

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



November 19, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-058

A. ACCIDENT INFORMATION

Place : Talking Rock, Georgia
Date : March 5, 2019
Vehicle : Hughes 369D, N89ZC
NTSB No. : ERA19FA118
Investigator : Chihoon Shin, AS-40

B. COMPONENTS EXAMINED

Overrunning clutch assembly part number 369A5350-51.

C. DETAILS OF THE EXAMINATION

Overall views of the submitted overrunning clutch assembly photographed as received are shown in figures 1 and 2. The clutch housing had been disassembled from the assembly before the assembly was received. The attachment flange at the aft end of the housing was fractured, and the outer race at the aft end of the clutch subassembly was also fractured. As installed on the helicopter, the overrunning clutch is located between the engine power and accessory unit and the main drive shaft. The input end of the clutch at the aft end of the assembly is driven by the engine power and accessory unit, and the output at the forward end of the clutch assembly drives the main drive shaft. The direction of rotation is clockwise as viewed looking toward the forward direction.¹

A diagram showing the parts of the overrunning clutch assembly is shown in figure 3. The diagram is included in the overhaul manual for the part number 369A5350-603 and -605 overrunning clutch assembly.² Several components of the clutch are shown labeled in the diagram, including the fractured outer race. A cutaway diagram adapted from the Component Overhaul Manual is shown in figure 4, where the outer race cross-section is shaded gray. The location of the primary fracture in the outer race is indicated with a red dashed line in figure 4.

On November 12, 2018, with 1,307.7 hours time in service since overhaul (TSOH), the accident clutch subassembly had been removed from another helicopter for inspection, and the outer race was rejected due to crack indications located at the forward

¹ Unless otherwise noted, clock references in the report will be oriented as viewed looking toward the forward direction.

² CSP-COM-5 *Component Overhaul Manual, Overrunning Clutch Part Number 369A5350-603, -605*, MD Helicopters, Inc., Mesa, Arizona.

end of the splines at the input end of the subassembly. The rejected outer race was replaced with a new outer race (part number 369A5352-5, serial number 5304-1012) that was manufactured October 18, 2018 consistent with markings observed on the accident outer race that read, "369A5352-5 REV K 5304 10-18-18 S/N 5304-1012 HEAT LOT NO. 264154 M NE". The accident overrunning clutch subassembly with the new outer race was installed on the accident helicopter on February 18, 2019, replacing an overrunning clutch subassembly that was removed for a periodic sprag bearing inspection. At the time of the accident, the installed overrunning clutch subassembly had 1,341 hours TSOH and 33.3 hours time in service since installation on the accident helicopter.

During assembly of the overrunning clutch subassembly as described in the Component Overhaul Manual, the lock washer (see figures 3 and 4) is installed as a flat washer. After the bearing retainer nut is installed on the assembly, the lock washer is crimped into recesses in the outer race and the bearing retainer nut to lock the nut in position. During a visual examination of the subassembly as-received, the crimp deformations in the lock washer were observed to be displaced relative to the recesses in the outer race and the bearing retainer nut as shown in figure 5 for two of the four crimps. Two aft-facing crimp deformations in the washer were displaced clockwise 0.12 inch for one crimp and 0.14 inch for the other crimp relative to each corresponding recess in the outer race. Two forward-facing crimps in the washer were also displaced clockwise approximately 0.13 inch for one crimp and 0.85 inch for the other crimp relative to each corresponding recess in the bearing retainer nut. The tightening direction of the bearing retainer nut is counterclockwise (nut surface moving upward in the views shown in figure 5), and all lock washer crimps were displaced toward the loosening direction of the nut relative to their corresponding recesses.

Before disassembling the overrunning clutch subassembly, the subassembly was sent to Varex Imaging Corporation, Franklin Park, Illinois, for imaging using X-ray computed tomography (CT).³ The CT data was then analyzed by Scott Warren from the NTSB Office of Aviation Safety, and a cross-sectional CT image of the subassembly is shown in figure 6. No gaps were noted in the CT images of the assembly where bearing races abutted to corresponding washer faces and shoulders, and the axes for the outer and inner races were found to be parallel.

Using a 3-millimeter touch probe attached to a Faro EDGE FaroArm coordinate measurement device,⁴ the shaft of the inner race and the outer surface of the outer race was probed to obtain coordinates that were then fit to cylinders using CAM2 Measure 10 software.⁵ The orientations of the two cylinder axes were compared, and the angular difference between the axes was determined to be 0.048 degrees.

After initial photography was completed on the subassembly, surface oil was cleaned from the outer race using a soft-bristle brush dipped in a solution of Alconox

³ Preliminary saw cuts (see figure 13) were made to expose the fatigue origin area as described later in the report before CT imaging was completed on the subassembly.

⁴ FARO Technologies, Inc., Lake Mary, Florida.

⁵ CAM2 Measure 10, version 10.4.1.21, FARO Technologies, Inc., Lake Mary, Florida (2014).

detergent and water for additional examination and macro photography of the fracture. Views of the forward side of the fracture in the outer race are shown in figures 7 and 8. The fracture consisted of a circumferential portion, a spiral portion that extended more than 360 degrees around the circumference, and a longitudinal portion that linked between the spiral faces. The various portions of the fracture are indicated in figure 7.

The circumferential portion of the fracture was located primarily in the fillet radius at the forward end of the input shaft portion of the outer race. Circumferential cracks shown in the middle and upper images in figure 7 extended clockwise and counterclockwise from the circumferential portion of the fracture. On the counterclockwise side of the circumferential portion of the fracture shown in the upper image in figure 7, the circumferential crack was continuous as the spiral crack branched counterclockwise and aft from the primary circumferential crack. An unlabeled arrow in the upper image in figure 7 indicates the direction of crack propagation along the spiral fracture away from the primary circumferential crack. The circumferential crack extended around 2/3 of the circumference as shown in figure 8, where labels indicate the locations of the circumferential crack tips.

Part of the spiral portion of the fracture had a flat fracture with curving crack arrest lines, features consistent with fatigue cracking. Fatigue propagation on a spiral plane is consistent with fatigue crack growth from cyclic torsion loads. The fatigue features on the spiral portion emanated from the area shown in the figure 7 upper image where the spiral crack branched from the primary circumferential crack. The location of the fatigue boundary on the spiral portion of the fracture is indicated in figure 8. The remainder of the spiral portion of the fracture and the longitudinal portion linking the spiral faces had matte gray features or smeared shiny features consistent with ductile overstress fracture. Portions of the fracture were obliterated by post-fracture contact between mating sides of the fracture.

The circumferential portion of the fracture was partly obscured from view by the mating shaft piece with spiral portions of the fracture. In order to obtain an unobstructed view of the primary fracture, a longitudinal cut was made through the shaft followed by an angled cut to remove a V-shaped notch. The V-shaped notch was then pinched to break open the circumferential portion of the fracture and remove the mating shaft piece. A view of the resulting opened fracture after cutting is shown in figure 9.

A closer view of the circumferential portion of the fracture is shown in figure 10. The fracture surface had flat features with radial marks emanating from the outer surface in the area identified as the origin area in figure 10. Unlabeled arrows in figure 10 indicate local crack propagation directions. An unopened portion of the circumferential crack continued clockwise from the longitudinal cut at the clockwise end of the origin area. Crack arrest lines consistent with fatigue crack propagation away from the origin area were observed clockwise of the origin area. In the origin area, the crack propagated from a broad origin area toward the interior of the outer race shaft. The origin area had a shiny appearance consistent with fracture surface recontact. A radial crack intersecting the fracture surface was observed within the origin area, and a crack that appeared to be a

continuation of the fracture from part of the origin area was observed on the interior surface.

The mating side of the fracture in the origin area is shown in figure 11. The fracture surface was rubbed and gouged consistent with fracture surface recontact. Another view of the origin area on the shaft side of the fracture is shown in figure 12. A possible ratchet mark was observed on the damaged fracture surface that appeared to be present on the mating surface as well.

Next, the overrunning clutch subassembly was disassembled. First, components forward of the bearing retainer nut were removed from the inner race. Next the bearing retainer nut was unscrewed from the outer race. Finally, the inner race and bearings were pressed out of the outer race.

The interior surfaces of the subassembly were generally covered with oil. The oil was wiped from the surfaces with an absorbent cloth to read information marked on the bearings. The outer race on the aft sprag bearing was marked "RI-2634SD610RDA3 MFR-83086". The cage on the sprag assembly was marked "Form-Sprag 369D25351 CL7605-81-5 031" and the aft face and an arrow with the characters "FORMSPRAG USA CL42315 S/N 7254 369D25351 -E" on the forward face. The outer race of the forward sprag bearing was marked "USA MRC R20" on the aft face and "J M 06" on the forward face.

Outer diameters of the aft and forward sprag bearings were measured using calipers. The outer diameters of the aft and forward sprag bearings were 1.622 inches and 2.246 inches, respectively. Corresponding inner diameters for bearing seats on the outer race as measured using a micrometer were 1.6249 inches for the aft bearing and 2.2498 inches for the forward bearing. The dimensions measured on the outer race were within engineering drawing tolerances for the specified inner diameters. The inner diameter of the outer race for the sprag assembly was also measured, and the measured inner diameter of 2.1549 inch was also within drawing specification.

Oil was cleaned from the interior surfaces of the bearing retainer nut, and fretting damage was observed on the interior contact face where the nut mated to the outer race of the forward sprag bearing as shown in figure 13. No fretting damage was noted on the mating forward face of the forward sprag bearing outer race. However, matching fretting damage was observed on the aft face consistent with fretting occurring during a prior installation where the bearing was installed with the opposite face in contact with the nut.

The separated outer race was placed in a degreasing solution to remove oily deposits and was subsequently submerged in acetone and cleaned using an ultrasonic cleaner. The cleaned piece was then placed in a scanning electron microscope (SEM) for examination. A mosaic of SEM images showing an overall view of the origin area is shown in figure 14, and closer views of a portion of the origin are shown in figure 15. Fracture features near the outer surface were obliterated by post-fracture smearing within

the origin area. Unlabeled arrows in figure 14 indicate local fatigue crack propagation directions emanating away from the damaged origin area.

Isolated areas of remaining fracture features within the origin area were observed near the outer surface of the overrunning clutch within the rectangle shown in the upper image in figure 15, an area that is shown at higher magnification in the lower image in figure 15. Within the smeared region, two pockets of intergranular fracture were observed within approximately 90 micrometers from the surface. Transgranular fracture features consistent with fatigue were observed 100 micrometers or more from the outer surface within the area shown in figure 15, and the fatigue features are shown at higher magnification in figure 16.

The outer surface of the outer race was examined where the primary crack continued clockwise around the circumference as shown in figures 17 and 18. Overall, the surface had an etched appearance with a surface texture that appeared to reveal the microstructure of the material. The primary crack had a faceted path that appeared to follow grain boundaries consistent with intergranular fracture. Multiple parallel cracks with similar intergranular features were observed within the fillet radius near the primary crack indicated in figure 17.

On the other side of the origin area, the fatigue crack propagated counterclockwise as shown by the unlabeled arrow furthest to the right in figure 14. A closer view of fatigue features adjacent to the surface away from the origin area is shown in figure 19. Transgranular fracture features were observed adjacent to the outer surface consistent with fatigue fracture. No intergranular fracture features were observed.

Further counterclockwise from the origin, a mosaic SEM image of the area where the spiral branching fatigue crack initiated from the primary circumferential crack is shown in figure 20. Fatigue features on the circumferential portion were consistent with fatigue crack propagation from the primary origin area toward the secondary origin associated with the spiral branching crack. A secondary fatigue origin area located at the circumferential fracture face was observed where the spiral portion of the fracture branched from the circumferential crack, and curving crack arrest lines were observed emanating from the secondary origin area consistent with fatigue crack propagation.

The outer surface of the outer race was examined where the primary crack continued counterclockwise around the circumference past the branching spiral crack as shown in figures 20 and 21. The surface had an etched appearance that was similar to features observed clockwise of the origin area. However, the crack path in this area was straighter than the crack at the opposite side of the origin (see figure 18), consistent with a transgranular fracture mechanism such as fatigue.

Next, additional cuts were made to expose the radial crack in the origin area (see figure 10) and the crack that continued toward the interior of the outer race. Two nearly radial saw cuts were made near the clockwise end of the circumferential crack as shown in figure 22 to remove the V-shaped piece shown in figure 23 that was later prepared for

metallurgical examination and hardness testing. Additional saw cuts were made near the radial crack to allow the radial crack to be pinched open. A view of the opened radial crack is shown in the lower image in figure 22. A secondary origin initiating at the primary crack surface was observed. Unlabeled arrows in figure 22 indicate local directions of fatigue crack propagation consisting of a continuation of the primary crack toward the interior of the outer race merged with a branching crack emanating radially outward from the secondary origin.

The section of the outer race shown in figure 23 was mounted, polished, and etched to facilitate a metallurgical examination, and the polished and etched microstructure is shown in figure 24. The sample was etched with a solution of 2 percent nitric acid in methanol (2% nital) revealing a microstructure consistent with tempered martensite. The microstructure at the surface of the fillet radius associated with the primary crack (see red circle in figure 23) had a similar appearance as shown in figure 25 with no evidence of distorted grains.

Core hardness of the overrunning clutch outer race was measured on the mounted cross-section of the overrunning clutch outer race using a Rockwell test machine set to the 30N scale. The average hardness measured in the middle of the cross-section was 41 HRC (60.2 HR30N), which was within the range of core hardness specified on the engineering drawing.

The metallurgical mount was then repolished and examined in the as-polished condition. Several microcracks were observed at the surface within the fillet at the forward end of the input shaft such as the crack shown in figure 26. The microcracks extended up to approximately 10 microns in depth. The metallurgical mount was further examined using the SEM, and an SEM image of the same microcrack shown in figure 26 is shown in figure 27. The microcrack branched at the tip, and the branching pattern appeared consistent with a path following grain boundaries.

After the SEM examination of the as-polished sample was completed, the metallurgical mount was repolished to remove a thin conductive coating that was applied to prevent charging of the mounting material,⁶ and the sample was etched again with 2% nital to facilitate an SEM examination of the etched sample. An SEM image of one of the microcracks within the fillet at the forward end of the shaft is shown in figure 28 after etching. The microcracks appeared to form at prior austenite grain boundaries.

⁶ Charging is the accumulation of negative charge on the surface that develops during electron imaging of nonconductive samples in a SEM under high vacuum and can result in distorted and overexposed images.

Manufacturing records related to the accident outer race were reviewed and compared to process specifications provided by MD Helicopters, Inc. The part had been heat treated including hardening processes to harden the splines on the input shaft and the surface that forms the outer race to the sprag assembly. The surfaces of the part were finished with a black oxide. The review of the manufacturing records related to heat treatment or surface conditioning revealed no anomalies.

Matthew R. Fox, Ph.D.
Senior Materials Engineer

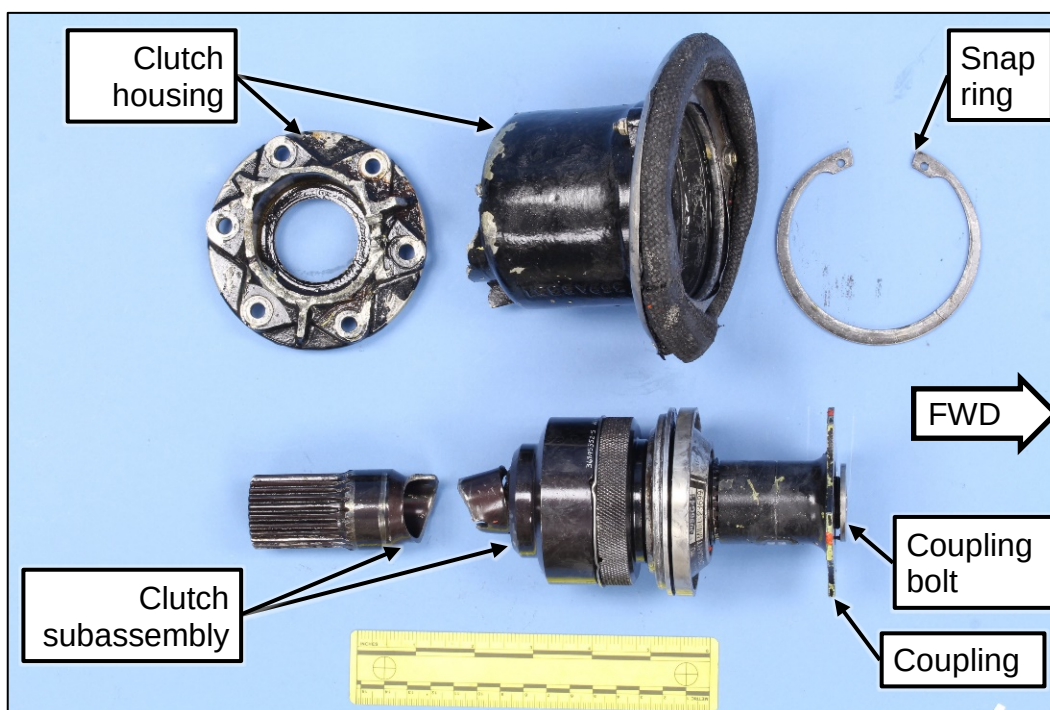


Figure 1. Overall view of the submitted overrunning clutch assembly as received with the housing disassembled from the subassembly.

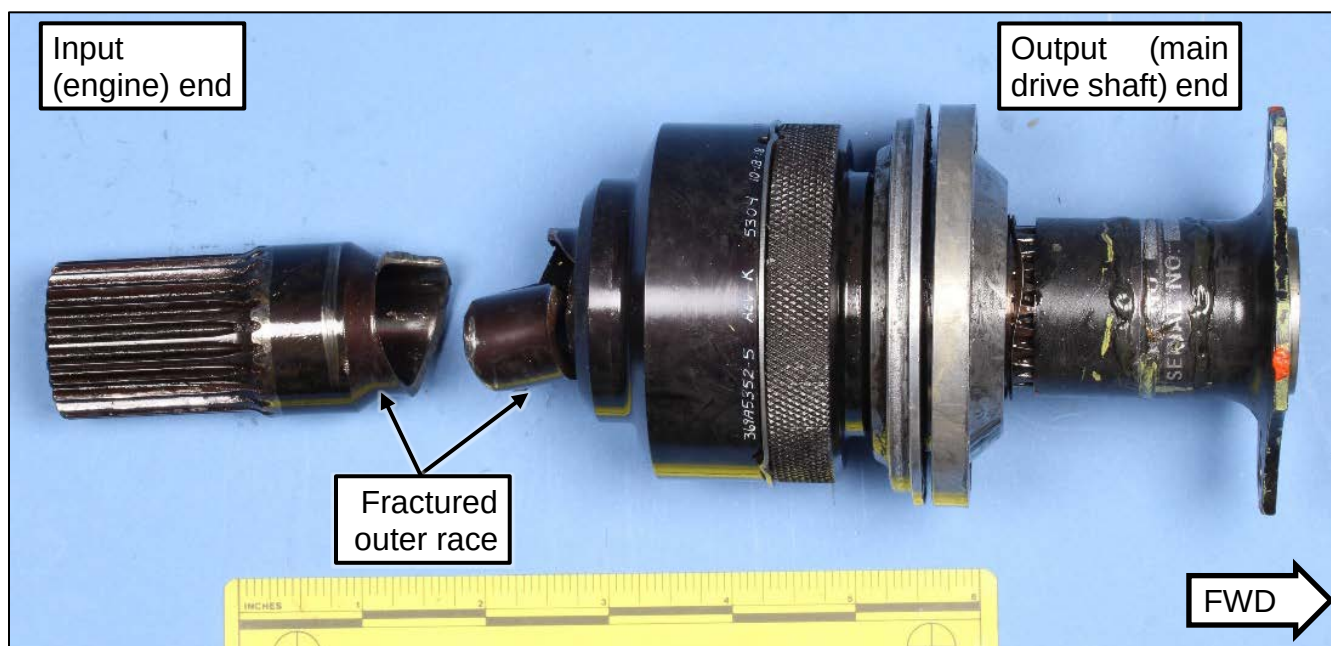


Figure 2. Closer view of the overrunning clutch subassembly showing the fractured outer race photographed as received.

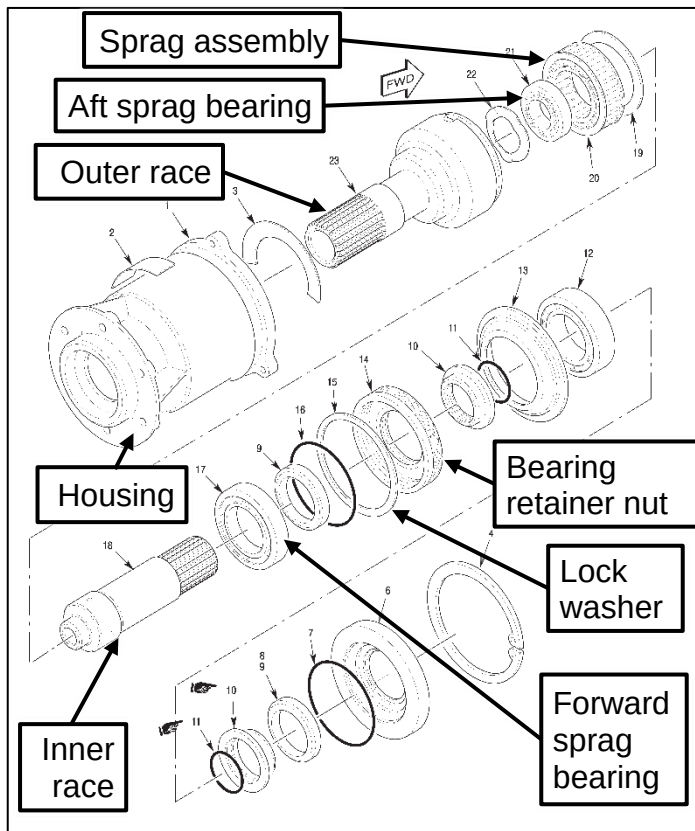


Figure 3. Parts diagram for the overrunning clutch assembly with selected components labeled. (Diagram from the Component Overhaul Manual provided courtesy of MD Helicopters, Inc.)

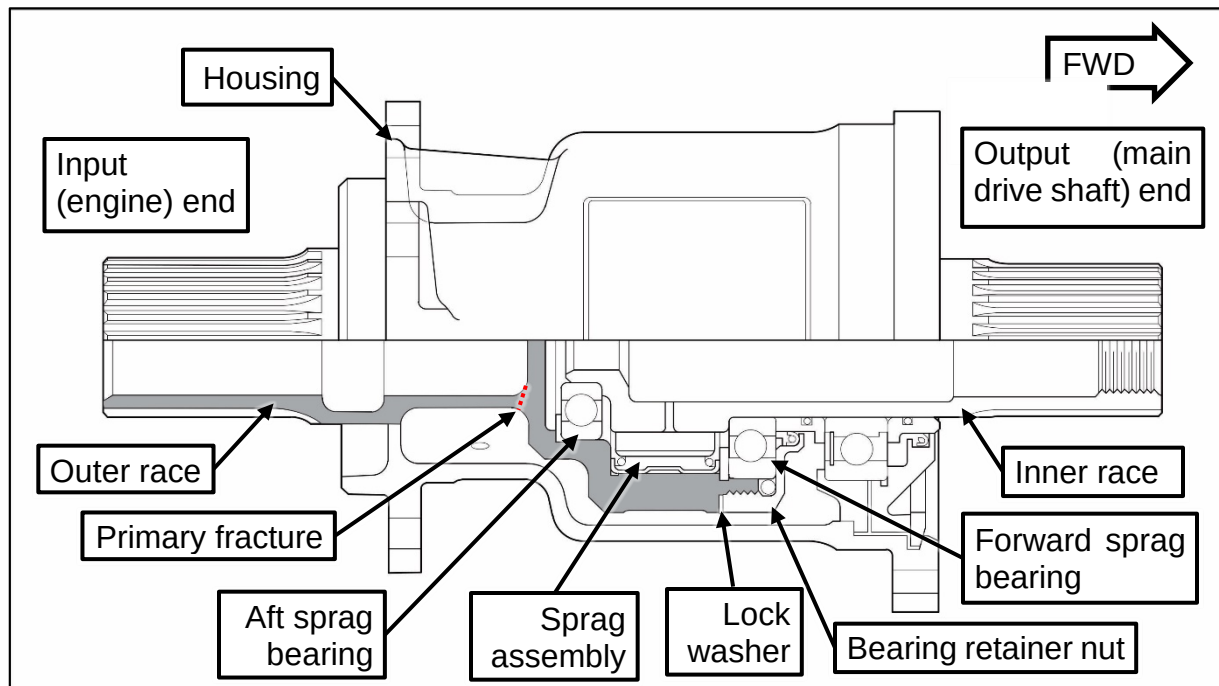


Figure 4. Cross-sectional cutaway diagram of the overrunning clutch assembly with the outer race cross-section highlighted in gray. (Adapted from the Component Overhaul Manual provided courtesy of MD Helicopters, Inc.)

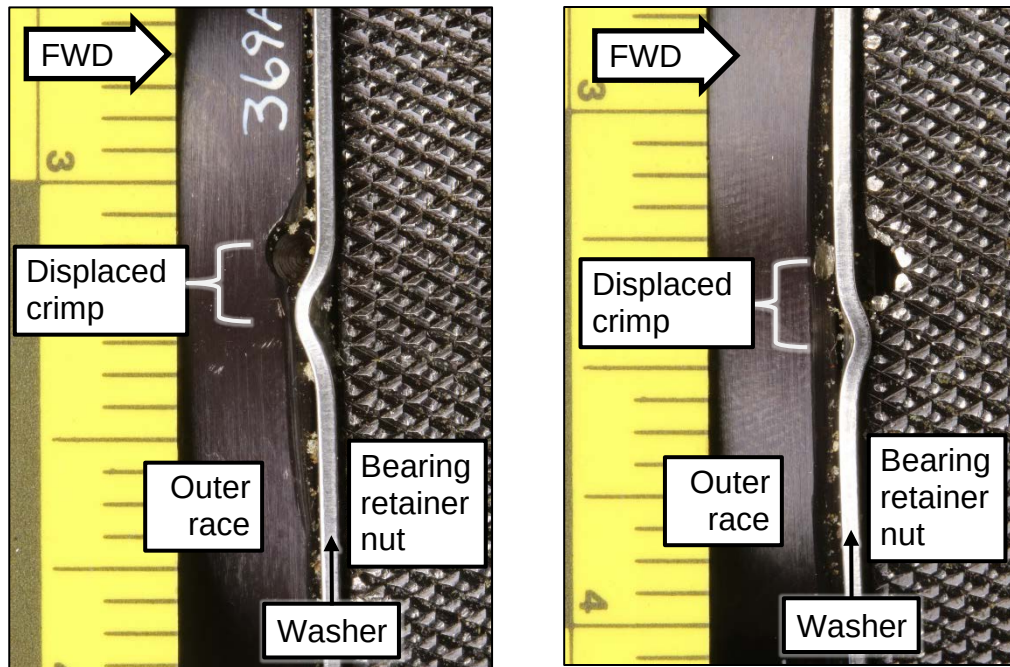


Figure 5. Close views of the outer race, washer, and bearing retainer nut showing displacement of the lock washer crimp deformations relative to locking recesses in the outer race and the bearing retainer nut.

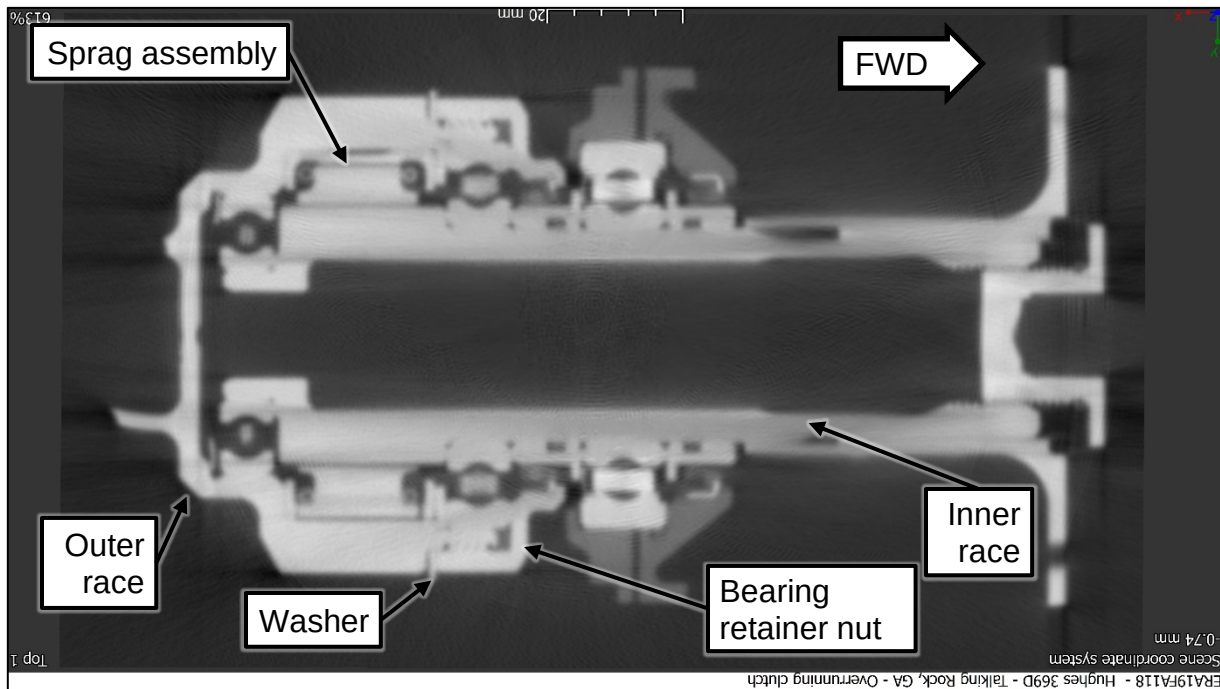
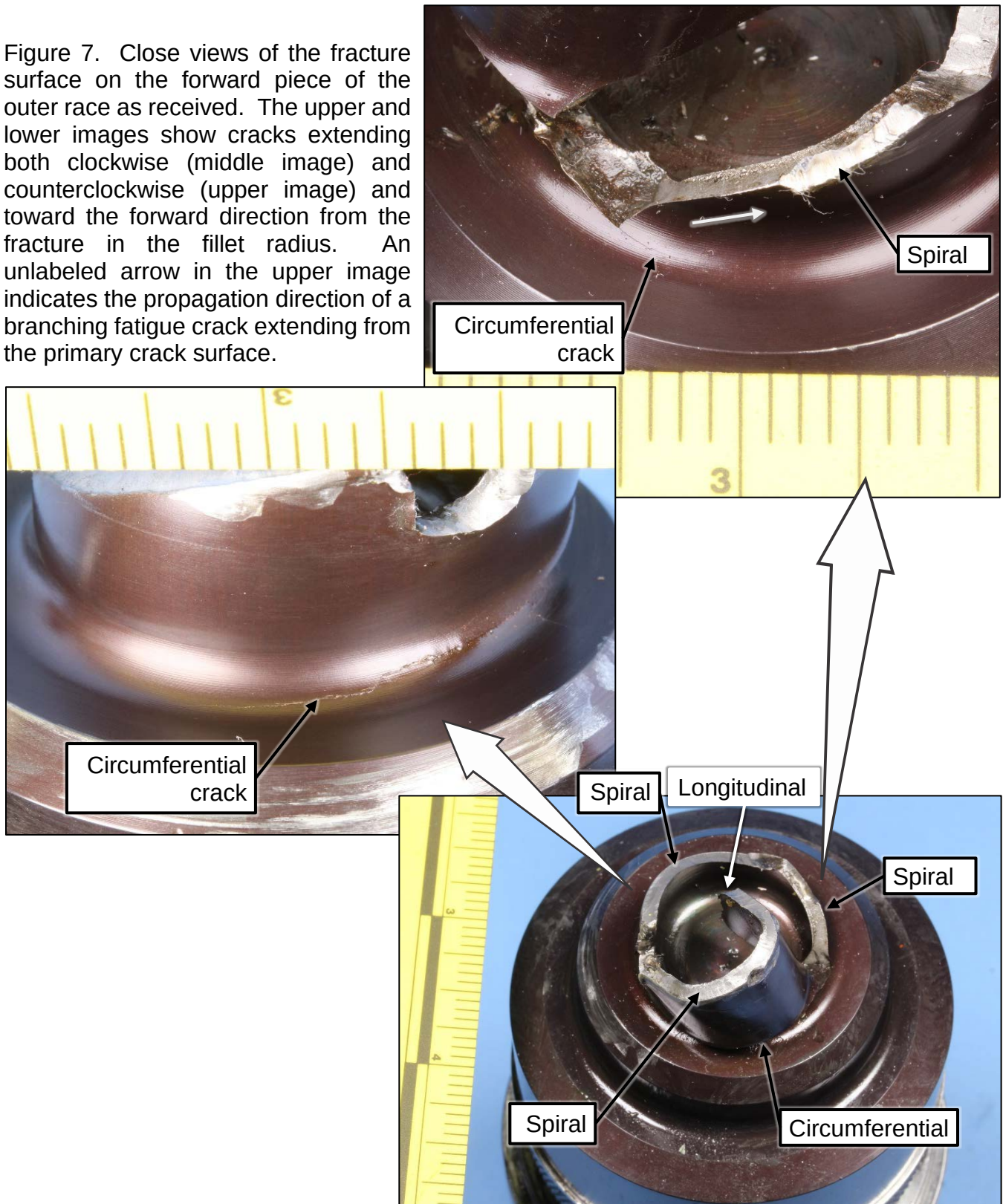


Figure 6. Cross-sectional image from an X-ray CT scan of the overrunning clutch subassembly before the subassembly was disassembled.

Figure 7. Close views of the fracture surface on the forward piece of the outer race as received. The upper and lower images show cracks extending both clockwise (middle image) and counterclockwise (upper image) and toward the forward direction from the fracture in the fillet radius. An unlabeled arrow in the upper image indicates the propagation direction of a branching fatigue crack extending from the primary crack surface.



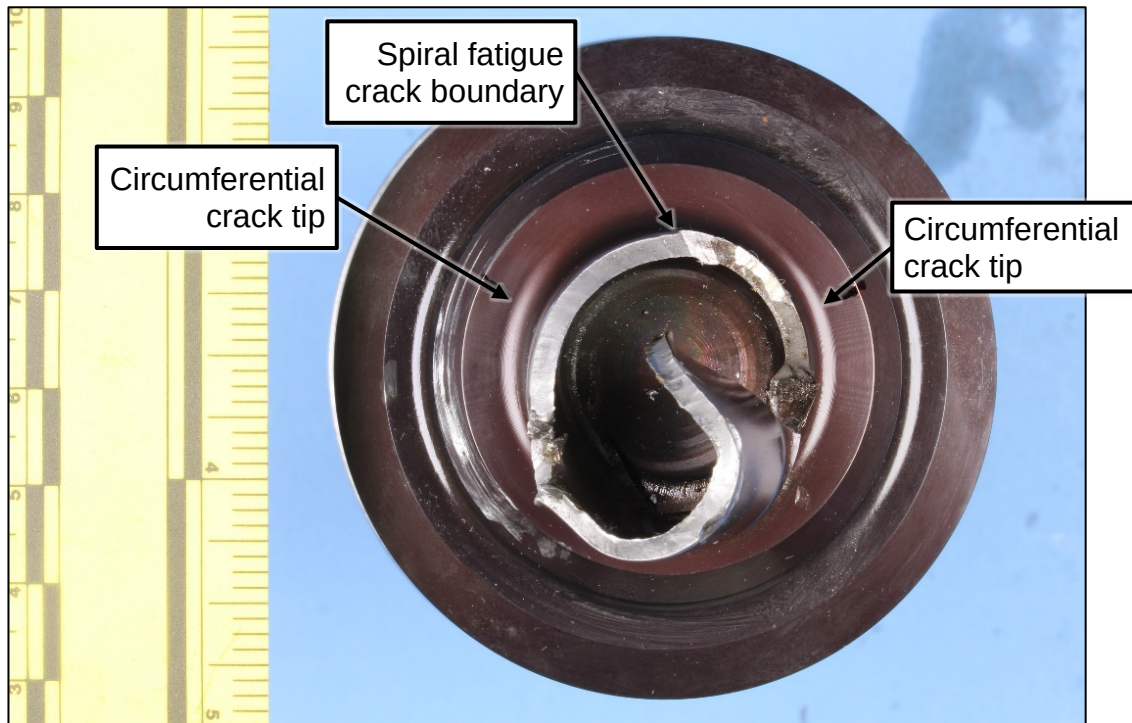


Figure 8. View looking forward showing the crack tips for the primary crack which extended around approximately 2/3 of the circumference and the boundary of the spiral branching fatigue crack.

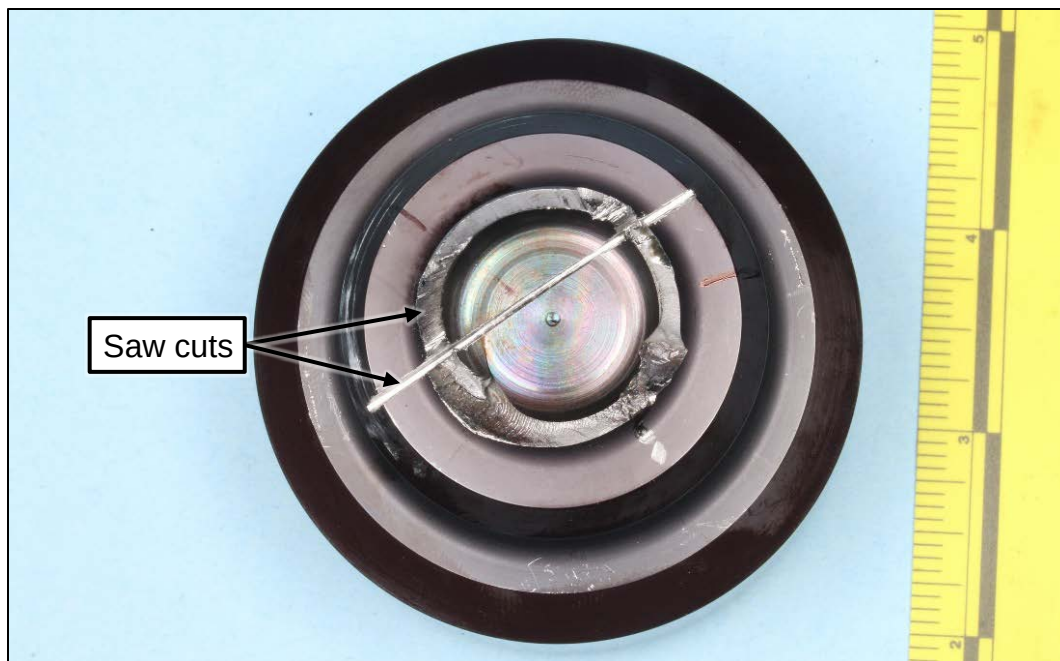


Figure 9. Fracture surface after cutting to remove the piece of input shaft that obscured much of the primary crack surface from view.

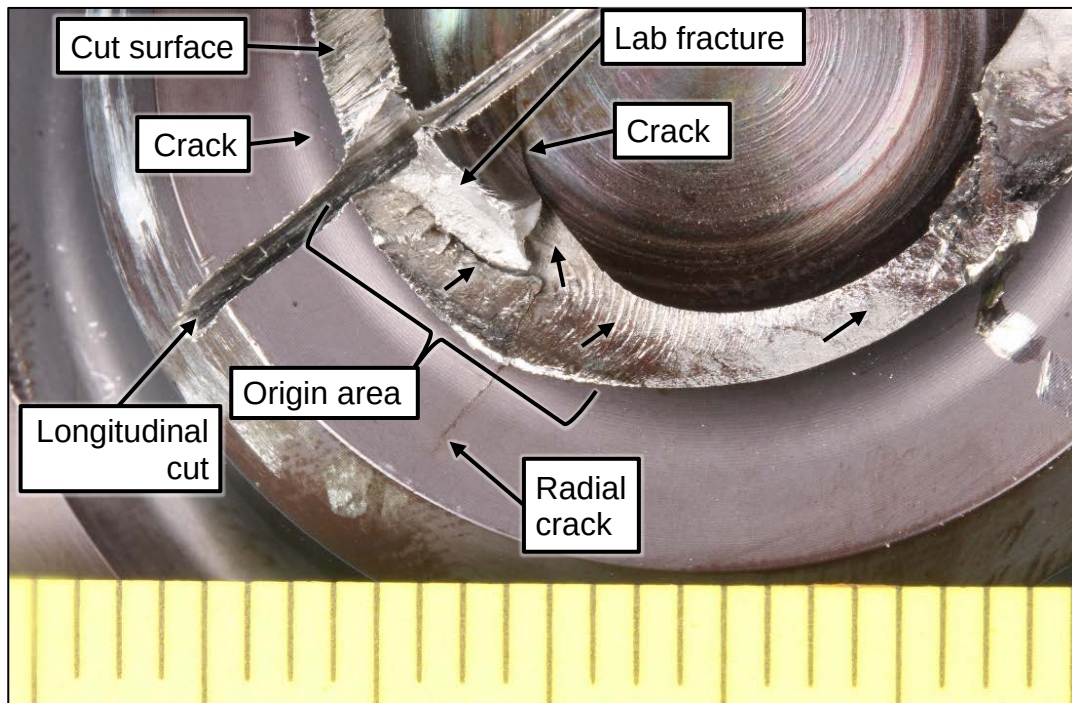


Figure 10. Closer view of the exposed origin area on the overrunning clutch. Unlabeled arrows indicate directions of crack propagation emanating from the broad origin area.

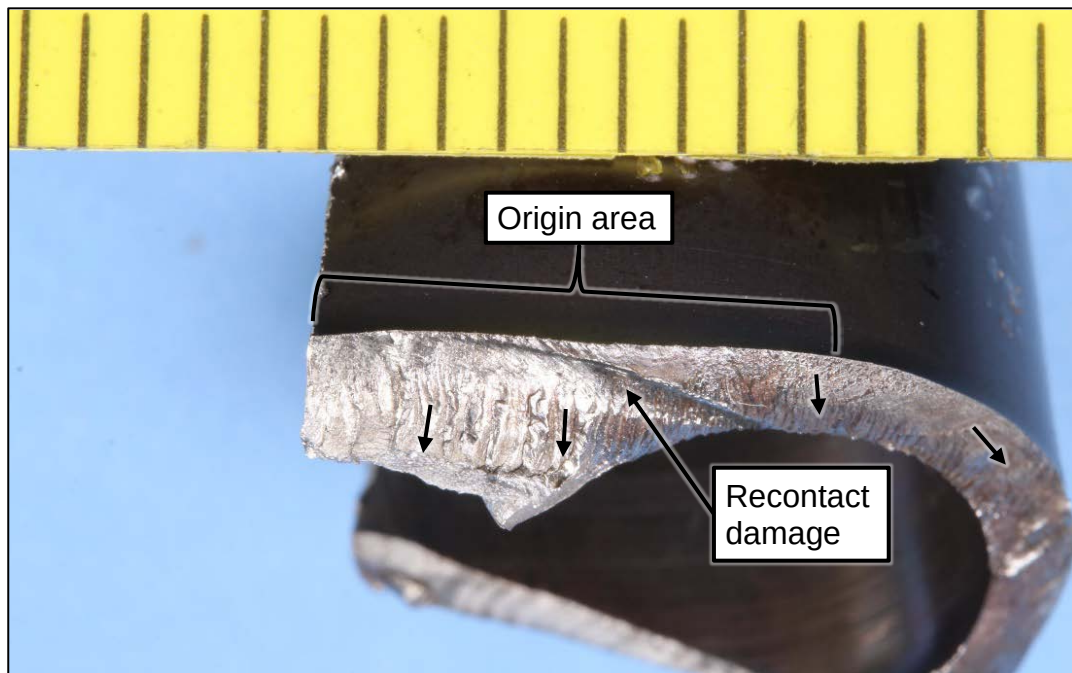


Figure 11. Origin area on the mating side of the fracture. Unlabeled arrows indicate crack propagation directions.

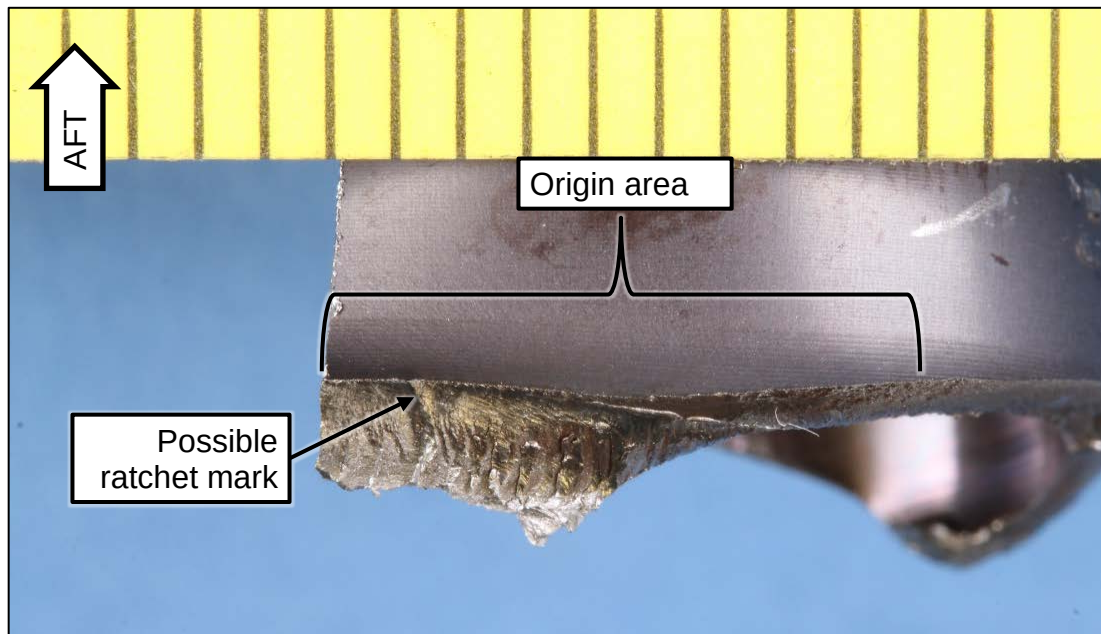


Figure 12. View of the shaft surface adjacent to the fracture at the origin area.



Figure 13. Fretting contact damage on the interior face of the bearing retainer nut.

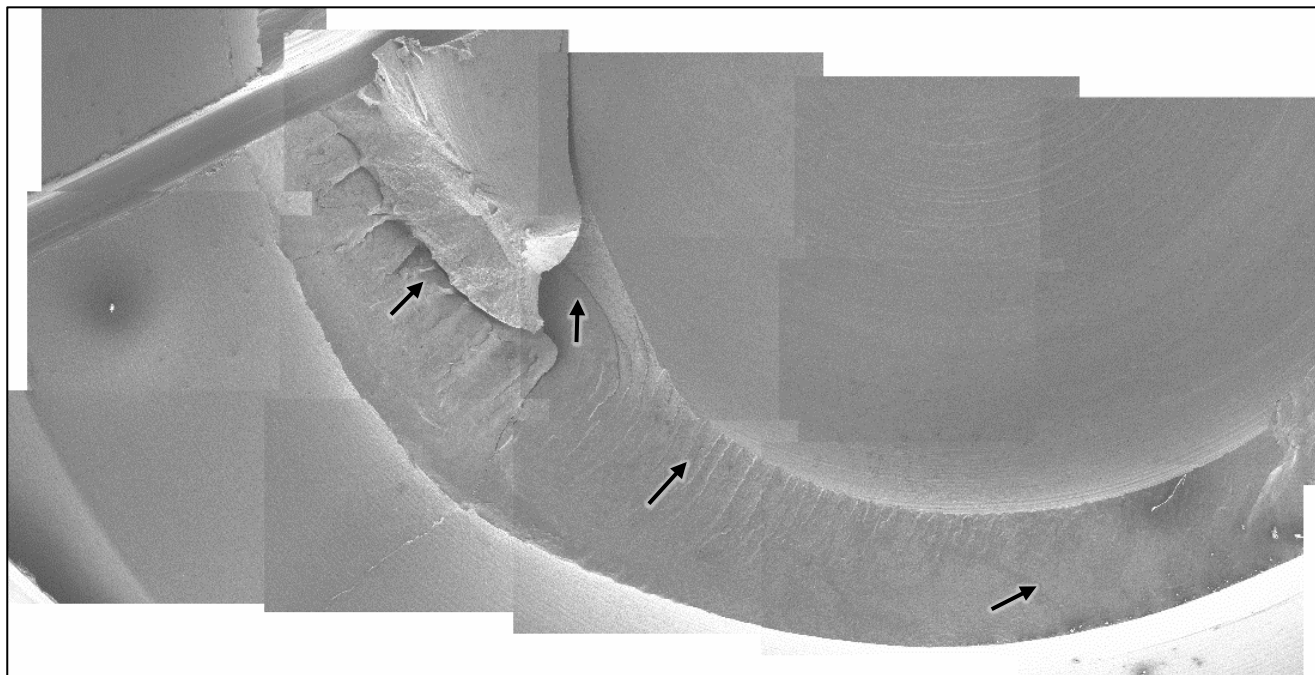


Figure 14. Mosaic SEM image of the origin area. Unlabeled arrows indicate local fatigue crack propagation directions.

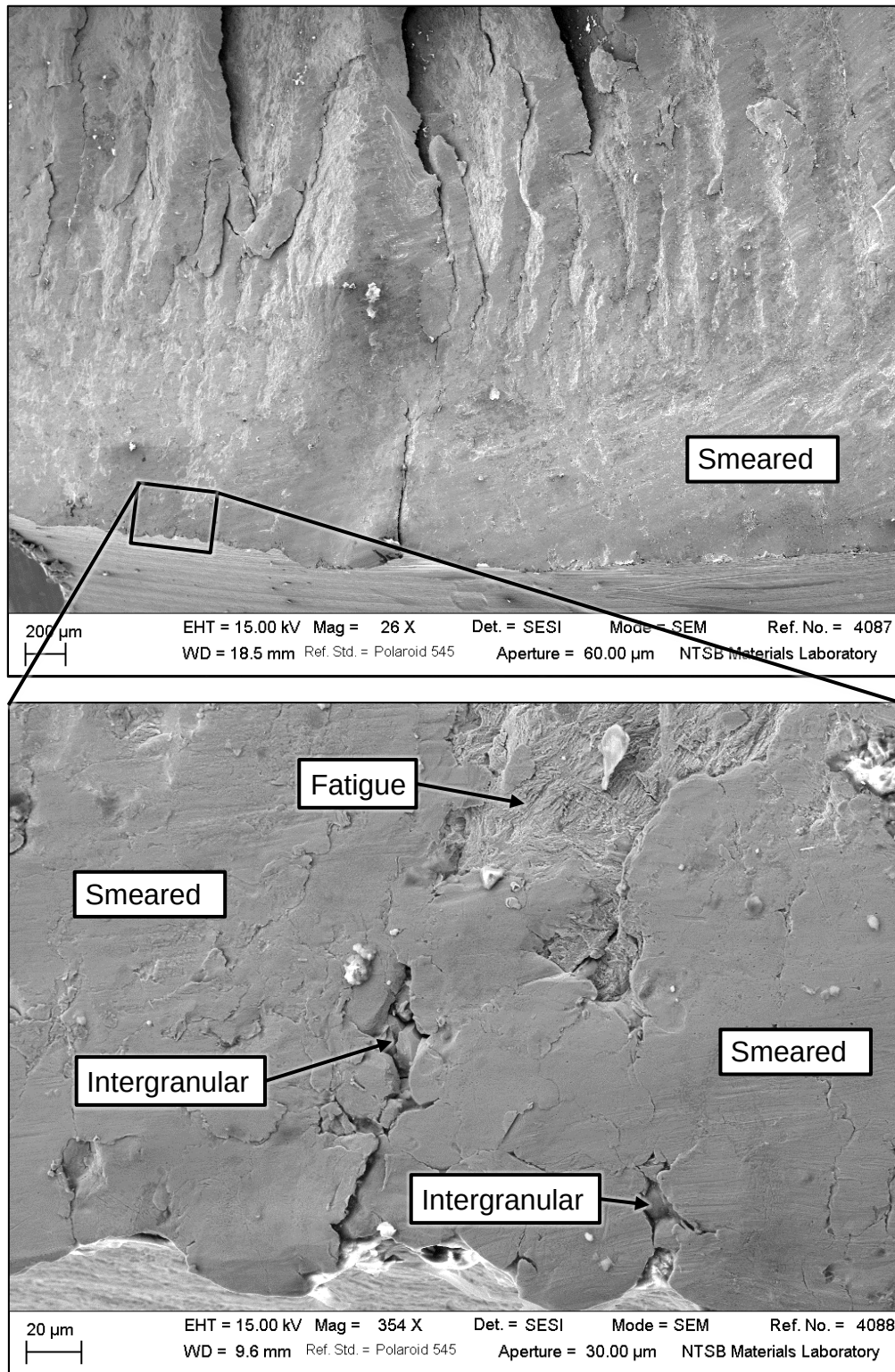


Figure 15. SEM images of the origin area.

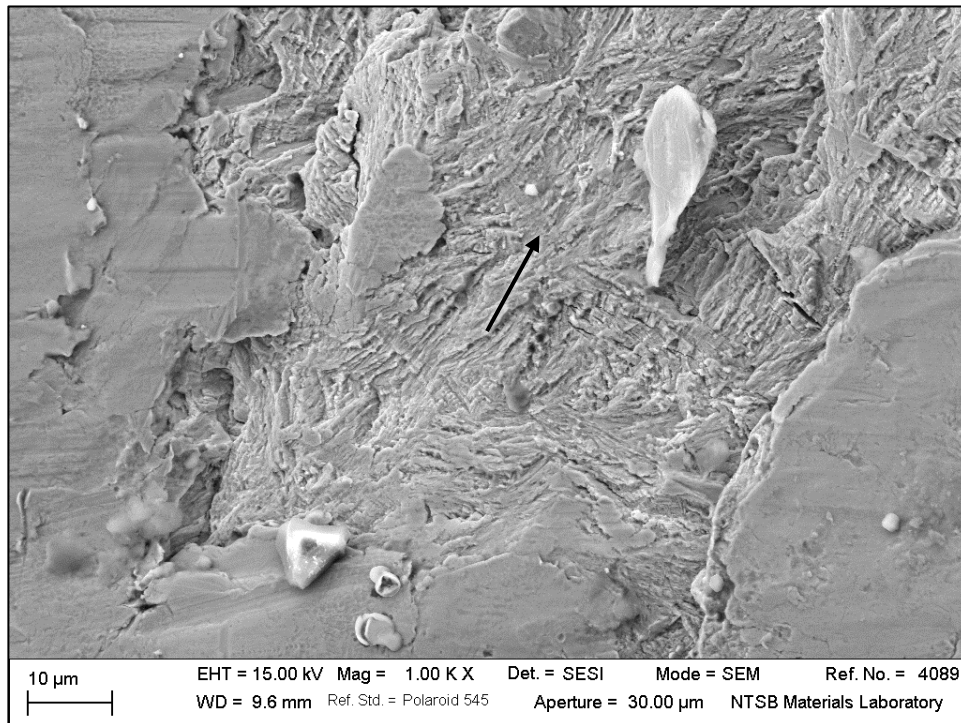


Figure 16. Closer view of fatigue features shown in the previous figure near the origin area. An unlabeled arrow indicates the general direction of fatigue crack propagation.

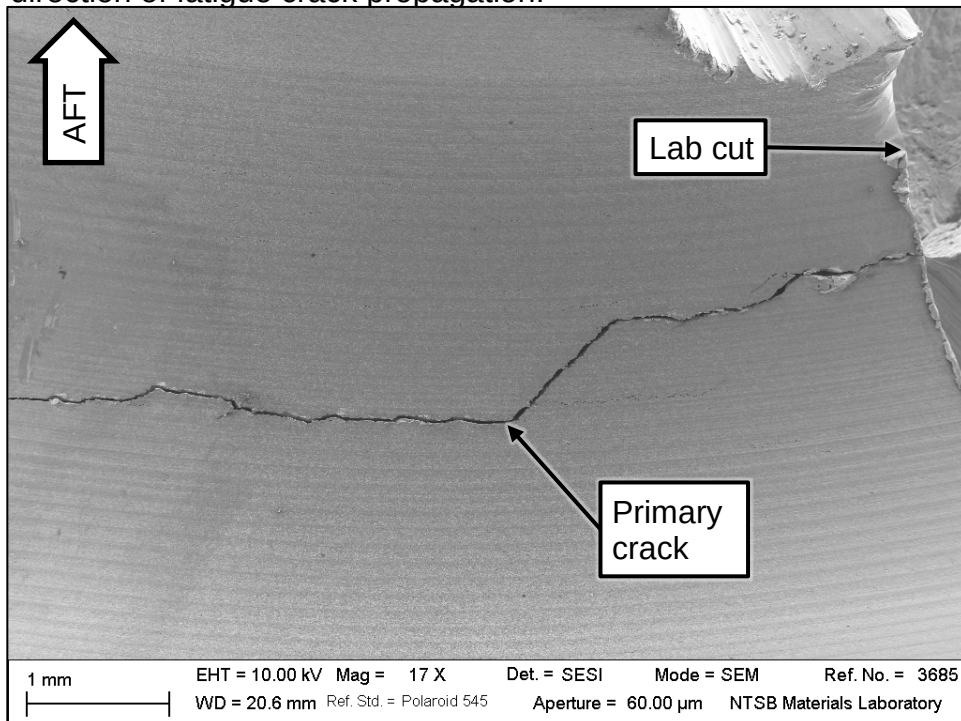


Figure 17. SEM image of the outer race fillet radius showing a portion of the primary crack clockwise of the lab cut.

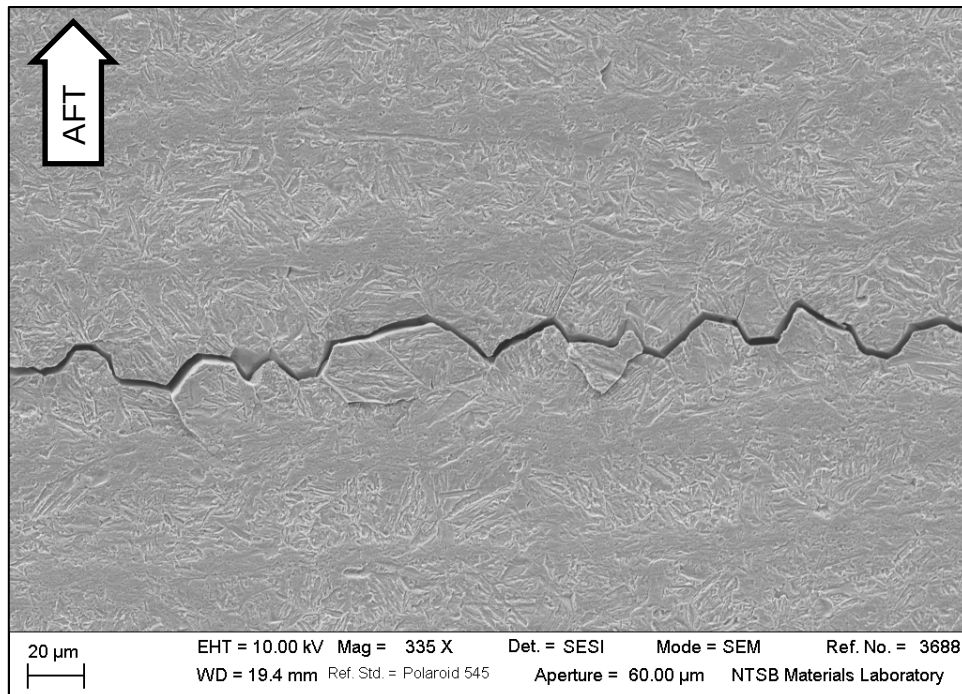


Figure 18. SEM image of the outer race fillet radius at higher magnification showing a portion of the primary crack clockwise of the lab cut.

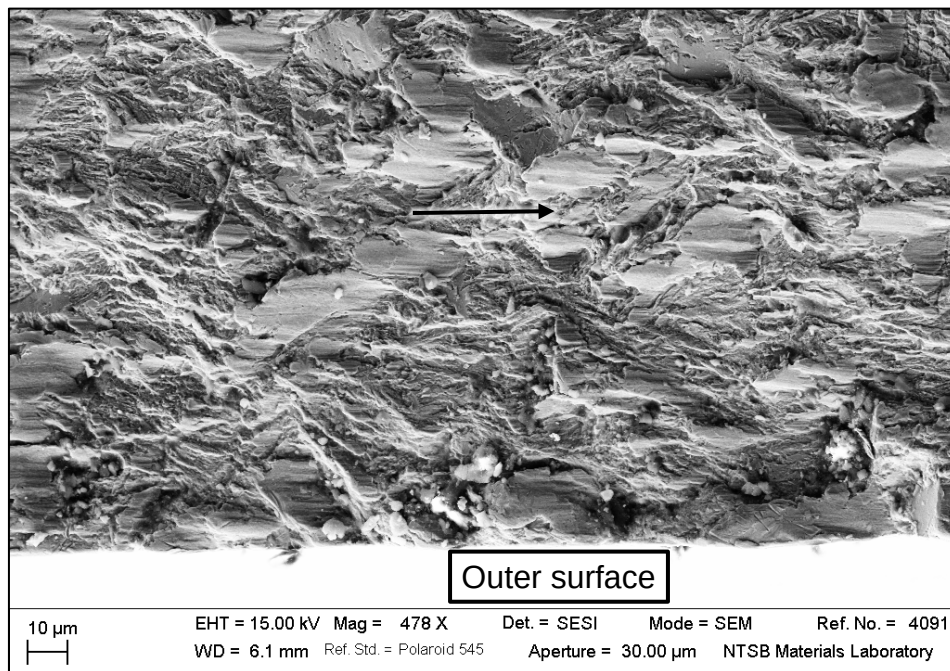


Figure 19. SEM image of fatigue fracture features near the outer surface further counterclockwise from origin. An unlabeled arrow indicates the general direction of fatigue crack propagation.

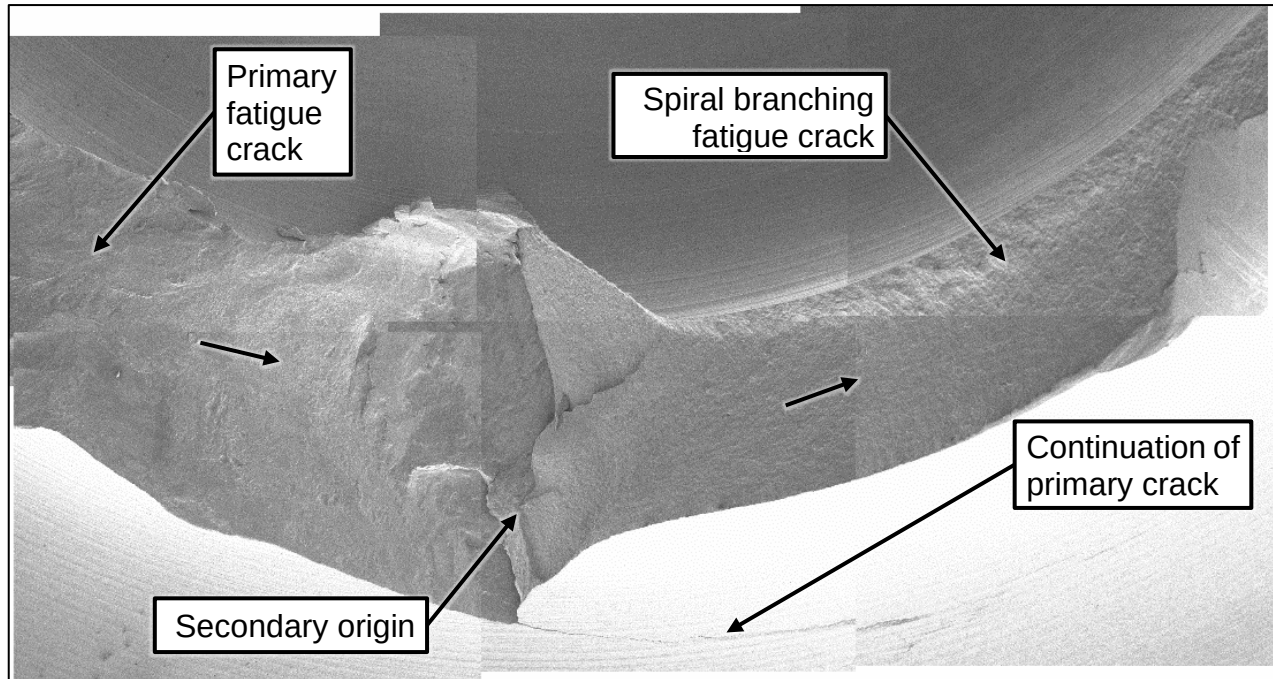


Figure 20. Mosaic SEM image of the secondary origin area associated with the spiral branching fatigue crack. Unlabeled arrows indicate local crack propagation directions.

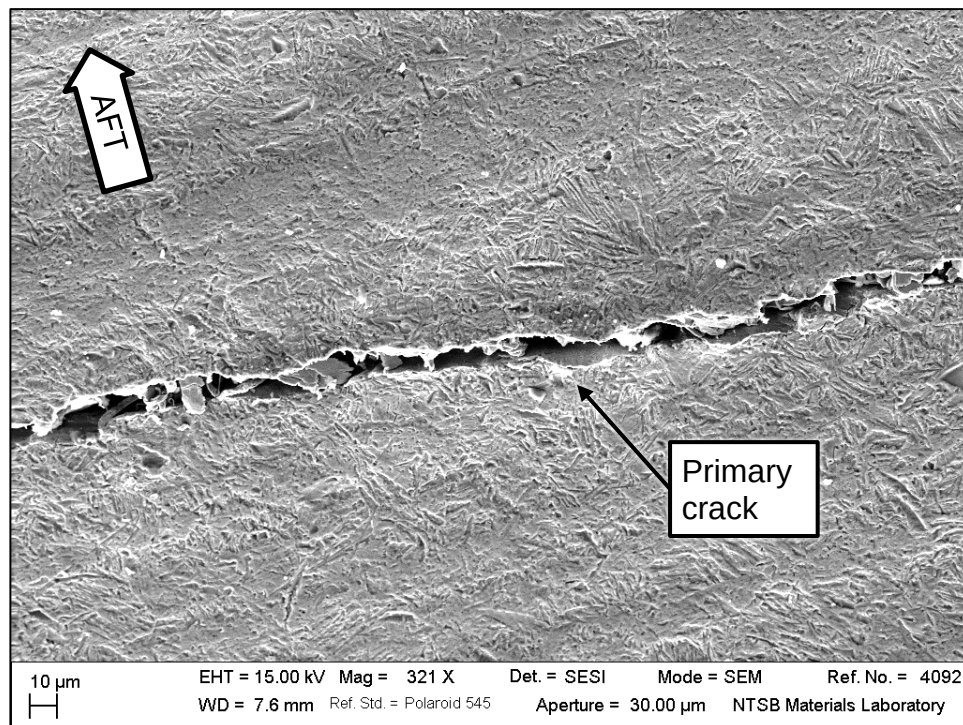


Figure 21. SEM image of the outer race fillet radius showing a portion of the primary crack counterclockwise of the branching spiral crack origin.

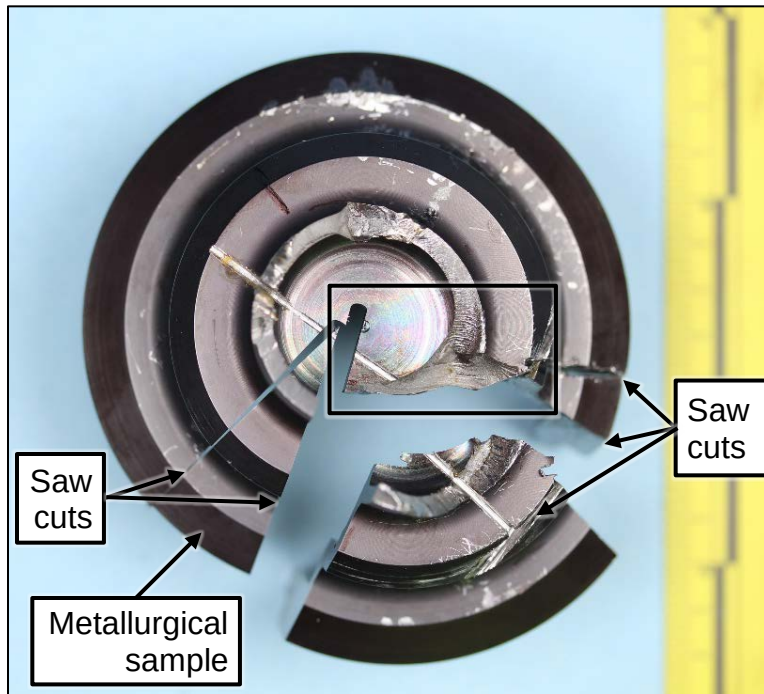
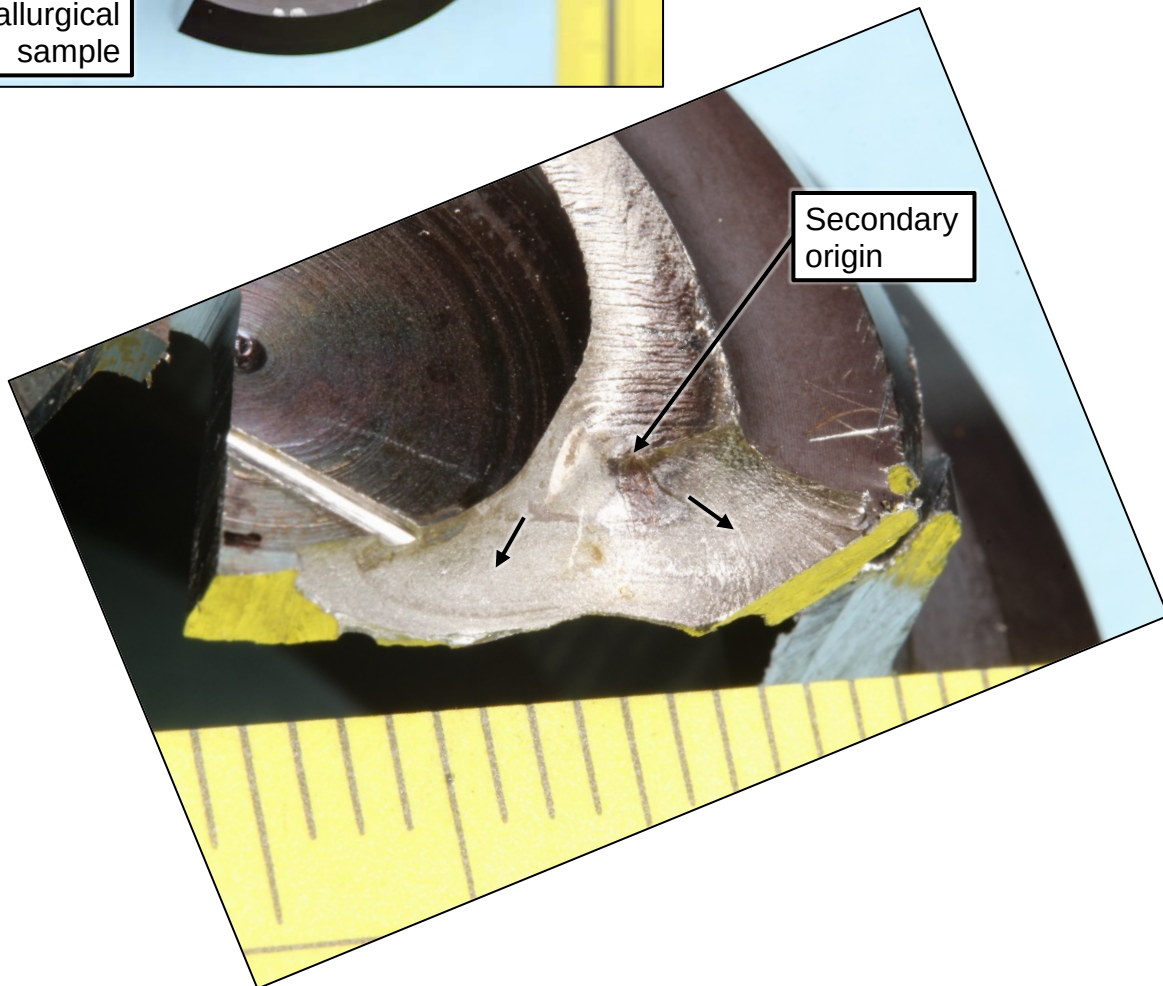


Figure 22. Overall photograph (upper image) of the overrunning clutch fracture surface after additional cuts were made to expose the radial branching crack and to prepare a sample for metallurgical examination. The area of the exposed radial crack outlined in a rectangle in the upper image is shown in the lower image, where unlabeled arrows indicate crack propagation directions and a secondary origin area on the radial crack fracture surface.



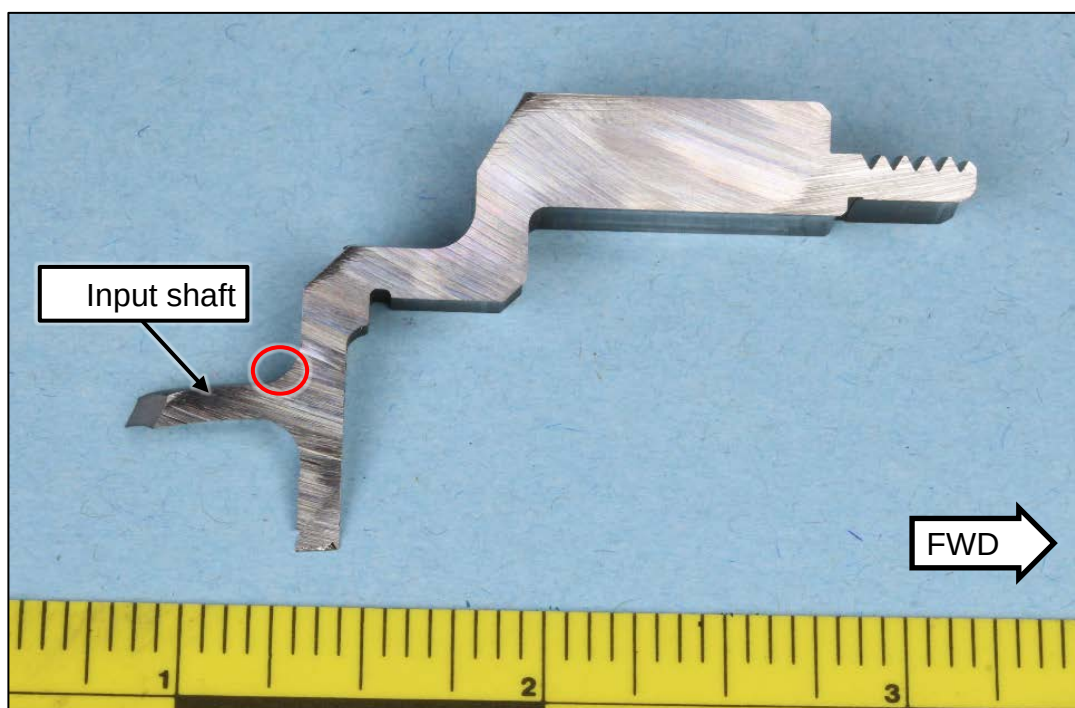


Figure 23. Cut sample of the outer race before mounting for metallurgical examination. The fillet radius associated with the primary fracture is circled.

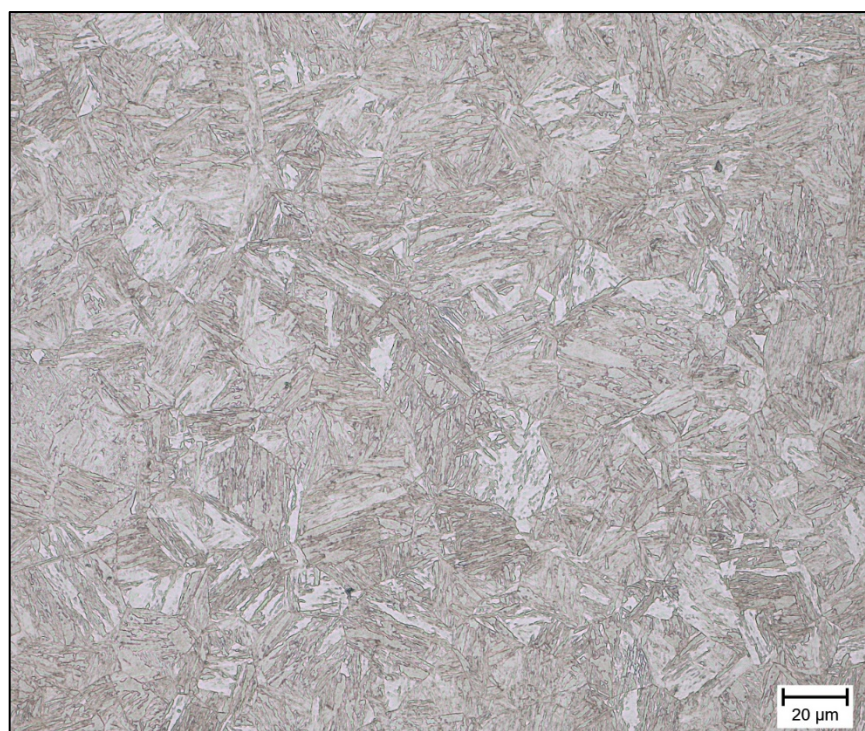


Figure 24. Typical microstructural features consistent with tempered martensite in the shaft (etched with 2% nital).

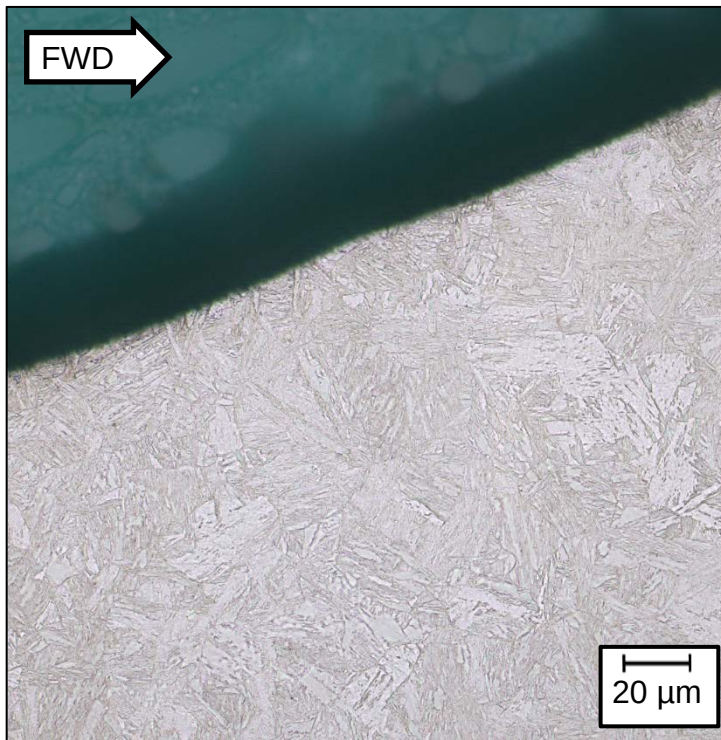


Figure 25. Etched cross-section showing typical microstructural features consistent with tempered martensite at the outer surface in the fillet radius at the forward end of the input shaft (etched with 2% nital).

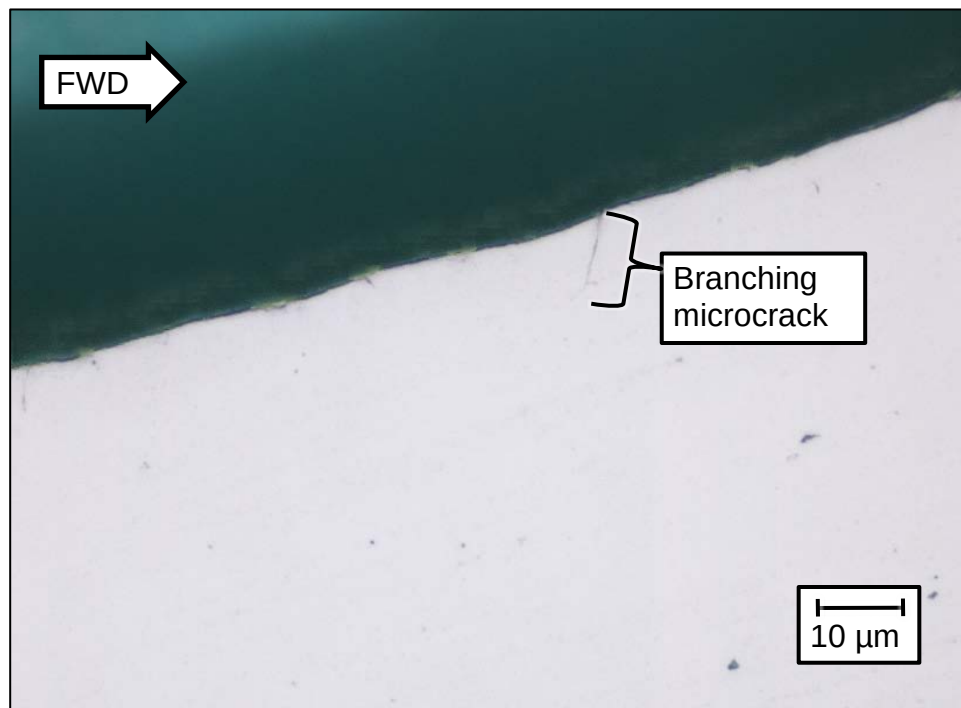


Figure 26. Fillet radius at the forward end of the input shaft showing a branching microcrack emanating from the outer surface on the as polished cross-section.

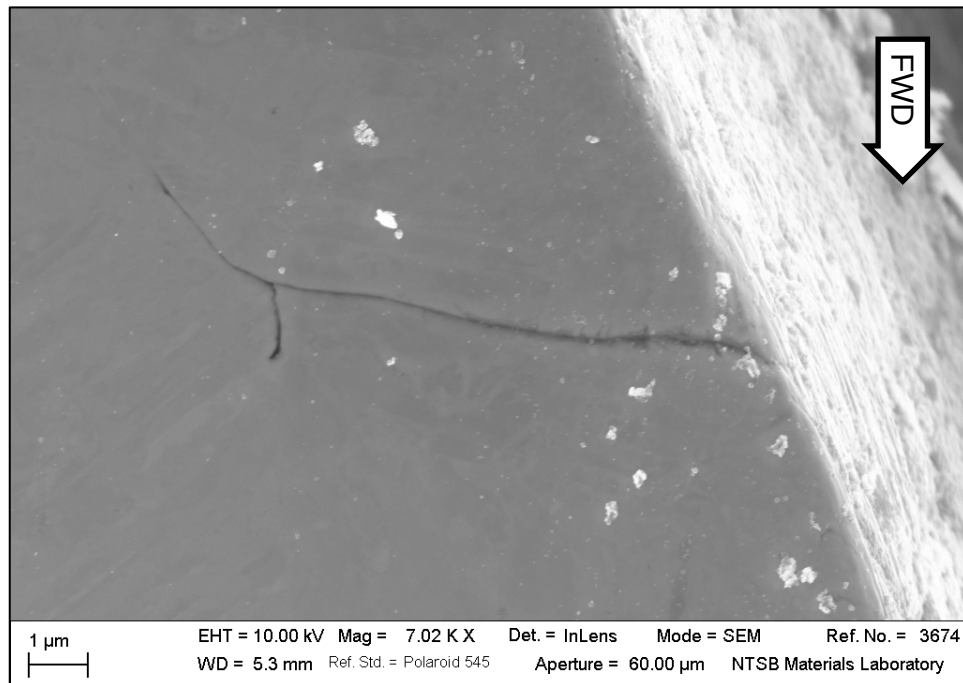


Figure 27. SEM image of the same branched surface microcrack shown in figure 26.

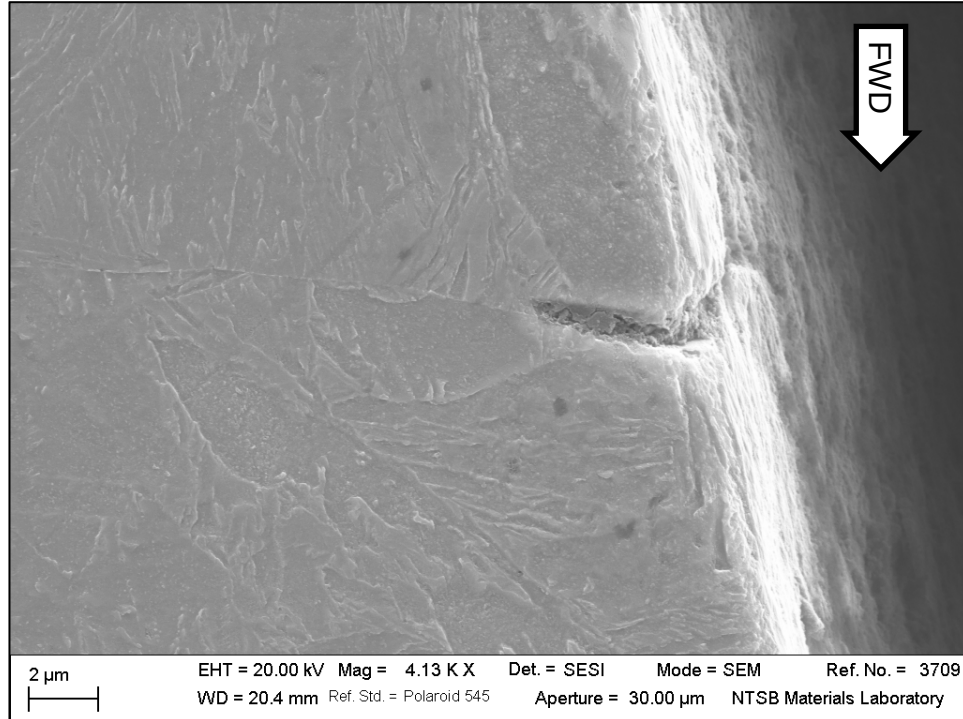


Figure 28. SEM image of the etched cross-section in the fillet radius at the forward end of the input shaft showing a microcrack emanating from the outer surface (etched with 2% nital).