

NATIONAL TRANSPORTATION SAFETY BOARD

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

January 3, 2023



MATERIALS LABORATORY ADDENDUM REPORT

Report No. 21-072B

1. ACCIDENT INFORMATION

Place : Attalla, Alabama
Date : December 12, 2020
Vehicle : Beech V35A, N5470U
NTSB No. : ERA21LA068
Investigator : Timothy Monville, AS-ERA

2. COMPONENTS EXAMINED

Remnants of an elevator control cable assembly with a fractured terminal end and bent turnbuckle

3. DETAILS OF THE EXAMINATION

This report is an addendum to the Materials Laboratory Factual Report on the remnants of a right aileron direct wire rope assembly from a Beech V35A accident near Attalla, AL. This report details an examination of two elevator cable assemblies. As described below, these cable remnants exhibited fractures in the turnbuckles and along the wire strands.

Figure 1 shows the longer of the two elevator primary control cable assemblies (also known as the elevator down cable, P/N 35-524651-7). This cable measured 94 inches long in total. One of the ends was consistent with a cut cable just outside the sleeve of a fork remnant (which was 2 inches long itself) (see Figure 2). This fracture surface is shown in Figure 3, which was stated to have adjacent to the bobweight—this portion was sectioned on scene after the accident. This section was 23 inches from the fork remnant to the swaged ball, and then 10 inches to an area of frayed and fractured wires.

Figure 3 shows the cut ends of the wires just outside the fork remnant. As shown in this figure and Figure 4, the fork remnant exhibited indications of having fractured. Both the wire ends, and the fracture surface of the fork exhibited white and brown-colored compounds, consistent with post-fracture contamination. As shown in Figure 4, the fork material adjacent to the fracture surface exhibited elongation on the surface opposite that which experienced compressive buckling. These features were consistent with deformation from bending. Figure 5 demonstrates the dull rough surface texture of the fork fracture surface, which was oriented outward at an approximately 45° angle. The fracture

surface revealed dimpled rupture when examined using a scanning electron microscope (SEM), shown in Figure 6. No other fracture features were observed. These features were consistent with fracture from bending overstress. The chemical composition of the fork remnant was examined using energy dispersive x-ray spectroscopy (EDS) and was found to exhibit a composition consistent with austenitic stainless steel.

The opposite end of the down cable remnant consisted of a series of fractured cable wires that had frayed outward. In addition, as shown at the bottom of Figure 1, several of the wire strands had frayed outward and had fractured (see Figure 7).

Figure 8 shows the side view of the frayed wire fracture end of the longer cable remnant. Half of the wires had been displaced in one direction, and the other half had been displaced in the other. The strand fractures were oriented in different directions, as illustrated in Figure 9 and Figure 10. The wire strand surfaces generally exhibited a dull, gritty texture, consistent with post-fracture contamination.

The wire strands from the long wire cable end fragment and the frayed ends were examined using an SEM. Several of the wire strand ends shown in Figure 11 are shown in Figure 12. All the strands exhibited contamination on the fracture and outer surfaces. This contamination was consistent with both post-fracture contamination and contamination (including material that had been applied) that was present prior to fracture.

Figure 13 shows a typical fractured strand, exhibiting darker contrast material in backscattered mode, consistent with post-fracture nonmetallic compounds. One of the areas absent said contamination is illustrated in Figure 13. This area showed necking and dimpled rupture, along with a slanted direction to the fracture surface, as highlighted in Figure 14 and Figure 15. These features were consistent with fracture from tensile overstress along a plane of maximum shear stress.

Figure 16 shows some of the frayed and fractured strands. A closer look at the fracture surface in the center of the figure is illustrated in Figure 17. Again, this surface exhibited dimpled rupture, consistent with fracture from overstress. None of the strands examined on any of the cable remnants showed any fracture features other than dimpled rupture or post-fracture damage.

Figure 18 shows the shorter of the two elevator cable assembly remnants, also called the elevator up cable (P/N NAS304-35-2087). This section measured 23.5 inches in length, with the cable separated on one end and the turnbuckle and terminal end fractured on the other. The length of the fractured turnbuckle assembly was 6.25 inches.

Figure 19 shows the fractured turnbuckle end, as received. This end consisted of a fractured terminal end inside of the brass eye turnbuckle (P/N AN165-22RL). The end exhibited oxidation in the form of iron oxide (rust) significant enough to obscure most of the features from being visible. In addition, this amount of rust had built up, concealing any gap between the end and turnbuckle control cable remnants when received by the Materials Laboratory. Figure 20 shows the cable end, where all the strands had fractured

in the same location. In addition, the fracture was perpendicular to the cable direction, and none of the strands had frayed outward from the main assembly.

The outer surface of the turnbuckle exhibited a marking stating “ACHILLES.” Figure 21 shows the area towards the fracture surface of the terminal end after removal from the turnbuckle. The end tapered toward the fracture surface and was discolored relative to areas farther away (towards the left in the figure). These areas would have been inside the turnbuckle, whereas the discolored regions would be exposed to the environment outside the brass turnbuckle. The grayish-blue discoloration was consistent with corrosion compounds, which were thick enough to obscure the underlying surface features of the end.

Figure 19 shows the fractured terminal end inside the bent turnbuckle. The turnbuckle was sectioned, and the broken terminal end was cleaned using an ultrasonic bath alternating between Evaporust and Alconox.^{1,2} Figure 22 and Figure 23 show the cleaned fractured end of the terminal end. The fracture surface, shown in Figure 24, exhibited a general cup shape. This necked shape near the fracture surface was consistent with the change in the aspect ratio of the terminal end, as detailed in the illustrated parts catalog (IPC). One area along the edge exhibited a general flat morphology, as demonstrated in Figure 25. This feature corresponded with a location on the fracture surface showing characteristics consistent with progressive cracking—ratchet marks and crack arrest marks. In addition, many cracks along the shaft of the end were oriented parallel to the fracture surface.

The fracture surface was examined using an SEM, and the edge with the progressive cracking features is shown in Figure 26. This area was approximately 0.25 circumferential inches long and 0.011 in (0.29 mm) deep. As shown in the figure, this region exhibited several ratchet marks oriented perpendicular to the edge. These features were consistent with multiple crack initiation sites (see Figure 27).

A closer view of this region revealed fatigue striations, consistent with fatigue crack propagation (Figure 27). These striations were oriented perpendicular to the longitudinal direction of the surface edge, consistent with inward crack growth. Removal of the surface oxides and contamination left much of the fracture surface altered, including exposing the underlying microstructure (consistent with the lamellar features of steels). These features were similar to, but were inconsistent with, fatigue striations.

Removal of the surface oxide also created some damage to the fracture surface edge. Most of the crack initiation sites exhibited damage consistent with post-fracture damage, such as from excessive corrosion or impact with an adjacent object. Figure 28 shows a closer view of one of the lesser damaged fatigue crack initiation sites. The initiation sites did not exhibit any outstanding material features, such as an inclusion or

¹ Alconox is a powdered cleaning detergent, containing primarily sodium bicarbonate and sodium alkylbenzene sulfonate, manufactured by Alconox, Inc., White Plains, NY.

² Evapo-Rust is a commercially-available chelating rust stripper currently manufactured CRC Industries, headquartered in Horsham Township, PA.

corrosion pit, but the edge was depressed inward at the initiation site. These features were consistent with those found along the parallel cracks along the shaft. Discernible fatigue striations were observed near this crack initiation site (Figure 29).

Further inward on the terminal end fracture surface, the surface exhibited dimpled rupture, consistent with subsequent overstress fracture (Figure 30). No other fracture features consistent with different failure modes were observed.

The parallel cracks outside the terminal end cylindrical surface (Figure 22 and Figure 23) were also examined using an SEM, as shown in Figure 31 and Figure 32. The other cracks exhibited similar features to the fracture surface, consistent with having undergone a post-cracking corrosive attack. With much of the surface compounds having been removed after cleaning, much of the compounds within the cracks had been removed as well.

The fracture surface was excised from the terminal end, and the remainder of the terminal end was vacuum cold-epoxy mounted, ground, and polished. This preparation provided a cross section of much of the terminal end, as illustrated in Figure 33. Multiple cracks were identified in this cross section, along with an undulating outer surface consistent with some corrosion pitting. The cracks had penetrated up to 0.01 in (0.25 mm) into the outer surface. This cross section also showed that the terminal end exhibited a grain flow direction parallel to the longitudinal direction, consistent with the forging direction.

Figure 34 shows a closer view of one of the cracks. The crack was adjacent to a corrosion pit, shown below in the figure. Both features contained nonmetallic compounds, as evidenced by their lack of reflectivity in the micrograph. Figure 35 shows a crack closer to the fracture surface. This crack exhibited a wider opening and was absent much of the nonmetallic compounds seen in the other cracks. These features were consistent with deformation under the tensile stresses that caused the fracture of the terminal end at the fatigue crack on the fracture surface.

Figure 36 shows another surface crack with nonmetallic compounds in its interior. This crack exhibited perpendicular branched cracking along the direction of the material grain flow. These secondary branched cracks also contained the nonmetallic compounds present in the main cracks and along the surface above the cracks and pits.

The metallographic cross section of the terminal end was examined using an SEM, and the crack in Figure 36 is shown in Figure 37 in a backscattered electron (BE) micrograph.³ From examination using EDS, as exemplified using the x-ray maps in Figure 38, the compounds in the crack were primarily consistent with iron oxide and some silicon

³ 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.

oxides. The silicon dioxides were found to be embedded in the iron oxides, as shown in Figure 39, when compared with the x-ray maps.

The chemical composition of the terminal end was inspected using EDS and was found to be consistent with carbon steel. As typified by the EDS spectrum in Figure 40, the oxide in the crack in Figure 39 exhibited chemical compositions consistent with corrosion products expected of carbon steel, primarily iron oxides. There were also elevated amounts of sodium, chlorine, and sulfur, consistent with constituents in salts corrosive to steel. In addition, some cadmium was present in the oxide, consistent with the end having been coated with cadmium.

Figure 41 and Figure 42 show representative cross sections of the cylindrical surface of the terminal end. These areas were rough and uneven, consistent with exposure to corrosive attack. As shown in these figures, cracks were found emanating from the sharper points of the roughened surface.

These observed features were consistent with the terminal end of the turnbuckle having fractured from fatigue that initiated at multiple locations due to surface corrosion and pitting. Once the fatigue crack had propagated inward to its terminal depth, the rest of the assembly fractured from overstress.

The hardness of the terminal end was inspected per ASTM E384.⁴ The hardness was found to average 26 HRC (269 HV₅₀₀), typical for normalized carbon steel.

Erik M Mueller
Materials Research Engineer

⁴ ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA.

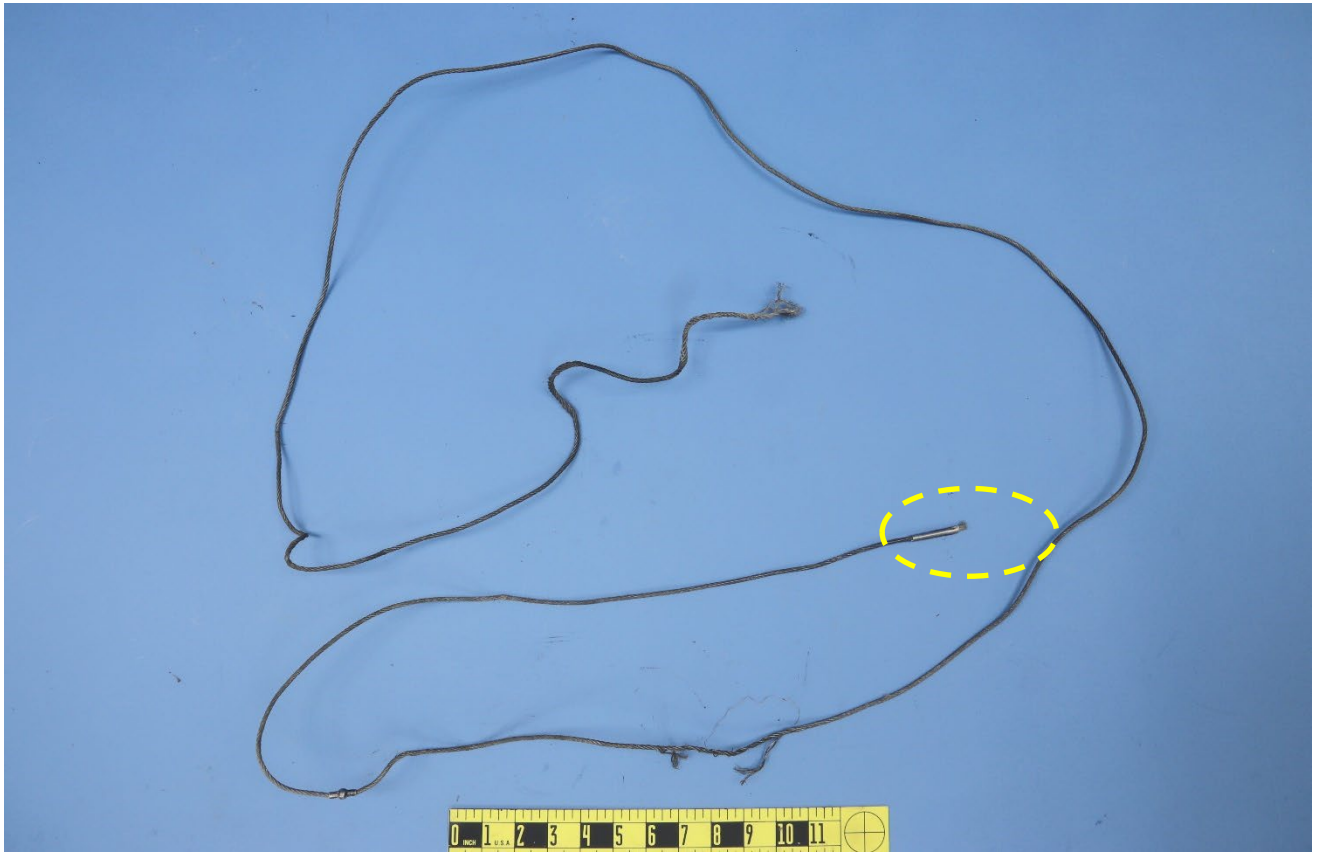


Figure 1 – View of the longer elevator, or down, cable remnant, as received. The circled fractured end is highlighted in Figure 2.



Figure 2 – View of the fractured fork with the cut wire strands, circled in Figure 1, showing the fractured end.



Figure 3 – View of the fracture surface of the wire strands and fork remnant in Figure 2.

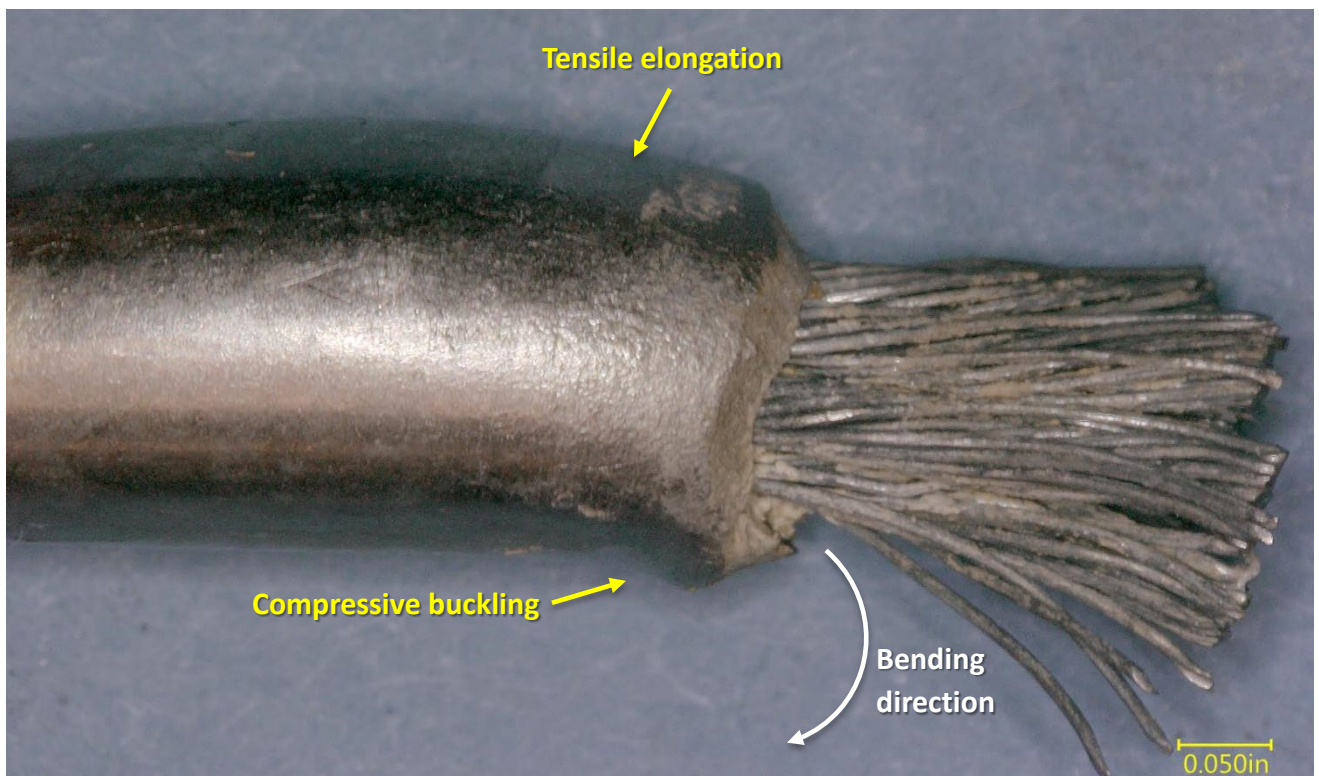


Figure 4 – View of the fractured fork remnant, from the side, annotated to show bending features.

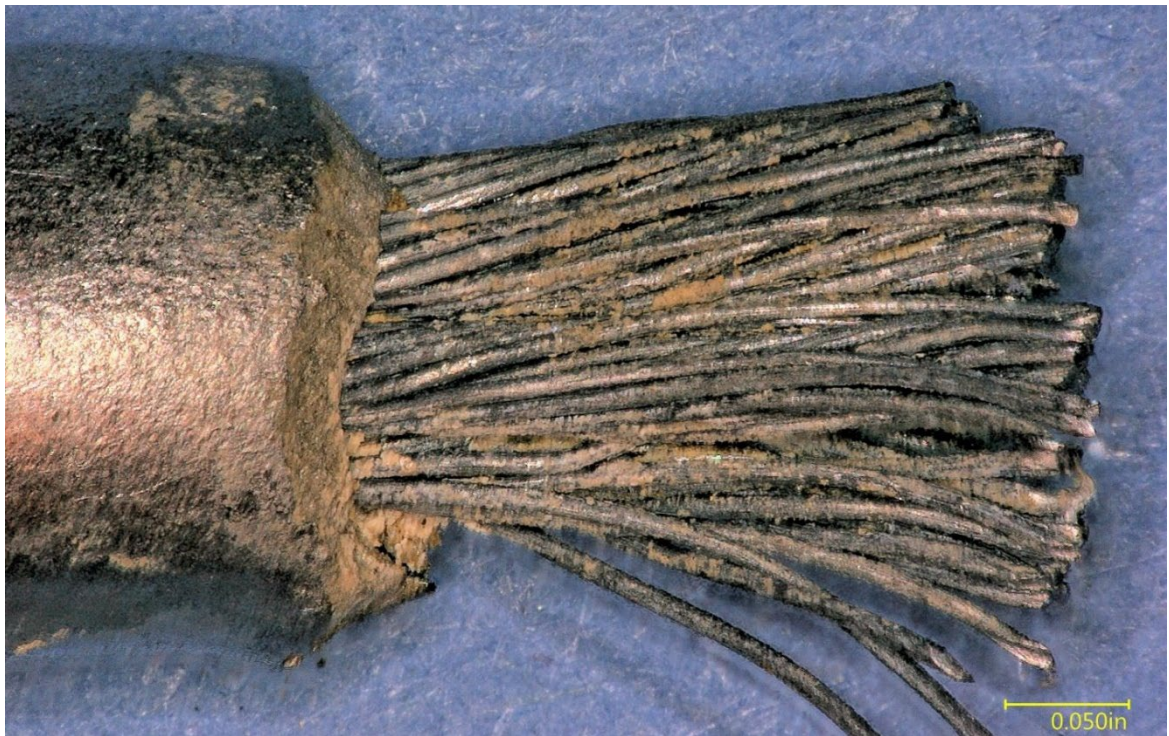


Figure 5 – Closer view of the fracture surface from the fork in Figure 4, rotated 90°.

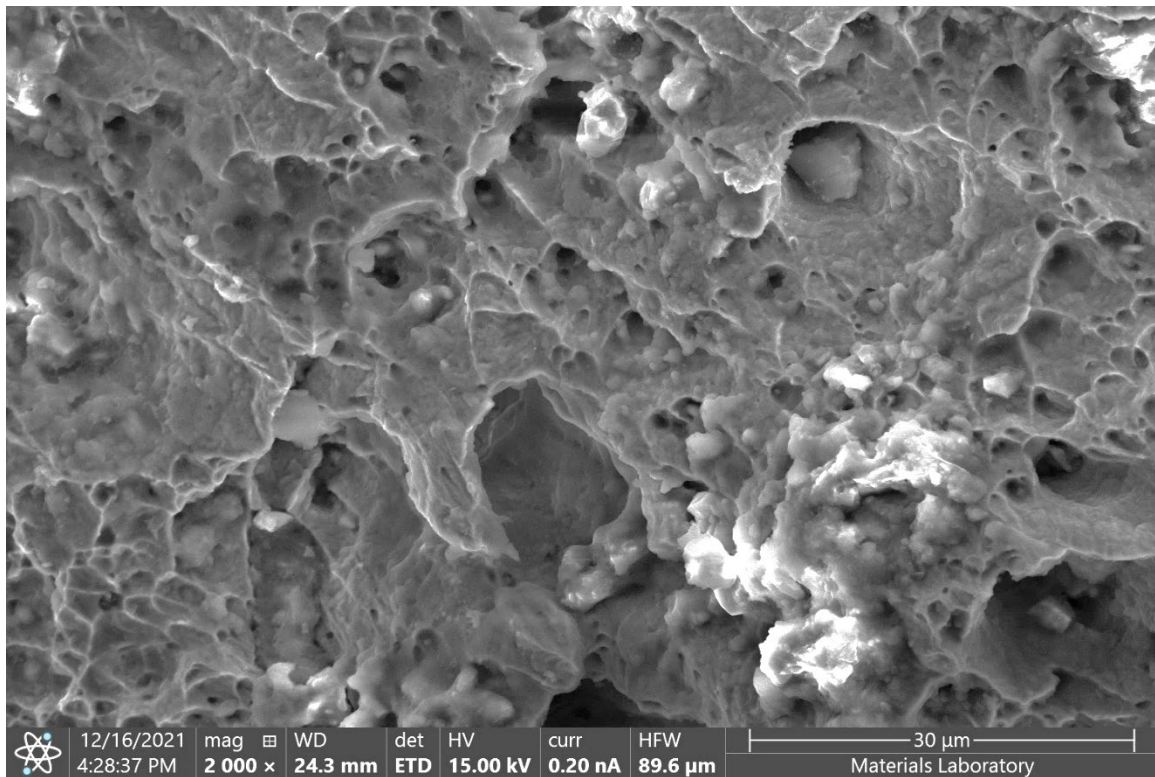


Figure 6 – Secondary electron (SE) micrograph of a typical area of dimpled rupture on the fork fracture surface.



Figure 7 – View of the frayed and fractured wire strands in the bottom of Figure 1.



Figure 8 – View of the fractured wire strands from the opposite end, as received.

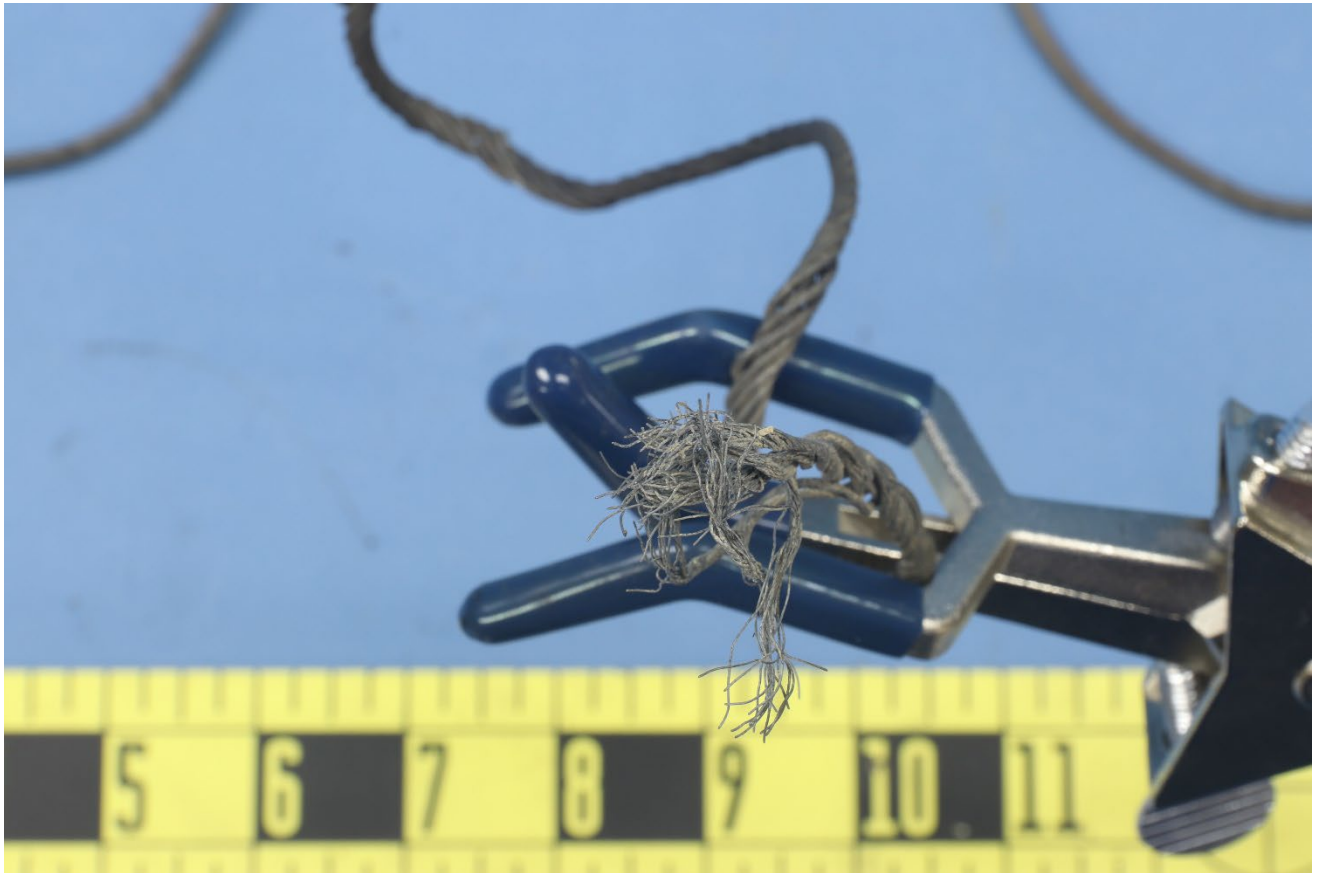


Figure 9 – View of the wire strand ends in Figure 8.



Figure 10 – View of some of the wire strands after sectioning.



Figure 11 – Closer view of the wire strand ends from Figure 10.



Figure 12 – SE micrograph of a set of fractured wires in the frayed area of the cable.

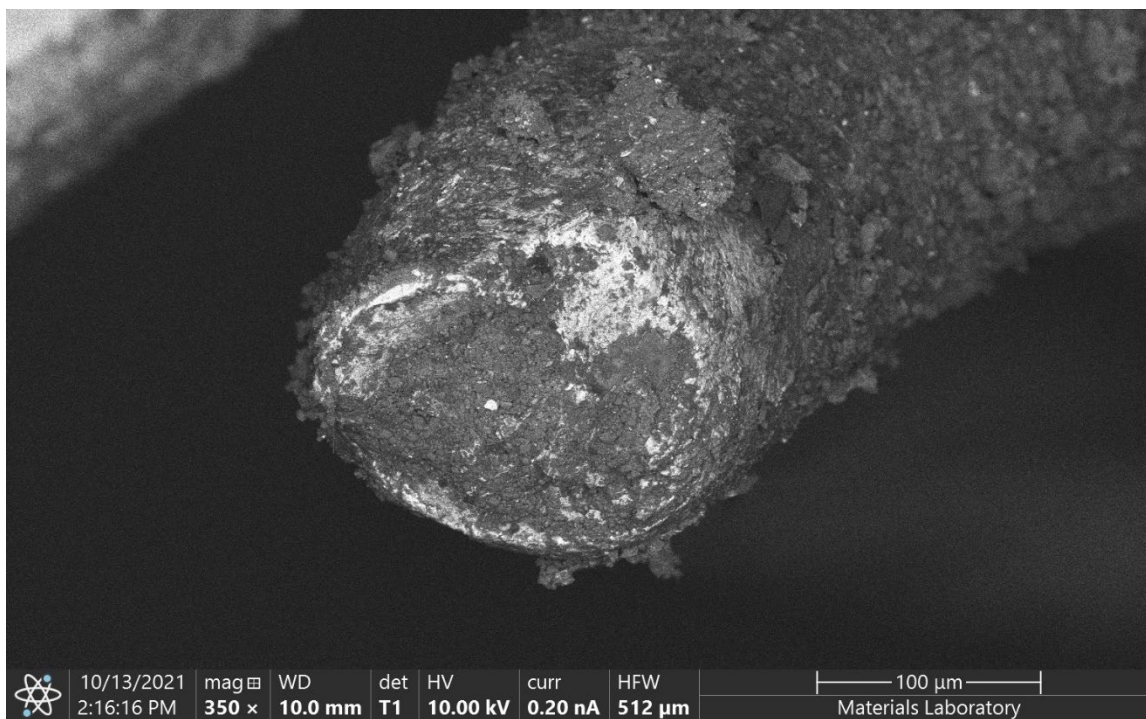


Figure 13 – Backscattered electron (BE) micrograph of a fractured strand end from Figure 12.

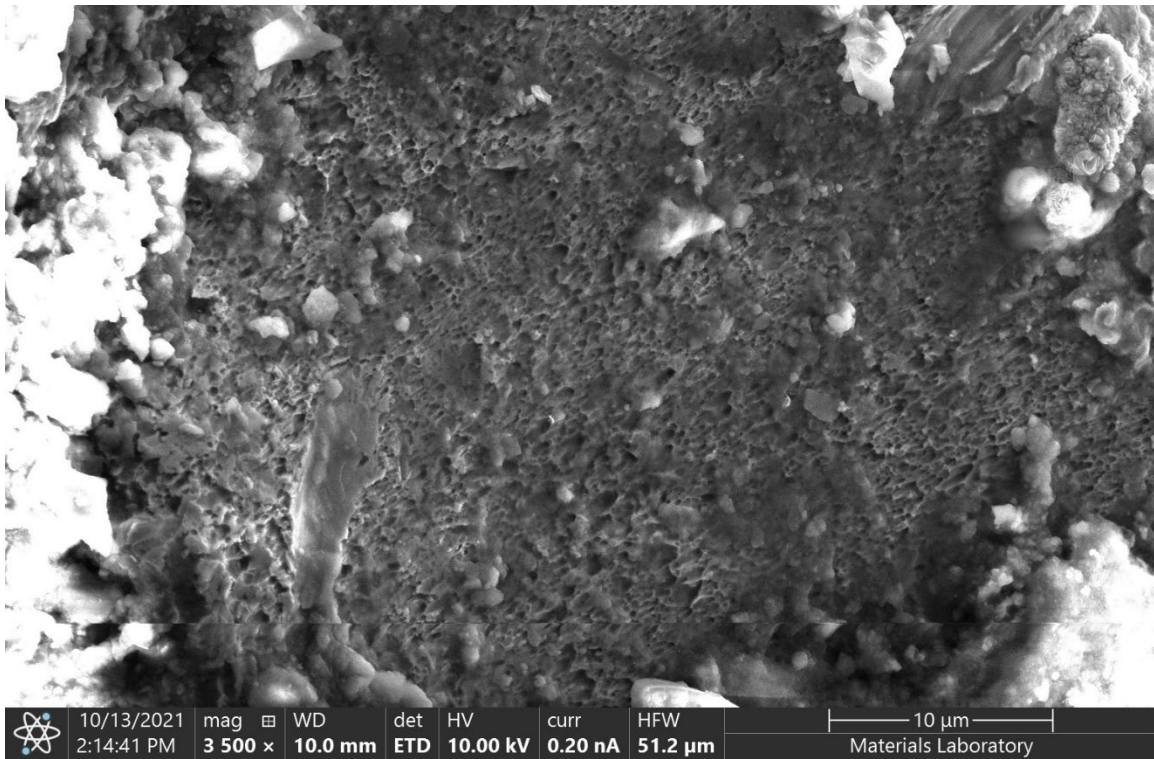


Figure 14 – SE micrograph of a closer area of the strand surface in Figure 13.

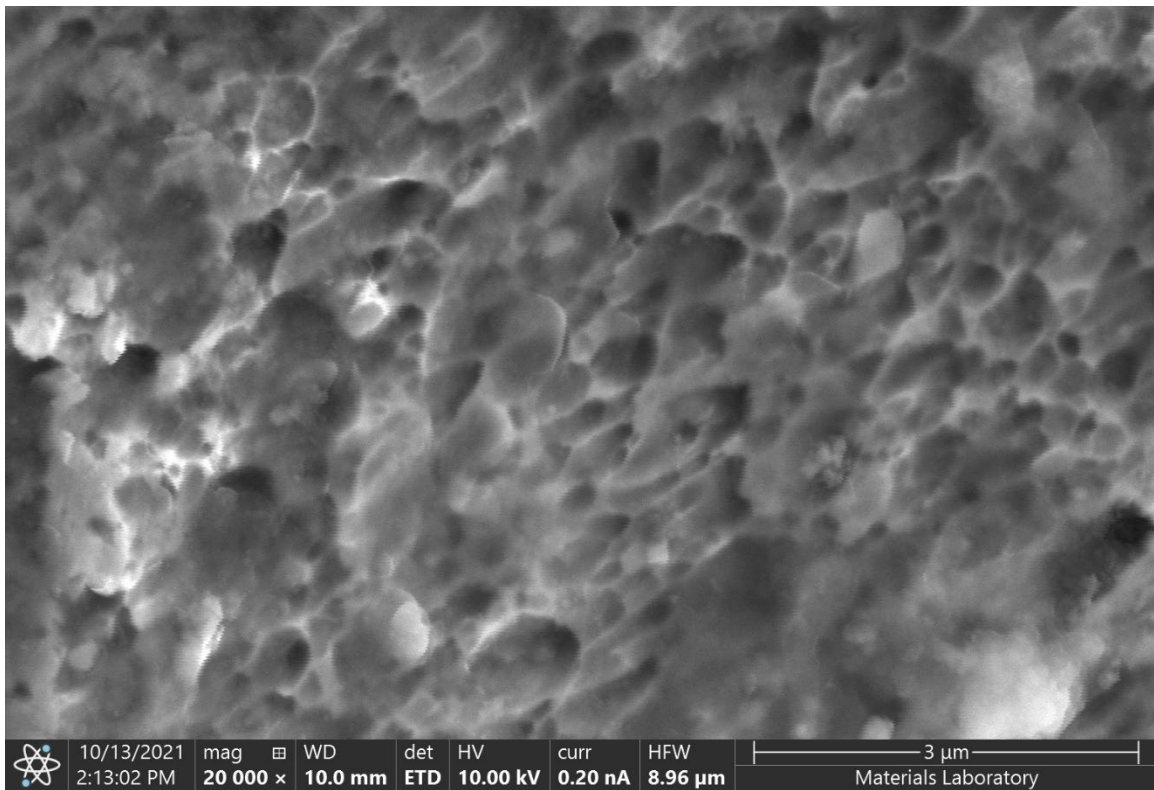


Figure 15 – SE micrograph of dimpled rupture features in Figure 14.

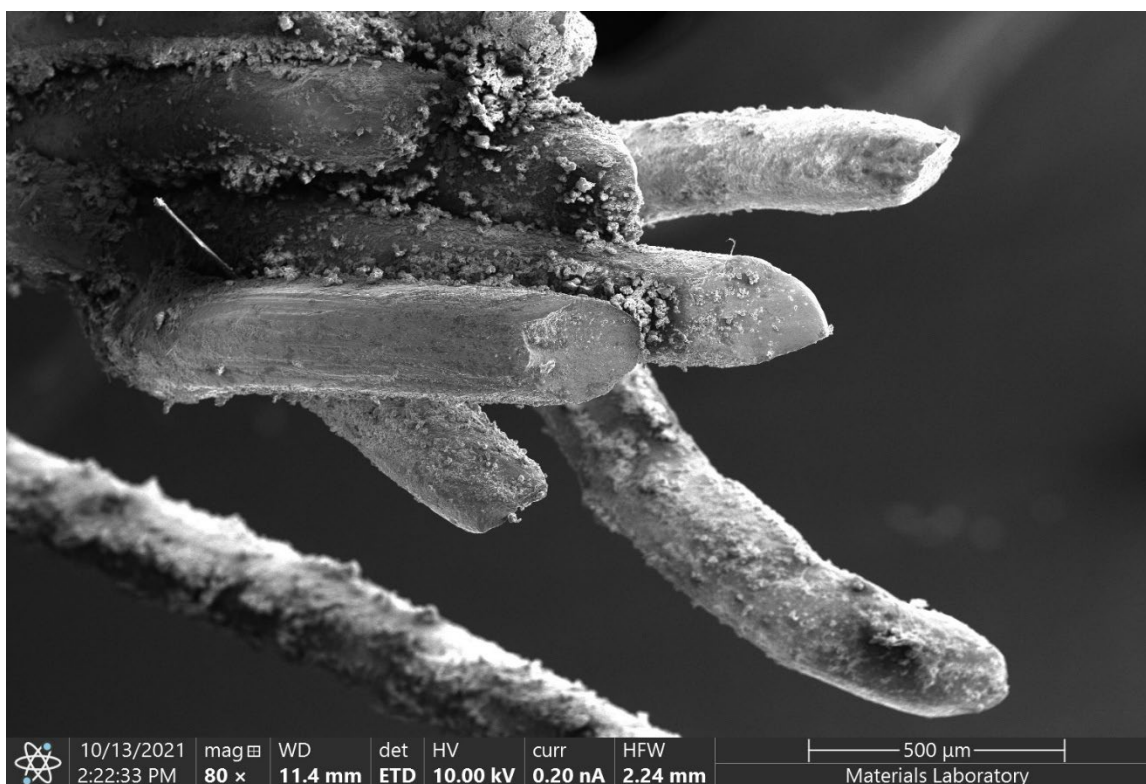


Figure 16 – SE micrograph of a set of fractured strands along the frayed area.

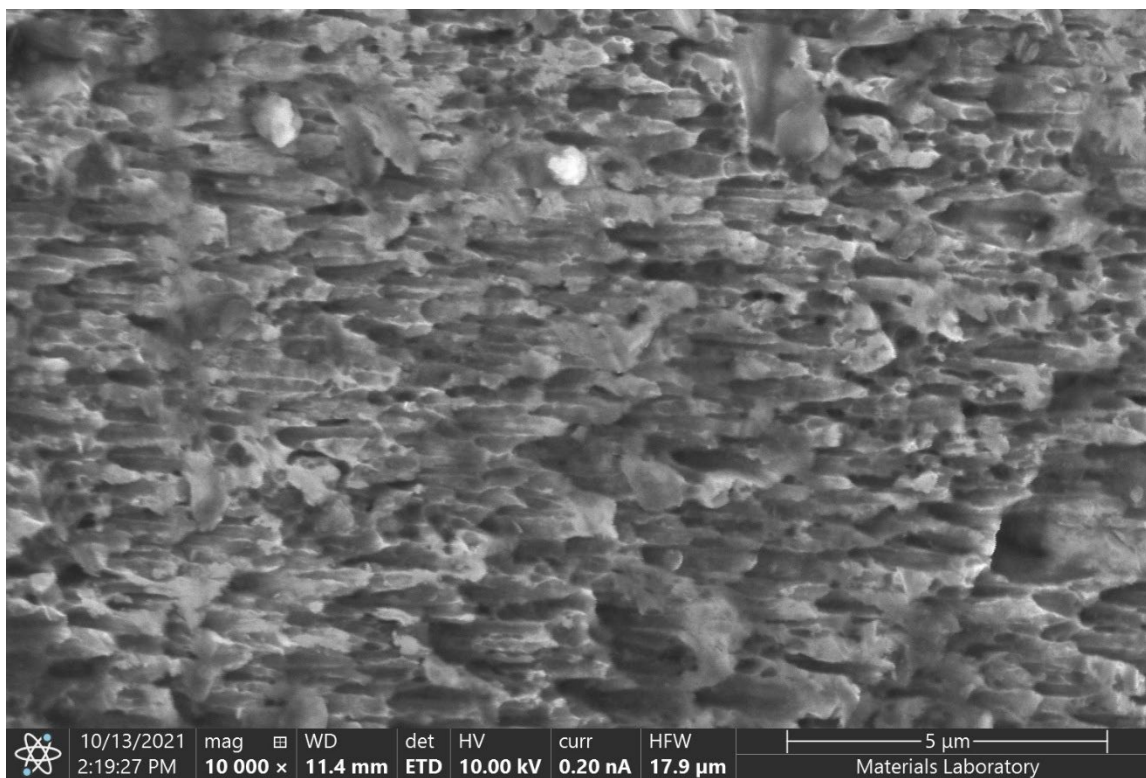


Figure 17 – SE micrograph of a closer area of the center strand fracture surface in Figure 16, showing dimpled rupture.

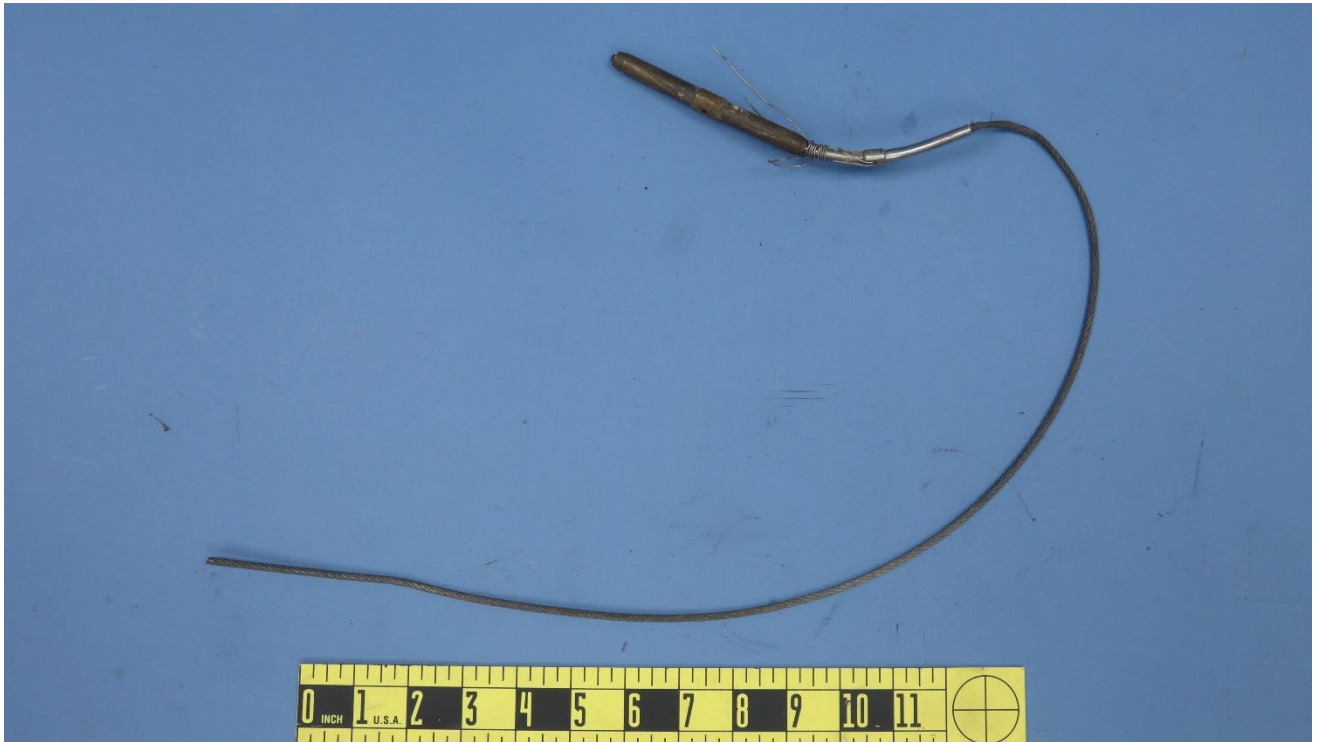


Figure 18 – The shorter elevator cable remnant, or up cable, showing the fractured turnbuckle.



Figure 19 – View of the turnbuckle with the fractured terminal end fracture surface, as received.



Figure 20 – View of the fracture surface of the strands from cable remnant in Figure 18.



Figure 21 – View of the fractured terminal end, after disassembly, but prior to cleaning.

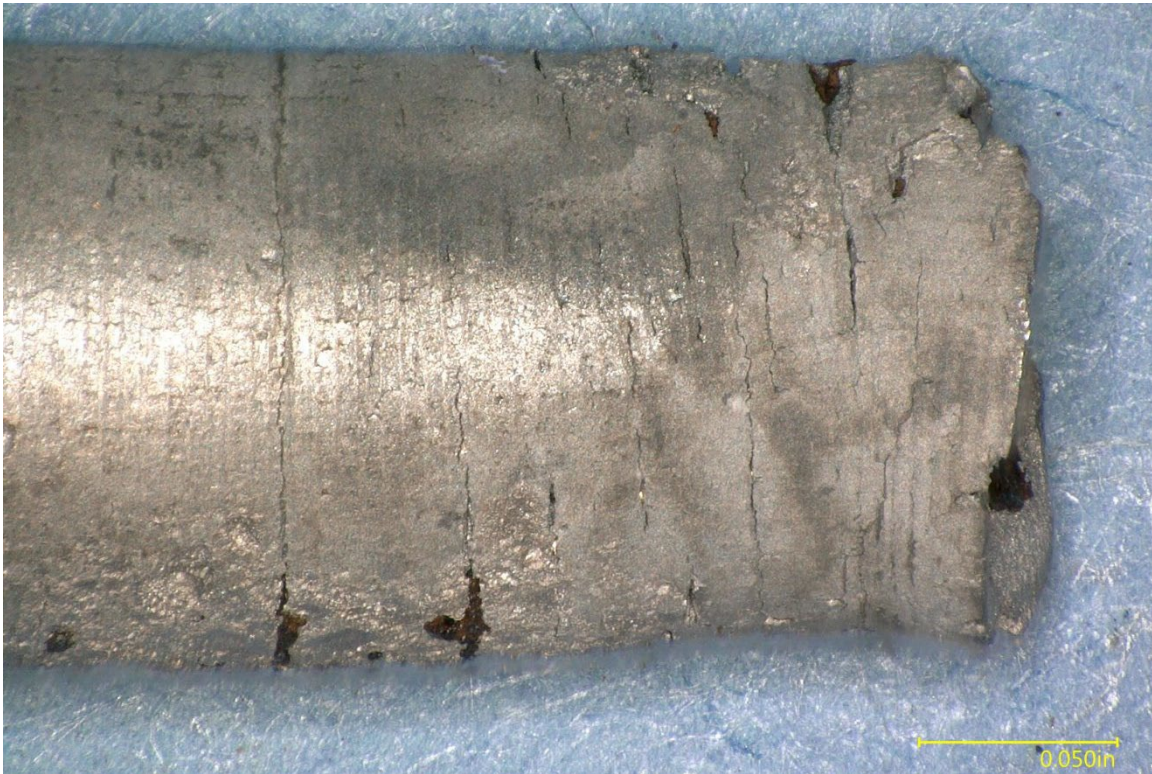


Figure 22 – Side view of the terminal end remnant near the fracture surface, showing a localized deformation near the surface, as well parallel surface cracks.



Figure 23 – The side of the end fracture, rotated 90° from Figure 22, showing a flattened area with some perpendicular secondary cracks.

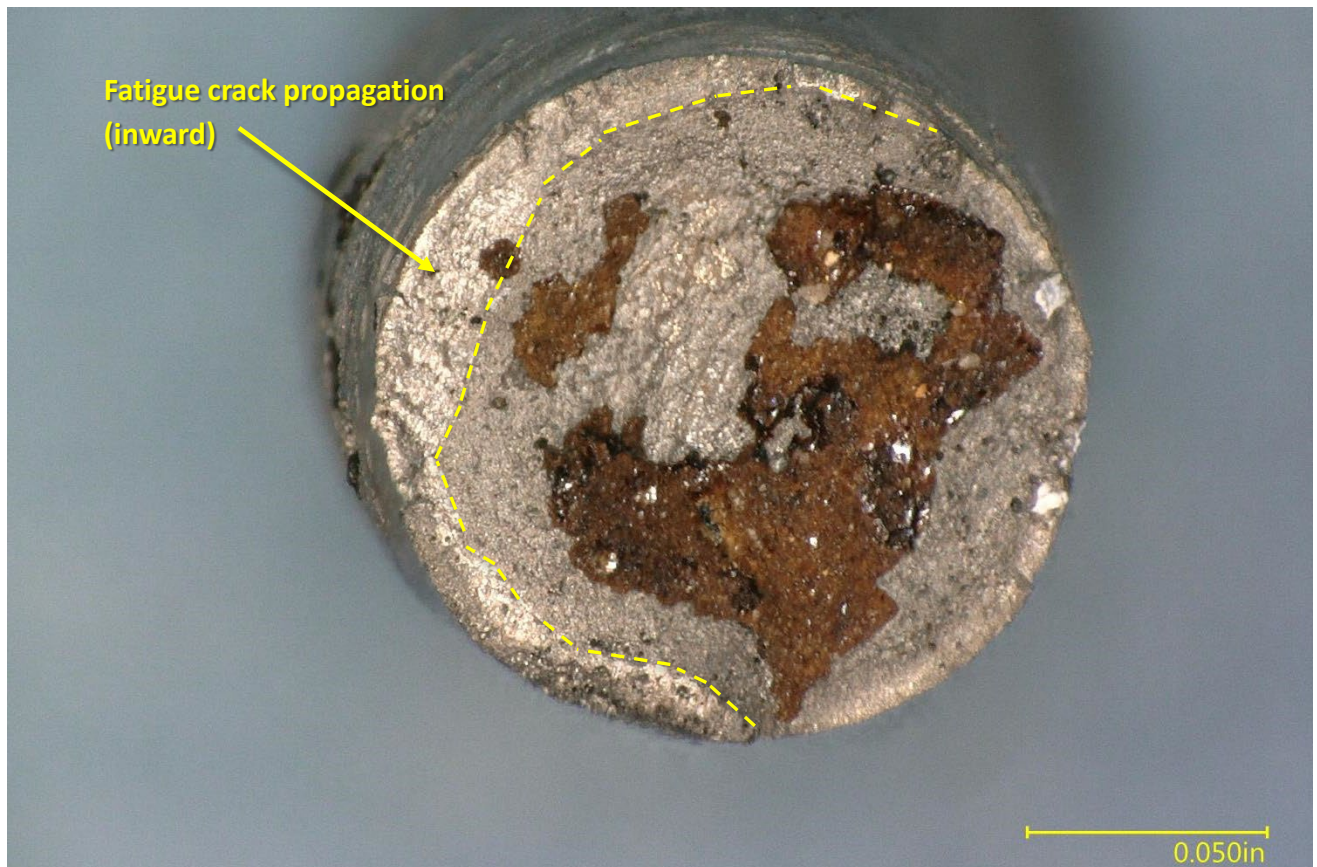


Figure 24 – View of the terminal end fracture surface after extensive cleaning (the brown areas were remnants of contamination/rust).



Figure 25 – SE micrograph of the edge of the end fracture surface, showing an area of ratchet marks and crack arrest marks.

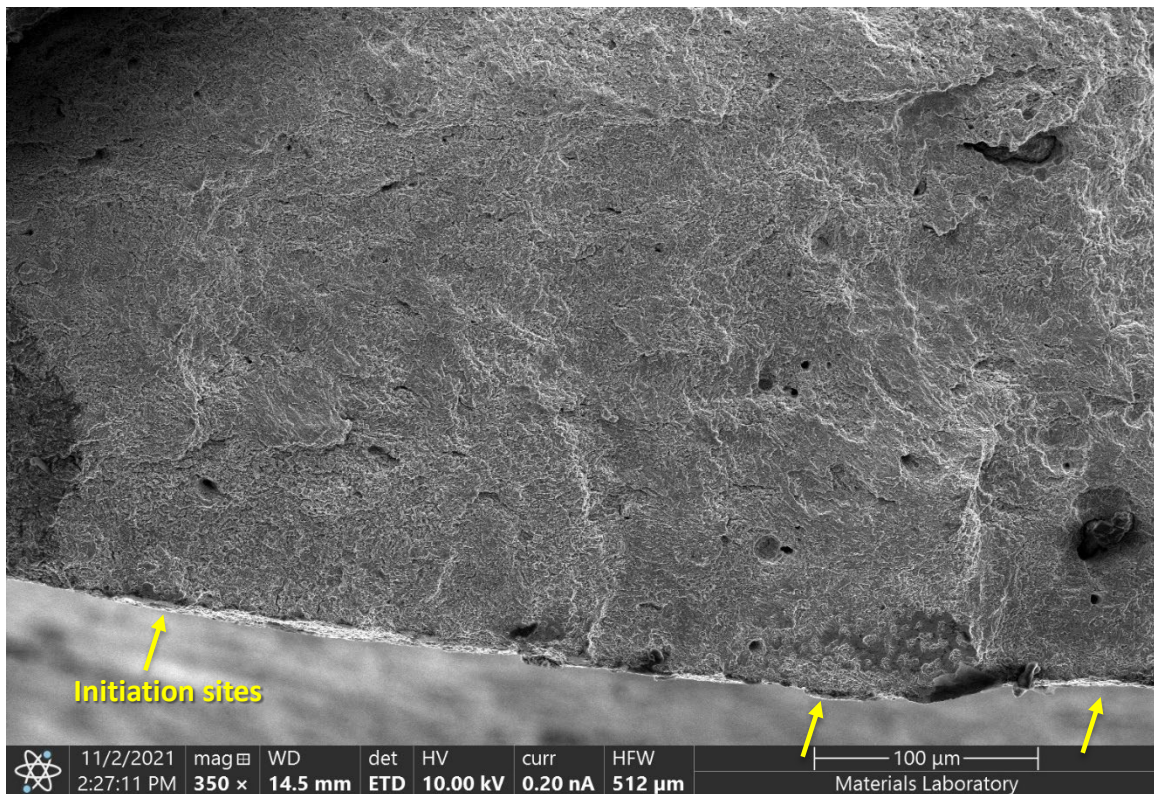


Figure 26 – SE micrograph showing a closer view of the depth of the fatigue region.

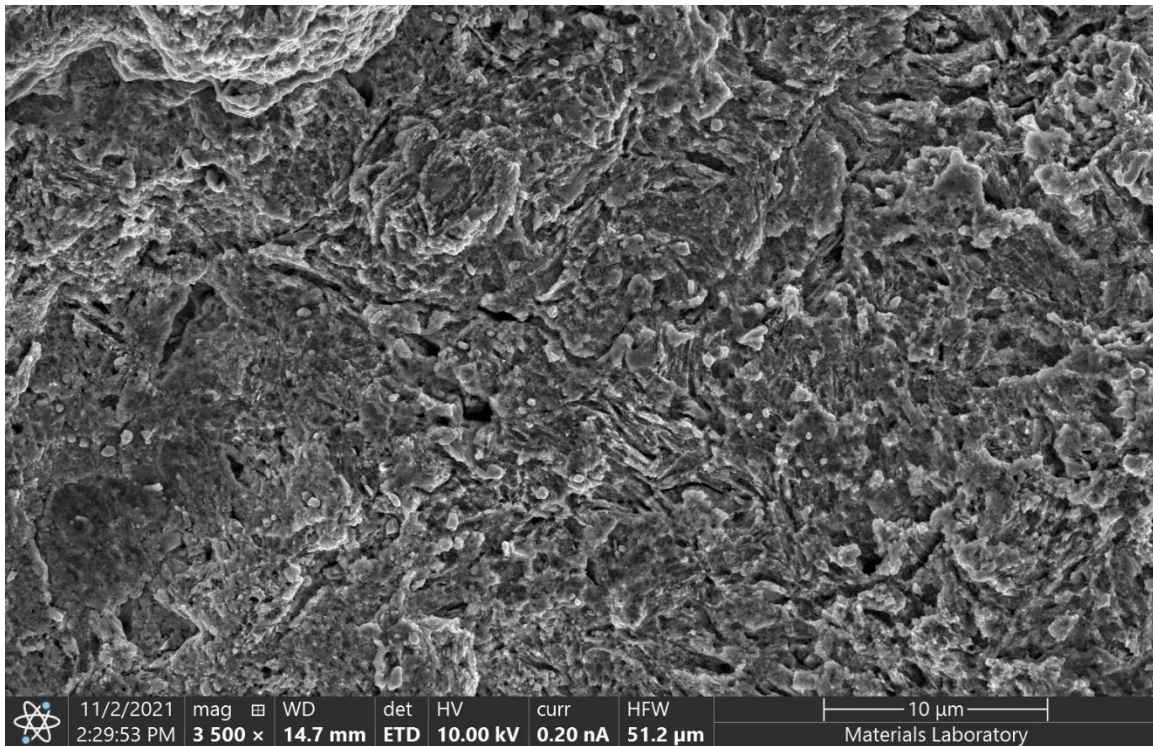


Figure 27 – SE micrograph of a typical area in Figure 26, showing fatigue striations.

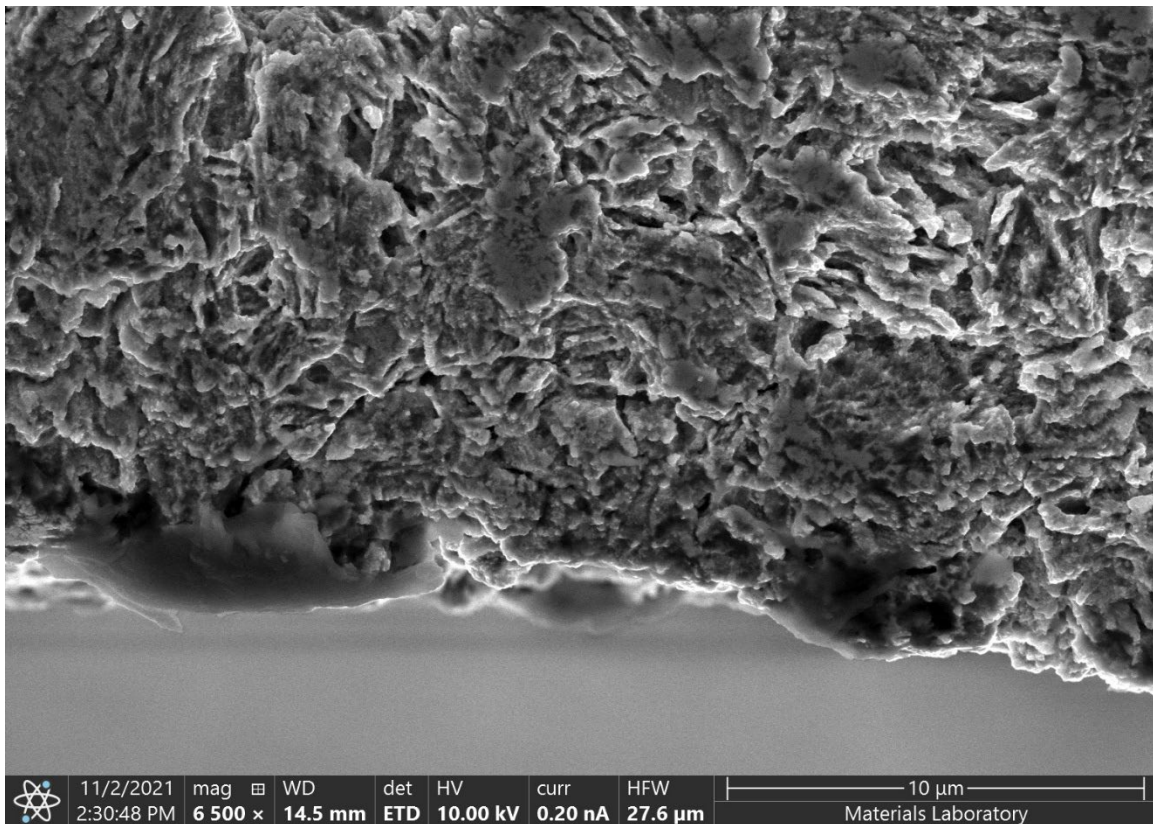


Figure 28 – SE micrograph of one of the fatigue crack initiation sites.

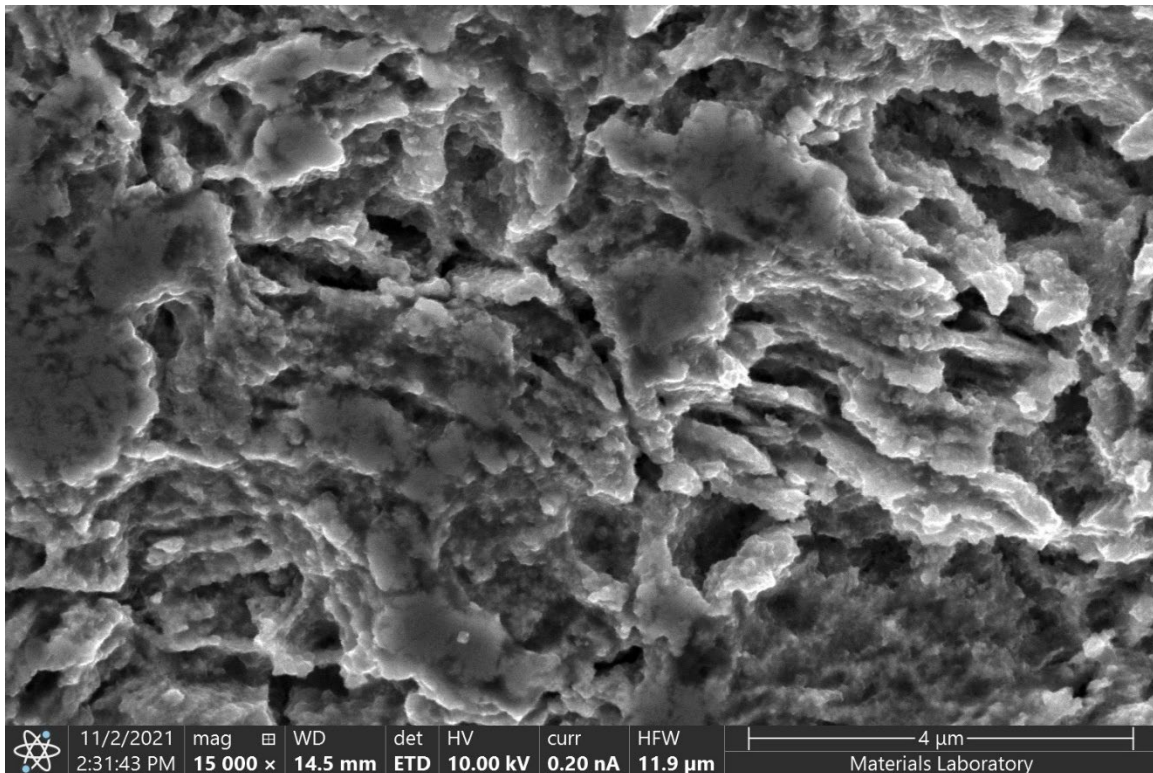


Figure 29 – SE micrograph of a closer view of striations emanating from the fatigue crack initiation site in Figure 28.

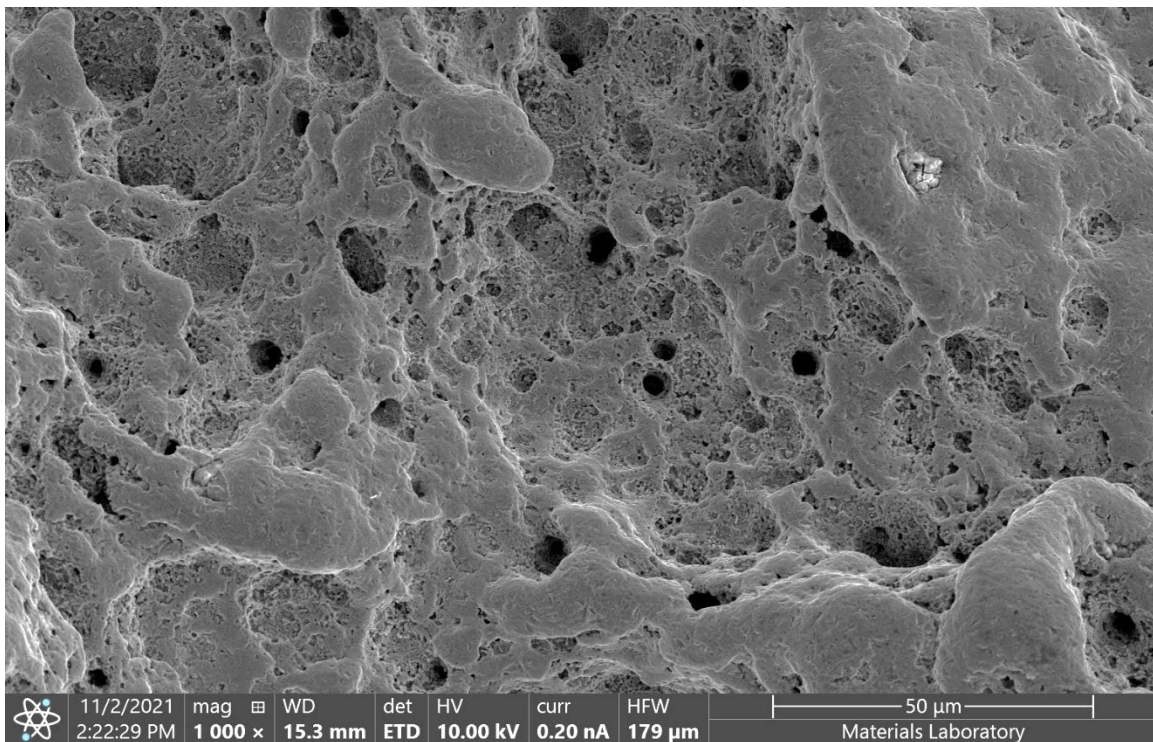


Figure 30 – SE micrograph of the inner overstress area of the terminal end, after cleaning, showing corroded remnants of dimpled rupture.

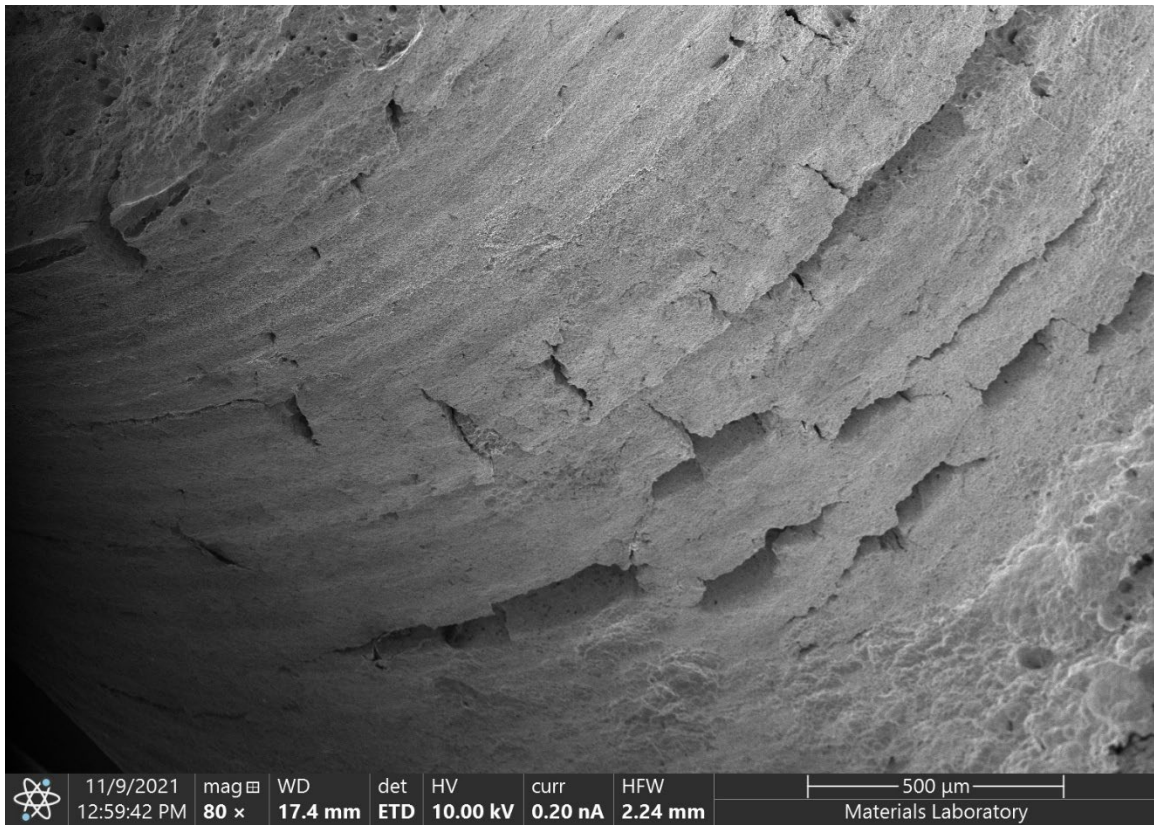


Figure 31 – SE micrograph of the outer surface of the terminal end below the fracture (upper left) showing multiple parallel cracks.

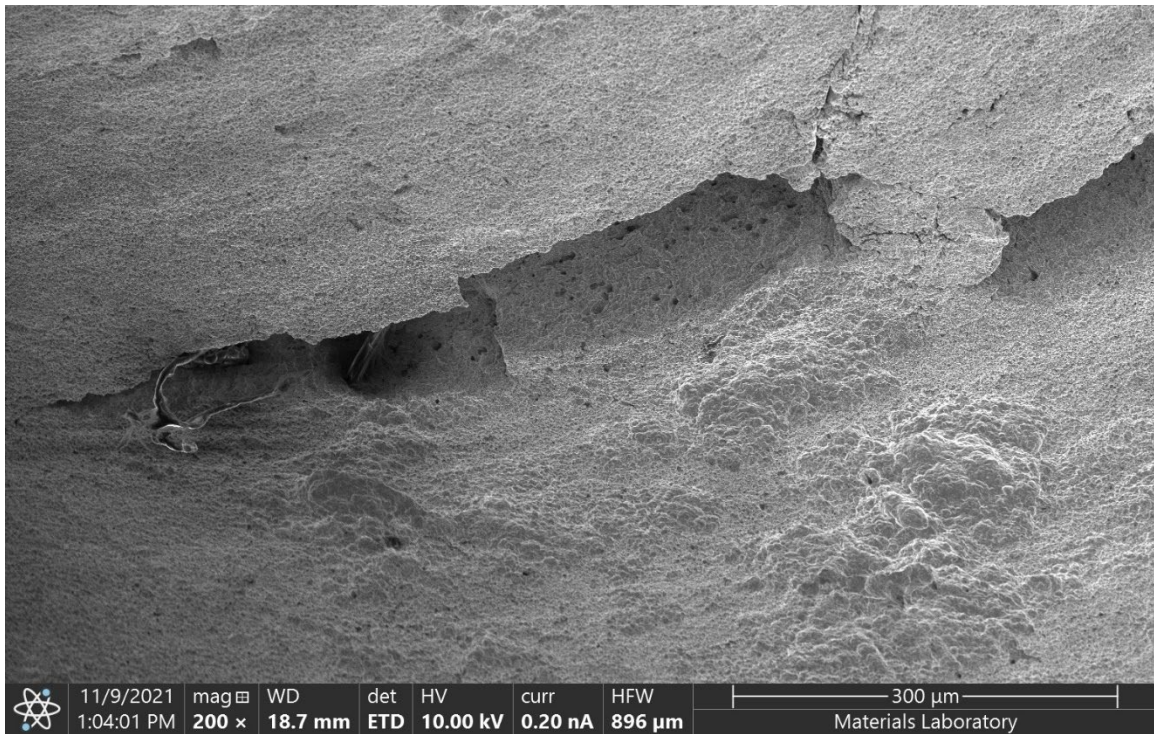


Figure 32 – SE micrograph of one of the parallel cracks in Figure 31.



Figure 33 – Bright-field (BF) optical micrograph of a cross section of the terminal end, after sectioning of the fracture surface end (~25X, etched from tap water).

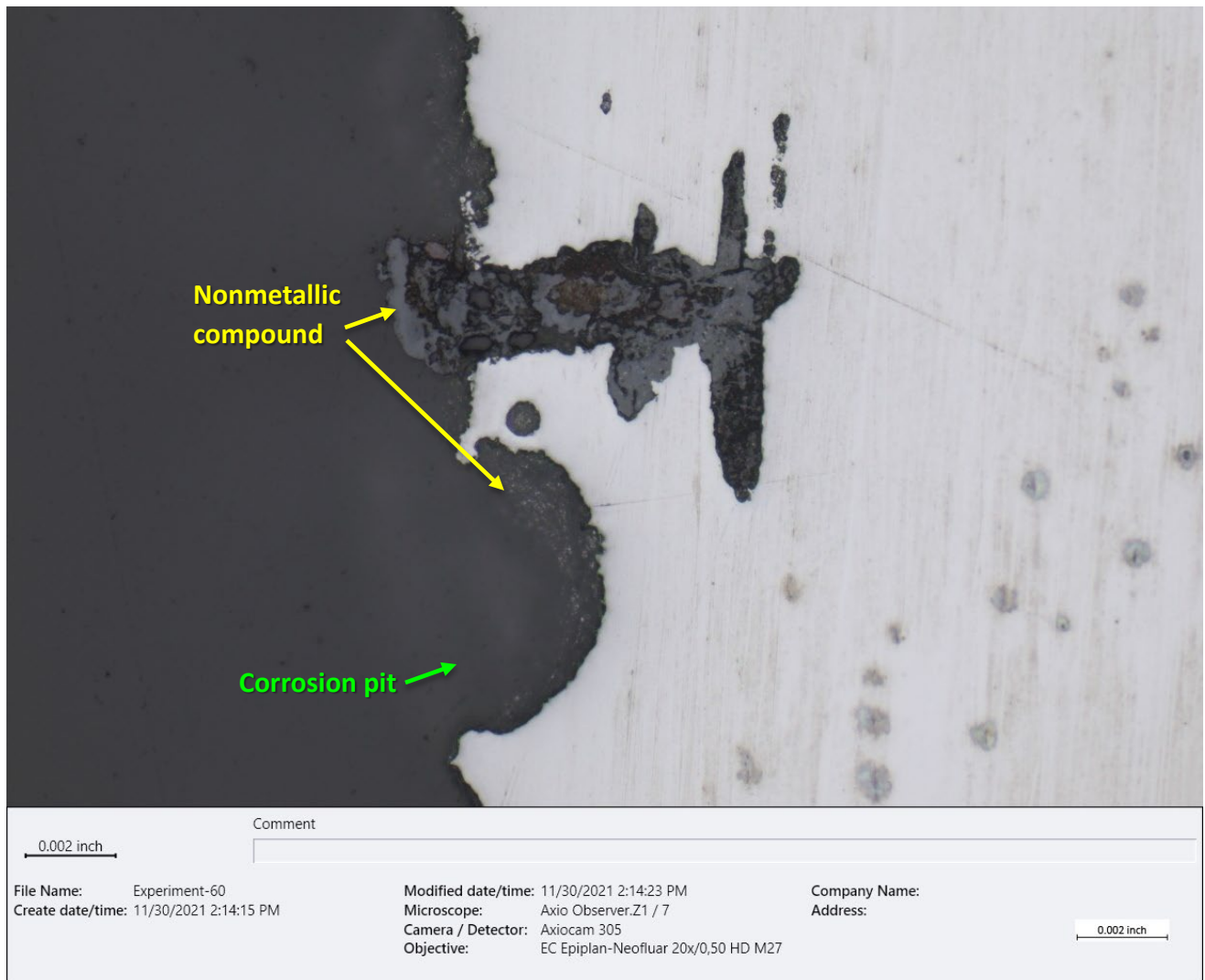


Figure 34 – BF optical micrograph of a corrosion pit adjacent to a crack with internal compounds (~200X, etched from tap water).

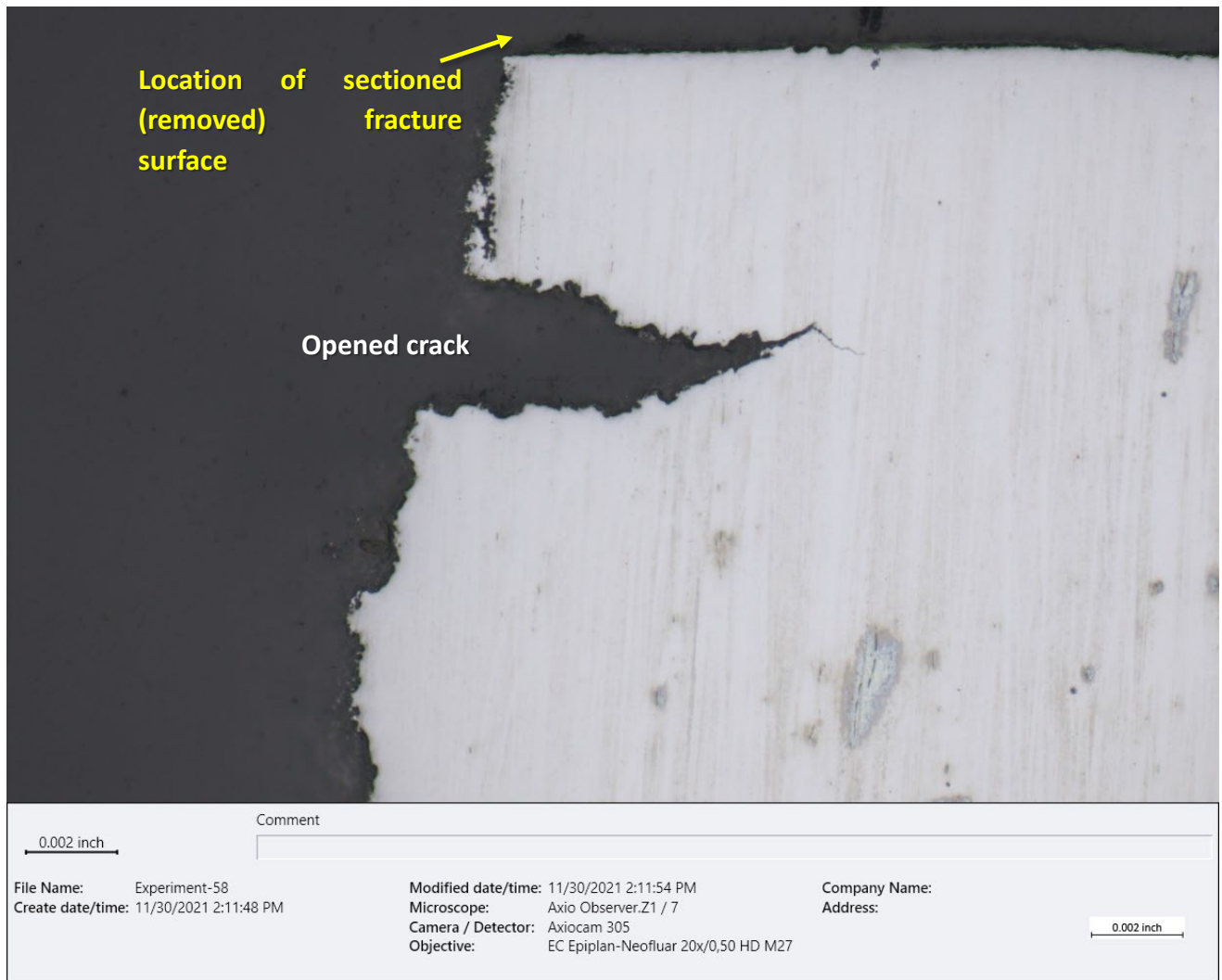


Figure 35 – BF optical micrograph of a opened crack near the fracture surface section (~200X, etched from tap water).



Figure 36 – BF optical micrograph of a crack from the sectioned terminal end, showing nonmetallic compounds along crack front and secondary cracks (~200X, etched from tap water).

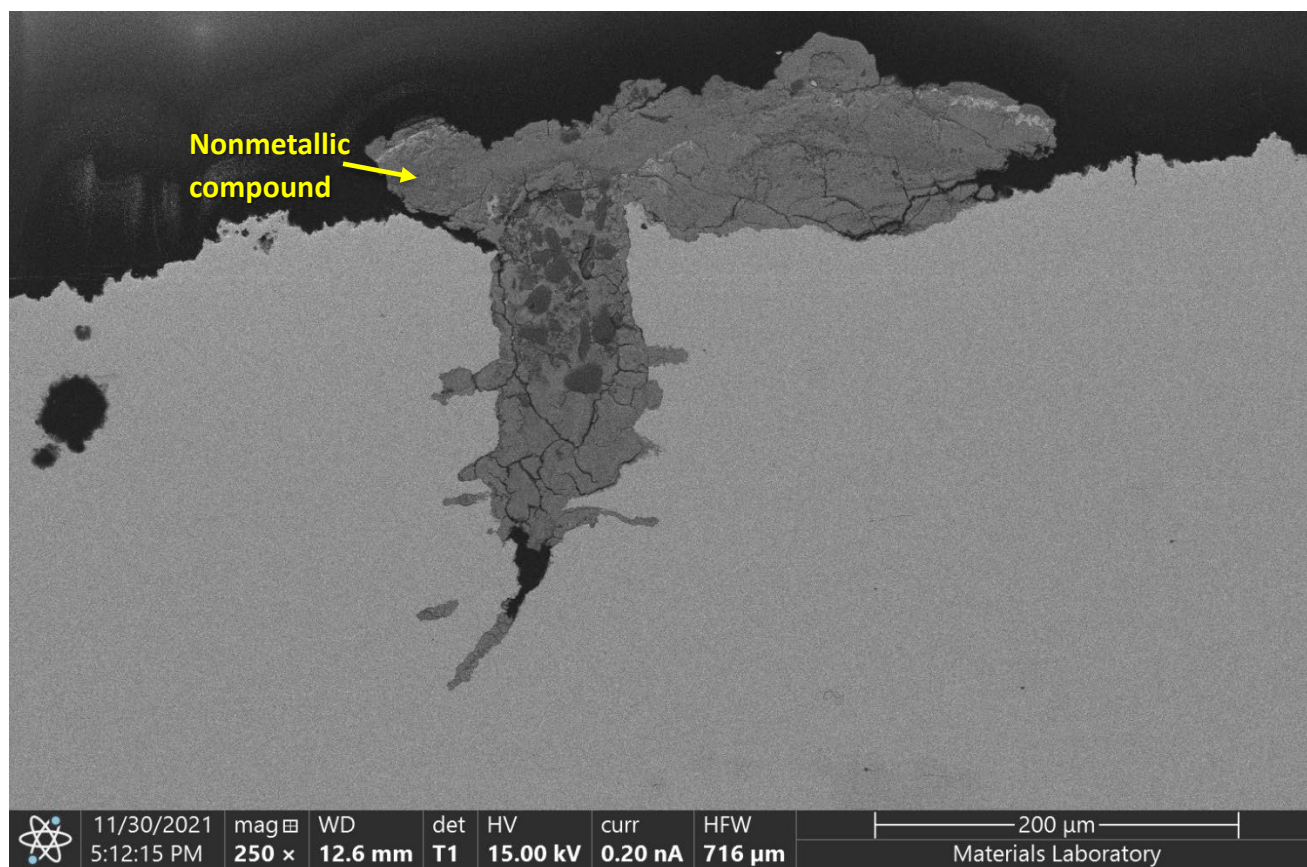


Figure 37 – BE micrograph of the crack and oxides shown in Figure 36, rotated 90°.

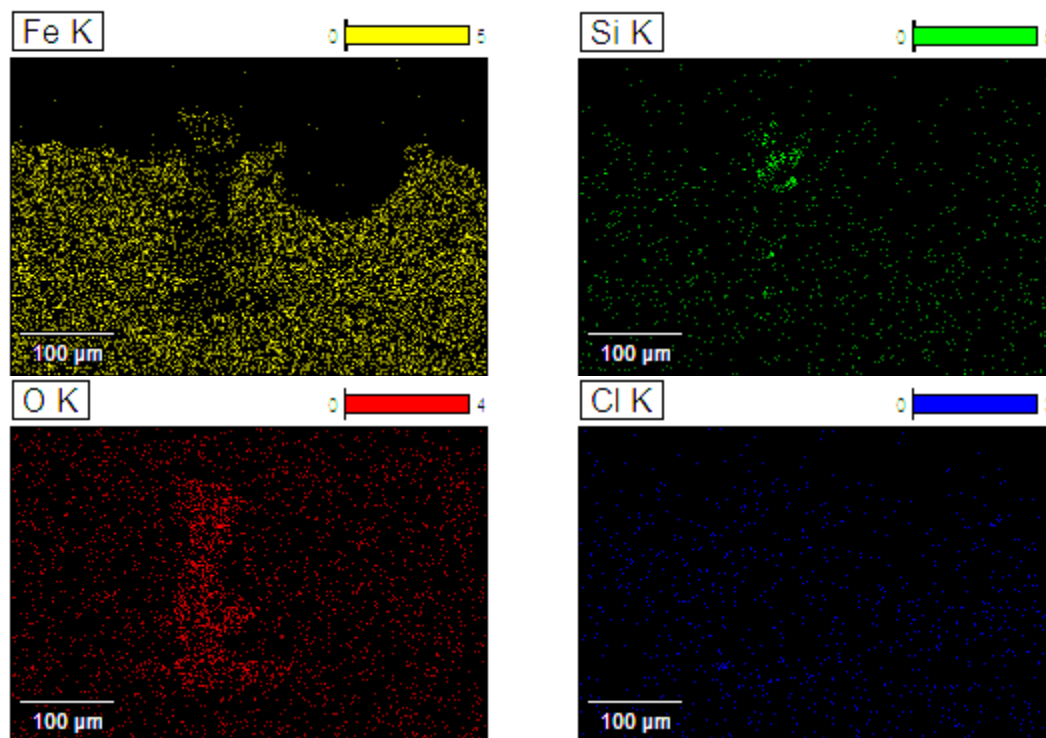


Figure 38 – X-ray maps of the area in Figure 37, showing relative intensities (concentrations) of Fe, Si, O, and Cl, respectively.

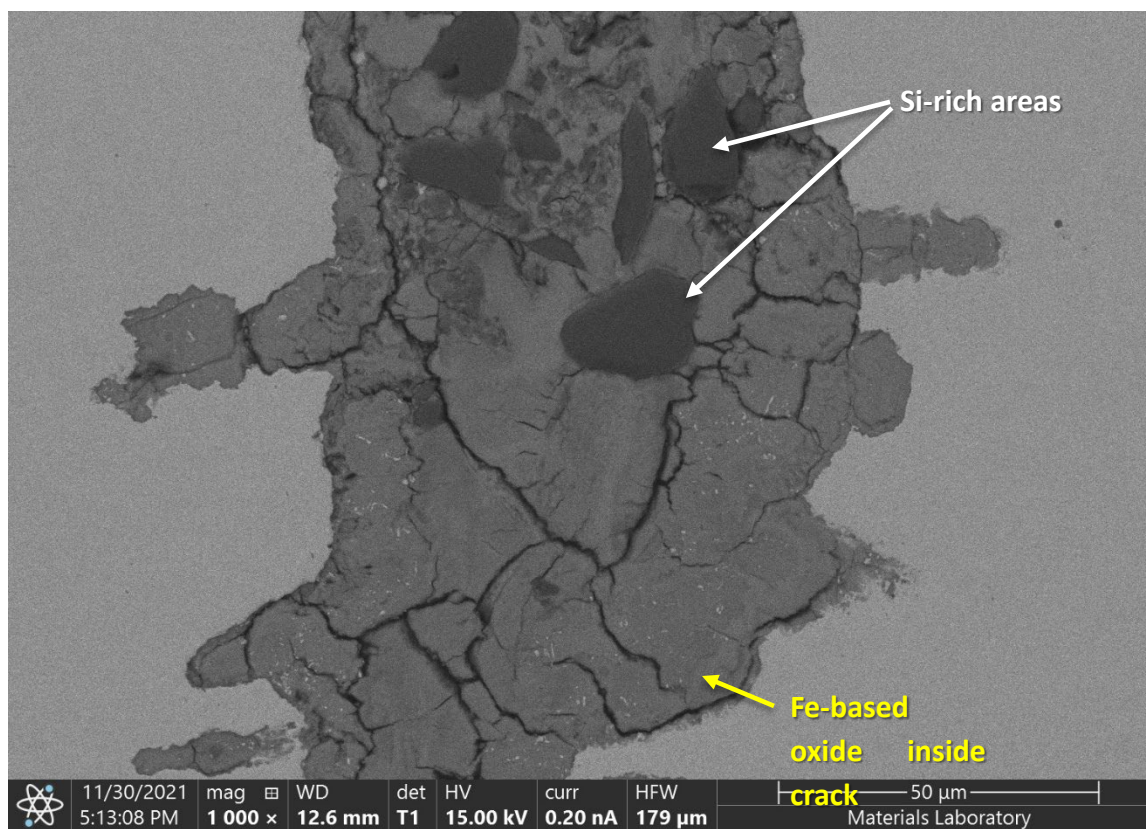


Figure 39 – BE micrograph of a closer view of the iron (dark gray) and silicon oxides (dark) in the crack in Figure 37.

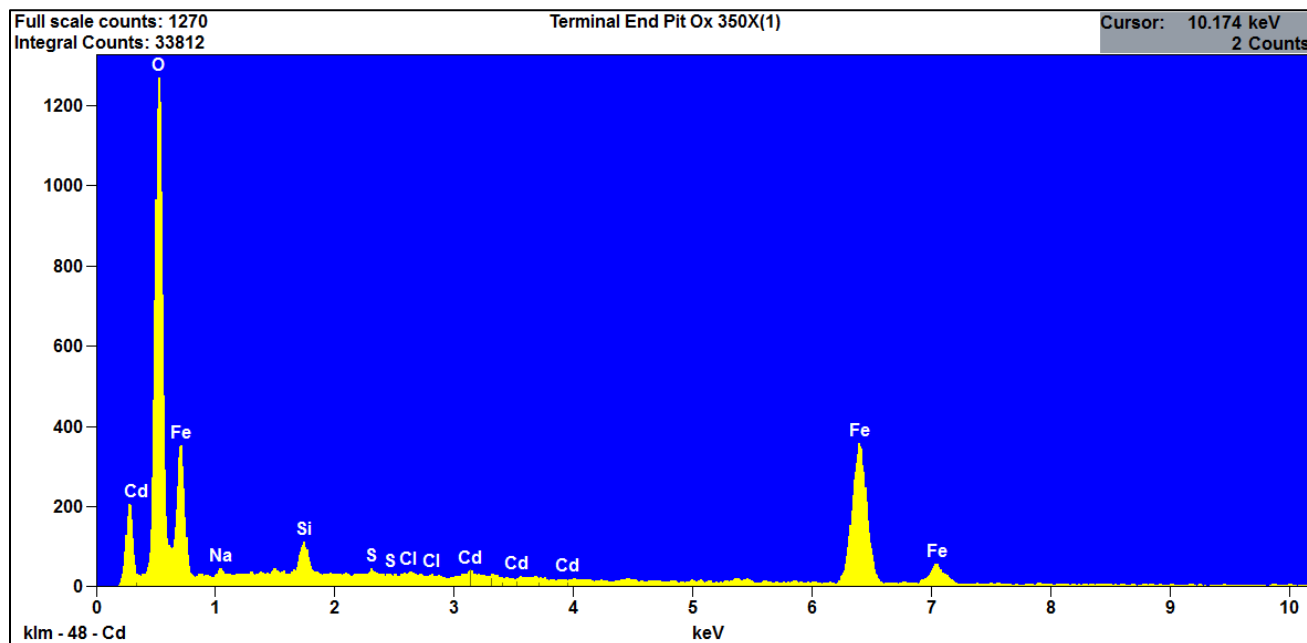


Figure 40 – EDS spectrum of a typical area in the gray oxide in Figure 39, showing minor amounts of Na, Cl, S, and Cd.

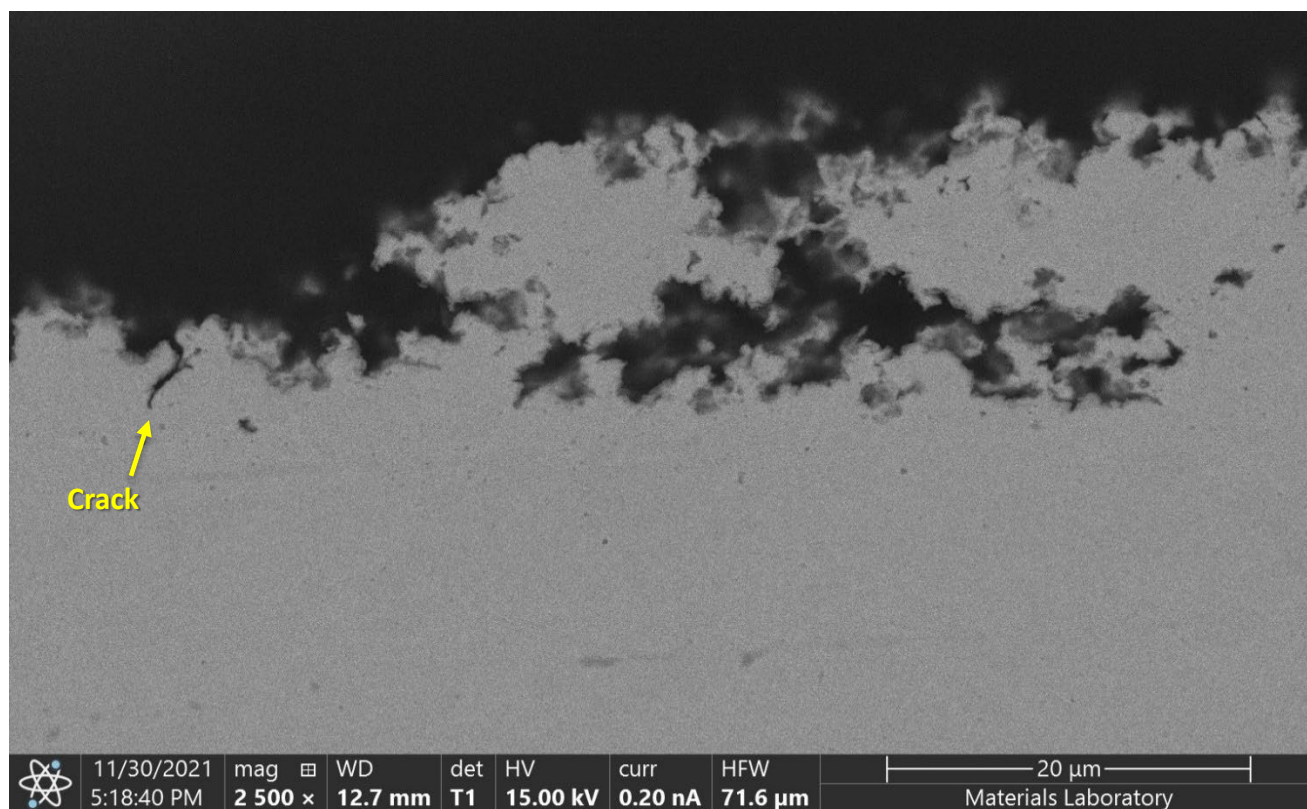


Figure 41 – BE micrograph of a typical area of the terminal end surface, showing a small crack.

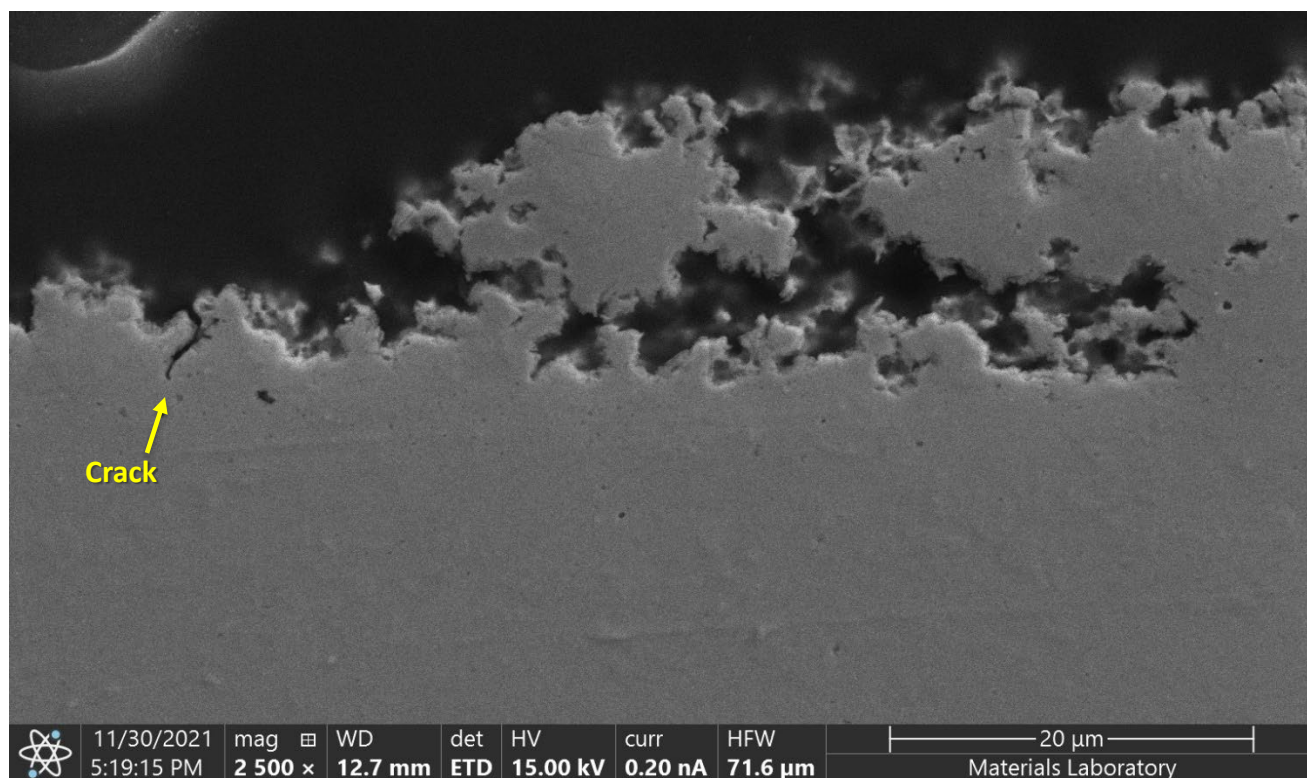


Figure 42 – SE micrograph of the same terminal end cross section location as Figure 41.