

NATIONAL TRANSPORTATION SAFETY BOARD

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



May 7, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-028

1. ACCIDENT INFORMATION

Place : Byron, California
Date : November 6, 2020
Vehicle : Vans RV-12, N975G
NTSB No. : WPR21LA049
Investigator : James Bledsoe, AS-WPR

2. COMPONENTS EXAMINED

Remnants of a crankshaft with attached connecting rods

3. DETAILS OF THE EXAMINATION

On November 6, 2020, about 1158 Pacific standard time, a Vans RV-12 airplane was substantially damaged when it was involved in an accident near Byron, CA. The pilot and passenger were uninjured. The pilot reported that they experienced a loss of engine power soon after departing. The airplane returned to land, but then departed the left side of the runway, striking a taxiway sign and coming to rest. The airplane was retained for further investigation, and several components from the UL Power 350iS were recovered and sent to the NTSB Materials Laboratory for additional examination.¹

Figure 1 shows the two crankshaft remnants, as received. These remnants were positioned in their relative locations at fracture, with the forward position facing to the left in the figure. The four connecting rod journals still had their respective rods and caps attached. In all cases, these parts were able to be easily rotated about their respective journals. The side faces of the rods and caps were each marked, and from forward to aft stated: '282', '148', '328', and '074'.

The crankshaft had fractured at a web just aft of the journal with the '148' connecting rod. Figure 2 shows both mating faces of the fracture surface, as received. The fracture exhibited a half-moon shape, having proceeded through approximately half the web. The fracture surface was relatively shiny and reflective, with some areas of heat tinting on the forward face (Figure 2b).

¹ The 350iS is a four-cylinder, horizontally opposed air-cooled gasoline engine made by ULPower Aero Engines, headquartered in Ypres, Belgium.

The connecting rods were disassembled by removing the nuts, bolts, and caps. The forward fracture surface was then sectioned and cleaned using acetone in an ultrasonic bath. Figures 3 and 4 show a closer view of the fracture surface details.

Figure 3 shows a series of repeating banded marks, consistent with crack arrest or beach marks. These features were consistent with progressive crack growth later determined to be fatigue. Tiny perpendicular marks were present, particularly near the initial areas of the fracture. These features were ratchet marks, consistent with multiple crack initiation sites.

These initiation sites were located along the edge of the fracture surface at the radius near the connecting rod journal surface. Figure 4 shows an angled view of the crack initiation sites and the adjacent journal surface. While the majority of the connecting rod journals were reflective with some circumferential wear marks, the region 0.05 inches closest to the radius (and fracture) were dull and visually distinctive. This contrast was exemplified in Figure 5, showing increased wear marks in this region.

The sectioned and cleaned fracture surface was examined using a scanning electron microscope (SEM). Figure 6 shows a typical area of the fracture surface. These features were consistent with crack arrest marks. A closer examination found more distinctive striations, as depicted in Figure 7. These features were consistent with fatigue crack propagation.

While observable by visual examination as shown in Figure 5, the fatigue crack initiation sites themselves had generally been obliterated by smearing, or post-fracture damage. Figure 8 typifies one such fatigue crack initiation site. Isolated areas of fatigue striations were present and oriented parallel to the fracture edge, consistent with having initiated at the journal radius surface.

The specimen was rotated to examine the connecting rod journal surface adjacent to the web fracture. Figure 9 shows a typical area of the fracture edge near the fatigue crack initiation region (inverted such that the fracture surface was on the bottom of the figure). As shown in the figure, the journal surface exhibited circumferentially oriented microscopic gouge marks. A closer view found these gouge marks present up to the edge, as well as near one fatigue crack initiation site (Figure 10). Examination of the journal surface away from the fracture surface did find wear marks. However, as illustrated in Figure 11, there were no gouge marks or deep valleys such as seen in Figures 9 and 10.

The chemical composition of the sectioned web was examined using energy dispersive x-ray spectroscopy (EDS). From the data obtained using this technique, the crankshaft was found to be consistent with an alloy steel, such as Type 4330 or 4340.

A cross section was taken through the journal and fracture surface. This section was mounted, polished, and etched using a 2% Nital solution.² Figure 12 shows a typical area of the crankshaft microstructure, located away from the surfaces. This microstructure

² Nital is a mixture of 2% concentrated nitric acid in ethanol.

exhibited equiaxed grains of ferrite and darker areas with a lath structure, consistent with tempered martensite.

Adjacent to the fracture surface, the microstructure exhibited a different structure, as illustrated in Figure 13. This figure shows the journal surface and radius adjacent to the fracture surface. The crack growth direction of the fatigue fracture is annotated on the figure for demonstration purposes. The flat journal surface was curving upward at the location of the fatigue starting, consistent with crack initiation at the radius between the journal and the web.

Figure 14 shows a thin white layer at the surface of the journal, as well as along the radius surface. This surface layer was approximately 10-20 μm (0.0004-0.0008 inches) in thickness. Examination with EDS found the area to contain nitrogen, indicating the part had been case hardened by nitriding. The underlying microstructural constituents had etched darker in many of the lath areas but revealed some lighter grains and features as well. Away from the radius, this nitride layer continued to be present on the journal surface, with some cracking present, parallel to the surface (see Figure 15).

Along the journal surface away from the fracture surface, the nitride layer was present, but thinner in depth (5-10 μm or 0.0002-0.0004 inches). There were also no indications of cracking, and the surface exhibited a lower roughness (compare Figure 16 to Figure 15).

The hardness of the cross section was examined using automatic microindentation hardness, per ASTM E384.³ A chart of the individual indent data is shown in Figure 17. This shows that the surface hardness was up to 55 HRC (630 HK₅₀₀) but dropped to an average of 26 HRC past a depth of 0.015 inches. These hardness data were consistent with those typical of a case hardening (nitriding) treatment on an alloy steel.

Erik M Mueller
Materials Research Engineer

³ ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA

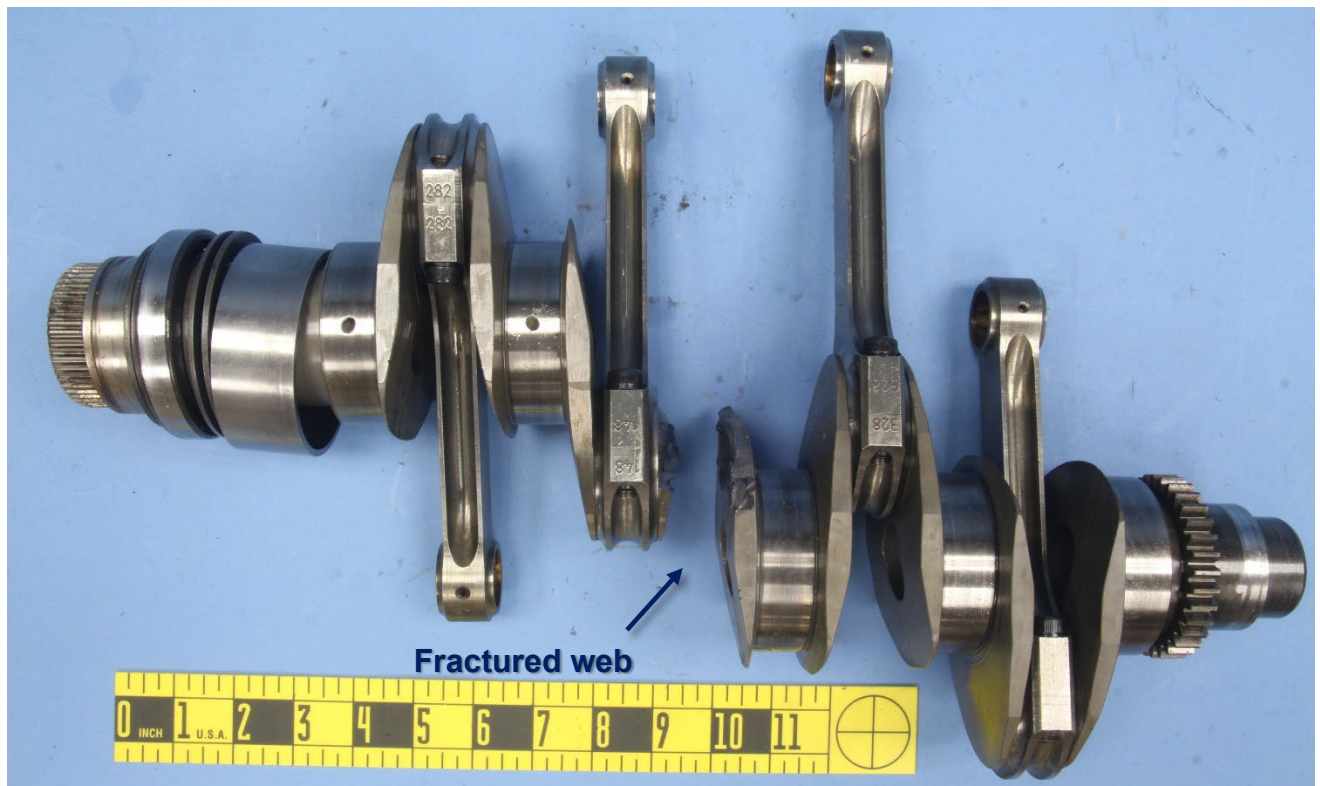


Figure 1 – View of the fractured crankshaft, as received. The fractured web location is labeled.

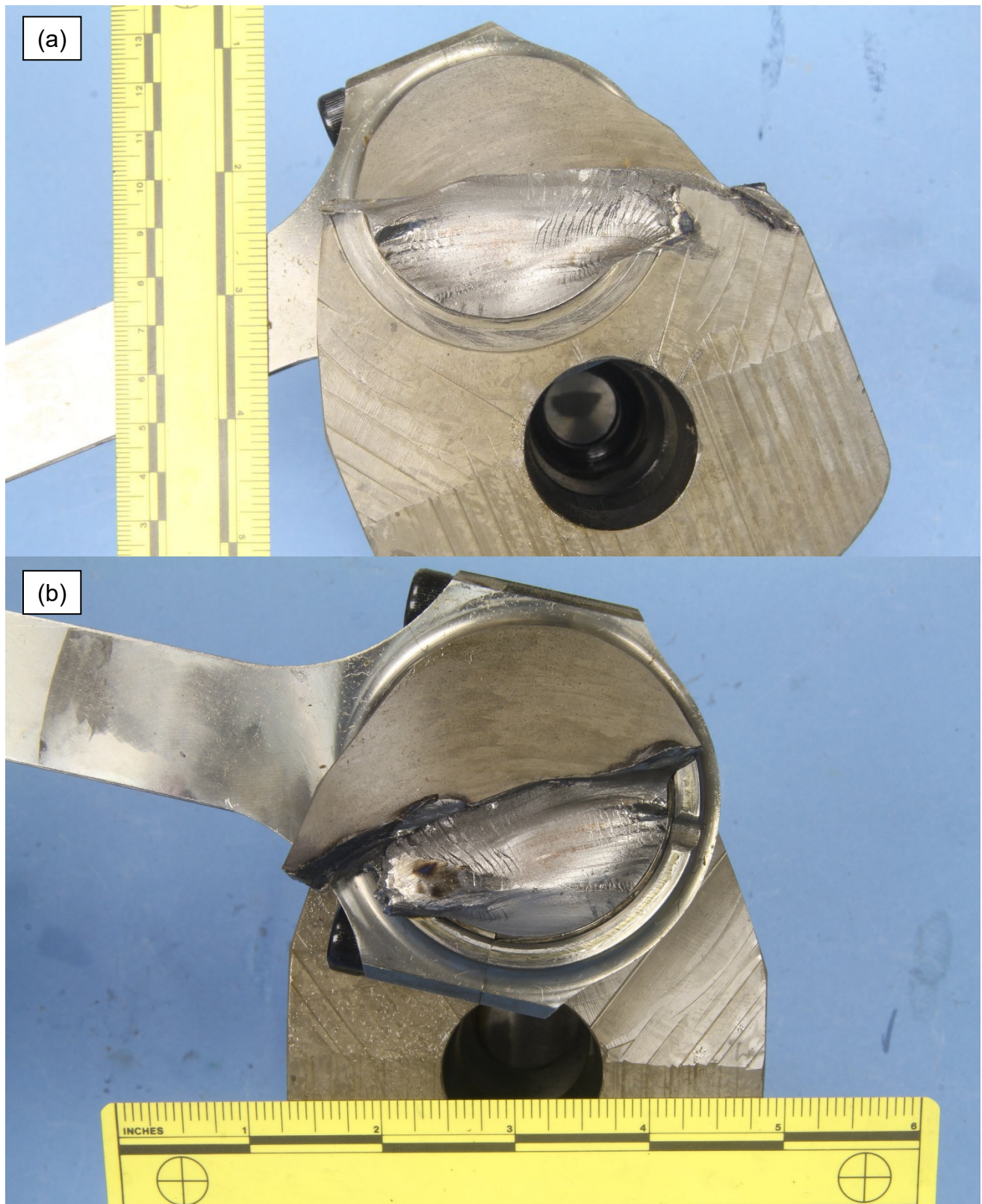


Figure 2 – The fracture surface of the crankshaft viewed from (a) aft and (b) forward sides.



Figure 3 – Closer view of the forward mating fracture surface, after sectioning and cleaning.



Figure 4 – View of the journal surface adjacent to the crack initiation sites of the fracture.

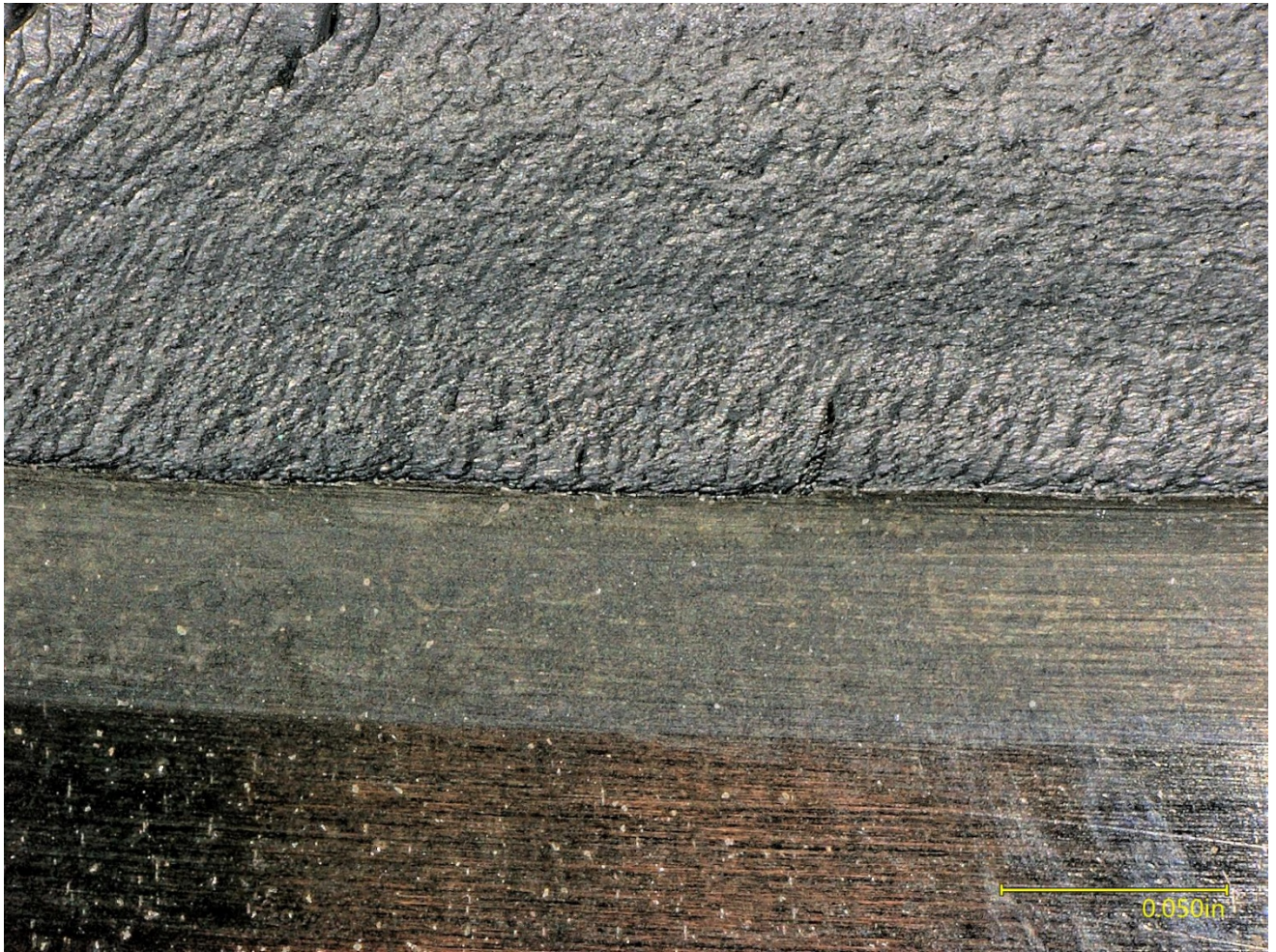


Figure 5 – Closer view of the connecting rod journal near the forward fracture surface initiation sites, showing the contrast of the two circumferential wear areas.

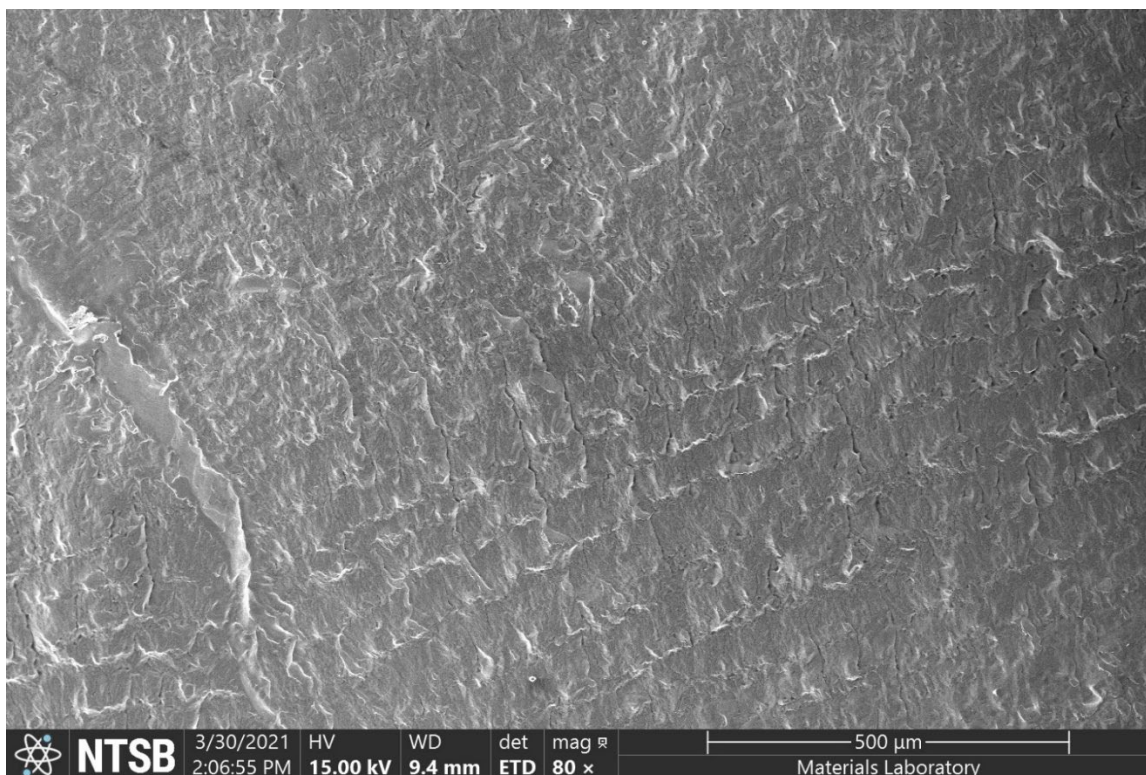


Figure 6 – Secondary electron (SE) micrograph of crack arrest marks on the crankshaft fracture surface.

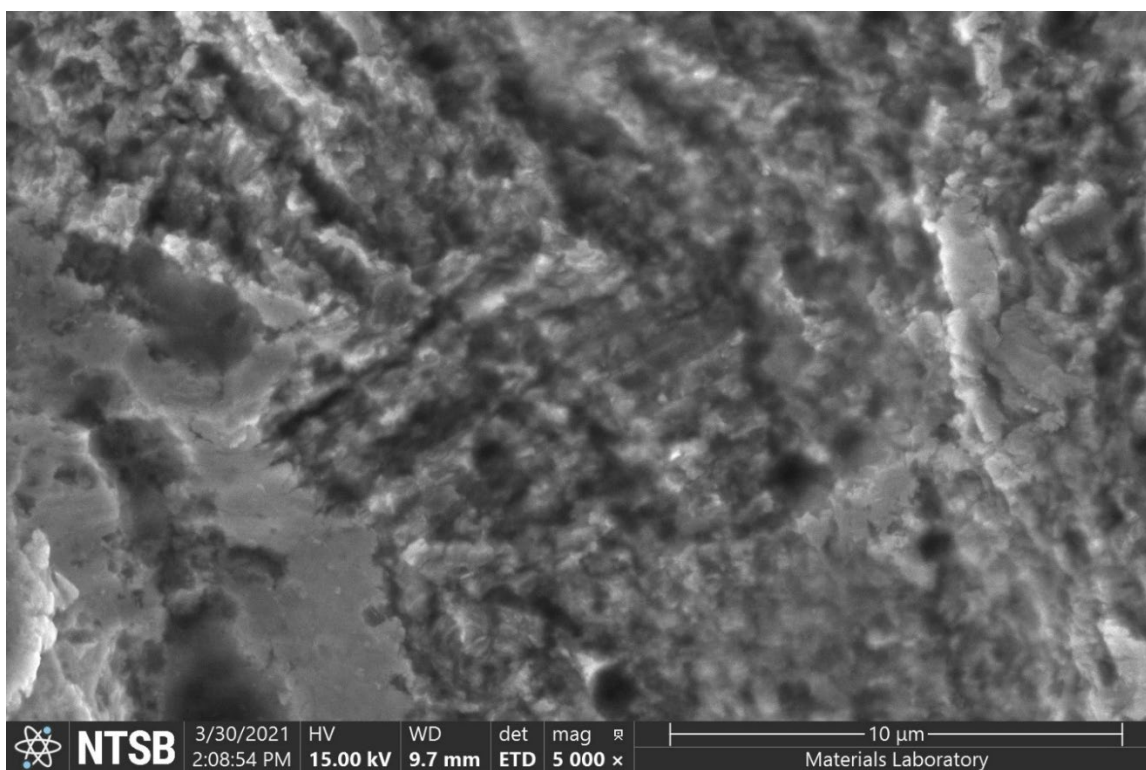


Figure 7 – SE micrograph of fatigue striations on the crankshaft fracture surface.

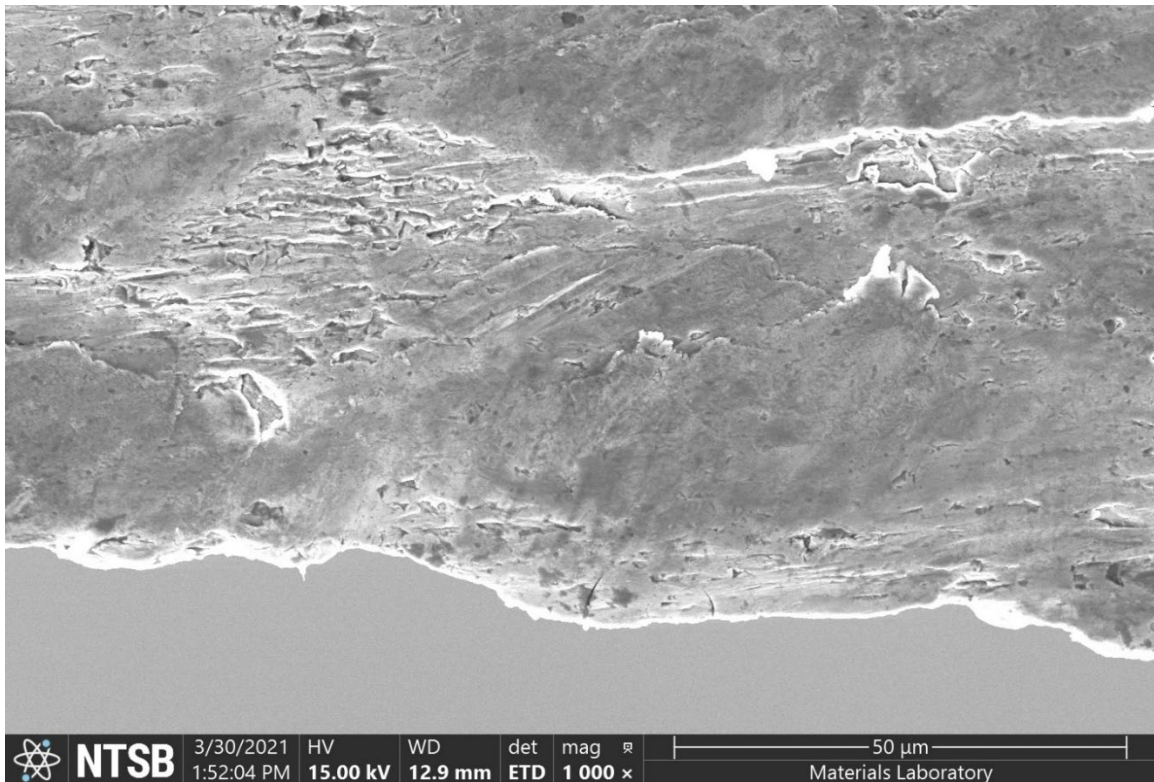


Figure 8 – SE micrograph of one of the fatigue crack initiation sites, showing post-fracture smearing among isolated areas of striations.

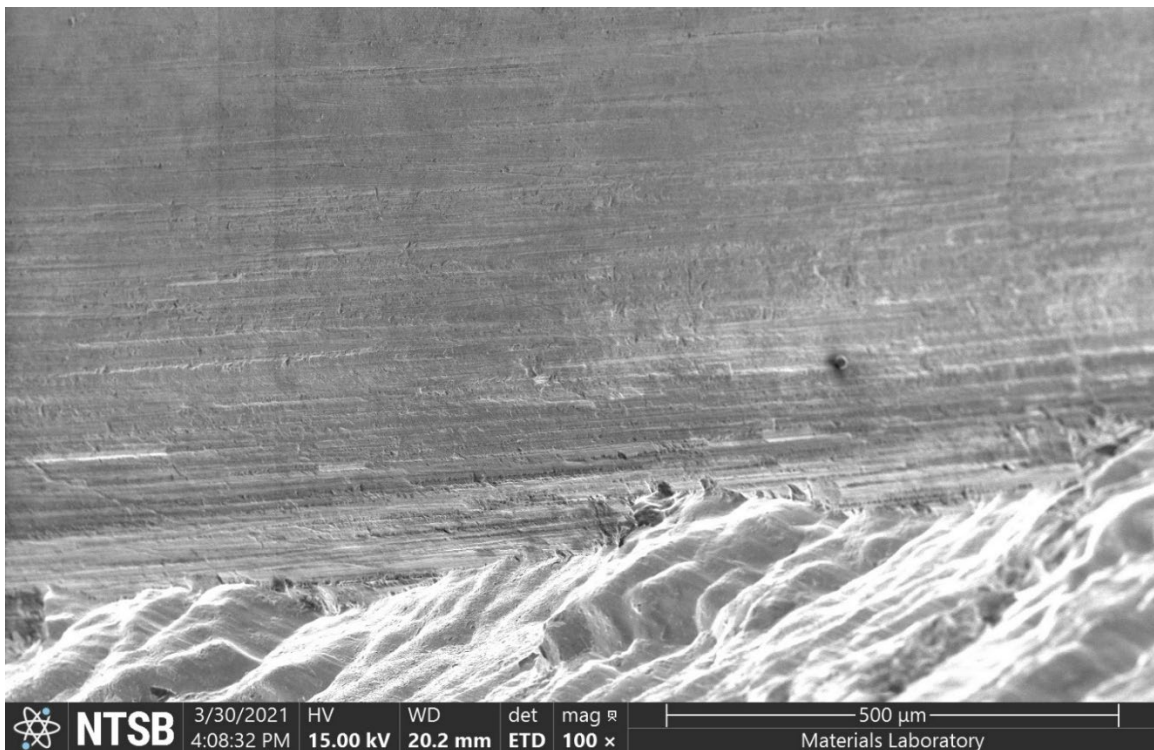


Figure 9 – SE micrograph of the journal adjacent to several crack initiation sites (bottom).

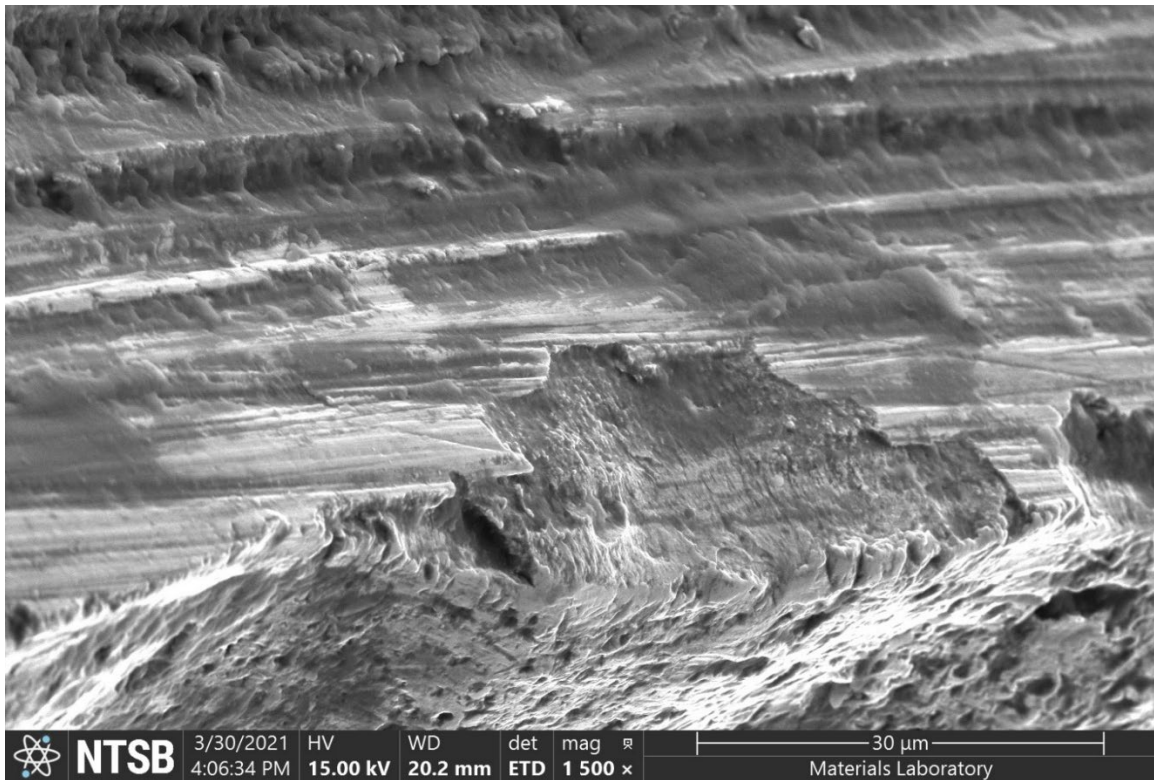


Figure 10 – SE micrograph of the more damaged journal surface, adjacent to a crack initiation site of the fracture surface.

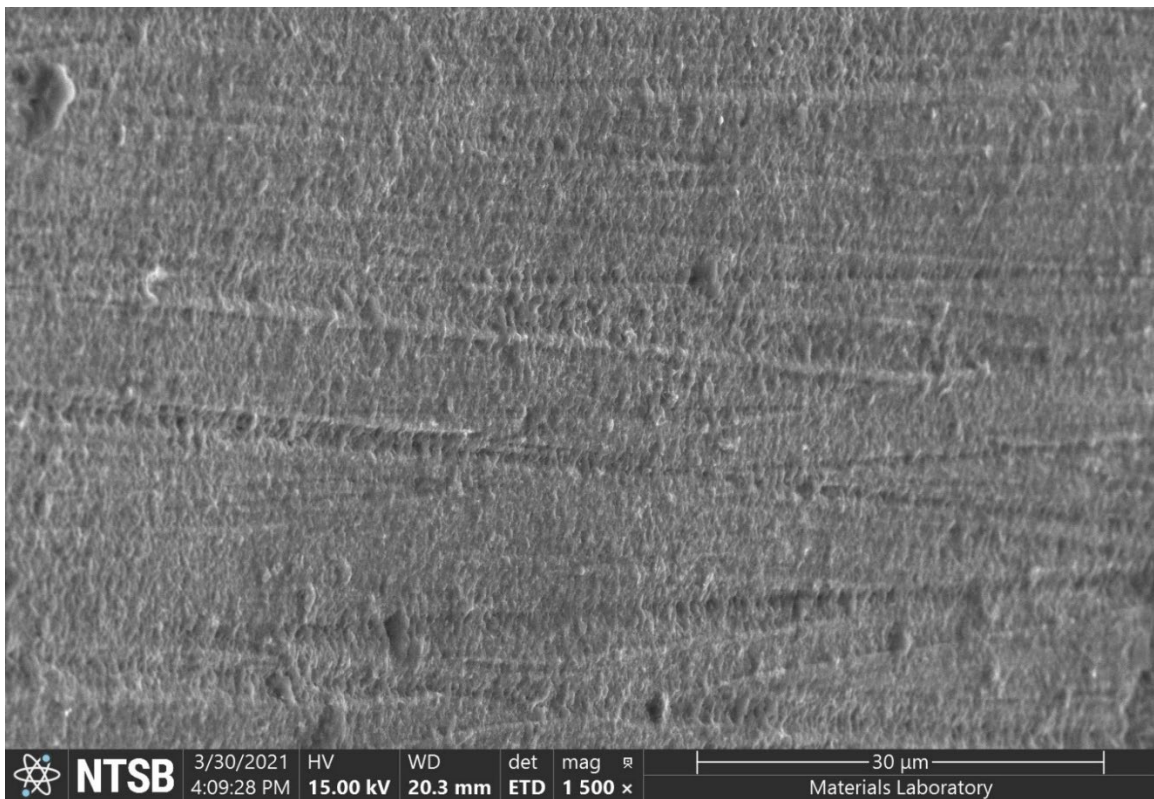


Figure 11 – SE micrograph of the journal surface away from the damaged region.

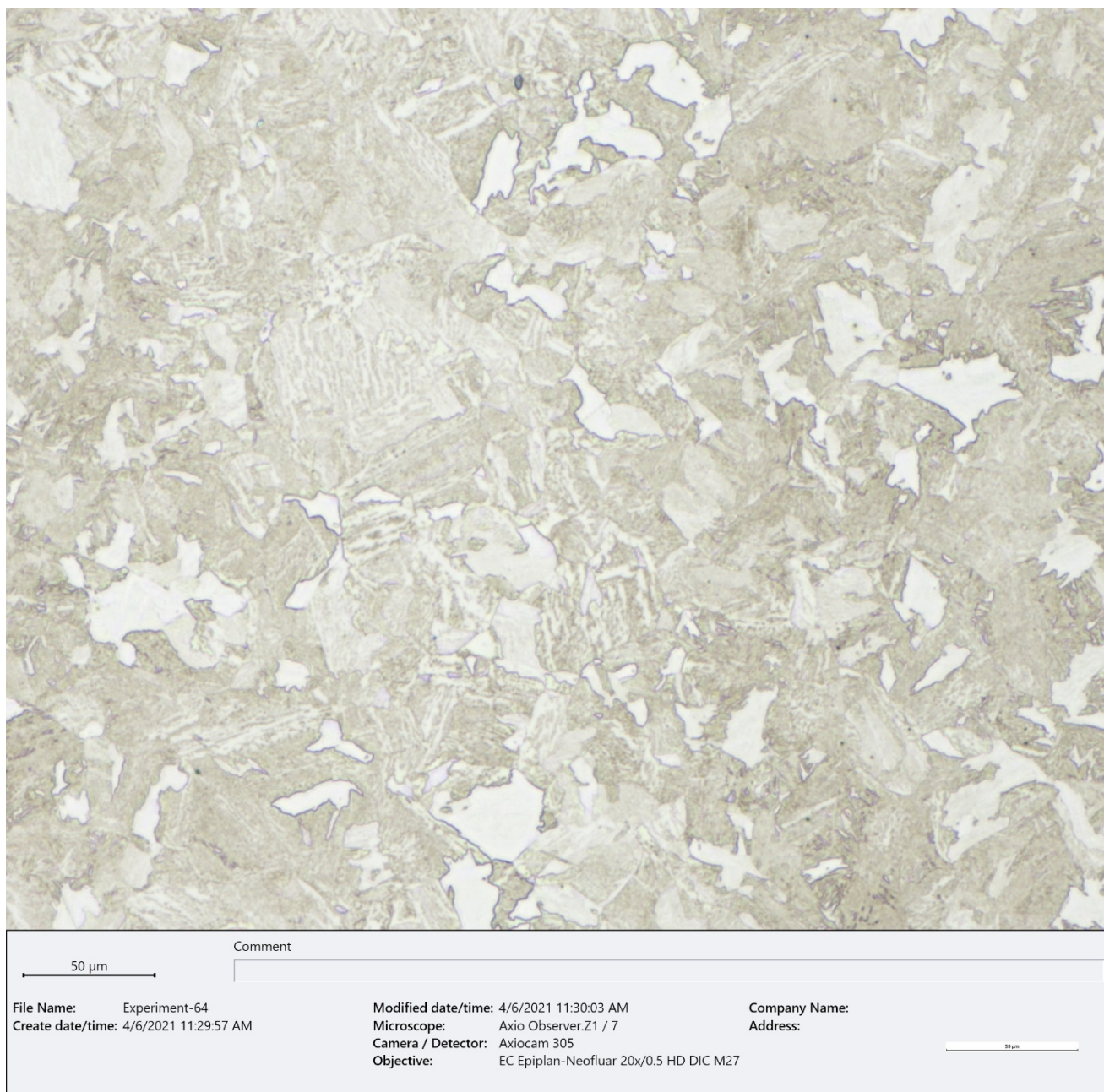


Figure 12 – BF optical micrograph of a typical area of the core crankshaft microstructure (~500X, etched 2% Nital).

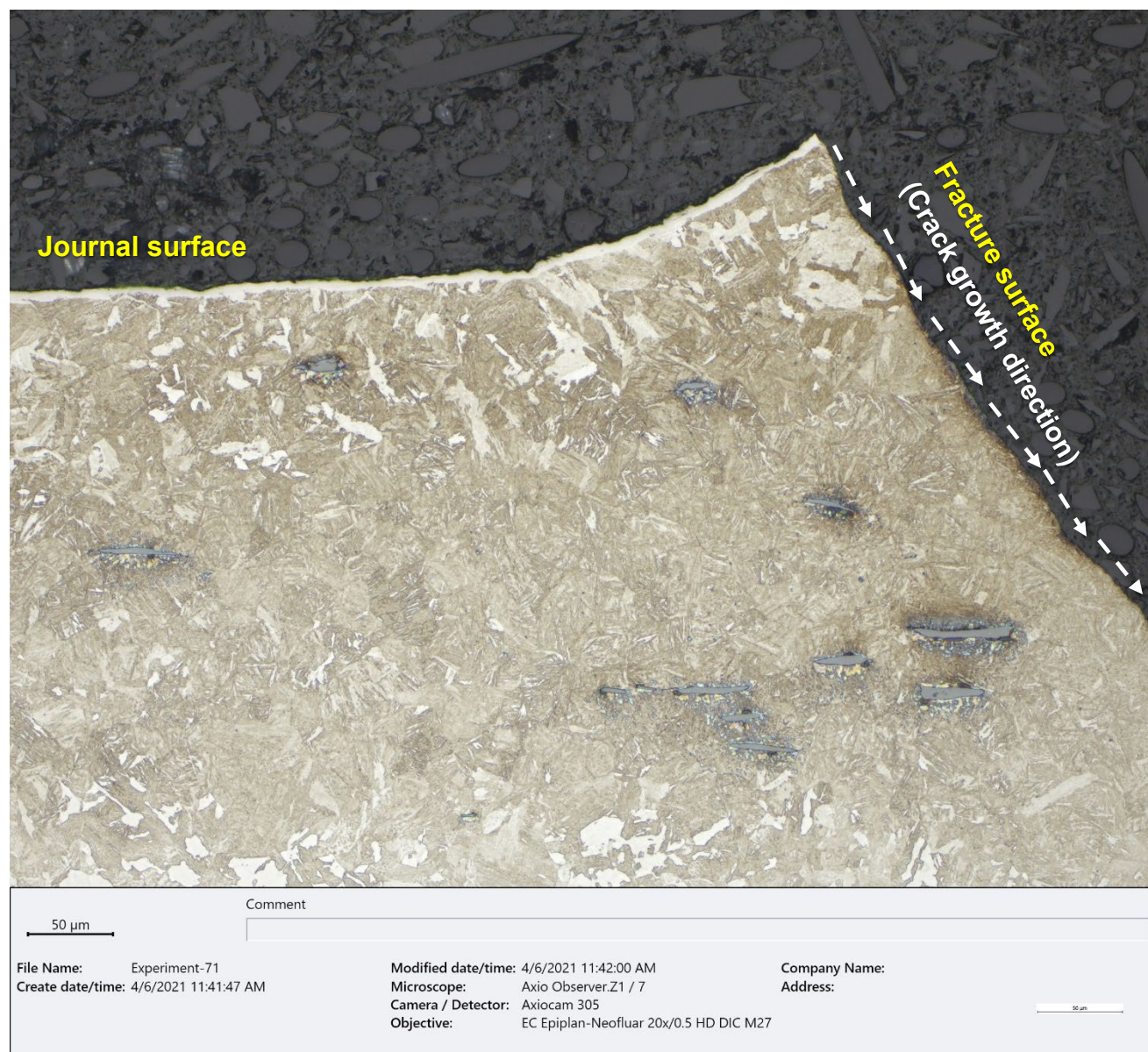


Figure 13 – BF optical micrograph of a cross section of the journal and the fracture surface, showing a surface white layer and different microstructure (~200X, etched 2% Nital).

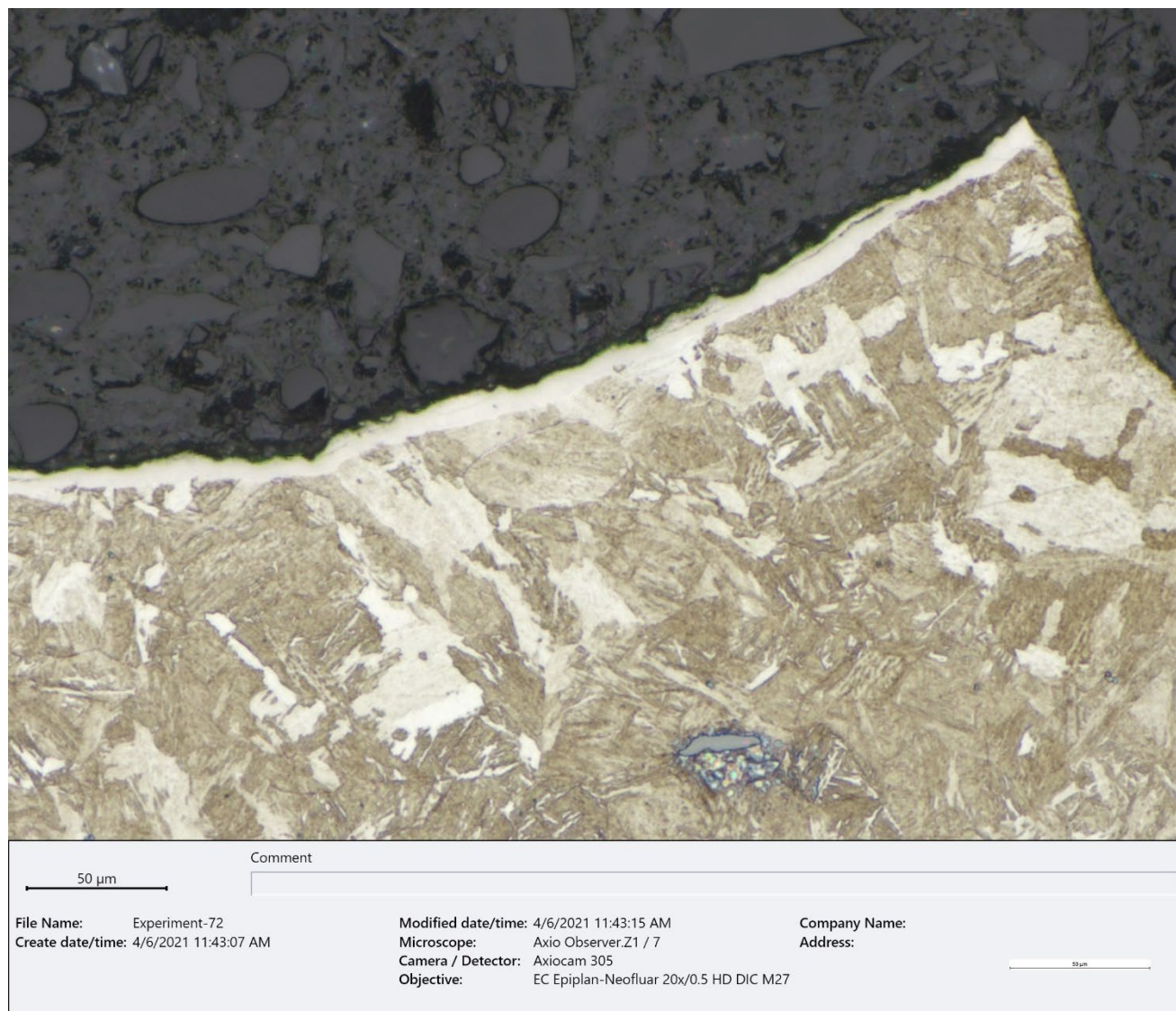


Figure 14 – BF optical micrograph of the edge of the fracture surface and damage area of the adjacent journal (~500X, etched 2% Nital). The white nitride layer exhibited cracking parallel to the surface.

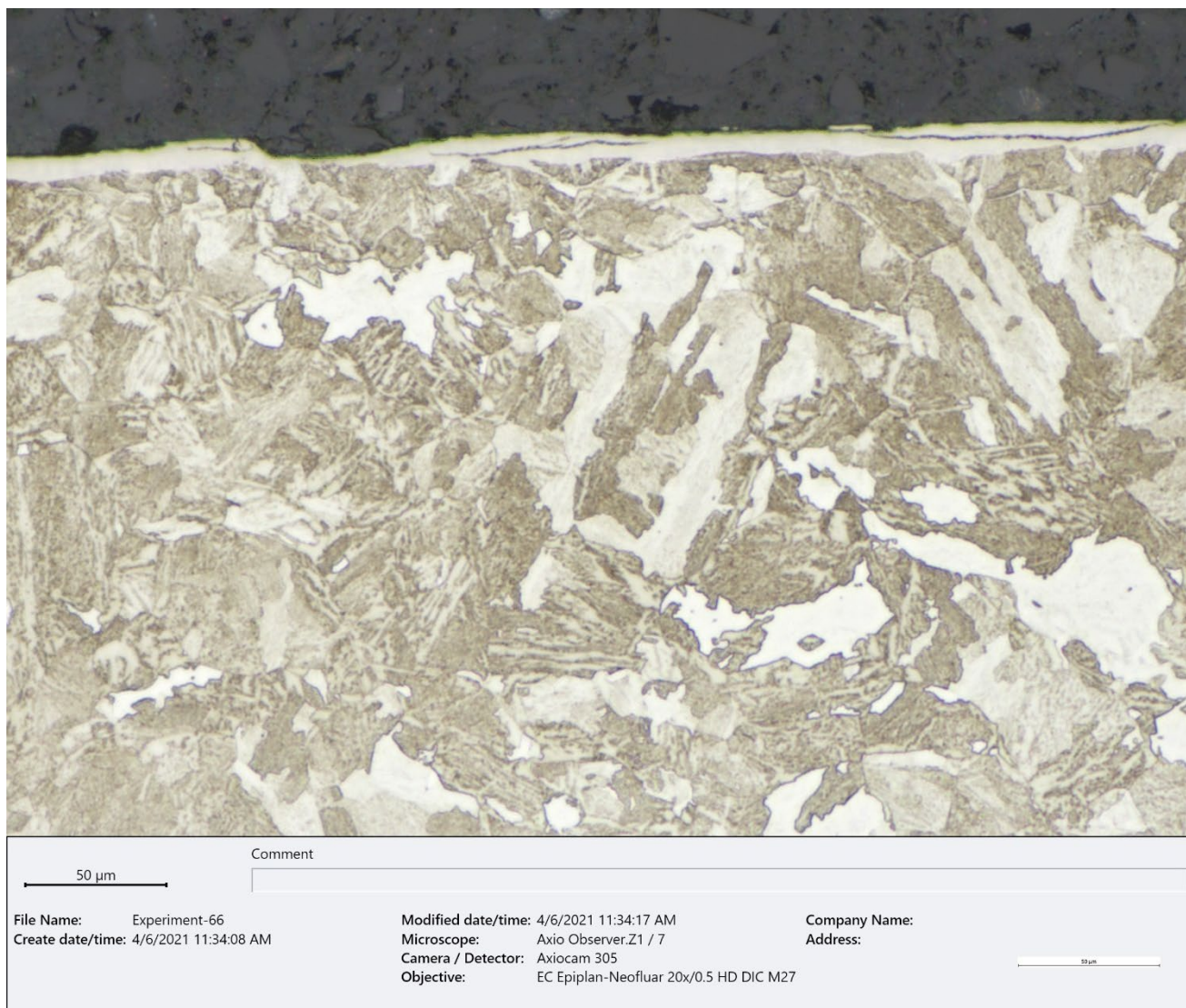


Figure 15 – BF optical micrograph of a cross section of the journal surface closer to the fracture surface edge (~500X, etched 2% Nital). The white nitride layer exhibited cracking parallel to the surface.

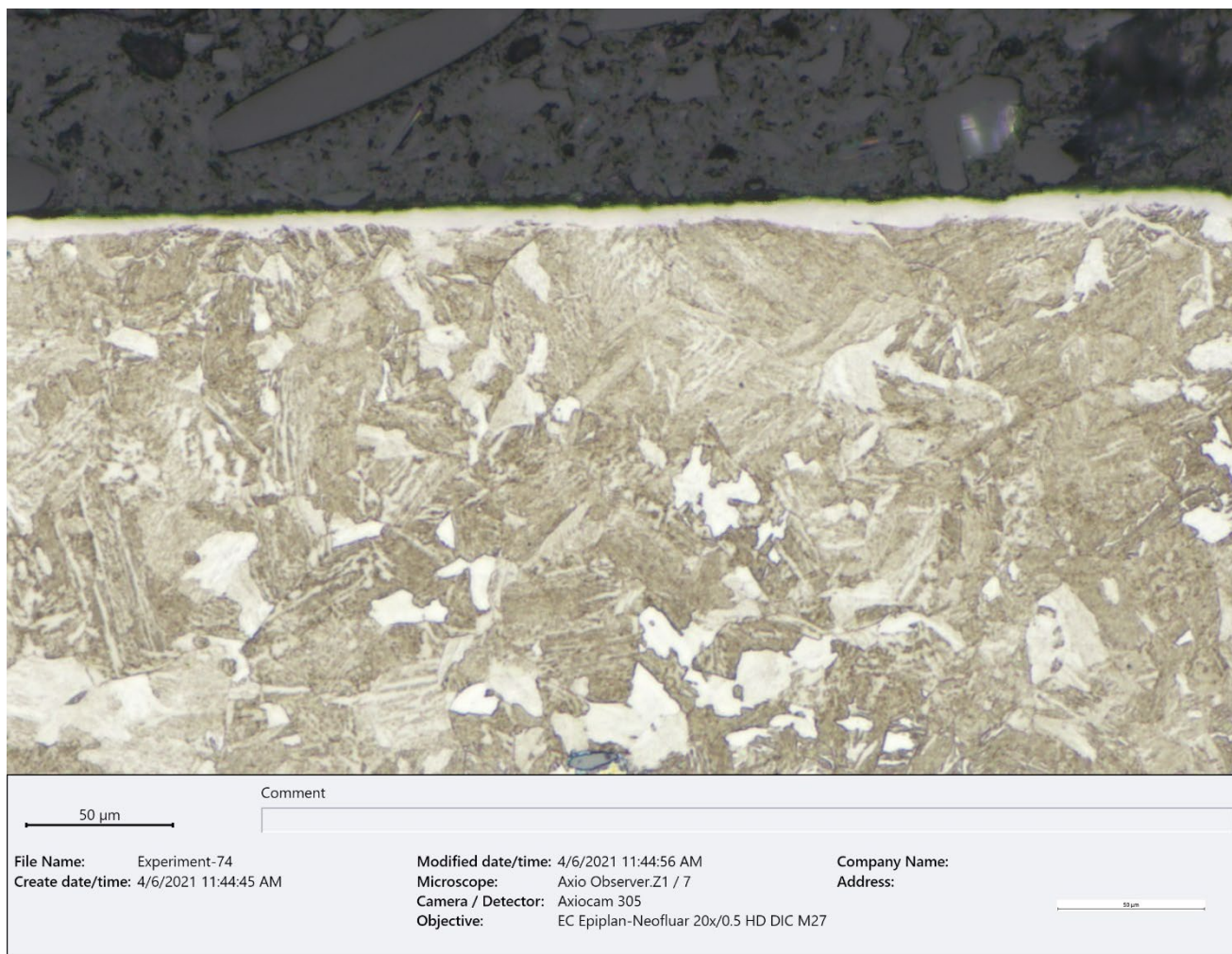


Figure 16 – BF optical micrograph of a cross section of the journal surface away from the fracture surface edge (~500X, etched 2% Nital). The surface exhibited a thin white nitride layer.

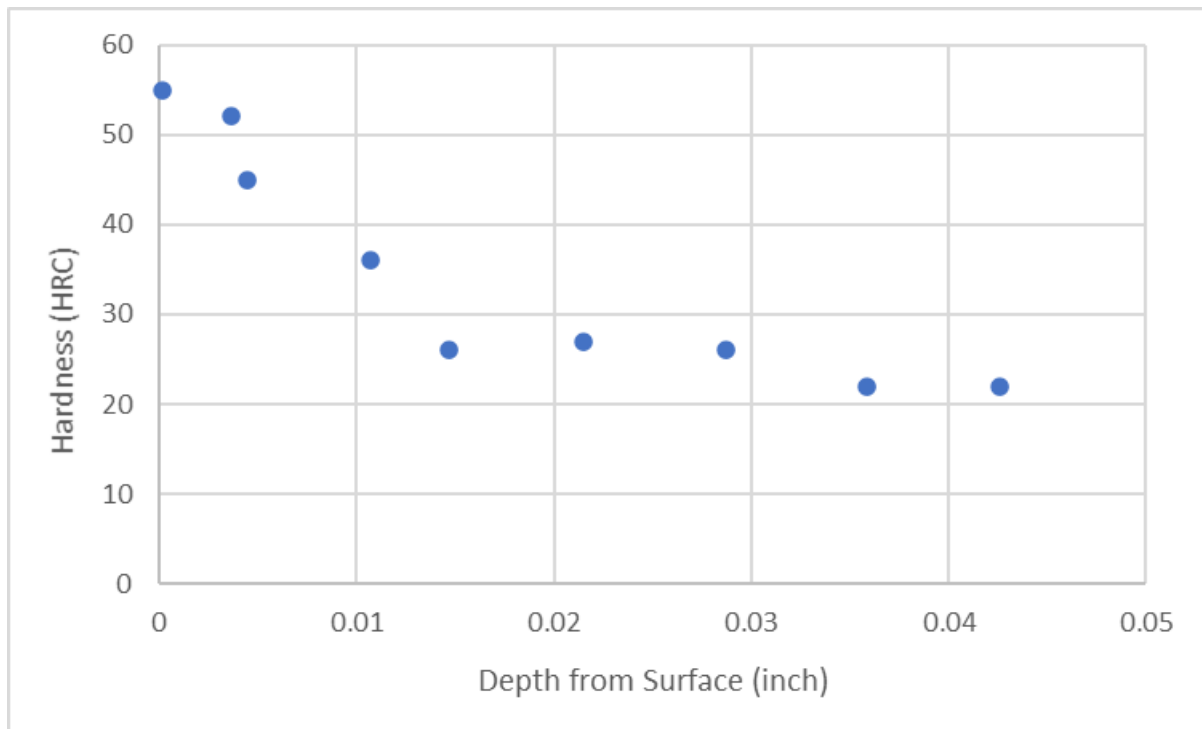


Figure 17 – Chart of microindentation hardness data from indents taken sequentially from the journal surface inward, in HRC (converted from HV₅₀₀).