

NATIONAL TRANSPORTATION SAFETY BOARD

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



March 19, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-005

1. ACCIDENT INFORMATION

Place : Union City, Tennessee
Date : September 15, 2017
Vehicle : Air Tractor AT-502, N4531K
NTSB No. : ERA17LA326
Investigator : Brian Rayner, AS-ERA

2. COMPONENTS EXAMINED

Parts of a compressor turbine wheel with blade fragments
Blade fragment with pin
Position pin

3. DETAILS OF THE EXAMINATION

On September 15, 2017, about 0915 central daylight time, an Air Tractor AT-502 was substantially damaged during a forced landing after a total loss of engine power near Union City, TN. The commercial pilot was not injured. In an interview with a Federal Aviation Administration (FAA) inspector, the pilot reported he heard a 'pop' and the engine stopped producing power. The engine was a Pratt & Whitney Canada PT6A-60A.¹ According to FAA records, the airplane was manufactured in 1990 and had accrued 5,490 total aircraft hours. The engine had been disassembled, and several components were sent to the NTSB Materials Laboratory for further examination.

Figure 1 shows the engine components received by the Materials Laboratory. These included the compressor turbine wheel, with 57 affixed but fractured turbine blades, and a single unattached blade with its pin. As shown in Figure 2, the unattached blade had been in place in the empty slot in the turbine wheel. A pin at that position was submitted separately and had been detached from the wheel. The remainder of the fractured blades from the views shown in Figure 2 were documented and are recorded in Appendix A.

¹ The Pratt & Whitney Canada PT6 is a turboprop aircraft engine produced by Pratt & Whitney Canada, consisting of a forward gas generator section supplying hot gas to a free power turbine, and a rear section with the intake and compressor.

Figure 3 and Figure 4 show the faces of the compressor turbine wheel from the upstream and downstream side (aft and forward), respectively. The removed pin from the empty blade slot had been taped to the lower left side of the wheel. After this initial documentation, the blades remaining in-place were all removed using a mallet and flat chisel.

Figure 5 shows the compressor turbine wheel from the upstream and downstream faces after removal of the blades. Figure 6 shows the slots with the pins in place, after removal of the blades. Overall, the wheel did not exhibit any indications of damage consistent with impacts, plastic deformation, or excessive wear. The dovetail slot for Blade 1 did not exhibit any indications of fretting, wear, or chatter marks. There were some shiny rub marks on some of the other dovetail slots, but it could not be determined whether these were the result of removing the blades. There was an overall reddish surface compound layer, particularly on the downstream side (Figure 5b). This was consistent with oxidation from combustion gasses, typical of the those experienced in the turbine sections of the turboprop engines.

Figure 7 shows the turbine blades, after removal, along with the unattached blade, viewed from the concave side. The free blade submitted separately was labeled Blade 1 for the purposes of this report. The other blades were labeled 2 through 58. These blades were numbered sequentially, increasing in number as rotated counterclockwise (opposite of normal rotation), as labeled in Figure 2. A more comprehensive series of images of all the removed blades, from both the concave and convex sides, is detailed in Appendix B.

All the blades were examined and measured. The lengths of blade airfoil remnants were measured from the tip of the fracture surface to the upper face of the platform using Vernier calipers. These data are laid out in Table 1. Four of the blades were selected for further examination—Blades 1, 25, 34, and 42. The markings on the dovetail platform side faces of each of these blades were documented in Table 2.

Figure 8 shows the convex and concave sides of Blade 1. Figure 9 shows a view of the fracture surface. The blade fracture surface was oriented parallel to the platform, with a rough fracture surface. The leading edge of the blade was deformed but was still intact. The trailing edge of the blade was missing chunks of material, consistent with impact with other components or objects.

Figure 10 shows the convex and concave sides of Blade 25. Figure 11 shows a view of the fracture surface. The fracture surface of this blade was generally V-shaped with respect to its orientation to the platform. The leading edge of the blade exhibited small impact marks, whereas much of the trailing edge was missing. The convex surface of the blade exhibited material loss at the fracture surface. This loss was such that 0.1 to 0.2 inches of the fracture surface on the convex side were missing. This damage is shown in Figure 10a, indicated by the removal of the outermost orange-colored oxide layer.

Figure 12 shows the convex and concave sides of Blade 34. Figure 13 shows a view of the fracture surface. Similar to Blade 25, the fracture surface of this blade was

generally V-shaped, although more rounded. The blade material closest to the fracture surface exhibited significant plastic deformation consistent with thinning or necking (see Figure 13). Portions of both the leading and trailing edges were missing, consistent with impact with other objects at high speed. The blade exhibited material loss of 0.1 to 0.2 inches of the convex side of the fracture surface, similar to that observed on Blade 25.

Figure 14 shows the convex and concave sides of Blade 42. Figure 15 shows a view of the fracture surface. On this component, most of the blade airfoil was missing, with only 0.186 inches of blade material remaining above the platform. The fracture surface of this blade was rough and tortuous, with no smoothing or severe necking at or near the fracture surface. .

The fracture surfaces of the above blades were examined using a scanning electron microscope (SEM). Figure 16 through Figure 19 show micrographs of selected areas of the Blade 25 fracture surface. This fracture surface was highlighted as this blade was considered one of the more damaged in the set based on initial visual examination but exhibited fracture features that had not been excessively oxidized, eroded, or damaged. Figure 16 shows the leading edge of the Blade 25 fracture surface. The edges of the fracture surface exhibited smearing, consistent with post fracture damage. This smearing exhibited localized rounding and plastic deformation, consistent with fracture at elevated temperatures.

Closer views of notable features in the fracture surface of Blade 25 are illustrated in Figure 17 through Figure 19. As shown in Figure 17, the fracture surface was generally varied in roughness and elevation. Figure 18 displays areas of tearing of the fracture surface. This tearing was consistent with rupture along grain boundaries in the blade, as typified by flat faceted features on the fracture surface. Other portions of the fracture surface exhibited features consistent with dimple rupture (lower right in Figure 18). Also noted on this fracture surface was separation along the dendrite/interdendritic interface, as typified in Figure 19. These fracture features were consistent with fracture at elevated temperatures.

In comparison, selected fractographs from the fracture surface of Blade 42 are illustrated in Figure 20 through Figure 23. This blade exhibited the least amount of blade material remaining above the platform. Figure 20 shows a view of the undamaged portions of the fracture surface near the leading edge. The portions closest to the convex surface on the leading edge exhibited smearing and rounding, consistent with post-fracture secondary damage at elevated temperature exposure.

Figure 21 shows the dendritic nature of the fracture surface morphology consistently observed on Blade 42. While this fracture surface did exhibit some surface oxidation (consistent with exposure to engine temperatures after fracture), the underlying fracture features could be more readily discerned using a SEM. As shown in Figure 22 and Figure 23, the fracture surface exhibited features consistent with fine ($< 1\ \mu\text{m}$) dimple rupture. In comparison, the dimple rupture features on the Blade 25 fracture surface were on the order of $10\ \mu\text{m}$ in size.

Blades 1, 25, 34, and 42 were cross-sectioned, vacuum mounted in slow-curing epoxy, polished, and etched with Marble's Reagent to examine the individual microstructures.² Areas above the platform and below the platform of each blade were contrasted to determine if there was any significant microstructure change, consistent with excessive temperature exposure.

Figure 24 through Figure 28 show the micrographs from Blade 1. Figure 24 and Figure 25 show typical areas of the blade microstructure below the platform. This microstructure was consistent with those typical for nickel-base superalloys, exhibiting a general matrix of nickel rich γ phase and semi-cuboidal γ' (Ni_3Al) phase, with "fan-shaped" lighter-colored globules of eutectic γ' and blocky carbides. The microstructure also showed a dendritic structure, typical of cast alloys. Equiaxed grain boundaries, consistent with a conventionally cast blade material, were also observed.

Figure 26 through Figure 28 show the microstructure near the Blade 1 fracture surface. This microstructure shows some rounding and shape change in the eutectic γ' phases. In addition, some resolutioning of the γ' was found in the microstructure near the blade fracture surface.

Figure 29 and Figure 30 show typical areas of the microstructure in the dovetail section below the platform of Blade 25. The microstructure was consistent with that in the dovetail of Blade 1. Figure 31 and Figure 32 show the Blade 25 microstructure at the fracture surface. As evident from the figures, the material below the fracture surface exhibited subsurface cracks. These cracks were located along grain boundaries that intersected the fracture surface. The grain boundary cracks often also exhibited oxidation and voids along the grain boundaries.

The microstructure near the Blade 25 fracture exhibited resolutioning of the γ' , but it was more pronounced than that observed near the fracture surface of Blade 1. In addition, much of the γ' exhibited rafting (or coalescence), which was consistent with a morphology change at high temperatures under stress. The microstructure was inspected using a SEM. Figure 33 shows the resolutioning and rafting of the γ' , along with the shape change of the eutectic γ' . This can be contrasted with the γ' morphology in the dovetail of the same blade, shown in Figure 34. In the dovetail, the γ' exhibited the semicuboidal shape, rather than a more rounded shape. The dovetail microstructure also contained smaller tertiary γ' phases in the γ -Ni matrix.

The chemical composition of the Blade 25 dovetail was inspected using energy dispersive X-ray spectroscopy (EDS). A typical spectrum is illustrated in Figure 35. The composition was consistent with Inconel 100 (IN 100). The subsurface grain boundary oxidation, shown in Figure 36, was inspected using EDS. The oxide material exhibited higher levels of Ti, Cr, and O, with minor amounts of Al, C, and Ni. The coating of Blade 34 was more adherent than that of Blade 25, and was inspected using EDS. This coating

² Marble's Reagent is an acidic solution designed to selectively etch particular microstructural features of some alloys and consists of 10 g CuSO_4 dissolved in 50 mL each of HCl and water.

was consistent with a platinum aluminide coating, typical of those commonly applied to some turbine blades. The coating in the case shown in Figure 37 exhibited cracking, particularly near the blade fracture surface.

The change in γ' morphology, resolutioning of γ' , subsurface grain boundary cracking with oxidation, and fracture surface features observed in Blades 1, 25, and 34 were consistent with features typical of high temperature deformation processes such as creep. There were no indications of fatigue cracking or hot corrosion observed that would have been severe enough to lead to fracture of the blades.

Figure 38 and Figure 39 show the microstructure of Blade 42. This microstructure was consistent with those observed in all of the examined dovetails of the three other blades. The fracture surface of the blade is shown in Figure 40. This fracture surface exhibited a more tortuous fracture surface than the other three blades. There were some noted grain boundary fractures, but these exhibited a parallel tearing morphology rather than cracking along the grain boundaries with intergranular oxidation. The microstructure near the fracture surface of Blade 42 is shown in Figure 41. There was some rafting of the γ' . However, no discernible resolutioning of the γ' was found. These features, along with the features observed on the fracture surface of this blade, were consistent with fracture from overstress under elevated temperatures at this location.

Erik M Mueller
Materials Research Engineer

Table 1 – The heights of the fracture surface of each blade, measured in inches from the platform upper surface to the fracture surface peak.

Blade Number	Fracture Surface Height (in)	Blade Number	Fracture Surface Height (in)	Blade Number	Fracture Surface Height (in)
1	0.730	21	0.486	41	0.198
2	0.730	22	0.594	42	0.186
3	0.728	23	0.344	43	0.180
4	0.714	24	0.458	44	0.329
5	0.759	25	0.596	45	0.192
6	0.708	26	0.418	46	0.290
7	0.704	27	0.456	47	0.207
8	0.672	28	0.571	48	0.234
9	0.746	29	0.152	49	0.630
10	0.746	30	0.375	50	0.558
11	0.736	31	0.370	51	0.142
12	0.538	32	0.520	52	0.510
13	0.551	33	0.464	53	0.376
14	0.616	34	0.554	54	0.687
15	0.630	35	0.138	55	0.642
16	0.564	36	0.402	56	0.760
17	0.252	37	0.262	57	0.762
18	0.518	38	0.431	58	0.756
19	0.159	39	0.298		
20	0.608	40	0.500		

Table 2 – Markings on the platform side faces of Blades 1, 25, 34, and 42. Markings with “...” indicate damaged areas.

Blade 1	Blade 25	Blade 34	Blade 42
1L909 FAA-PMA	1L909 FAA-PMA	1L909 FAA-PMA	1L909 FAA-PMA
1.245	1.239	1.238	1.237
E30457401-01 C	E30457401-01 C	E30457401-01 C	E30457401-01 C
1201...	12010	12010	12010

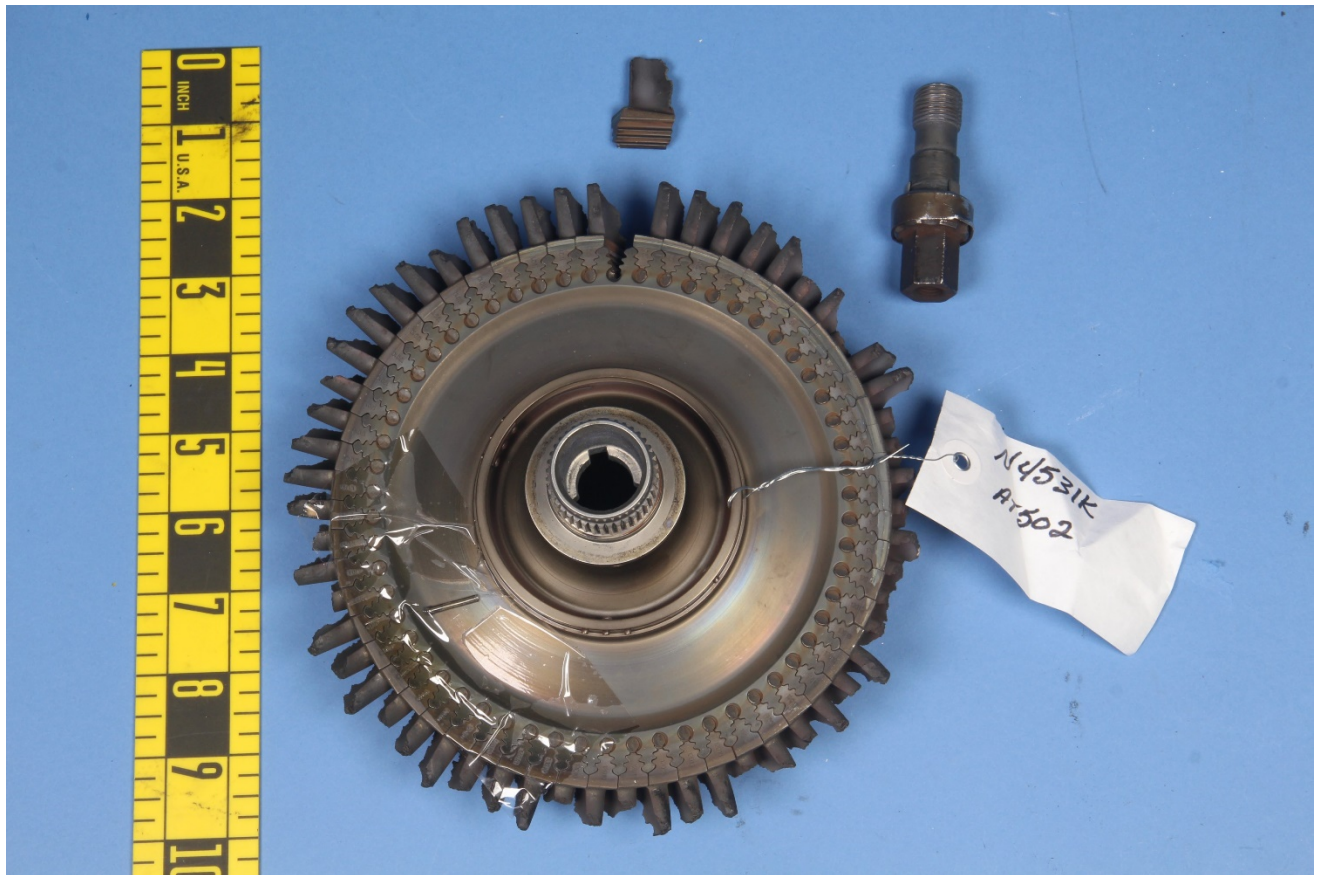


Figure 1 – The turbine wheel, loose blade, pin, and position nut, as received.

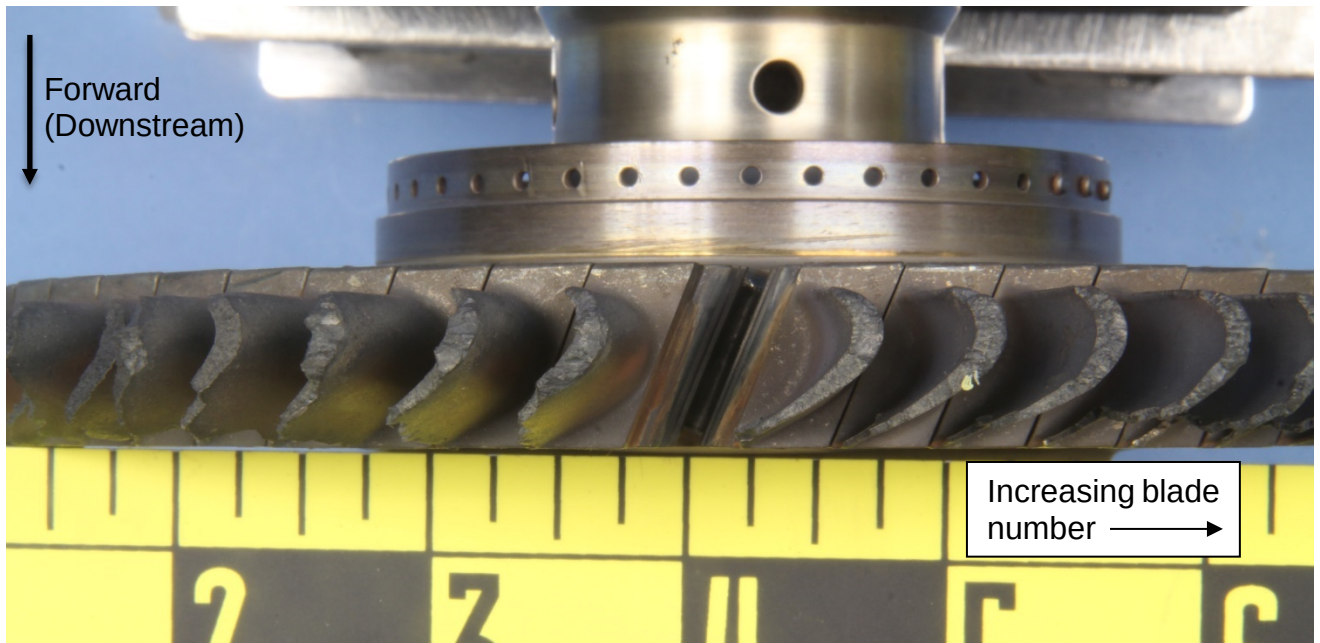


Figure 2 – View of the slot on the turbine wheel where the missing blade was located.

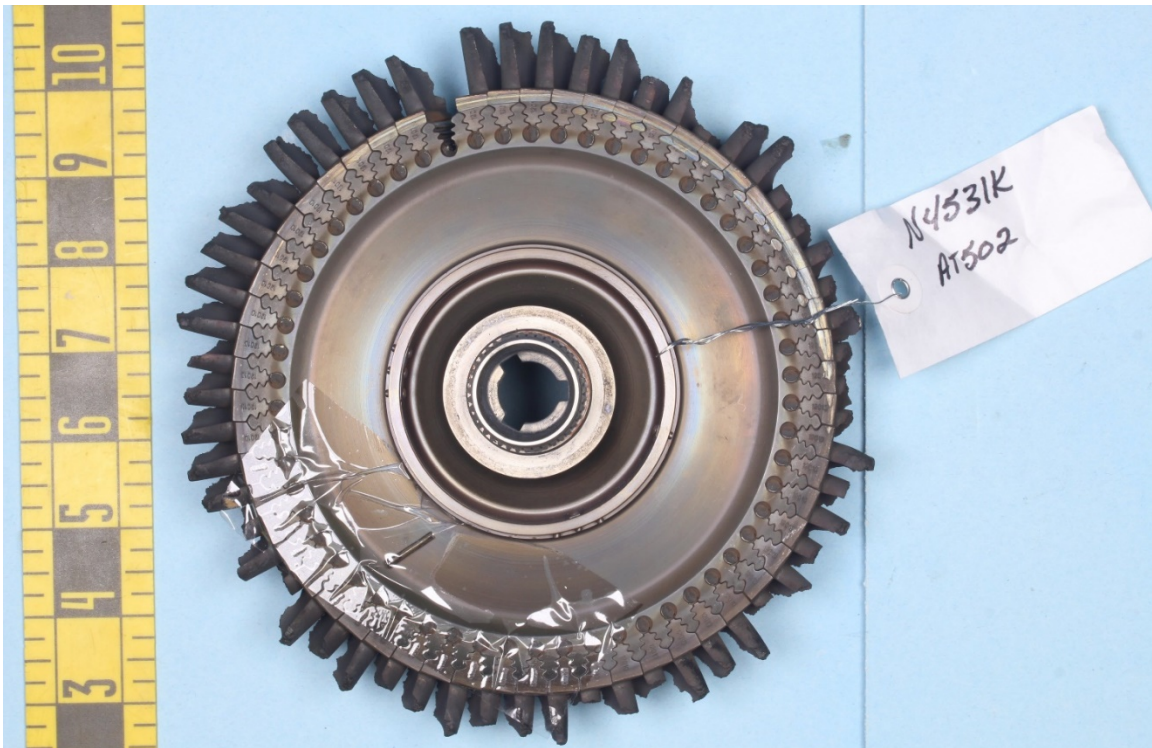


Figure 3 – The upstream or aft face of the turbine wheel with broken blades, as received. The removed pin from the empty blade slot had been taped to the lower left side of the wheel.

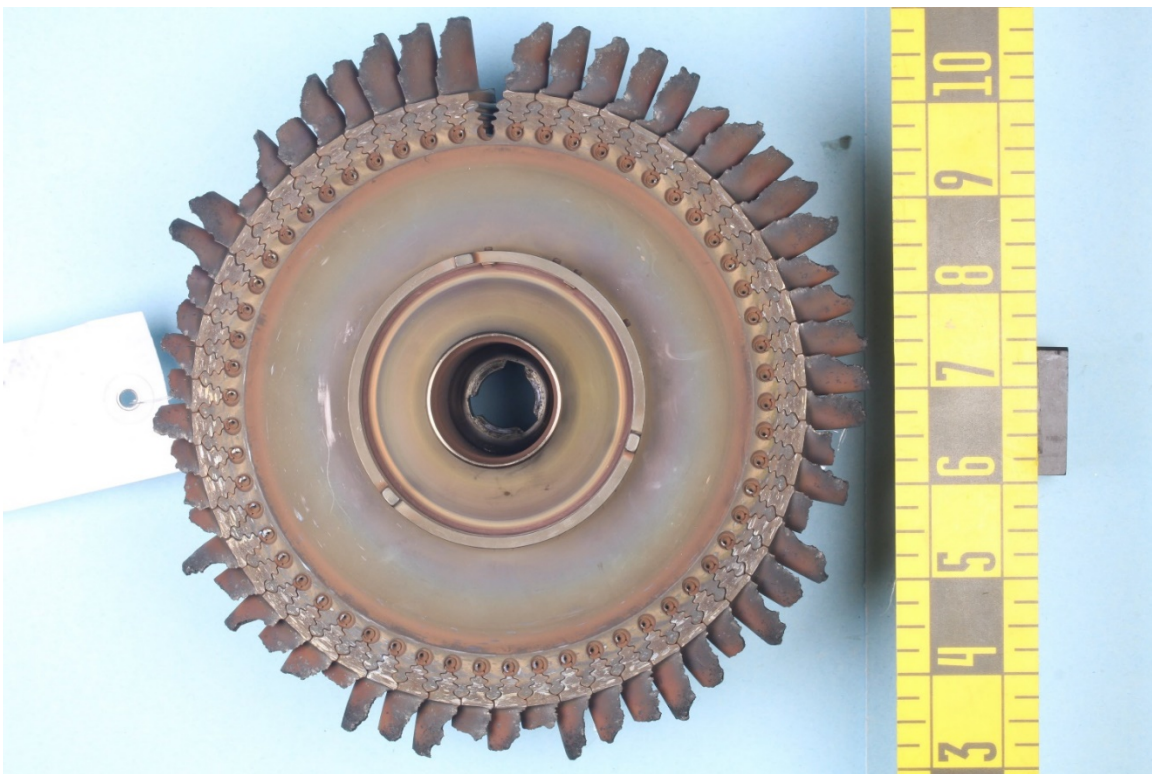


Figure 4 – The downstream or forward face of the turbine wheel with broken blades, as received.

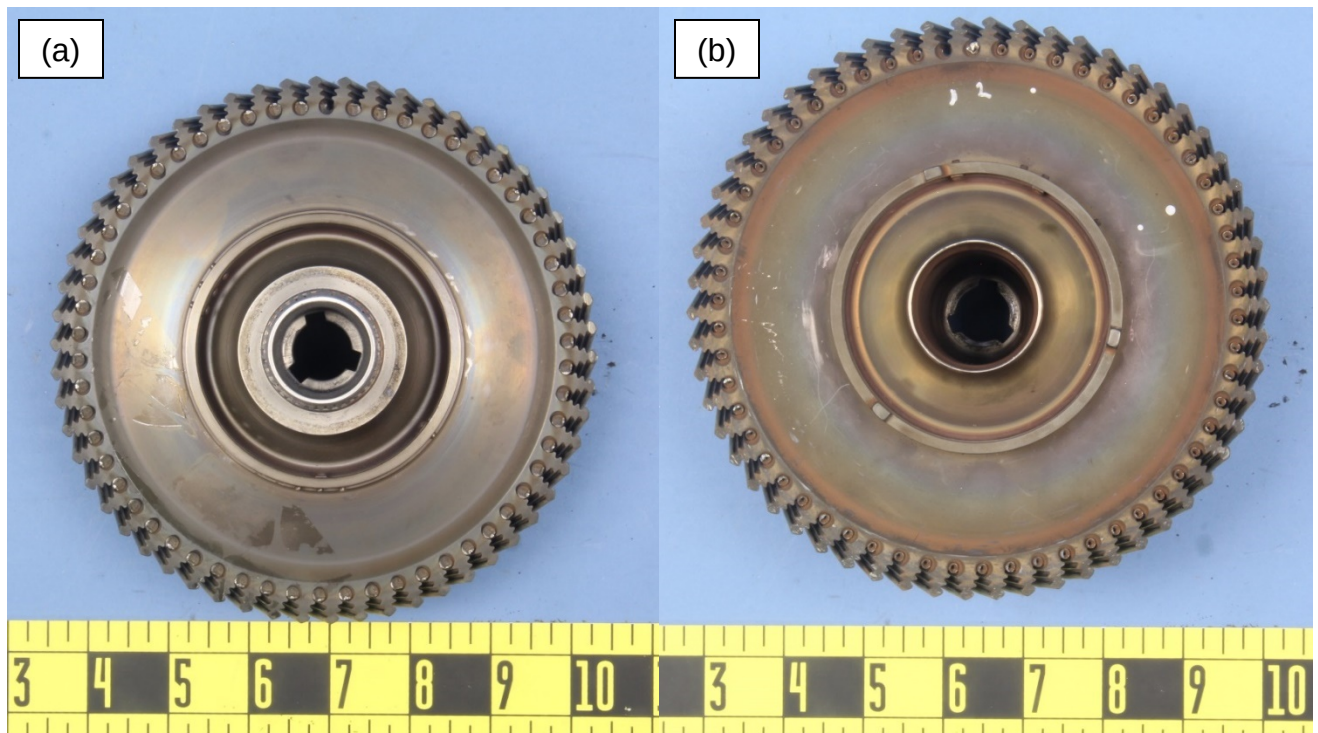


Figure 5 – The turbine wheel after removal of the blades, viewed from the (a) upstream and (b) downstream faces.

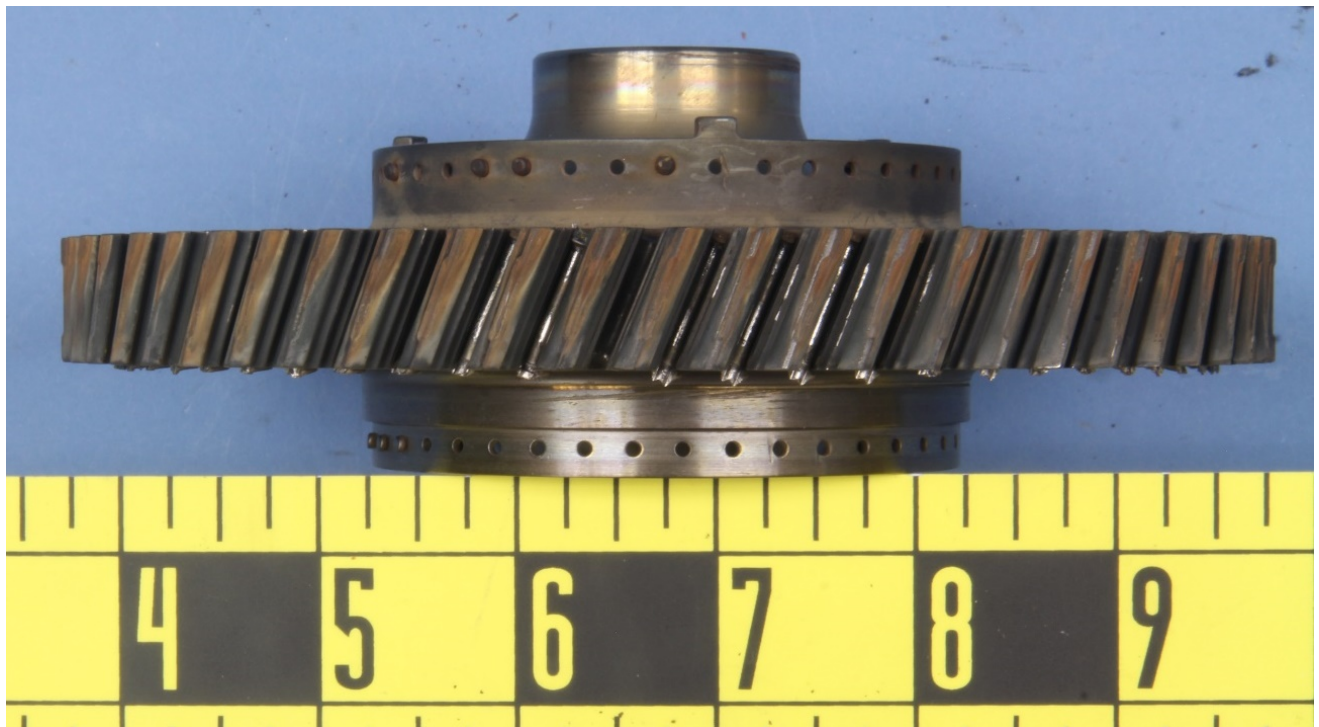


Figure 6 – Some of the slots of the turbine wheel, after removing the blades.



Figure 7 – The blades removed from the turbine wheel, labeled 2 through 58, along with Blade 1, viewed from the convex sides.

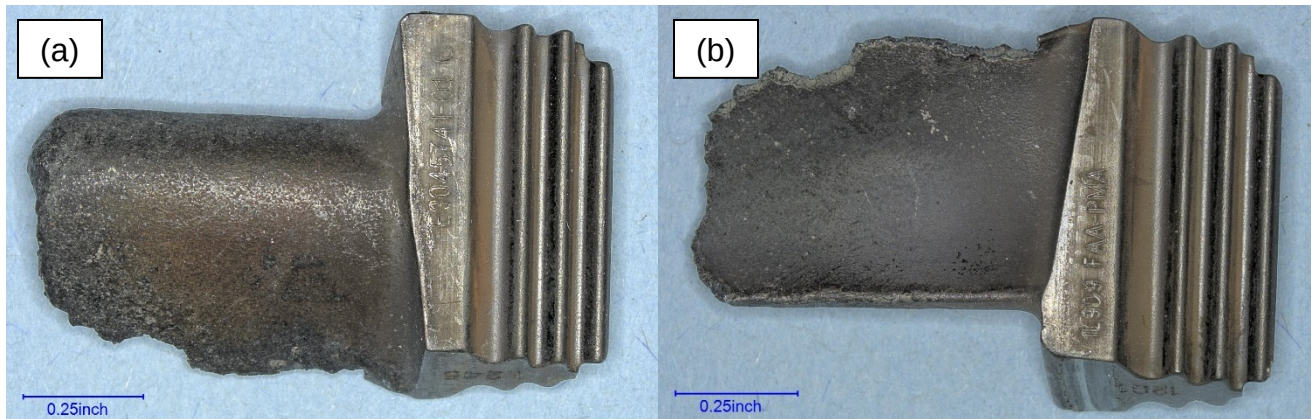


Figure 8 – The blade submitted loose, labeled Blade 1, viewed from the (a) convex and (b) concave side.



Figure 9 – The fracture surface of Blade 1.

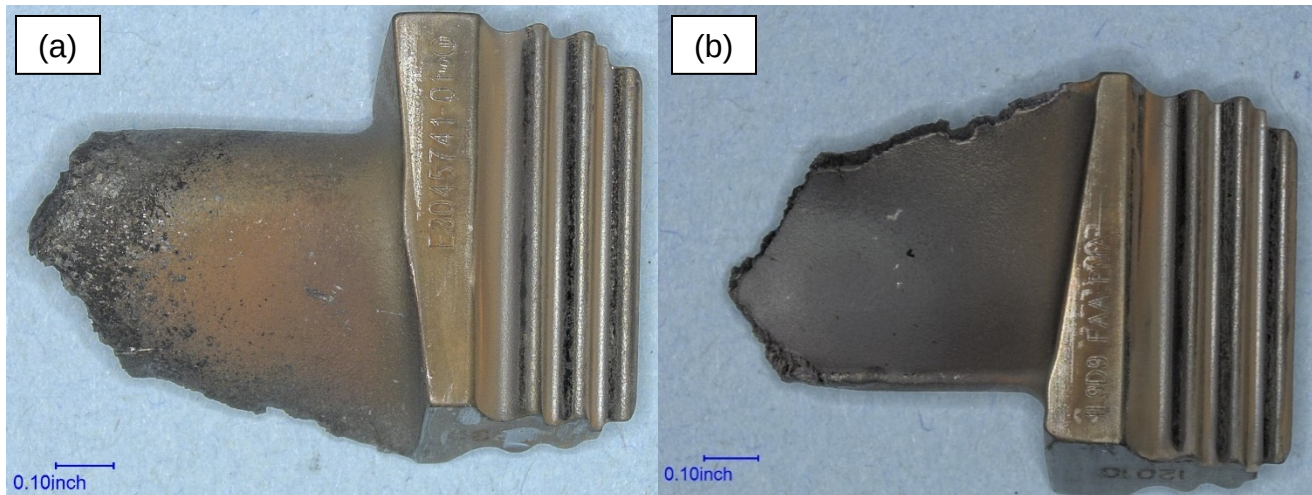


Figure 10 – Blade 25 viewed from the (a) convex and (b) concave side.



Figure 11 – The fracture surface of Blade 25.

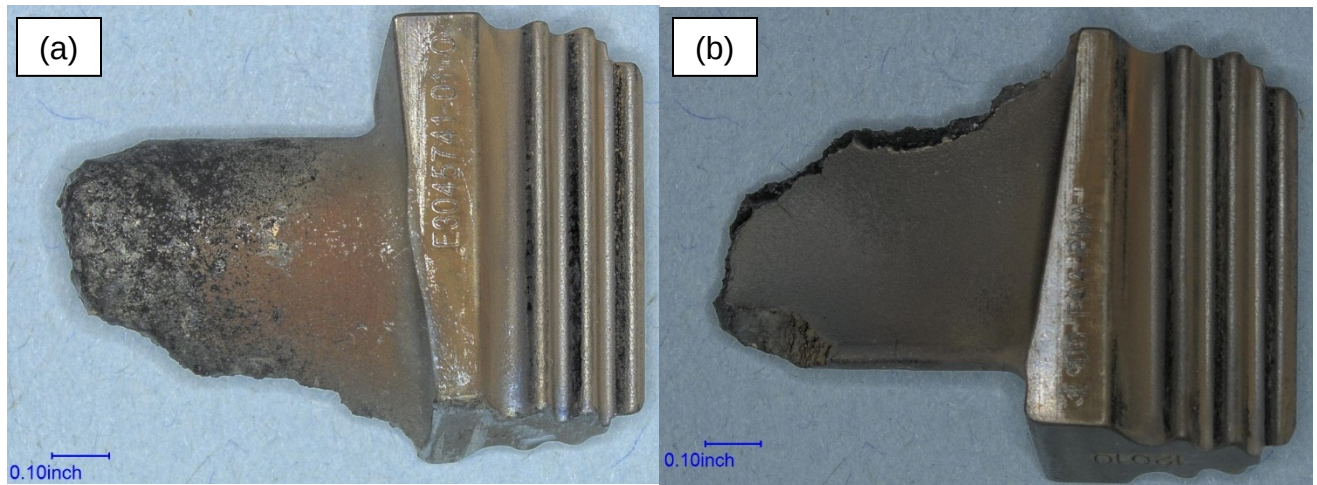


Figure 12 – Blade 34 viewed from the (a) convex and (b) concave side.

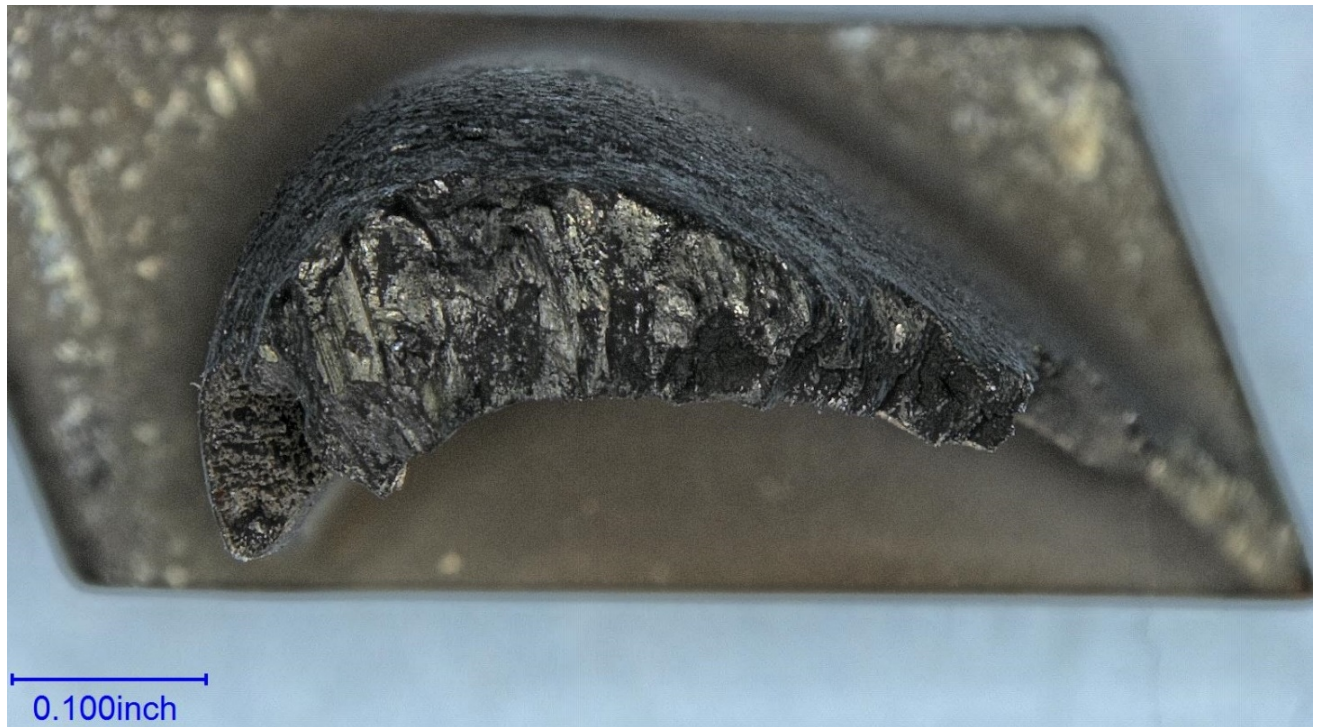


Figure 13 – The fracture surface of Blade 34.

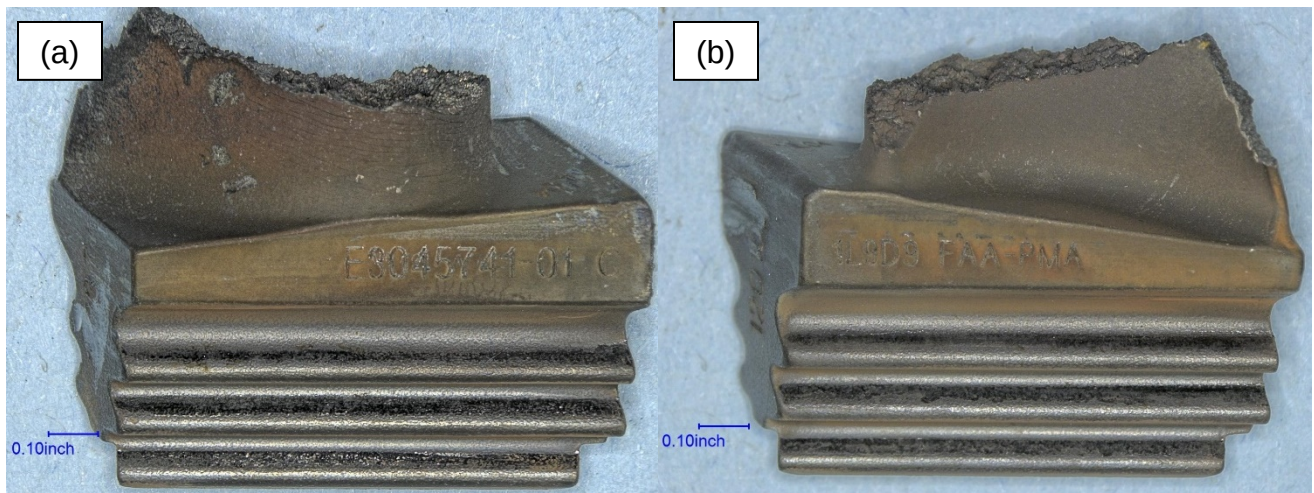


Figure 14 – Blade 42 viewed from the (a) convex and (b) concave side.

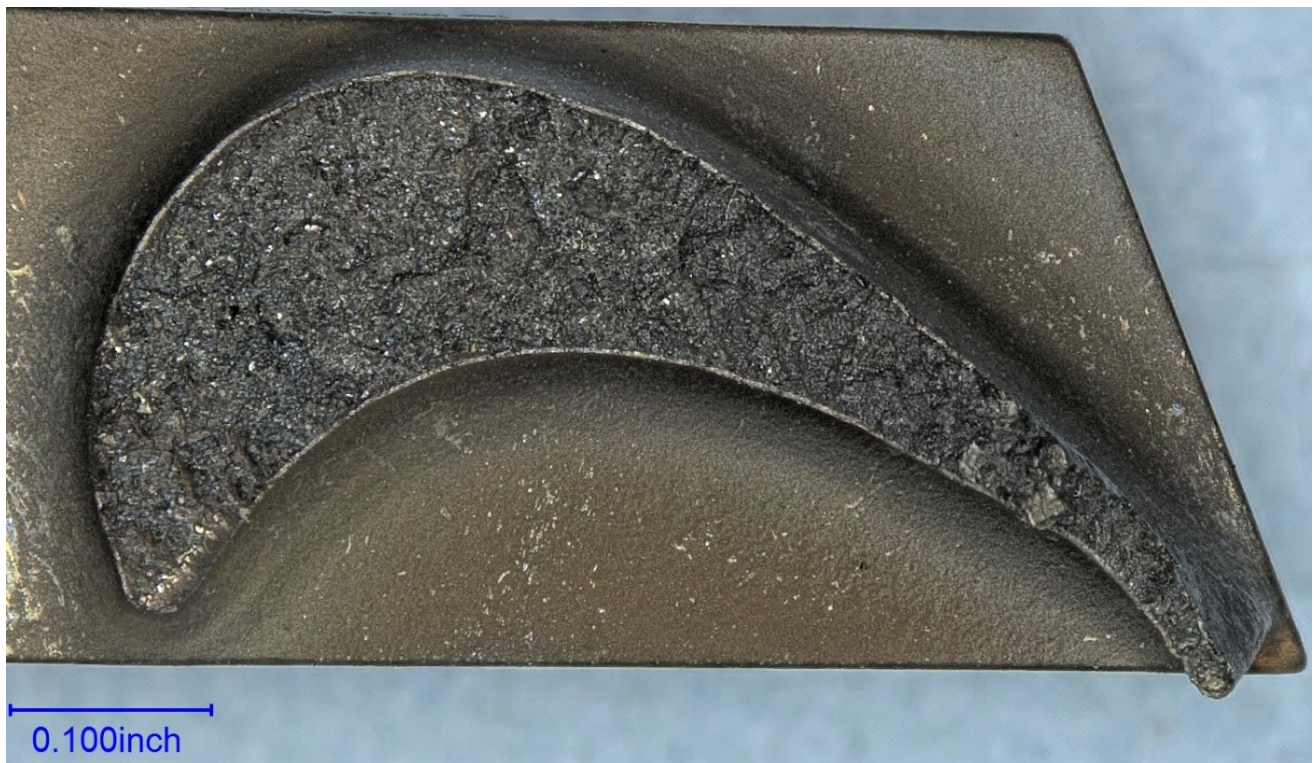


Figure 15 – The fracture surface of Blade 42.

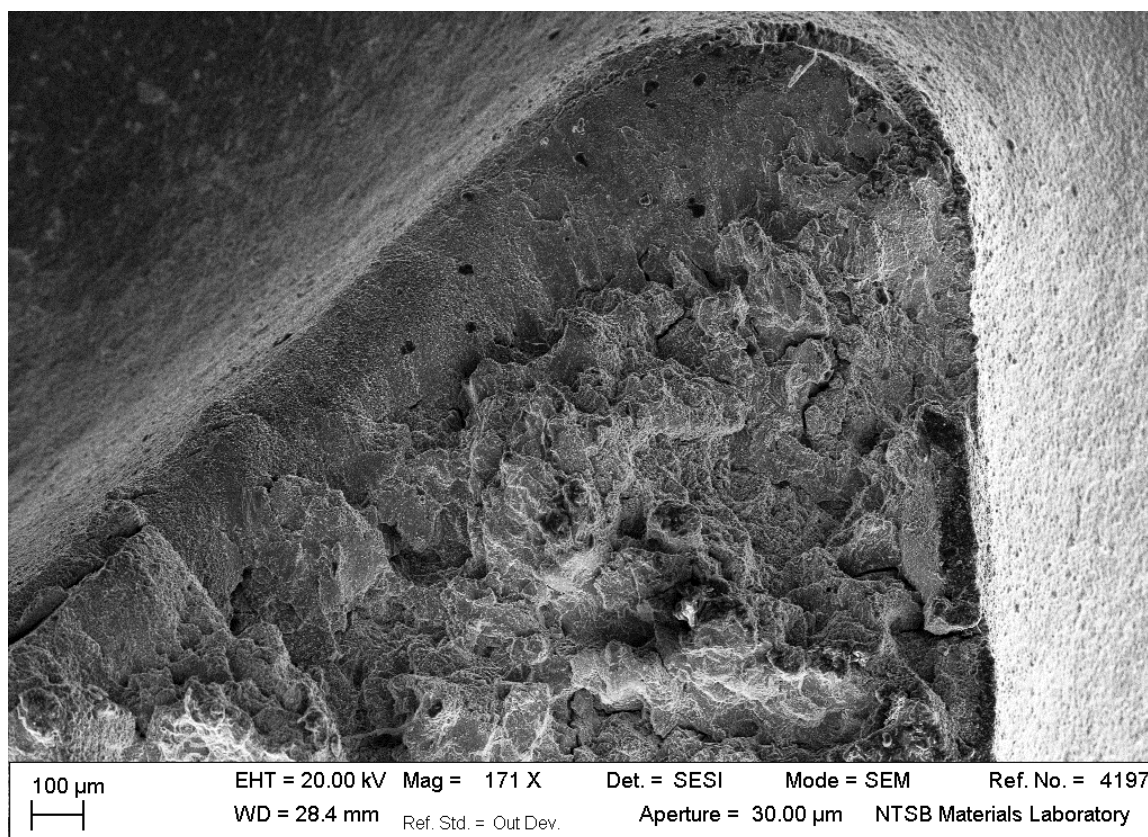


Figure 16 – Secondary electron (SE) micrograph of the leading edge of the Blade 25 fracture surface.

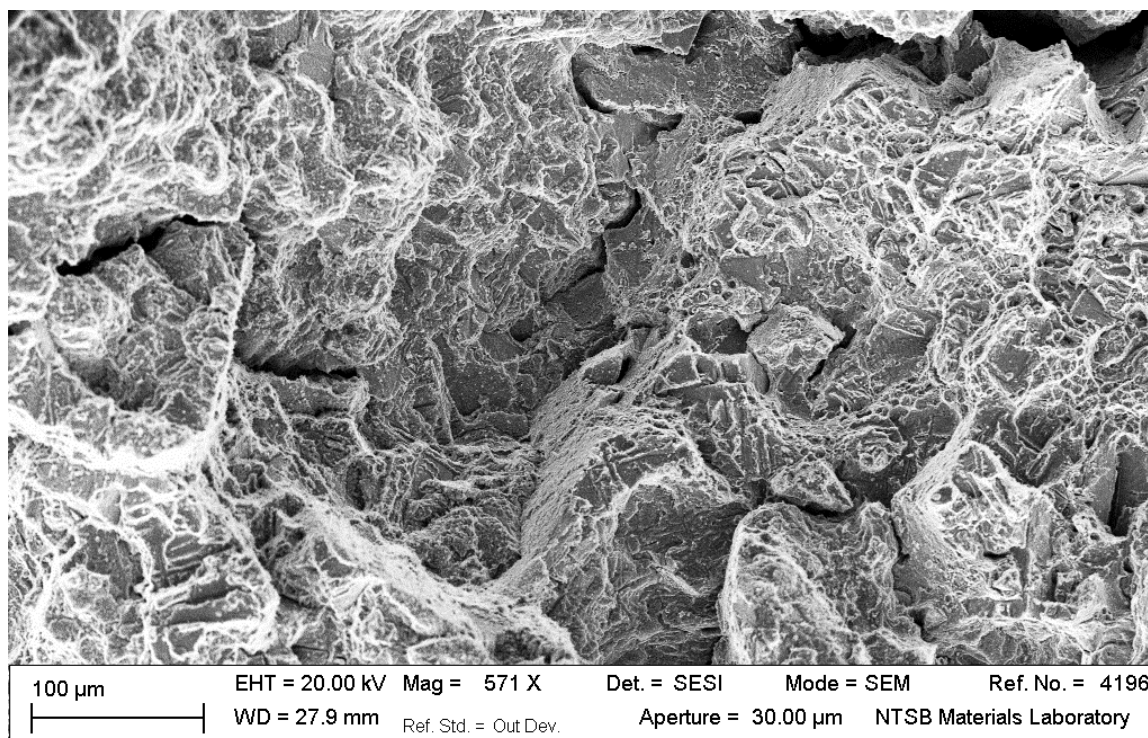


Figure 17 – SE micrograph showing a closer view of fracture features on the Blade 25.

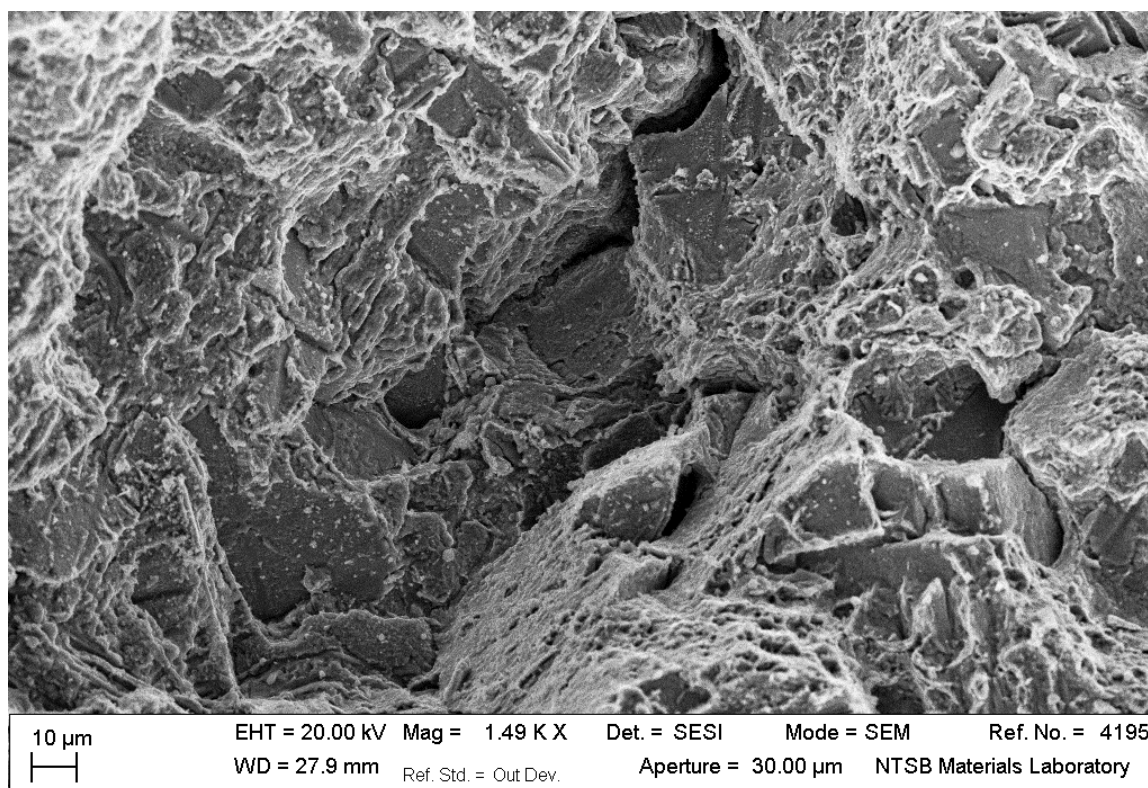


Figure 18 – SE micrograph of intergranular fissures on the Blade 25 fracture surface.

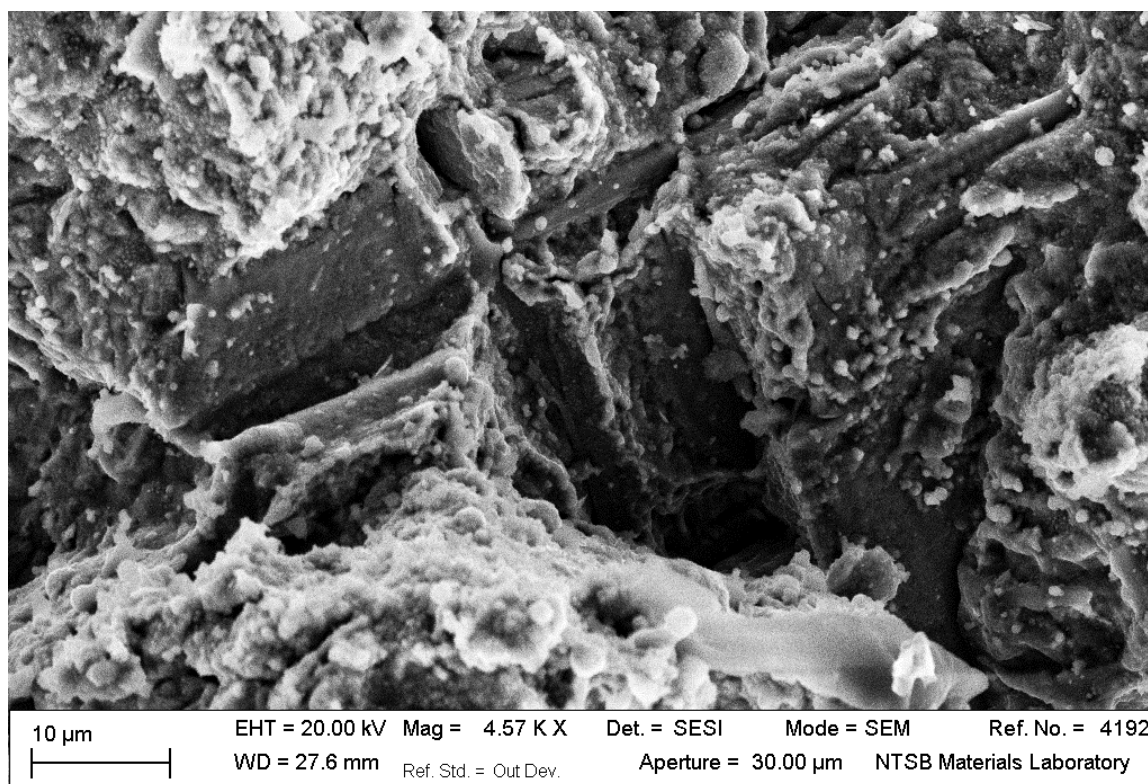


Figure 19 – SE micrograph showing tearing between the dendrites and interdendritic material on the Blade 25 fracture surface.

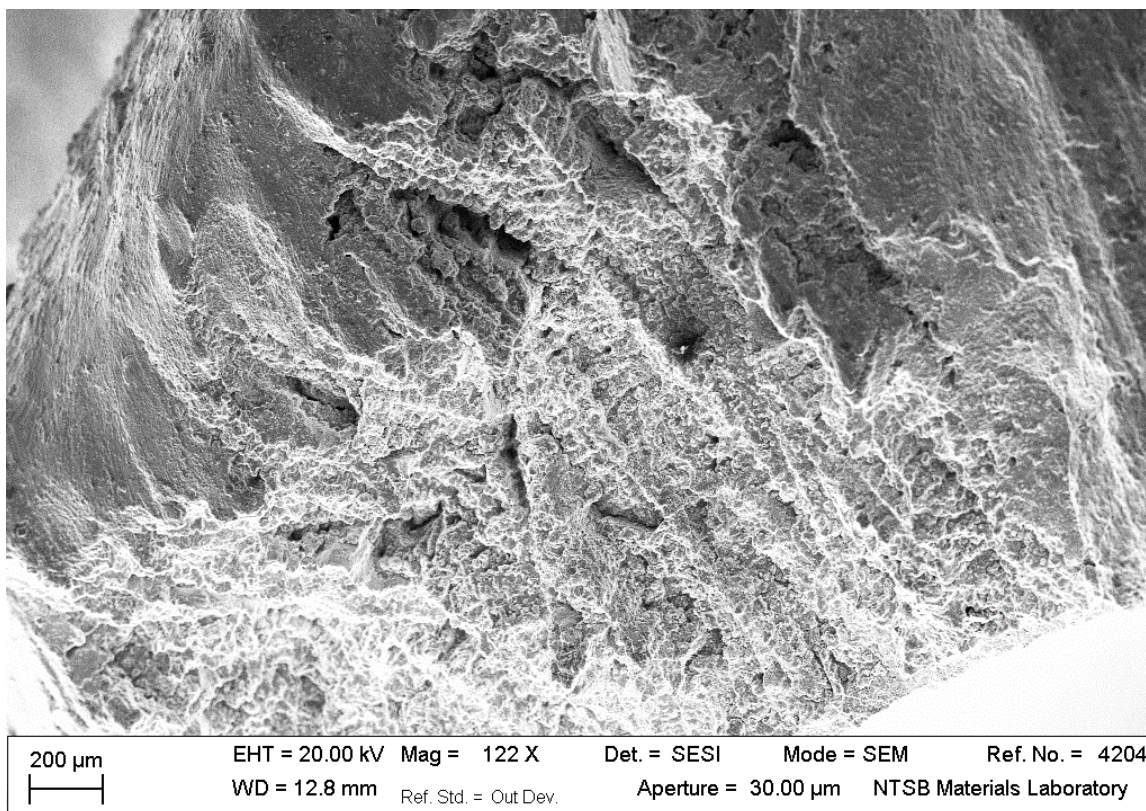


Figure 20 – SE micrograph of the leading-edge portion of the Blade 42 fracture surface.

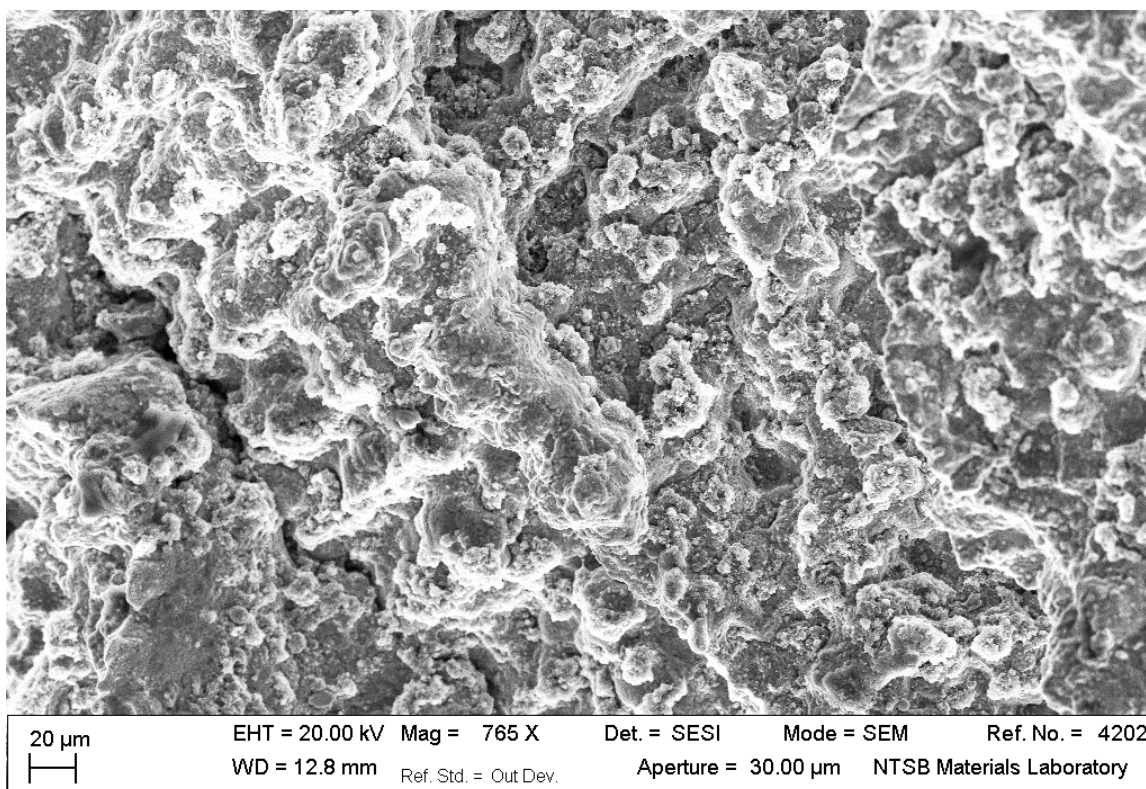


Figure 21 – SE micrograph showing a closer view of the Blade 42 fracture surface.

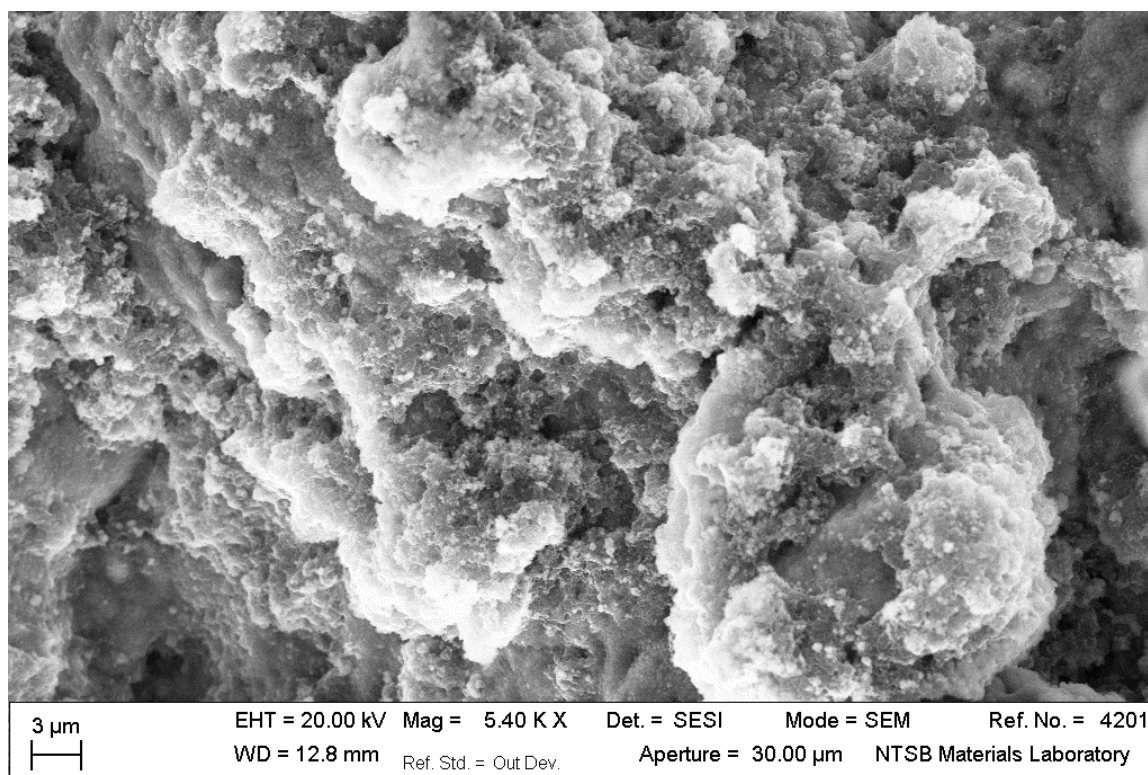


Figure 22 – SE micrograph of a magnified view of the Blade 42 fracture surface in Figure 21, showing dimple rupture.

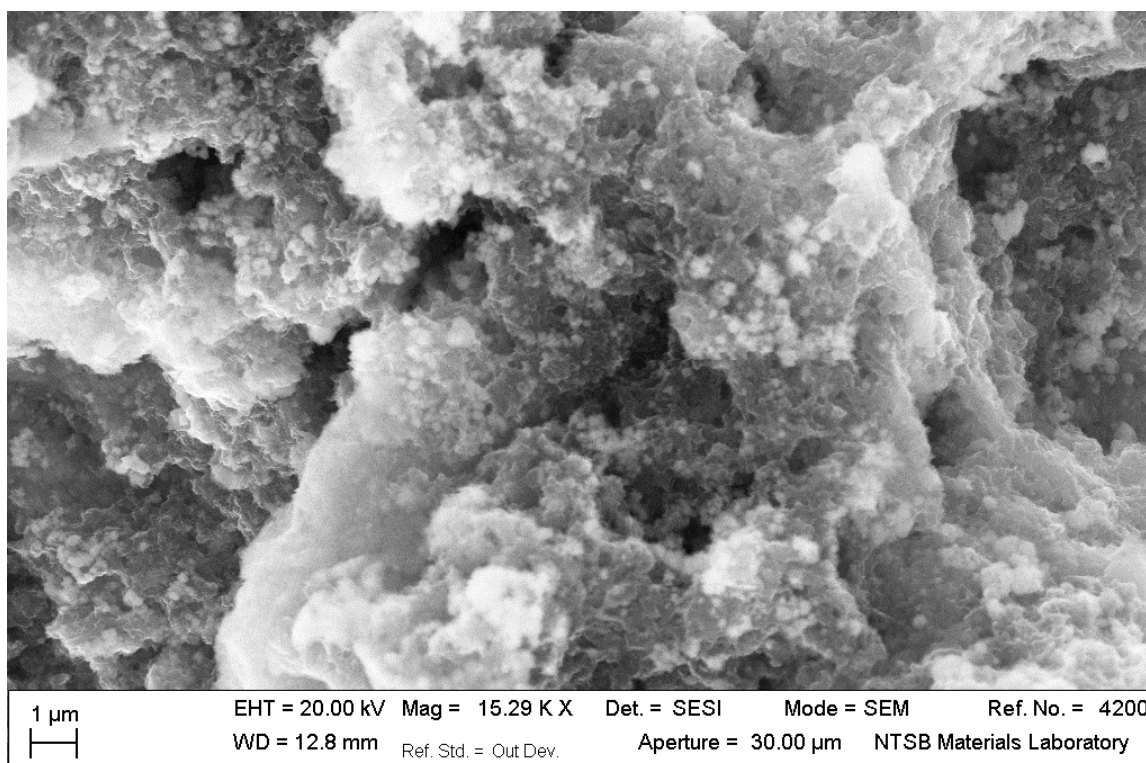


Figure 23 – SE micrograph of a closer view of the dimple rupture on the Blade 42 fracture surface in Figure 22.

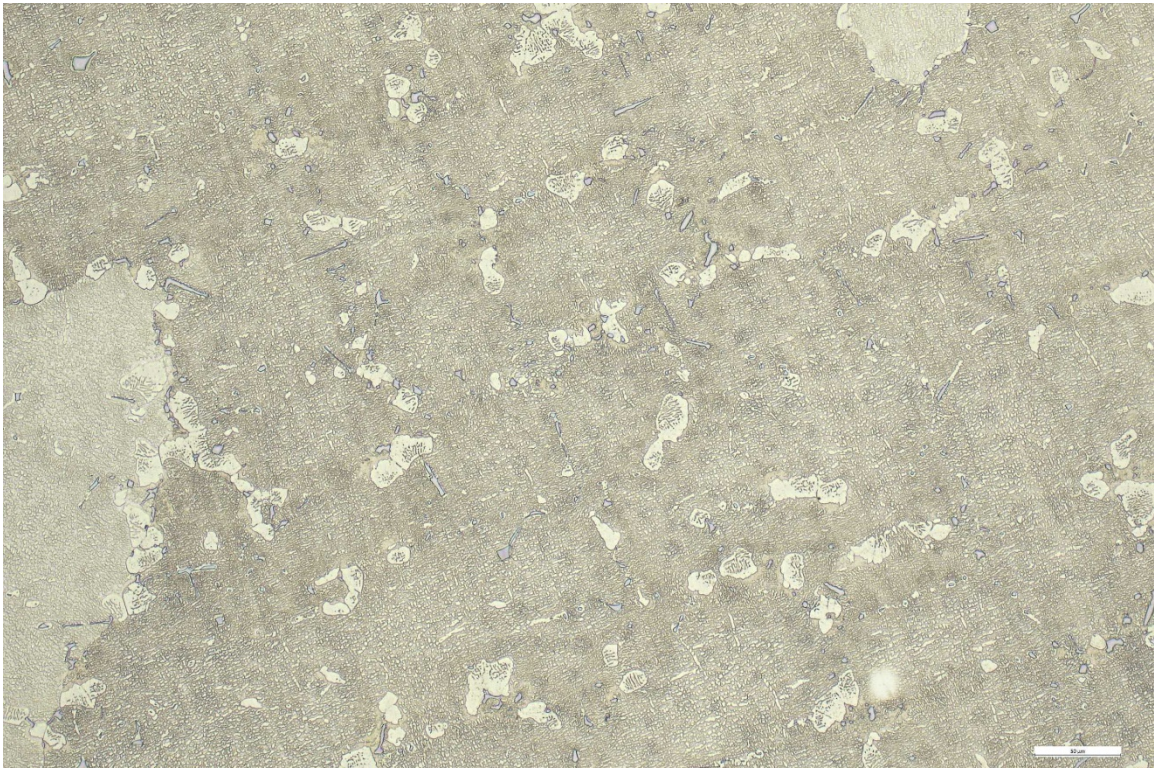


Figure 24 – Bright field (BF) micrograph of the Blade 1 dovetail microstructure (~200X, etched Marble's Reagent).

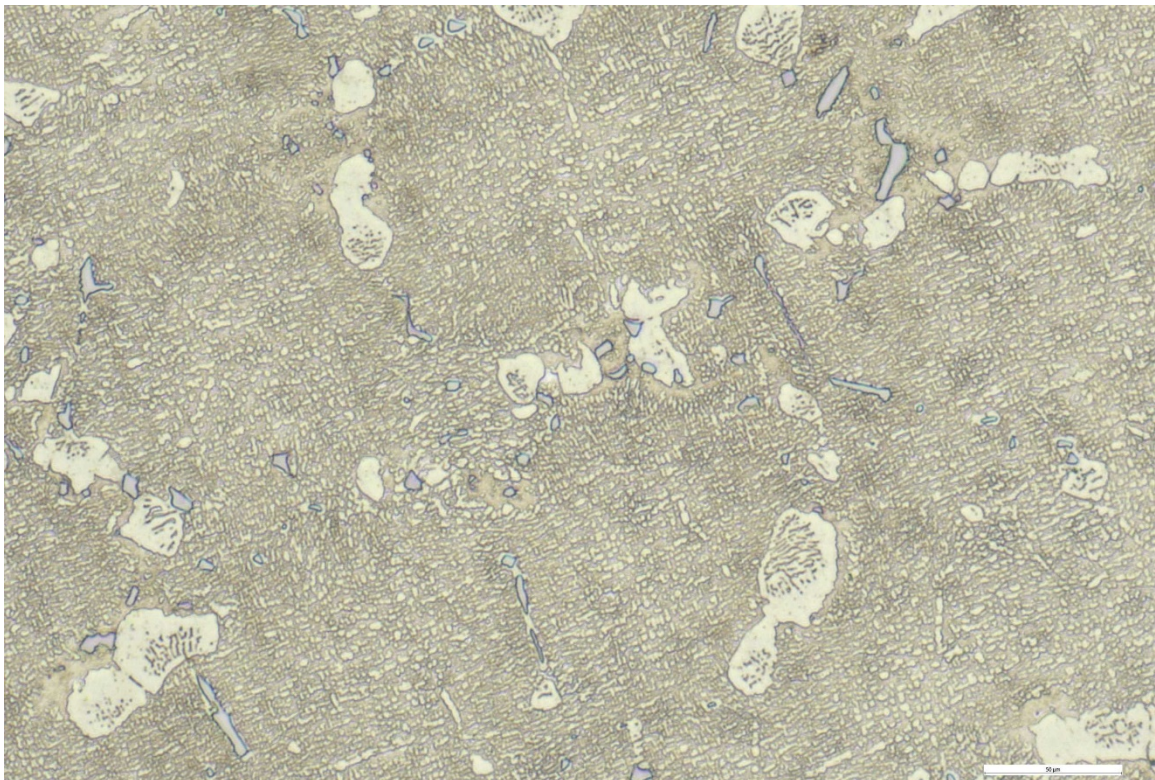


Figure 25 – Bright field (BF) micrograph of the Blade 1 dovetail microstructure (~500X, etched Marble's Reagent).

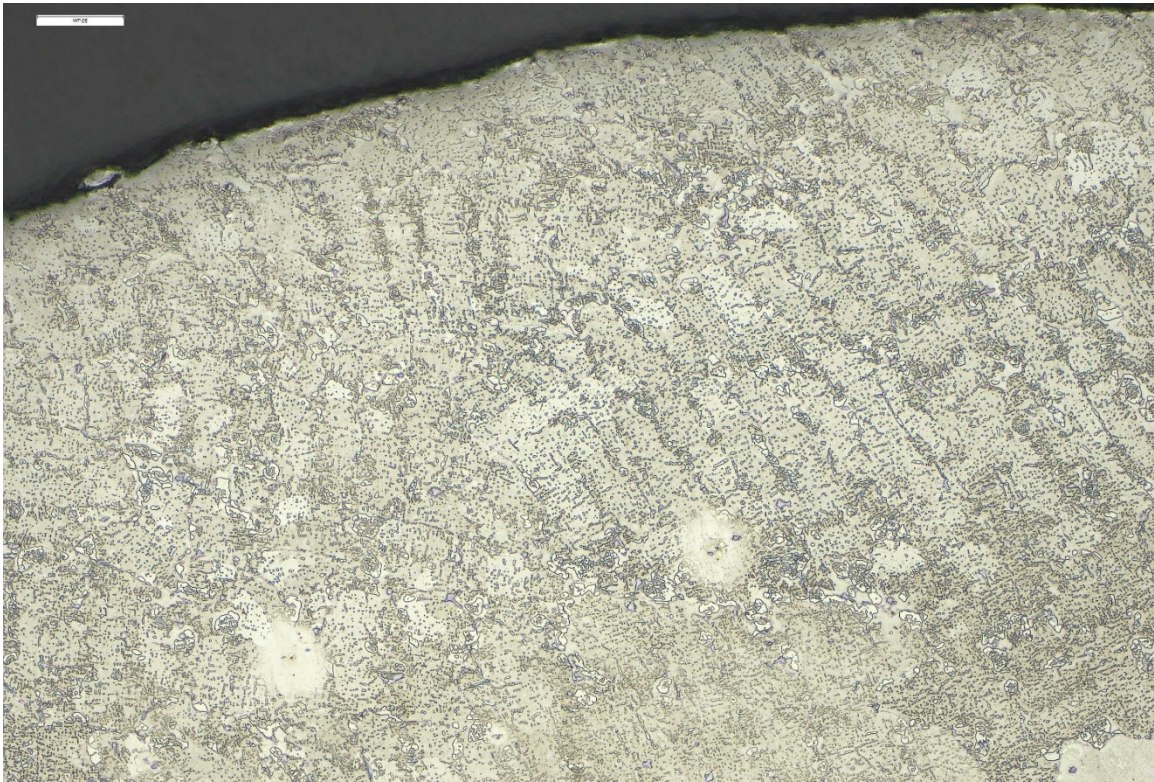


Figure 26 – Bright field (BF) micrograph of the microstructure in a cross section of Blade 1 fracture surface (~200X, etched Marble's Reagent).

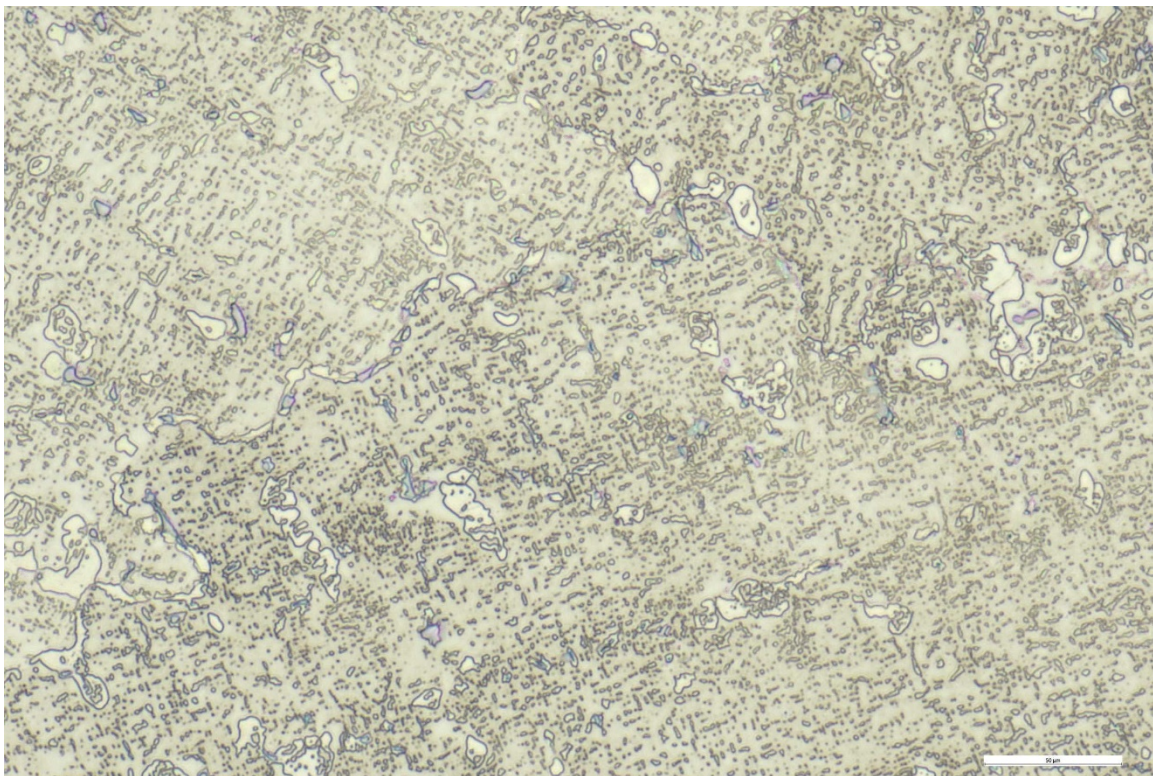


Figure 27 – Bright field (BF) micrograph of the microstructure near the Blade 1 fracture surface (~500X, etched Marble's Reagent).

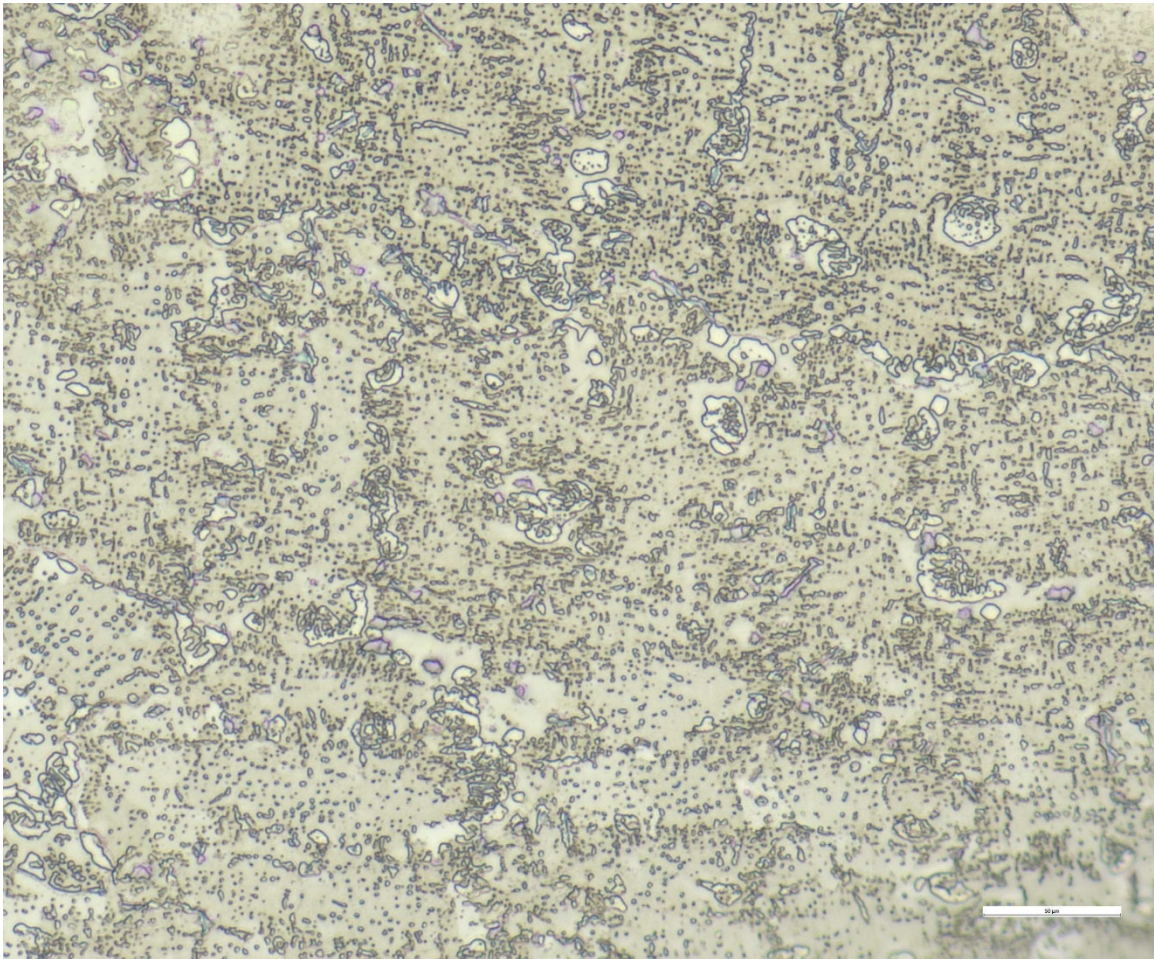


Figure 28 – Bright field (BF) micrograph of the microstructure near the Blade 1 fracture surface (~500X, etched Marble's Reagent).

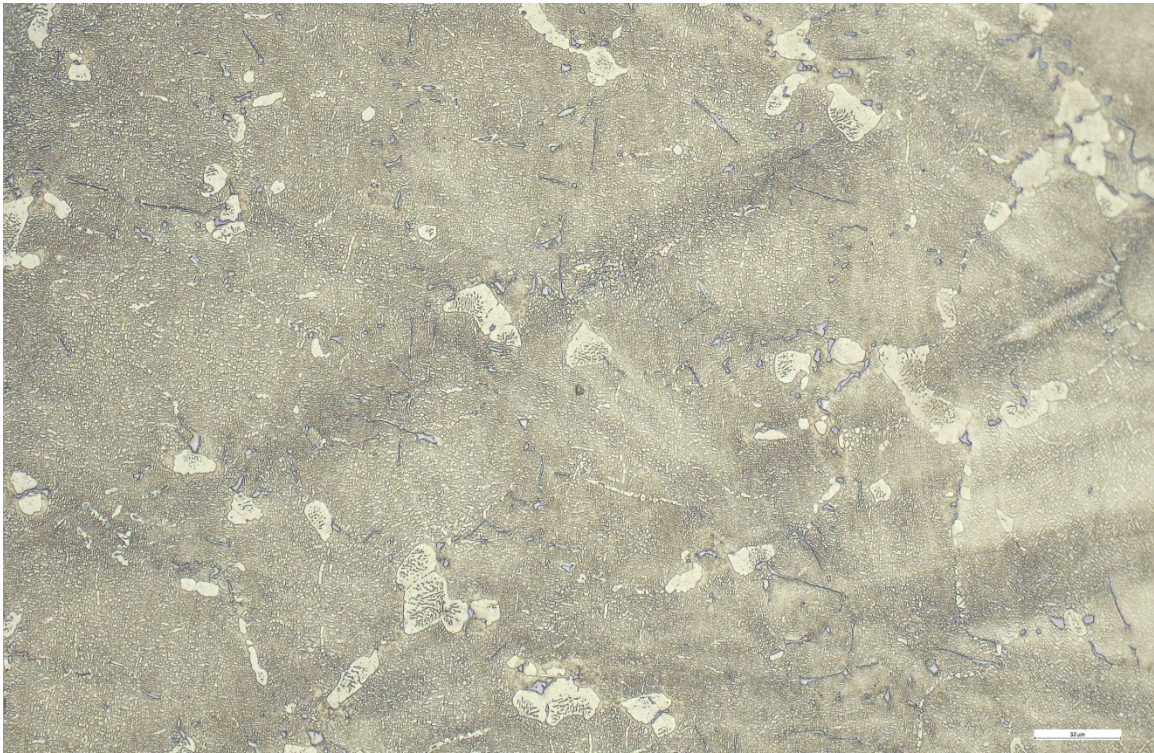


Figure 29 – Bright field (BF) micrograph of the microstructure in the Blade 25 dovetail (~200X, etched Marble's Reagent).

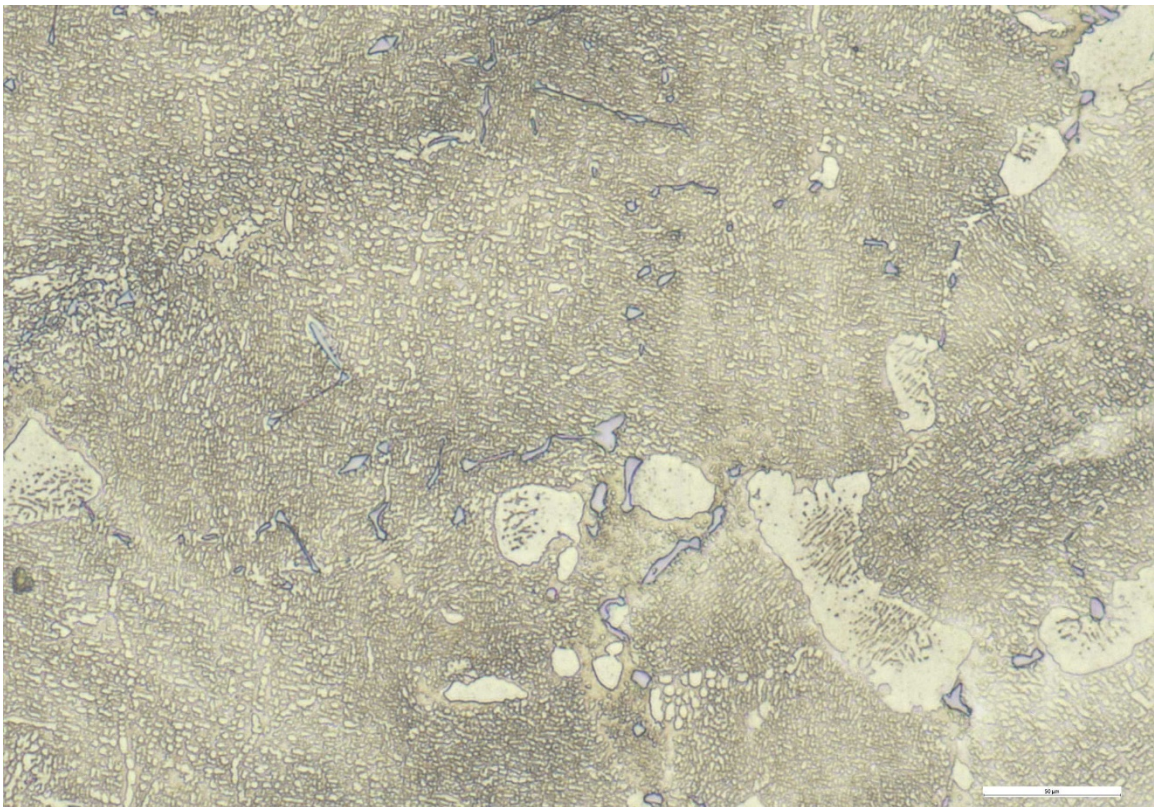


Figure 30 – Bright field (BF) micrograph of the microstructure in the Blade 25 dovetail (~500X, etched Marble's Reagent).



Figure 31 – Bright field (BF) micrograph of the microstructure at a cross section through the Blade 25 fracture surface (~200X, etched Marble's Reagent).

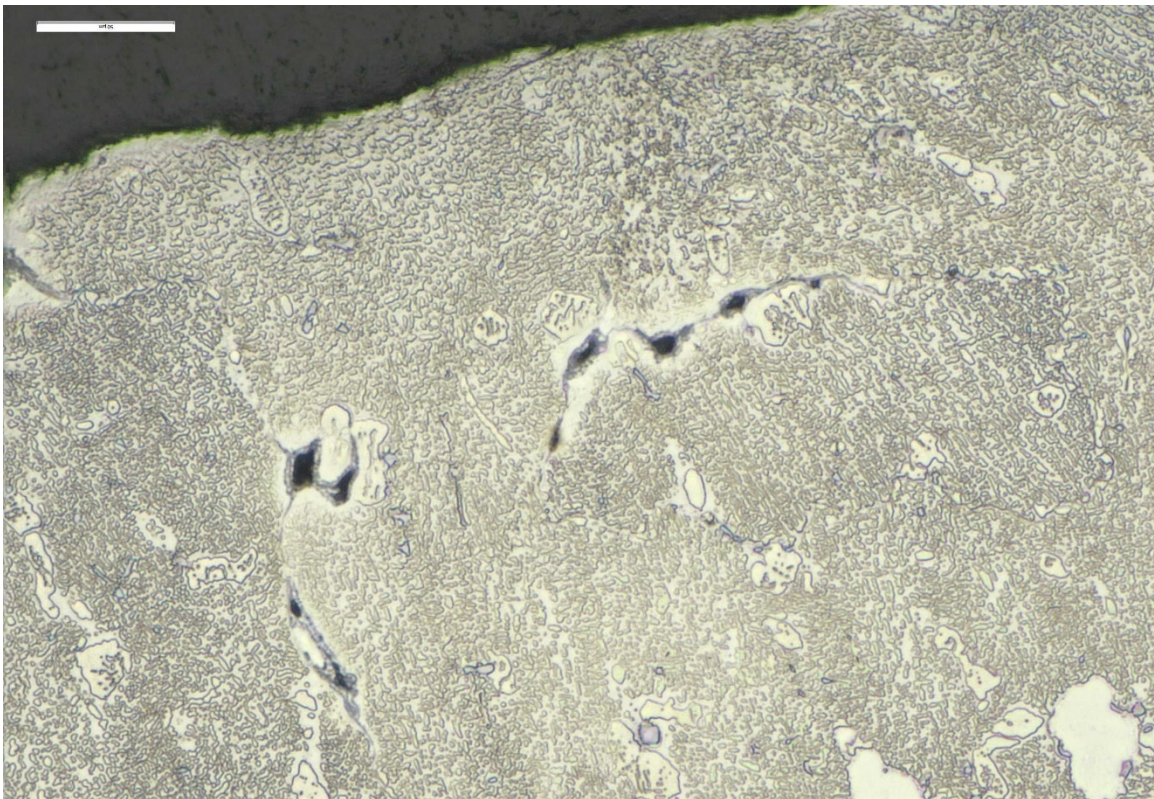


Figure 32 – Bright field (BF) micrograph of the microstructure at a cross section through the Blade 25 fracture surface (~500X, etched Marble's Reagent).

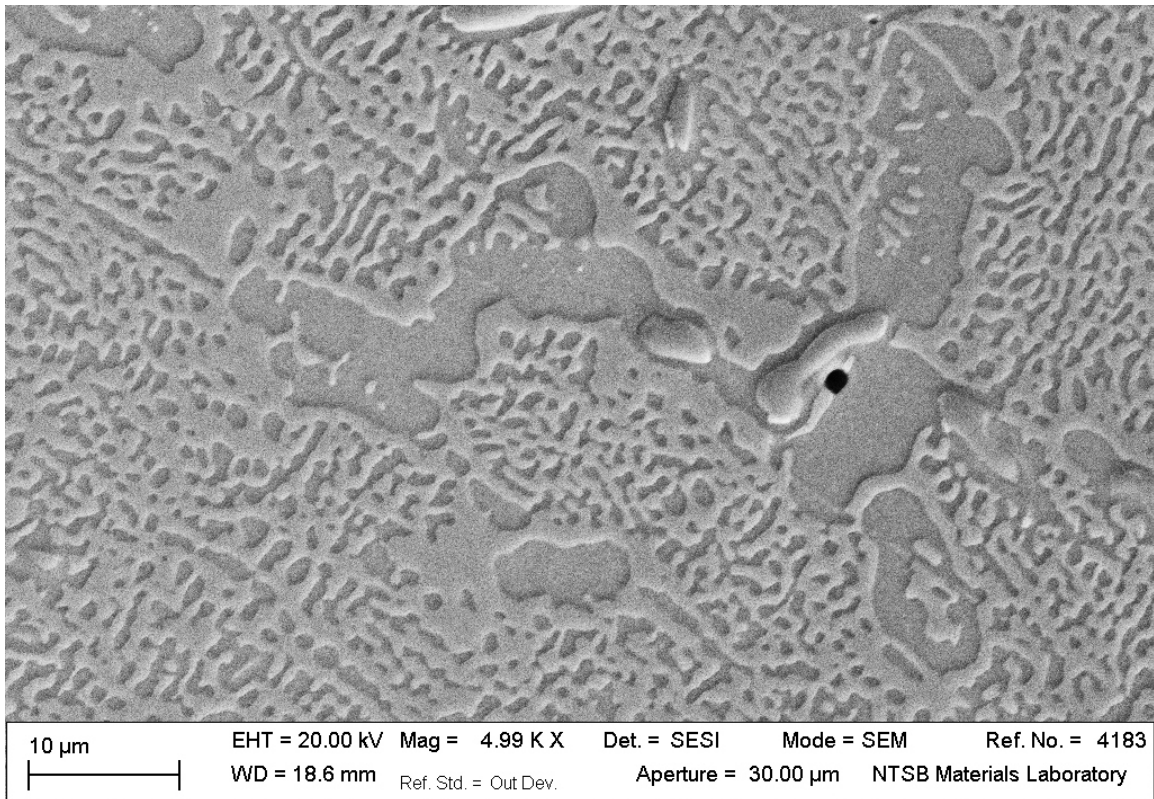


Figure 33 – SE micrograph of the microstructure of Blade 25 near the fracture surface (etched Marble's Reagent).

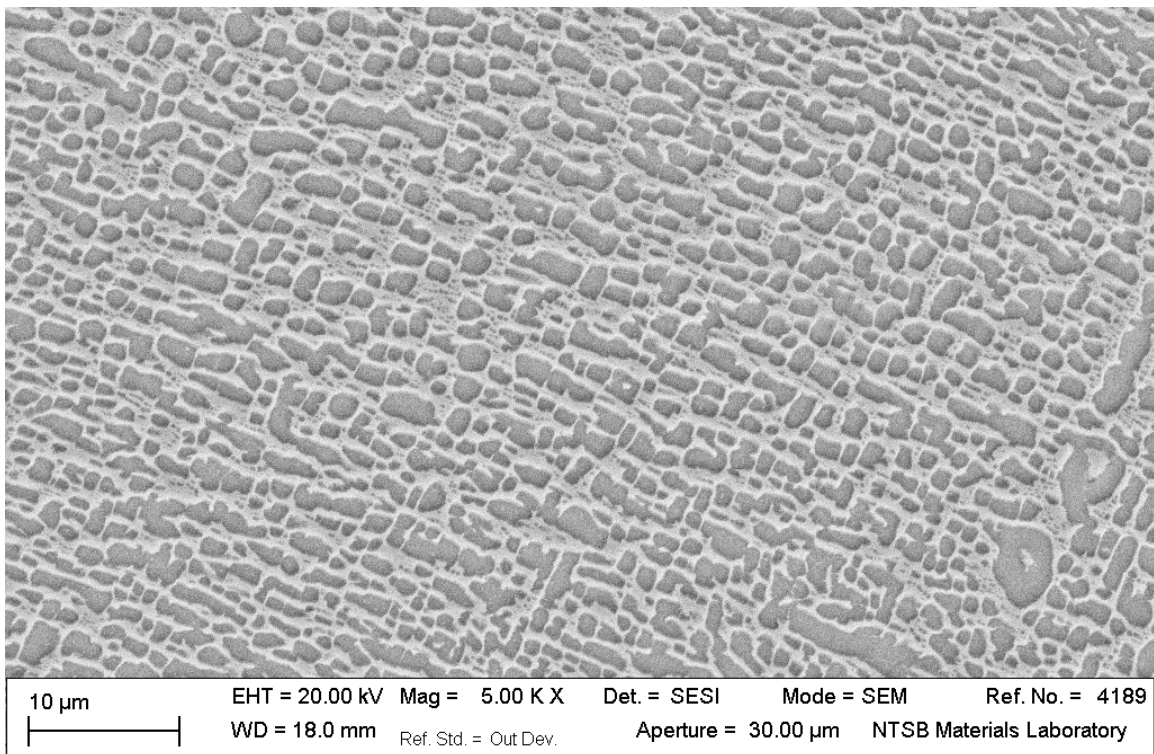


Figure 34 – SE micrograph of the microstructure of Blade 25 in the dovetail (etched Marble's Reagent).

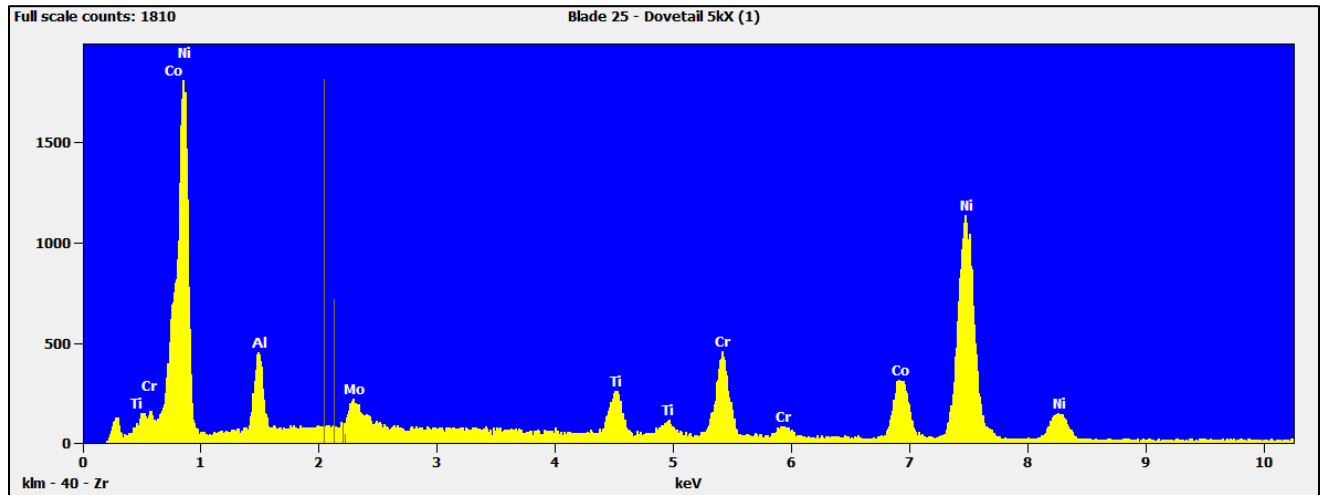


Figure 35 – Typical EDS spectrum from the dovetail of Blade 25.

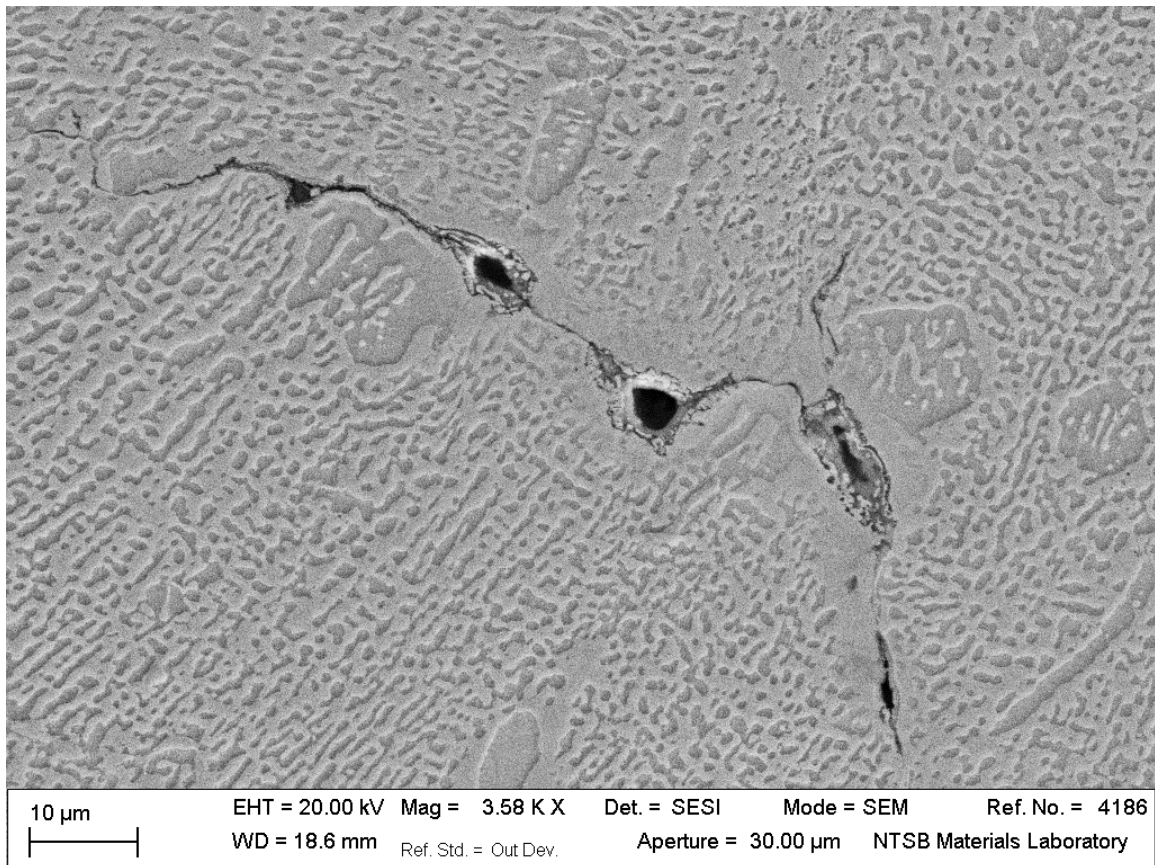


Figure 36 – SE micrograph of a subsurface crack near the Blade 25 fracture surface, showing oxide along the crack.

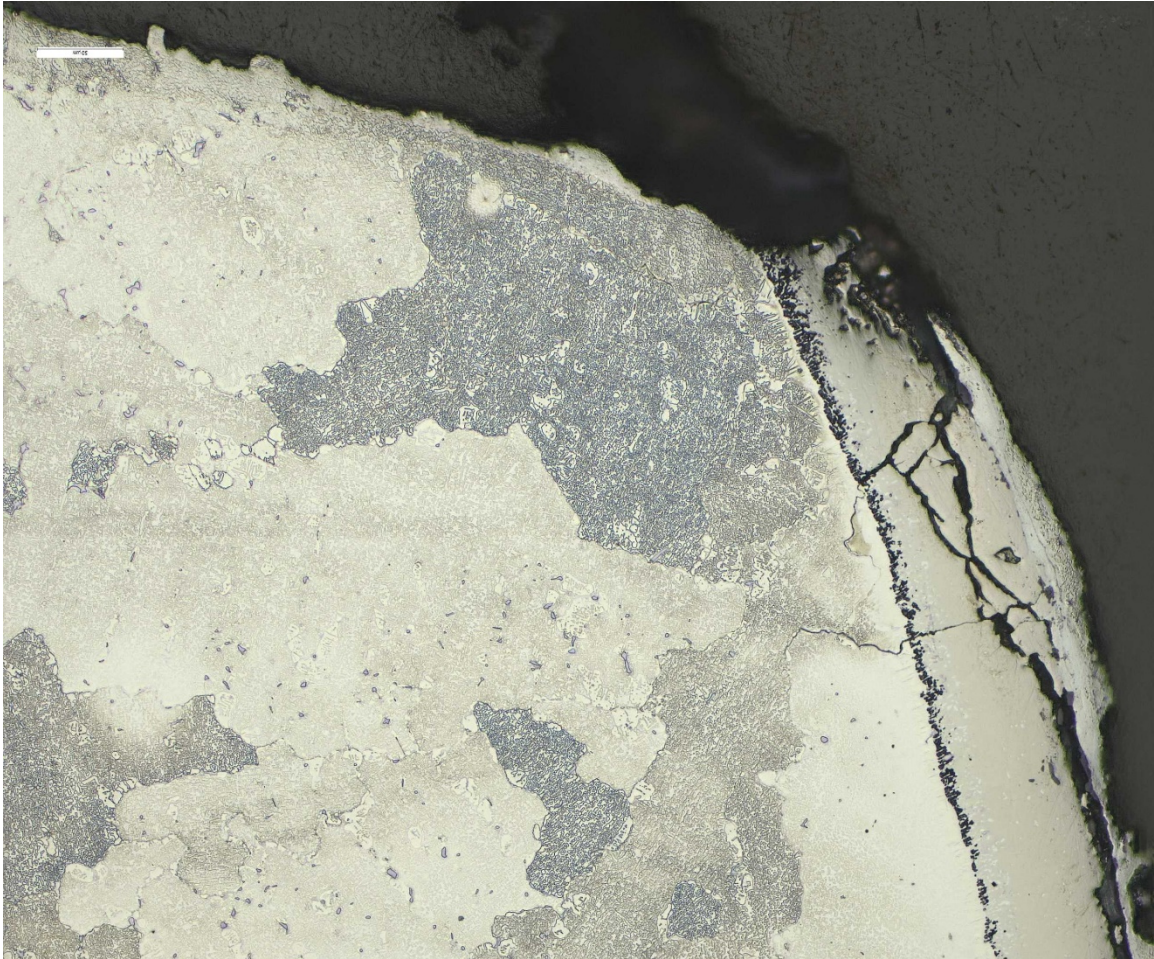


Figure 37 – BF micrograph of the microstructure through a cross section of the fracture surface of Blade 34, with part of the cracked coating (~200X, etched Marble's Reagent).

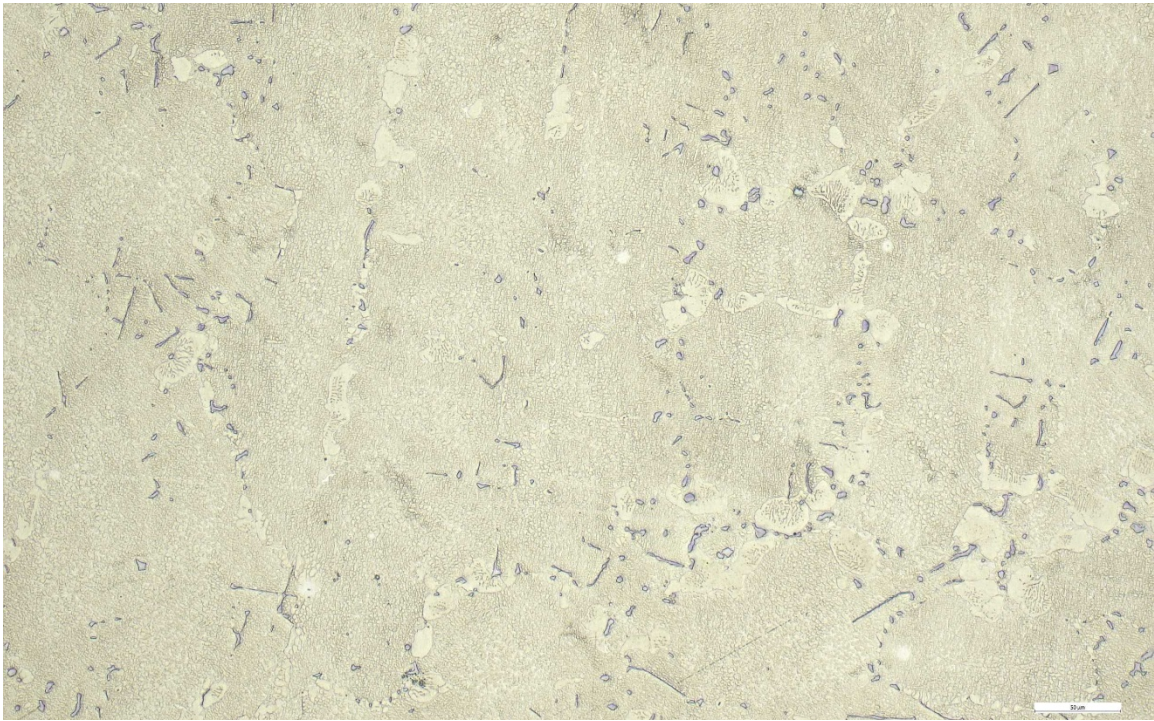


Figure 38 – BF micrograph of the microstructure in the Blade 42 dovetail (~200X, etched Marble's Reagent).

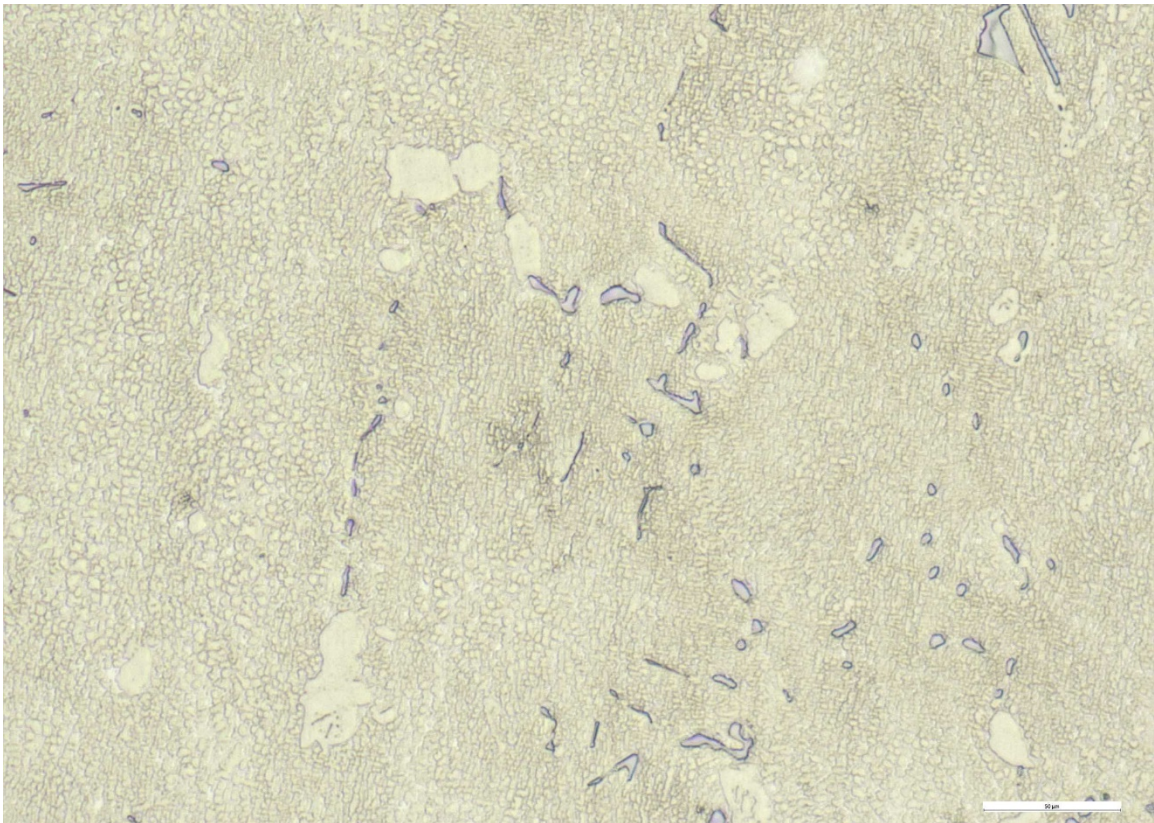


Figure 39 – BF micrograph of the microstructure in the Blade 42 dovetail (~500X, etched Marble's Reagent).

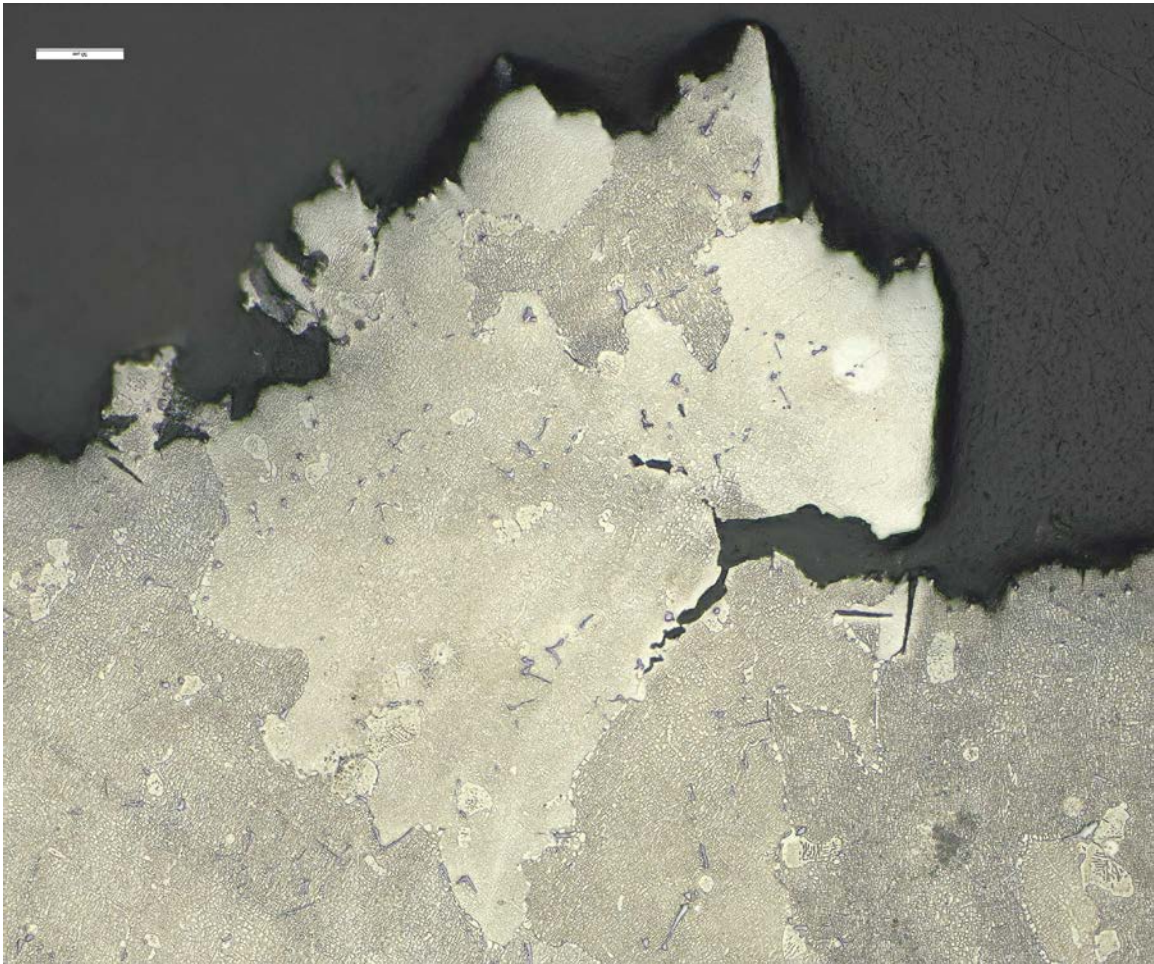


Figure 40 – BF micrograph of the microstructure through a cross section of the fracture surface of Blade 42 (~500X, etched Marble's Reagent).

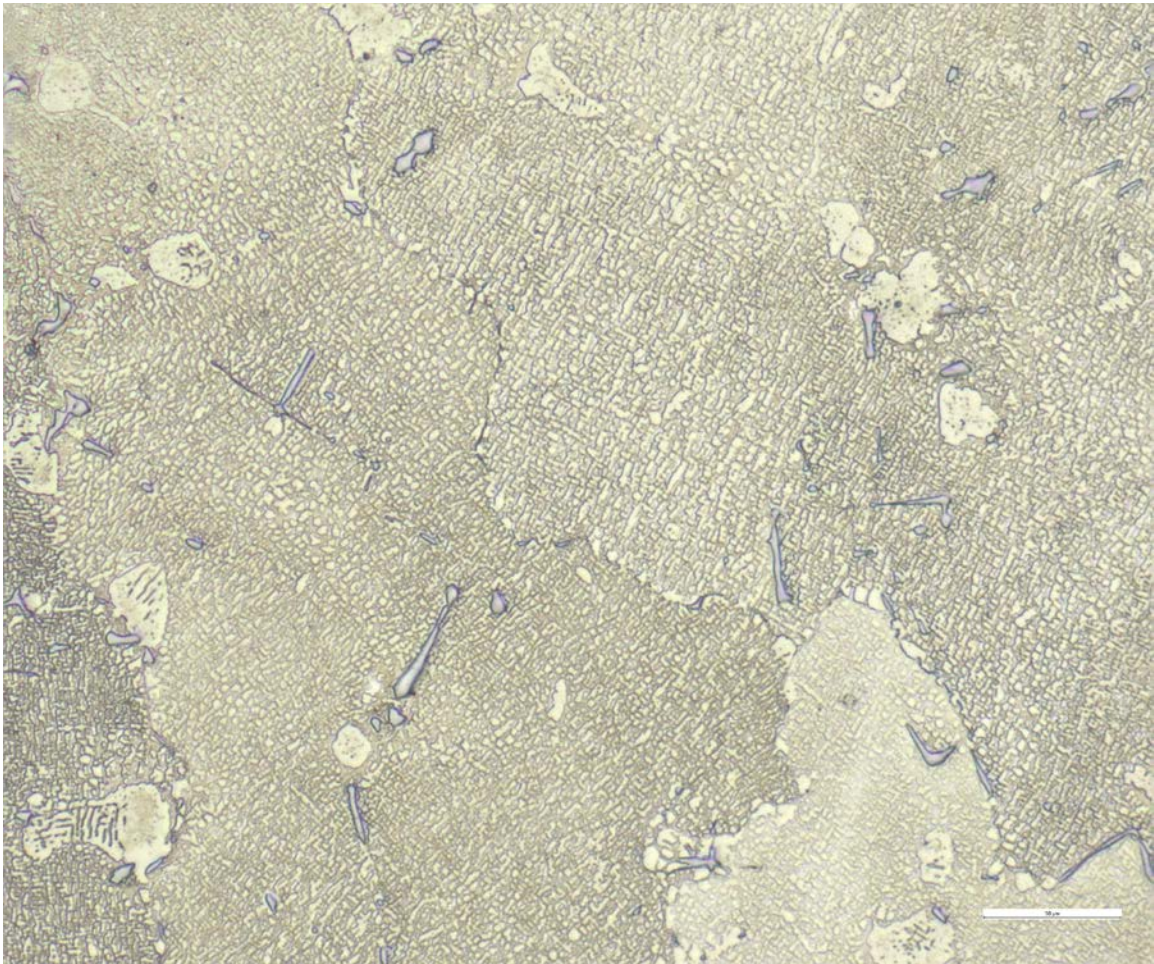


Figure 41 – BF micrograph of the microstructure near the fracture surface of Blade 34, with part of the cracked coating (~500X, etched Marble's Reagent).

4. APPENDIX A

Photodocumentation of Blade Fracture Surfaces As-Received

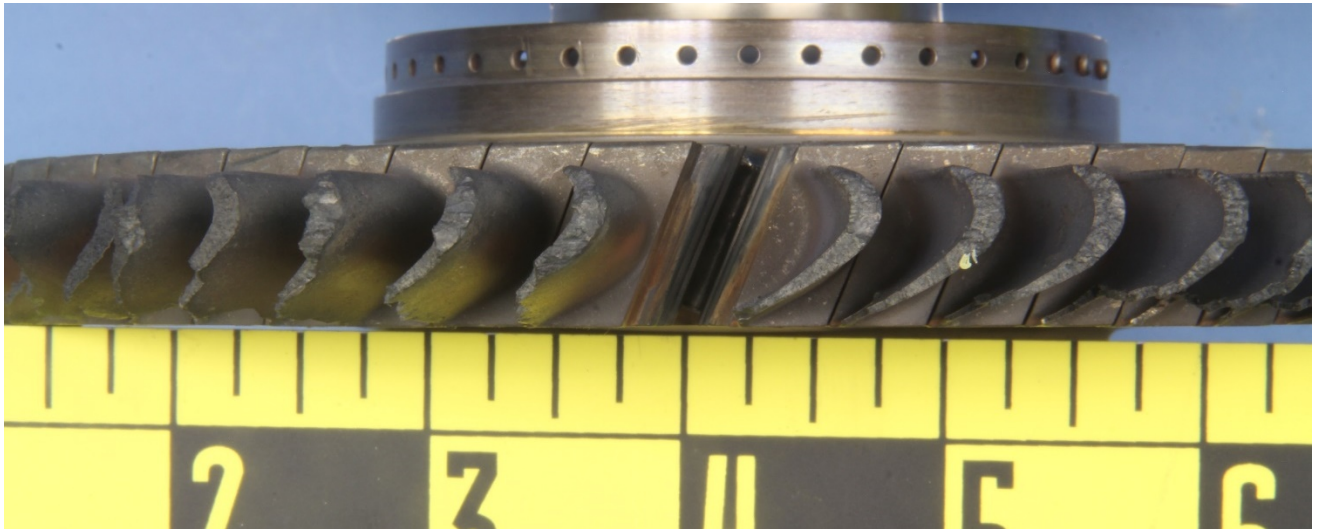


Figure A-1: The turbine wheel, as received, positioned to show the blade fracture surfaces.

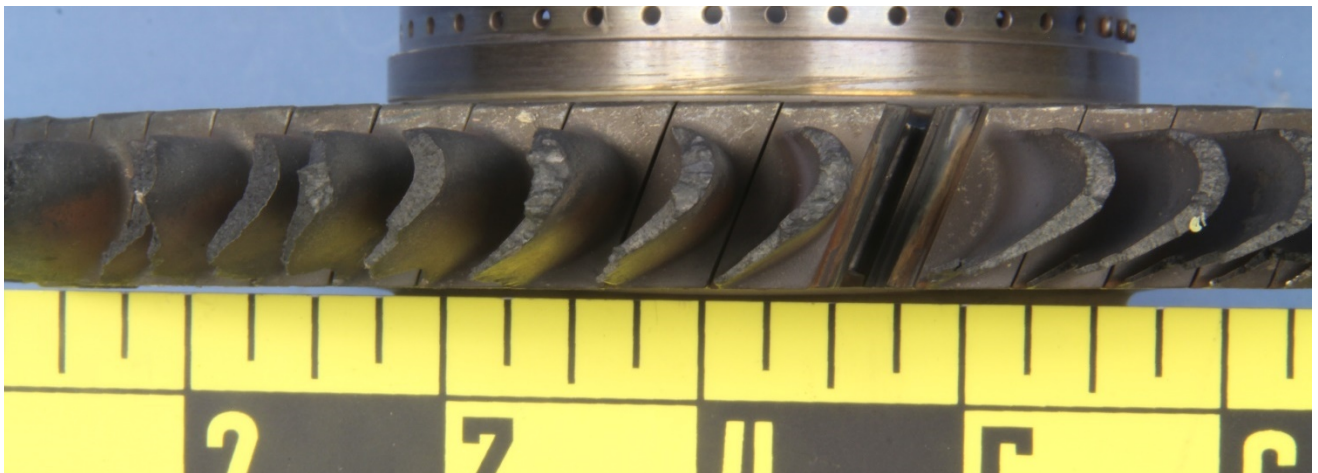


Figure A-2: The turbine wheel, as received, positioned to show the blade fracture surfaces.

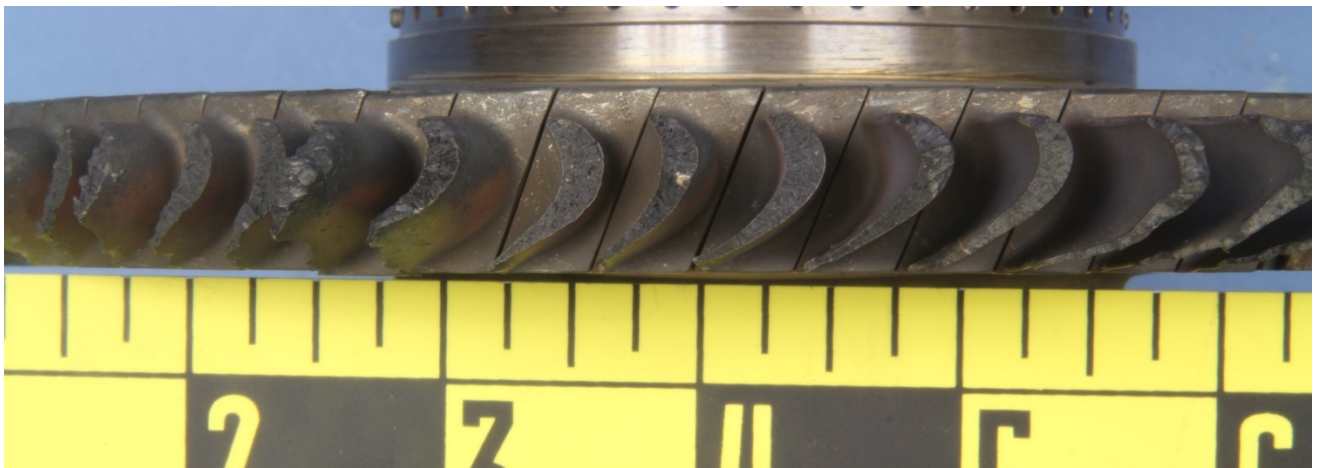


Figure A-3: The turbine wheel, as received, positioned to show the blade fracture surfaces.

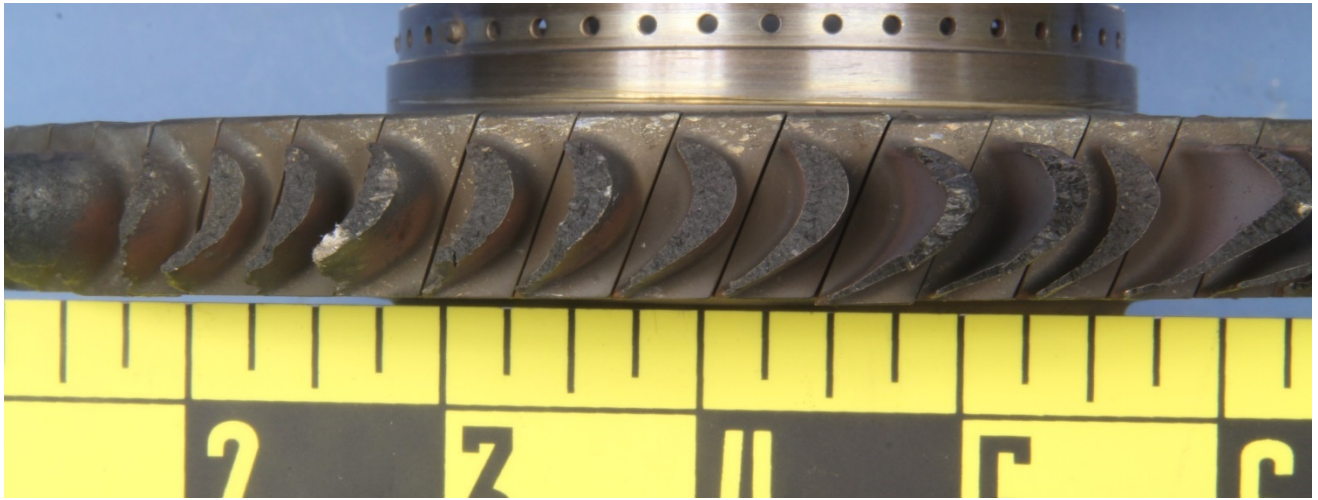


Figure A-4: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-5: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-6: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-7: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-8: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-9: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-10: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-11: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-12: The turbine wheel, as received, positioned to show the blade fracture surfaces.



Figure A-13: The turbine wheel, as received, positioned to show the blade fracture surfaces.

5. APPENDIX B

Photodocumentation of Blades after Removal

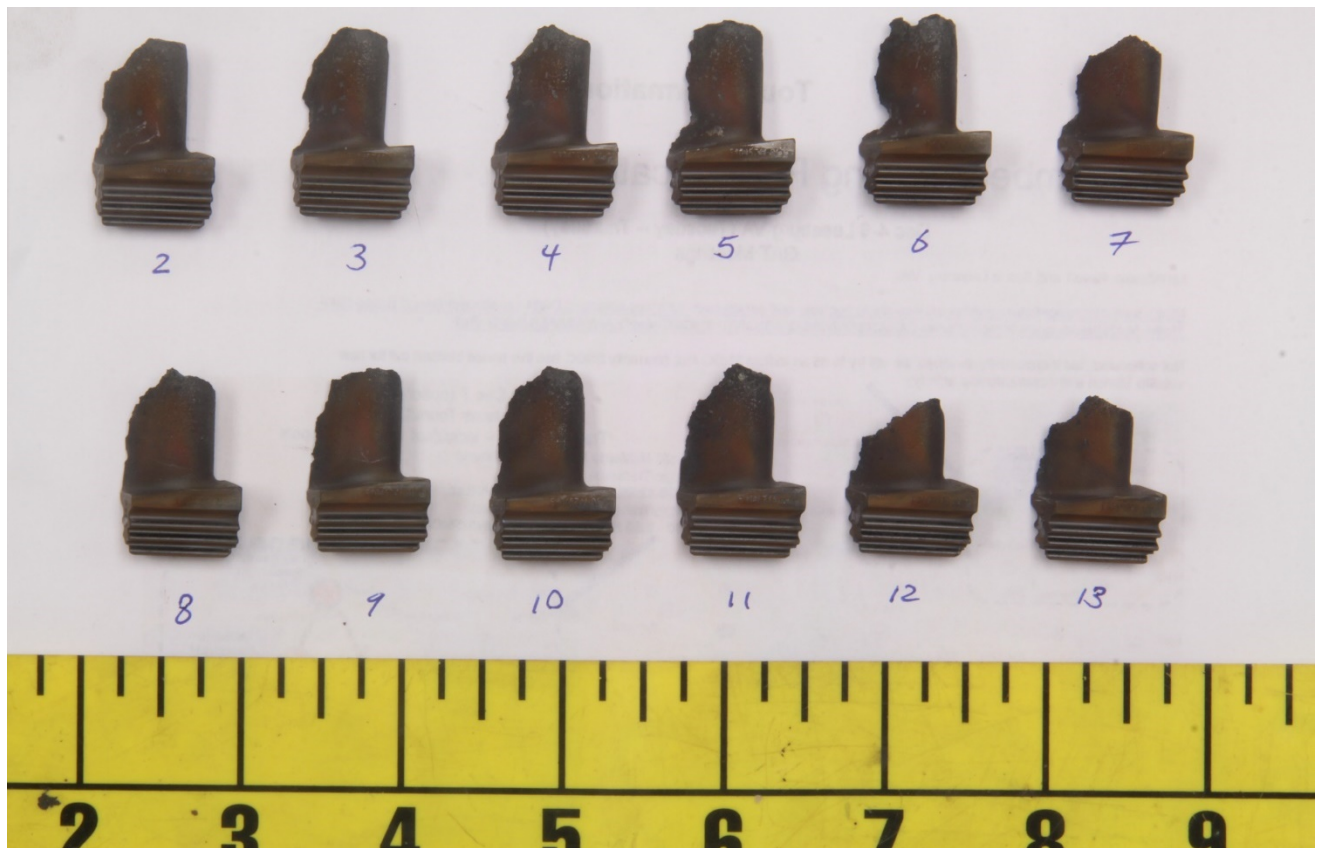


Figure B-1 – Fractured turbine blades 2 through 13, viewed from the convex side.

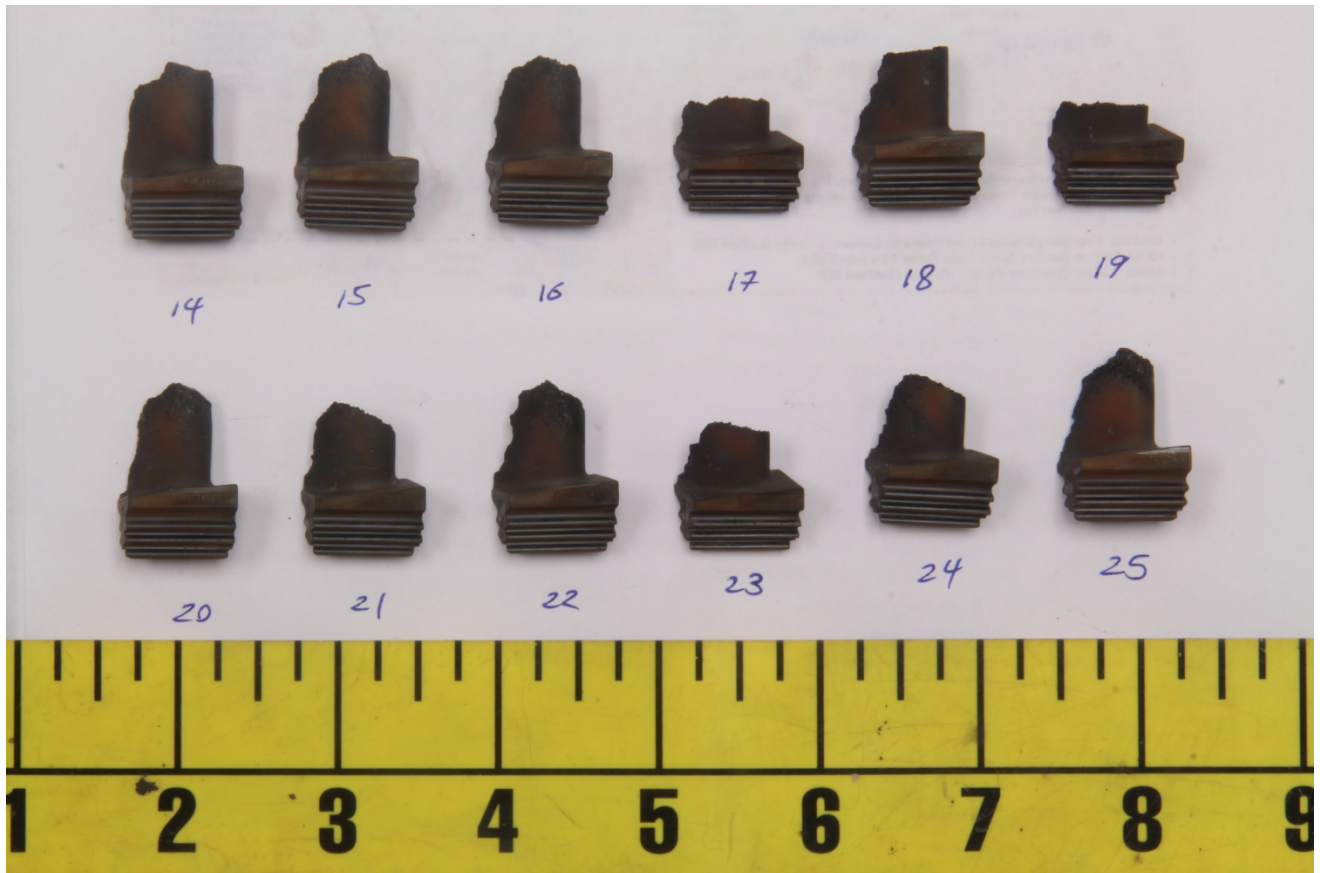


Figure B-2 – Fractured turbine blades 14 through 25, viewed from the convex side.

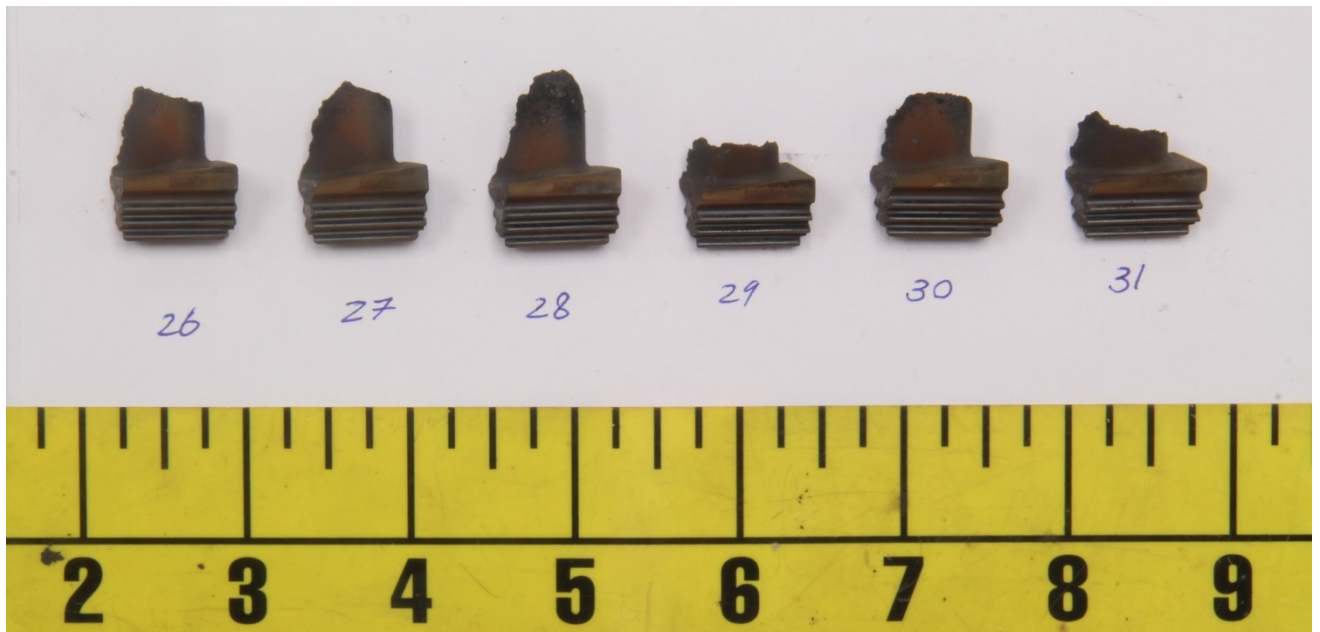


Figure B-3 – Fractured turbine blades 26 through 31, viewed from the convex side.

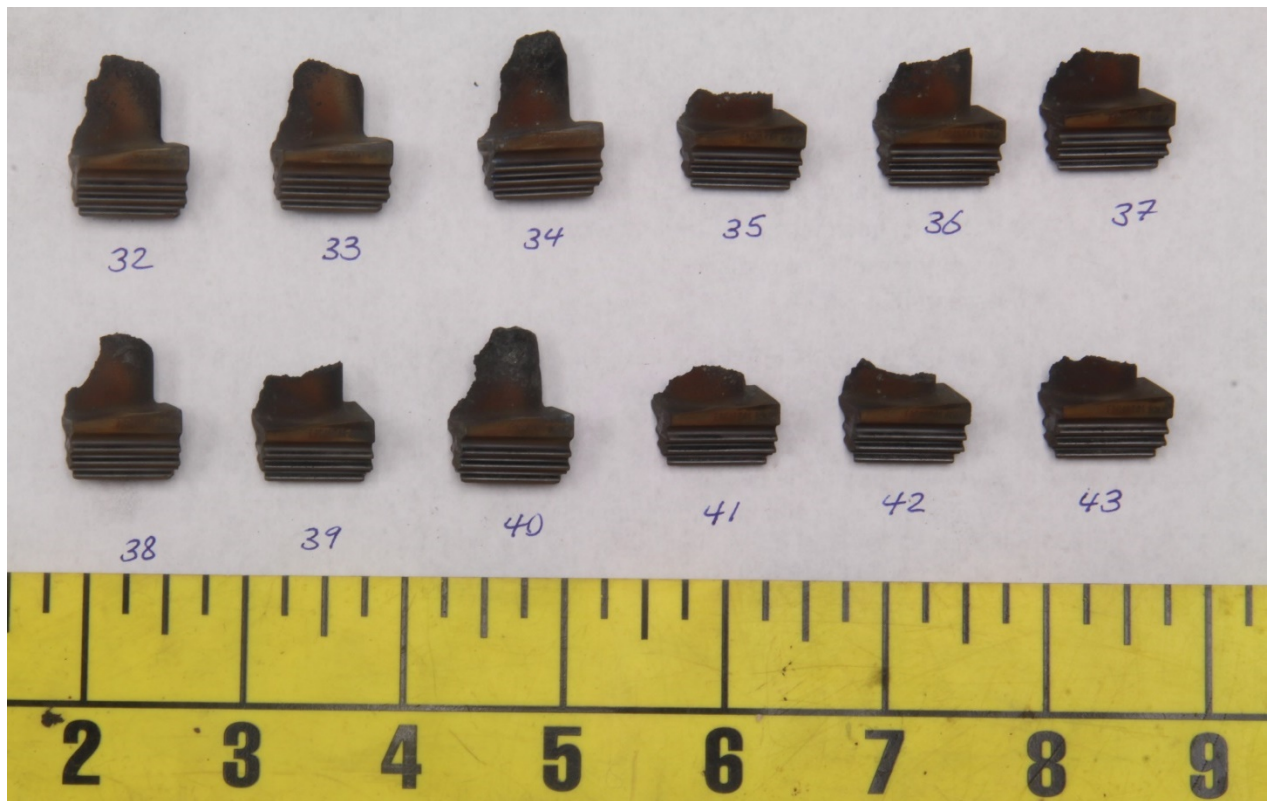


Figure B-4 – Fractured turbine blades 32 through 43, viewed from the convex side.

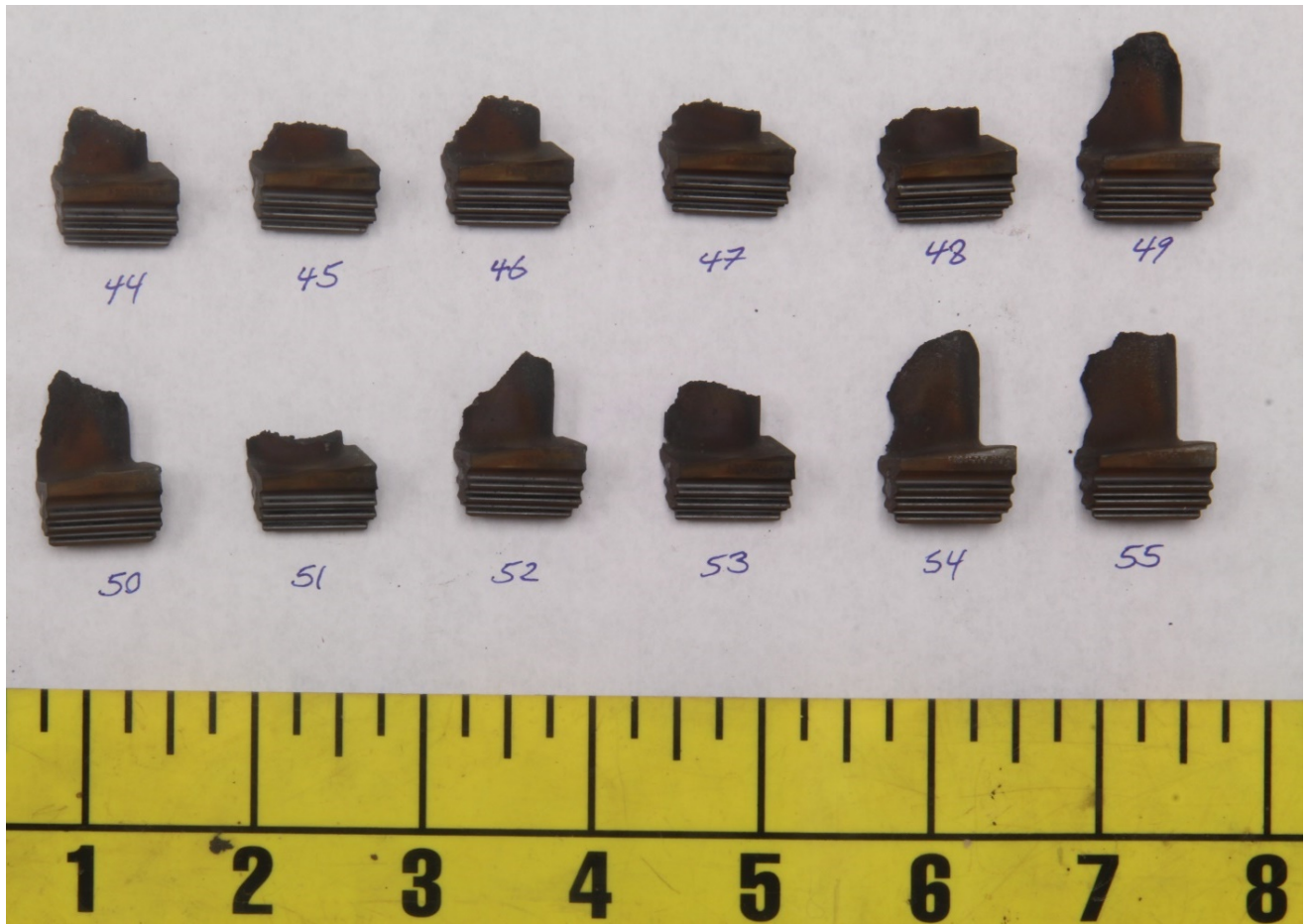


Figure B-5 – Fractured turbine blades 44 through 55, viewed from the convex side.

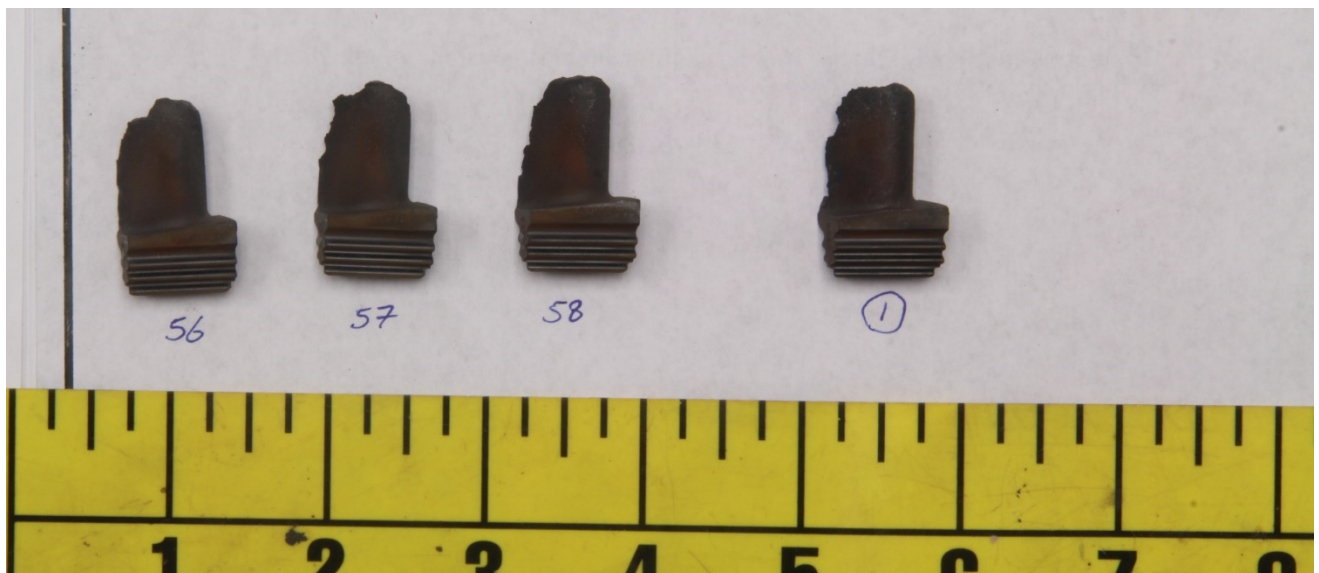


Figure B-6 – Fractured turbine blades 56 through 58, along with Blade 1, viewed from the convex side.

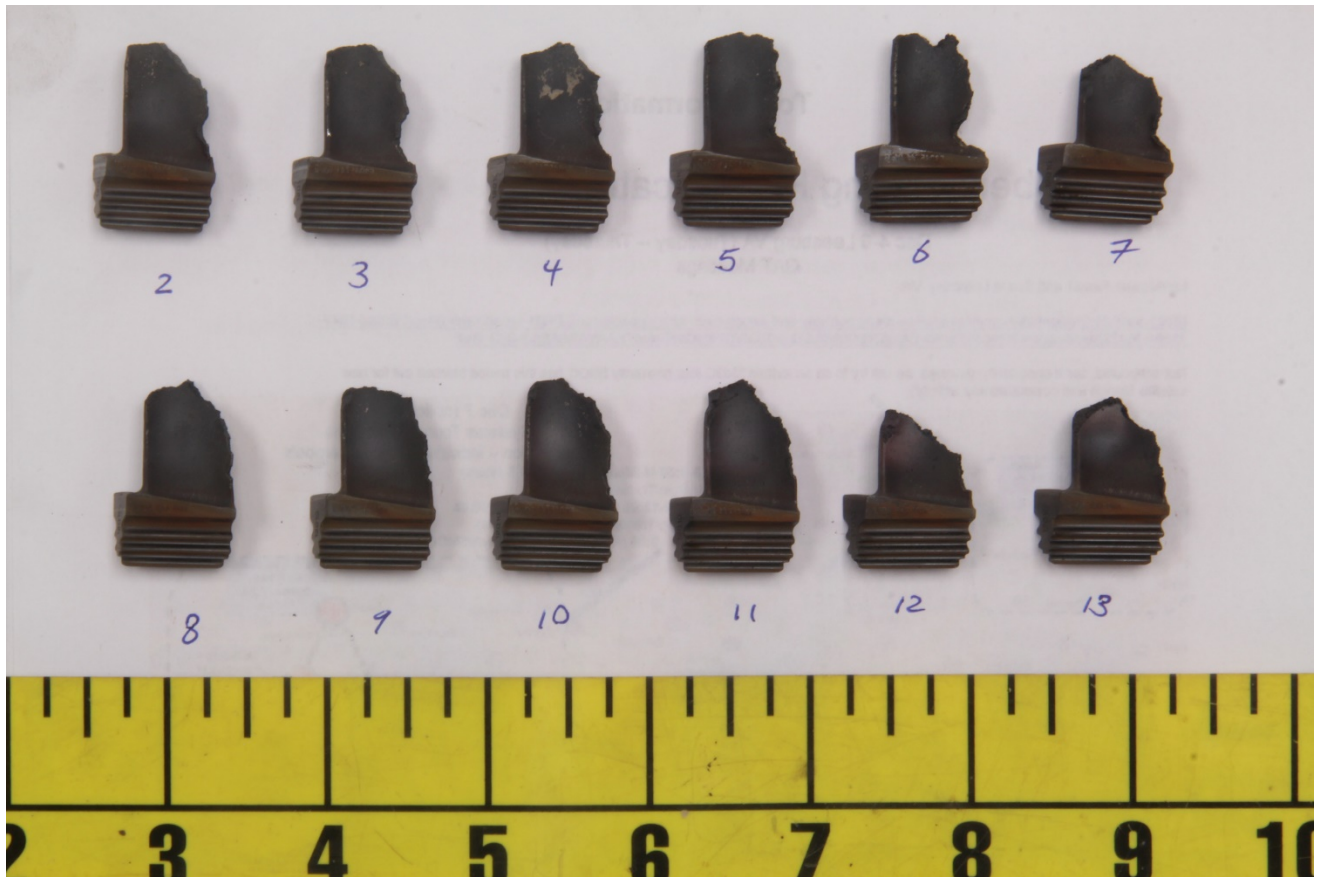


Figure B-7 – Fractured turbine blades 2 through 13, viewed from the concave side.



Figure B-8 – Fractured turbine blades 14 through 25, viewed from the concave side.

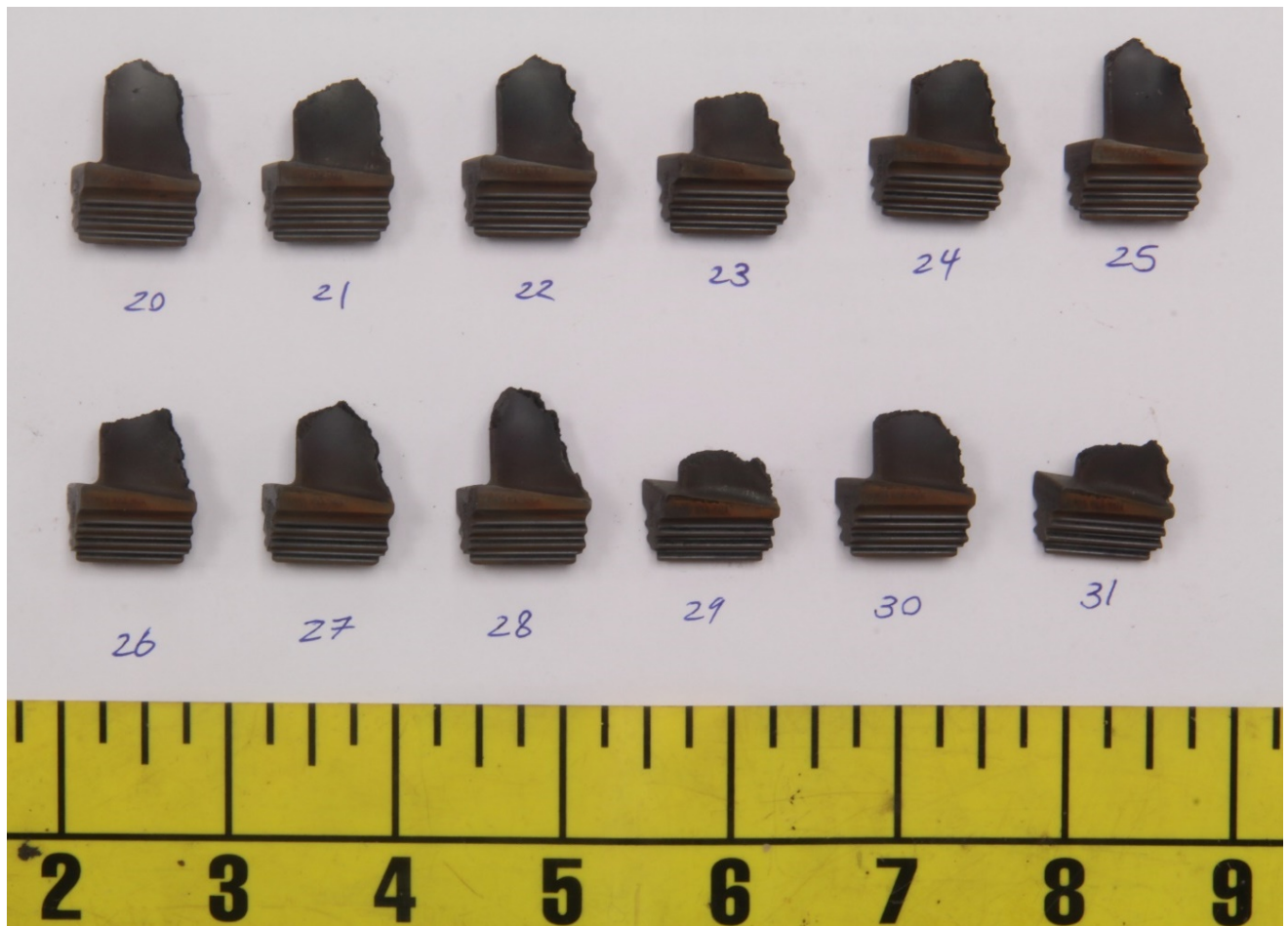


Figure B-9 – Fractured turbine blades 20 through 31, viewed from the concave side.

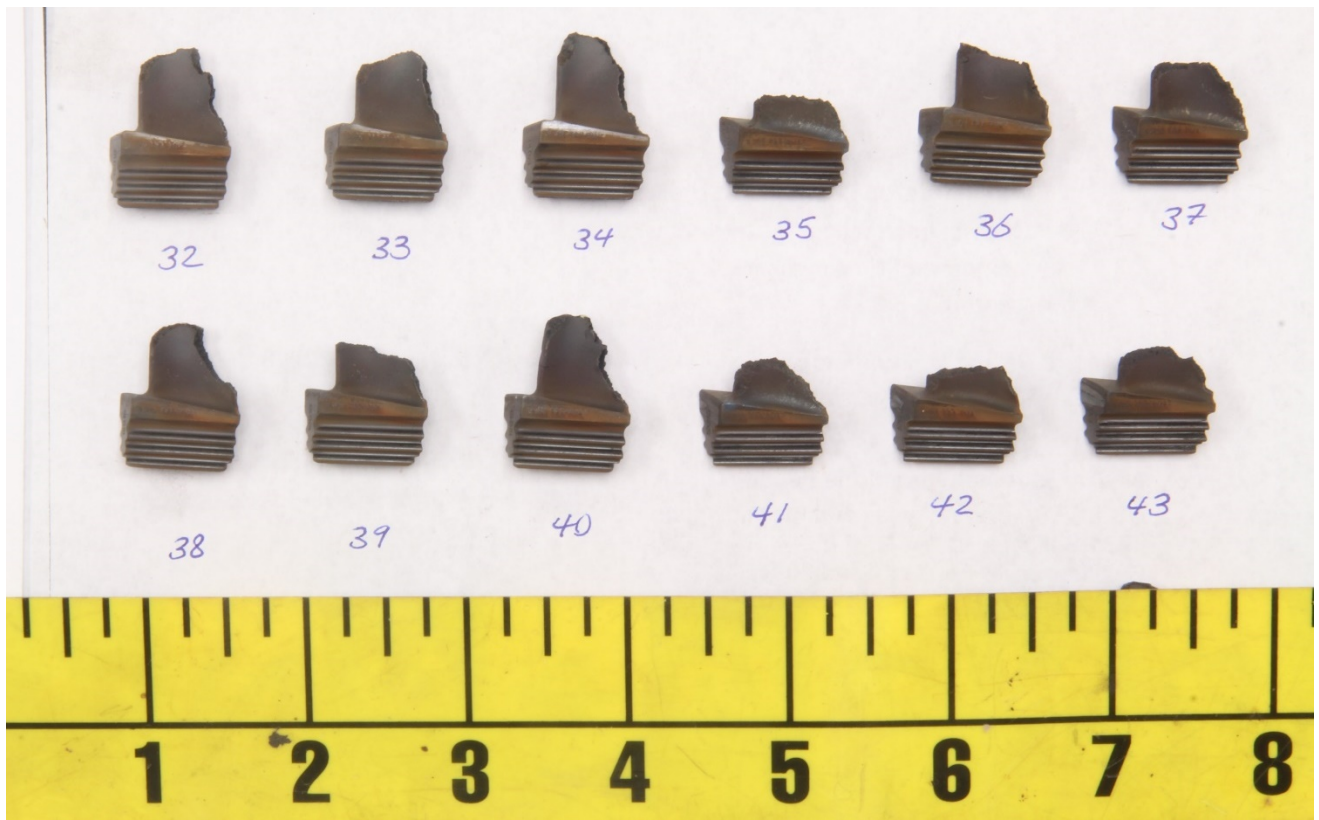


Figure B-10 – Fractured turbine blades 32 through 43, viewed from the concave side.

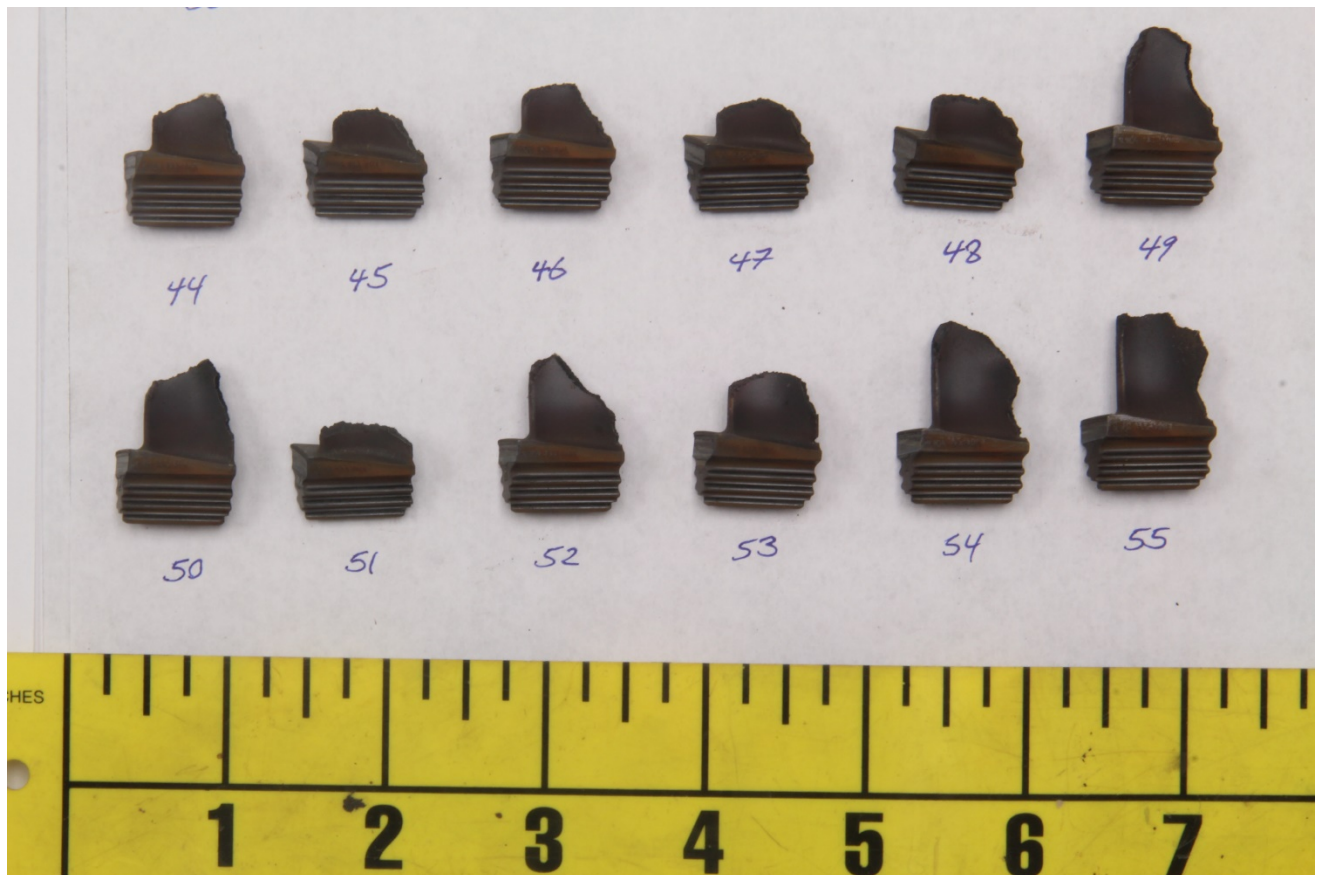


Figure B-11 – Fractured turbine blades 44 through 55, viewed from the concave side.

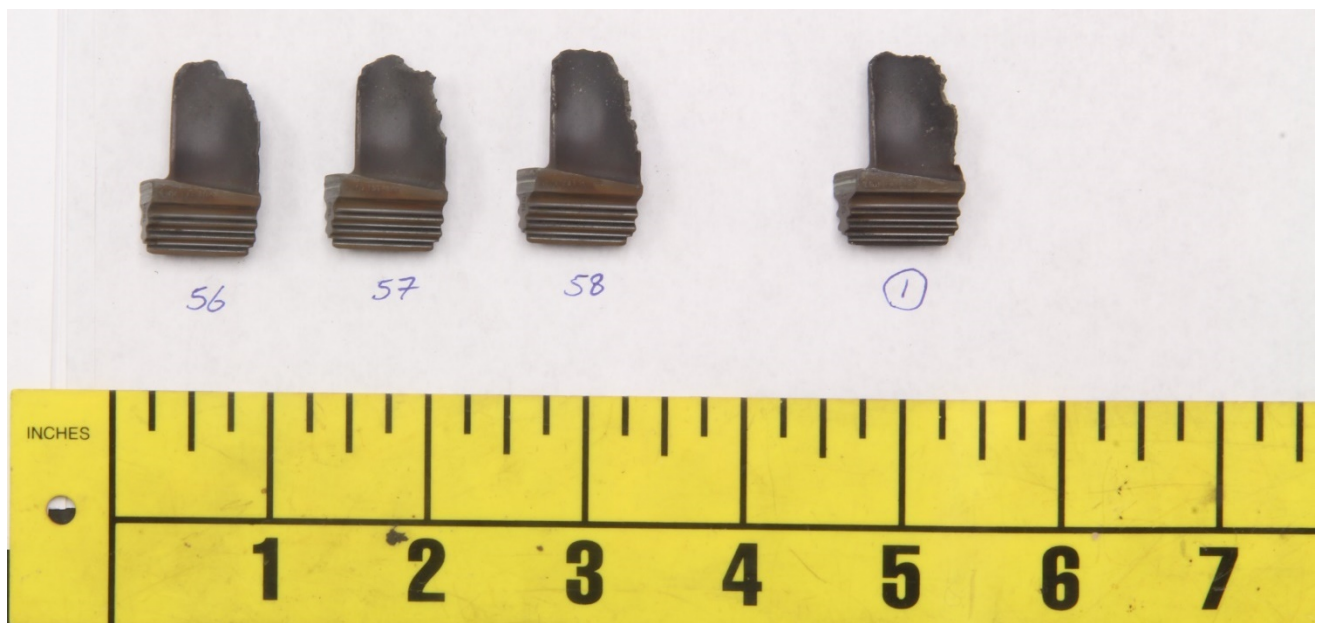


Figure B-12 – Fractured turbine blades 56 through 58, along with Blade 1, viewed from the concave side.