

NATIONAL TRANSPORTATION SAFETY BOARD

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



April 9, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 22-016

1. ACCIDENT INFORMATION

Place : Eagle Butte, SD
Date : July 11, 2021
Vehicle : Cessna 172F, N5340R
NTSB No. : CEN21LA316
Investigator : Shaun Williams, AS-CEN

2. COMPONENTS EXAMINED

Connecting rod remnants
Cylinder assembly
Piston and pin

3. DETAILS OF THE EXAMINATION

On July 11, 2021, about 0915 mountain daylight time, a Cessna 172F sustained substantial damage when it was involved in an accident near Eagle Butte, SD. The people onboard were not injured. The pilot reported a high engine oil temperature along with hearing a loud noise. After the engine lost power, the pilot executed a forced landing in a wheat field. A post-accident examination revealed a large hole in the forward section of the engine case from the Continental O-300-D reciprocating engine (S/N 29130-D-4-D).¹ The components from a #6 cylinder were sent to the NTSB Materials Laboratory for additional examination.

The cylinder assembly is shown from different angles in Figures 1 through 3. Several of the cooling fins of the cylinder exterior had been deformed from bending, as exemplified in Figure 1. The fins, as well as the other assembled components, exhibited dark-colored deposits, consistent with oils and greases, as shown in Figure 2.

The oil cover on the top of the cylinder assembly had been removed prior to receipt at the NTSB. As shown in Figure 3a, the rockers, retainers, and springs were still intact, and the parts exhibited no indications or witness marks suggesting damage to these

¹ The O-300-D is a direct drive, air-cooled, flat six-cylinder aircraft reciprocating engine built by Teledyne Continental Motors, headquartered in Mobile, AL.

components. However, as shown in Figure 3b, the underside or skirt opening of the cylinder did exhibit damage, consistent with fracture of the connecting rod.

The connecting rod was still attached to the piston via the piston pin, and these were still jammed inside the cylinder bore, as received. The cylinder skirt exhibited outward bending deformation and tearing, located 180° from each other, as well as along the rocking locations of the connecting rod. The width of these impacts and tears were consistent with the flange width of the neck of the connecting rod remnant. These features were consistent with the flanges of the connecting rod impacting the cylinder after fracture.

Figure 4 shows a closer view of one of the fracture surfaces on the connecting rod. This fracture surface exhibited two distinct regions, one with a flatter, smoother area, and one with a rougher, duller area. As such, the piston was removed from the cylinder, and the subassembly was undone to isolate the connecting rod remnant.

Figure 5 and Figure 6 show the removed connecting rod positioned next to the smaller fragments of the rod and cap, received separately. The markings on the connecting rod web stated, "530186 AES 7". The rod had fractured in two places, near the H-shaped neck transition to the crankshaft bore yoke. The connecting rod cap had fractured in the location facing opposite from the rod body. Each attachment bolt had also fractured, although they were still jammed into their respective rod cap remnants.

Figure 7 shows the connecting rod viewed from the side. The rod had bent out of plane perpendicular to the web direction. In addition, the opposite surfaces of the rod exhibited gouge and rubbing marks at the bend location. These witness marks, having worn off the surface material, were reflective relative to the rest of the connecting rod surface. These features were consistent with repeated contact against the cylinder skirt.

One of the liberated connecting rod remnants was sectioned and cleaned with acetone to facilitate examination of the fracture surface. Figure 8 shows the mating side of the fracture surface displayed in Figure 4. This surface exhibited two distinct fracture regimes. In the upper half of the area displayed in Figure 8, the fracture surface exhibited ratchet marks and crack arrest marks, consistent with progressive cracking, later determined to be fatigue. The middle of the fracture surface exhibited a flatter, mottled texture. This was consistent with rubbing and impact of the fracture surface, typical of post-fracture damage from interaction with adjacent metallic parts.

Figure 9 shows a closer view of the ratchet marks, indicative of the merging of multiple cracks progressing inward (downward in the figure). These marks were consistent with multiple crack initiation sites, located along the outer surface of the connecting rod near the attachment bolt hole. Figures 10 and 11 show an angled view of some of the crack initiation sites. This figure demonstrates some of the parallel machine marks on the surface, which were deep enough to deflect light and retain oil prior to cleaning.

The connecting rod fracture surface was examined using a field emission scanning electron microscope (SEM). As typified in Figure 12, the progressive region of the fracture

surface exhibited fatigue striations, consistent with fatigue crack propagation. While much of the fracture surface had been damaged from post-fracture smearing, fatigue striations were prevalent throughout the surface. As can be seen in isolated areas in Figure 13, fatigue striations were present adjacent to the initiation sites. Figure 14 shows some of these striations. Outside of the fatigue crack, dimpled rupture was observed—these features were consistent with subsequent overstress fracture (see Figure 15).

Figures 16 and 17 show one of the fatigue crack initiation sites of the connecting rod. These figures exemplify the ratchet marks bounding this fatigue crack and show the river patterns emanating from the initiation site at the edge. Closer examination of the edge with the initiation site did not reveal any features of note. As shown by the lack of contrast in Figure 16, there were no dissimilar materials consistent with a corrosion pit or inclusion at that location.² However, similar to the visual image of the connecting rod outer surface in Figure 11, Figure 16 and Figure 17 show the parallel surface marks. These marks, which were also parallel to the fracture surface, were collocated with the fatigue crack initiation sites.

One of the fracture surfaces was cross-sectioned, mounted, polished, and etched with a 2% nital solution.³ Figure 18 shows a typical area of the core microstructure of the connecting rod. This micrograph shows the generally equiaxed grain structure, with grains of fine unresolved pearlite, ferrite, and proeutectoid ferrite around the pearlite grains.

Figures 19 and 20 show a cross section through the edge with the crack initiation sites. As depicted in the figures, the surface exhibited undulations, consistent with some of the marks on the outer surface of the connecting rod in Figure 16. In these micrographs, there were no indications of parallel or branched cracks. Other areas of the outer surface of the connecting rod exhibited areas with a white layer along with underlying deformed and flattened grains (Figure 21). These features were consistent with an untempered martensite layer, which can be caused by grinding, sliding, or other high frictional heat input to the surface, such that the microstructure was deformed and changes phase upon heating above 1350 °F (727 °C).

In summary, the connecting rod fractured from a fatigue crack that initiated at multiple sites along the outer surface at the transition from the neck to the crankshaft bore. The fatigue crack propagated about halfway through the connecting rod cross section before the remainder fractured from overstress. The fatigue initiation sites were collocated with deep grinding marks.

² Backscattered electrons: SEM micrographs produced using backscattered electrons display contrast that is associated with the atomic numbers of the elements in the micrograph. Materials containing elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

³ 2% Nital – a mixture of 2% concentrated nitric acid (HNO₃) in ethanol (C₂H₅OH).

The chemical composition was inspected using energy dispersive x-ray spectroscopy (EDS). The composition was consistent with an alloy steel. The hardness was examined per ASTM E18.⁴ The hardness averaged 24 HRC.

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⁴ ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.



Figure 1 – View of the cylinder exterior, showing deformed fins.

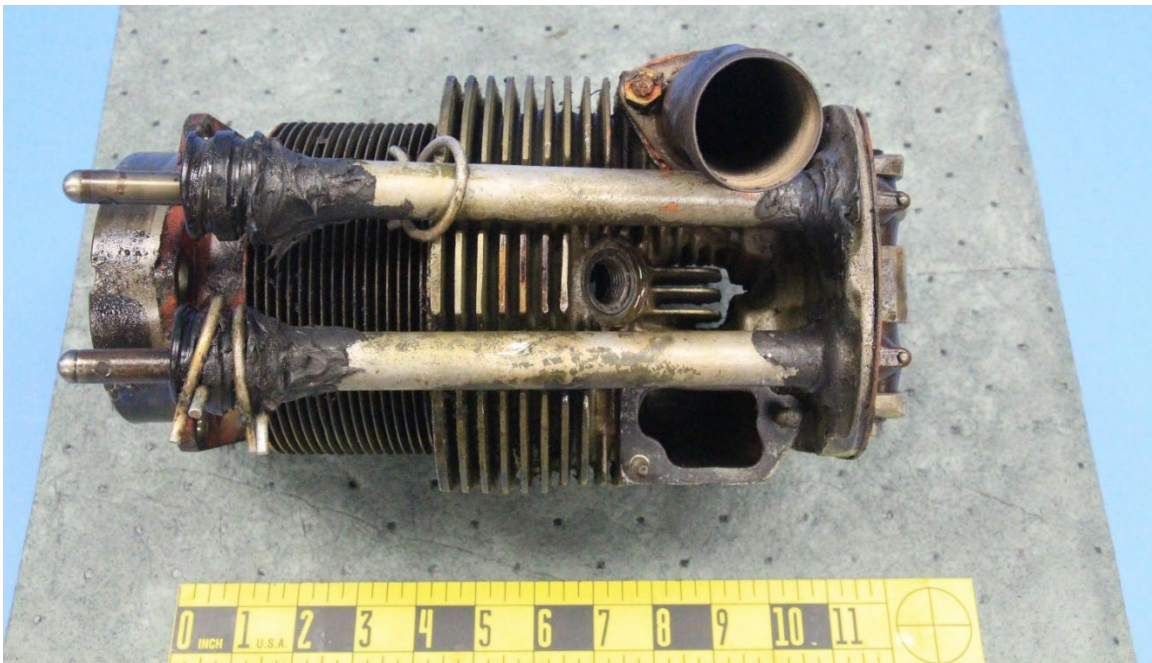


Figure 2 – The cylinder as received, viewed from the exhaust and intake manifolds.

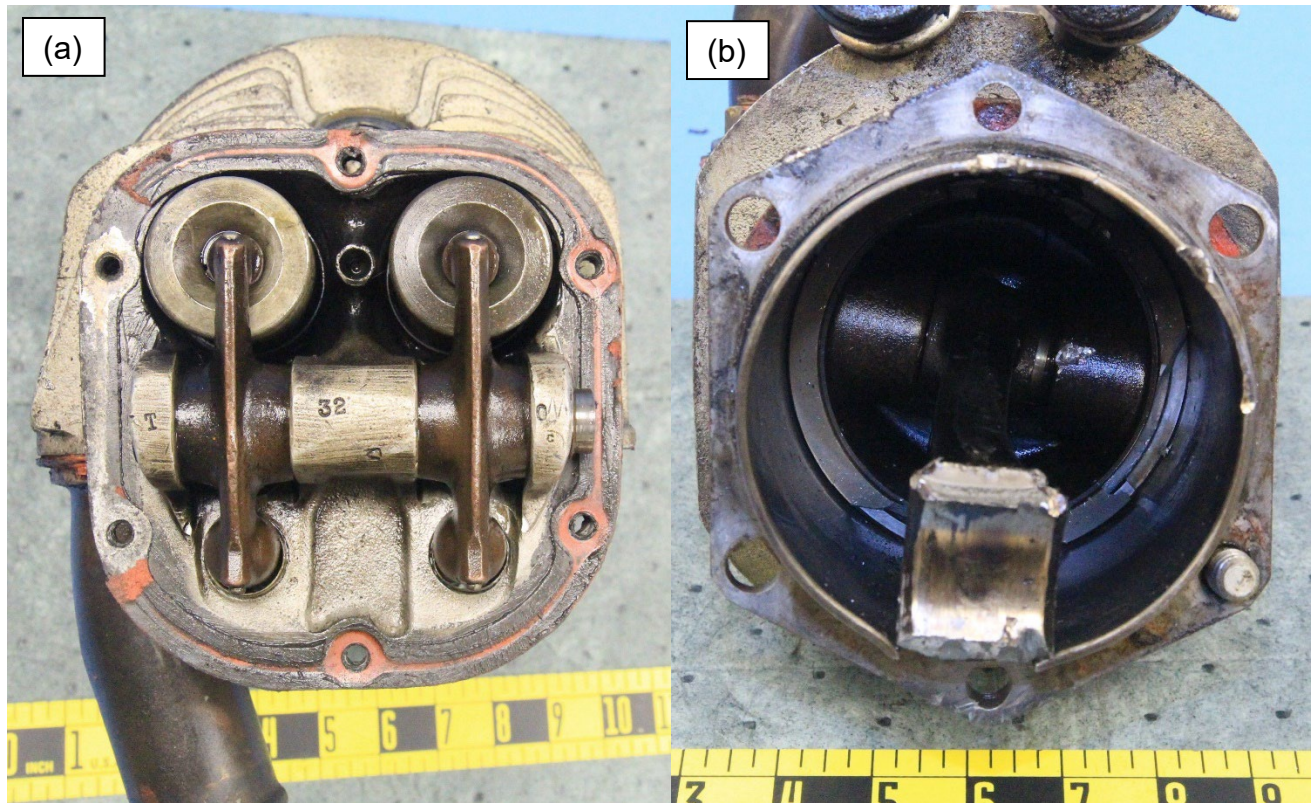


Figure 3 – View of the cylinder from (a) the rocker arms and (b) the skirt, showing the remnants of the connecting rod.

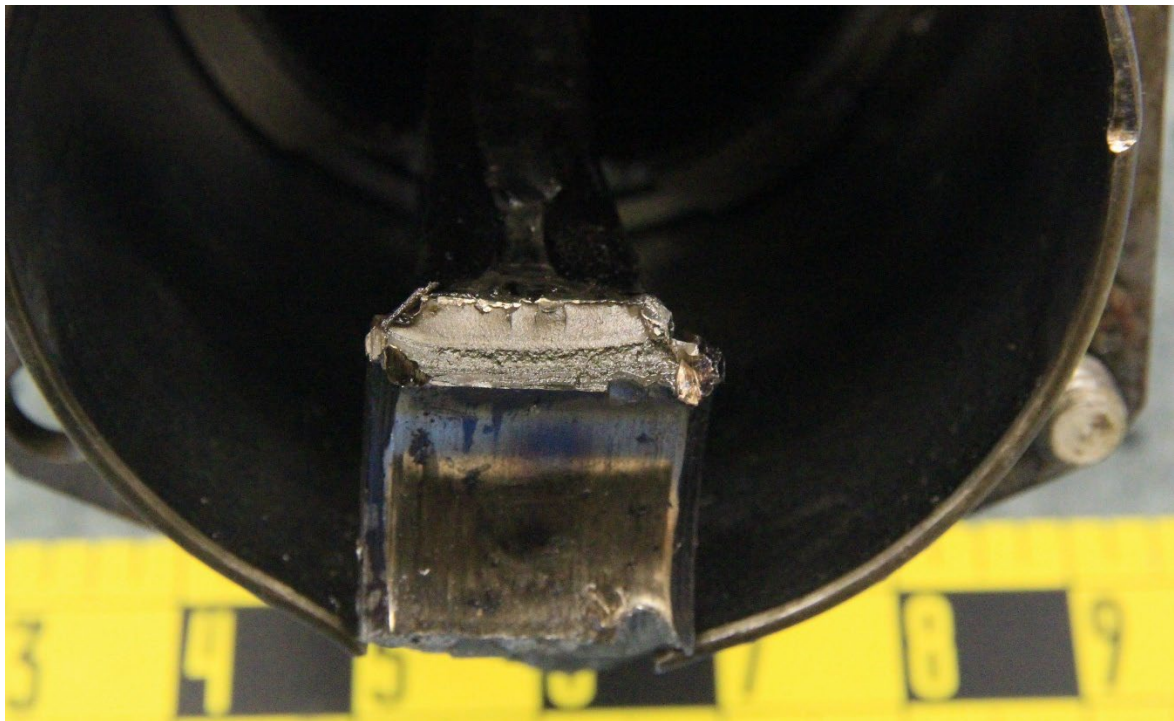


Figure 4 – Closer view of the connecting rod remnant from the cylinder skirt, showing the fracture surface.



Figure 5 – View of the reconstructed connecting rod and cap remnants, after removal from the cylinder.



Figure 6 – View of the connecting rod remnants, viewed opposite shown in Figure 5.



Figure 7 – View of the connecting rod from the flange, showing bending deformation and gouging and wear marks.



Figure 8 – View of the connecting rod fracture surface.



Figure 9 – Closer view of the connecting rod fracture surface, showing parallel ratchet marks consistent with multiple fatigue crack initiation sites.



Figure 10 – View of the external connecting rod surface at the crack initiation sites, showing marks on the surface.



Figure 11 – Opposite view of the fatigue crack initiation sites on the connecting rod.

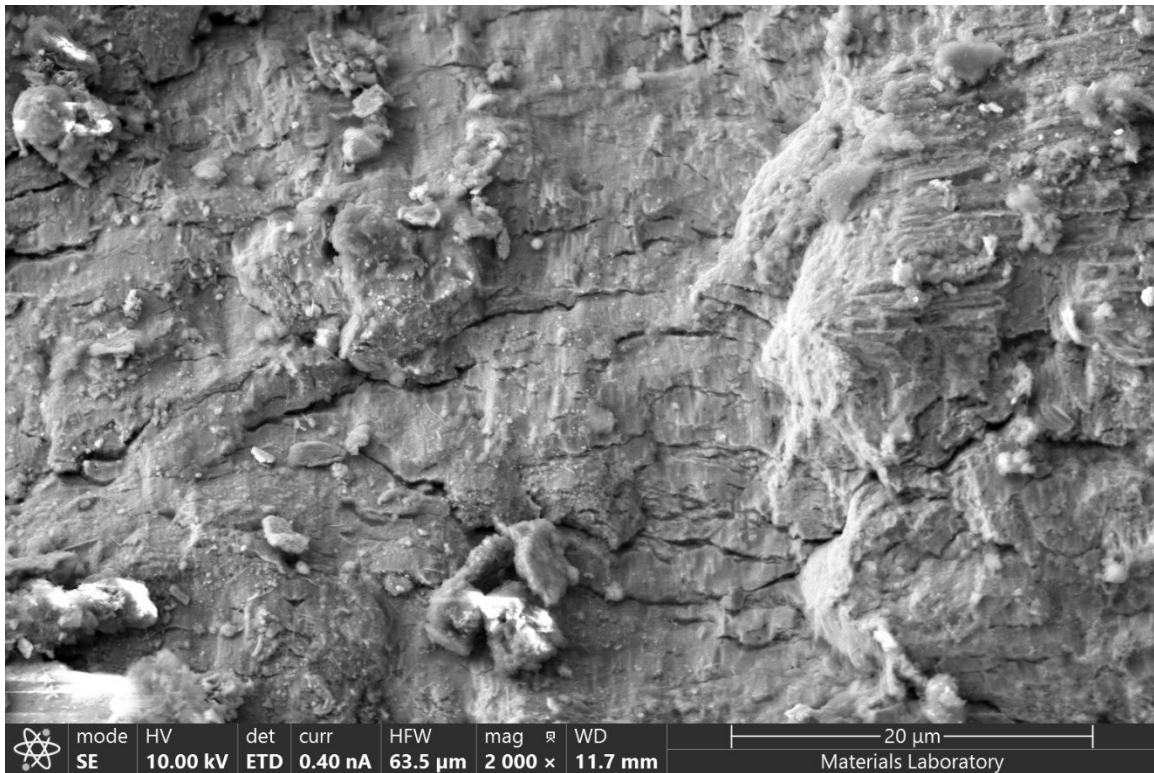


Figure 12 – Secondary electron (SE) micrograph of fatigue striations on the fracture surface.

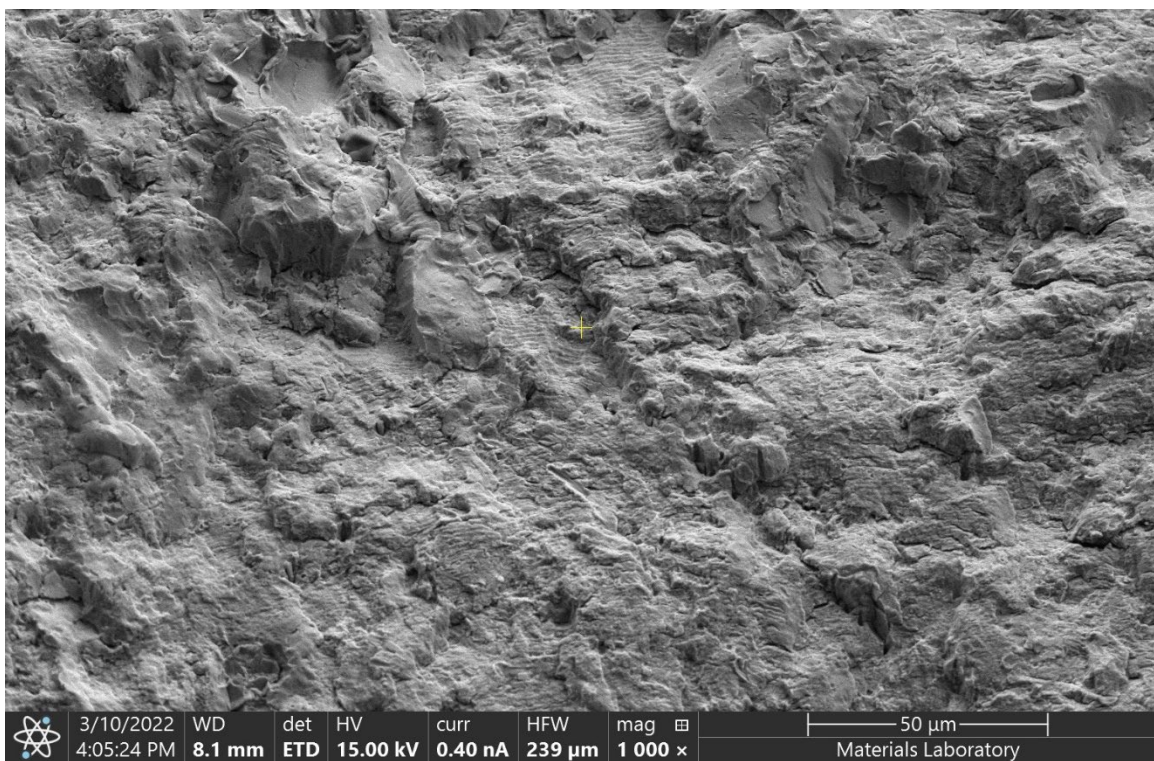


Figure 13 – SE micrograph of the fracture surface near an initiation site.

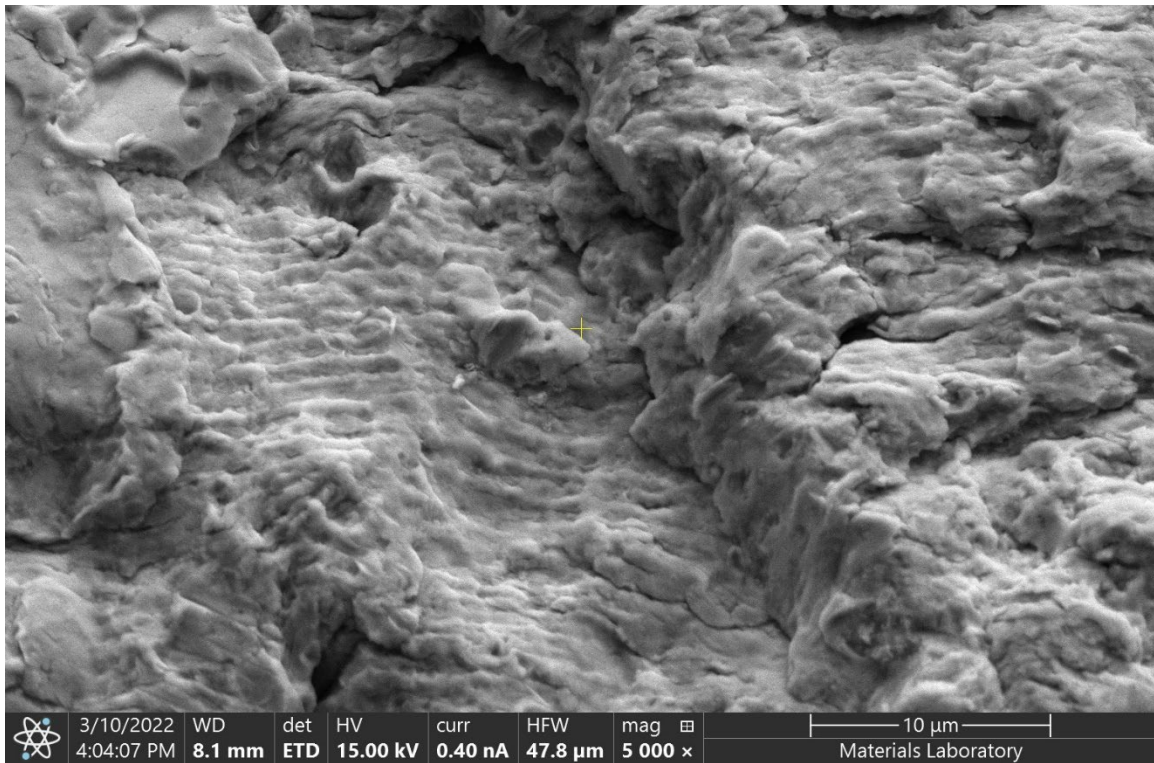


Figure 14 – SE micrograph of fatigue striations in the region in Figure 13.

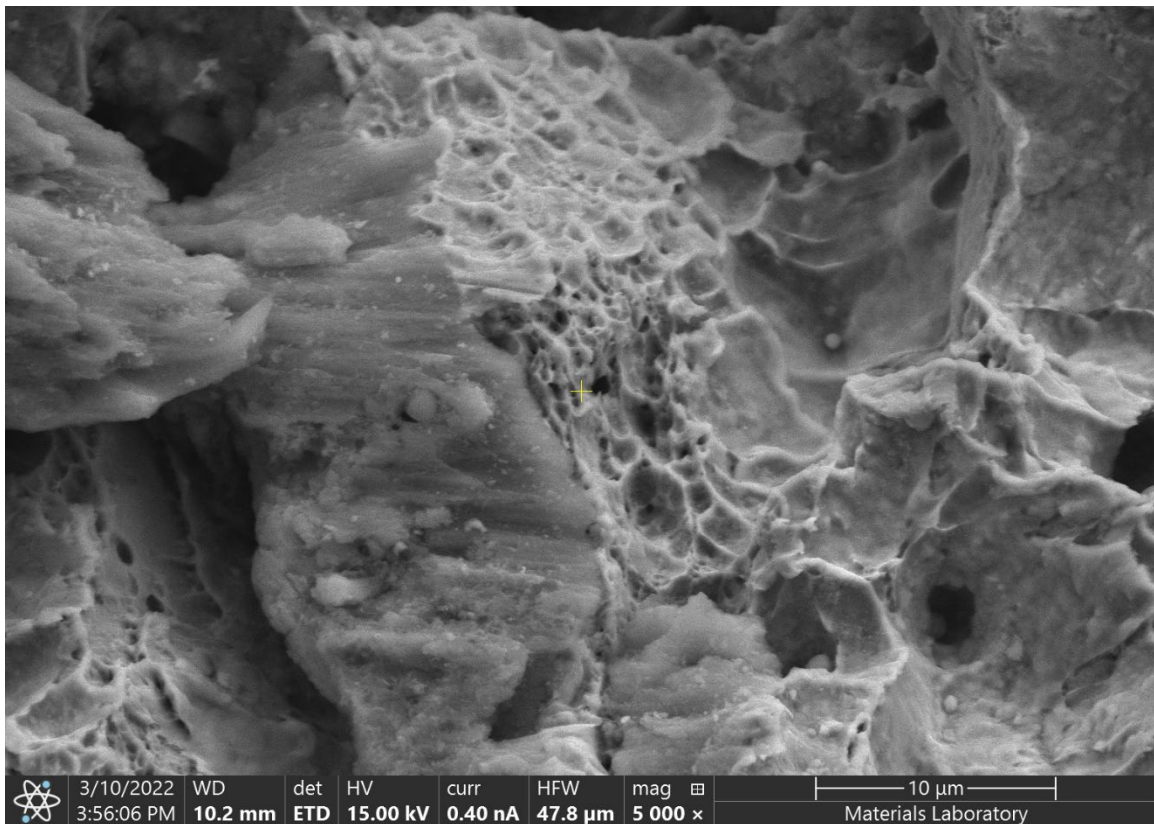


Figure 15 – SE micrograph of dimpled rupture outside the fatigue crack.

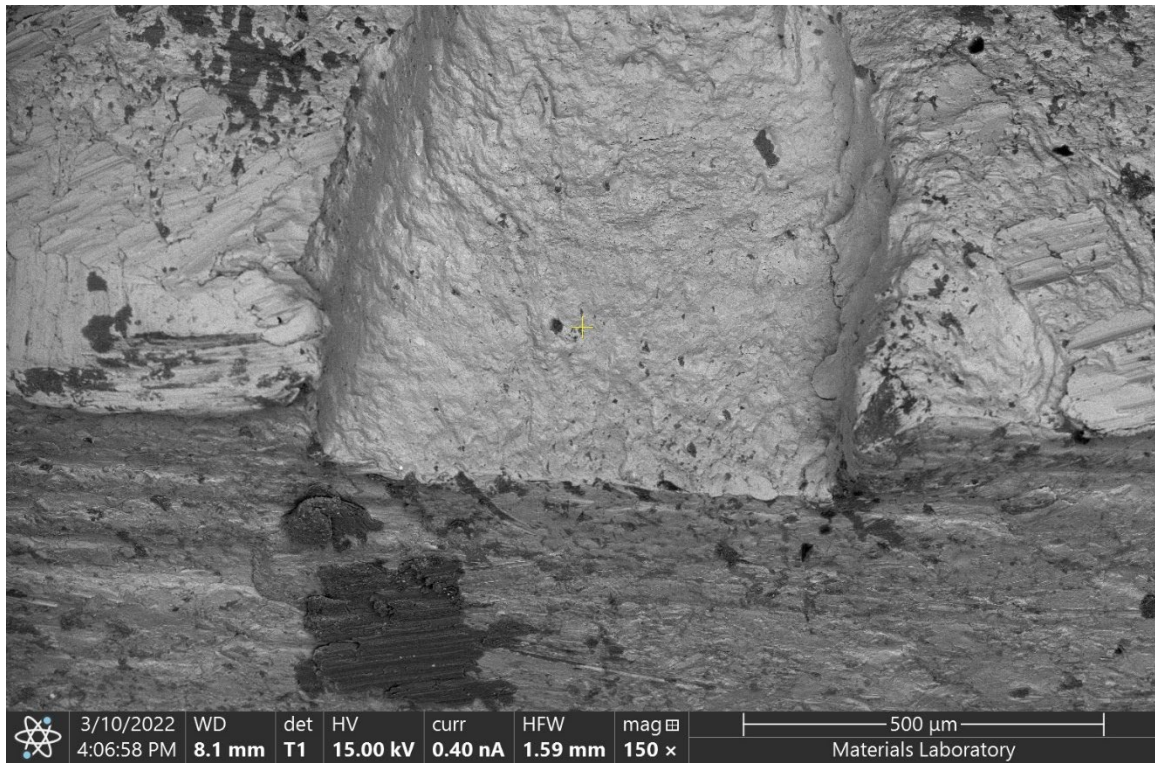


Figure 16 – Backscattered electron (BE) micrograph of a fatigue crack initiation site.

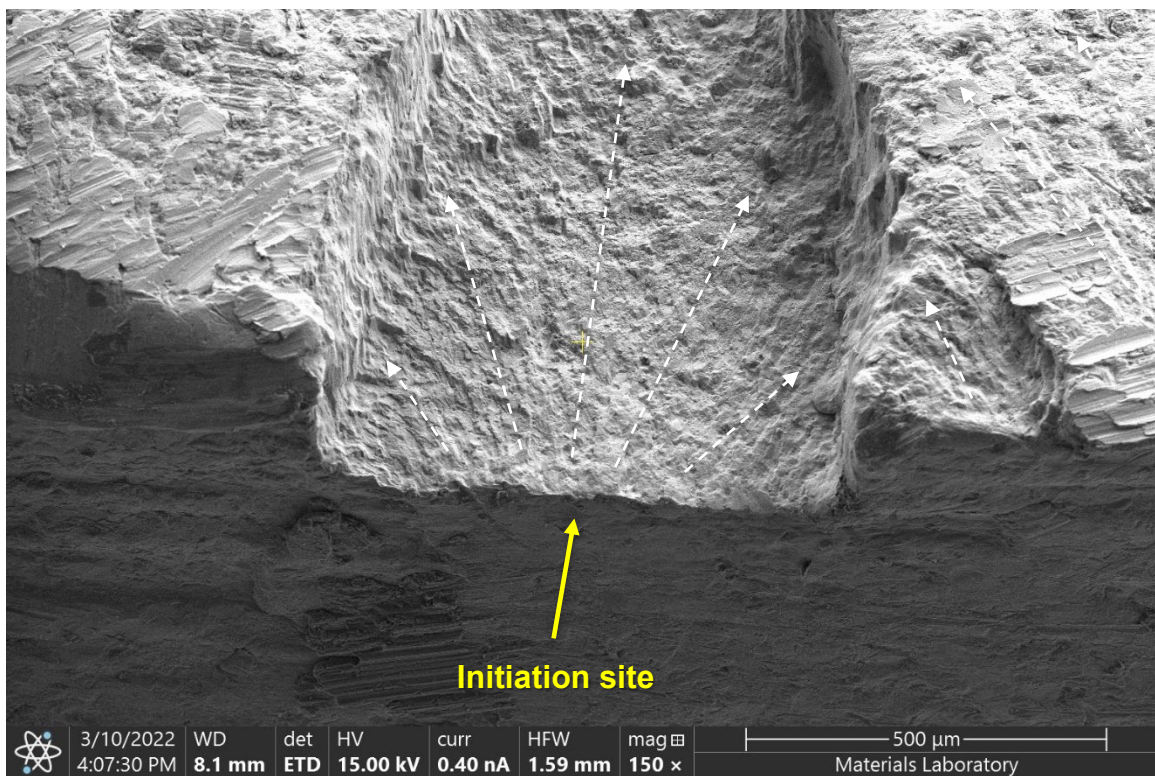


Figure 17 – SE micrograph of the initiation site in Figure 16.

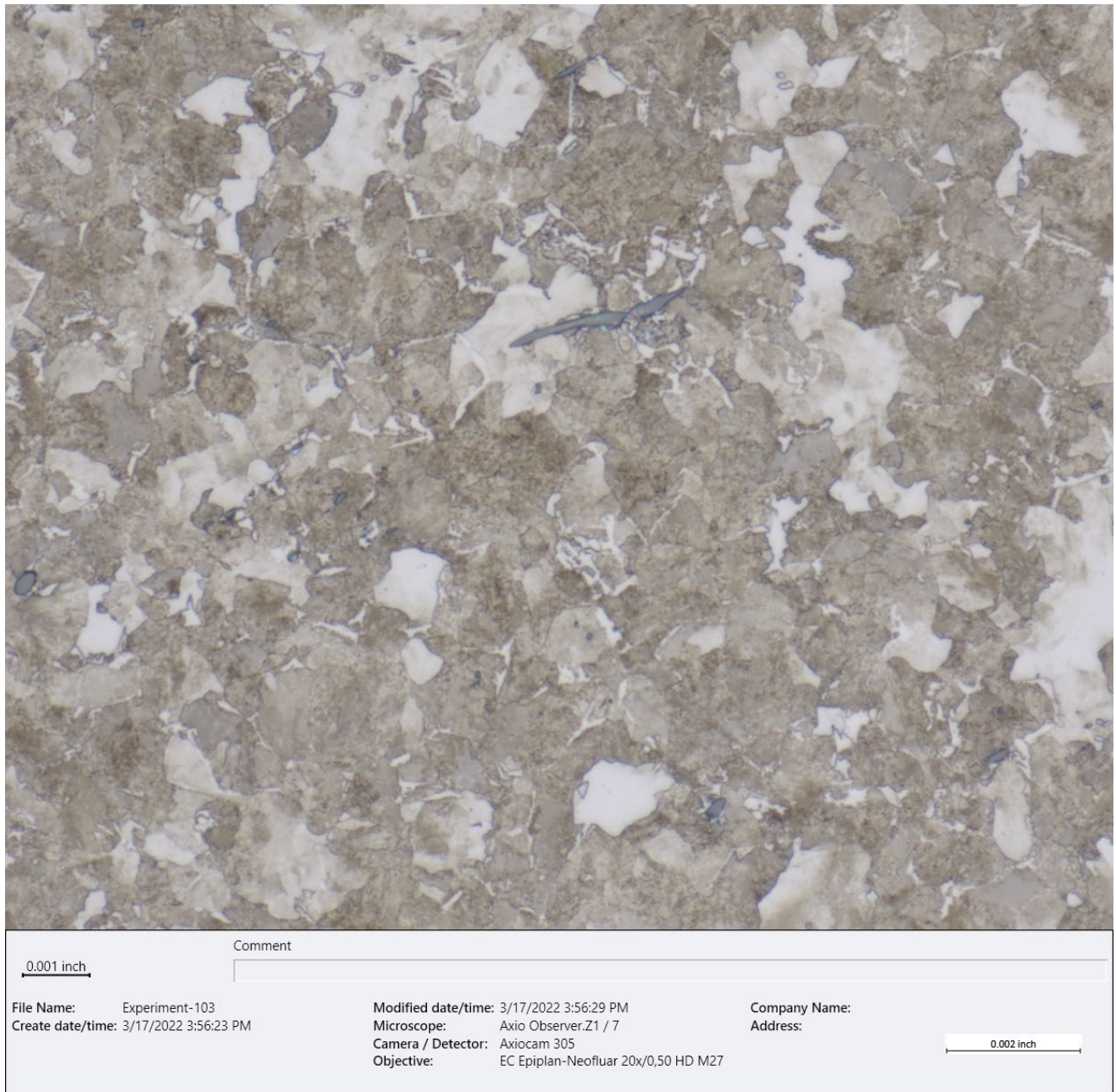


Figure 18 – Bright-field (BF) optical micrograph of a typical area of the connecting rod microstructure (~500X, etched 2% nital).

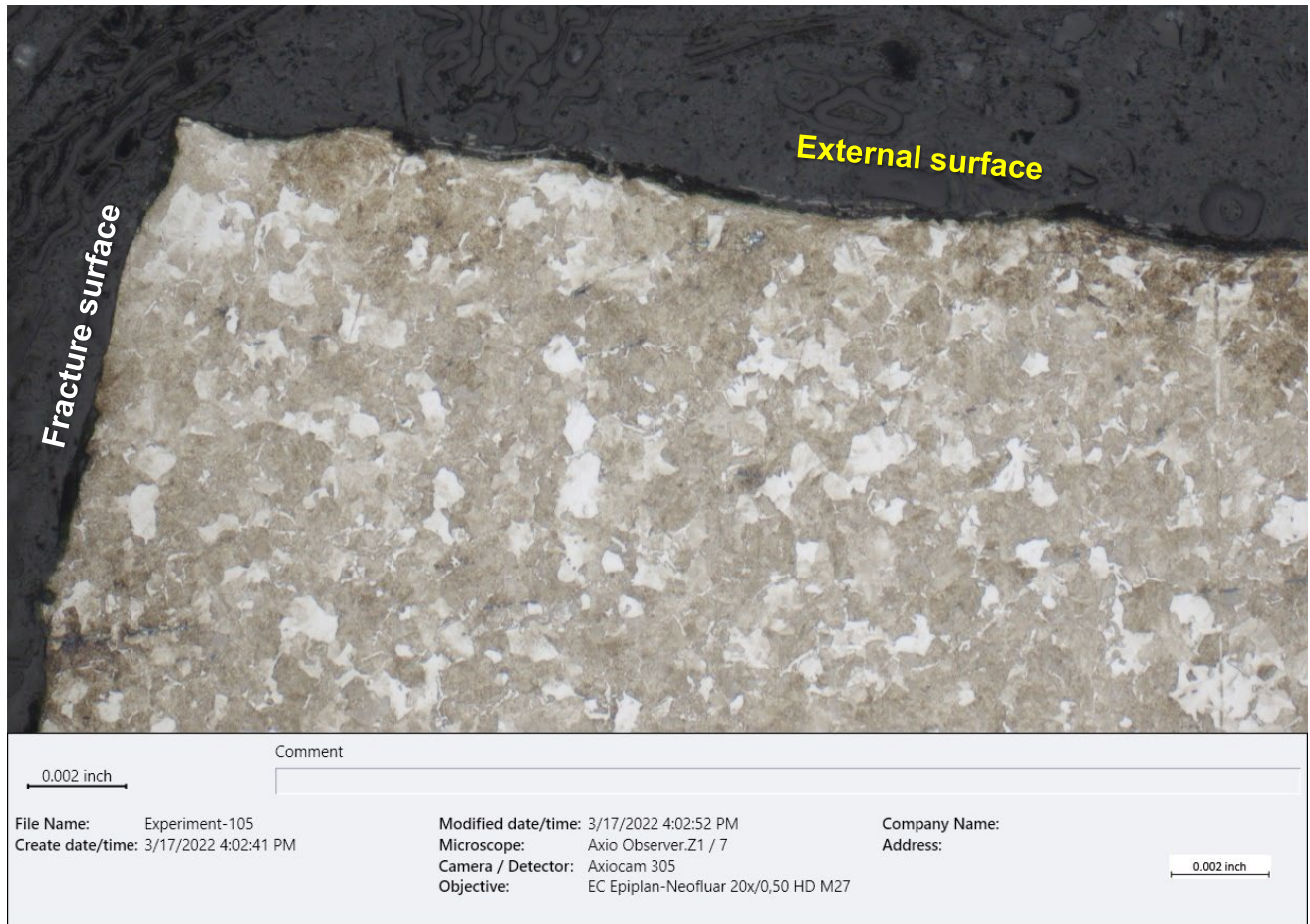


Figure 19 – BF optical micrograph of a cross-section of the fracture surface with the crack initiation surface (~200X, etched 2% nital).

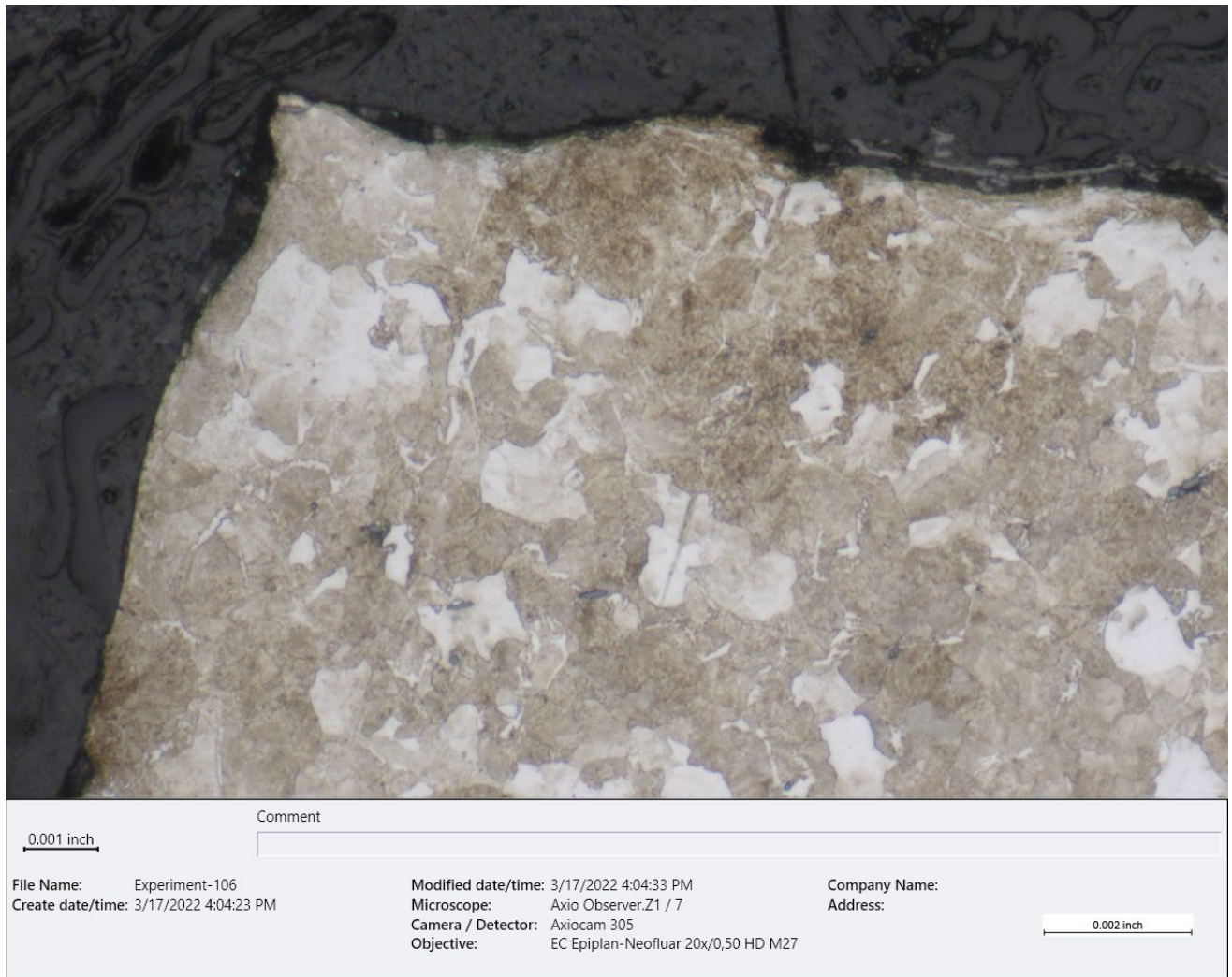


Figure 20 – BF optical micrograph of a cross-section of the fracture surface with the crack initiation surface (~500X, etched 2% nital).



Figure 21 – BF optical micrograph of a distressed area of the connecting rod surface, showing deformed grains and untempered martensite (~200X, etched 2% Nital).