

Lycoming Engines

Report No. LN-18054, Materials Laboratory Investigation Report of the Fractured Roller Tappet Assembly, follows this page and is included after appropriate authorization from Lycoming per a redacted Proprietary Notice Restriction contained on the cover of each page of the report.



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Technical Report

Investigation of Fractured Roller Tappet Assembly from Engine TIO-540-AJ1A
Serial Number L-7625-61E in Support of NTSB Investigation

Report No. LN-18054

3/17/2019

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REPORT NO. LN-18054

MATERIALS LABORATORY INVESTIGATION REPORT

ENGINE DATA

TYPE TIO-540-AJ1A

S/N L-7625-61E

HOURS 1844.8 TSO

APPLICATION D. O. H. S.

PART DATA

NAME Roller Tappet and Others

NUMBER LRT23381 and Others

S/N See Below

TIME 1844.8 TSO

DATE RECEIVED 10/23/2018

SIR No. N/A

SUBMITTED BY

PHONE x

☒ FIELD ☐ TEST ☐ OTHER

PHOTOGRAPHS: ☒ Y ☐ N

TYPE REPORT: ☐ Informal ☒ Formal ☐ Warranty Pending ☐ Info Only / Self-Assigned

AFTER COMPLETION OF INVESTIGATION:

☐ Dispose parts ☐ Return parts to submitter ☐ Store until _____ and then dispose

☒ Other Hold until 1/15/

REASON FOR SUBMITTAL / WORK REQUIRED:

Engine TOT: 5040.9/ TSO: 1844.8 D/A: 8-22-2018, Reg: N35442. Parts submitted to Lycoming Materials Lab: Crankcase, P/N 11F24124-S7-70 S/N K0220; Camshaft, P/N 15N23374; Roller Tappets (12), P/N LRT23381. Determine cause of failure for air safety investigation.

INVESTIGATION RESULTS:

Summary

Engine TIO-540-AJ1A serial number L-7625-61E with 1844.8 hours TSO was involved in an accident on August 22, 2018 (see NTSB Preliminary Accident Report Number ERA18LA228). The crash site investigation was halted and the engine returned to Lycoming for teardown investigation after the #4 exhaust roller tappet was observed to be fractured.

The #4 exhaust roller tappet assembly, camshaft, and other components detailed in this report were evaluated in the Lycoming Materials Lab in support of the investigation. Severe spalling and galling damage was observed on the #4 exhaust camshaft lobe along with the outside diameter of the associated roller tappet roller. Additionally, spalling was observed within the #4 exhaust roller tappet body ears supporting the roller shaft. Evidence of fatigue, in the form of fatigue striations, was observed on one of the #4 exhaust roller tappet body ear fracture surfaces. Witness marks on the inside of the crankcase bore holding the #4 exhaust roller tappet along with the uneven wear pattern on the #4 exhaust cam lobe might indicate that slight rocking of the roller tappet occurred in the case at some point.

(summary continued on next page)

The root cause of the fractured roller tappet was not determined but was not due to a material nonconformance of the roller tappet assembly or the camshaft. The severe wear between the roller and camshaft likely led to non-standard loading conditions, perhaps worsened by or caused by, slight rocking of the roller tappet in the crankcase bore, ultimately resulting in failure of the roller tappet body and the release of the roller, roller shaft, and needle bearings.

1. Samples and Identification

Engine TIO-540-AJ1A serial number L-7625-61E with 1844.8 hours TSO was involved in an accident on August 22, 2018 (see NTSB Preliminary Accident Report Number ERA18LA228). The crash site investigation was halted and the engine returned to Lycoming for teardown investigation after the #4 exhaust roller was observed to be fractured. The engine also had damage to the crankcase, camshaft, #4 intake push rod, #1 intake push rod, and suspected roller tappet debris in the sump (see Lycoming SIR Teardown Report for this engine for additional details).

The following items from this engine were submitted to the Lycoming Materials Lab following teardown inspection in Lycoming's FAA/NTSB teardown room:

- Crankcase
 - P/N 11F24124-S7-70, S/N K0220
- Camshaft
 - P/N 15N23374, S/N 3111, Vendor Code V5379
- Roller Tappets (Qty. 12)
 - LRT23381, Date Code 112306 (#2 Intake, #4 Intake, #6 Intake)
 - LRT23381, Date Code 112406 (all others)
- #4 Exhaust Push Rod
 - P/N 15F19957-63, Date Code 50-07, V5600
- #4 Exhaust Rocker
 - P/N 17F23342, Date Code 3211
- #4 Exhaust Hydraulic Plunger
 - P/N 15B26066, Manufacturing ID 17E11IM
- Fragments and Chips from Sump
- Oil Filter

2. Investigation Results

2.1 Crankcase

The crankcase, as documented in the teardown report, displayed contact damage in the form of various gouging/contact marks likely from secondary damage following fracture of the roller tappet assembly as debris was moved around the crankcase during continued operation. Shown in Figure 1, the fractured #4 exhaust roller tappet body is visible along with contact damage to the crankcase possibly from the roller and/or the roller shaft. Components of the roller tappet assembly were found and recovered from the sump as shown in Figure 2. Examination in the Materials Lab following initial teardown found additional witness marks, likely from the roller, as shown in Figure 3. The crankcase bore, shown in Figure 4, holding the #4 exhaust roller tappet was found in good condition, with no abnormal scoring or wear. If the roller tappet shaft had shifted laterally during operation while still retained by the body ears, it would be expected to see some scoring on the bore walls. Below the #4 exhaust tappet bore, witness marks were observed on the crankcase from contact with the #4 exhaust roller tappet, as shown in Figure 5, possibly indicating some rocking of the roller tappet inside the crankcase. Dimensional inspection of the crankcase roller tappet bore dimensions which prevent rotation of the roller tappet assembly with respect to the case was performed using go/no-go gages on all six roller tappet bores, which were found conforming.



Figure 1. Witness mark in crankcase likely from the roller shaft based on the diameter and position.
(Photo from SIR image file)

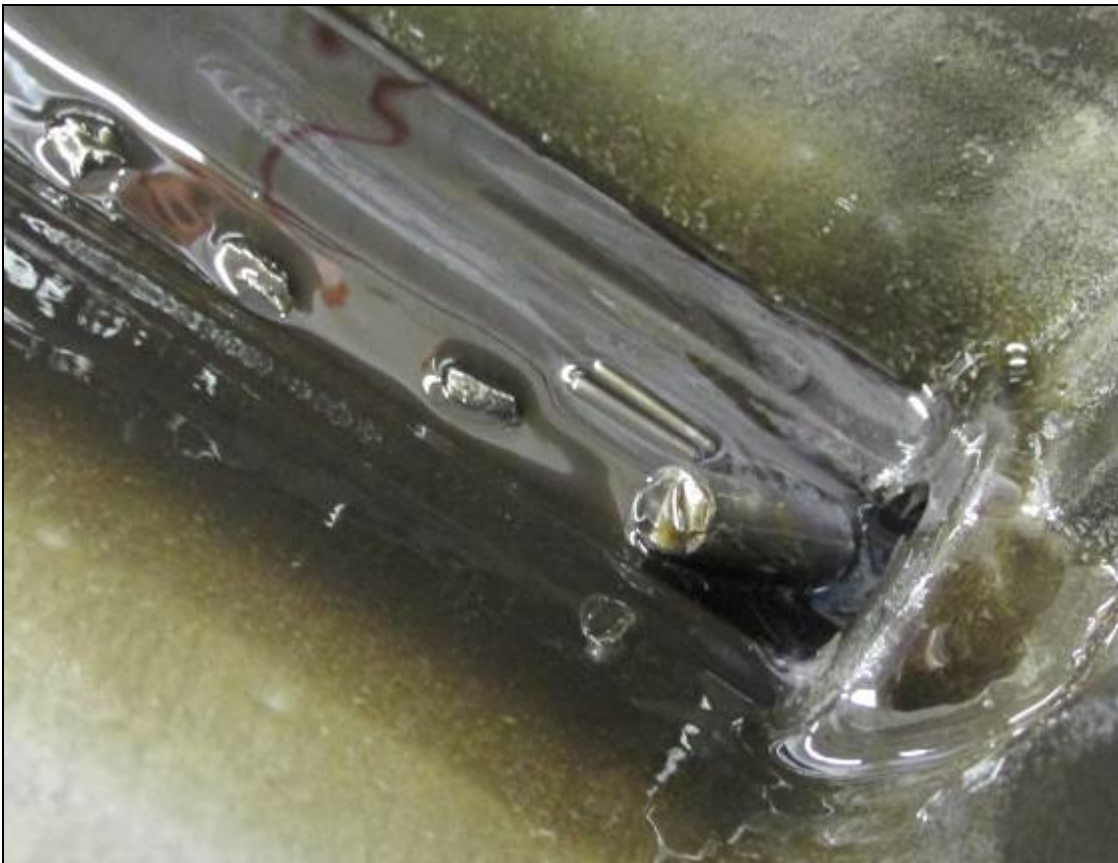


Figure 2. Components of the roller tappet were discovered in the sump during teardown. (Photo from SIR image file)

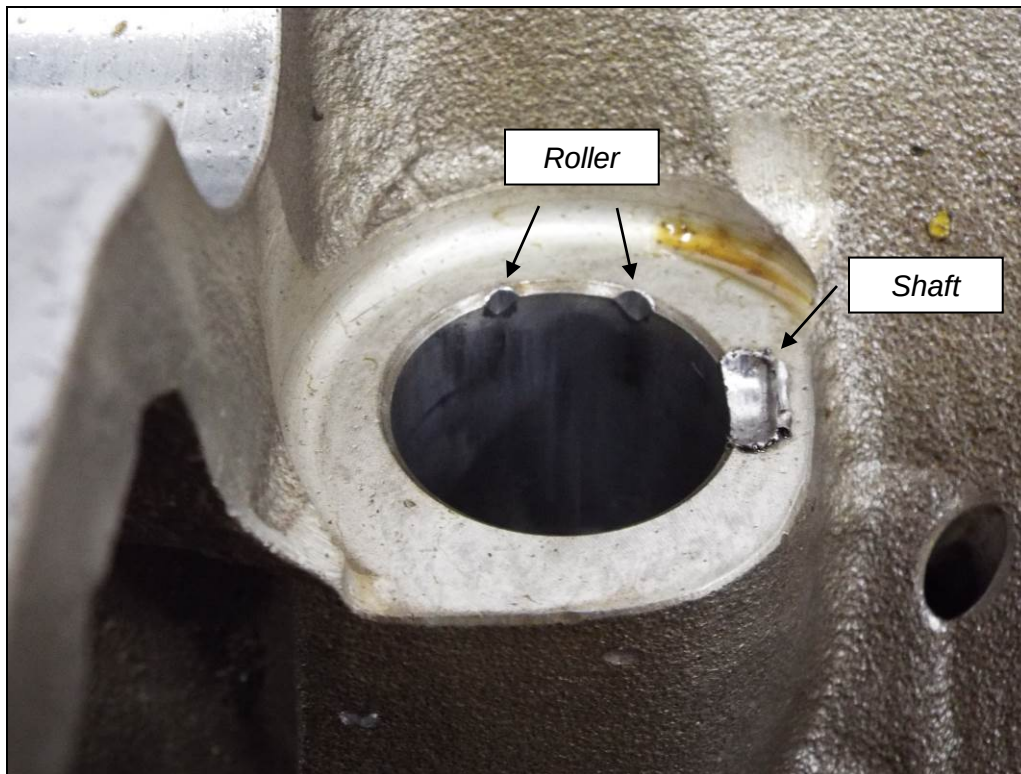
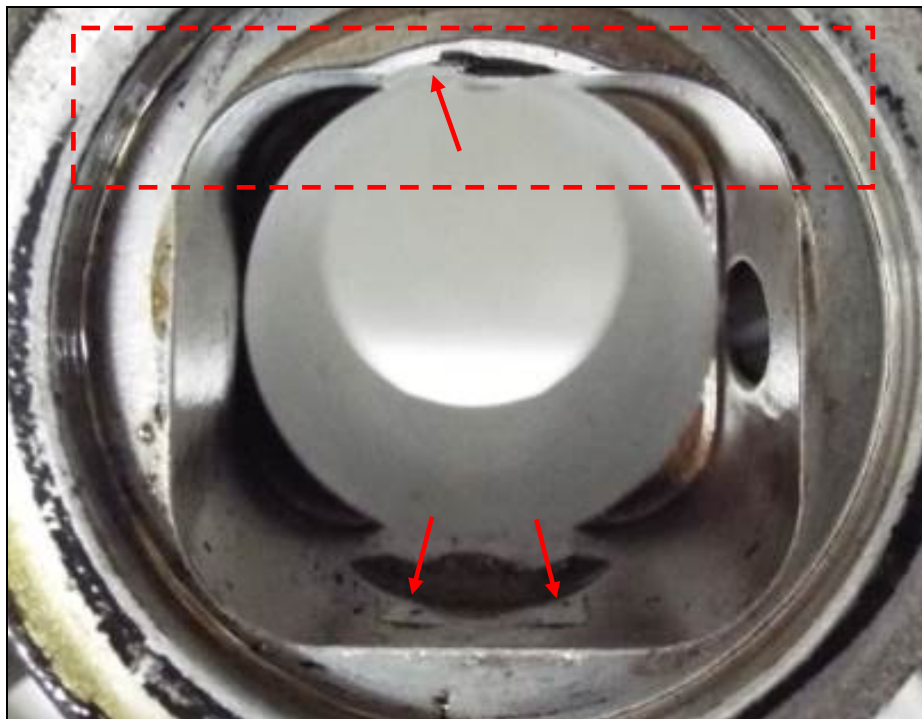


Figure 3. Witness marks likely from the tappet roller and shaft.



Figure 4. Crankcase tappet bore of #4 exhaust roller tappet, viewed from inside of case, with no abnormal wear.



2.2 Camshaft

The camshaft displayed severe wear on the #4 exhaust lobe, as shown in Figures 6-7. The #4 exhaust lobe exhibit signs of galling and spalling. Minor damage was observed along the length of the camshaft, appearing as secondary contact marks as material contacted the camshaft during continued operation. The #5 exhaust lobe, shown in Figure 8, also showed some wear damage but was much less severe than the #4 exhaust lobe. The case hardness, case depth, core hardness, and microstructure of the camshaft were conforming. Measurement results of the camshaft are provided in Table 1-2.

Cross sections of the #4 and #5 exhaust cam lobes were prepared for metallographic evaluation. Shown in Figure 9-10, the severely damaged #4 exhaust cam lobe exhibited re-hardening from the frictional heating, adhered material (likely from the roller based on the Nital etched microstructure), deformed grains due to surface damage, and cracks at the near surface. The #5 exhaust cam lobe, shown in Figure 11, exhibited a conforming case and core microstructure.

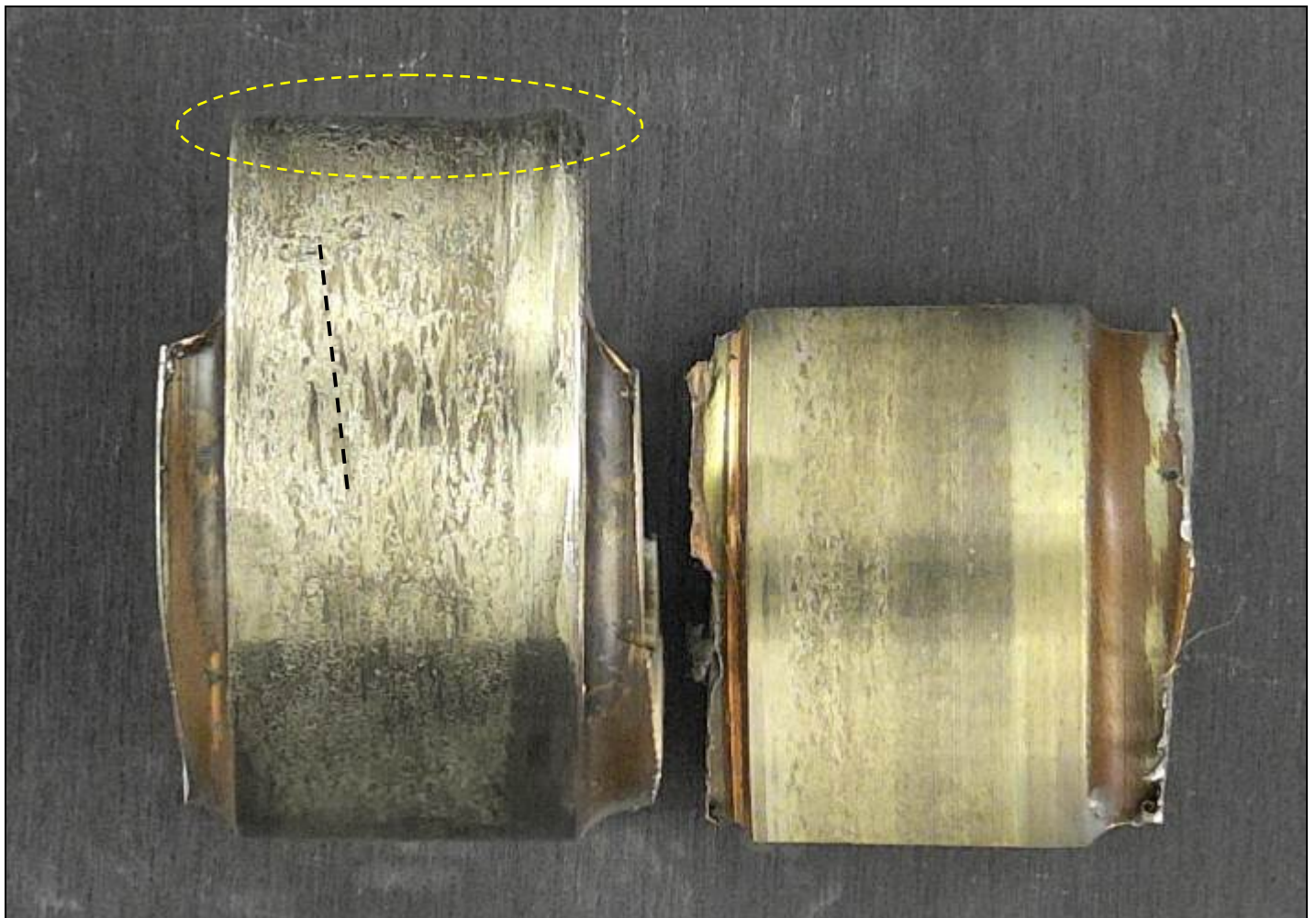
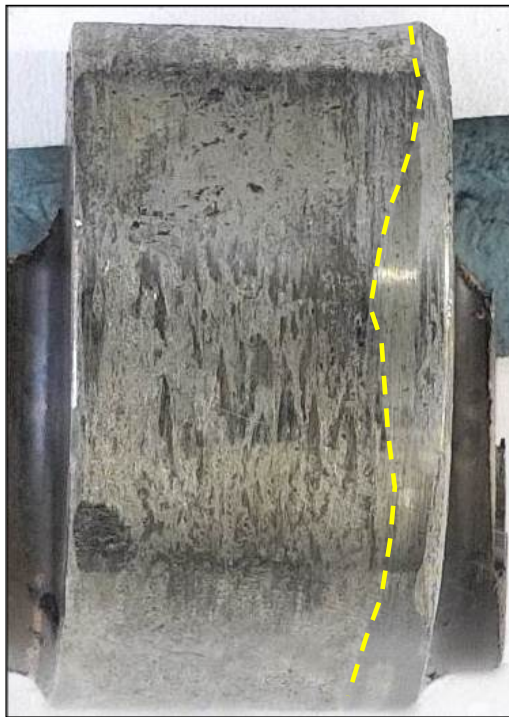


Figure 6. (Top) Wavy wear pattern on the damaged #4 exhaust cam lobe shown after sectioning. (Bottom Left) Severely damaged region of #4 exhaust lobe. (Bottom Right) Less damaged backside of #4 exhaust lobe.

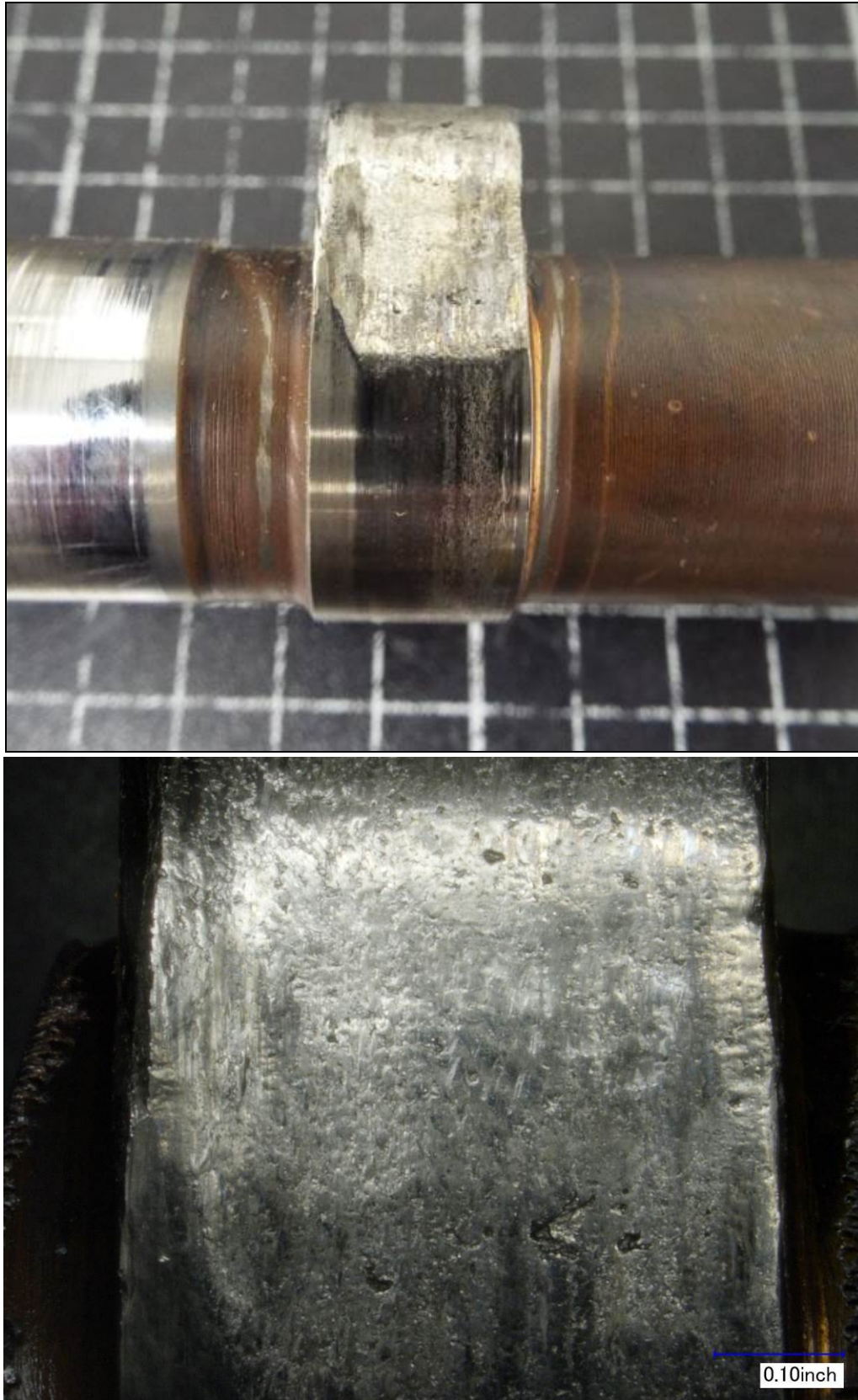


Figure 7. Severely damaged #4 exhaust lobe.

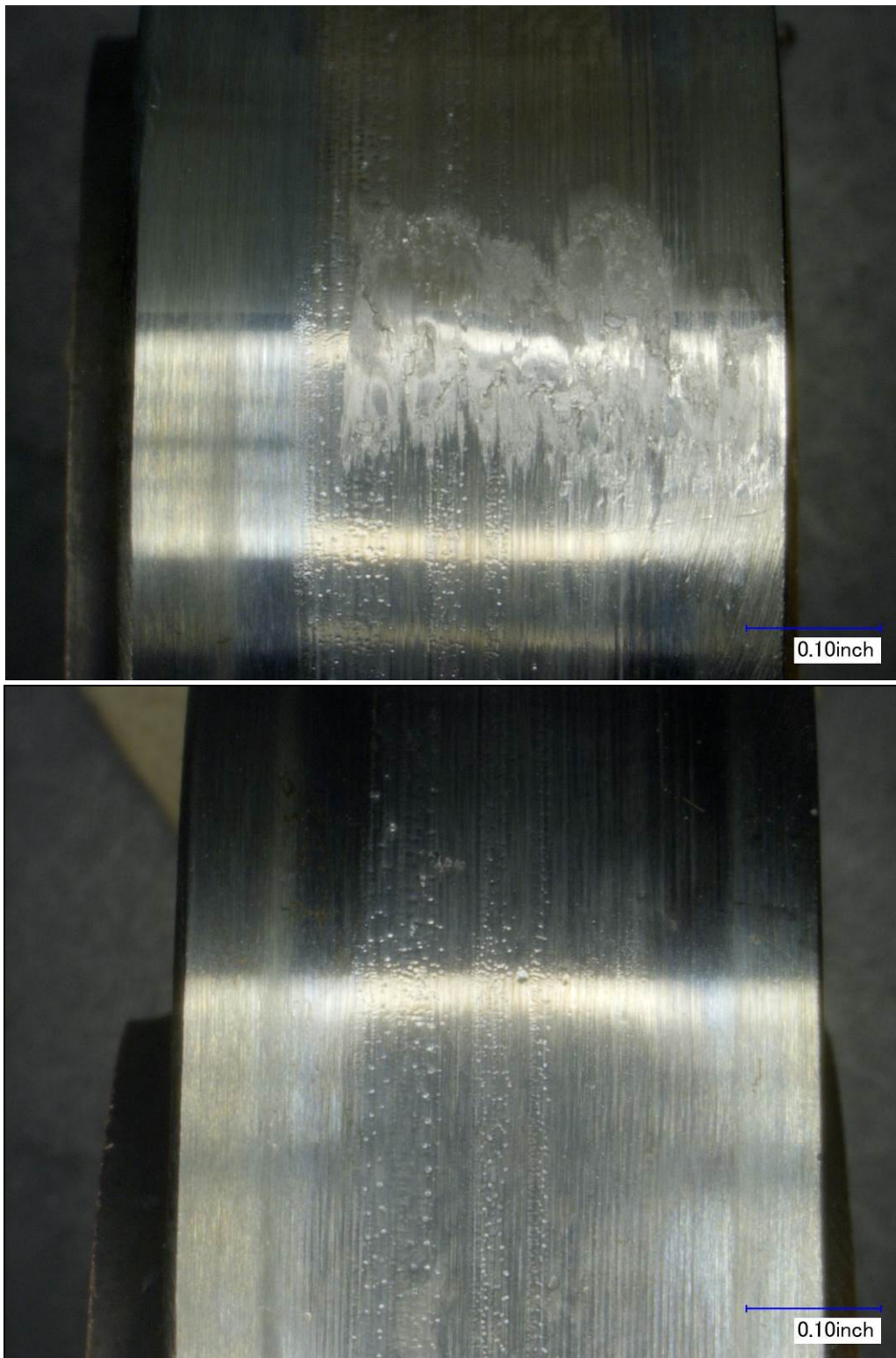


Figure 8. #5 Exhaust Lobe of Camshaft with Slight Damage.

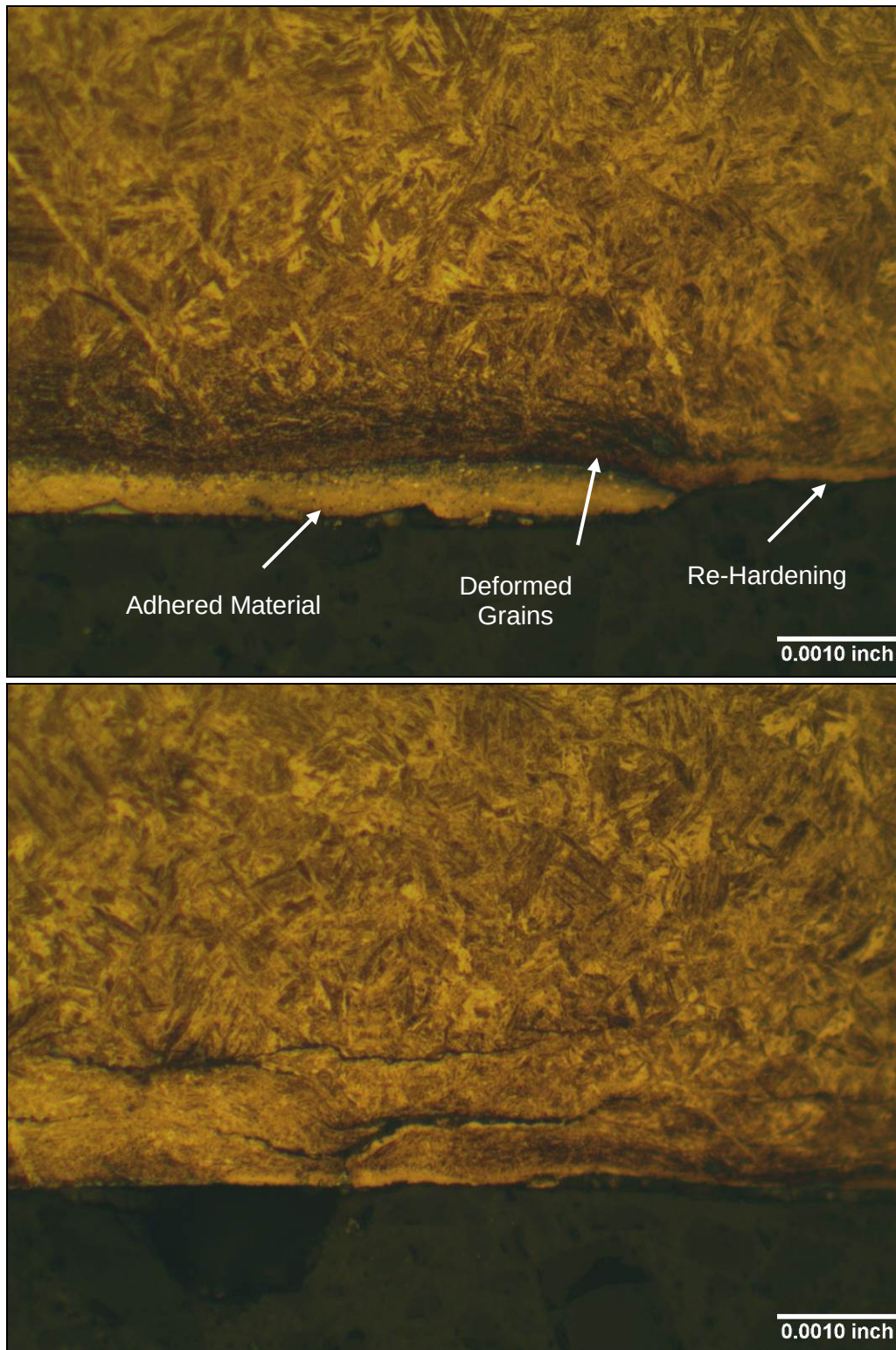


Figure 9. #4 Exhaust Lobe Severely Damaged Region, Nital etched. (Top) Deformed near surface grains, re-hardening, and adhered material. (Bottom) Cracking along the near surface.

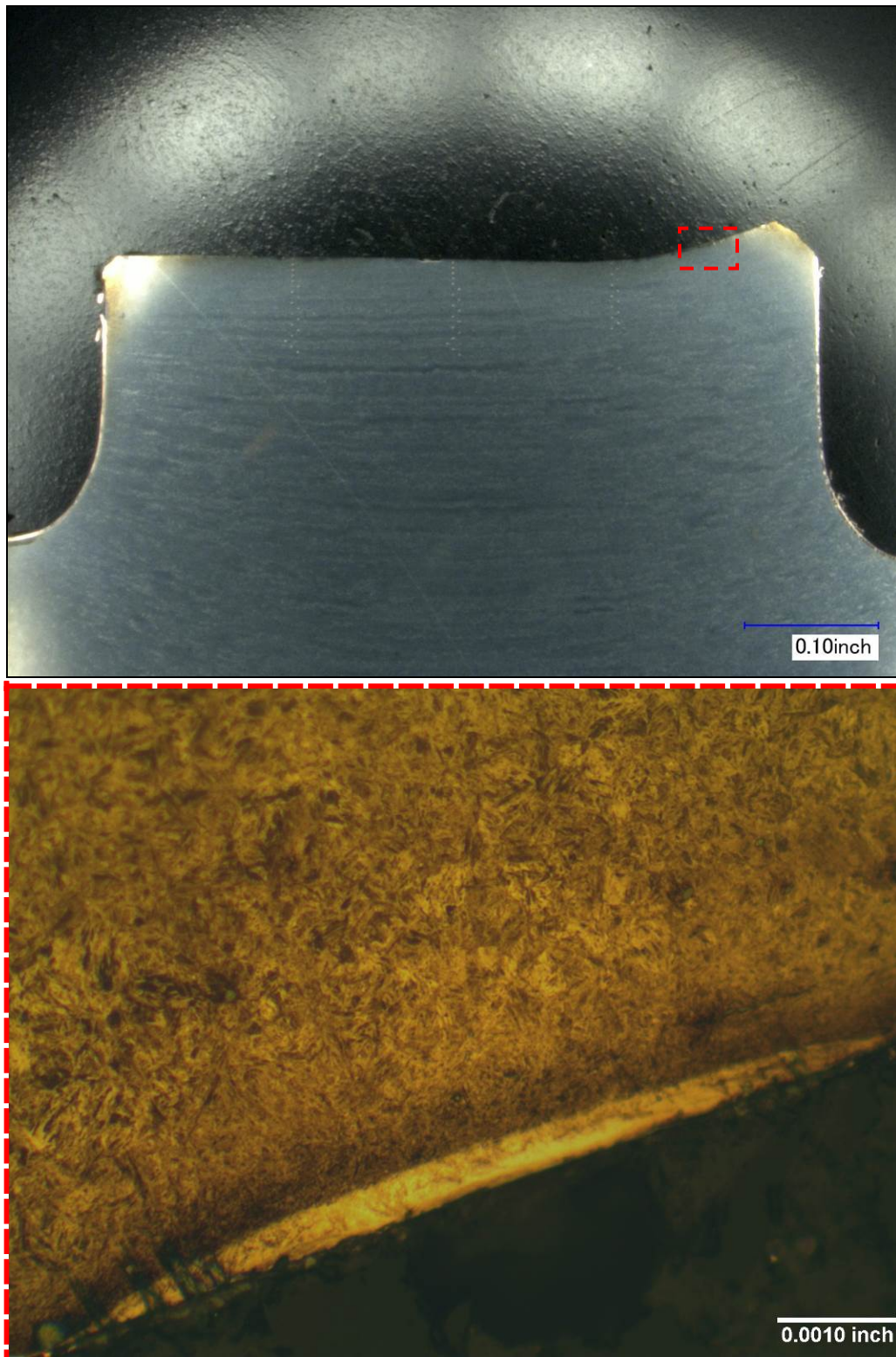


Figure 10. (Top) #4 Exhaust Lobe Severely Damaged Region, Nital etched, showing the amount of deformation and wear on the cam lobe. (Bottom) Re-hardening zone from frictional heating.

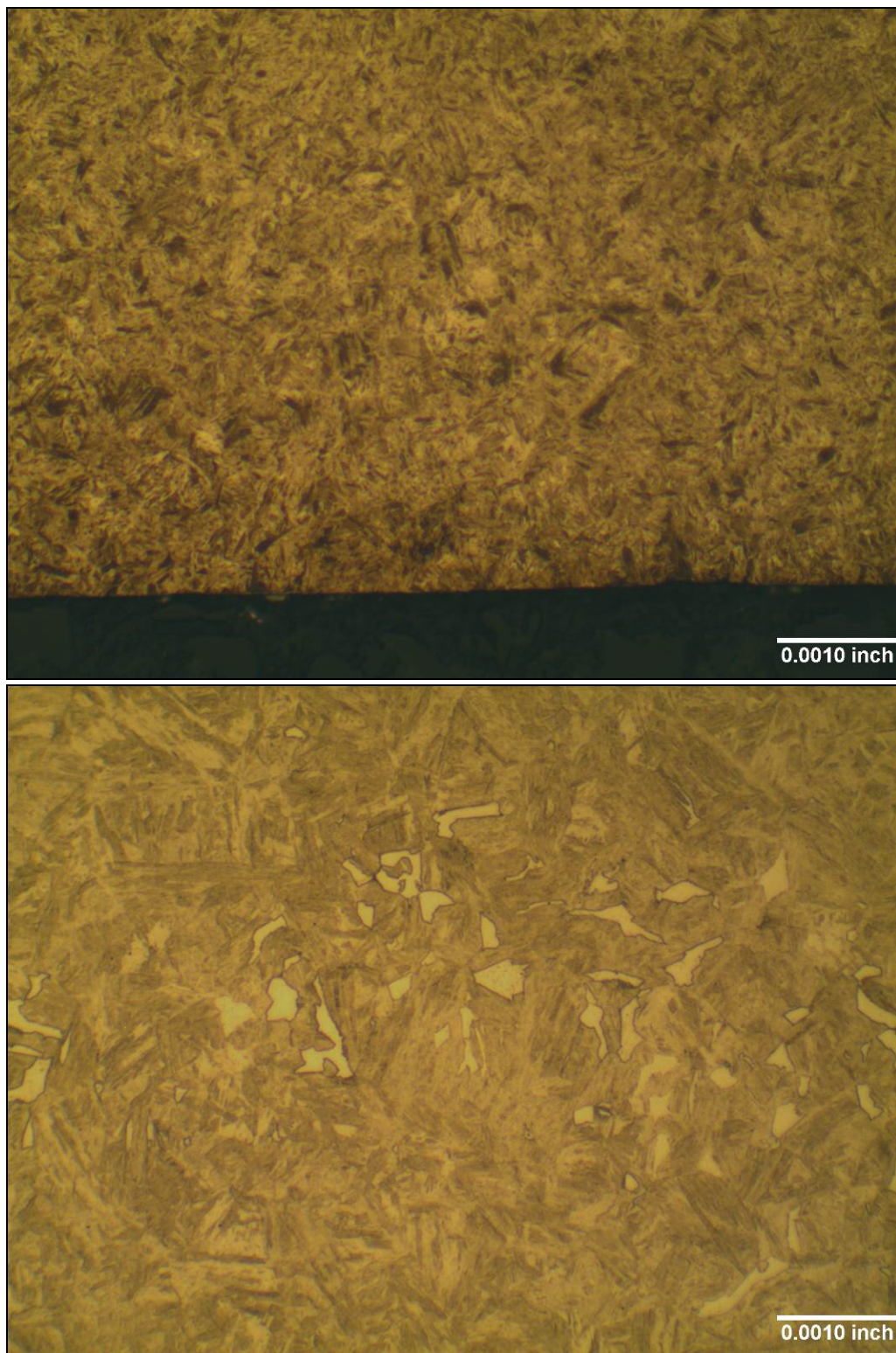


Figure 11. (*Top*) Case of tempered martensite and (*Bottom*) Core of tempered martensite and ferrite of #5 Exhaust Cam Lobe

2.3 Roller Tappets

Shown in Figure 12, the #4 exhaust roller tappet was found to be fractured with the roller, needle bearings, and shaft no longer retained by the tappet body. Both ears of the roller body which retain the shaft were fractured. The other 11 roller tappet assemblies were found in overall good condition. Both sides of the shaft were staked on the remaining 11 shafts of the roller tappet assemblies.

The #4 exhaust roller tappet components were evaluated for conformance, including selected key dimensions, material chemistry, hardness, case hardness, case depths, and microstructure as applicable to the individual components. The measurement results are provided in Table 3. Each of the evaluated components was conforming to engineering requirements.

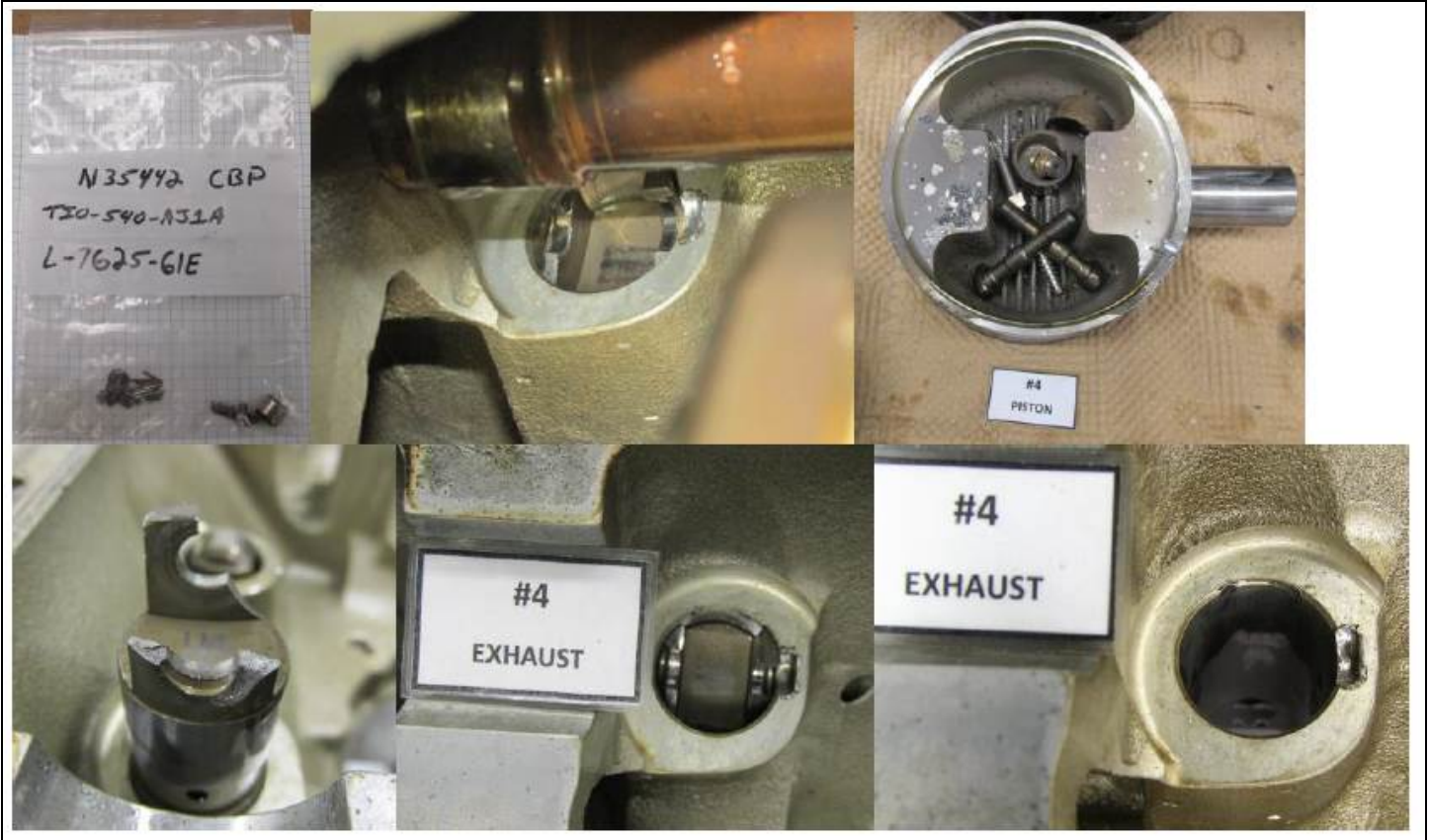


Figure 12. Fracture #4 Exhaust Roller Tappet documented during SIR Teardown.
(Photo from SIR image file)

The roller body was found to have both ears fractured, shown in Figure 13. The roller body ear fracture surfaces were examined using stereomicroscopy, digital microscopy, and scanning electron microscopy (SEM). Spalling of the case was observed around the shaft bores on the body along with witness marks from the roller and needle bearings on the inside of the body ears, shown in Figure 14-15. The witness marks from the roller appeared deeper on one ear compared to the other. The microstructure was predominately tempered martensite in the case region of the body ear, but also showed grain deformation on the bore surface, spalled grains at the edge of the ear towards the roller, retained austenite in the case, and a coarse grain structure, as shown in Figure 16. The retained austenite and coarse grain structure are observations only and are not a nonconformance. In Figures 17-19, SEM images show the spalling at the shaft bore edges of the body. The bore surface also showed some plastic deformations on the surface, also visible in Figure 17. The core regions generally exhibited ductile tearing as shown in Figure 20. Figure 21 shows a region of fatigue on one of the body ear fragment fracture surfaces.



Figure 13. Macro photos of the fractured #4 exhaust roller tappet assembly.

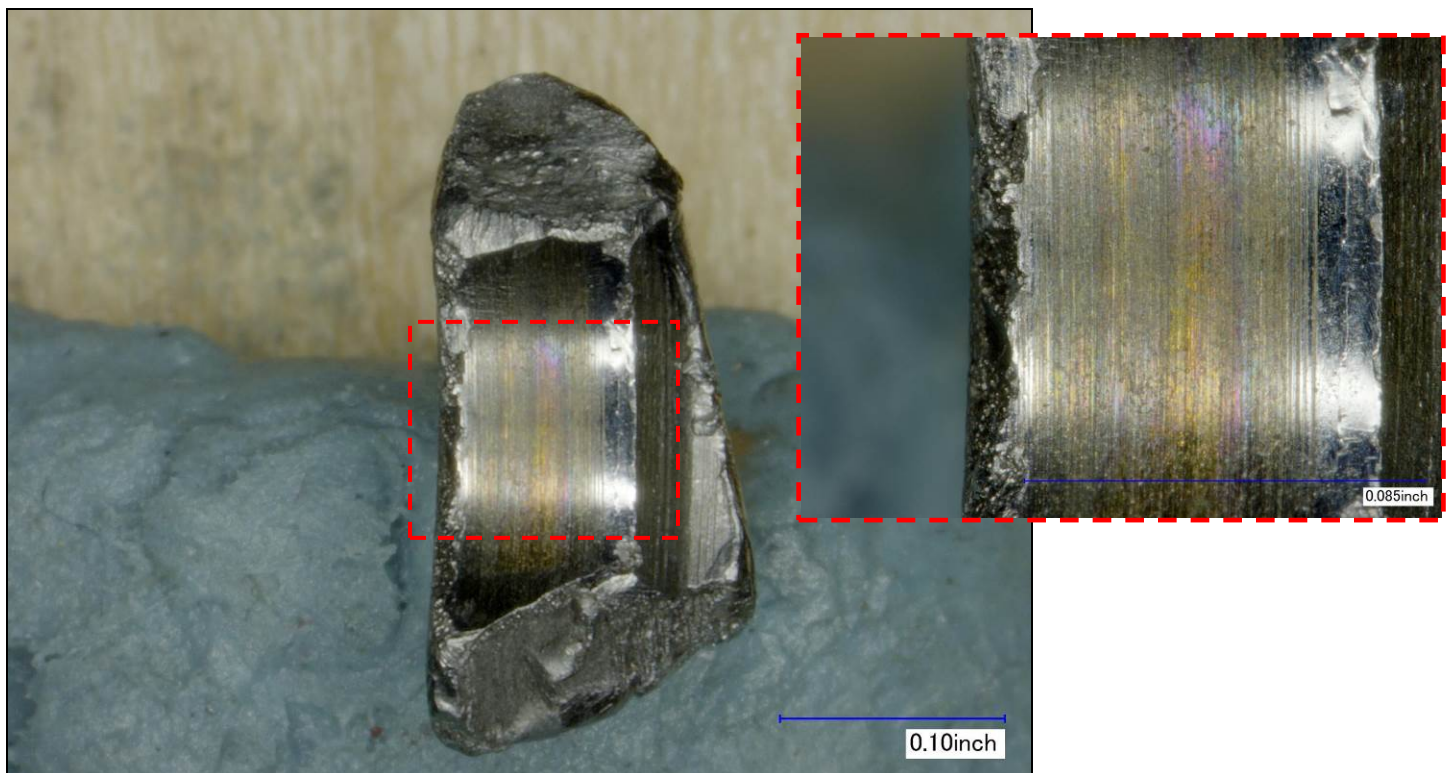


Figure 14. Roller body shaft bore with spalling at bore edges.



Figure 15. Witness marks from the roller and needle bearings.

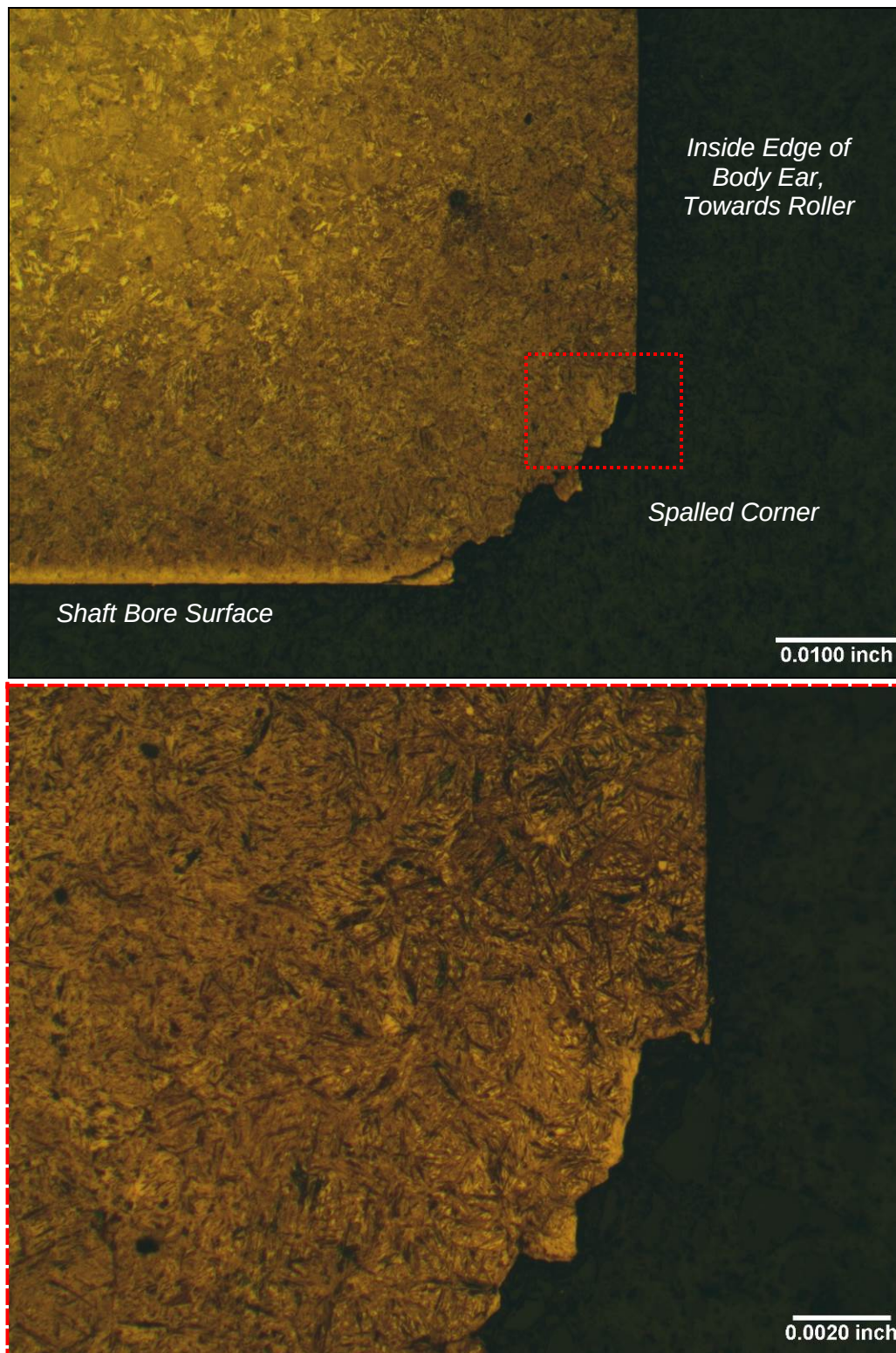


Figure 16. Microstructure of roller body ear showing grain deformation at the bore surface, retained austenite, and coarse grain size.

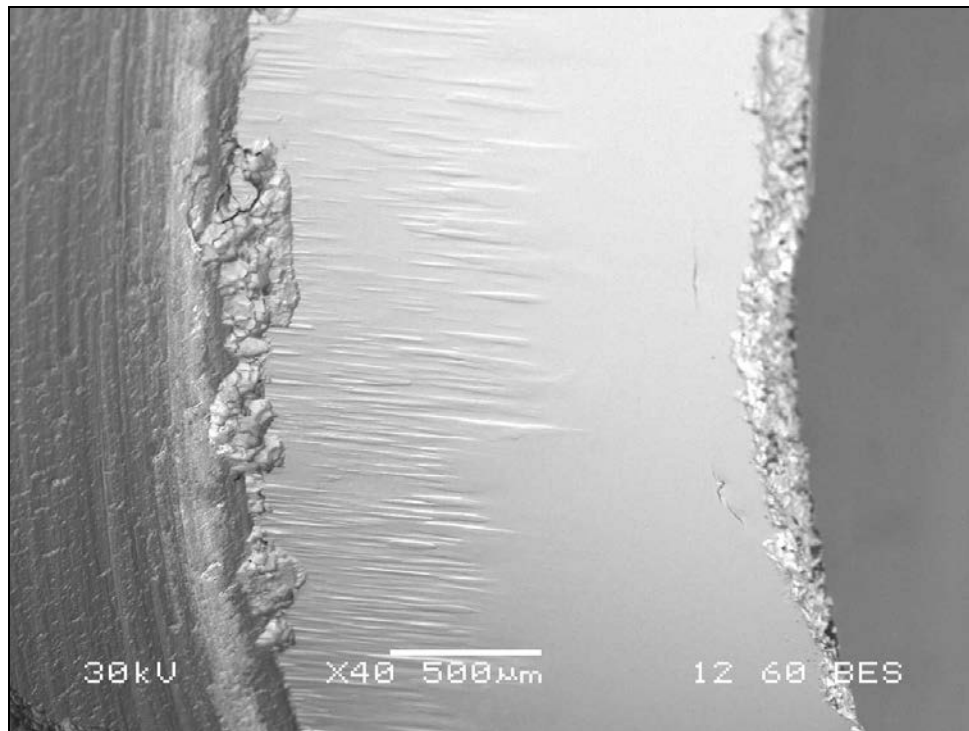


Figure 17. SEM image in backscatter mode showing spalling at the edges of the body in contact with the shaft. Also visible are on the bore surface are plastic deformations.

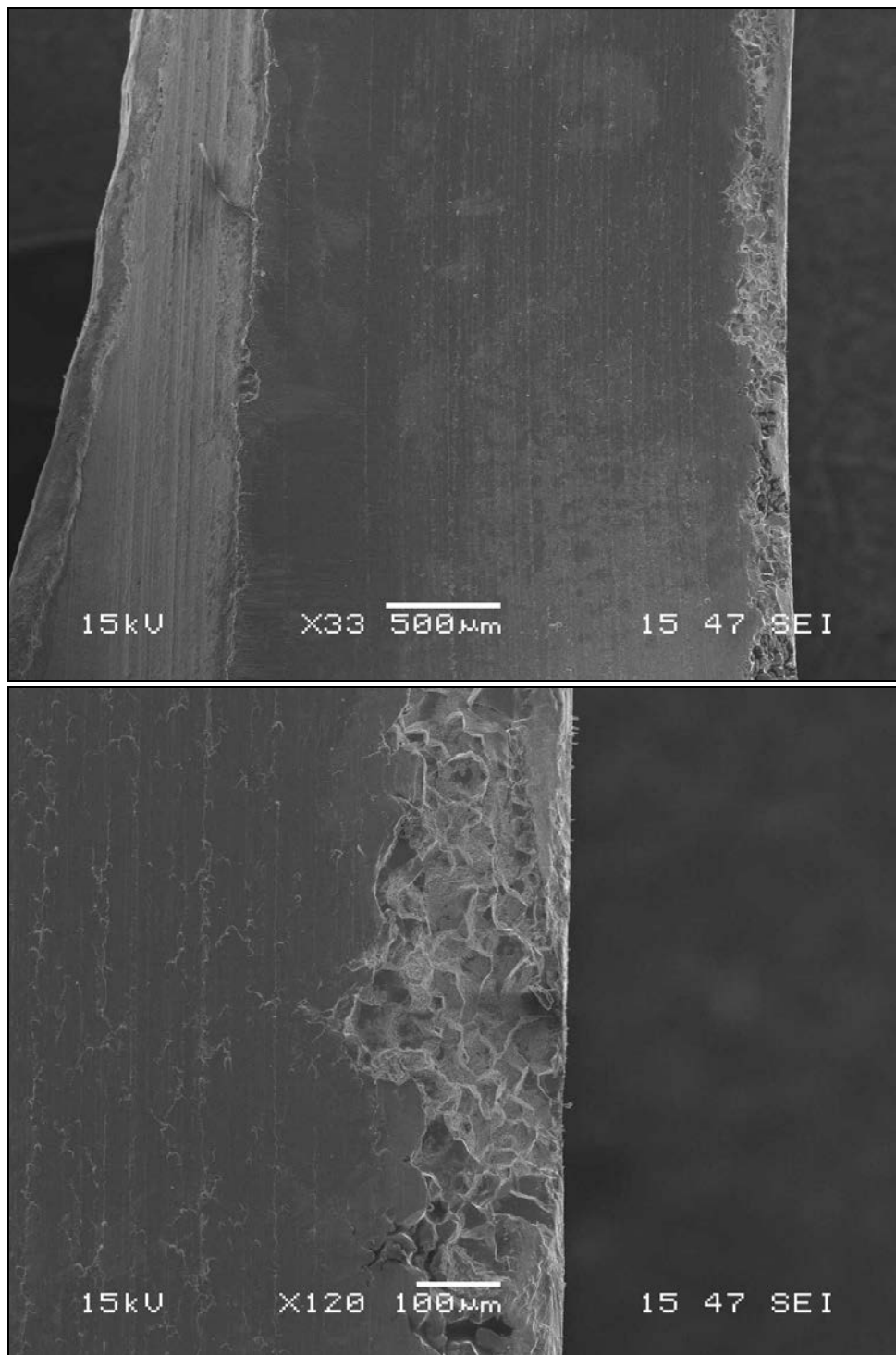


Figure 18. (Top) Inside diameter of shaft bore of body. (Bottom) Higher magnification showing spalling at inside edge of shaft ear (side towards roller and needle bearings).

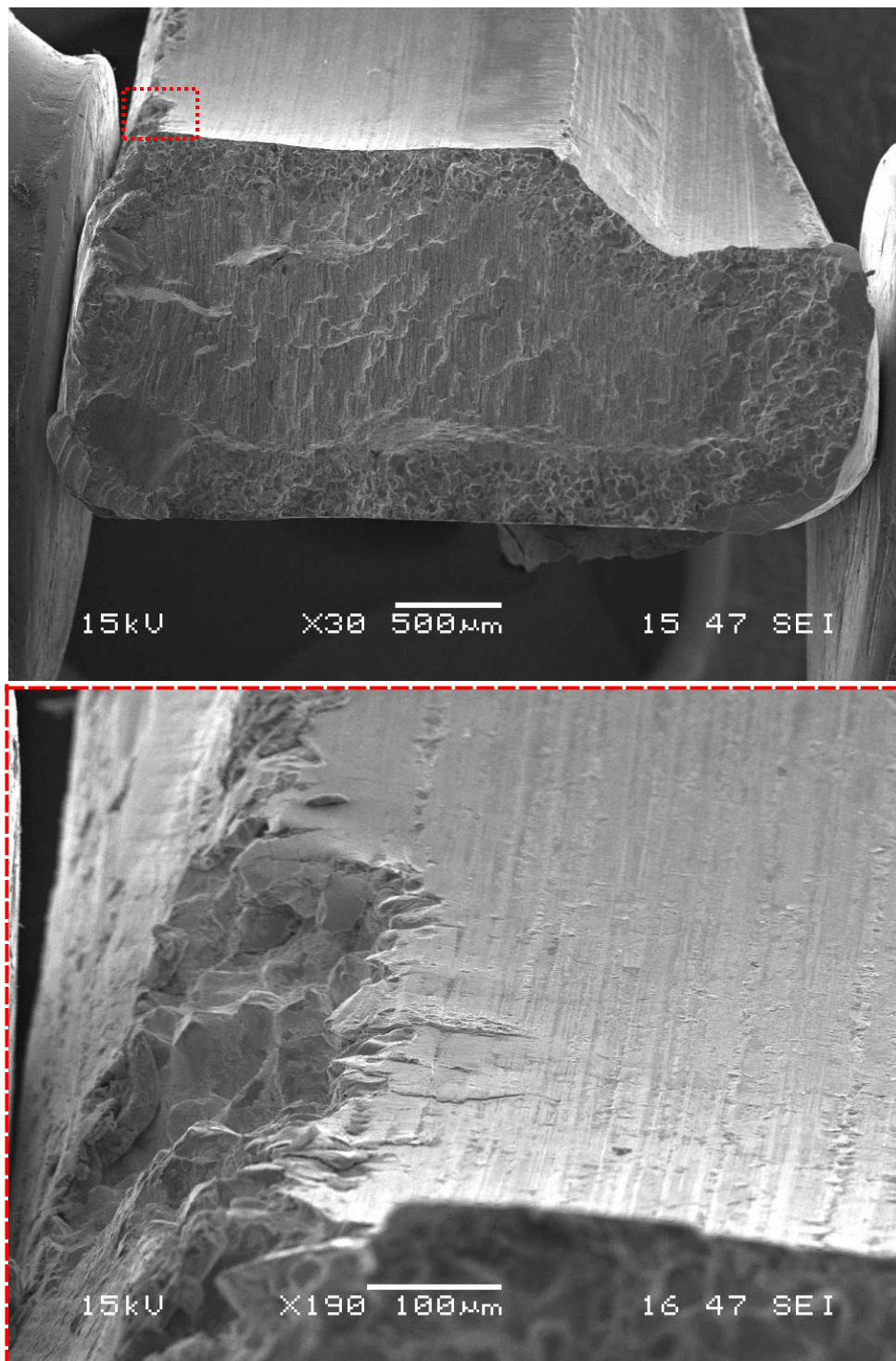


Figure 19. (Top) Roller body ear fracture surface. (Bottom) Spalled inside edge towards the roller side of the body ear.

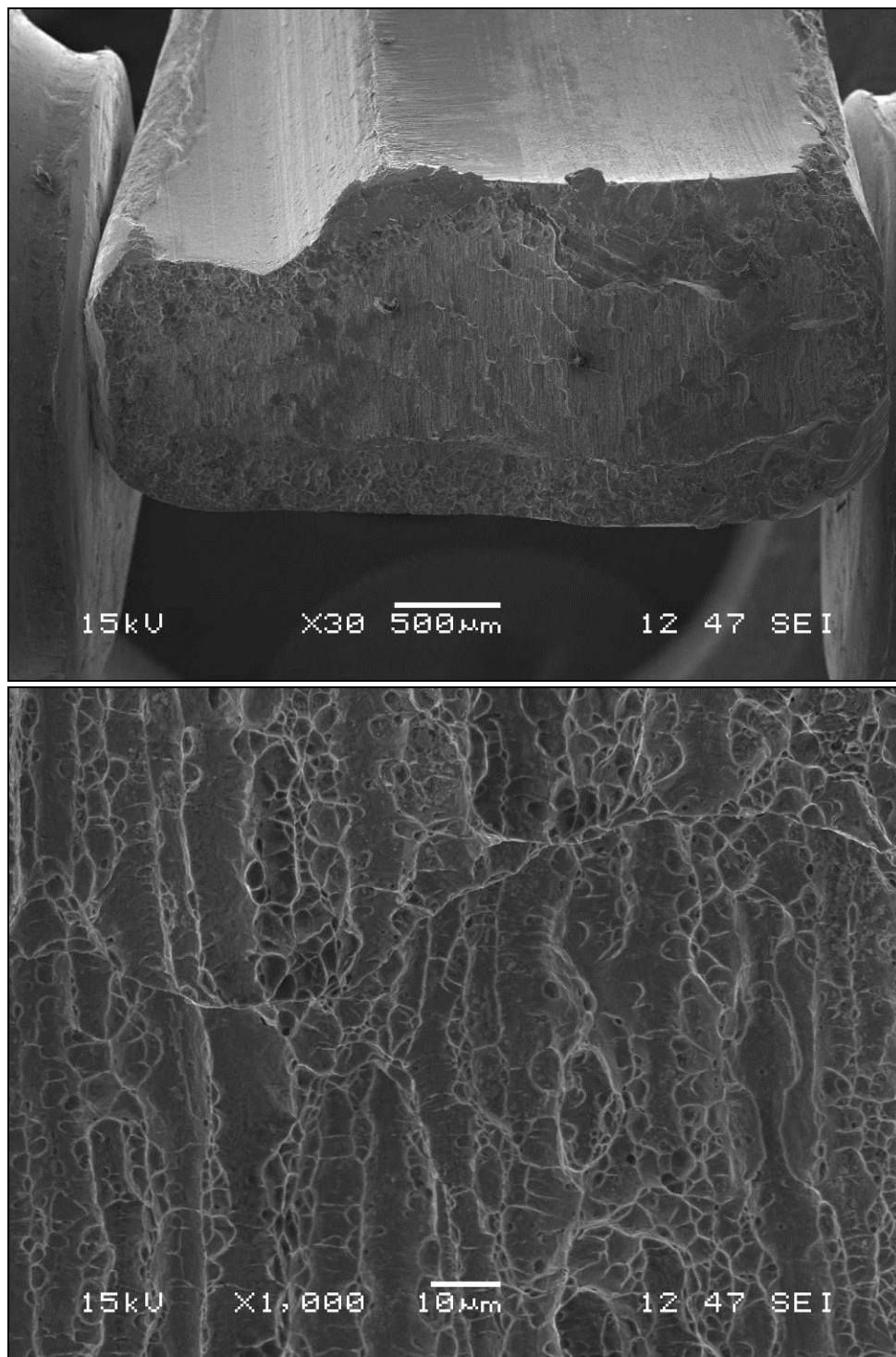


Figure 20. (Top) Brittle fracture within the case of the roller body shaft ear and ductile tearing through the core region (Bottom).

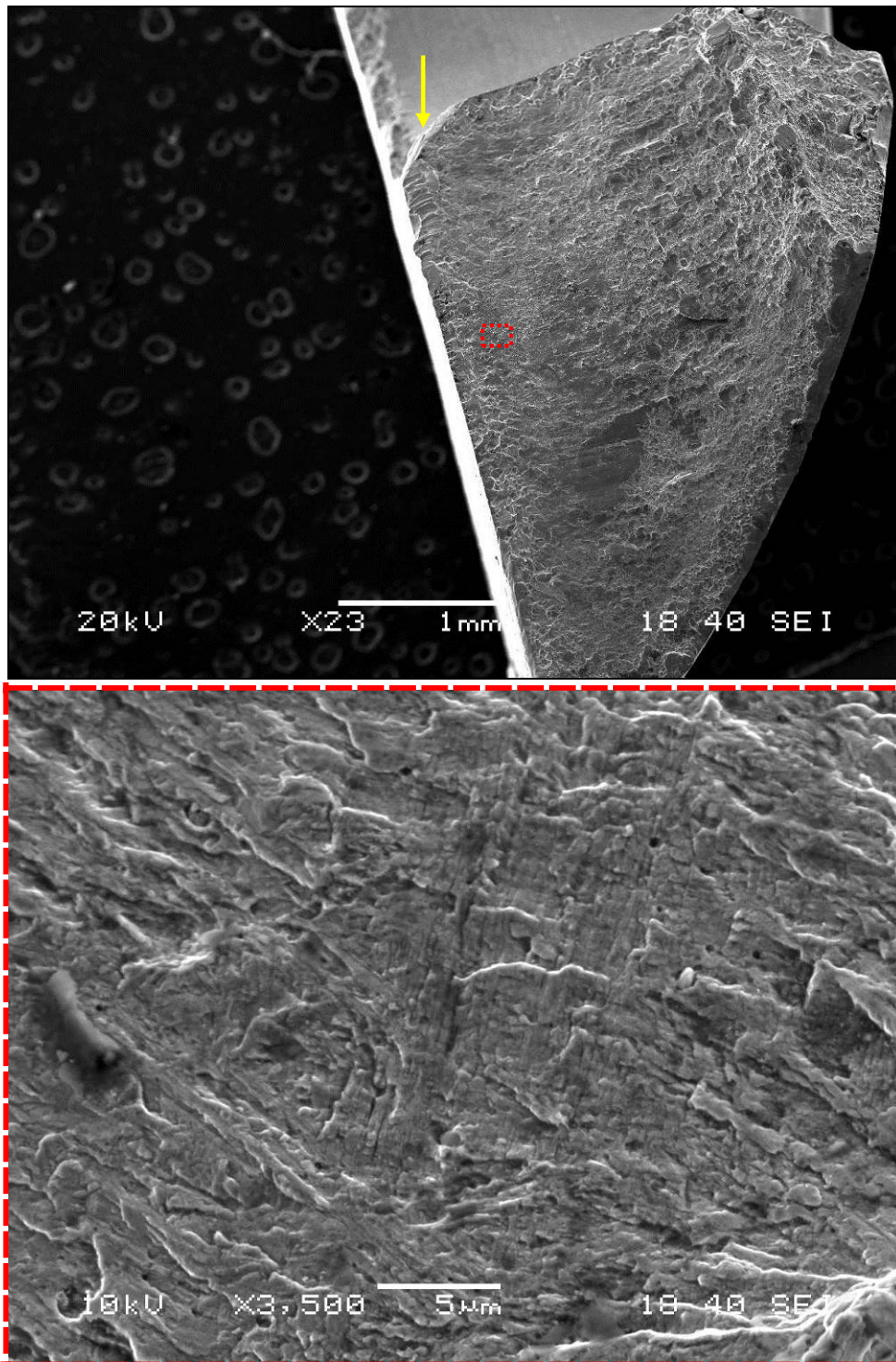


Figure 21. One of the roller body shaft ear fracture surfaces showed signs of fatigue, with faint fatigue striations. The yellow arrow indicates the likely fatigue crack origin near the inside corner of the bore.

The roller had separated into multiple fragments, showing evidence of brittle fracture originating at the outside diameter in a severely spalled region, shown in Figure 22. Another fragment of the roller showed evidence of fracture origin at the inside diameter, as shown in Figure 23. The roller displayed signs of significant wear and spalling on the OD, consistent with the severe wear observed on the corresponding camshaft lobe. Some areas of the ID were in good condition, as visible in Figure 22, but other regions were galled and/or spalled, shown in Figure 23 and 24.

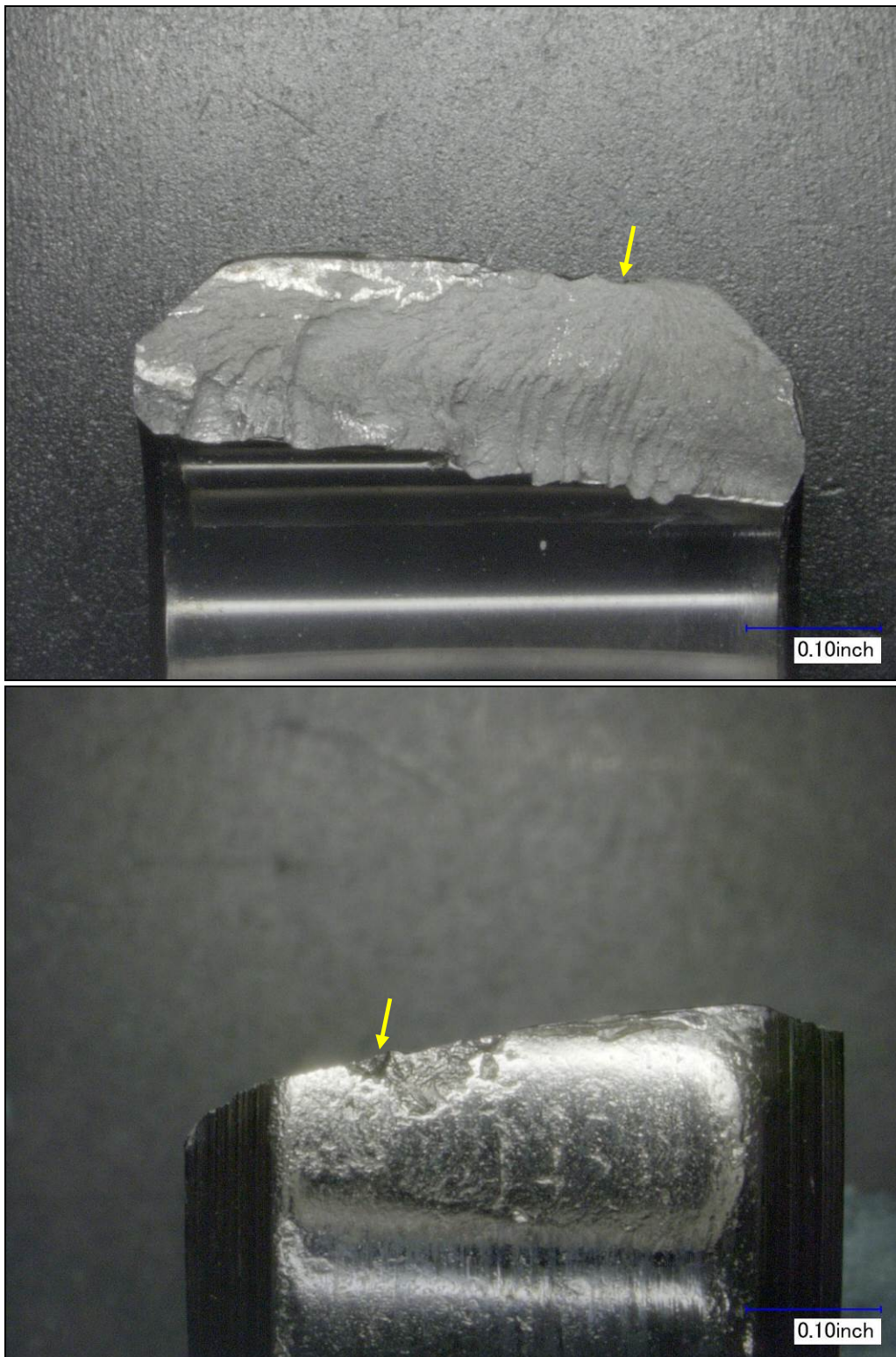


Figure 22. (Top) Fracture surface of roller with possible origin at the outside diameter denoted by the yellow arrow. The inside diameter of this roller segment is in good condition. (Bottom) Outside diameter of the same region had signs of severe spalling.

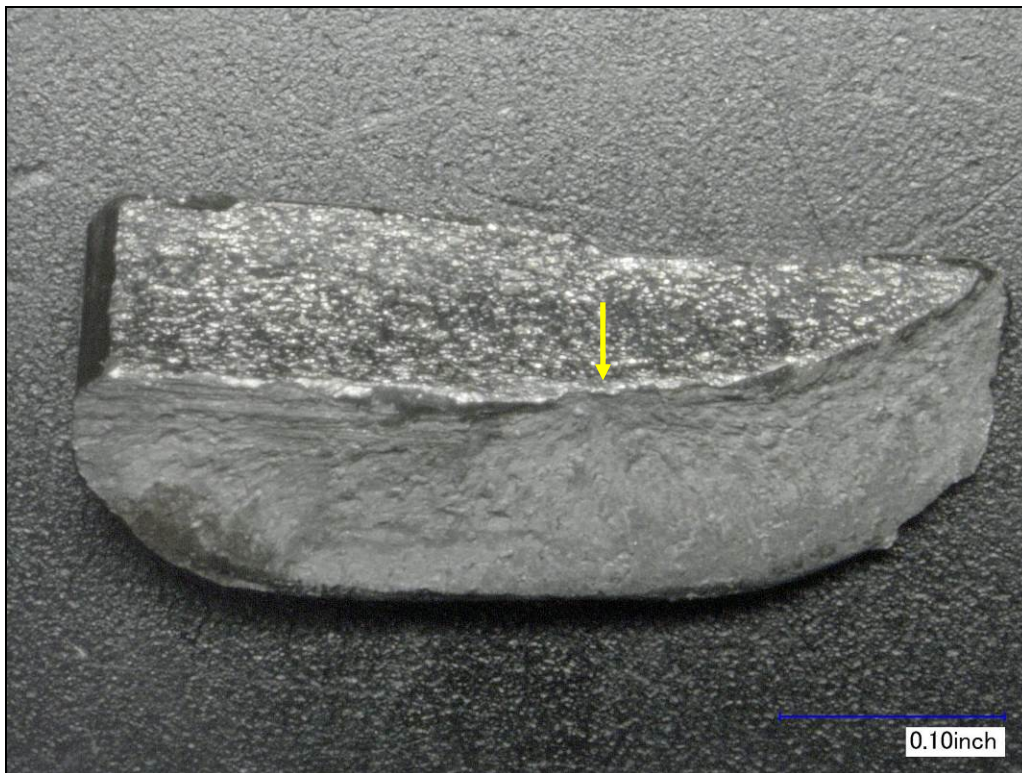


Figure 23. Roller ID with a fracture origin at the ID denoted by the yellow arrow.

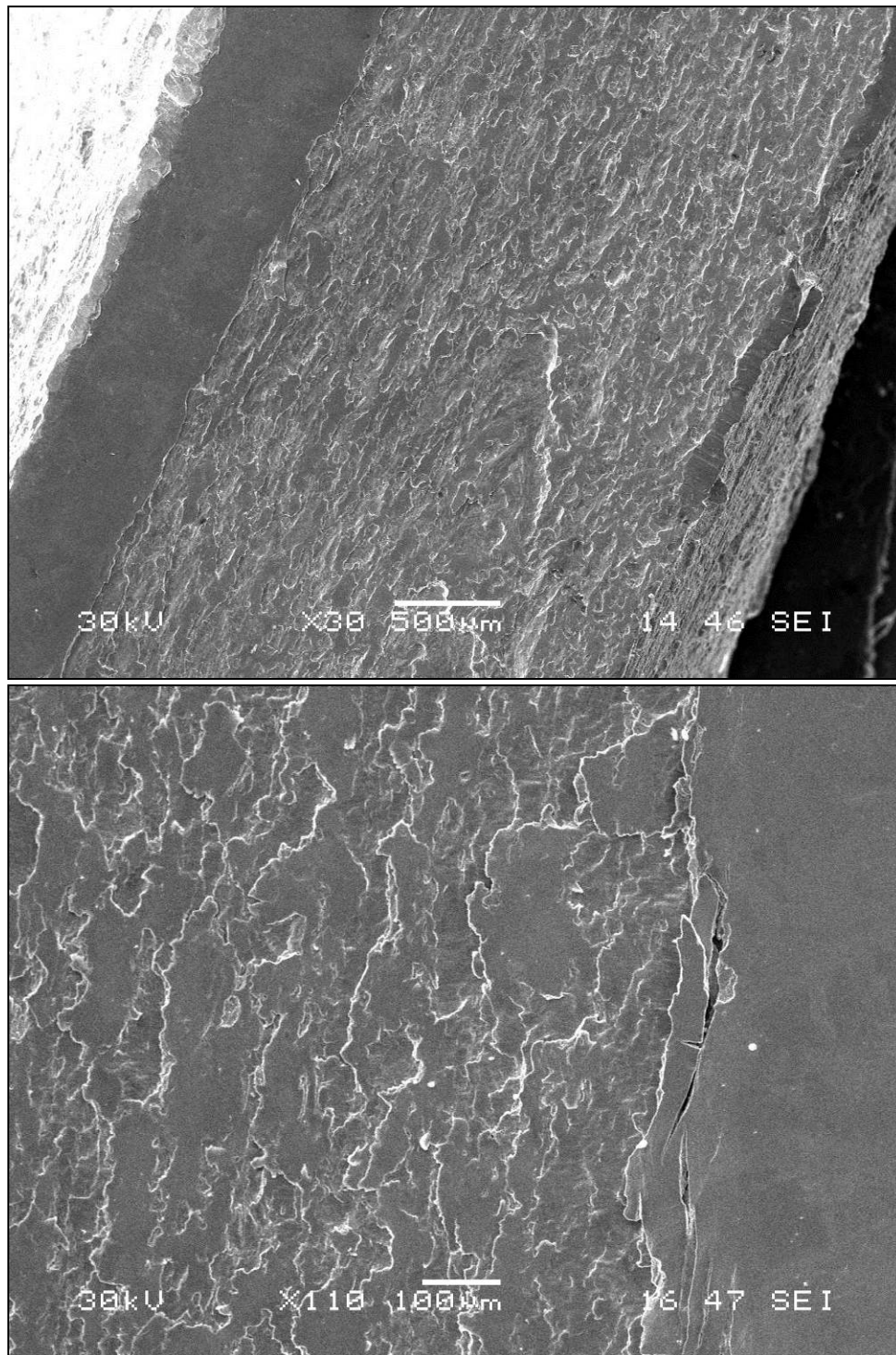


Figure 24. (Top) The inside surface of some segments of the roller showed signs of galling/spalling. (Bottom) SEM image of the damaged inside diameter of a roller segment.

The needle bearings were found in overall good condition.

The shaft was damaged mostly on the two ends and some areas of the midsection. One end of the shaft showed the staking indent, while the other end was too badly damaged to retain any evidence of the staking indent as shown in Figure 25.



Figure 25. Both ends of the shaft are shown. In the top image, yellow arrows indicate the indent from the staking operation. In the bottom image, the opposite end of the shaft is badly damaged.

2.4 Hydraulic Lifter Assembly, Rocker Arm, and Push Rod from #4 Exhaust

The hydraulic lifter assembly from the #4 exhaust is shown in Figure 26 in the as-received condition in the Materials Lab. The lifter assembly was then tested in accordance with the 15B26066 acceptance standard leakdown test defined in LPS-551 Section V. The leakdown rate was higher than the acceptance criteria of LPS-551 Section V of 10-30 seconds, measuring 41.4 seconds when tested as-received while coated in engine oil. The hydraulic lifter assembly was then purged three times with the Brayco 460 test fluid, and re-run, this time measuring 32.7 seconds. Run a third time, with no additional purging with test fluid, a result of 34.0 seconds was measured. The assembly was then purged three more times, and re-tested, measuring 37.8 seconds. The hydraulic lifter assembly was nonconforming for the leakdown test; however it was within material review board acceptance limits and not considered a contributor to this failure. No additional evaluation of the lifter was performed.

The rocker arm and push rod did not show signs of abnormal wear.



Figure 26. Hydraulic Lifter Assembly.

2.5 Oil Filter

The oil filter was examined and found to contain an expected amount of fine chips based on the engine damage, as shown Figure 27. A representative selection of approximately 18 chips were cleaned in trichloroethylene and examined using energy dispersive x-ray spectroscopy.

Three chips of 52100 steel (likely from the roller tappet assembly roller or shaft), two copper plating chips (camshaft, valve guides, rocker arms, connecting rod bolts), five aluminum alloy chips (likely from pistons or accessory housing), and eight aluminum alloy chips (likely from the crankcase).



Figure 27. Typical regions showing the amount of chips found in the oil filter upon examination.

3.0 Summary

Severe spalling and galling damage was observed on the #4 exhaust camshaft lobe along with the outside diameter of the associated roller tappet roller. Additionally, spalling was observed within the #4 exhaust roller tappet body ears supporting the roller shaft. Evidence of fatigue, in the form of fatigue striations, was observed on one of the #4 exhaust roller tappet body ear fracture surfaces. Witness marks on the inside of the crankcase bore holding the #4 exhaust roller tappet along with the uneven wear on the #4 exhaust cam lobe might indicate that slight rocking of the roller tappet occurred in the case at some point.

The root cause of the fractured roller tappet was not determined but was not due to a material nonconformance of the roller tappet assembly or the camshaft. The severe wear between the roller and camshaft likely led to non-standard loading conditions, perhaps worsened by or caused by, slight rocking of the roller tappet in the crankcase bore, ultimately resulting in failure of the roller tappet body and the release of the roller, roller shaft, and needle bearings.
