

NATIONAL TRANSPORTATION SAFETY BOARD

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



August 7, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-048

1. ACCIDENT INFORMATION

Place : Redmond, Oregon
Date : February 7, 2021
Vehicle : Piper PA-44-180, N125MG
NTSB No. : WPR21LA117
Investigator : Fabian Salazar, AS-WPR

2. COMPONENTS EXAMINED

Remnants of a right main landing gear strut assembly
Bolted torque links

3. DETAILS OF THE EXAMINATION

On February 7, 2021, about 1400 Pacific standard time, a Piper PA-44-180 was substantially damaged when it was involved in an accident in Redmond, OR. Several components from the right main landing gear were sent to the NTSB Materials Laboratory for examination.

Figure 1 shows the components of the landing gear, as received. Figure 2 shows the location of the fractured strut piston. The fracture location of the piston was inside the cylinder bore within the wheel fork assembly. The fractured remnant of the strut piston and its fracture surface is shown in Figure 3.

Figures 4 and 5 show the strut piston, as received from the side. The piston had fractured circumferentially mating with the fracture remnant inside the fork cylinder bore. The fractured end shown in Figure 5 demonstrates the location of the fracture through the bolt holes in the strut piston. There was also a dark circumferential line approximately 0.5 inches from the lowest end of the fracture surface, and 0.25 inches away from the holes, consistent with the outer face of the mating fork cylinder bore edges.

Figure 6 and Figure 7 show a planar and angled view of the piston fracture surface. For the most part, the fracture surface exhibited a slanted morphology, angled inward. The exceptions were the areas of the fracture surface near the attachment hole on the bottom of Figure 6 and Figure 7. These areas were generally flatter and more reflective, exhibiting characteristics consistent with thumbnail-shaped cracks.

The fractured end of the upper strut piston fragment was sectioned and cleaned in an ultrasonic bath using acetone. Figure 8 shows the fracture surface after sectioning and cleaning. The two thumbnail cracks were present on the bottom of the figure adjacent to the attachment hole. These thumbnail cracks corresponded with the area of the fracture surface that was oriented perpendicular to the piston longitudinal direction, rather than oriented at an inward slant.

The thumbnail cracks to the right and to the left of the hole in Figure 8 are highlighted in Figure 9 and Figure 10, respectively. For the purposes of this report, these cracks will be referred to as the left and right cracks based on the positions in Figure 8 and 10. The fracture surfaces in both figures exhibited crack arrest, or beach, marks propagating circumferentially into the piston cross section emanating from the hole. The right crack was 0.21 inches in length, and the left crack was 0.33 in length, and both encompassed maximum widths equivalent to the piston wall thickness of 0.125 inches.

Figures 11 and 12 show closer views of the cross-drilled hole bore, which was used for the attachment bolt. The bore surface exhibited circumferential wear and machining marks. The inward-facing edge of the bore exhibited a protruding lip, consistent with plastic deformation inward. The radial edges of the bore, where the thumbnail cracks had initiated, exhibited circumferentially oriented linear features, consistent with ratchet marks. Ratchet marks were consistent with multiple crack initiation sites. Figure 13 shows a closer view of the bore, which highlights some of the wear marks present on the surface. Further, pits were found present along the surface of the bore.

The sectioned fracture surface was examined using a scanning electron microscope (SEM). Typical areas of the thumbnail cracks exhibited striations, consistent with fatigue crack propagation (Figures 14 and 15). These fatigue features are typical of many high strength steels, where the striations are often fine or indistinct. Outside of the fatigue cracks, the fracture surface exhibited dimpled rupture, consistent with overstress fracture of ductile materials (see Figure 16 and Figure 17).

Disparate features were observed on the edge of the fracture surface at the outer surface, as shown in Figure 18.¹ This fracture region exhibited faceted features with cleavage fracture, typical of materials exhibiting limited ductility. Examination of this region by energy dispersive x-ray spectroscopy (EDS) found mostly chromium. These features and chemical composition were consistent with those of subsequent overstress fracture of a chromium electrodeposition layer, commonly applied to contact surfaces of landing gear struts.

Figure 19 shows a closer view of the crack initiation site of the right side fatigue crack. The initiation region exhibited several ratchet marks, consistent with multiple crack initiation sites that coalesced during early propagation. The initiation site highlighted in

¹ 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.

Figure 19 exhibited a small divot at the surface. A closer view of this site, shown in Figure 20, revealed the presence of non-metallic compounds, indicative of corrosion products.

These features were consistent with corrosion pitting. Examination of the compounds within the pits using EDS found them to be consistent with iron oxides. The compounds also exhibited elements typical of salts, such as Na, K, and Cl. There was also cadmium present, consistent with a prior cadmium coating application.

Figure 21 shows the crack initiation site on the opposite, or left facing, fatigue crack. While closer to the inner surface of the strut piston, the initiation site was also located along the bore. This initiation site exhibited a feature consistent with a corrosion pit at this crack initiation site. Similar to the right side thumbnail crack, the left side crack exhibited fatigue striations. This fatigue crack also exhibited secondary cracks, as shown in Figure 22, in addition to pit-like features on the fracture surface. These pits were consistent with post-cracking corrosion of the fatigue crack, which had been cleaned off prior to examination in the SEM.

Examination of the inner surface of the piston found widespread areas of corrosion products, as illustrated in the darker gray and black areas in Figure 24. The inner surface showed alternating areas of bare steel and iron-based oxides, as demonstrated by the x-ray maps in Figure 25. The x-ray maps also discovered sporadic areas of cadmium remnants near the edge with the bore. A faint chromium response was observed in the bolt hole bore. The edges with corrosion pits were exemplified by areas of high Na and K.

The piston bore was cross sectioned, mounted, and polished for metallographic examination. Several areas exhibited pits containing corrosion compounds, as typified in Figure 26. Examination of these compounds using EDS found compositions consistent with iron oxides, along with Na and K. Figure 27 also shows an area with some shallow cracking near the surface associated with a corrosion pit.

The polished cross section was etched using a 2% Nital solution, and the corner between the fracture surface and the bore is illustrated in Figure 28. The material adjacent to the bore surface exhibited grain deformation and flow parallel to the bore surface, consistent with the effects of machining of the hole. The microstructure exhibited a tempered martensite microstructure, typical of this composition.

The only other component submitted that exhibited visible damage was the attachment bolt between the upper and lower torque links, pictured in Figure 29. These components attach to the forward side of the NLG assembly. The bolt was intact and still attached to the links. However, it was plastically deformed in bending, consistent with the excessive downward displacements typical of a landing gear collapse.

Erik M Mueller
Materials Research Engineer



Figure 1 – The landing gear components, as received.

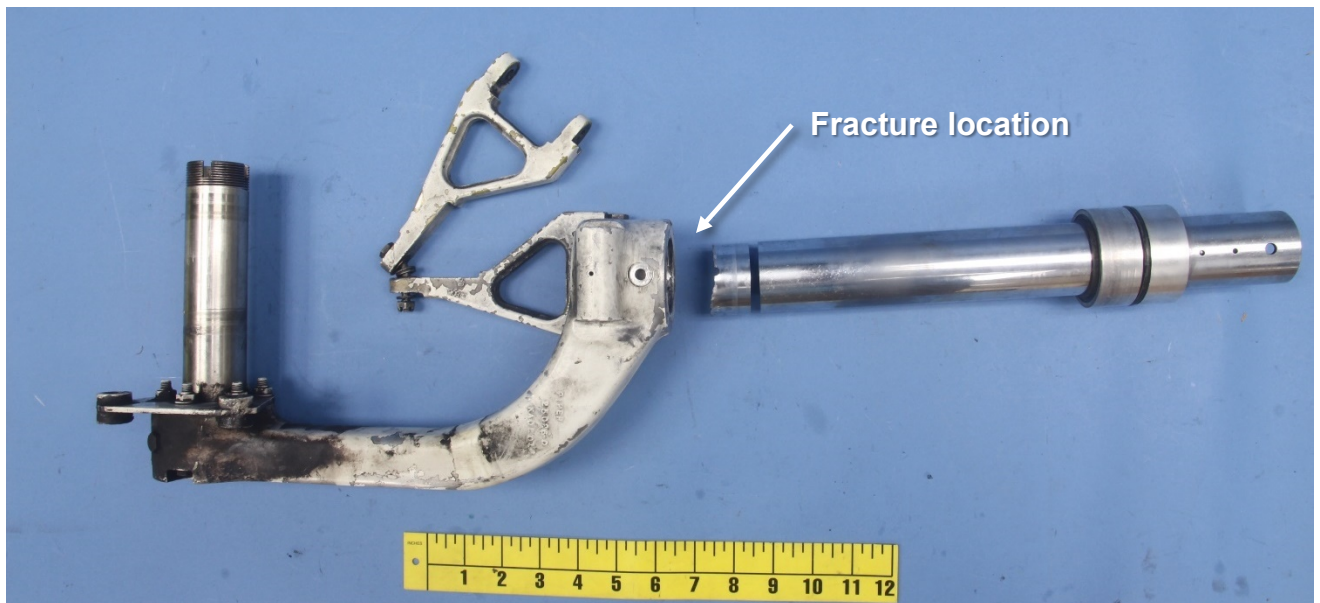


Figure 2 – Reconstruction of the landing gear strut piston as positioned prior to fracture.

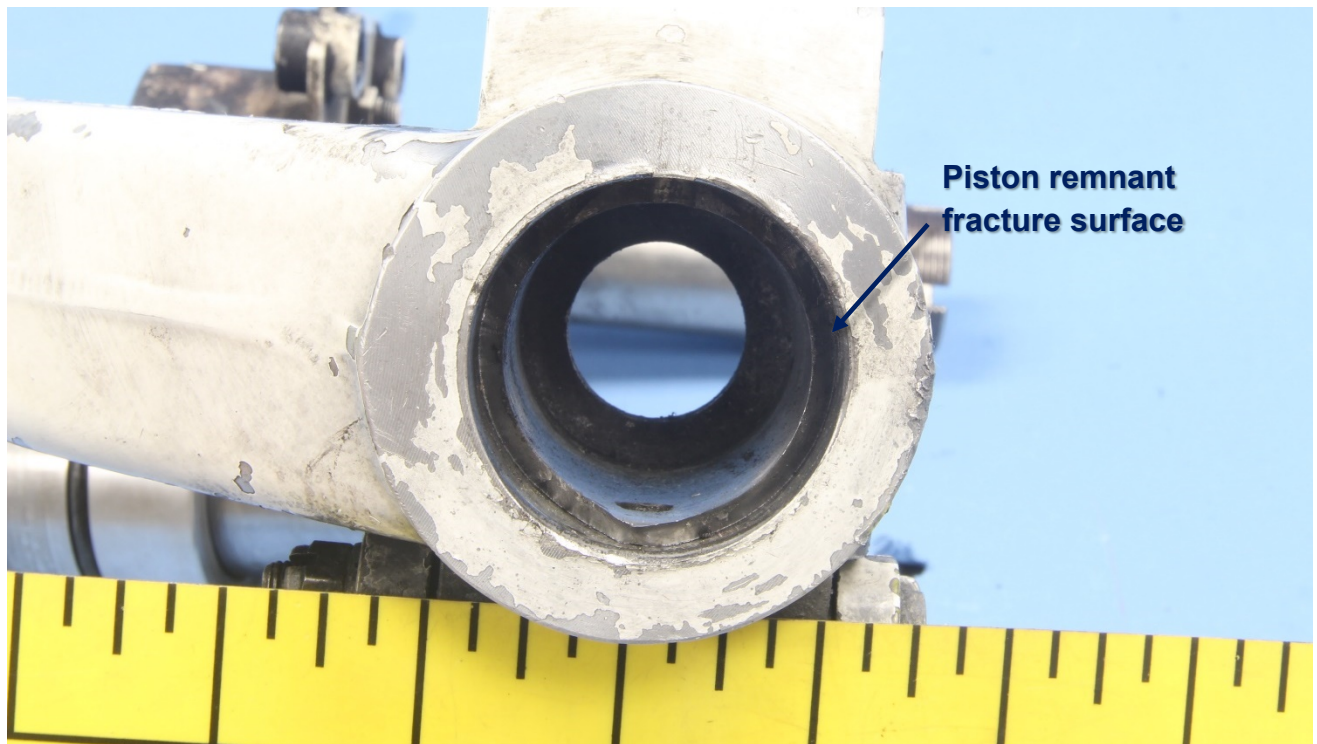


Figure 3 – View of the fracture surface of the piston fragment inside the cylinder bore.

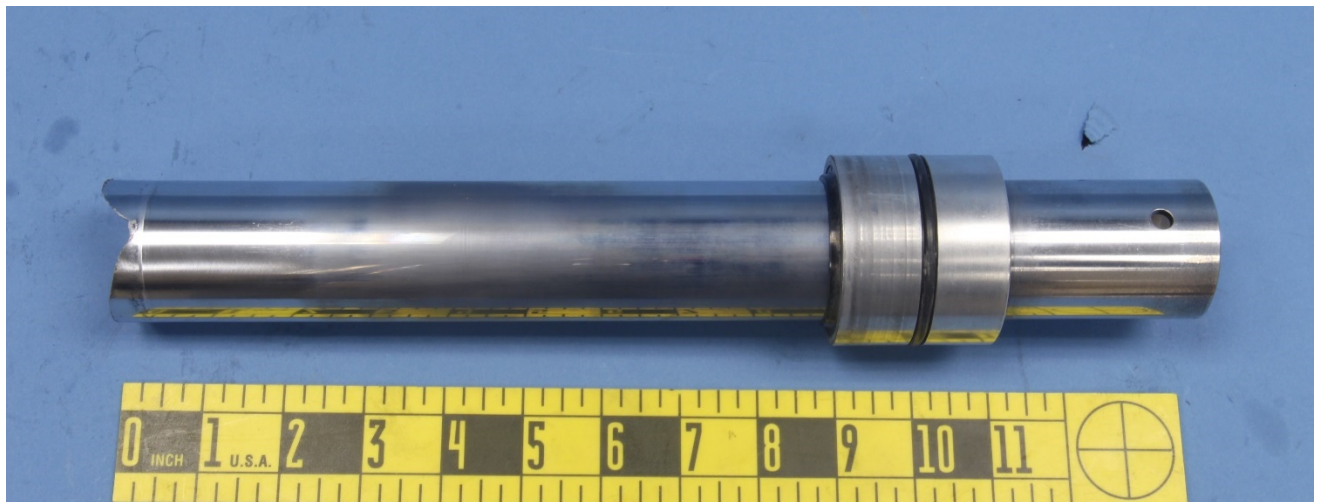


Figure 4 – Side view of the fractured landing gear strut piston, as received.

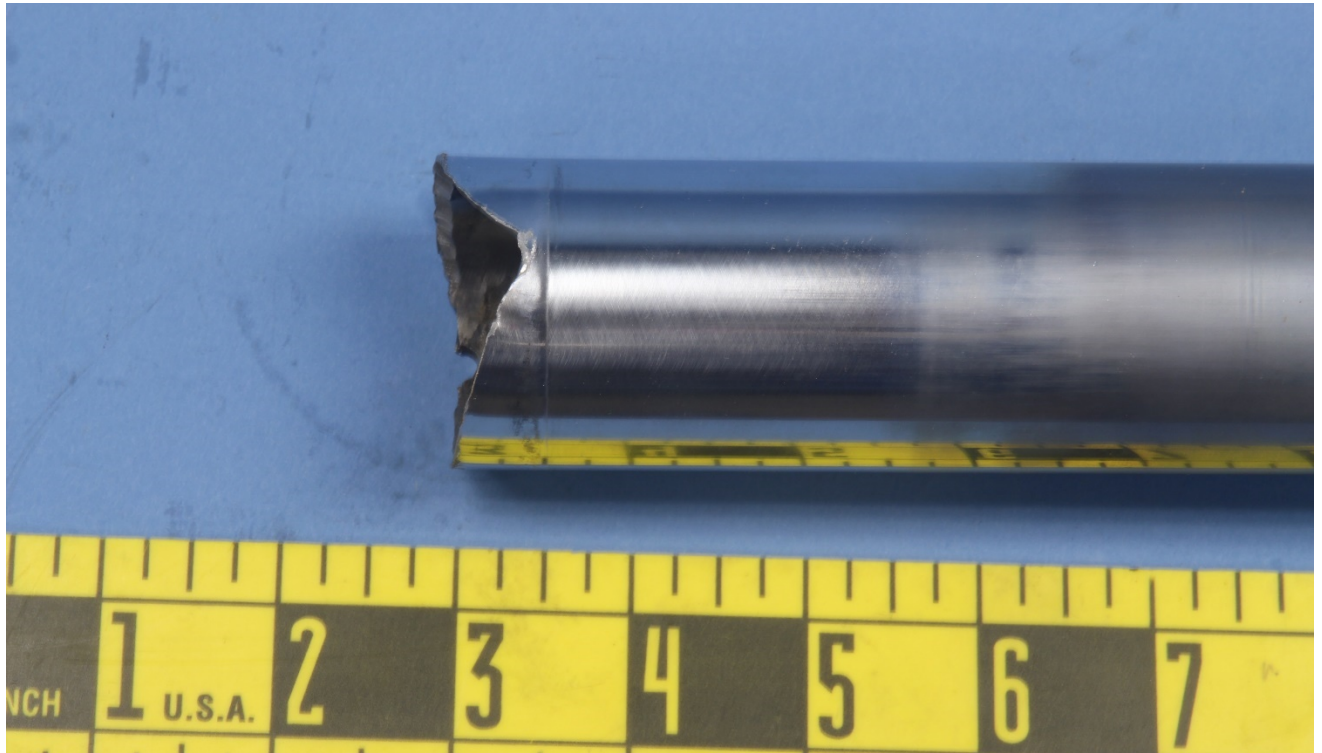


Figure 5 – Closer view of the fracture surface of the strut piston in Figure 4.

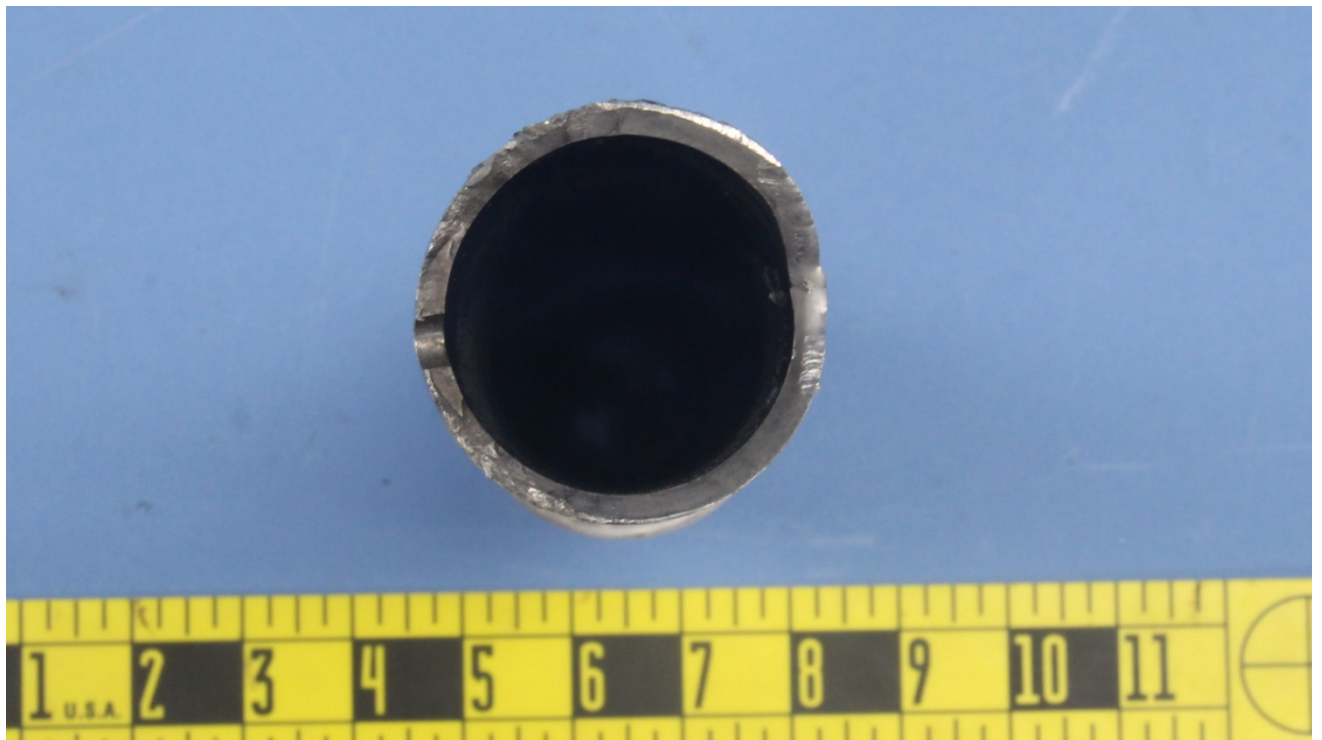


Figure 6 – Planar view of the piston fracture surface.

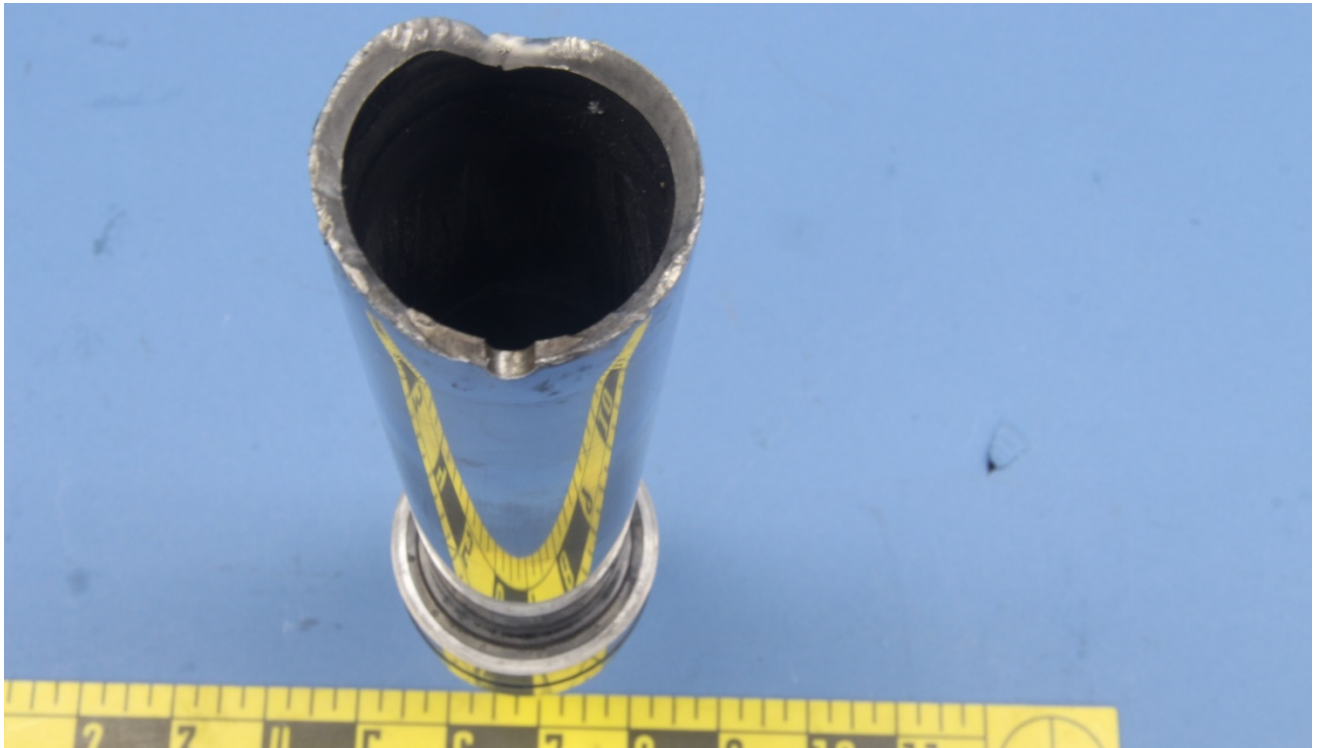


Figure 7 – Angled view of the piston fracture surface, showing two small thumbnail cracks near an attachment hole.

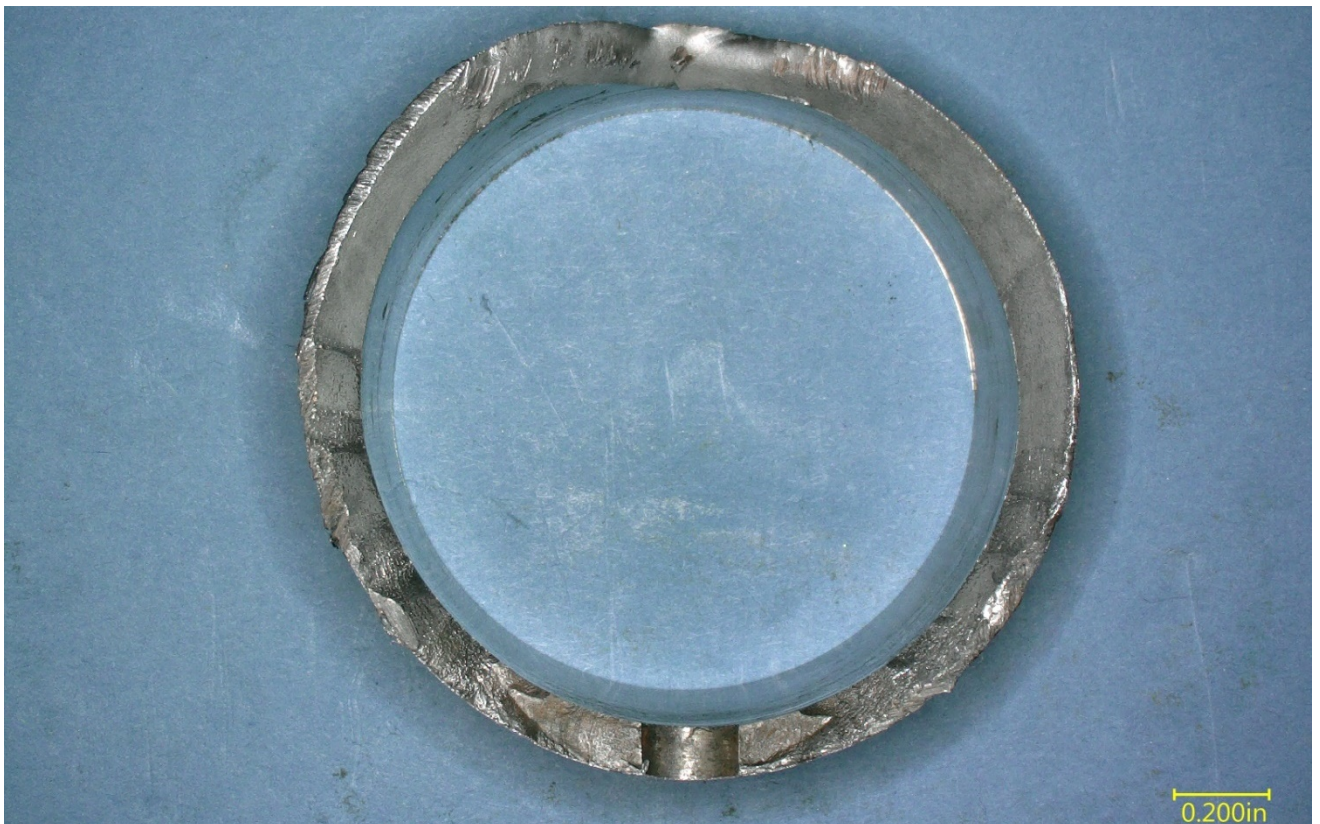


Figure 8 – Planar view of the piston fracture surface, after sectioning and cleaning.



Figure 9 – View of the thumbnail crack on to the right of the hole in Figure 8.



Figure 10 – View of the thumbnail crack on to the left of the hole in Figure 8.

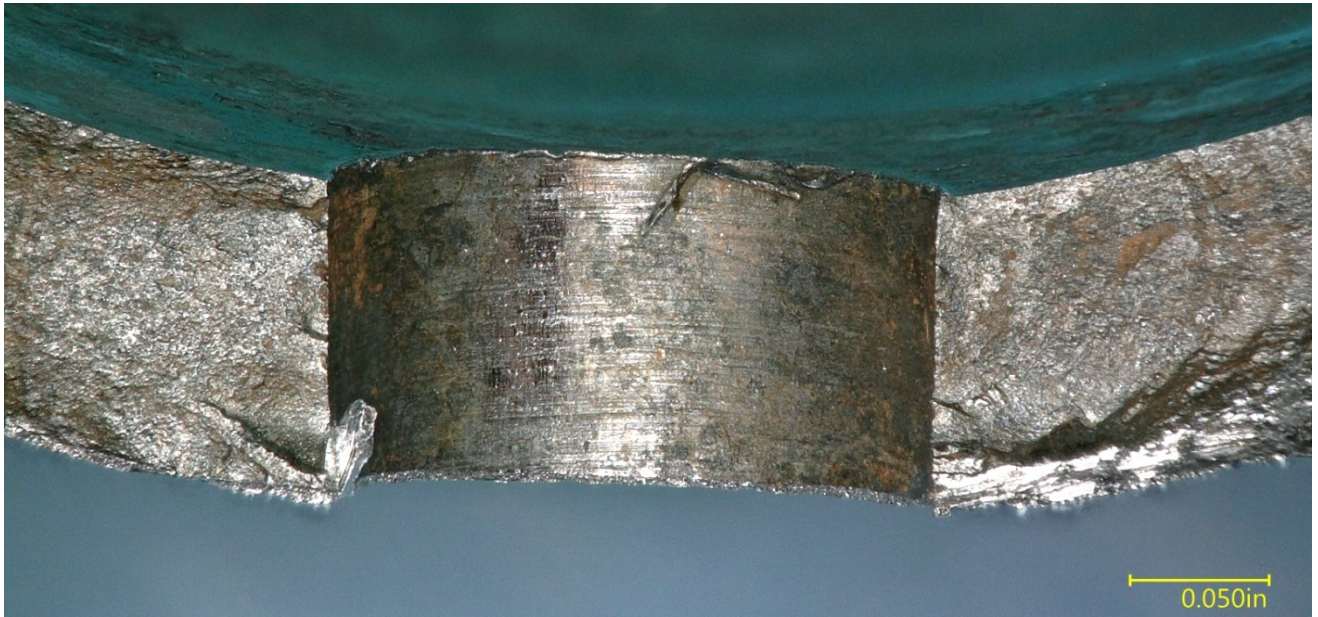


Figure 11 – View of the hole of the piston fracture surface, showing initiation sites of the two thumbnail cracks.



Figure 12 – Angled view showing the interior of the piston cylinder at the hole and cracks.

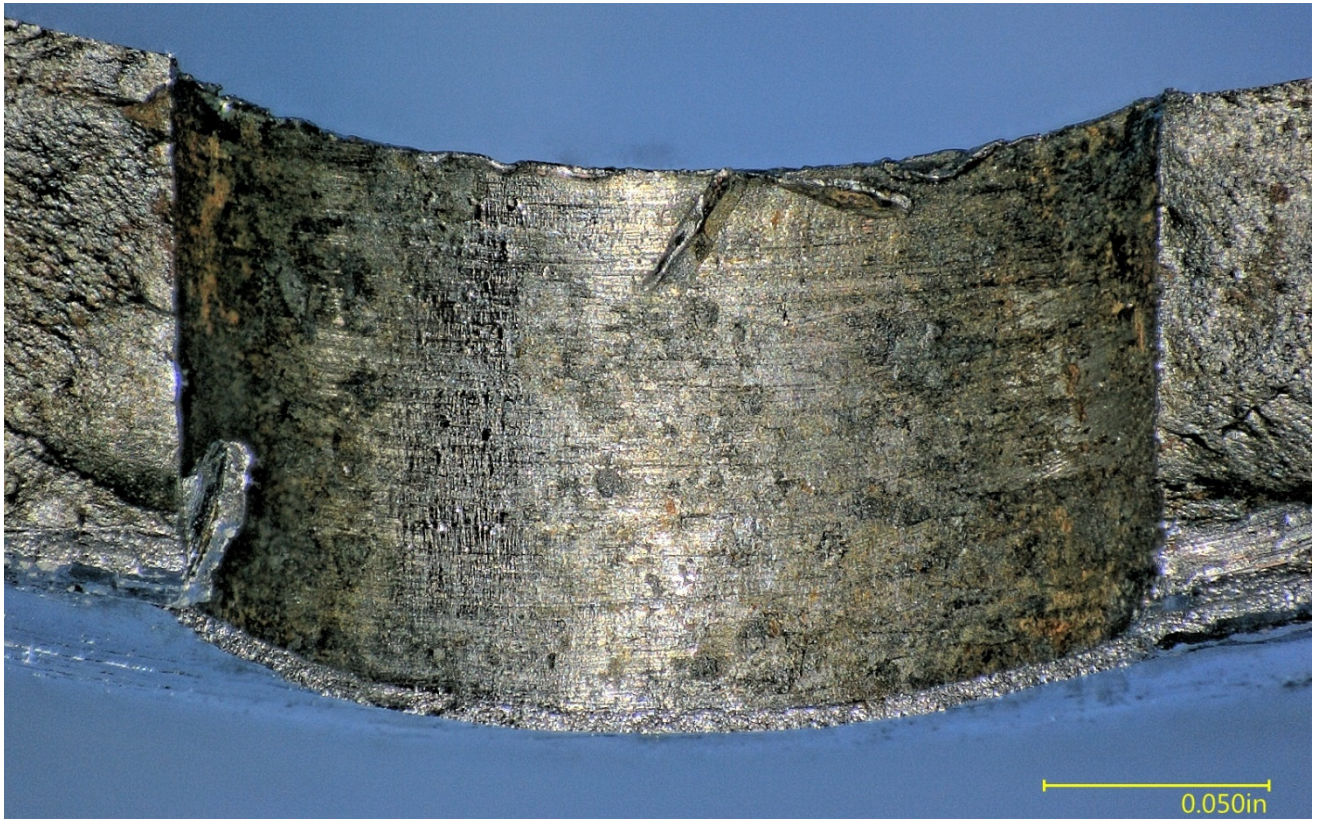


Figure 13 – Closer view of the hole surface, showing small pits and divots.

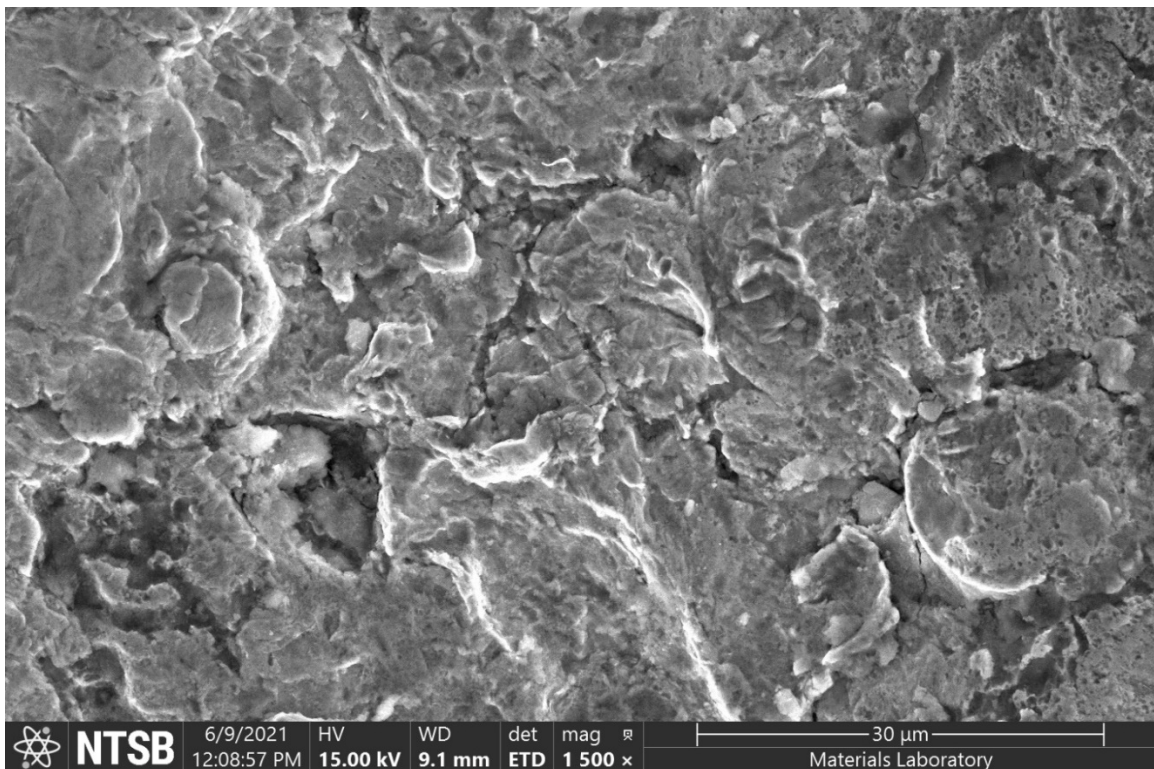


Figure 14 – Secondary electron (SE) of a typical area of the right thumbnail crack.

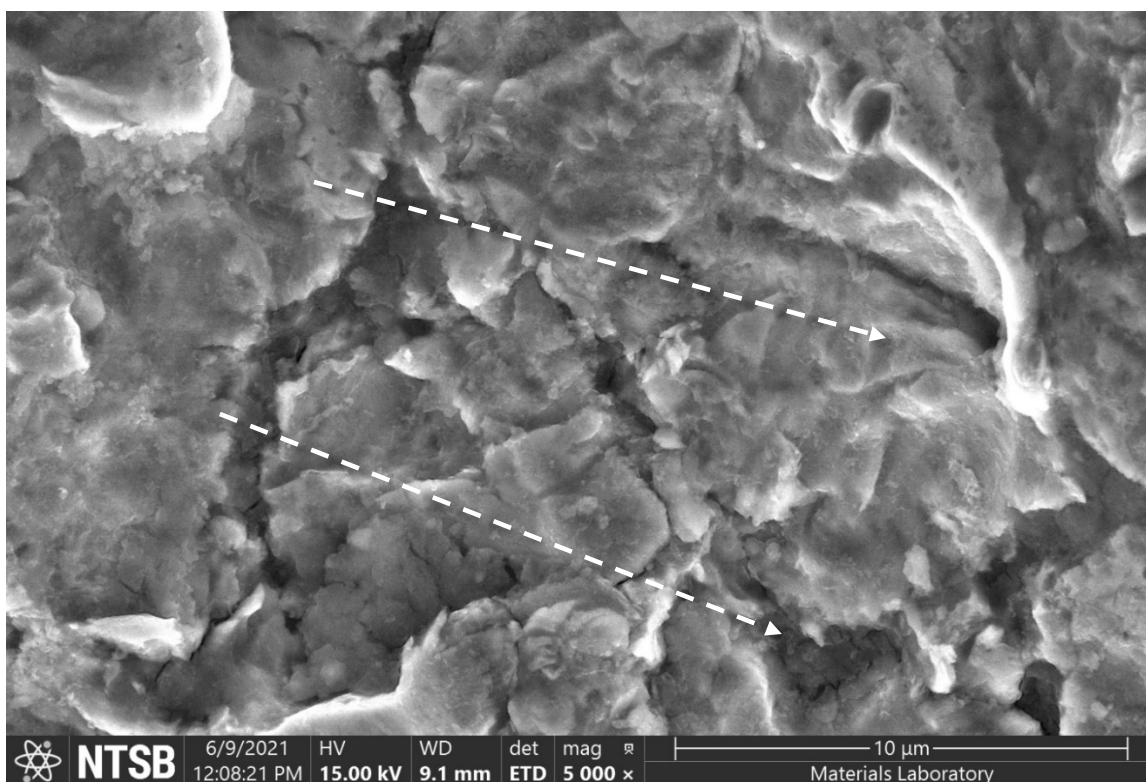


Figure 15 – SE micrograph of a closer view of an area in Figure 14, showing fatigue striations. The crack growth direction is annotated (dashed arrows).

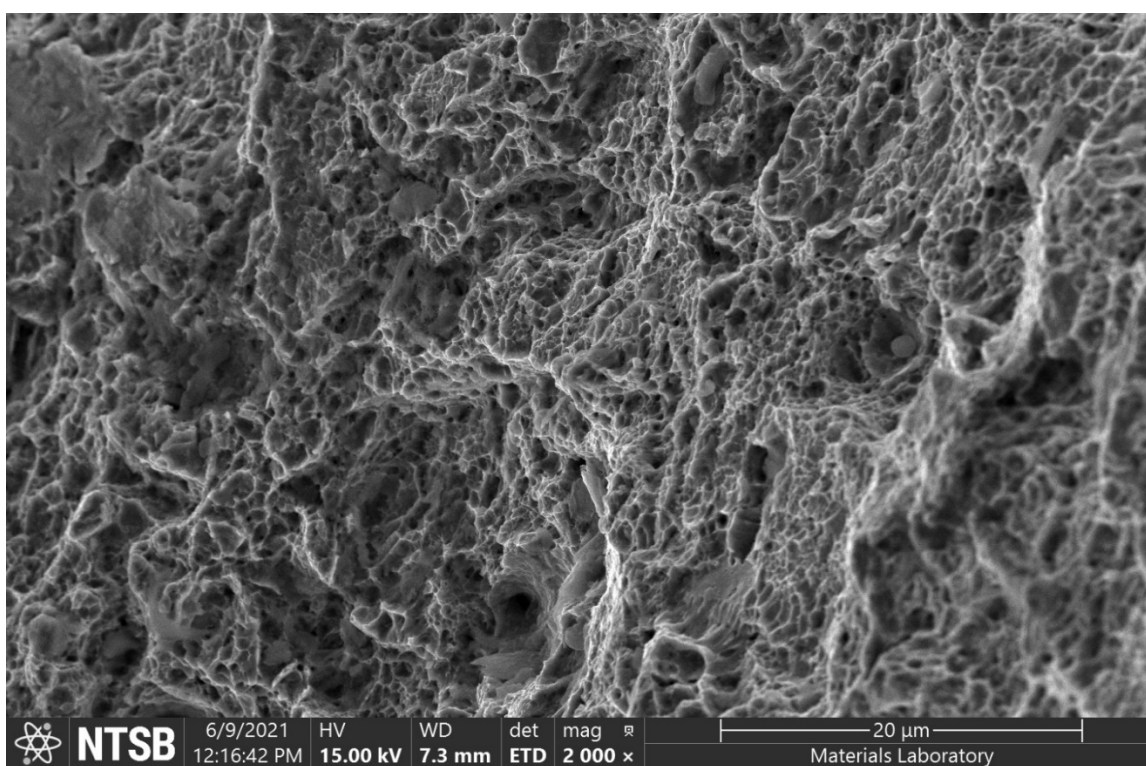


Figure 16 – SE micrograph of a typical area of the fracture surface outside the fatigue cracking.

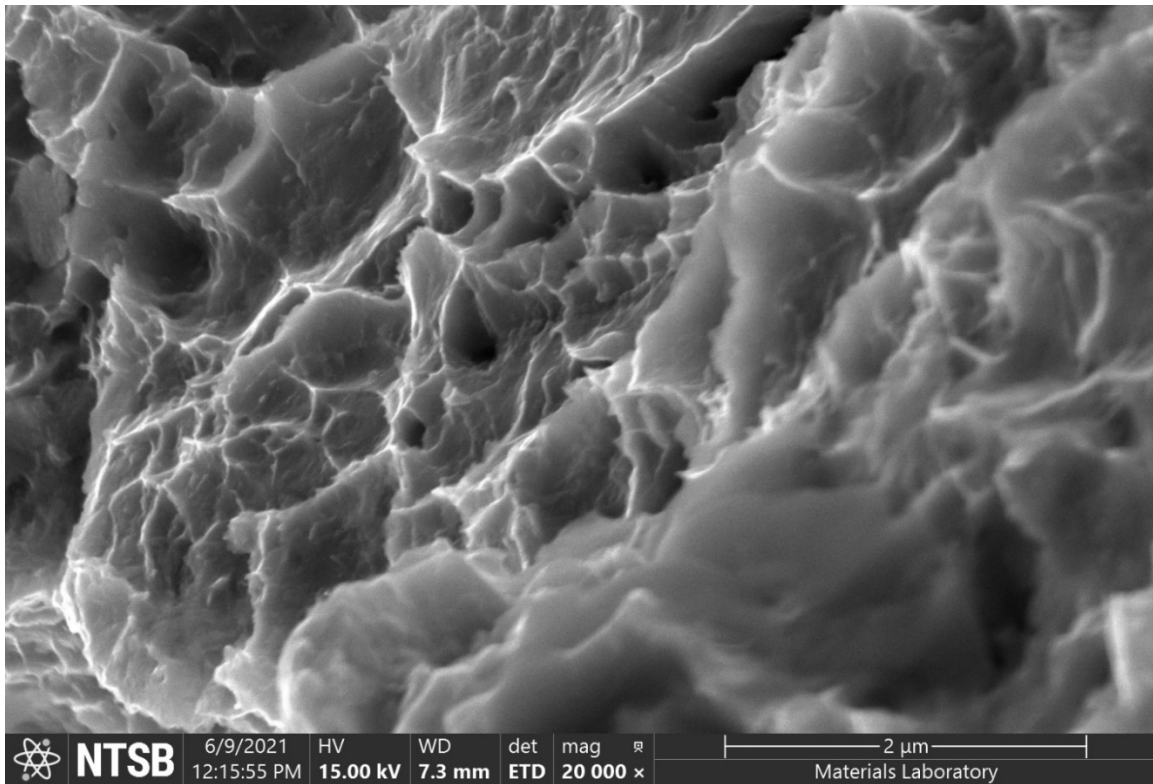


Figure 17 – SE micrograph of a closer of the dimpled rupture in Figure 16.

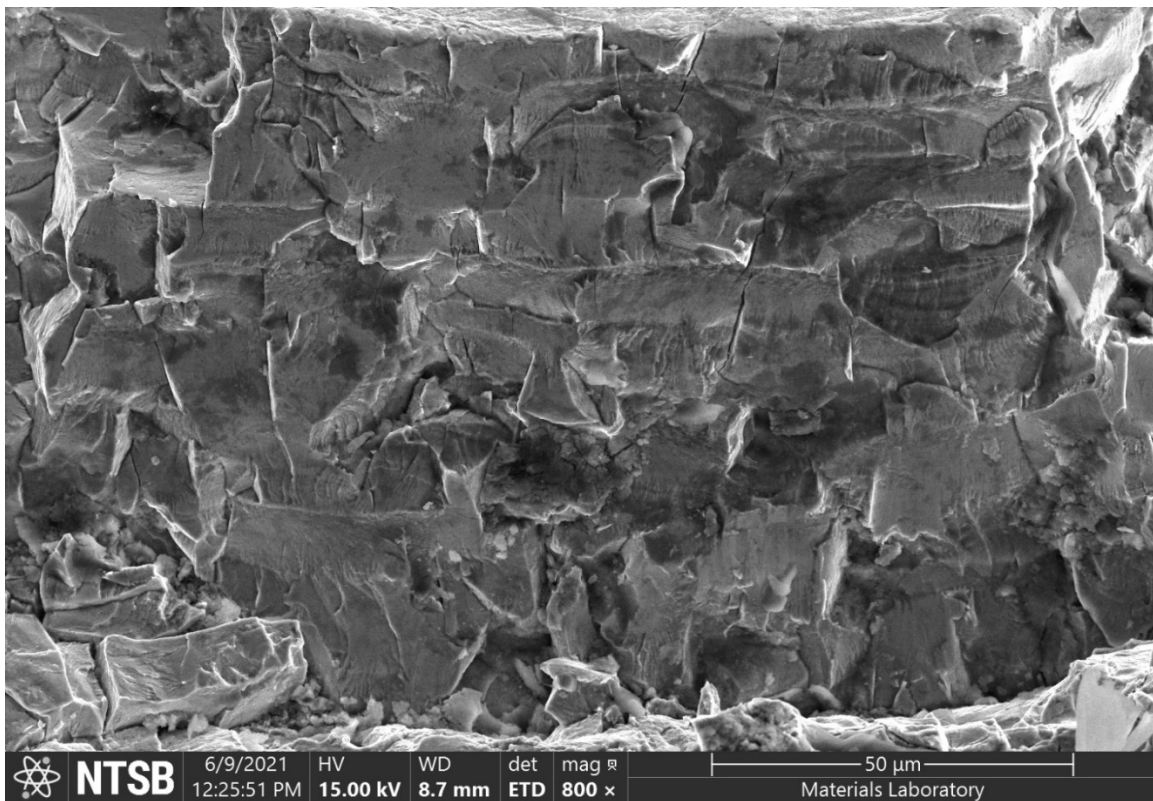


Figure 18 – SE micrograph of the fractured remnant of a external chromium layer.

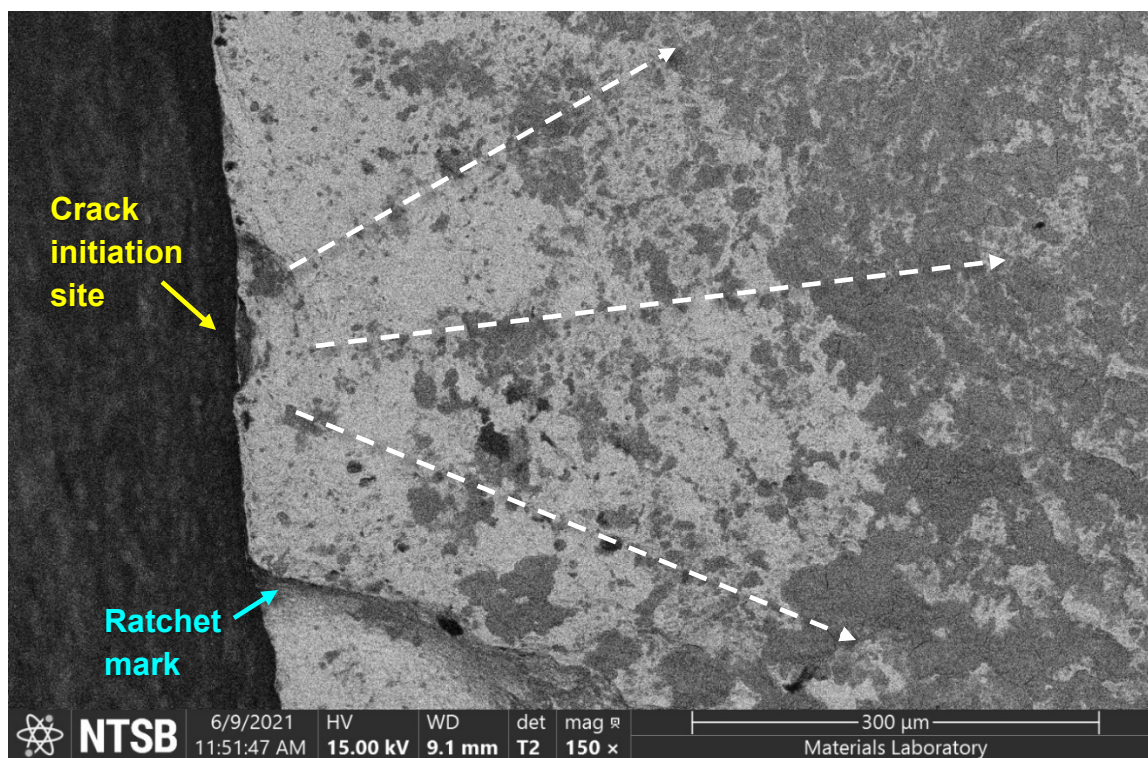


Figure 19 – Backscattered electron (BE) micrograph of the crack initiation site of the right side fatigue crack.

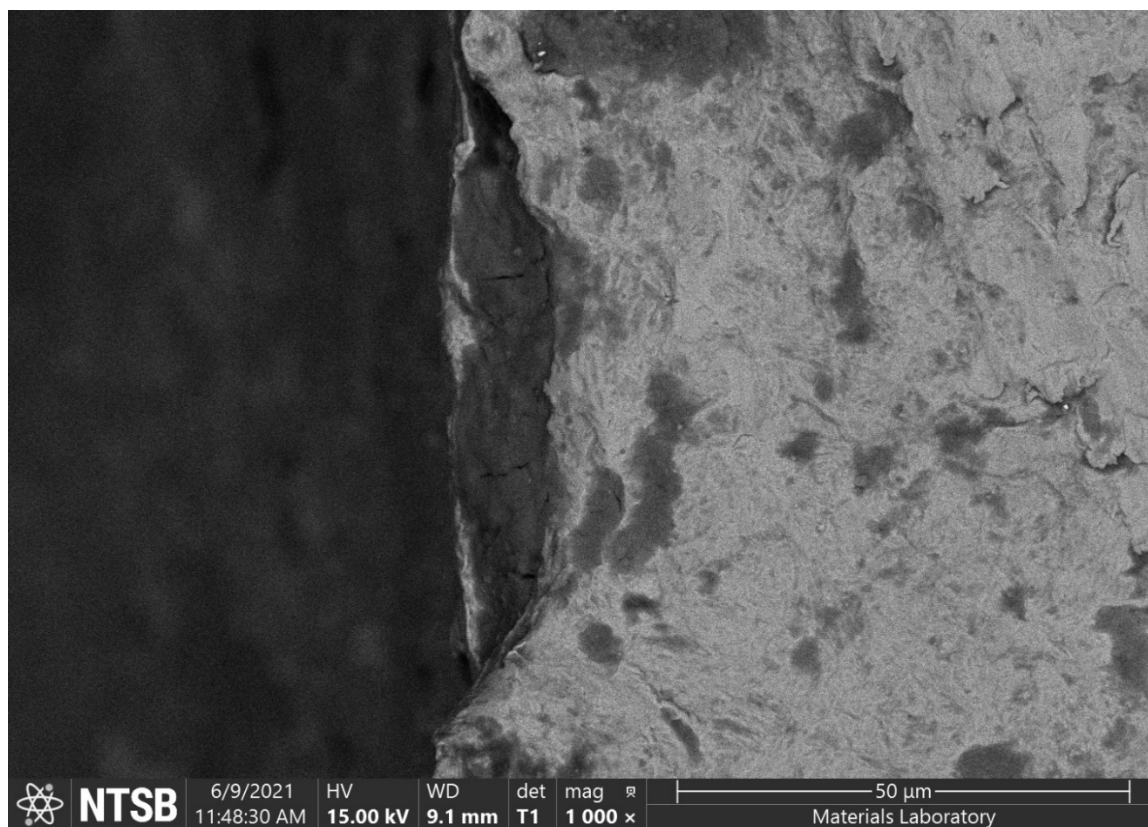


Figure 20 – BE micrograph of a corrosion pit at the crack initiation site.

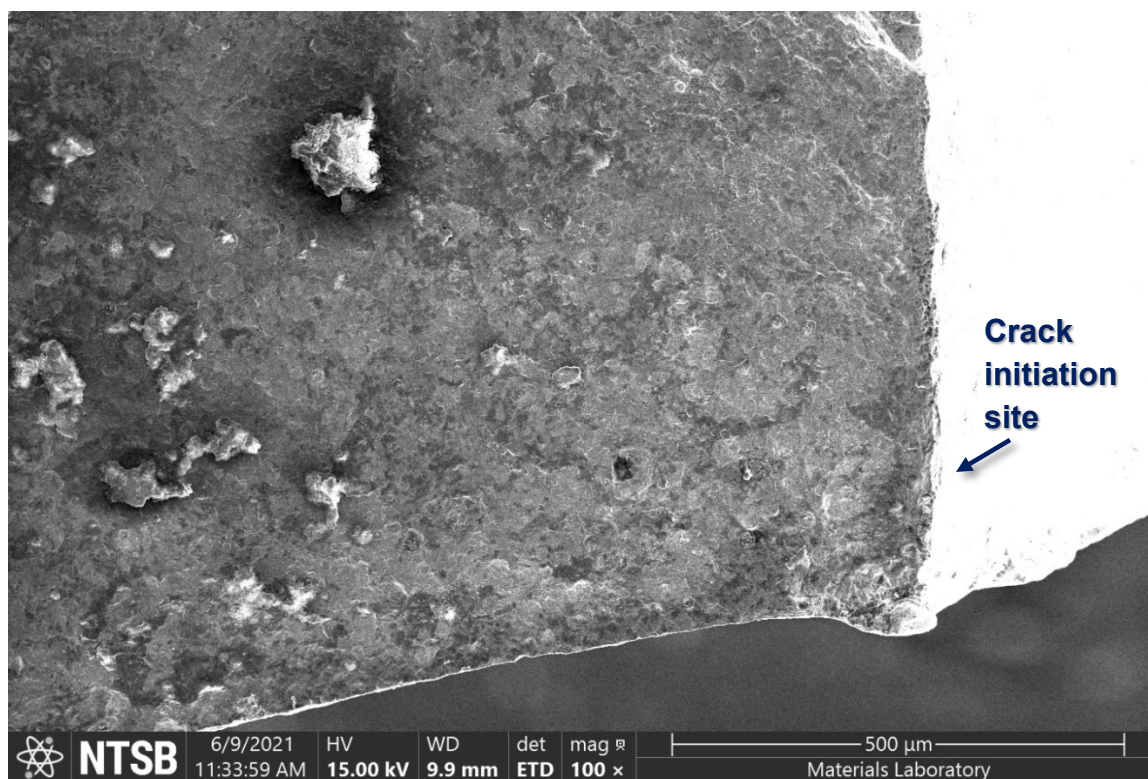


Figure 21 – View of the outer edge corner of the left fatigue crack, showing a crack initiation site.

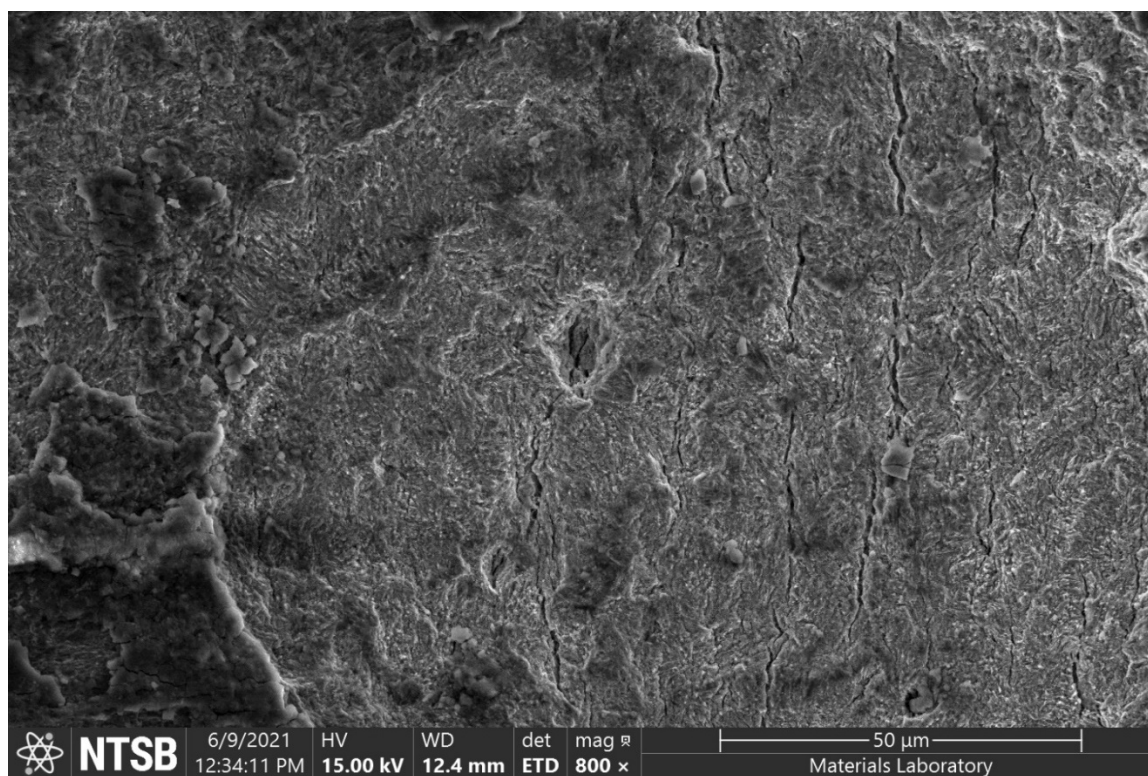


Figure 22 – View of a typical area of the left fatigue crack, showing secondary cracking and surface damage post-cleaning.

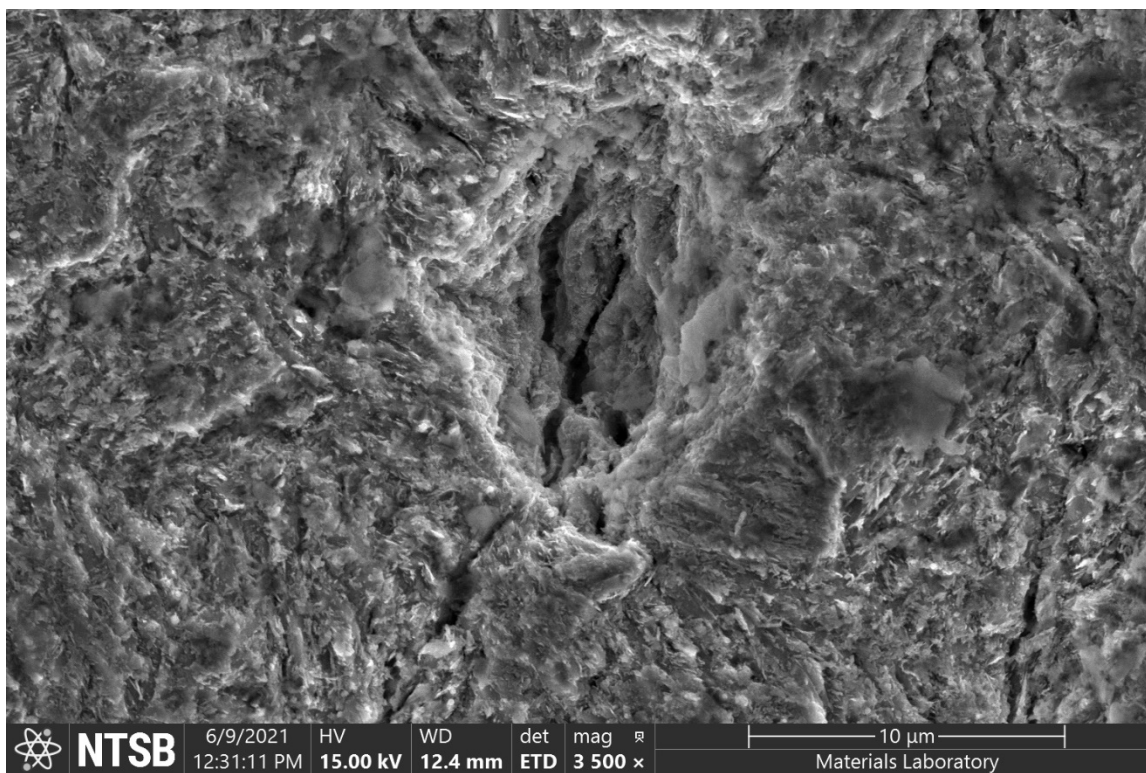


Figure 23 – SE micrograph of a closer view of the secondary crack and surface pit in Figure 22.

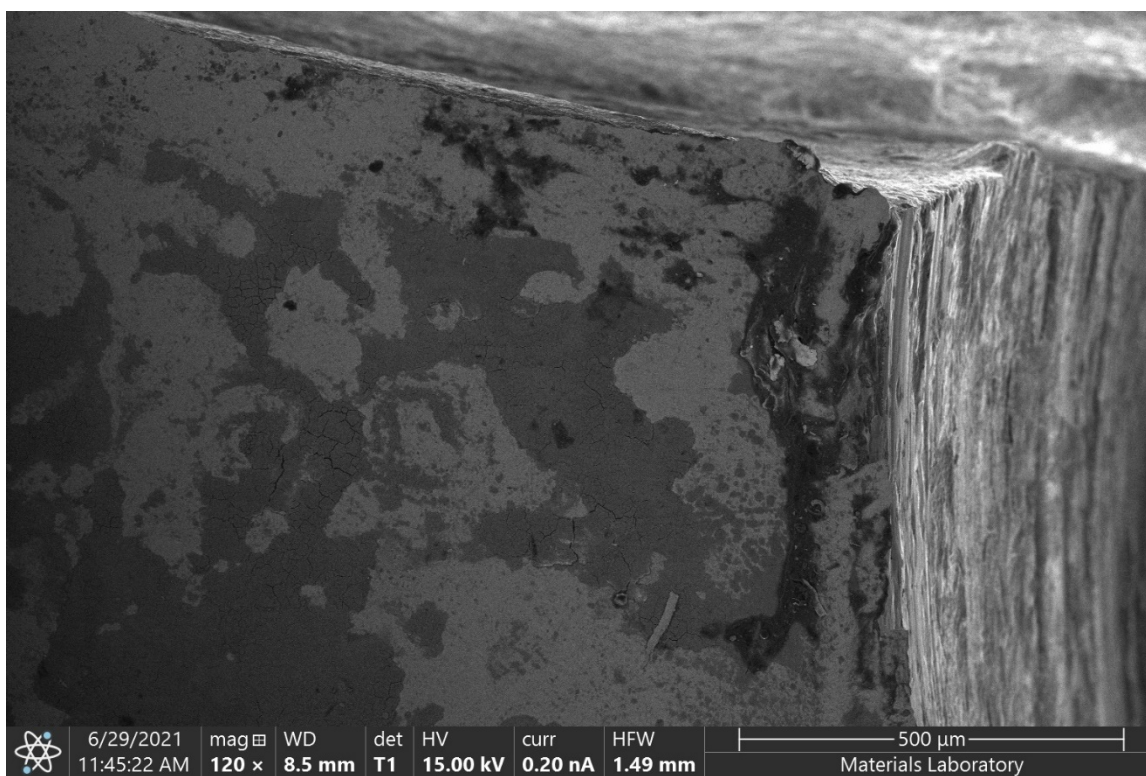


Figure 24 – BE micrograph of the inner cylinder surface at the right fatigue crack edge corner.

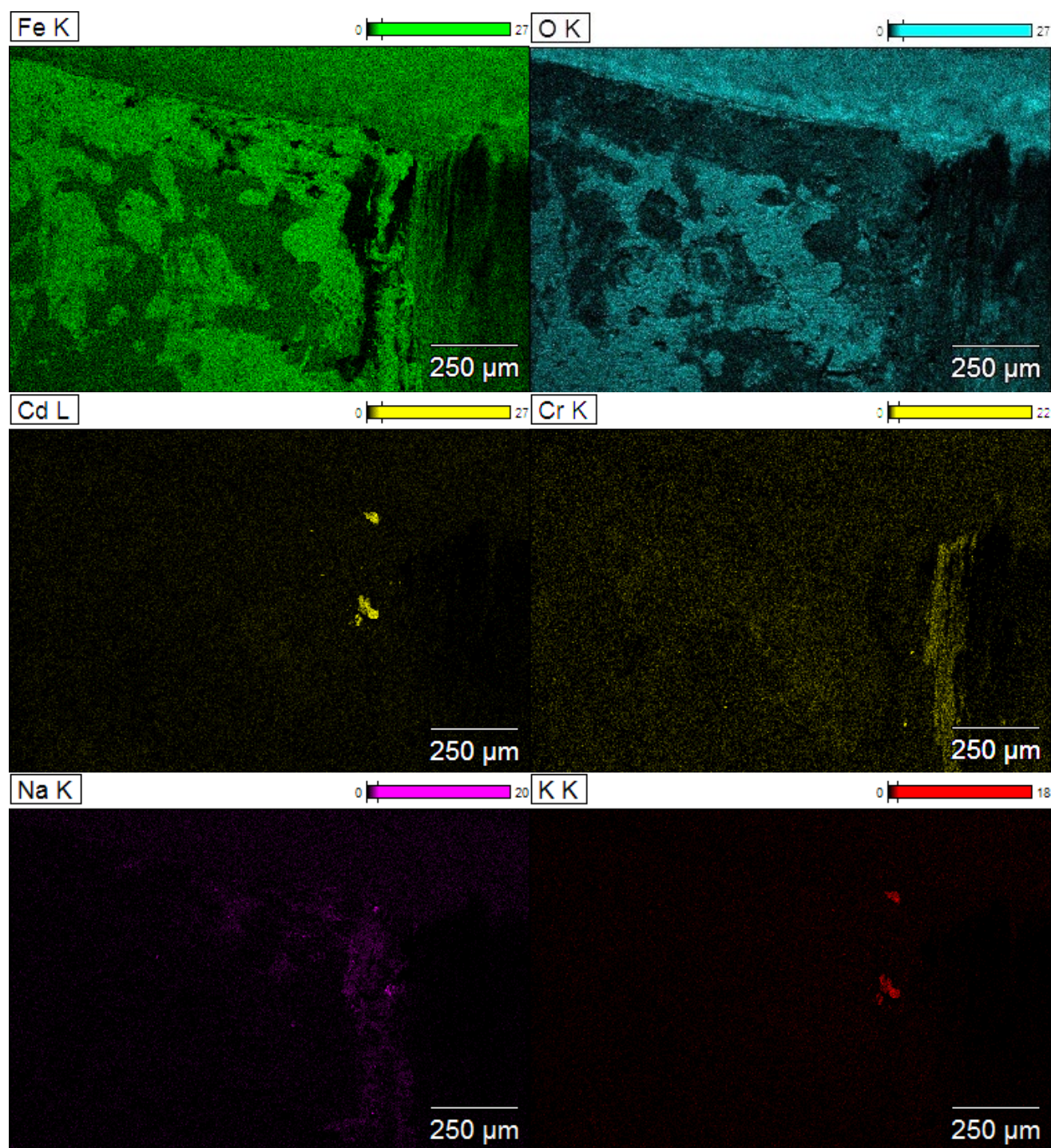


Figure 25 – X-ray maps from EDS scans of Figure 24, showing relative concentrations of Fe, O, Cd, Cr, Na, and K.

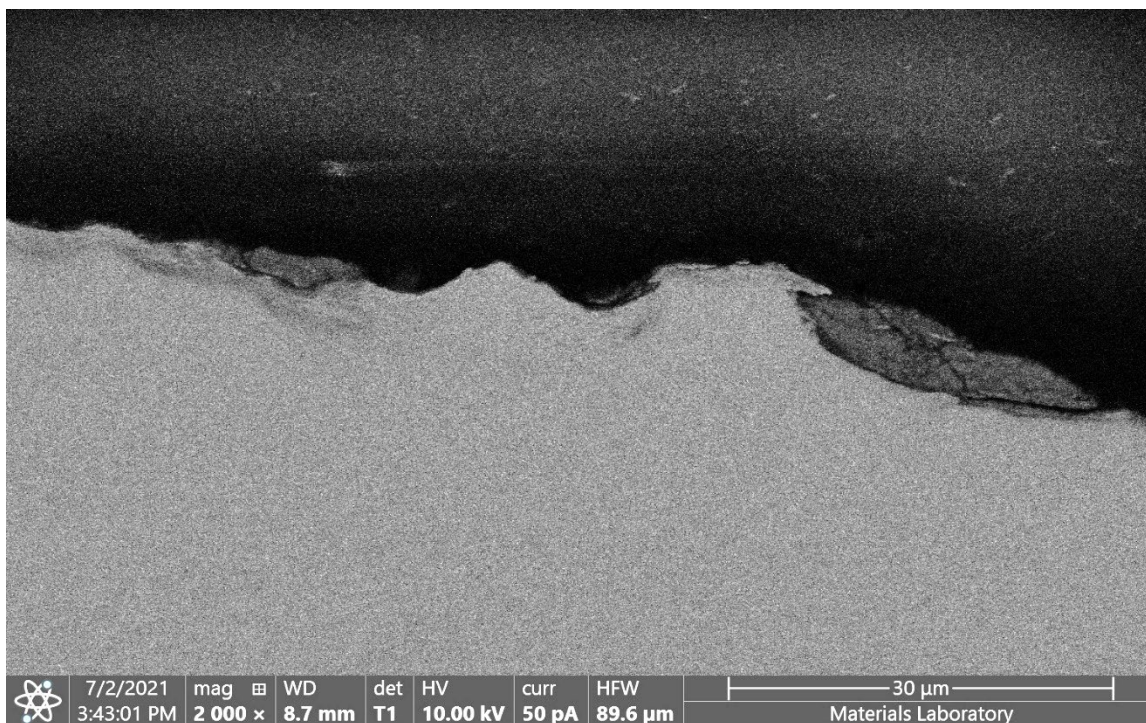


Figure 26 – BE micrograph of a cross section through a corrosion pit.

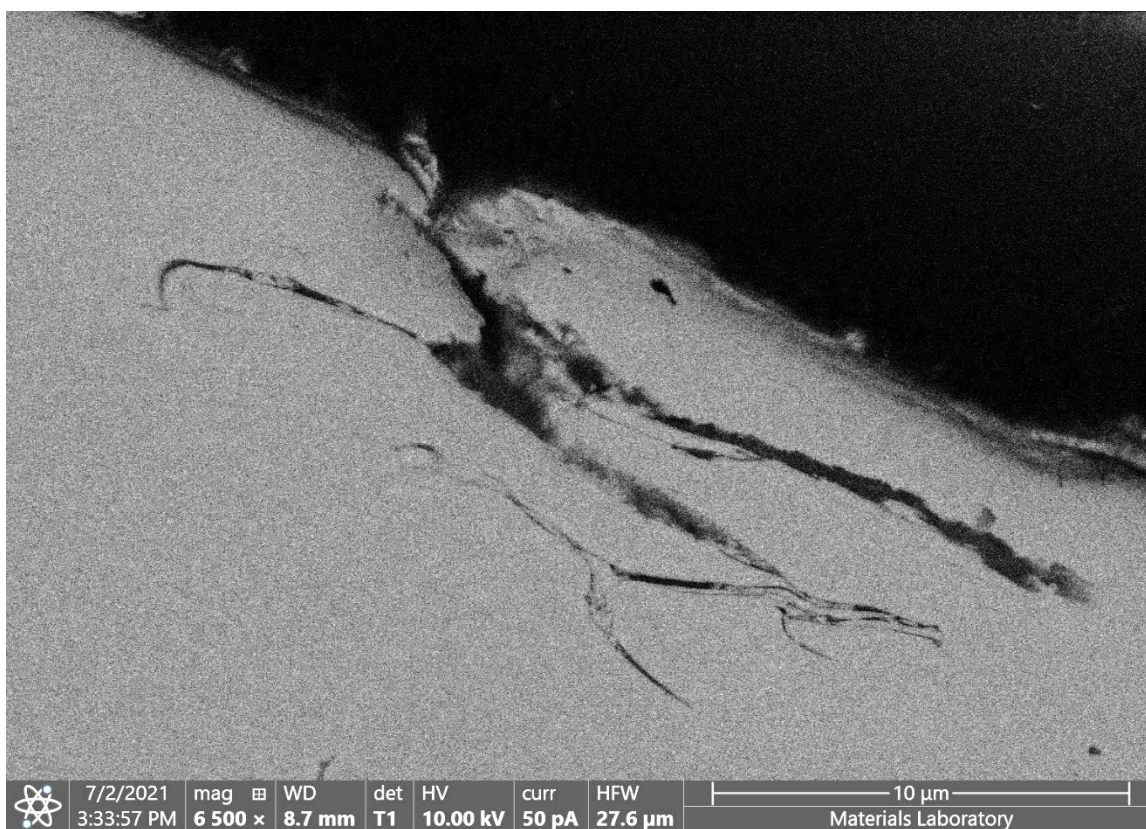


Figure 27 – BE micrograph of a cross section through a small surface crack.

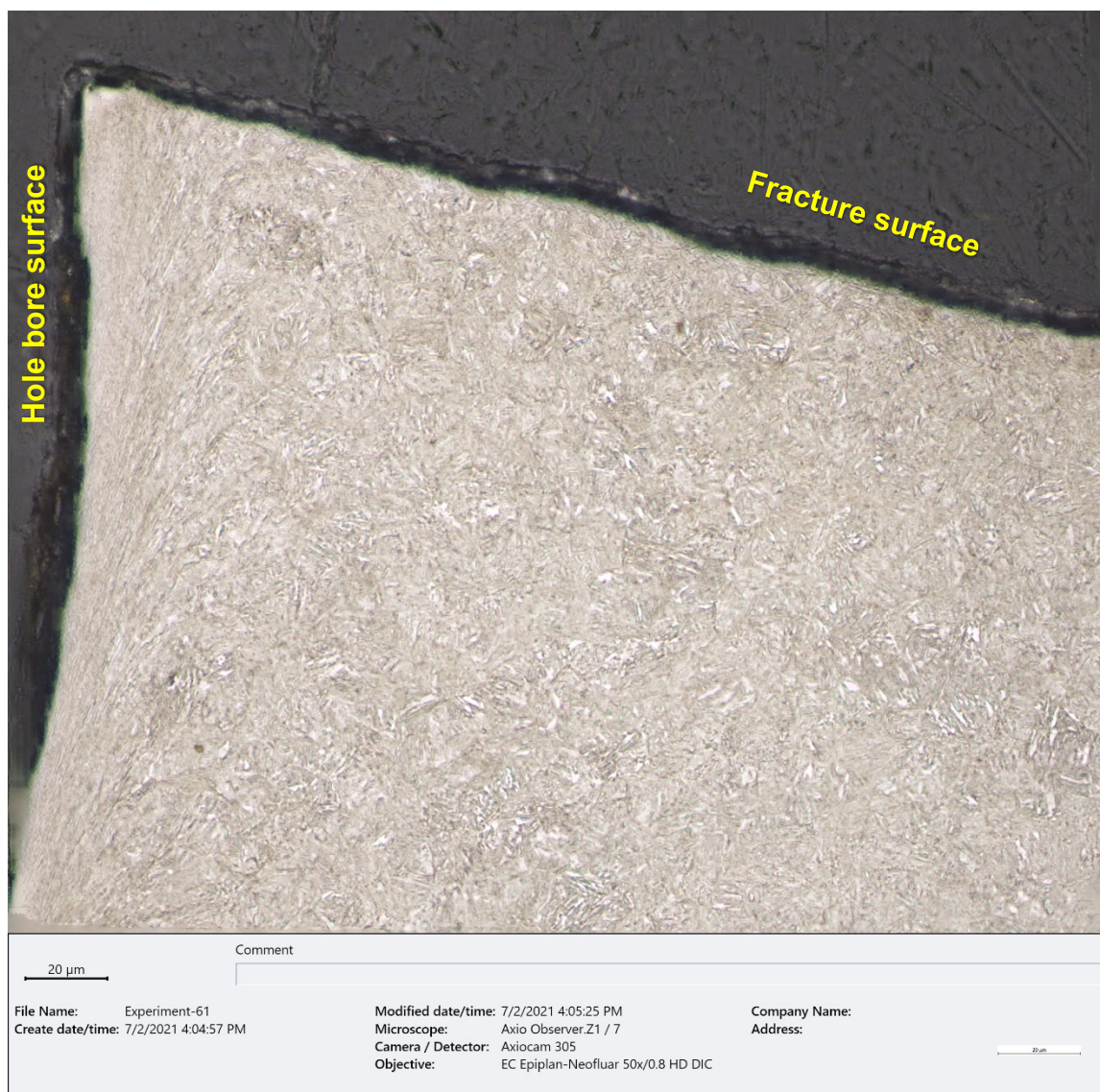


Figure 28 – Bright-field optical micrograph of the corner of the fracture surface against the fastener hole bore (etched 2% Nital, ~200X).



Figure 29 – View of a bent (but intact) attachment bolt connecting the two upper and lower torque links.