

NATIONAL TRANSPORTATION SAFETY BOARD

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



April 26, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 22-025

1. ACCIDENT INFORMATION

Place : Grand Forks, North Dakota
Date : August 21, 2018
Vehicle : Air Tractor AT-400, N7300M
NTSB No. : WPR18LA234
Investigator : Andrew Swick, AS-WPR

2. COMPONENTS EXAMINED

Remnants of turbine blades

3. DETAILS OF THE EXAMINATION

On August 21, 2018, about 0850 central daylight time, an Air Tractor AT-400 sustained substantial damage when it impacted a field 6 miles north of Grand Forks, ND. The commercial pilot, sole occupant of the airplane, was seriously injured. During impact with the ground, the forward fuselage, empennage and both wings sustained substantial damage. Eighteen turbine blades from the PT6A engine were sent to the NTSB Materials Laboratory for further examination.¹

Figure 1 shows the turbine blades from the concave side, as received. For the purposes of this report, the blades were labeled 1 through 10 for the shortest blades, and A-H for the blades with larger remnants of blade material above the platform. As the initiating blades in turbine engine failures typically have little remaining material above the platform, the blades were divided based on remnant height—blades below 0.5 inches in remaining blade height were labeled 1 through 10, those above were labeled A through H. Using calipers, the heights of the blade material above the platform was measured, noting the highest and shortest lengths from the top of the platform, as displayed in Table I. In addition, the distance from the bottom of the dovetail to the top of the platform on the leading edge side was measured, as recorded in Table I.

¹ The PT6 is a turboprop aircraft engine consisting of a gas generator with accessory gearbox and a free power turbine, produced by Pratt & Whitney Canada, headquartered in Longueuil, Quebec.

All the blades exhibited markings on the sides of the dovetail and platform. While often worn or covered with deposits, the markings were consistent with each other on each blade and stated the following:

*FAA-PMA
E3013102 E
13017-1
1L9D9*

Figure 2 shows the fracture surfaces of the 10 shortest blade remnants. These fracture surfaces were all scrutinized using optical light microscopes to search for distinct areas of features on the fracture surfaces of Blades 1 through 10. While all the fracture surfaces were examined, the surfaces of Blades 7 through 10 are highlighted in this report from Figure 3 to Figure 11.

Figure 3 shows an overall montage of the fracture surface of Blade 8. As was typically found on all the blade remnants in this case, the surfaces exhibited areas of dark coloring, along with light gray to dark orange areas, consistent with surface oxidation and combustion deposits. These deposits were typical of exposure to high temperature environments. In addition, the fracture surfaces themselves exhibited a general rough and tortuous surface texture, with a dull and dark luster.

Figures 4 and 5 show closer views of the fracture surface from the leading and trailing edges, respectively. While at lower magnifications, these areas appeared flatter and lighter in color than the rest of the fracture surface, closer examination found mottled features with localized perpendicular material deformation, consistent with post-fracture smearing.

Figure 6 shows an overall montage of the Blade 7 fracture. This fracture exhibited darker deposits, primarily on the convex side of the fracture and platform, and the leading edge. While there were dark deposits on the leading edge portion of the fracture surface (see Figure 7), the fracture features in this area were consistent with those over the rest of the fracture surface.

In addition, the trailing edge of the Blade 7 fracture exhibited a higher elevation relative to the platform, along with a local area of flatter, but angled fracture profile. This was similar to that seen on the trailing edge of Blade 9, shown in Figure 8. However, closer examination of the trailing edge areas found fracture features consistent with the rest of the fracture surfaces of Blades 7 and 9. In addition, the leading edge of Blade 9 exhibited smearing outward along and towards the concave side of the blade, highlighted in Figure 9.

Figure 10 shows the fracture surface of Blade 10, which also had a different trailing edge profile than the rest of the surface, albeit more angled and faceted. The leading edge of Blade 10's fracture surface also appeared more reflective and flatter—this area exhibited deformation and flattening consistent with post-fracture smearing (Figure 11).

Like the other blades, the trailing edge of the fracture surface exhibited features consistent with the rest of the fracture surface.

Several of the blades were examined using a field emission scanning electron microscope (FESEM) after sequential ultrasonic cleaning using acetone and an aqueous solution with Alconox detergent.² Figure 12 shows an overall view of the leading edge of the Blade 7 fracture surface, whereas Figure 13 shows a closer view. From the backscattered imaging, no large areas of dissimilar material were observed.³ The secondary image showed areas that had not been obliterated by post-fracture smearing, which appeared rougher. As typified in Figure 14, these areas exhibited dimpled rupture, consistent with overstress fracture in tension.

The leading edge of the Blade 8 fracture surface is shown in Figure 15. This fracture surface exhibited more pronounced peak and valley elevations, much of which had been damaged from impacts and smearing, consistent with post-fracture damage. Figure 16 shows a closer look at some of the damage. While the area in Figure 16 does show some parallel repeating lines, this region was surrounded by slanted dimpled rupture, consistent with overstress in shear.

Overall, the fracture surfaces of the blades presented faceted features, as exemplified by the Blade 8 area shown in Figure 17. This fracture consisted of random plateaus and facets, along with cross-shaped features—these were consistent with fracture along the dendritic constituents and equiaxed grains boundaries typical of conventionally-cast turbine blades. As shown in Figures 18 and 19, the fracture features along the dendrites were relatively flat in morphology, whereas the fractures in the interdendritic regions exhibited more pronounced dimpled rupture.

Blade D was sectioned vertically, mounted, polished, and etched with Kalling's Reagent #2.⁴ A typical area of the dovetail below the platform is illustrated in Figure 20, revealing the equiaxed grain microstructure, along with the dendritic nature of the casting. The primary dendrites and grains were oriented randomly, consistent with conventional casting of the blade.

Figure 21 shows a typical spectrum from an energy dispersive x-ray spectroscopy (EDS) examination of the dovetail region of Blade D. As demonstrated by the peaks of nickel, chromium, aluminum, and titanium, among other elements, the composition was consistent with a nickel-based superalloy casting, such as IN 713C. Figure 22 shows a closer view of the microstructure in the dovetail. This micrograph demonstrates the smaller semi-cuboidal γ' phase, along with larger primary carbides. Not shown in this micrograph

² Alconox is a powdered cleaning detergent, containing primarily sodium bicarbonate and sodium alkylbenzene sulfonate, manufactured by Alconox, Inc., White Plains, NY.

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.

⁴ Kalling's Reagent #2 is a solution of hydrochloric acid, cupric chloride, and ethanol.

were also areas of eutectic γ' and secondary carbides between grains. This microstructure was typical of a heat-treated Ni-based superalloy casting.

The microstructure was contrasted with that in the upper part of the blade remnant, near the fracture surface. As demonstrated by Figure 23, there were more carbides along the grain boundaries, along with some coarsening of the eutectic γ' . Some of the small γ' had spheroidized and/or elongated, but there were no indications of widespread coarsening or re-solutioning of these constituents.

Figure 24 shows a cross section through the Blade D fracture surface, showing a rough, undulating surface, along with sub-surface cracking. This cracking, and the fracture surface path, were located along the interdendritic areas of the microstructure, consistent with the features observed on the fracture surface. Also of note was sub-surface damage on the convex side, as illustrated in Figure 25. This showed internal erosion and cracking within the 0.010 inches below the blade surface.

Due to the sub-surface damage found in Blade D, the fracture surface was also examined using a FESEM. Figure 26 shows an overall view of the Blade D leading edge fracture surface—this surface exhibited widespread surface contamination, which manifested as darker contrast areas in the BE image. The lighter colored areas were consistent with uncontaminated areas of the fracture surface, as typified in Figure 27. While there was some smearing damage on the fracture, slanted dimpled rupture features were apparent. Some of the edges of the dimples themselves had been damaged, as exemplified by the smearing in Figure 28. This was the only type of fracture features observed on the Blade D fracture surface, which did not exhibit features consistent with progressive cracking, corrosion, or high temperature stress rupture.

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Table I – List of the lengths of the blade remnants above the platform, along with the minimum depth of the dovetail including the platform.

Blade No	Short Height Above Platform (in)	Long Height Above Platform (in)	Min. Depth Including Platform (in)
1	0.172	0.341	0.400
2	0.118	0.119	0.396
3	0.272	0.420	0.406
4	0.146	0.343	0.399
5	0.046	0.185	0.399
6	0.384	0.407	0.394
7	0.029	0.152	0.404
8	0.000	0.103	0.404
9	0.000	0.065	0.384
10	0.000	0.118	0.390
A	0.814	1.066	0.404
B	0.749	0.997	0.400
C	0.716	0.964	0.393
D	0.682	0.862	0.385
E	0.804	0.935	0.401
F	0.983	1.166	0.396
G	0.764	0.921	0.396
H	1.009	1.112	0.400

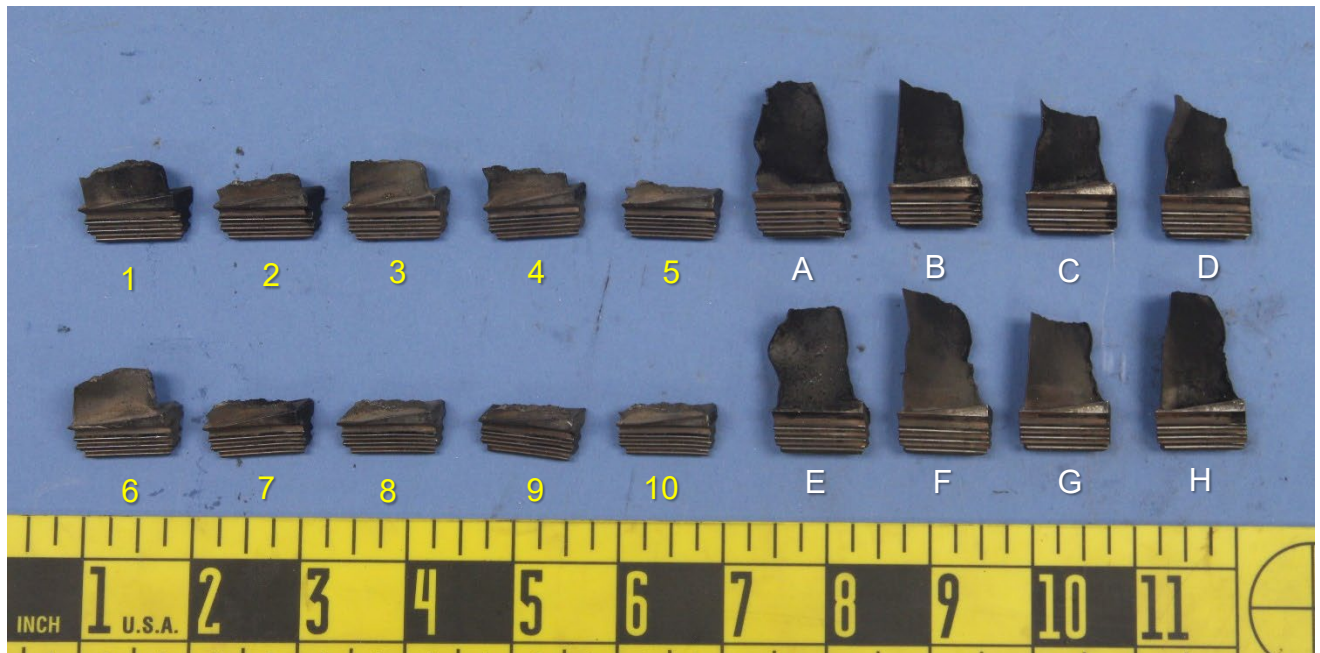


Figure 1 – View of the turbine blade remnants, as received.



Figure 2 – Views of the fracture surfaces of the shortest blade remnants, on the left in Figure 1.



Figure 3 – The fracture surface of Blade 8.

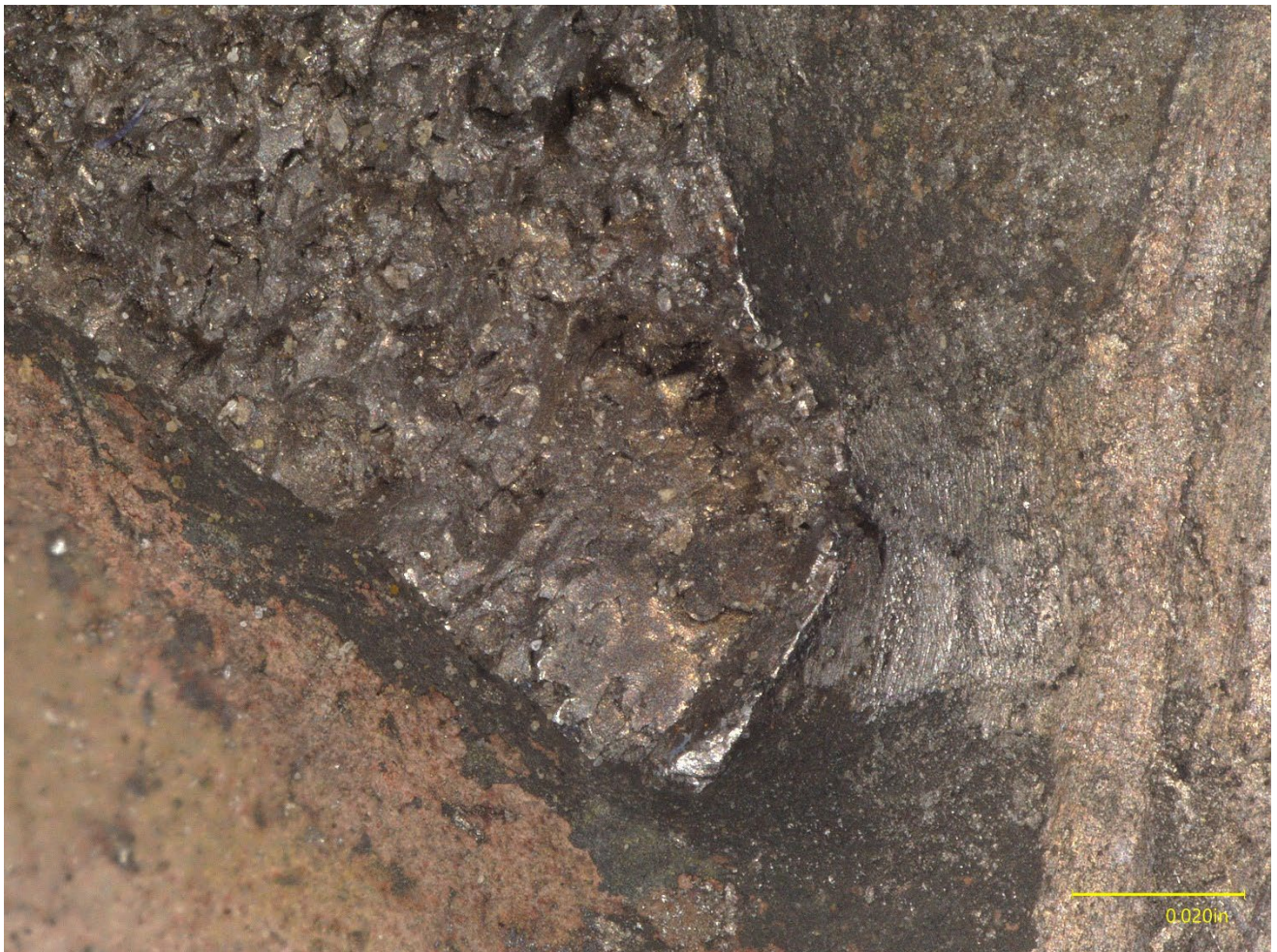


Figure 4 – Closer view of the leading edge of the Blade 8 fracture surface.

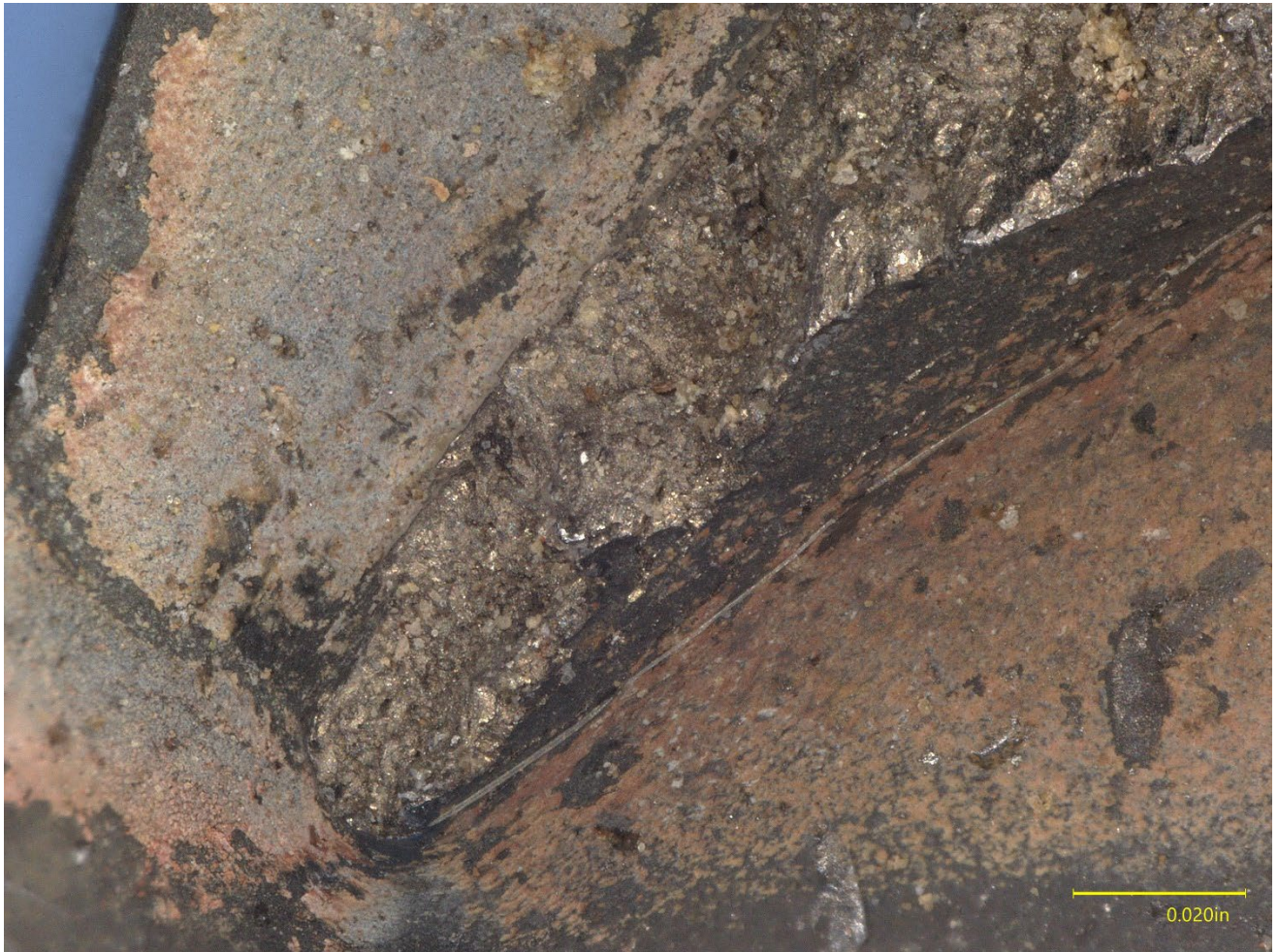


Figure 5 – Closer view of the trailing edge of the Blade 8 fracture surface.



Figure 6 – The fracture surface of Blade 7.



Figure 7 – Closer view of the leading edge of the Blade 7 fracture surface.



Figure 8 – The fracture surface of Blade 9.

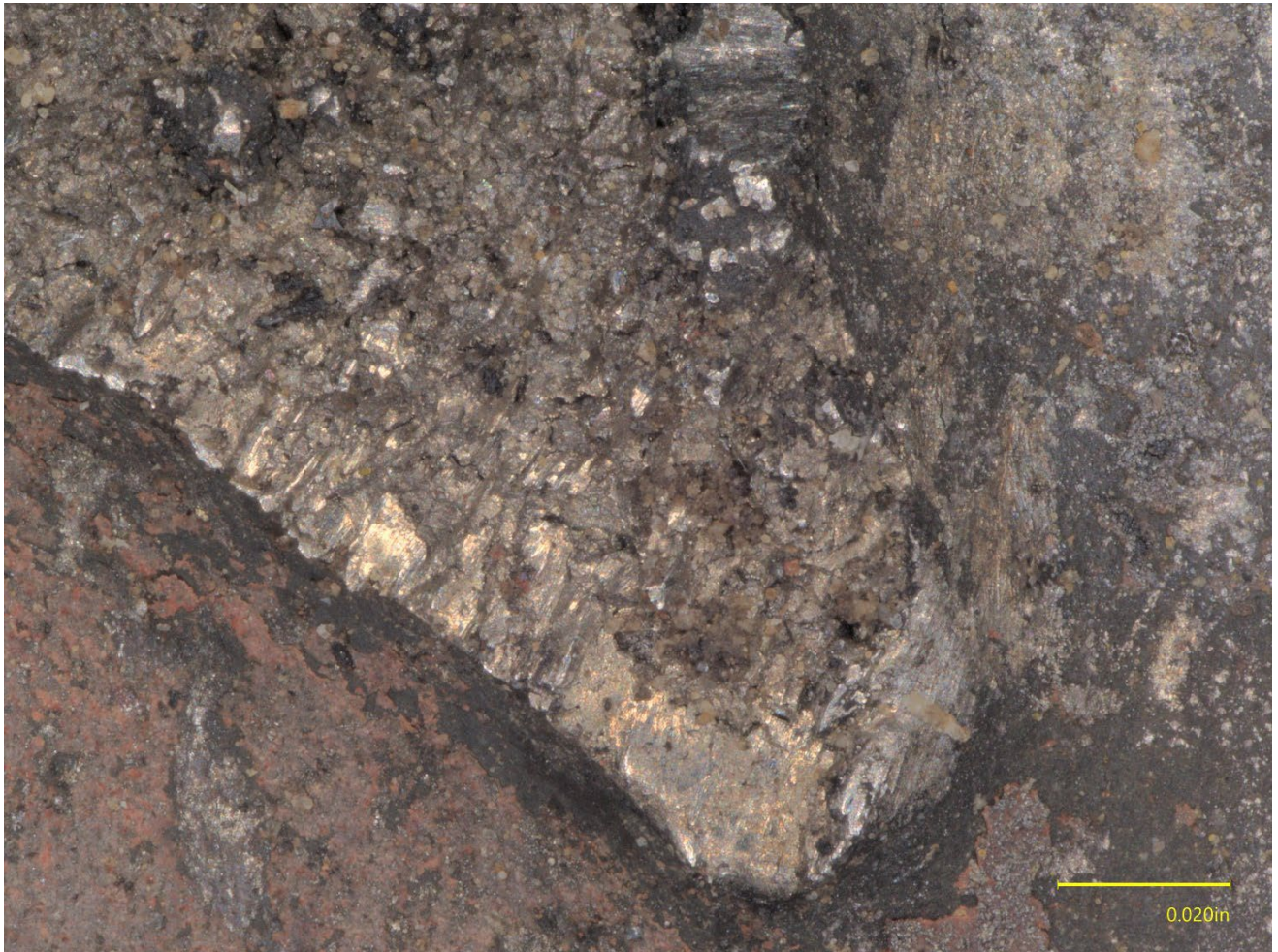


Figure 9 – Closer view of the leading edge of the Blade 9 fracture surface.



Figure 10 – The fracture surface of Blade 10.



Figure 11 – Closer view of the leading edge of the Blade 10 fracture surface.



Figure 12 – Backscattered electron (BE) micrograph of the leading edge of the Blade 7 fracture surface.

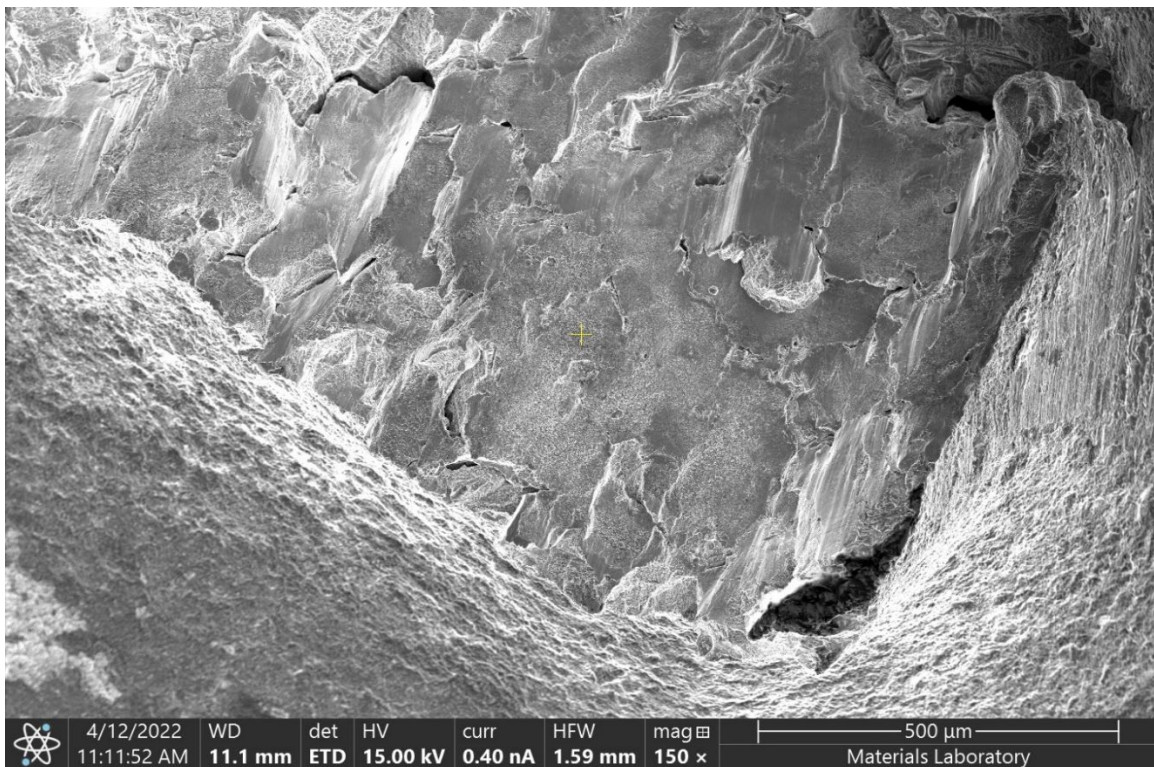


Figure 13 – SE micrograph of a closer view of the Blade 7 leading edge fracture, showing rough dimpled rupture with smoother smeared regions.

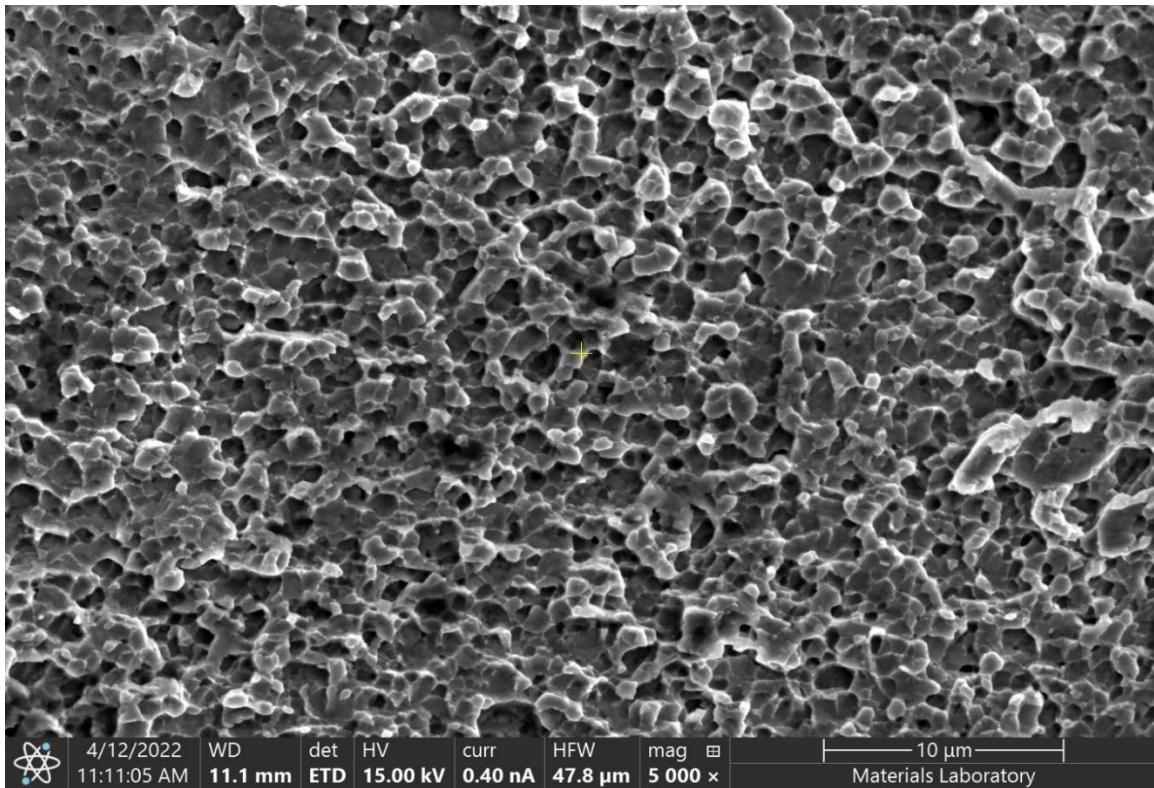


Figure 14 – SE micrograph of fine dimpled rupture in Figure 13.

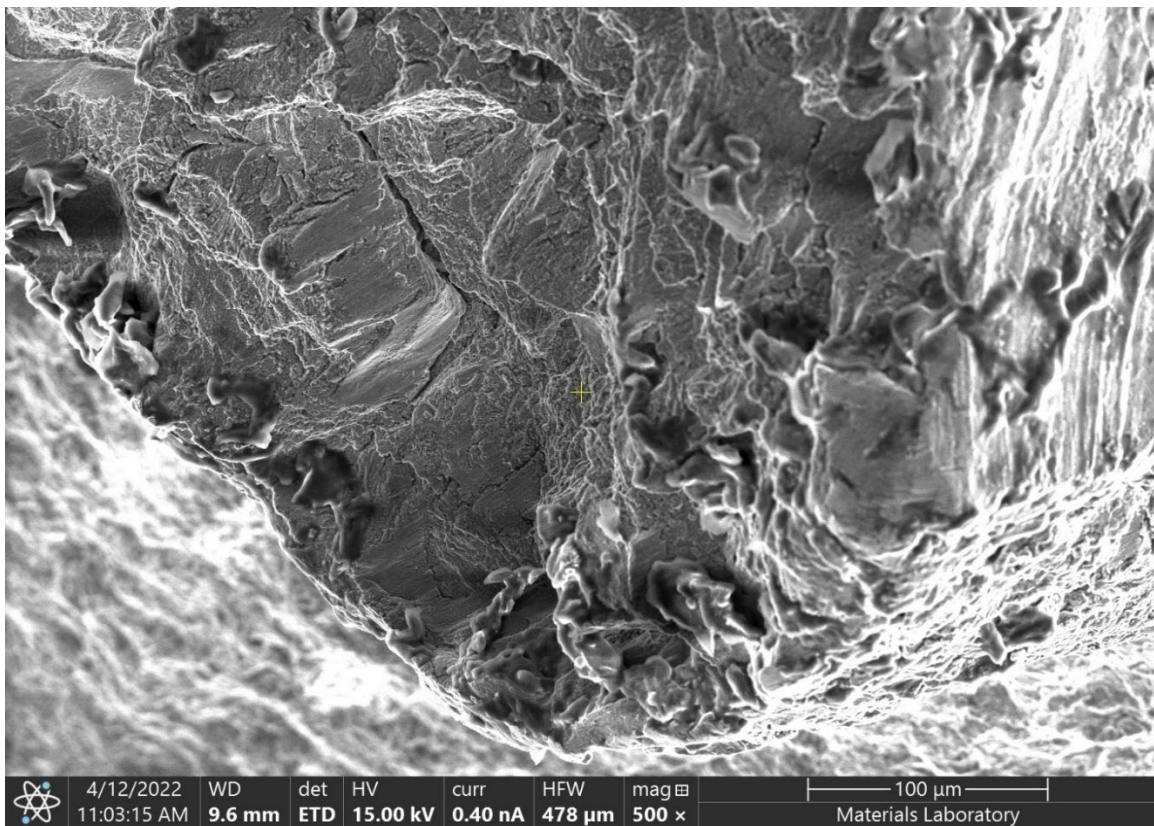


Figure 15 – SE micrograph of the fracture surface at the leading edge of Blade 8.

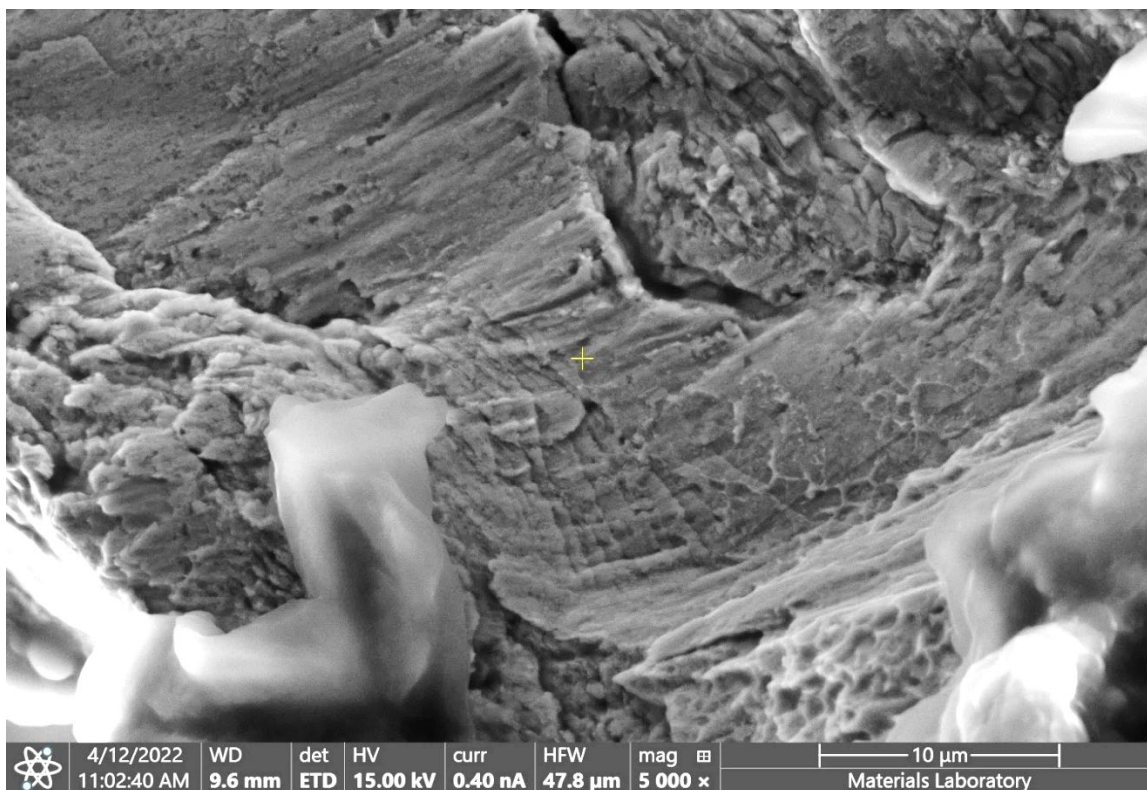


Figure 16 – SE micrograph of dimpled rupture and smearing streaks in Figure 15.

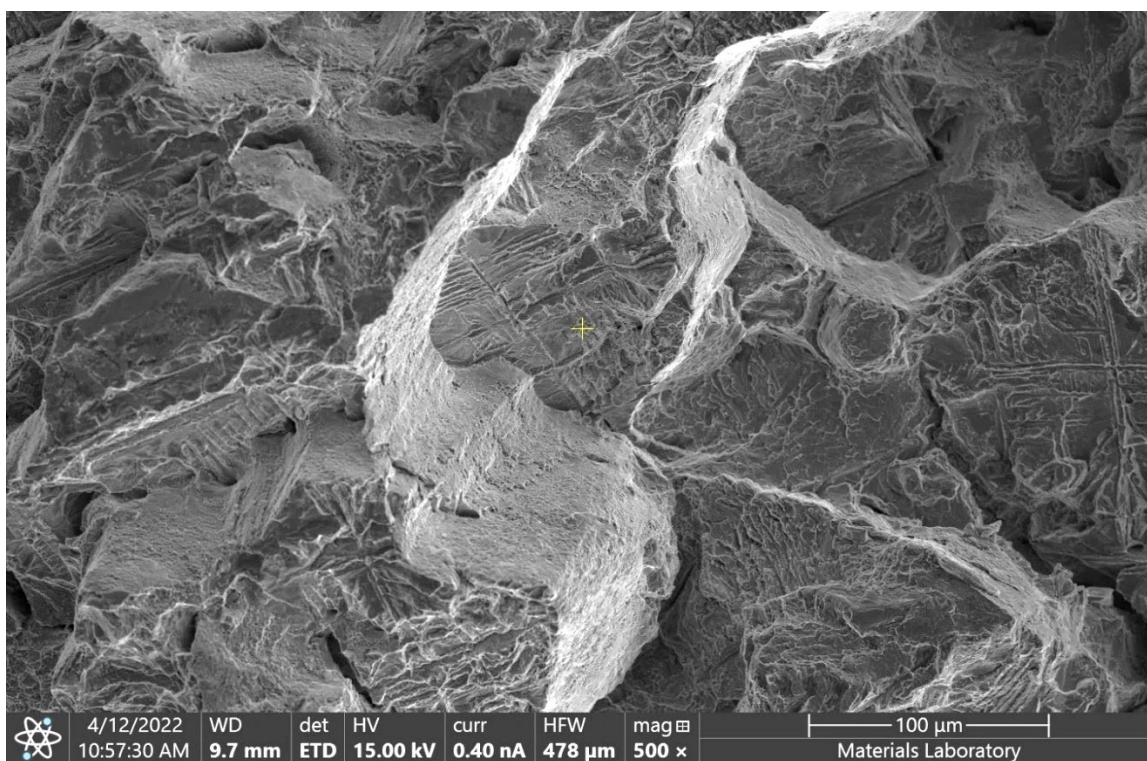


Figure 17 – SE micrograph of a typical area of the Blade 8 fracture surface, showing ridges and planes consistent with the dendritic microstructure and grain orientation.

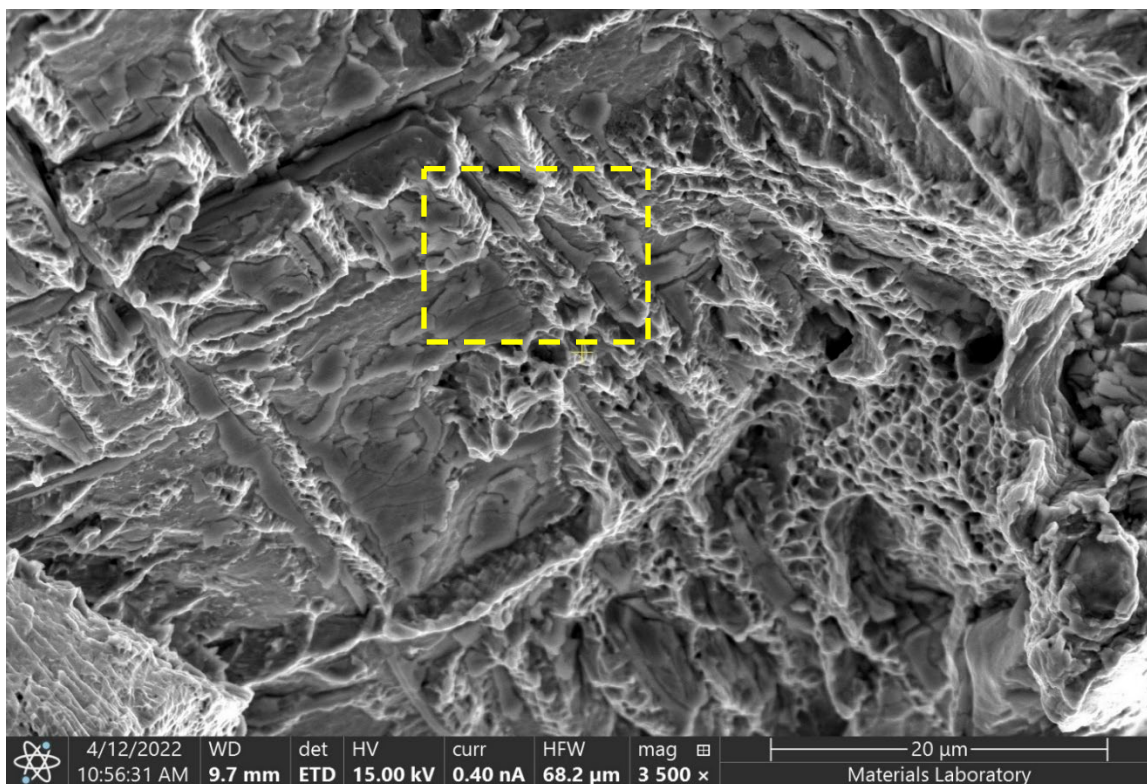


Figure 18 – SE micrograph of dimpled rupture in the interdendritic regions of the Blade 8 fracture surface. The boxed area is highlighted in Figure 19.

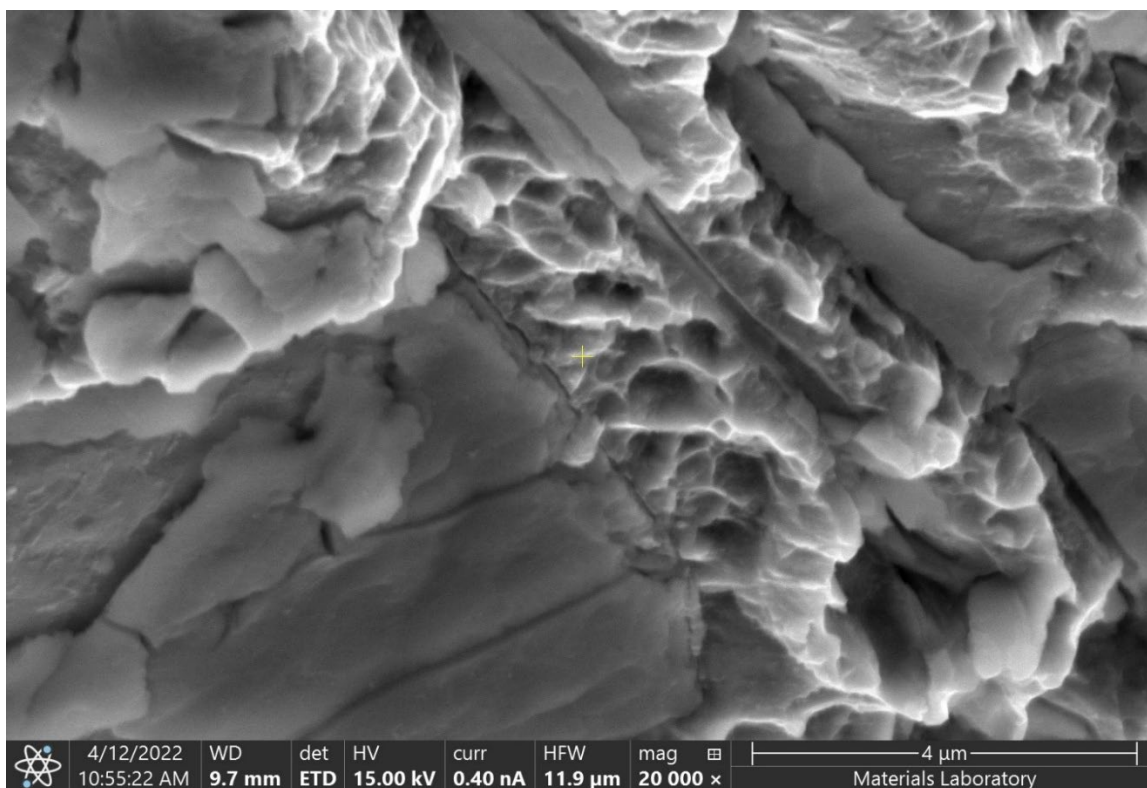


Figure 19 – SE micrograph of a closer view of the dimpled rupture in Figure 18.



Figure 20 – Bright-field (BF) optical micrograph of a typical cross section of the Blade D dovetail (~50X, etched Kallings Reagent #2).

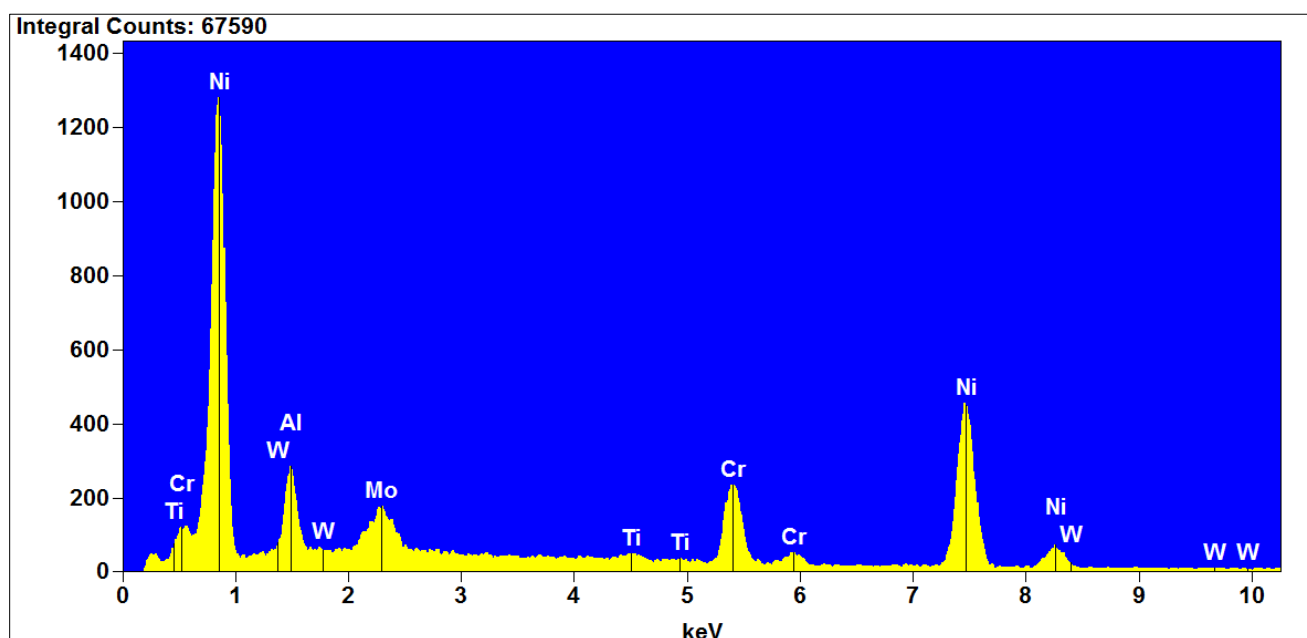


Figure 21 – EDS spectrum of a typical area of the dovetail cross-section of turbine blade D.



Figure 22 – BF optical micrograph showing a typical view of the dovetail microstructure in Blade D, showing primary carbides and the small, semi-cuboidal γ' phases (~1000X, etched Kallings Reagent #2).

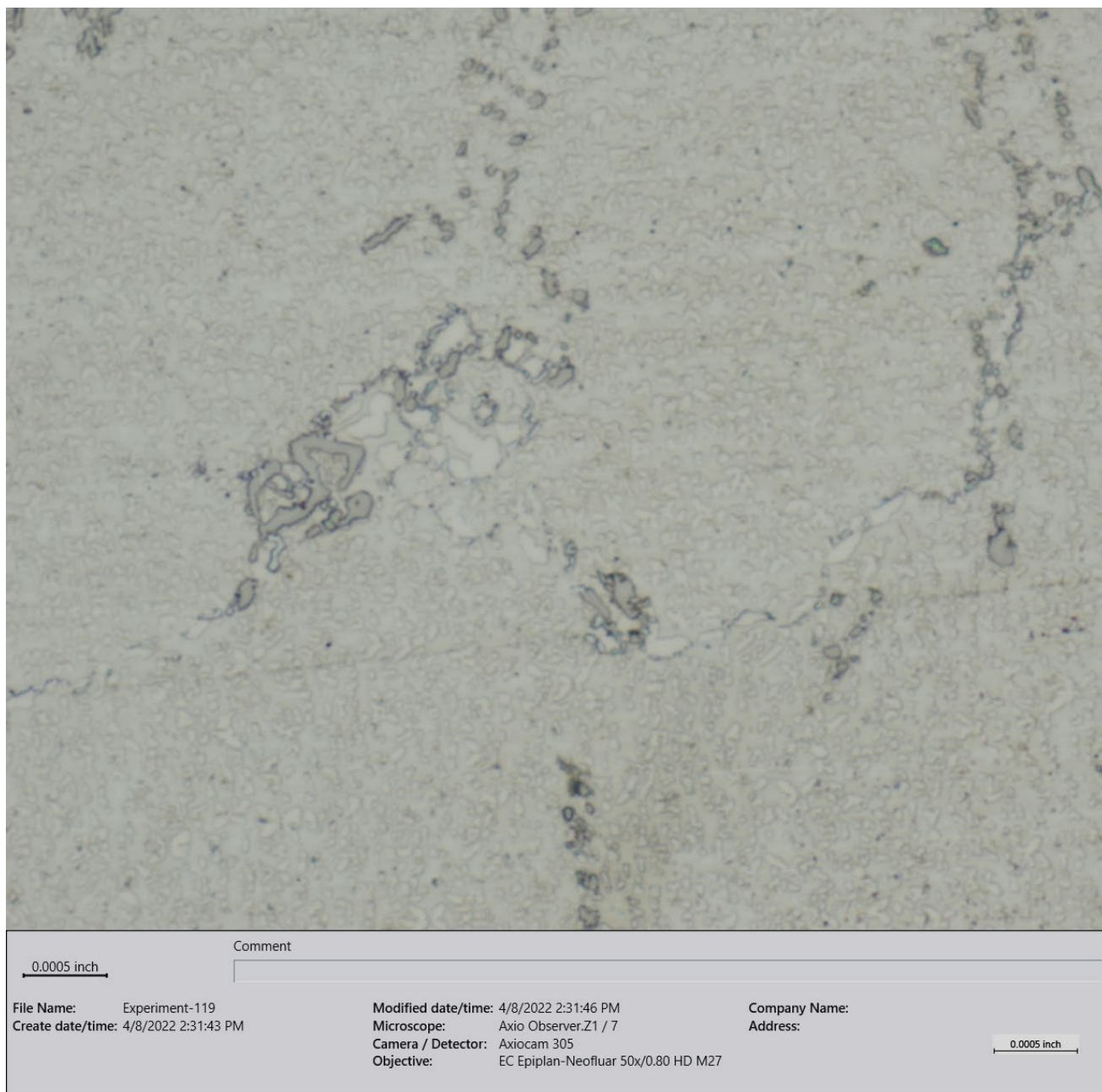


Figure 23 – BF optical micrograph of a typical area of the microstructure near the Blade D fracture surface, showing some rafting and coalescing of the γ' phase (~1000X, etched Kallings Reagent #2).

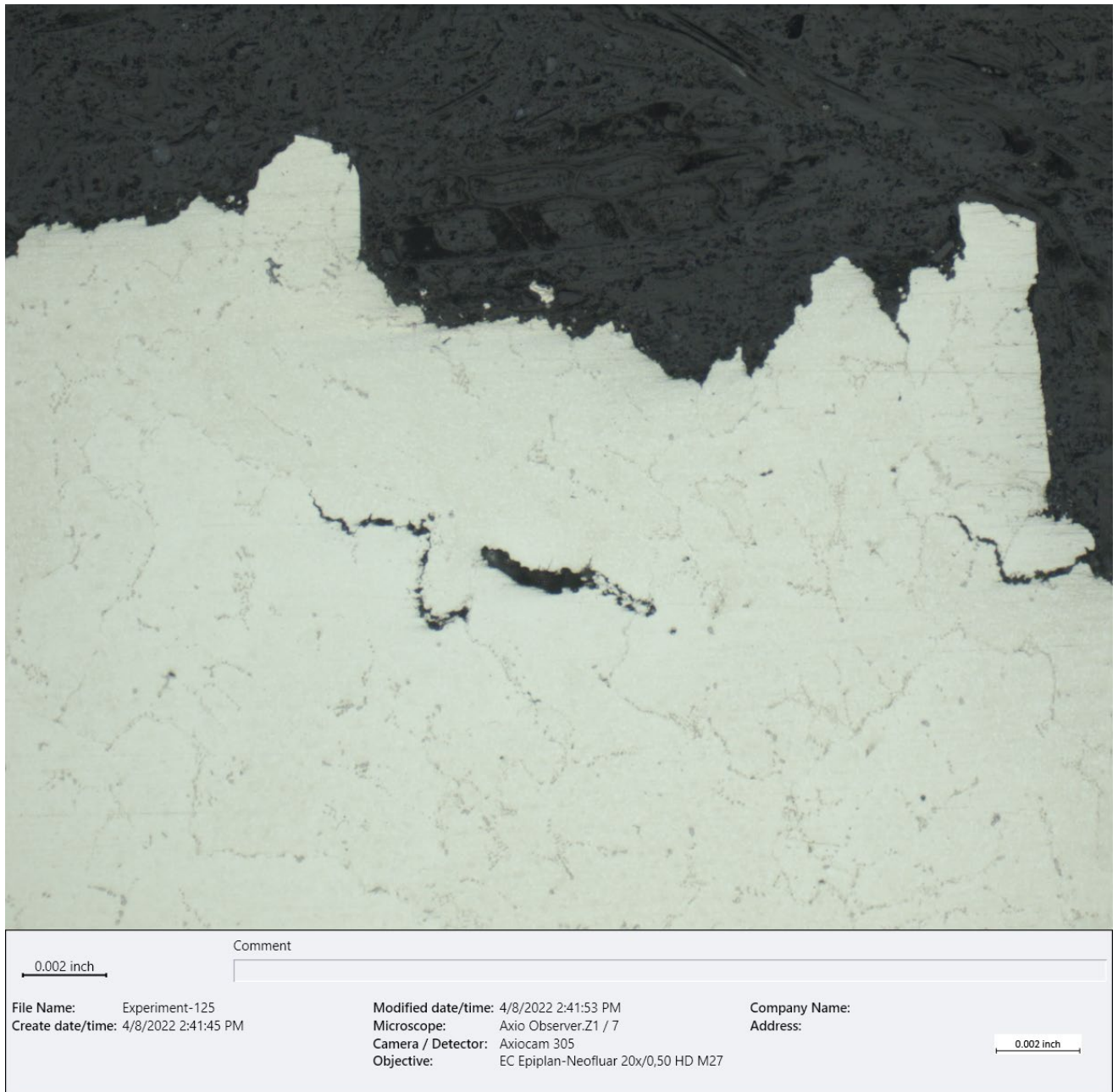


Figure 24 – BF optical micrograph of sub-surface intergranular cracks below the Blade D fracture surface (~200X, etched Kallings Reagent #2).

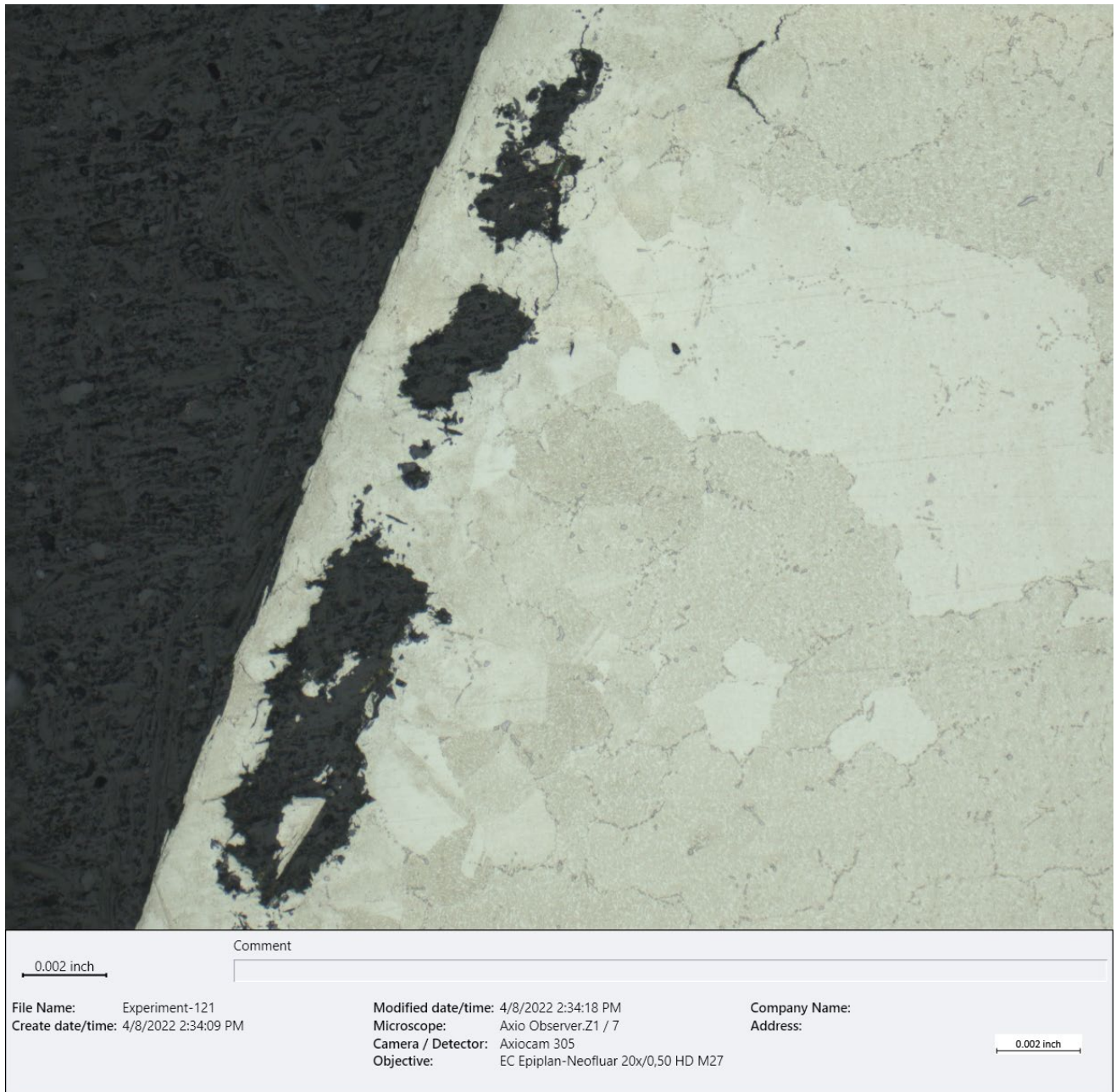


Figure 25 – BF optical micrograph of sub surface damage and cracks on the concave side of Blade D (~200X, etched Kallings Reagent #2).

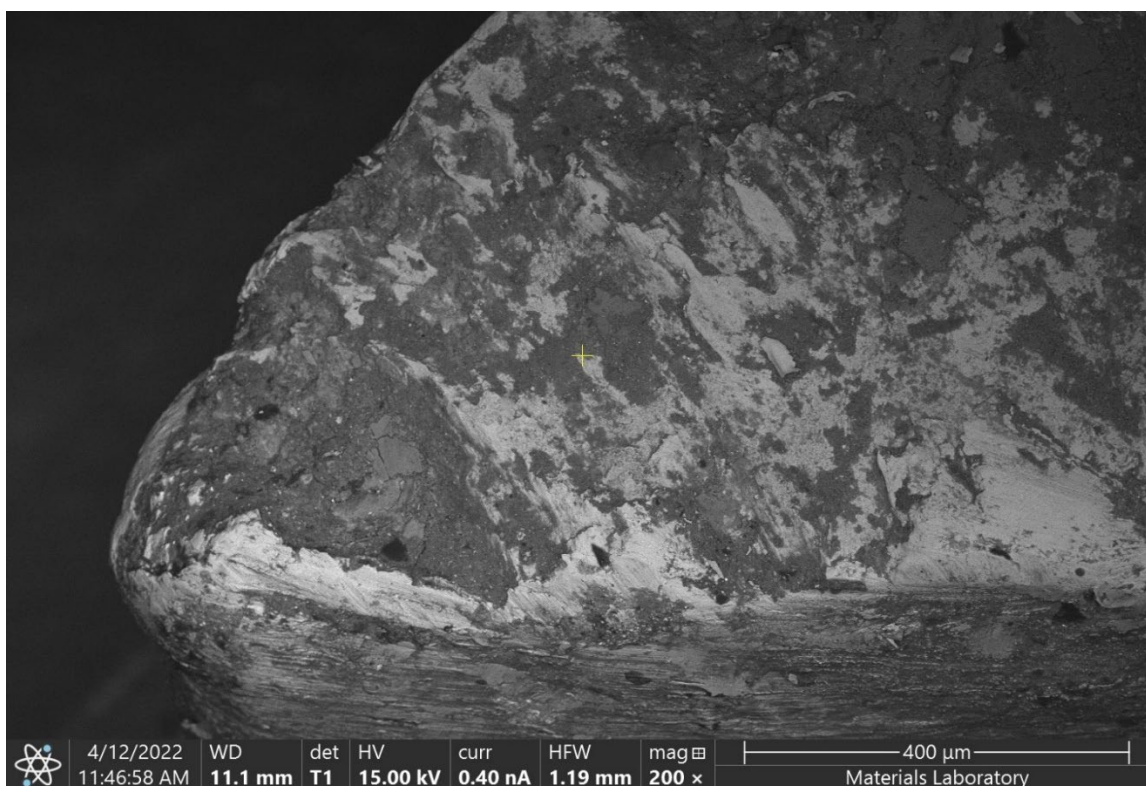


Figure 26 – BE micrograph of the leading edge of Blade D fracture surface.

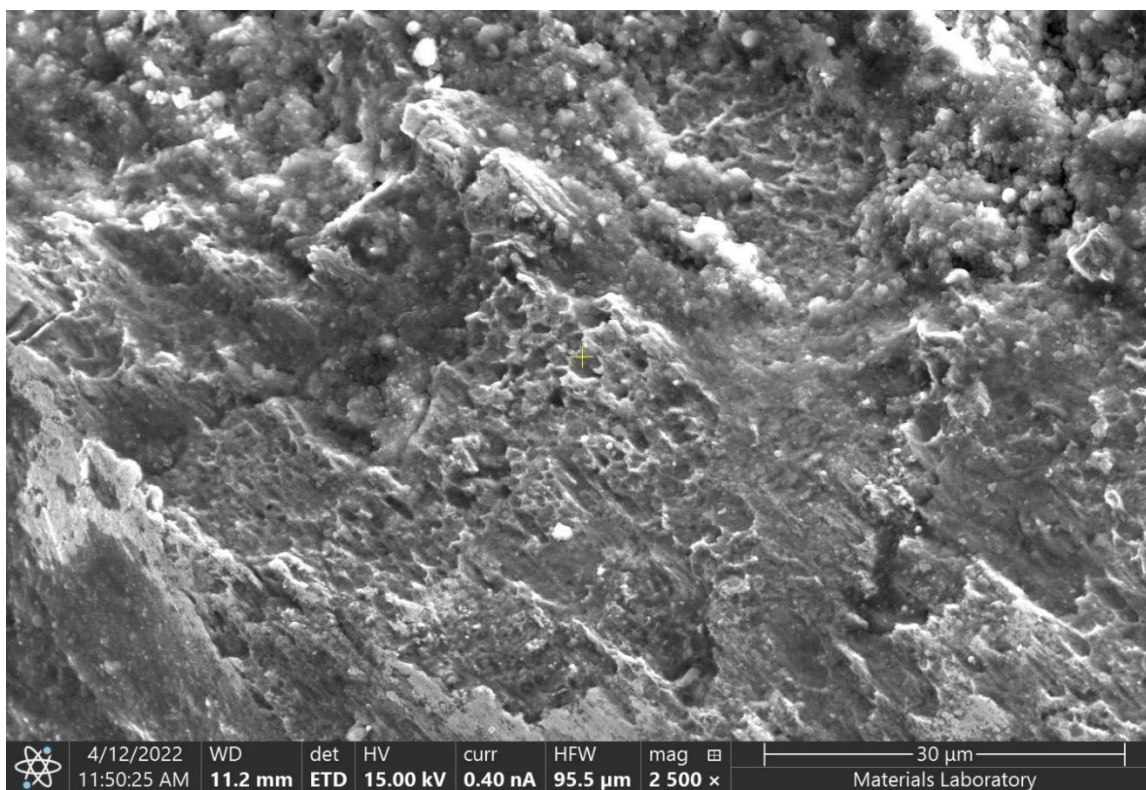


Figure 27 – SE micrograph of dimpled rupture in the less damaged areas in Figure 26.

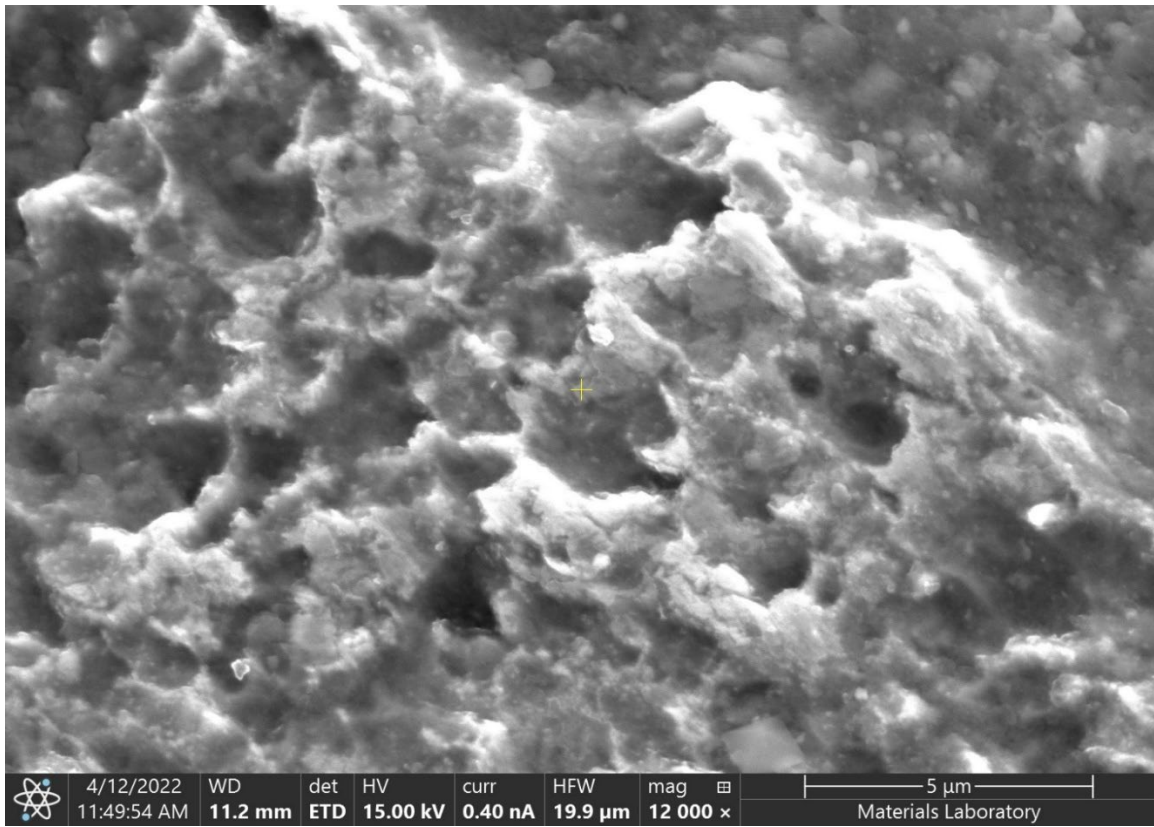


Figure 28 – SE micrograph of the smoothed and rounded dimple crests on Blade D.