

NATIONAL TRANSPORTATION SAFETY BOARD

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

December 17, 2021



MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-086

1. ACCIDENT INFORMATION

Place : Lodi, California
Date : April 28, 2020
Vehicle : Cessna 177, N3386T
NTSB No. : WPR20LA133
Investigator : Joshua Cawthra, AS-WPR

2. COMPONENTS EXAMINED

#3 and #4 cylinders
Remnants of pistons
Remnants of connecting rods

3. DETAILS OF THE EXAMINATION

On April 28, 2020, about 1752 Pacific daylight time, a Cessna 177 airplane was substantially damaged during an accident near Lodi, CA. The pilot sustained minor injuries. The student pilot reported that about 15 minutes after takeoff, oil was seen on the windscreen followed by a loud noise and a loss of engine power. The pilot attempted to restart the engine but was unsuccessful, and they initiated a forced landing to a nearby field. Post-accident examination of the airplane by a Federal Aviation Administration (FAA) inspector revealed the airplane had sustained structural damage to the fuselage. Several components from the O-360-A1A engine were sent to the NTSB Materials Laboratory for additional examination.¹

Figures 1 and 2 show different views of the #3 cylinder, as received. Much of the cylinder assembly, particularly on the exterior, exhibited damage consistent with that typically observed from being in service, including grayish discolorations on the exterior surfaces and oil deposits. However, as seen in the upper left of Figure 1 and the upper right of Figure 2b, the skirt of the cylinder was missing material, with the adjacent skirt material bent inward and with localized fractures and tears.

¹ The Lycoming O-360 is a family of four-cylinder, direct-drive, horizontally opposed, air-cooled, piston aircraft engines, manufactured by Lycoming Engines headquartered in Williamsport, PA.

Also shown in Figure 2b was the underside of the piston still wedged inside the cylinder when received. While intact overall, the piston exhibited multiple fracture surfaces, consistent with areas containing the pin having broken downward. These fracture surfaces exhibited either rough dull features, or flat shiny and high directional features. These were consistent with fracture from overstress, and subsequent post-fracture smearing, respectively. There were no features consistent with progressive cracking or corrosive attack on this cylinder assembly.

The connecting rod from this cylinder is shown from different web faces in Figure 4. The rod assembly had been disassembled from the engine and reassembled prior to receipt. The markings on the part flange stated "LW-11750" and in the web stated, "LW-11488 W 10-6". The neck of the connecting rod had been twisted approximately 90°, most pronounced near the piston pin bore. In addition, the rod exhibited more discoloration in this area, consistent with oil decomposition and subsequent deposits, typical of exposure to higher temperatures.

The piston pin exhibited circumferential wear marks, consistent with typical patterns of pins rotating in service. The edge of the pin did exhibit impact marks and gouges, consistent with impact against another metallic object.

Figure 4 and Figure 5 show the #4 cylinder assembly from different locations. Figure 4 shows the side with the intake and exhaust manifolds, while the top of the cylinder with the rocker arms, retainers, and springs is depicted in Figure 2a. Figure 2b shows the underside of the piston, which had also been wedged against the walls of the cylinder. Unlike the other piston, this one was intact, with no fractures of the skirt or pin bore—the pin was still secure inside the piston, along with a remnant of the connecting rod. The recesses of the piston did exhibit shavings of metal, along with gouging on a corner of the skirt flange. These features were consistent with impact against a moving metallic object.

The spark plugs and piston assembly were removed from the cylinder, exposing the interior of the cylinder (shown in Figure 6). While there were no indications of impact, gouging, or spalling damage to the cylinder crown or valve seats, these surfaces did exhibit deposits thick enough to exhibit flaky layers. These deposits exhibited a reflective brown appearance, consistent with lead oxide-based compounds that buildup in reciprocating engines from deposits of combustion byproducts using avgas.

Similarly, the piston crown shown in Figure 7 exhibited these deposits, consisting of a mottled, flaky layered appearance, with brown and yellowish hues. One of the removed spark plugs, shown in Figure 8, also exhibited dark deposits on the electrode surfaces. However, the deposits on the spark plug were not thick enough to create contact between the electrodes on the spark plug head.

Figure 9 and Figure 10 show the fractured remnants of the connecting rod, after disassembly and positioning. The marking on the web stated "LW-11-88 W 10-3". The connecting rod had fractured in two locations, one adjacent to the yoke transition on the right of the figures, and the other 1.15 inches from the piston bore on the other side. The

remnant pictured on the left in the figures was the one that had been removed from inside the cylinder assembly. The total length from the end to the fracture surface was 2.41 inches.

The middle web section exhibited multiple areas of locally deformed material, mostly along the protruding flange surfaces. These features were consistent with this remnant having been impacted by adjacent components in multiple locations. The fracture surface between this remnant and the crankshaft bore surfaces exhibited a general rounded but perpendicular orientation in the upper half of Figure 9, but then a more angled orientation, with localized buckling on the flanges. This was consistent with bending towards that direction. The rough orientation and texture suggested overstress fracture, but the mating surfaces were damaged from post-fracture impact, with no discernible fracture features present.

The other fracture surface of the connecting rod, towards the pin side, was relatively flat and oriented perpendicular to the rod longitudinal direction. The fracture on the pin side remnant was relatively smooth, exhibiting few elevated features. Figures 11 and 12 show more detailed views of the rod remnant fracture surface, with Figure 11 containing annotations. Most of the fracture surface, which was generally flat in orientation, exhibited crack arrest marks, indicative of progressive crack growth. Later examination of these regions found them to be consistent with fatigue. The last 0.04 to 0.07 inches of the fracture surface exhibited a rougher, more undulating surface texture—this area was consistent with subsequent overstress fracture. Therefore, the fatigue crack covered about 95% of the rod flange-to-flange cross section, measured as approximately 1.086 inches.

The lack of ratchet marks suggested a single initiation site, as shown in Figure 13. This site was located at the inside corner of a flange edge. The river patterns and crack arrest marks were consistent with having emanated from this feature. When viewed at an angle (Figure 14), the feature was collocated with an area of local plastic deformation and wear. As shown in the figure, the outer flange surface had been smoothed, and deformed over the side of the inner flange surface (Figure 15).

The connecting rod fracture surface was examined using a scanning electron microscope (SEM). As typified in Figure 16 located near the initiation site, the majority of the fracture surface exhibited fatigue striations, consistent with fatigue crack propagation. As exemplified in Figure 17, these striations exhibited both large and smaller features, consistent with spectrum loading typical of high rpm reciprocating engines.

Towards the end of the fatigue crack, these striations became more unevenly spaced, with secondary cracking parallel to the striations, and tearing perpendicular to the striations (see Figure 18). These features were consistent with more rapid and unstable crack propagation at the end of the fracture sequence. The features on the fracture surface beyond the fatigue crack exhibited slanted dimpled rupture, consistent with subsequent tensile overstress in shear (Figure 19).

Figures 20 and 21 show closer views of the fatigue crack initiation site. These figures illustrate river patterns emanating from near the corner, which consisted of a flattened, angled feature. The backscattered micrograph showed material contrast consistent with the presence of lower atomic weight material.² This feature was examined using energy dispersive x-ray spectroscopy (EDS).

As compiled using x-ray maps in Figure 22, the area exhibited an absence of Fe and O, but exhibited elevated levels of Si and Al. As EDS data found the connecting rod remnant to exhibit a chemical composition consistent with an alloy steel (such as Type 4340), the presence of Si and Al would be consistent with impact against another metallic part. Figure 23 shows another closer view, exemplifying the material transfer at the crack initiation site. This figure also demonstrated the localized buckling, consistent with an impact depression in the rod flange corner. A typical EDS spectrum of the dissimilar material, showing large peaks of Al, Si, O, S, and Pb, is illustrated in Figure 24.

The remnant of the connecting rod was sectioned, cold epoxy mounted, polished, and etched using a 2% nital solution.³ Figure 25 shows a cross section through the flange corner where the fatigue crack initiation site was located (arrow). The plastically deformed metal protrudes downward slightly in the figure (to the right of the arrow). A closer view in Figure 26 shows damage to the location, as well as the remnants of dissimilar material on the surface. Examination using EDS found the dissimilar material to be consistent with that shown in Figure 24. This initiation site also exhibited more inward damage and localized folds or cracks, consistent with stress risers that typically initiate fatigue cracks under cyclic stresses.

In contrast, Figures 27 and 28 show the opposite corner of the connecting rod (rotated to be a similar orientation to Figure 23). This corner exhibited a relatively smooth transition, with no indications of impact damage. The closer view in Figure 28 showed a relatively smooth surface, with no sharp peaks or valleys in the cross section. There was no visible dissimilar material present at or along the surface.

The hardness of the connecting rod cross section was examined per ASTM E18.⁴ The hardness of the connecting rod core averaged 32 HRC, typical of this material and tempered martensite microstructure as shown in Figure 28.

Erik M Mueller
Materials Research Engineer

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

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

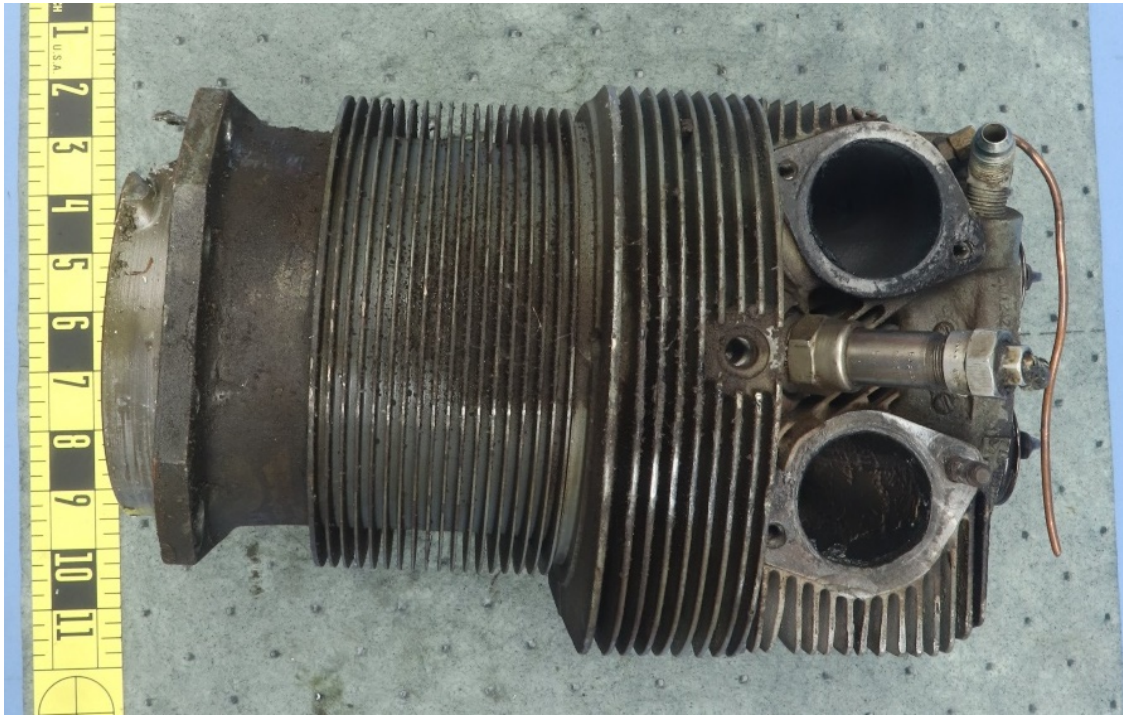


Figure 1 – View of the #3 cylinder, from the intake and exhaust manifold openings.

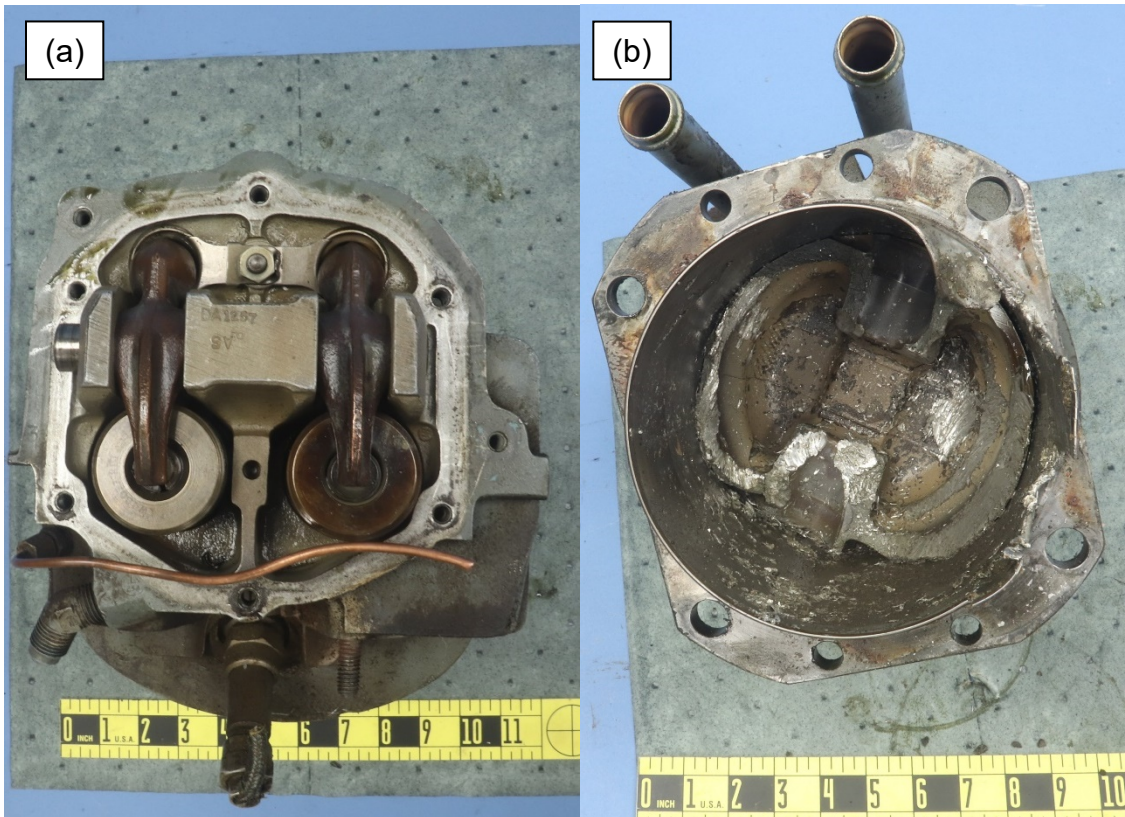


Figure 2 – View of the #3 cylinder assembly from the (a) upper (rocker arm) position and (b) underside or piston position.



Figure 3 – View of the connecting rod recovered from the #3 cylinder, showing a 90° twist from (a) the marked flange face and (b) the opposite flange face.

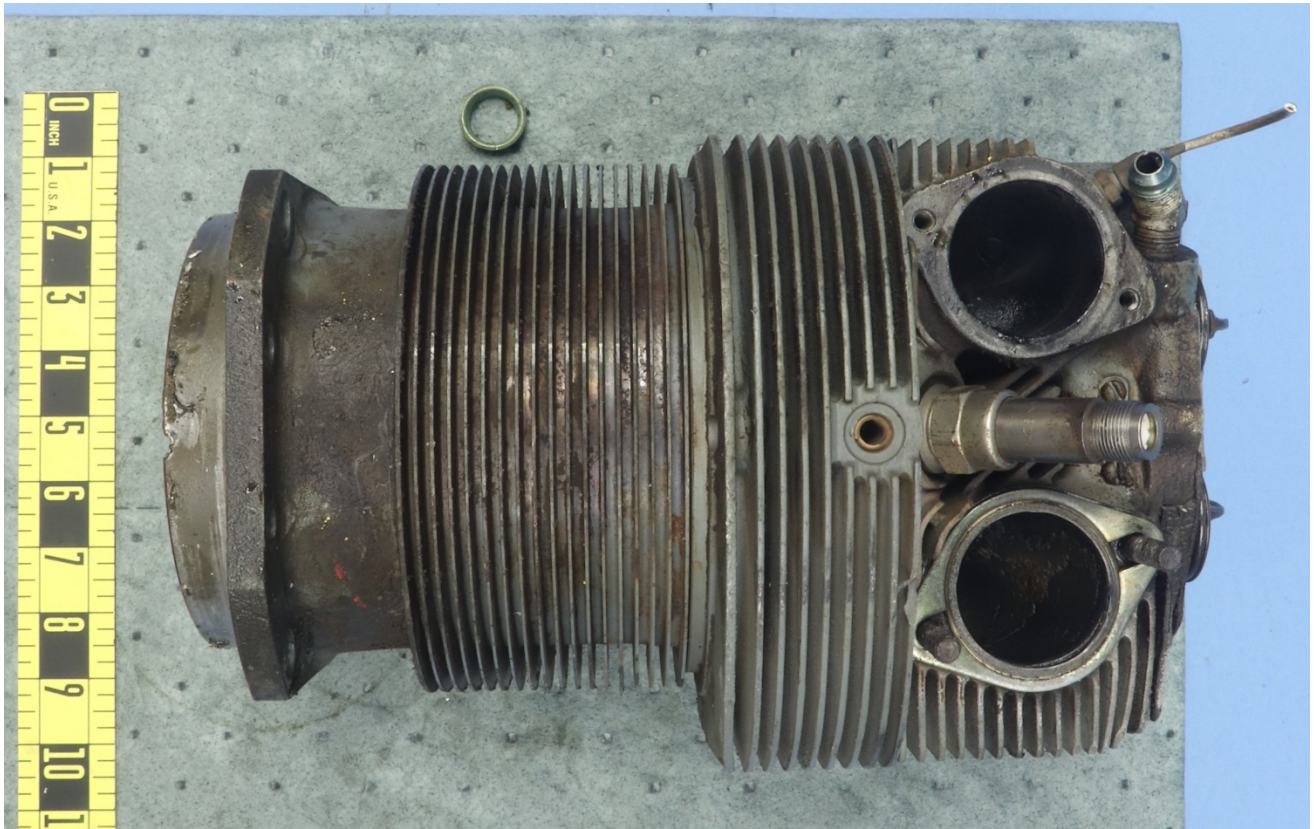


Figure 4 – View of the #4 cylinder assembly from the manifold side.

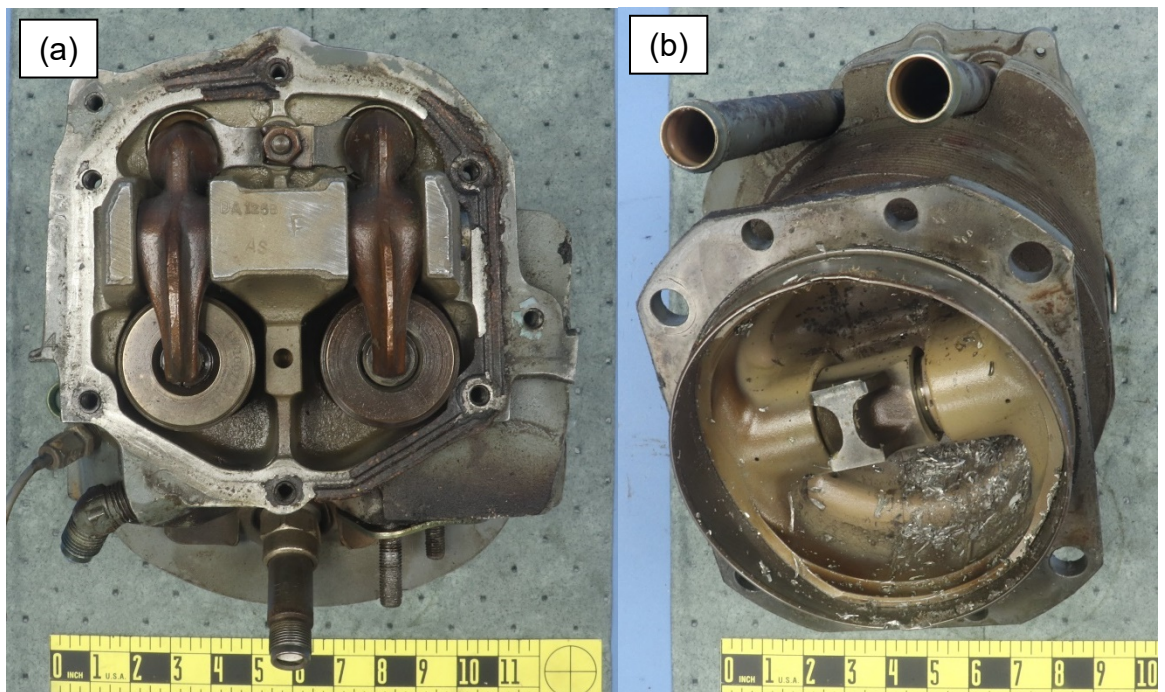


Figure 5 – The #4 cylinder assembly, as received, viewed from (a) the opened top section with the rocker arms and (b) the bottom piston position. The piston contained a remnant of the connecting rod secured by the piston pin.



Figure 6 – View of the interior bore surfaces and valve seats of the #4 cylinder after removal of the piston and spark plugs.



Figure 7 – View of the #4 piston crown, after removal. The surface exhibited deposits consistent with combustion products thick enough to begin spalling.



Figure 8 – View of the #4 spark plug after removal from (a) the side and (b) the electrode.



Figure 9 – View of the #4 connecting rod remnants, positioned after removal of the pin remnant from the piston, viewed from the marked web side.

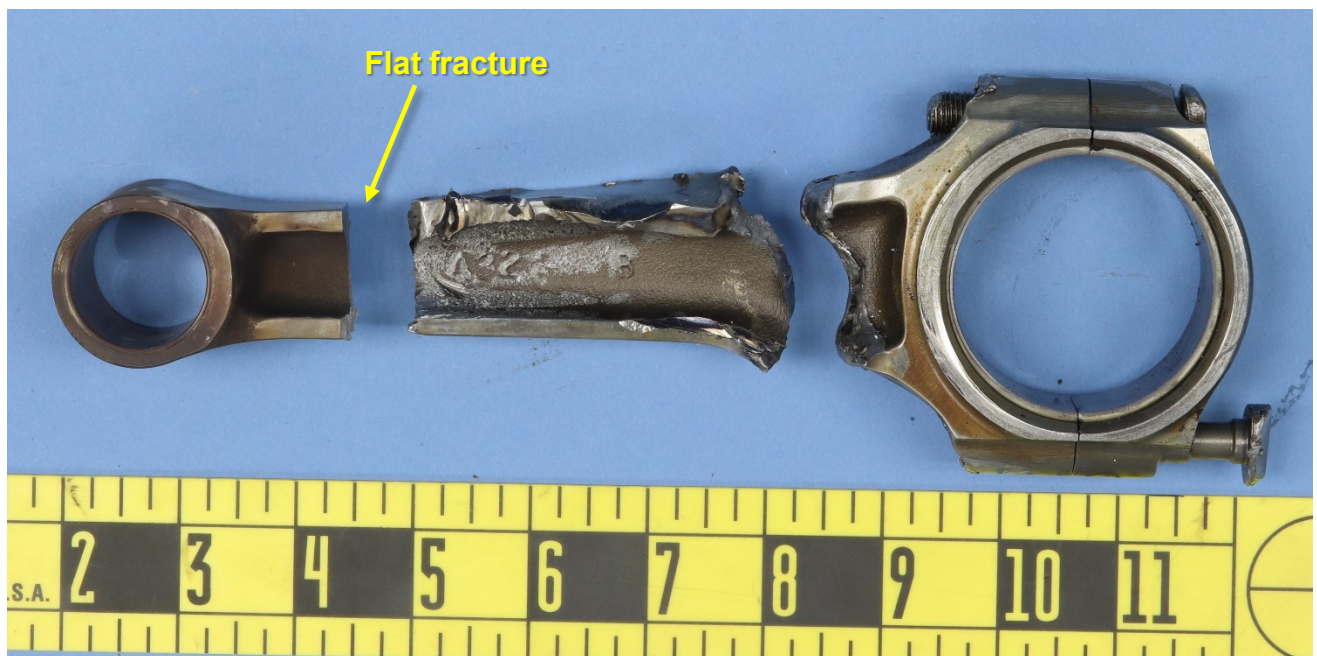


Figure 10 – View of the #4 connecting rod remnants, positioned after removal of the pin remnant from the piston, viewed opposite that in Figure 9.

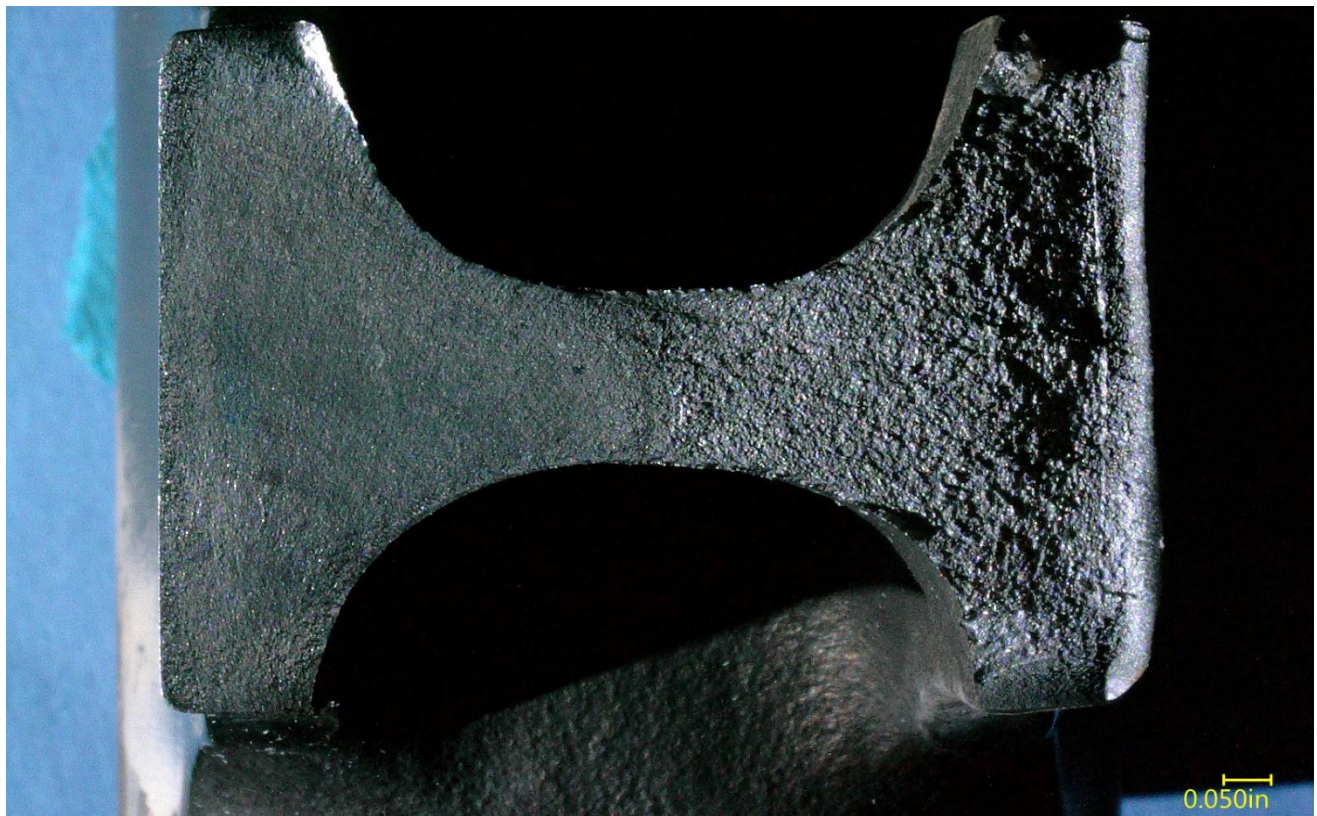
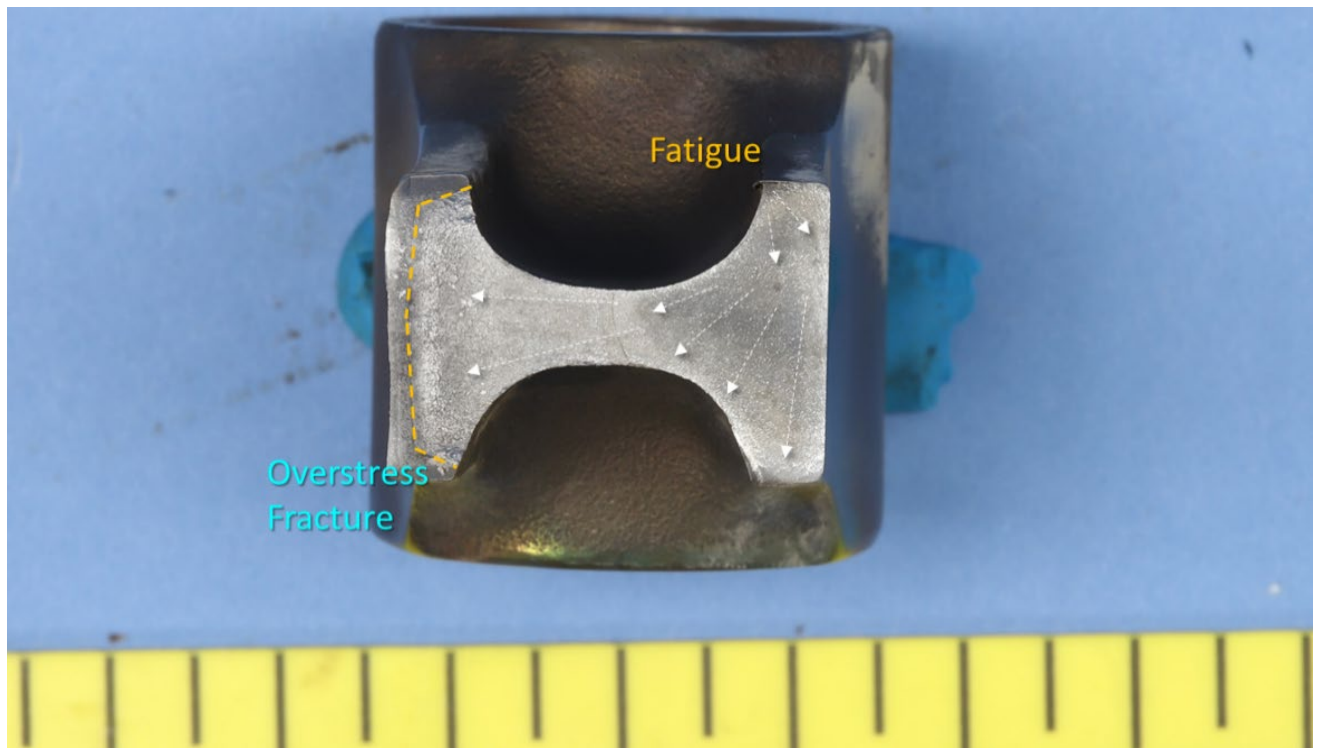


Figure 12 – Closer view of the fracture surface from Figure 11, using oblique lighting to highlight the surface features.

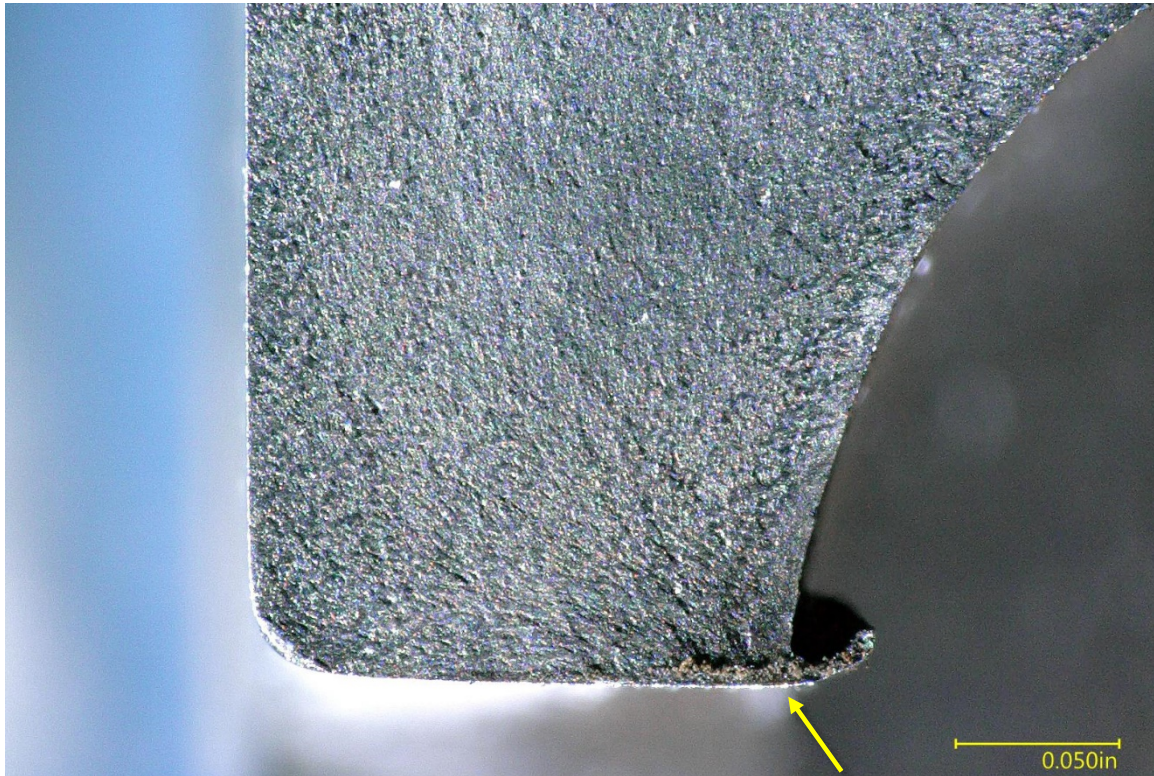


Figure 13 – View of the crack initiation site (arrow) of the fatigue crack on the connecting rod fracture surface.

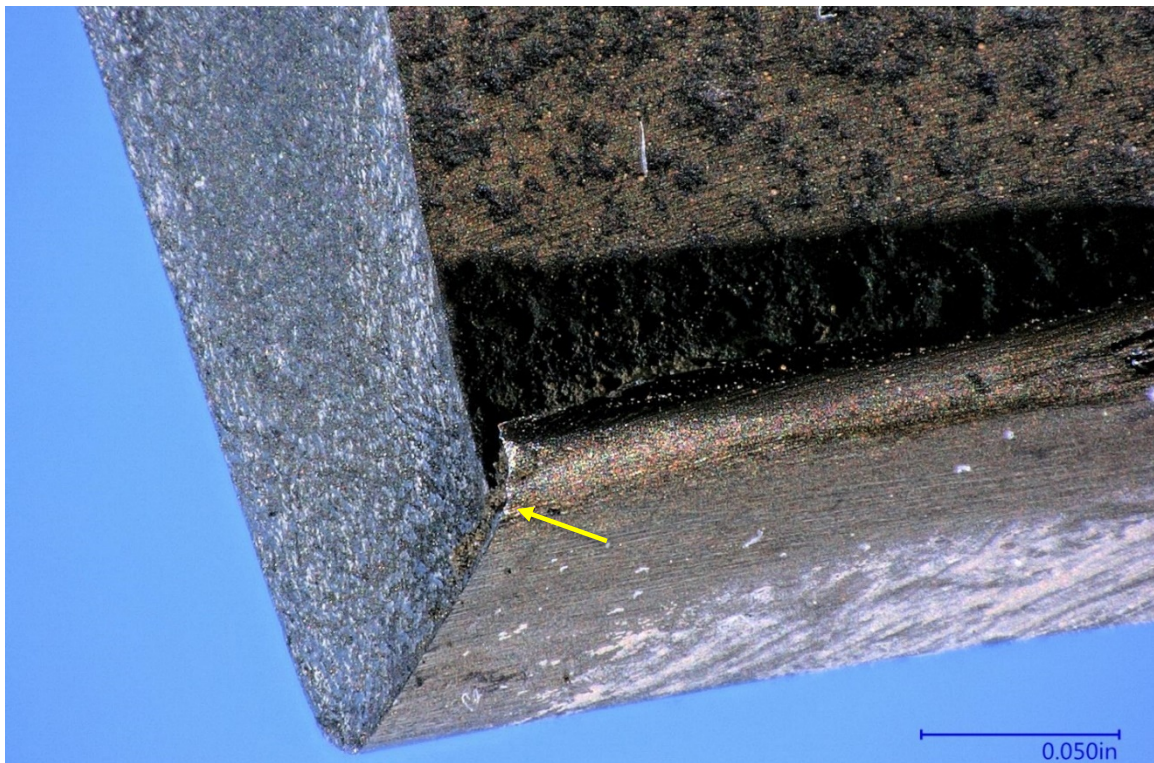


Figure 14 – Angled view of the crack initiation site (arrow), showing inward deformation of the flange side.



Figure 15 – Side angle view of the crack initiation site.

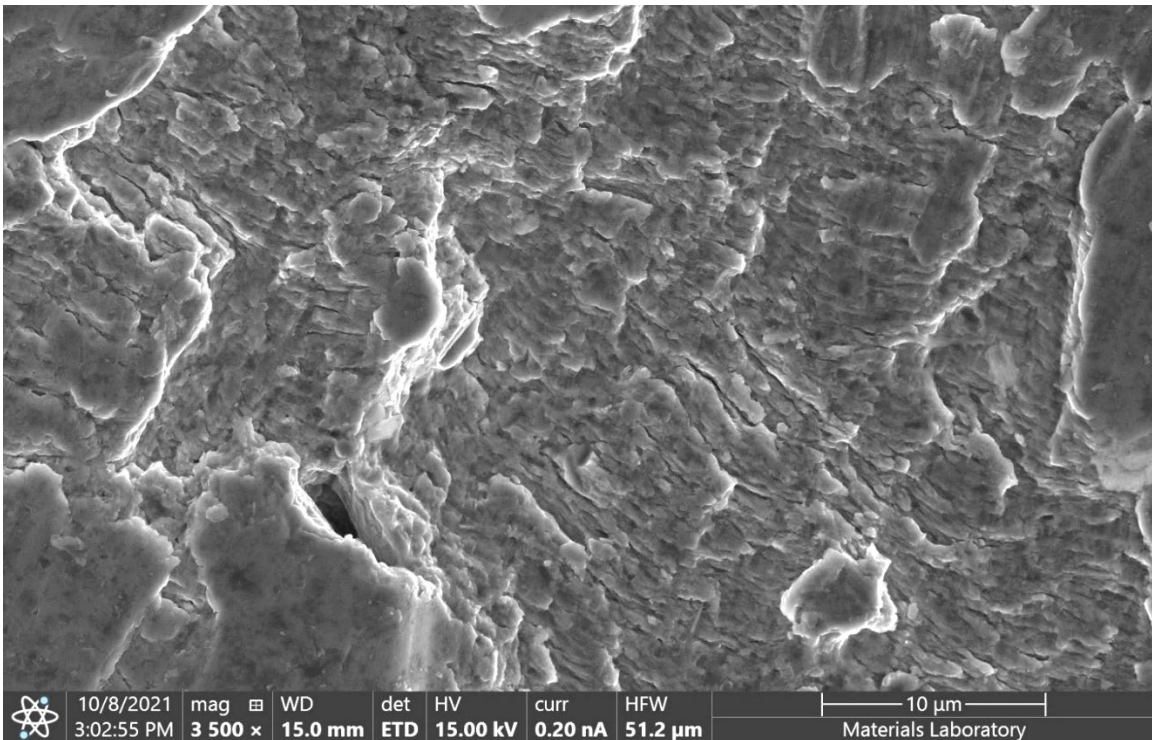


Figure 16 – Secondary electron (SE) micrograph of fatigue striations near the initiation corner.

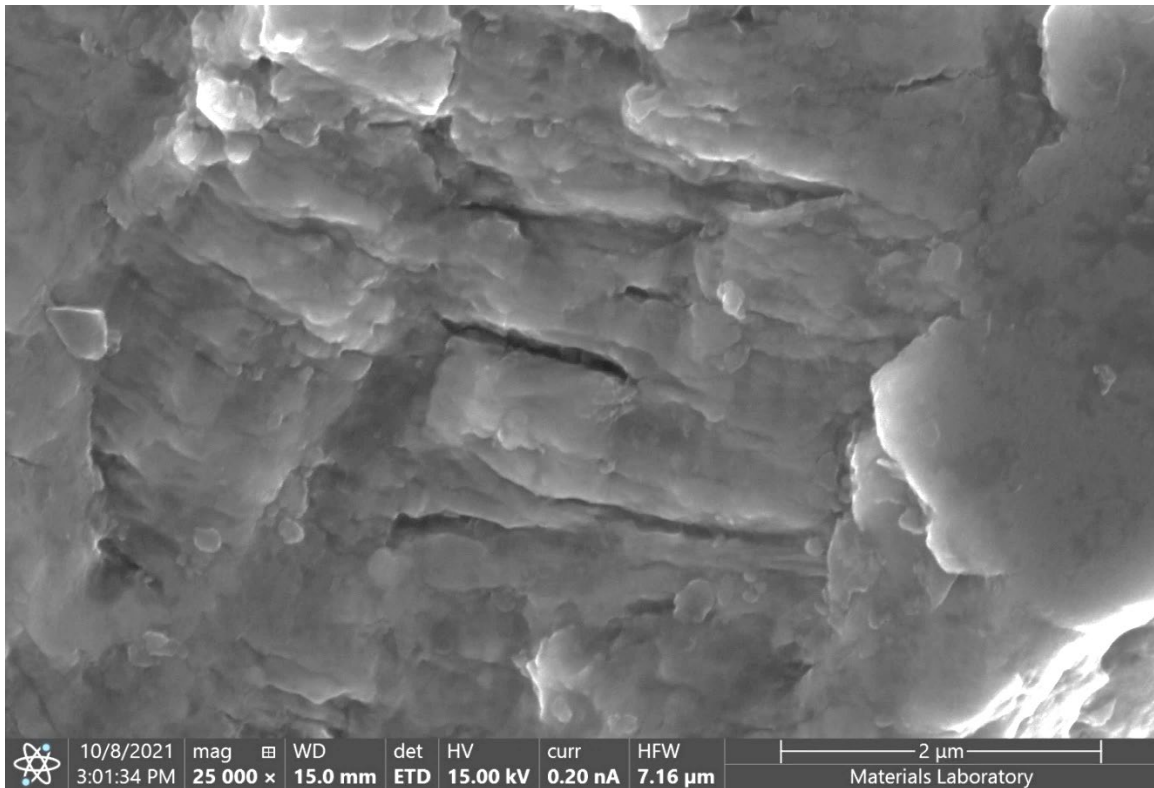


Figure 17 – SE micrograph of a closer view of the striations in Figure 16.

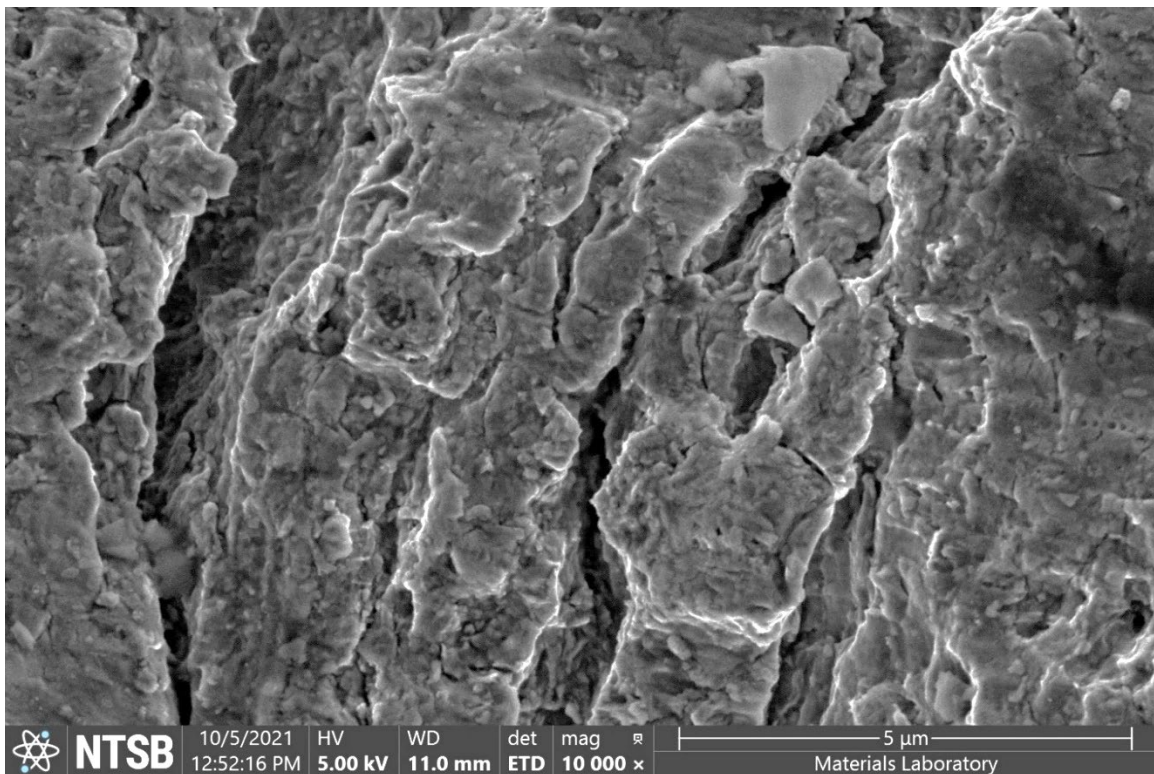


Figure 18 – SE micrograph of striations and secondary cracking at the end of the fatigue crack.

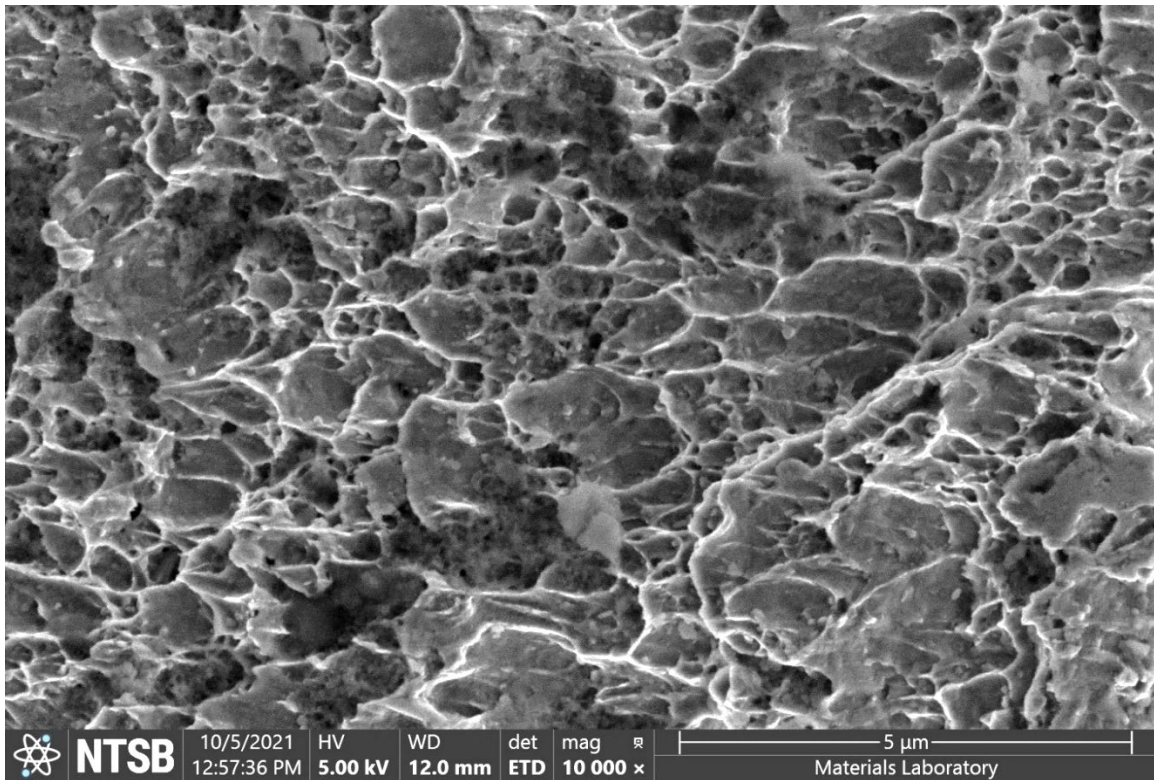


Figure 19 – SE micrograph of slanted dimpled rupture outside the fatigue crack.

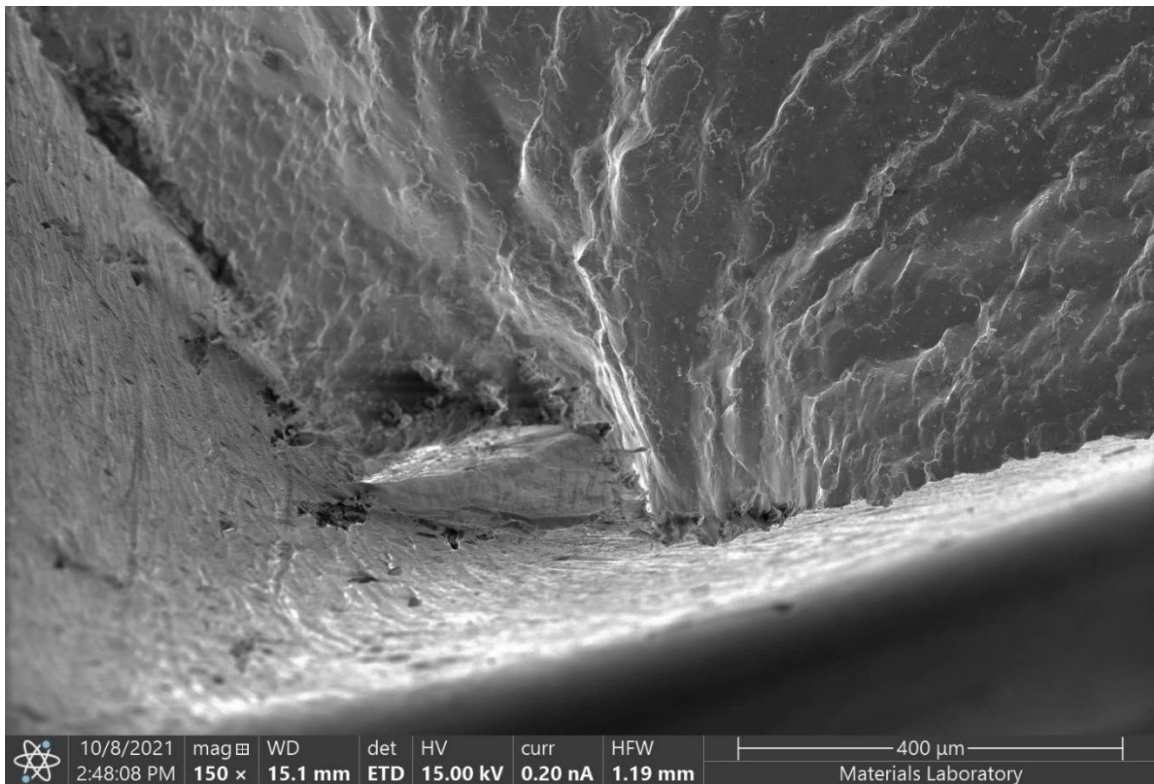


Figure 20 – SE micrograph of the fatigue crack initiation site.

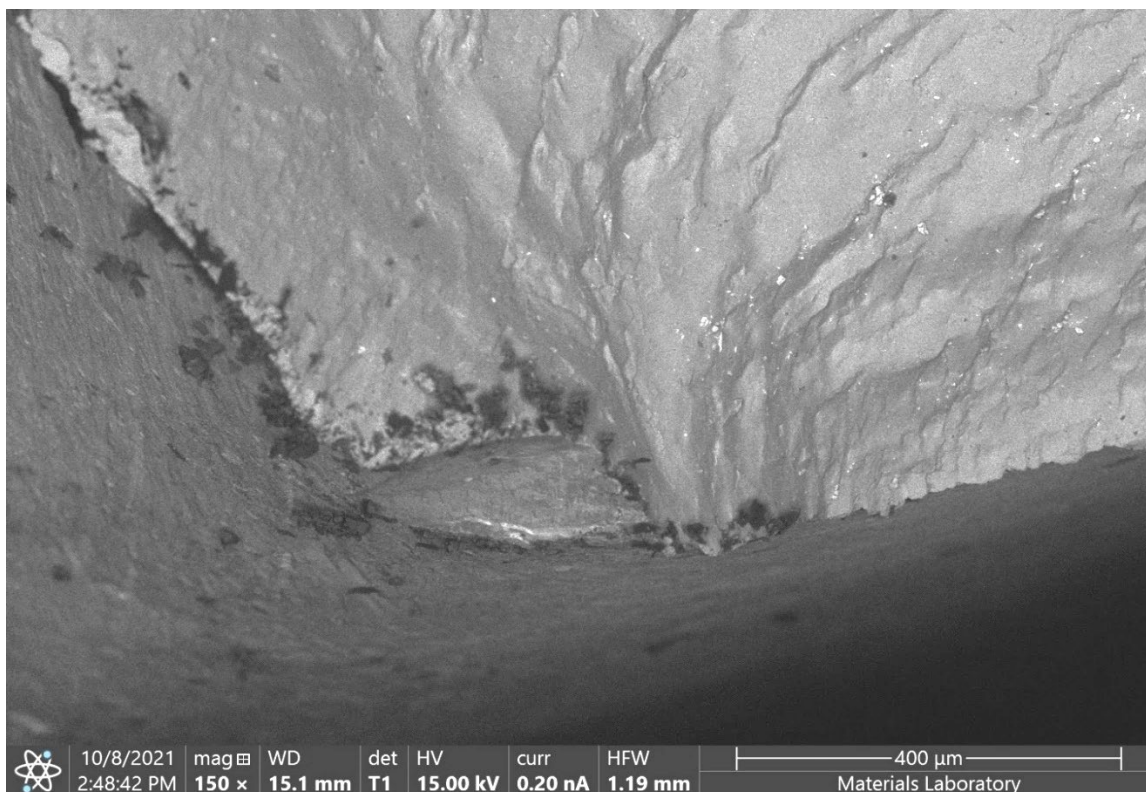


Figure 21 – Backscattered electron (BE) micrograph of the fatigue crack initiation site.

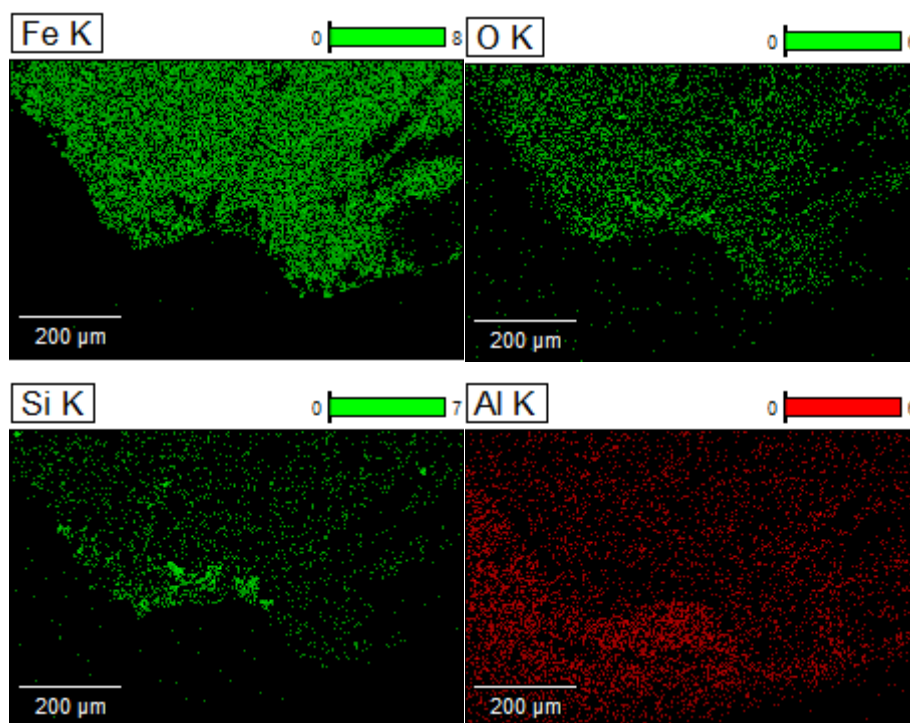


Figure 22 – X-ray maps of the initiation site in Figure 20, showing higher concentrations of Fe, O, Si, and Al, respectively.

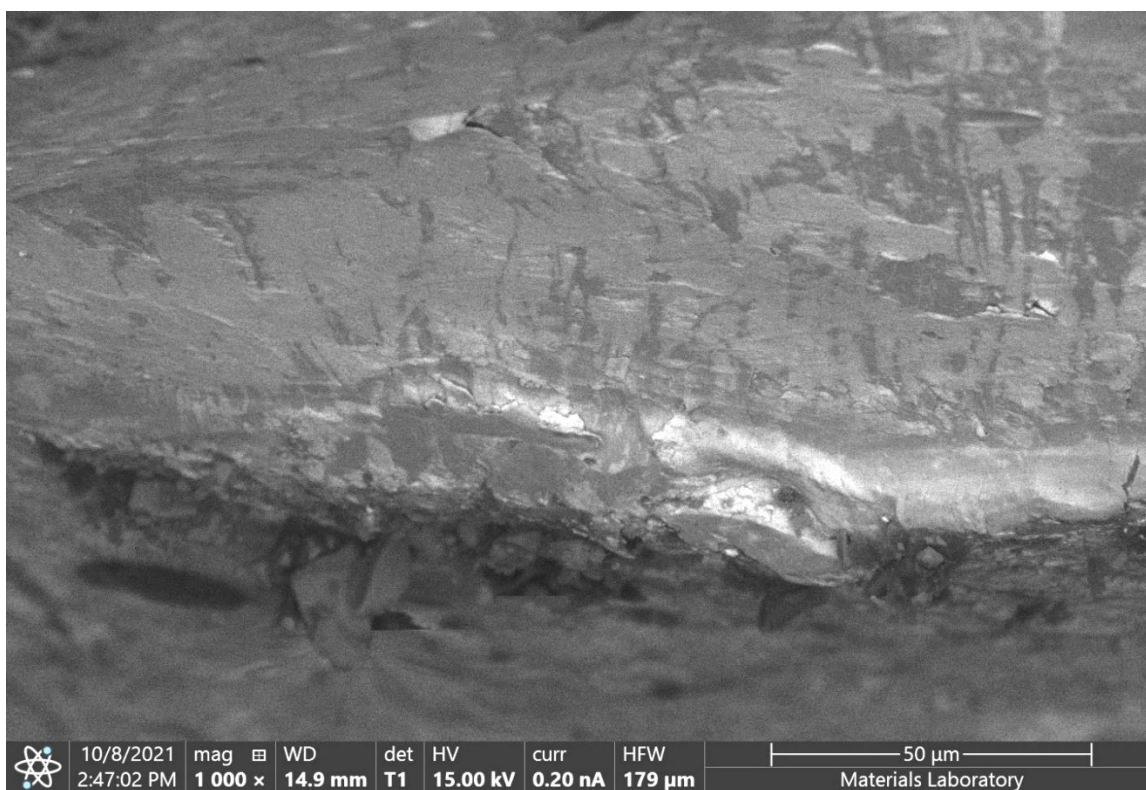


Figure 23 – BE micrograph of the crack initiation site, showing localized deformation and darker contrast material.

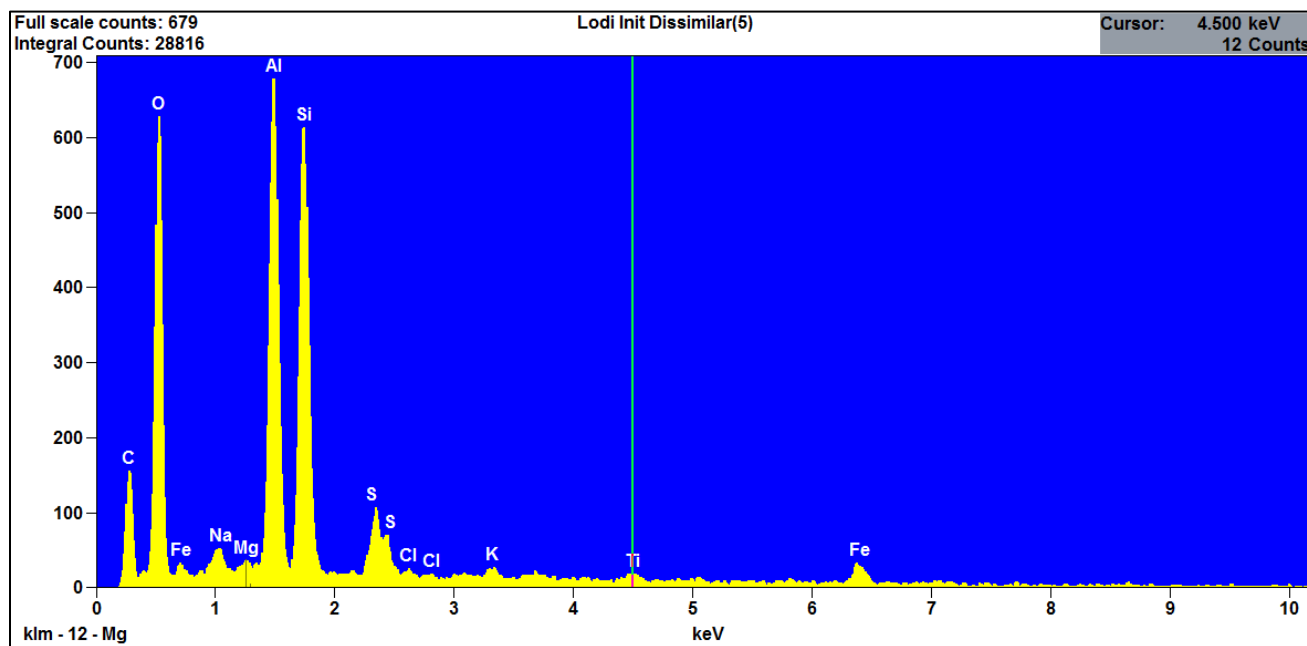


Figure 24 – EDS spectrum of the dissimilar material at the fatigue crack initiation site.



Figure 25 – Bright-field (BF) optical micrograph of the cross section through the crack initiation site (~50X, etched 2% Nital).



Figure 26 – BF micrograph of a closer view of the initiation site corner (~200X, etched 2% Nital).

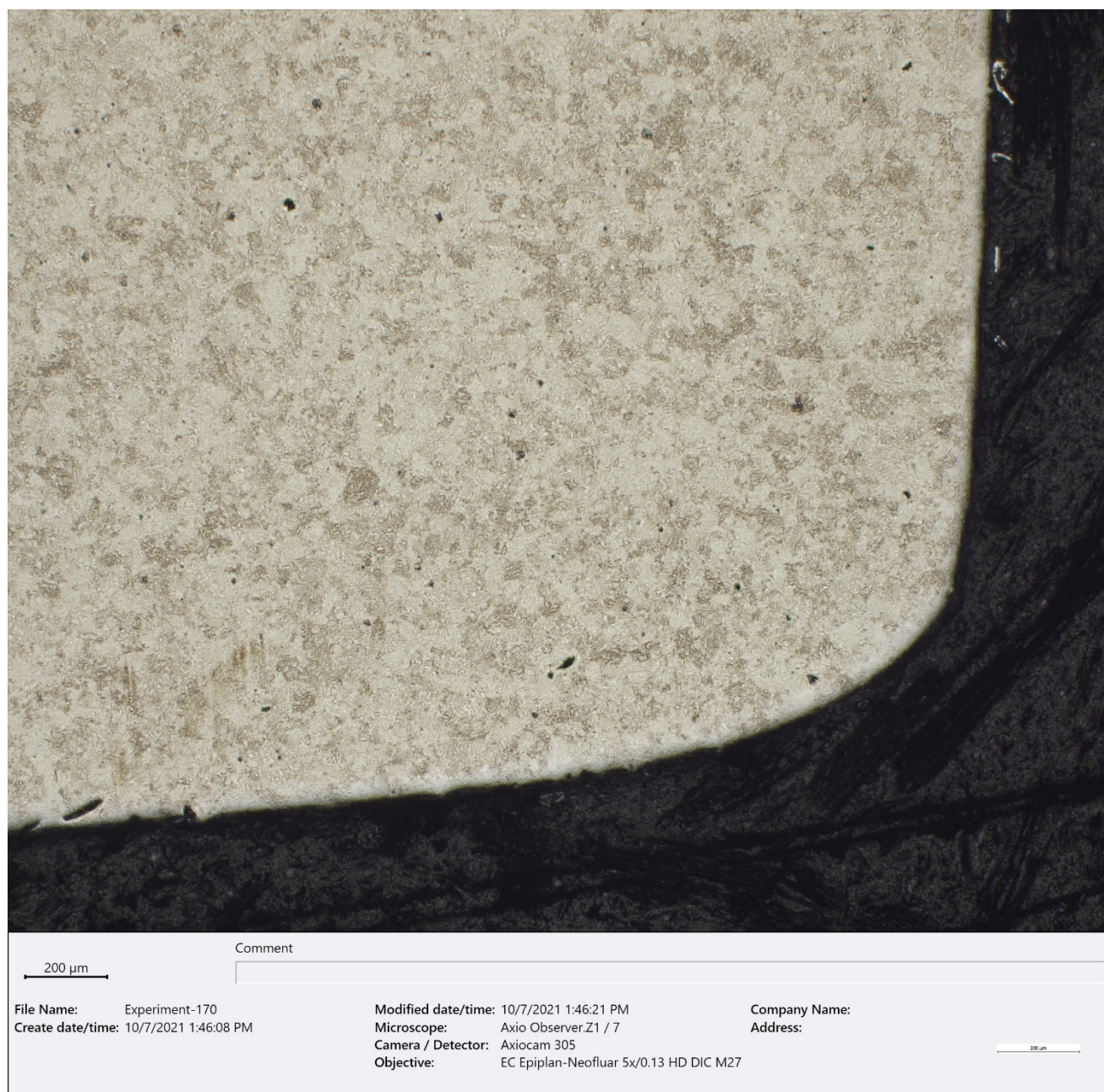


Figure 27 – BF optical micrograph of the lower opposite corner of the connecting rod (~50X, etched 2% Nital).

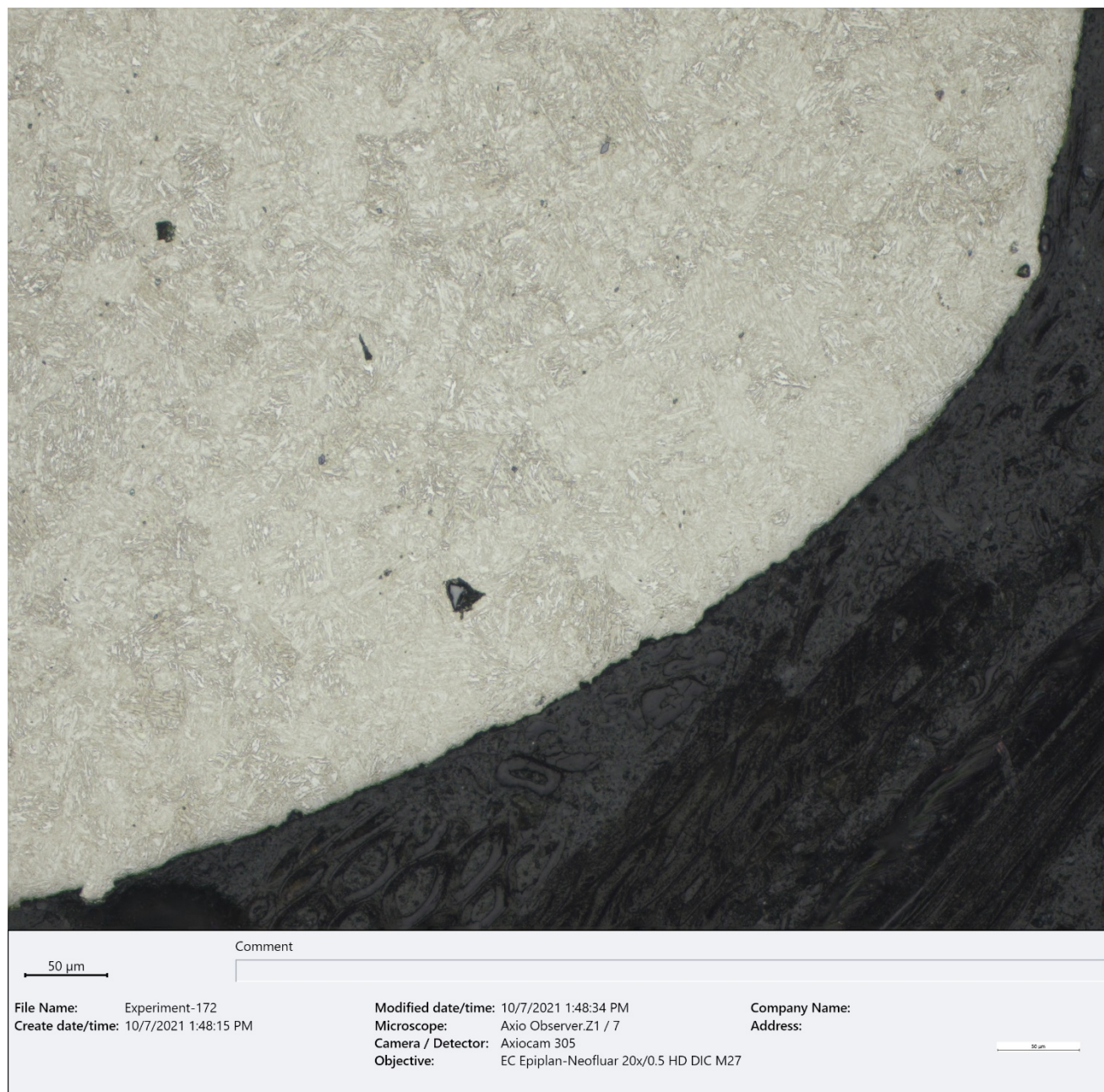


Figure 28 – BF optical micrograph of the corner in (~200X, etched 2% Nital).