

ERA22FA086

POWERPLANTS

Group Chair's Factual Report - Attachment # 3

Honeywell Materials Laboratory Report, Engine Serial Number, P54128

June 27, 2023

**Pages 1-27 of
ERS-ASYS-PENG-MA-0000856-A are
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BACKGROUND

Engine S/N P54128 was the subject of an NTSB investigation of Aircraft N54GP that was involved in an accident near Bedford, New Hampshire.

PROBLEM STATEMENT

Conduct investigation of the separated turbine blade, Blade 1, from the 1st stage rotor assembly P/N 3107080-1, S/N 3-03501-1120.

Conduct temperature analysis of the submitted 2nd stage turbine rotor blades (P/N 3102106-10) for comparison purposes.

SUMMARY/CONCLUSIONS

- Blade 1 exhibited a separation through the airfoil at approximately 0.38” from the platform as measured from the leading edge. The fracture surface was oxidized and had a rough appearance suggestive of a stress rupture type mechanism.
- A cross section through Blade 1 revealed oxidation and alloy depletion along the fracture surface.
- The microstructural features of Blade 1 near the fracture surface suggested exposure to metal temperatures near 1700°F over a period of time between 10 and 100 hours.
- Energy dispersive X-ray (EDX) analysis of the Blade 1 fracture surface revealed an oxidized nickel alloy similar to the specified IN100 base material.
- Analysis of the Blade 1 coating composition was indicative of a diffused aluminum and silicon coating.
- The IN100 blade base material and the aluminum/silicon coating would indicate that the Blade 1 part number was likely 3101512-10.
- Erosion damage was observed on the leading edges of the 36 submitted 1st stage turbine blades.

PART NAME:	1 st Stage Turbine Blade
PART NUMBER:	3101512-10
PART S/N:	Not Reported

MODEL/PROGRAM:	TPE331-10UA-511G
MODEL/PROGRAM S/N:	P54128
OPERATING TIME:	9414 hours
OPERATING CYCLES:	8625 cycles

MATERIAL:	IN100
MATERIAL SPEC:	EMS55089/EMS52330

SUPPLIER:	Not Reported
SUPPLIER P/N:	Not Reported

- Microexamination of representative blades from the submitted 2nd stage turbine rotor revealed microstructural features suggestive of exposures to metal temperatures near 2200°F over a period of time between 10 and 100 hours.
- See Findings.

Findings

TPE331-10UA-511G engine S/N P54128 was the subject of an NTSB investigation of Aircraft N54GP that was involved in an accident near Bedford, New Hampshire.

The blades from the 1st stage rotor assembly (P/N 3107080-1, S/N 3-03501-1120) were submitted after one of the blades had separated through the airfoil (Figure 1). The blades were identified 1-36, clockwise, aft looking forward. The logbook stated that the 1st stage rotor assembly had 9414 hours and 8625 cycles as of 11/30/2021.

The 2nd stage turbine rotor (P/N 3102160-10, S/N 020134508540) was submitted for comparison purposes. The logbook stated that the 2nd stage turbine rotor had 7861.5 hours and 7773 cycles.

The coupling shaft (P/N 894119-1, Lot Number 4557) was submitted to determine the fracture mode of the separated aft end of the shaft and is reported in ERS-ASYS-PENG-MA-0000924.

1st Stage Blades

MACROEXAMINATION

Blade 1 exhibited a separation through the airfoil at approximately 0.38" from the platform as measured from the leading edge. The fracture surface was oxidized and had a rough appearance (Figures 2-3). The markings on the Blade 1 platform appeared to be "1512-1 23151-241." No distinct part number markings were observed on the blade.

Erosion damage was observed on the leading edge of each of the submitted blades. The erosion on Blades 30, 35, and 36 appeared to have penetrated through the leading edge cooling hole. Blades 29, 30, 31, 34, 35, and 36 exhibited separations at the trailing edges. Dents were observed on the suction side of Blades 13, 21, and 34. Figure 4 shows representative blades exhibiting leading edge erosion and a trailing edge separation.

SCANNING ELECTRON MICROSCOPE (SEM) EXAMINATION

SEM examination was performed on the Blade 1 airfoil separation. The fracture surface was oxidized and had a rough appearance suggestive of a stress rupture-type of separation (Figure 5). No signs of cyclic fatigue propagation or material defects were observed on the fracture surface.

SEM examination was performed on the Blade 35 trailing edge separation. The fracture features were oxidized and rough in appearance suggestive of a high temperature overload or stress rupture-type mechanism (Figure 6). No signs of cyclic fatigue propagation or material defects were observed on the fracture surface.

MICROEXAMINATION

A cross section was prepared through the mid-chord region of the Blade 1 fracture surface (Figures 7-8). Oxidation and alloy depletion were observed along the fracture surface. It was noted that the oxidation/alloy depletion observed on the fracture surface was more predominant on the pressure side wall than the suction side wall of Blade 1 (Figures 7B and 8A). Cracks and voids were observed along the grain boundaries adjacent to the fracture surface. Several coating cracks were observed in the pressure and suction sides of the

blade and in the cooling passage. Evidence of sigma phase along the coating/blade interface was observed. In comparison to heat treat standards for coated IN100 at 1, 10, 100, and 1000 hours of exposure, the microstructural features of Blade 1 suggested exposure to metal temperatures near 1700°F over a period of time between 10 and 100 hours.

Cross sections were prepared through Blade 5 (not shown) and Blade 16 (Figures 9-10) at the leading edge, mid-chord region, and trailing edge for comparison purposes. Grain boundary coarsening was observed in multiple locations. The cross section prepared through the Blade 16 leading edge exhibited a region with interconnected cracks and voids along the grain boundaries in the suction side of the blade (Figure 9C). Multiple coating cracks were observed predominantly on the leading edge cross sections prepared through the blades. Evidence of sigma phase along the coating/blade interface was observed in Blades 5 and 16. The microstructure features of Blades 5 and 16 suggested exposures to metal temperatures near 1900°F over a period of time between 10 and 100 hours.

Evaluation of the Blade 1 microstructure near the firtree was indicative of a temperature exposure below 1600°F (Figure 11).

The presence of sigma phase along the coating/blade interface, the grain boundary voids and cracks, and the coating cracks in Blade 1 were indicative of a stress-rupture fracture mechanism.

CHEMISTRY

Scanning electron microscope and energy dispersive X-ray (EDX) analyses were performed on the Blade 1 cross section to determine the coating composition (Figures 12-13). The coating was evaluated near the blade platform, away from the separation. Elemental dot maps and EDX spectra showed concentrations of aluminum and silicon in the coating suggestive of a diffused aluminum/silicon coating.

The base material of Blade 1 was indicative of the specified IN100 material, as determined by EDX analysis (Figure 14).

The IN100 blade base material and the aluminum/silicon coating would indicate that the Blade 1 part number was likely 3101512-10.

2nd Stage Turbine Rotor

MACROEXAMINATION

The 2nd stage turbine rotor was submitted for comparison purposes (Figures 15-16). Damage was observed on the leading edges of the blades the tips. No blade separations were observed on the 2nd stage blades. For the purposes of this report, the blades were numbered 1-38 in the clockwise direction, aft looking forward, with Blade 1 aligned with the high curvic.

MICROEXAMINATION

Blades 1 and 19 were removed from the turbine rotor for microstructural evaluation (Figure 17). Cross sections were prepared through Blade 1 (Figures 18-19) and Blade 19 (Figure 20) at the leading edge, mid-chord region, and trailing edge for comparison purposes. Oxidation and alloy depletion were observed

at the blade tips, pressure, and suction sides of the blades. Resolution of the gamma prime phase was observed in the cross sections analyzed. In comparison to heat treat standards for uncoated Mar-M247 at 1, 10, 100, and 1000 hours of exposure, the microstructural features of Blades 1 and 19 suggested exposures to metal temperatures near 2200°F over a period of time between 10 and 100 hours.

Evaluation of the Blade 19 microstructure near the platform was indicative of a temperature exposure near 2000°F over a period of time between 10 and 100 hours (Figure 21).

CHEMISTRY

EDX analysis of the base material of the 2nd stage turbine rotor blades revealed a nickel alloy similar to the specified Mar-M247 base material (Figure 22).

Blade Thermal Profiles

Diagrams showing the thermal models for the 1st stage blade and 2nd stage rotor at steady state conditions are shown in Figure 23. The 1st stage blade exhibited ~200°F difference in the measured airfoil temperatures compared to the thermal model. The 2nd stage blade exhibited ~600°F difference in the measured airfoil temperatures compared to the thermal model.

**Figure 1.**

Images showing the (A) pressure and (B) suction sides of the 1st stage turbine blades from TPE331-10UA-511G engine S/N P54128, in the as-received condition. The blades were numbered 1-36, as indicated. Blade 1 exhibited a separation through the airfoil (red arrows). Separations at the tip near the trailing edge were observed on multiple blades (pink arrows in (A)). Dents were observed on the suction sides of multiple blades (yellow arrows in (B)). Close-up images of Blade 1 are shown in Figures 2-3. Close-up images of Blades 16 and 35 are shown in Figure 4.

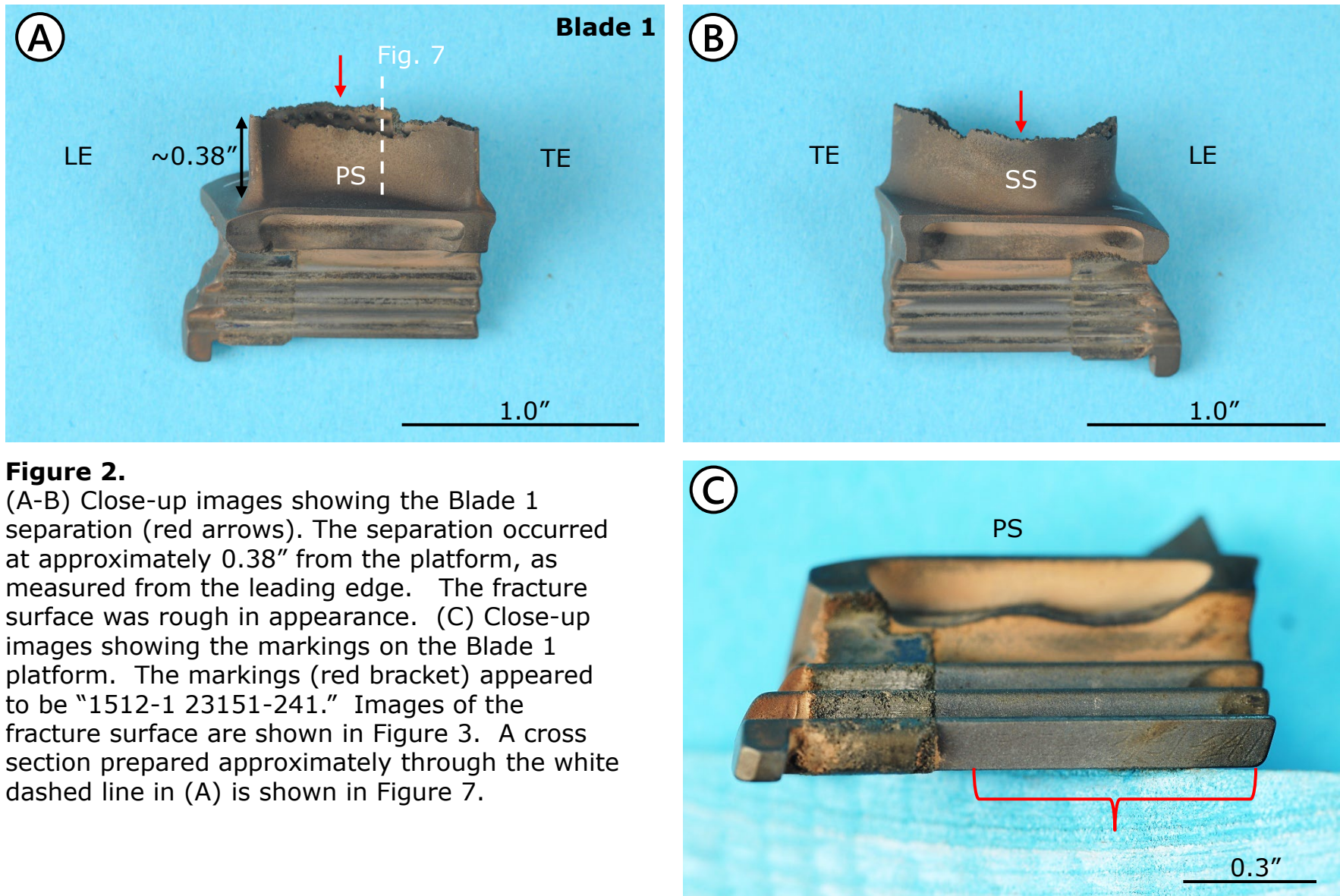


Figure 2.

(A-B) Close-up images showing the Blade 1 separation (red arrows). The separation occurred at approximately 0.38" from the platform, as measured from the leading edge. The fracture surface was rough in appearance. (C) Close-up images showing the markings on the Blade 1 platform. The markings (red bracket) appeared to be "1512-1 23151-241." Images of the fracture surface are shown in Figure 3. A cross section prepared approximately through the white dashed line in (A) is shown in Figure 7.

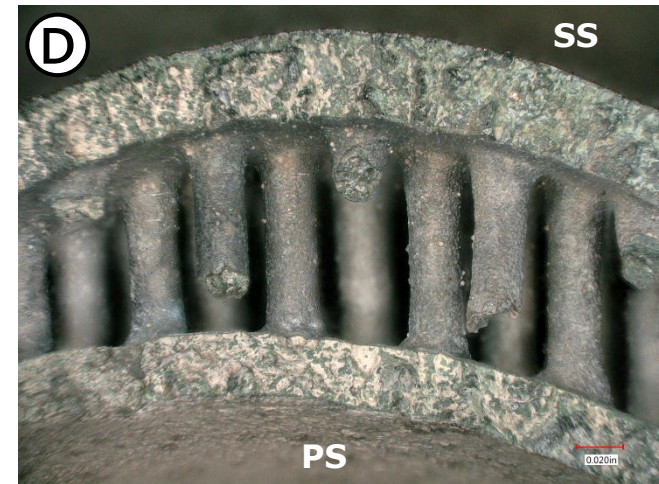
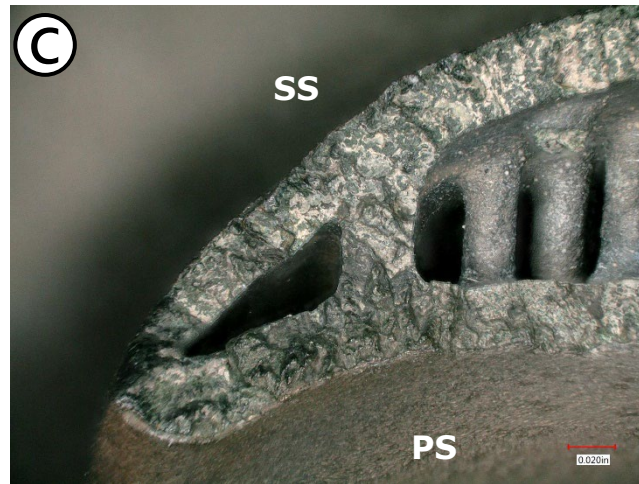
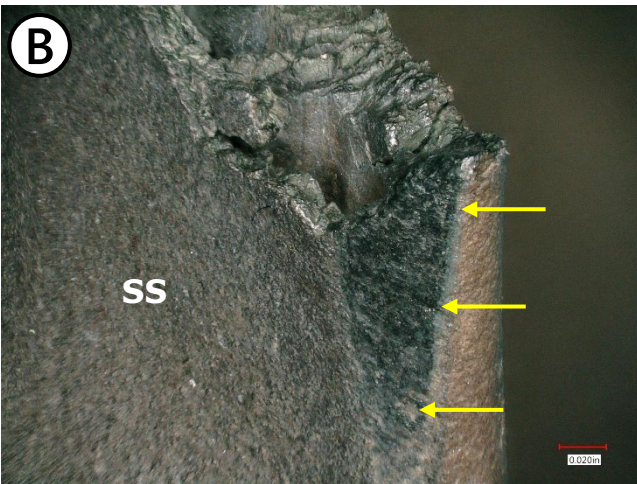
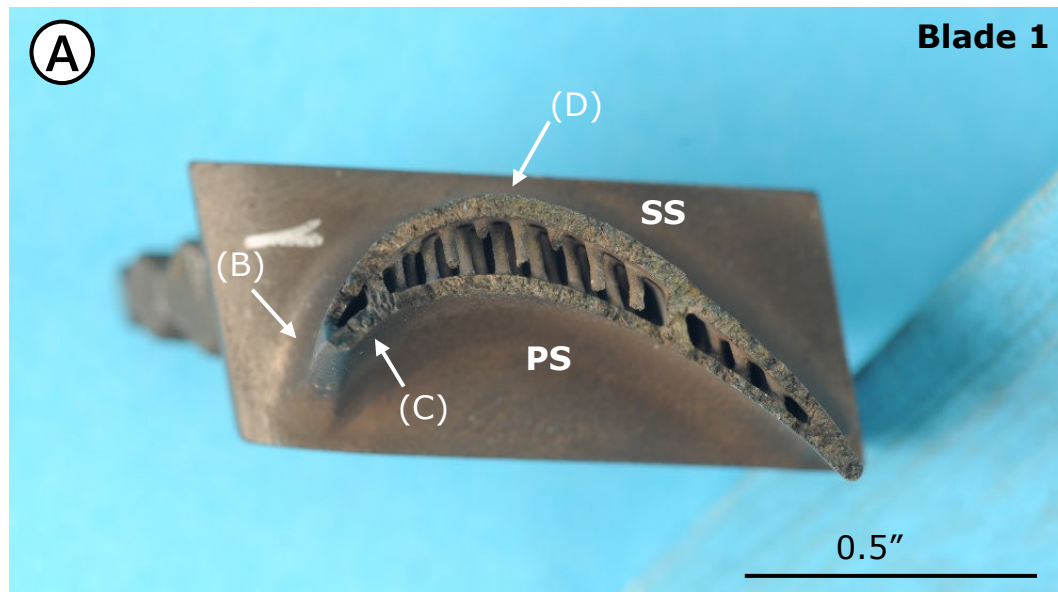


Figure 3.
(A-D) Close-up images showing the fracture features of the Blade 1 separation (reference Figure 2). The fracture surface was rough in appearance. The yellow arrows in (B) identify erosion on the leading edge of the airfoil. Scanning electron microscope (SEM) images of the Blade 1 fracture surface are shown in Figure 5.

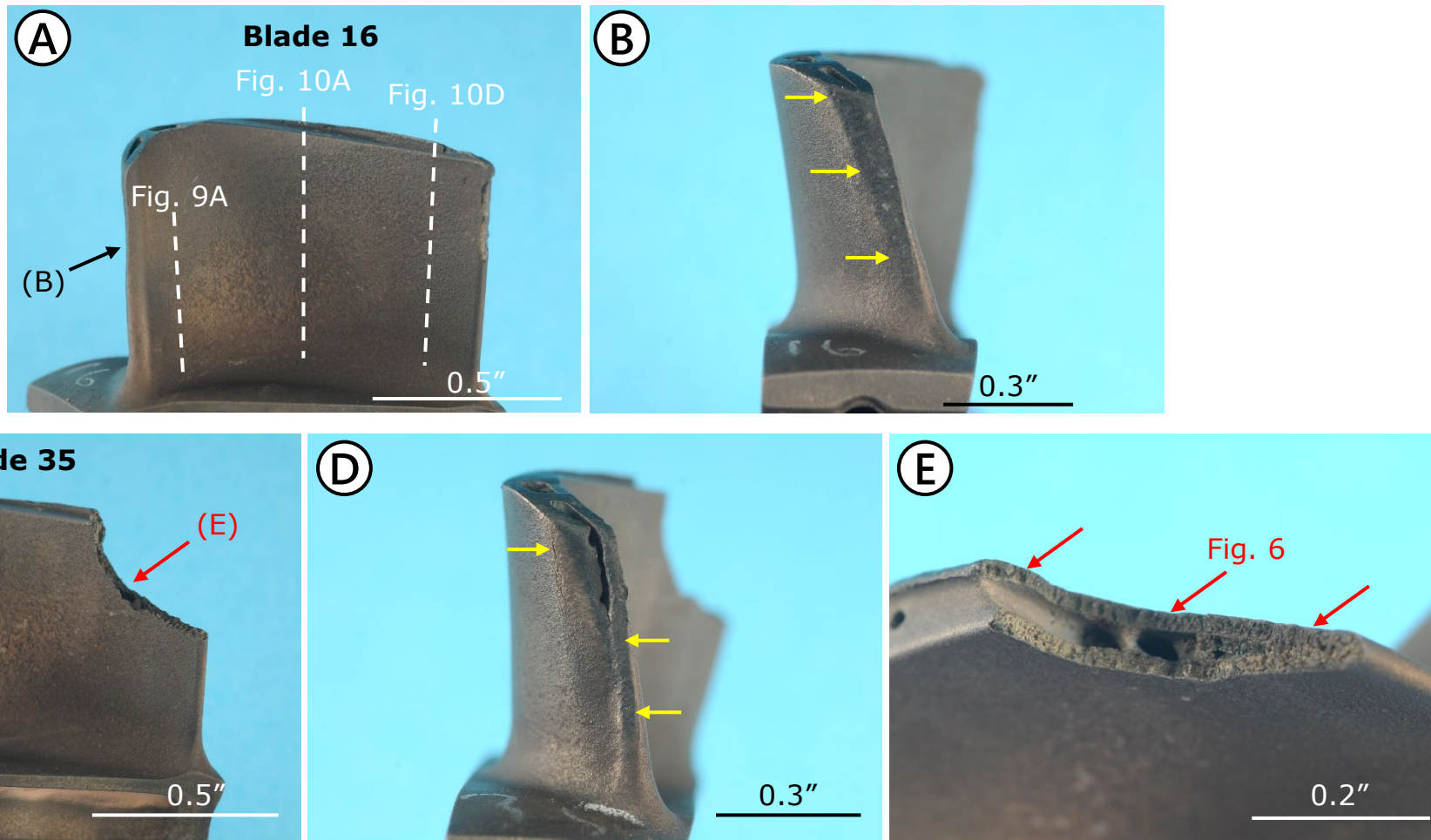


Figure 4. Close-up images showing the condition of (A-B) Blade 16 and (C-E) Blade 35. Erosion was observed on the leading edge of the blades (yellow arrows in (B) and (D)). The erosion on Blade 35 appeared to have penetrated through the leading edge cooling passage. A trailing edge separation was observed in Blade 35 (red arrows in (C) and (E)). SEM documentation of the fracture surface in (E) is shown in Figure 6. Cross sections prepared approximately through the white dashed lines in (A) are shown in Figures 9 and 10, as indicated.

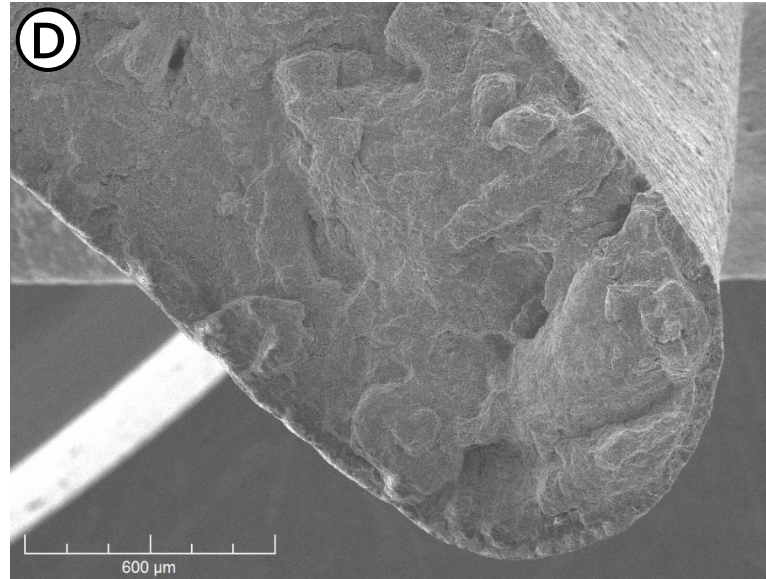
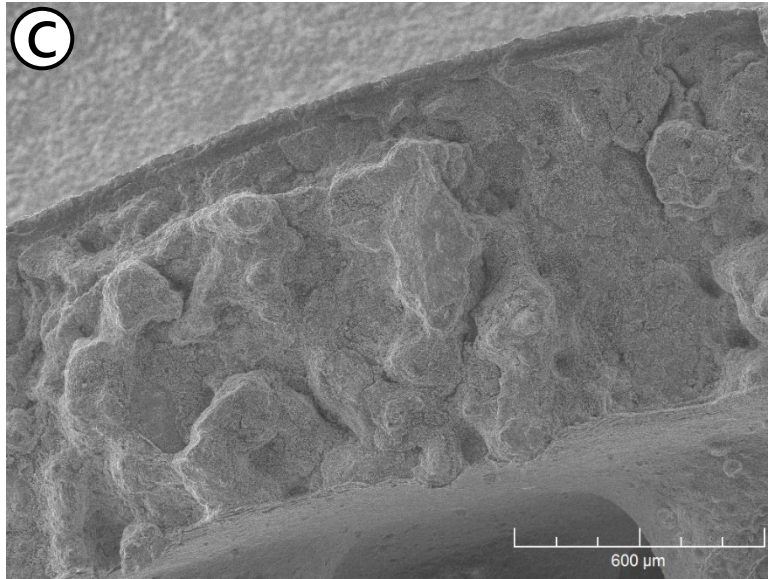
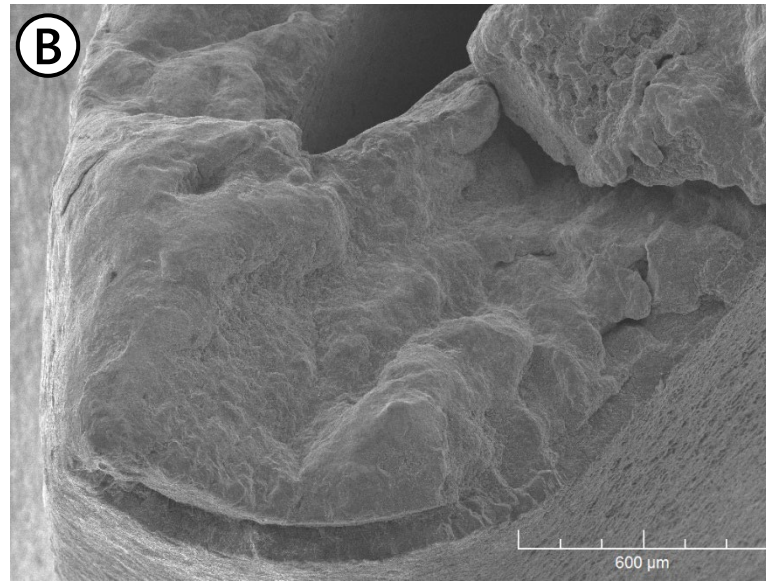
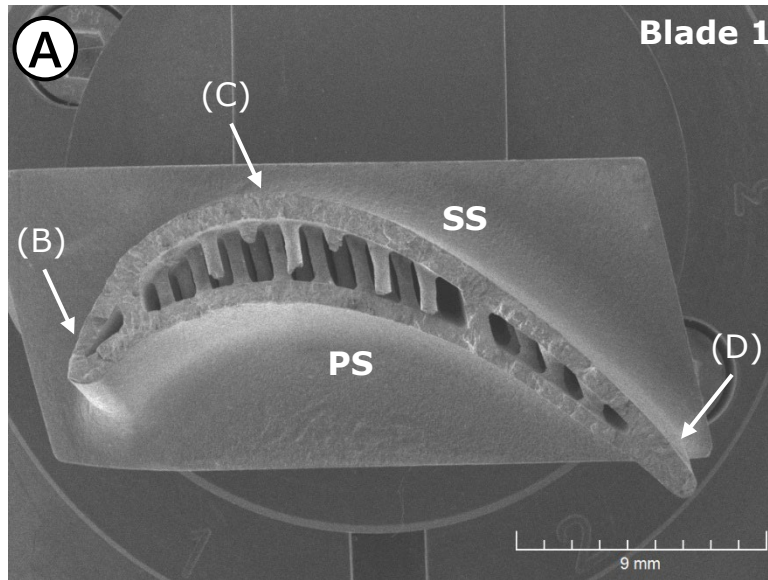


Figure 5.
(A-D) Secondary electron (SE) SEM images showing representative fracture features of the Blade 1 separation. The fracture features were oxidized and rough in appearance, suggestive of a stress rupture-type mechanism. No signs of cyclic fatigue propagation or material defects were observed on the fracture surface.

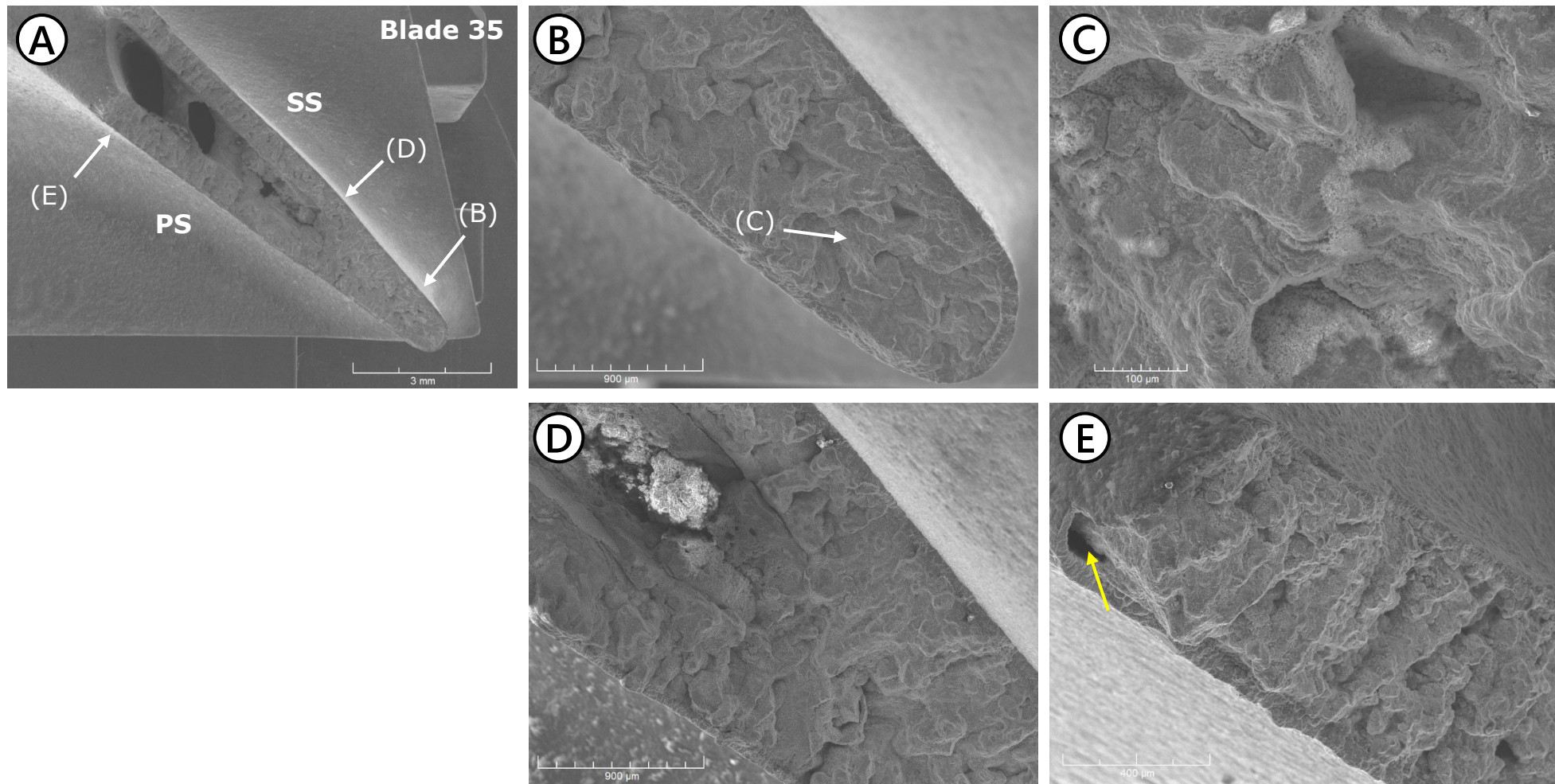
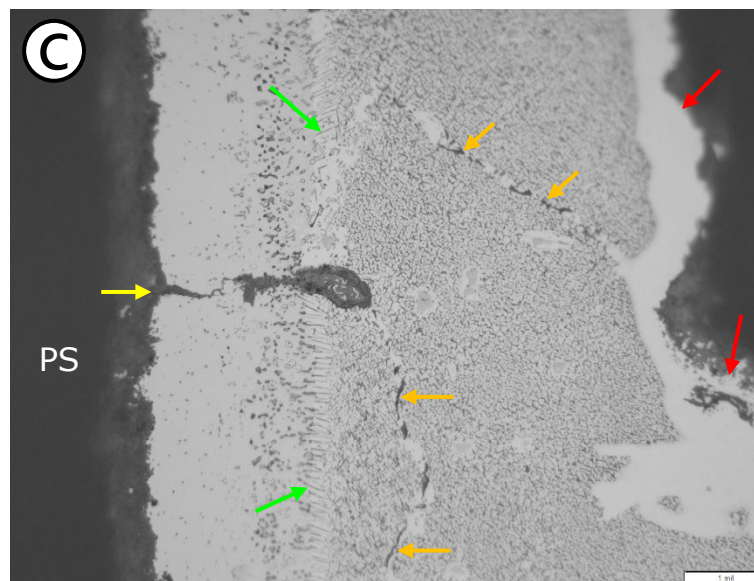
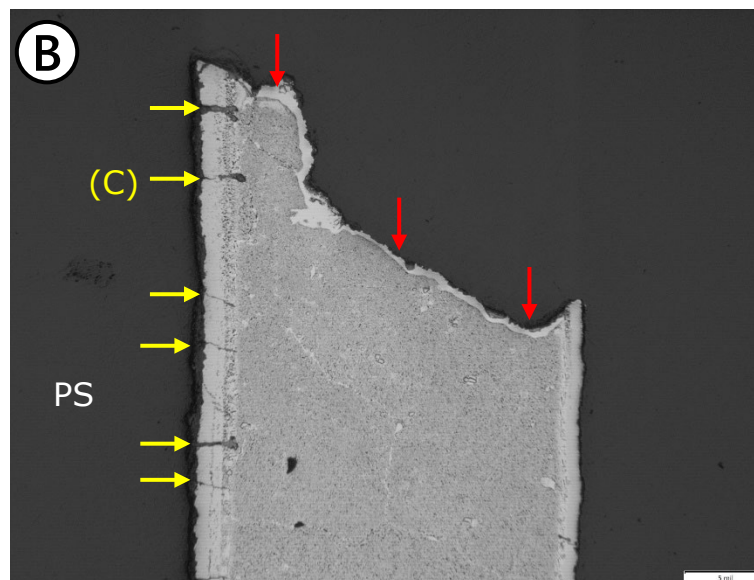
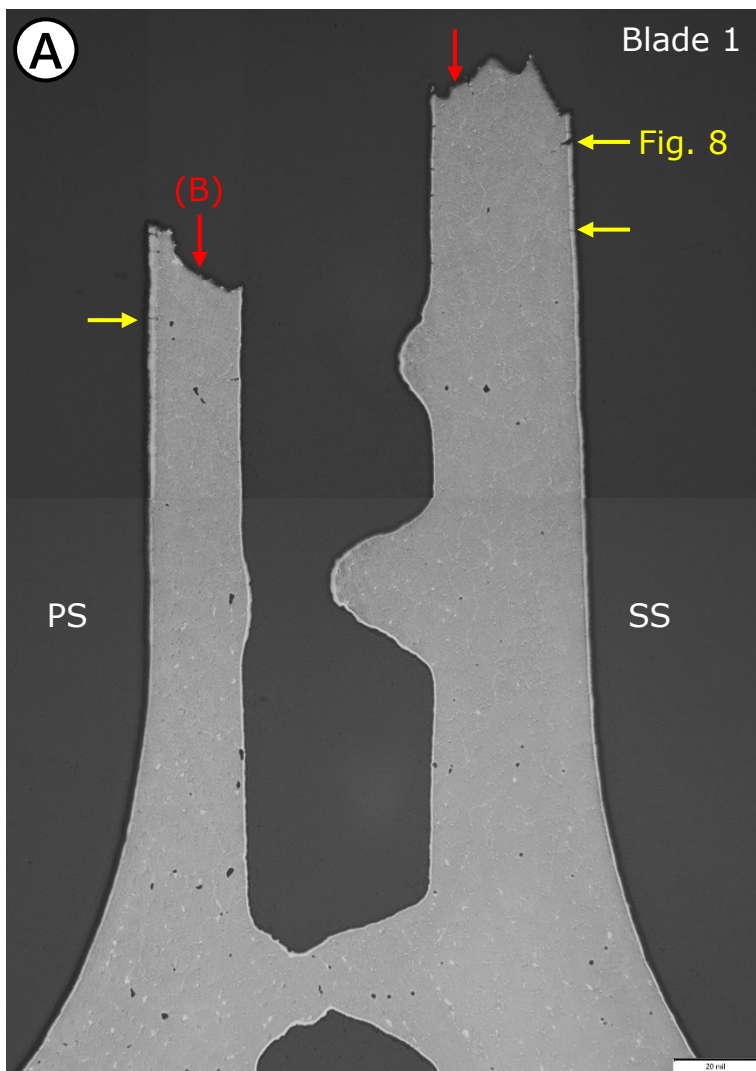
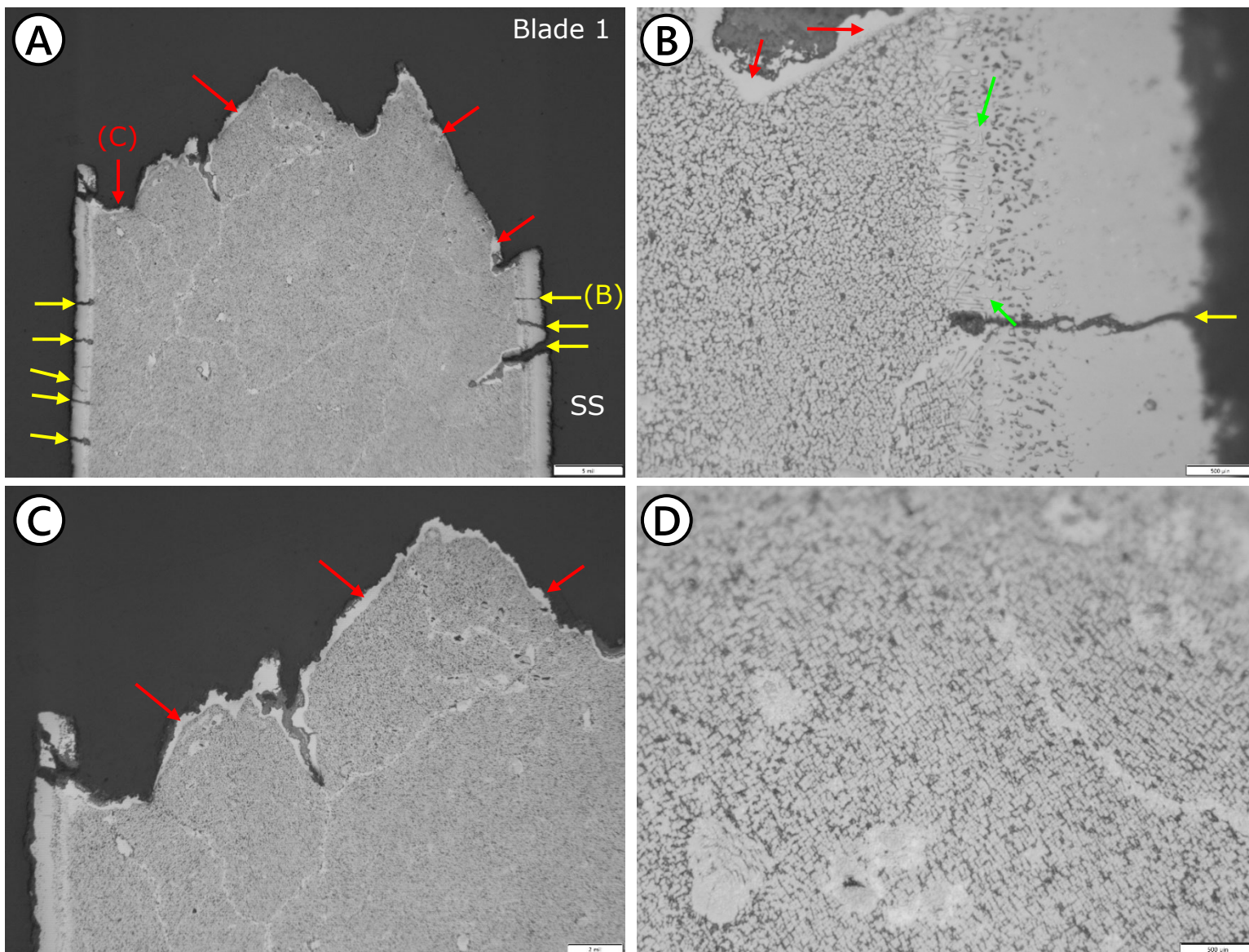


Figure 6.

(A-E) SE SEM images showing the trailing edge separation of Blade 35 (reference Figure 4). The fracture features were oxidized and rough in appearance, suggestive of a high temperature overload or stress rupture-type mechanism. The yellow arrow in (E) identifies a void between the coating and the blade material. No signs of cyclic fatigue propagation or material defects were observed on the fracture surface.

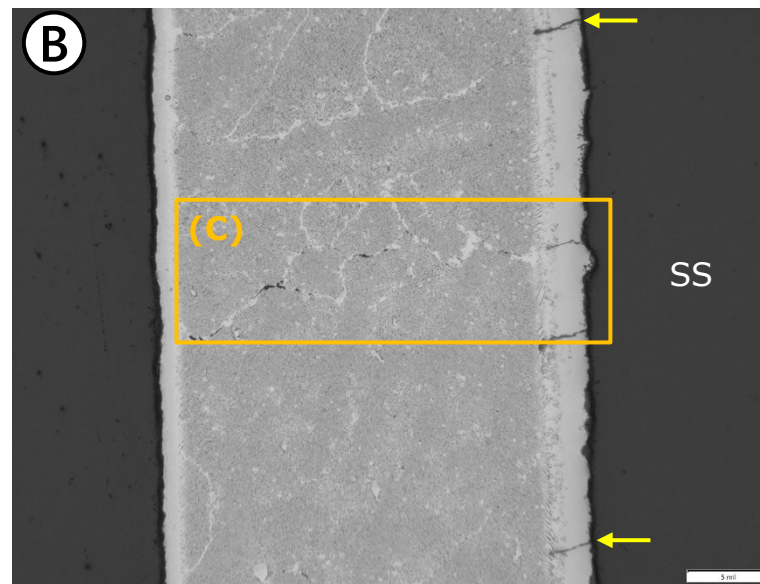
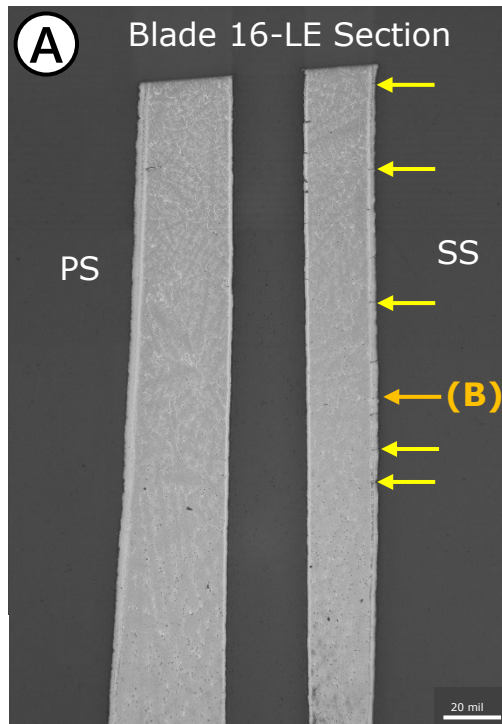
**Figure 7.**

(A-C) Cross section prepared through the Blade 1 fracture surface near the mid-chord (reference Figure 2A). Oxidation and alloy depletion was observed on the fracture surface (red arrows). The yellow arrows identify cracks in the coating. The orange arrows identify cracking and voids along the grain boundaries. The green arrows in (C) identify sigma phase (acicular structure) noted along the coating/blade interface. The presence of sigma phase and gamma prime microstructure were indicative of exposures to metal temperatures near 1700°F over a period between 10 and 100 hours. Images of the area identified in (A) are shown in Figure 8. Etchant: 10% Oxalic acid, electrolytic.

**Figure 8.**

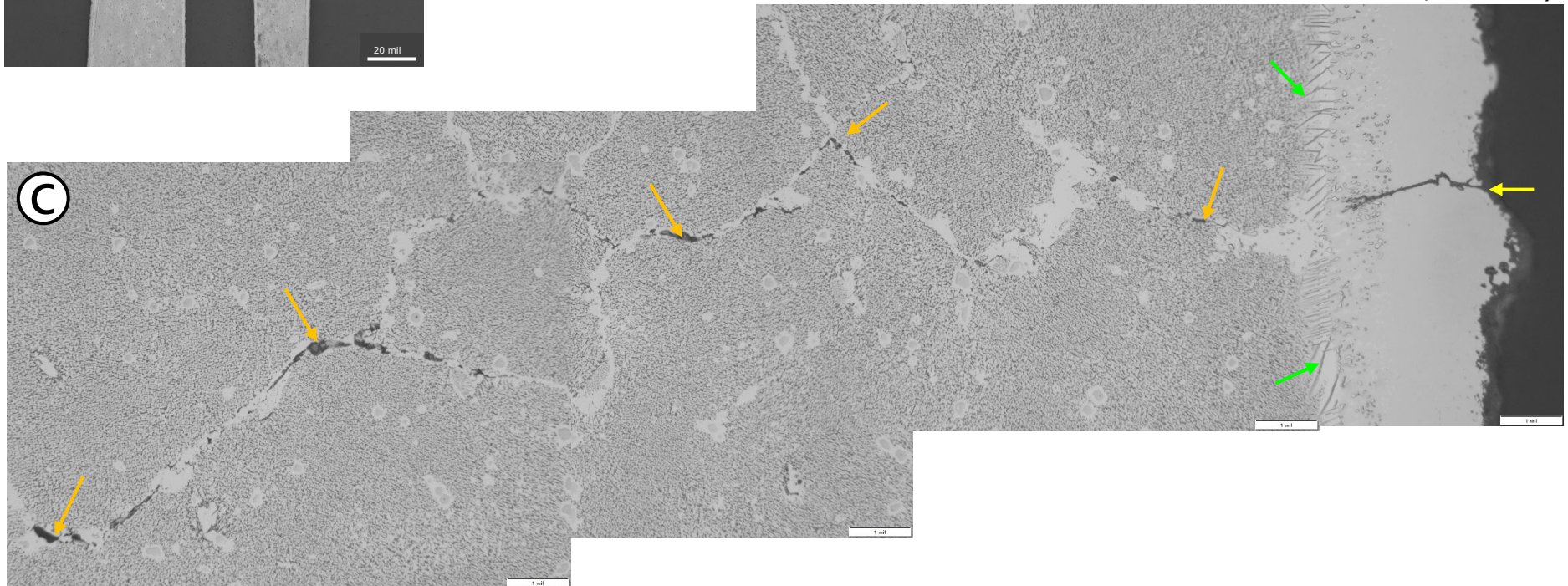
(A-C) Cross section showing the suction side wall of the Blade 1 fracture surface identified in Figure 7A. Oxidation and alloy depletion was observed on the fracture surface (red arrows). It was noted that the oxidation/alloy depletion on the fracture surface was more predominant on the pressure side wall than the suction side wall (reference Figure 7B). The yellow arrows identify cracks in the coating. The green arrows in (B) identify sigma phase (acicular structure) noted along the coating/blade interface.

(D) Representative image showing the microstructure near the fracture surface. The presence of sigma phase and gamma prime microstructure were indicative of exposures to metal temperatures near 1700°F over a period between 10 and 100 hours. Etchant: 10% Oxalic acid, electrolytic.

**Figure 9.**

(A-C) Cross section prepared through the leading edge of Blade 16 (reference Figure 4A). The yellow arrows identify cracks in the coating. The orange arrows and box identify cracking and voids along the grain boundaries. The green arrows in (C) identify sigma phase (acicular structure) noted along the coating/blade interface. Coarsening of the grain boundaries and presence of sigma phase were indicative of exposures to metal temperatures near 1900°F over a period between 10 and 100 hours.

Etchant: 10% Oxalic acid, electrolytic.



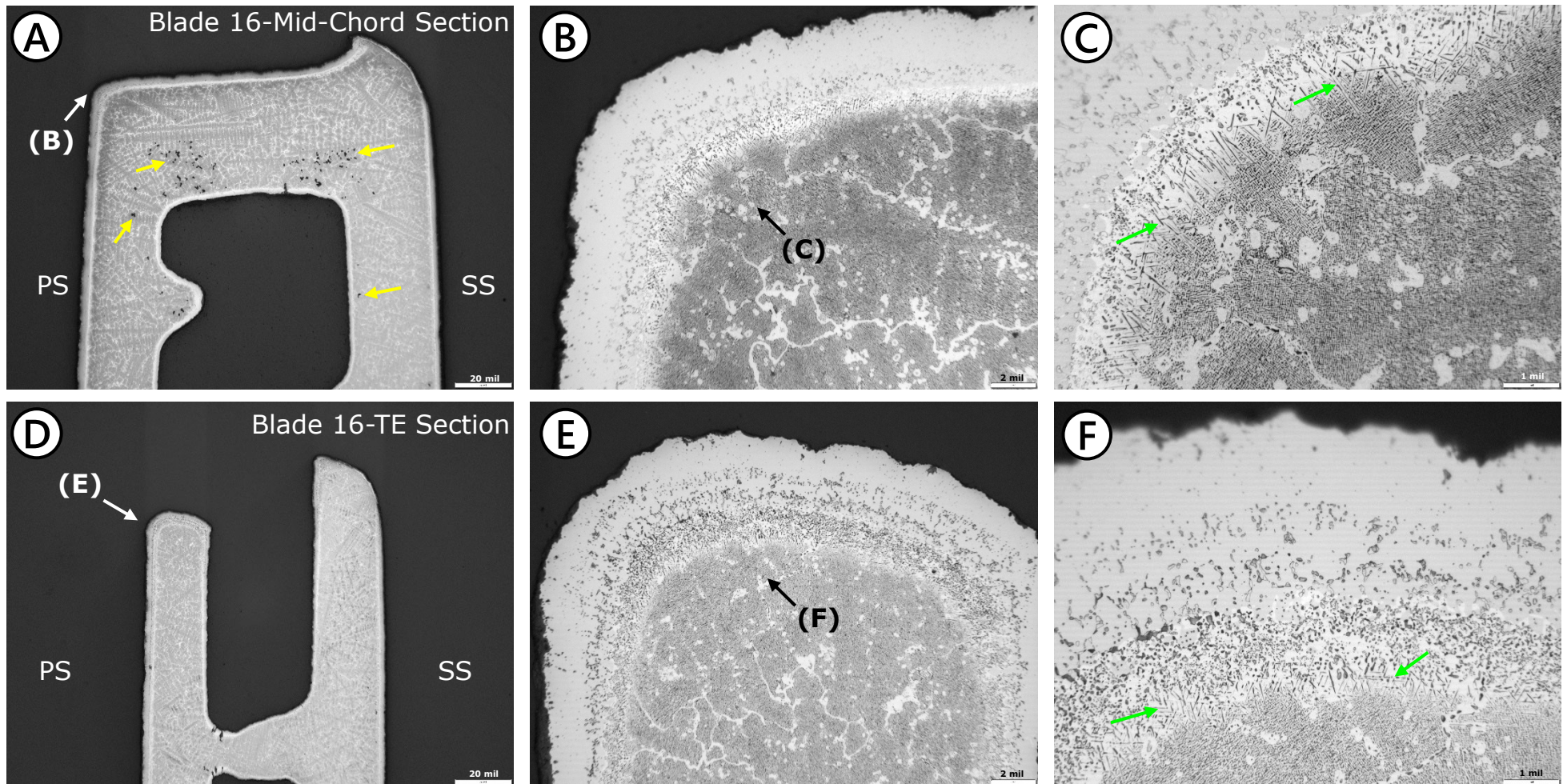


Figure 10.

Cross sections prepared through the (A-C) mid-chord and (D-E) trailing edge of Blade 16 (reference Figure 4A). The yellow arrows in (A) identify porosity. The green arrows in (C) and (F) identify sigma phase (acicular structure) noted along the coating/blade interface. Coarsening of the grain boundaries and presence of sigma phase were indicative of exposures to metal temperatures near 1900°F over a period between 10 and 100 hours.

Etchant: 10% Oxalic acid, electrolytic.

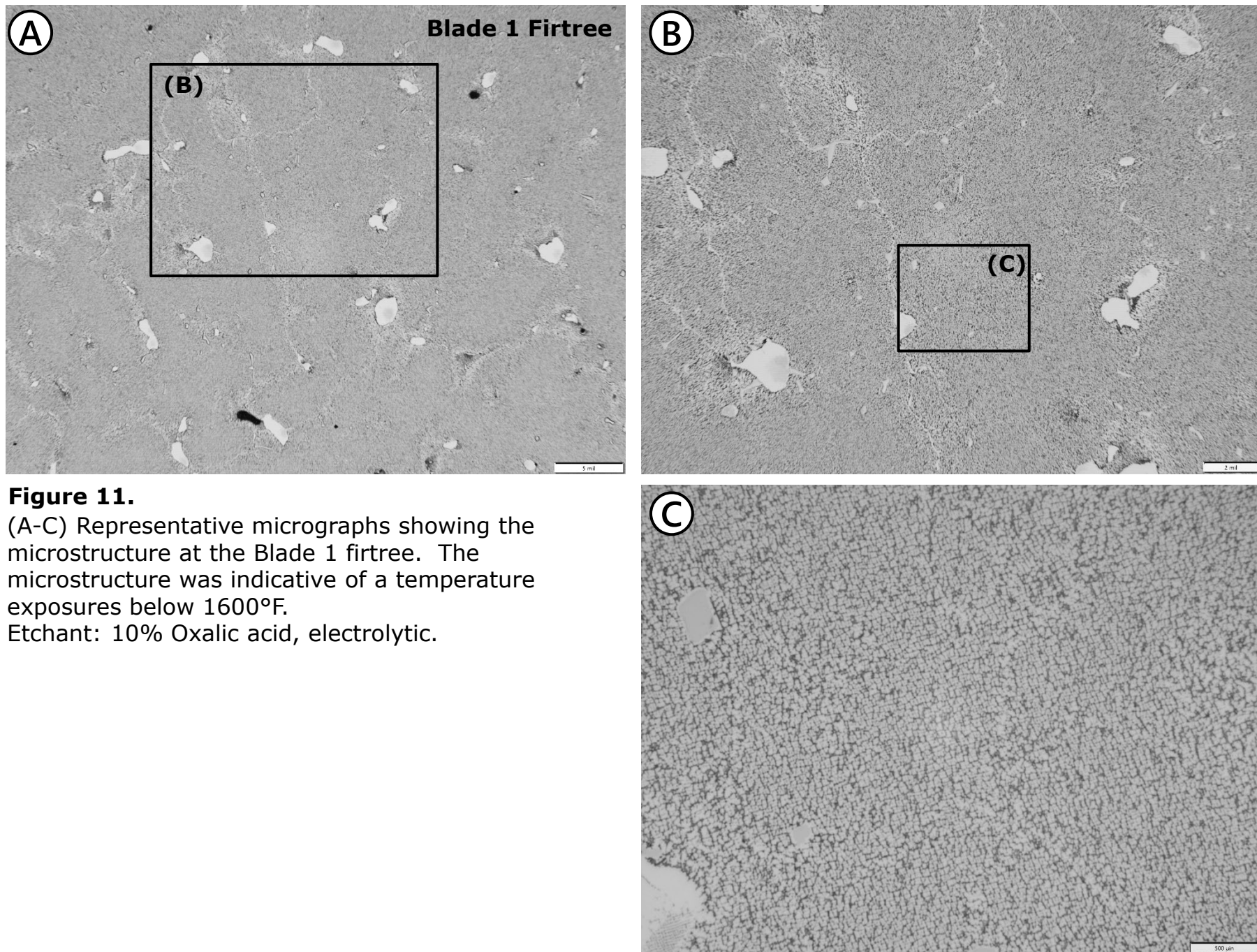
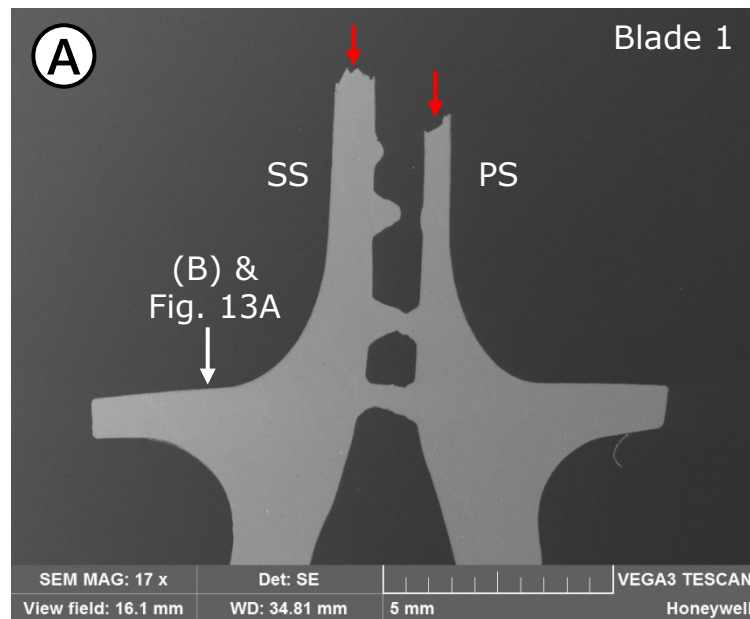


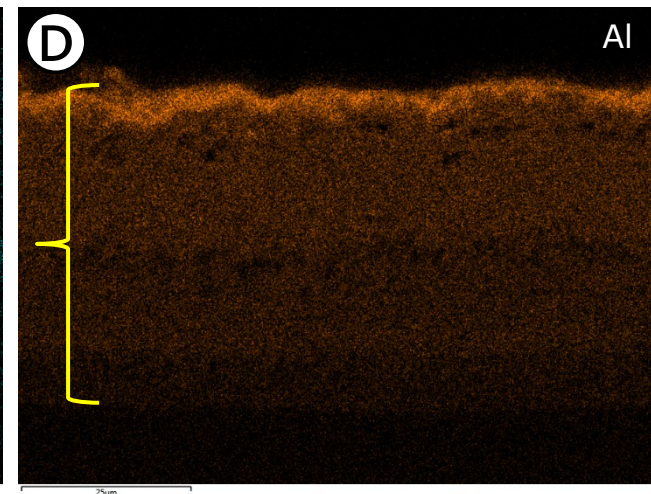
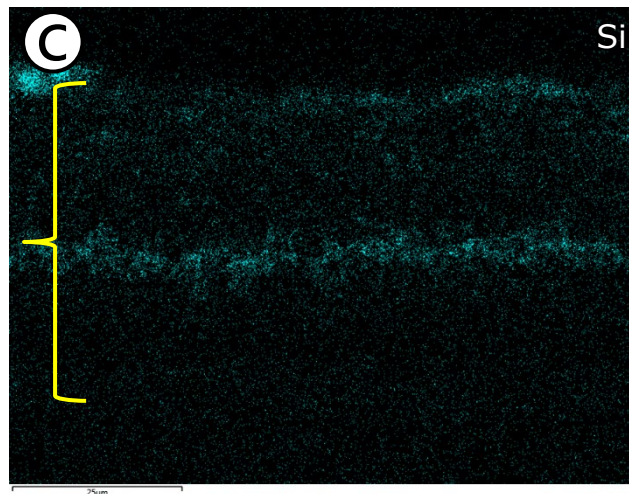
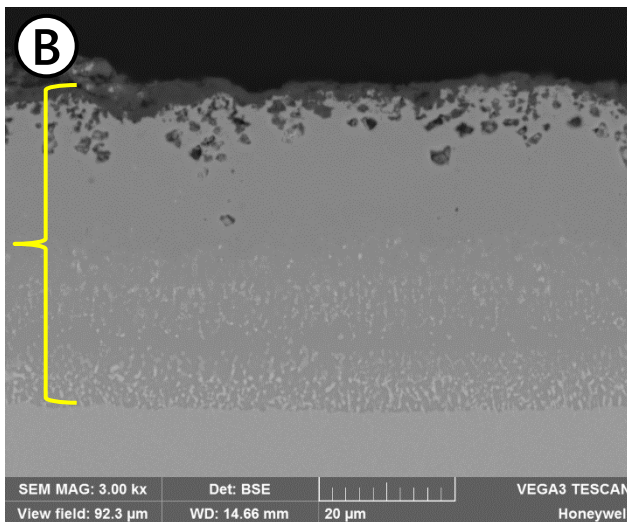
Figure 11.

(A-C) Representative micrographs showing the microstructure at the Blade 1 firtree. The microstructure was indicative of a temperature exposures below 1600°F.

Etchant: 10% Oxalic acid, electrolytic.

**Figure 12.**

(A-B) BSE SEM images showing the coating at the platform of Blade 1. The blade fracture surface is identified by the red arrows in (A). (C-D) Element dot maps for silicon and aluminum, respectively, of the area shown in (B). The yellow brackets in (B-D) outline the coating thickness. The silicon concentration suggested that the coating applied was a diffused aluminum/silicon coating. Reference Figure 13 for energy dispersive X-ray (EDX) analysis of the coating.



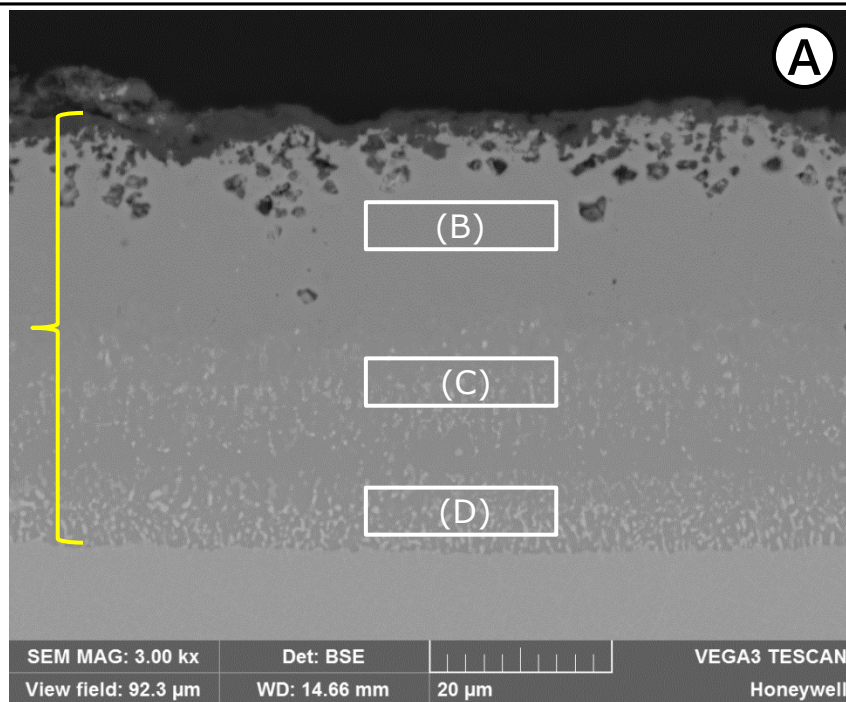
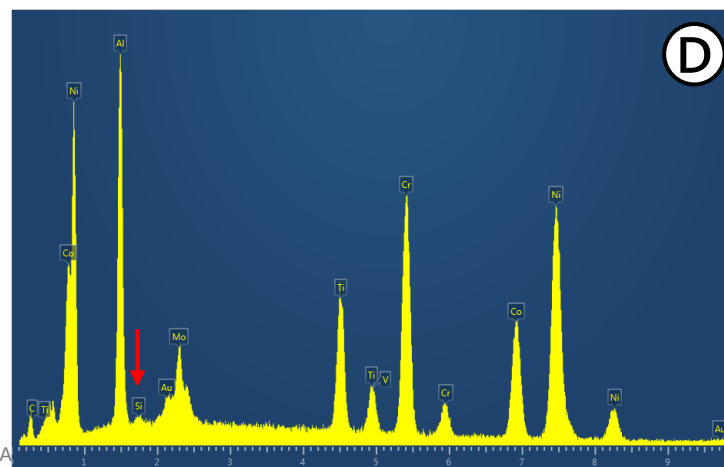
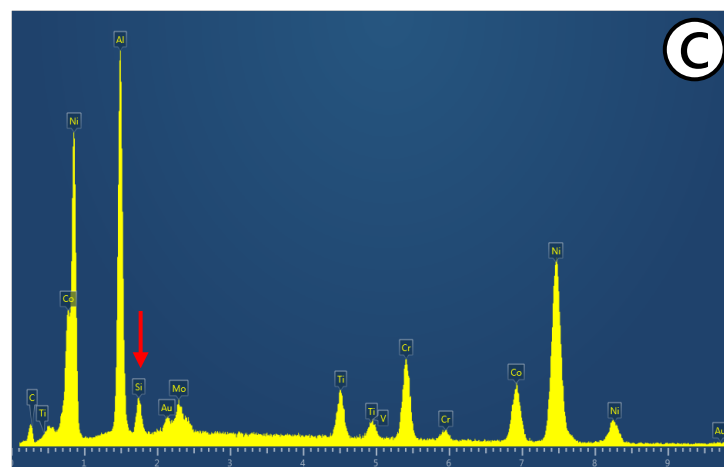
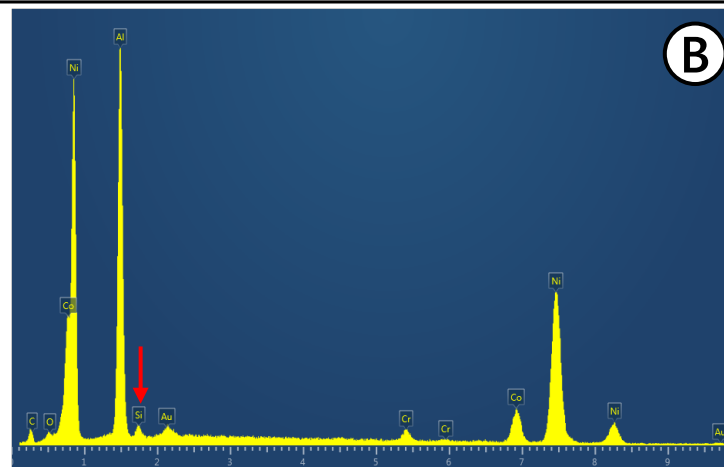


Figure 13.

(A) BSE SEM image showing the coating (yellow bracket) in Blade 1 at the platform (reference Figure 12). (B-D) EDX spectra produced from analysis of the areas outlined in (A). The silicon content in the spectra (red arrows) suggested that the coating applied was a diffused aluminum/silicon coating. Note that the gold (Au) peaks in the spectra resulted from the sputter coating applied for SEM conductivity purposes.



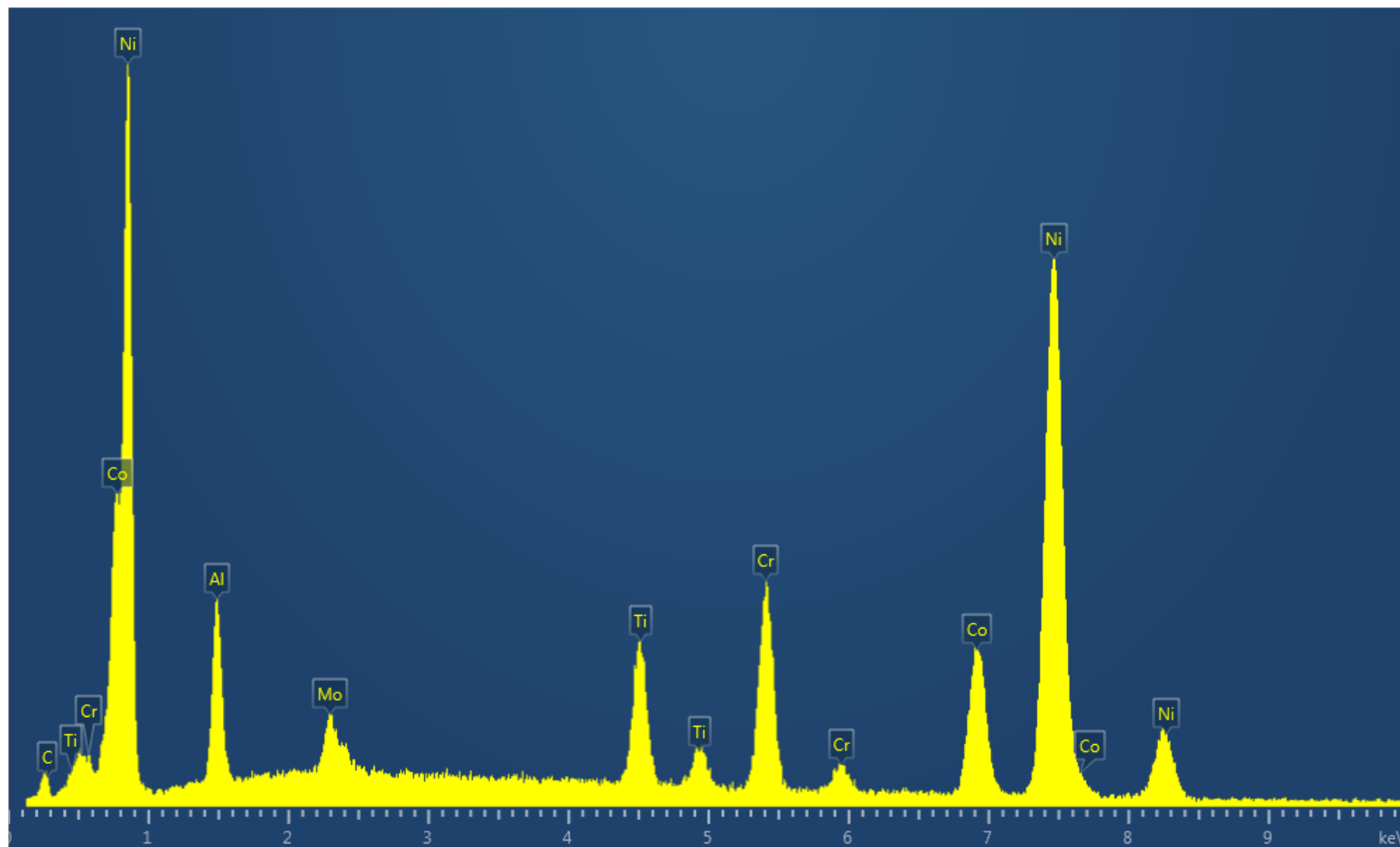


Figure 14.

Representative EDX spectrum produced from analysis of the Blade 1 base material. The spectrum was indicative of a nickel base alloy similar to the specified IN100 base material.

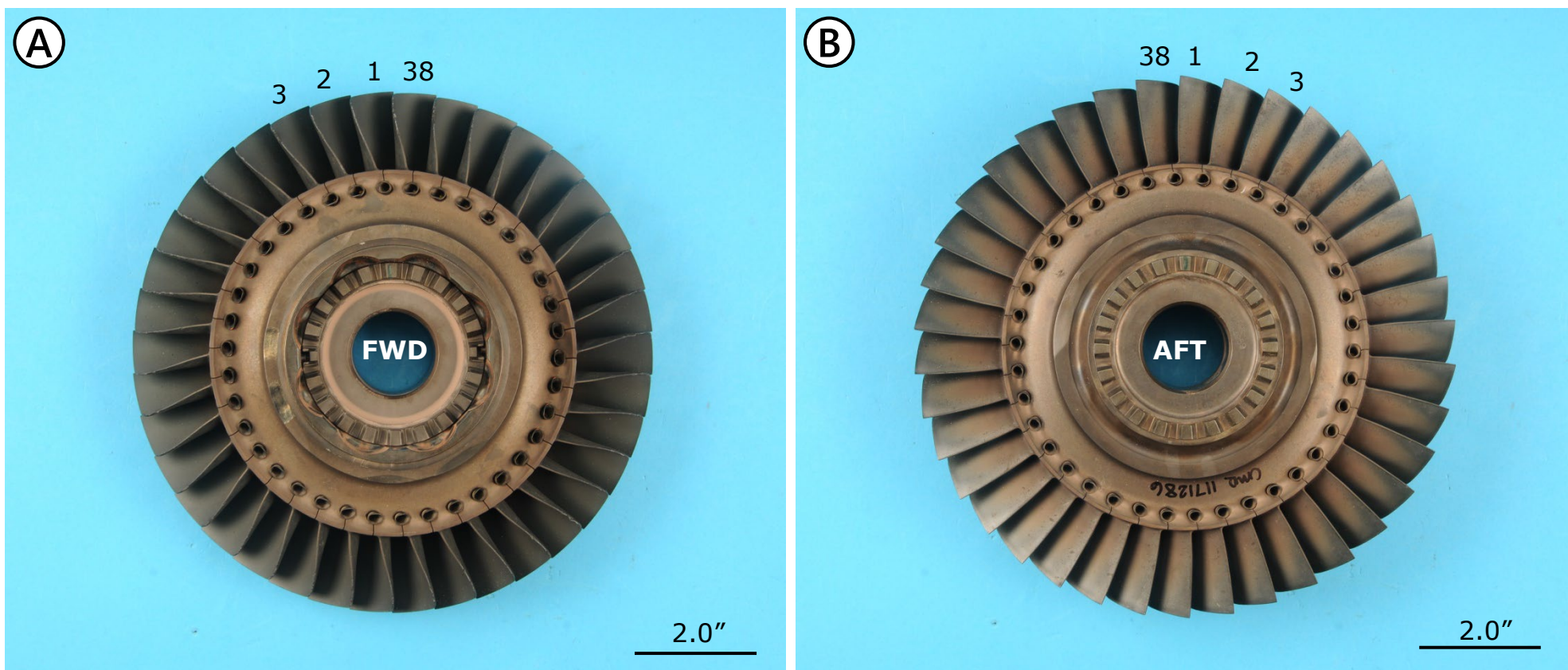


Figure 15.

Images showing the (A) forward and (B) aft sides of the 2nd stage turbine rotor (P/N 3102106-10) from TPE331-10UA-511G engine S/N P54128, in the as-received condition. For the purposes of this report, the blades were numbered 1-38 in the clockwise direction aft looking forward with Blade 1 aligned with the high curvic. Close-up images of the blades are shown in Figure 16. Blades 1 and 19 were removed for analysis and are shown in Figure 17.

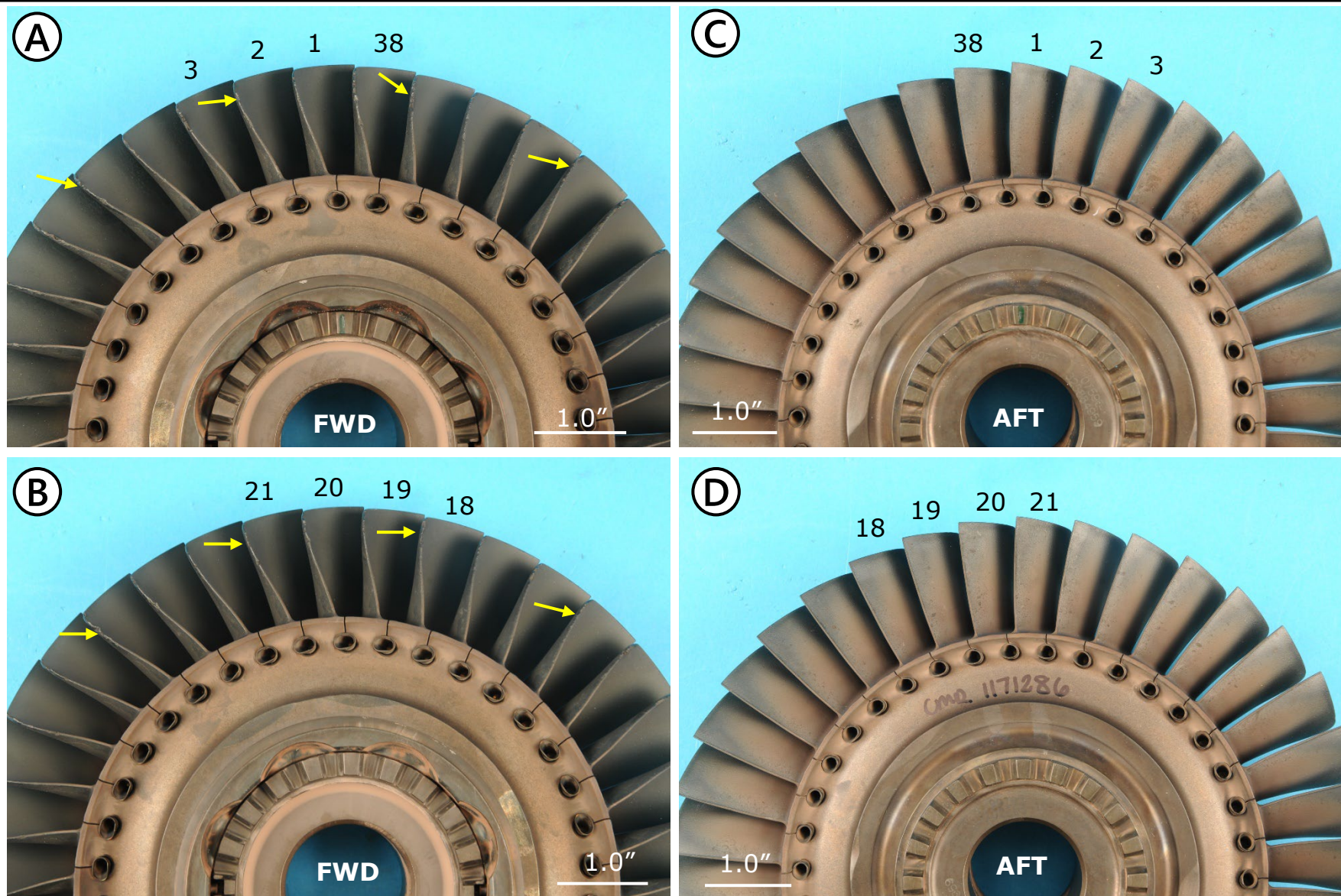


Figure 16.

Close-up images of the (A-B) forward and (C-D) aft sides of the 2nd stage turbine rotor. No blade separations were observed. Damage was observed on the leading edges of the blades near the tips (yellow arrows in (A-B)).

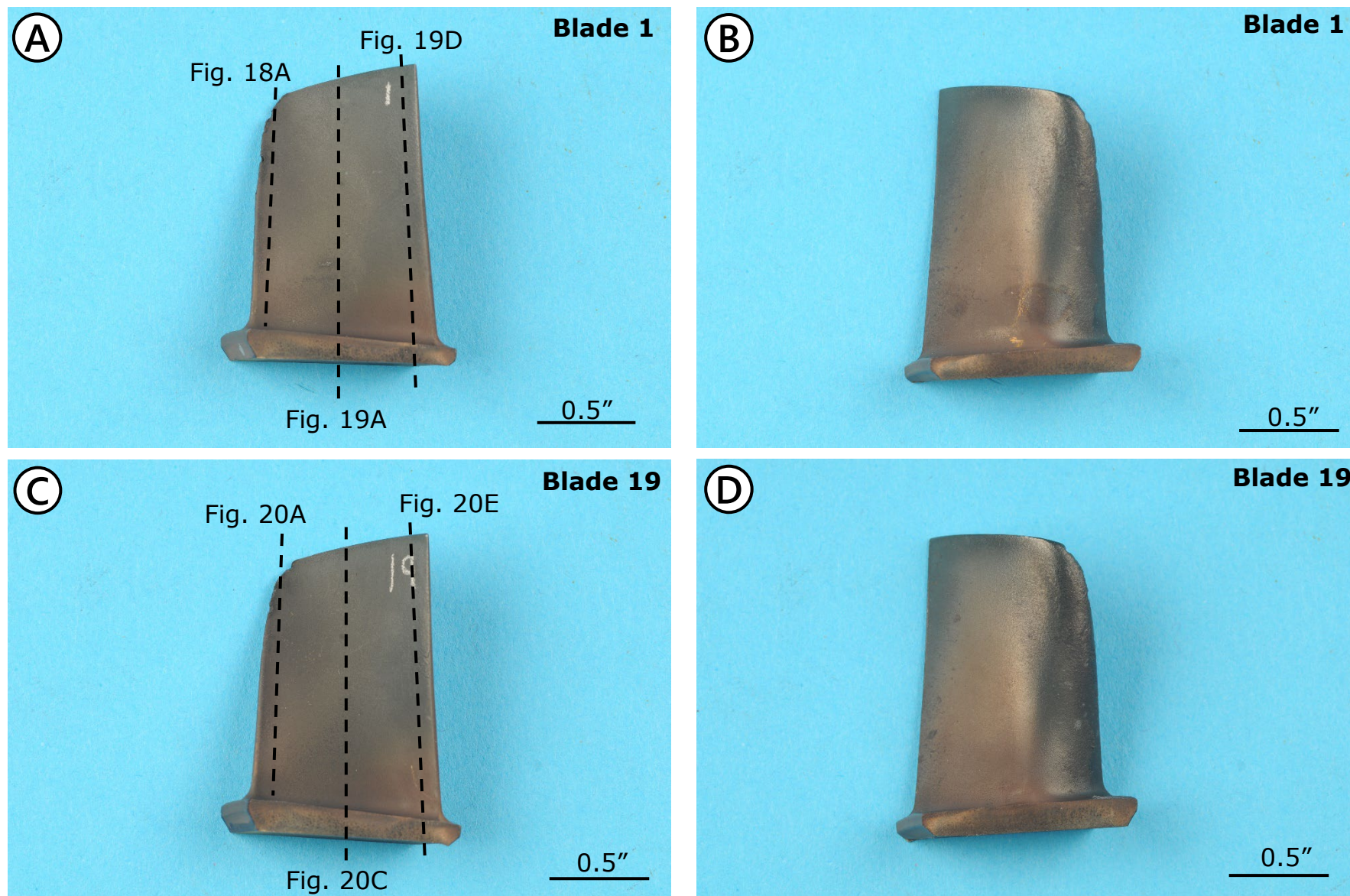


Figure 17.

Close-up images showing (A-B) Blade 1 and (C-D) Blade 19 after sectioning. Cross sections prepared through the areas identified by the black dashed lines are shown in Figures 18-20.

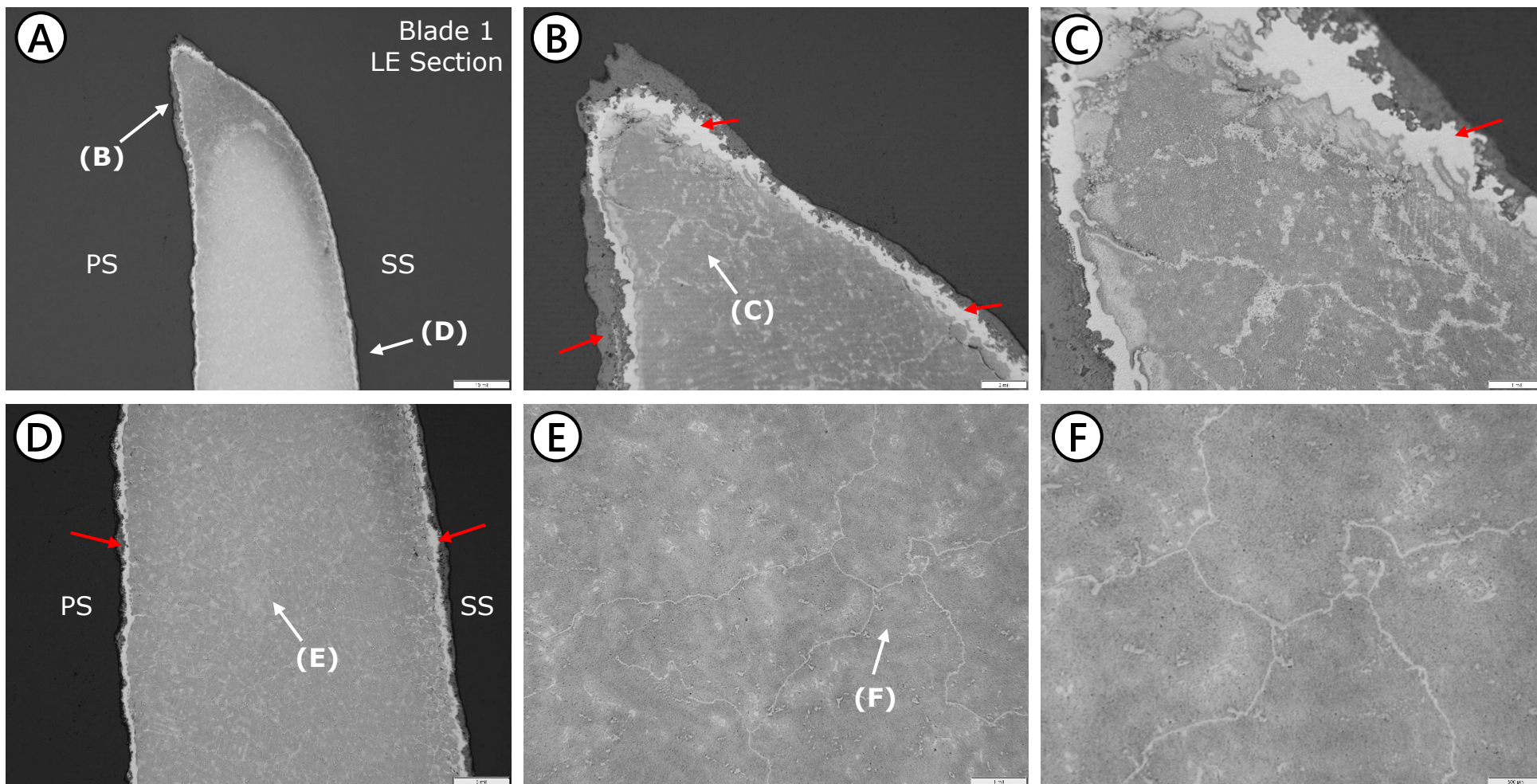


Figure 18.

(A-F) Cross section prepared through the Blade 1 leading edge of the 2nd stage turbine rotor (reference Figure 17A). Oxidation and alloy depletion were observed on the blade tip and pressure and suction sides (red arrows in (B-D)). The resolution of the gamma prime was indicative of exposures to metal temperatures near 2200°F over a period of time between 10 and 100 hours. .
Etchant: 10% Oxalic acid, electrolytic.

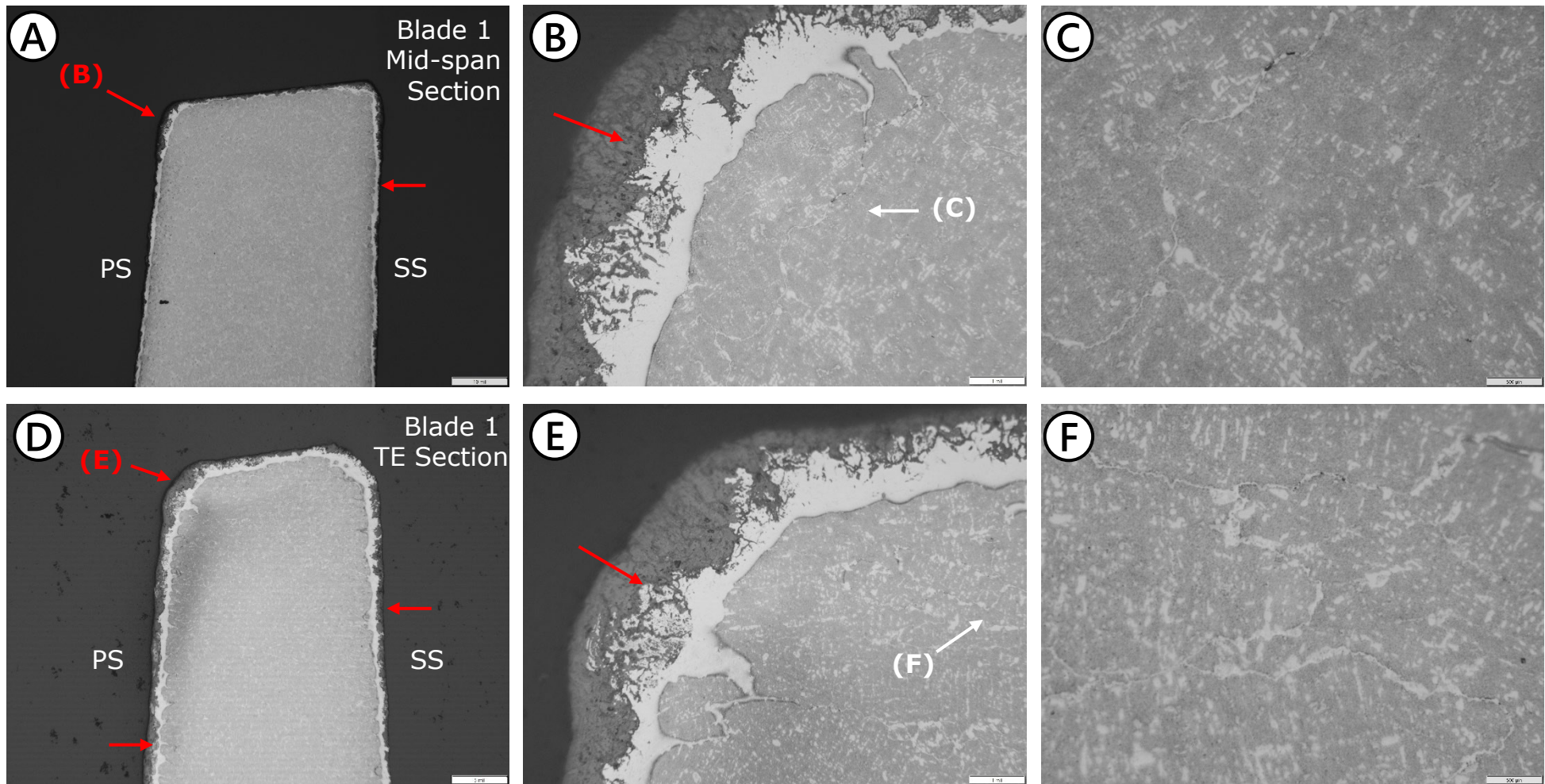


Figure 19.

(A-F) Cross sections prepared through the (A-C) midspan and (D-F) trailing edge of Blade 1 from the 2nd stage turbine rotor (reference Figure 17A). Oxidation and alloy depletion were observed on the blade tip and pressure and suction sides (red arrows in (A-B) and (D-E)). The resolutioning of the gamma prime was indicative of exposures to metal temperatures near 2200°F over a period of time between 10 and 100 hours. Etchant: 10% Oxalic acid, electrolytic.

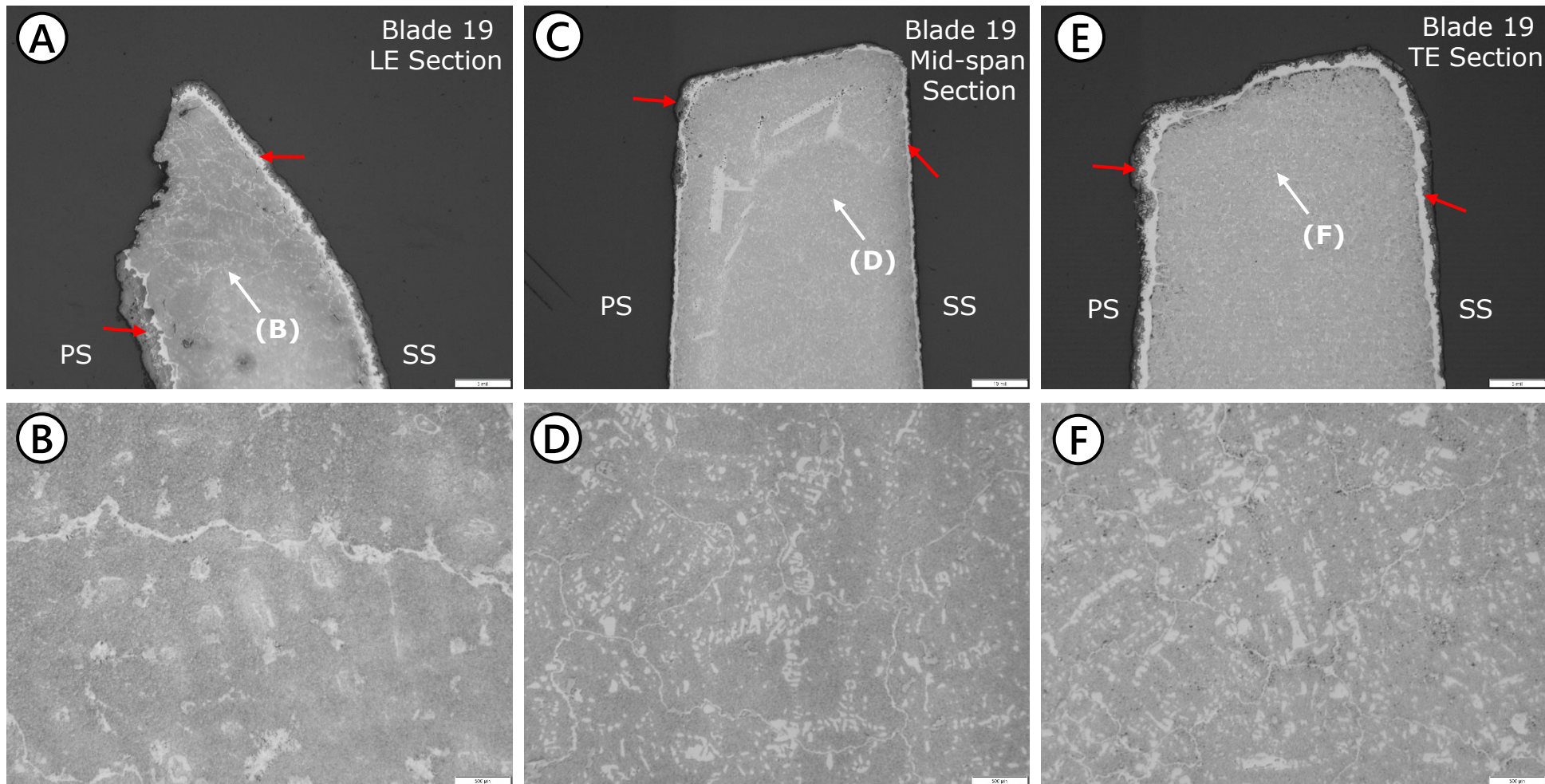


Figure 20.

Cross sections prepared through the (A-B) leading edge, (C-D) midspan, and (E-F) trailing edge of Blade 19 from the 2nd stage turbine rotor (reference Figure 17C). Oxidation and alloy depletion were observed on the blade tip and pressure and suction sides (red arrows in (A), (C), and (E)). The resolution of the gamma prime was indicative of exposures to metal temperatures near 2200°F over a period of time between 10 and 100 hours.

Etchant: 10% Oxalic acid, electrolytic.

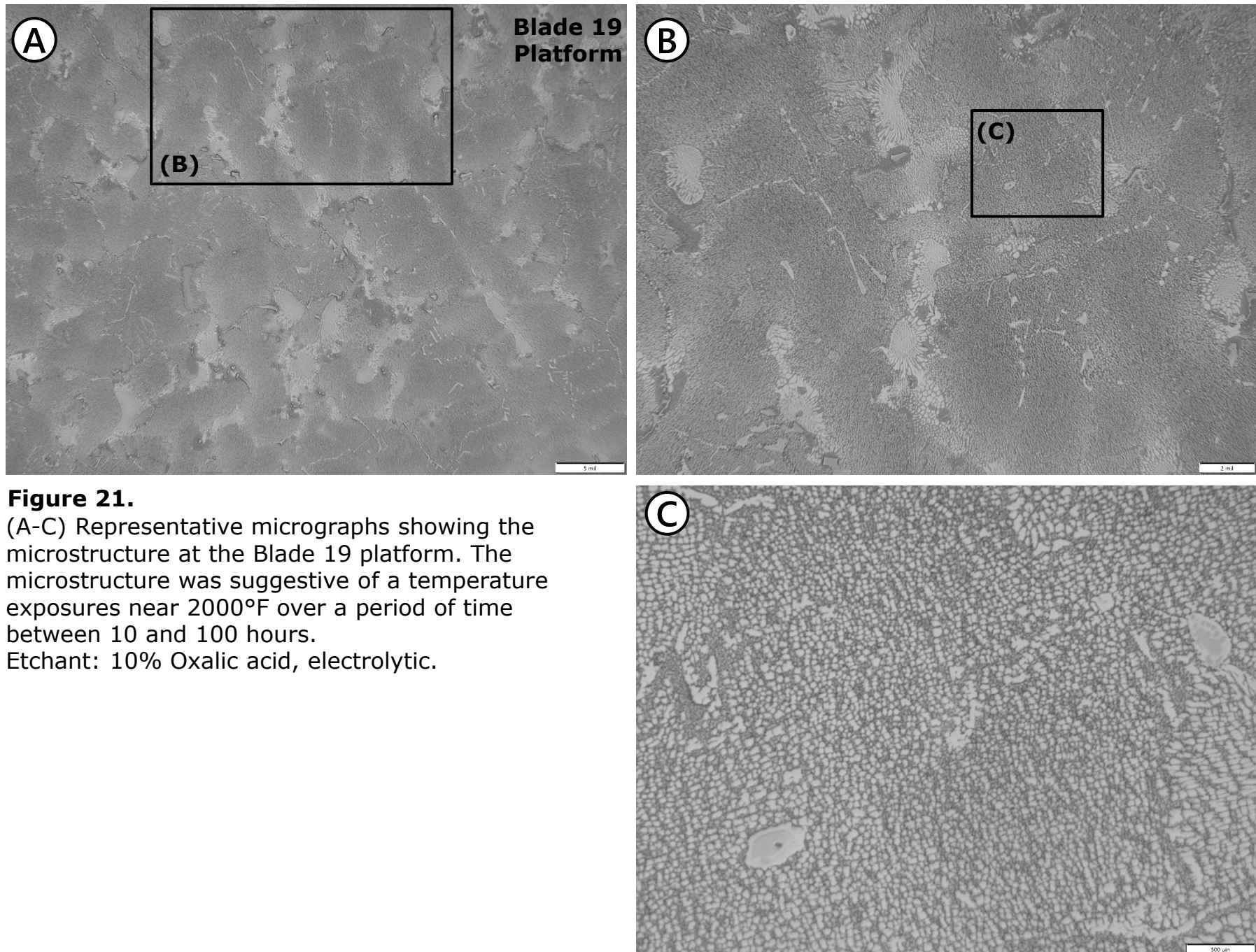


Figure 21.

(A-C) Representative micrographs showing the microstructure at the Blade 19 platform. The microstructure was suggestive of a temperature exposures near 2000°F over a period of time between 10 and 100 hours.

Etchant: 10% Oxalic acid, electrolytic.

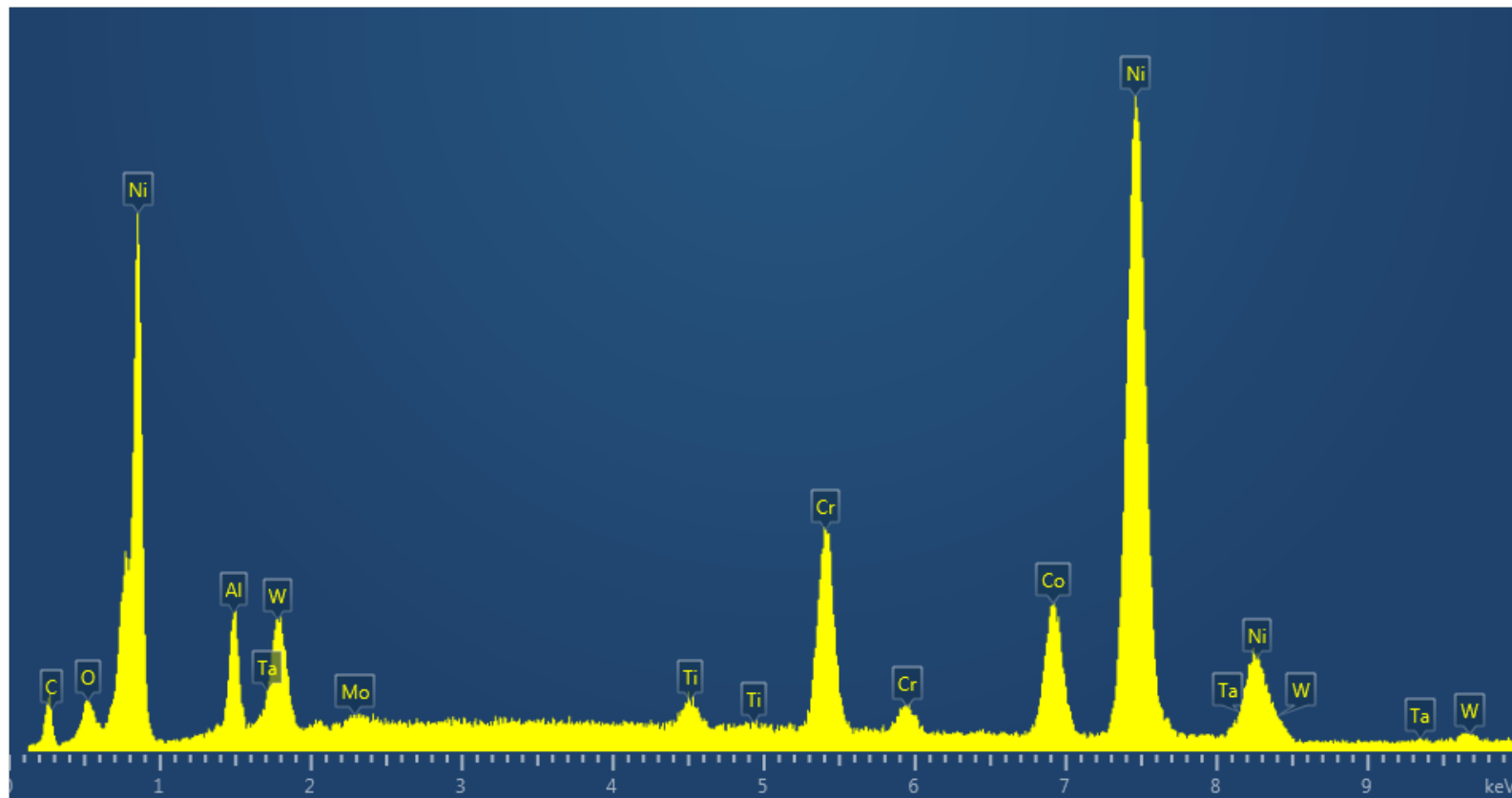


Figure 22.
Representative EDX spectrum produced from analysis of the 2nd stage turbine rotor blades. The spectrum was indicative of a nickel base alloy similar to the specified Mar-M247 base material.

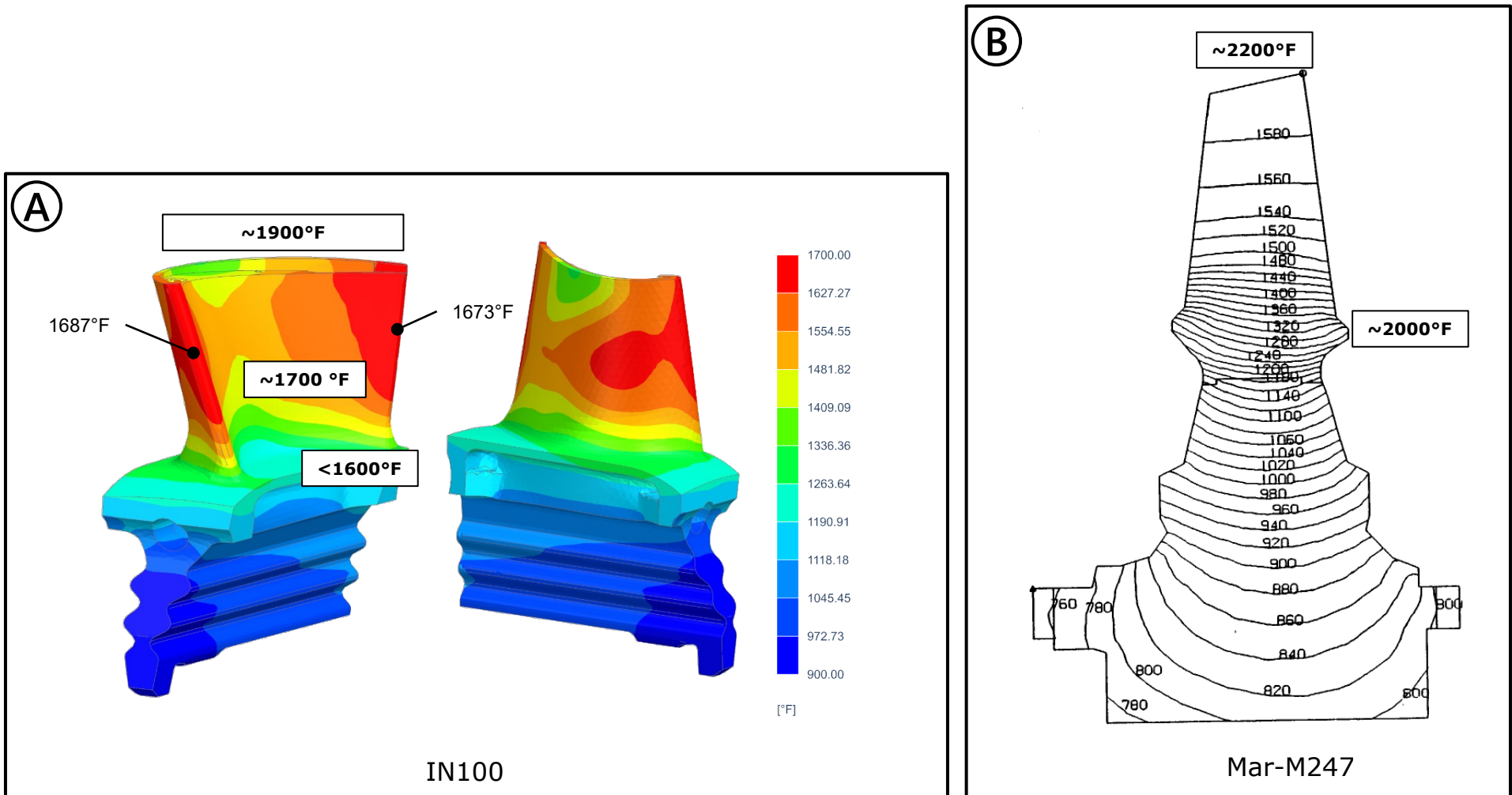


Figure 23.

Diagrams showing the thermal models for the (A) 1st stage blade and (B) 2nd stage rotor at steady state conditions. The white boxes outlined the temperature estimates performed on the approximate locations of the blades analyzed (e.g. platform, mid-span, and tips). The 1st stage blade exhibited ~200°F difference in the measured airfoil temperatures compared to the thermal model. The 2nd stage blade exhibited ~600°F difference in the measured airfoil temperatures compared to the thermal model.