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 Rolls-Royce Corporation P.O. Box 420 Indianapolis, Indiana 46206-0420 USA		PAGE 1 OF 83	REPORT NO. 15FA8-072-PR
TITLE METALLURGICAL INVESTIGATION OF A THIRD STAGE TURBINE WHEEL P/N 23065818 REMOVED FROM M250-C20J ENGINE CAE832989 OPERATED BY FLY HANGAR 13 LLC.		PREPARED <i>Signatures on File</i>	
		APPROVED <i>Signatures on File</i> DATE December 22, 2015	

Identification

Part Name: Third Stage Turbine Wheel
Part Number: 23065818
Part S/N: X597059
Total Part Time: 930 Hours (TSO)
Engine Model: M250-C20J
Engine S/N: CAE832989
Removal Station: Rolls-Royce Corporation, Indianapolis, IN.
User: Fly Hangar 13 LLC

Foreword

The air safety investigator's report indicated the aircraft was fueled and loaded for an agriculture spray operation on August 18, 2015. The aircraft reportedly flew for approximately 10 minutes when the pilot reported a power loss event followed by a hard landing and subsequent damage to the airframe.

The subject engine was disassembled at the Rolls-Royce Corporation Indianapolis facility on October 5, 2015 under the guidance of representatives from the NTSB. Preliminary examinations revealed the third stage turbine wheel was found to be missing five airfoils (fractured near the root) and portions of the shroud were also liberated. Several other engine components which suffered damage were submitted along with the third stage turbine wheel to the Rolls-Royce Corporation Materials Laboratory for documentation and metallurgical investigation. The engine components selected for more detailed examinations are listed in *Table 1*.

Findings

- Five airfoils on the third stage turbine wheel cracked in fatigue, initiating from the trailing edge root area and progressing forward until final fracture occurred in overload. All five cracks initiated and progressed in fatigue. Two additional rim cracks were found in the trailing edge side of the wheel rim.
- The aft exhaust collector flange cracked around the entire circumference of the assembly and separated. The fractures were consistent with tensile overload. The ID and aft face of the flange had been dimensionally restored using thermal spray.
- The No. 4 bearing separator fractured at two locations on the aft side and one location on the forward side. All of the fractures were consistent with fatigue. The OD surface of the bearing outer ring was scored.

4. Damage observed and documented on the other components submitted to the laboratory was considered secondary to the liberated of five airfoils on the third stage turbine wheel.

Results

Table 1 lists the engine components submitted to the Rolls-Royce Corporation Materials Laboratory for detailed examination and metallurgical investigation. A photograph of the components in the as-received condition is shown in Figure 1.

Table 1: Engine components submitted to the laboratory.

Part Name	Part Number	Serial Number
Third stage turbine wheel	23065818	X597059
Third stage turbine nozzle	23069744A	X584325
Fourth stage turbine nozzle	23055939	X591294
Fourth stage turbine wheel	23055944F	X595256
Exhaust collector	6879879D	23435
No. 4 bearing	M250-10109E	NWH11-0632
No. 3 bearing	M250-10109E	NWH11-0725
Pinion gear	6889700	UG44227
First stage turbine wheel	M250-10223	X607813
Second stage turbine wheel	23073854A	X608397
Turbine tie bolt	23068265A	NM79371
Power turbine inner shaft	23071307	KU101317
Turbine to compressor coupling	6898977	UT21507

Third Stage Turbine Wheel

Visual Examination

Figure 2 and Figure 3 show leading edge (aft looking forward) and trailing edge (forward looking aft) views of the third stage turbine wheel respectively. The blades were numbered sequentially clockwise (leading edge view) beginning with one of the fractured airfoils as shown in Figure 2. Five airfoils cracked and liberated just outboard of the rim at airfoil locations 1, 2, 3, 22, and 24. Remnants of the shroud revealed the original locations of three of the slots between airfoils 7 and 8, 14 and 15, and 28 and 29 indicating the fractures on airfoils 1 and 22 occurred on the trailing airfoil in the seven airfoil packet. Visual and fluorescent penetrant inspection (FPI) of the wheel revealed two additional rim cracks near the trailing edge radii of airfoils 8 and 15 (Figure 3).

The third and fourth stage turbine wheels were reassembled using the alignment marks on the hub and photographs were taken at 90-degree intervals as shown in Figure 4 through Figure 7. The maximum wear damage on the inter-stage knife seals on the trailing edge side of the third stage wheel occurred between airfoils 8 through 12 (Figure 6), approximately 90-degrees clockwise (aft looking forward) from the fractured 1 through 3 airfoils.

Fractography and Metallographic Examination

Figure 8 shows a radial view of the airfoil No. 1 fracture. The crack initiated from the trailing edge and progressed approximately 0.39 inch in fatigue to approximately mid chord of the airfoil before final

fracture occurred in overload. The rim surface was low angle lit to show the casting wax weld location in relationship to the airfoil trailing edge (Figure 9). The crack initiated approximately 0.024 inch above the rim and angled inward toward the rim as illustrated in Figure 10. Scanning electron microscope (SEM) images of the origin area are shown in Figure 11 through Figure 13. No obvious material anomalies were observed at the origin.

Figure 14 shows a radial view of the airfoil No. 2 fracture. The crack initiated from the trailing edge and progressed approximately 0.58 inch in fatigue before final fracture occurred in overload. The rim surface was low angle lit to show the casting wax weld location in relationship to the airfoil trailing edge (Figure 15). The crack initiated approximately 0.025 inch above the rim and angled inward toward the rim as illustrated in Figure 16. Scanning electron microscope (SEM) images of the origin area are shown in Figure 17 through Figure 19. No obvious material anomalies were observed at the origin. The dark spot on the photograph in Figure 19 is less dense debris deposited on the surface.

Figure 20 shows a radial view of the airfoil No. 3 fracture. The crack initiated from the trailing edge and progressed approximately 0.51 inch long in fatigue before final fracture occurred in overload. The rim surface was low angle lit to show the casting wax weld location in relationship to the airfoil trailing edge (Figure 21). The crack initiated approximately 0.042 inch above the rim at a Stage I fatigue facet. The facet angled sharply inward toward the rim as illustrated in Figure 22 before turning and progressing transversely across the airfoil. Scanning electron microscope (SEM) images of the origin area are shown in Figure 23 through Figure 25. No obvious material anomalies were observed at the origin.

Figure 26 shows a radial view of the airfoil No. 22 fracture. The crack initiated from the trailing edge and progressed approximately 0.58 inch long in fatigue before final fracture occurred in overload. The rim surface was low angle lit to show the casting wax weld location in relationship to the airfoil trailing edge (Figure 27). The crack initiated approximately 0.015 inch above the rim and angled inward toward the rim as illustrated in Figure 28. Scanning electron microscope (SEM) images of the origin area are shown in Figure 29 through Figure 31. No obvious material anomalies were observed at the origin.

Figure 32 shows a radial view of the airfoil No. 24 fracture. The crack initiated from the trailing edge and progressed approximately 0.55 inch long in fatigue before final fracture occurred in overload. The rim surface was low angle lit to show the casting wax weld location in relationship to the airfoil trailing edge (Figure 33). The crack initiated approximately 0.026 inch above the rim and angled inward toward the rim as illustrated in Figure 34. Scanning electron microscope (SEM) images of the origin area are shown in Figure 35 through Figure 37. No obvious material anomalies were observed at the origin.

A rim crack measuring approximately 0.05 inch long and oriented radially was observed near the trailing edge root area of airfoil No. 8 as shown in Figure 38. A cross-section through the crack is shown in Figure 39 and Figure 40. The crack length measured 0.022 inch. The crack was transgranular and oxidized but no alloy depletion was observed along the crack path.

Another rim crack was observed near the trailing edge root area of airfoil No. 15 as shown in Figure 41. The crack was opened in the laboratory and is shown in Figure 42 and Figure 43. Two cracks initiated on two parallel planes and the total crack width measured 0.056 inch and the total depth measured 0.022 inch.

Hardness

The average hardness on the rim cross section of the third stage turbine wheel measured 40 HRC (averaged value of 70.5, 70.4, and 70.2 HRA) which met the component definition.

Chemistry

Semi-quantitative x-ray fluorescence (XRF) analysis determined that the third stage turbine wheel was consistent with the material type required by the component definition.

Third Stage Turbine Nozzle

Visual Examination

Figure 44 and Figure 45 show leading edge (aft looking forward) and trailing edge (forward looking aft) views of the third stage turbine nozzle respectively. Several of the trailing edge surfaces were impact damaged and material was liberated. The rim surface outboard of the airfoils (TE view) shows significant scoring and impact damage. The hub positioning tabs were not damaged. No destructive evaluations of the nozzle were conducted.

Fourth Stage Turbine Nozzle

Visual Examination

Figure 46 and Figure 47 show leading edge (aft looking forward) and trailing edge (forward looking aft) views of the fourth stage turbine nozzle assembly respectively. Two airfoils were missing and examination of the fracture surfaces revealed features consistent with overload. The outboard portions of all of the leading edge surfaces were damaged and several of the trailing edge surfaces were impact damaged and material was liberated. The separated diaphragm will be discussed below.

Four views of the blade track for the third stage turbine wheel are shown in Figure 48. Portions of the blade track were fractured and missing. The entire circumference of the blade track was rubbed from contact against the third stage turbine wheel shroud and knife seals.

Impact damage was also observed on the eight positioning tabs around the outer diameter as illustrated in Figure 49. The damage is located on the side of the tang opposite the direction of the power turbine rotation. In addition, the diaphragm detached from the bore and is shown in Figure 50 through Figure 52.

No destructive evaluations of the fourth stage turbine nozzle assembly were conducted.

Fourth Stage Turbine Wheel

Visual Examination

Figure 53 and Figure 54 show leading edge (aft looking forward) and trailing edge (forward looking aft) views of the fourth stage turbine wheel respectively. All of the airfoils were intact but many were impact damaged. No destructive evaluations of the fourth stage turbine wheel were conducted.

Exhaust Collector

Visual Examination

The aft flange of the exhaust collector cracked and separated and is shown in Figure 55. Representative photographs of the fracture are shown in Figure 56. The fracture features were consistent around the circumference and were indicative of overload.

Fractography

A section of the exhaust collector flange was removed and examined using the SEM. Representative SEM images of the fracture are shown in Figure 57 and Figure 58. The fracture features were a mixture of cleavage and equiaxed ductile dimples. The fracture features were consistent with overload. The fracture was a few inches aft of the weld joint.

Metallographic Examination

A cross-section through the flange is shown in Figure 59. The aft surface and ID surface of the flange had been dimensionally restored with thermal spray. The parent material in the flange wall was slightly tapered and measured 0.0936 inch thick near the inboard portion of the flange and 0.0970 inch thick near the outer diameter. The ID wall thickness was also tapered and measured 0.0347 inch near the fracture and 0.0370 inch thick adjacent to the flange fillet radius. A representative photograph of the thermal spray microstructure is shown in the lower image in Figure 60. There were a few cracks in the thermal spray coating and along the OD surface of the wall, forward of the flange.

No. 4 Bearing

Visual Examination

The No. 4 bearing was removed from the pinion gear as shown in Figure 61. End views of the bearing (Figure 62 and Figure 63) revealed the separator was fractured and the aft side end wall from one of the aft pockets liberated (Figure 62). The liberated section was one of the six (6) scalloped pocket that was slightly smaller (radial thickness) than in other areas. This fractured and liberated section was recovered. The forward side rail was also cracked at the same pocket location (Figure 63), but was not liberated. The OD surface of the outer ring exhibited circumferential score marks (Figure 64).

The bearing was disassembled and the separator fractures are shown in Figure 65 and Figure 66. The fracture showed beach marks consistent with fatigue progression. Detailed fractographic evaluations of the fractures were not conducted.

No. 3 Bearing

Visual Examination

A forward looking aft view of the No. 3 bearing still installed on the pinion gear is shown in Figure 67. Also shown is the No 2 ½ bearing in the center of the pinion gear. No cracks were observed on either side of the separator and no score marks were seen on the outer ring OD (Figure 68). No destructive evaluations of the No. 3 bearing were conducted.

Pinion Gear

Visual Examination

The pinion gear was examined under magnification and no teeth were chipped or spalled. A wear pattern was evident on the drive side of the gear teeth as shown in Figure 68. The internal splines that engage the power turbine to pinion gear coupling were undamaged. No destructive evaluations of the pinion gear were conducted.

First Stage Turbine Wheel

Visual Examination

Figure 69 shows a leading edge (aft looking forward) view of the first stage turbine wheel. All of the airfoils were intact and no obvious thermal distress or damage was observed on any of the airfoils. No destructive evaluations of the first stage turbine wheel were conducted.

Second Stage Turbine Wheel

Visual Examination

Figure 70 shows a trailing edge (forward looking aft) view of the second stage turbine wheel. All of the airfoils were intact and no obvious thermal distress or damage was observed on any of the airfoils. No destructive evaluations of the second stage turbine wheel were conducted.

Turbine Tie Bolt and Nut

Visual Examination

The turbine tie bolt and nut used to clamp the first and second stage turbine wheels are shown in Figure 71. The OD surface of the tie bolt head was damaged as well as the forward portion of the turbine splined adapter splines (Figure 72). Multiple diagonal cracks were also evident on the drive side of the turbine splined adapter splines.

Power Turbine Inner Shaft

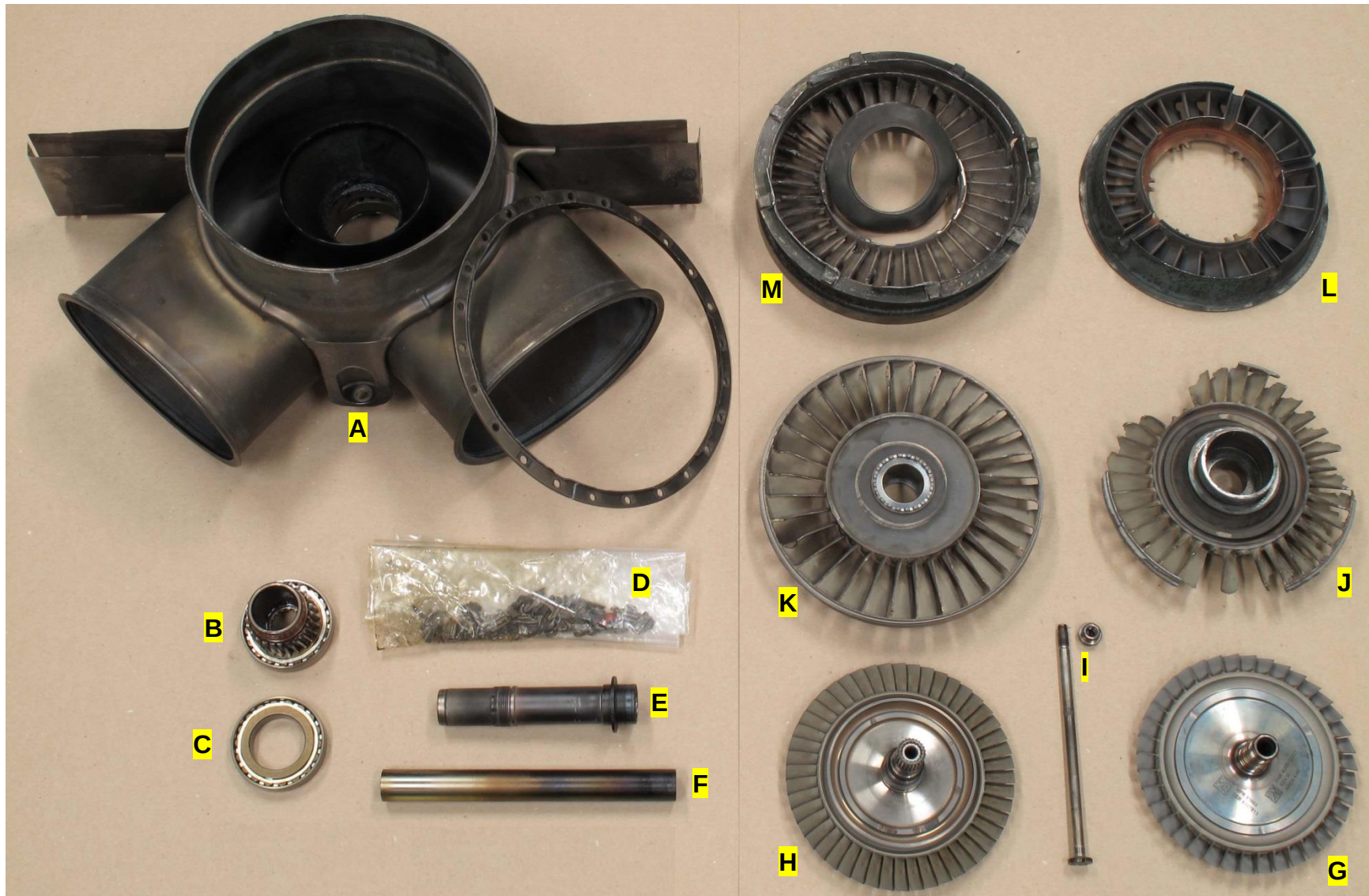
Visual Examination

The power turbine inner shaft is shown in Figure 73. A few rub marks were observed on the OD of the shaft. The ID surface of the shaft at the aft end was scored as shown in Figure 74 through Figure 76. No destructive evaluations of the shaft were conducted.

Turbine to Compressor Coupling

Visual Examination

The turbine to compressor coupling is shown in Figure 77. Score marks were observed on the OD surface at the aft end of the shaft and on the aft face. The internal splines showed no evidence of cracking or torsional deformation. No destructive evaluations of the coupling were conducted.



(A) exhaust collector assembly, (B) pinion gear and No. 3 bearing, (C) No. 4 bearing, (D) fragments, (E) power turbine inner shaft, (F) turbine to compressor coupling, (G) first stage turbine wheel, (H) second stage turbine wheel, (I) turbine tie bolt and nut, (J) third stage turbine wheel, (K) fourth stage turbine wheel, (L) third stage turbine nozzle, (M) fourth stage turbine nozzle

Figure 1. Photograph showing the as-received condition of the engine components submitted to the laboratory.

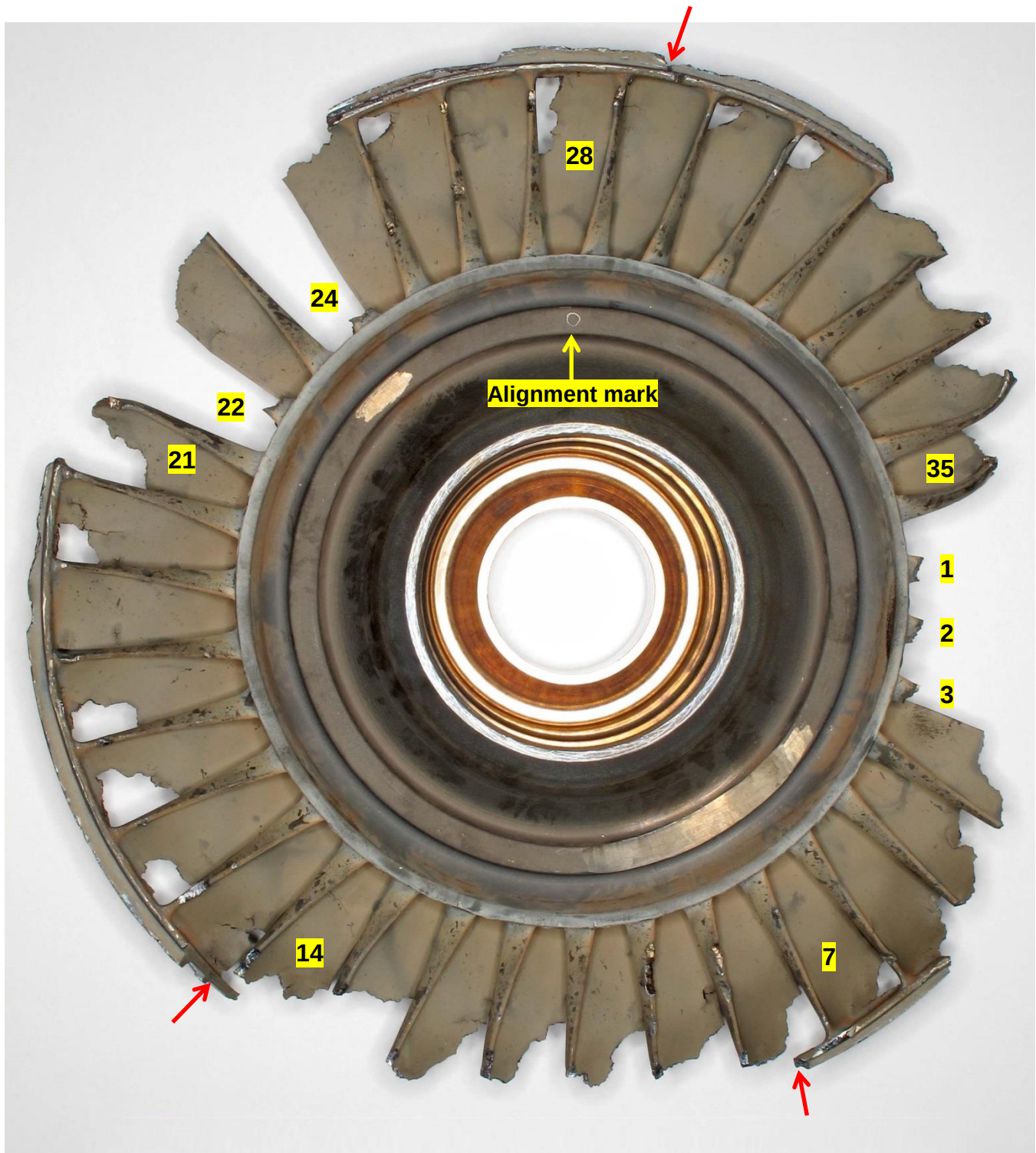


Figure 2. Aft looking forward view of the third stage turbine wheel. Airfoil Nos. 1, 2, 3, 22, and 24 were liberated. The arrows point to the slot locations in the shroud.

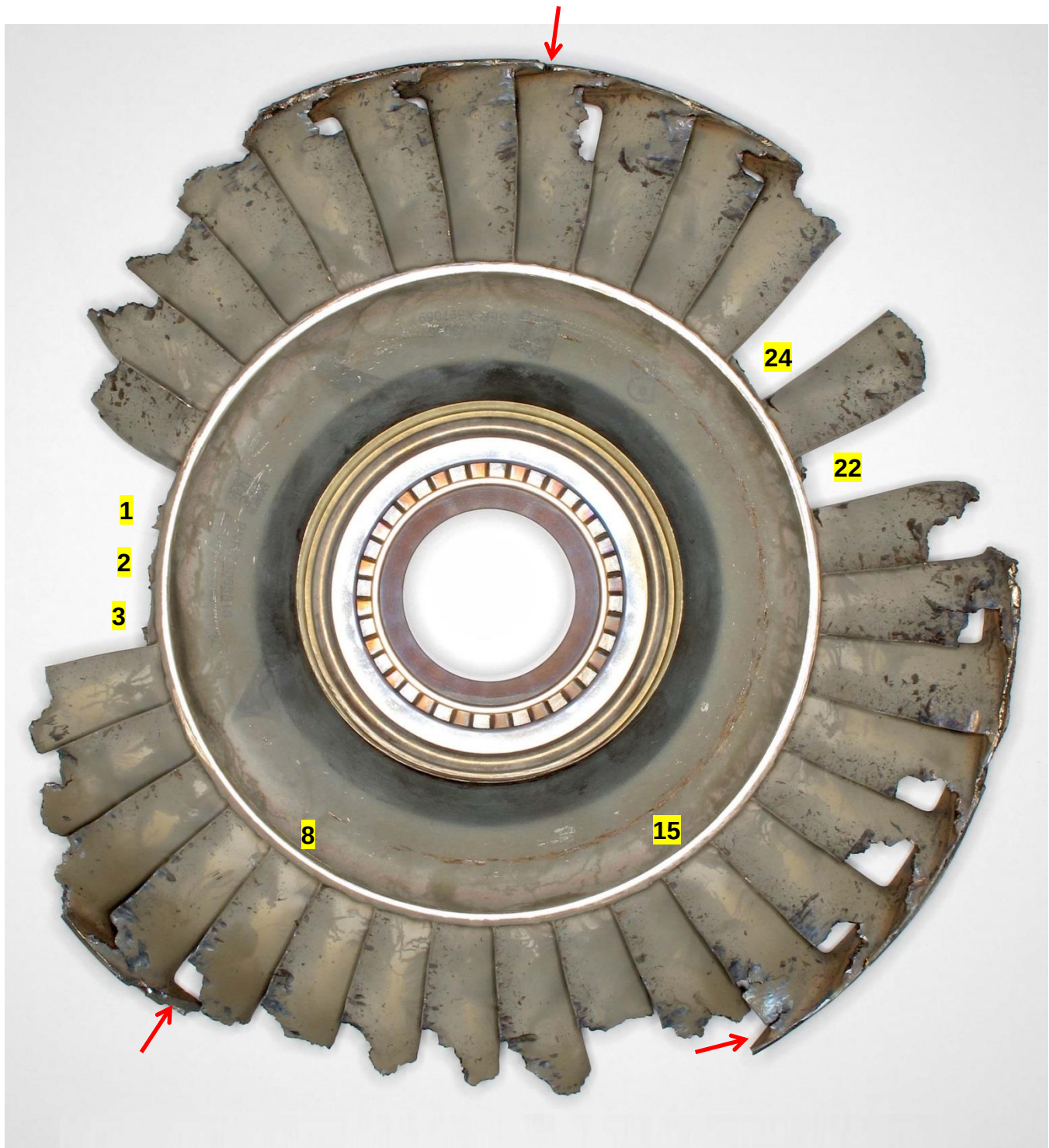
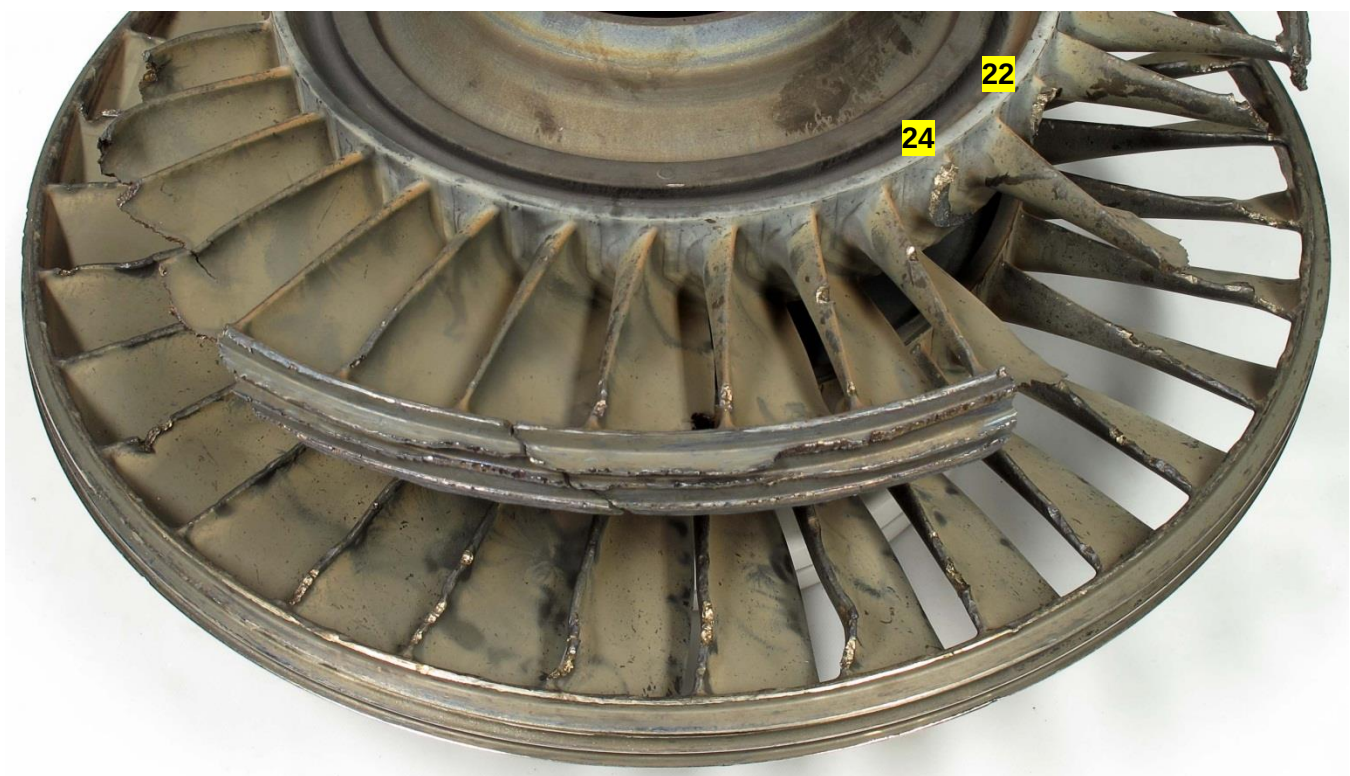
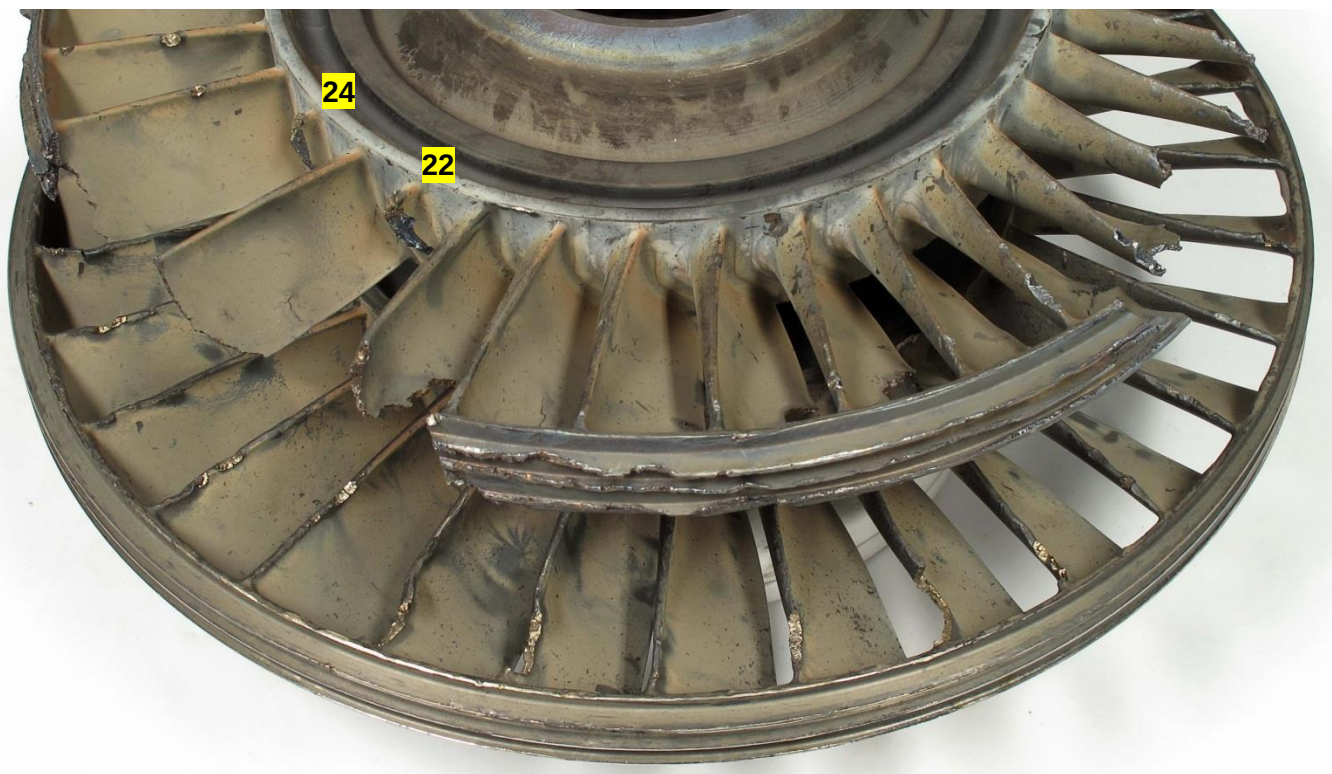


Figure 3. Forward looking aft view of the third stage turbine wheel. The arrows point to the slot locations in the shroud. Rim cracks were observed at airfoil Nos. 8 and 15.



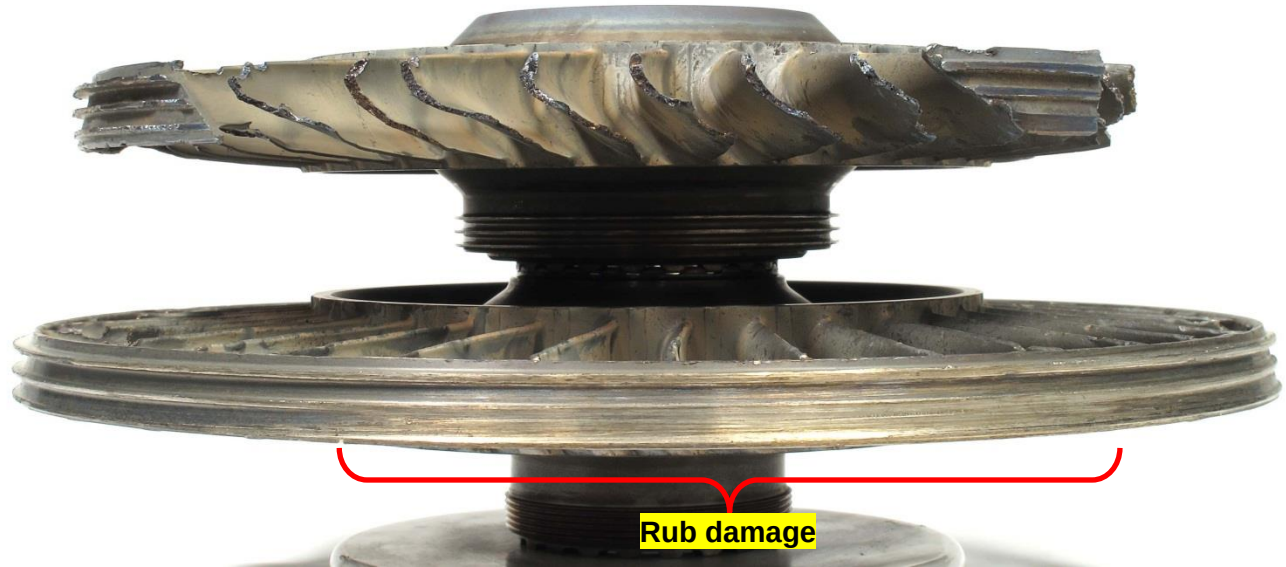
0-degrees

Figure 4. Photographs of the third and fourth stage turbine wheels positioned together based on the alignment marks on the hub.



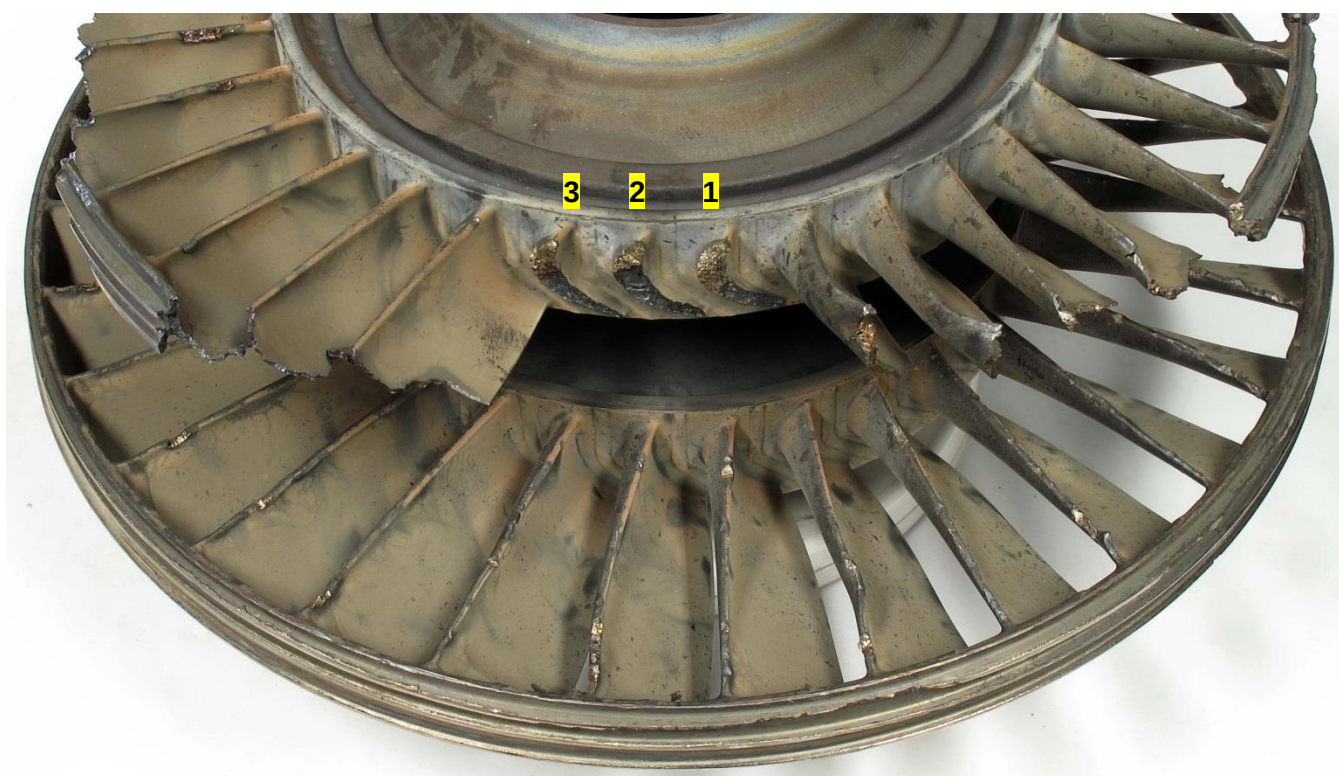
90-degrees

Figure 5. Photographs of the third and fourth stage turbine wheels positioned together based on the alignment marks on the hub.



180-degrees

Figure 6. Photographs of the third and fourth stage turbine wheels positioned together based on the alignment marks on the hub.



270-degrees

Figure 7. Photographs of the third and fourth stage turbine wheels positioned together based on the alignment marks on the hub.

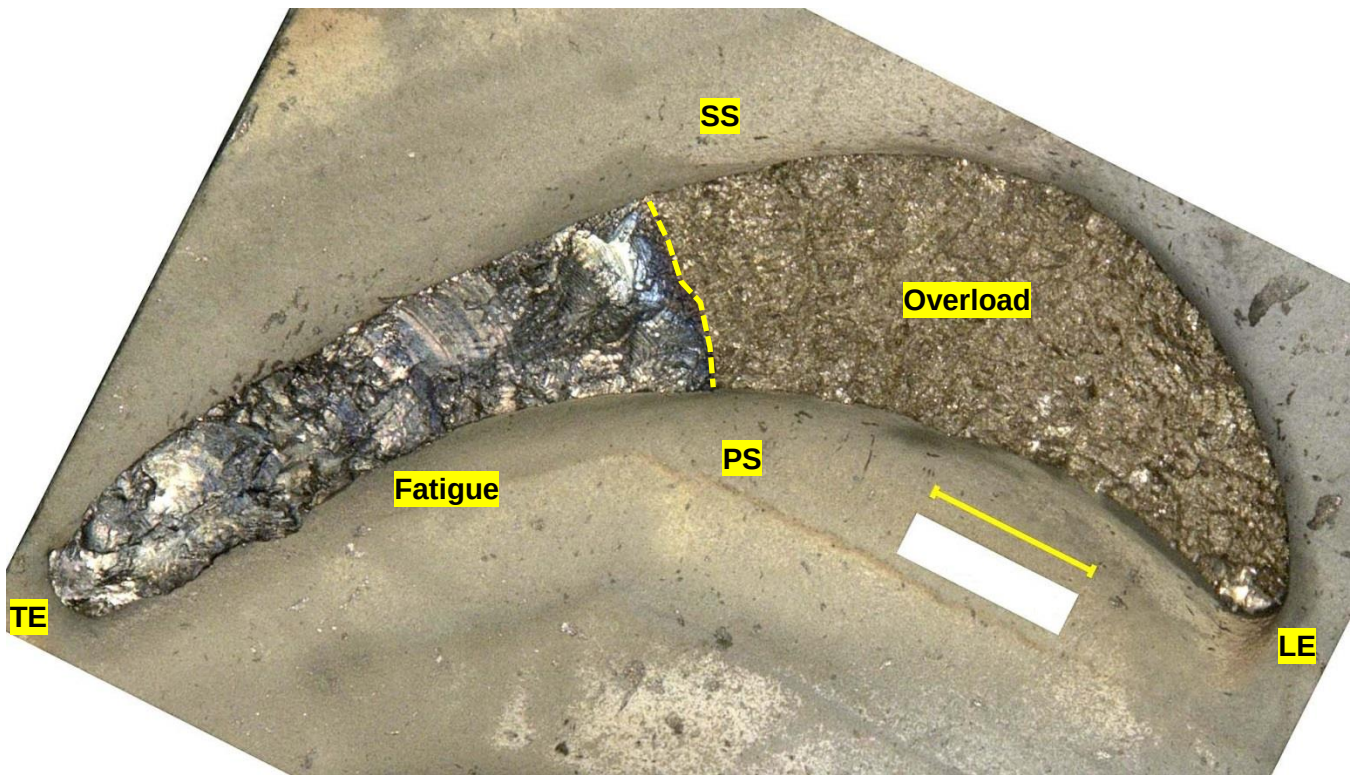


Figure 8. Photographs showing the fractured third stage turbine wheel airfoil No. 1.

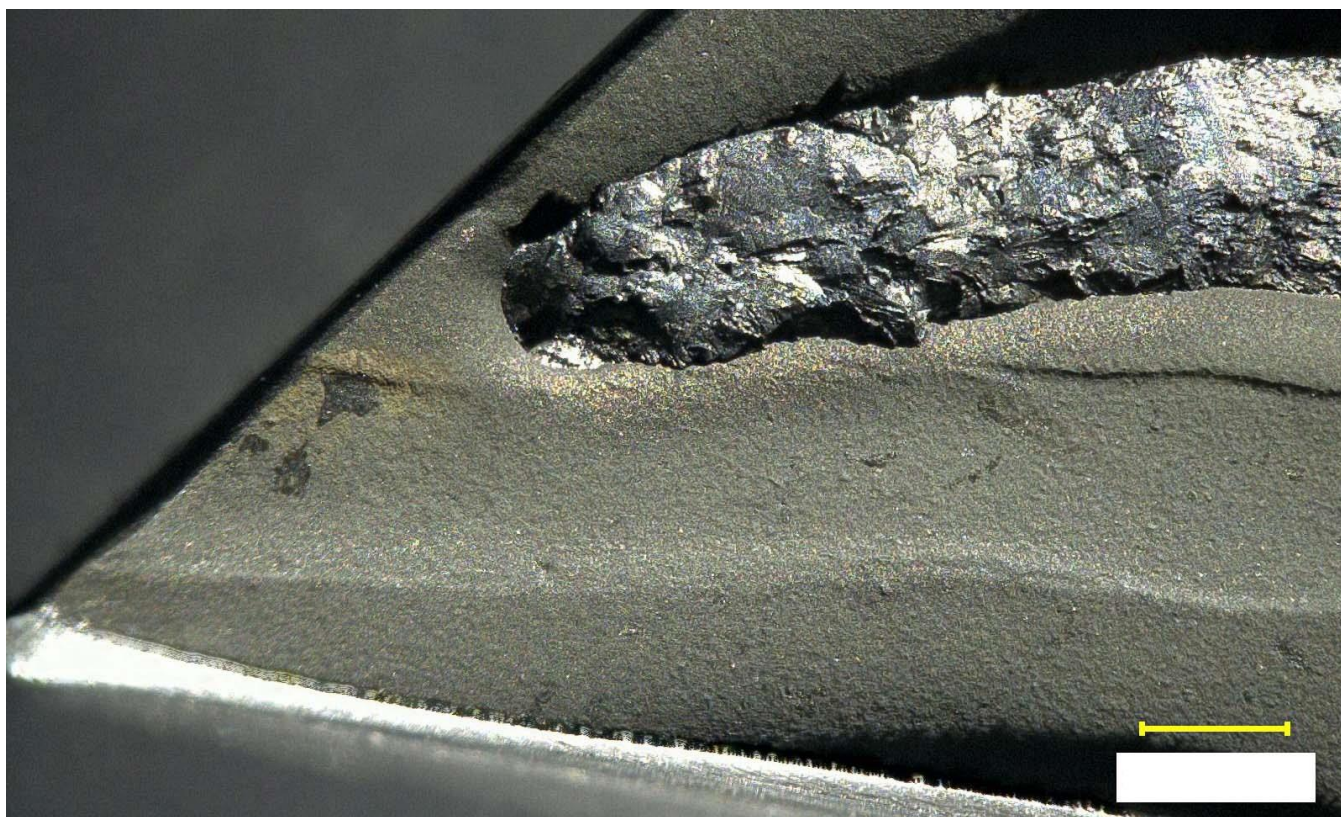


Figure 9. Low angle lighting showing the casting wax weld adjacent to the airfoil No. 1 trailing edge.

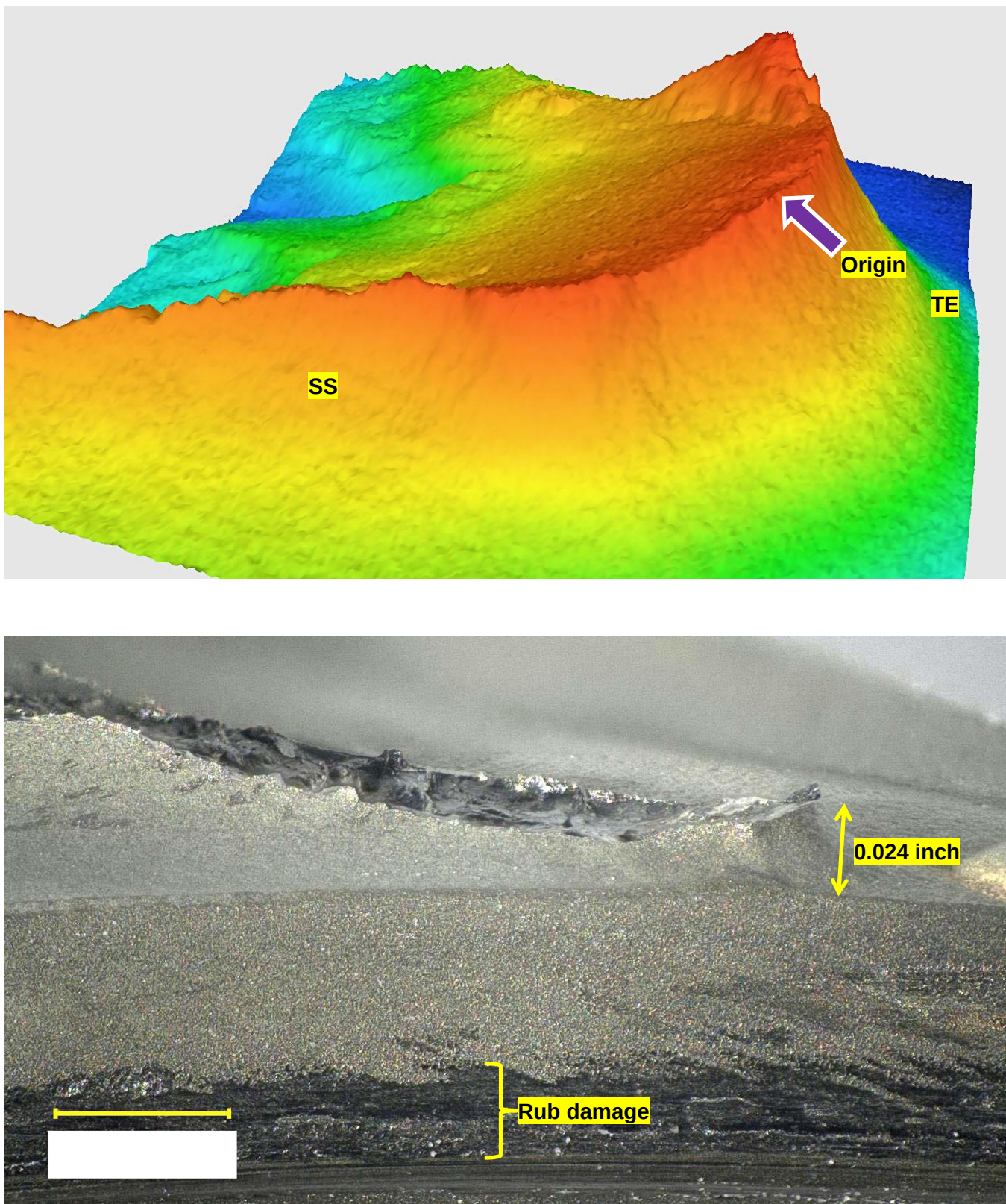


Figure 10. The lower image shows a view perpendicular to the trailing edge rim face of the airfoil No. 1 fracture. The upper image was generated with a confocal laser scanning microscope (CLSM) showing the orientation of the fatigue crack. Note the rub damage on the rim face.

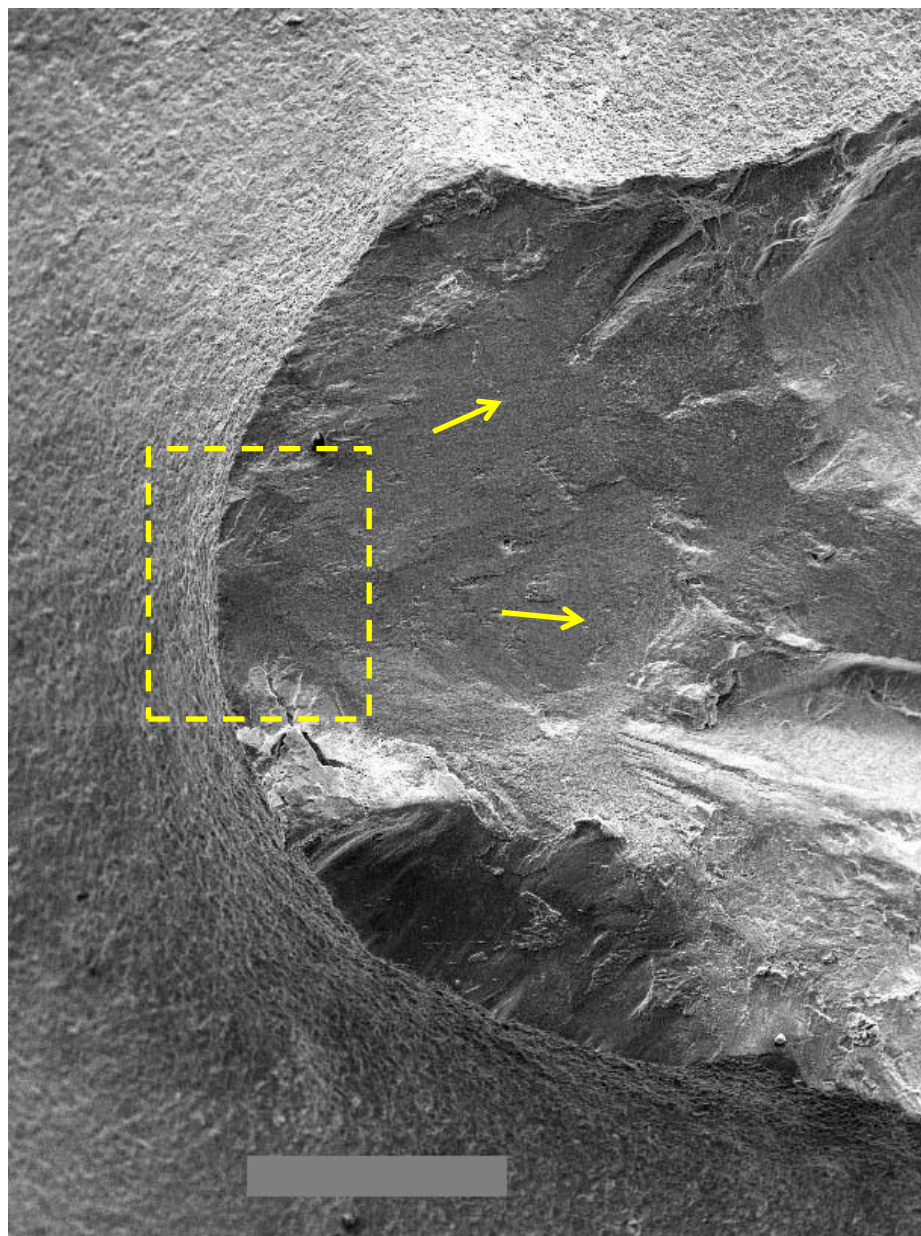


Figure 11. SEM photograph of the airfoil No. 1 crack origin area. The arrows show the crack propagation directions. Detailed views of the fatigue origin are shown in the following figures.

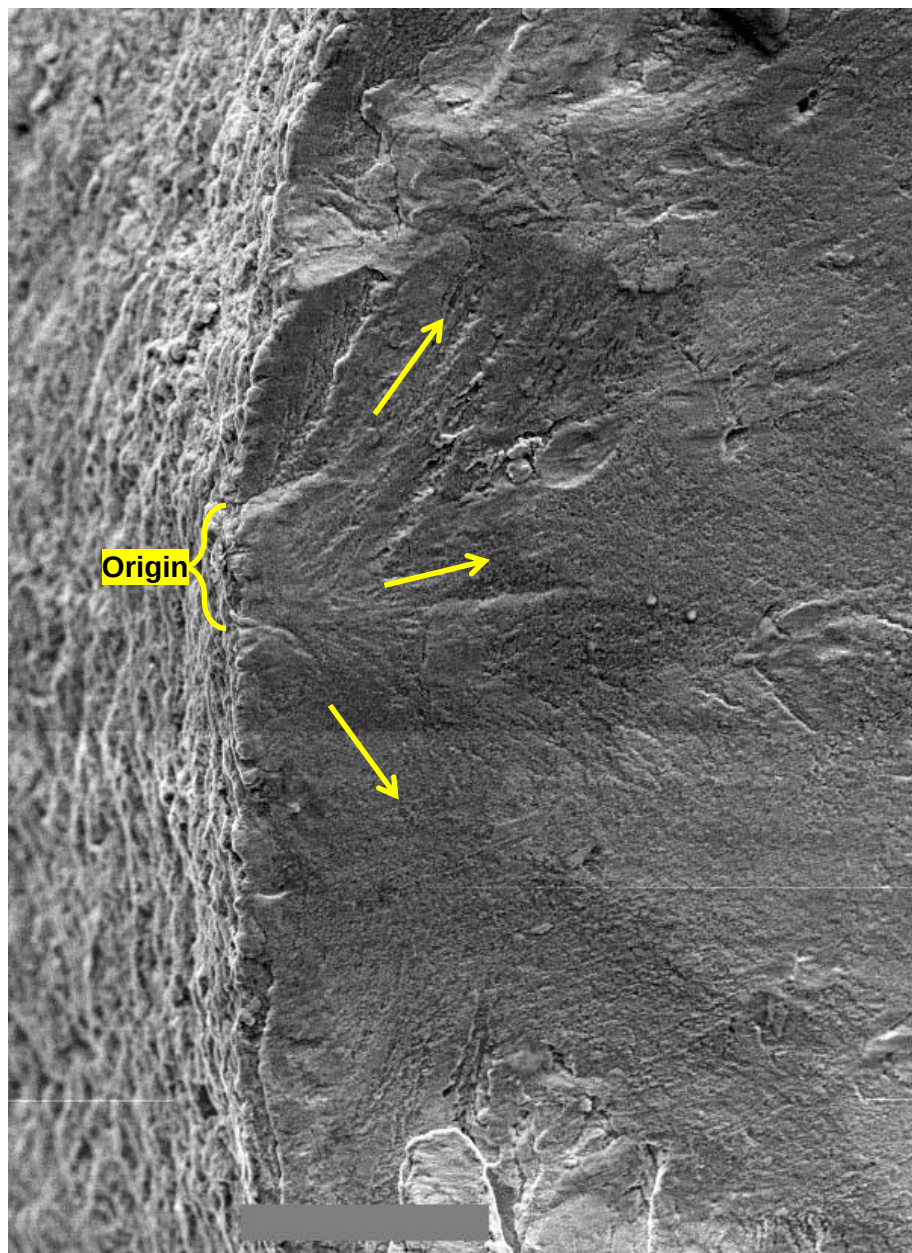


Figure 12. SEM photograph of the airfoil No. 1 crack origin area. The arrows show the crack propagation directions. A detailed view of the fatigue origin is shown in the following figure.

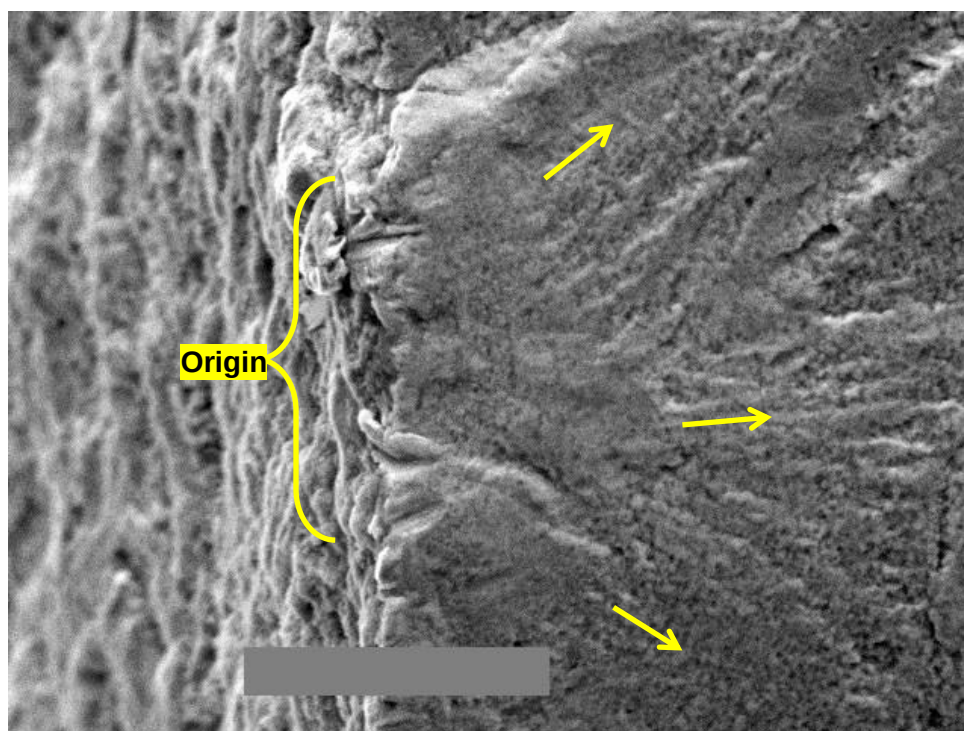
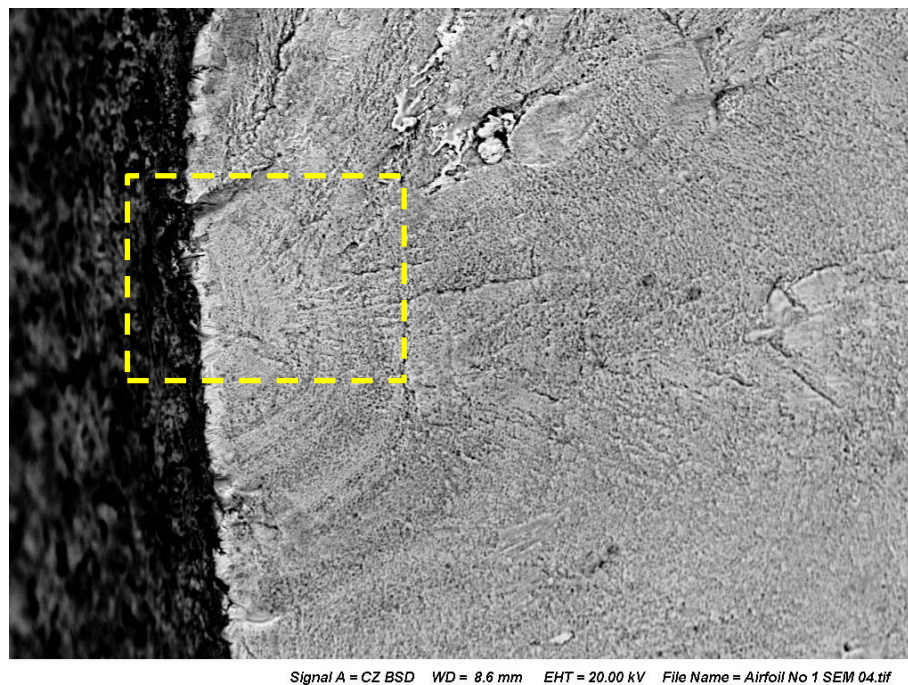


Figure 13. Detailed views of the airfoil No. 1 fatigue origin. The upper photograph is a backscatter image.

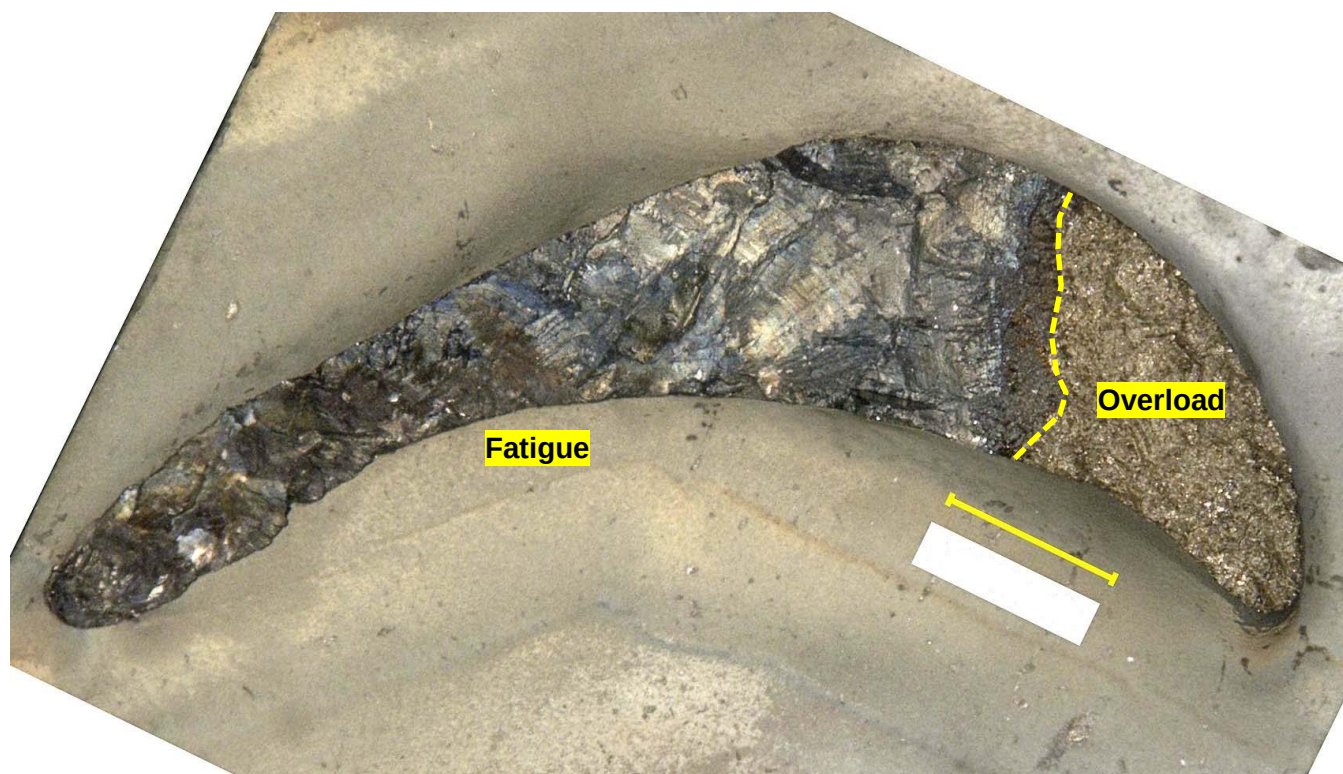


Figure 14. Photographs showing the fractured third stage turbine wheel airfoil No. 2.



Figure 15. Low angle lighting showing the casting wax weld adjacent to the airfoil No. 2 trailing edge.

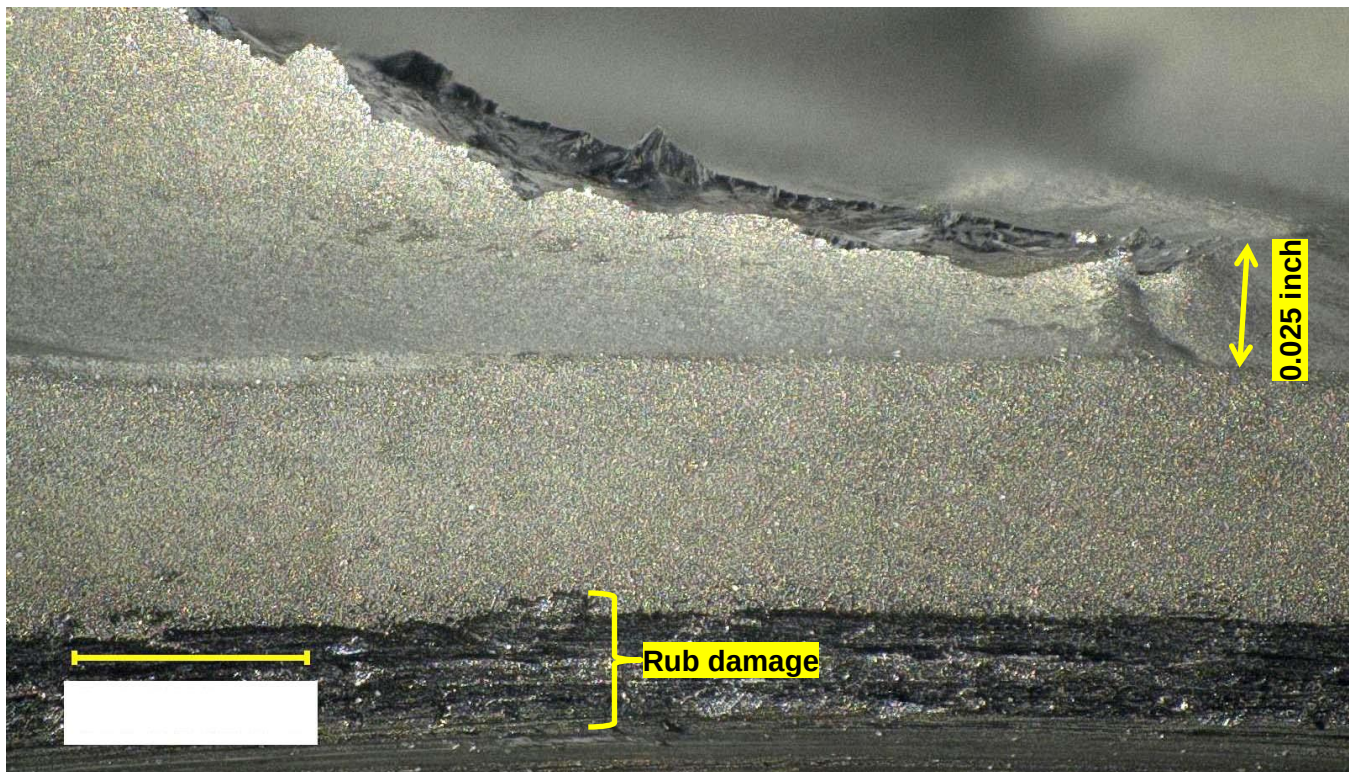
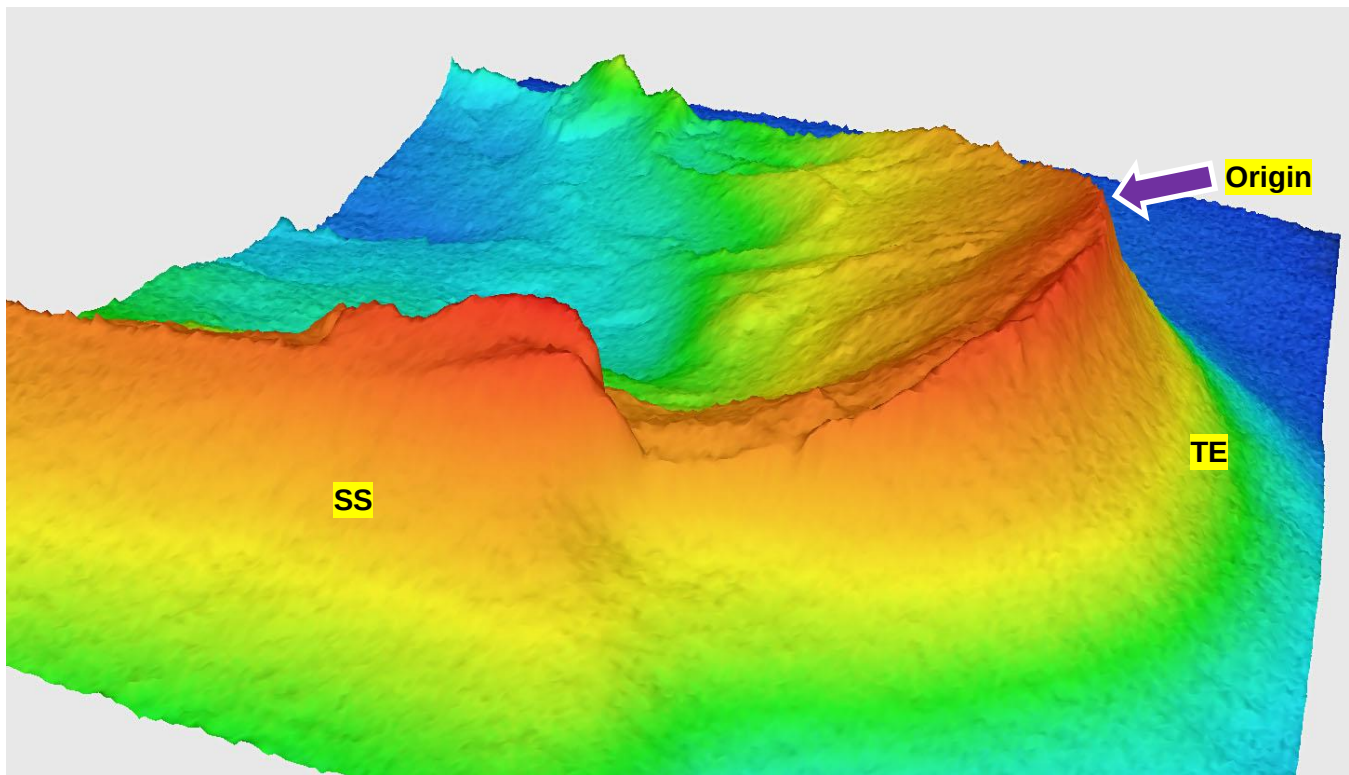


Figure 16. The lower image shows a view perpendicular to the rim face of the airfoil No. 2 fracture. The upper image was generated with a CLSM showing the orientation of the fatigue crack. Note the rub damage on the rim face.

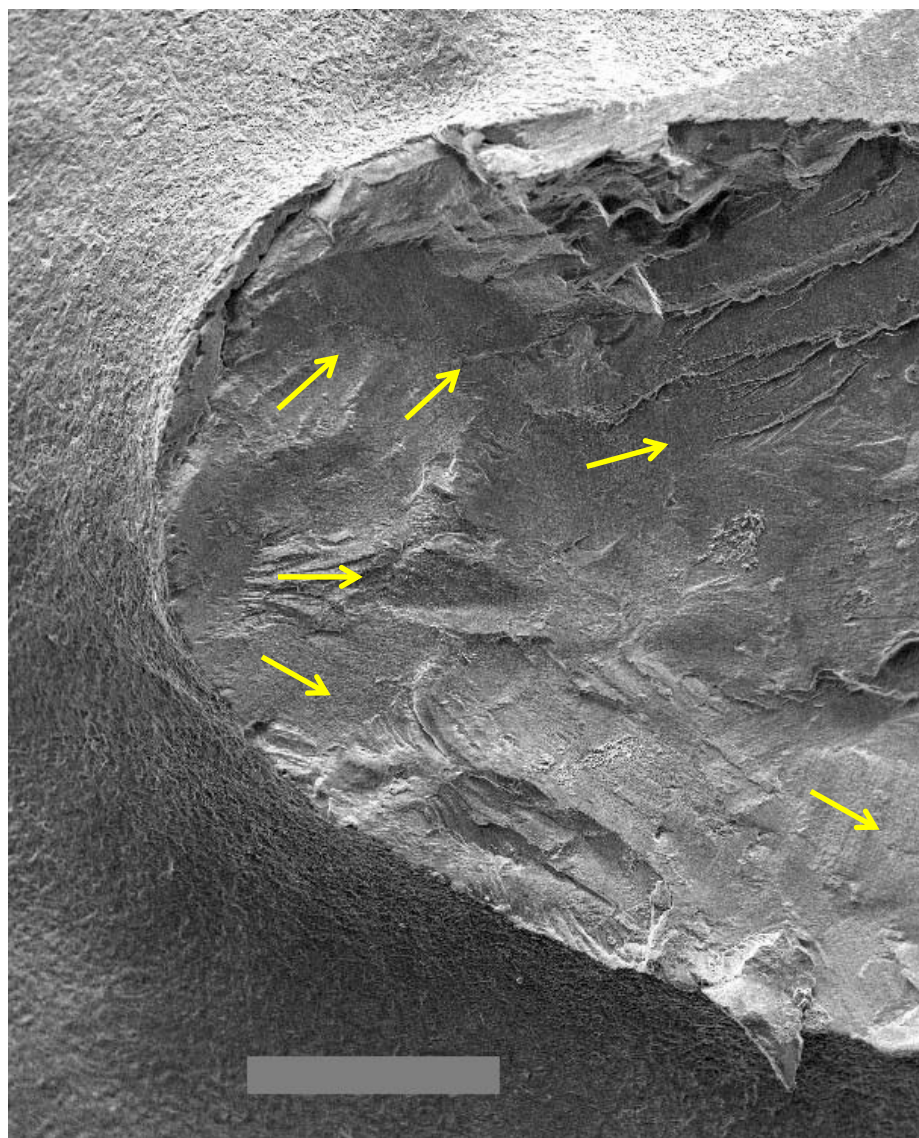


Figure 17. SEM photograph of the airfoil No. 2 crack origin area. The arrows show the crack propagation directions. A detailed view of the fatigue origin is shown in the following figure.

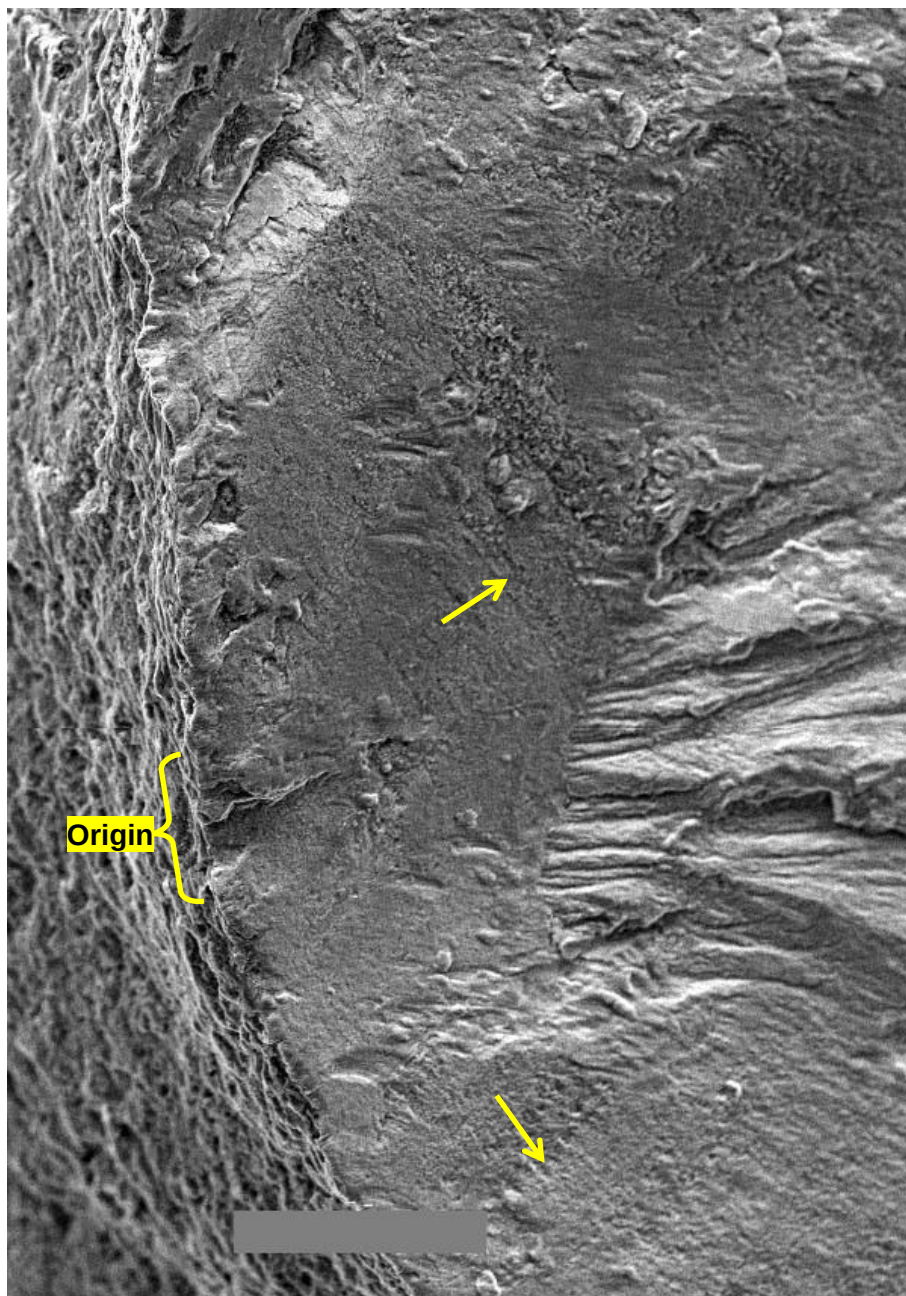
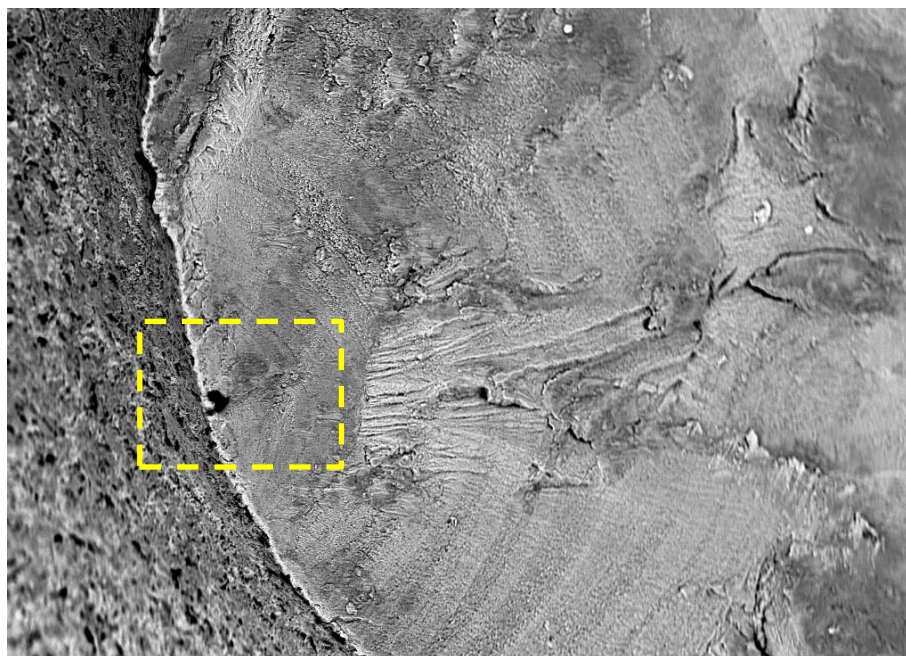
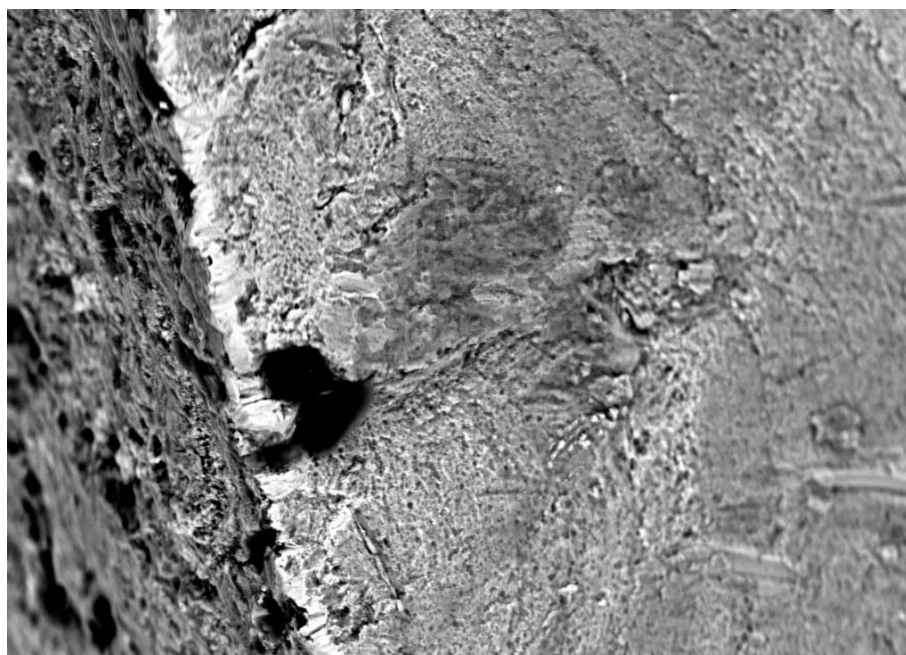


Figure 18. Detailed view of the airfoil No. 2 fatigue origin. The arrows show the crack propagation directions.



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Figure 19. Backscatter electron images of the airfoil No. 2 fatigue origin.

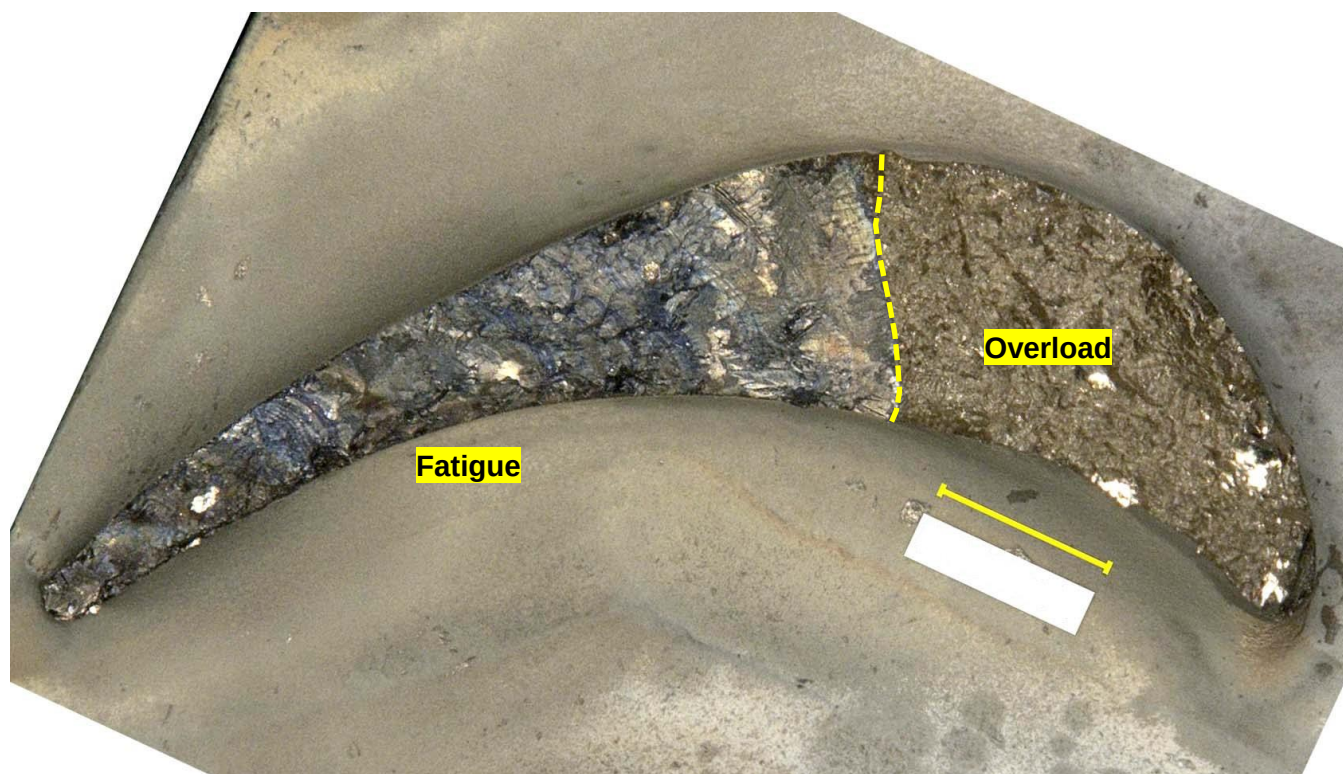


Figure 20. Photographs showing the fractured third stage turbine wheel airfoil No. 3.



Figure 21. Low angle lighting showing the casting wax weld adjacent to the airfoil No. 3 trailing edge.

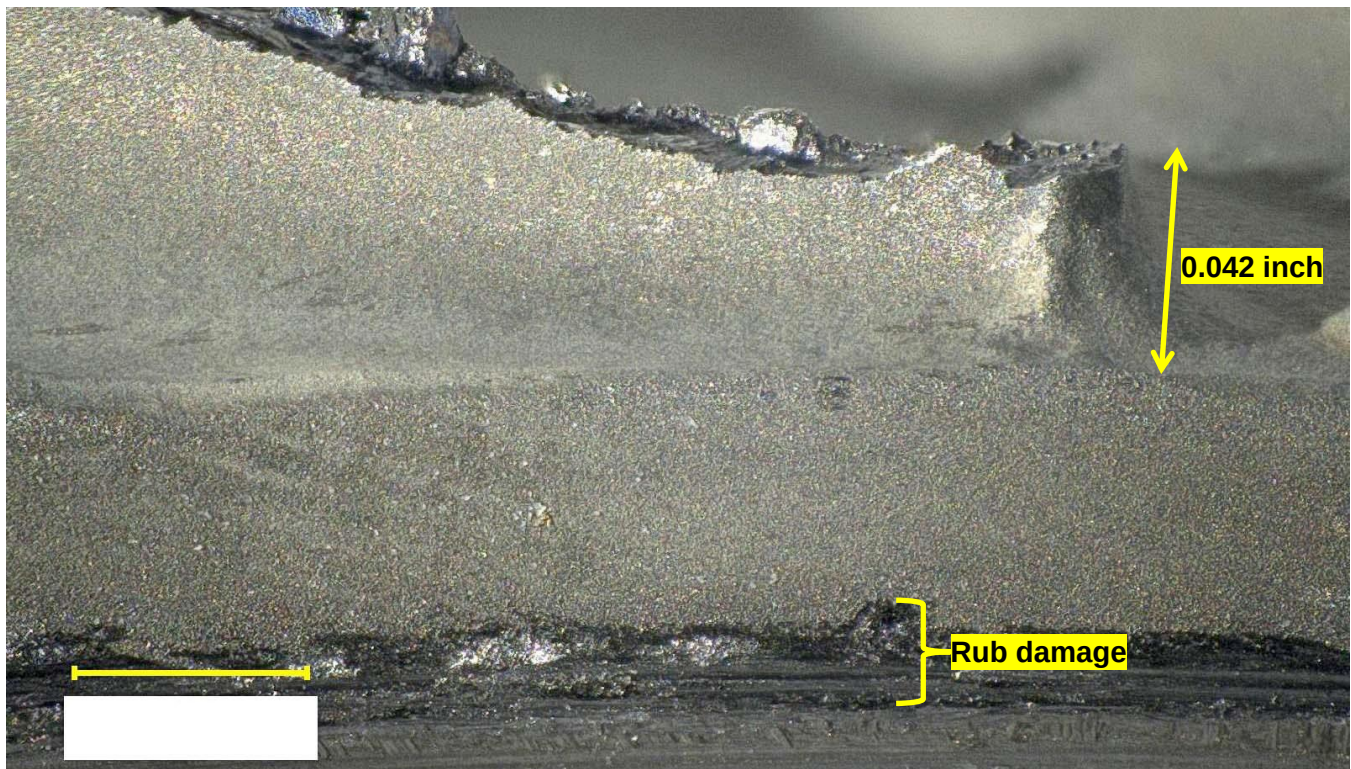
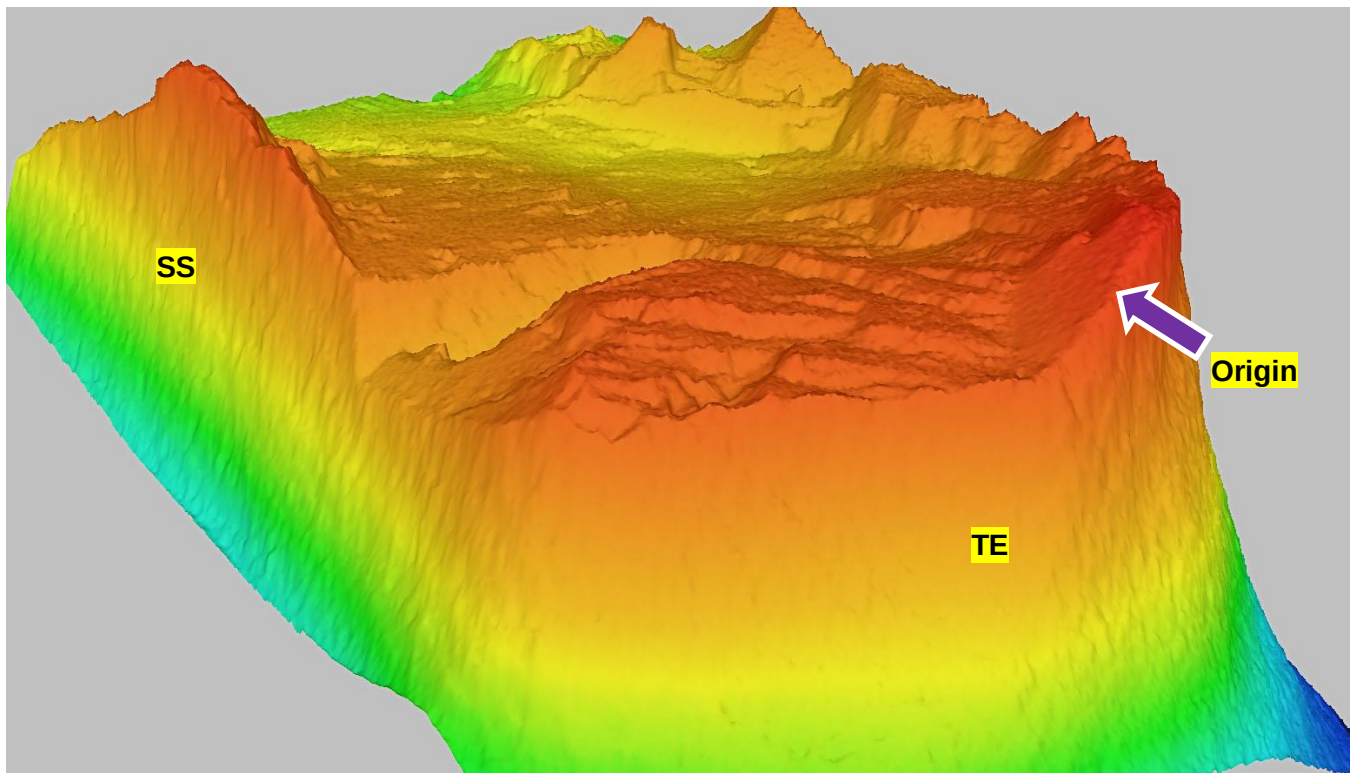


Figure 22. The lower image shows a view perpendicular to the rim face of the airfoil No. 3 fracture. The upper image was generated with a CLSM showing the orientation of the fatigue crack. Note the rub damage on the rim face.

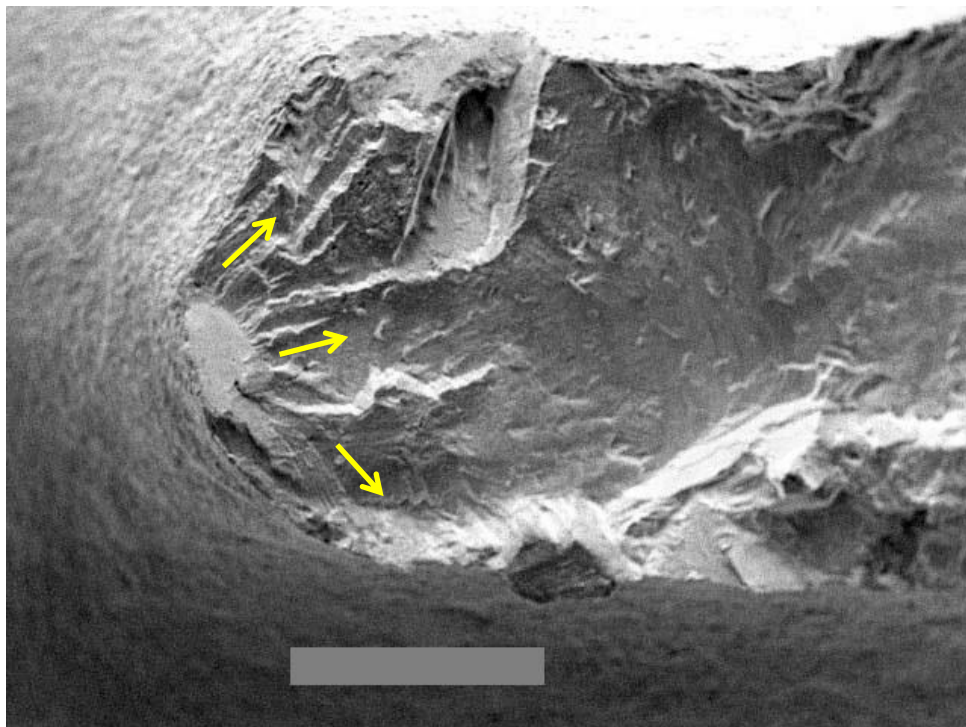


Figure 23. SEM photograph of the airfoil No. 3 crack origin area. The arrows show the crack propagation directions. A detailed view of the fatigue origin is shown in the following figure.

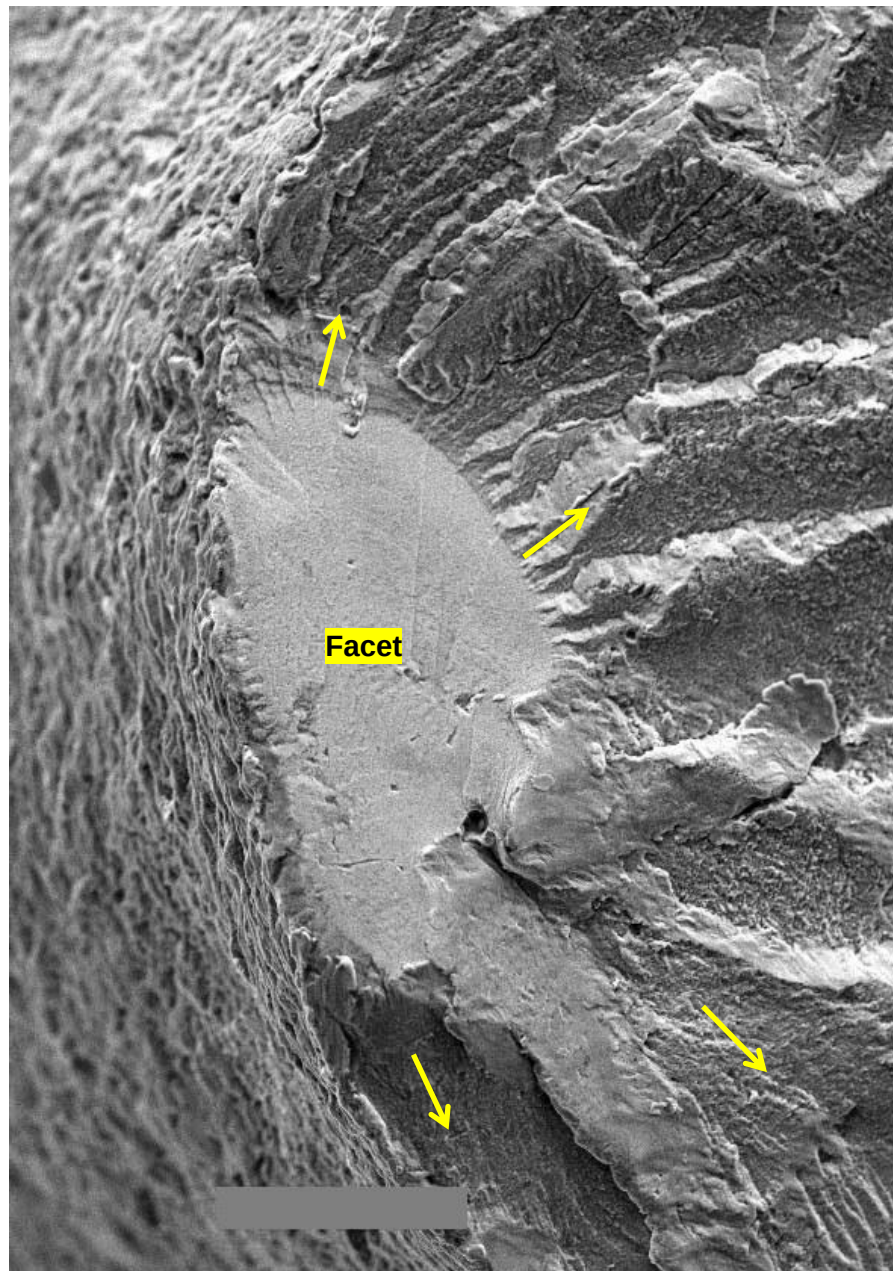
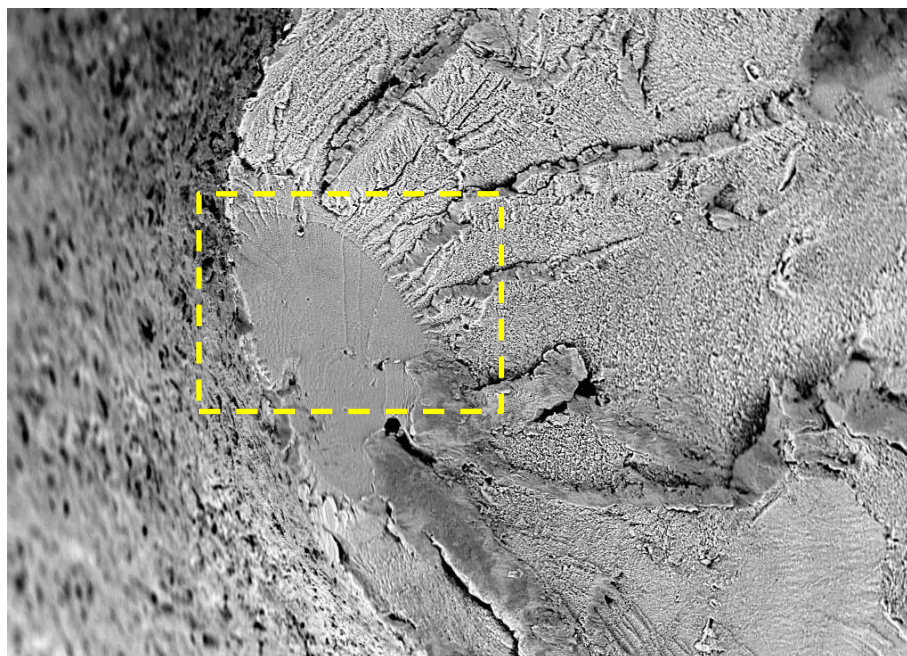
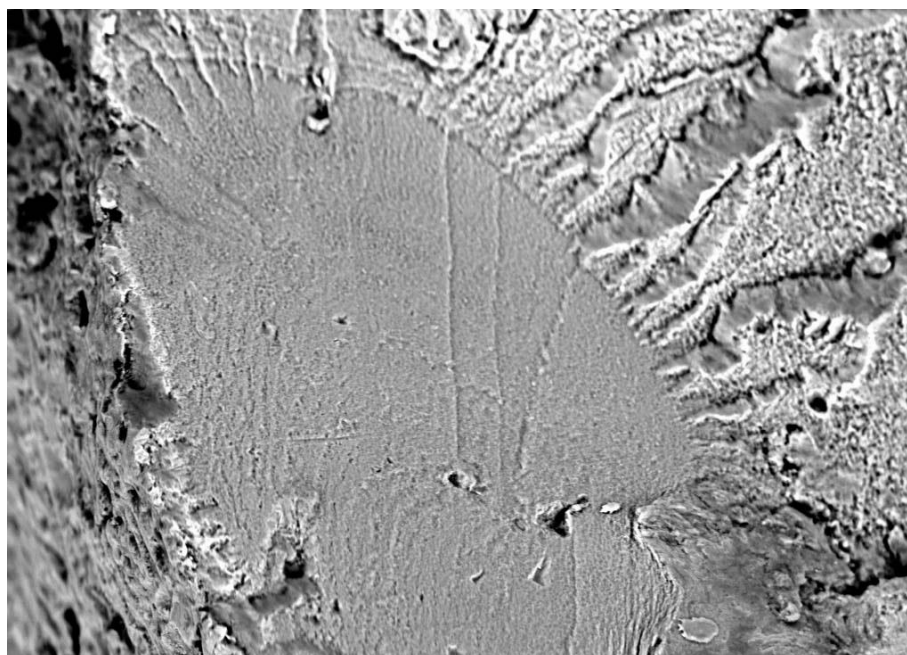


Figure 24. Detailed view of the airfoil No. 3 fatigue origin. The arrows show the crack propagation directions emanating from the facet.



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Figure 25. Backscatter electron images of the airfoil No. 3 fatigue origin.

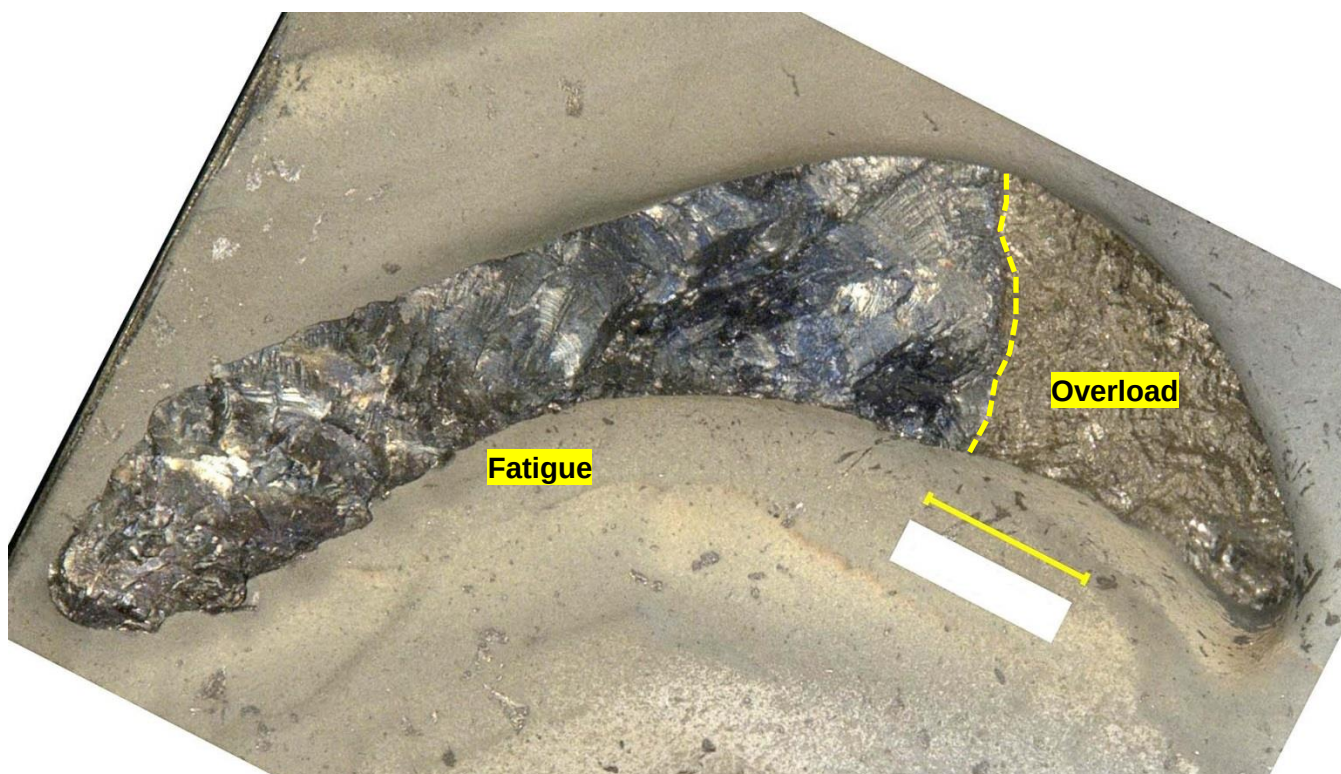


Figure 26. Photographs showing the fractured third stage turbine wheel airfoil No. 22.



Figure 27. Low angle lighting showing the casting wax weld adjacent to the airfoil No. 22 trailing edge.

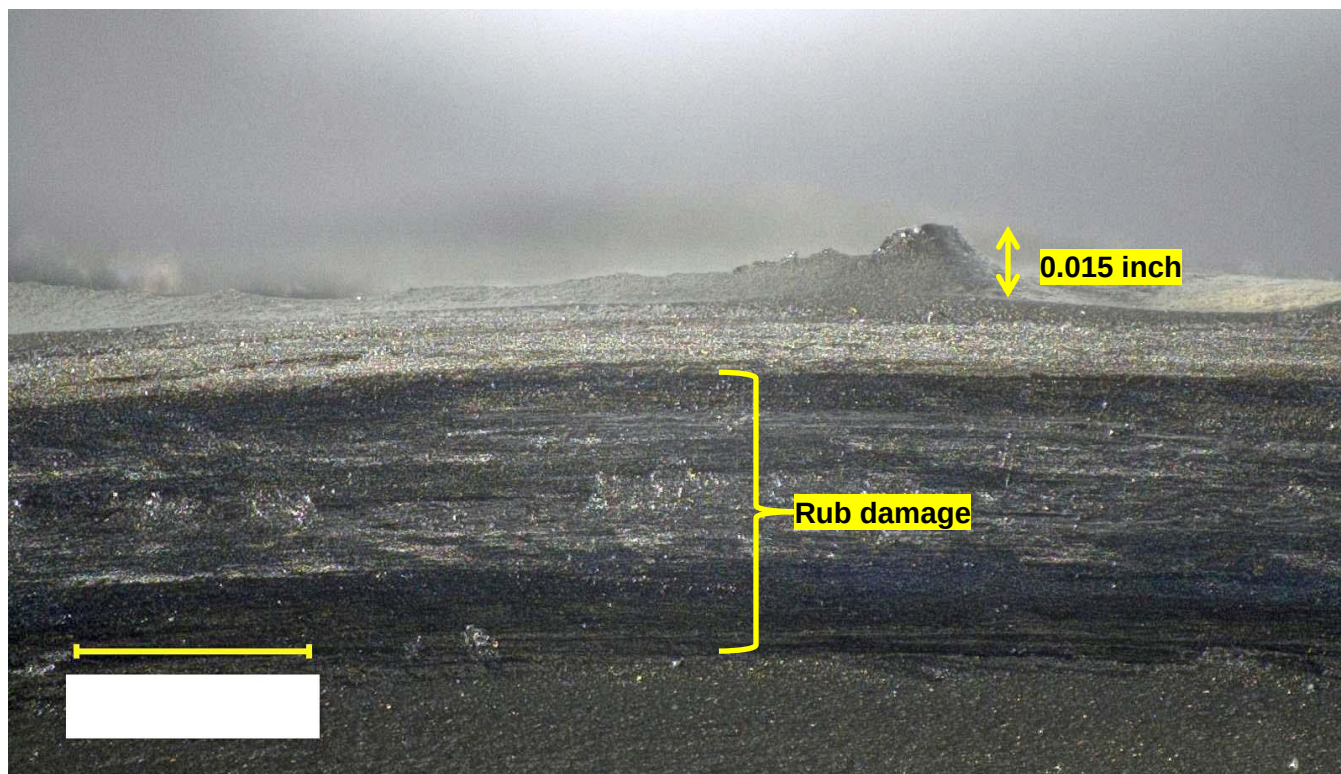
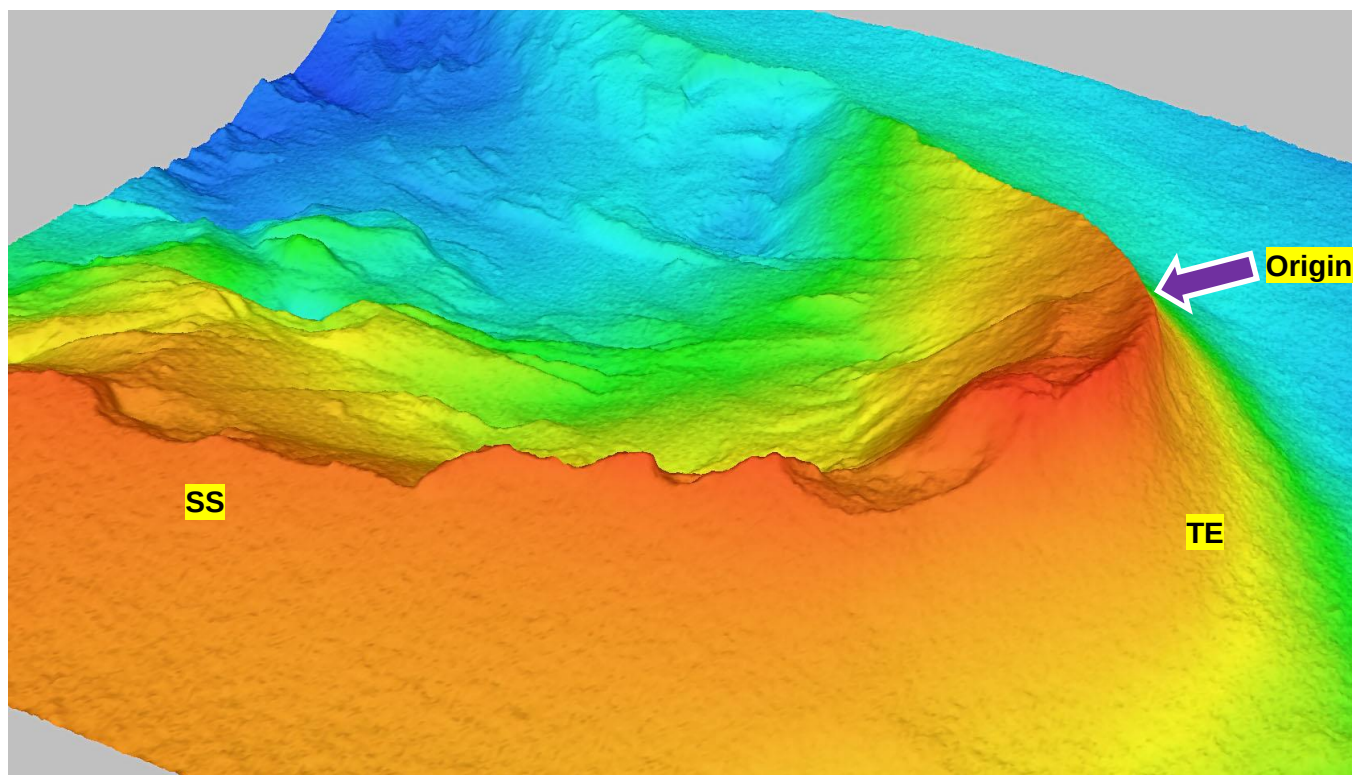


Figure 28. The lower image shows a view perpendicular to the rim face of the airfoil No. 22 fracture. The upper image was generated with a CLSM showing the orientation of the fatigue crack. Note the rub damage on the rim face.

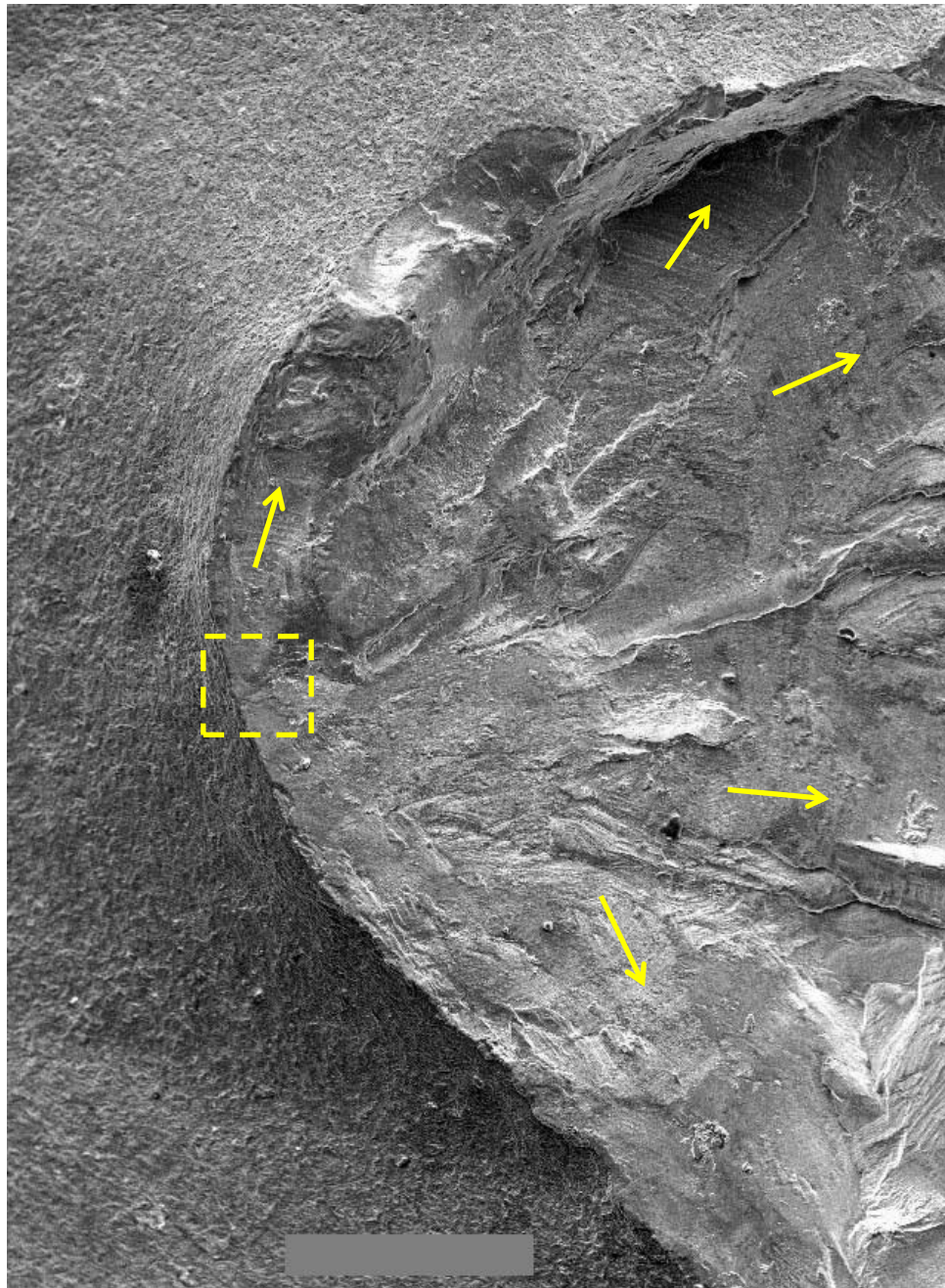


Figure 29. SEM photograph of the airfoil No. 22 crack origin area. The arrows show the crack propagation directions. Detailed views of the fatigue origin are shown in the following figure.

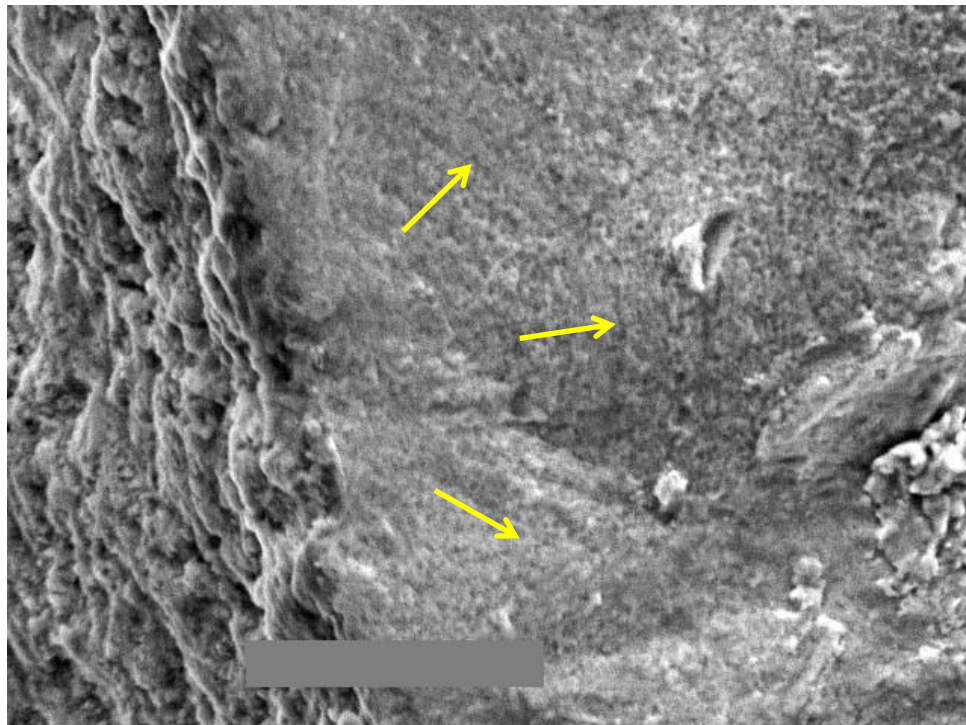
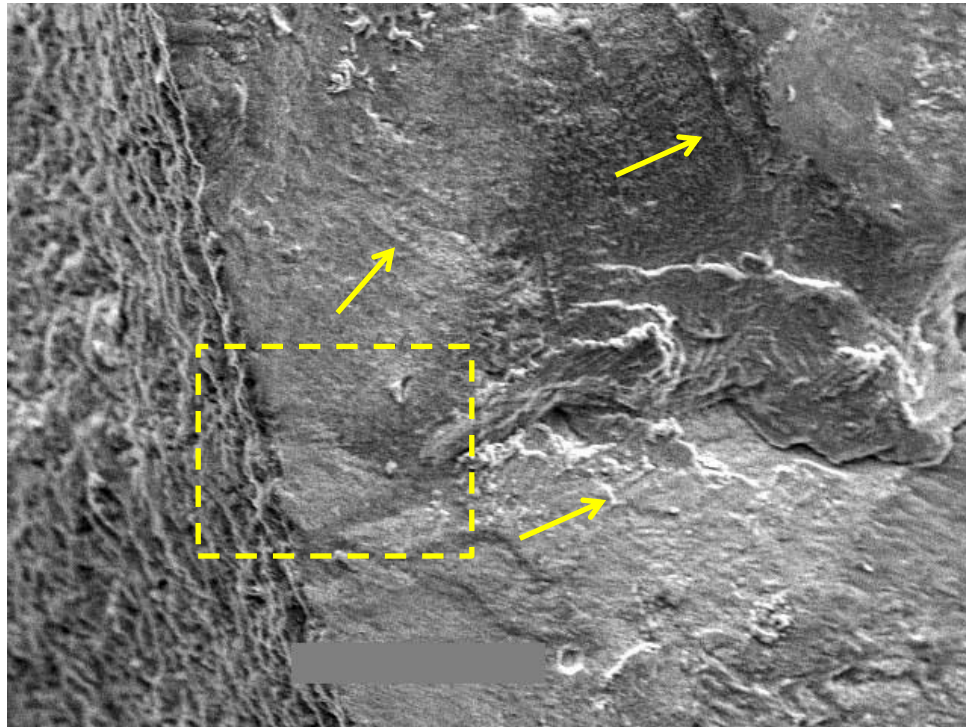
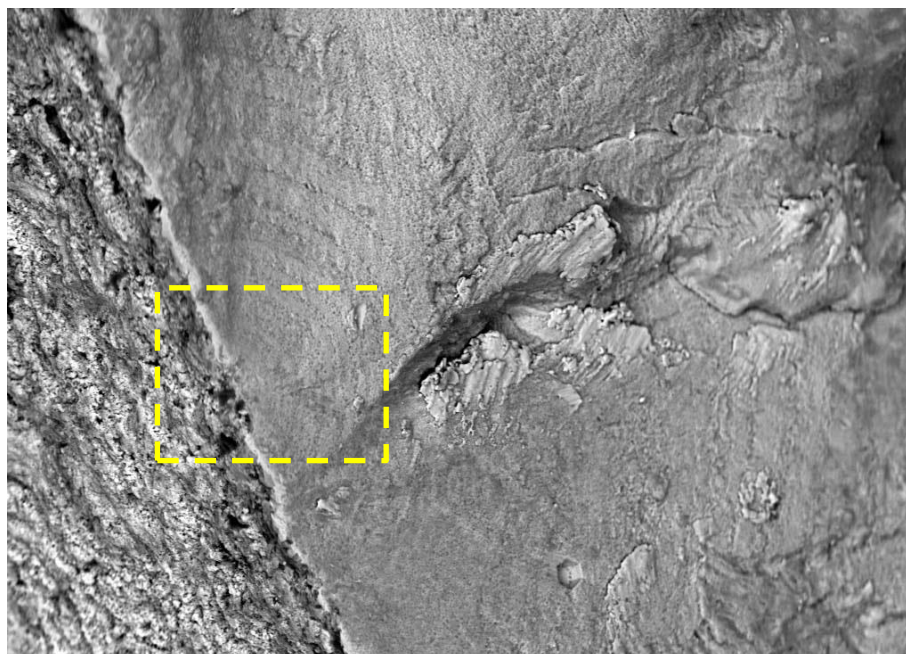
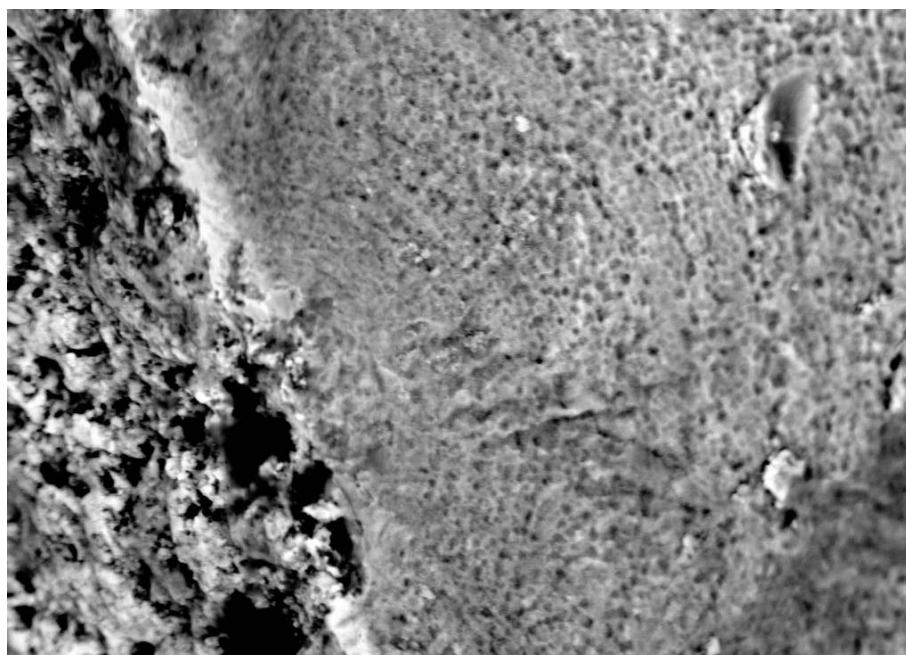


Figure 30. Detailed views of the airfoil No. 22 fatigue origin.



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Figure 31. Backscatter electron images of the airfoil No. 22 fatigue origin.

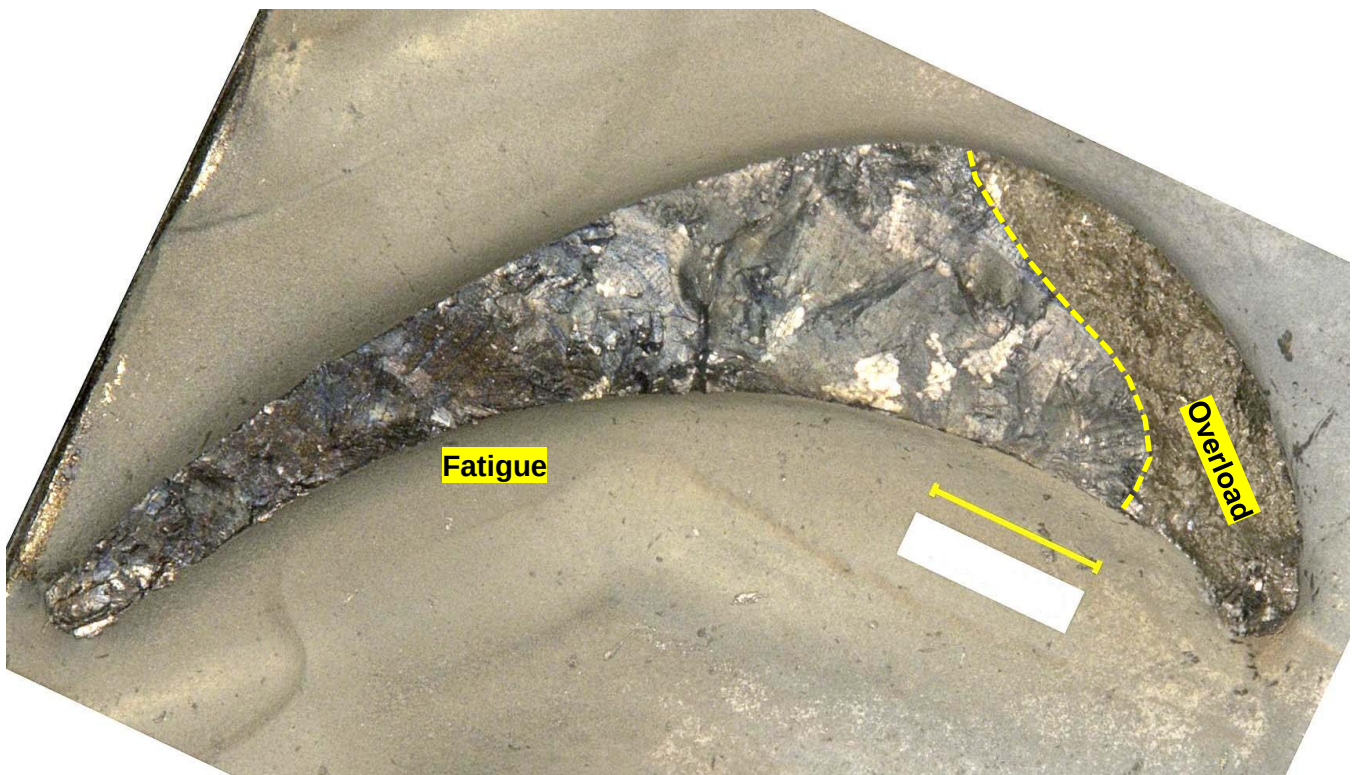


Figure 32. Photographs showing the fractured third stage turbine wheel airfoil No. 24.



Figure 33. Low angle lighting showing the casting wax weld adjacent to the airfoil No. 24 trailing edge.

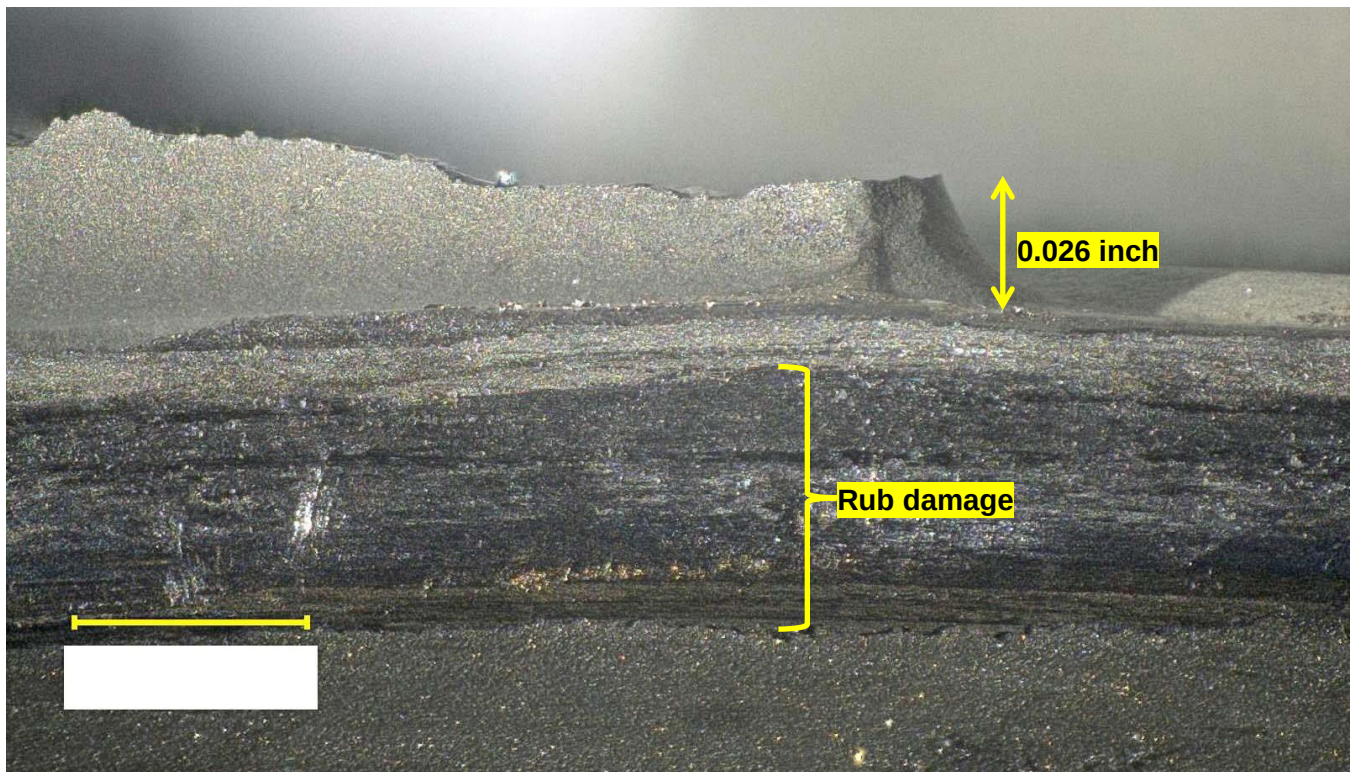
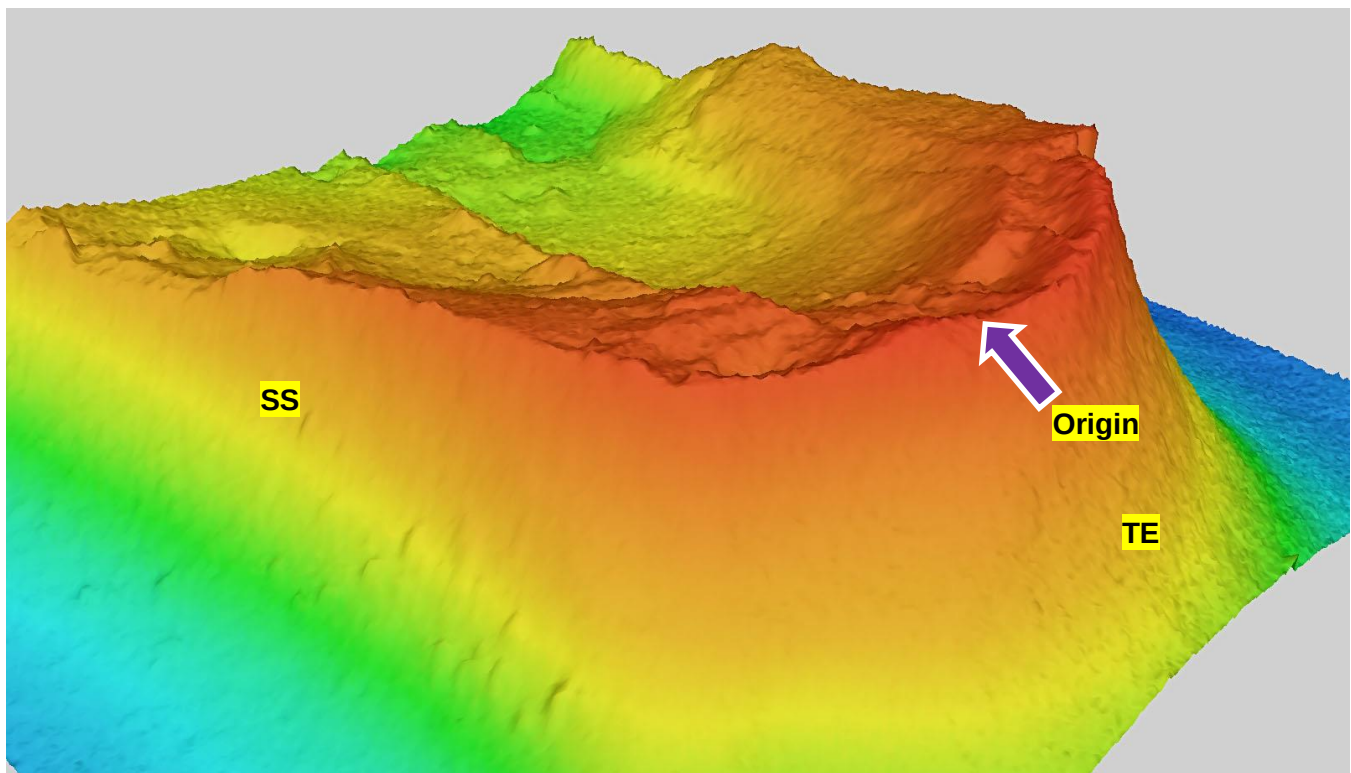


Figure 34. The lower image shows a view perpendicular to the rim face of the airfoil No. 24 fracture. The upper image was generated with a CLSM showing the orientation of the fatigue crack. Note the rub damage on the rim face.

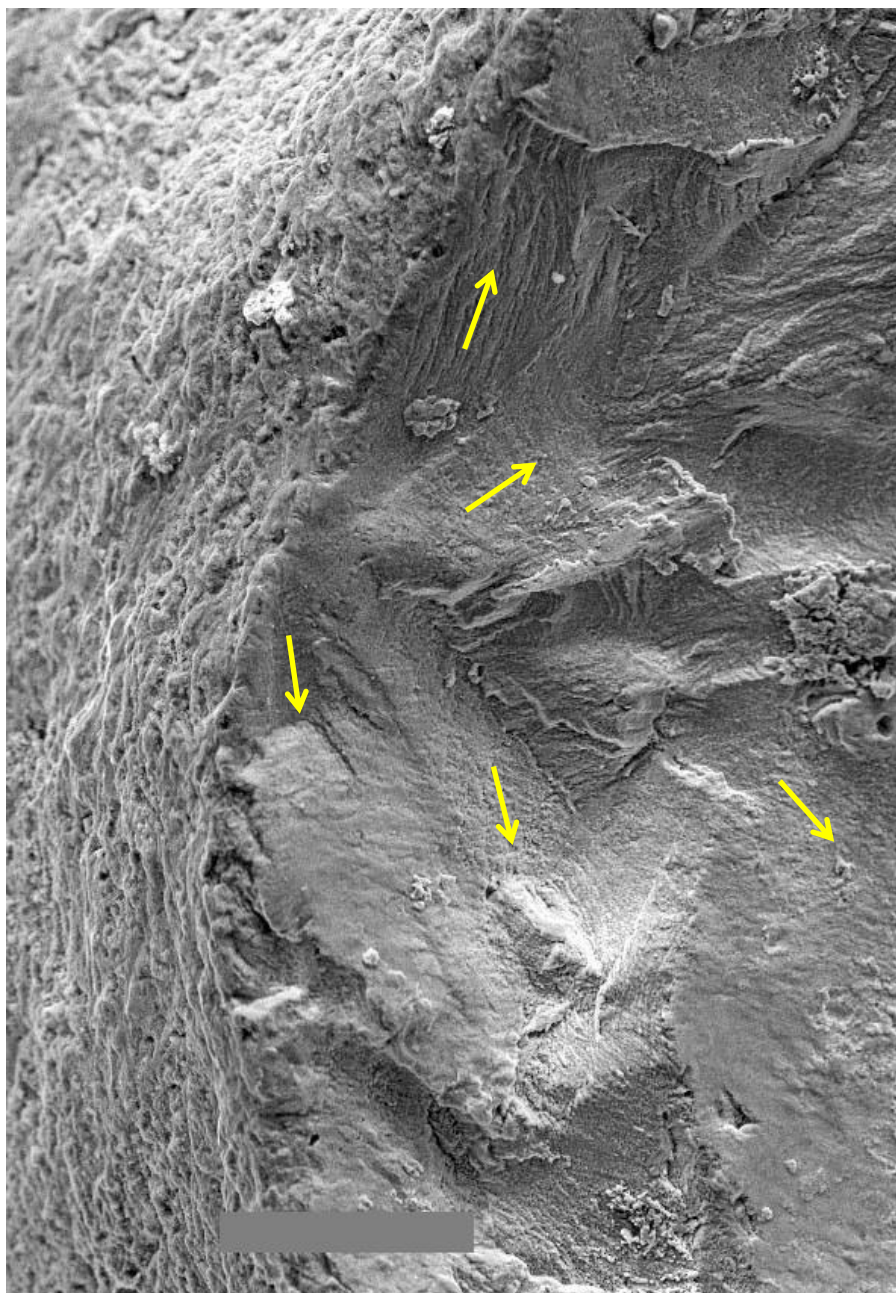


Figure 35. SEM photograph of the airfoil No. 24 crack origin area. The arrows show the crack propagation directions. A detailed view of the fatigue origin is shown in the following figure.

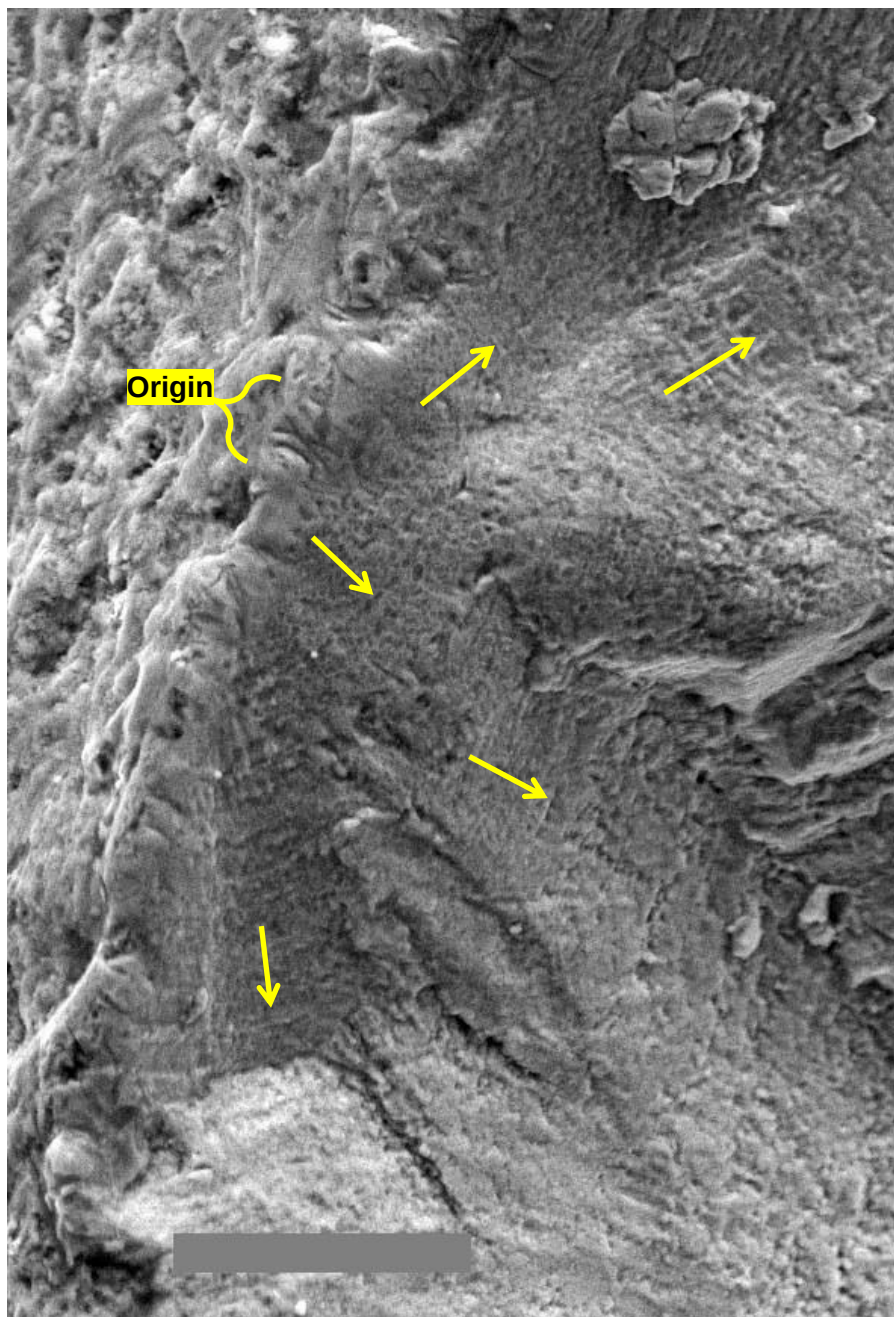
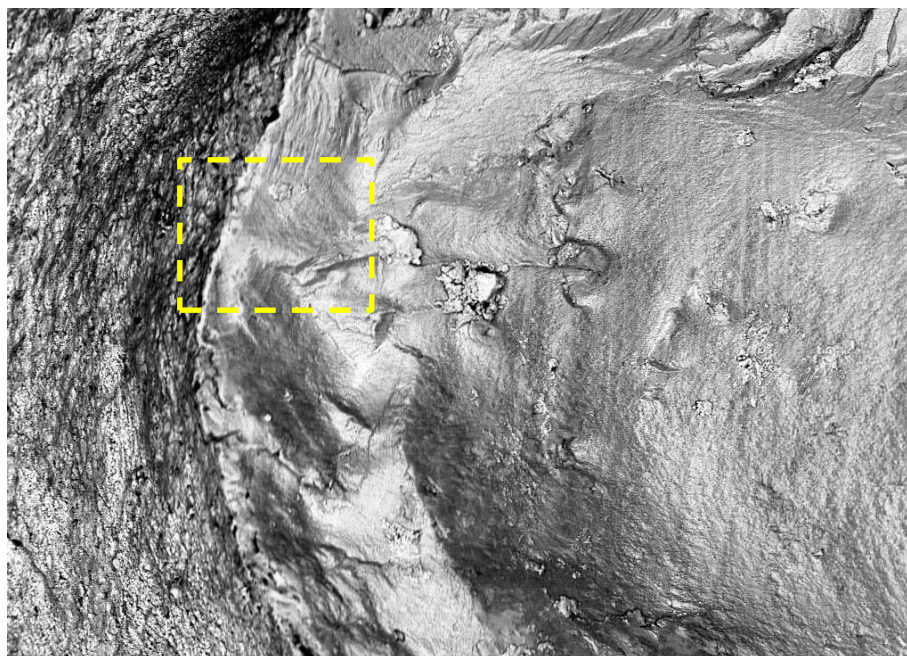
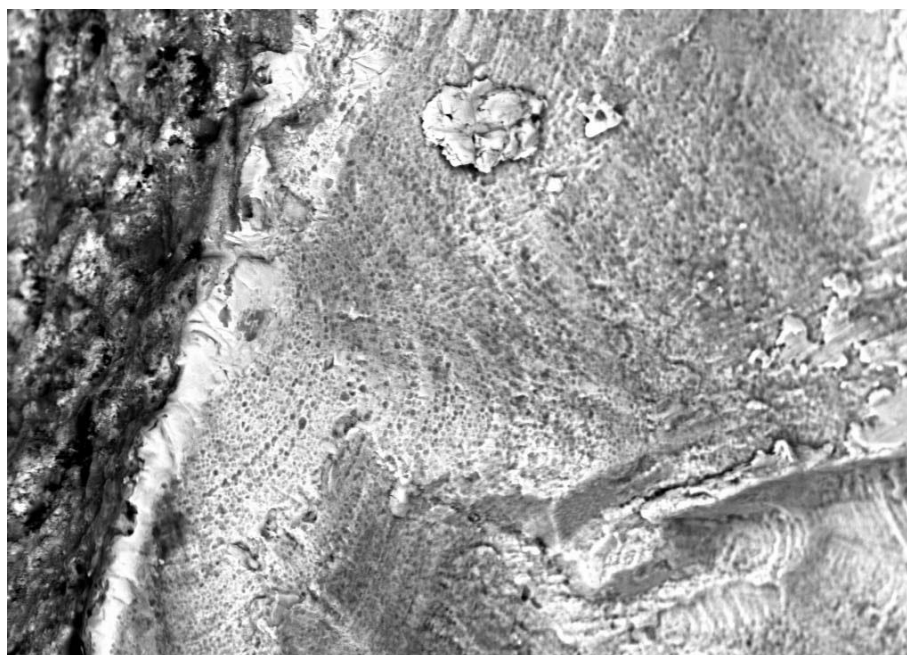


Figure 36. Detailed view of the airfoil No. 24 fatigue origin.



Signal A = CZ BSD WD = 20.3 mm EHT = 20.00 kV File Name = Airfoil No 24 SEM 02.tif



Signal A = CZ BSD WD = 10.7 mm EHT = 20.00 kV File Name = Airfoil No 24 SEM 03.tif

Figure 37. Backscatter electron images of the airfoil No. 24 fatigue origin.

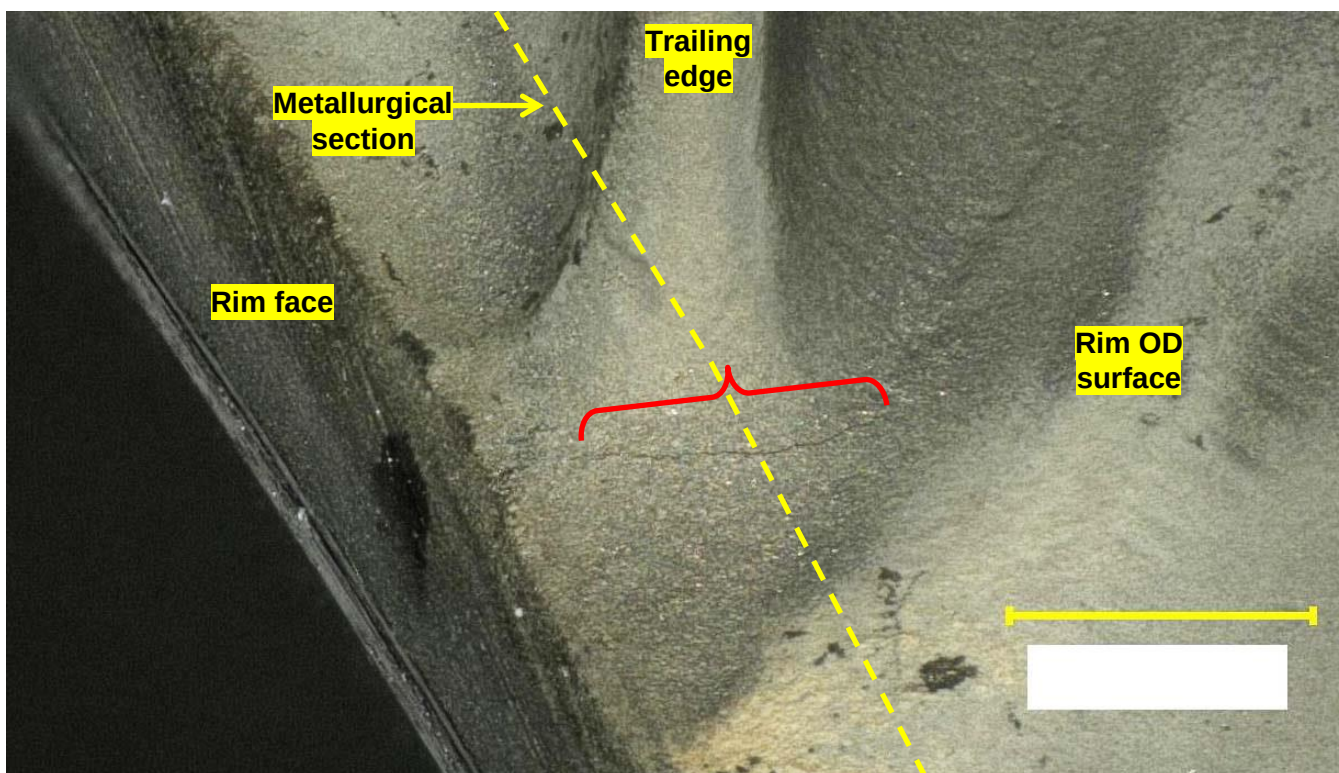
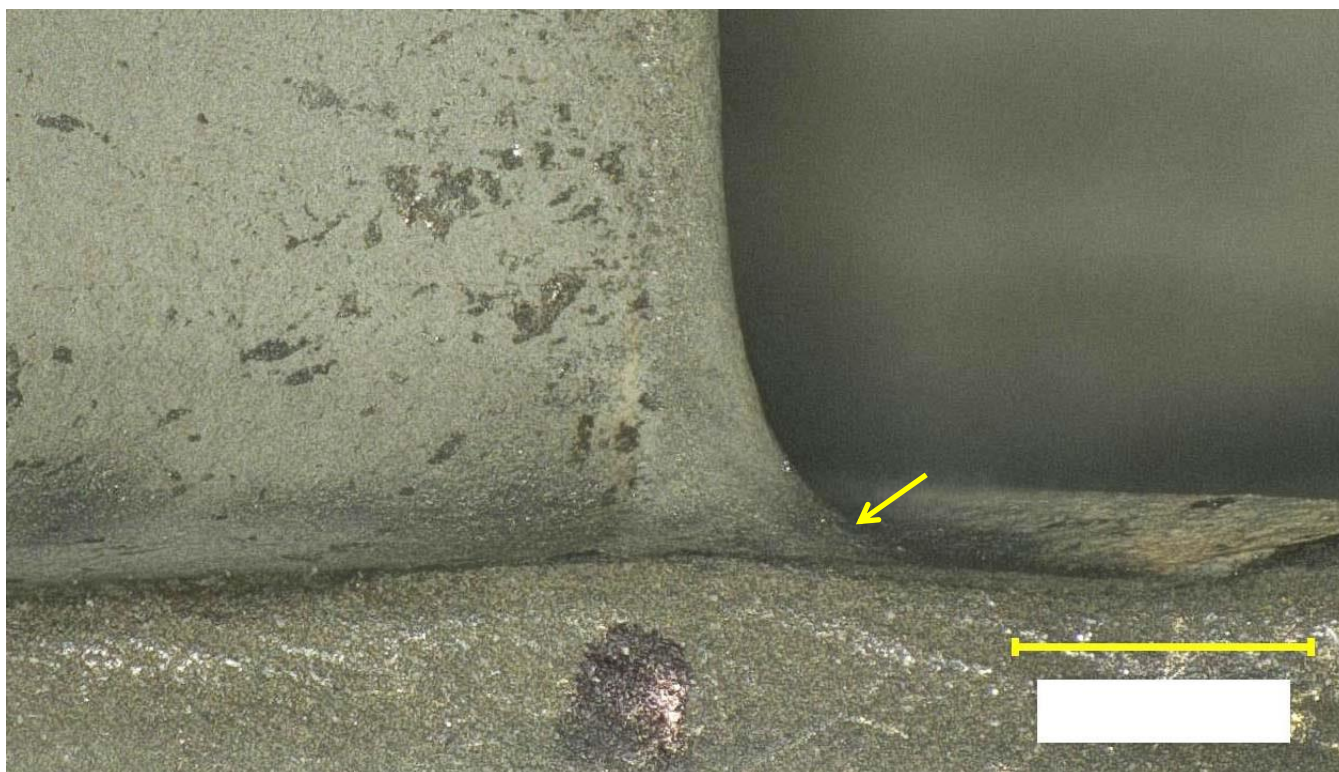


Figure 38. Photographs of the rim crack at the airfoil No. 8 trailing edge root. The dashed line identifies the orientation of the metallurgical section.

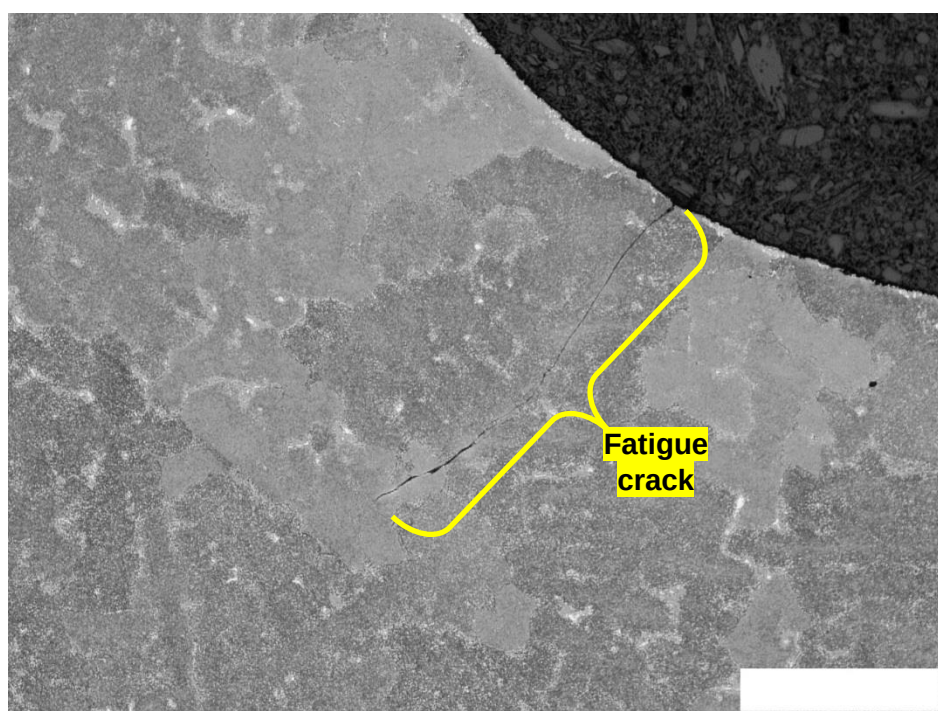
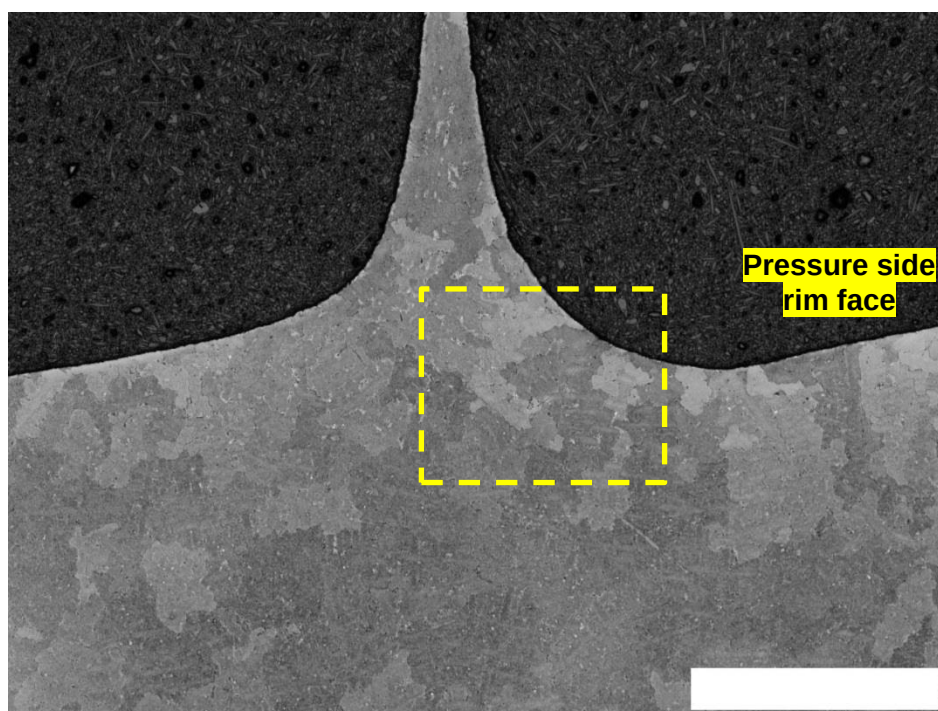


Figure 39. Photographs showing the fatigue crack just outboard of the rim surface. Etchant: MT

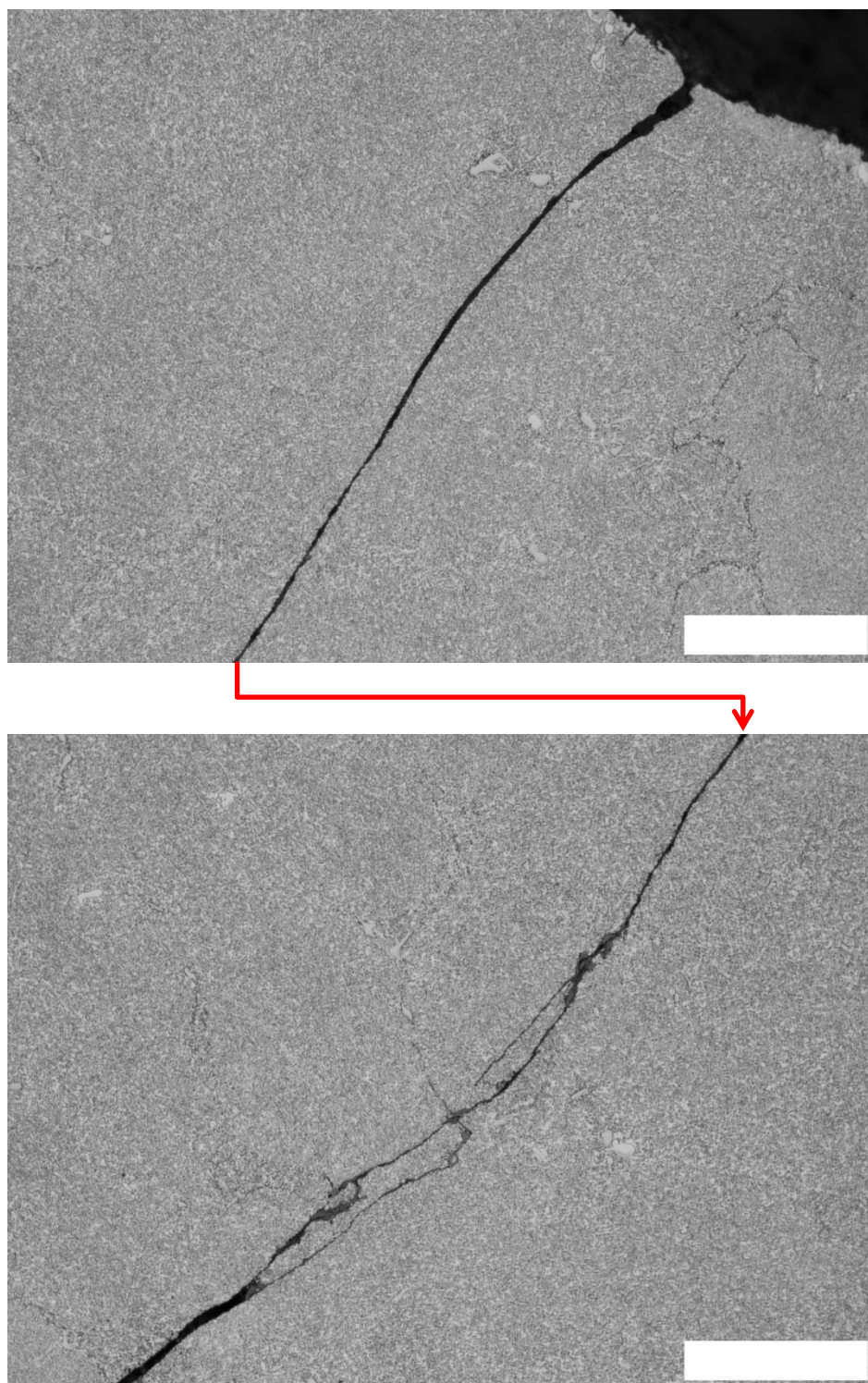


Figure 40. Detailed views of the fatigue crack at the rim surface. Etchant: MT

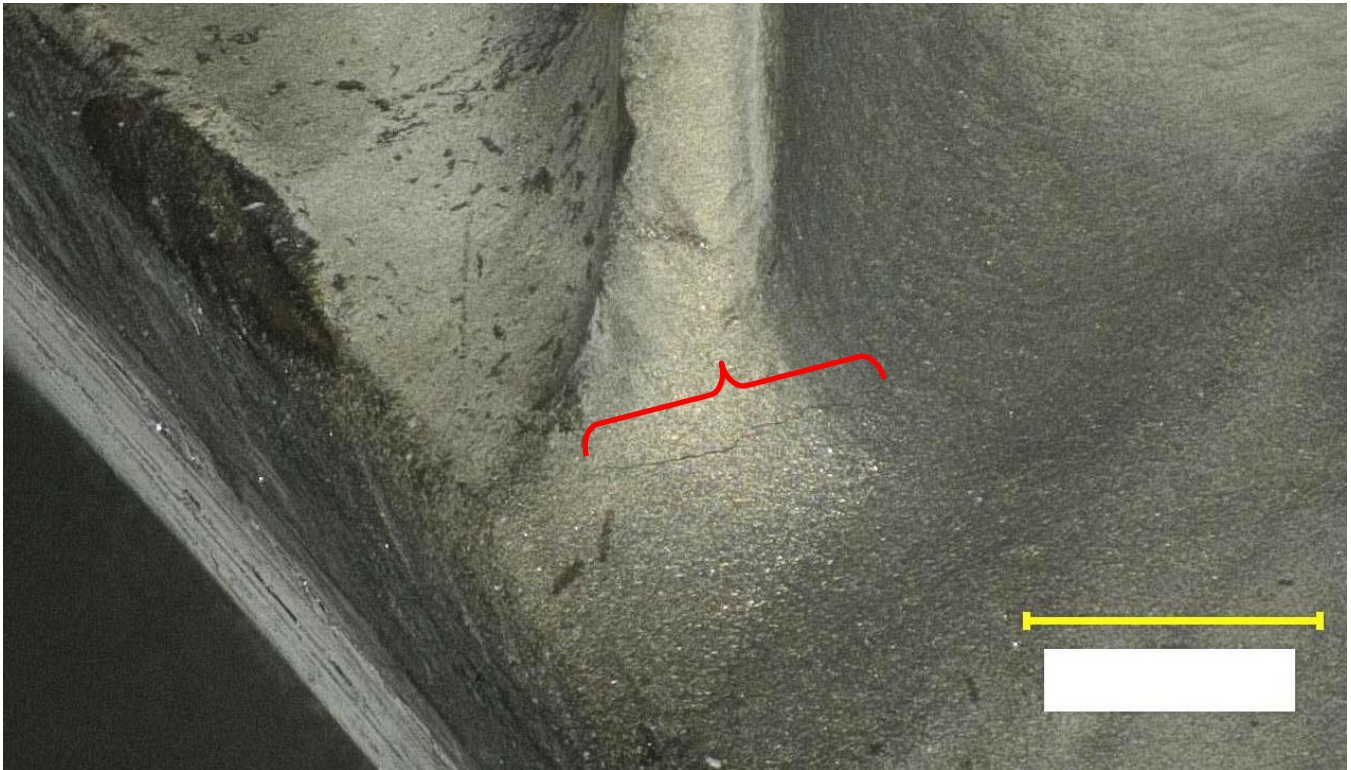
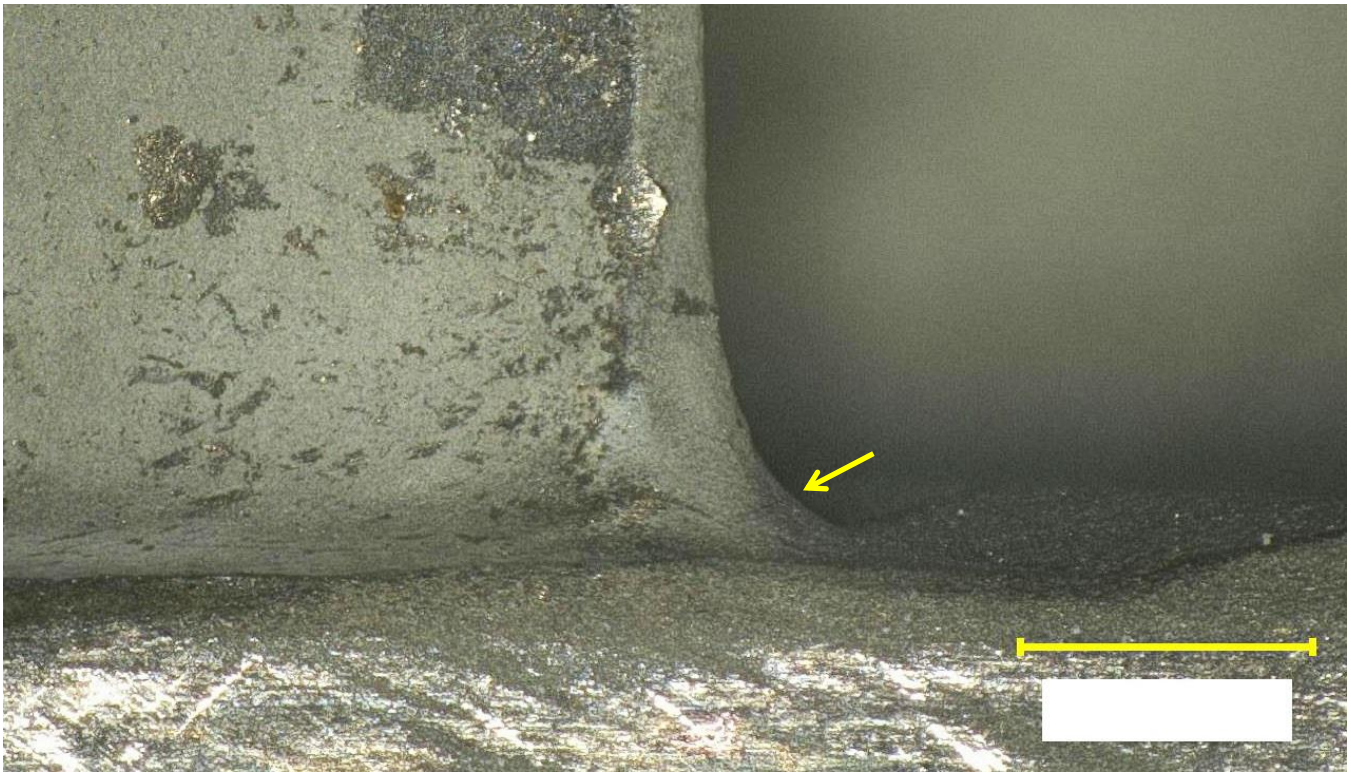


Figure 41. Photographs of the rim crack at the airfoil No. 15 trailing edge root.

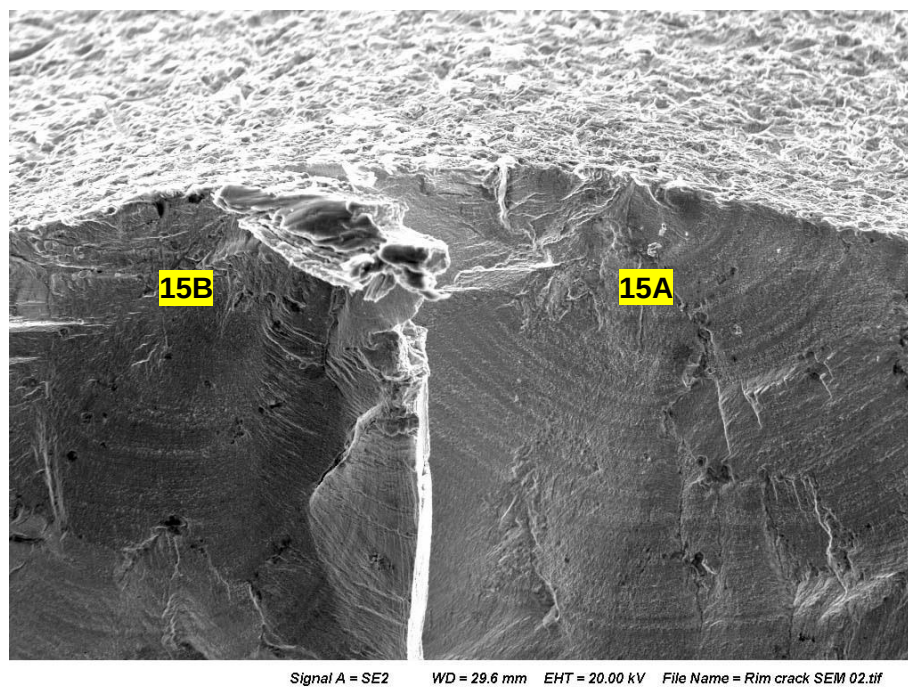
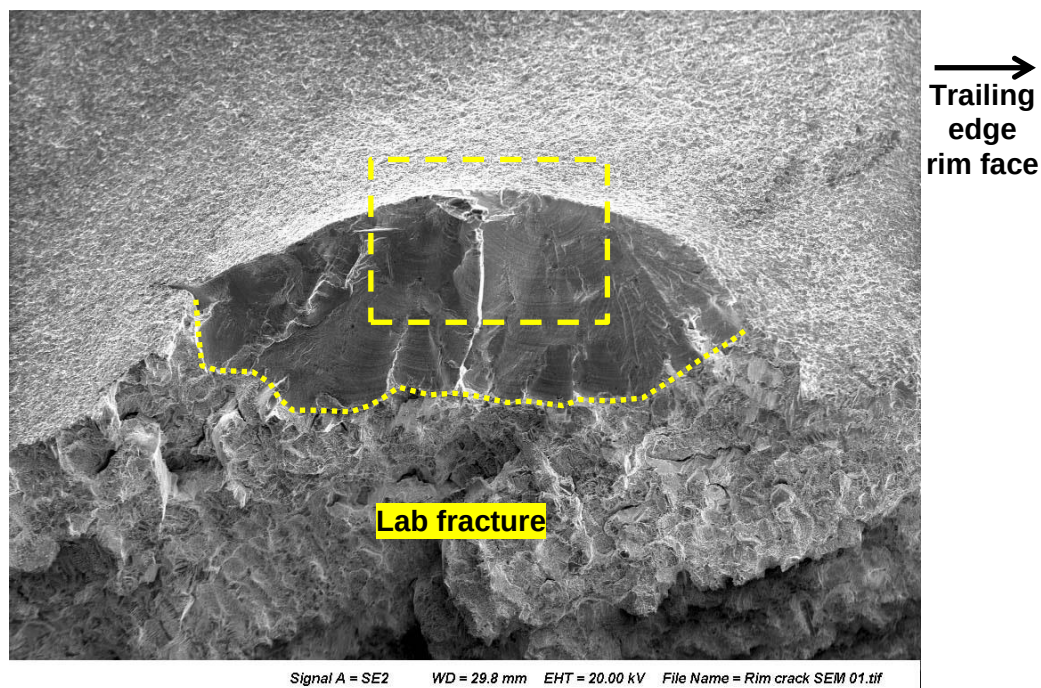
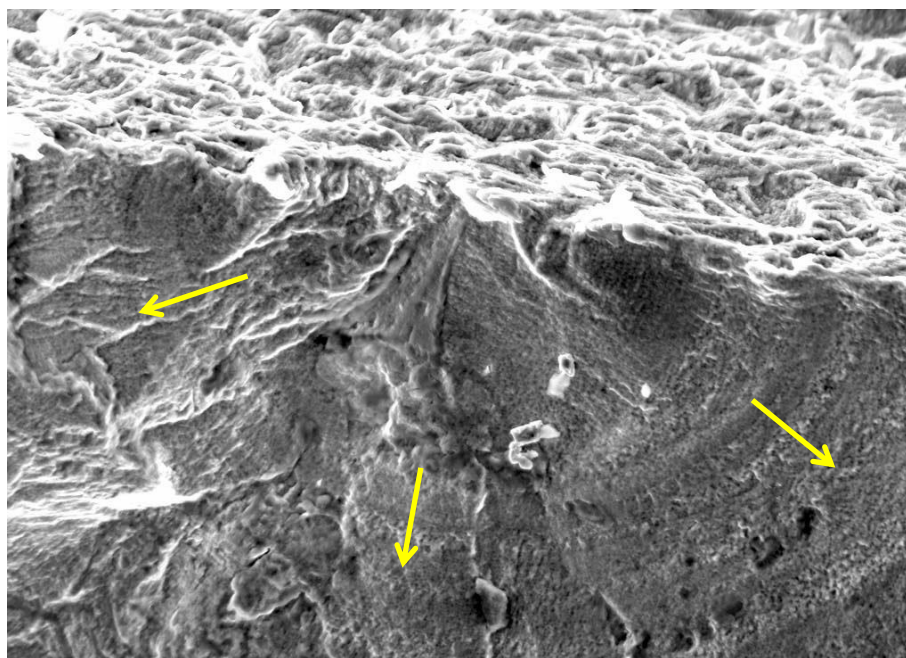
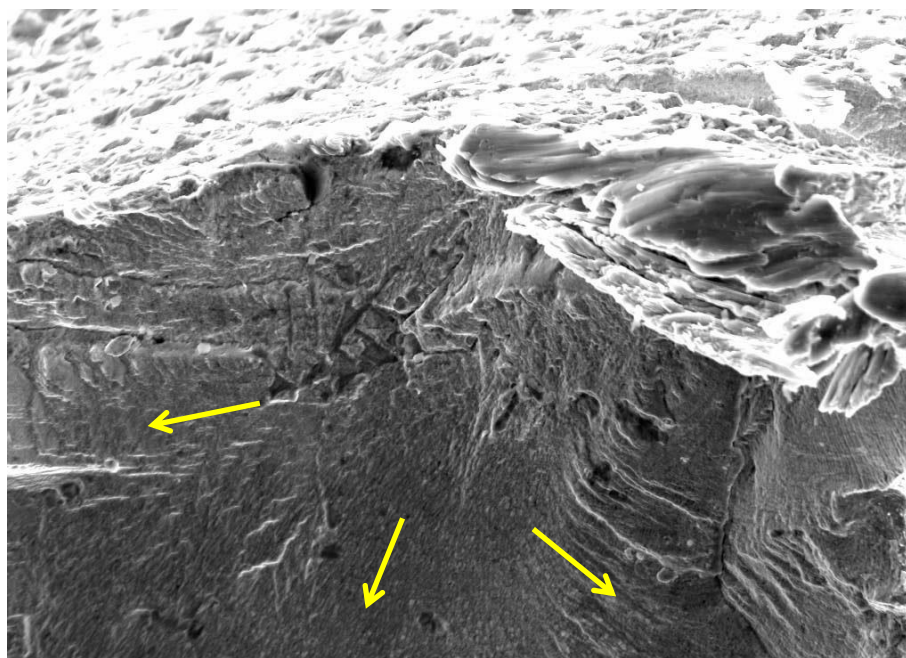


Figure 42. SEM photographs of the rim crack at airfoil No. 15 (see previous figure). Two cracks initiated on parallel planes. The combined crack size was approximately 0.063 inch wide by 0.021 inch deep. Detailed views of 15A and 15B are shown in the following figure.



Location 15A



Location 15B

Figure 43. Detailed photographs of the fatigue origins at locations 15A and 15B. The origin at location 15B was damaged during the opening of the cracks. The arrows indicate the crack propagation directions.



Figure 44. Aft looking forward view of the third stage turbine nozzle.



Figure 45. Forward looking aft view of the third stage turbine nozzle showing the damage to the trailing edge vane surfaces.

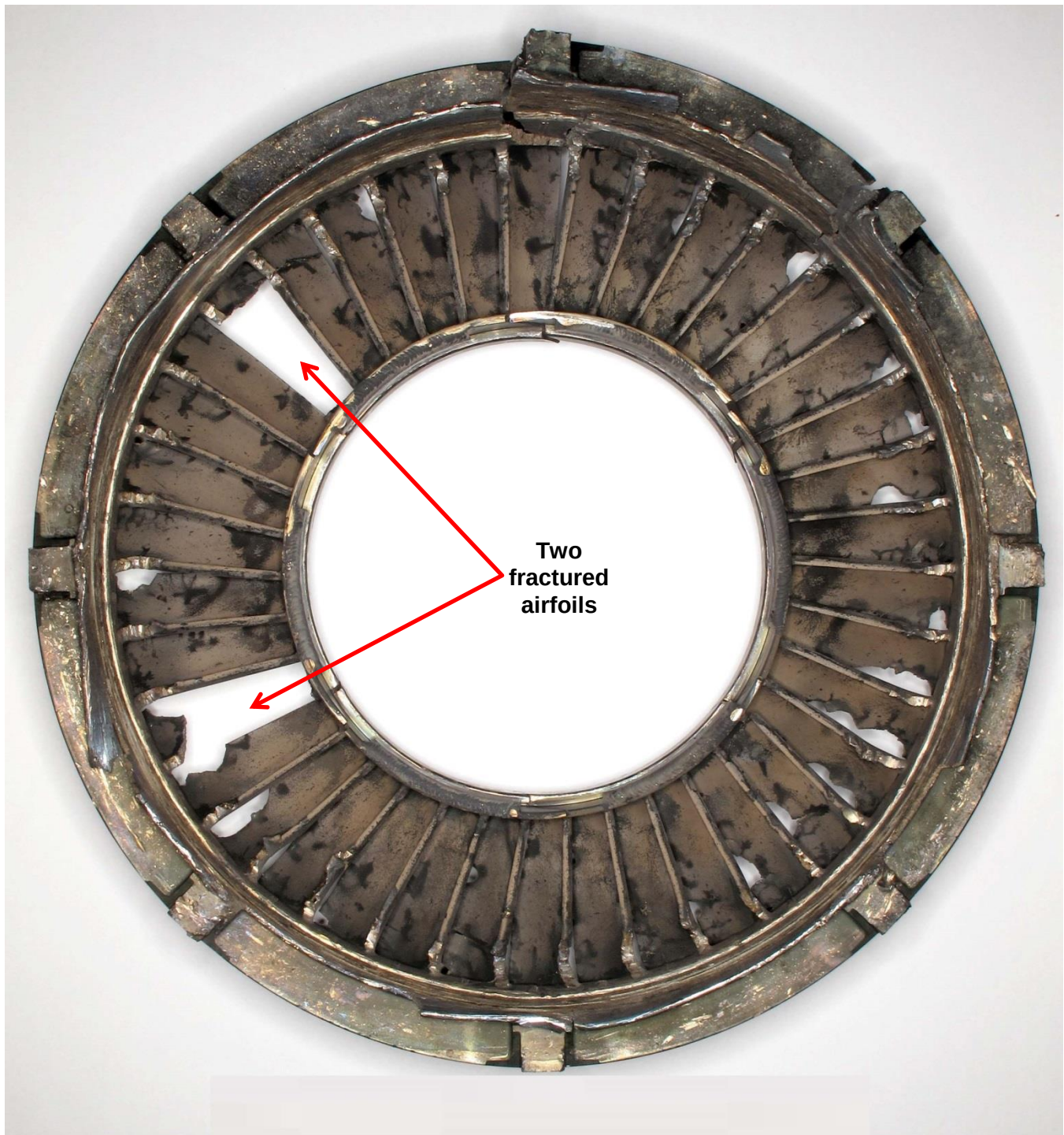


Figure 46. Aft looking forward view of the fourth stage turbine nozzle assembly. Note two airfoils and the diaphragm had separated from the assembly.



Figure 47. Forward looking aft view of the fourth stage turbine nozzle assembly showing the damage to the vane trailing edge surfaces.

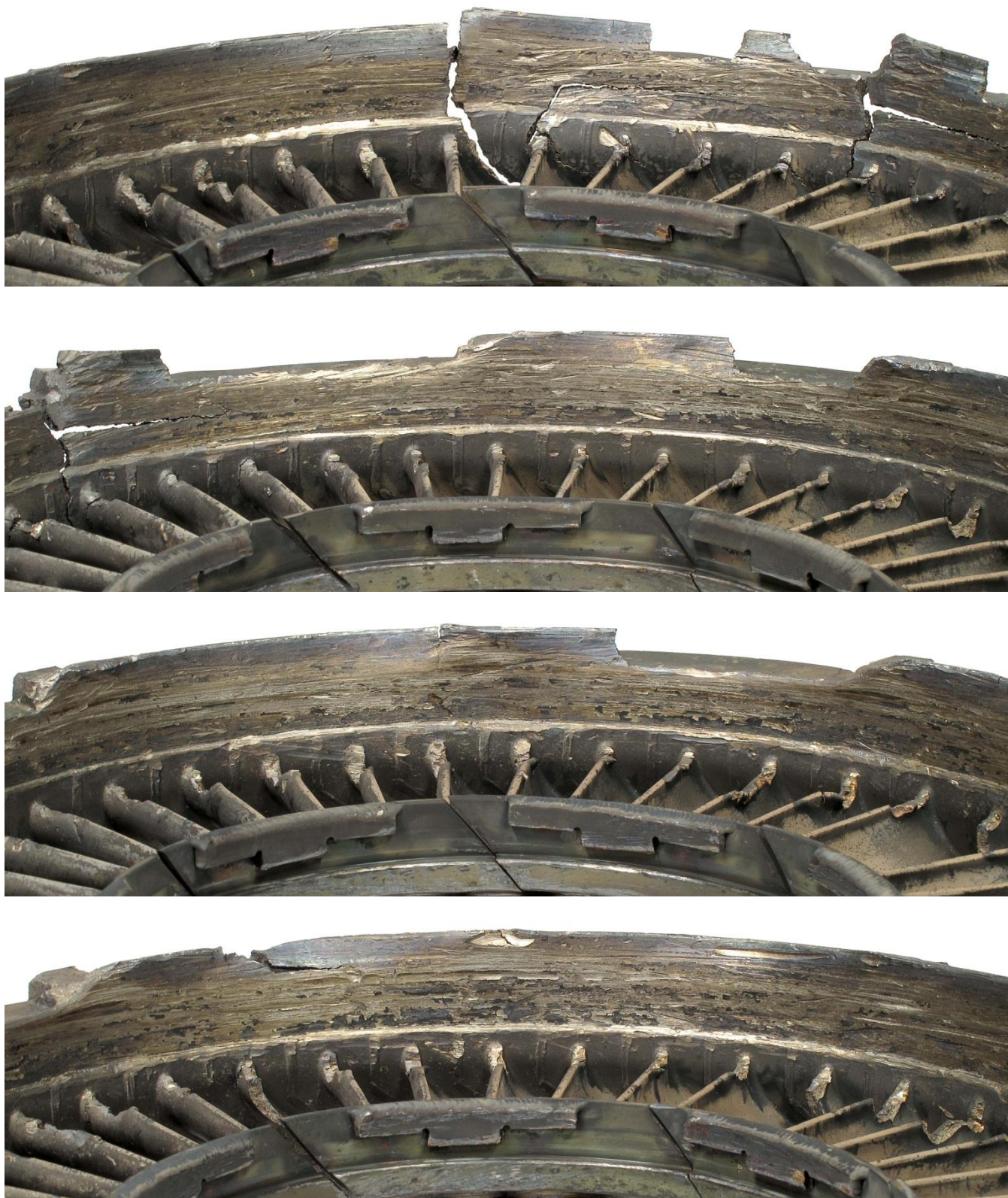


Figure 48. 90-degree views showing the damage to the fourth stage turbine nozzle blade track for the third stage turbine wheel.

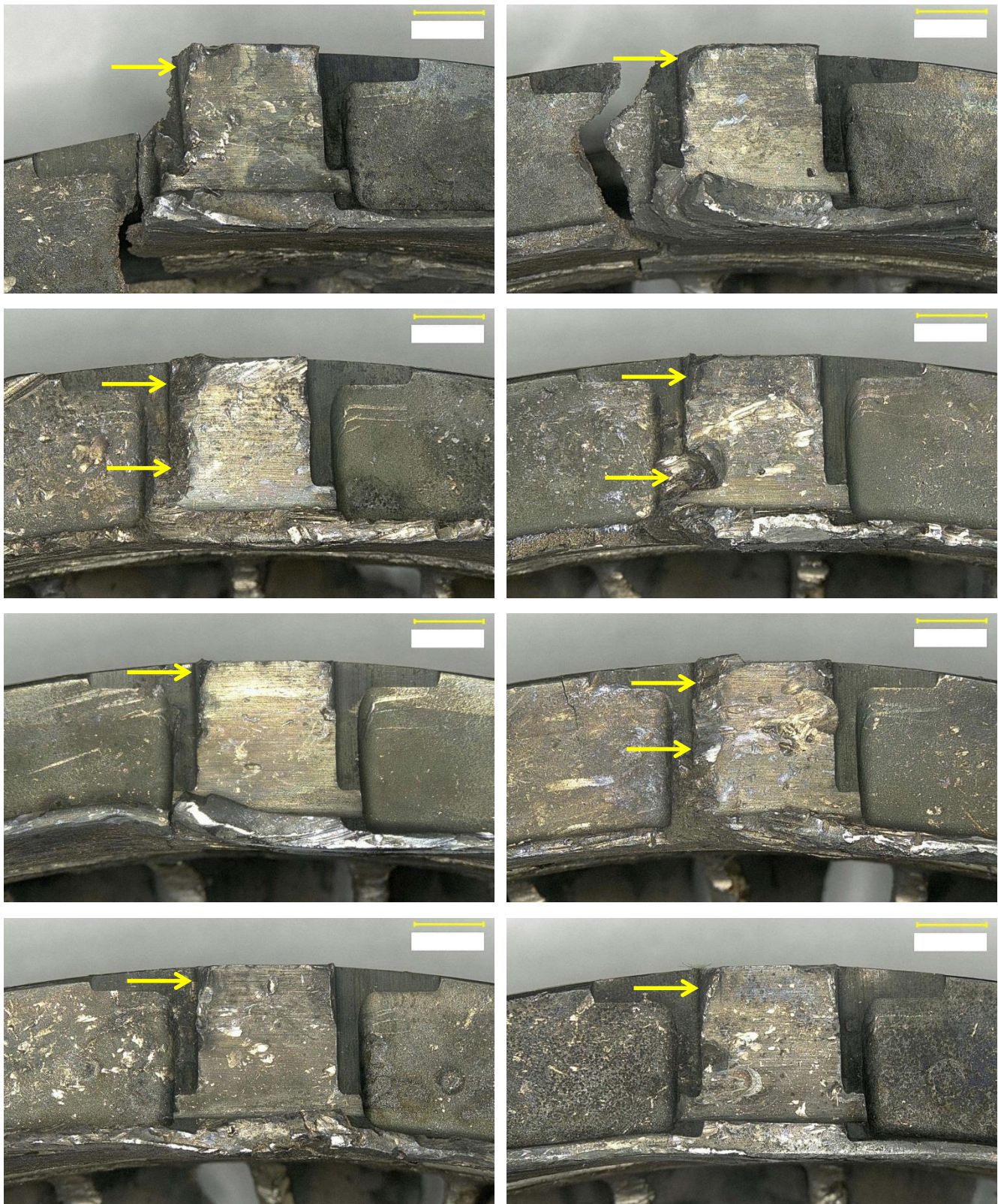


Figure 49. Photographs documenting the damage to the fourth stage turbine nozzle positioning tangs (arrows). Note the damage is on the side of the tang opposite the direction of the PT rotation.



Figure 50. Photograph of the diaphragm that detached from the bore of the fourth stage turbine nozzle (aft looking forward view).



Figure 51. Photograph of the diaphragm that detached from the bore of the fourth stage turbine nozzle (forward looking aft view).



Figure 52. Detailed views showing the rub damage to the bore of the fourth stage turbine wheel diaphragm.



Figure 53. Aft looking forward view of the fourth stage turbine wheel. Note the damage to the airfoil leading edge surfaces.



Figure 54. Forward looking aft view of the fourth stage turbine wheel.



Figure 55. Forward looking aft view of the fractured exhaust collector flange. Detailed photographs of the boxed area are shown in the following figures.

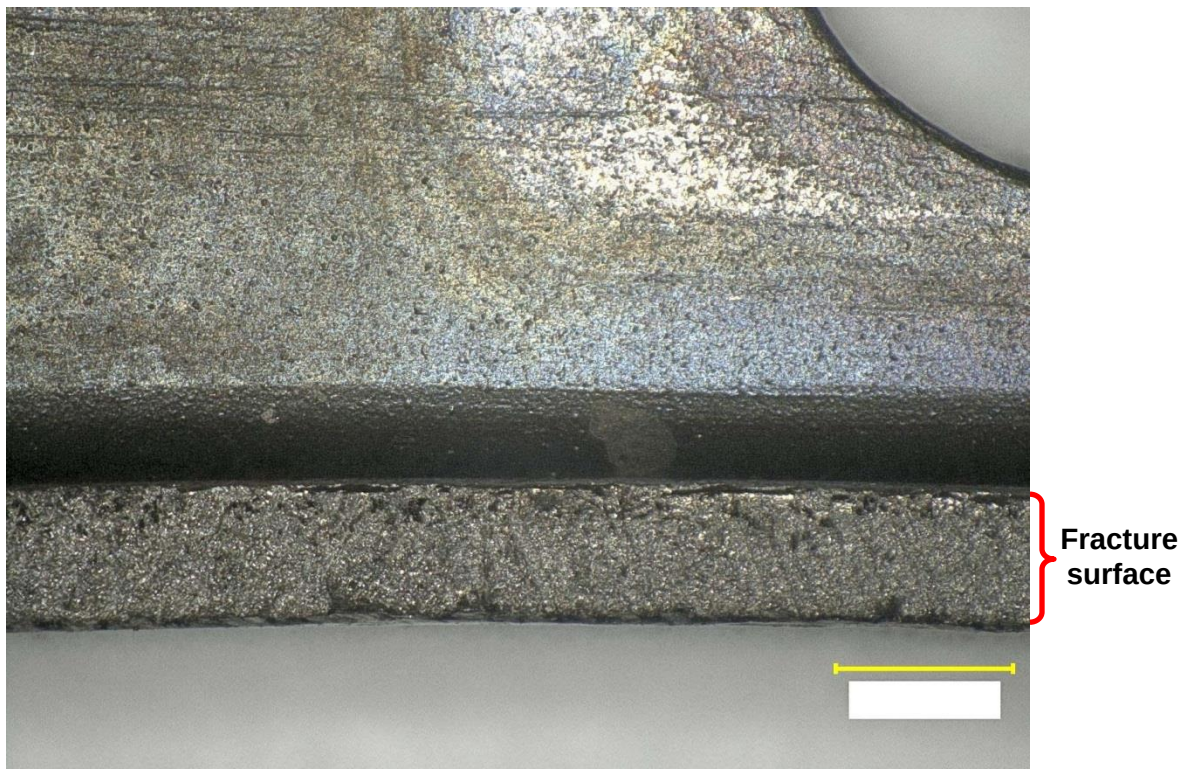
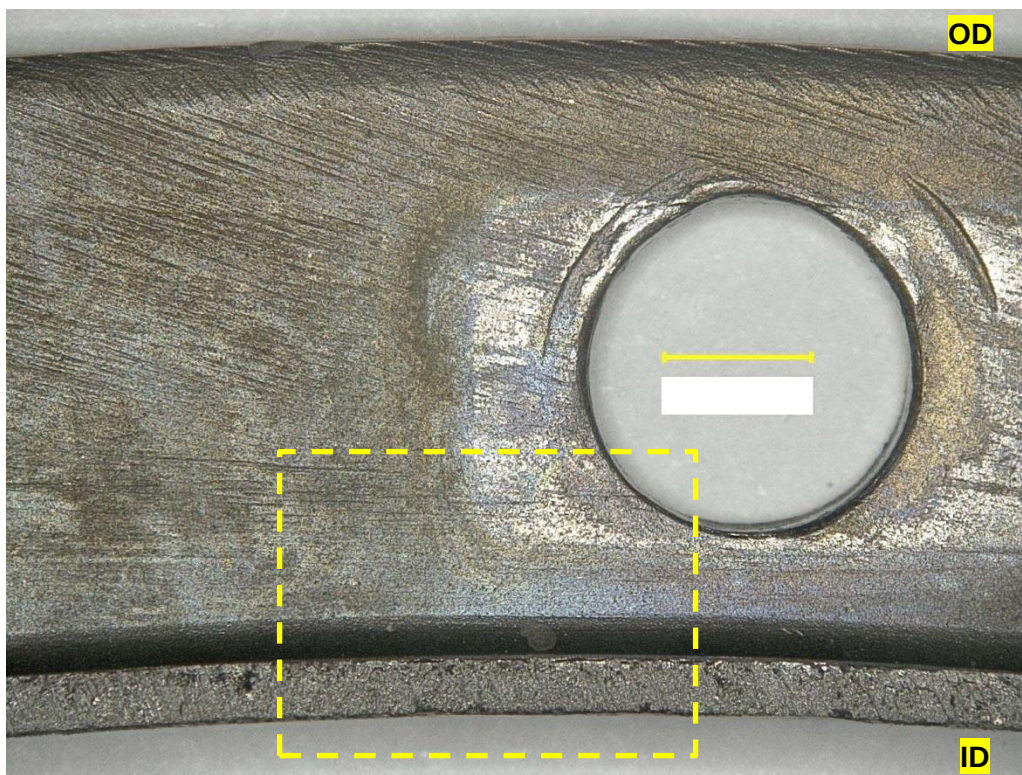


Figure 56. Photographs of a representative area around the circumference of the fractured exhaust collector flange.

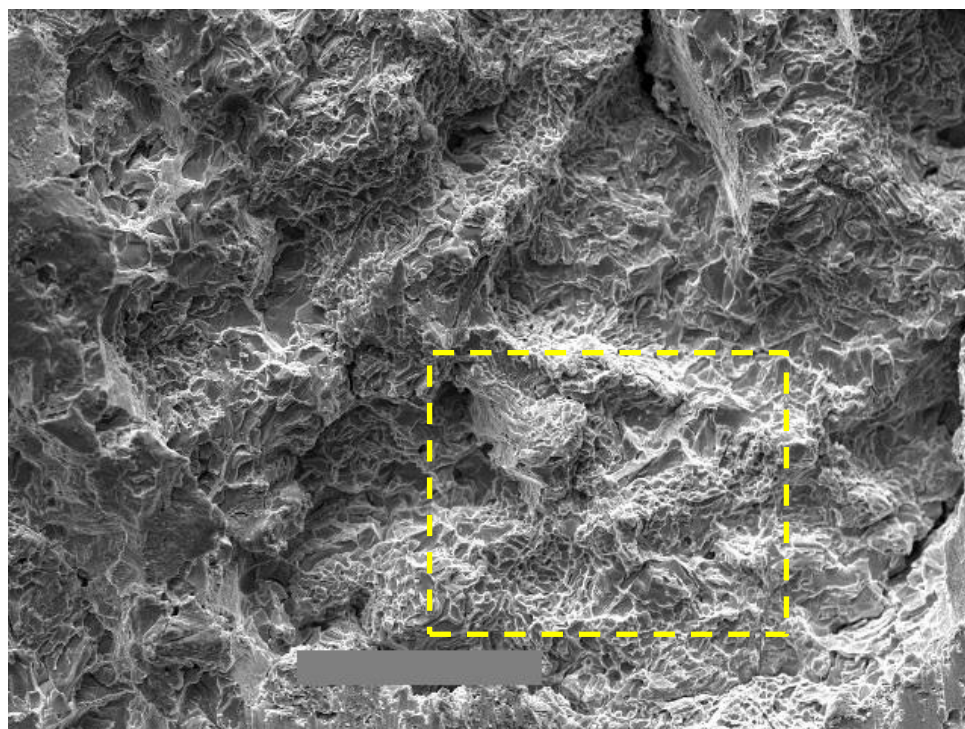
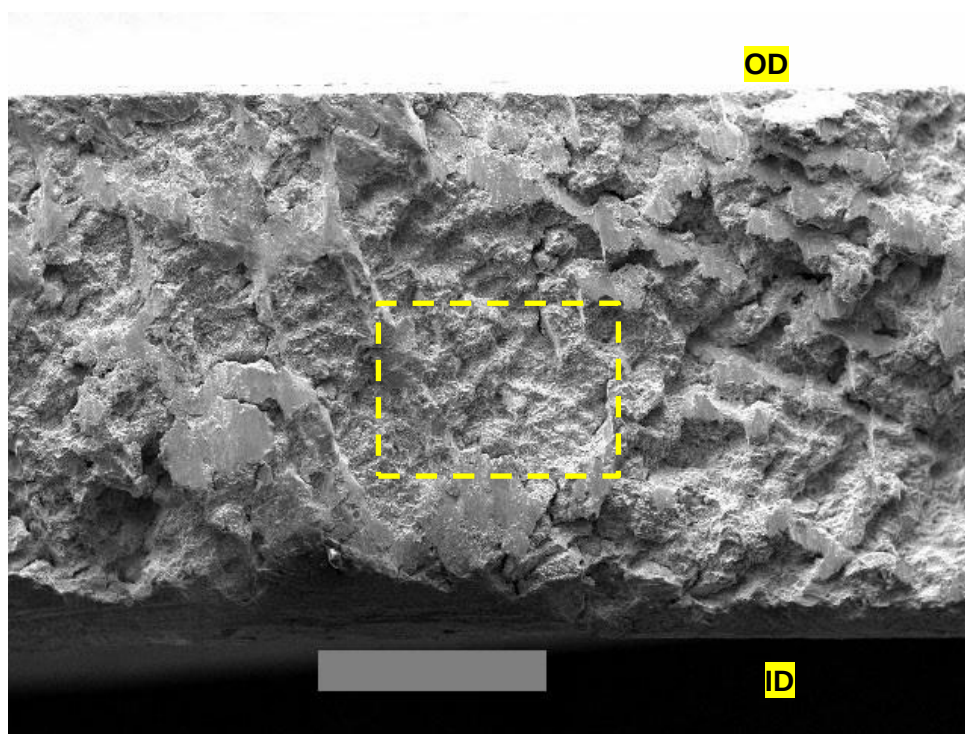


Figure 57. Representative SEM photographs documenting the exhaust collector flange fracture. The features were consistent with tensile overload.

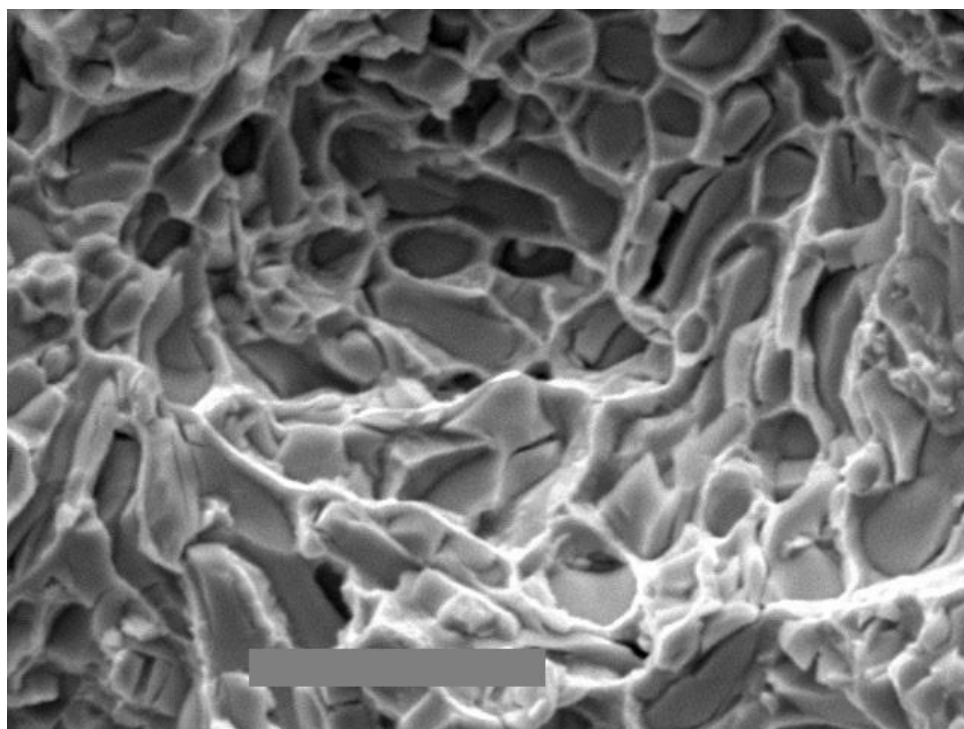
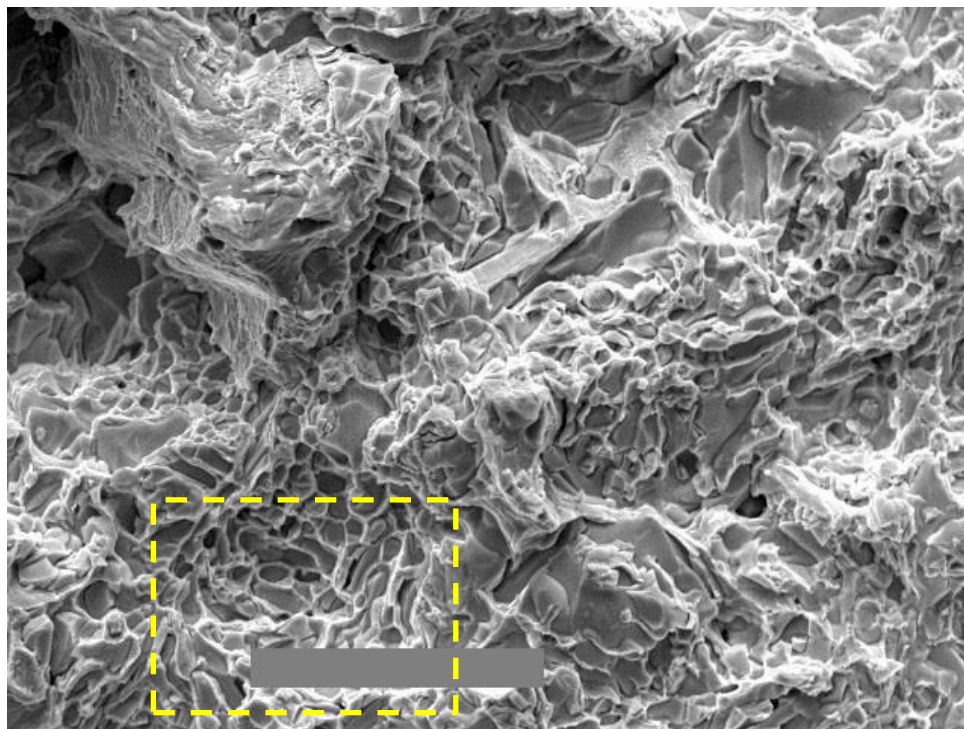


Figure 58. Representative SEM photographs documenting the exhaust collector flange fracture. The features were consistent with tensile overload.

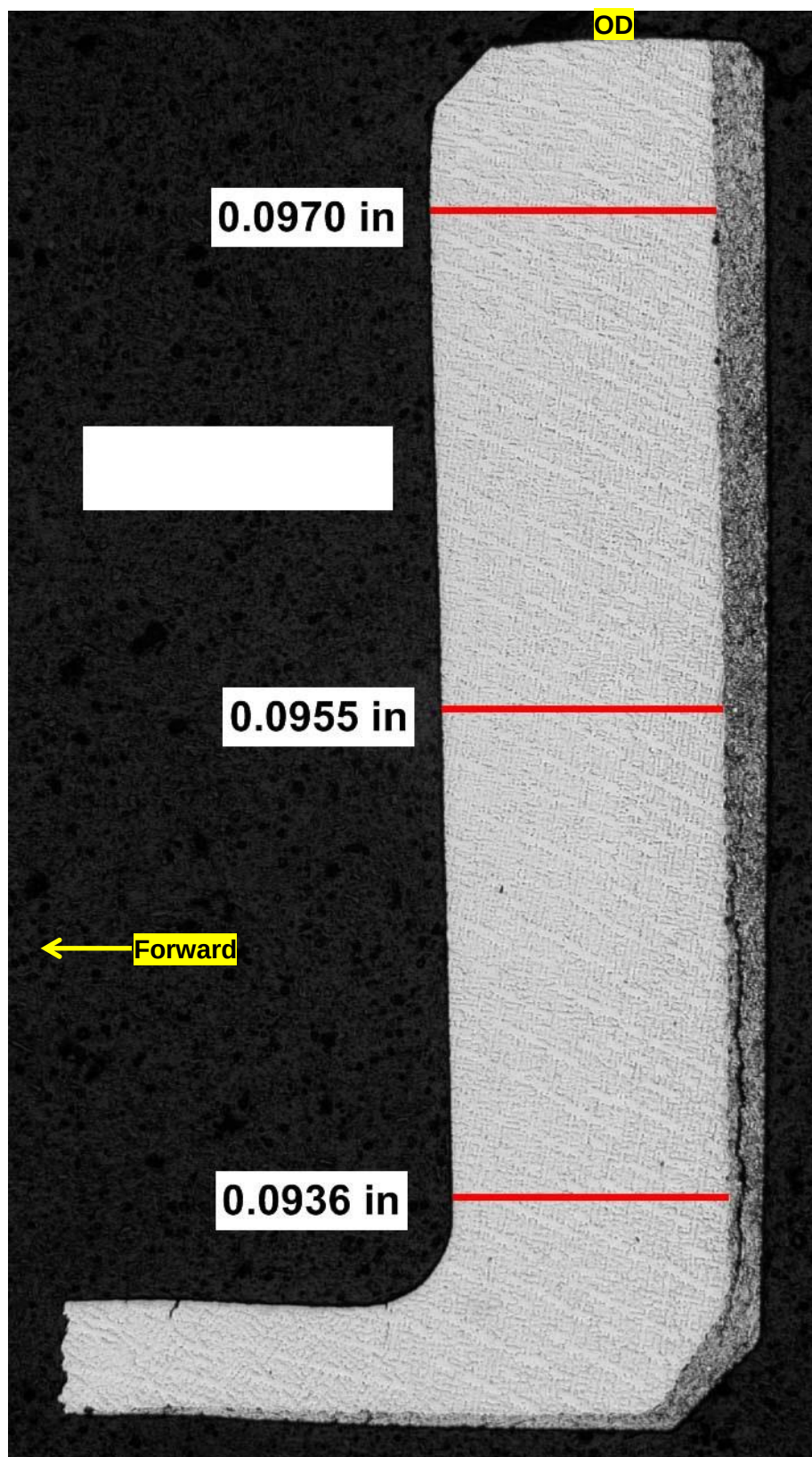


Figure 59. Cross-section through the fractured exhaust collector flange showing the thermal spray dimensional restoration of the bolted flange surface and ID surface.

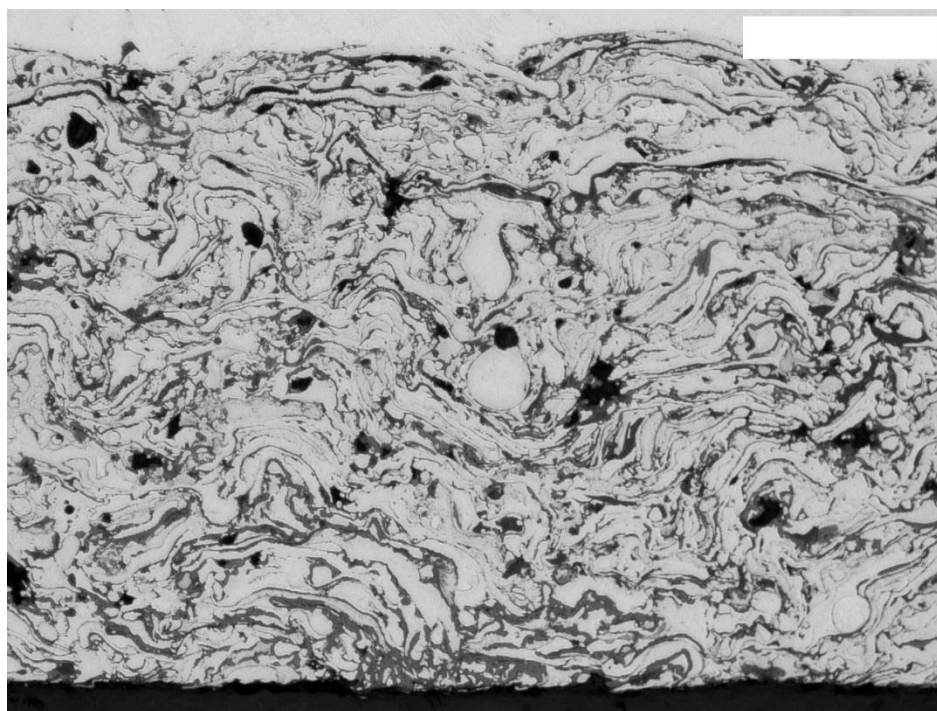
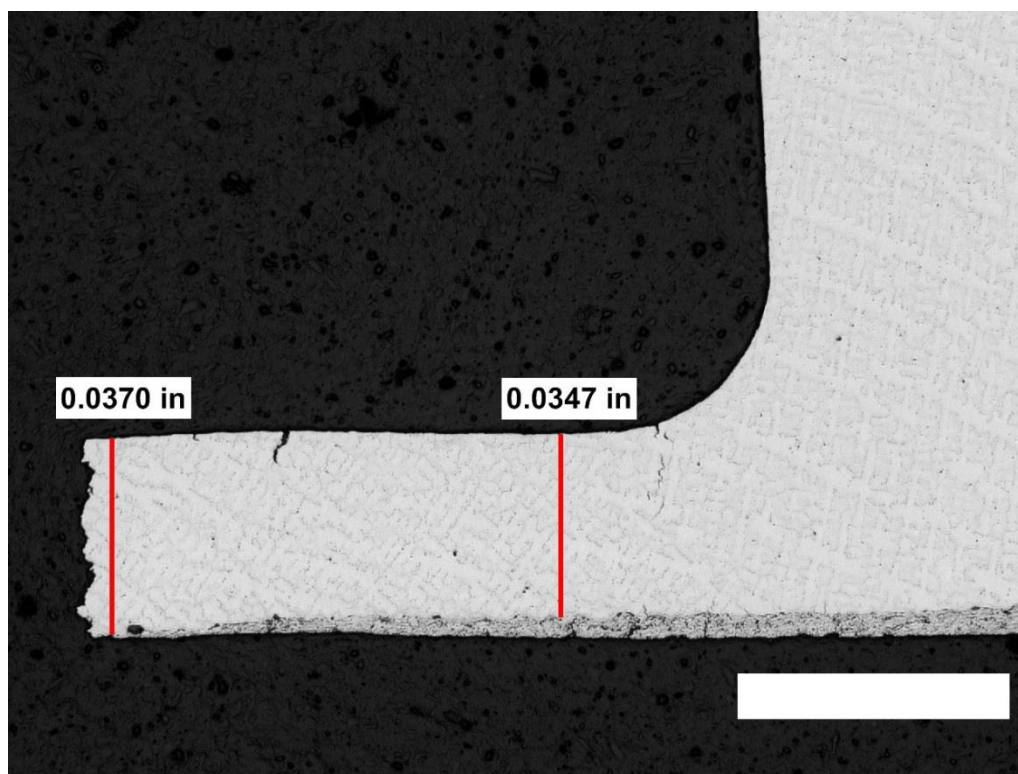


Figure 60. The upper photograph shows the wall thickness of the exhaust collector dash 2 detail. The lower photograph shows a representative photograph of the thermal spray material used for dimensional restoration.

← Forward

No. 3 bearing

Pinion gear

No. 4 bearing



Figure 61. Photograph of the No. 3 bearing, pinion gear, and No. 4 bearing (after removal from the pinion gear).



Figure 62. Aft looking forward view of the No. 4 bearing. The bracket highlights the portion of the separator that fractured.

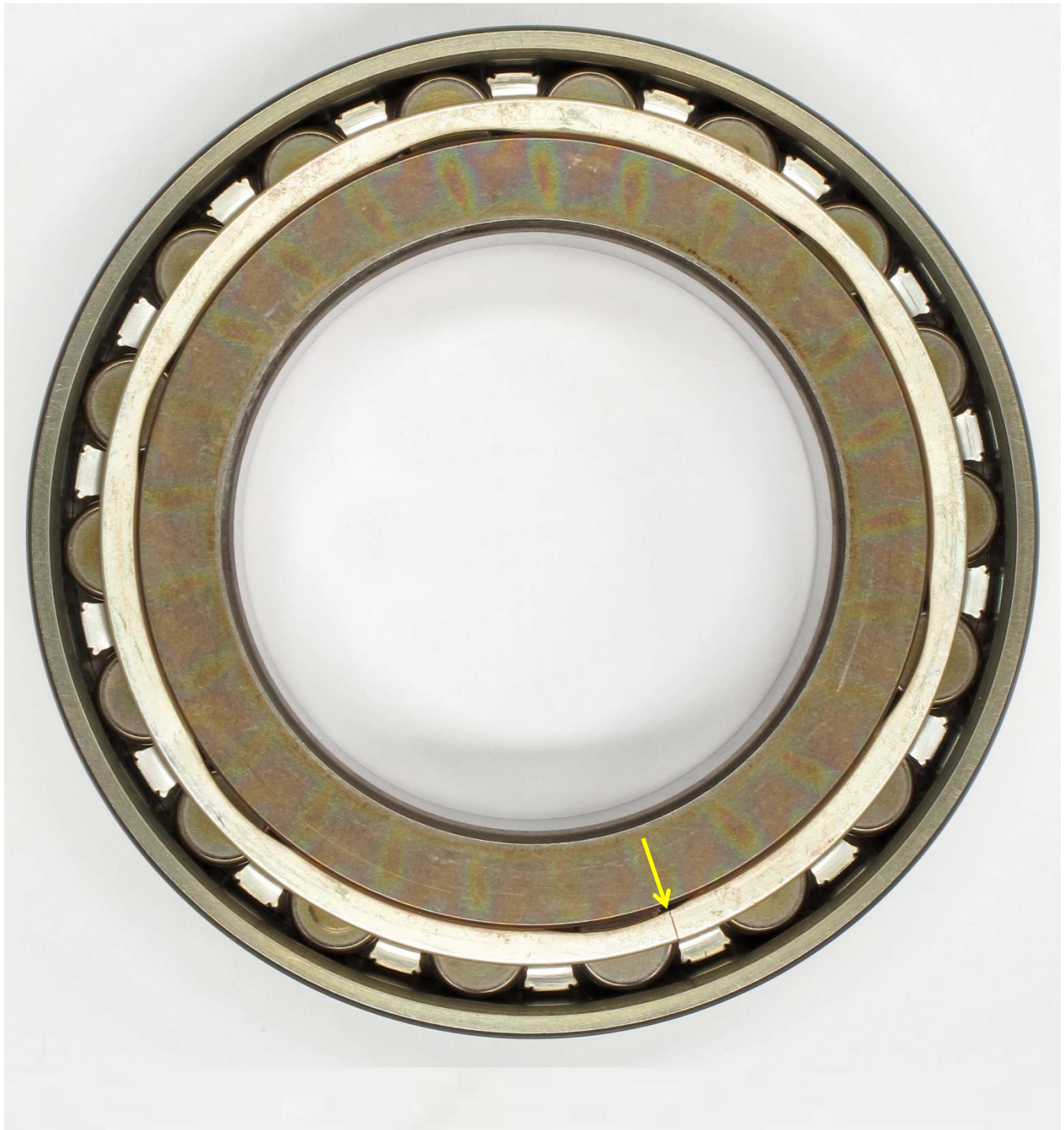


Figure 63. Forward looking aft view of the No. 4 bearing. The arrow points to a crack in the separator that aligns with the mission section shown in the previous figure.



Figure 64. Photograph of the outer ring OD surface showing circumferential score marks.

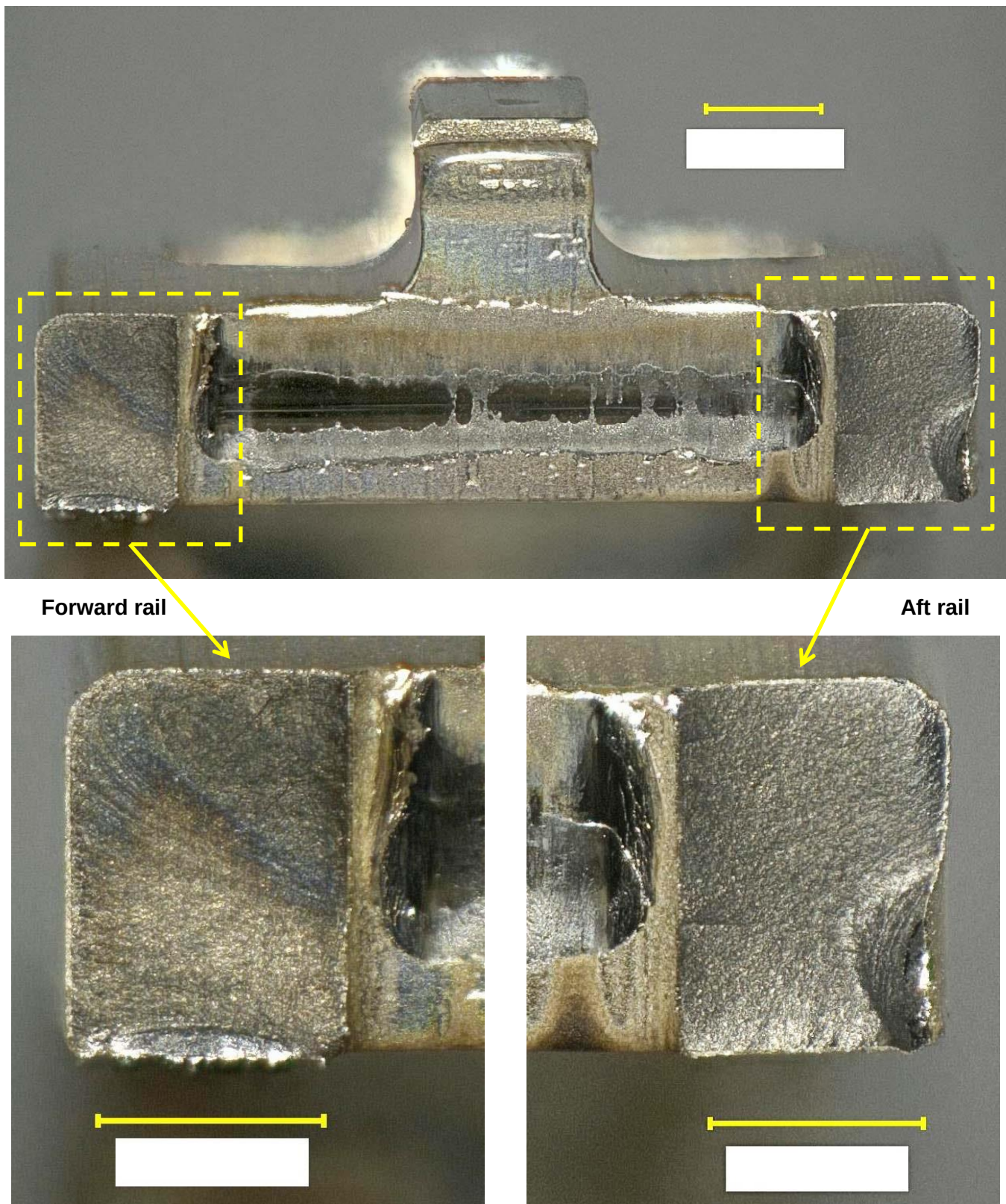
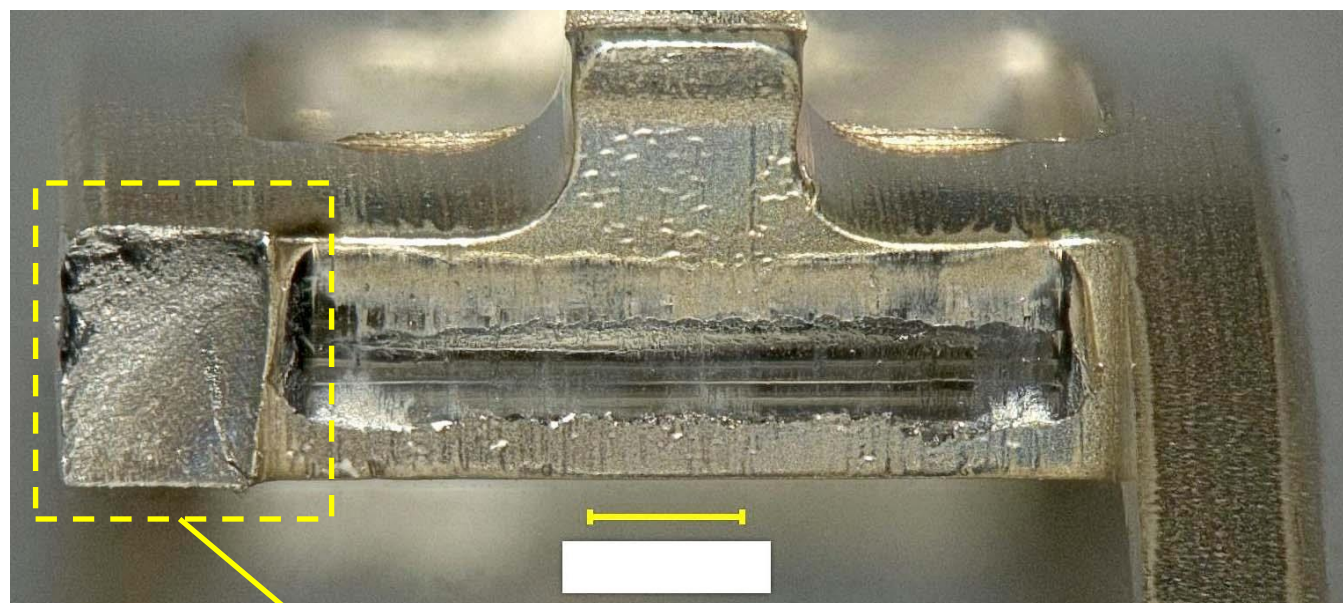


Figure 65. Photographs documenting the No. 4 bearing separator fractures.



Aft rail

Forward rail

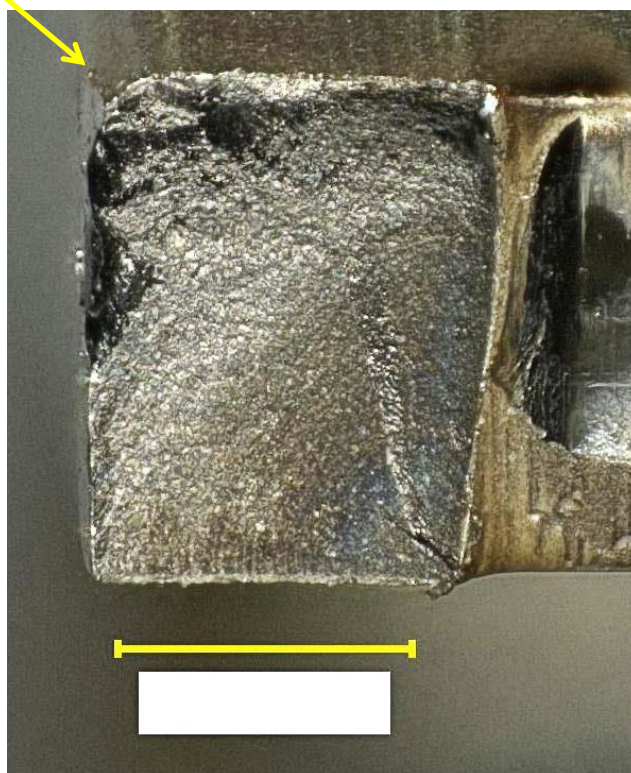


Figure 66. Photographs documenting the No. 4 bearing separator fractures.

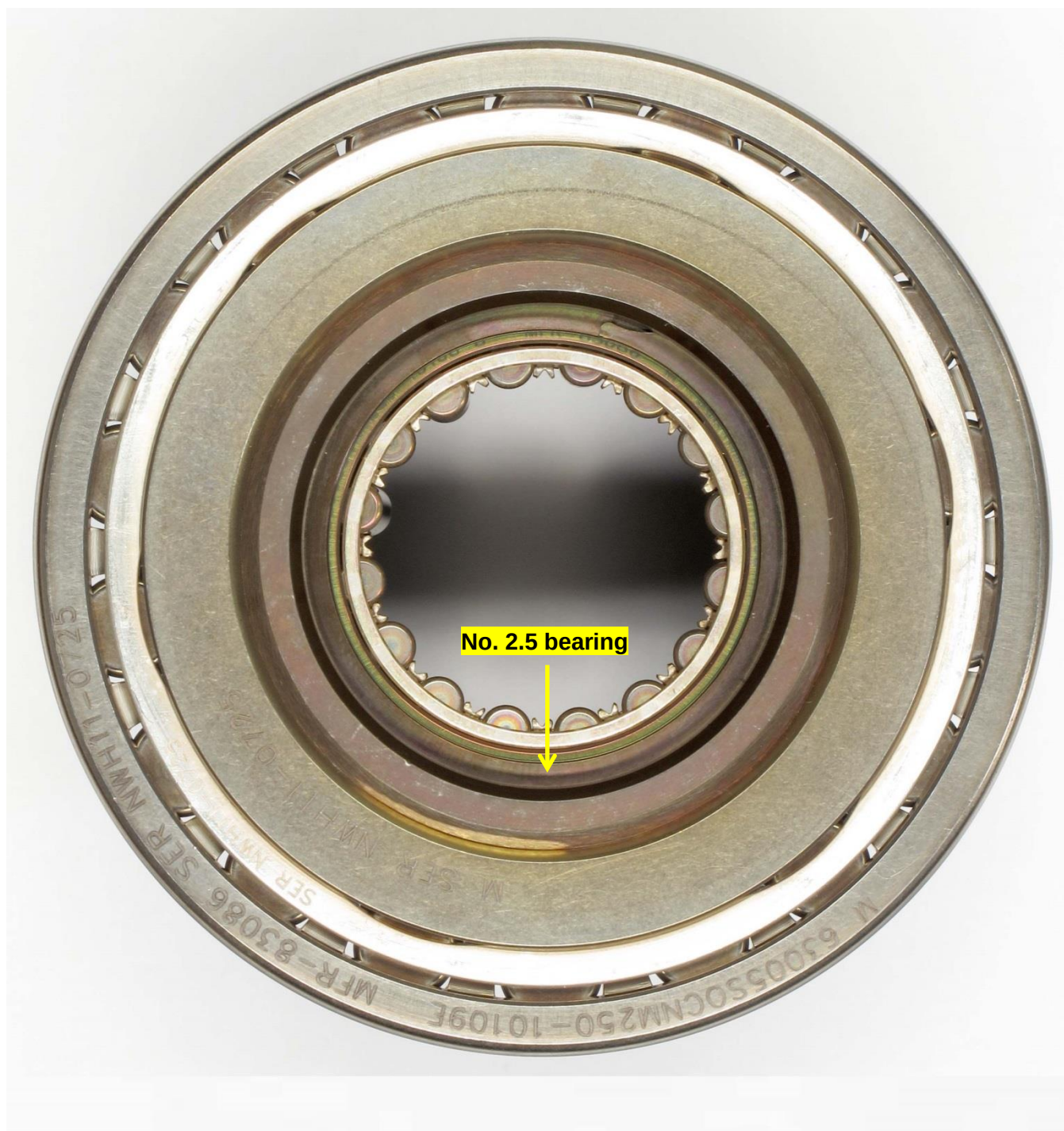


Figure 67. Forward looking aft view of the No. 3 bearing.

← Forward

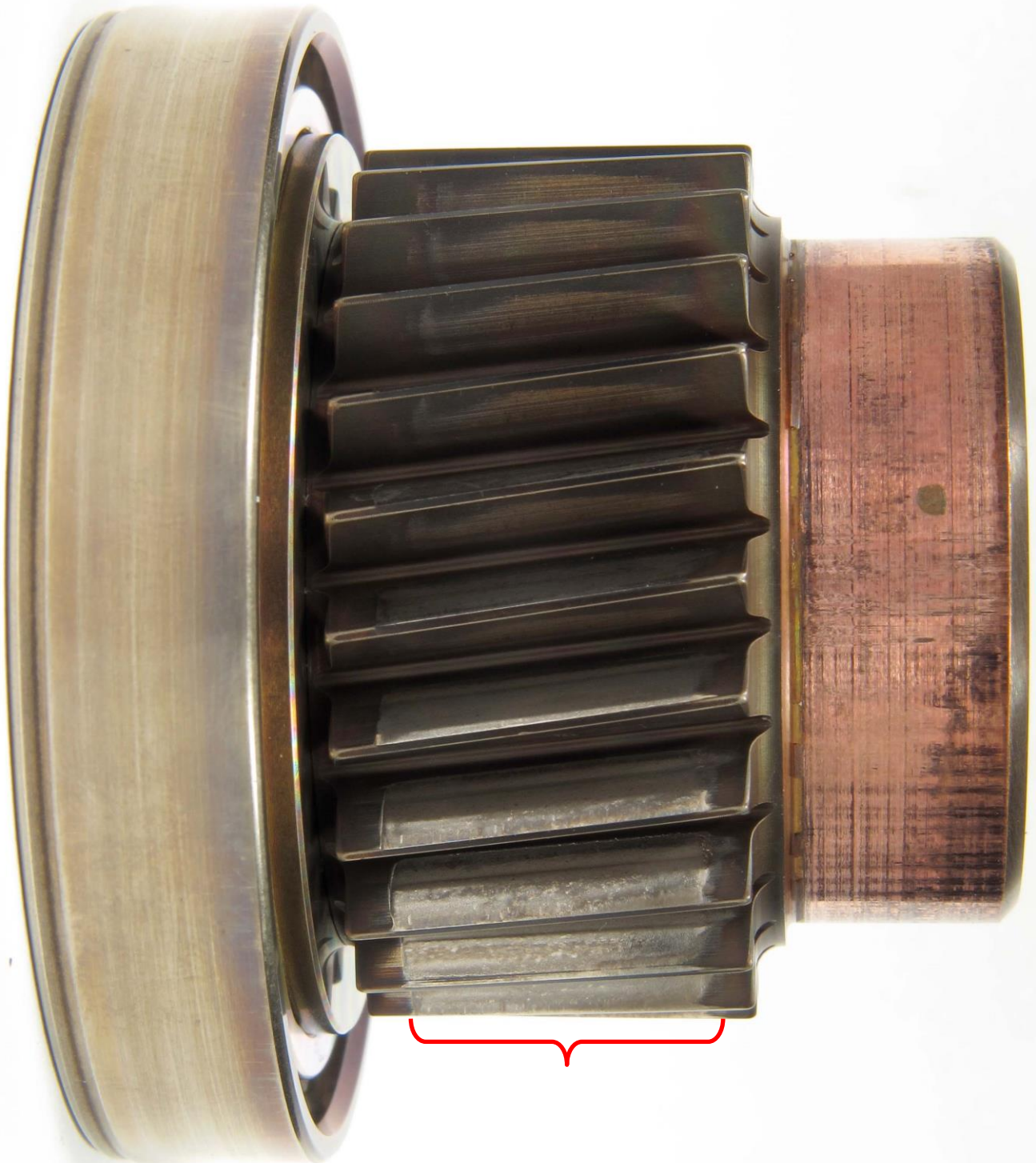


Figure 68. Detailed view of the wear pattern (bracket) on the pinion gear teeth (drive side).



Figure 69. Aft looking forward view of the first stage turbine wheel.



Figure 70. Forward looking aft view of the second stage turbine wheel.

↑
Forward



Figure 71. Photograph of the turbine tie bolt and nut.

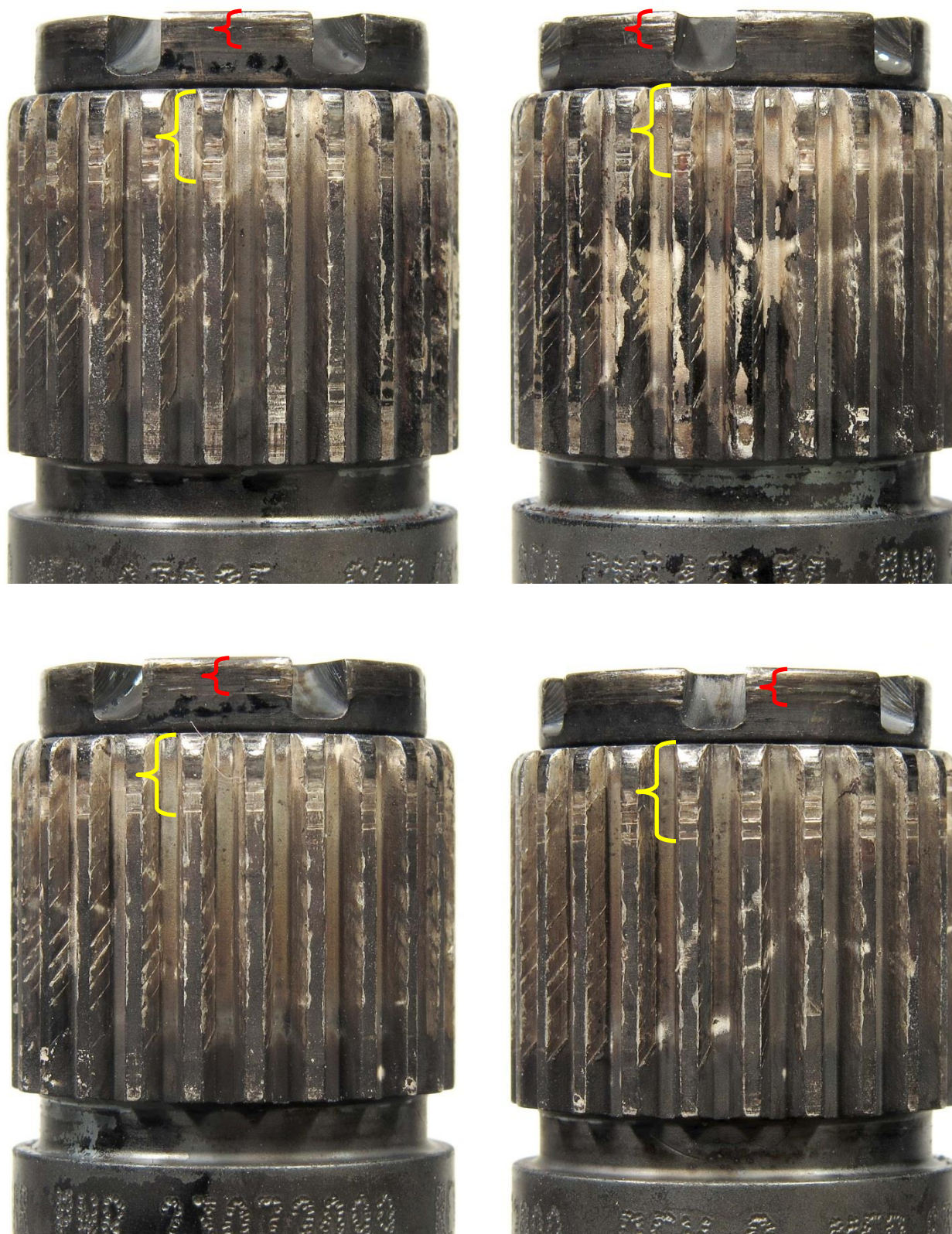
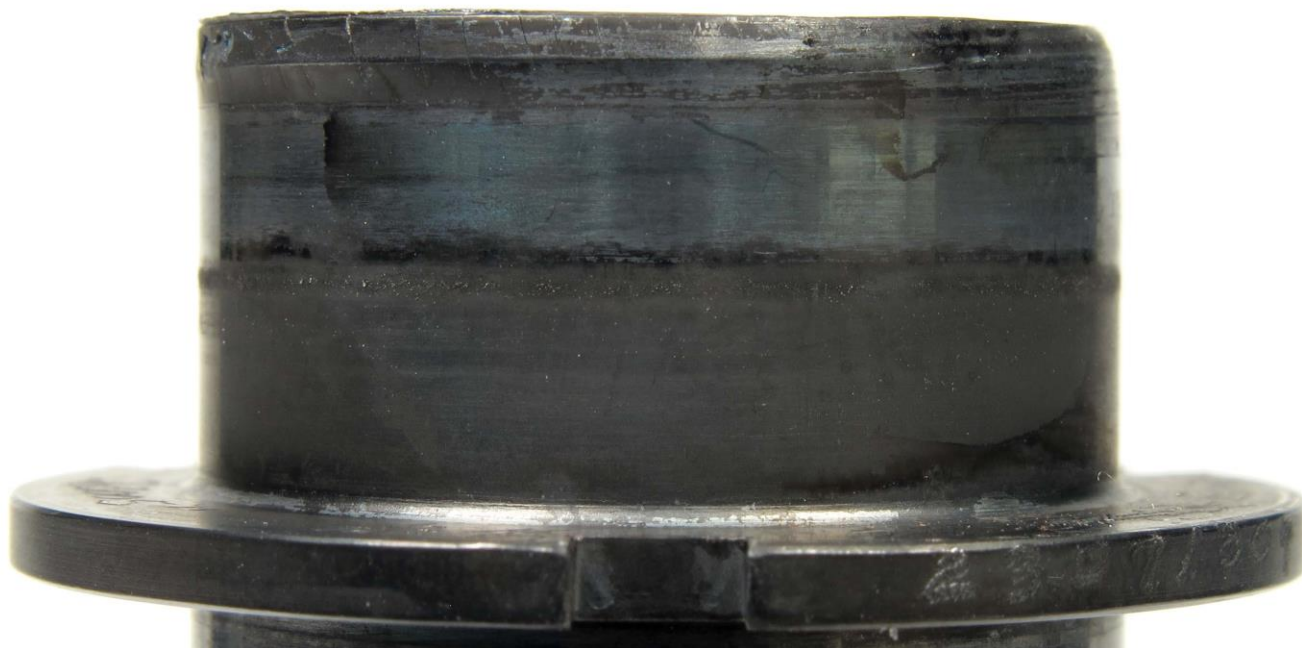


Figure 72. 90-degree views of the wear damage to the head of the turbine tie bolt (red bracket) and turbine splined adapter (yellow bracket).



Figure 73. Photograph of the power turbine inner shaft.



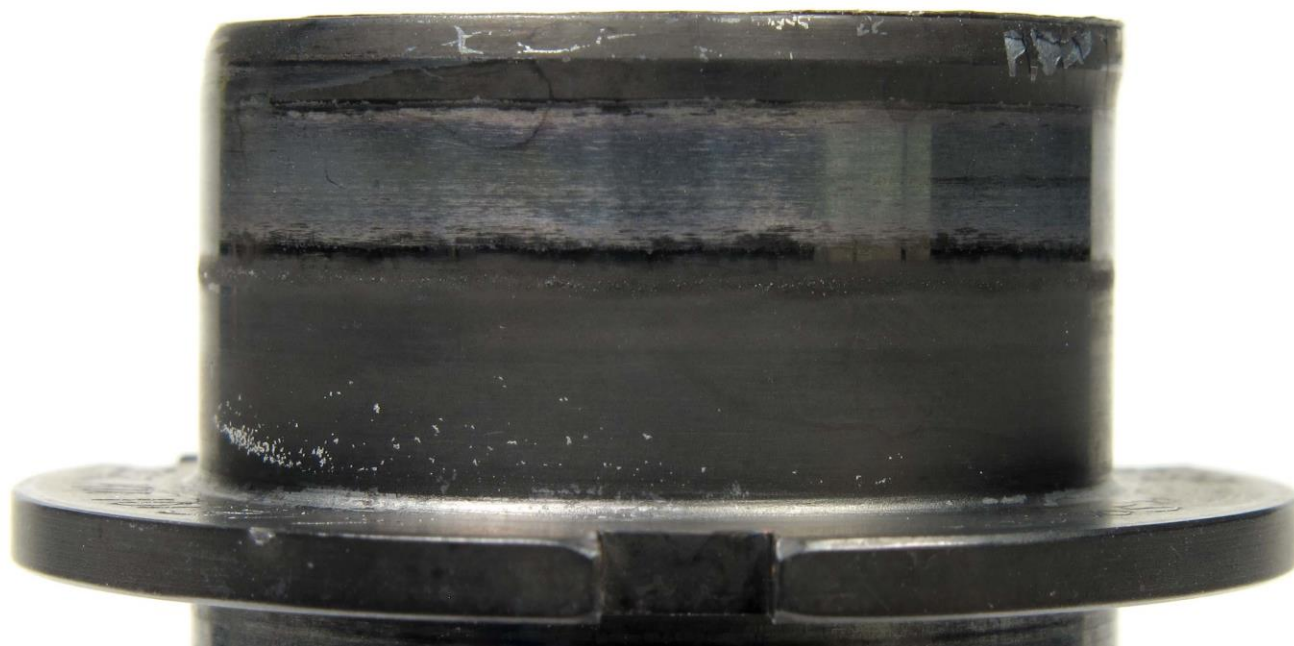
0-degrees

Figure 74. Photographs showing the damage to the ID surface at the aft end of the power turbine inner shaft (upper image). The lower image shows the condition of the No. 6 bearing inner ring raceway.



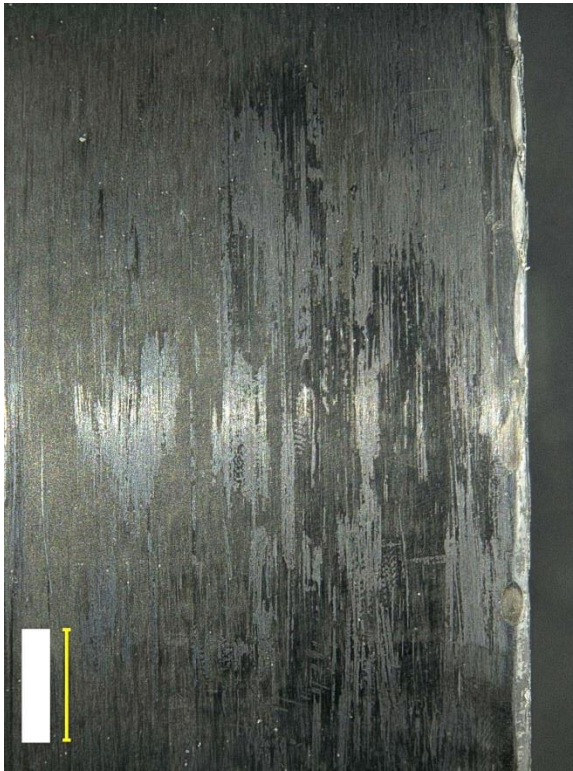
120-degrees

Figure 75. Photographs showing the damage to the ID surface at the aft end of the power turbine inner shaft (upper image). The lower image shows the condition of the No. 6 bearing inner ring raceway.



240-degrees

Figure 76. Photographs showing the damage to the ID surface at the aft end of the power turbine inner shaft (upper image). The lower image shows the condition of the No. 6 bearing inner ring raceway.



← Forward

Score marks



Figure 77. Photographs of the turbine to compressor coupling showing the scoring damage on the aft end OD surface.