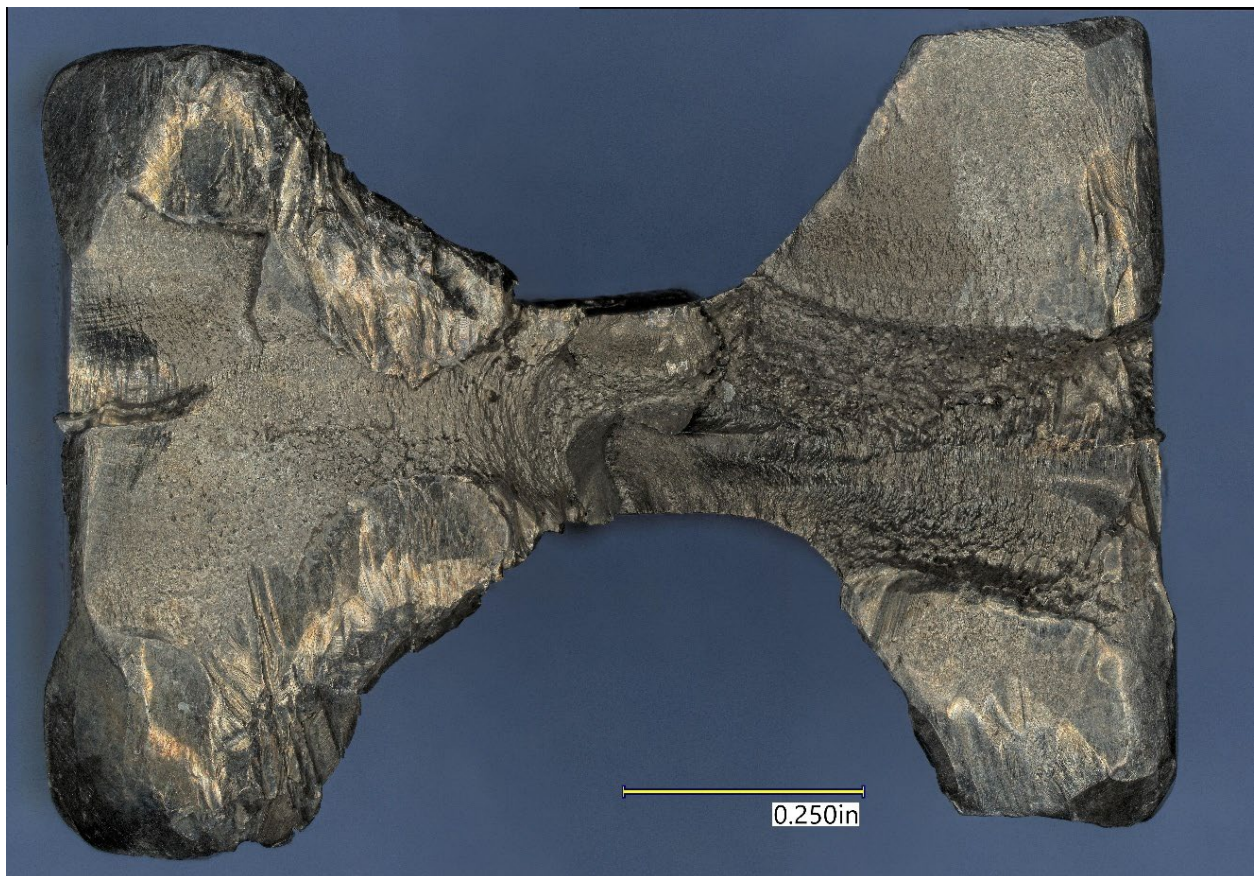


Figure 28. Montage of the fracture surface, showing the corner cracking features.



Figure 29. Closer view of the crack arrest marks from the lower left of Figure 28.

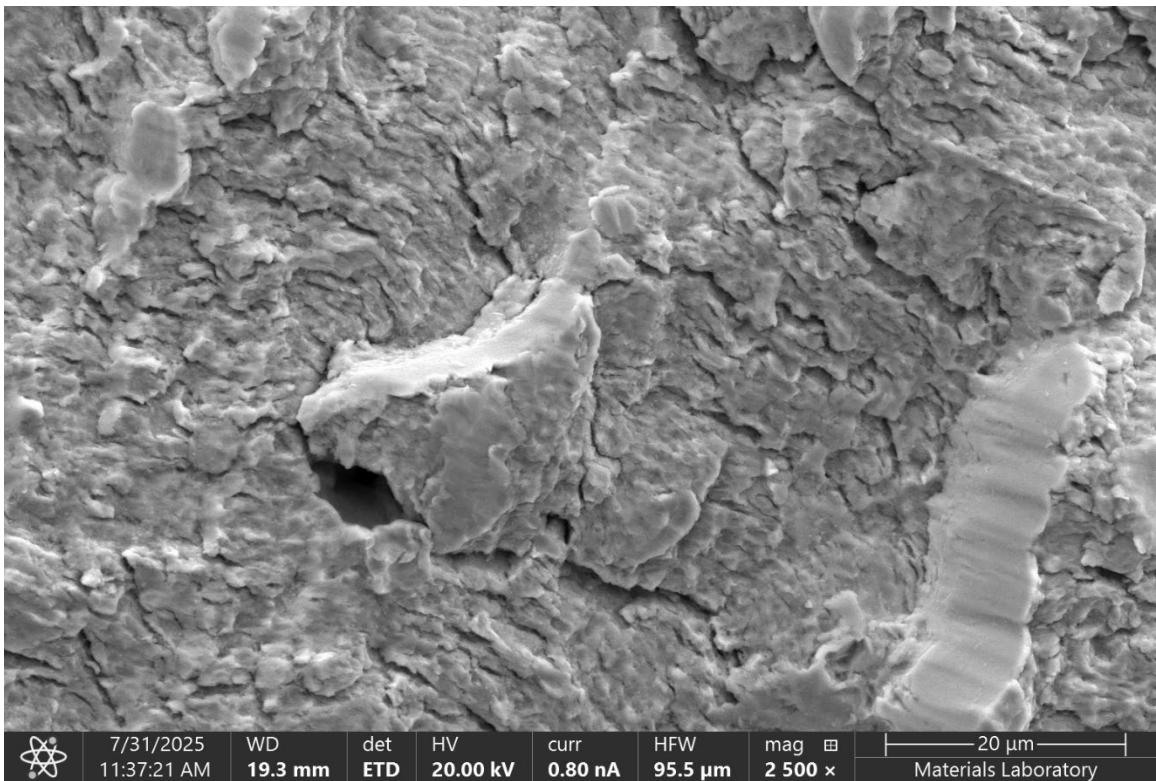


Figure 30. Backscattered electron (BE) micrograph of striations on the connecting rod fracture surface.

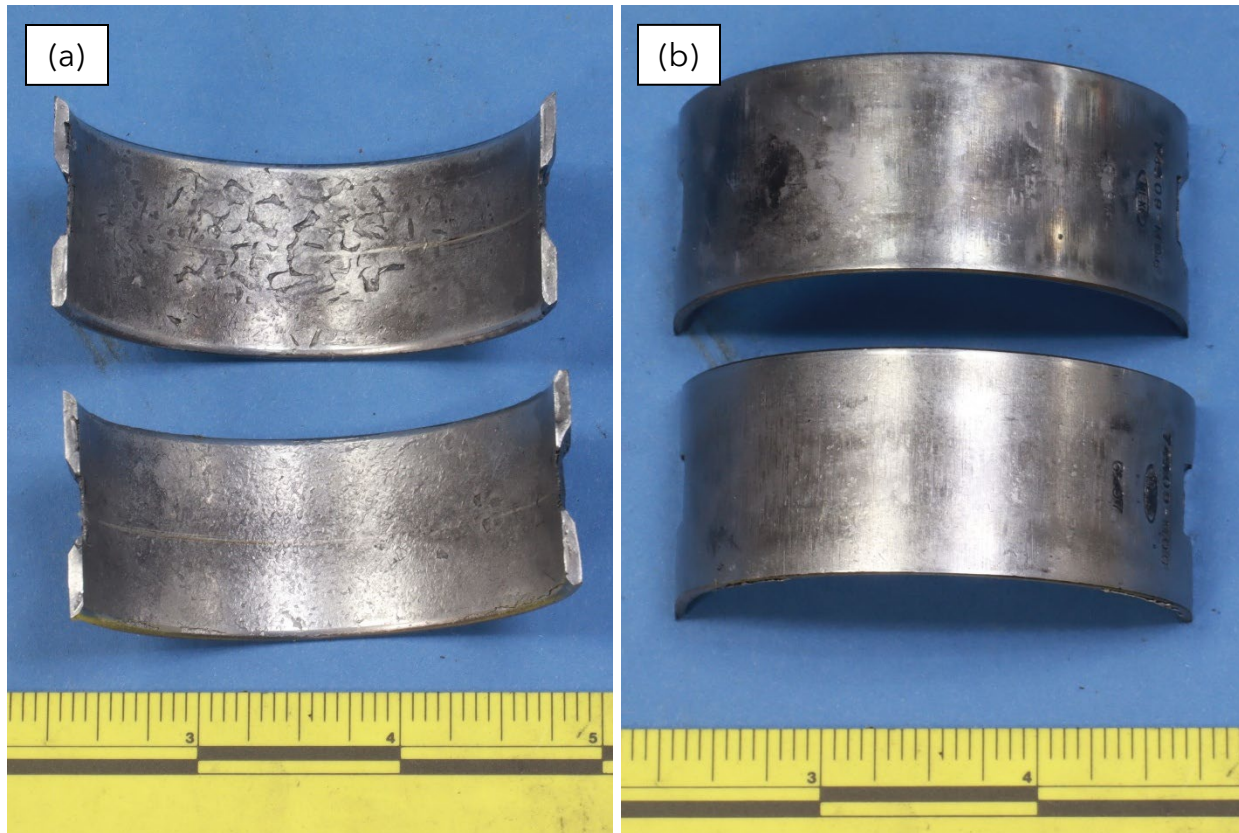


Figure 31. View of (a) the interior surfaces of the C4 bearing, and (b) the outside surface of the C4 bearing.



Figure 32. Exterior of the C4 bearing, showing the part numbers and markings.



Figure 33. Spalling damage on the ID surfaces of the C4 bearing from Figure 31a.