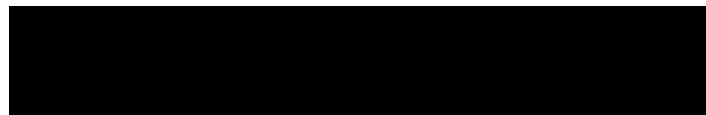




Materials Investigation Laboratory report



EXPORT CONTROL CLASSIFICATION

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Materials Investigation – Laboratory Report

P&WC #2470 (2024-01)

Investigation performed in accordance with MCL Manual Section AC-35

Part No.: 3120872-01	RFA No: [REDACTED]	Report No.: [REDACTED]
Part Name: BLADE-TURBINE	Date Received: 2024-03-20	Page 3 of 17
Serial No.: Various	Engine Model: PT6T-3	Eng. Serial No.: 60529
Service time: TSN: Ukn CSN Ukn TSO: Ukn CSO Ukn	Service time: TSN: Ukn CSN Ukn TSO: Ukn CSO: Ukn	
Material Specification: [REDACTED]	Installation: ---	
Heat Code: [REDACTED]	Operator: ROGERS ROBIN M	
Process Specification: [REDACTED]	Event Type: [REDACTED]	
Supplier: ---	Event Category: [REDACTED]	
Additional information: During the accident investigation it was found that the PT blades on the engine 60529 were broken. These parts were sent for investigation to determine the root cause.		
Investigation Required: [REDACTED]		
Requested by: [REDACTED]	Organization: [REDACTED]	

CONCLUSIONS

This addendum was raised to confirm mechanical damage on blade fractures as “secondary damage”. Changes are in bold.

- Visual examination of all 41 turbine blades (P/N 3120872-01) showed fractographic features consistent with overload fracture. Plastic deformation and **mechanical** damage (such as rubbing damage, scrapes, dents and tears) elsewhere on the blades was consistent with **secondary** damage sustained during blade fragmentation during rotational motion. Consequently, it is likely that fracture and release of the outermost fragment(s) of the blades led to a cascade of fracture and damage during the distress event. No evidence of cracking by any progressive mechanisms such as fatigue, thermal fatigue or creep were observed.
- SEM examination of the fracture surface of select blades chosen from various locations around the circumference of the disc did not show any evidence of excessive heating or metallurgical anomalies sufficiently large to have promoted fracture of these blades. While some fused magnesium-rich substance was observed on blade #37 (as well as possibly other blades in the set) and possible fused material was observed on the fracture surface of blade #12, these were considered secondary damage features sustained after fracture of the blades (i.e. as a result of the post-incident fire).
- Metallurgical cross sectioning of blades #1, #12, #23, #24, and #32 revealed that blades from heat codes [REDACTED] exhibited coarsening, rafting, solutioning and local reprecipitation of γ' phases (evidence of overheating leading to microstructural alteration) while blades from heat codes [REDACTED] did not. As heat codes [REDACTED] represented most of the two sets of three blades (positioned diametrically opposite to one another) and did not exhibit any microstructural evidence of overheating, it is likely that these six blades were replaced during an overhaul after the original blades were subjected to overheating cycle(s).
- Consequently, as evidence of overheating was observed on the entire cross section of the affected blades (including in the root) with no evidence of microvoids or microfissures (which would suggest creep damage) it is unlikely that this microstructure developed during service. It follows that the overheated microstructural condition (specifically reprecipitation/solutioning on the entire length of the blade) likely developed during manufacturing (or a subsequent heat treatment).
- Despite the evidence of overheating, the hardness of all blades subjected to microstructural examination was within the range [REDACTED] specified [REDACTED]. The chemical composition of select blades from the original set and one blade from heat code [REDACTED] as determined by semi-quantitative and standardless EDS showed relatively similar chemical composition and all evaluated blades exhibited alloying elements in ratio's consistent with those required [REDACTED].

A discussion follows on the next page:

Reported by: [REDACTED]	Reviewed by: [REDACTED]
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DISCUSSION

- Based on the metallographic examination of select blades associated with the original heat codes (), the blades from these heat codes installed on this engine are considered to exhibit advanced levels of overheating through the entire length (including in the root). In the event a microstructural examination was performed at a previous overhaul, the condition should have been rejected as per specification – Microstructural standard for turbine blades. Even if the root, usually used as reference, presents a similar microstructure as the rest of the airfoil, the fact that it presents solutioning is a cause for rejection.
- As two sets of three blades located diametrically opposite as assembled on the disc seem “new” and didn’t present any evidence of overheating, it is probable that the original blade set was subjected to a microstructural evaluation for thermal history. If it is available, a verification of this microstructural evaluation report may provide insights on the condition of these blades and reasoning for acceptance if it is the case.



Figure 1 General view of forty-one (41) turbine blades (P/N 3120872-01) viewed from the suction (top) and pressure (bottom) sides, as received for examination. The blades were numbered at disassembly. The blades mostly generally displayed markings associated with heat codes [REDACTED] and [REDACTED] excluding two sets of three blades located diametrically opposite as assembled on the disc (blades #41: [REDACTED], #1: [REDACTED], #2: [REDACTED], #21: [REDACTED], #22: [REDACTED], #23: [REDACTED]). All blades were fractured at various heights and exhibited mechanical damage consistent with impact damage (i.e. most likely domestic object damage or DOD). Limited evidence of necking was observed.



Figure 2 General view of typical blades (#12, #19, #31 and #37) from the set (shown from the pressure and suction sides). Blades #19 and #37 were fractured at approximately 0.595in and 0.630in above the platform respectively. The trailing edge of both these blades was distorted due to impact damage. In contrast, blades #12 and #31 were fractured further up the blade (i.e. approximately 1.769in and 1.302in above the platform respectively) and exhibited limited impact damage apart from small chips/dents on the trailing edges of the blades. All examined blades exhibited limited evidence of necking which suggests no contribution from creep damage lead to the distress.

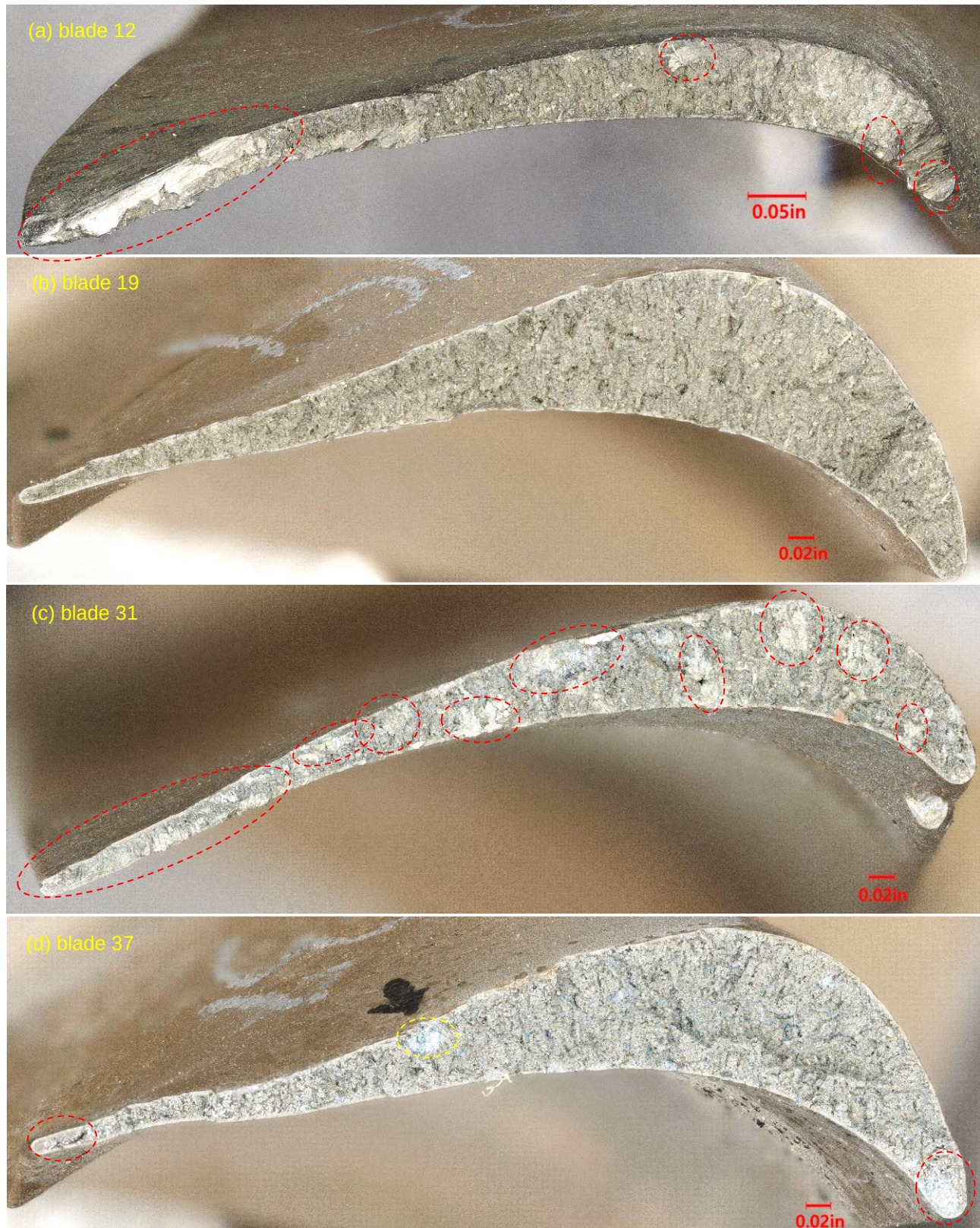


Figure 3 Stereoscopic microscopy showed that the fracture surface of all turbine blades generally exhibited comparable rough topography. Typical fracture surface appearance of blades #12, #19, #31 and #37 is shown above. One area exhibiting a lustrous surface appearance on blade #37 (circled in yellow) which was not consistent with smearing or rubbing damage (as observed on other blades in the regions outlined in red). Figure 4e shows the typical appearance (by SEM) of these regions.

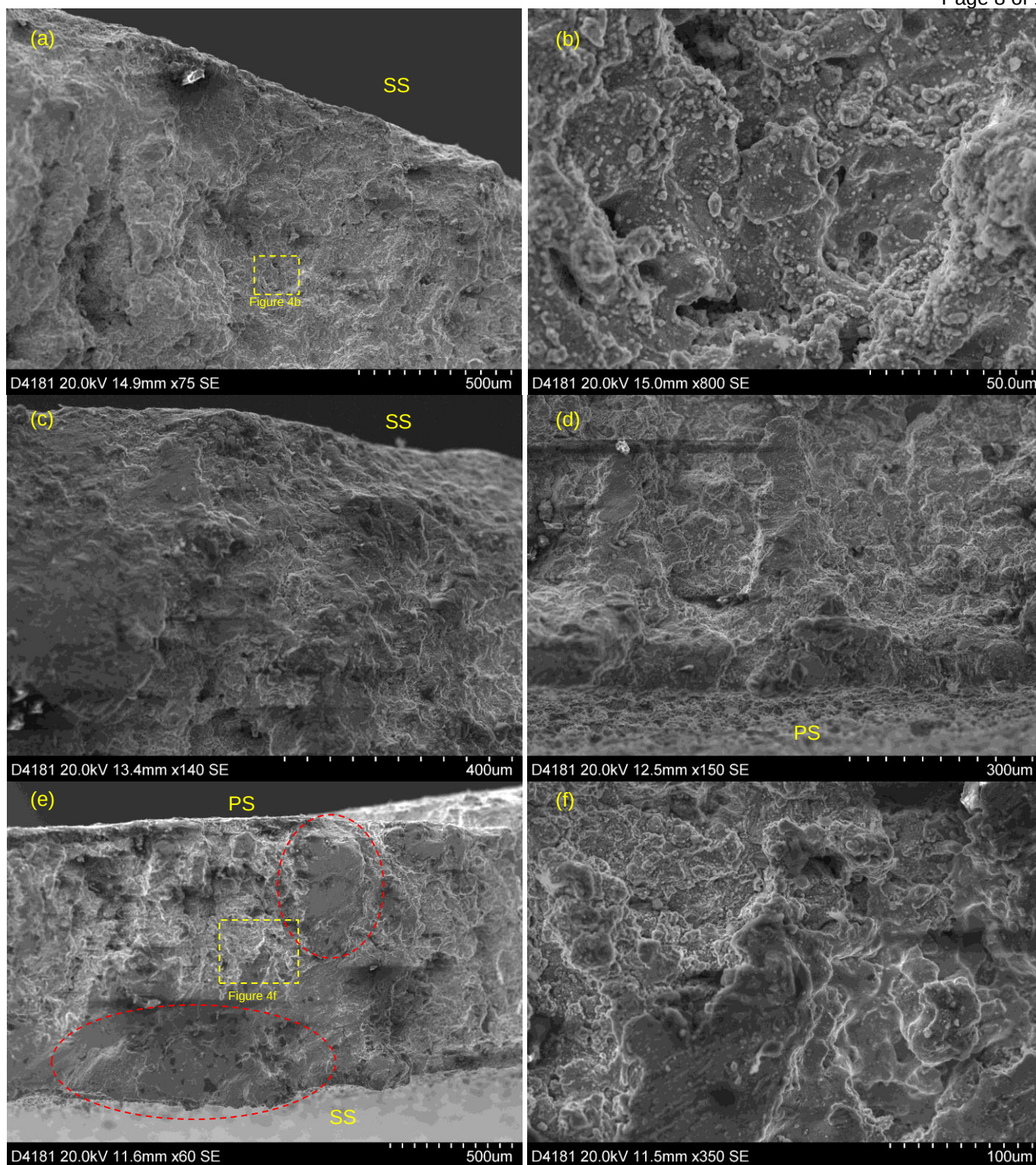


Figure 4 Appearance of typical fracture regions on blade #12. The fracture surface was generally covered with splattered material and dispersed areas of post-fracture mechanical damage such as smearing/rubbing. Despite the fused appearance and dispersed areas of post-fracture damage, the blade fracture exhibited features consistent with overload fracture. Smearing and rubbing damage features generally had a flattened appearance, like those circled in red in Figure 4e, **consistent with secondary rubbing damage**.

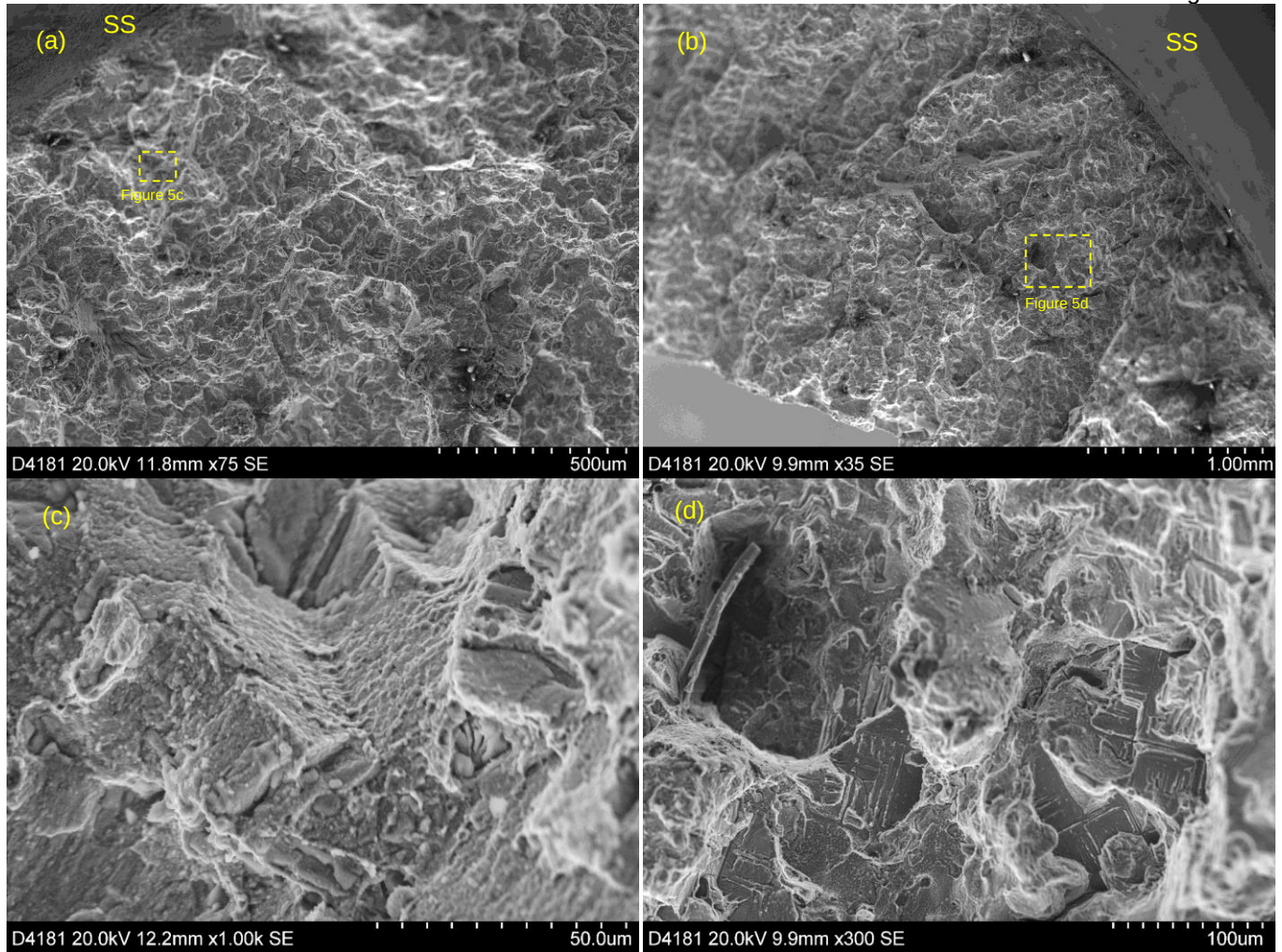


Figure 5 Blade #19, which fractured much closer to the platform than blade #12, did not exhibit a splattered appearance. In lieu of splattered material, the fracture generally exhibited a fine dimpled appearance with select areas exhibiting cleavage-like fracture from secondary phases (such as Chinese script carbides) as shown in Figure 5d. The fracture surface appearance was consistent with ductile overload.

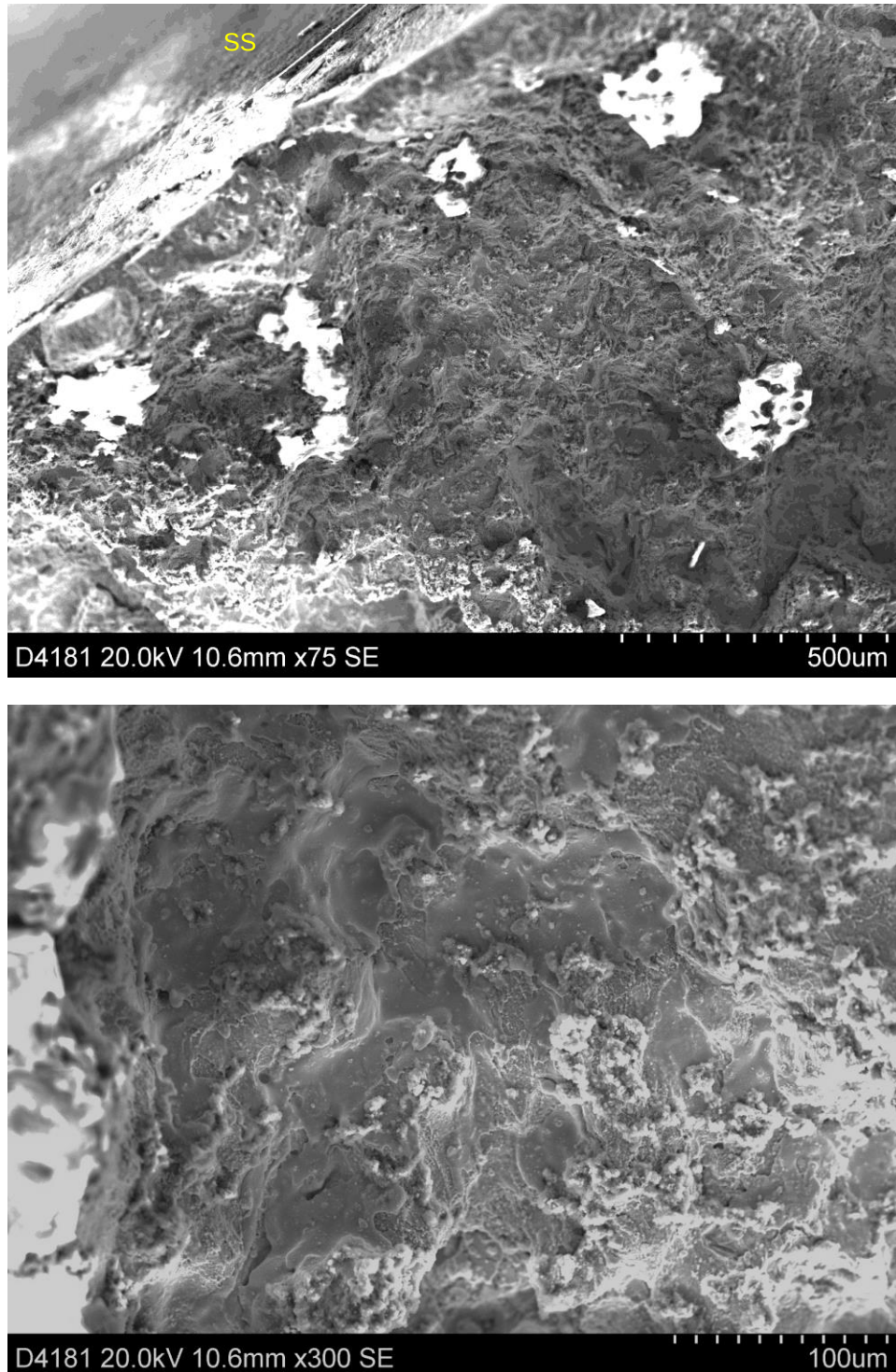
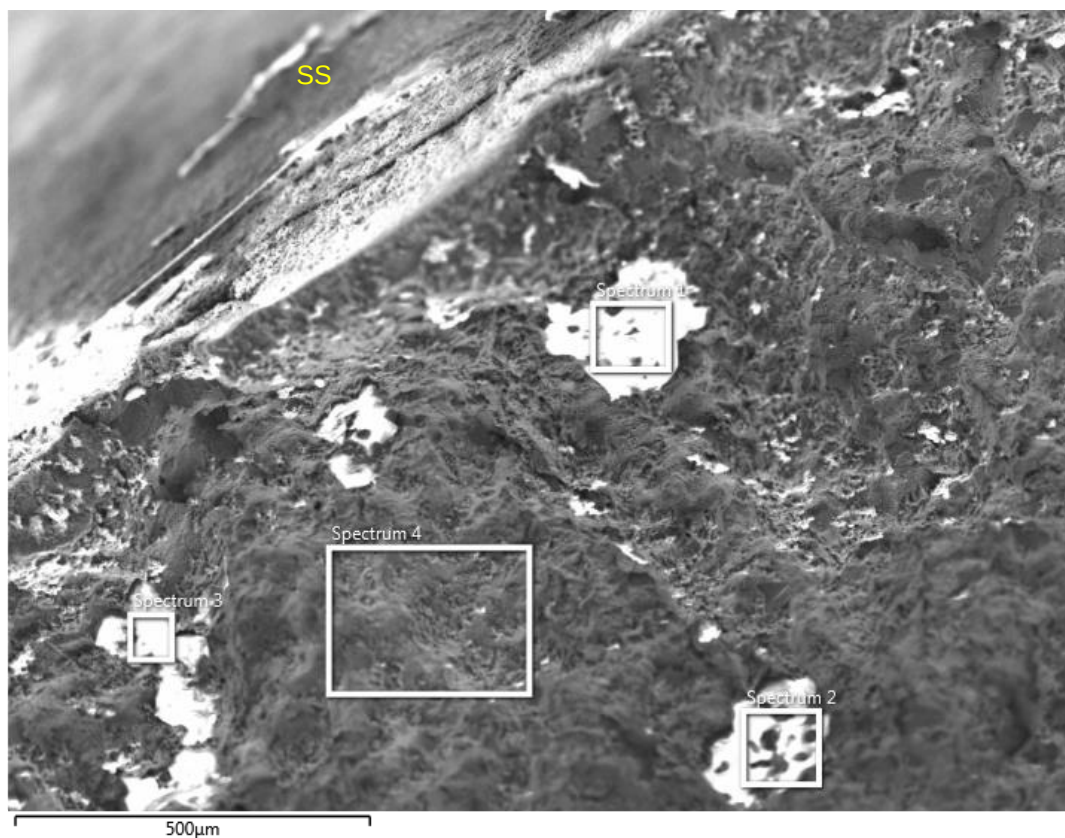


Figure 6 General view of the lustrous region on the fracture surface of blade #37. This region exhibited a melted appearance similar to that observed on blade #12. The splattered/fused material generally flowed over the fracture surface from the suction side towards the pressure side. The remaining fracture surface appearance exhibited a morphology similar to that shown in Figure 5: namely fracture features consistent with “ductile overload”.



Element	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
C [1]	20.26	21.23	21.94	22.99
O [1]	62.52	58.60	62.83	15.61
Mg	15.39	15.18	14.31	11.54
Al				0.80
Si				0.88
P				0.23
Ti	0.14	0.36		1.68
Cr	0.18	0.57	0.11	7.82
Fe				3.23
Co		0.70		
Ni	1.22	2.77	0.82	33.53
Zn	0.28	0.27		1.22
Mo		0.32		0.46

[1] Light elements cannot be adequately quantified by EDS and the results are only included for comparison purposes.

Figure 7 Semiquantitative and standardless EDS completed on the lustrous region of the fracture surface from blade 37 showed notably high levels of magnesium. This suggests the resolidified material likely deposited/splattered onto the fracture surface from another magnesium-rich part (most probably the casing) after fracture occurred.

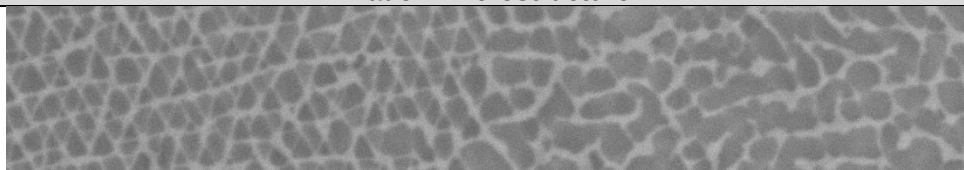
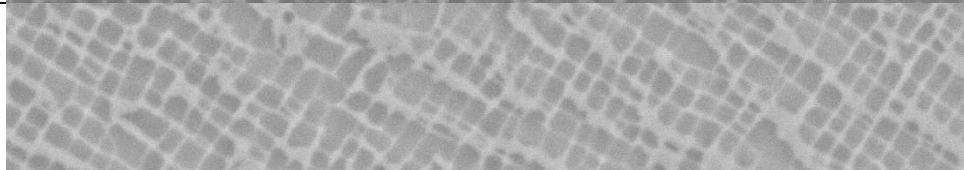
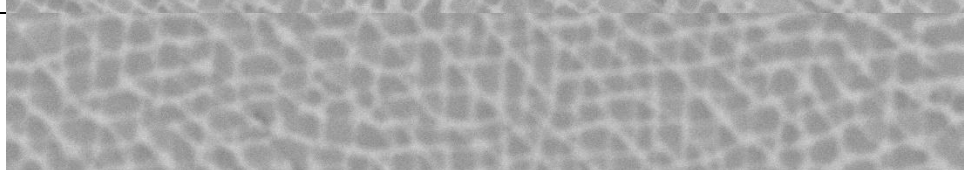
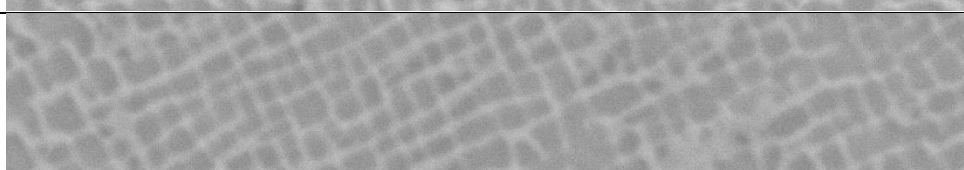
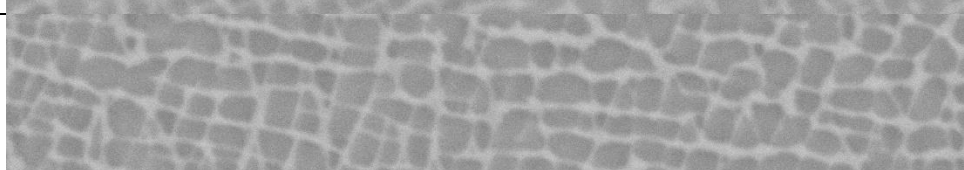
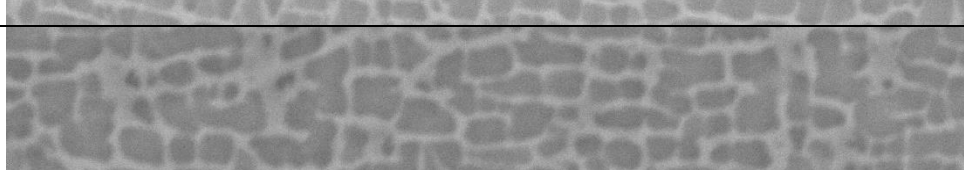
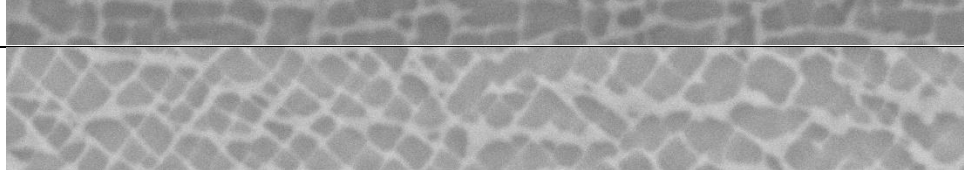
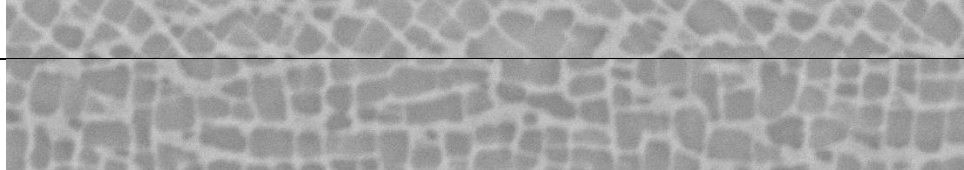
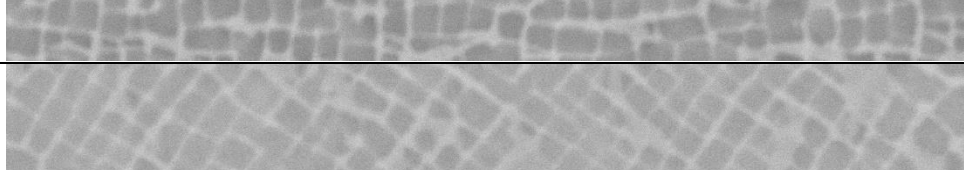
Location	Observations	Blade 1 microstructure
36 mm 1.42 in	Unaffected	
35 mm 1.38 in	Unaffected	
30 mm 1.18 in	Unaffected	
25 mm 0.98 in	Unaffected	
20 mm 0.79 in	Unaffected	
15 mm 0.59 in	Unaffected	
10 mm 0.39 in	Unaffected	
5 mm 0.20 in	Unaffected	
0 mm Platform	Unaffected	
D4181 20.0kV 12.1mm x4.00k BSECOMP 50Pa 10.0um		

Figure 8 Microstructure evaluation of blade 1 (HC [REDACTED]) at 0.125" from the trailing edge. The evaluation was completed up to 36mm (1.42 in) from the platform due to the fractured condition. The microstructure of the blade was relatively unchanged from platform to the fracture indicating no evidence of overheating nor rafting. Etchant: [REDACTED].

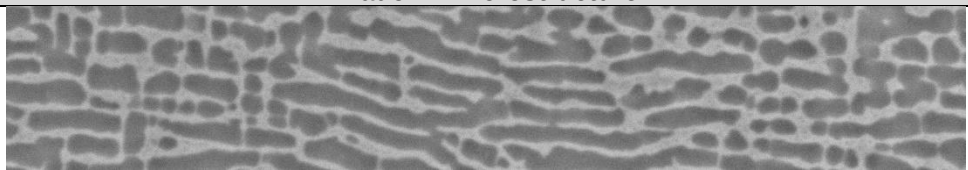
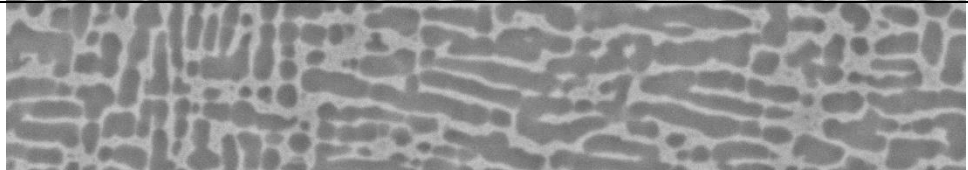
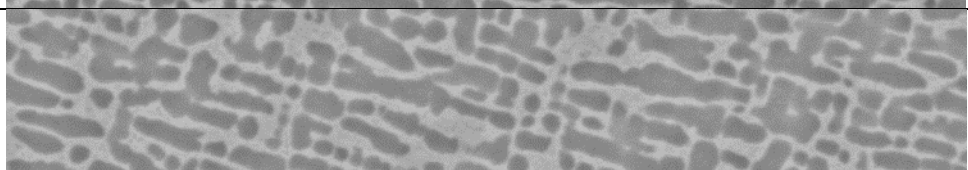
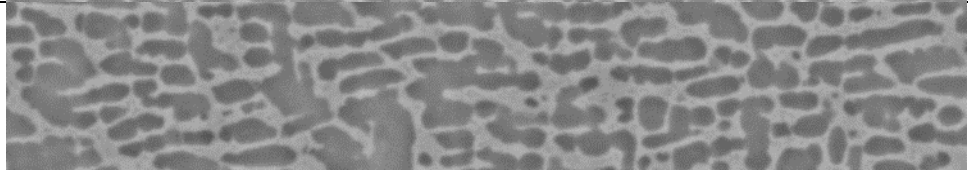
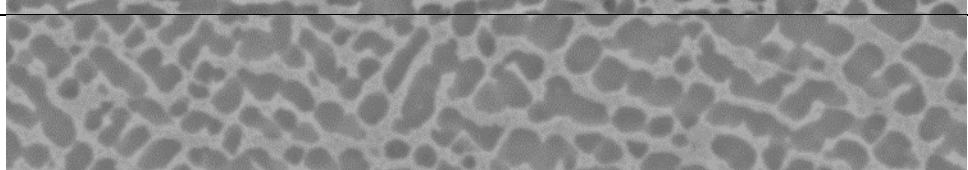
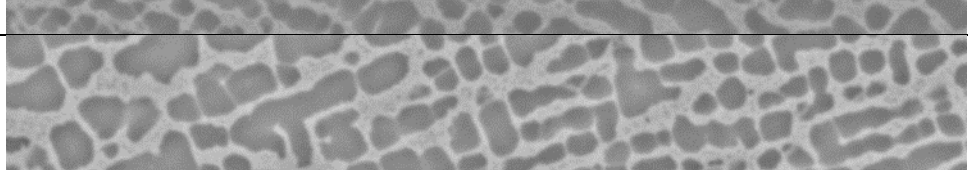
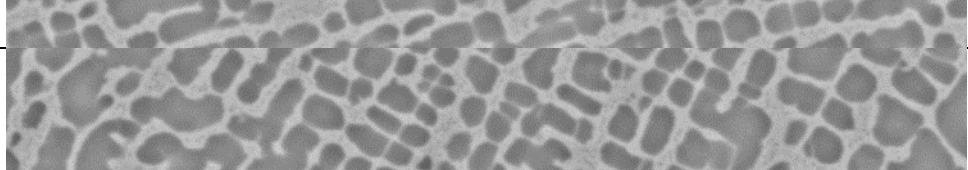
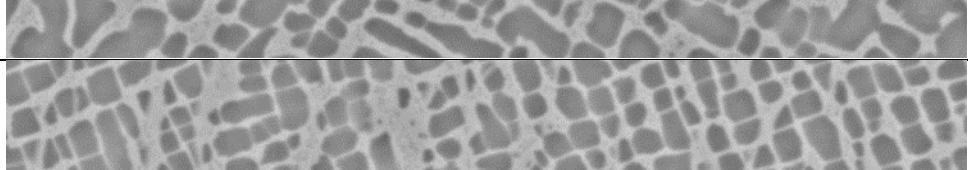
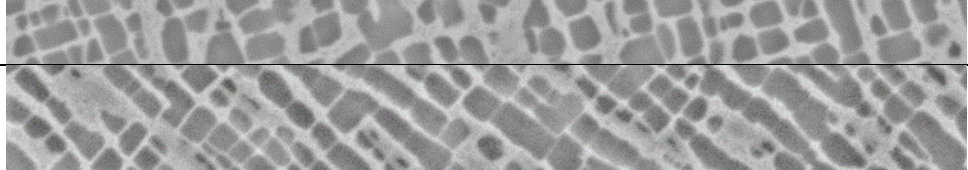
Location	Observations	Blade 12 microstructure
48 mm 1.89 in	Rafting + Solutioning	
45 mm 1.77 in	Rafting + Solutioning	
40 mm 1.57 in	Rafting + Solutioning	
30 mm 1.18 in	Rafting + Solutioning	
20 mm 0.79 in	Coarsening + Solutioning	
10 mm 0.39 in	Coarsening + Solutioning	
5 mm 0.20 in	Coarsening + Solutioning	
0 mm Platform	Solutioning	
Root	Solutioning	
		D4181 20.0kV 9.2mm x4.00k BSECOMP 50Pa 10.0um

Figure 9 Microstructure evaluation of blade 12 (HC [REDACTED]) at 0.125" from the trailing edge. The evaluation was completed up to 48mm (1.89 in) from the platform due to the fractured condition. The microstructure of the blade (including in the root) exhibited solutioning as well a reprecipitation which would be consistent with overheating. Etchant: [REDACTED].

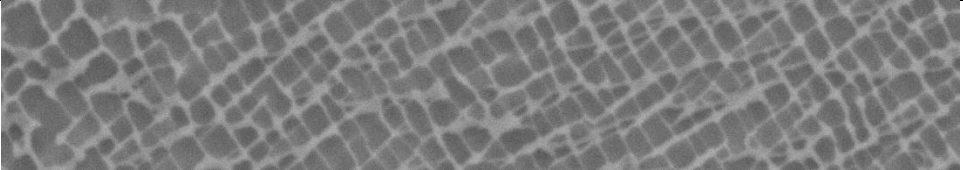
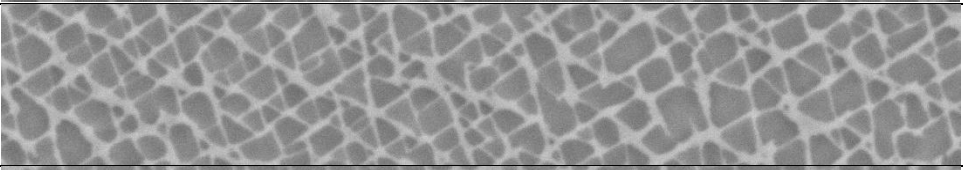
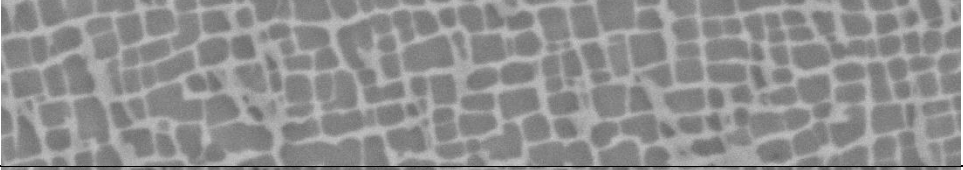
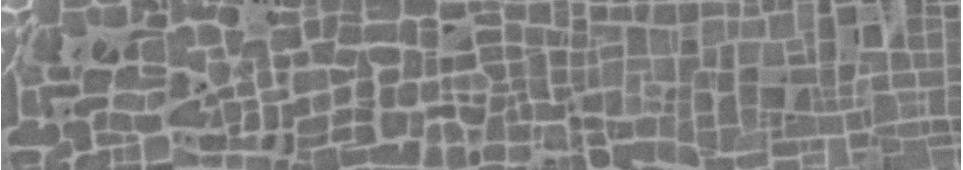
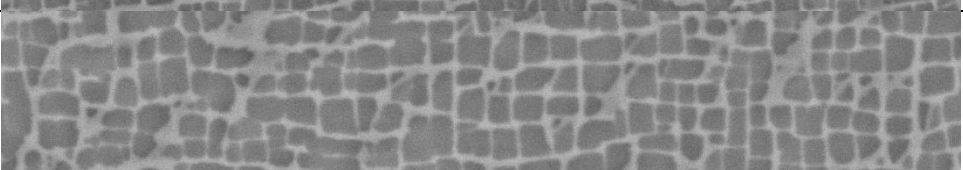
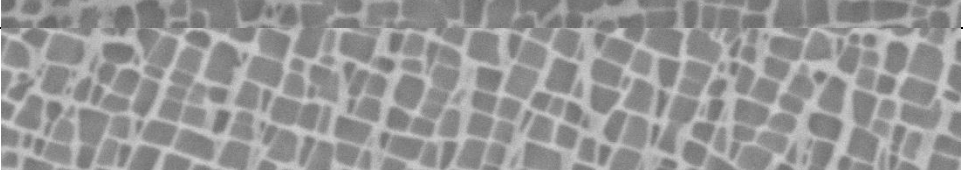
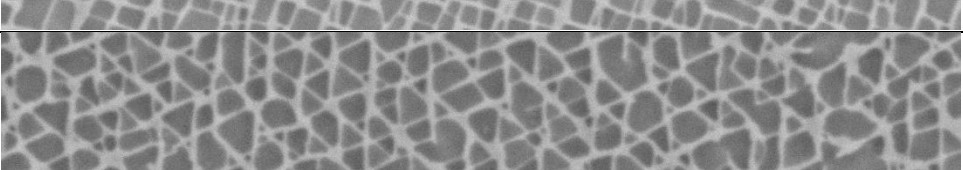
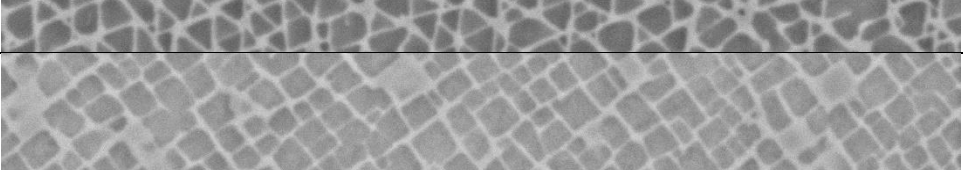
Location	Observations	Blade 23 microstructure
36 mm 1.42 in	Unaffected	
30 mm 1.18 in	Unaffected	
25 mm 0.98 in	Unaffected	
20 mm 0.79 in	Unaffected	
15 mm 0.59 in	Unaffected	
10 mm 0.39 in	Unaffected	
5 mm 0.20 in	Unaffected	
0 mm Platform	Unaffected	

Figure 10 Microstructure evaluation of blade 23 (HC [REDACTED]) at 0.125" from the trailing edge. The evaluation was completed up to 36mm (1.42 in) from the platform due to the fractured condition. The microstructure of the blade was relatively unchanged from platform to the fracture indicating no evidence of overheating nor rafting. Etchant: [REDACTED].

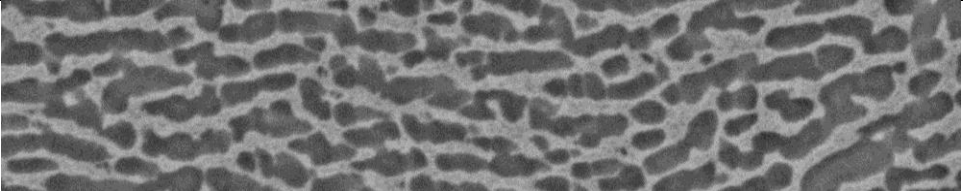
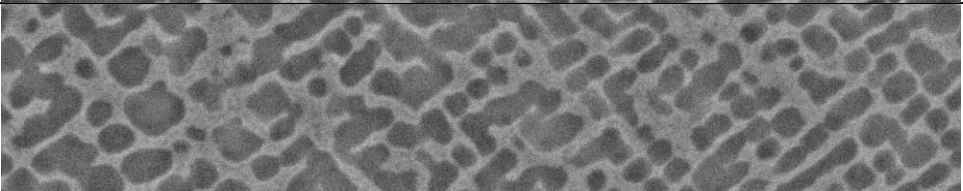
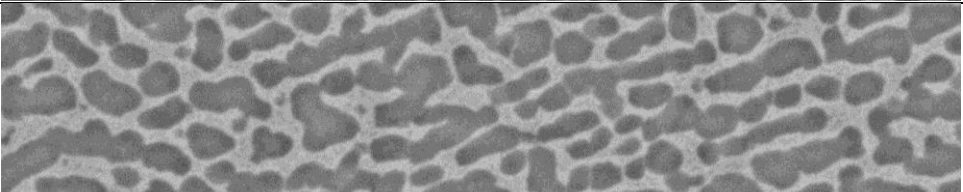
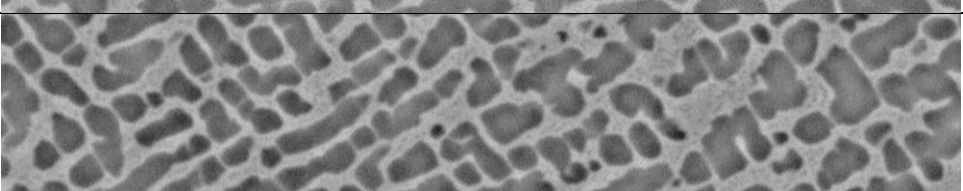
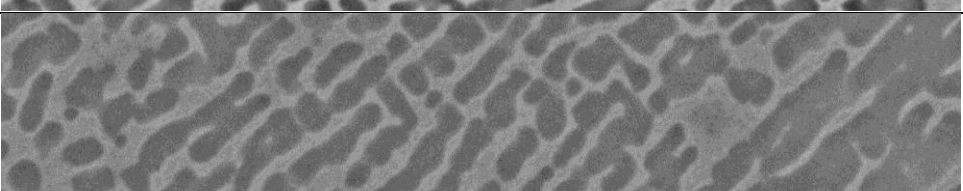
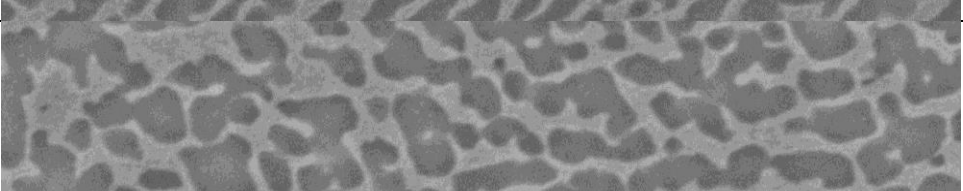
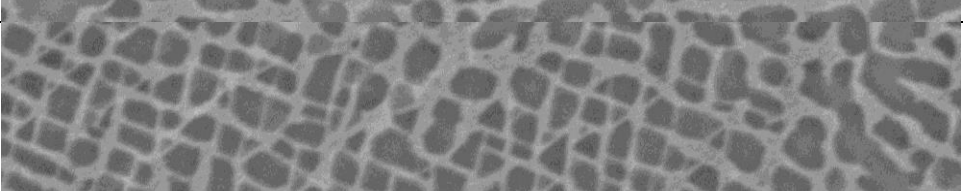
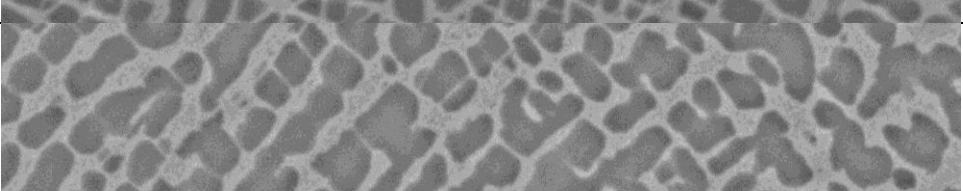
Location	Observations	Blade 24 microstructure
40 mm 1.57 in	Rafting + Solutioning	
30 mm 1.18 in	Rafting + Solutioning	
20 mm 0.79 in	Rafting+ Solutioning	
15 mm 0.59 in	Rafting + Solutioning	
10 mm 0.39 in	Rafting + Solutioning	
5 mm 0.20 in	Coarsening+ Solutioning	
0 mm Platform	Coarsening + Solutioning	
Root	Coarsening + Solutioning	
		D4181 20.0kV 12.1mm x4.00k BSECOMP 50Pa 10.0um

Figure 11 Microstructure evaluation of blade 24 (HC [REDACTED]) at 0.125" from the trailing edge. The evaluation was completed up to 40mm (1.57 in) from the platform due to the fractured condition. The microstructure of the blade (including in the Root) exhibited solutioning as well a reprecipitation which would be consistent with overheating. Etchant: [REDACTED].

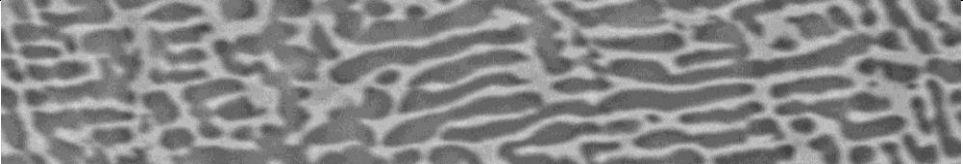
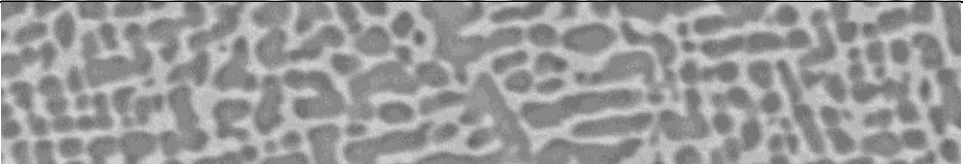
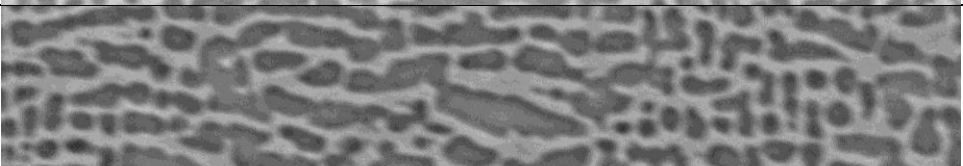
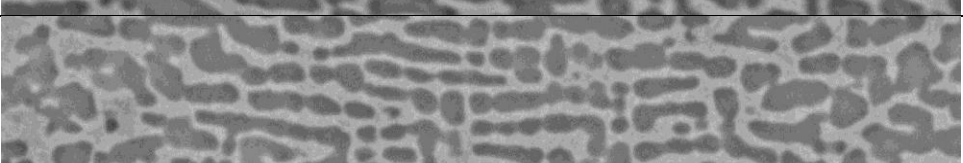
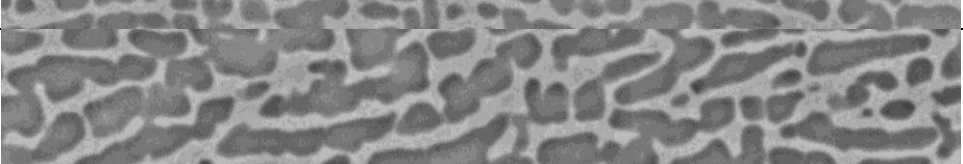
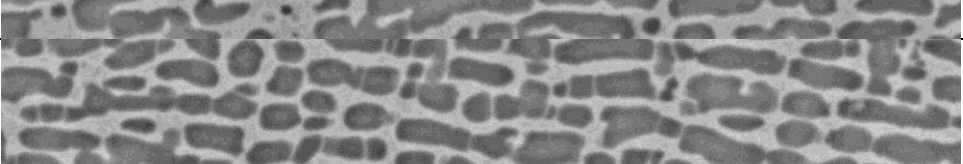
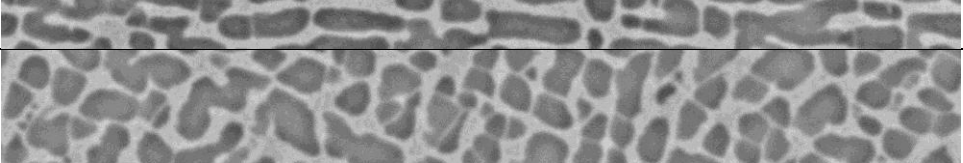
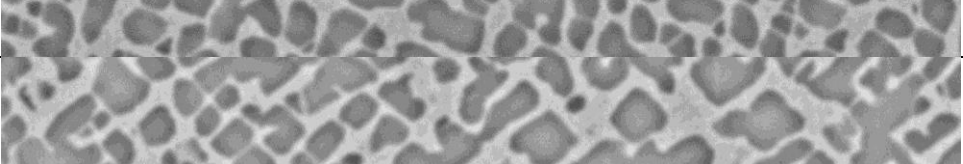
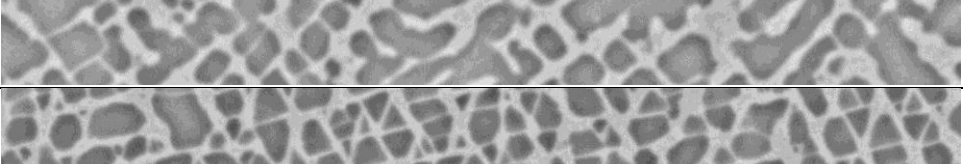
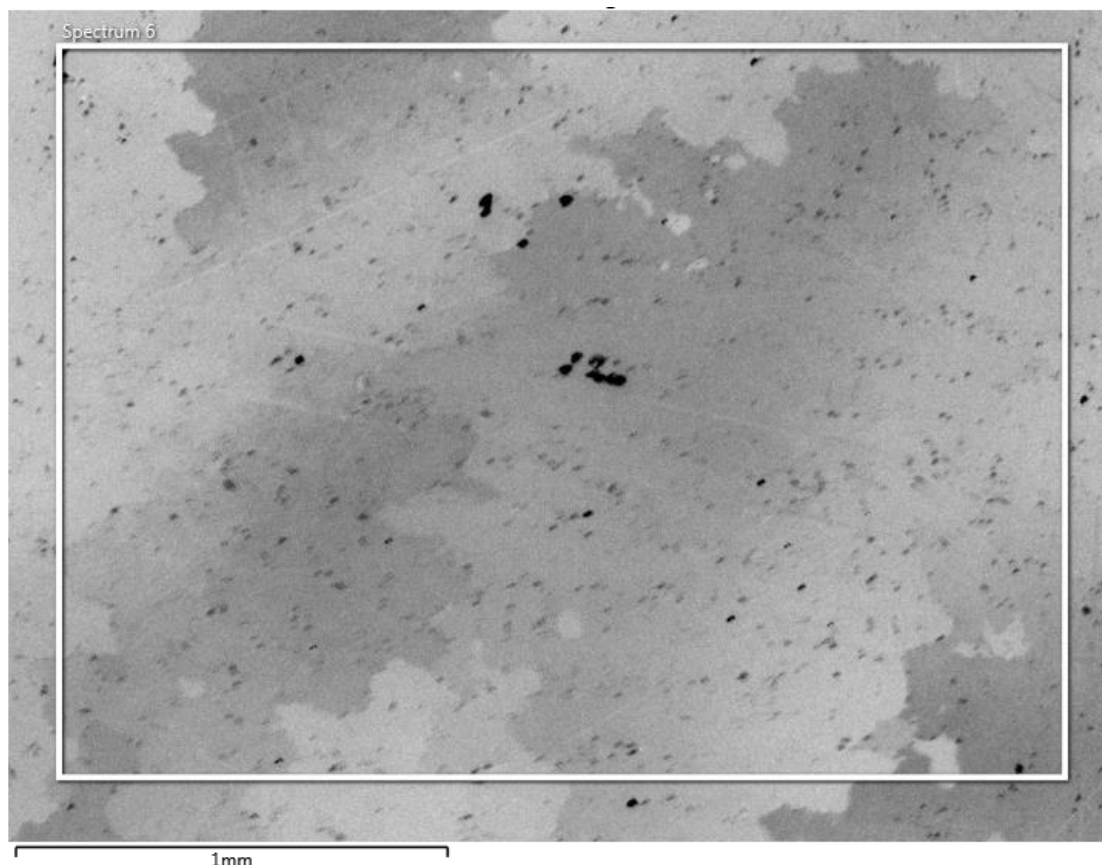
Location	Observations	Blade 32 microstructure
46.5 mm 1.83 in	Rafting + Solutioning	
45 mm 1.77 in	Rafting + Solutioning	
40 mm 1.57 in	Rafting + Solutioning	
30 mm 1.18 in	Rafting + Solutioning	
20 mm 0.79 in	Rafting+ Solutioning	
15 mm 0.59 in	Rafting + Solutioning	
5 mm 0.20 in	Coarseming + Solutioning	
0 mm Platform	Coarsening + Solutioning	
Root	Solutioning	
		D4181 20.0kV 11.0mm x4.00k BSECOMP 50Pa 10.0um

Figure 12 Microstructure evaluation of blade 32 (HC [REDACTED]) at 0.125" from the trailing edge. The evaluation was completed up to 46.5mm (1.83 in) from the platform due to the fractured condition. The microstructure of the blade (including in the Root) exhibited solutioning as well a reprecipitation which would be consistent with overheating. Etchant: [REDACTED].



Element	Spectrum 7 Blade #1	Spectrum 8 Blade #24	Spectrum 6 Blade #32	
C ^[1]				
Al				
Si				
Ti				
V				
Cr				
Co				
Ni				
Mo				

[1] Light elements cannot be adequately quantified by EDS and the measurements were deconvoluted from the analysis results.

[2] also specifies requirements for which were not detected in quantifiable levels by semiquantitative and standardless EDS.

Figure 13 Semiquantitative and standardless EDS was completed on the metallographic sections through blades #1, #24 and #32. The major alloying elements of the blade material were present in ratio's essentially consistent with the requirements of and no significant difference was noted between the blades from heat code and heat code .

Hardness testing of blades #1, #24 and #32 was completed on the same metallographic sections using the Vickers microhardness testing method. The average hardness of the blades measured , and respectively which converts to , and per ASTM E140. All individual and average hardness values met the requirements specified in .