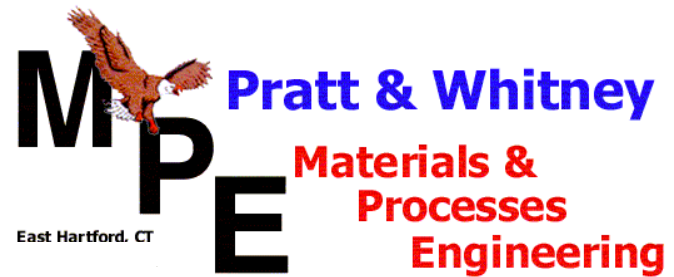


Metallurgical Investigation Final Report



Subject: Metallurgical Investigation of Fan Blades No. 11 and No. 10 from PW4077 Engine 777049

Date: October 9, 2018

Summary and Conclusions:

S/N CBDUAT7364 (Blade #11): The transverse fracture through the airfoil of fan blade S/N CBDUAT7364 (Blade #11) was due to fatigue, which initiated ~6.7" outboard of the root bottom face internally at cavity FA along the transition radius between the convex side wall and an internal spanwise rib. The fatigue origin area was slightly sub-surface, ~1-2 grains deep, within a small zone that had been obscured by secondary rub damage. Further non-destructive and destructive examinations of the fatigue origin area found no evidence of manufacturing or material abnormalities. Other than surface roughness, which exhibited an Ra of 67µin adjacent to the origin compared to a limit of 63µin max, all other geometric features evaluated by MPE were within limits. Microstructures from this blade were all typical of properly processed Titanium 6Al-4V fan blade alloy.

The early crack progression from the fatigue origin area exhibited predominantly faceted growth mixed with occasional areas of fatigue striations. The FESEM examination also identified ~2 apparent micro-textured regions (MTR's) which exhibited near fully faceted growth that tended to propagate in the chordwise direction, i.e. along the MTR. Subsequent evaluation of these MTR areas via tilt fractography and OIM confirmed the presence of multiple contiguous grains that exhibited very similar basal plane orientations, which were also not far from perpendicular (i.e. within ~30°) relative to the local principal stress direction provided by P&W Structures Engineering. Beyond this early progression zone, about 0.032" deep, the fatigue crack transitioned to a predominantly striated growth mode, consistent with stable low cycle fatigue (LCF) growth. A striation count from 0.032 to 0.153" deep estimated 5500 cycles of LCF crack propagation within the stable zone. Beyond the stable LCF zone, the crack surface exhibited unstable progression, leading ultimately to final fracture.

S/N CBDUAT7363 (Blade #10): The following fan blade in the hub, S/N CBDUAT7363 (Blade #10), fractured transversely through the airfoil ~23" to 27" outboard of the root bottom. The fracture was due to shear/tensile overstress as a result of a secondary impact with the fractured airfoil from Blade #11. All of the blade cavity geometric features evaluated by MPE were within limits. Metallographic evaluation of Blade #10 at a location similar to the Blade #11 fracture origin found no evidence of microstructural deformation or alpha case along the internal surfaces, no anomalies associated with the diffusion bond in the rib, and a bulk microstructure that was acceptable to requirements.

Details of Examination:**S/N CBDUAT7364 (Blade #11)**

Visual examination of Blade #11 revealed a transverse fracture through the airfoil 4.52” – 8.05” outboard of root bottom as measured from leading edge to trailing edge. A large portion of the airfoil that was released upon fracture was recovered from the engine and submitted along with the root portion. This airfoil portion, which was heavily damaged following liberation, weighed 13.9 lbs. The root portion measured 10.7 lbs. (**Figures 1 – 3**). For reference, the weight of an exemplar intact fan blade was measured at 33.6 lbs.

Visual examination of the fracture surface (inboard half of fracture) revealed evidence of fatigue progression from the transition between the internal surface of the convex side wall and the internal rib separating cavities FA and EA, ~6.7” outboard of the root bottom (**Figure 4**). A raised band of coarse machining marks (e.g. a machining mismatch) was observed on the internal cavity surface at the fatigue origin. Initial replication of this feature revealed it measured ~0.050” wide and had a step height of ~0.004” (**Figures 5 – 7**). The surface roughness of the mismatch was an Ra of 67 µin, as measured via stylus profilometer, compared to the limit of 63 µin max.

The outboard half of the fracture on the recovered airfoil portion was also visually reviewed and found to exhibit extensive secondary damage to the origin area including spanwise tearing between the convex wall and rib and along the adjacent diffusion bond line of the rib (**Figure 8**). Due to the extensive damage, no further analysis of this portion of the blade was completed.

The part manufacture and repair identification markings located on the root bottom are shown in **Figure 9**.

The fracture surface was sectioned from the root portion of the blade for further examination. Binocular microscope and field emission scanning electron microscope (FESEM) examinations of the fracture surface revealed fatigue had progressed at an angle from perpendicular to the blade spanwise direction. The fatigue origin area was more steeply angled, resulting in a step which divided the fatigue progression into two halves. A high magnification FESEM examination of the cavity surface at the fatigue origin did not find evidence of damage due to “sparks” or “chips”, as referenced in PW4G-112-A72-246 (**Figures 10 – 12**). The plane of the fatigue origin zone measured ~9° off the spanwise axis of the blade when using the machining pass as a guide (**Figure 13**). The fracture plane very close to the origin measured ~63° off the spanwise axis, which appeared to be close to perpendicular to the primary stress direction based on data provided by P&W Structures Engineering (**Figure 14**). The fatigue origin zone could be traced to an area slightly sub-surface, ~1-2 grains deep. The origin zone itself had been smeared due to secondary damage, removing fracture features, so an individual grain origin could not be identified (**Figure 15**). Some dark staining had been noted optically on the fracture surface locally in the area surrounding the fatigue origin and in the early stages of fatigue progression. While most of this staining was removed via ultrasonic cleaning in preparation for FESEM examination, some residue remained on the surface. Energy dispersive spectroscopy (EDS) of multiple residue particles revealed two typical particles types, both of which were suggestive of extraneous surface contamination (e.g. dirt) (**Figure 16**). Fatigue had progressed in forward, aft, and through-

thickness directions within the convex side wall, and into the adjacent spanwise rib separating cavities FA and EA. Predominantly faceted growth mixed with striations was found within 0.032" of the origin. Several areas of fully faceted growth were also detected within these early stages of fatigue progression. These areas were suggestive of micro-texture regions (MTR's). The FESEM examination suggested the presence of MTR zones close to the fracture origin. Given the lack of fatigue arrest lines in this area, it was unclear how to define the size of the initiation zone. The use of a 2 to 1 aspect ratio would likely underestimate the size of the initiation zone considering the presence of the chordwise MTR's near the origin. In other words, the crack growth parallel with the airfoil sidewall along the MTR's was likely to be faster than the crack growth in the through thickness direction. As a result, a minimum crack initiation zone was estimated at $\sim 0.032 \times 0.100$ " by including the lengths of the 2 MTR zones nearest the fracture origin. The crack width estimate of 0.100" should be considered a lower bound, since further crack growth in this direction could easily have occurred prior to reaching 0.032" in depth. The crack depth estimate of 0.032" for the initiation zone should be considered fairly precise, since it was based on a fracture mode transition from predominantly faceted to predominantly striated growth, i.e. stable LCF.

Beyond 0.032" deep from the origin was a region of predominantly fatigue striations, suggesting stable low cycle fatigue (LCF) propagation (**Figures 17 – 19**). A striation count performed within a rectangular zone through this stable LCF region ~ 0.032 " – 0.153" from the origin estimated 5500 cycles of LCF crack propagation (**Figure 20**). The blade was last inspected via thermal acoustic imaging (TAI) ~ 1400 cycles ago in 2015. Based on the striation count data, the crack would have been ~ 0.094 " deep at that time. The extent of the stable LCF propagation zone measured approximately 0.153" - 0.189" from the origin. Beyond the stable LCF zone, the fracture mode exhibited a mix of faceted growth with occasional areas of coarse striations as well as a gradual transition to dimple rupture with increasing distance from the origin. The mixed-in dimple rupture features suggested a transition to unstable cracking. The faceted growth in this area was consistent with crack extremity areas of hollow fan blade fatigue specimen that were tested under dwell LCF conditions. It was considered possible that a high cycle fatigue (HCF) driver may also have been contributing to crack growth beyond the stable LCF zone, although HCF progression would have been expected to form bands of faceted growth, which were not observed. The onset of bulk dimple rupture (e.g. unstable tearing) ranged between 0.336" (in rib) and 0.851" (in convex side wall) from the origin (**Figure 21**).

Tilt fractography of the fracture surface MTR's and adjacent areas was subsequently completed using an electron backscatter diffraction (EBSD) system attached to the FESEM. This analysis method can determine the crystallographic orientation of individual grains intersecting the fracture plane by analyzing the fracture surface directly. The fracture was setup in the FESEM such that the orientation data could be plotted with respect to the predicted primary stress axis. This was done by eye such that the normal to the macroscopic fracture plane aligned with the normal direction axis of the EBSD system. The crystallographic orientations of thirty-eight (38) individual facets on the fracture surface were determined. Orientation data collected in the MTR's adjacent to both sides of the origin indicated that one contiguous MTR was possible through the stepped origin area. If separate MTRs were present, then they had very similar orientations (**Figures 22 – 24**). The mixed mode band of crack growth adjacent to the near origin MTR exhibited both faceted grains and grains exhibiting striations. Faceted grains from this area also exhibited basal orientations close to perpendicular to the stress axis. The striated grains had

basal orientations tilted $>50^\circ$ from the stress axis (**Figure 25**). Orientations were determined in two cases where a transition in crack growth mode from faceted to striated was observed in directly adjacent grains within the mixed mode region. In both cases, the faceted grains had basal plane orientations close to perpendicular to the stress axis, while the directly adjacent striated grains had basal plane orientations $>75^\circ$ from the stress axis (**Figures 26 – 27**).

In tandem with the FESEM evaluations of the fracture surface, a metallographic section was prepared $\sim 1 - 1.5''$ inboard of the fracture plane for evaluation of the internal cavity surface, wall-to-rib transition geometry corresponding to the fatigue origin area, and bulk microstructure. The section was oriented chordwise (but at the same angle as the fracture plane) and contained both convex and concave side walls within the forward end of cavity FA, and the aft end of cavity EA, and the adjoining spanwise rib (**Figure 28**). Step height of the machining mismatch in the section measured $0.004'' - 0.005''$, which met the requirement. Machining mark height and spacing within the mismatch measured up to $\sim 0.0005''$ and $0.005''$, respectively. The size of the transition radii on either side of the mismatch were also approximated via best-fit circles and appeared to meet the requirements (**Figure 29**). A similar transition geometry with a machining mismatch was also observed within the transition radius on the opposite side of the rib, at the aft end of cavity EA (**Figure 30**). Examination of the section after etching to reveal microstructure showed no microstructural deformation along the as-machined internal cavity surfaces, including at the mismatch associated with the origin area (**Figure 31**). No alpha case was observed along the internal cavity surfaces (**Figure 32**). Bulk microstructure in the section was acceptable to the material specification requirements (**Figure 33**).

Prior to destructive evaluation of the fracture origin area, acetate tape replications were collected to preserve the fracture surface. One fracture surface replica was sent to United Airlines per their request. A second was retained by P&W MPE. Once it was deemed that all non-destructive examination of the fracture surface had been exhausted, a metallographic section was prepared into the fatigue origin area (**Figures 34 – 36**). The section was ground and polished until the plane intersected the origin as perpendicular as possible to the airfoil spanwise direction (a near-chordwise plane). Examination of the section after etching to reveal microstructure confirmed no evidence of microstructural damage from “sparks” or “chips” or deformation from abusive machining along the internal cavity surface, and no microstructural anomalies at the origin (**Figure 37**).

An orientation image mapping (OIM) evaluation of the fatigue origin section completed via EBSD/FESEM confirmed that an MTR band containing grains with similar basal plane orientations intersected the fracture origin area (**Figure 38**). Additional MTR bands were identified in nearby areas. Two of the MTR bands could be correlated with areas identified as MTR's during the fracture surface examination (**Figure 39**). A photomicrograph montage of the section taken at the same magnification and orientation as the OIM image (after etching the section to reveal microstructure) is shown in **Figure 40** for comparison. This microstructure was acceptable to the material specification requirements.

S/N CBDUAT7363 (Blade #10)

Visual examination of Blade #10, the following fan blade in the fan hub, revealed a transverse fracture through the airfoil ~23” – 27” outboard of the root bottom as measured from trailing edge to leading edge. An incomplete portion of the released airfoil containing the leading edge and the mating fracture half was also recovered from the engine. This portion, which exhibited heavy secondary damage, weighed 4.1 lbs. The inboard portion of the blade weighed 24.6 lbs. The fracture was due to shear/tensile overstress; no evidence of fatigue progression was observed. Directionality of overstress features observed during a binocular microscope examination of the fracture surface indicated that the fracture had initiated primarily from a puncture in the concave side wall ~21.5” outboard of root bottom and ~5.5” forward of the trailing edge. Two additional punctures in the concave side, ~19” and ~17.5” outboard of root bottom, were aligned with the first. The damage was consistent with having been induced by the inboard edge of the released portion of Blade #11 airfoil (**Figures 41 – 44**). The part manufacture and repair identification markings located on the root bottom are shown in **Figure 45**.

TAI inspection of Blade #10 revealed no crack indications in the long cavities of the blade (BA, CA, DA, EA, FA, and GA). Rib indications detected further outboard in the trapezoidal cavities coincided with the damage induced by impact from the released Blade #11 airfoil. It was verified by the MPE Non-Destructive Evaluation group that the indications were not present during the prior 2015 TAI inspection based on an expert review of those scans.

The blade was sectioned chordwise where shown in **Figure 46** (bounding the area corresponding to the fracture origin location on Blade #11) and each internal cavity was filleted open to examine the as-machined features in comparison to Blade #11. Examination typically revealed machining mismatches/cusps at the wall-to-rib transitions that were less prominent than what was observed on Blade #11 (**Figure 47**).

A chordwise metallographic section was prepared through Blade #10 at a location similar to the section prepared through Blade #11 shown in Figure 28. Review of the section revealed a slight machining mismatch (~0.002” step height) in the transition between the convex side wall and rib, no evidence of microstructural deformation or alpha case along the internal surfaces, no anomalies associated with the diffusion bond in the rib, and a bulk microstructure that appeared acceptable to the specification requirements (**Figure 48**).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination



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CV SIDE

CC SIDE

PART WEIGHT:
ROOT PORTION = 10.7 lbs.
AIRFOIL PORTION = 13.9 lbs.

Figure 1 - Overall views of primary fractured Blade #11.
Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination

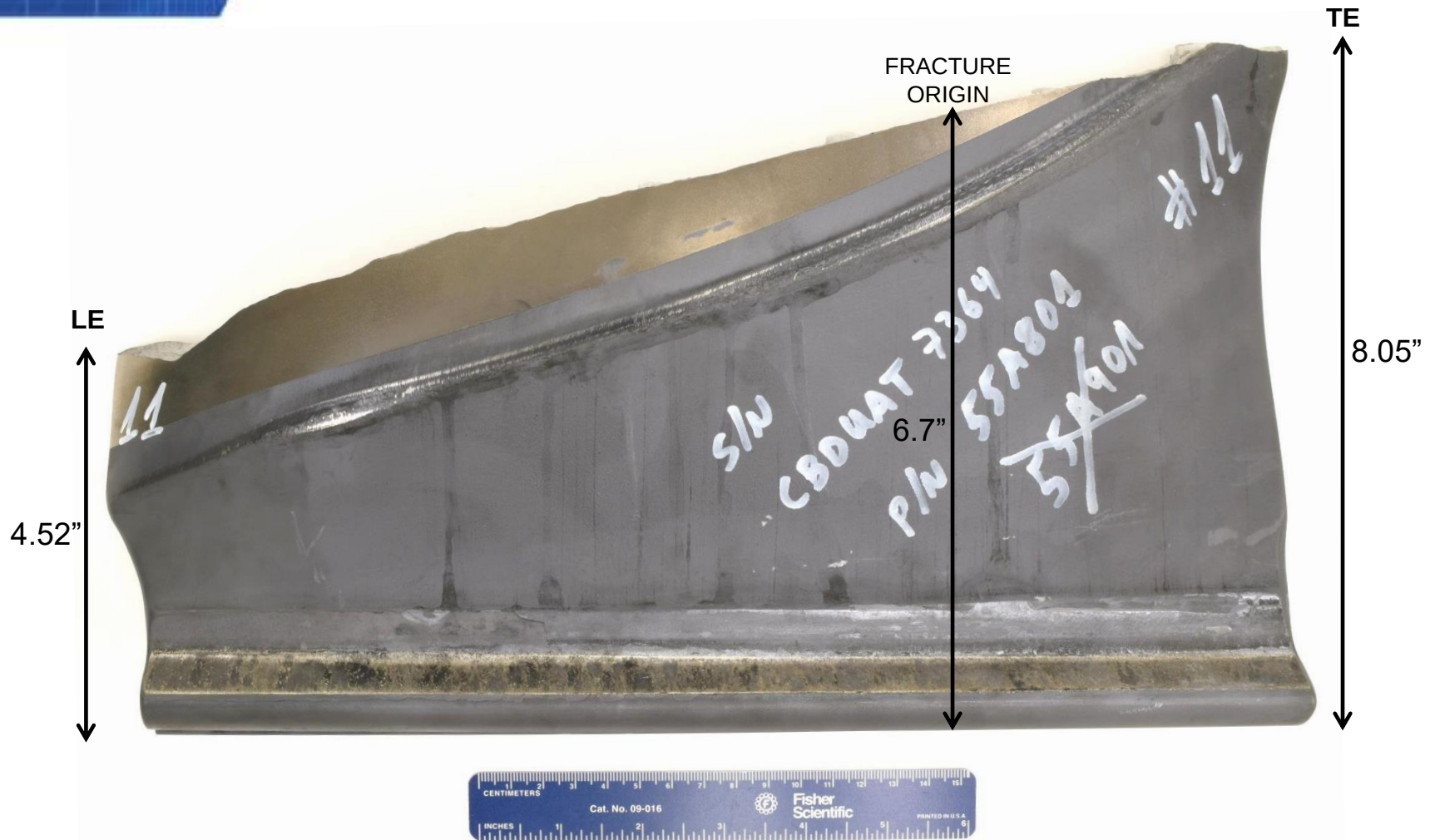


Figure 2 - Overall view of Blade #11, root portion, convex side.
Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination



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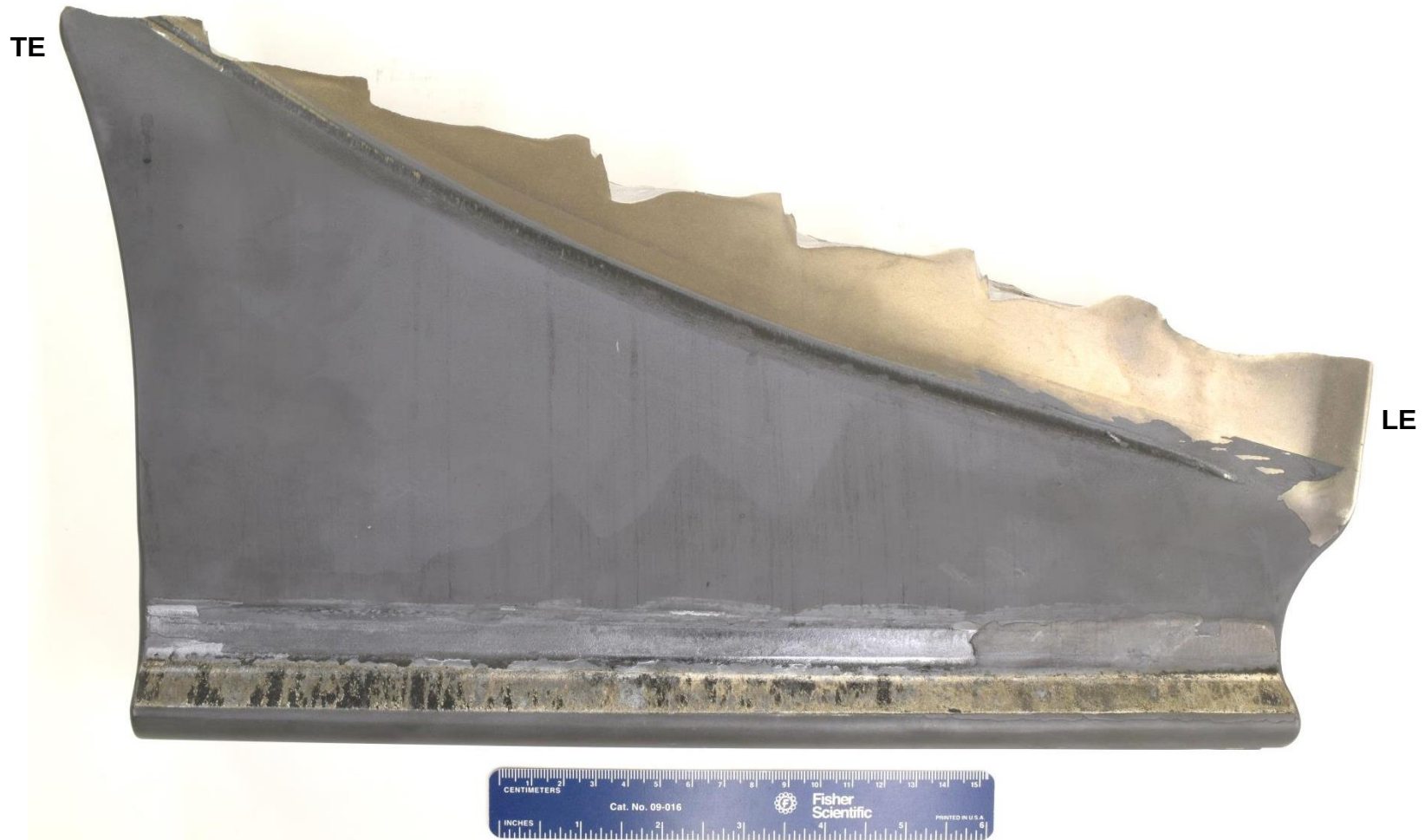


Figure 3 - Overall view of Blade #11, root portion, concave side.
Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination

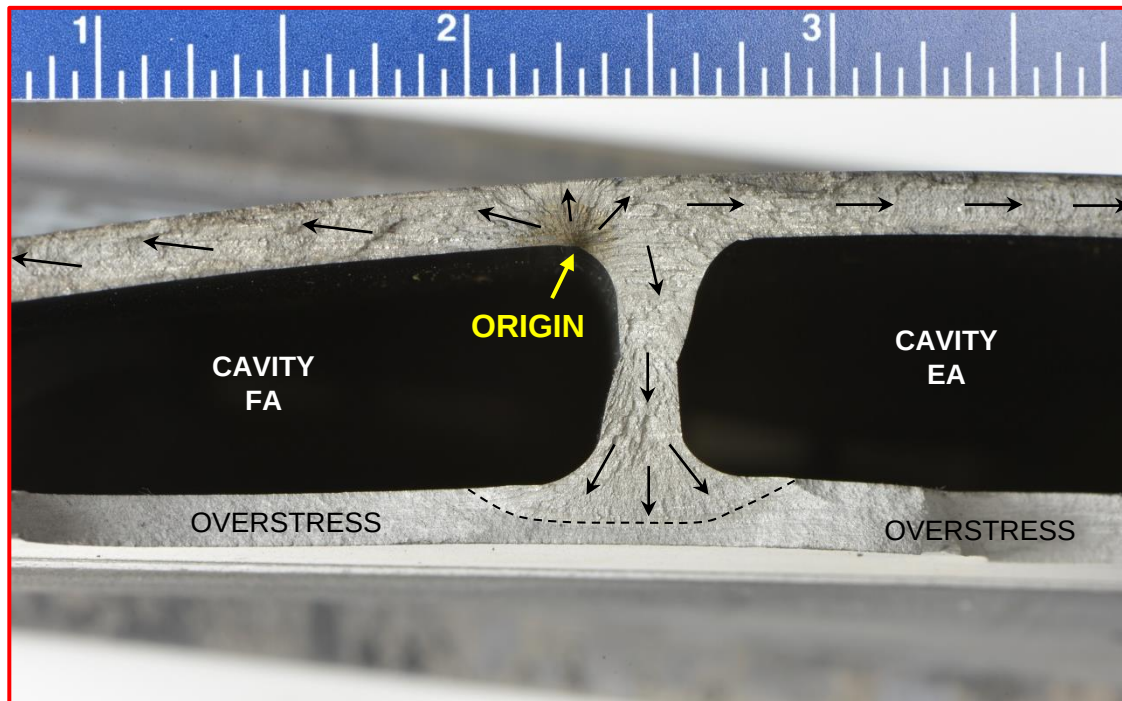
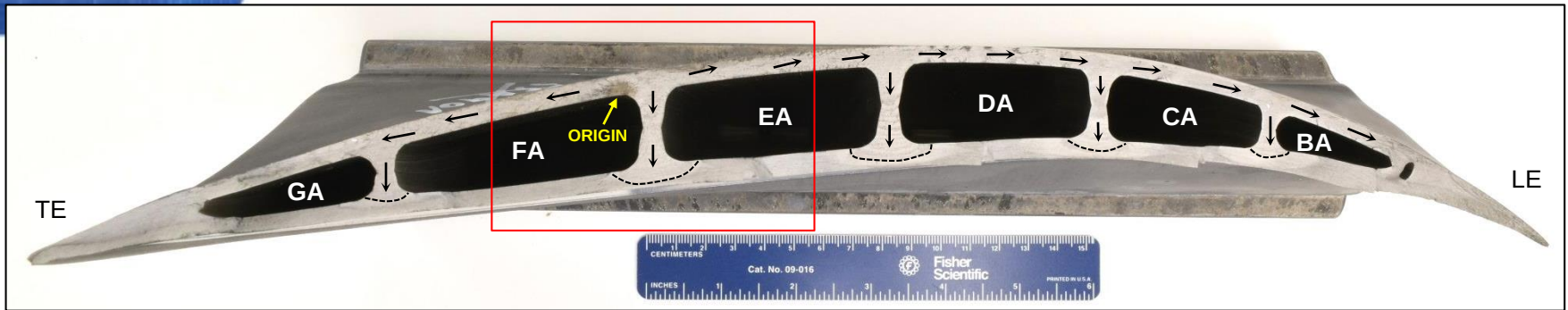


Figure 4 - Overall and close-up views of Blade #11 (root portion) fracture surface showing propagation from fatigue origin on the internal side of the convex wall at forward end of cavity FA.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination

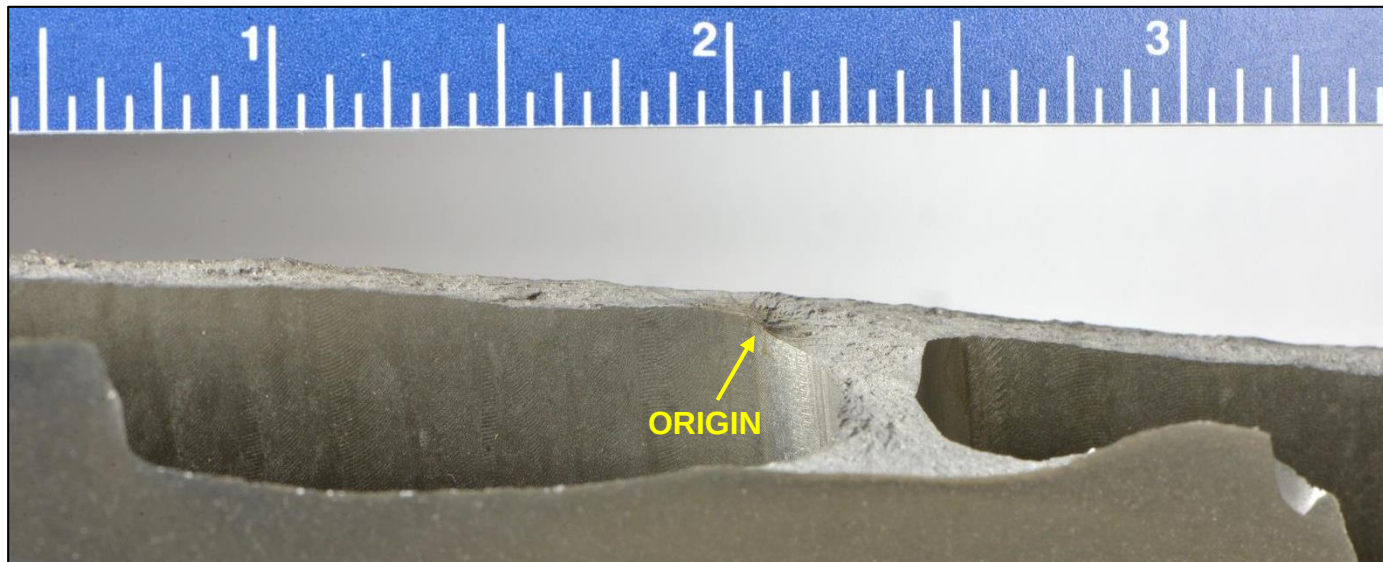
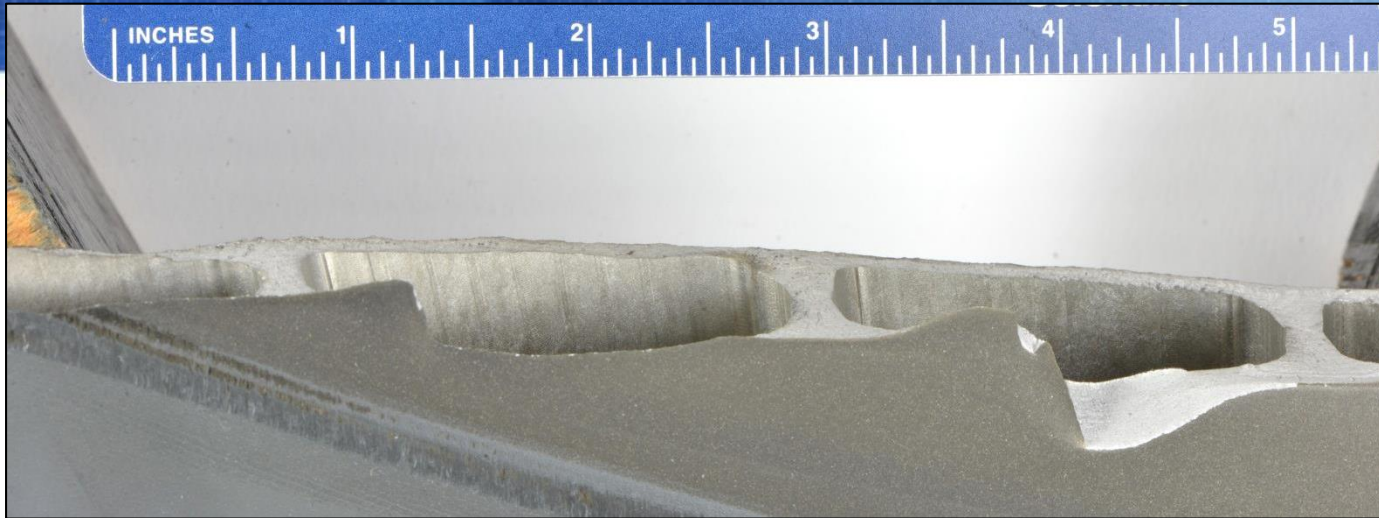


Figure 5 - Angled views of internal cavity side of convex wall at cavities FA and EA.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope Examination of Replicas

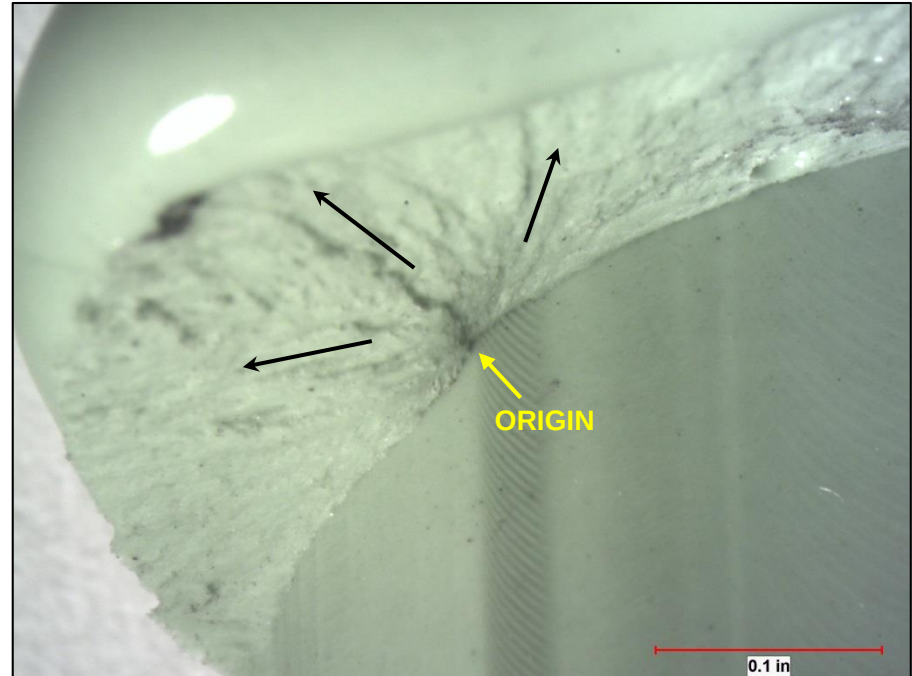
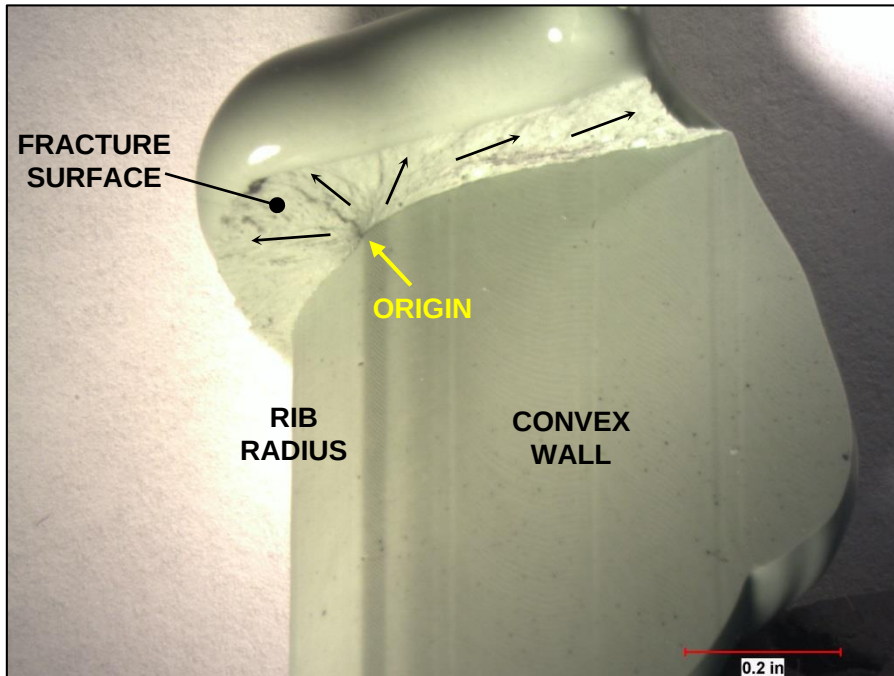


Figure 6 - Close-up views of polyvinylsiloxane rubber replica taken of internal cavity radius geometry at fatigue origin location.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope Examination of Replicas



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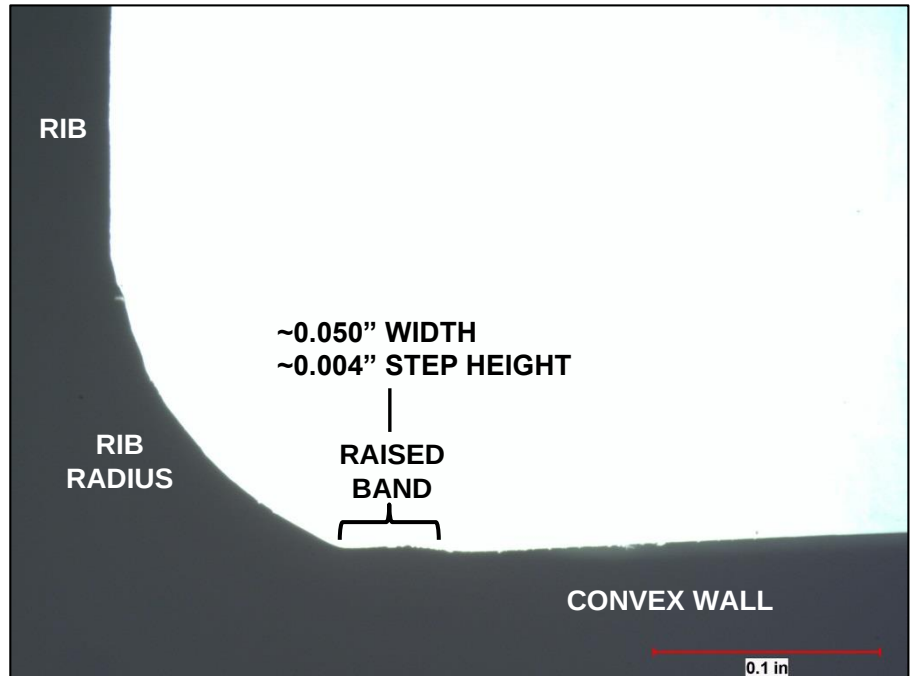
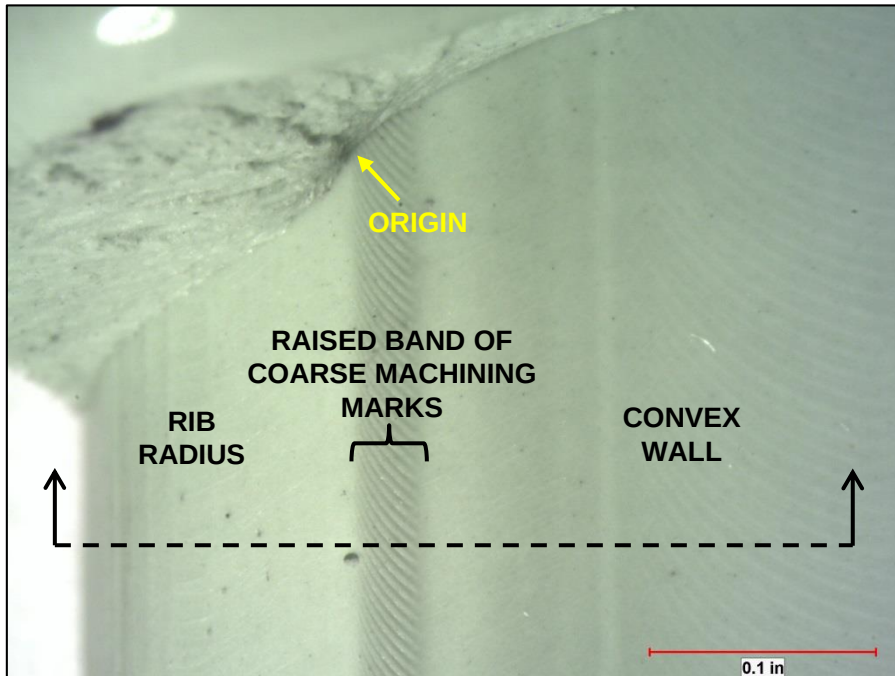


Figure 7 - Higher magnification views of polyvinylsiloxane rubber replica of internal cavity radius geometry at fatigue origin location.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Visual Examination

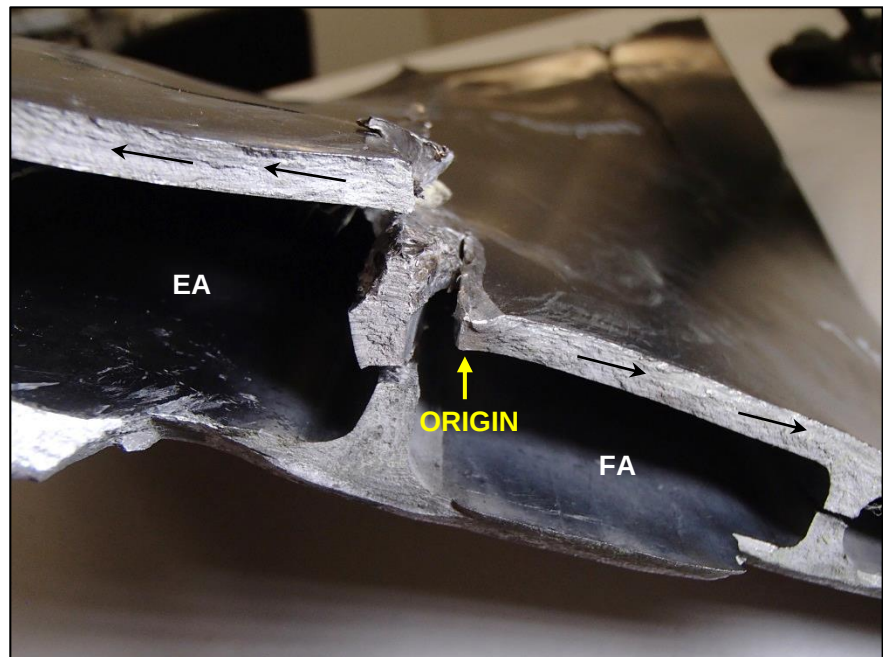
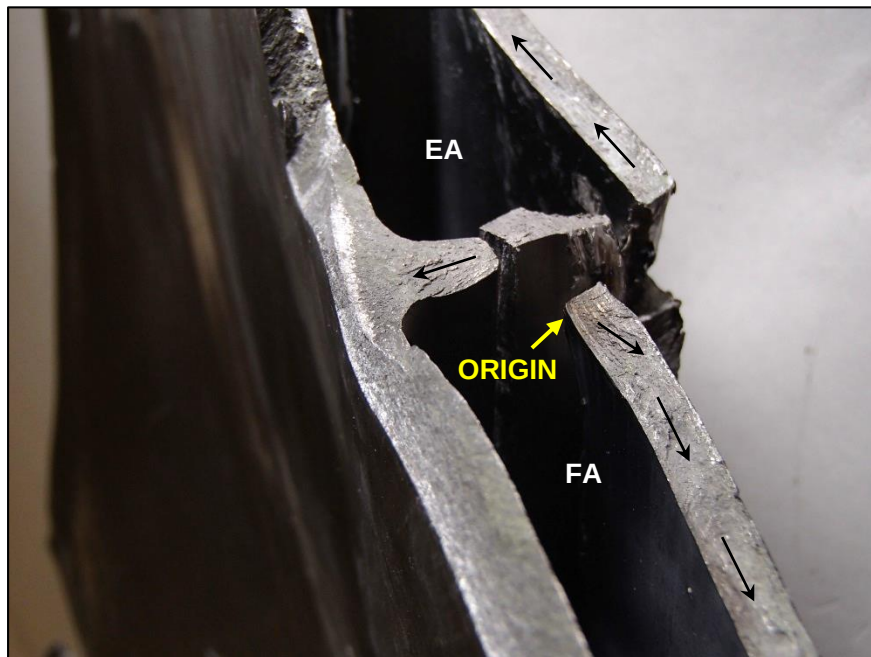


Figure 8 - Overall and close-up views of Blade #11 (airfoil portion) fracture surface and fatigue origin.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Part Markings



ASSY 55A901-A S/N CBDUAT7364

55A801 (Vibropeened marking)

Convex Skin H/C: RABAE0034

Concave Skin H/C: RAAAP0010

R-01, R-02, A72 286 (Vibropeened markings)

Figure 9 – Close-up views of Blade #11 part markings on root bottom.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope Examination

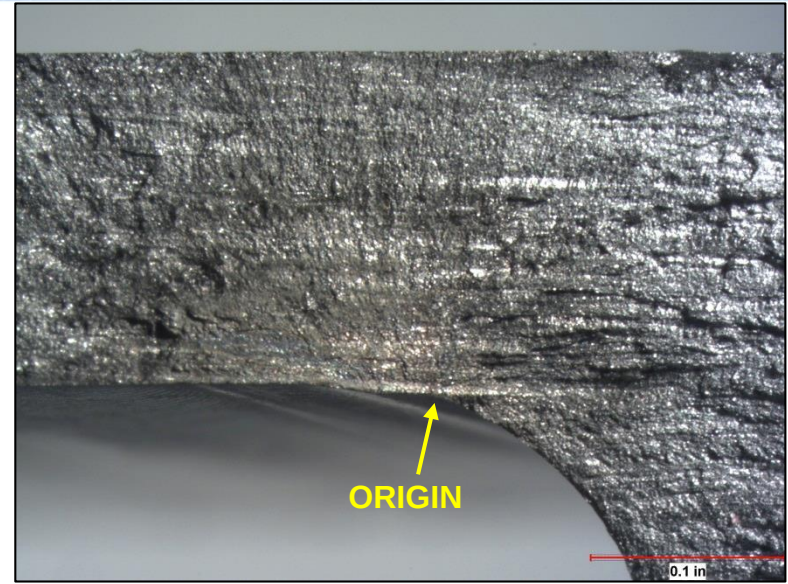
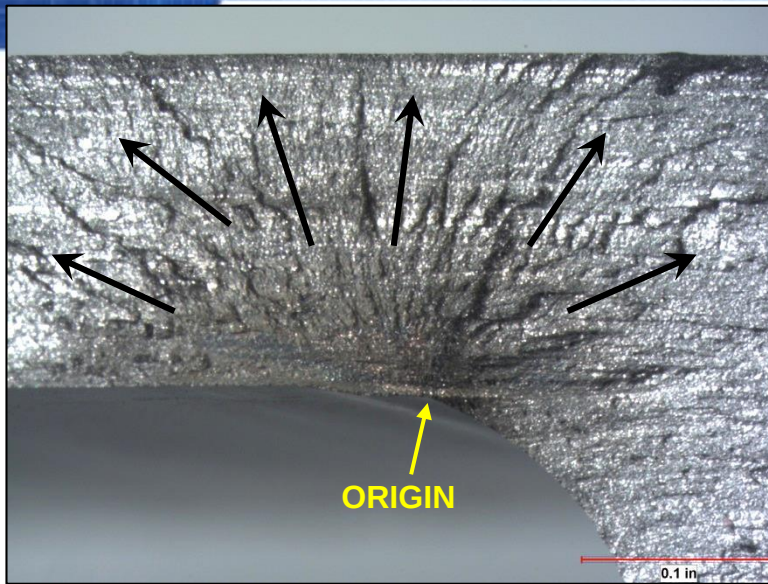
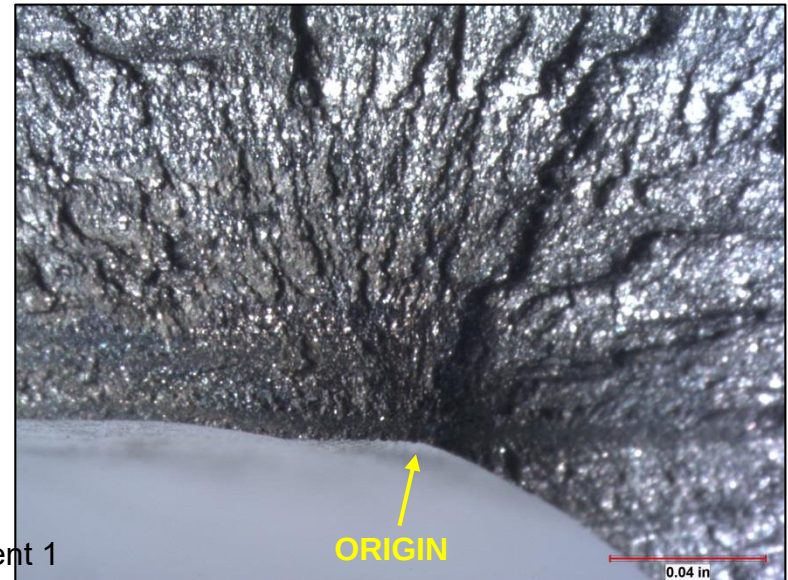


Figure 10 - Higher magnification views of fatigue origin area.



Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope Examination

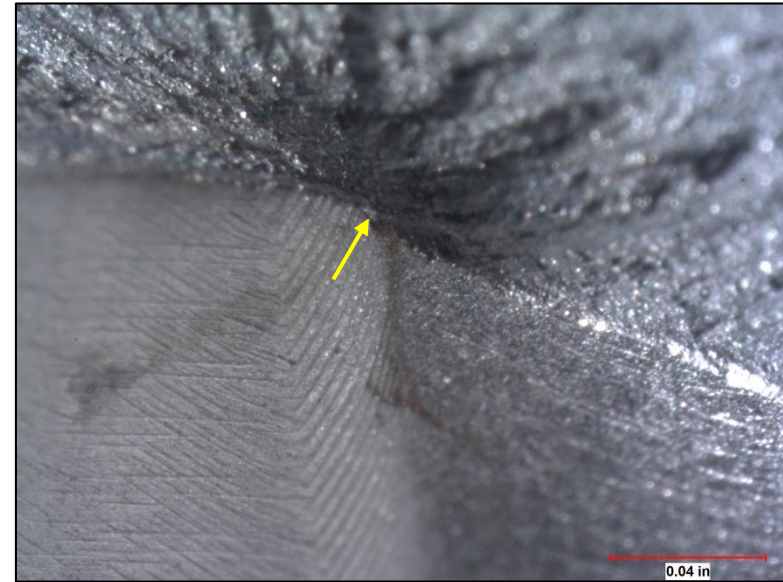
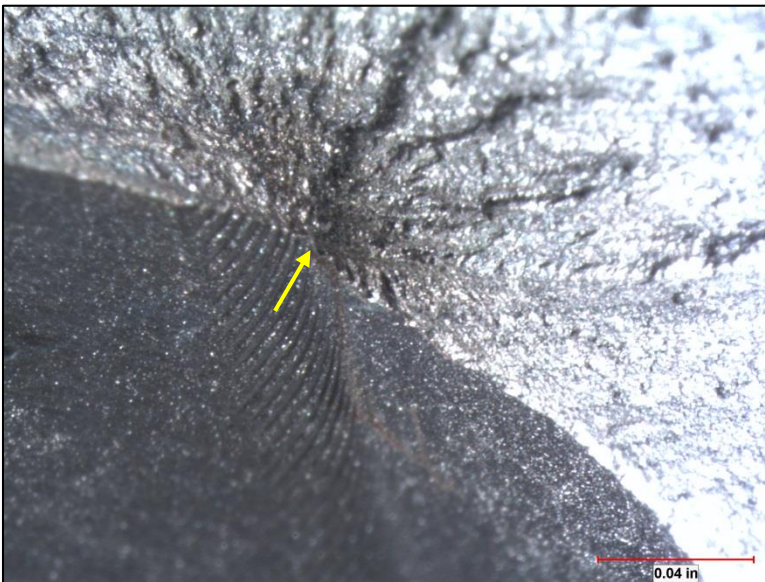
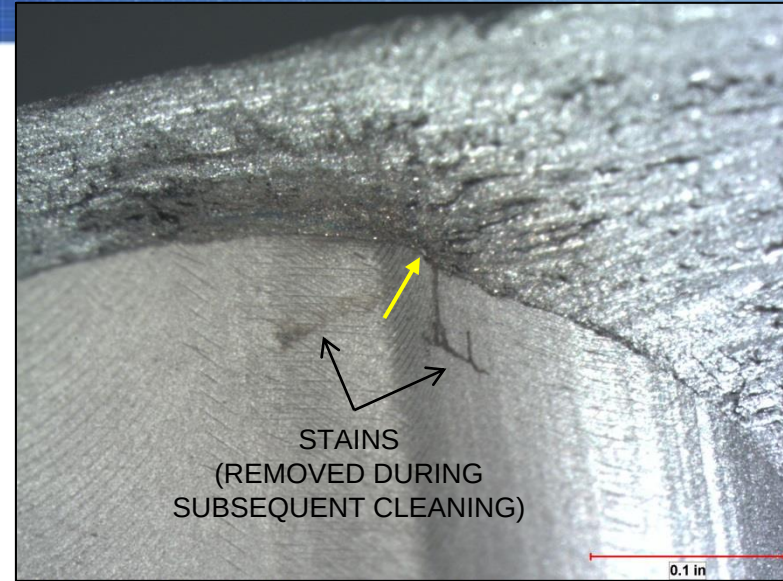
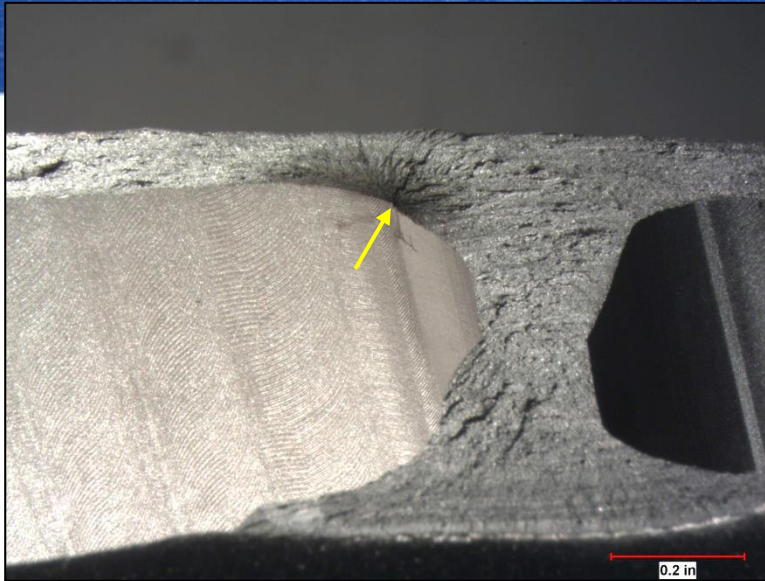


Figure 11 - Higher magnification views of fatigue origin area, tilted to show internal cavity FA surface machining features.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope / SEM Examination

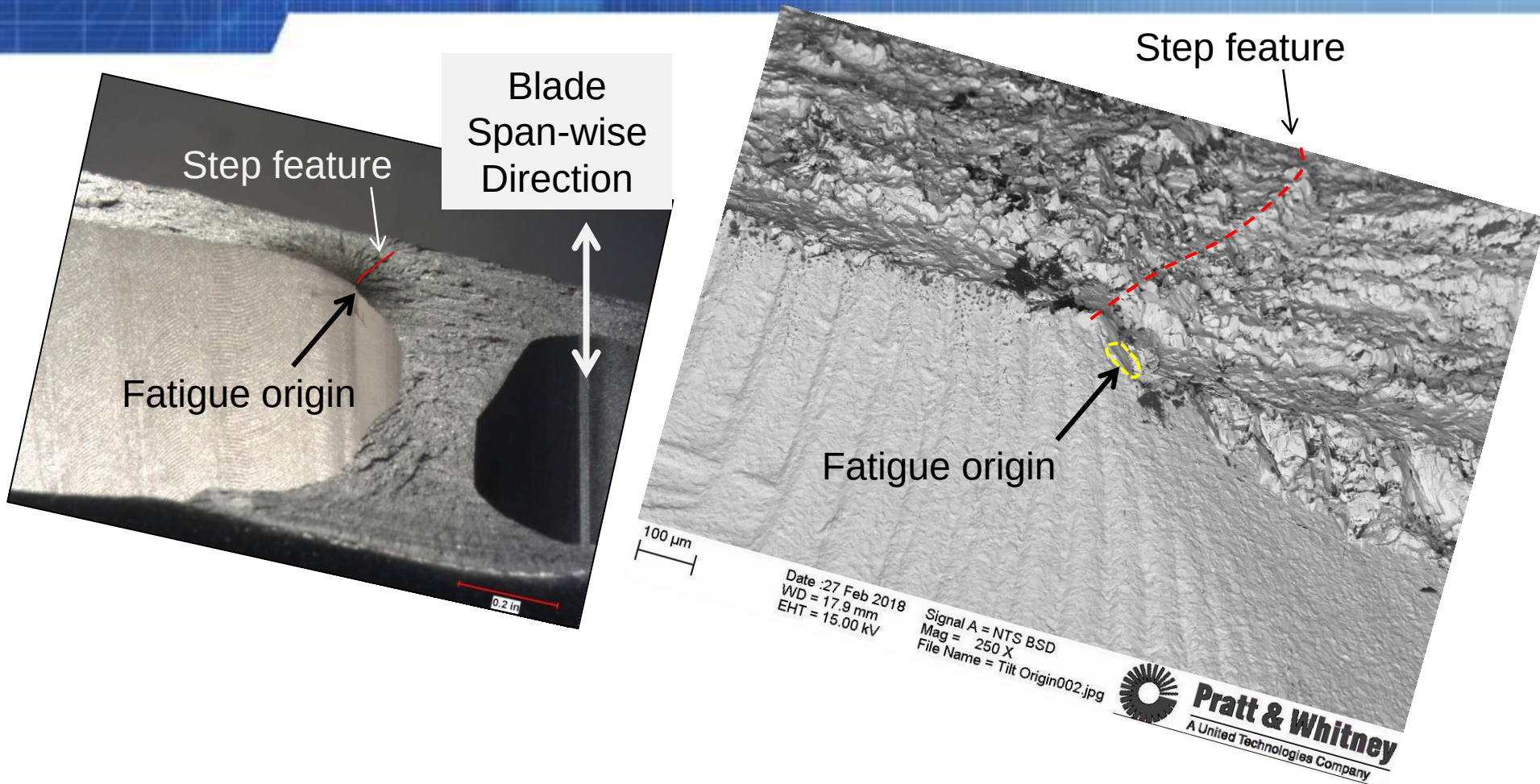


Figure 12 - The fracture progressed at an angle from perpendicular to the blade spanwise direction. The fatigue origin area was more steeply angled, resulting in a step which divided the fatigue progression into two halves. A high magnification examination of the cavity surface adjacent to the fatigue origin did not find evidence of damage due to “sparks” or “chips”. Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Binocular Microscope Examination

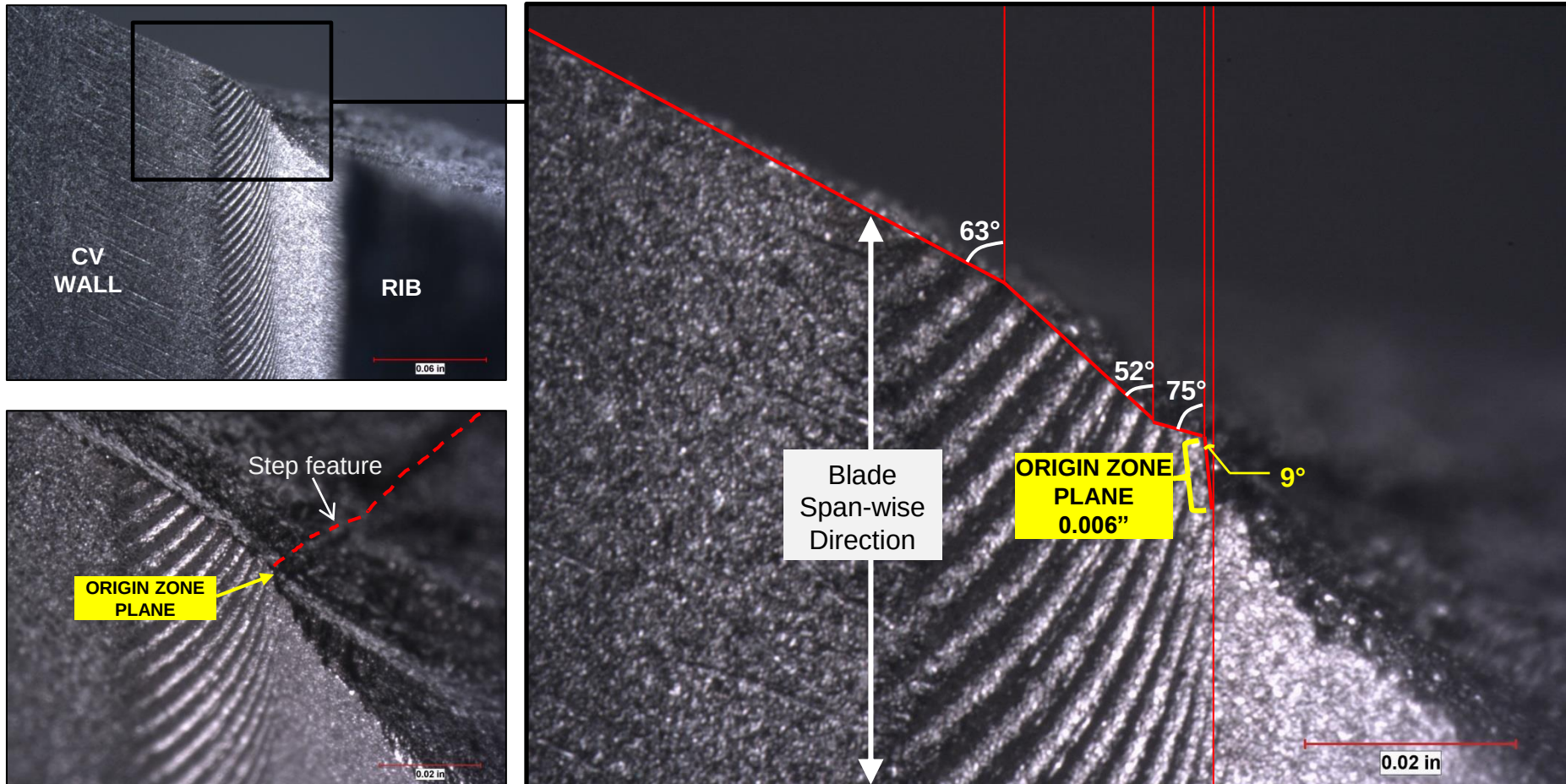


Figure 13 – The plane of the fatigue origin zone measured $\sim 9^\circ$ off the span-wise axis of the blade when using the machining pass as a guide.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination

Span-wise
Rolling direction

chord-wise
Rolling direction

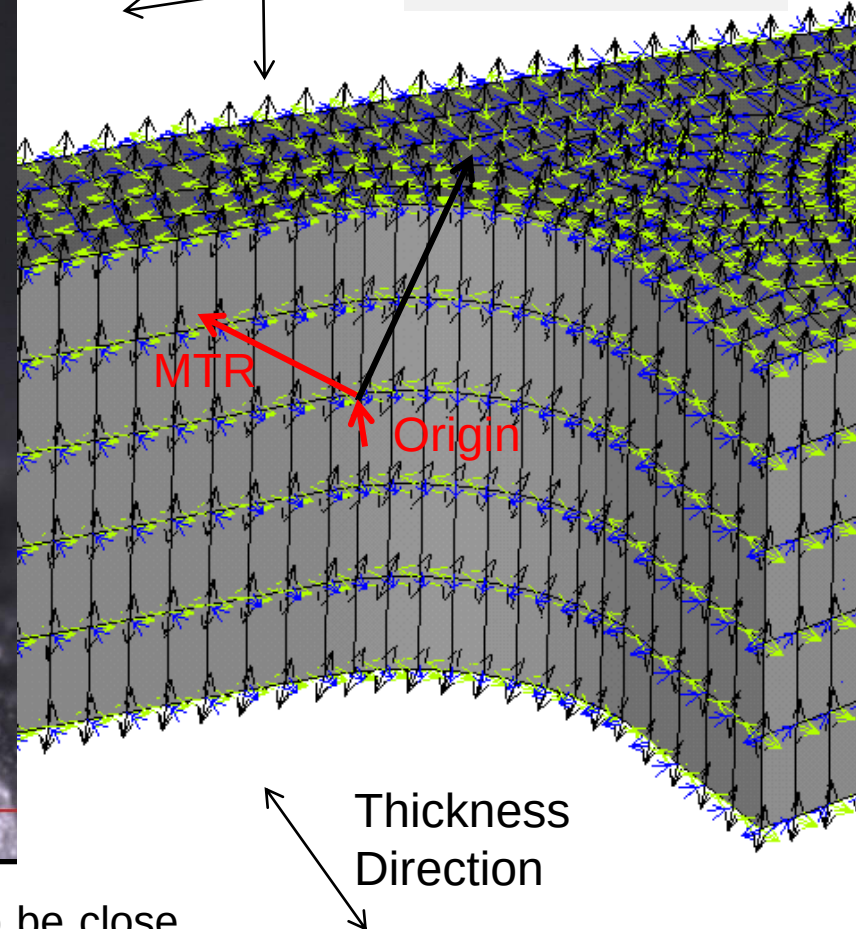
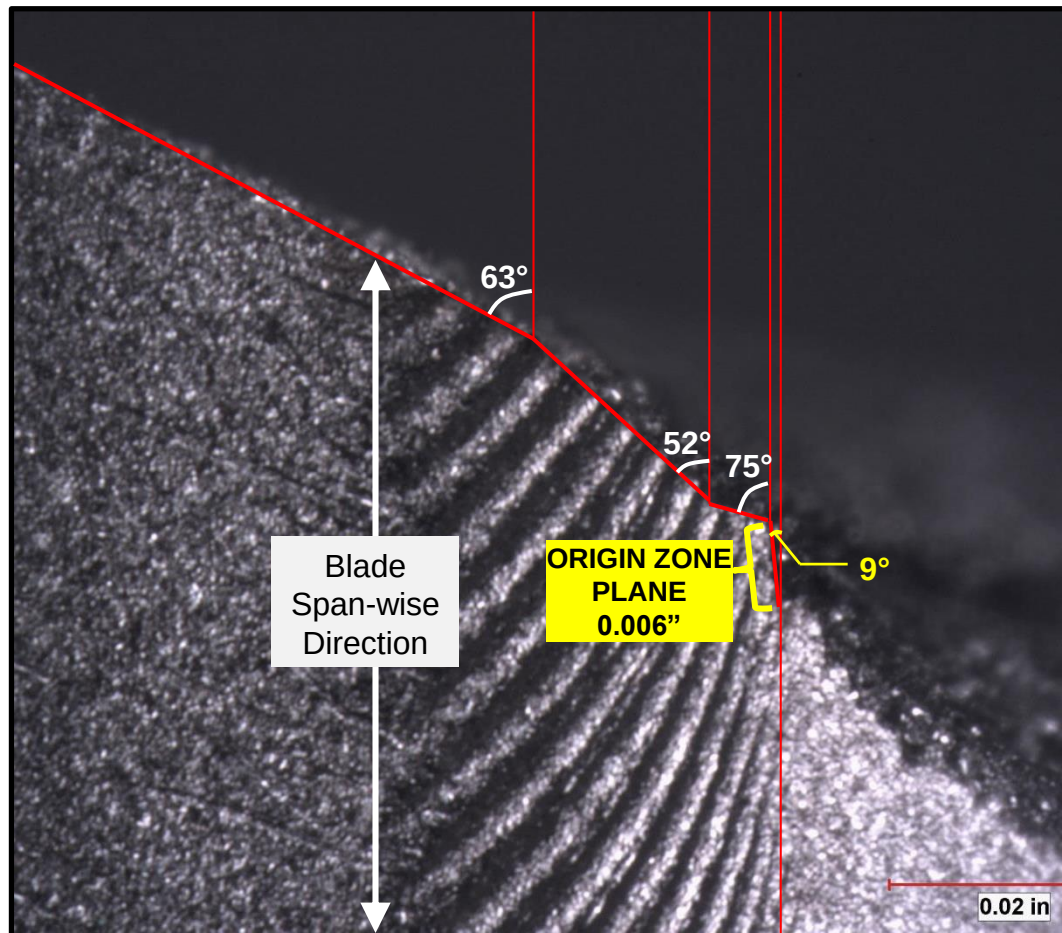


Figure 14 - Fracture surface 63° tilt area appeared to be close to perpendicular to the primary stress direction.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination

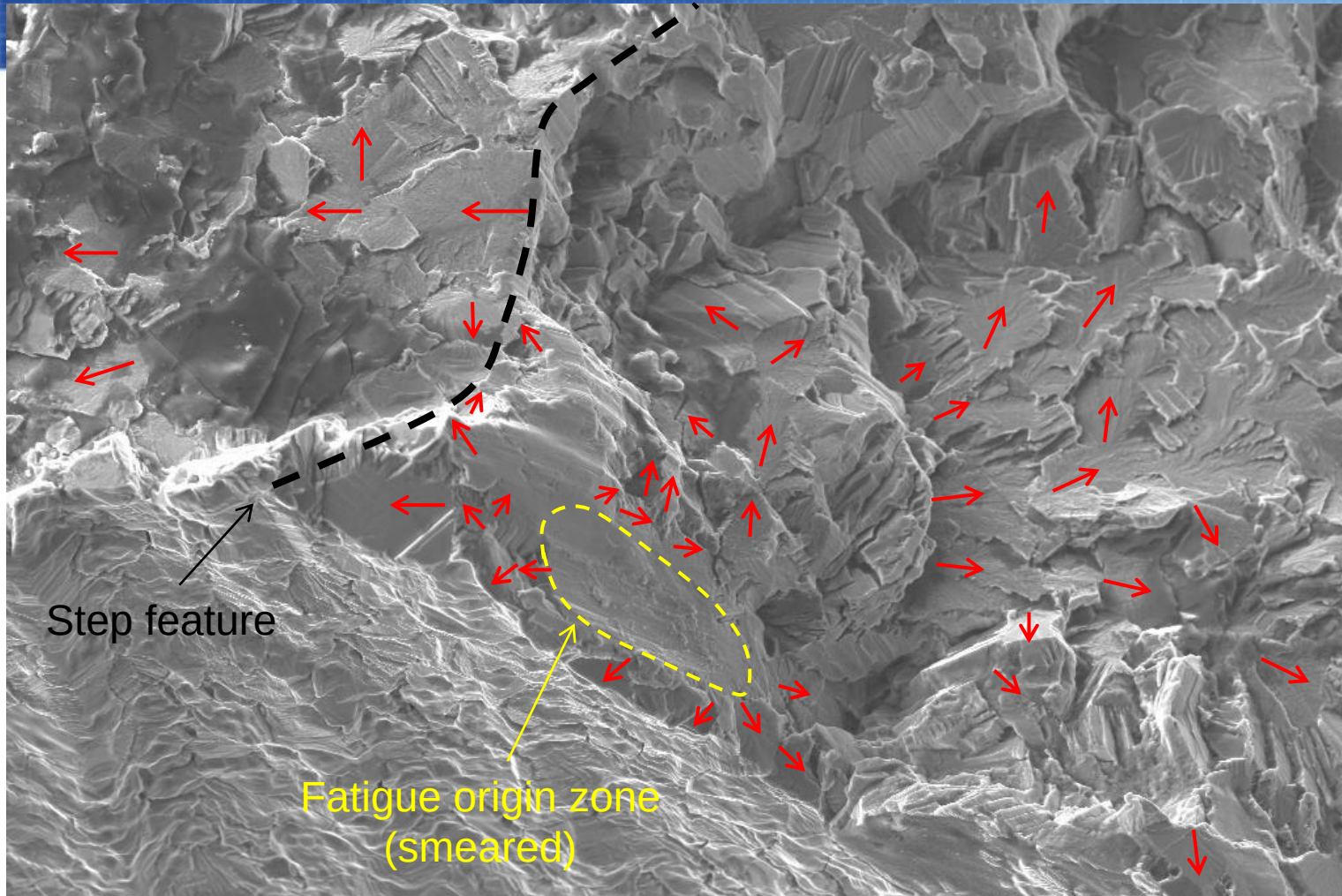


Figure 15 - Showing crack initiation details. The fatigue origin zone could be traced to an area slightly sub-surface, ~1-2 grains deep. The origin zone itself had been smeared due to secondary damage, removing fracture features, so an individual grain origin could not be identified.

Attachment 1

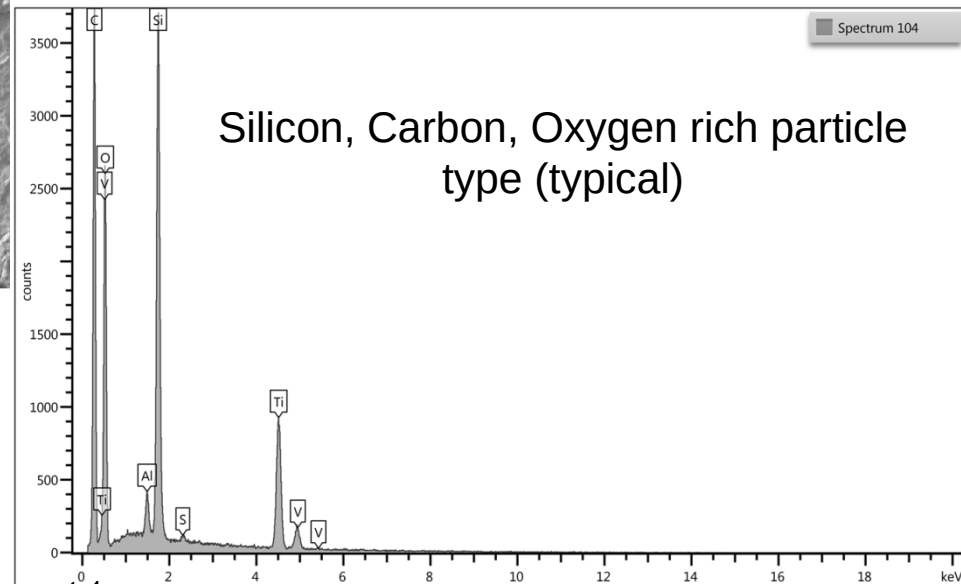
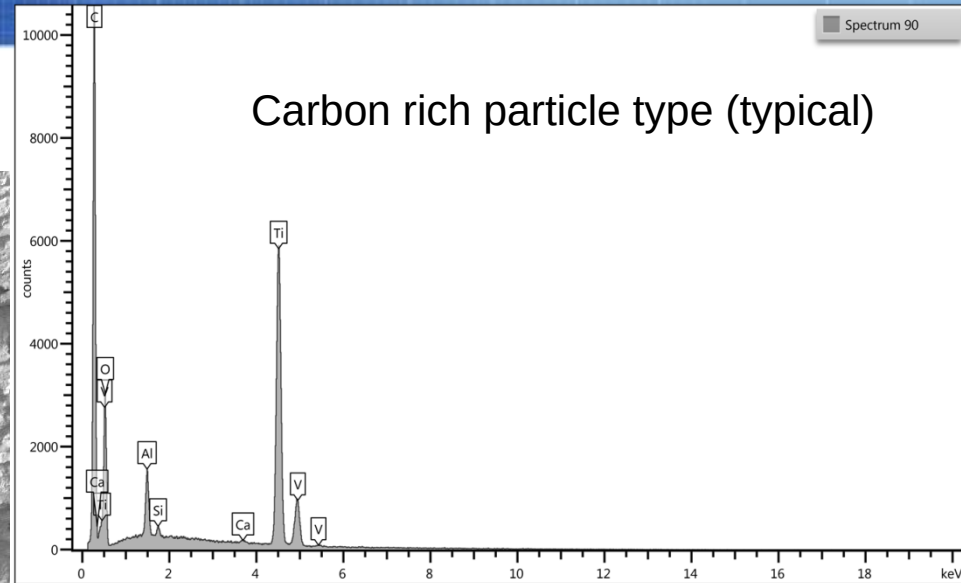
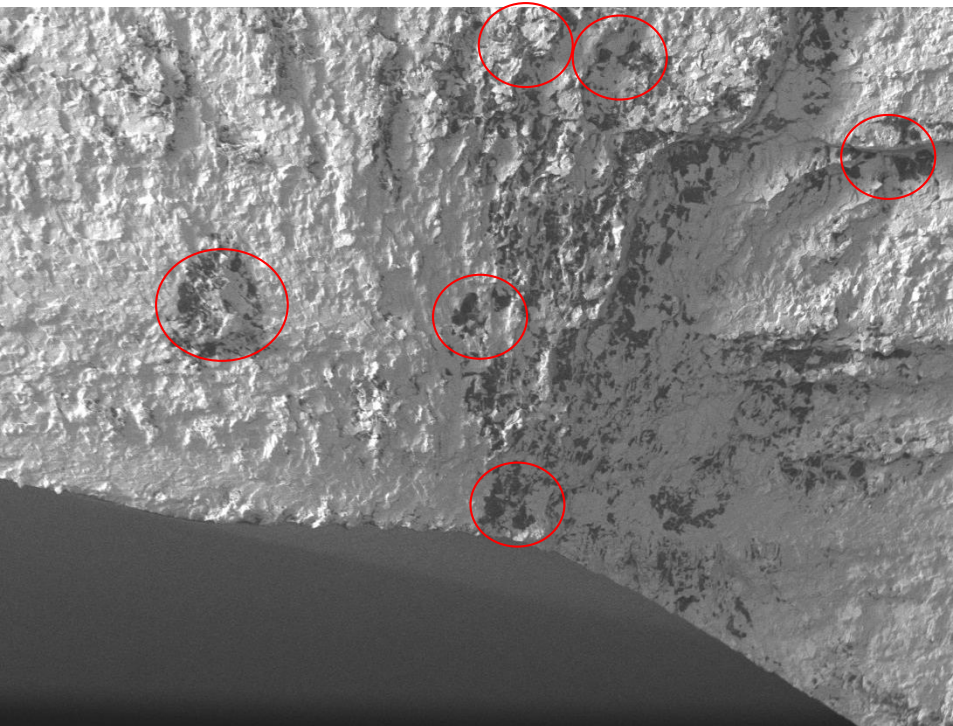


Figure 16 - Multiple particles analyzed from circled areas. Two typical particles types, shown at right, suggestive of surface contamination (dirt).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination

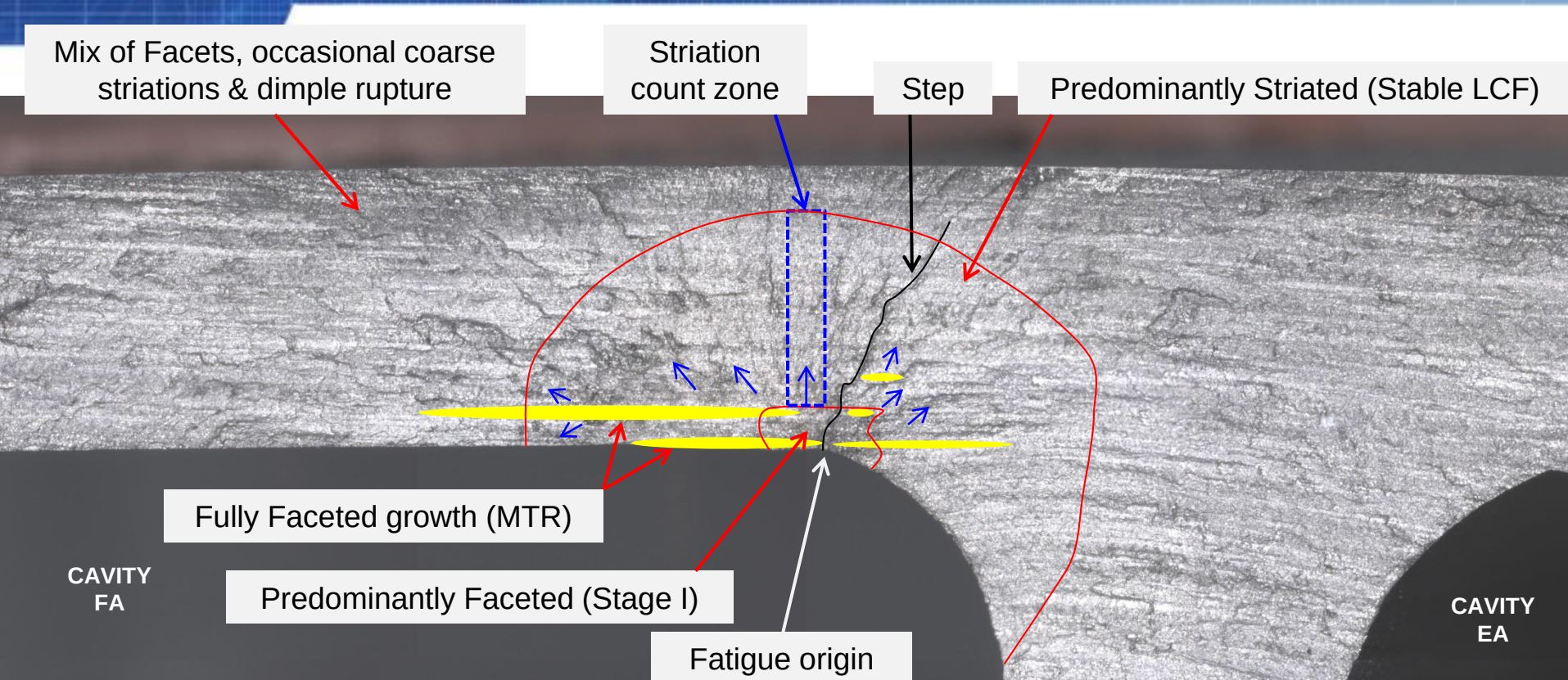


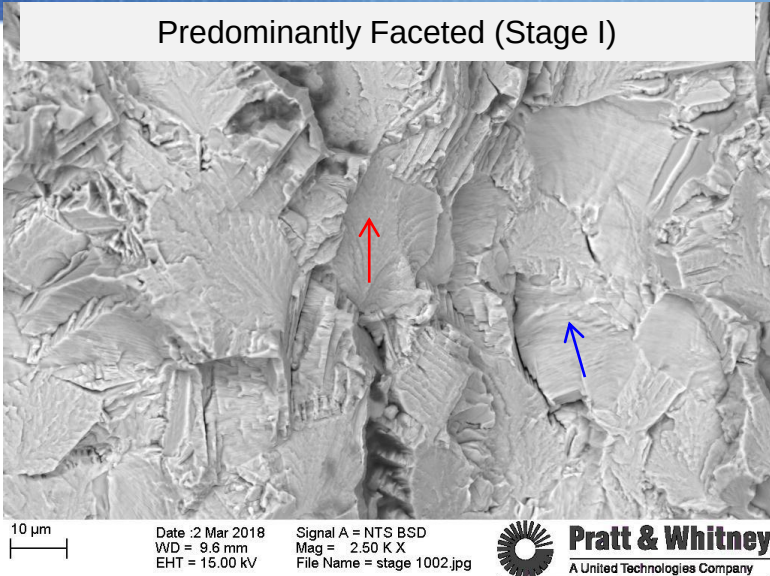
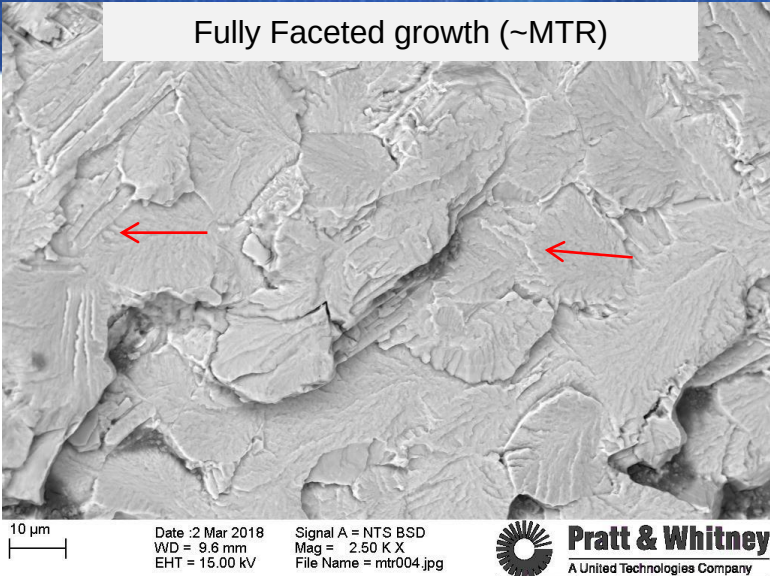
Figure 17 - Showing regions of fatigue crack propagation beyond the origin zone.

- Predominantly faceted growth mixed with striations was found within 0.032" of origin.
- Several areas of fully faceted growth were detected (yellow zones) suggestive of micro-texture regions (MTR's). Note these were associated with early fatigue progression and not fatigue initiation.
- Beyond 0.032" from the origin was a region of predominantly fatigue striations, suggesting stable LCF. The striation count was performed in this region within the blue box.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination



Mixed Facets & coarse striations (beyond stable LCF)

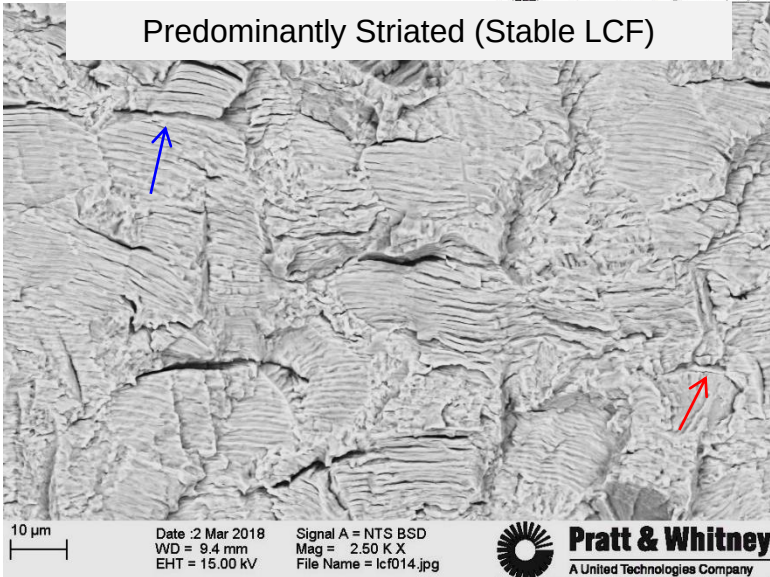
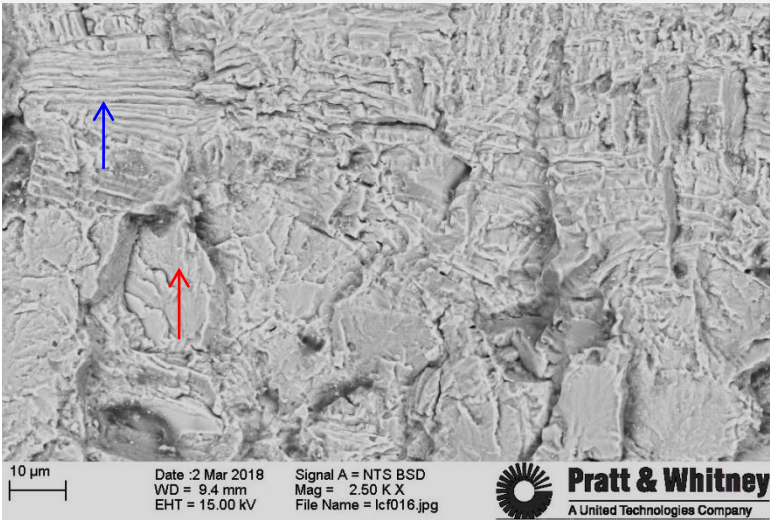


Figure 18 - Showing typical fatigue modes. Arrows denote direction of fatigue progression.

PW4077 P777049 Fan Blade Fracture Investigation

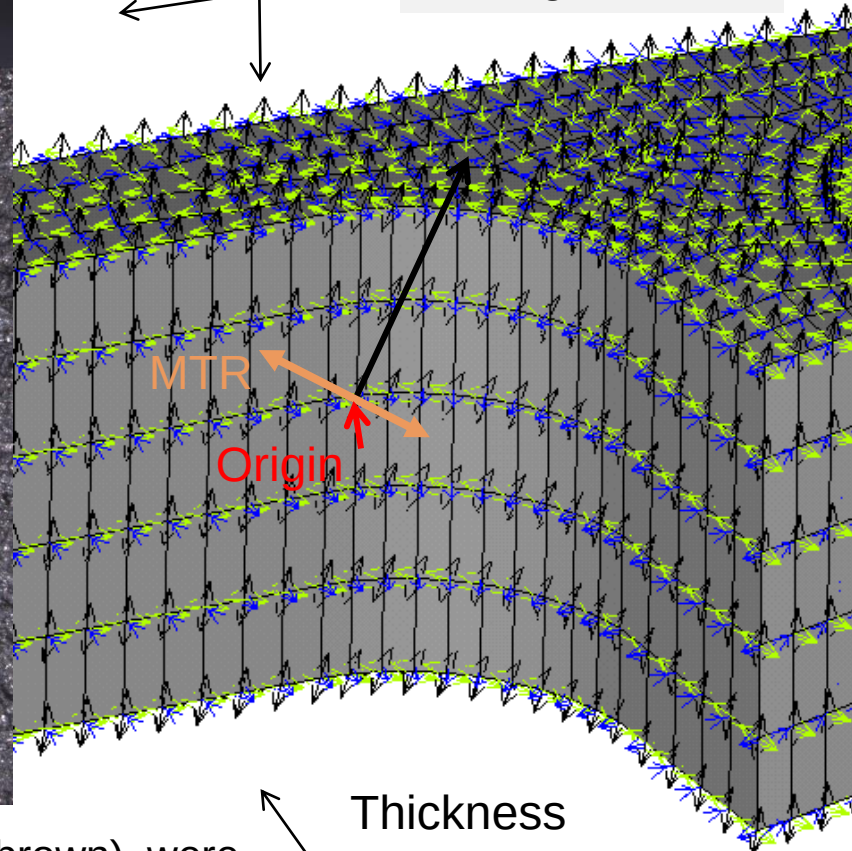
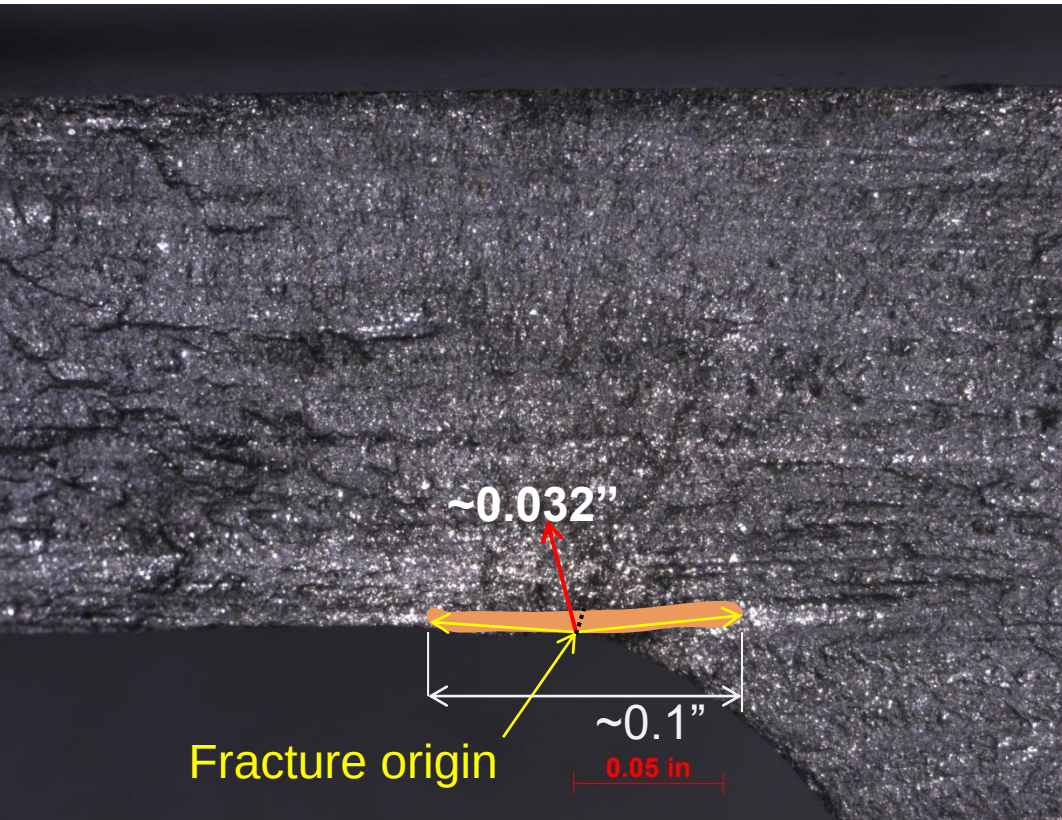
Blade #11 SEM Examination



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Span-wise
Rolling direction

chord-wise
Rolling direction



Thickness
Direction

Figure 19 – The FESEM exam suggested MTR's (brown) were present near the fracture origin. The estimated size of the crack initiation zone including the MTR's was $\sim 0.032 \times 0.100$ ".

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination

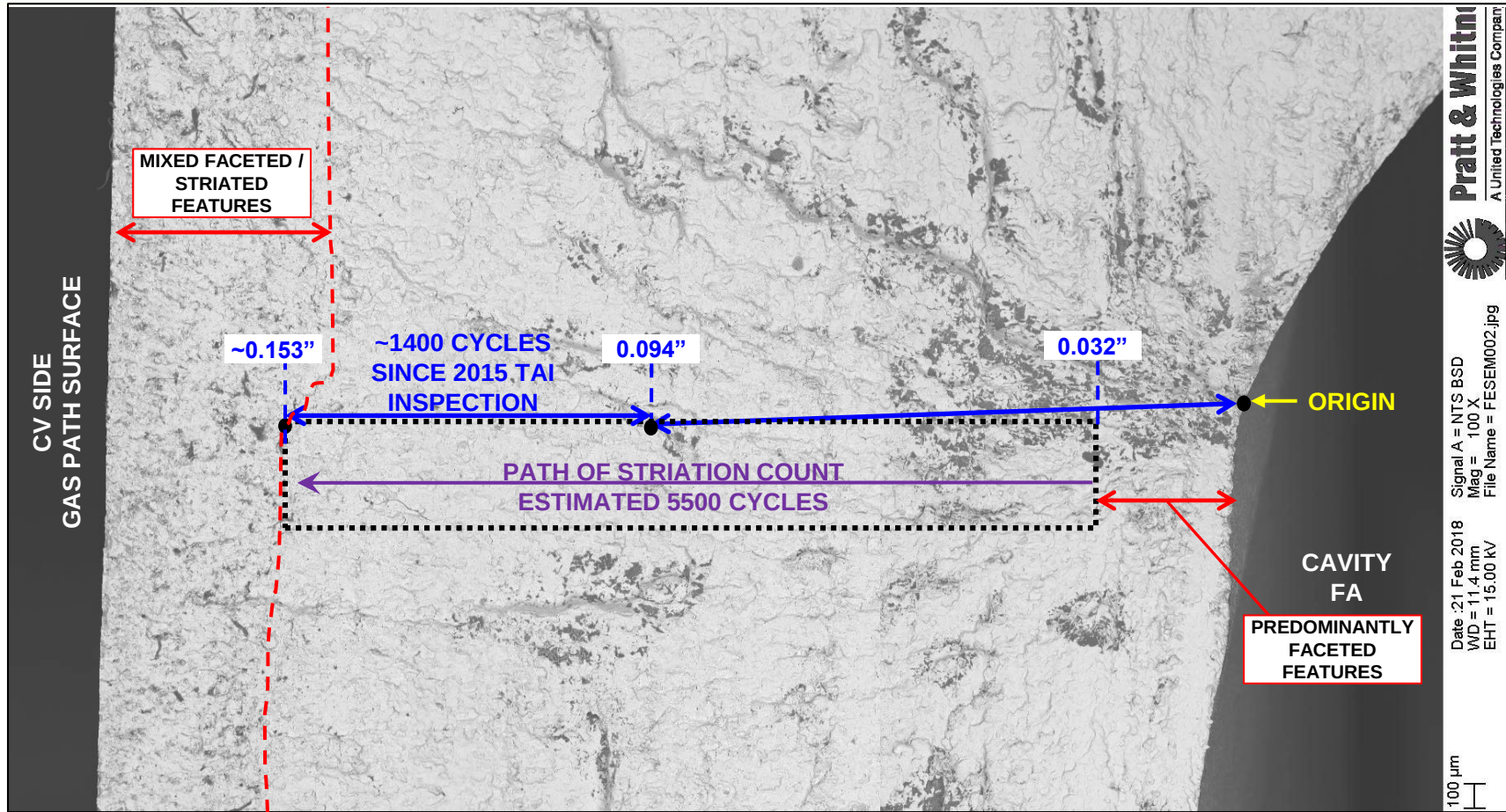


Figure 20 - Predominantly striated fatigue crack growth (LCF) was observed ~0.032" - 0.153" from origin. Striation count within rectangular zone through this region estimated 5500 cycles of LCF crack propagation. Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 SEM Examination

Onset of bulk dimple rupture

Extent of Striated zone (Stable LCF)

Onset of bulk dimple rupture

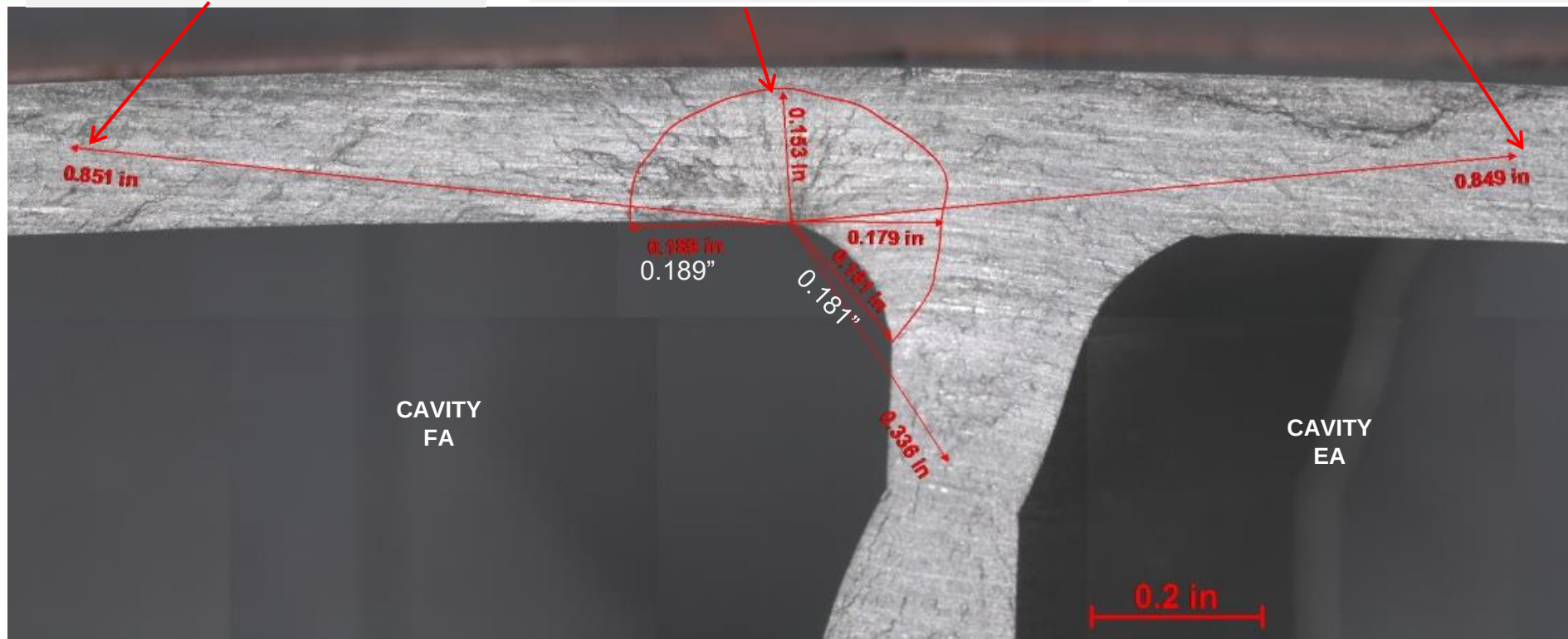


Figure 21 –

- Showing extent of stable LCF zone, which measured up to 0.153 - 0.189" from the origin.
- Beyond the stable LCF zone, the fracture mode exhibited a mix of faceted growth with occasional areas of coarse striations as well as a gradual transition to dimple rupture with increasing distance from the origin.
- The onset of bulk dimple rupture (e.g. un-stable tearing) ranged between 0.336" (in rib) and 0.851" (in convex side wall), from the origin.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

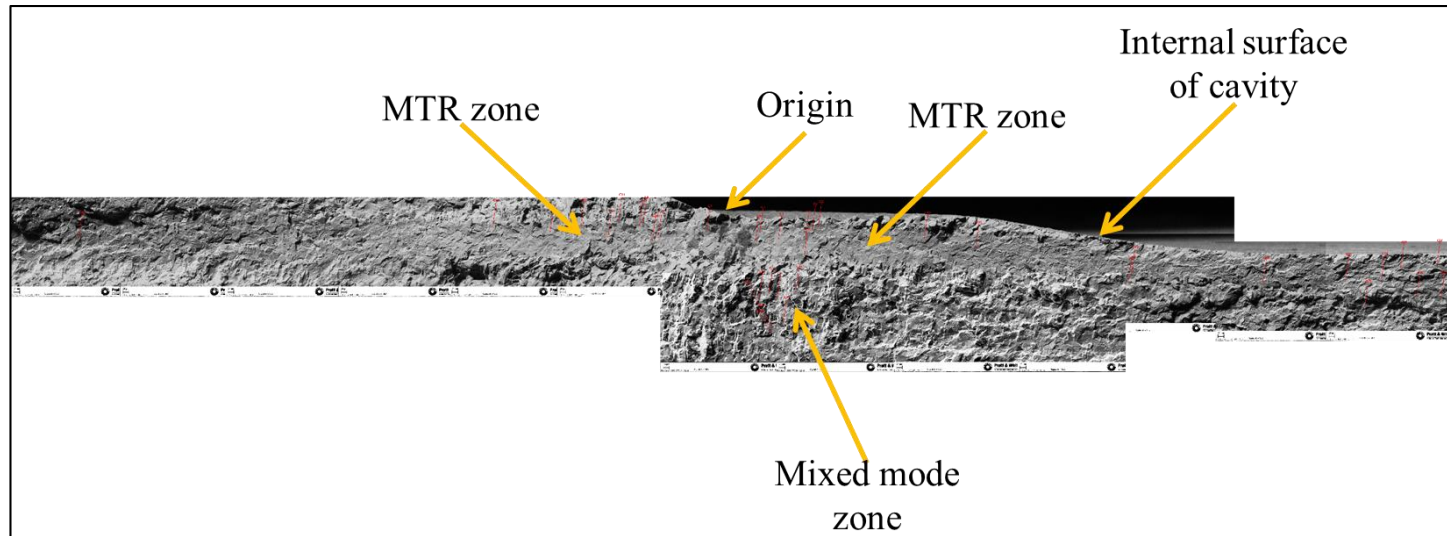
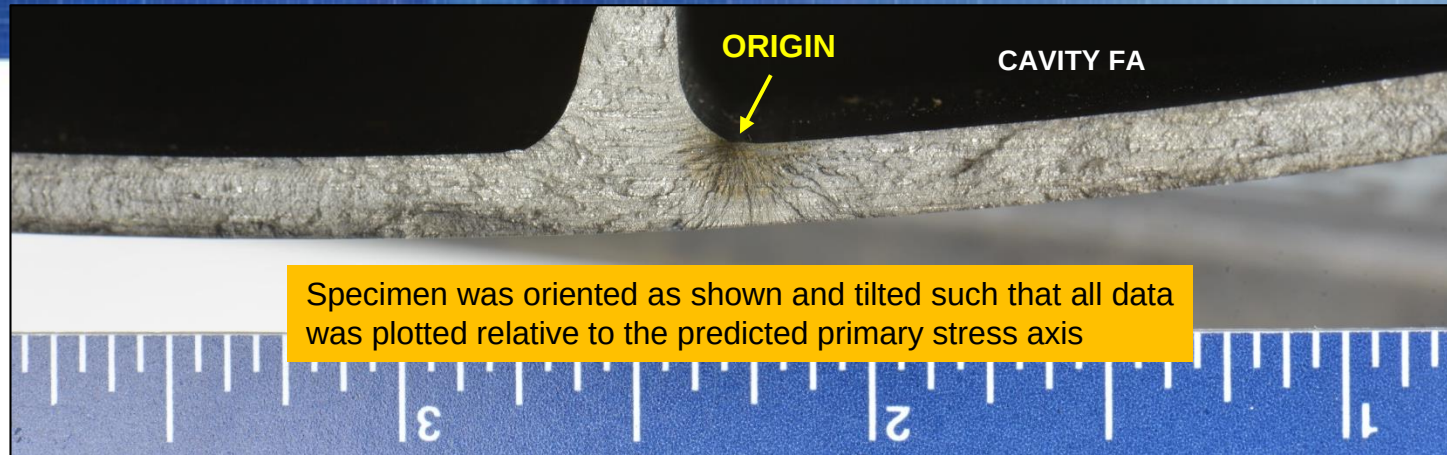


Figure 22 – Macro image of fracture surface (top) showing orientation used during EBSD scanning and secondary electron SEM image of fracture surface (bottom) showing origin and associated micro-texture region (MTR).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

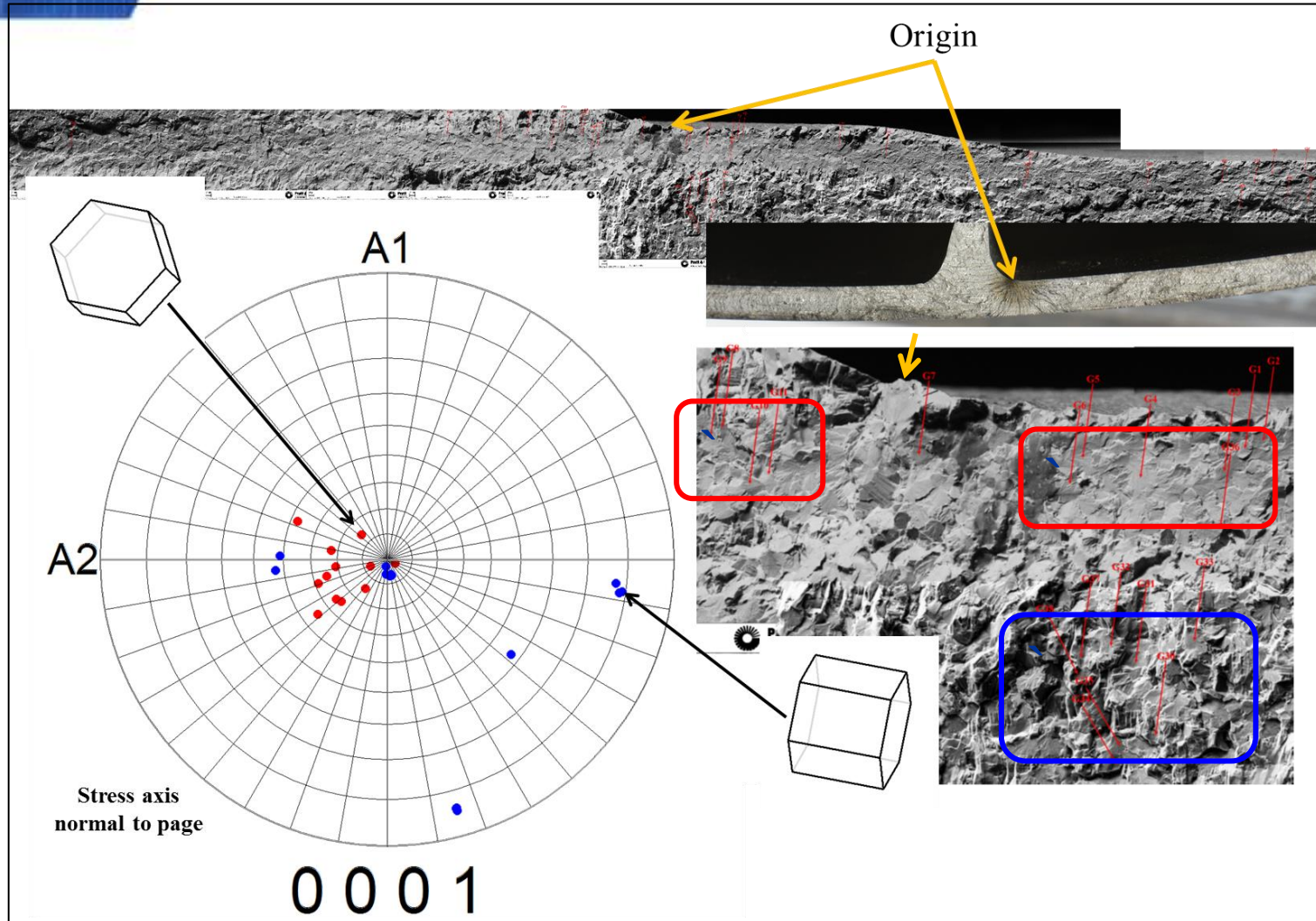


Figure 23 – Basal plane orientations in the MTR passing through the origin (red) and mixed mode region (blue).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

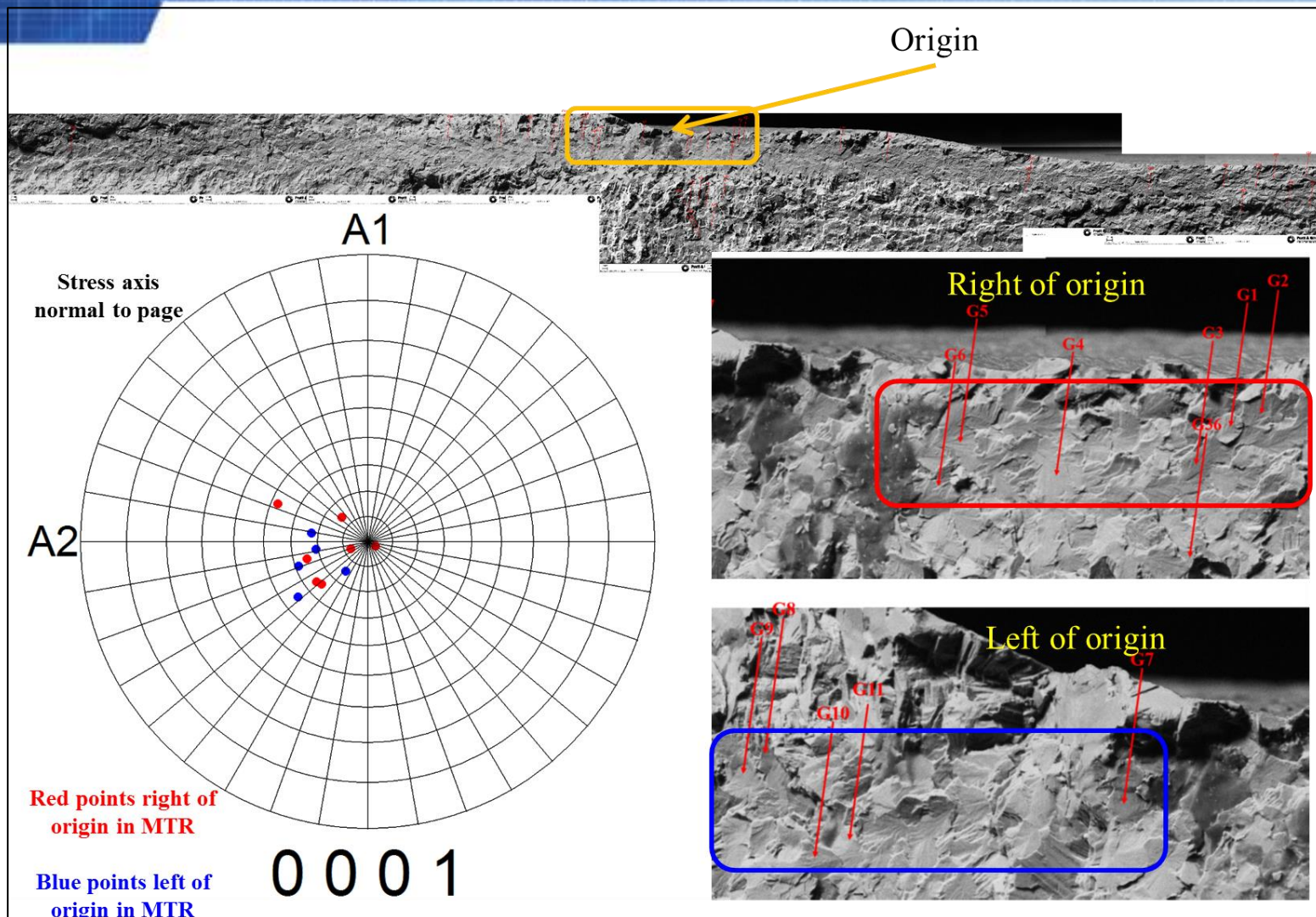


Figure 24 – Comingling of grain orientations in the MTR either side of the origin indicate that a single contiguous MTR is possible.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

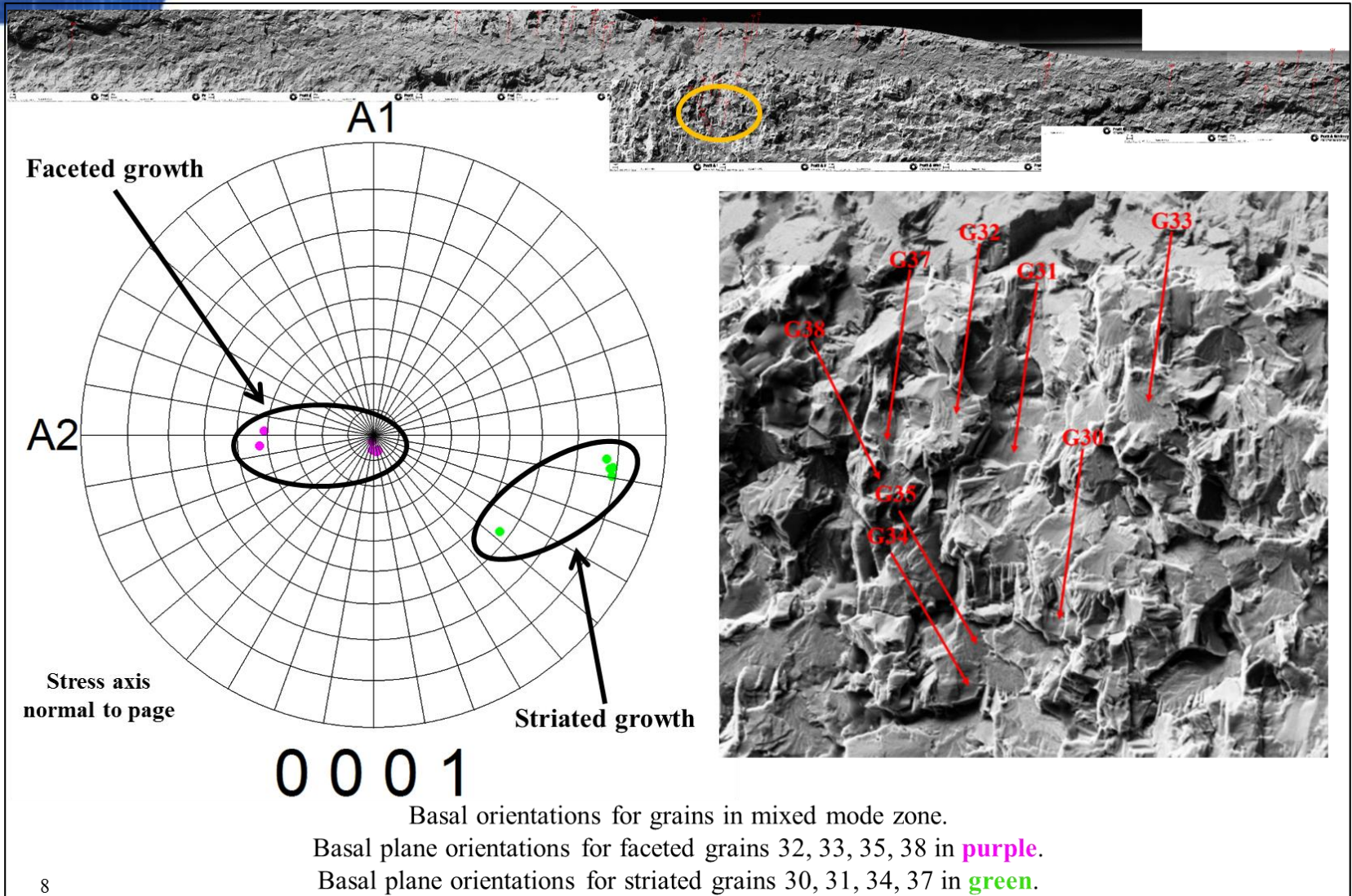


Figure 25 – Basal plane orientations for grains in mixed mode zone.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

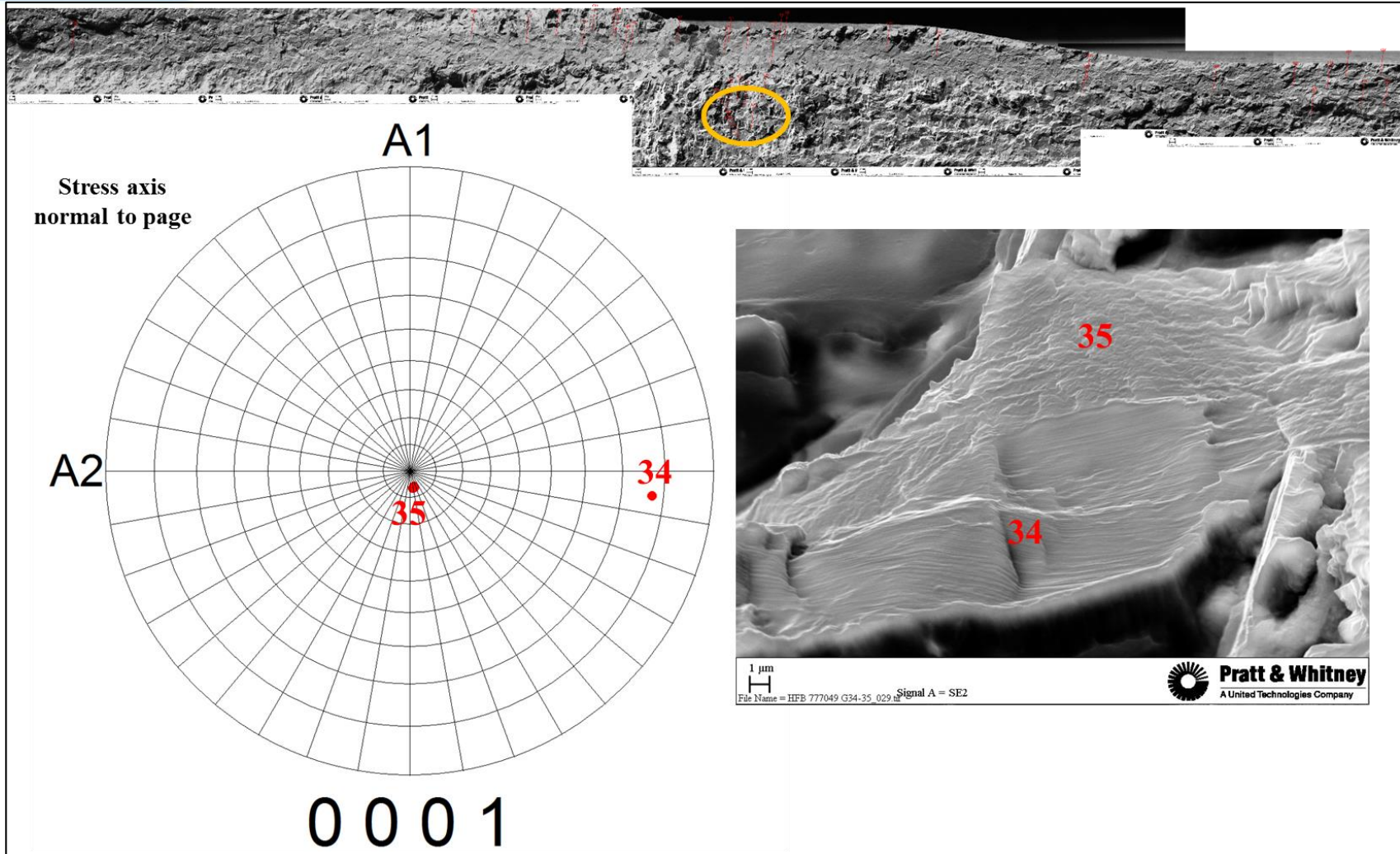


Figure 26 – Basal plane orientations associated with striated growth (34) and faceted growth (35).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) Tilt Fractography

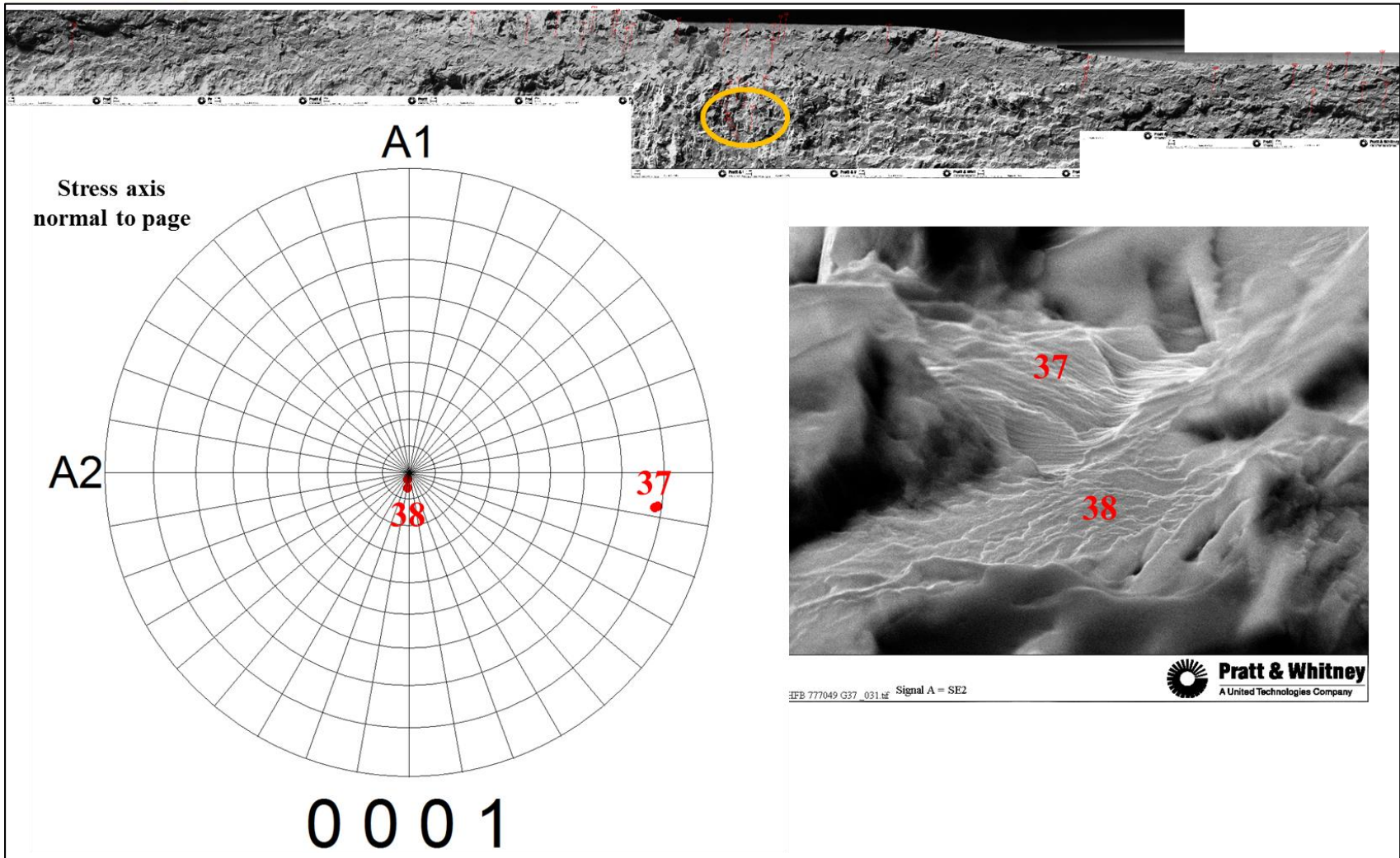


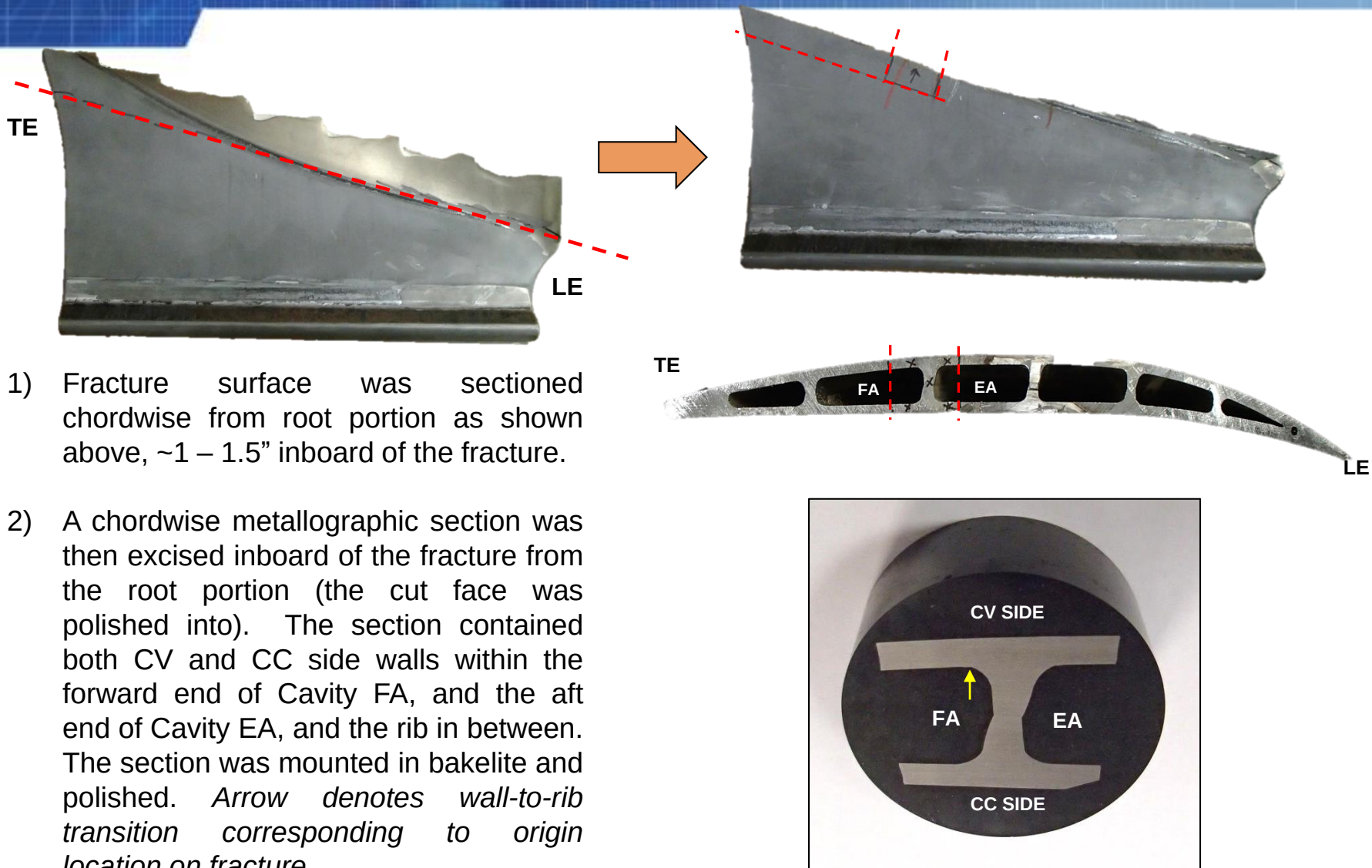
Figure 27 – Basal plane orientations associated with striated growth (37) and faceted growth (38).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)



Pratt & Whitney
A United Technologies Company



Attachment 1
Figure 28

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)

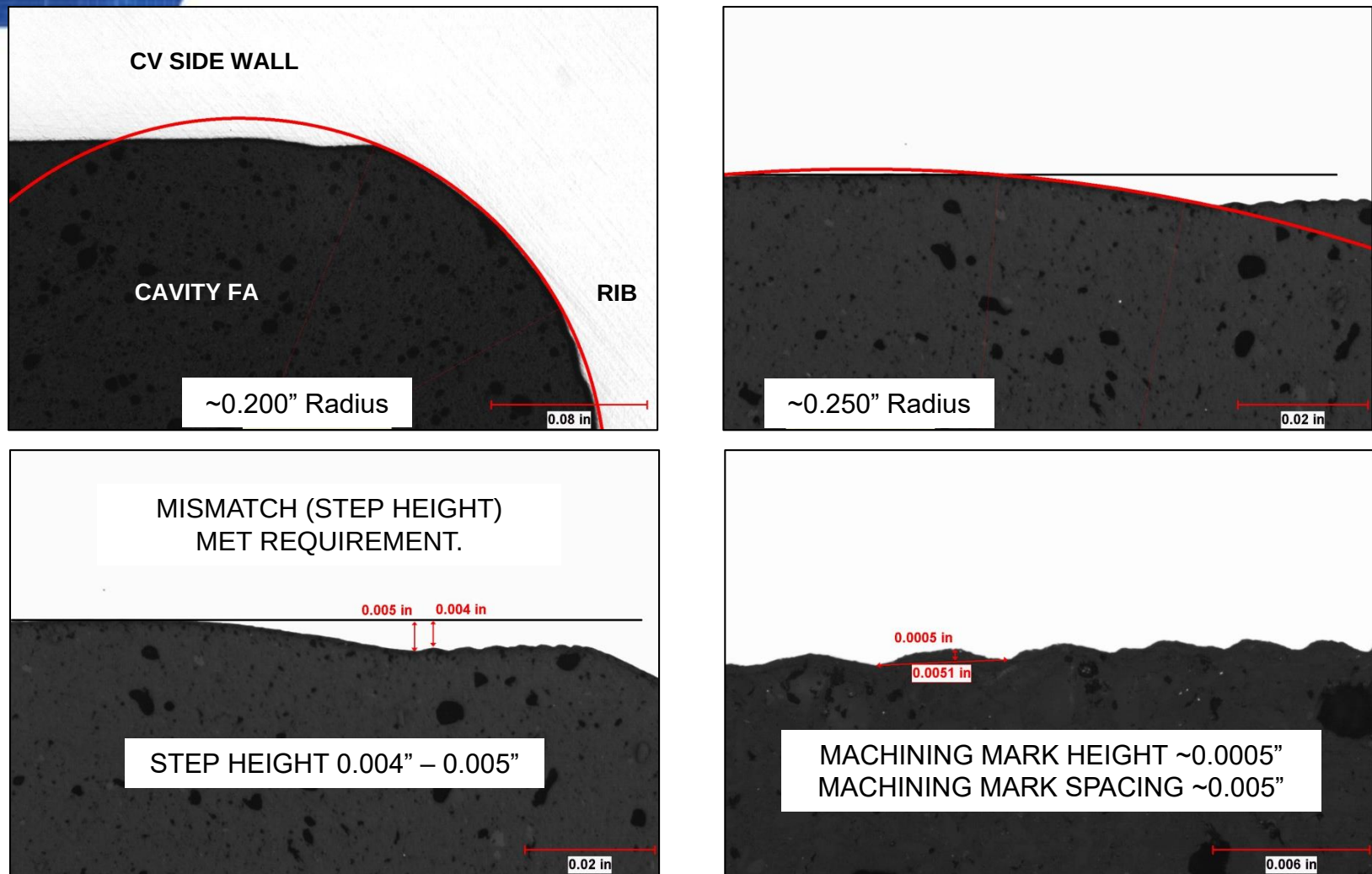


Figure 29 - Photomicrographs of section in un-etched condition with wall-to-rib transition geometry measurements.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)

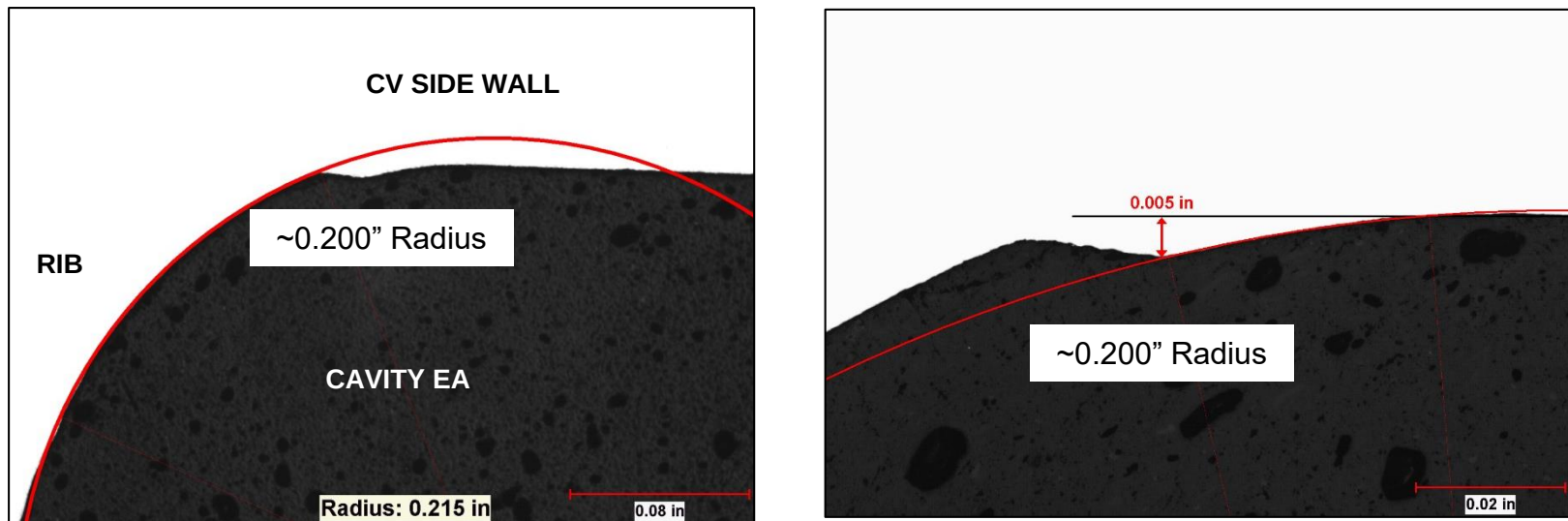


Figure 30 - Photomicrographs of section in un-etched condition with wall-to-rib transition geometry measurements.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)

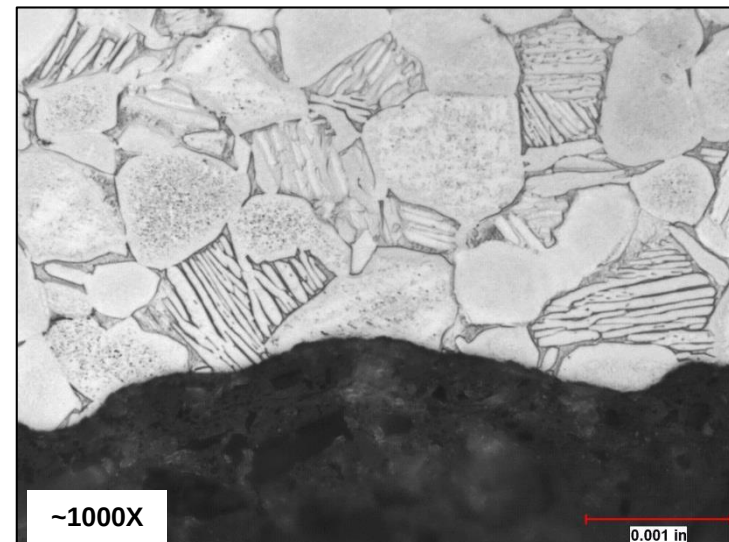
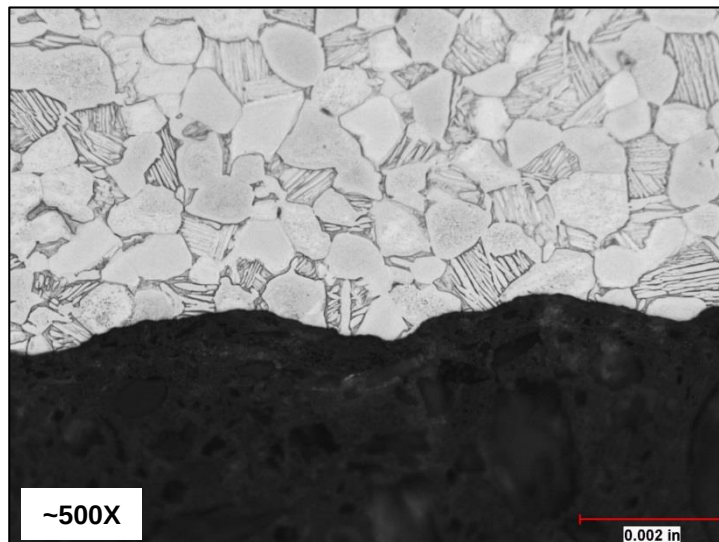
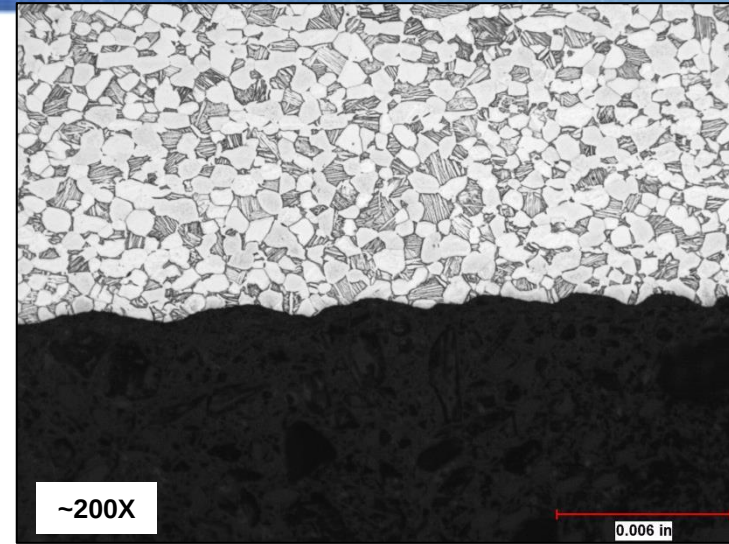
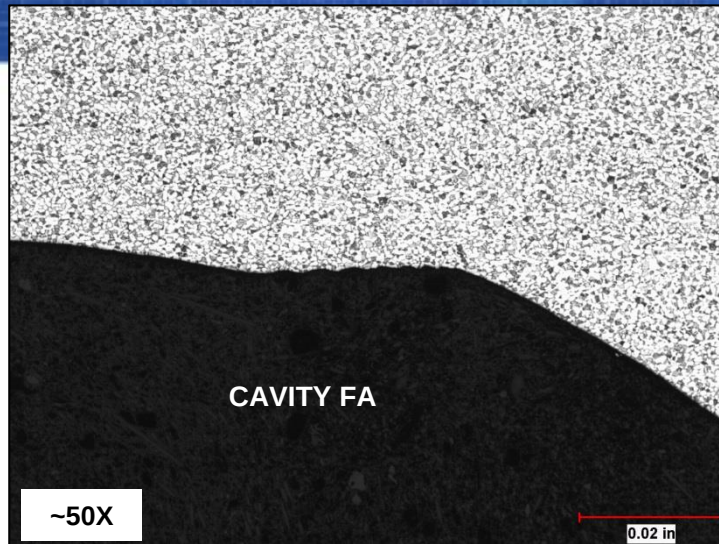


Figure 31 - Examination of the section after etching revealed no microstructural deformation along the as-machined internal cavity surface. Attachment 1

Etchant: Kroll's Etch

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)

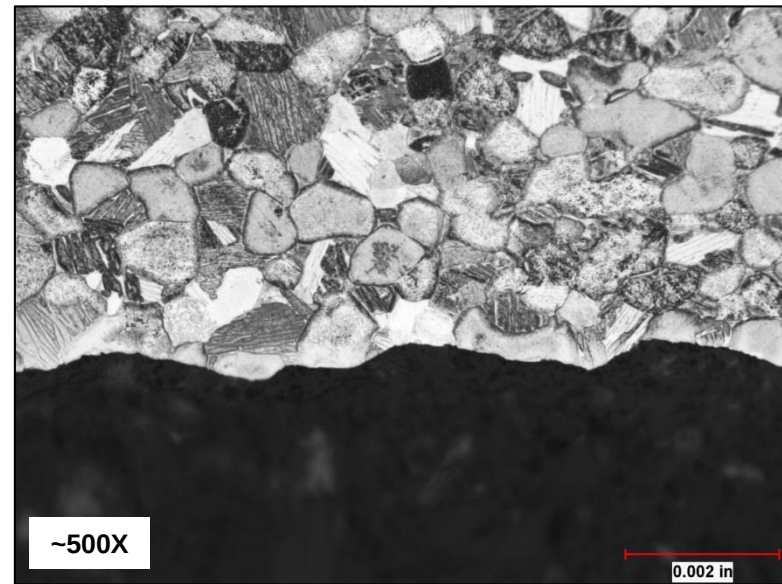
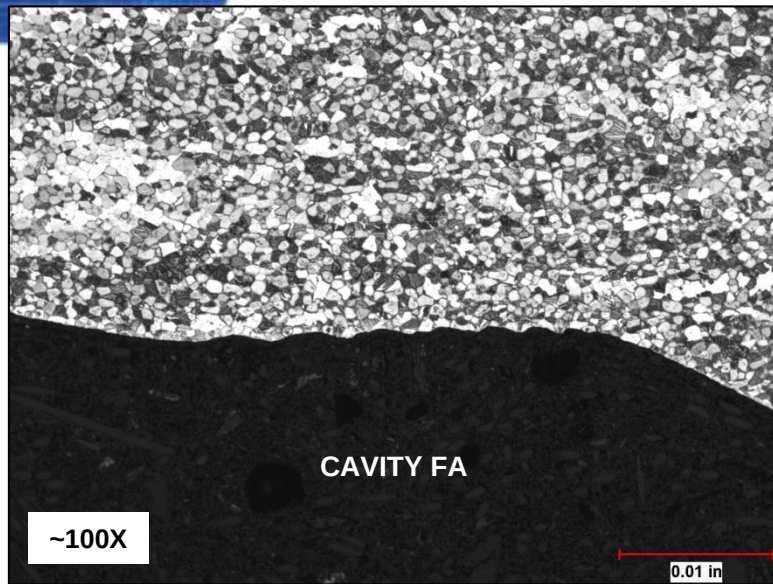
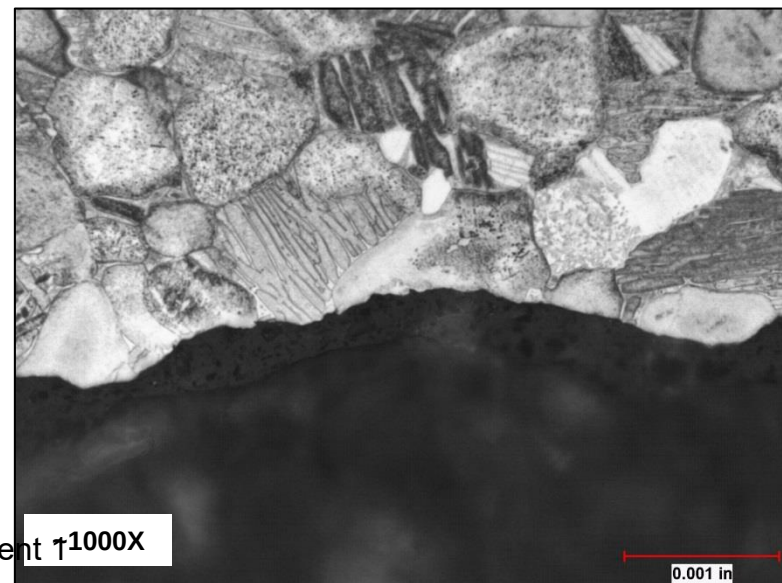


Figure 32 - Examination revealed no alpha case along the internal cavity surface.

Etchant: 2% HF



Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Inboard of Fracture)

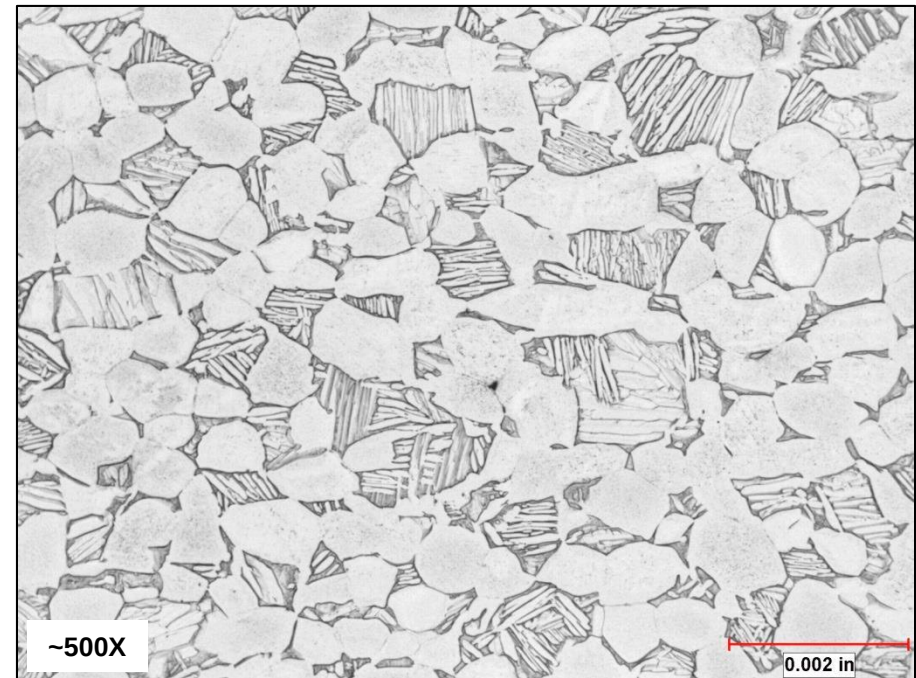
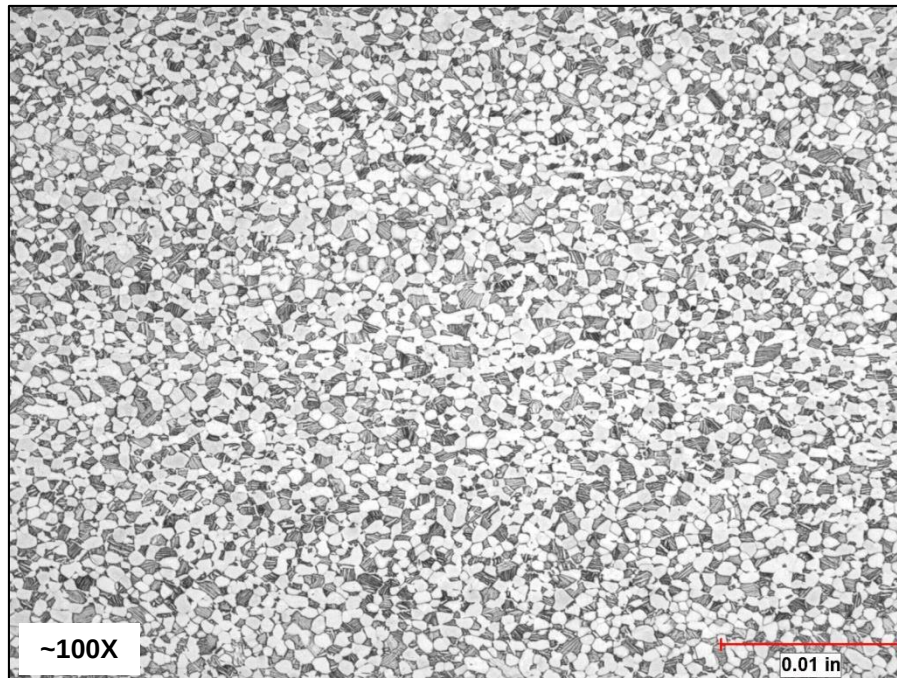


Figure 33 - Bulk microstructure was acceptable to specification requirements.

Etchant: Kroll's Etch

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Origin Section)

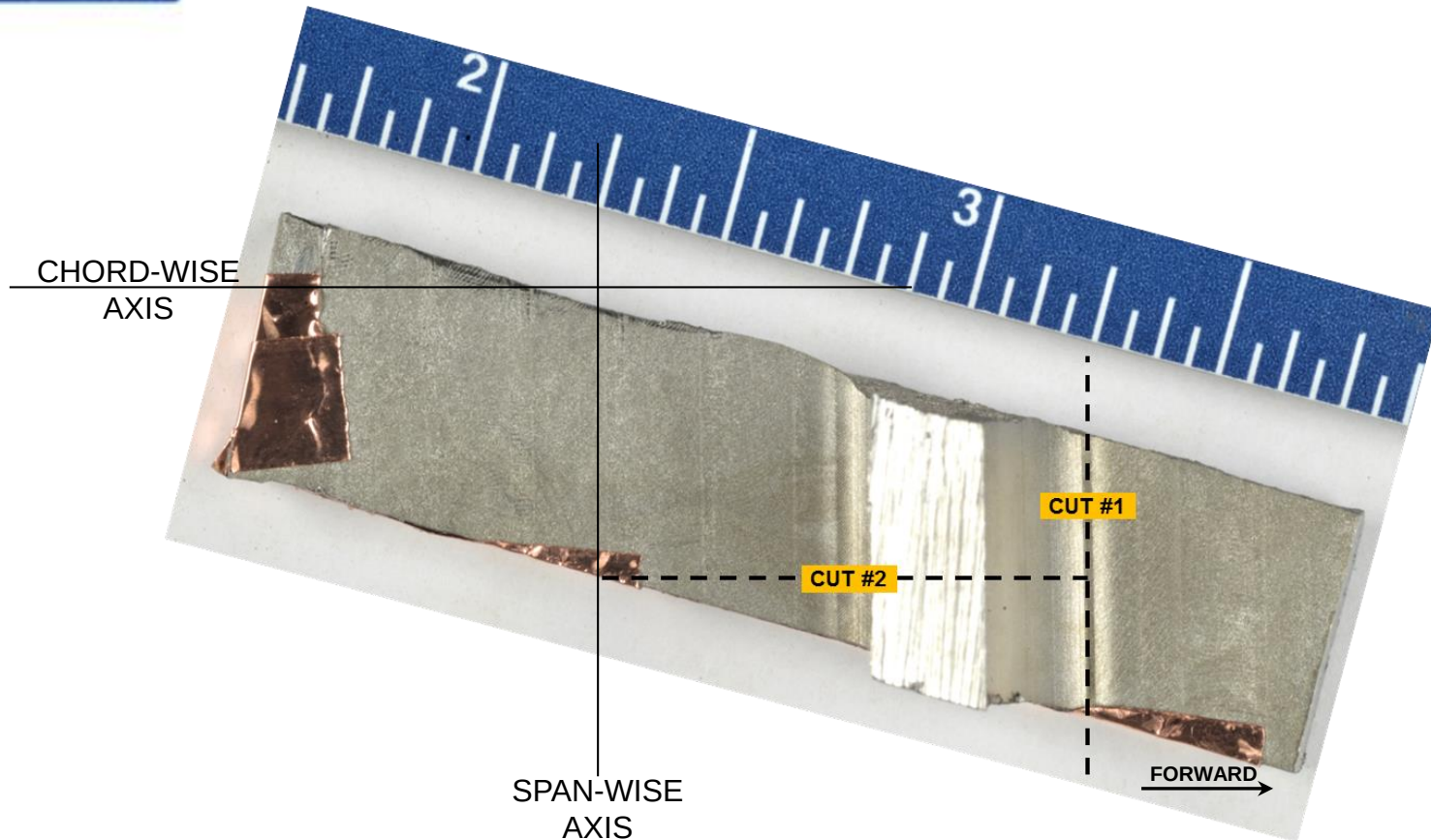


Figure 34 - Two transverse cuts were made through the CV wall where shown (cut #1 & #2) to square-up the piece of interest to be mounted using machining passes as guides for approximate span-wise axis. The portion of the fracture forward of cut #1 was preserved.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Origin Section)

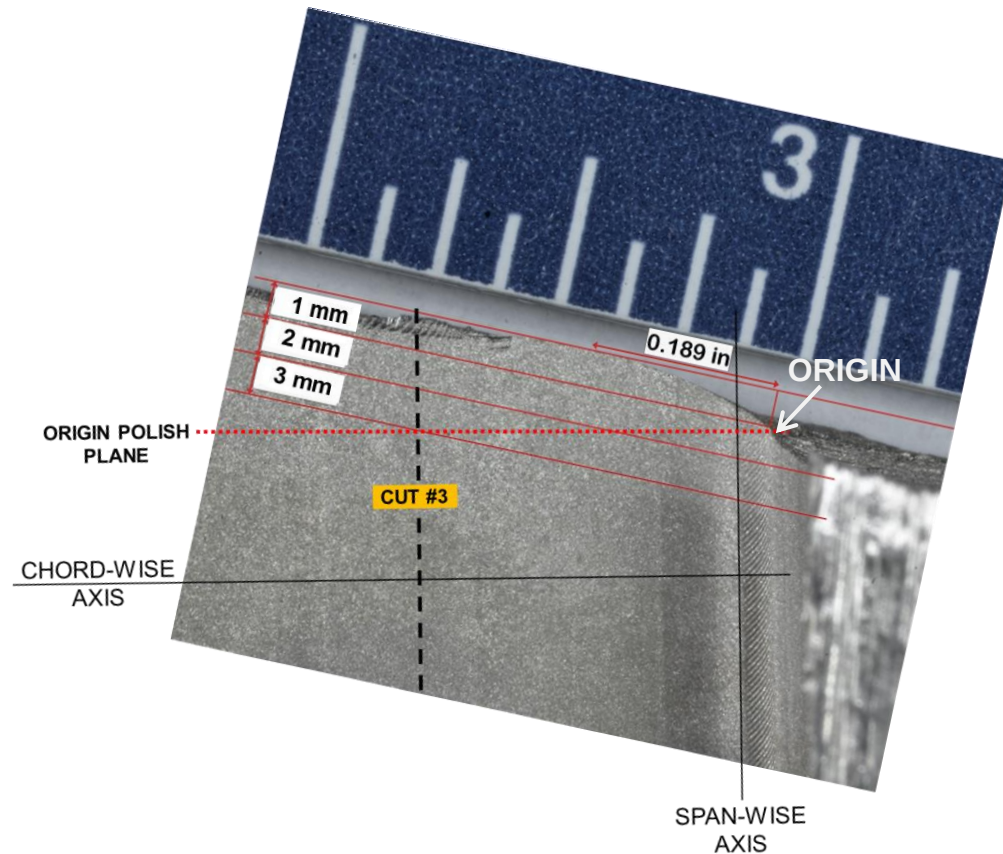
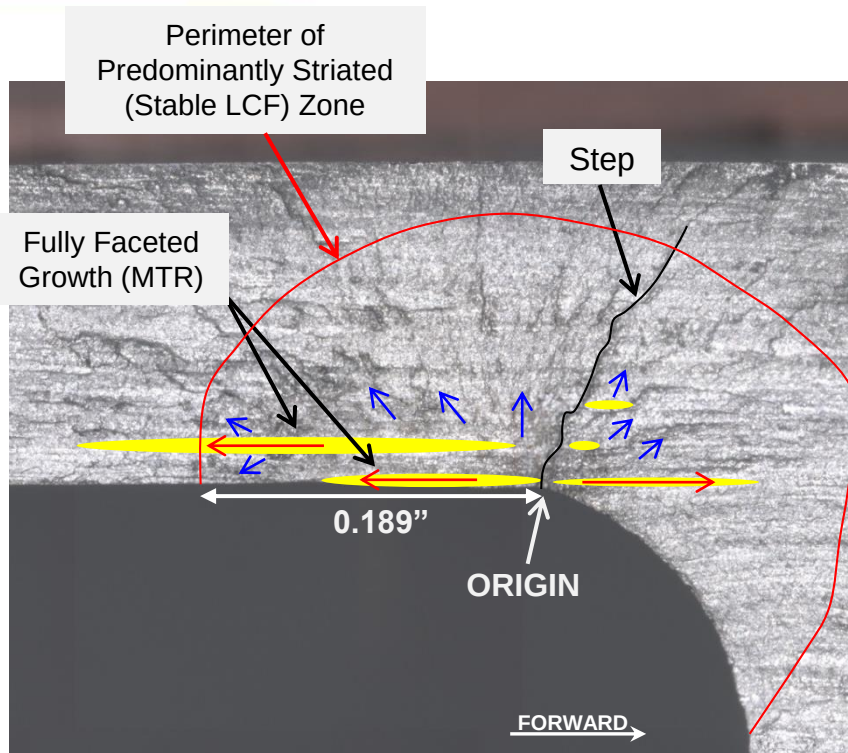


Figure 35 - A transverse cut was made through the CV wall where shown (cut #3). The portion of the fracture surface aft of the cut line was preserved.

PW4077 P777049 Fan Blade Fracture Investigation Blade #11 Metallographic Evaluation (Origin Section)

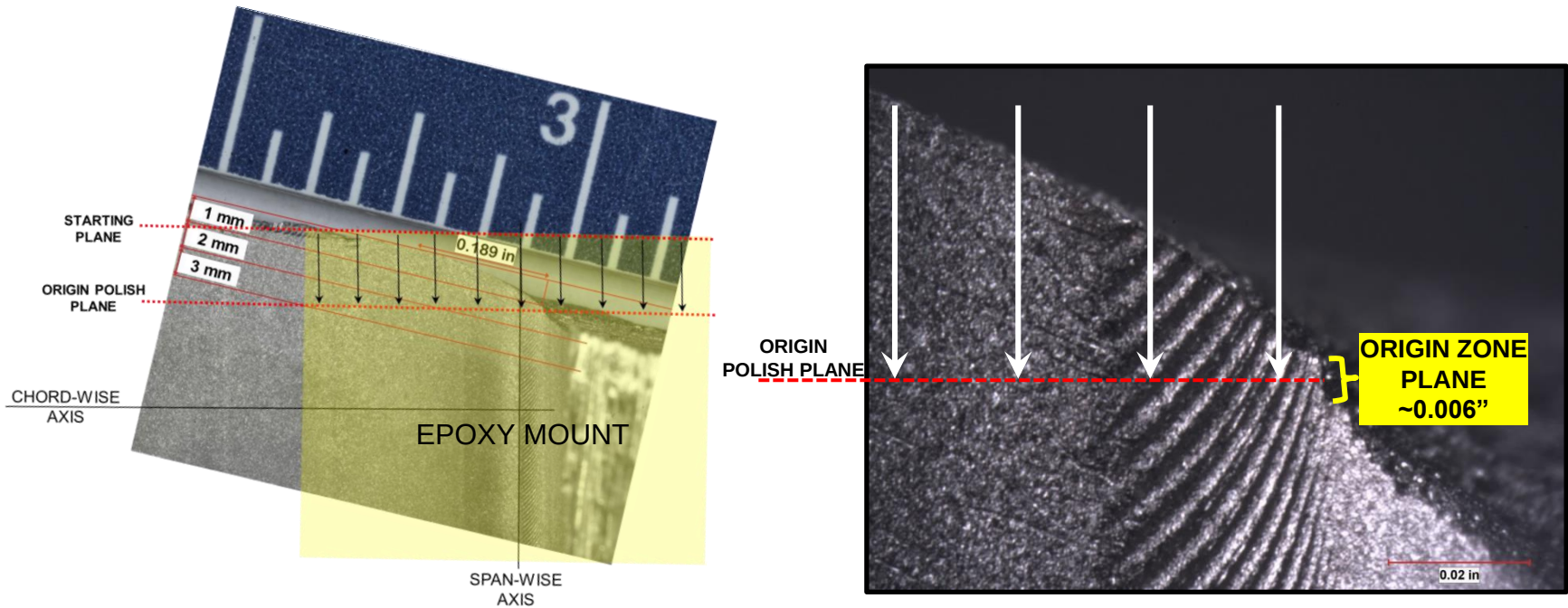


Figure 36 - The fracture surface was mounted down at an angle in clear epoxy. The mount was ground and polished in the direction of the arrows to the plane intersecting the origin, as perpendicular to origin as possible (a near-chordwise plane). The origin plane was a ~ 0.006 " target.

PW4077 P777049 Fan Blade Fracture Investigation Blade #11 Metallographic Evaluation (Origin Section)

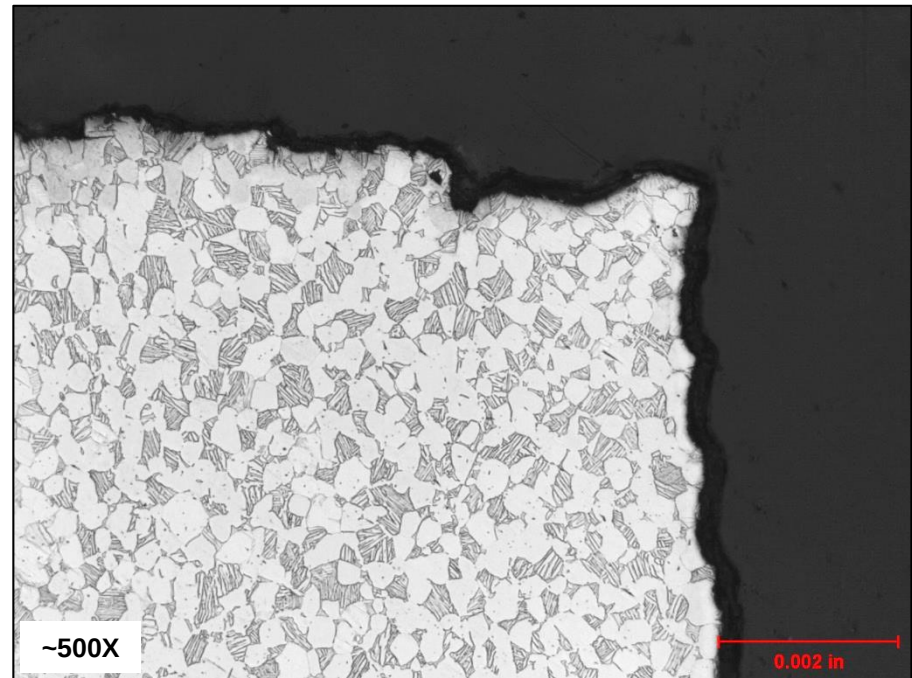
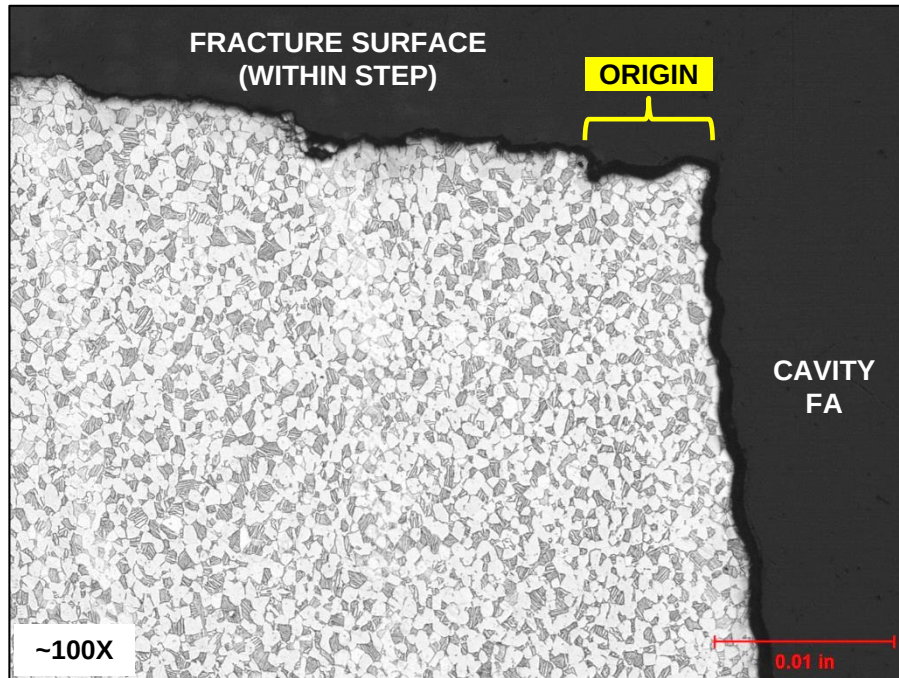


Figure 37 - Photomicrographs of metallographic section prepared through origin showing no microstructural anomalies.

Etchant: Kroll's Etch

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) of Origin Section

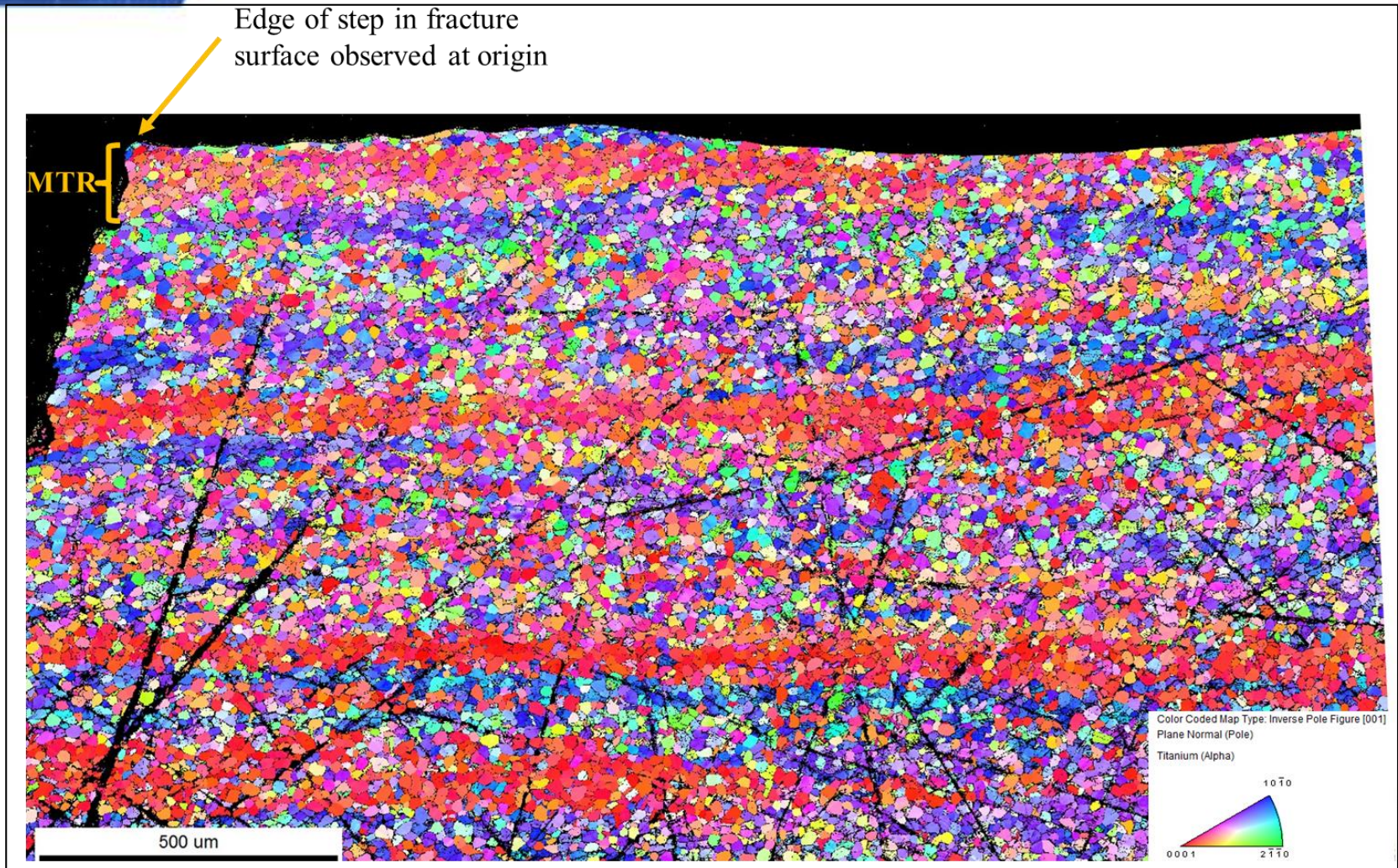


Figure 38 – EBSD scan of micro polished into origin. Microtexture band is evident at origin, confirming fracture surface observations. The black lines represent sample preparation artifacts.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 OIM (EBSD) of Origin Section

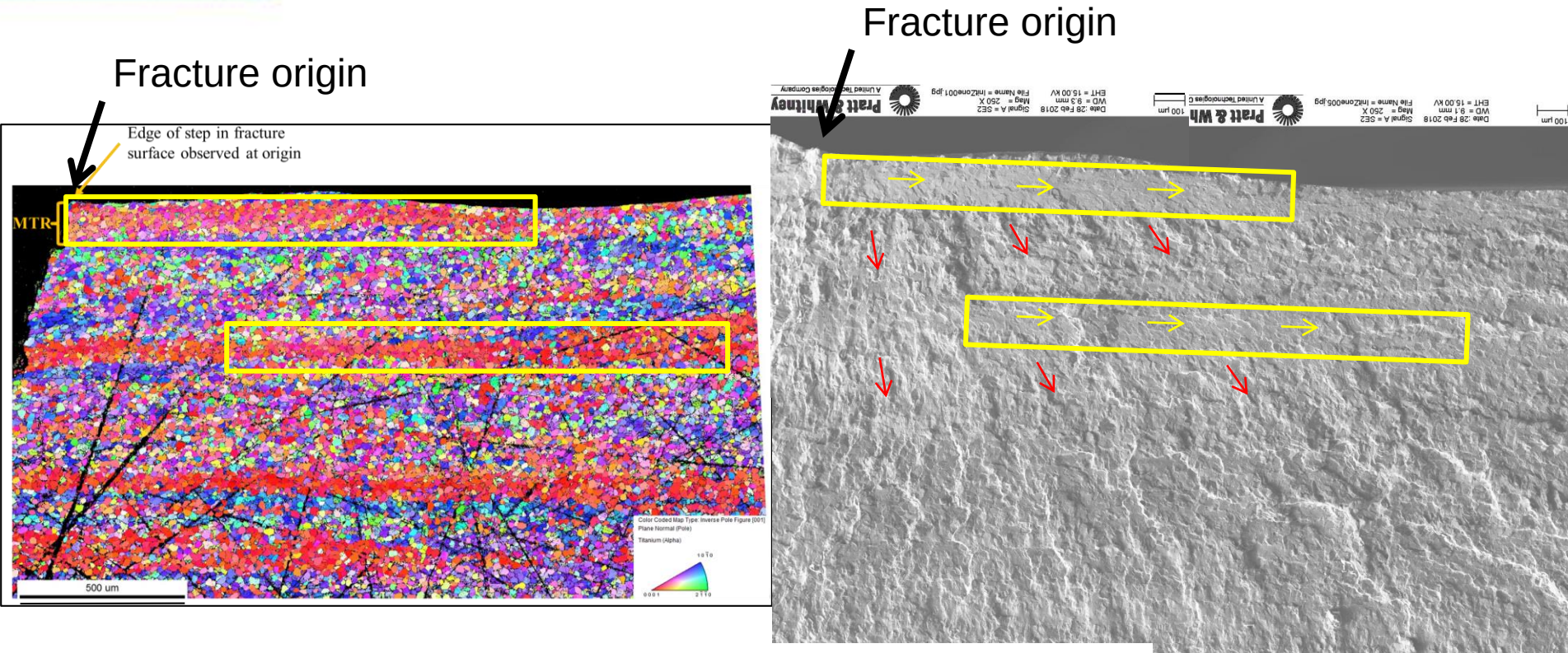


Figure 39 – EBSD scan of micro polished into origin (left) and (right) prior fracture surface appearance for same area at similar magnification. The yellow boxes show micro-texture bands with similar near basal grain orientations coincided with areas of fully faceted growth progressing chord-wise or along the MTR (yellow arrows). Typical fatigue progression directions are also shown (red arrows).

PW4077 P777049 Fan Blade Fracture Investigation

Blade #11 Metallographic Evaluation (Origin Section)

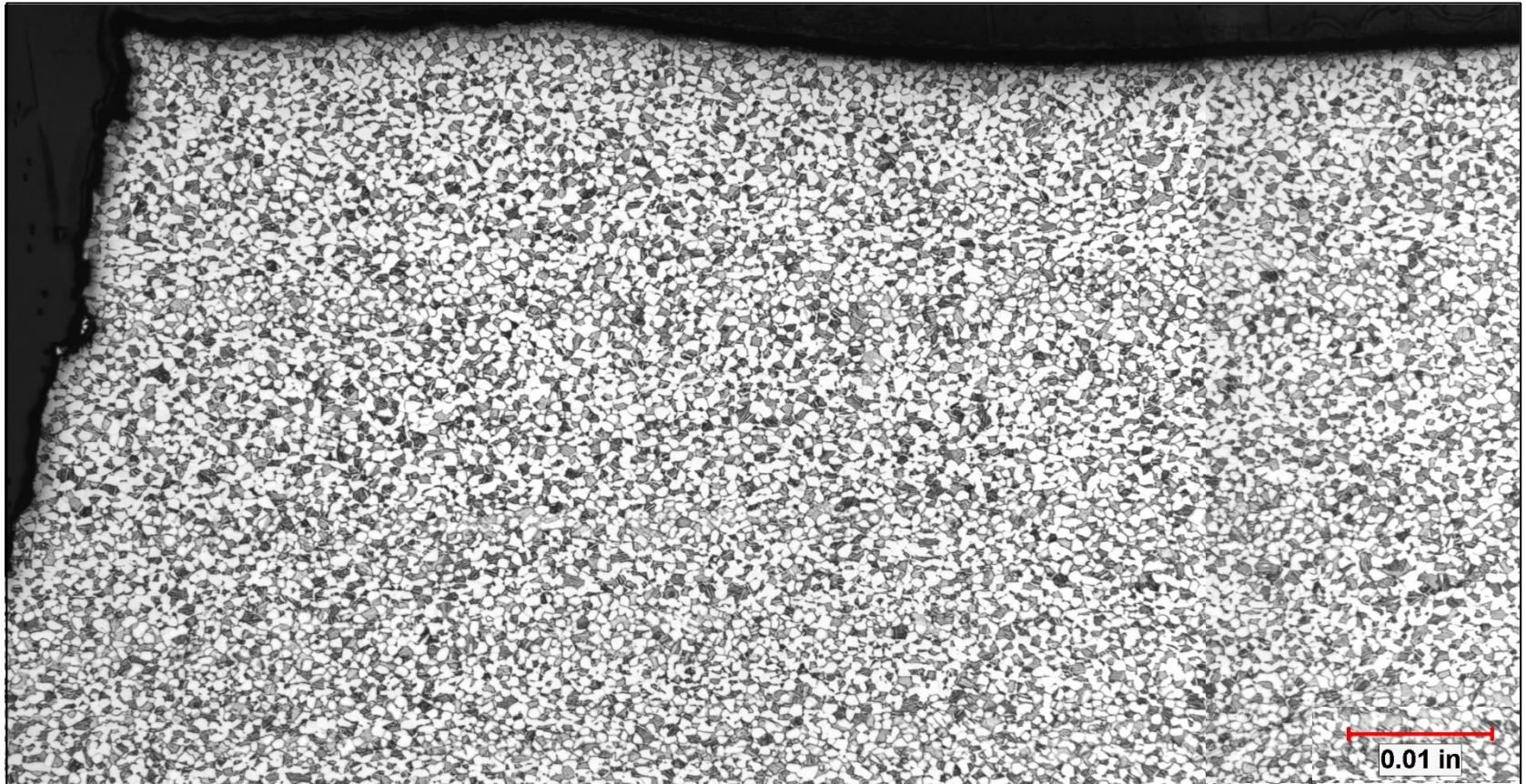
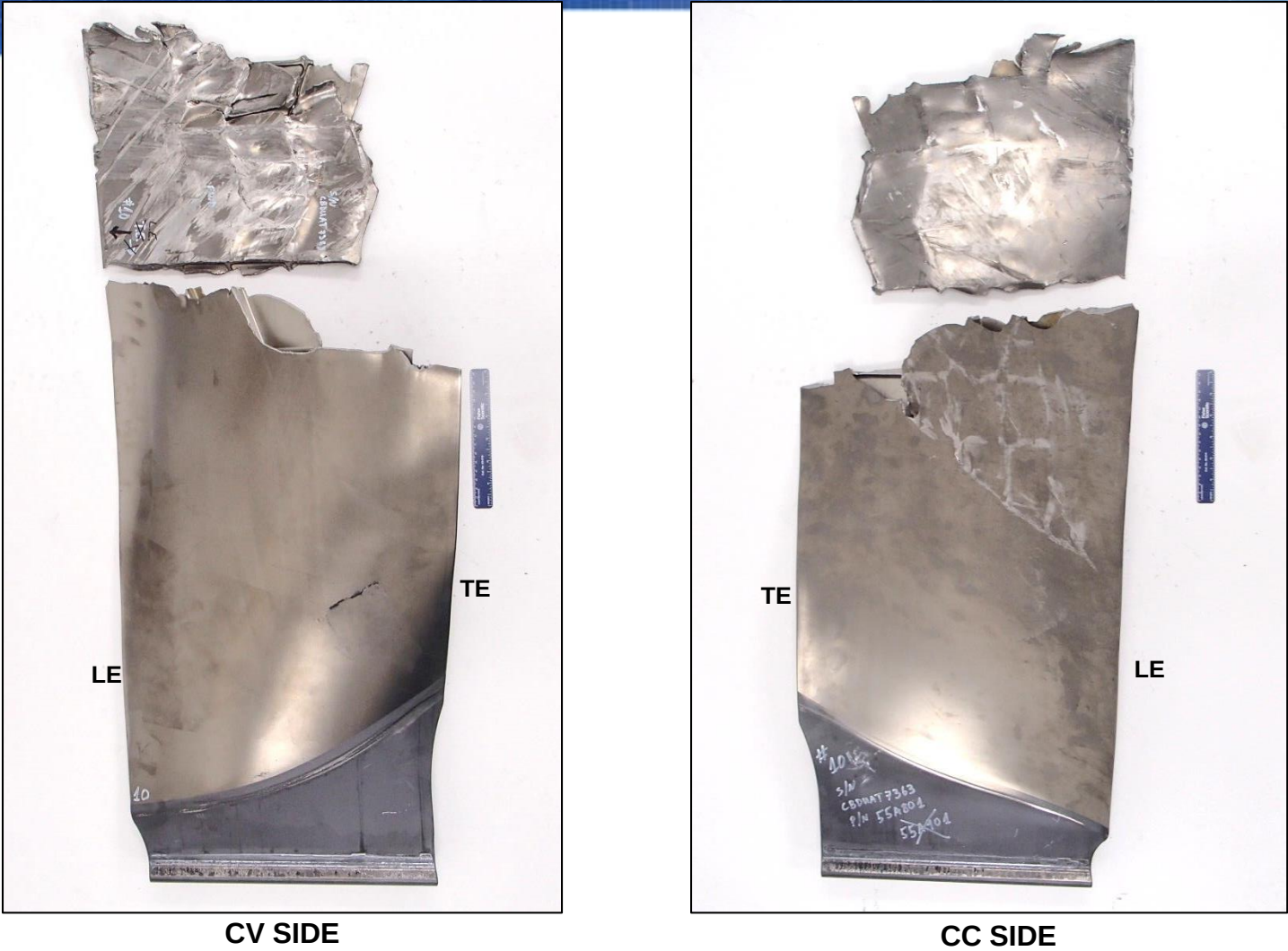


Figure 40 - Photomicrograph montage of origin area after etching metallographic section, taken at similar magnification and orientation as EBSD scan from Figure 39. The microstructure in this area was consistent with properly processed Ti-6Al-4V fan blade material.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Visual Examination



PART WEIGHT:
INBOARD PORTION = 24.6 lbs.
RECOVERED PORTION = 4.1 lbs.

Figure 41 - Overall views of fractured following Blade #10.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Visual Examination

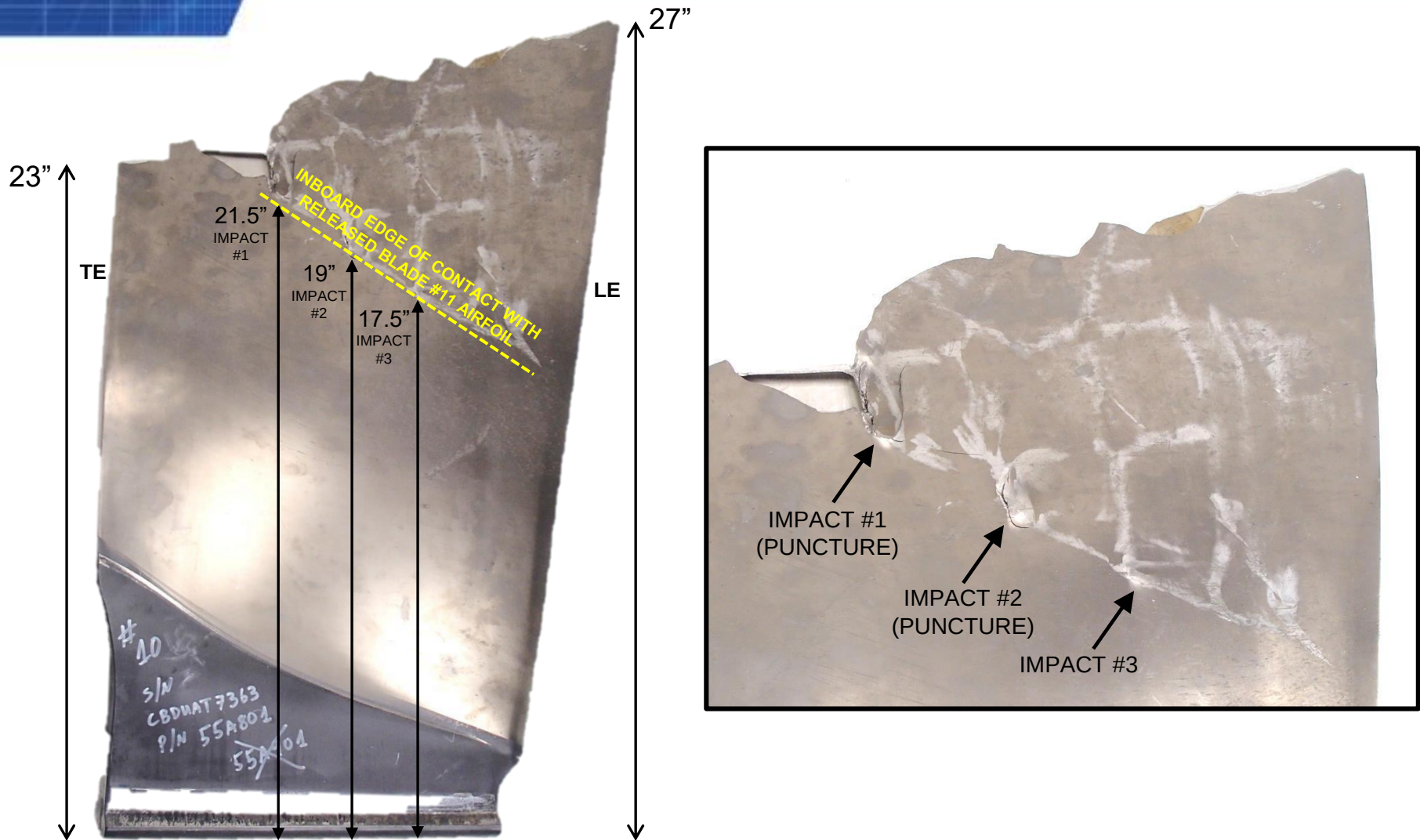


Figure 42 - Overall view of Blade #10, inboard portion, concave side.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Visual Examination

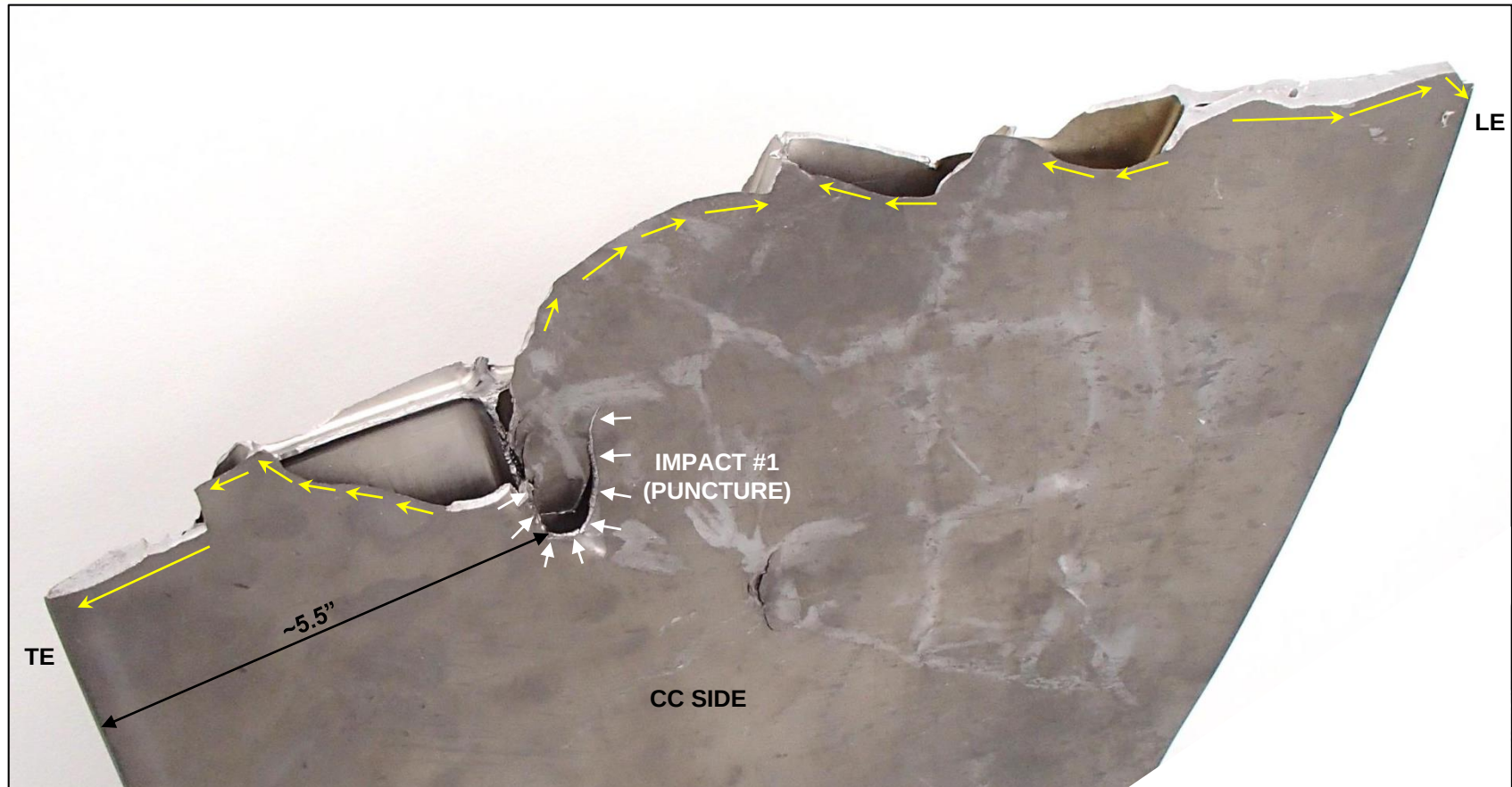


Figure 43 - Close-up view of Blade #10 fracture, inboard portion, from concave side. Directionality of overstress features (arrows) indicated fracture emanated primarily from puncture in concave wall ~21.5" above root bottom and ~5.5" forward of the trailing edge.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Visual Examination

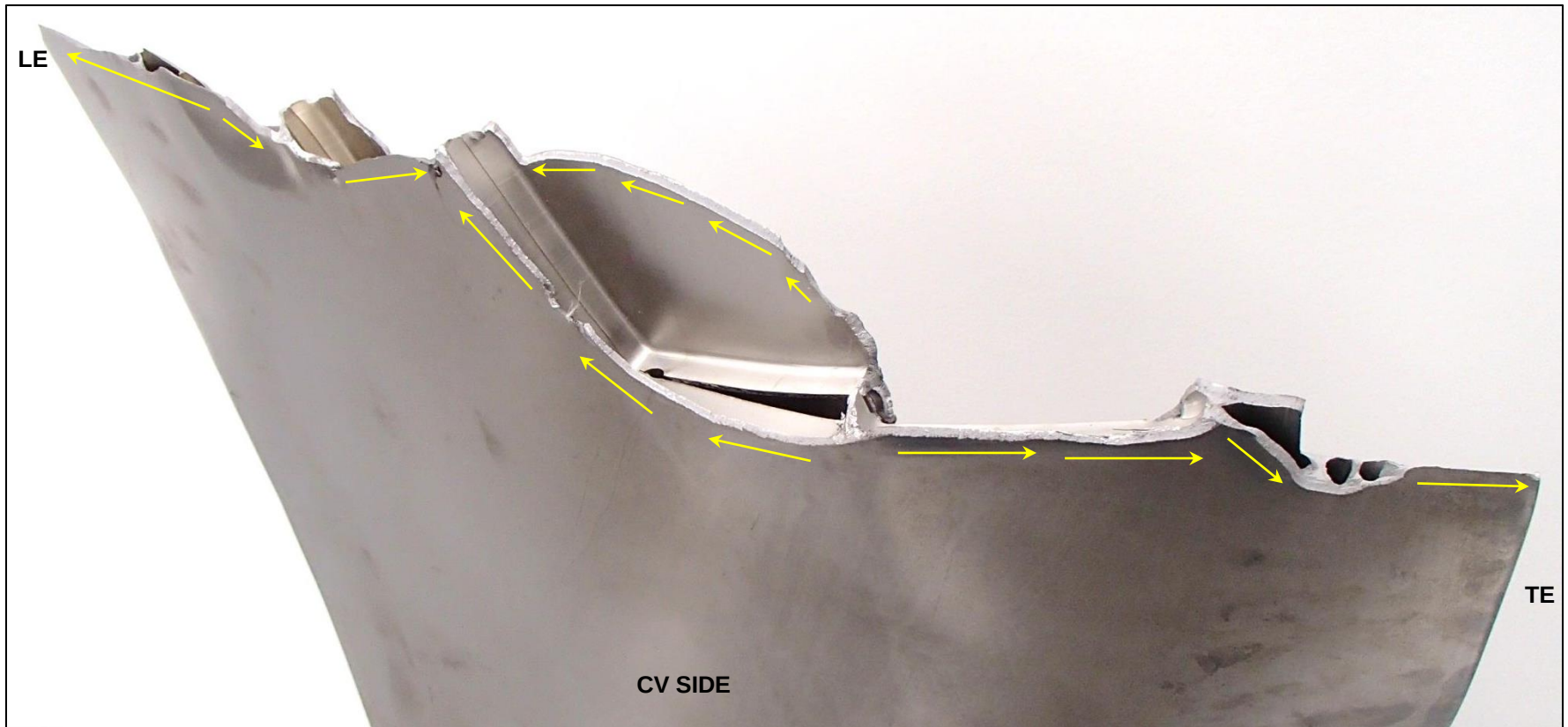


Figure 44 - Close-up view of Blade #10 fracture, inboard portion, from convex side. Directionality of overstress features (arrows) indicated fracture emanated primarily from puncture in concave wall ~21.5" above root bottom.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Part Markings



ASSY 55A901-A S/N CBDUAT7363
55A801 (Vibropeened marking)
Convex Skin H/C: RAAAR0026
Concave Skin H/C: RAAAN0024
R-01, R-02, A72 286 (Vibropeened markings)

Figure 45 – Close-up views of Blade #10 part markings on root bottom.

Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Internal Cavity Features

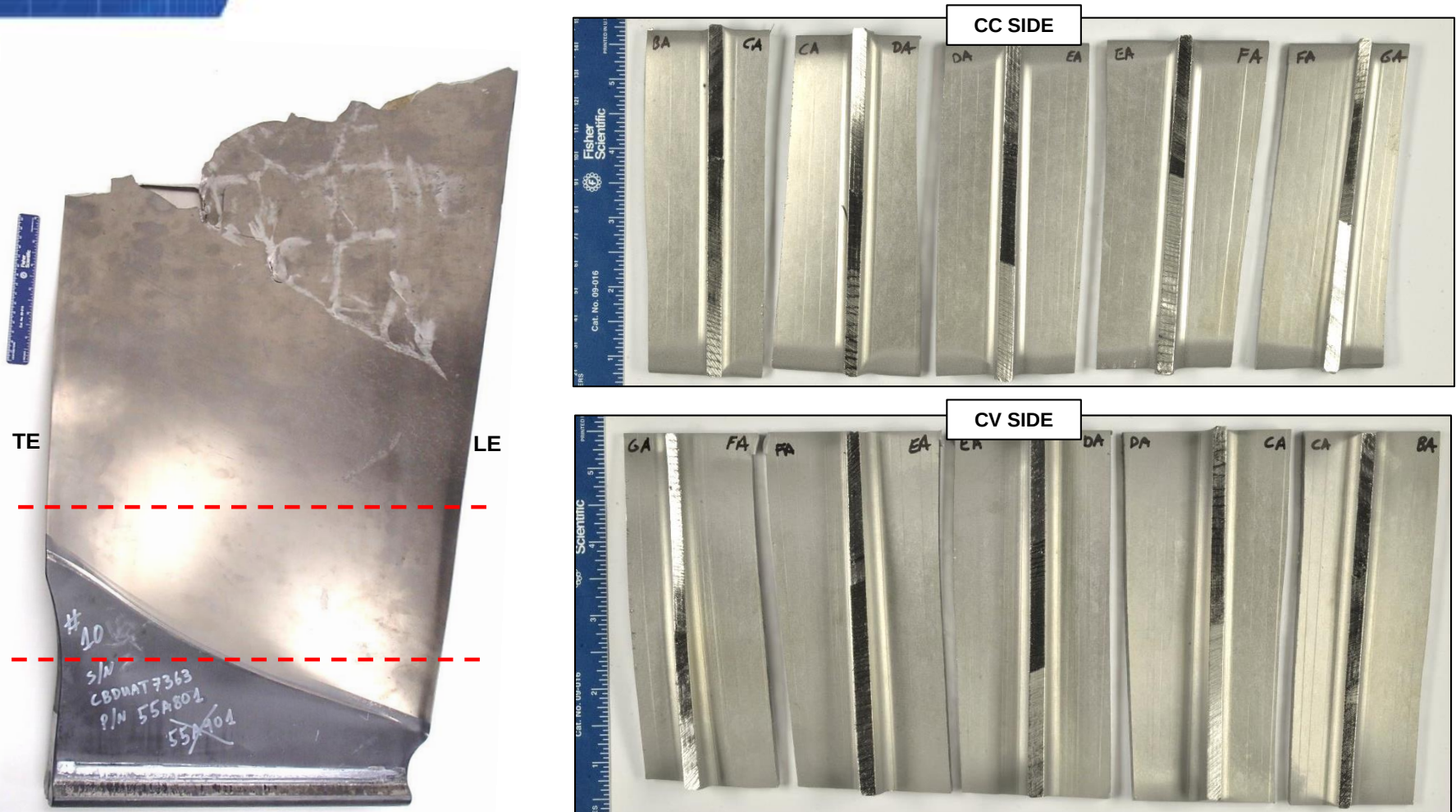


Figure 46 - Blade #10 was sectioned chordwise where shown (bounding the area corresponding to the fracture origin location on Blade #11) and each internal cavity was filleted open to examine the as-machined features in comparison to Blade #11 Attachment 1

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Internal Cavity Features

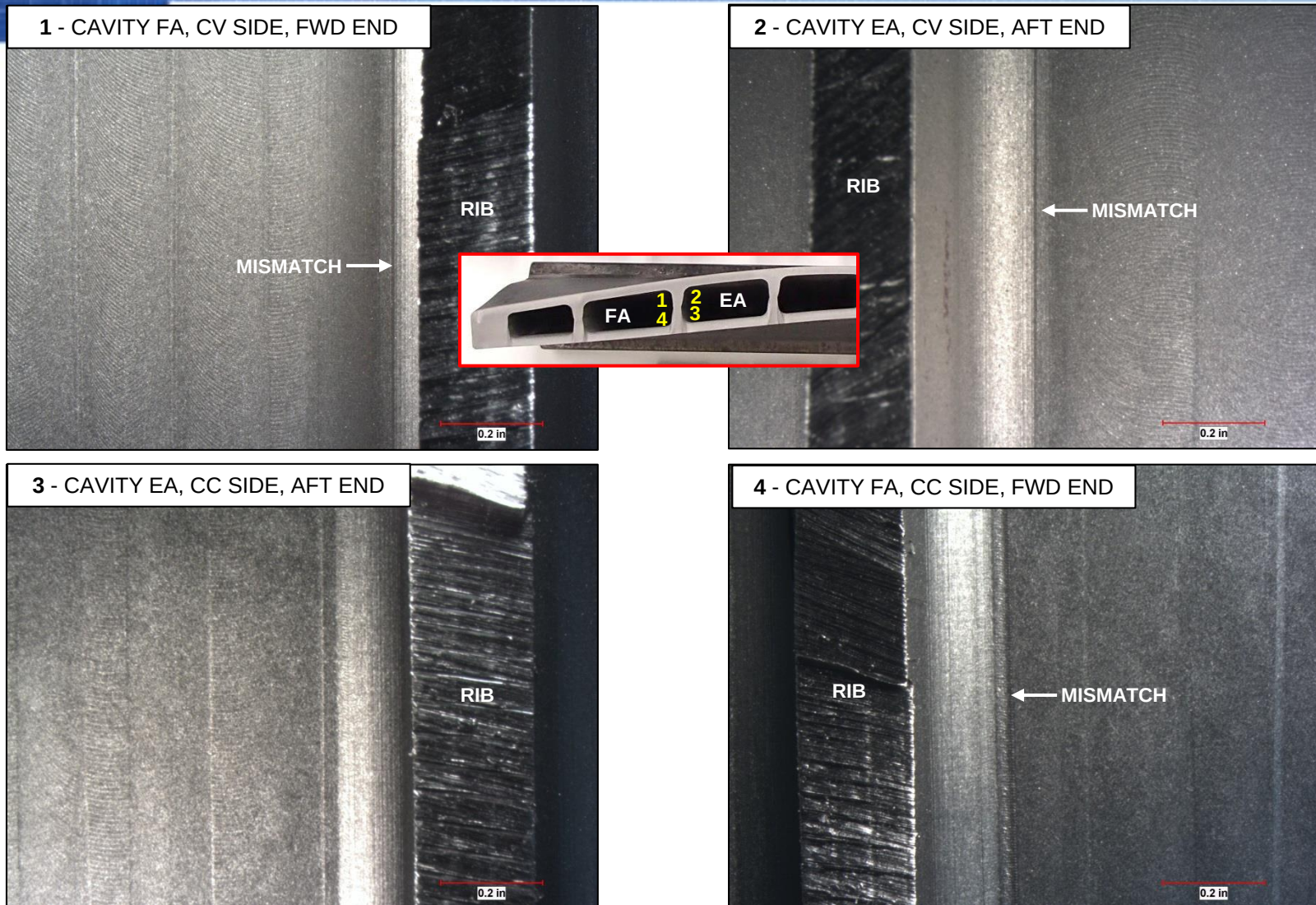


Figure 47 - Examination of the internal cavities typically revealed machining mismatches at the wall-to-rib transitions that were less prominent than what was observed on Blade #11.

PW4077 P777049 Fan Blade Fracture Investigation

Blade #10 Metallographic Evaluation (Chordwise Section)

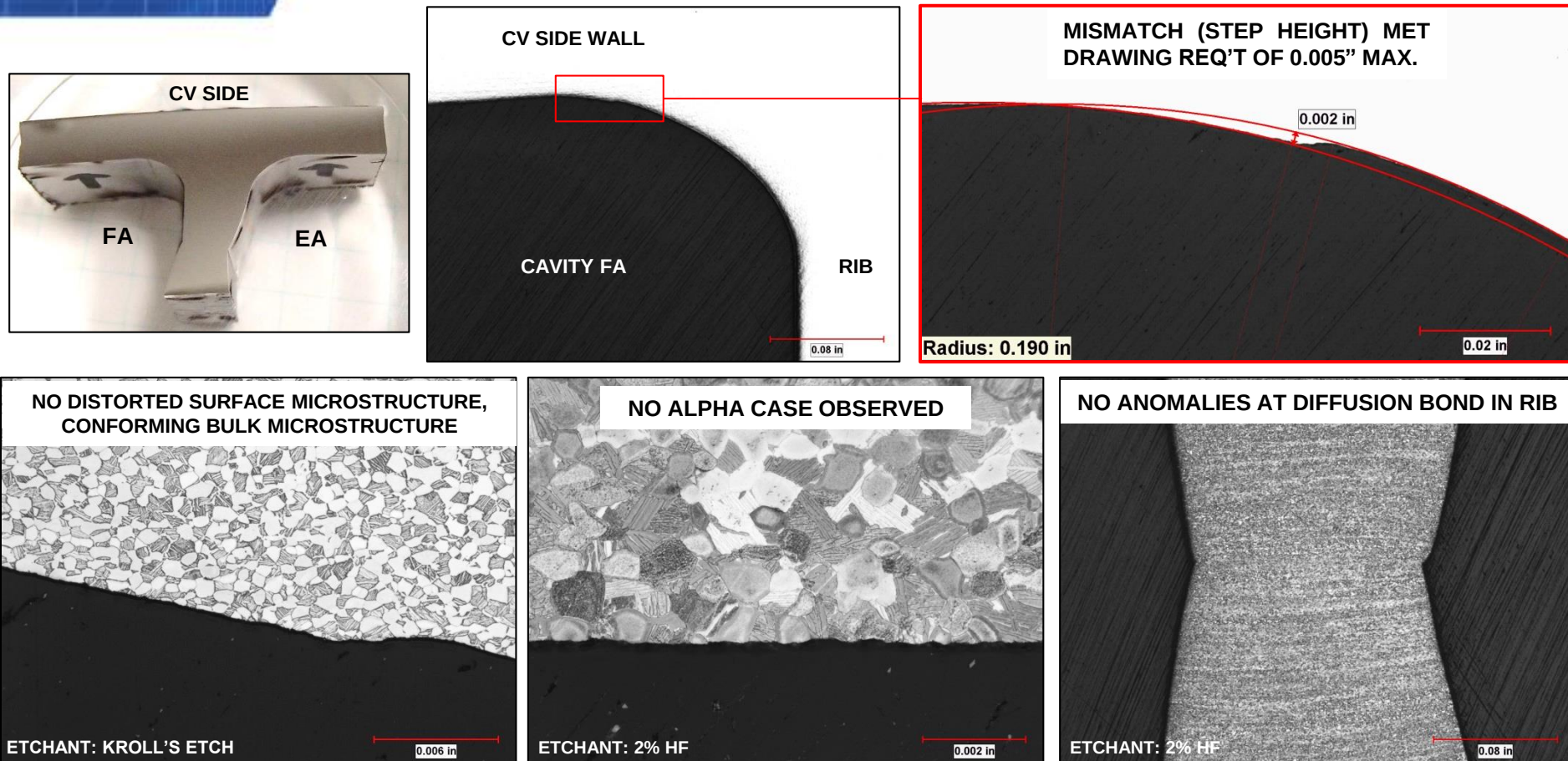


Figure 48 - A chordwise metallographic section was prepared through Blade #10 at a location similar to the section prepared through Blade #11 shown in Figure 28. Review of the section revealed a slight machining mismatch (~0.002" step height) in the transition between the convex side wall and rib, no evidence of microstructural deformation or alpha case along the internal surfaces, no anomalies associated with the diffusion bond in the rib, and a bulk microstructure that appeared acceptable to the specification requirements.

Attachment 1