

Metallurgical Investigation Report

FA Log No. 2017- 18137

METALLURGICAL EVALUATION OF A RELEASED FAN BLADE FROM ENDEAVOR AIRLINES CF34-3B1

ESN 873-642
S/N KGACA251
P/N 6018T30P14

Case Docket ENG17IA008

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GE Aviation
Engineering Material Systems



imagination at work

Background

On the 23rd of January 2017, a CF34-3B1 powered CRJ200 operated by Endeavor Airlines experienced a fan blade separation event. The aircraft was climbing through 8,000 feet when the flight crew reported a loud bang, high ITT indication, high fan vibration, and thrust reverser unlock indication on the number 2 engine. The crew completed the checklist to secure the engine including a commanded shutdown. Aircraft returned to the departure airport where a normal single engine landing was made. Ground inspection revealed one fan blade had separated through the blade tang pin holes and was lodged in the fan case.

GE Aviation Services Engineering and GE Flight Safety personnel were on-site along with airline and NTSB personnel for removal and initial inspection of the engine. The event blade was identified as P/N 6018T30P14, S/N KGACA251. The metallurgical evaluation of the event blade was conducted at the National Transportation Safety Board (NTSB) in Washington, DC.

Blade S/N KGACA251 had accumulated 18,063 cycles at the time of separation. The forged 6018T30P14 fan blades are manufactured from Ti-8Al-1Mo-1V material per GE Aviation specification C50TF26 CL-B.

Observations

The fan blade that experienced the separation event was identified as P/N 6018T30P14, S//N KGACA251, installed in Slot No. 22 of the disk. The fan blade fractured near the midpoint of the forward and mid tangs of the pin holes. The aft tang separated by tensile overload just outboard of the pin hole. The inboard portion of the forward and aft tangs were not recovered. The inboard portion of the mid-tang was the only inboard section of the fan blade that was recovered. See pages 11-12.

Both outboard forward tang fractures and one of the outboard mid tang fractures were obscured by transferred aluminum from the separation event. See pages 13-15. The fracture surfaces were submersed in a solution of 10% sodium hydroxide for approximately 10 minutes which removed the majority of the transferred aluminum from the fracture surfaces. Only two small residual areas of transferred aluminum were left on one of the mid tang fractures that was remote from the origin area. Visual examination of the tangs found no indication of blending or polishing to the forward face. Visual examination of the pin holes revealed a generous radius with no evidence of any obvious nicks or dents near the fracture. Visual evidence of 100% shot peen coverage was observed.

The fracture surface of the forward tang at the 9 o'clock (ALF) position exhibited the largest planar fracture region indicative of being the primary fracture. Limited shear lips were observed at the outer peripheries of the pin hole fracture at the 9 o'clock position. By contrast, the 3 o'clock fracture exhibited a more pronounced shear lip area. Both outboard mid tang fracture surfaces also exhibited pronounced shear lip areas, tensile cracking of the pin hole surface adjacent to the fracture, and smaller planar fracture regions supporting mid tang crack initiation was secondary to the forward tang cracking. See pages 16-19.

Observations

SEM evaluation of the fracture surfaces confirmed the primary fatigue initiation from the pin hole surface of the forward tang at the 9 o'clock (ALF) position as evidenced by a larger area exhibiting striated fatigue. The 3 o'clock (ALF) position of the forward tang and both sides of the mid tang also showed fatigue initiation from the pin hole surfaces but exhibited coarser striations and smaller fatigue zones as compared to the fracture surface on the forward tang at the 9 o'clock position. The fracture morphology on all four fracture surfaces was consistent with low cycle fatigue with coarse striations observed. Striation count indicated approximately 2560 cycles of propagation on forward tang at the 9 o'clock (ALF) position fracture surface. See pages 20-25.

Metallographic evaluation within the origin areas showed microstructure typical for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1 with no evidence of material anomalies or manufacturing deficiencies. Metallographic evaluation of the fatigue origins revealed some texturing of the microstructure. See pages 26-29.

The metallographic mounts were sent to GE Global Research Center (GRC) in Niskayuna, New York for electron backscatter diffraction (EBSD) to evaluate the structure for aligned alpha colonies. EBSD results showed the alpha colonies were not aligned to the crystallographic orientation that would be susceptible to dwell-time fatigue crack initiation. The texturing noted was considered typical for the bar stock used to forge the fan blades. See pages 30-32.

Records indicated event blade S/N KGACA251 was subjected to a creep hot forming repair process at ATI in the United Kingdom following a bird-strike event while installed in ESN 872-972 in 2007. The blade is placed in a "hot box" or "casket" between two ceramic dies to form the airfoil back to acceptable dimensions. The hot form process is sufficient to relax the compressive residual stress imparted by the shot peening in the pin holes and form an oxygen-stabilized layer on the surface referred to as alpha case. See pages 33-34.

Observations

Metallographic evaluation of the face of the mid tang from blade S/N KGACA251 found approximately 0.0002 inch (2/10th mil) of alpha case consistent with predicted alpha case formation for the time and temperatures used for the creep hot forming process on the titanium alloy Ti 6Al-2Mo-4Zr-2Sn. See pages 33-34.

Residual stress analysis was performed on the pin holes from the event blade S/N KGACA251 and four additional fan blades. Results of the residual stress analysis showed a significant amount of the compressive residual stress from the original shot peening was lost during the creep hot forming process and subsequently was not restored (repeened). See pages 35-36.

Visual examination of the blade set from ESN 873-642 revealed that one blade (No. 09) with a “KGA” serial number prefix (similar to event blade S/N KGACA251) exhibited a larger pin hole radii compared to the remaining twenty-six (26) blades which exhibited an “MAE” serial number prefix. Subsequent measurements revealed blade No. 09 had radii that exceeded the maximum allowed per the drawing. Measurements of the failed blade (No. 22) showed it also had radii that exceeded the drawing limit. Subsequent analysis showed this condition had a minimal effect on stress and was not considered a major contributor. See pages 37-40.

Additional Inspections

May 2012 records indicated that the event fan blade was repaired per Repair 12 indicating a major blend (airfoil) and polish of forward tang. Visual examination of the tangs near the fracture locations showed no evidence of blending or other repair.

Tang thickness measurements taken adjacent to the fractures show:

Forward tang 3 o'clock (ALF) 0.304 inch

Forward tang 9 o'clock (ALF) 0.303 inch

Mid tang 3 o'clock (ALF) 0.599 inch

Mid tang 9 o'clock (ALF) 0.599 inch

Repair documents indicates the forward tang shall be a minimum of 0.296 inch and the mid tang shall be a minimum of 0.591 inch. Measurements indicated both the forward and mid tangs meet the thickness requirements. The aft tang had separated by tensile overload outboard of the pin hole and was not recovered.

Pin Holes

Eddy current inspection (ECI) was performed on the pin holes of the remaining twenty-seven (27) fan blades from the engine set with no indication of cracking. Thickness measurements of the tangs for all blades in the set met drawing requirements.

CMM measurements performed at the NTSB lab extrapolated the diameters to be 0.7508 inch which met new-make requirements. Maintenance manual indicates the hole can be a maximum diameter of 0.7535 inch

Pin No. 22

Part markings: 99207- 4029T16P17, 14039, S/N SRCA4717

The pin is manufactured from IN718 nickel-based material. Visual examination found some small isolated areas of fretting and light galling and looked similar to the remaining pins from the same engine.

Diameter measurements using a digital micrometer found:

0.7455 inch near the forward collar, 0.7456 inch near the center, and 0.7451 inch at the aft end all of which met drawing requirements.

S/N KGA CA251 Blade History

- Fan blade S/N KGACA251 was a Tect-Utica forging/machining from Allvac material: Lot# 003668, Heat Code ECY-B, Heat# 368L, Forging S/Ns CA230 to CA259
- GE PEAR data show S/N KGACA251 assembled in ESN 872-972 then shipped to Business Jet Solutions (Dallas, TX) in April 2001. Engine transferred to FLEXJET in Aug/Sept 2004 with approximately 1950 cycles.
- Standard Aero reports working on ESN 872-972 in December 2007 as a field repair. The engine experienced a bird strike and four (4) blades were replaced. Three of the four blades replaced were scrapped and one was deemed repairable which was blade S/N KGACA251.
- Blade S/N KGACA251 was sent to ATI for repair where it was hot reform repaired and was recertified February 2008 with 4243 cycles reported on the blade.
- Standard Aero records show the blade being installed in ESN 873-749 on April 17, 2008. Without entering revenue service, the blade was installed on ESN 873-642 by Pinnacle Engine Shop June 27, 2008.
- In June 2012, ESN 873-642 entered Standard Aero shop. The blade was reworked: "Major Blend, Polish Forward Tang, and Apply Molydag and Molykote Coatings". Also complied with SB 72-0106 (Eddy Current Inspection). Blade had 10,736 cycles.
- Blade S/N KGACA251 had accumulated 18,063 cycles when the blade separation event occurred.

Summary

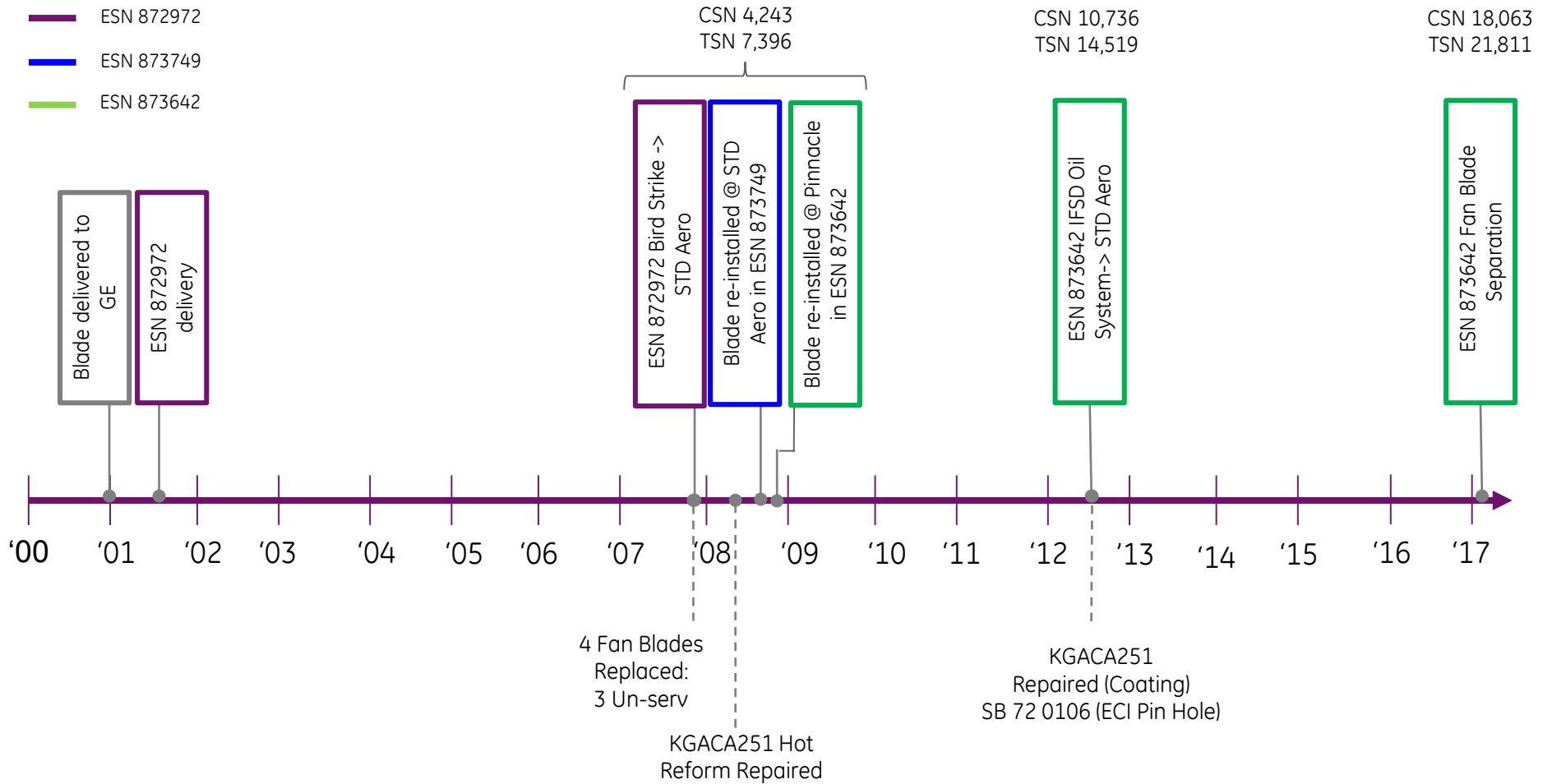
Metallurgical evaluation of event blade S/N KGACA251 at the NTSB lab established no obvious root cause findings. Visual and SEM evaluation of the fracture surfaces found the primary fatigue initiation was in the pin hole of the forward tang at the 9 o'clock (ALF) position. SEM evaluation of the fracture surface revealed the fatigue initiated from the surface of the pin hole. The 3 o'clock (ALF) position of the forward tang and both sides of the mid tang also exhibited fatigue initiation from the pin hole surfaces. The fracture morphology on all four fracture surfaces was consistent with low cycle fatigue mechanisms exhibiting coarser fatigue striations. Striation count indicated approximately 2560 cycles of propagation on the fracture surface of forward tang at the 9 o'clock (ALF) position.

Metallographic evaluation of the origin areas showed typical microstructure for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1V with no evidence of material anomalies or manufacturing deficiency.

Records indicated that blade S/N KGACA251 was hot form repaired at ATI in the United Kingdom following a bird-strike event while installed in ESN 872-972 in 2007. The process is a creep hot forming process of the airfoil by placing the blade in a "hot box" or "casket" between two ceramic dies to reform the airfoil back to acceptable dimensions. Time and temperature for the hot forming process is sufficient to relax the compressive residual stress from the shot peening in the pin holes and form an oxygen-stabilized layer on the blade surface referred to as alpha case.

Residual stress analysis was performed on the pin holes from the event blade S/N KGACA251 and four additional fan blades. Results of the residual stress analysis showed a significant amount of the compressive residual stress from the original shot peening was lost during the creep hot forming process and subsequently was not restored resulting in a pin hole surface condition that was susceptible to crack initiation.

Fan Blade Timeline (S/N KGACA251)



<u>Sample Identification:</u>	<u>S/N: KGACA251</u> Fan Blade	
<u>GEA Job # 17-20</u>	<u>%</u>	
Oxygen	.129	.129
Nitrogen	.010	
Aluminum	7.51	7.55
Molybdenum	.99	
Vanadium	.95	
Iron	.12	
Yttrium	<.0005	
Boron	<.0005	
Tin	<.002	
Copper	.0027	
Manganese	.0034	
Zirconium	<.002	

Cert Test Results
12/08/2000

0.11

0.004

7.52 (Min 7.50 Max 8.50)

0.97 (Min 0.75 Max 1.25)

0.93

0.08

0.0010

<0.0010

0.01

<0.01

<0.01

0.01

HEAT NUMBER: 568L HEAT CODE: ECY

BLADE NO: KGA CA288

SERIAL NUMBER RANGE: KGA CA086 - KGA CA755

ALLOY: Ti 8-1-1

VENDOR OF

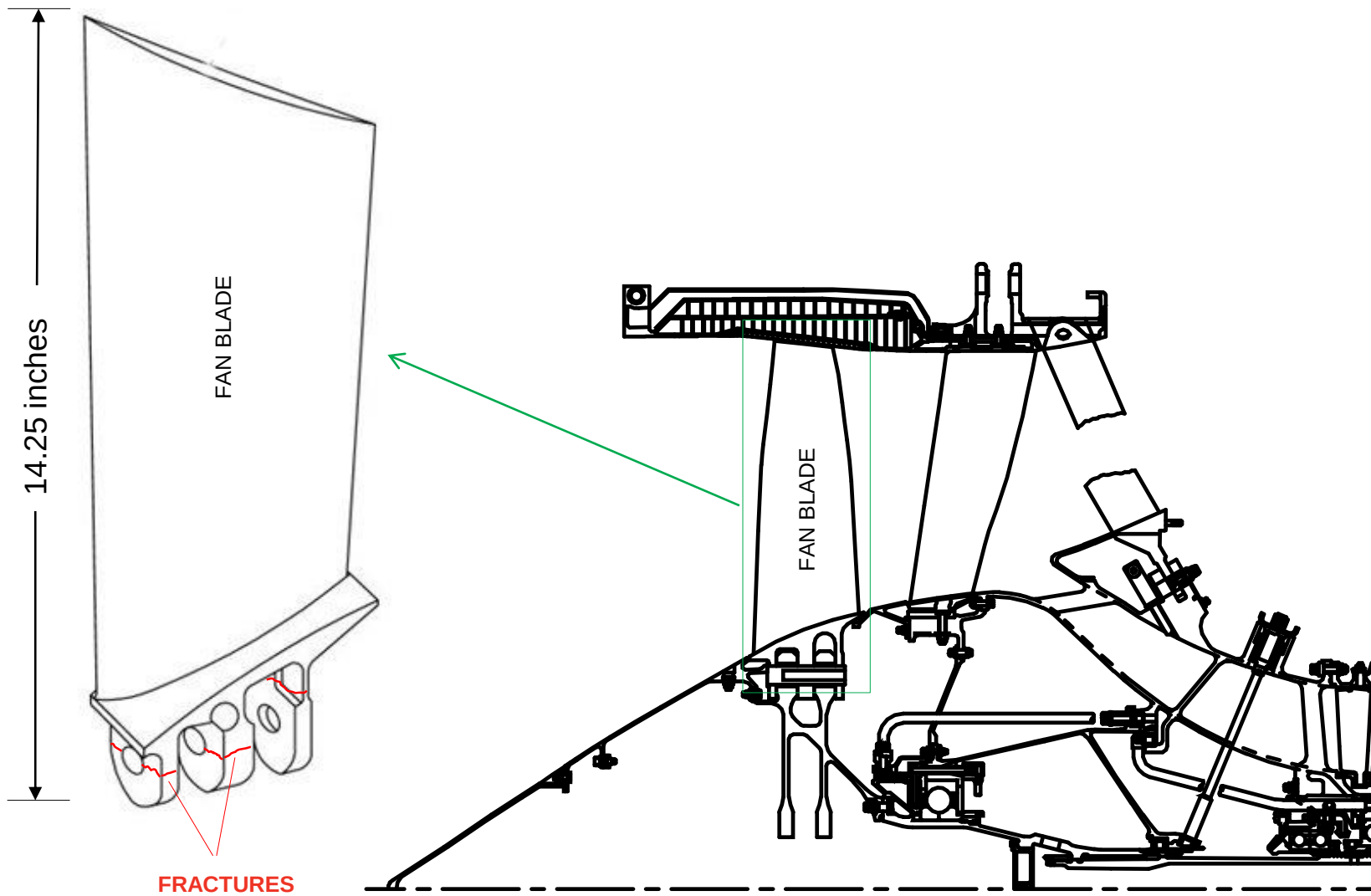
RAW MATERIAL: Teledyne Allvac

Chemical analysis of a sample from the event blade (S/N KGACA251) showed similar results for the main constituents of aluminum and molybdenum as compared to the cert test results from December 2000.

Cert Test Results 12 / 08 / 2000

Min	Ti	Al	Mo	V	C	Fe	N	O	Y	B
Max	Base	7.50	0.75	0.75						
Actual	Base	8.50	1.25	1.25	0.08	0.30	0.05	.15	0.0050	0.0014
	Bal.	7.52	.97	.93	.005	.08	.004	.11	.0010	<.0010

Min	H	Sn	Cu	Mn	Zr	Other elements	H ₂
Max	0.0125	0.10	0.10	0.10	0.10	0.10	Blade Analysis
Actual	.0047	.01	<.01	<.01	.01	<.02	0.0125%
							0.0086%



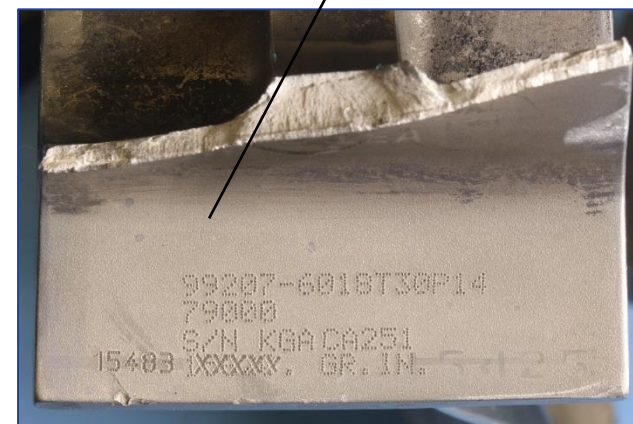
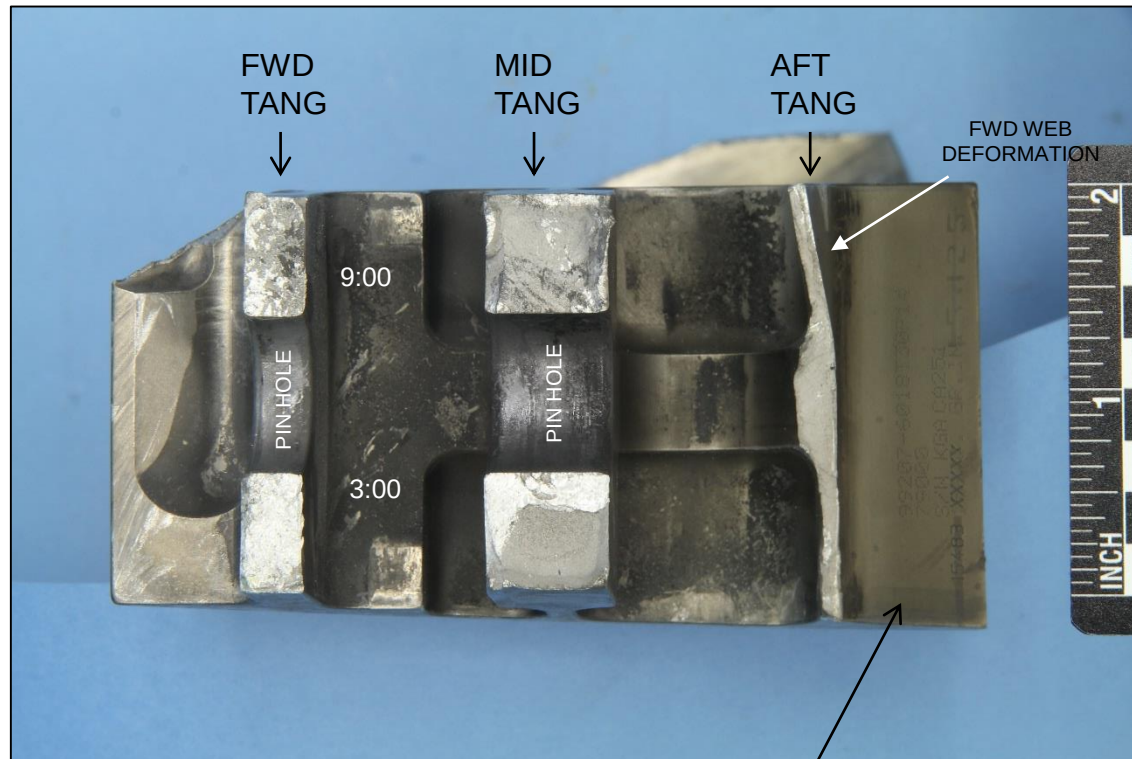
The illustration above shows the location of the fan blade in the CF34 engine. The fracture occurred through the mid point of the forward and mid pin tangs as depicted by the red lines.



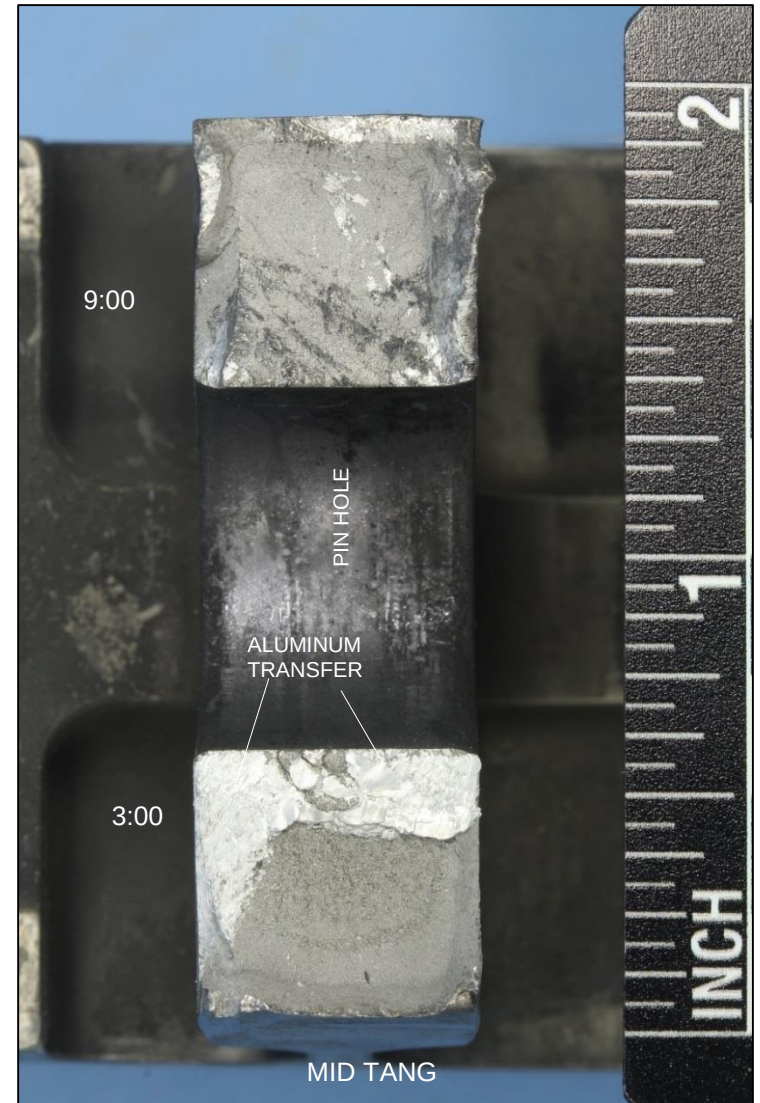
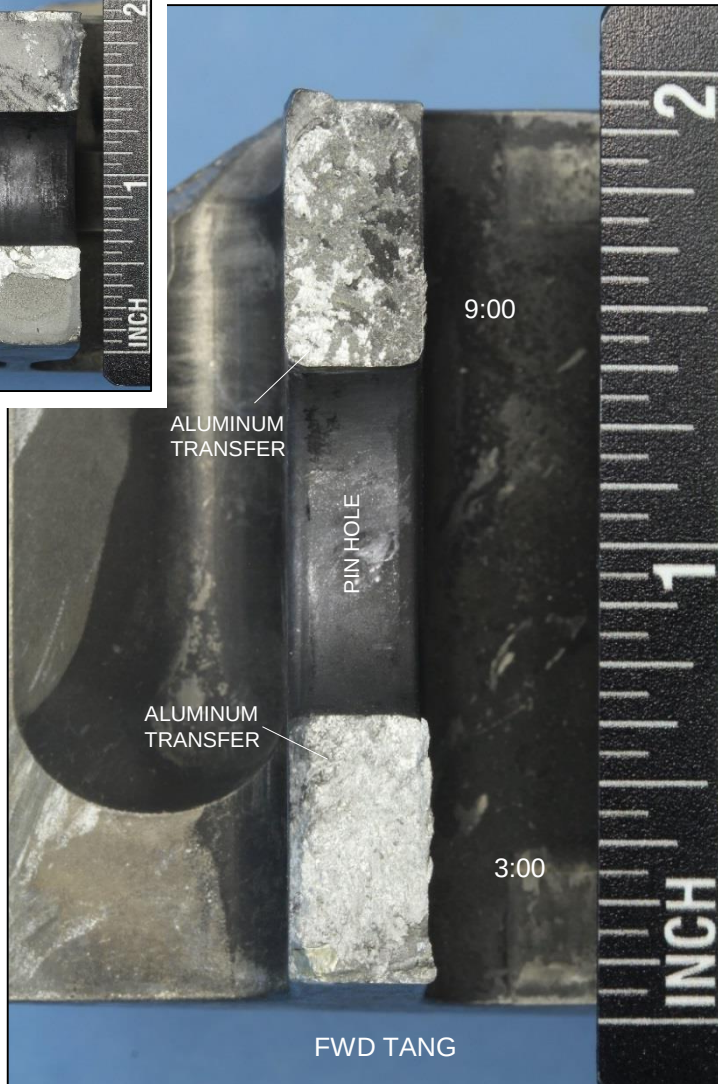
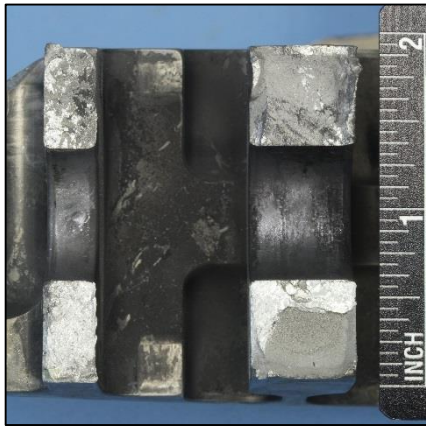
PIN

UNRECOVERED
INBOARD FWD TANG
FRACTURE

UNRECOVERED
INBOARD AFT TANG
FRACTURE



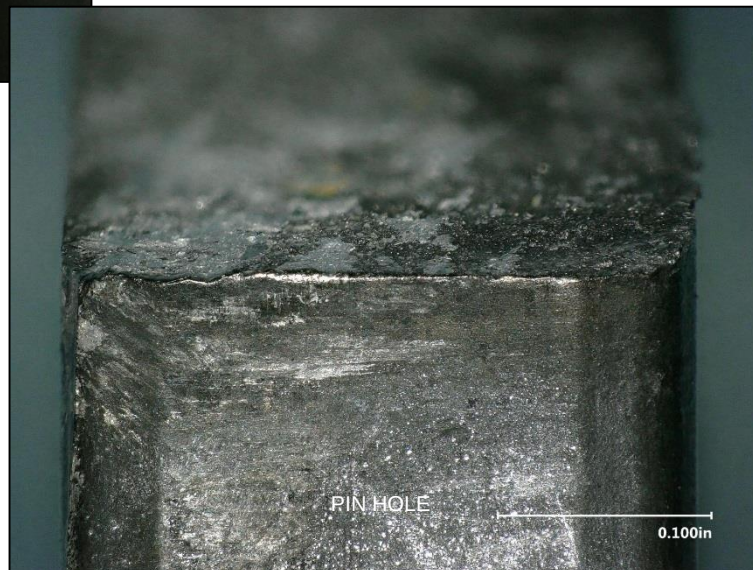
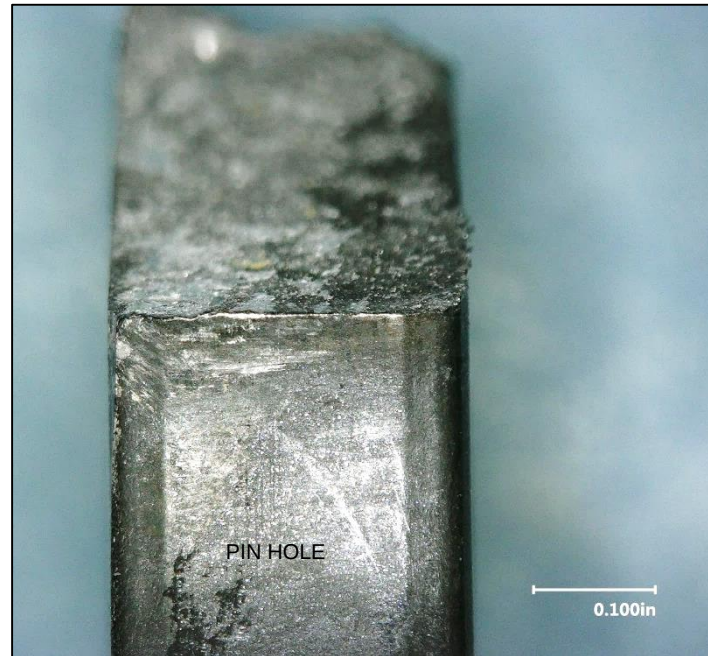
Views of the 6018T30P14 fan blade from ESN 873-642 which was identified as S/N KGACA251 per the part markings on the platform. The fracture surfaces were designated as 3 o'clock and 9 o'clock aft looking forward for reference in this report. The fracture of the aft tang was secondary as the fracture occurred outboard of the pin hole and the remaining portion of the web was plastically deformed forward consistent with the final separation of the fan blade.



Additional views of the 6018T30P14 fan blade from ESN 873-642 which was identified as S/N KGACA251 per the part markings on the platform. The fracture surfaces exhibited transferred aluminum from the separation event. The aluminum was subsequently removed by chemical immersion.

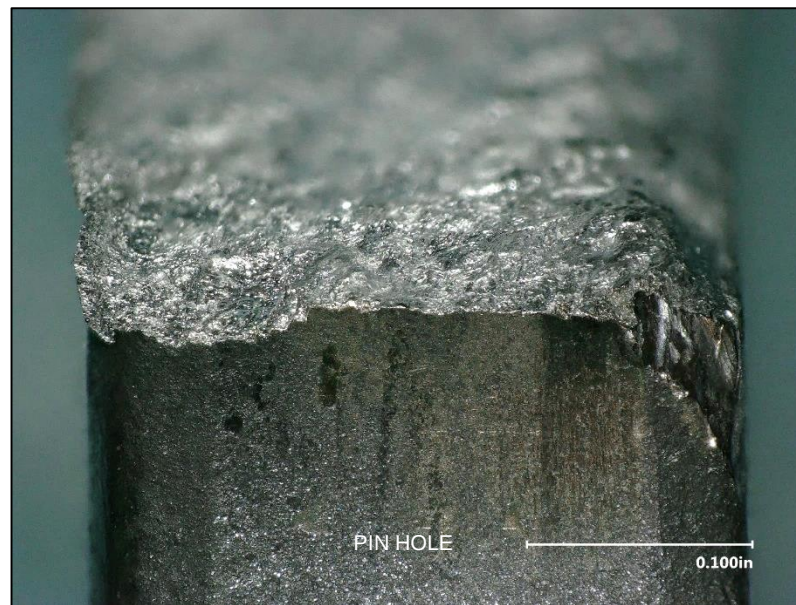
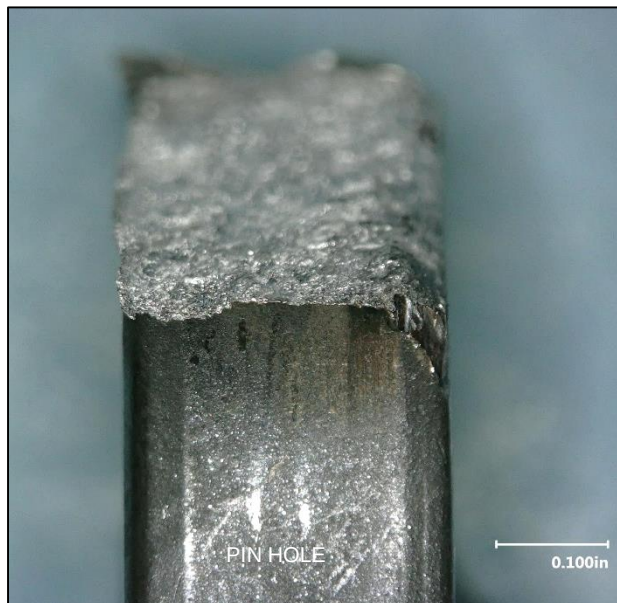


FWD TANG
9 O'CLOCK

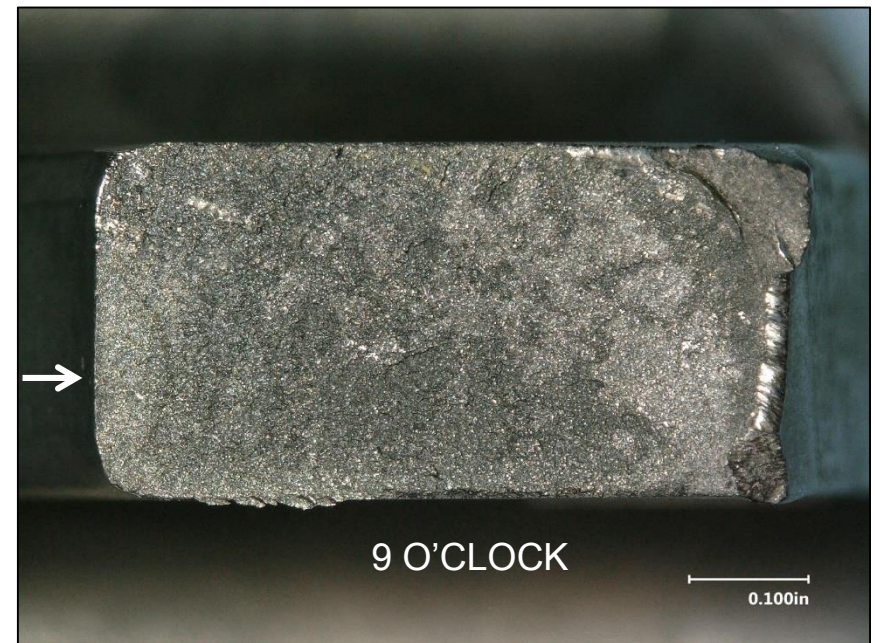
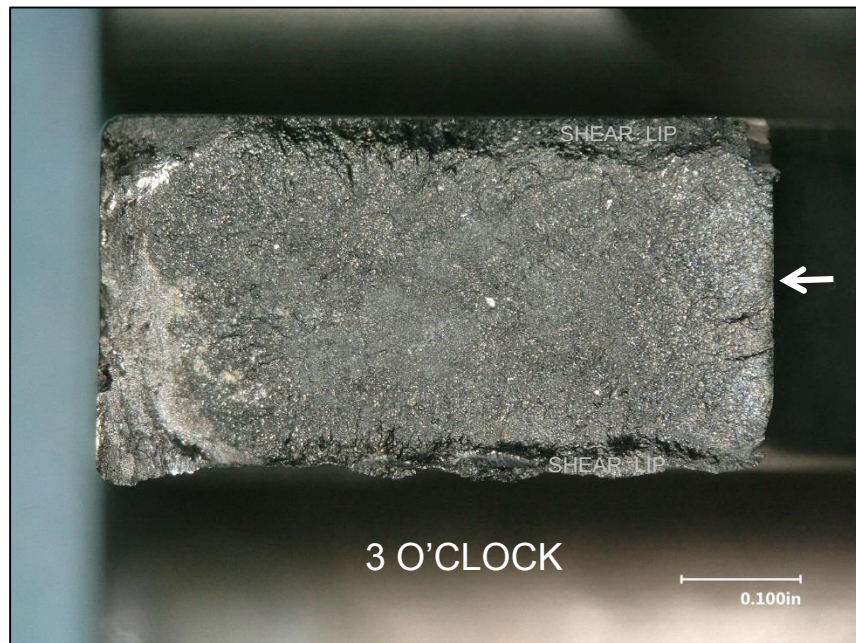
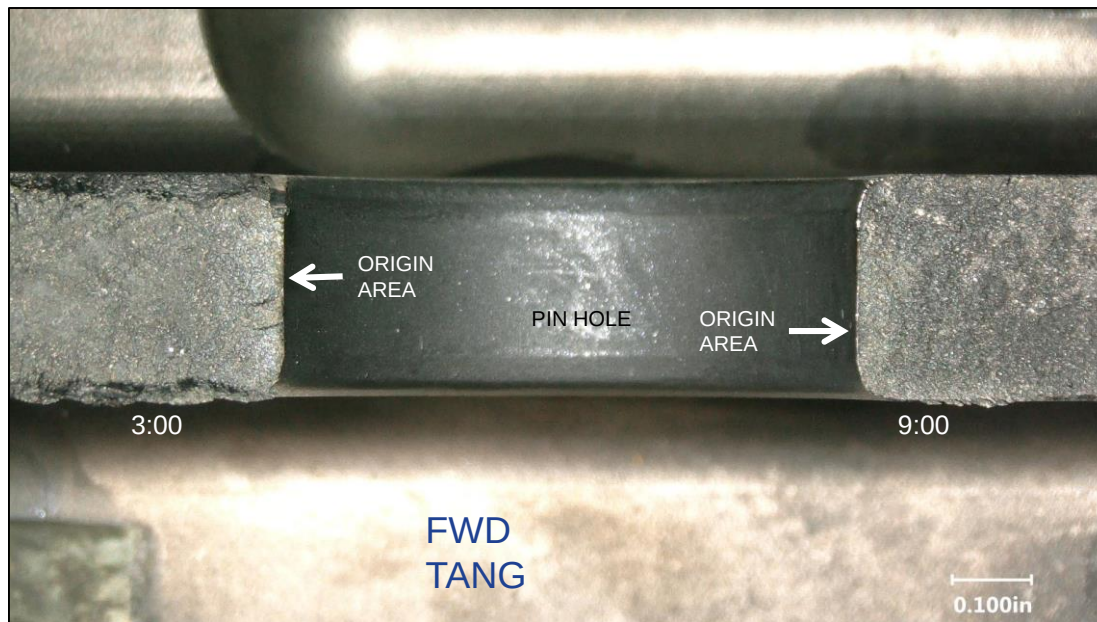


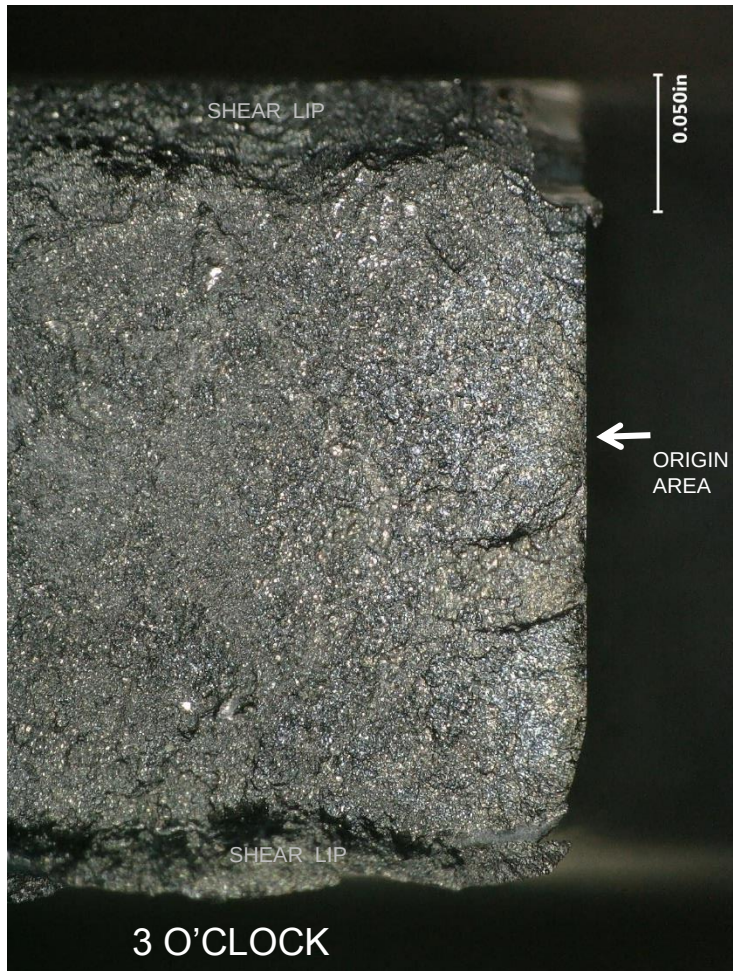
Views of the forward tang fracture at the 9 o'clock (ALF) position. Visual examination found no evidence of blending from a repair operation.

FWD TANG
3 O'CLOCK

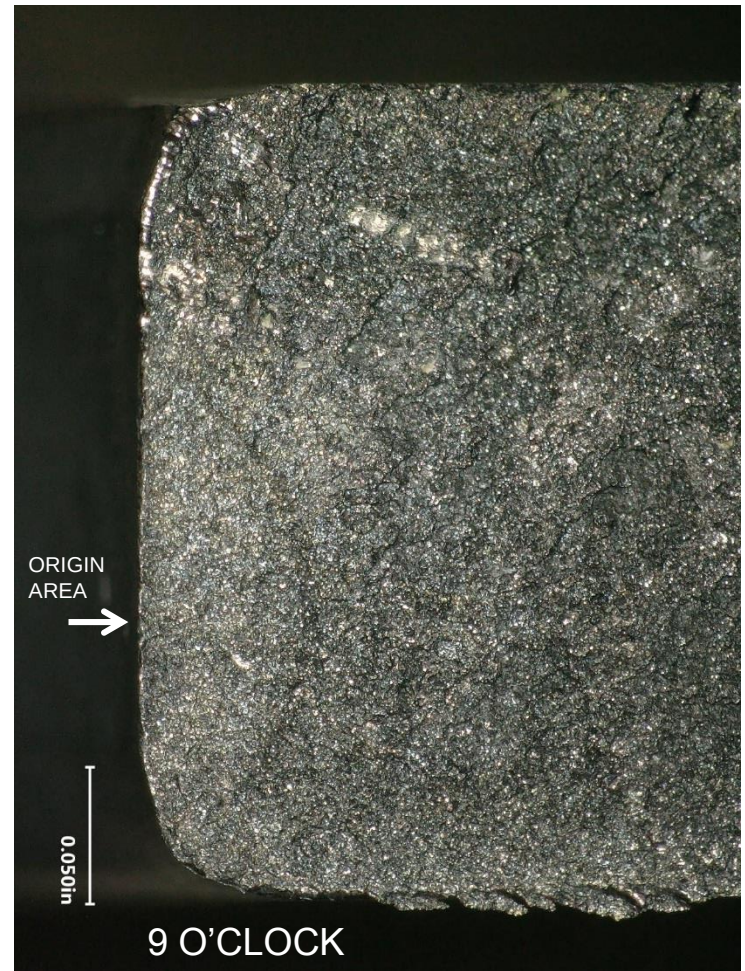


Views of the forward tang fracture at the 3 o'clock (ALF) position. Visual examination found no evidence of blending from a repair operation. The fracture surface was obscured by transferred aluminum.





FWD TANG

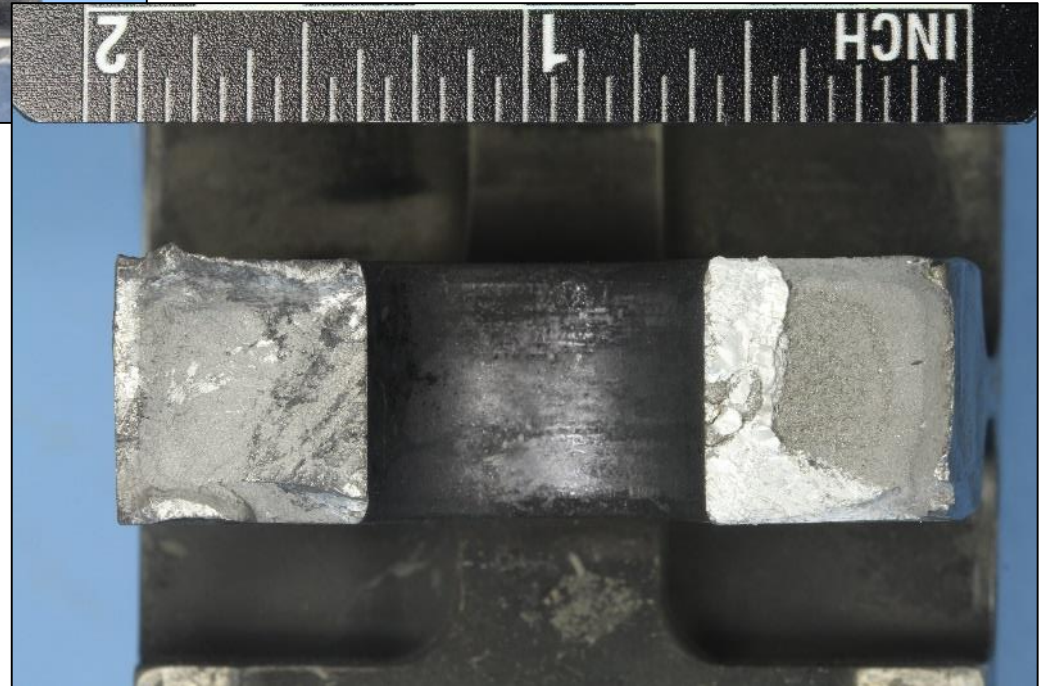


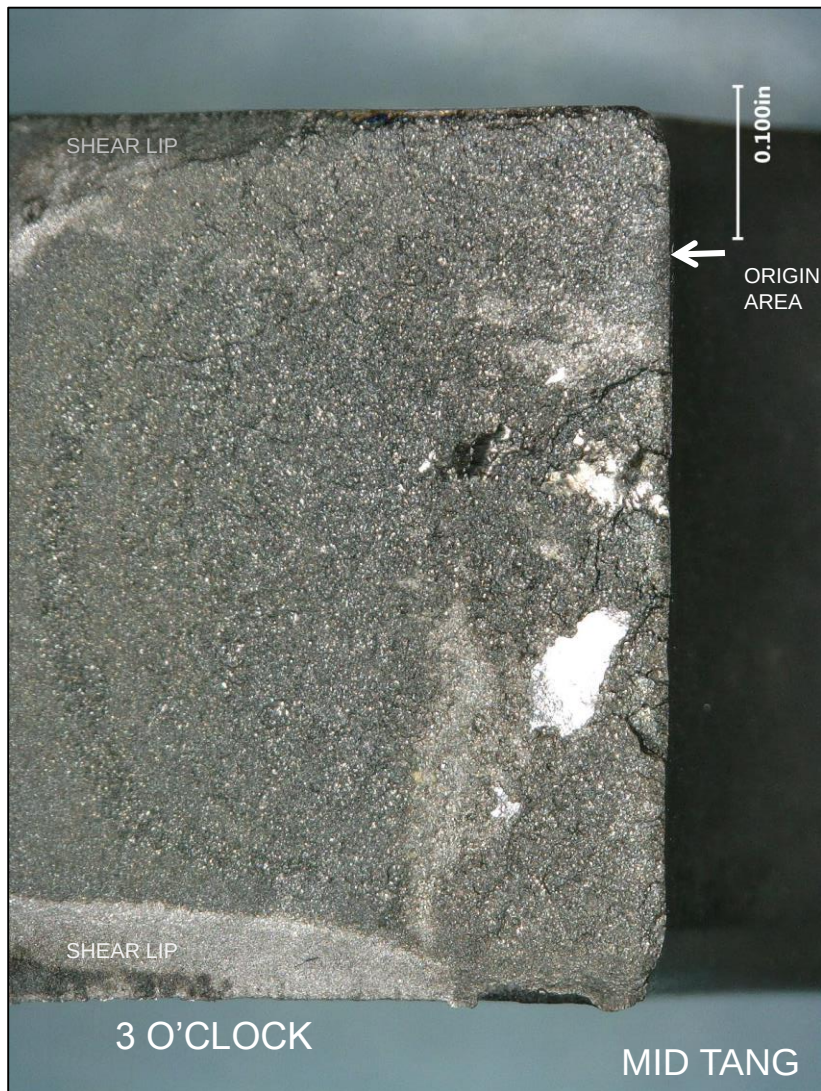
Additional views of the fracture surface on the forward tang after chemically removing the transferred aluminum. The white arrows indicate the location of the fatigue origins on the pin hole surface.



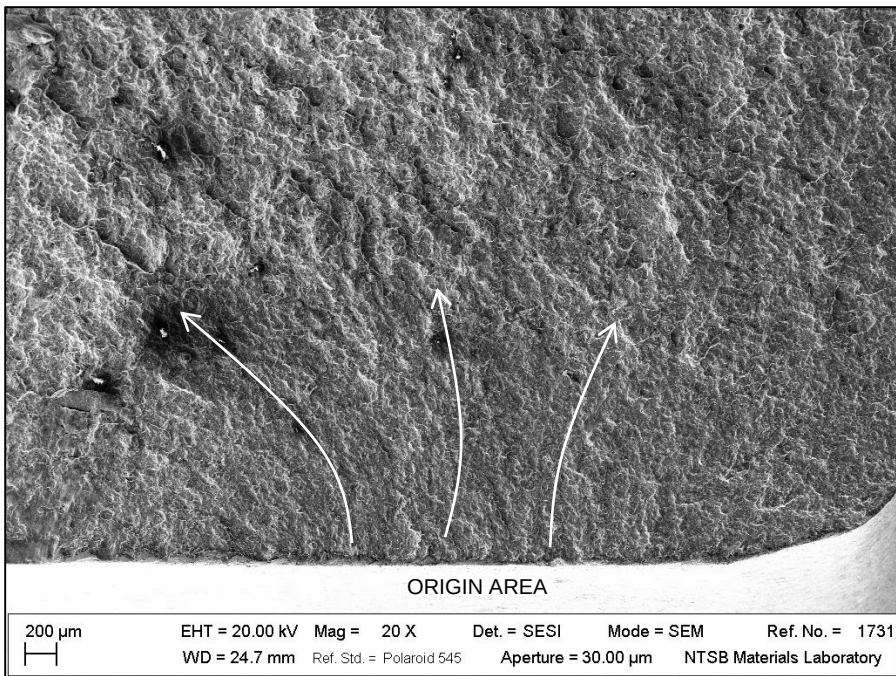
MID TANG

Views of the fractures on the mid tang. Visual examination found no evidence of blending from a repair operation.



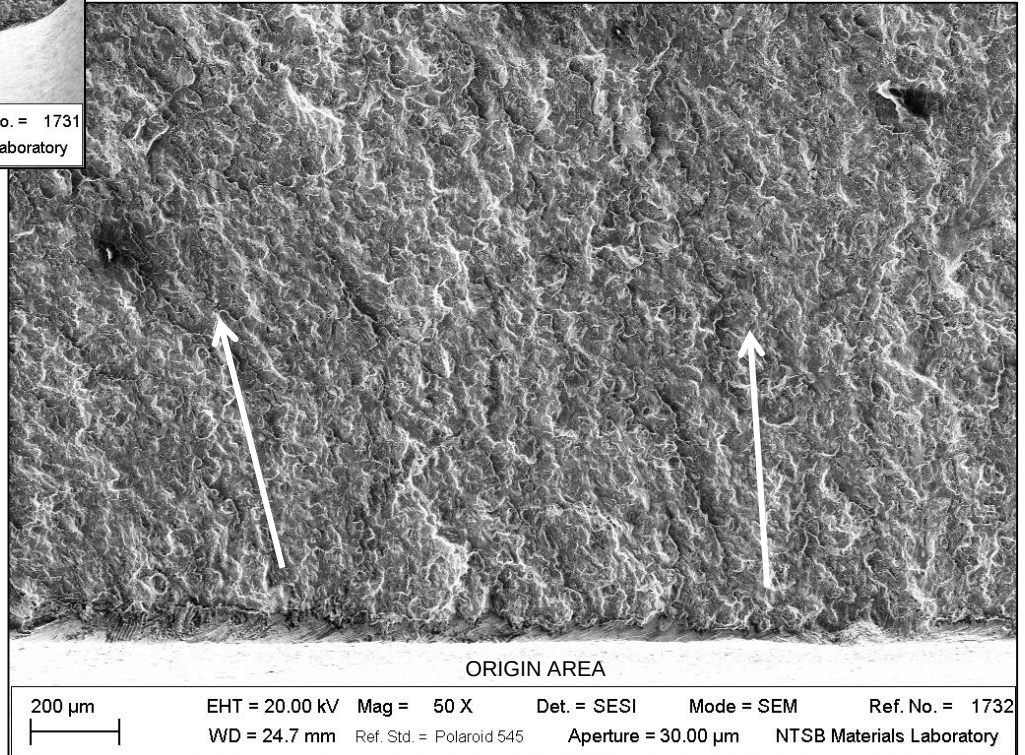
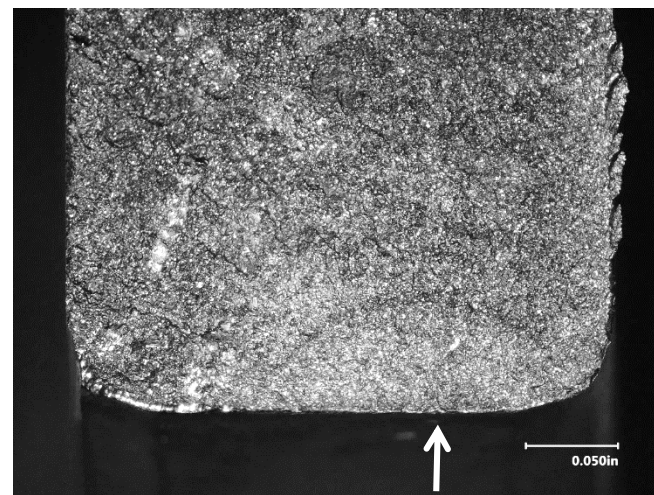


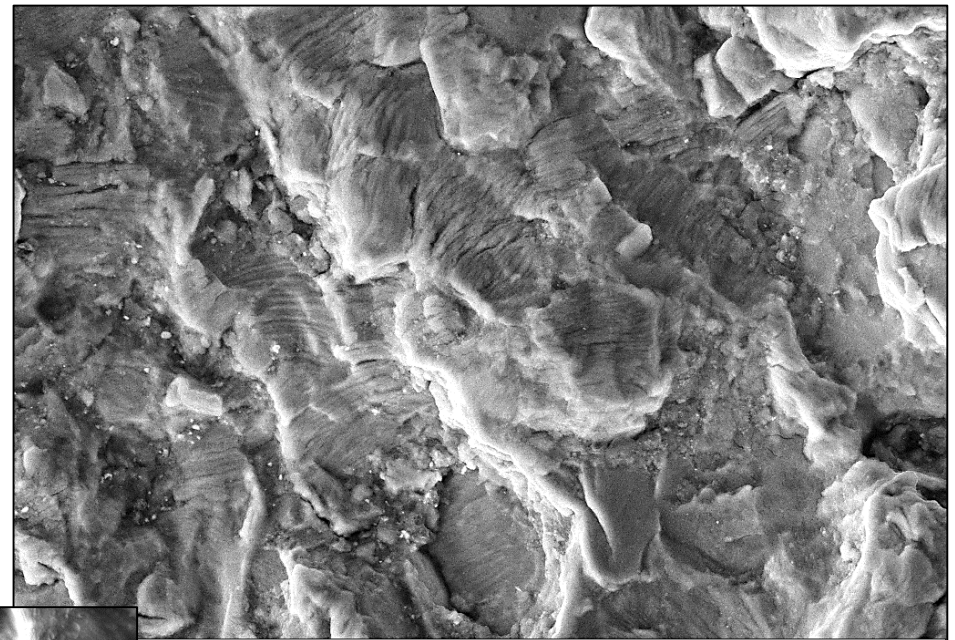
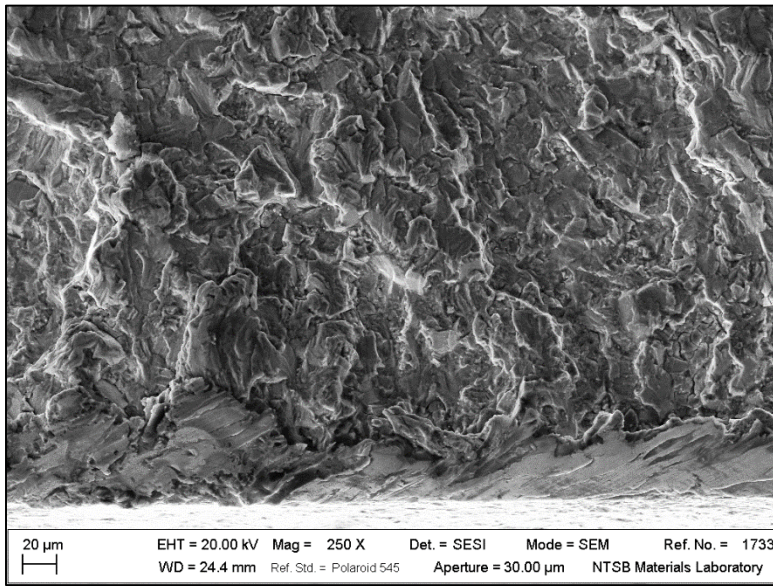
Views of the fracture surface on the mid tang after chemically removing the transferred aluminum. The white arrows indicate the location of the fatigue origins on the pin hole surface.



FWD TANG 9 O'CLOCK

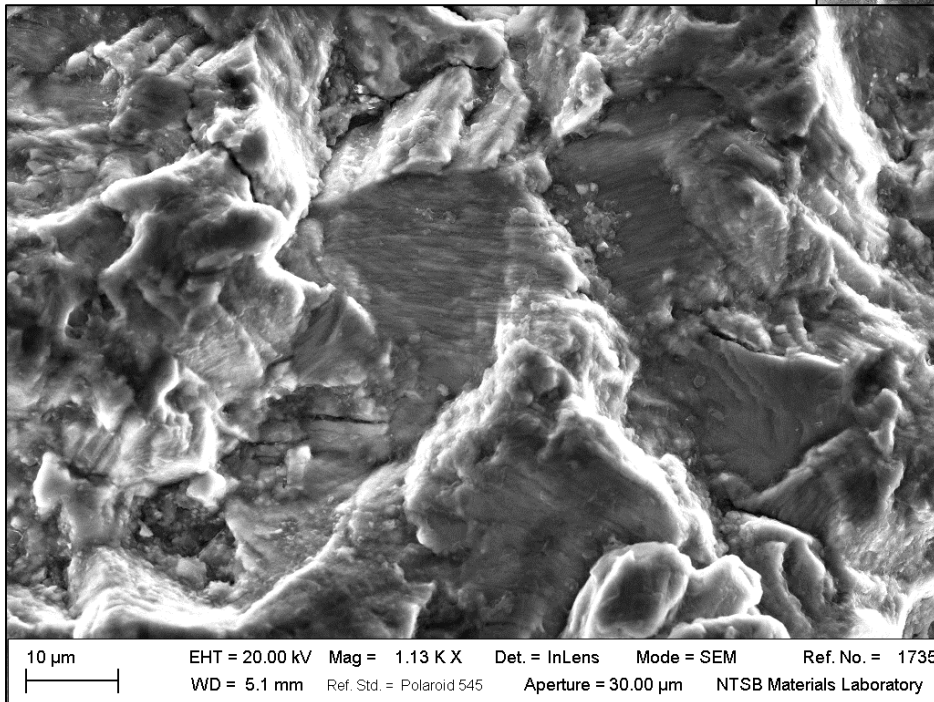
SEM evaluation of the fracture surface on the forward tang 9 o'clock location confirmed the origin to be at the surface of the pin hole. No evidence of material anomalies or damage was observed.

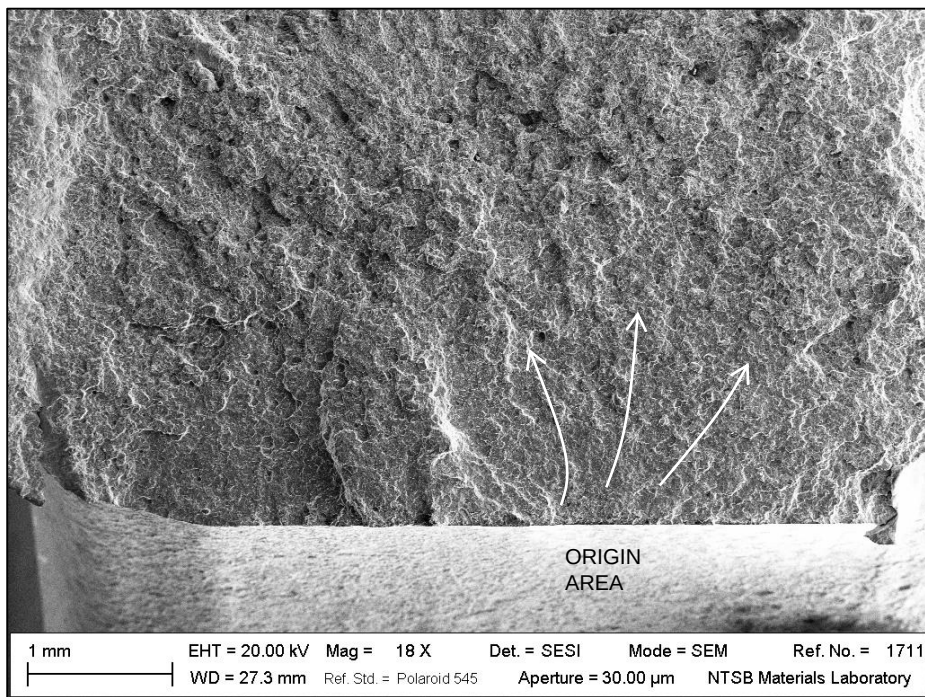




FWD TANG 9 O'CLOCK

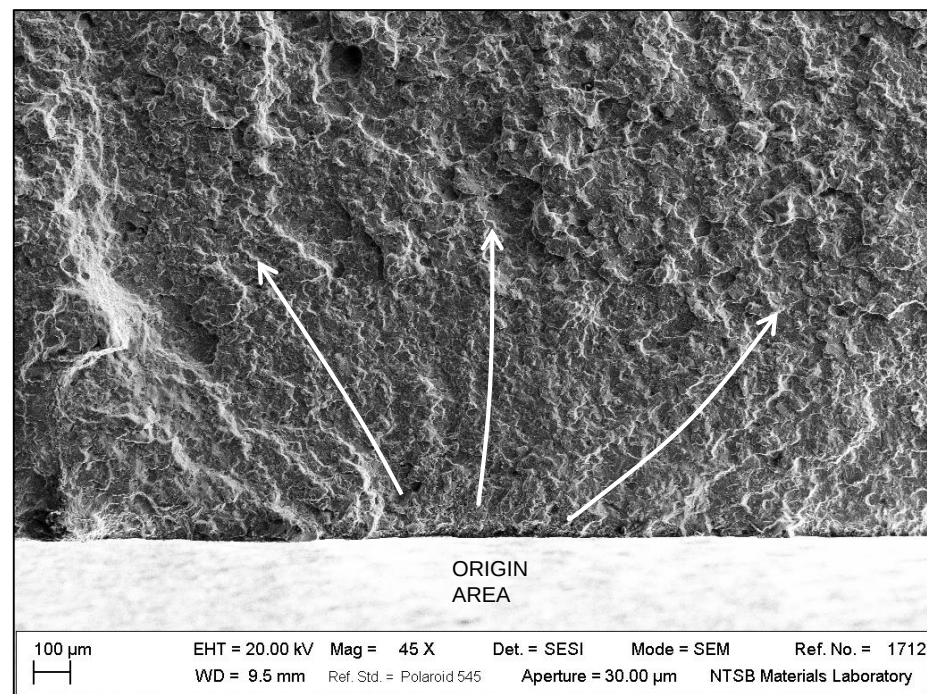
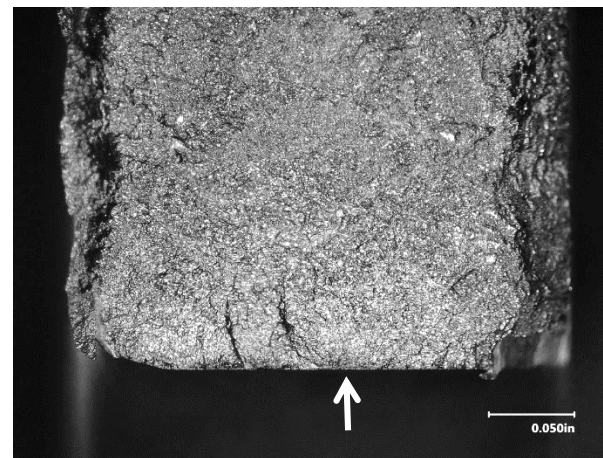
SEM views of the fracture surface at the origin area at the 9 o'clock position on the forward tang. Striated fatigue features were observed consistent with crack initiation and propagation by low cycle fatigue. No evidence of material anomalies or damage was observed.

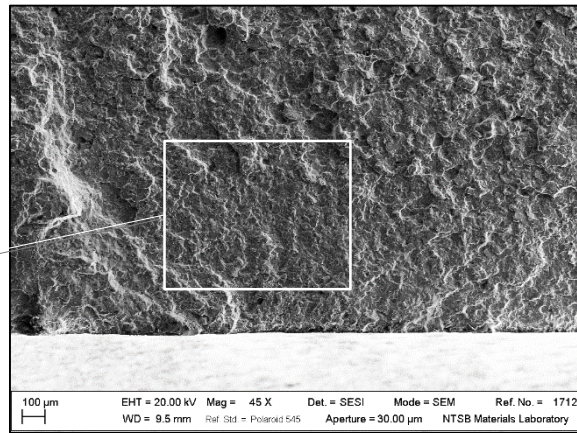
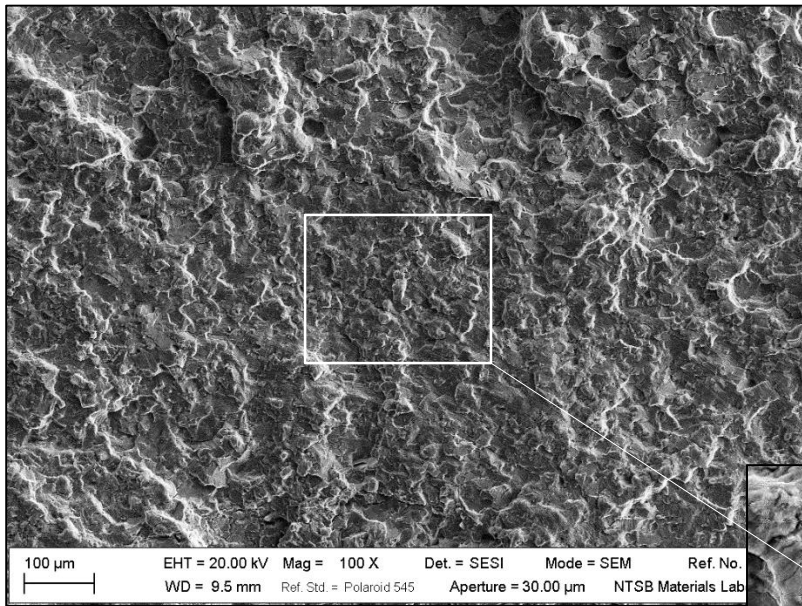




FWD TANG 3 O'CLOCK

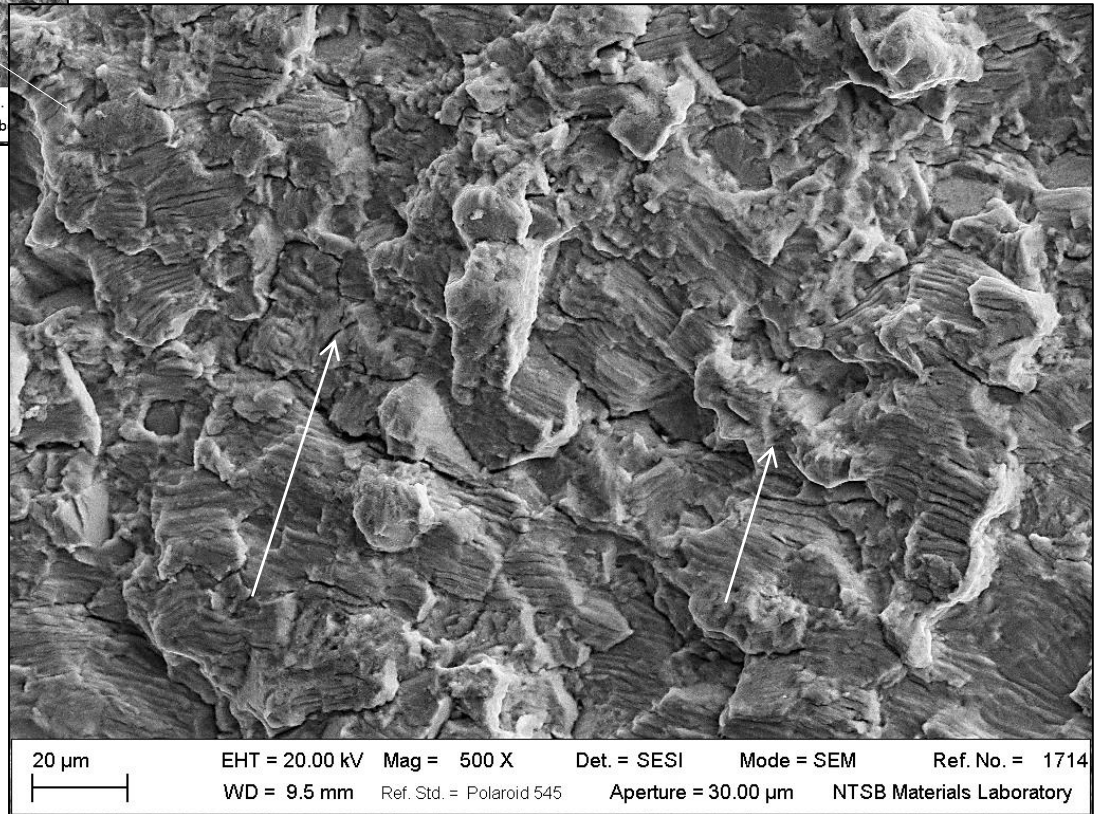
SEM evaluation of the fracture surface on the forward tang 3 o'clock location confirmed the origin to be at the surface of the pin hole. No evidence of material anomalies or damage was observed.

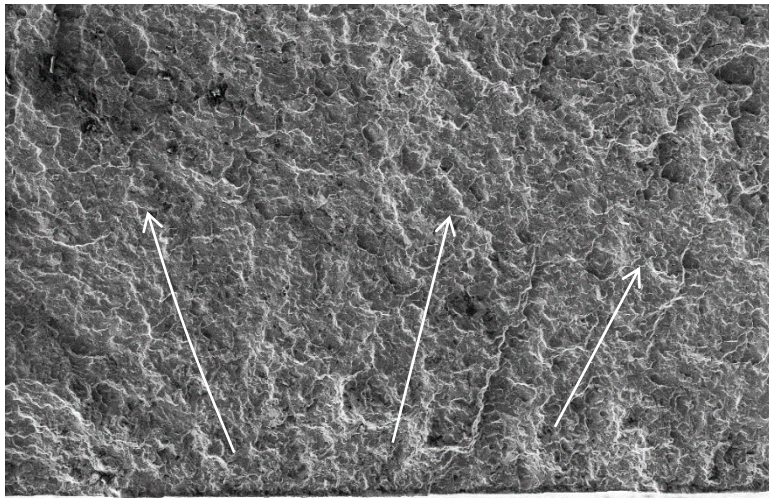




FWD TANG 3 O'CLOCK

SEM views of the fracture surface at the origin area at the 3 o'clock position on the forward tang. Striated fatigue features were observed consistent with crack initiation and propagation by low cycle fatigue. No evidence of material anomalies or damage was observed.

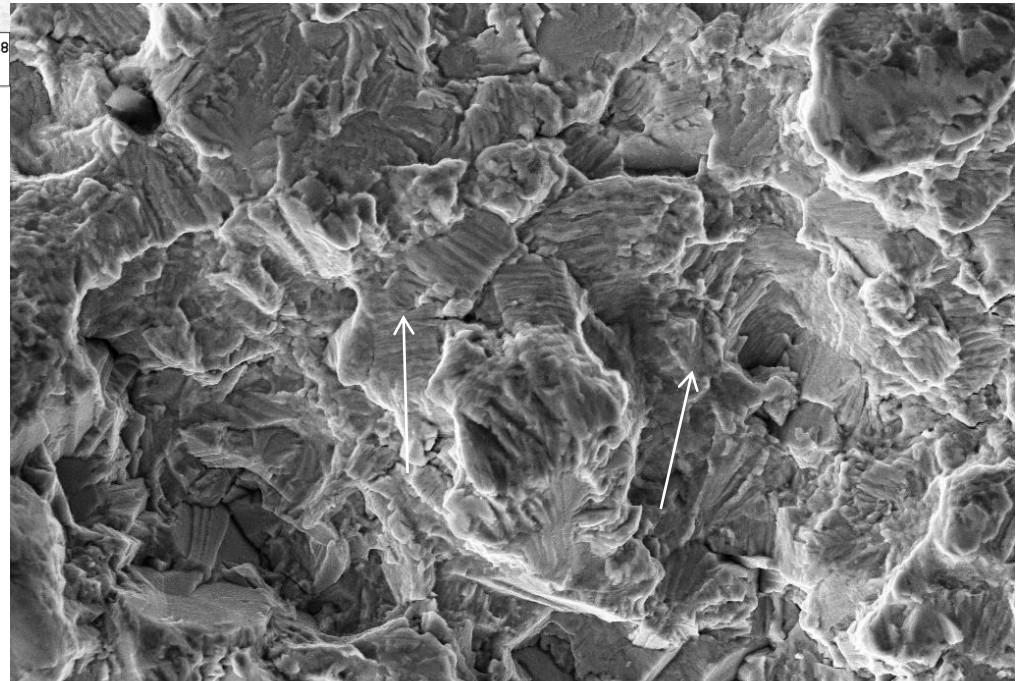
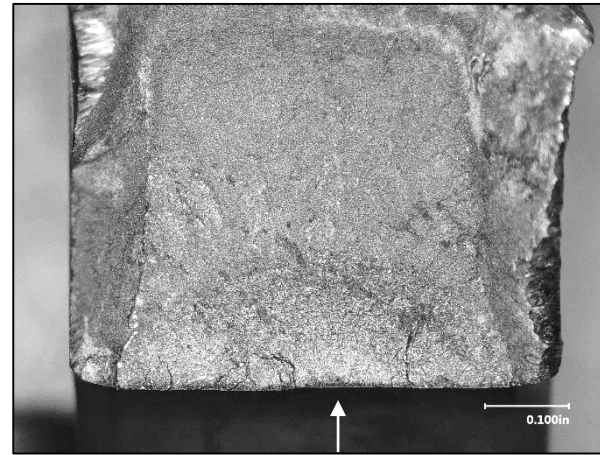




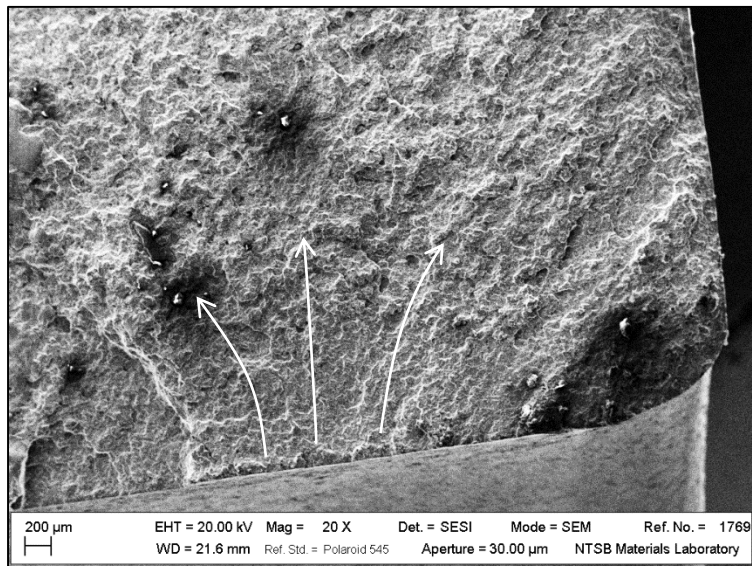
100 μ m EHT = 20.00 kV Mag = 52 X Det = SESI Mode = SEM Ref. No. = 1748
WD = 21.0 mm Ref. Std. = Polaroid 545 Aperture = 30.00 μ m NTSB Materials Laboratory

MID TANG 9 O'CLOCK

SEM evaluation of the fracture surface on the mid tang 9 o'clock location confirmed the origin to be at the surface of the pin hole. Striated fatigue features were observed consistent with crack initiation and propagation by low cycle fatigue. No evidence of material anomalies or damage was observed.

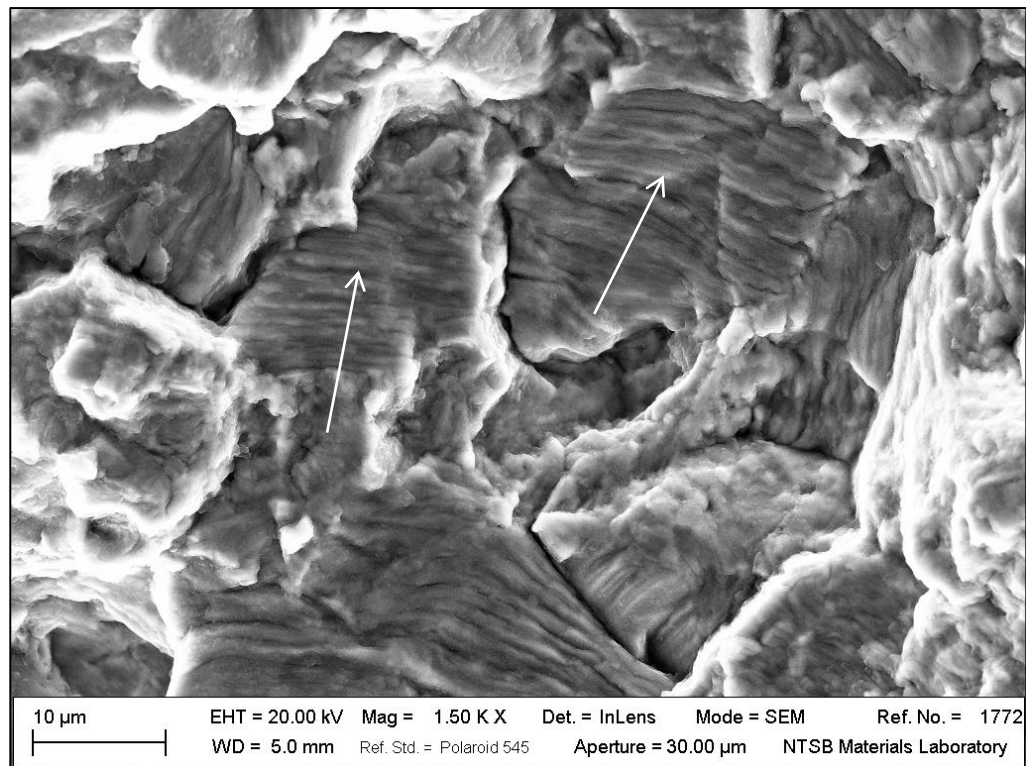
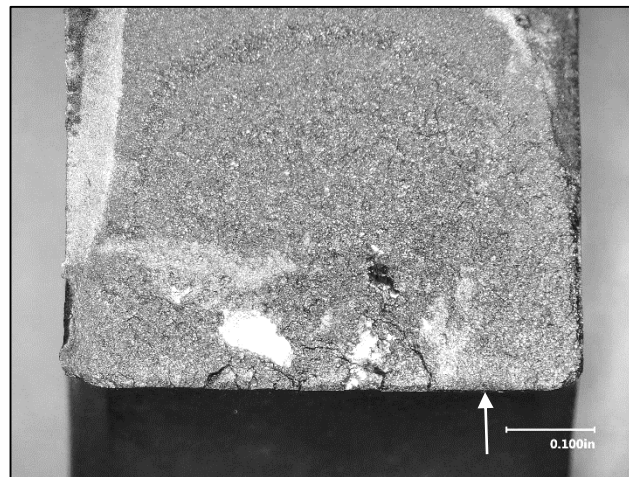


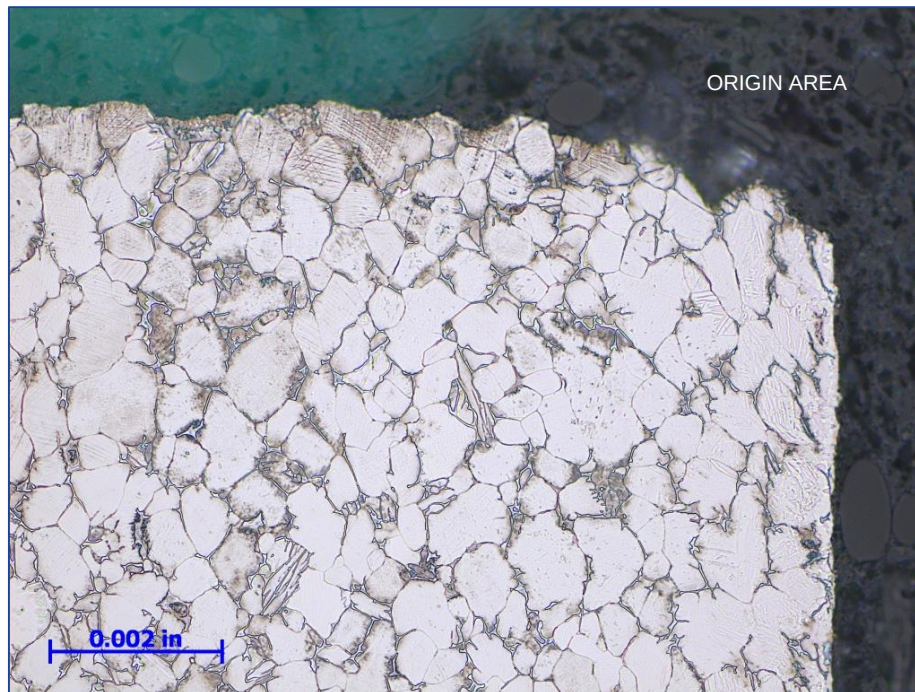
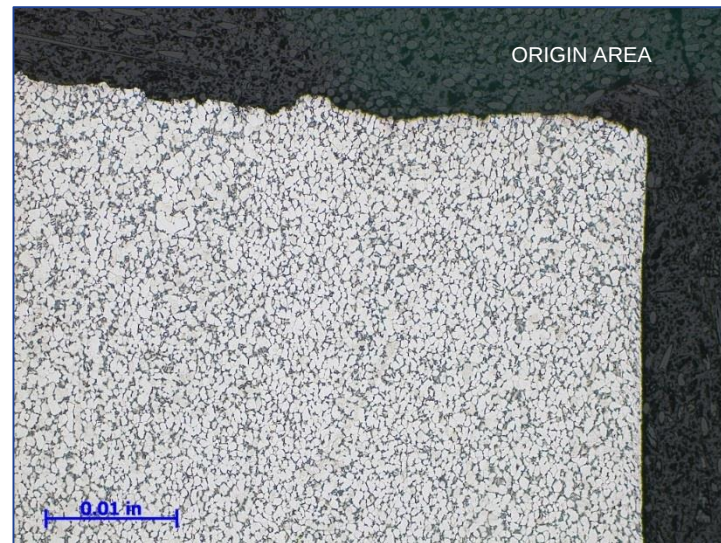
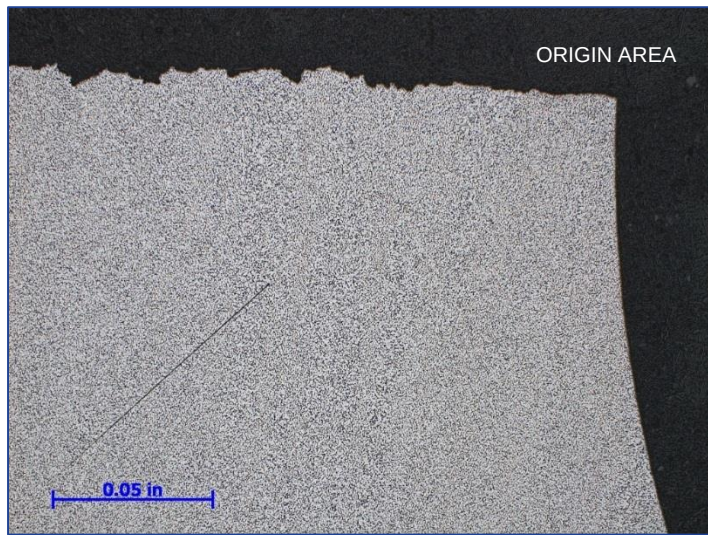
10 μ m EHT = 20.00 kV Mag = 500 X Det = SESI Mode = SEM Ref. No. = 1750
WD = 21.2 mm Ref. Std. = Polaroid 545 Aperture = 30.00 μ m NTSB Materials Laboratory



MID TANG 3 O'CLOCK

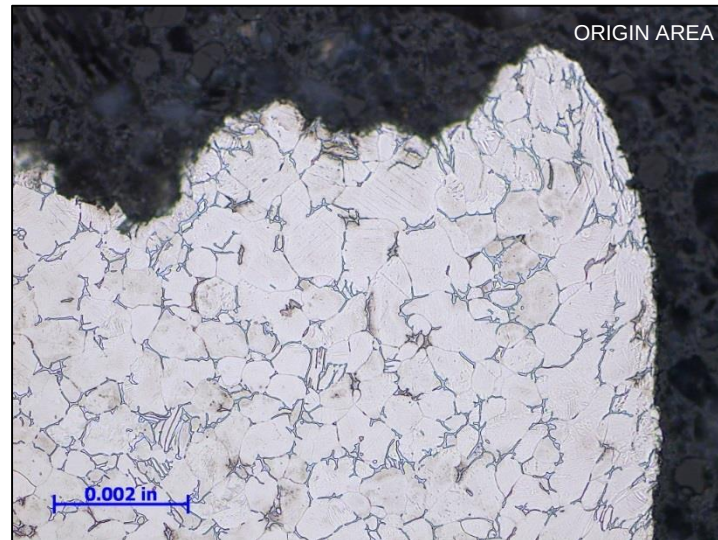
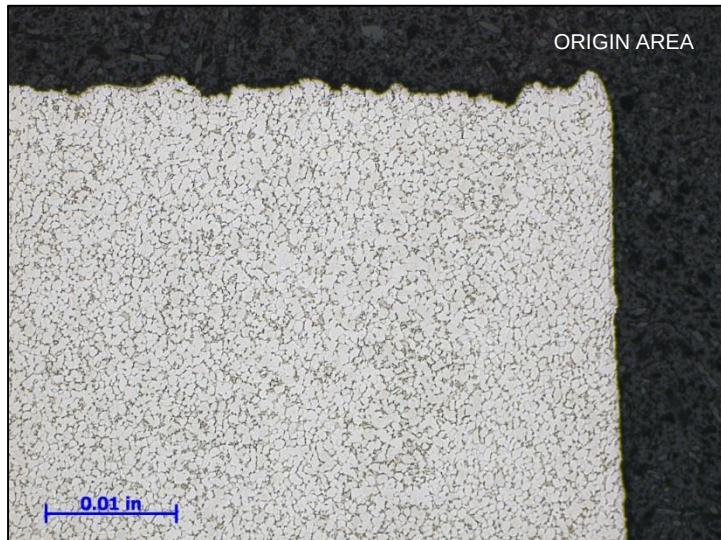
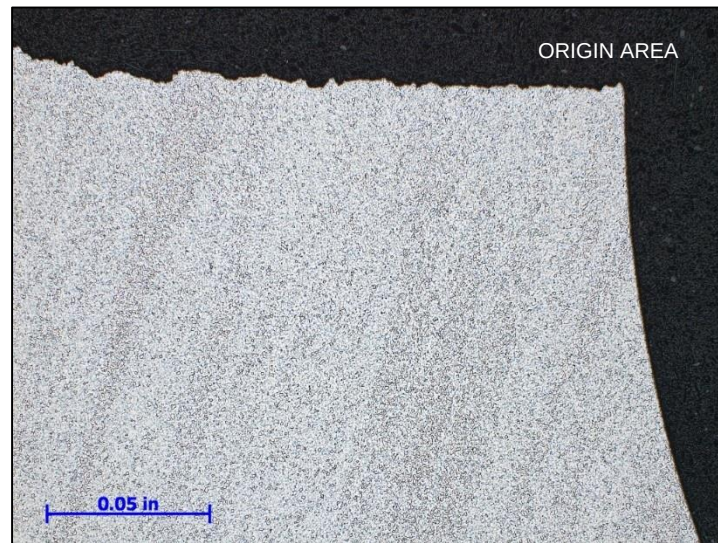
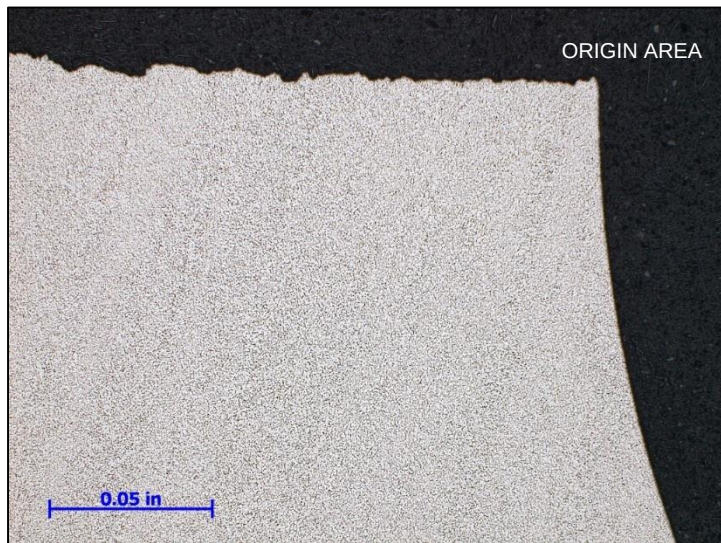
SEM evaluation of the fracture surface on the mid tang 9 o'clock location confirmed the origin to be at the surface of the pin hole. Striated fatigue features were observed consistent with crack initiation and propagation by low cycle fatigue. No evidence of material anomalies or damage was observed.





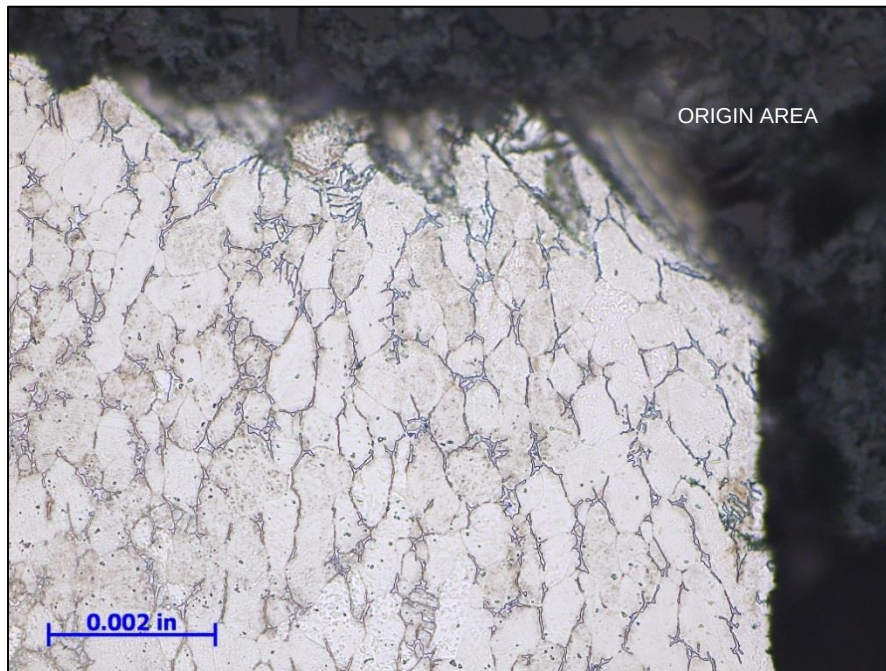
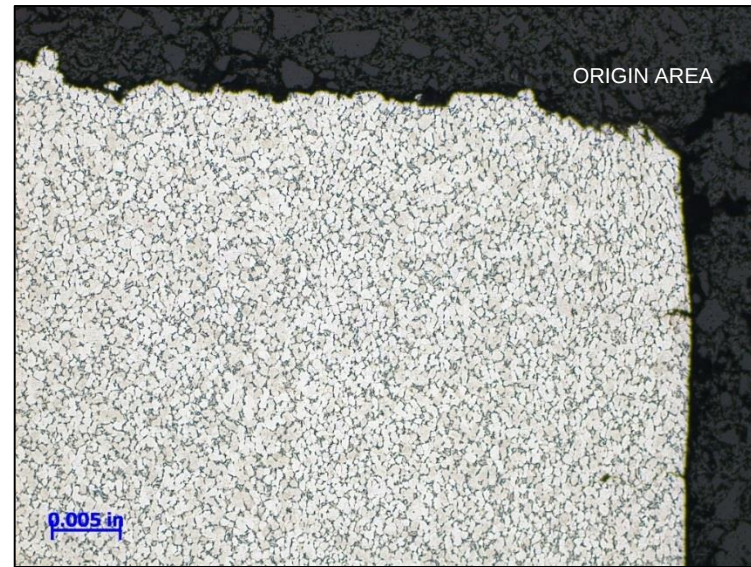
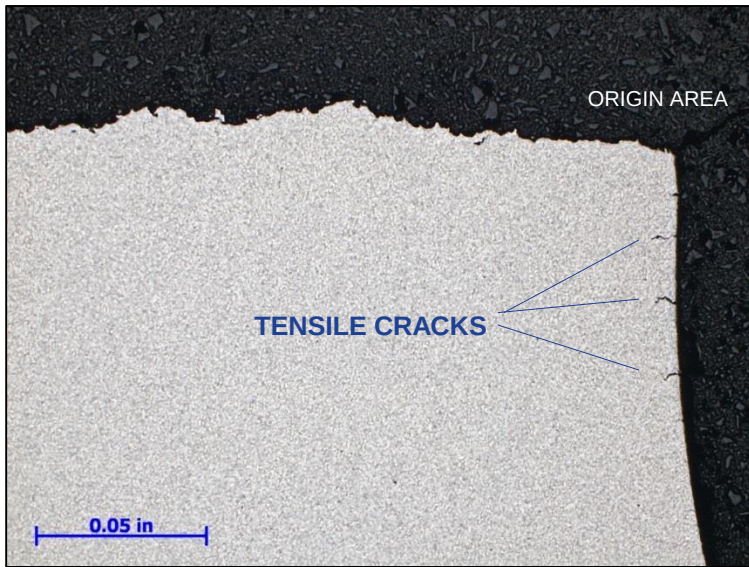
FWD TANG 3 O'CLOCK

Metallographic evaluation of the origin area on the forward tang at the 3 o'clock position showed typical microstructure for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1V with no evidence of material anomalies or manufacturing deficiency. Metallographic evaluation of the fatigue origins revealed some texturing of the microstructure.



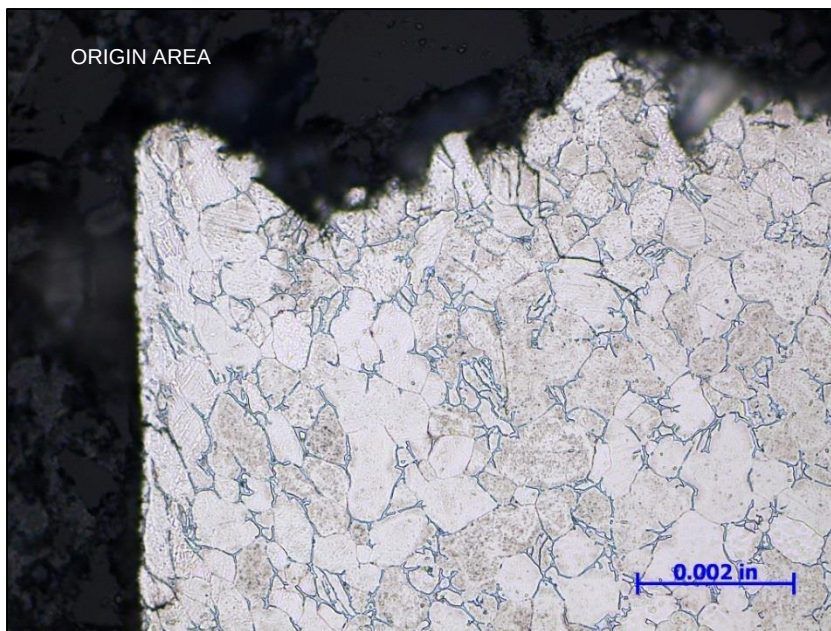
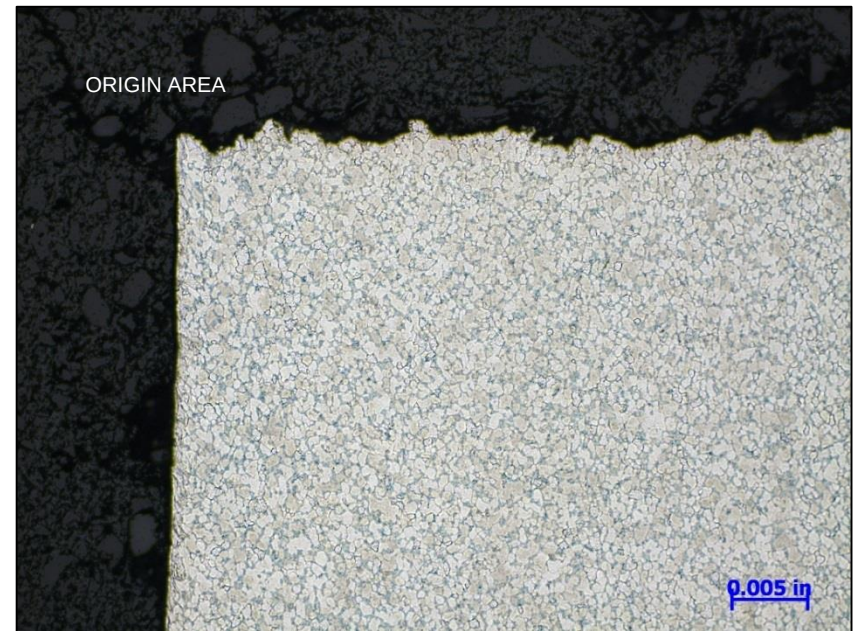
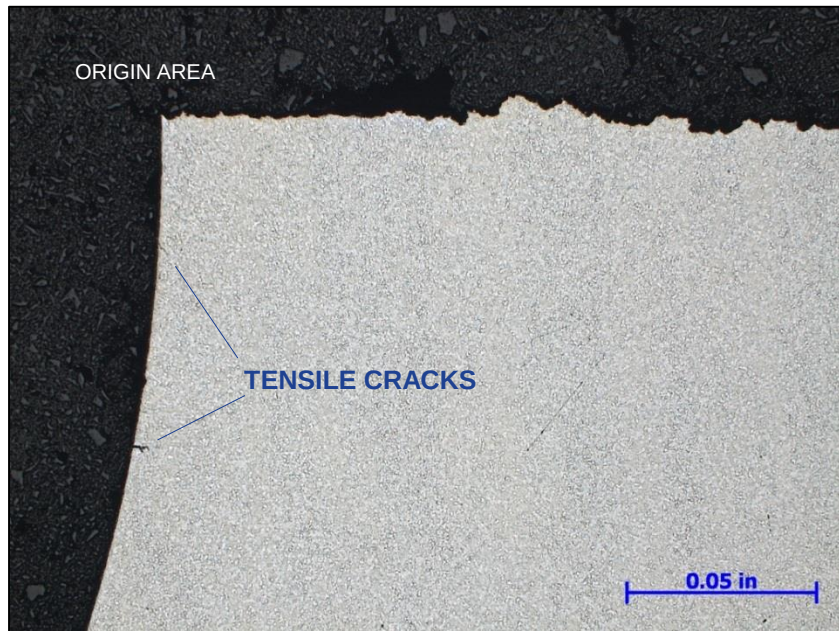
FWD TANG 9 O'CLOCK

Metallographic evaluation of the origin area on the forward tang at the 9 o'clock position showed typical microstructure for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1V with no evidence of material anomalies or manufacturing deficiency. Metallographic evaluation of the fatigue origins revealed some texturing of the microstructure.



MID TANG 3 O'CLOCK

Metallographic evaluation of the origin area on the aft tang at the 3 o'clock position showed typical microstructure for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1V with no evidence of material anomalies or manufacturing deficiency. Metallographic evaluation revealed tensile cracking on the surface of the pin hole.



MID TANG 9 O'CLOCK

Metallographic evaluation of the origin area on the aft tang at the 9 o'clock position showed typical microstructure for properly processed near-alpha titanium alloy Ti-8Al-1Mo-1V with no evidence of material anomalies or manufacturing deficiency. Metallographic evaluation revealed tensile cracking on the surface of the pin hole.

Electron Backscatter Diffraction

Metallographic evaluation of the fatigue origins revealed some texturing of the microstructure. The metallographic mounts were sent to GRC for electron backscatter diffraction (EBSD) to check for aligned colonies. EBSD results showed the alpha colonies were not aligned to the crystallographic orientation that would be susceptible to dwell-time fatigue initiation. The texturing noted is considered typical for the bar stock used to forge the fan blades. The following shows the results of the EBSD analysis conducted at GE Research Center (GRC) in Niskayuna, New York.

Summary

Mapping

- JEOL 6610 SEM
- 20kV accelerating voltage
- Step size = 2 μ m
- Scan area: 95 mils in X, 105 mils in Y
- Ignored beta

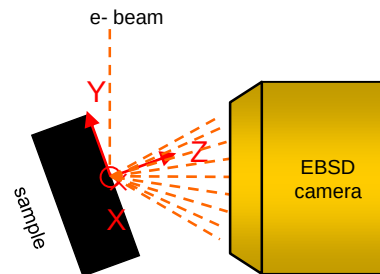
Observations

- Both samples contain multiple colonies of two different textures
 - one with basal planes aligned perpendicular to samples' x-axis
 - the other with basal planes aligned perpendicular to z-axis
- A colony with the z-axis alignment appears to associate with the initiation site of the 9-o-clock sample. Not sure this is true for the 3-o-clock sample.

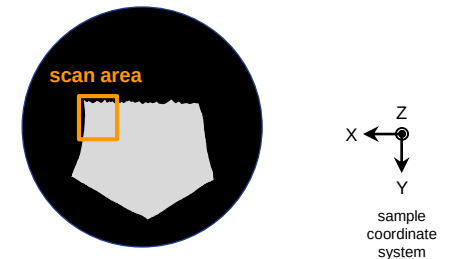
Samples

- FWD TANG 3-o-clock FWD looking AFT
- FWD TANG 9-o-clock AFT looking FWD

side view



top view

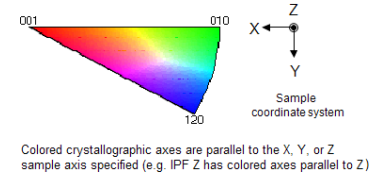
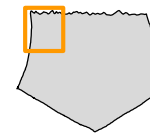


Electron Backscatter Diffraction

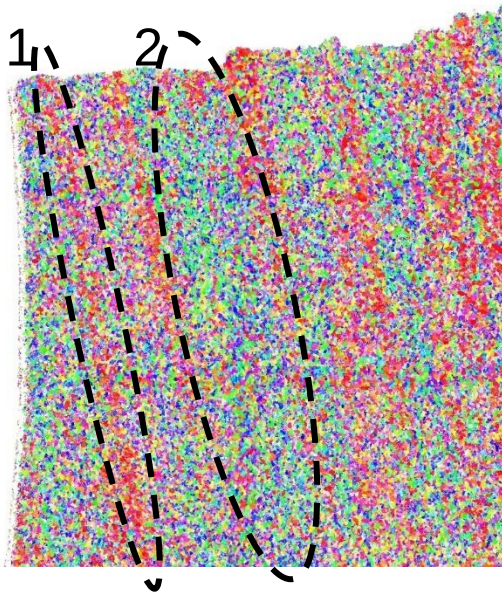
FWD-TANG 3-o-clock FWD-looking-AFT

two colony types: 1) basal planes perpendicular to the specimen's x-axis, 2) basal plane perpendicular to z-axis

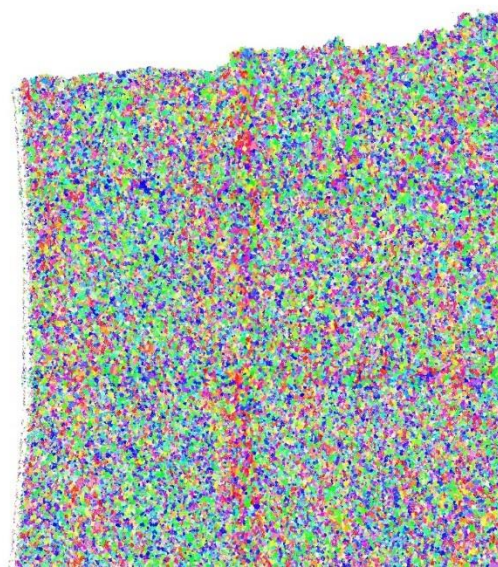
scan area



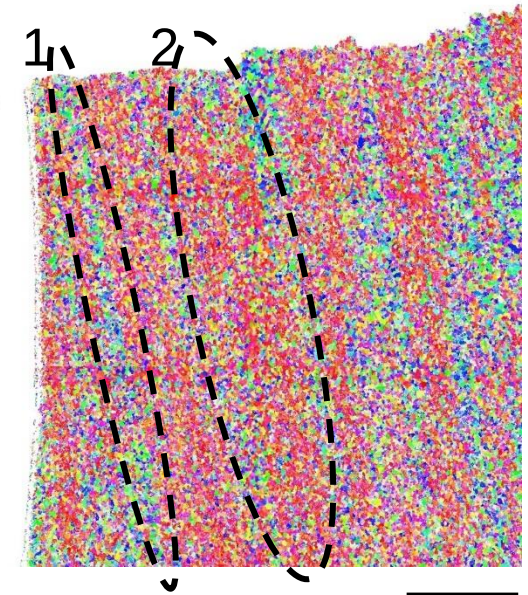
IPF-X



IPF-Y



IPF-Z



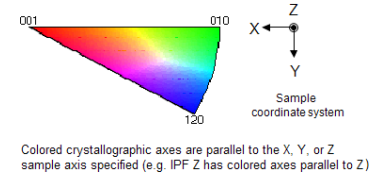
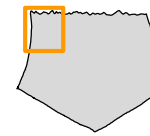
20mils

Electron Backscatter Diffraction

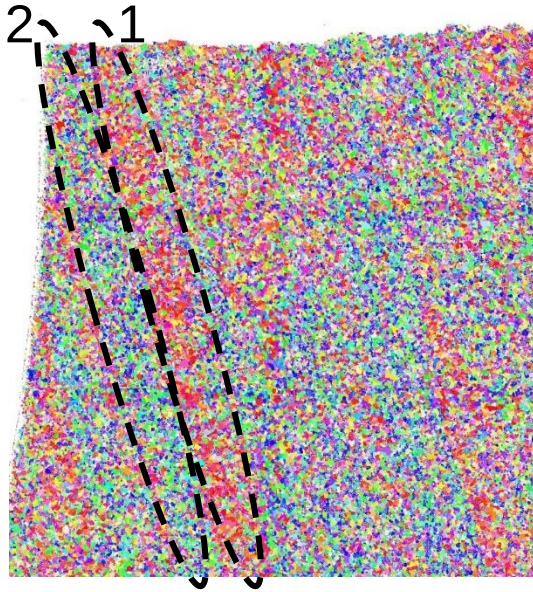
FWD-TANG 9-o-clock AFT-looking-FWD

two colony types: 1) basal planes perpendicular to the specimen's x-axis, 2) basal plane perpendicular to z-axis

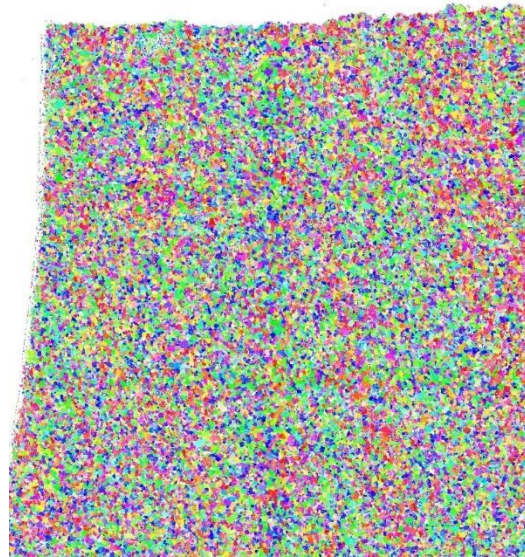
scan area



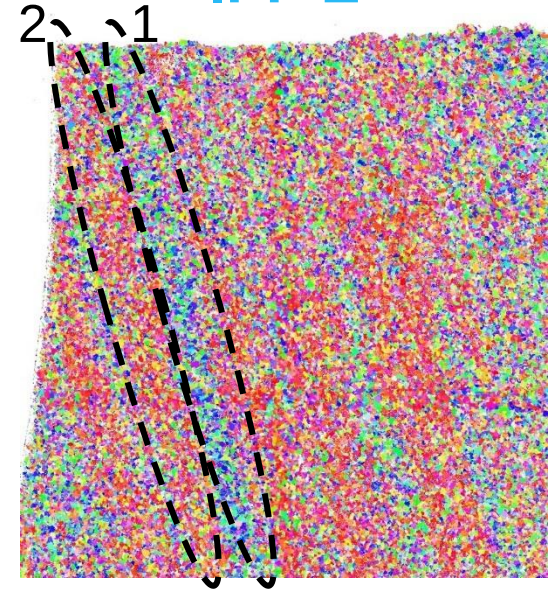
IPF-X



IPF-Y



IPF-Z

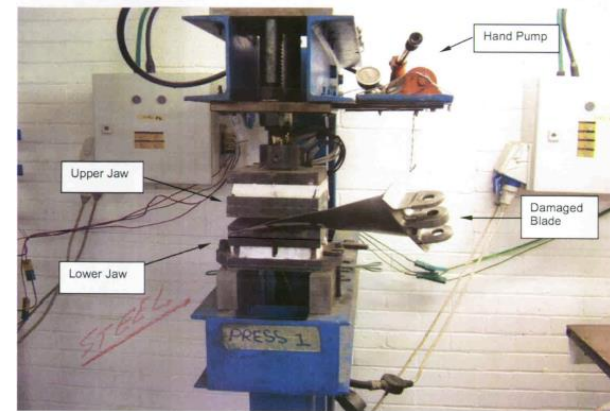


20mils

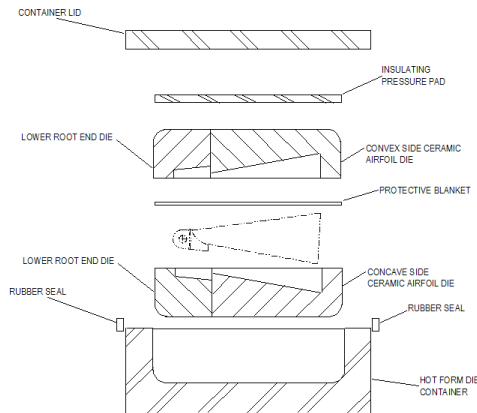
KGa CA251 Repairs at ATI-UK:

REPAIRED IAW : ATA 72-21-00/ATA 72-21-12.
REPAIRS 4 (ROOT & PIN HOLES, 7, 10, 11, 12,
REI-13471 (L/E PATCH & HOT REFORM)
MOMENT WEIGHT: 15,483
TSN: 7396.40 CSN: 4243.00

If necessary, locally straighten the severe bends of the blade by locally preheat the damaged areas and straighten the bends of the blade using a press.



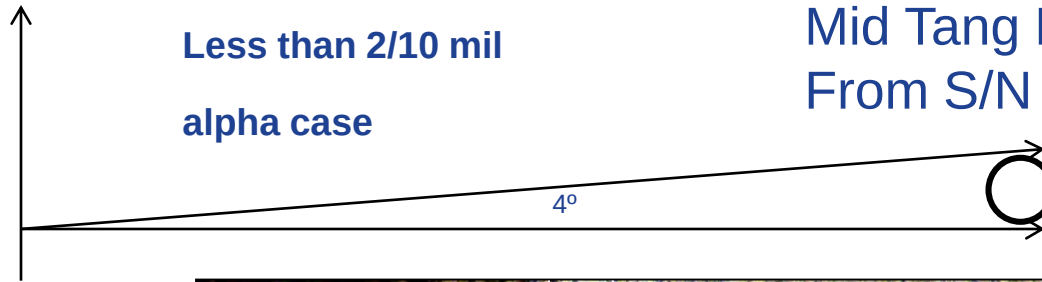
Do a creep hot form of the airfoil by placing the blade in a “hot box” or “casket” between two ceramic dies to “reform” airfoil to acceptable dimensions.



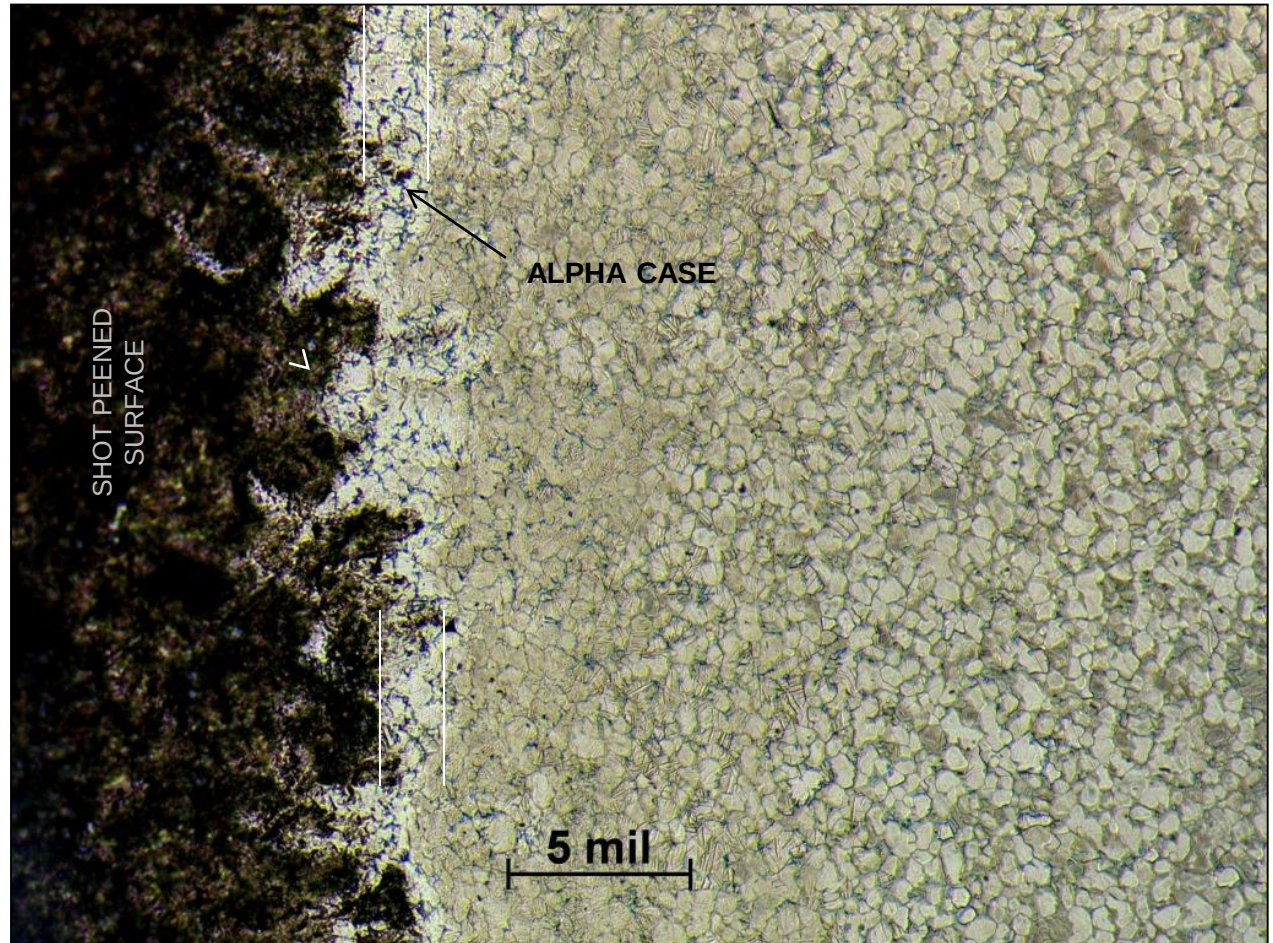
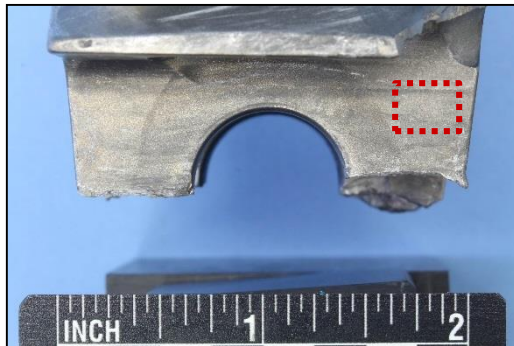
HOT FORMING CASKET

Less than 2/10 mil
alpha case

Mid Tang Face
From S/N KGACA251

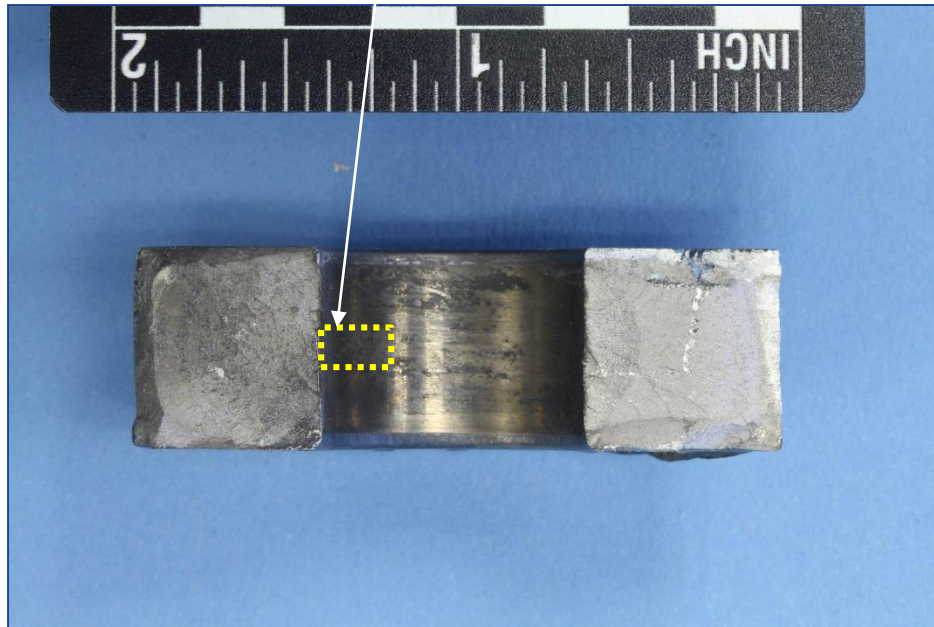


Metallographic evaluation of blade S/N KGACA251 was performed by mounting the specimen on a 4° angle. Ammonium bifluoride etch revealed a white layer at the surface that was consistent with alpha case. Metallographic evaluation of S/N KGAK5302 showed no evidence of alpha case.

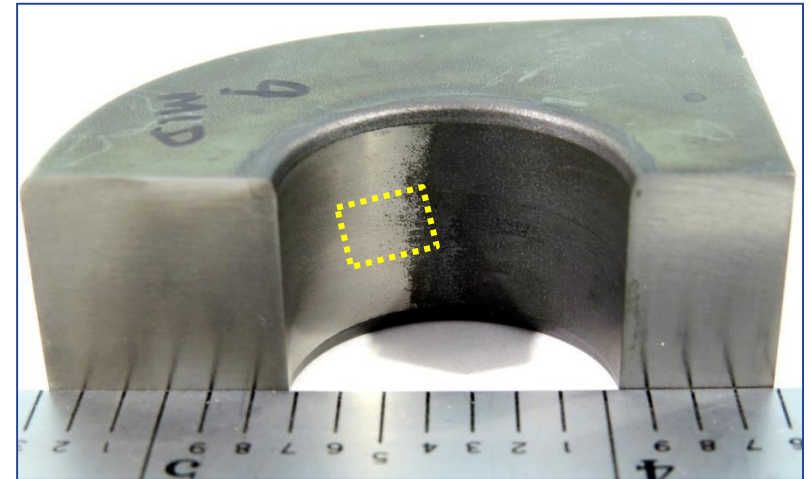




S/N KGACA251



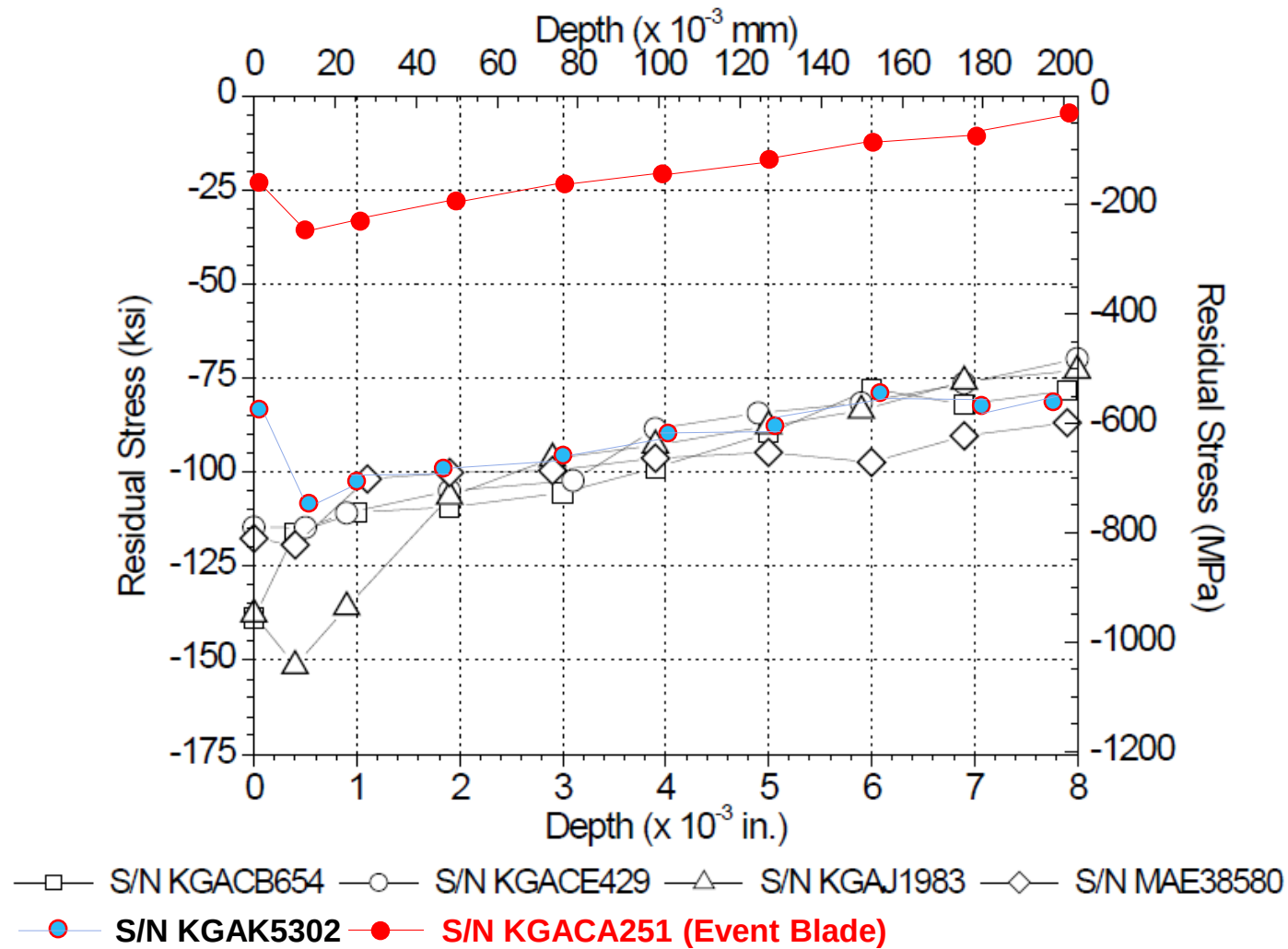
Residual Stress Analysis

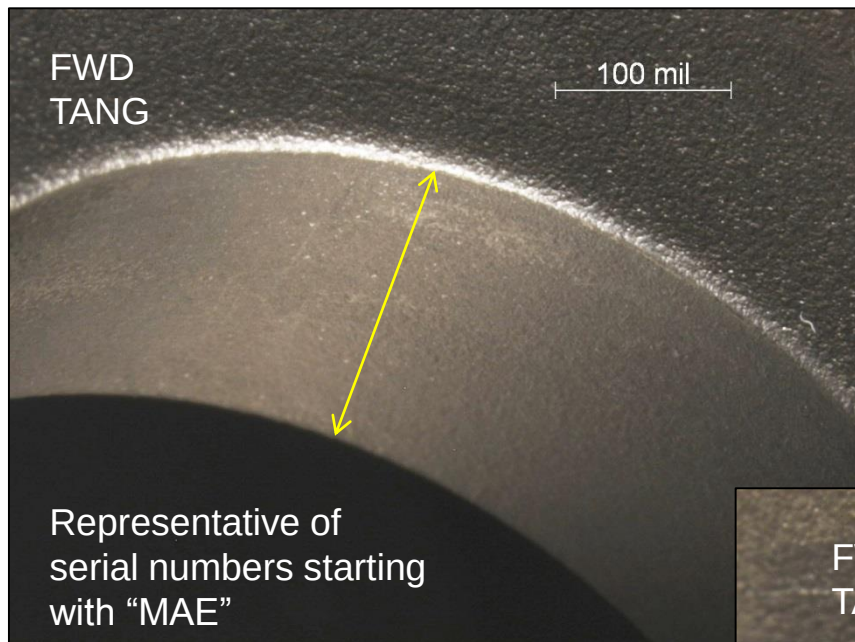


Representative of the additional four fan blade mid tangs

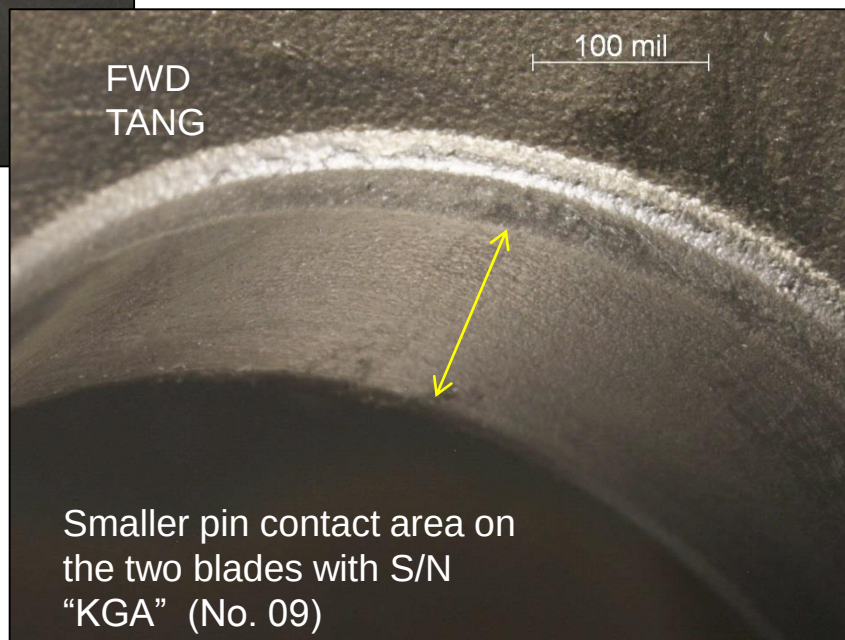
Residual stress analysis was performed on the pin holes from the event blade S/N KGACA251 and four additional fan blades at the area indicated on the mid tangs shown above. Results of the residual stress analysis showed a significant amount of the compressive residual stress from the original shot peening was lost during the creep hot form process and subsequently was not restored. See page 36.

HOOP RESIDUAL STRESS DISTRIBUTION





Visual examination of the blade set from ESN 873-642 revealed that one blade (No. 09) with a "KGA" serial number similar to the event blade S/N KGACA251 exhibited pin hole radii much larger than the remaining twenty-six (26) blades. Subsequent measurements revealed blade No. 09 had radii that exceeded the maximum allowed per the drawing. Measurements of the failed blade (No. 22) showed it also had radii exceeding the drawing limit. Subsequent analysis showed this condition had a minimal effect on stress and was not considered a major contributor.

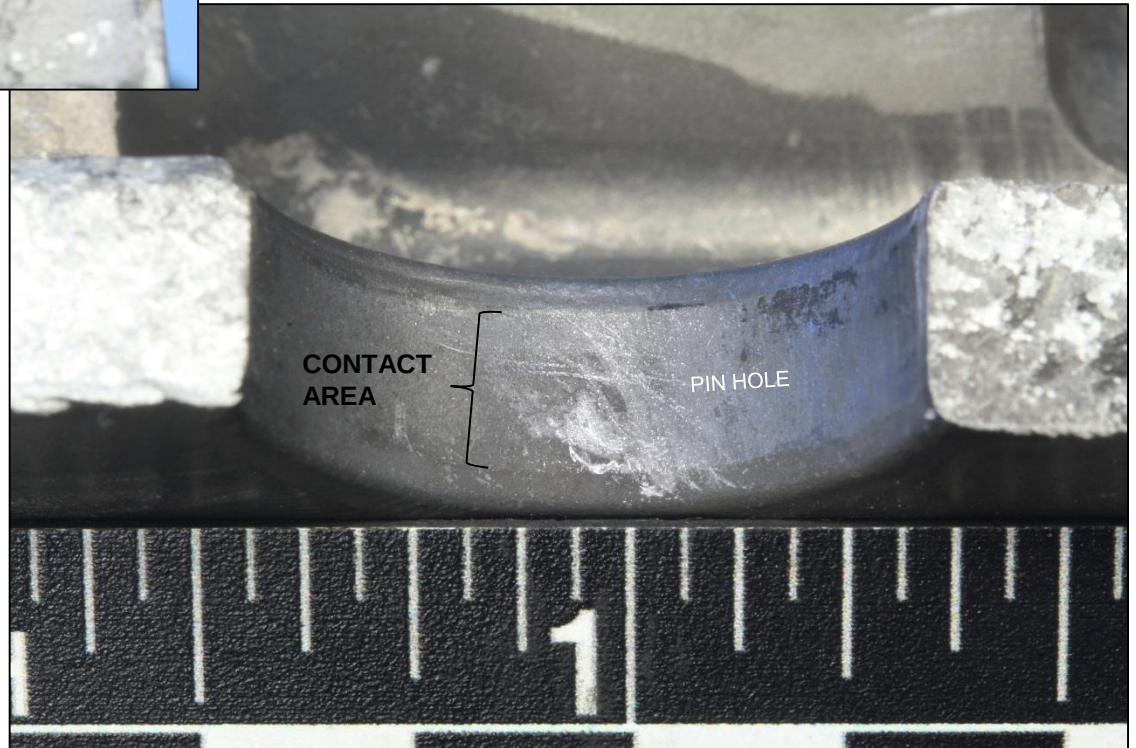


The following slides show representative photos illustrating the over-max radii condition observed on the "KGA" serial number fan blades.

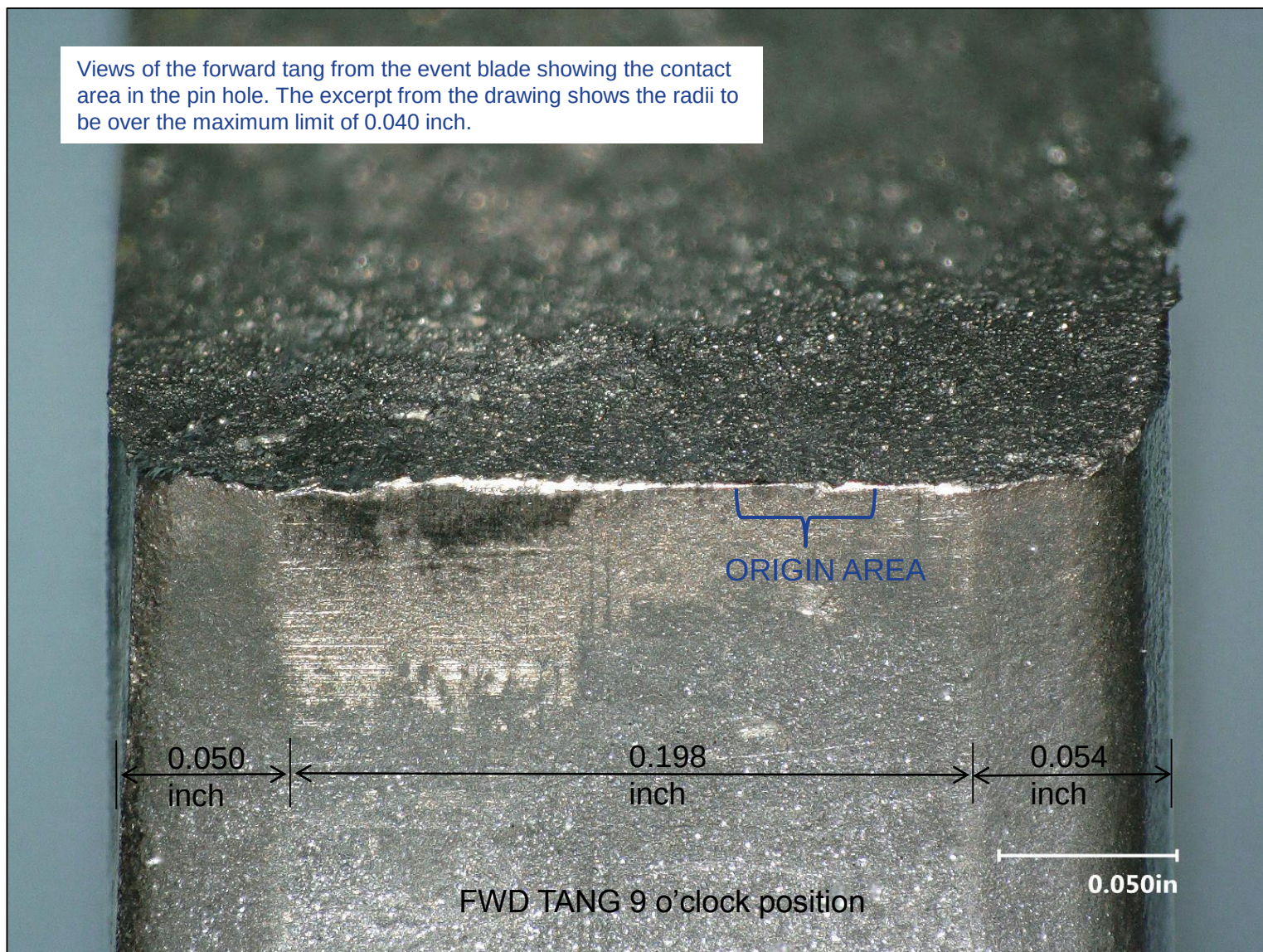


FWD TANG

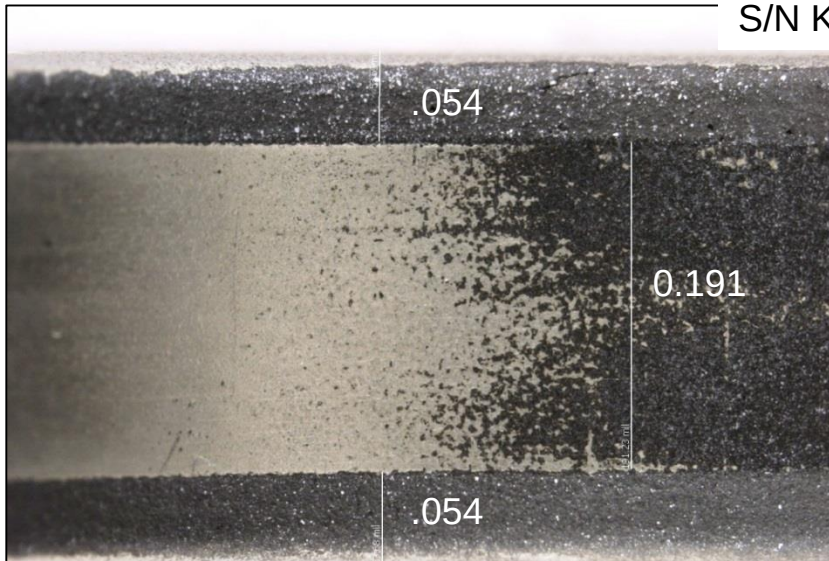
Views of the forward tang from the event blade showing the contact area in the pin hole.



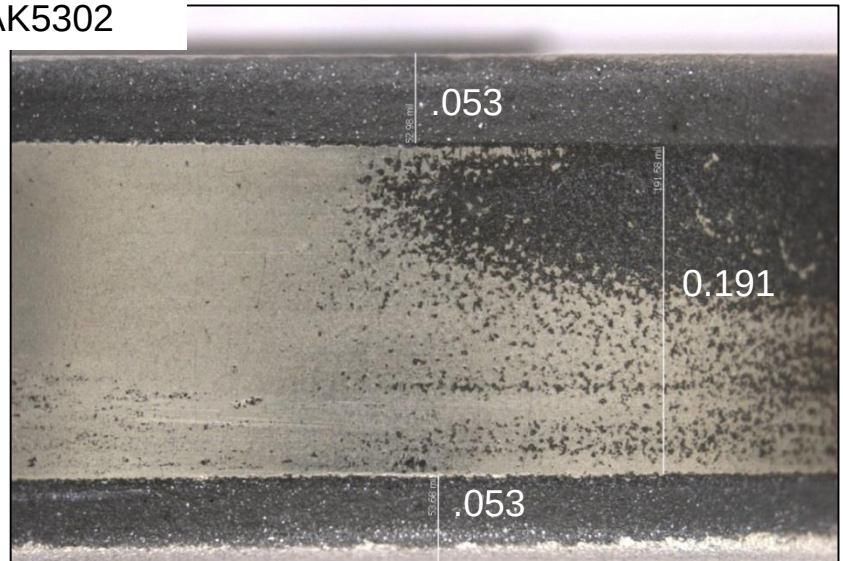
Views of the forward tang from the event blade showing the contact area in the pin hole. The excerpt from the drawing shows the radii to be over the maximum limit of 0.040 inch.



S/N KGAK5302

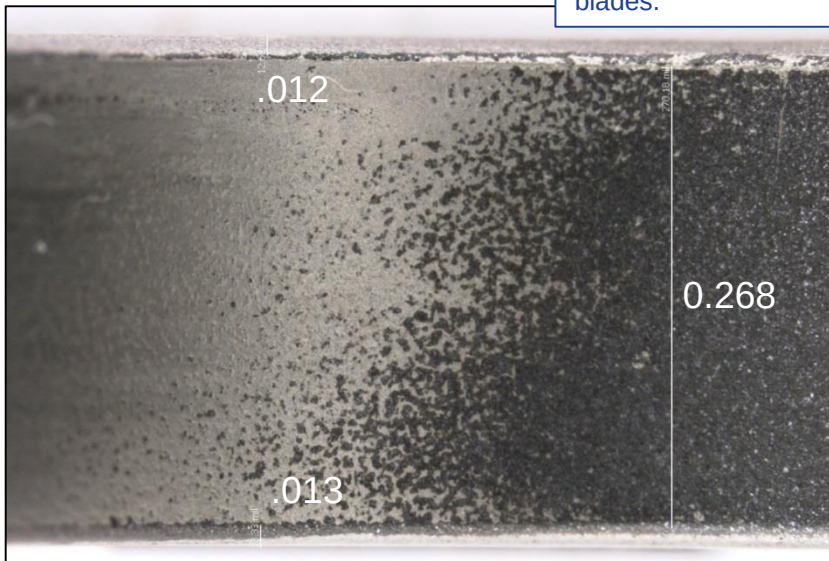


3 o'clock

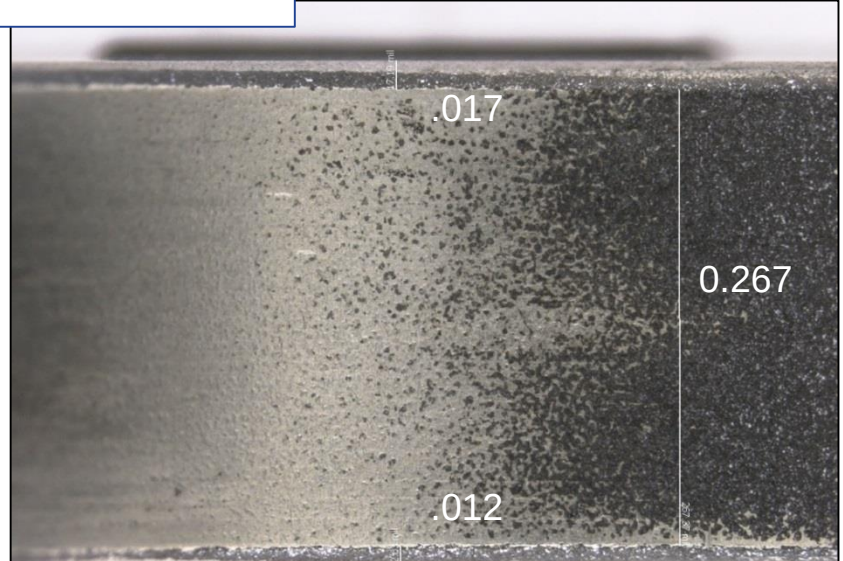


9 o'clock

Representative photos showing the contact area difference between the "MAE" and the "KGA" fan blades.



3 o'clock



9 o'clock

S/N MAE38251