

NATIONAL TRANSPORTATION SAFETY BOARD

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



January 10, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 17-039

A. ACCIDENT INFORMATION

Place : Baltimore, Maryland
Date : January 23, 2017
Vehicle : Bombardier CRJ200, N8986B
NTSB No. : ENG17IA008
Investigator : Robert Hunsberger, AS-40

B. COMPONENTS EXAMINED

The following pieces from a GE CF34-3B1 turbofan engine, ESN: 873-642:

- 1) Fan blade with fractured forward, middle, and aft tangs (P/N: 6018T30P14, S/N: KGACA251, Cycles Since New: 18,063);
- 2) Inboard piece of middle tang;
- 3) Fan blade retention pin (P/N: 4029T16P17, S/N: SRCA4717).

C. DETAILS OF THE EXAMINATION

On January 23, 2017, about 1830 eastern standard time (EST), a Bombardier CRJ200, N8986B, operated by Endeavor Air sustained a No. 2 (right) engine fan blade separation during initial climb from Baltimore-Washington International Airport (BWI)-Baltimore, Maryland. The crew reported hearing a loud bang immediately followed by vibration and a No. 2 engine overtemperature warning. The crew returned to BWI and landed without incident.

The separated fan blade, the inboard piece of the middle tang,¹ and the blade retention pin (figure 1) were sent to the NTSB Materials Laboratory where a group examination was conducted from February 8, 2017 through February 10, 2017 with the following persons in attendance:

Donald Kramer, Ph.D. – Materials Engineer, NTSB
Robert Hunsberger – Aerospace Engineer, NTSB
Ron Duvelius – Failure Analysis, GE Aviation
Derek Wallraff – Fleet Technical Specialist, Endeavor Airlines
Eric West – Air Safety Investigator, FAA

¹ The inboard pieces of the forward and aft tangs were not recovered.

1. Visual examination

The CF34-3B1 fan blade has three tangs below the platform with a hole in the center of each tang to accommodate insertion of a retention pin. The retention pin also inserts through holes on the rim of the fan disk, thereby coupling the blades to the disk. On the accident fan blade, the forward and middle tangs were fractured through the pin holes at approximately the 3 o'clock and 9 o'clock positions, while the aft tang was fractured radially outboard of the pin hole, but below the platform, as shown in figures 1 – 3.² The forward tang fracture surfaces were generally oriented in the axial/circumferential plane and exhibited smeared metal deposits that were identified as aluminum using x-ray fluorescence spectroscopy. The middle tang fracture surfaces exhibited a similar appearance with the addition of 45° shear lips that were observed along the forward, aft, and outer edges of both the 3 o'clock and 9 o'clock positions. The aft tang exhibited torsion deformation and a 45° inclined fracture surface that was consistent with a ductile overstress fracture. The forward and aft faces of the tangs exhibited a dimpled appearance, consistent with applied shot peening. The pin hole surfaces adjacent to the fractures occasionally exhibited a burnished appearance consistent with pin contact.

The aluminum deposits were removed from the forward and middle tang fracture surfaces by sectioning the tang regions from the rest of the blade and immersing them in a 10% sodium hydroxide solution until the deposits were sufficiently removed to allow examination of the fracture surfaces in a scanning electron microscope (SEM). The fracture surfaces were cleaned by gentle scrubbing using an alkaline detergent and nylon bristle brush followed by immersion in an acetone-filled beaker placed in a sonicating bath. The cleaned fracture surfaces are shown in figures 4 – 7 for the forward tang 9 o'clock position, forward tang 3 o'clock position, middle tang 9 o'clock position, and middle tang 3 o'clock position, respectively.

All of the fracture surfaces exhibited curved crack arrest lines near the pin hole surface that were consistent with crack initiation at the pin hole. The arrest lines at the forward tang 9 o'clock position originated from a single origin located approximately 0.090 inch from the aft face of the tang. In contrast, at the other positions (figures 5 – 7), ratchet marks were observed along the pin hole edge, consistent with multiple initiation sites.

2. Electron microscope examination

The forward and middle tang fracture surfaces were examined by SEM. Each fracture surface exhibited regularly spaced striated features close to the pin hole surface that progressed away from the hole and toward the outer edge at their respective position, consistent with low cycle fatigue (LCF) (see figure 8 for an example of striations observed on the forward tang 9 o'clock position fracture surface). At increasing distance from the pin hole, the fracture surfaces transitioned to a smeared appearance where striations

² Clock positions for each pin hole were assigned with the blade oriented in a vertical upright orientation viewed aft looking forward.

could no longer be resolved and then transitioned to a ductile dimple appearance, consistent with tensile overstress. The fracture surfaces were examined close to the pin hole surfaces for any apparent microstructural anomalies that could have led to LCF crack initiation but none were found.

For each fracture surface, the striation density as a function of distance from the pin hole was measured in the LCF region on a series of SEM images starting at the pin hole and proceeding outward until the transition to the smeared region (cyclic tensile region). For the forward tang 9 o'clock position, the series was started at the single origin, 0.090 inch from the aft face of the tang. For the other straps, the series was taken where visual LCF crack arrest lines were observed furthest from the pin hole: 0.131 inch from the forward face for the forward tang 3 o'clock position, 0.330 inch from the forward face for the middle tang 9 o'clock position, and 0.106 inch from the forward face for the middle tang 3 o'clock position. The images used for the striation density measurements are included in appendix A and the density measurements are shown in tables 1 through 4. The density was measured by counting a series of successive striation marks on an SEM image and dividing by the distance spanned by those striations.

3. Microstructure evaluation near pin hole

The material microstructure adjacent to the pinhole and the fracture surface at each position was examined for any apparent microstructural anomalies. The tang fractures were cross-sectioned, mounted, ground, and polished in accordance with laboratory procedure. The tang fractures were sectioned off to one side of the desired plane of polish, which was the same location chosen for the SEM striation counting reported above in section 2. The distance from the section plane to the desired plane of polish was measured using a digital optical microscope. After each sample was mounted, the thickness of the mount was measured with a micrometer. The thickness of the mount was monitored as material was removed by grinding until the plane of polish was within approximately 0.005 inch of the desired location. The mounted samples were then processed through final grinding and polishing. According to GE, the blade was manufactured from 2-inch diameter wrought barstock of alloy Ti-8Al-1Mo-1V. The polished samples were thus etched with Kroll's reagent (92 parts water, 6 parts nitric acid, 2 parts hydrofluoric acid) for titanium and titanium alloys.

The etched cross sections are shown in figures 9 – 12 for the forward tang 9 o'clock position, forward tang 3 o'clock position, middle tang 9 o'clock position, and middle tang 3 o'clock position, respectively. Examination of the etched cross sections revealed the following:

1. There was visually apparent microstructural texture at the forward tang 9 o'clock position as indicated in figure 9a;
2. There was one apparent surface crack at the middle tang 9 o'clock position pin hole as indicated in figure 11a;
3. There were multiple surface cracks at the middle tang 3 o'clock position pin hole as indicated in figure 12a;

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4. There were no indications of heavily deformed microstructure along the pin hole surfaces as seen in figures 9b, 10b, 11b, and 12b.

See the GE Metallurgical Investigation Report in Appendix B for additional material characterization.

4. Dimensional measurements

Dimensional attributes of the fan blade tangs and the pin were measured using micrometers, or calipers when necessary, with the following results:

- Forward tang thickness, 9 o'clock position – 0.303 inch;
- Forward tang thickness, 3 o'clock position – 0.304 inch;
- Middle tang thickness, 9 o'clock position – 0.599 inch;
- Middle tang thickness, 3 o'clock position – 0.599 inch;
- Forward face of forward tang to aft face of middle tang distance – 9 o'clock side – 1.762 inch;
- Forward face of forward tang to aft face of middle tang distance – 3 o'clock side – 1.763 inch;
- Pin diameter near forward collar – 0.7455 inch;
- Pin diameter near aft end – 0.7451 inch.

The forward tang thickness at the 9 o'clock and 3 o'clock positions exceeded the maximum thickness limit by 0.001 inch and 0.002 inch, respectively. The remaining dimensional attributes were in accordance with their respective requirements.

The forward and middle tang hole diameters were measured on the outboard half of the tang using a tabletop coordinate measurement machine (CMM) equipped with 3-mm diameter alumina touch probe with a single point precision of 0.020 mm. The diameter measurements were as follows:

- Forward tang: diameter – 0.7514 inch; form – 0.0006 inch;
- Middle tang: diameter – 0.7508 inch; form – 0.0007 inch.

Both diameter measurements were within the maintenance manual maximum diameter allowance of 0.7535 inch and within the instrument's measurement error of the maximum new make maximum diameter.

Donald Kramer, Ph.D.
Sr. Materials Engineer

Table 1: Striation count and density data for the forward tang 9 o'clock position.

Distance from pinhole, inch	N	Distance, μm	Density, $\text{N}/\mu\text{m}$	Density, N/inch
0.023	13	6.738	1.929	49010
0.023	10	5.513	1.814	46070
0.029	9	5.227	1.722	43730
0.029	9	5.698	1.580	40120
0.029	8	5.091	1.571	39910
0.036	7	7.644	0.916	23260
0.036	8	8.763	0.913	23190
0.036	5	4.319	1.158	29400
0.044	6	4.801	1.250	31740
0.044	8	6.024	1.328	33730
0.053	5	5.742	0.8708	22120
0.053	10	11.70	0.8544	21700
0.072	6	11.27	0.5326	13530
0.072	7	10.76	0.6503	16520
0.103	5	13.54	0.3693	9390
0.103	3	6.780	0.4425	11240
0.103	6	10.34	0.5803	14740
0.112	4	10.92	0.3663	9304
0.112	11	29.82	0.3689	9370
0.112	5	11.39	0.4390	11150
0.120	5	14.07	0.3554	9026
0.141	4	17.60	0.2273	5773
0.141	4	16.65	0.2402	6102
0.150	—	—	—	—

Table 2: Striation count and density data for the forward tang 3 o'clock position.

Distance from pinhole, inch	N	Distance, μm	Density, $\text{N}/\mu\text{m}$	Density, N/inch
0.013	5	11.75	0.4255	10810
0.013	4	11.26	0.3552	9022
0.013	3	5.81	0.516	13100
0.020	5	11.76	0.4252	10800
0.020	5	12.11	0.4129	10490
0.020	4	9.96	0.402	10200
0.026	4	13.70	0.2920	7417
0.026	3	8.27	0.363	9215
0.037	6	19.65	0.3053	7755
0.037	6	19.00	0.3158	8021
0.046	5	19.49	0.2565	6515
0.046	4	15.10	0.2649	6728
0.063	3	12.95	0.2317	5885
0.063	4	15.12	0.2646	6721
0.070	—	—	—	—

Table 3: Striation count and density data for the middle tang 9 o'clock position.

Distance from pinhole, inch	N	Distance, μm	Density, $\text{N}/\mu\text{m}$	Density, N/inch
0.006	6	1.966	3.052	77520
0.006	7	2.043	3.426	87020
0.014	6	5.189	1.156	29360
0.014	7	5.994	1.168	29670
0.014	6	4.290	1.399	35530
0.020	4	7.651	0.5228	13280
0.020	5	8.011	0.6241	15850
0.020	7	9.987	0.7009	17800
0.026	7	13.63	0.5137	13050
0.026	9	15.36	0.5858	14880
0.034	5	14.21	0.3519	8938
0.034	4	7.730	0.5175	13140
0.035	11	20.18	0.5452	13850
0.039	5	11.44	0.4371	11100
0.039	4	7.410	0.5398	13710
0.045	7	18.47	0.379	9627
0.045	5	11.28	0.4433	11260
0.052	—	—	—	—

Table 4: Striation count and density data for the middle tang 3 o'clock position.

Distance from pinhole, inch	N	Distance, μm	Density, $\text{N}/\mu\text{m}$	Density, N/inch
0.012	6	3.575	1.678	42620
0.012	10	6.235	1.604	40740
0.014	5	6.265	0.7981	20270
0.014	6	6.927	0.8662	22000
0.014	8	10.70	0.7475	18990
0.019	8	11.33	0.7063	17940
0.019	7	9.325	0.7507	19070
0.019	13	17.74	0.7330	18620
0.022	5	10.05	0.4975	12640
0.022	4	8.560	0.4673	11870
0.022	5	10.80	0.4630	11760
0.032	7	17.20	0.4070	10340
0.032	4	7.820	0.5115	12990
0.032	5	9.750	0.5128	13030
0.037	7	18.85	0.3714	9434
0.037	5	12.89	0.3879	9853
0.045	—	—	—	—

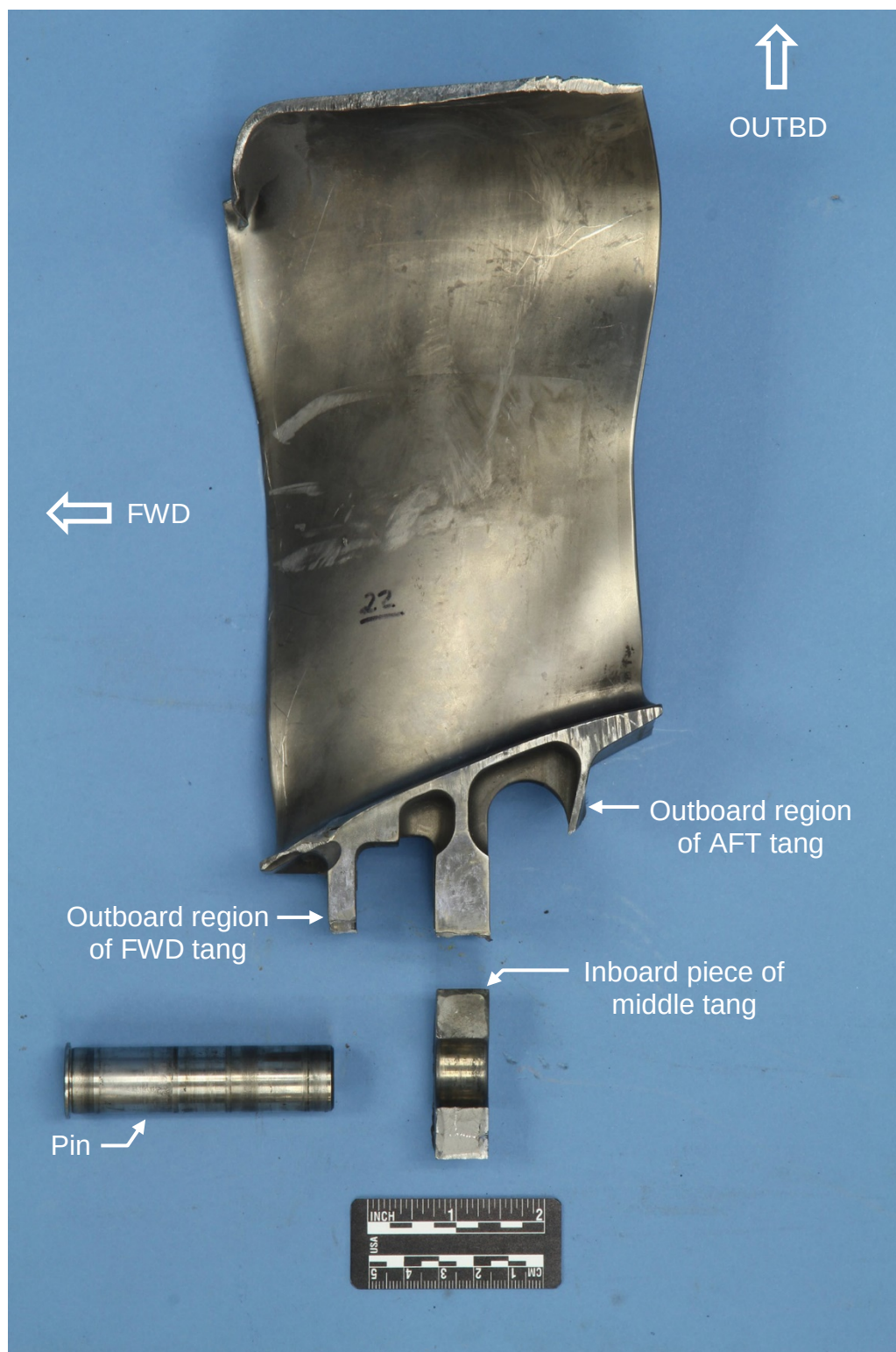


Figure 1: The outboard portion of the fan blade, inboard portion of the middle tang, and the retention pin, as received.

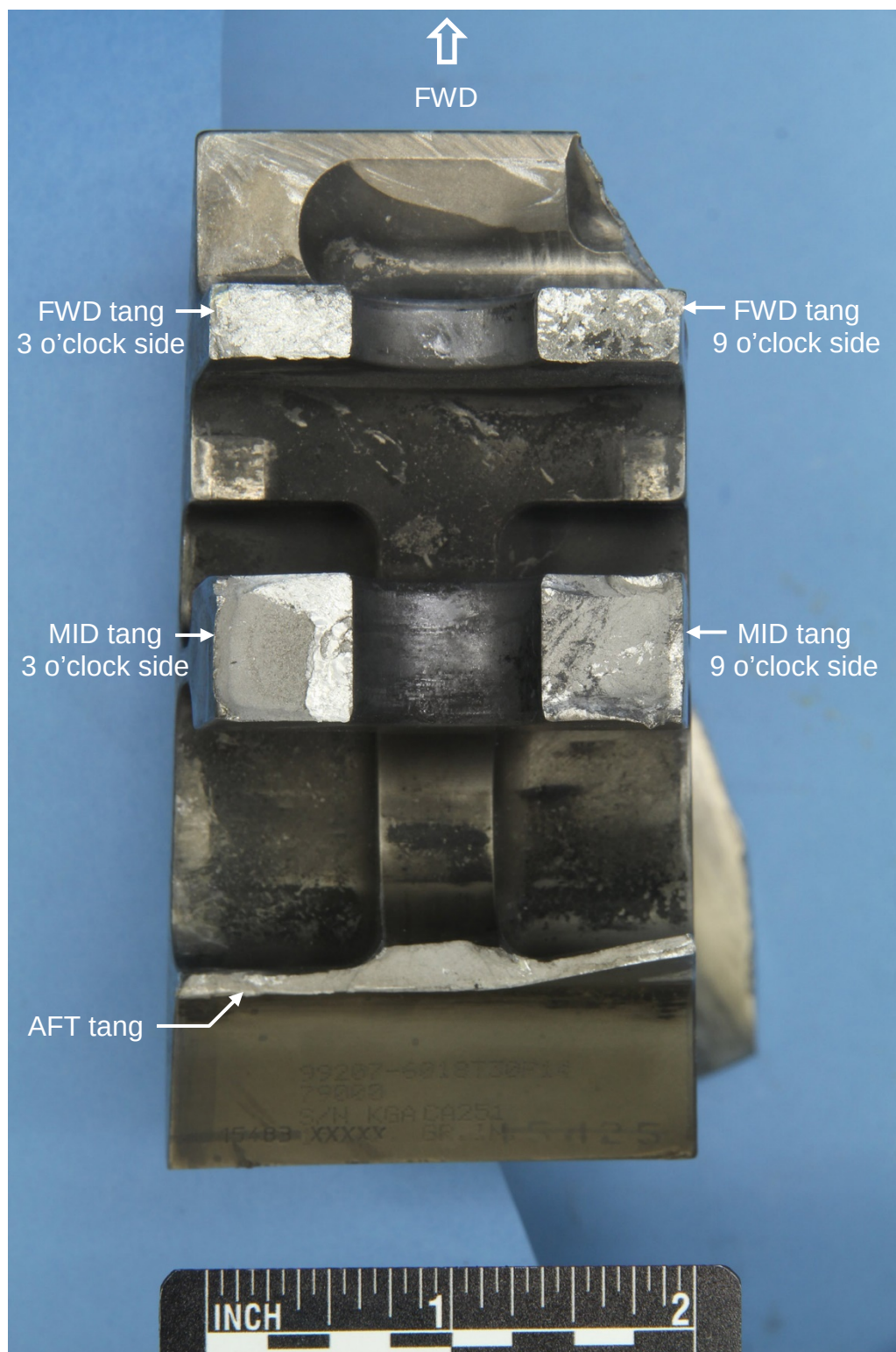


Figure 2: Image of the fractured fan blade tangs viewed looking radially outward. Smeared aluminum deposits were observed on the forward and middle tangs.



Figure 3: a) Image of the outboard portion of the fractured forward tang, viewed forward looking aft and b) image of the inboard portion of the fractured middle tang, viewed aft looking forward.

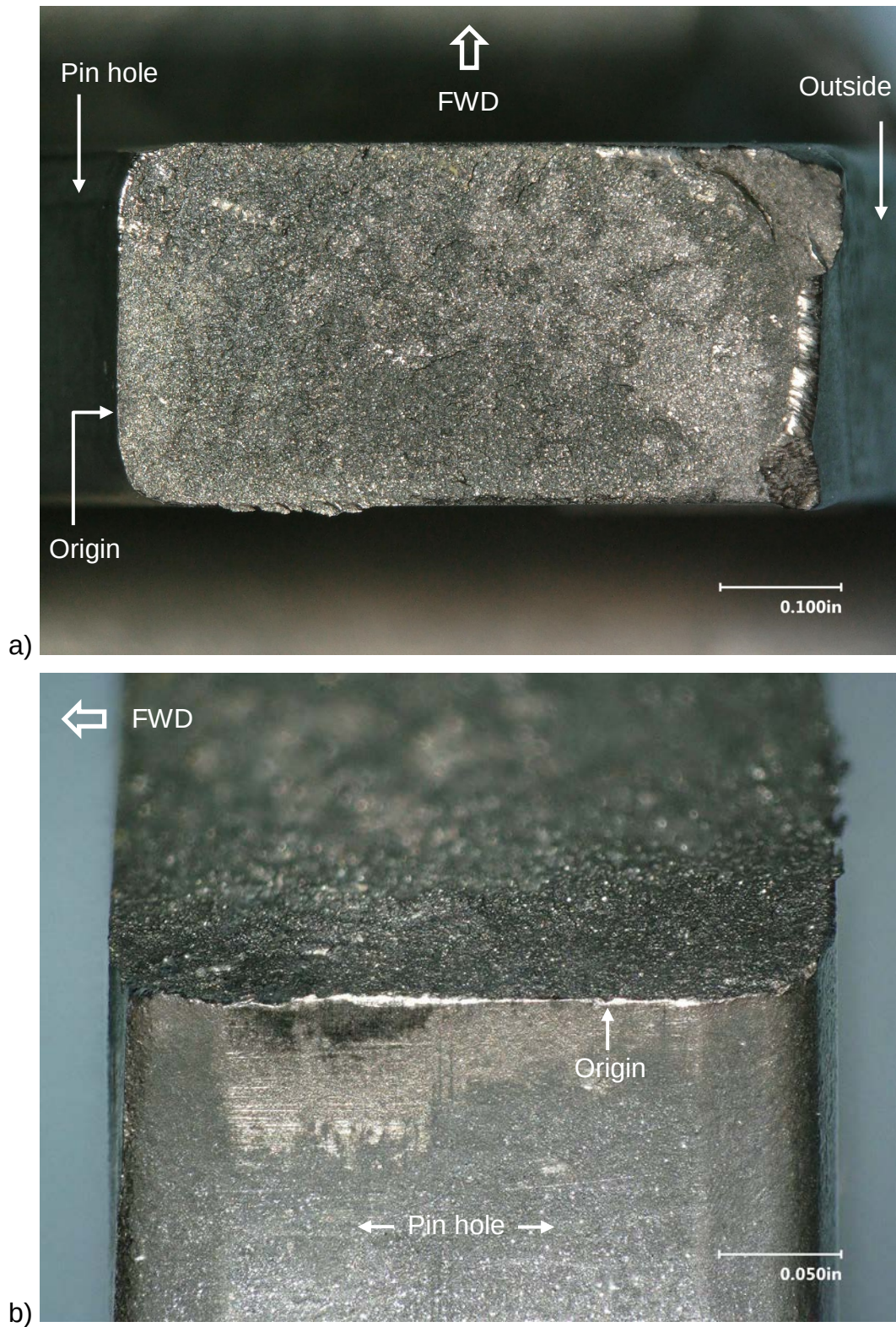


Figure 4: Images of the forward tang 9 o'clock position fracture surface after cleaning: a) image of the fracture surface, viewed looking radially outward and b) inclined view showing the intersection of the fracture with the pin hole.

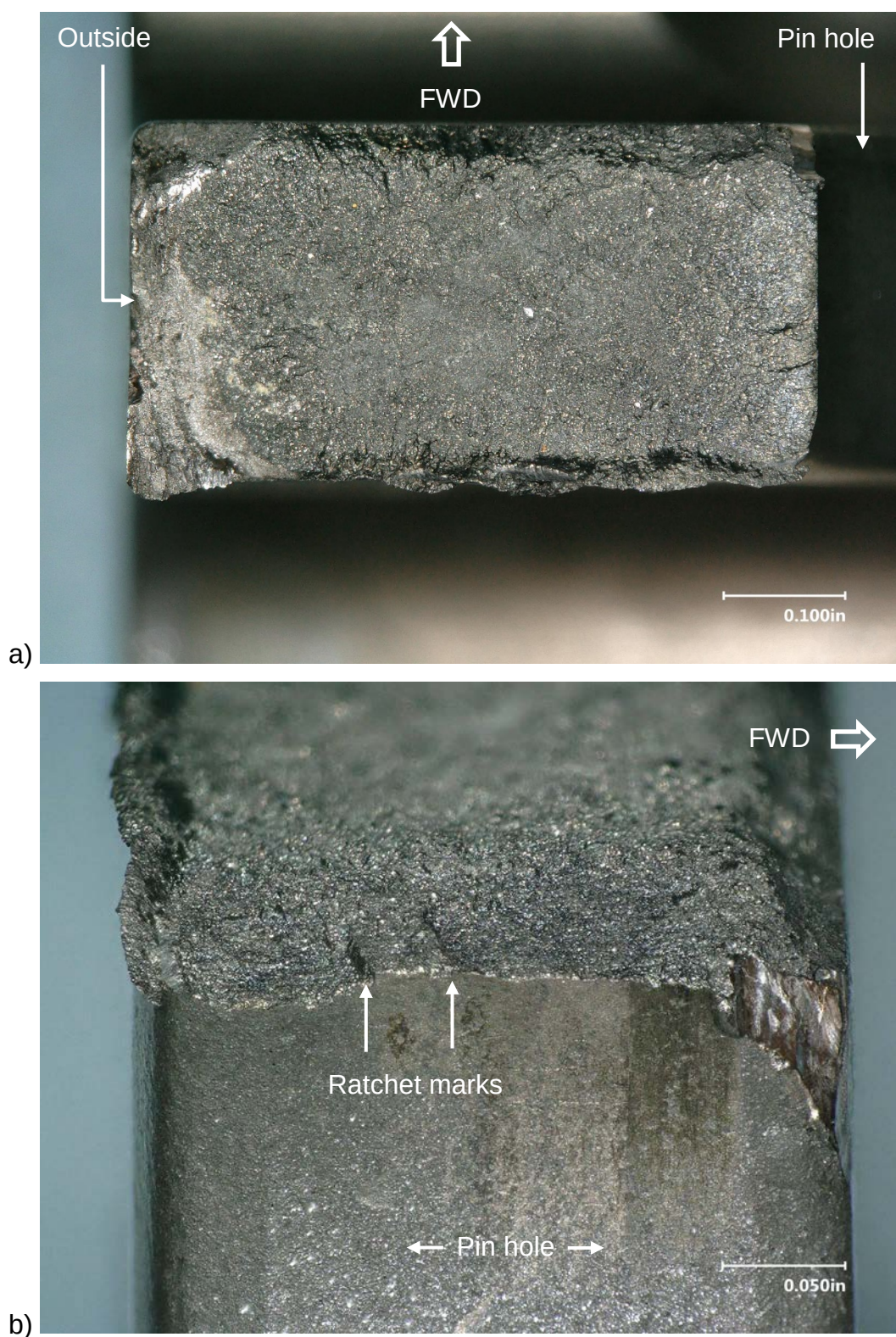


Figure 5: Images of the forward tang 3 o'clock position fracture surface after cleaning: a) image of the fracture surface, viewed looking radially outward and b) inclined view showing the intersection of the fracture with the pin hole.

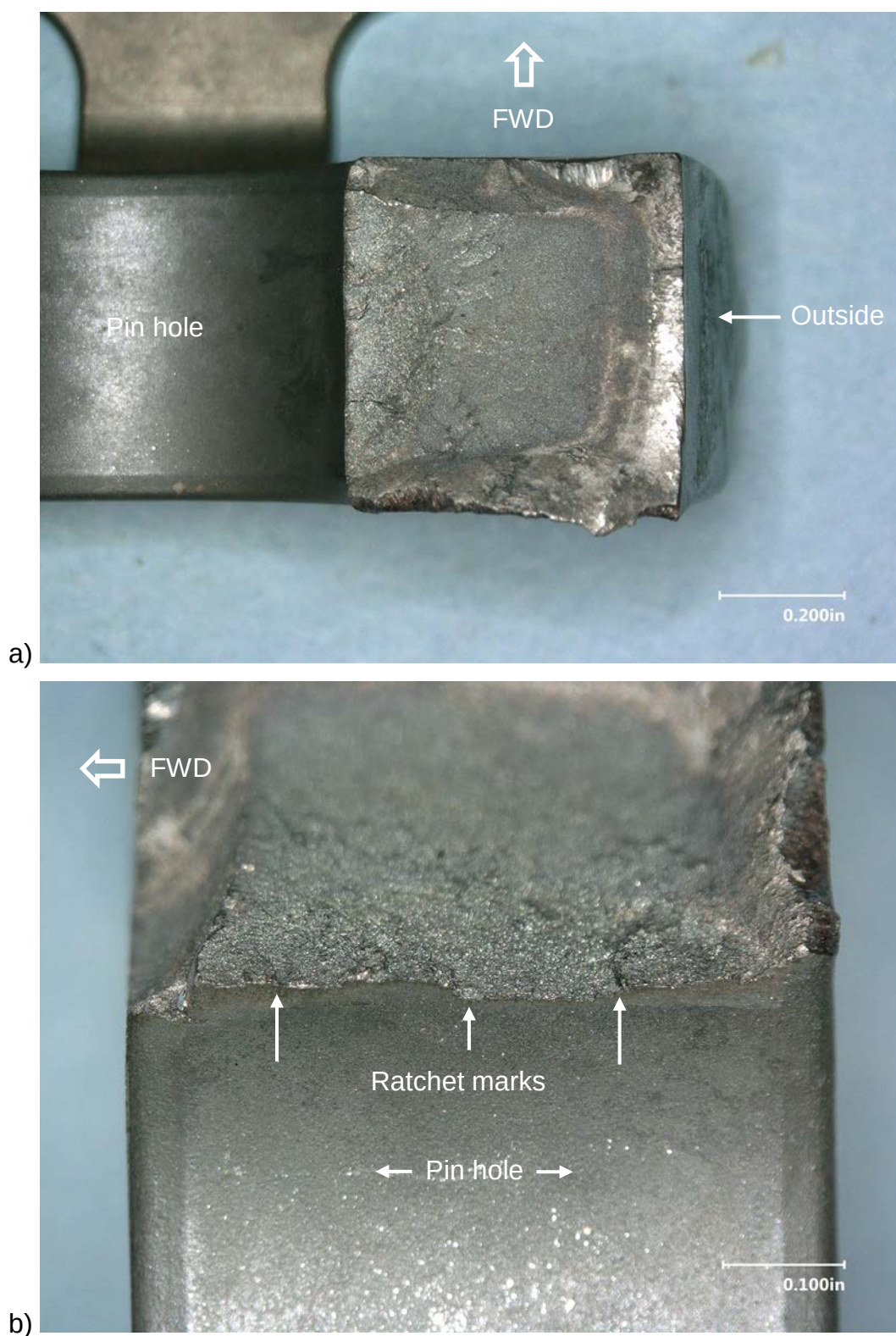


Figure 6: Images of the middle tang 9 o'clock position fracture surface after cleaning: a) image of the fracture surface, viewed looking radially outward and b) inclined view showing the intersection of the fracture with the pin hole.

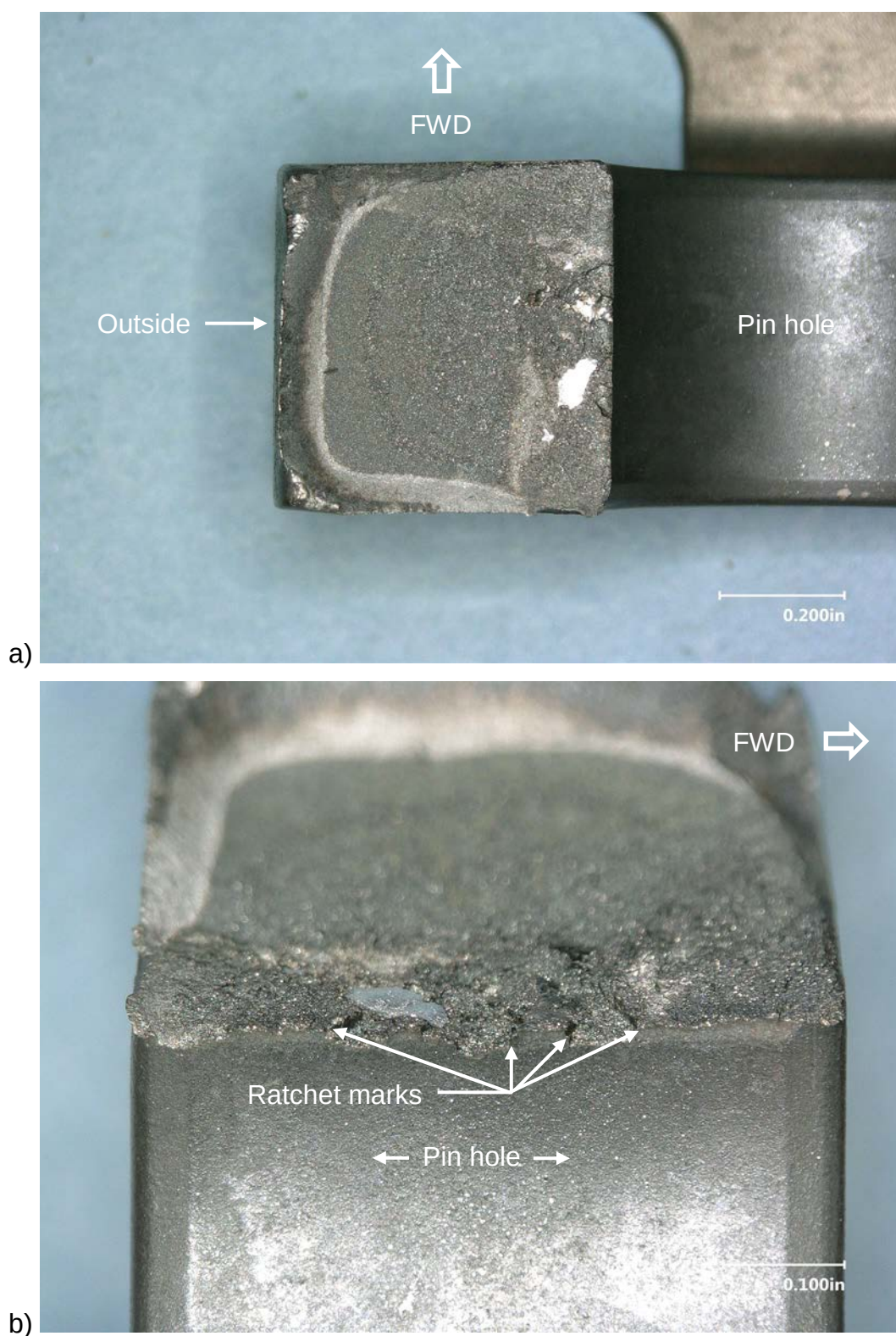


Figure 7: Images of the middle tang 3 o'clock position fracture surface after cleaning: a) image of the fracture surface, viewed looking radially outward and b) inclined view showing the intersection of the fracture with the pin hole.

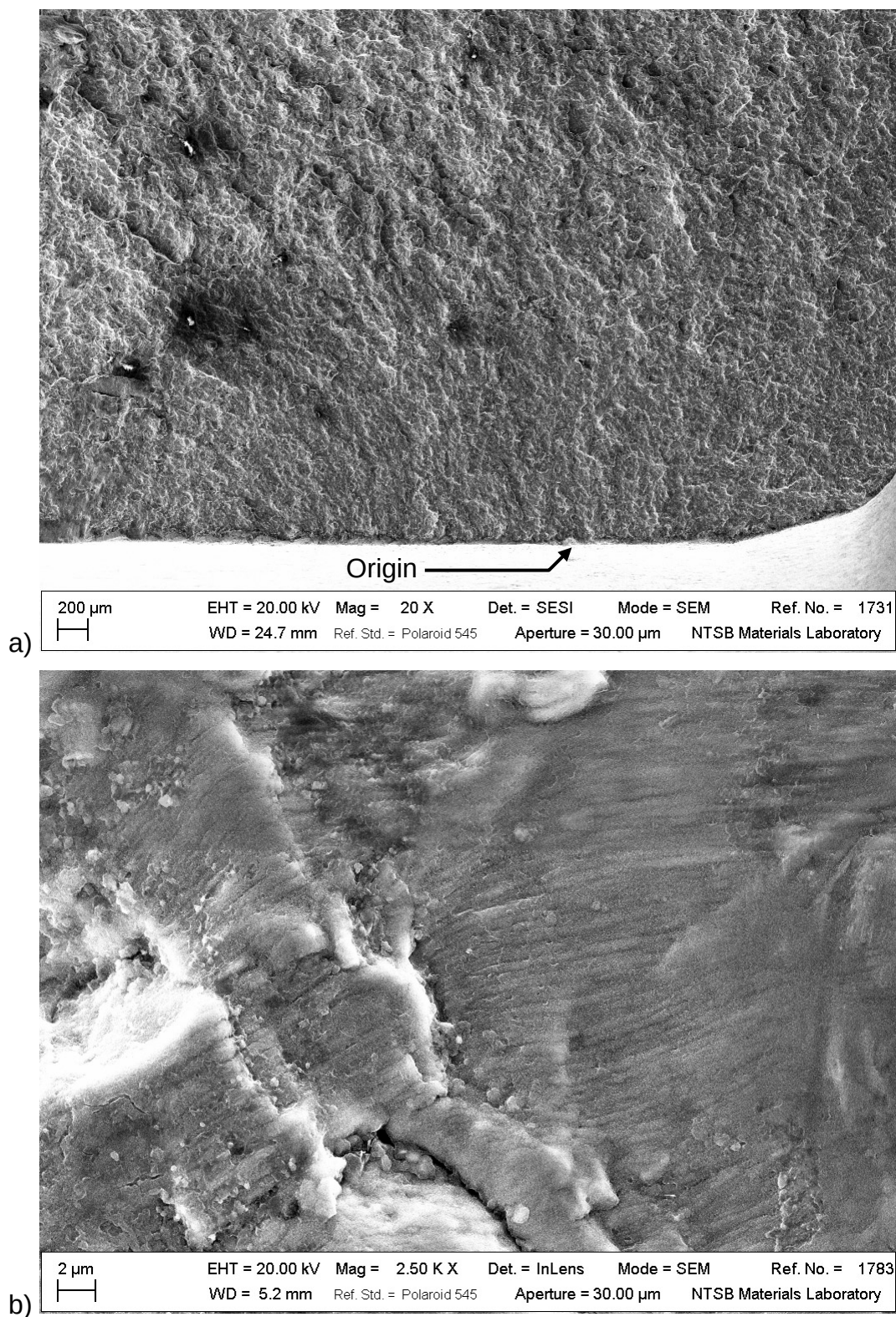


Figure 8: Scanning electron microscope images of the forward tang 9 o'clock position fracture surface: a) Image of the origin area and b) image taken 0.023 inch from the pin hole surface showing fatigue striations.

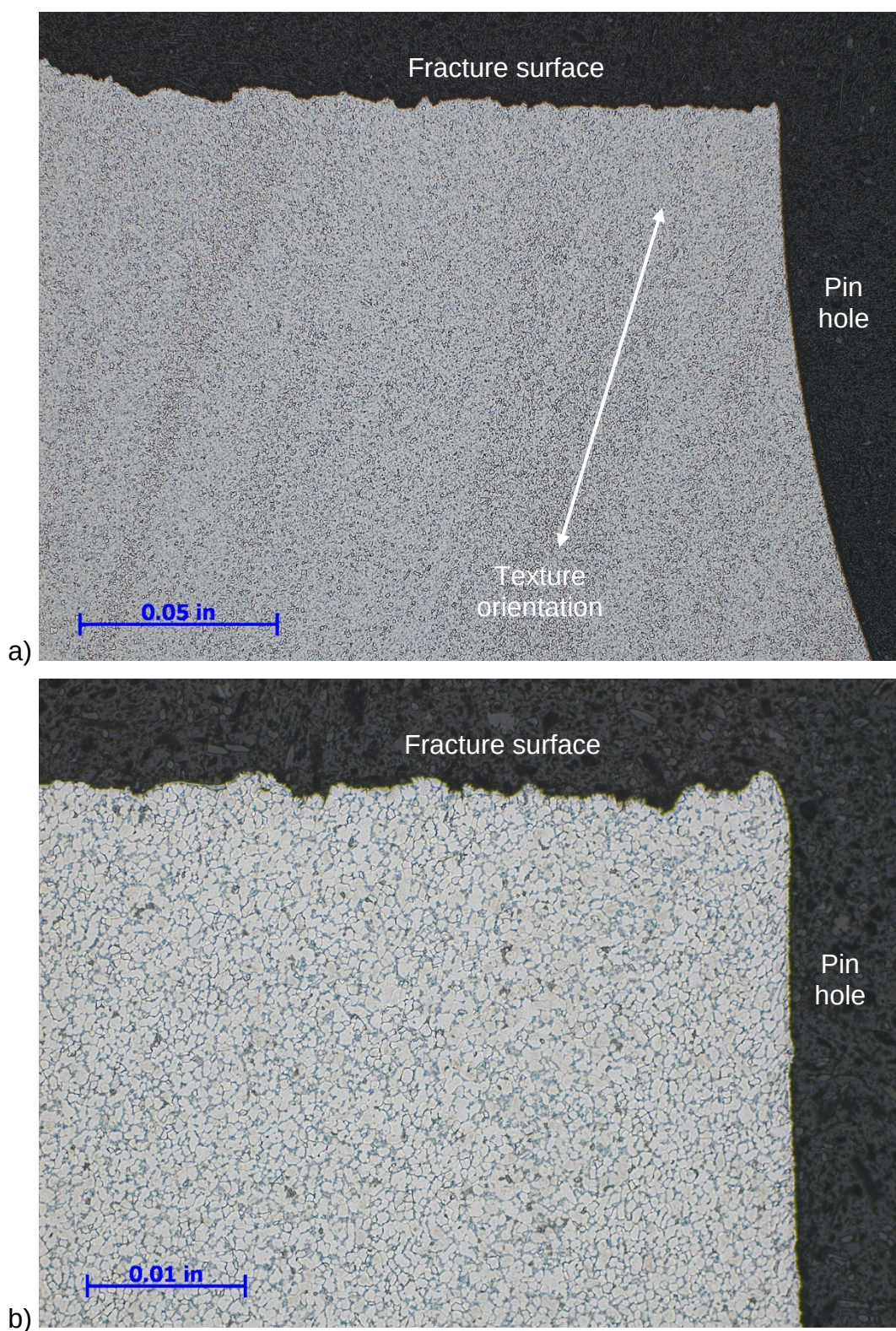


Figure 9: Polished and etched metallographic cross sections at the forward tang 9 o'clock position (Kroll's reagent): a) 25X objective image showing texture orientation and b) 100X objective image showing material condition along pin hole.

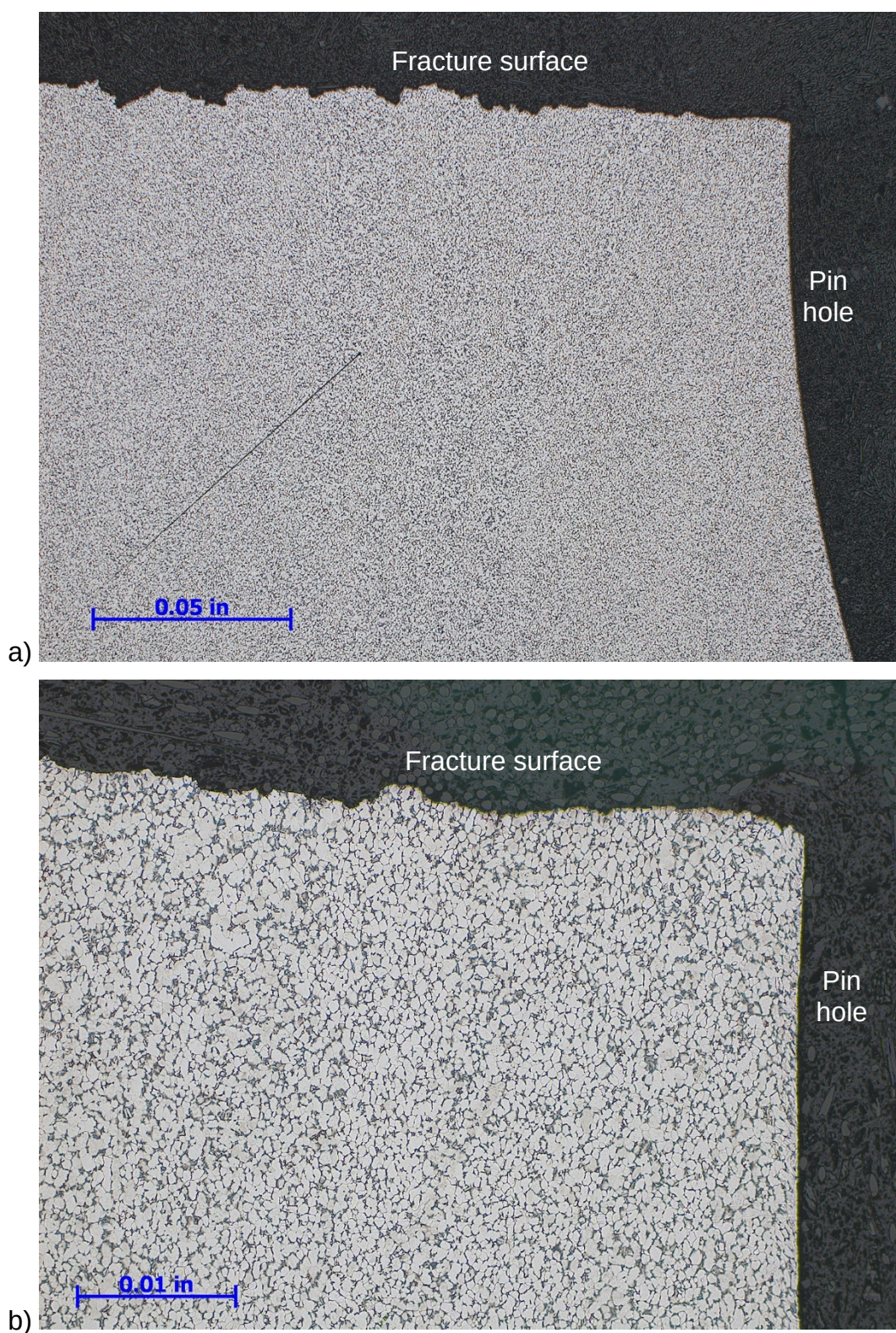


Figure 10: Polished and etched metallographic cross sections at the forward tang 3 o'clock position (Kroll's reagent): a) 25X objective image showing no apparent texture and b) 100X objective image showing material condition along pin hole.

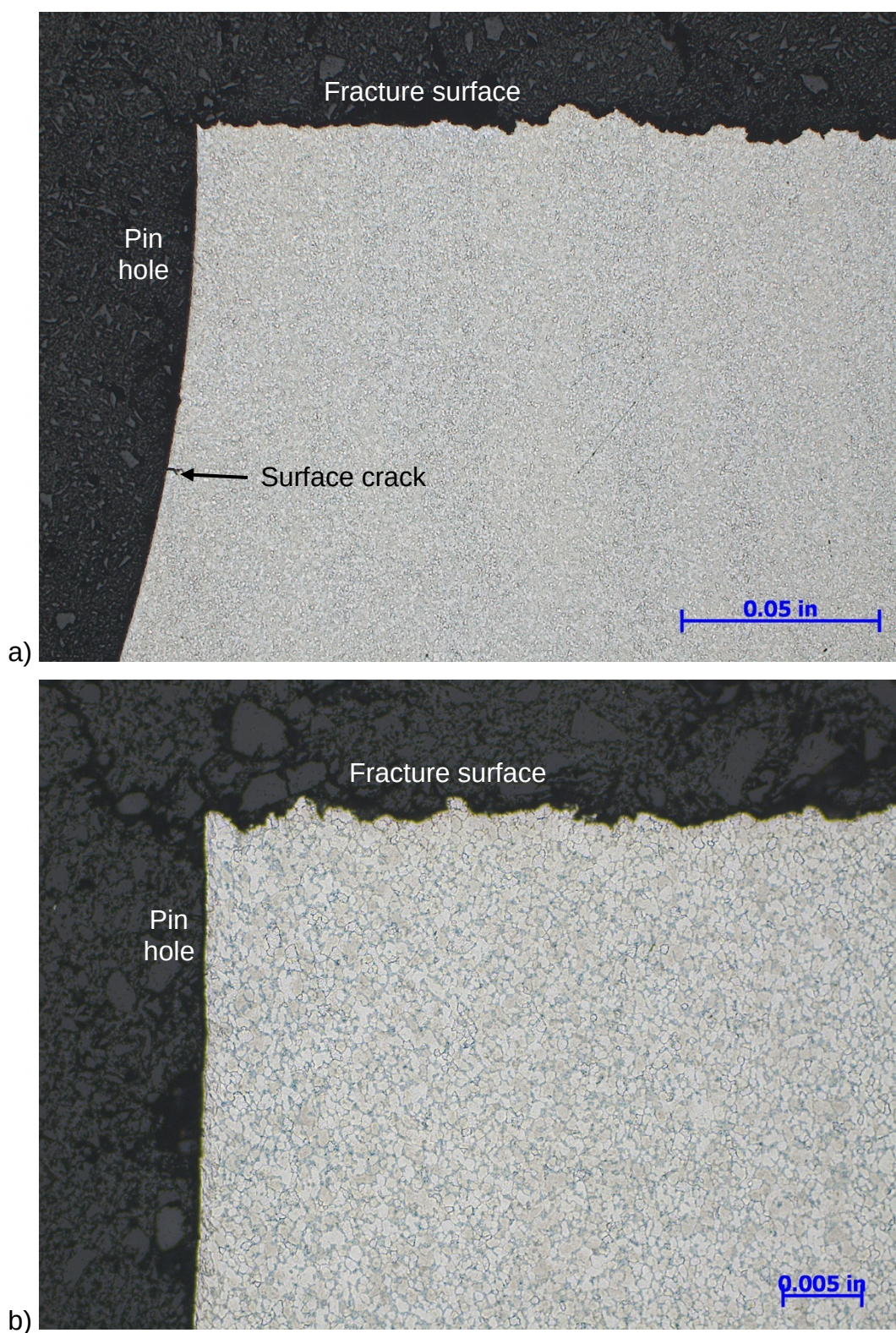


Figure 11: Polished and etched metallographic cross sections at the middle tang 9 o'clock position (Kroll's reagent): a) 25X objective image showing no apparent texture and one surface crack and b) 100X objective image showing material condition along pin hole.

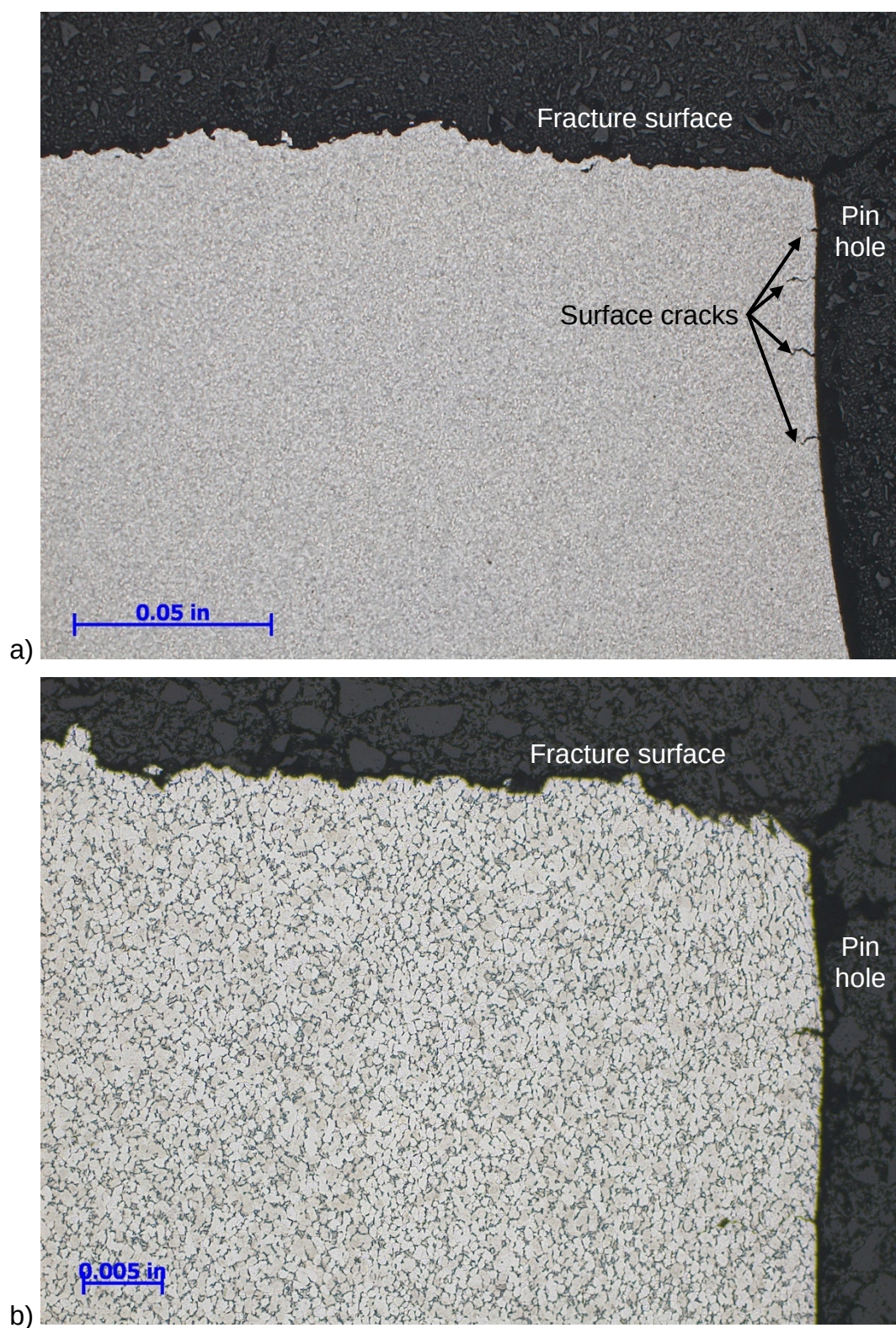
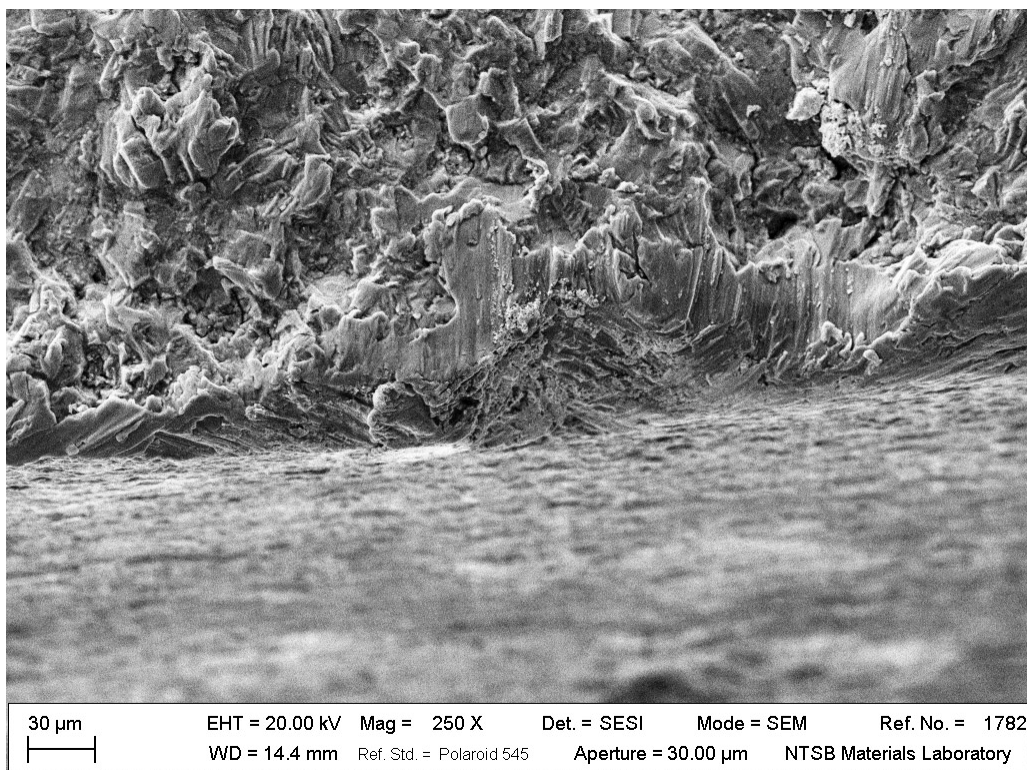
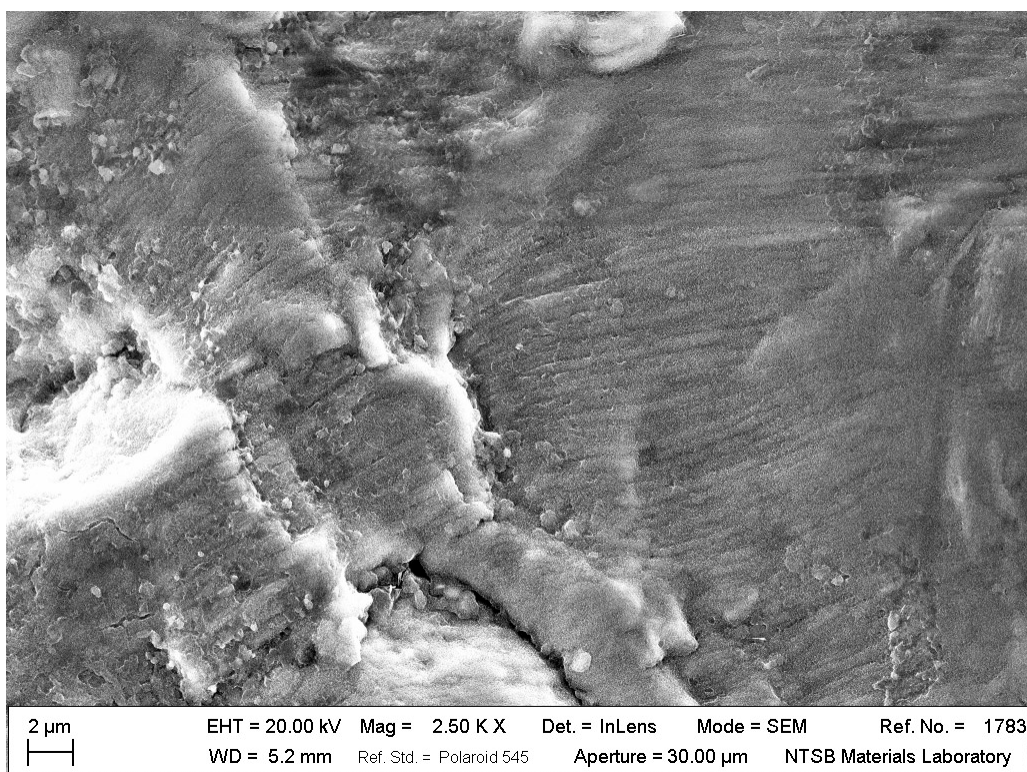


Figure 12: Polished and etched metallographic cross sections at the middle tang 3 o'clock position (Kroll's reagent): a) 25X objective image showing no apparent texture and multiple surface cracks and b) 100X objective image showing material condition along pin hole.

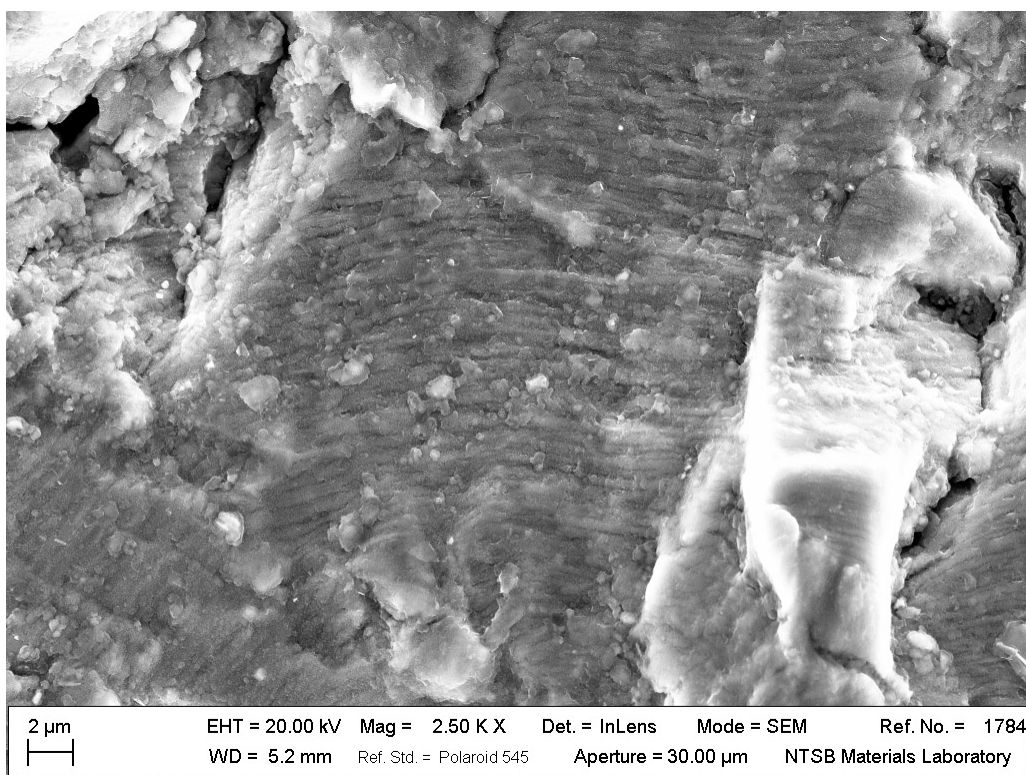
**APPENDIX A: SCANNING ELECTRON MICROSCOPE IMAGES USED FOR STRIATION
DENSITY MEASUREMENTS**

A.1. Forward tang 9 o'clock position

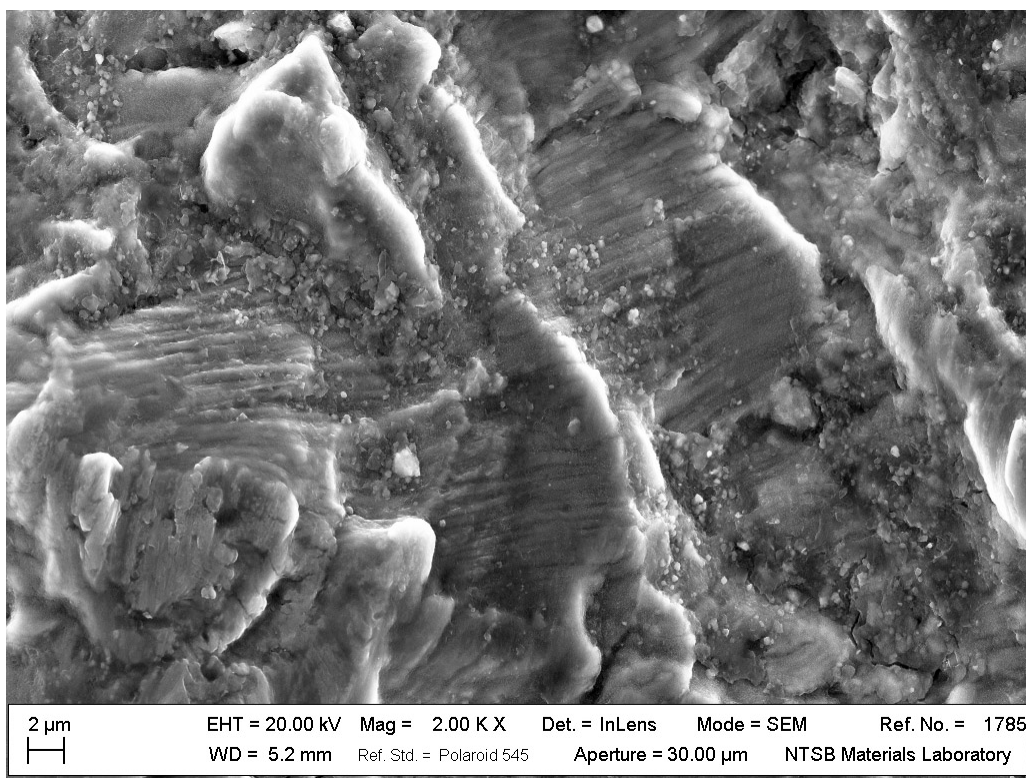
Distance along crack path = 0.000 inch



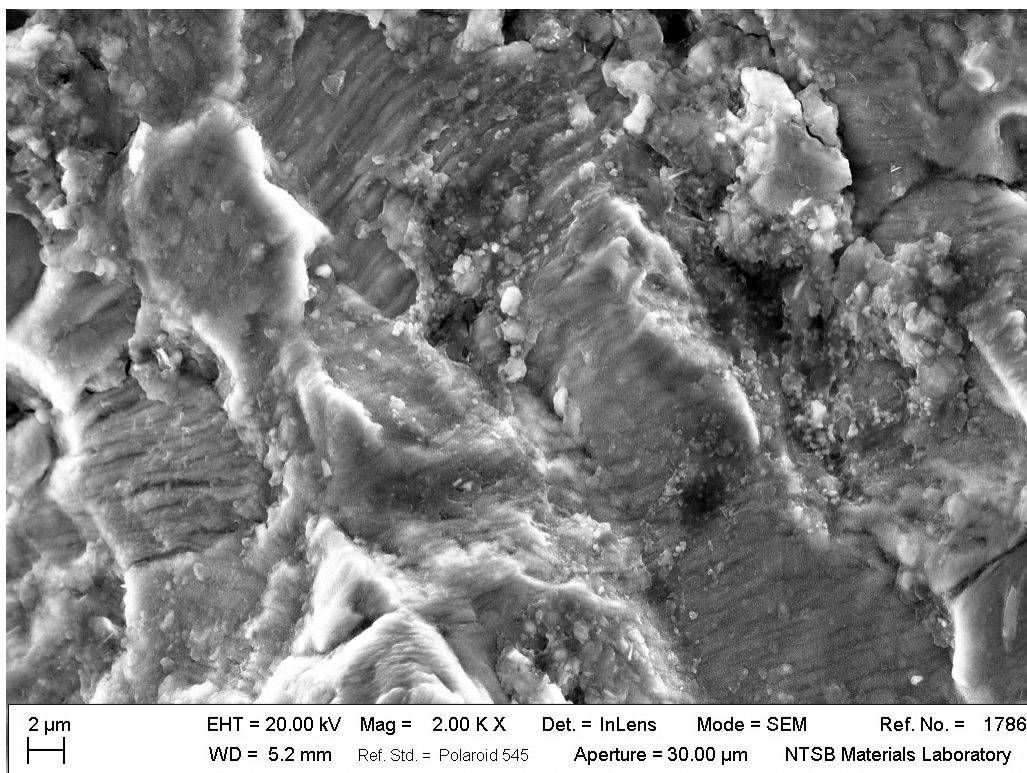
Distance along crack path = 0.023 inch



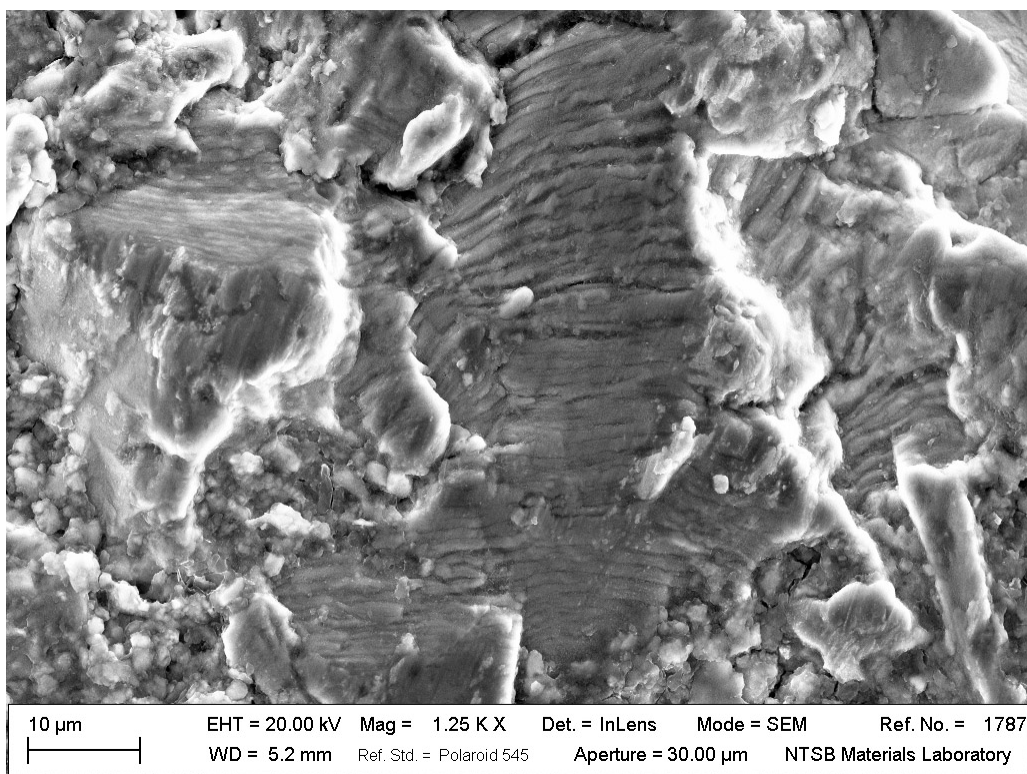
Distance along crack path = 0.029 inch



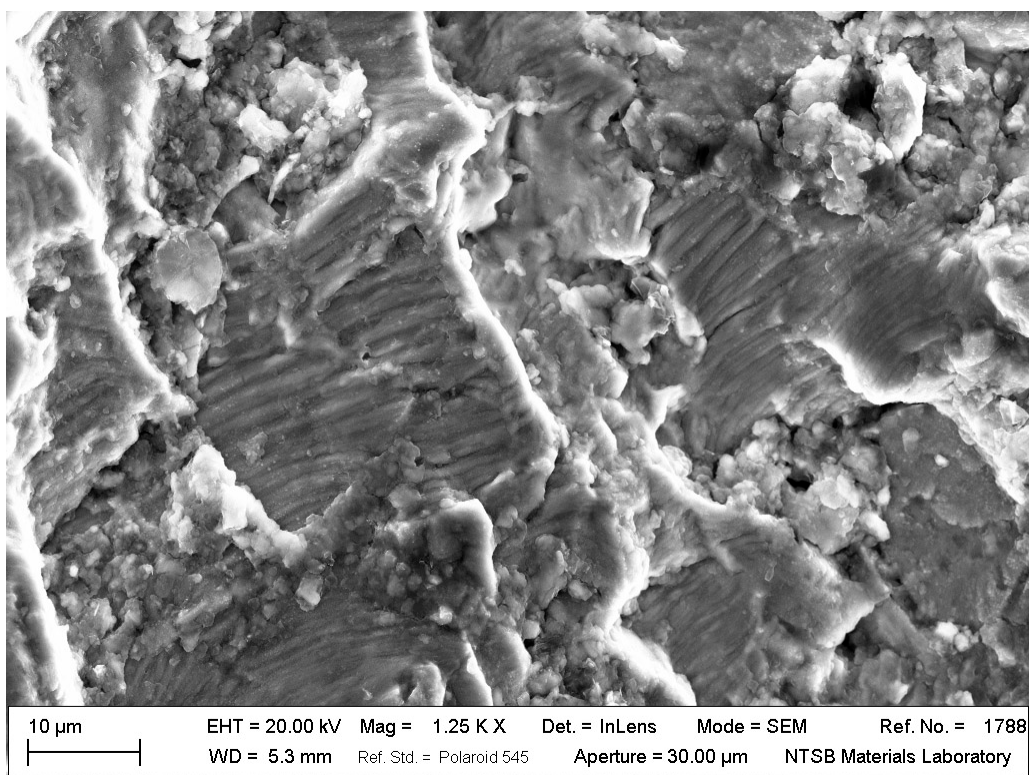
Distance along crack path = 0.036 inch



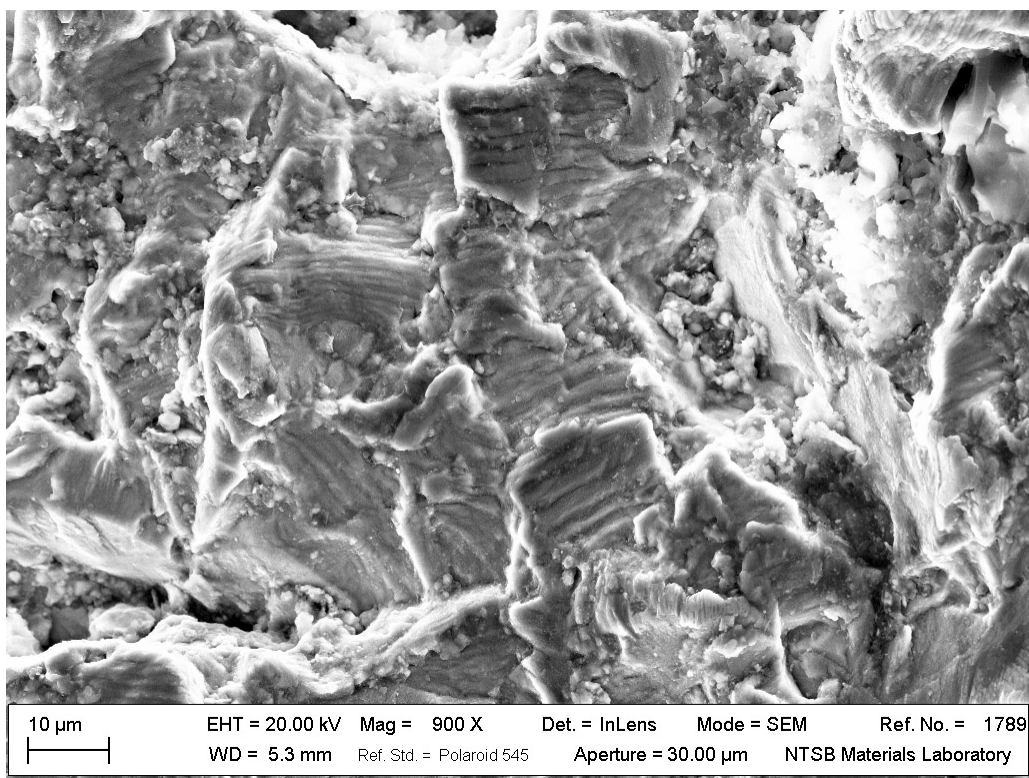
Distance along crack path = 0.044 inch



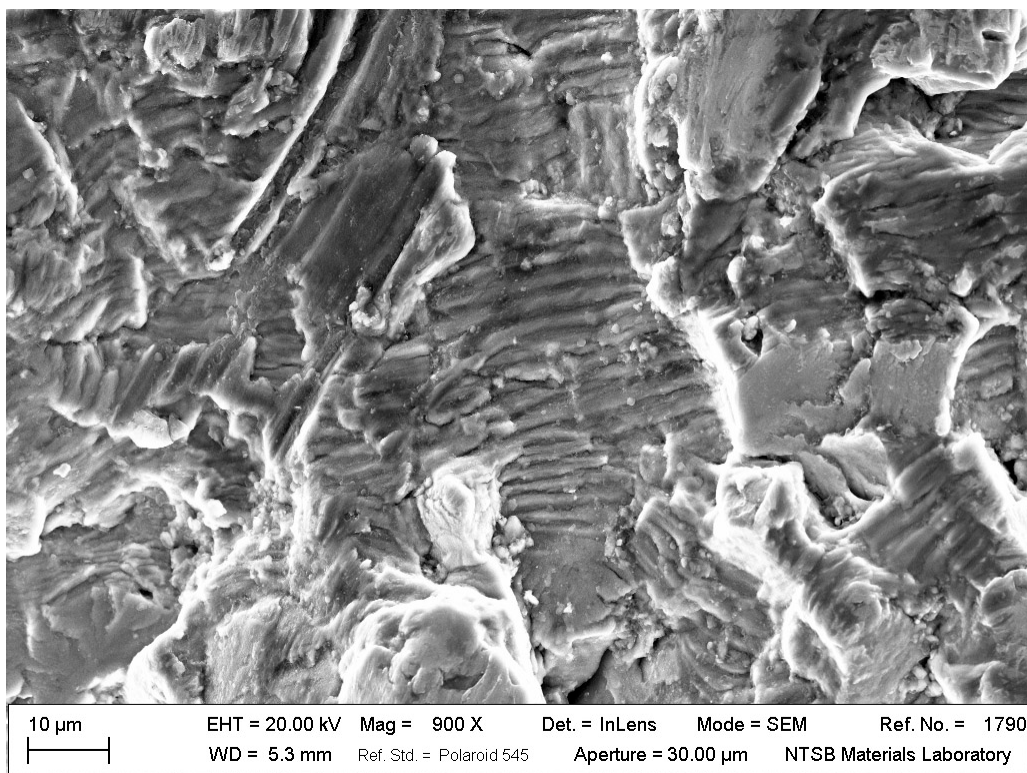
Distance along crack path = 0.053 inch



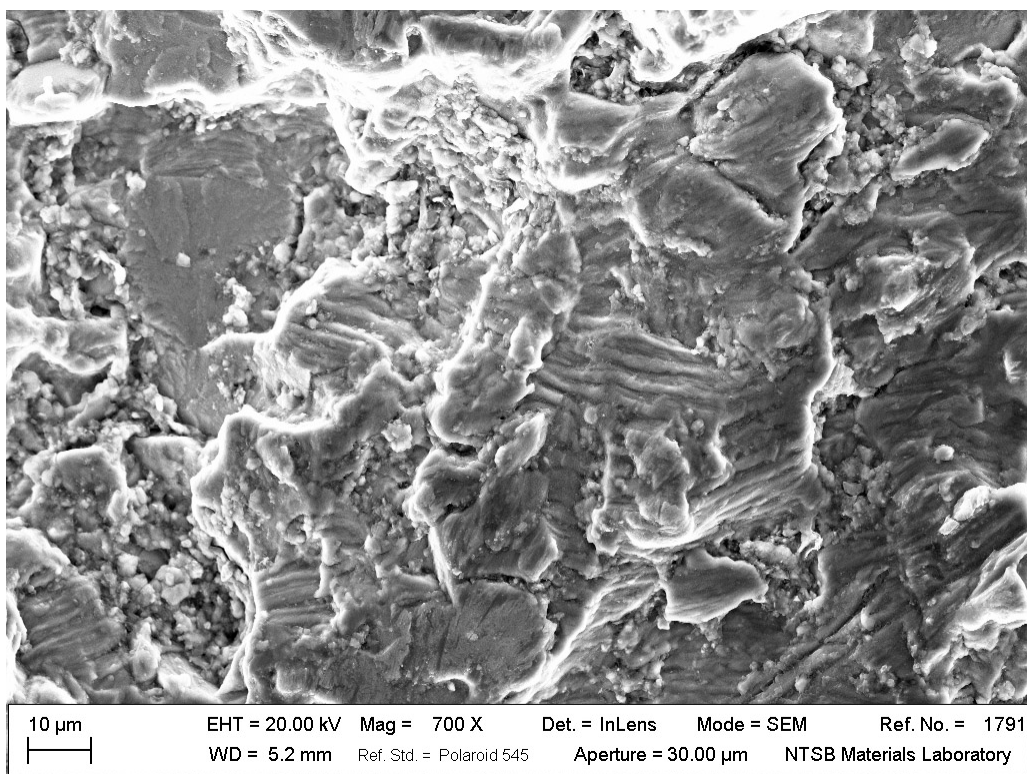
Distance along crack path = 0.072 inch



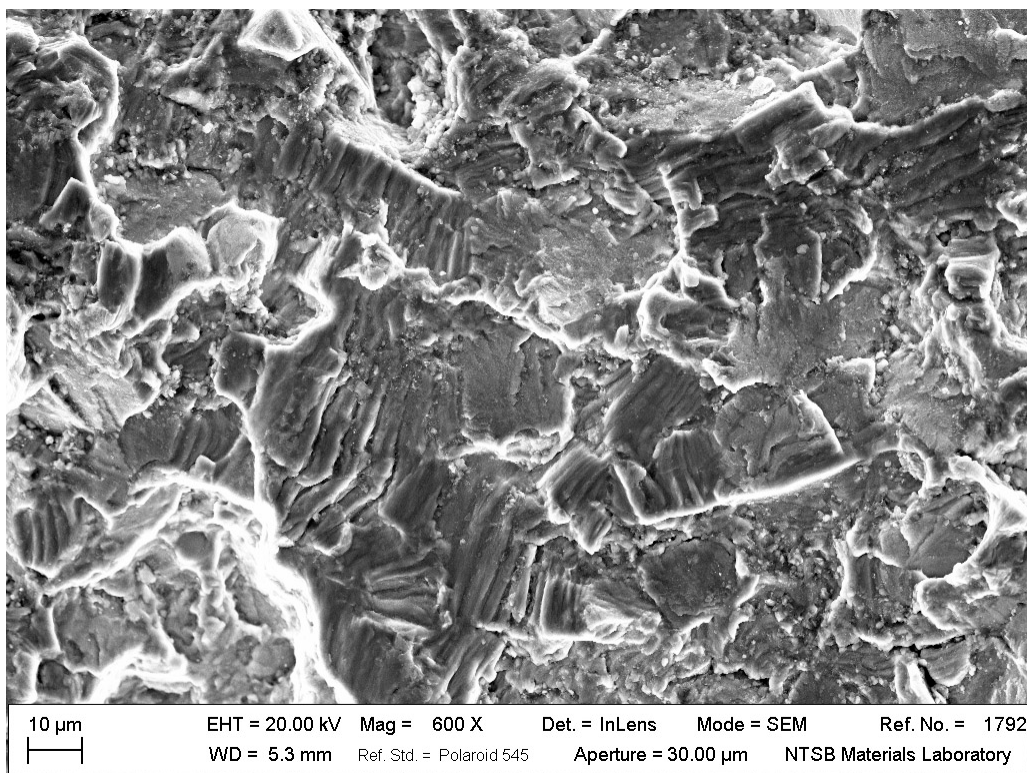
Distance along crack path = 0.103 inch



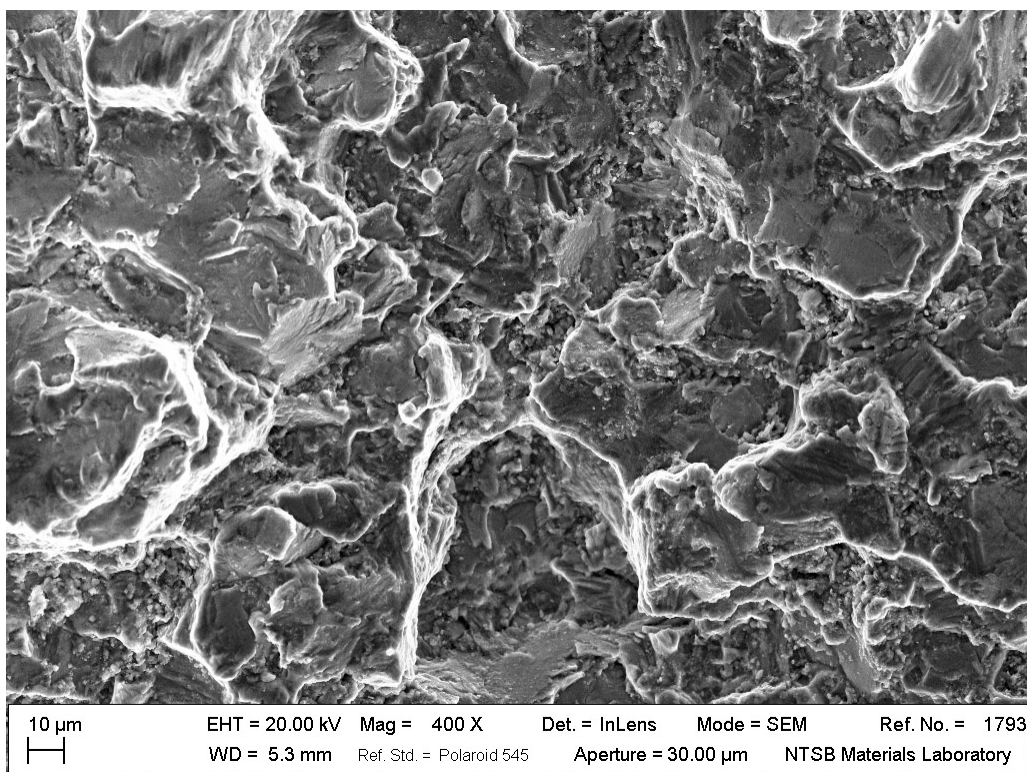
Distance along crack path = 0.112 inch



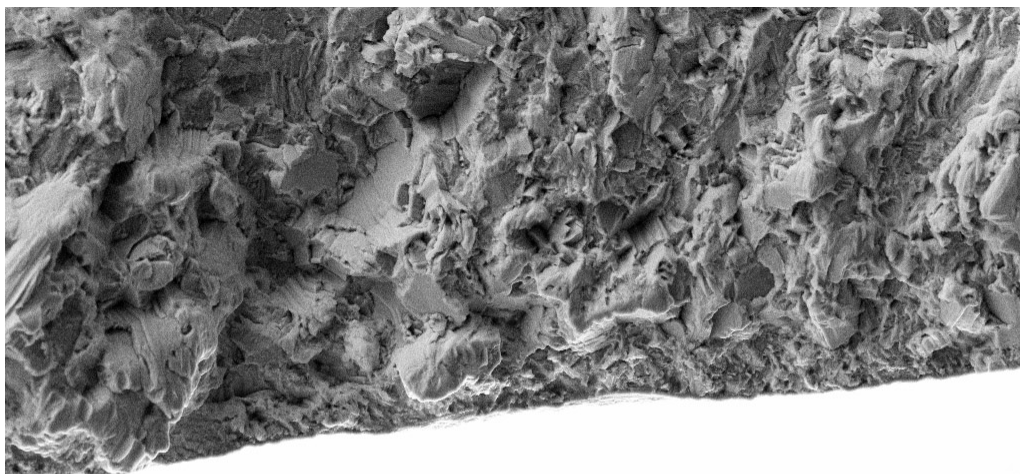
Distance along crack path = 0.120 inch



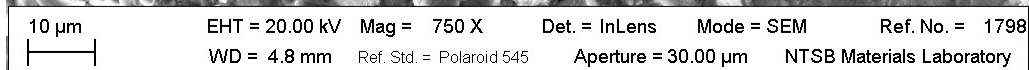
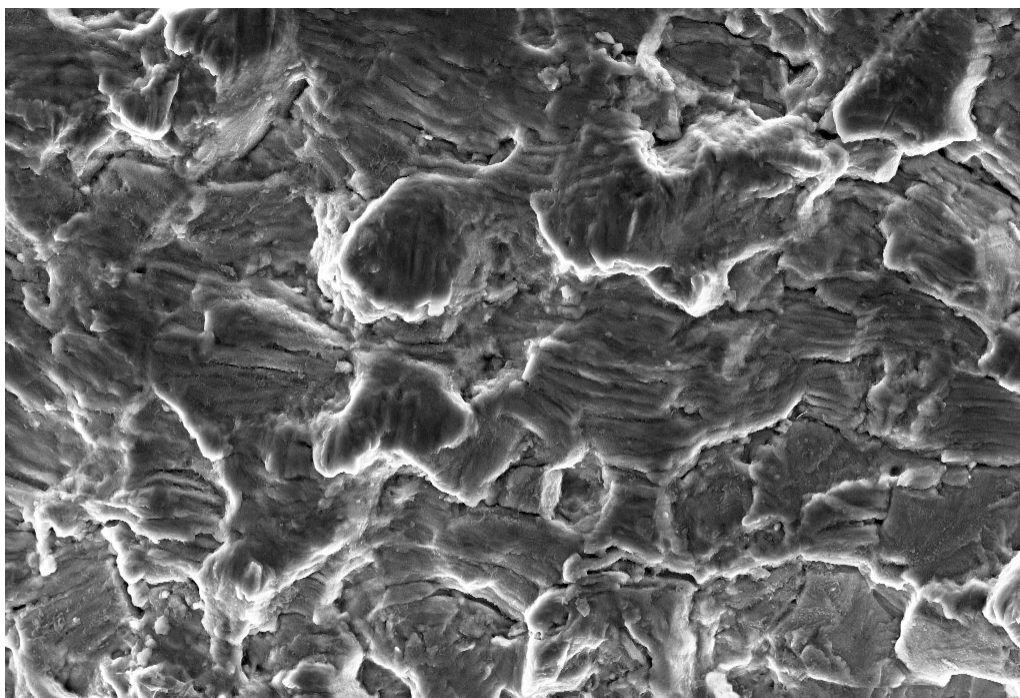
Distance along crack path = 0.141 inch



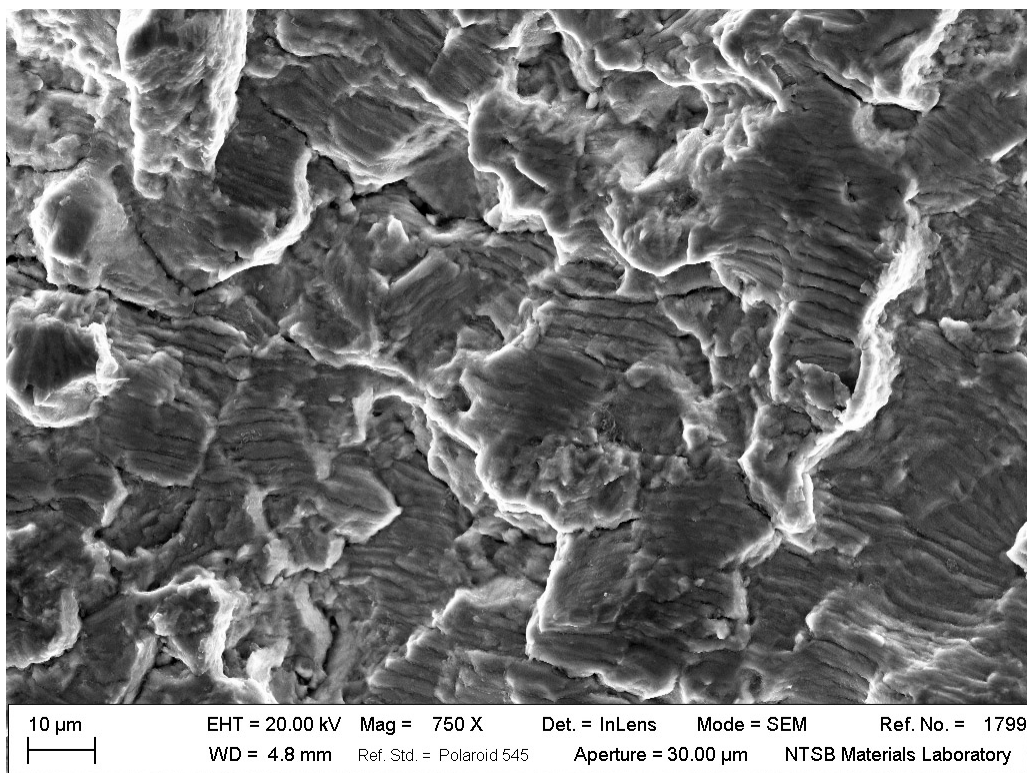
Distance along crack path = 0.150 inch

A.2. Forward tang 3 o'clock position

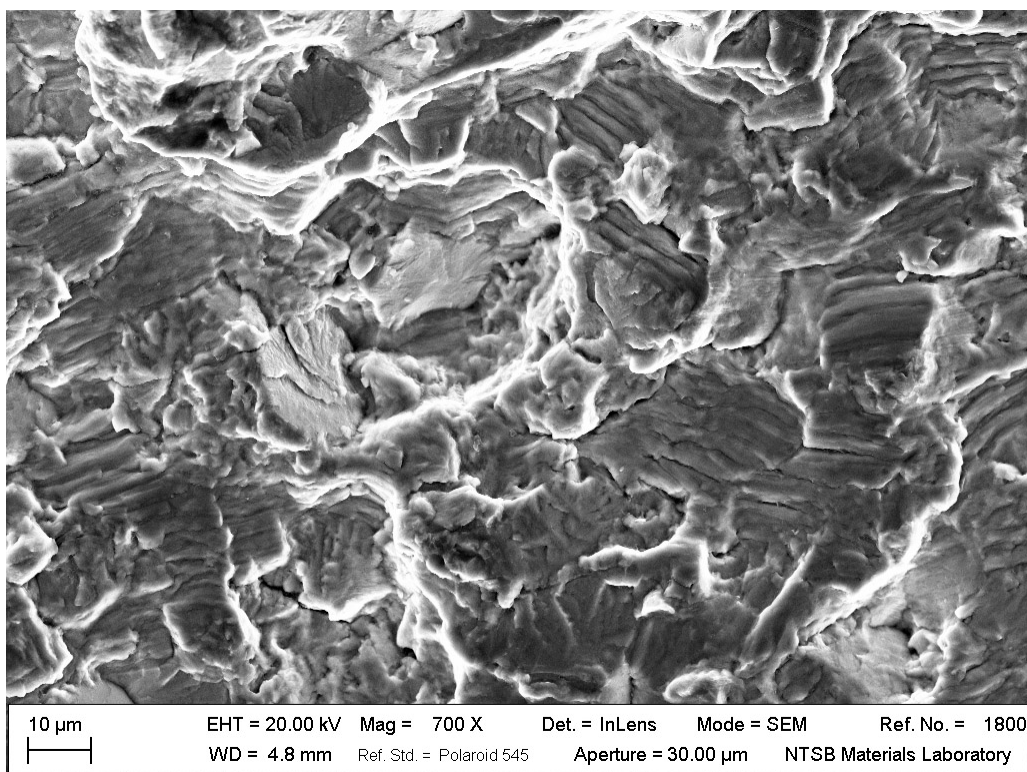
Distance along crack path = 0.000 inch



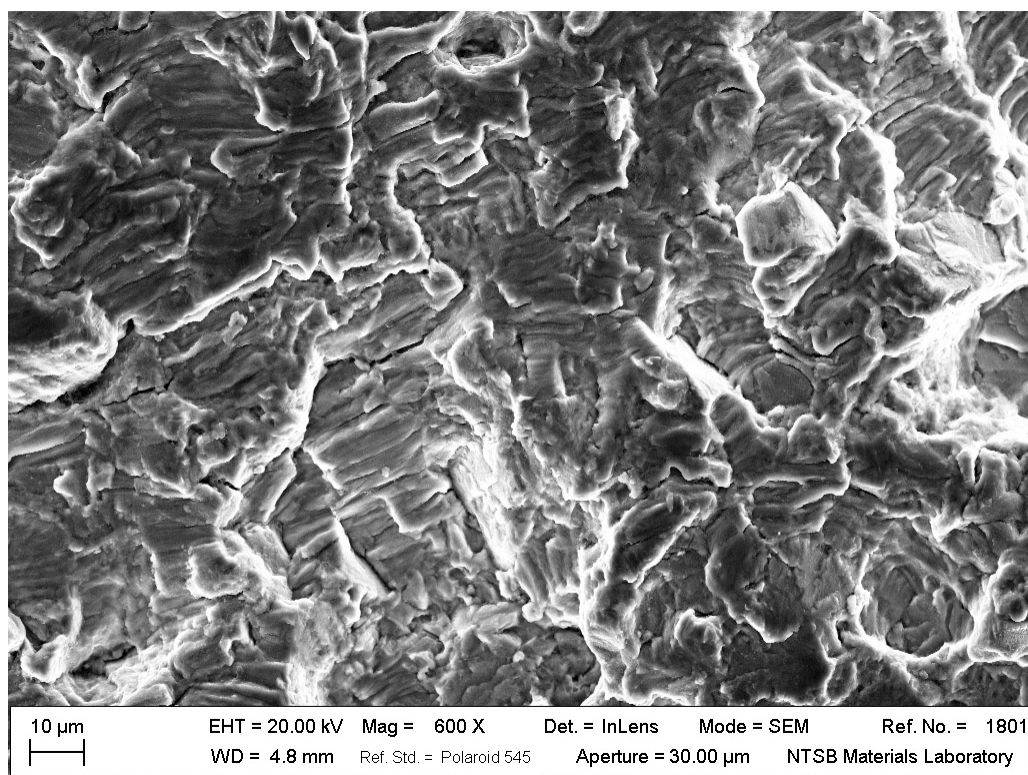
Distance along crack path = 0.013 inch



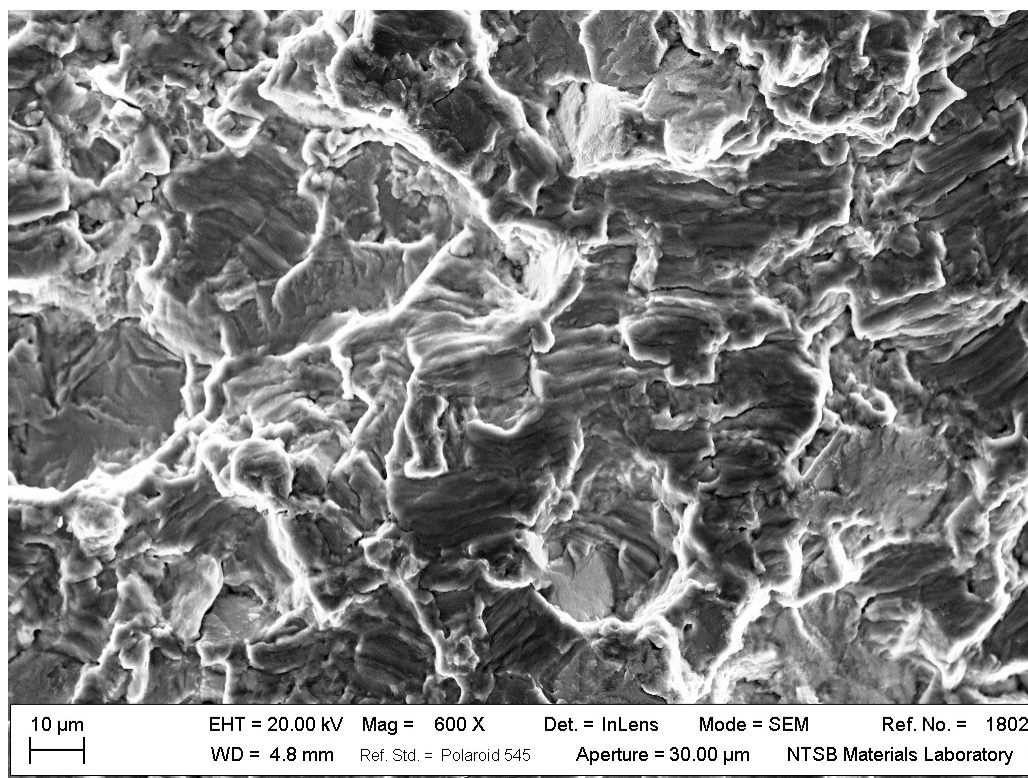
Distance along crack path = 0.020 inch



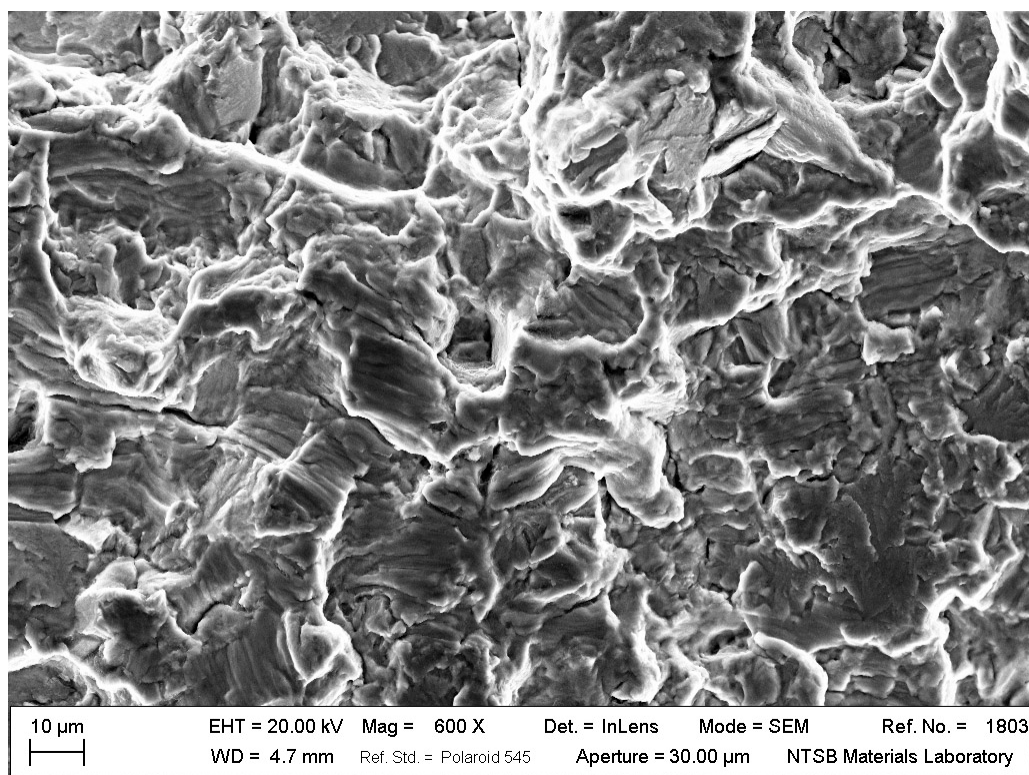
Distance along crack path = 0.026 inch



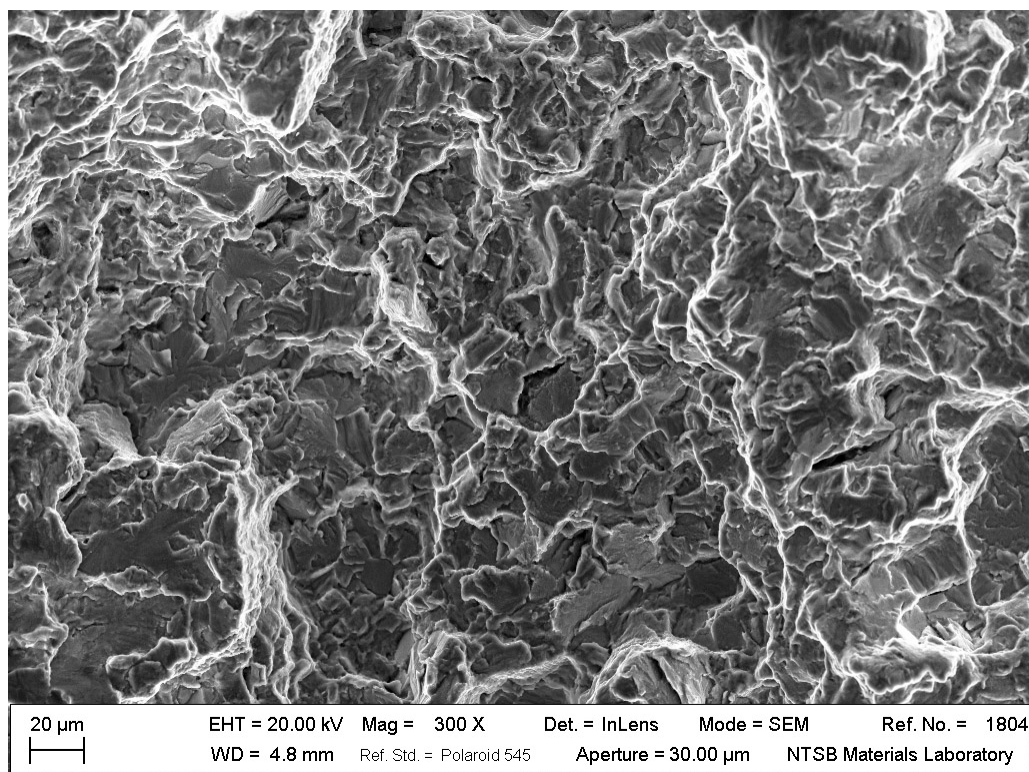
Distance along crack path = 0.037 inch



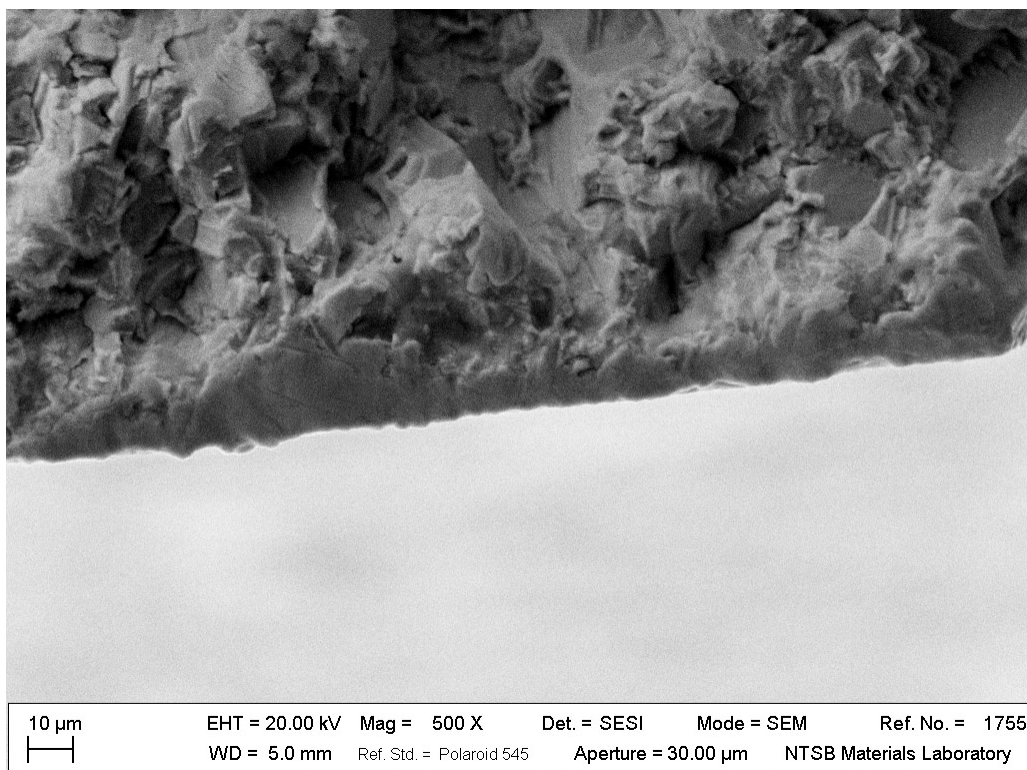
Distance along crack path = 0.046 inch



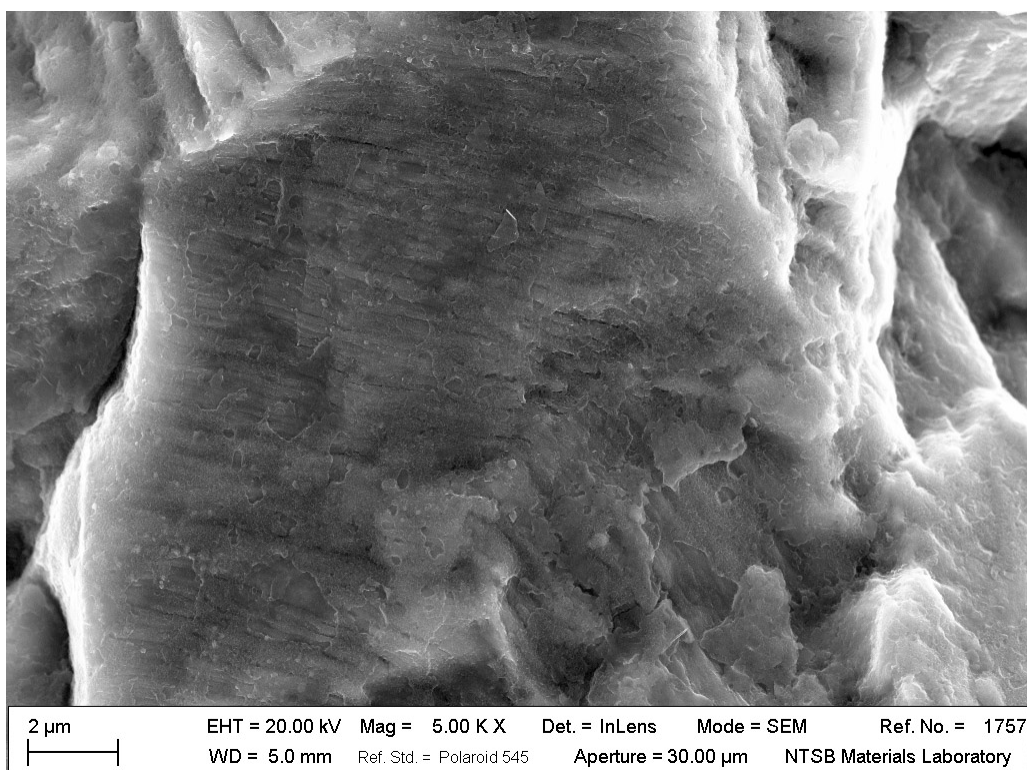
Distance along crack path = 0.063 inch



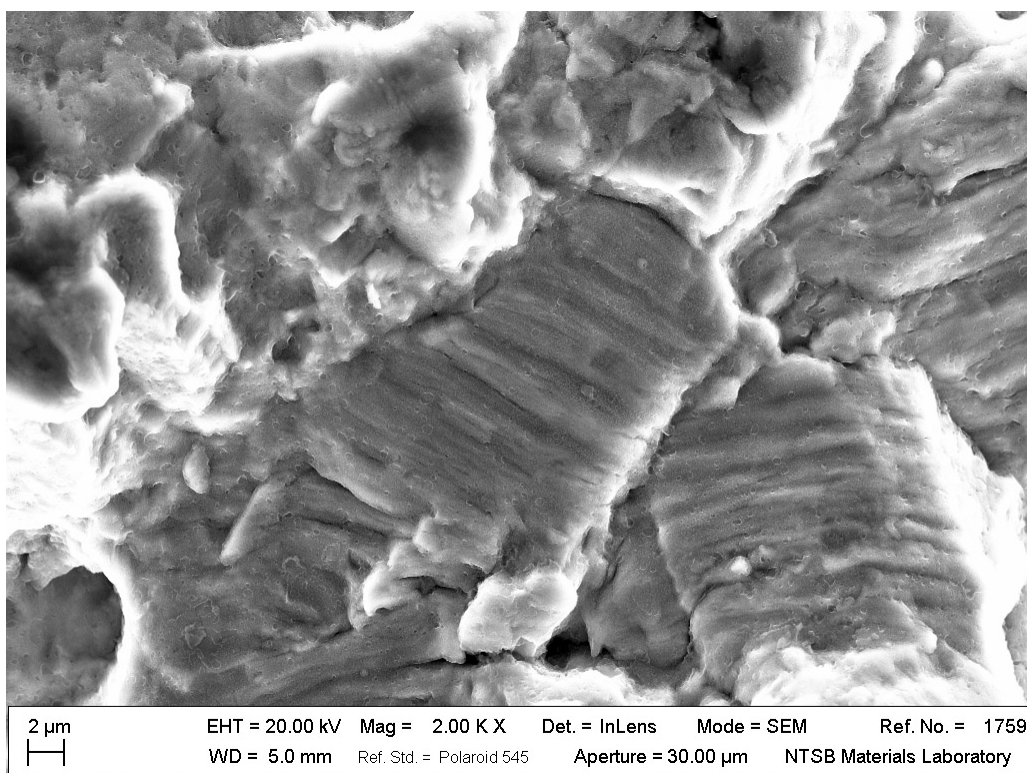
Distance along crack path = 0.070 inch

A.3. Middle tang 9 o'clock position

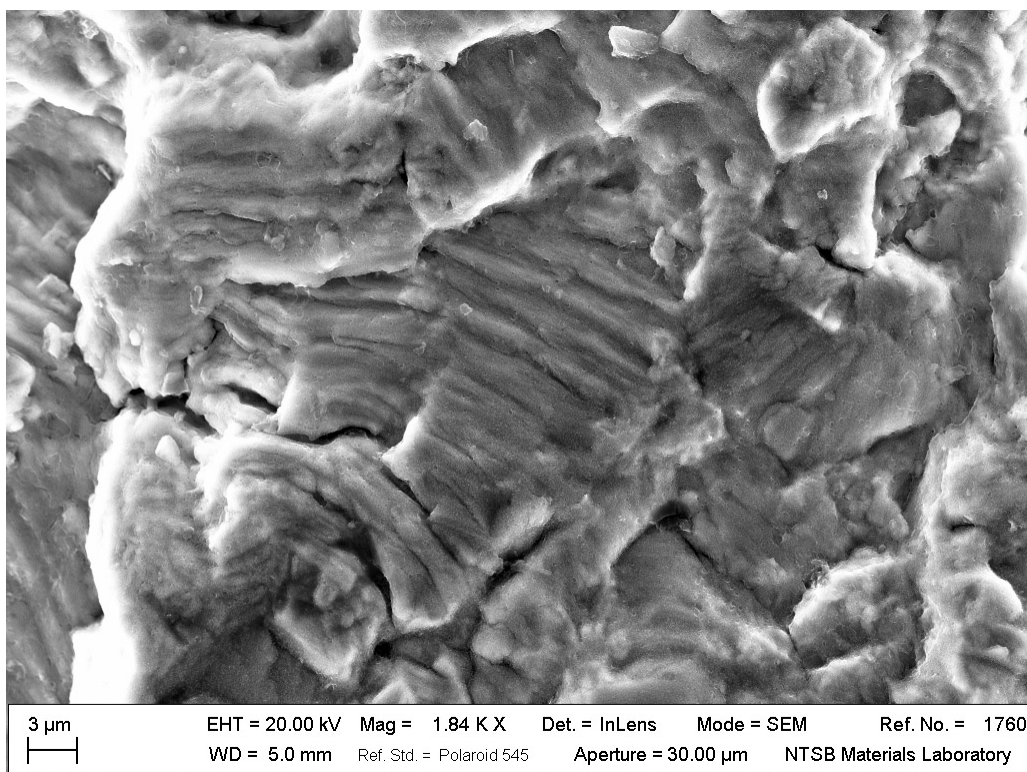
Distance along crack path = 0.000 inch



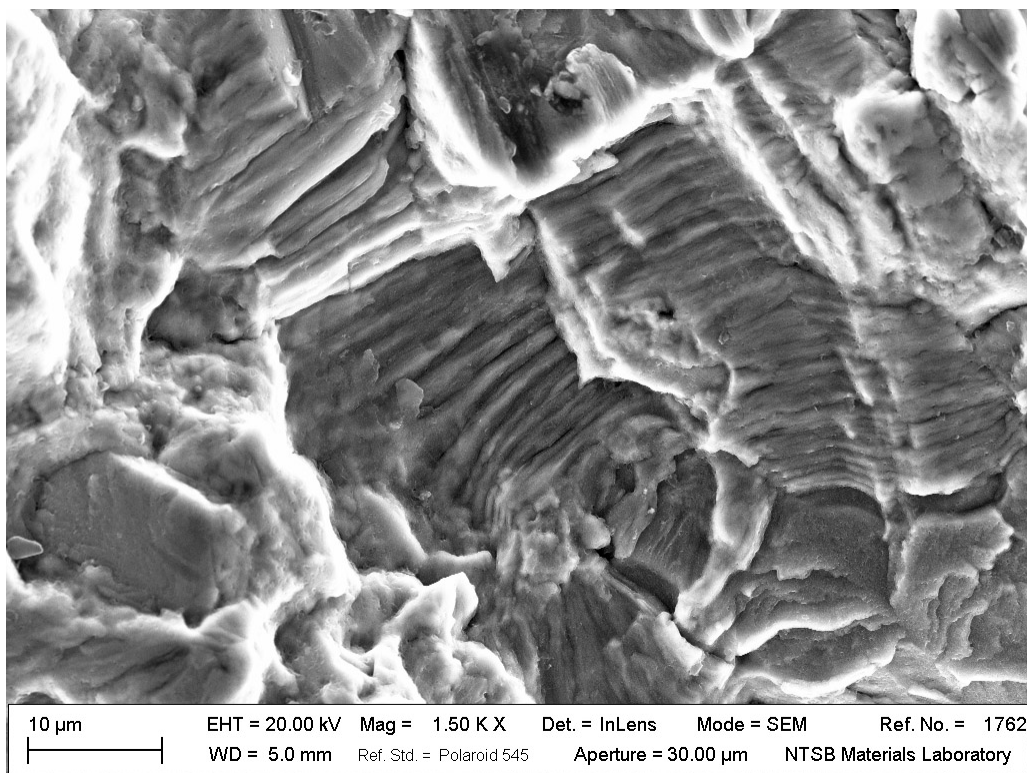
Distance along crack path = 0.006 inch



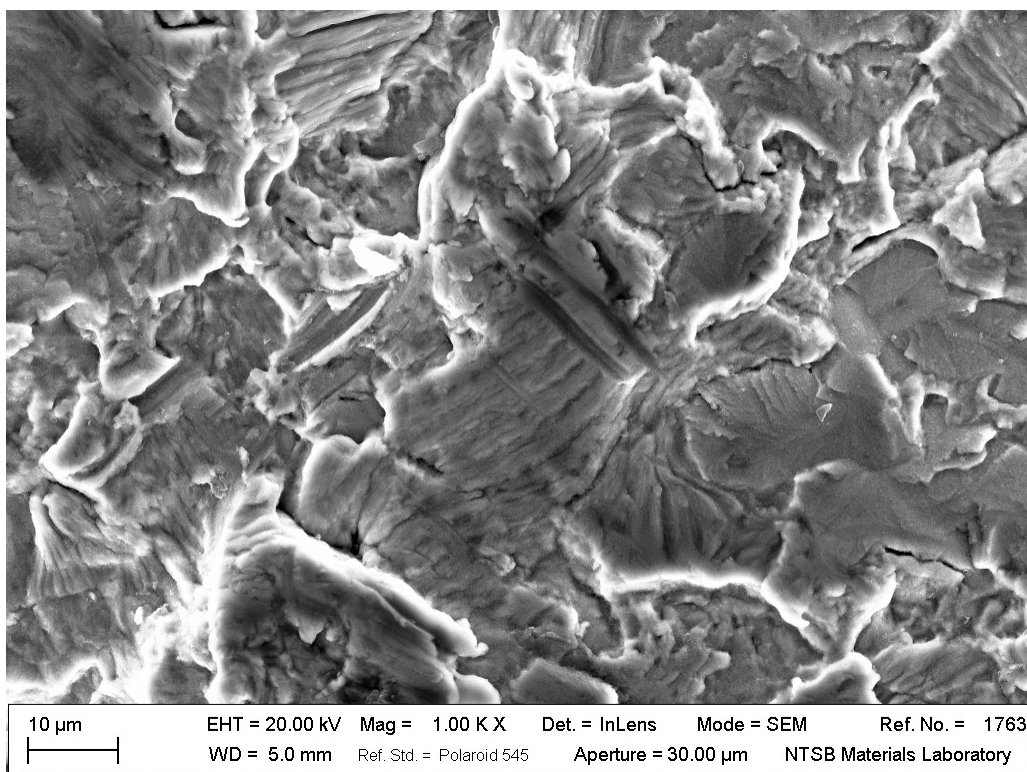
Distance along crack path = 0.014 inch



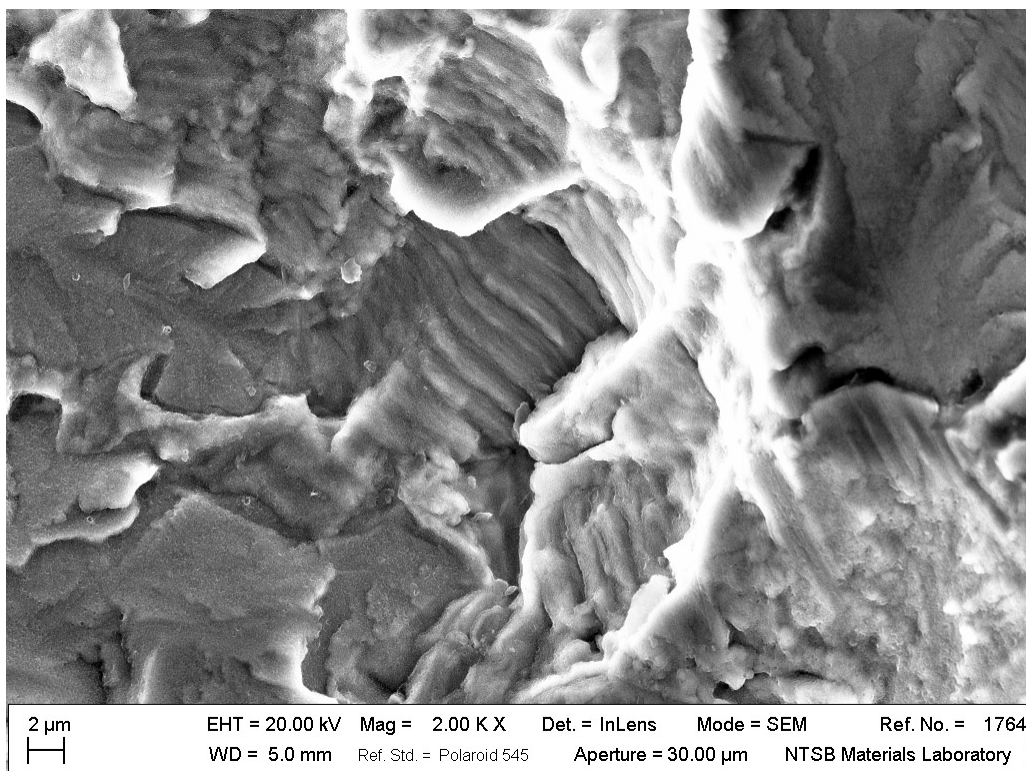
Distance along crack path = 0.020 inch



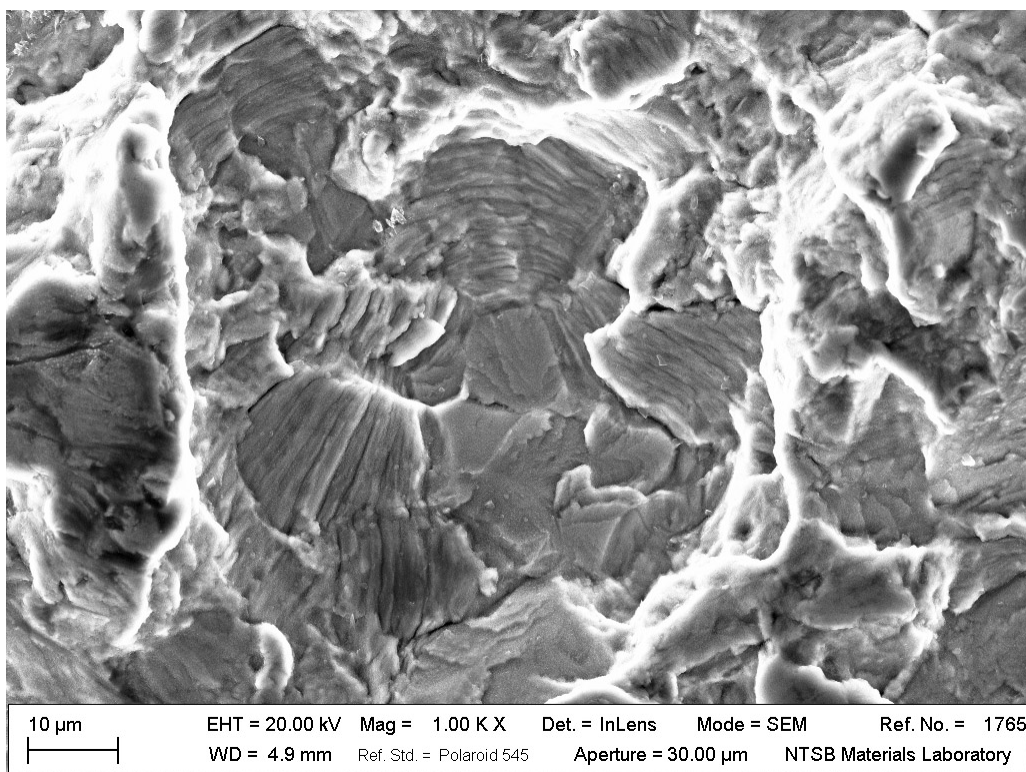
Distance along crack path = 0.026 inch



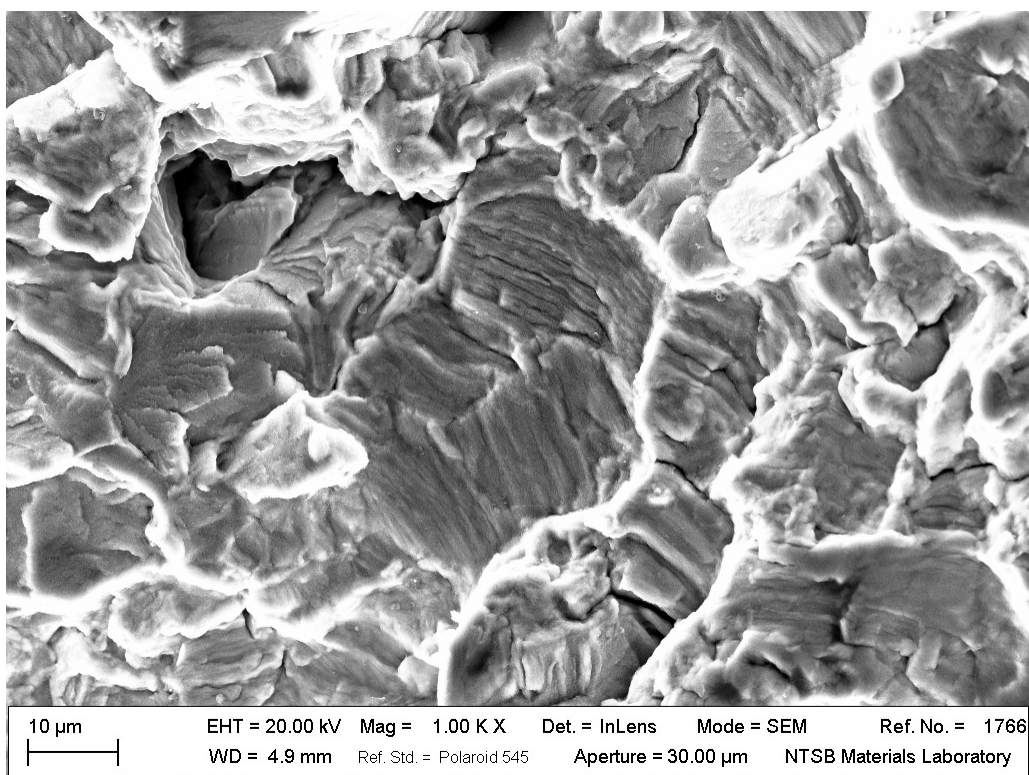
Distance along crack path = 0.034 inch



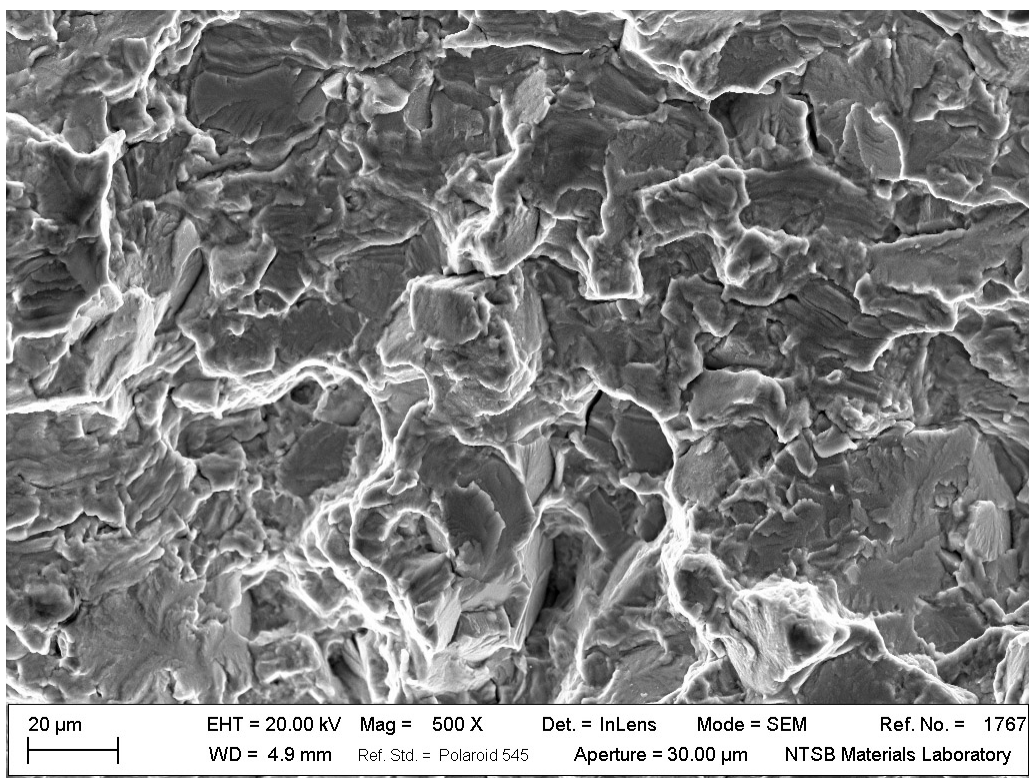
Distance along crack path = 0.035 inch



Distance along crack path = 0.039 inch



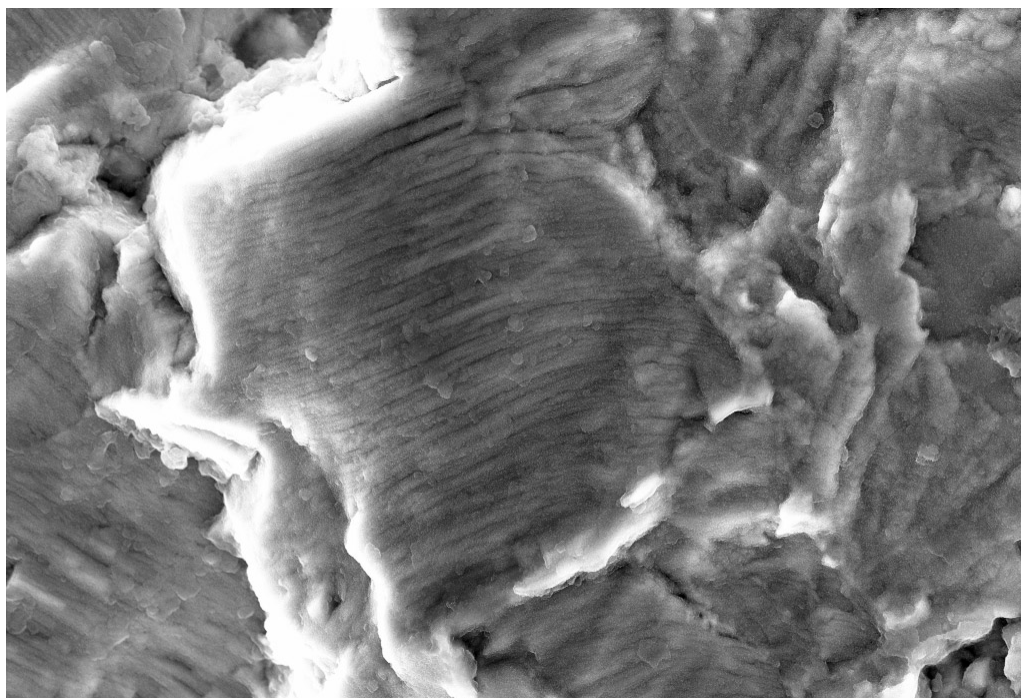
Distance along crack path = 0.045 inch



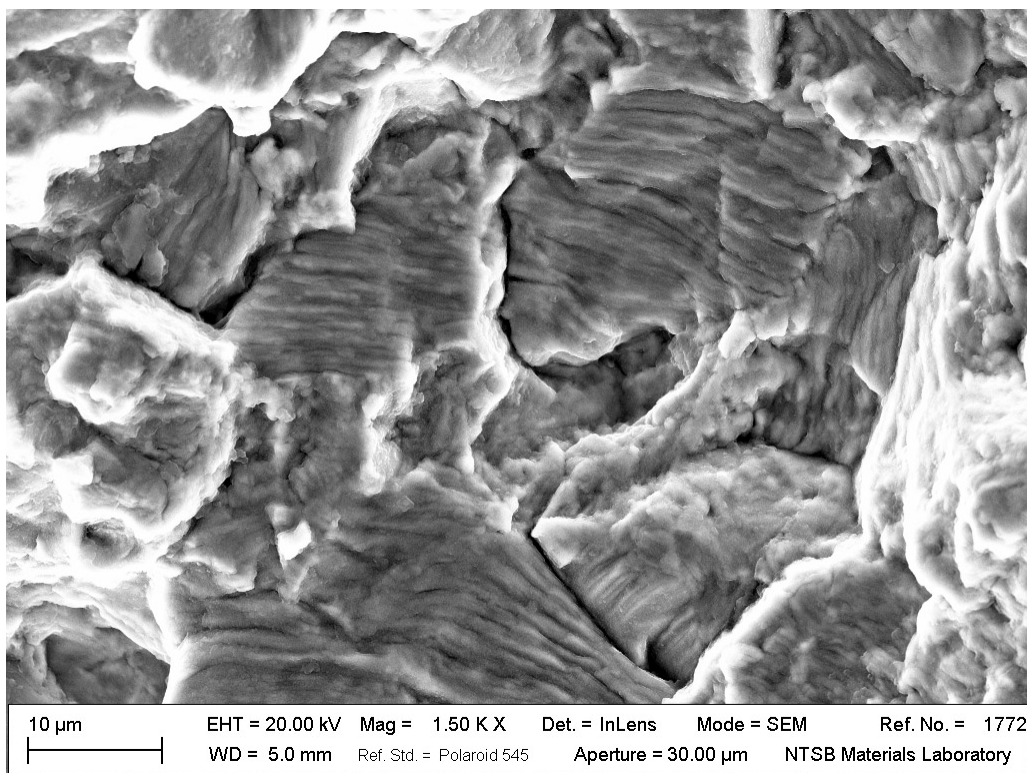
Distance along crack path = 0.052 inch

A.4. Middle tang 3 o'clock position

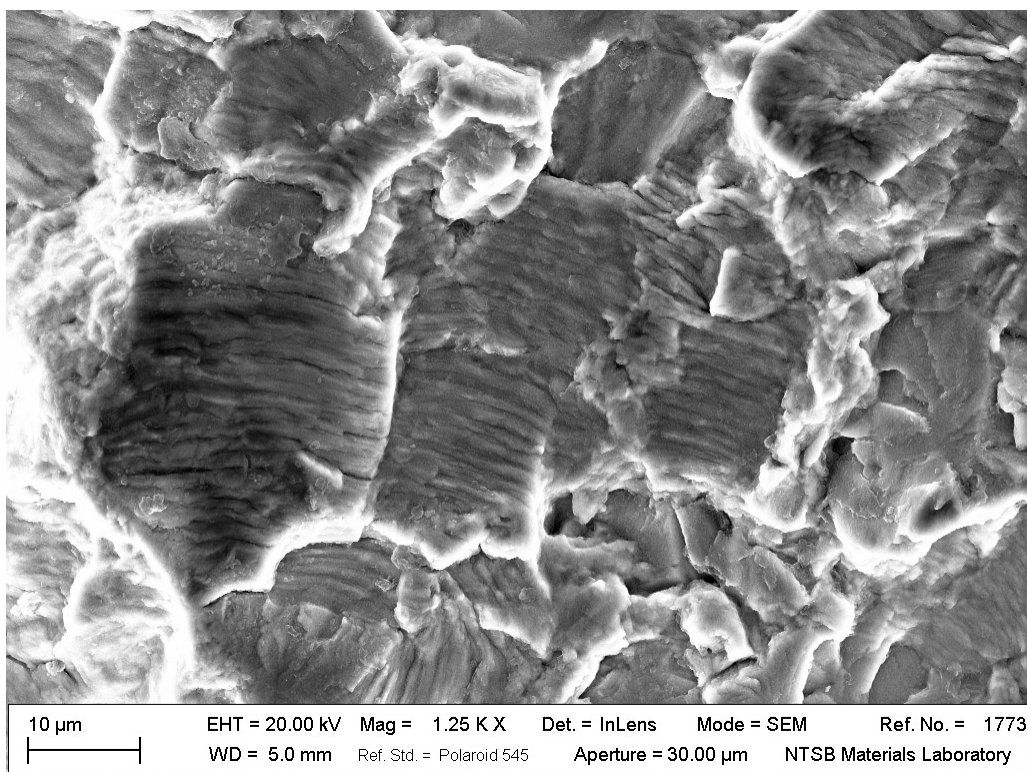
Distance along crack path = 0.000 inch



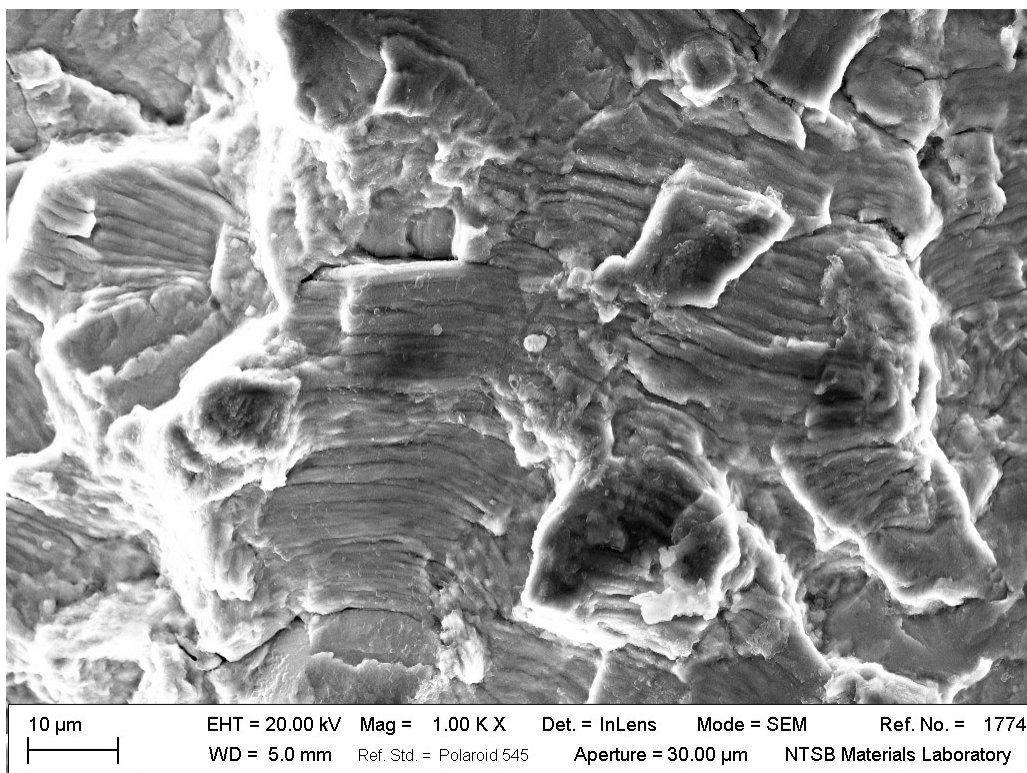
Distance along crack path = 0.012 inch



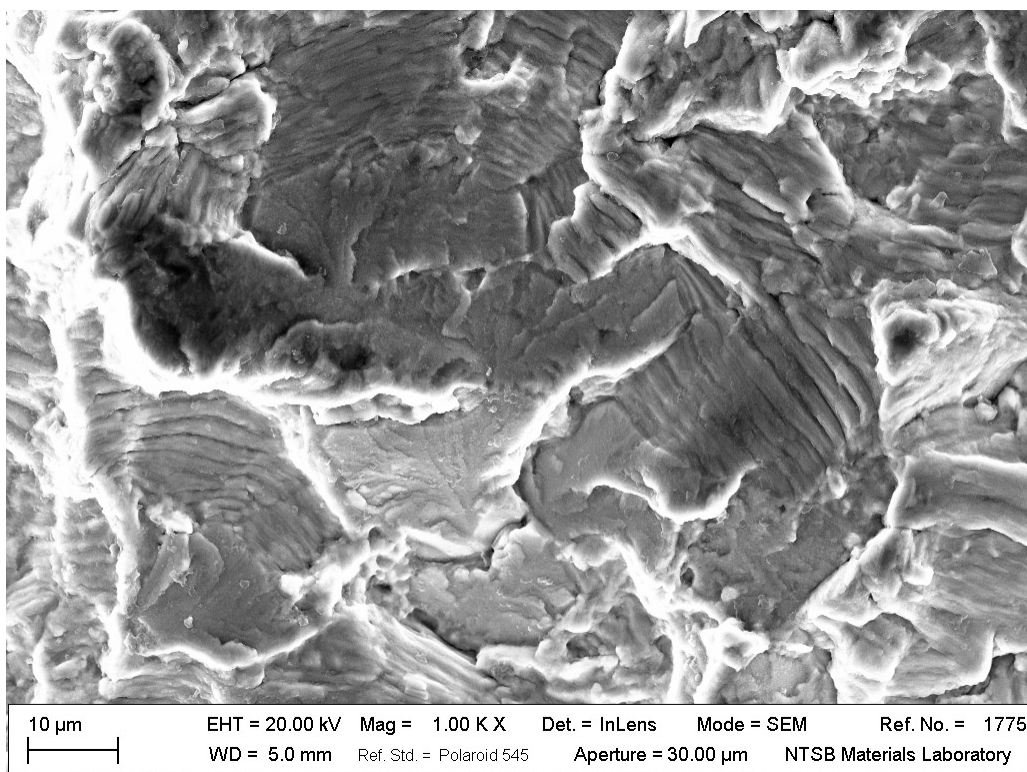
Distance along crack path = 0.014 inch



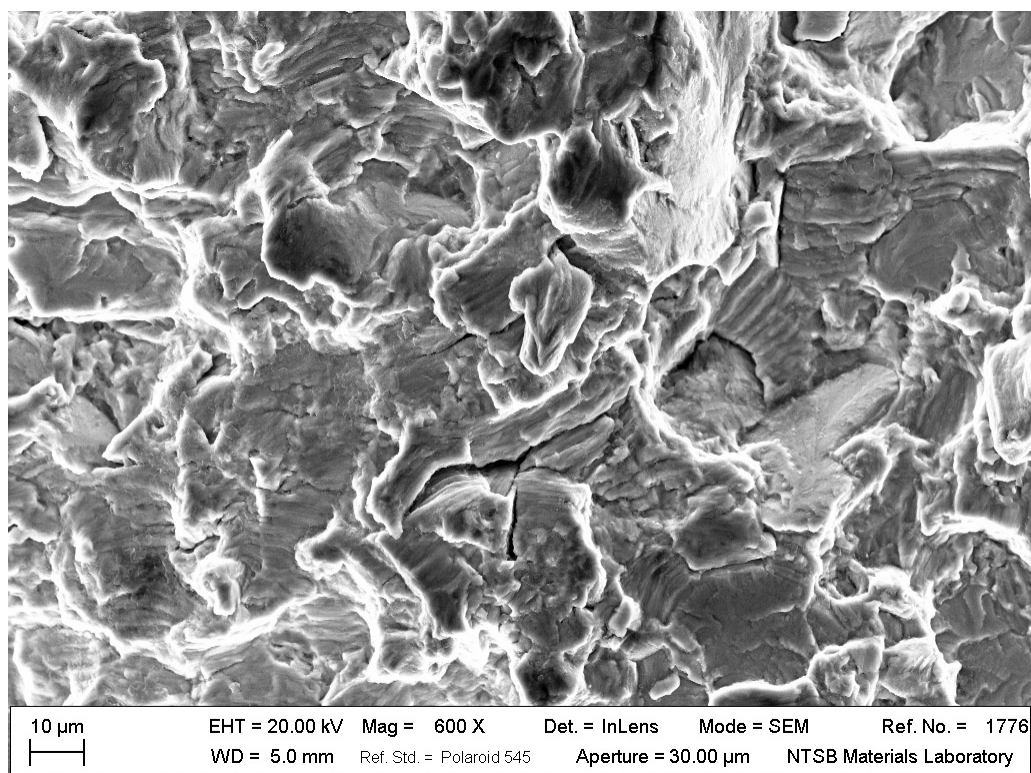
Distance along crack path = 0.019 inch



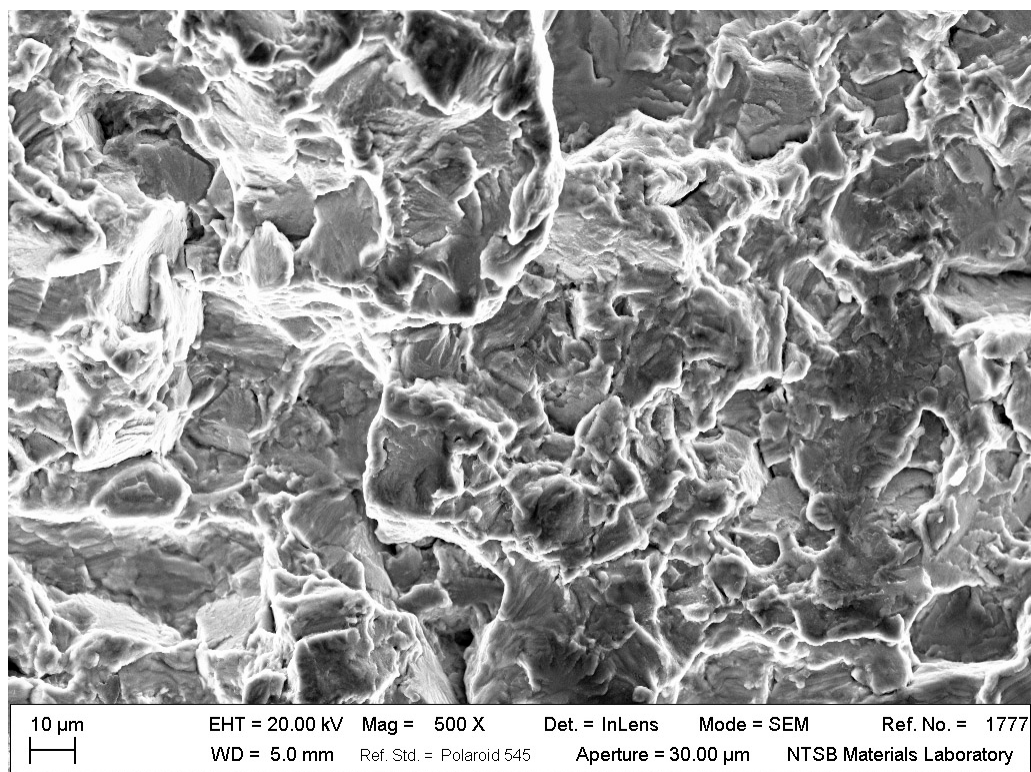
Distance along crack path = 0.022 inch



Distance along crack path = 0.032 inch



Distance along crack path = 0.037 inch



Distance along crack path = 0.045 inch