# ATTACHMENT 1

**POWERPLANT GROUP CHAIRMAN'S FACTUAL REPORT**

**ENG22LA002**

IAE Metallurgical Report Titled "Metallurgical Investigation of (certain parts) from PW1100G Engine 771708", dated December 16, 2021

# Metallurgical Investigation

**Subject:** **Metallurgical Investigation of (certain parts) from PW1100G Engine 771708**
**Date:** **December 16, 2021**

**Summary and Conclusions:**

The CP09 tube cracked due to fatigue, which initiated at multiple origins along the outer diameter of the tube. It seems likely that the fatigue was driven by TMS motion. Tube wall thickness at the fracture location was 21.4% below nominal thickness.

Two bolts that retain the TMS Lower Aft Case Mount fractured due to shear overstress. Secondary damage to the mount and the bolt fracture surfaces indicates that bolt fracture resulted in TMS motion.

It is known that this engine, operated by Spirit Airlines, experienced a bird strike event.

## 1.0 Details of Examination

Schematics of engine externals showing the relative location of the CP09 tube and TMS mounting hardware are shown in **Figure 1** and **Figure 2** for reference. Hardware submitted for investigation included one cracked PN 5318103-01 CP09 tube (**Figure 3**), one PN 5315179-01A TMS upper aft link (**Figure 4**), one PN 5318008-01E TMS Upper Aft Case Mount and three mounting bolts (**Figure 5**), one PN 5318316-01 TMS Lower Aft Case Mount with one intact mounting bolt and two fractured mounting bolts (PN ST1503-12) (**Figure 6**), and one PN 5327400-01 TMS Forward Case Mount (**Figure 7**). Visual and binocular microscope review of the TMS upper aft link, the TMS upper aft case mount, and the TMS forward case mount did not reveal any cracks or distress.

The crack in the CP09 tube was in a straight region of tube near the PN 5314525 Tube to Boss Elbow. The crack was fractured open to allow examination of the crack surface. An additional cut was made between the crack surface and the Tube to Boss Elbow to facilitate examination. The sample was then ultrasonically cleaned in a mild alkali solution of Blue Gold Industrial Cleaner[1] for ten minutes and rinsed with isopropyl alcohol. Optical microscopic review of the cleaned surface revealed a region of fatigue progressing through wall from the external surface. The fatigue region and origin location are shown in **Figure 8**. The wall thickness at the origin region was 21.4% below nominal thickness.

The sample was then reviewed using a scanning electron microscope (SEM). The entire crack surface was mapped at 65 times magnification, and the resulting montage was stitched using Thermofisher's MAPS software[2]. The sample was then removed from the SEM for additional cleaning. The crack surface was lightly brushed with a new toothbrush and soapy water, followed by five minutes of ultrasonic cleaning in Blue Gold solution followed by another five minutes of ultrasonic cleaning in isopropyl alcohol. The sample was then further reviewed using a SEM, which revealed that this second round of cleaning was largely successful. Increasingly higher magnification montages were captured and stitched of the fatigue region as well and the origin region. The fatigue region appeared to be transgranular and was striated through thickness. Multiple origins were present along the outer diameter surface of the tube, and some regions were rubbed out. Clamshell shaped arrest lines were clearly evident across the latter half of the fatigue progression, and the apex of these arrests used to trace back the likely location of the primary origin as shown in **Figure 9**. A series of SEM images along the path from this origin to the apex of the arrest line that was closest to the inner diameter (ID) surface is presented in **Figures 10 – 14**. While striated progression was evident in most fields of view, the extent of secondary rubbing damage to the crack surface made it difficult to find regions with enough well-formed striations to confidently calculate striation spacing. The best location found is shown in **Figure 12**. This location, approximately 5/8 through thickness, exhibited an average striation spacing that suggested a local growth rate of 1.68E-5 inch per cycle. Tube composition was verified at two locations along this path using energy dispersive spectroscopy (EDS), and a representative spectrum of this analysis is shown in **Figure 13**. The analysis revealed a composition that was similar to the composition specified for tube, AMS 5557 (321 SS).

[1] https://www.bluegoldcleaners.com/Our-Products/Blue-Gold-Industrial-Cleaner
[2] https://www.thermofisher.com/us/en/home/electron-microscopy/products/software-em-3d-vis/maps-software.html

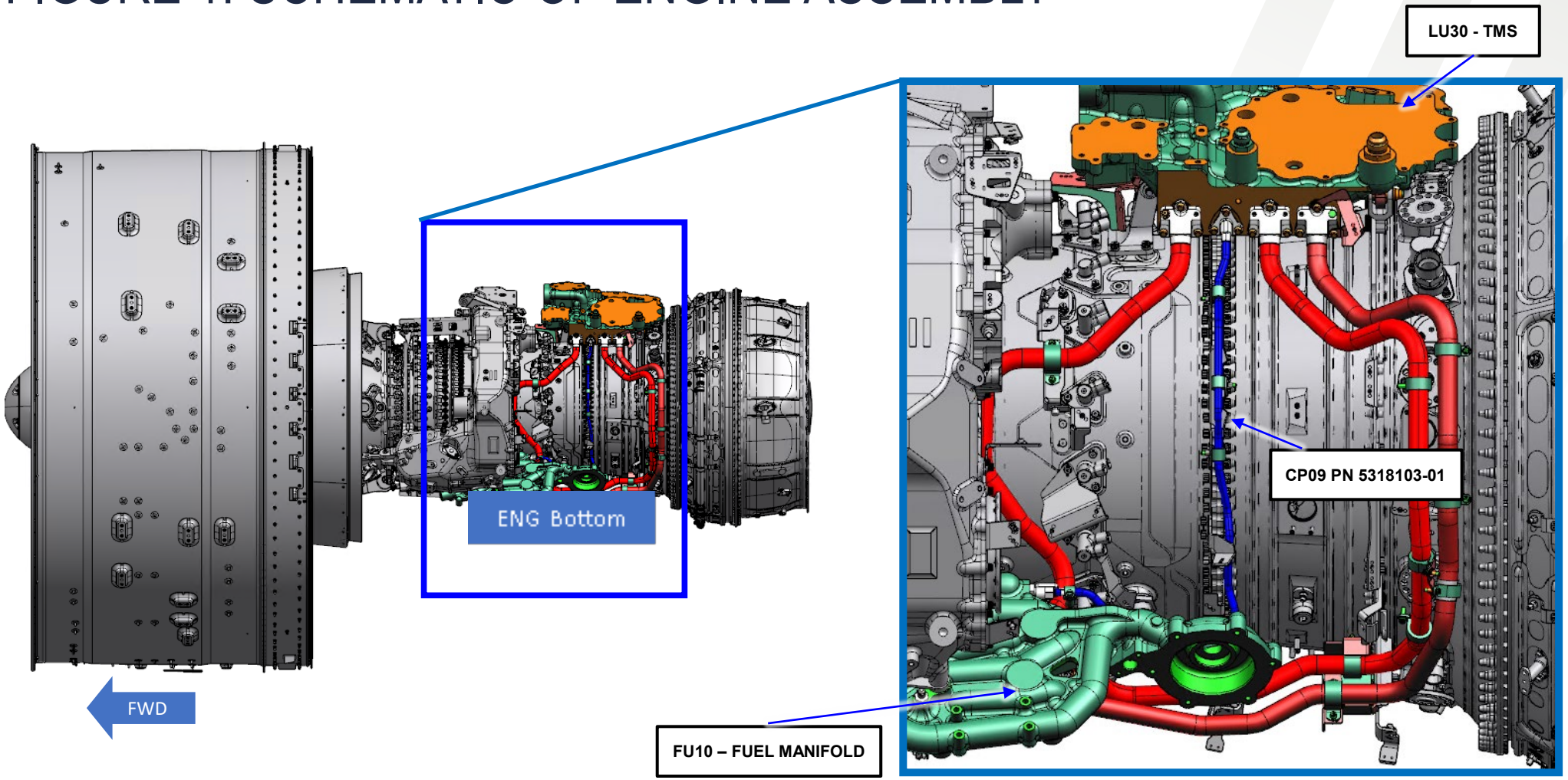
The fractured ST1503-12 bolts in the PN 5318316-01 TMS Lower Aft Case Mount were examined. Optical review revealed that the fracture surfaces and surrounding area of the case mount exhibited large area fractions of secondary damage (**Figure 15**). Both bolts were examined using a SEM. All regions of both fracture surfaces that were not smeared with secondary damage exhibited dimpled fracture features, indicative of an over-stress fracture mode (**Figures 16 and 17**). Microscopic inspection of the intact bolt associated with this assembly found cracks in several thread roots. The bolt appeared to be straight; there was no evidence of bending. The cracking was documented from three different rotational orientations of the bolt, as shown in **Figures 18 – 20**. A crack was fractured open, and the resulting exposed surfaces are shown in **Figure 21**. Optical microscopic review of the crack surface revealed features typical of shear overstress. SEM examination found dimples similar to those documented for the fractured bolts over much of the surface (**Figures 22 and 23**). However, a short, shallow band of striated fatigue progression was observed along the outer diameter as shown in **Figure 24 and Figure 25**.

Two metallographic sections were prepared through the CP09 tube. One section was made through a straight section of the tube away from the crack for wall thickness verification. At that location, wall thickness around the circumference measured at 8 locations that were all within 0.001 inch of nominal, meeting specification requirements (**Figure 26**). A section made through the fracture surface origin revealed that tube wall thickness gradually reduced approaching the fracture surface, possibly due to necking, with wall thickness locally reduced 21.4% relative to nominal (**Figure 27**). Etching of these samples revealed a grain size of 9, which conformed to the AMS 5557 requirement of 5 or finer. Also, it was clear that the fracture surface was outside of the weld. Two shallow secondary cracks parallel to the fracture surface were observed (**Figure 28**). No evidence of continuous intergranular carbide precipitation was observed in the etched condition at 500 times magnification.

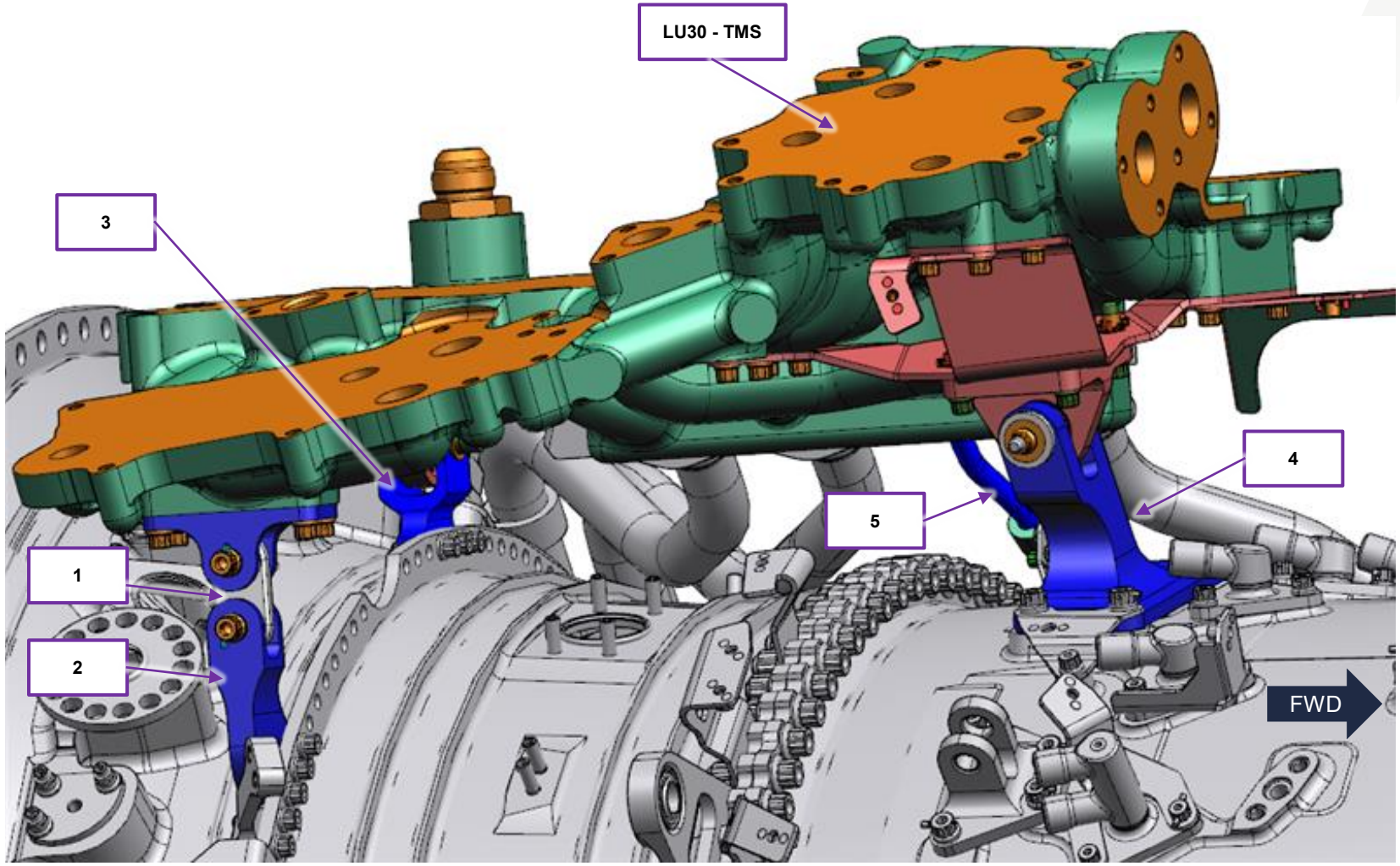
Metallographic review of a ST1503-12 bolt revealed that grain size of the bolt was 6, which conformed to the AMS 5708 requirement of 3 or finer (**Figure 29**). Hardness of the bolt was measured at 5 locations and ranged from 37.3 to 39.2 HRC, which conformed to the AMS 5708 requirement of 32-42 HRC. The fracture surface was predominantly intergranular

SEM EDS analysis of the tube revealed a chemistry similar to AMS 5557 (321 SS). EDS of the bolt revealed a chemistry similar to AMS 5508 (Waspaloy) (**Figure 30**).

# FIGURE 1: SCHEMATIC OF ENGINE ASSEMBLY

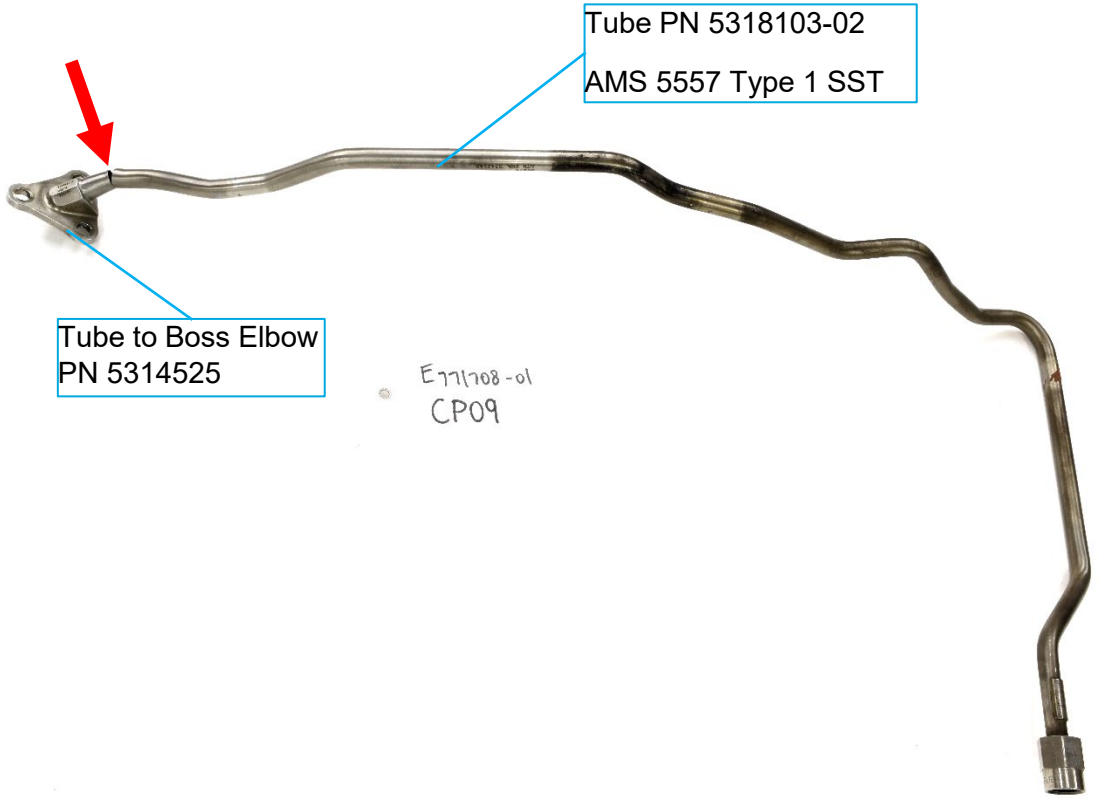


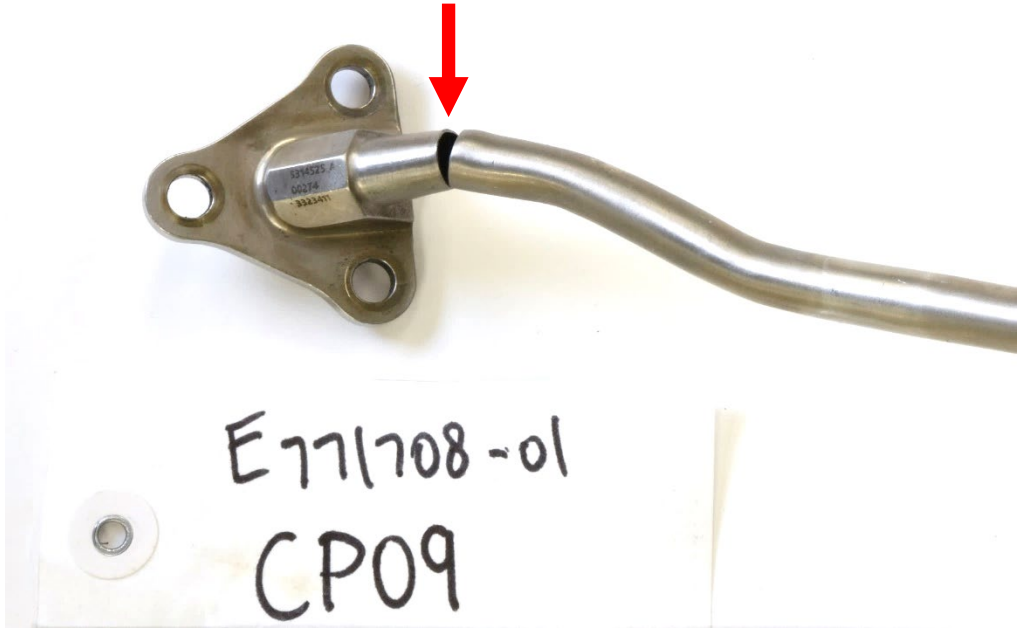
# FIGURE 2: TMS MOUNT OVERVIEW




1) PN 5315179-01 TMS Upper Aft Link (AMS 5666 Ni Alloy)
2) PN 5318008-01 TMS Upper Aft Case Mount (AMS 5666 Ni Alloy)
3) PN 5318316-01 TMS Lower Aft Case Mount (AMS 5666 Ni Alloy)
4) PN 5327400-01 TMS Forward Case Mount (AMS 5666 or 5599 INCO 625 Ni Alloy)
5) PN 5318103-02 CP09 Tube

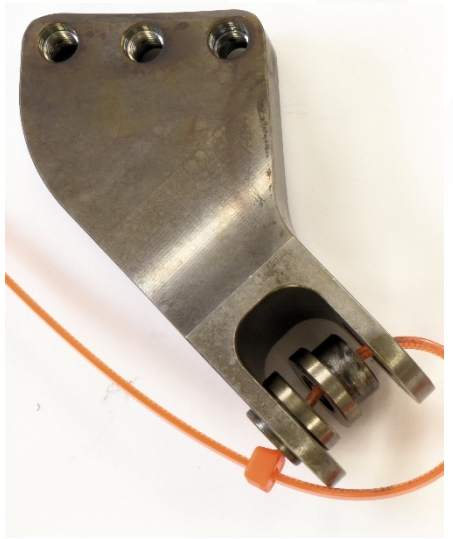
# FIGURE 3: CRACKED CP09 TUBE



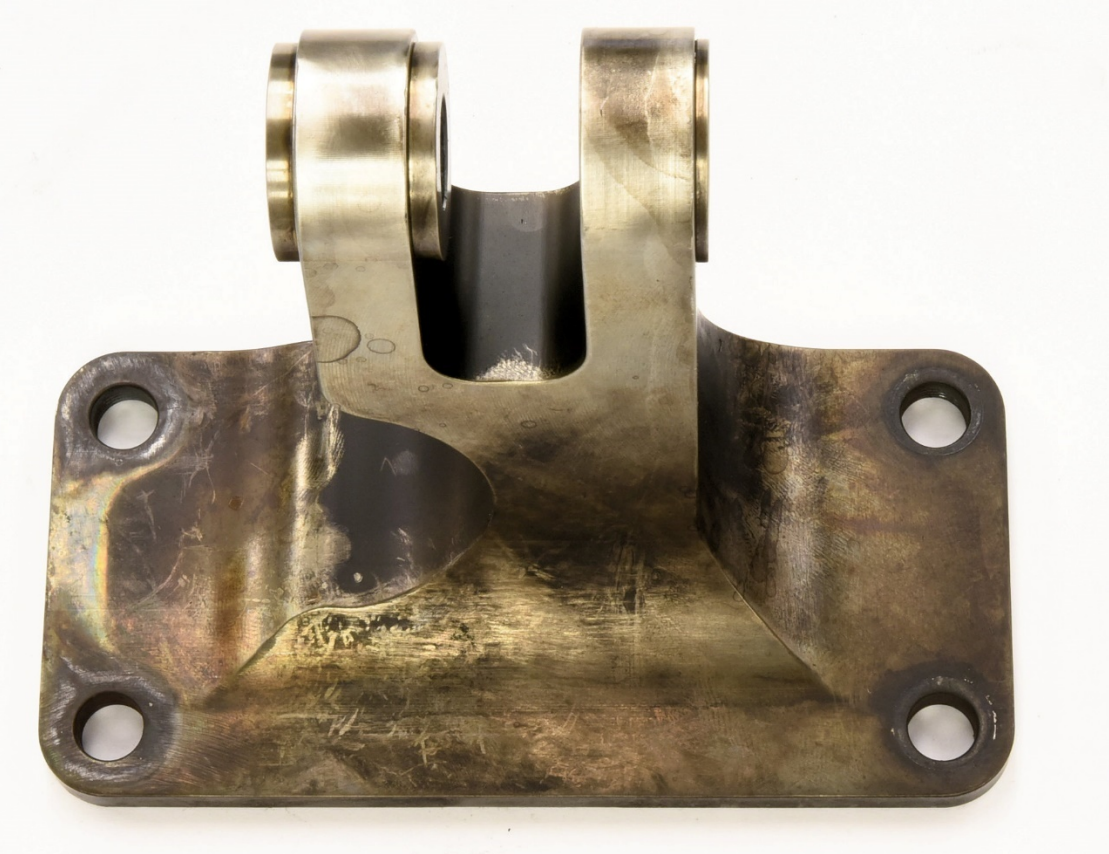
# FIGURE 4: PN 5315179-01A TMS UPPER AFT LINK


# FIGURE 5: PN 5318008-01E TMS UPPER AFT CASE MOUNT

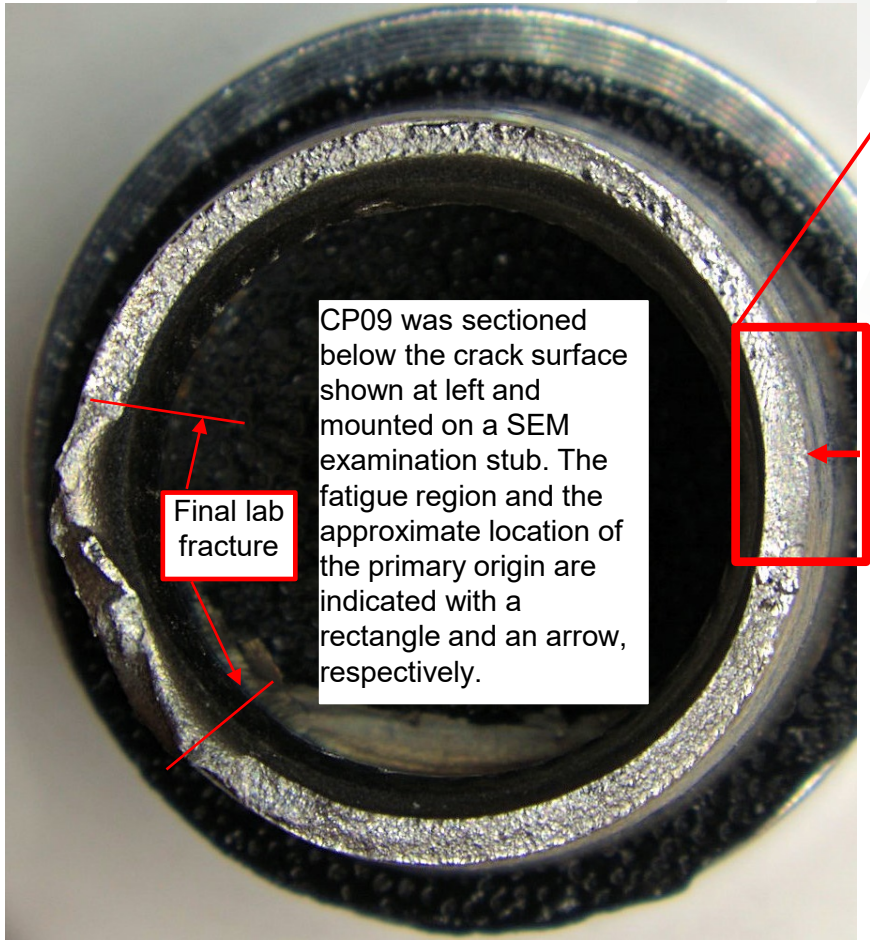
# FIGURE 6: PN 5318316-01 TMS LOWER AFT CASE MOUNT


# FIGURE 7: PN 5327400-01 TMS FORWARD CASE MOUNT



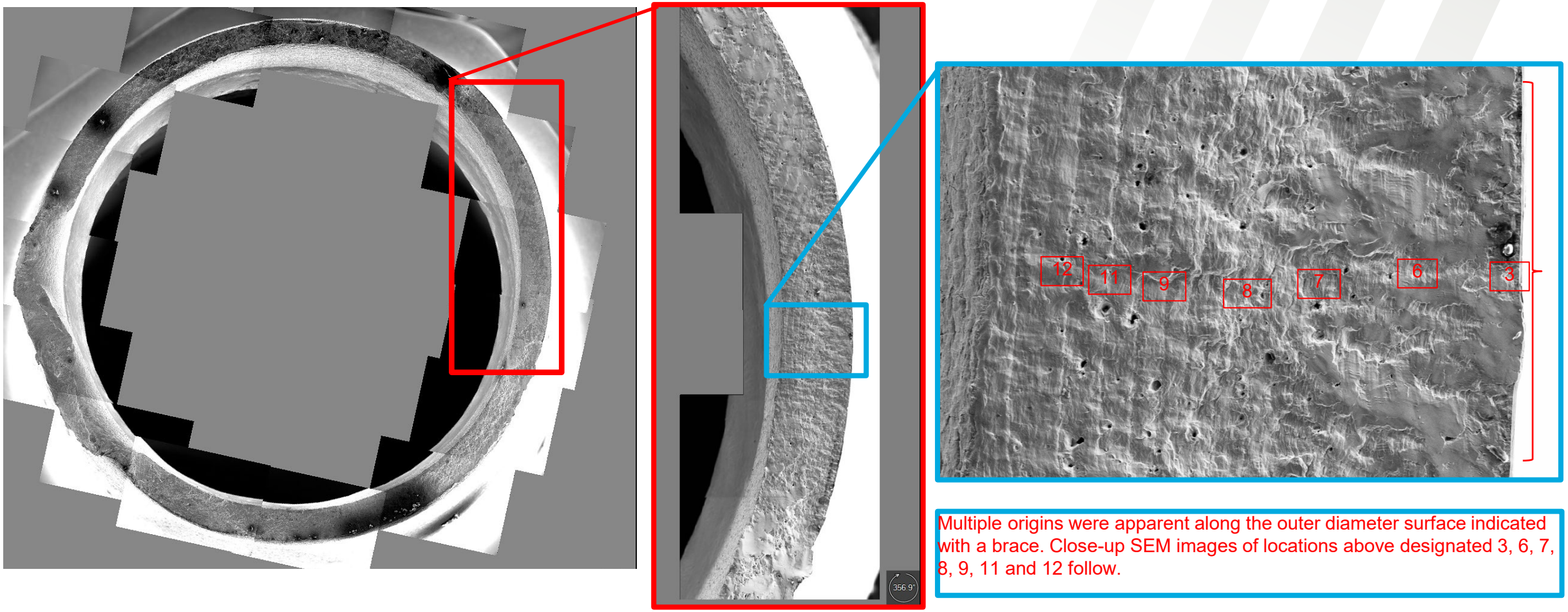
# FIGURE 8: CRACK IN CP09 TUBE WAS FRACTURED OPEN

Arrow drawn on part indicates the approximate location of the fatigue origin




Through-wall fatigue region.
Overstress cracking elsewhere.

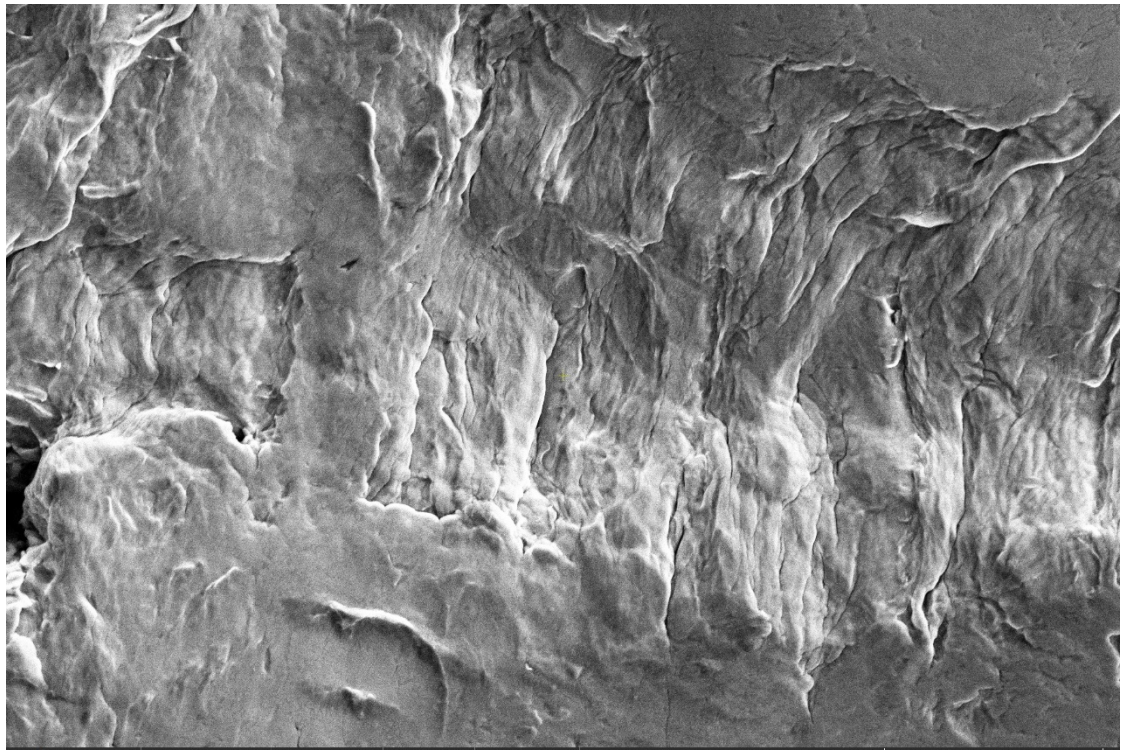
# FIGURE 9: SEM EXAMINATION OF CP09 CRACK SURFACE




Multiple origins were apparent along the outer diameter surface indicated with a brace. Close-up SEM images of locations above designated 3, 6, 7, 8, 9, 11 and 12 follow.

# FIGURE 10: SEM EXAMINATION OF CP09 CRACK SURFACE LOCATIONS 3 AND 6

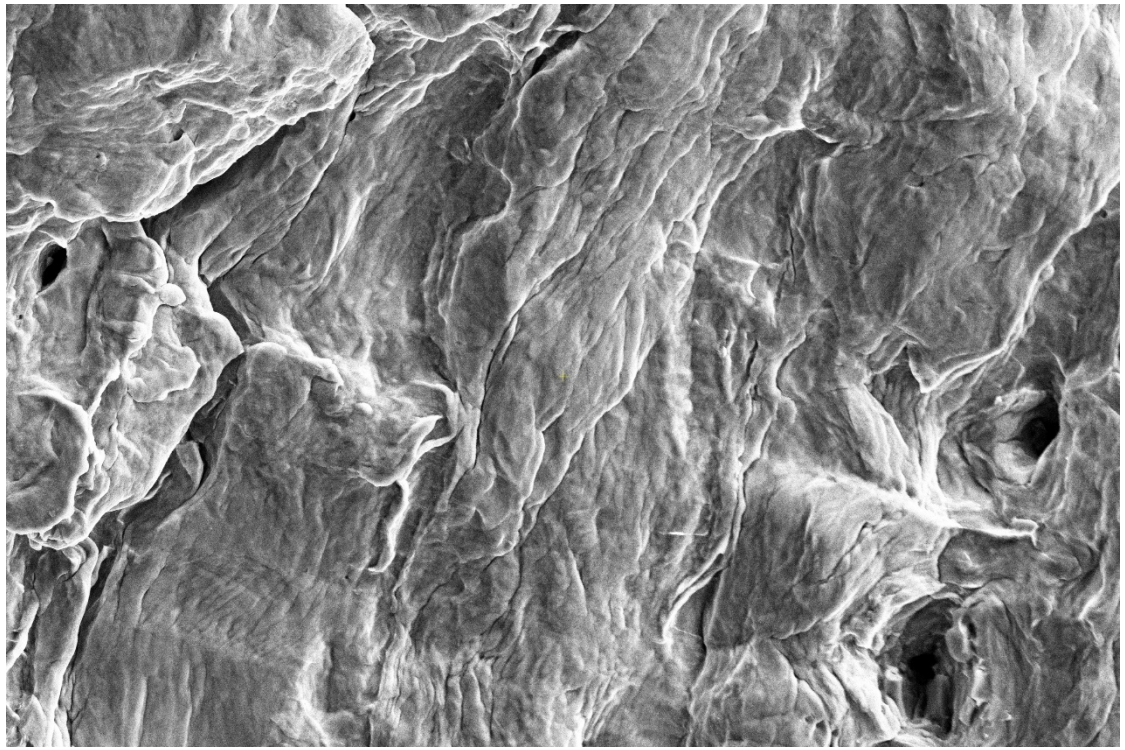
Location 6



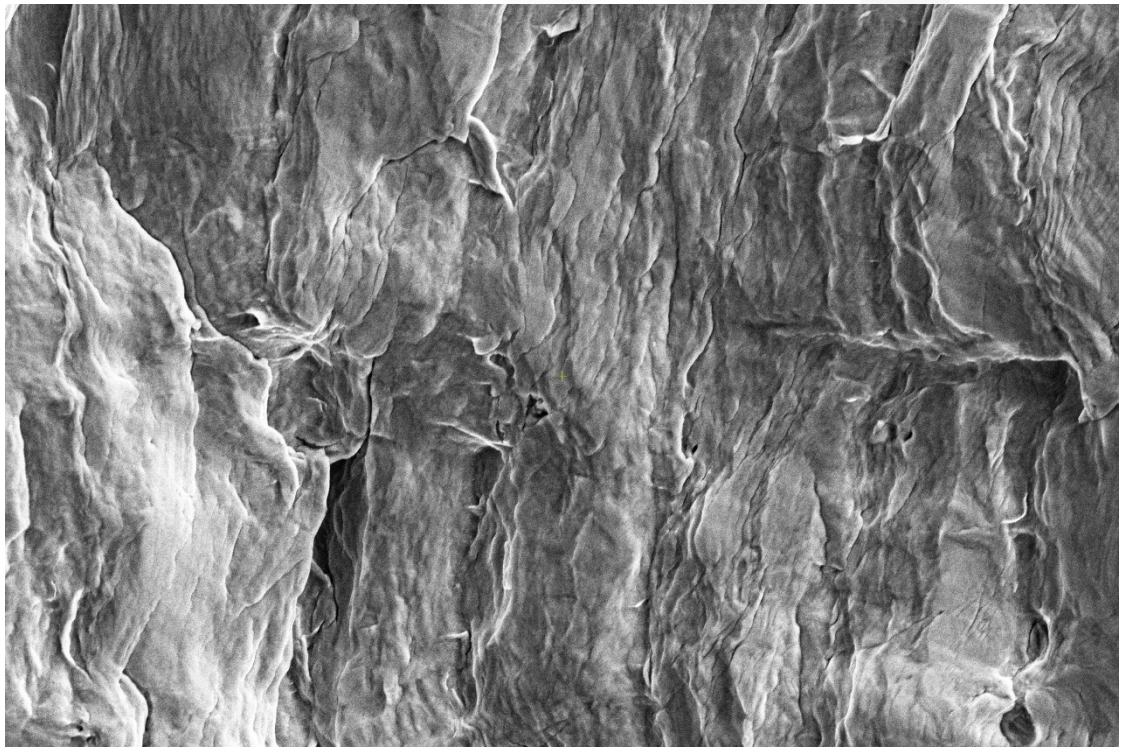
Location 3

# FIGURE 11: SEM EXAMINATION OF CP09 CRACK SURFACE LOCATIONS 7 AND 8

Location 8

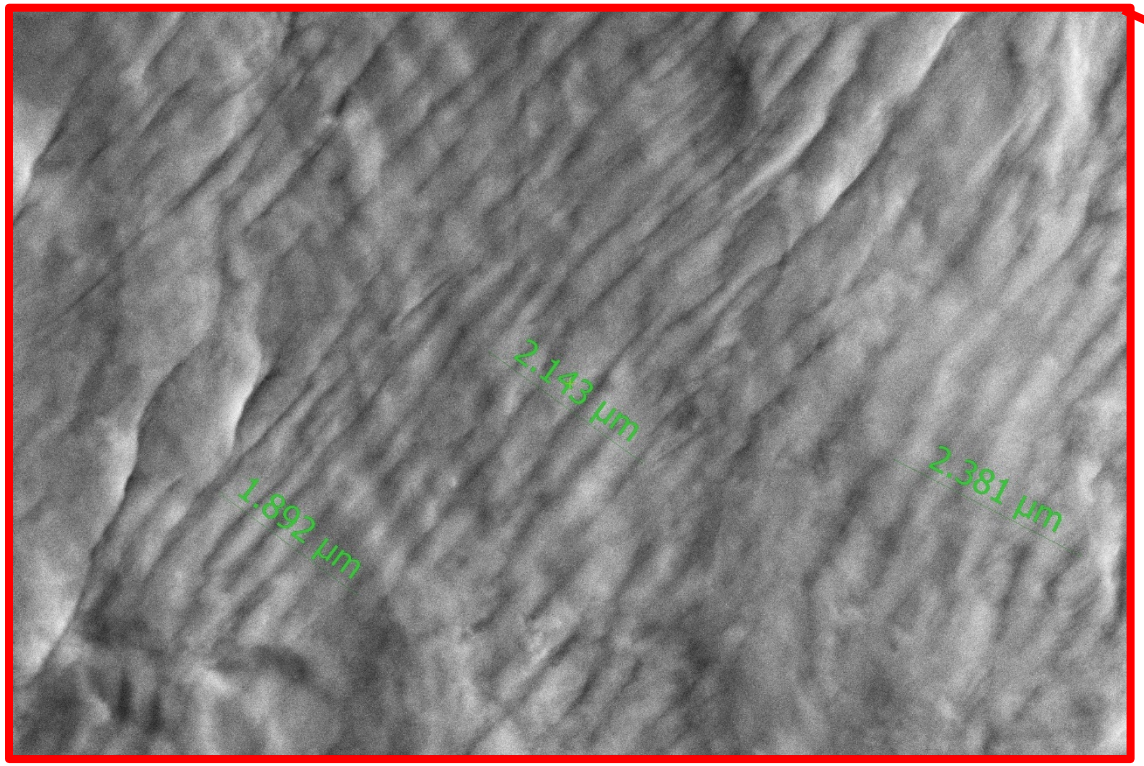


Location 7

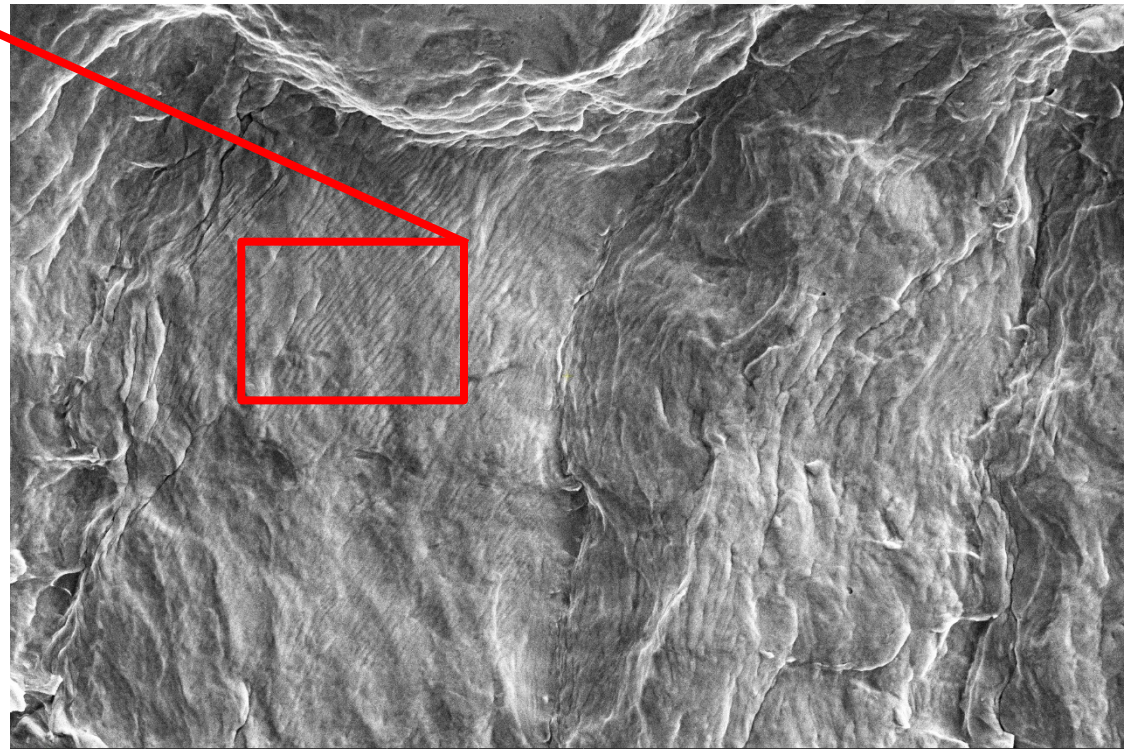


# FIGURE 12: SEM EXAMINATION OF CP09 CRACK SURFACE LOCATION 9

Spacing of striations in this field of view was approximately 1.68E-5 in. / cycle.

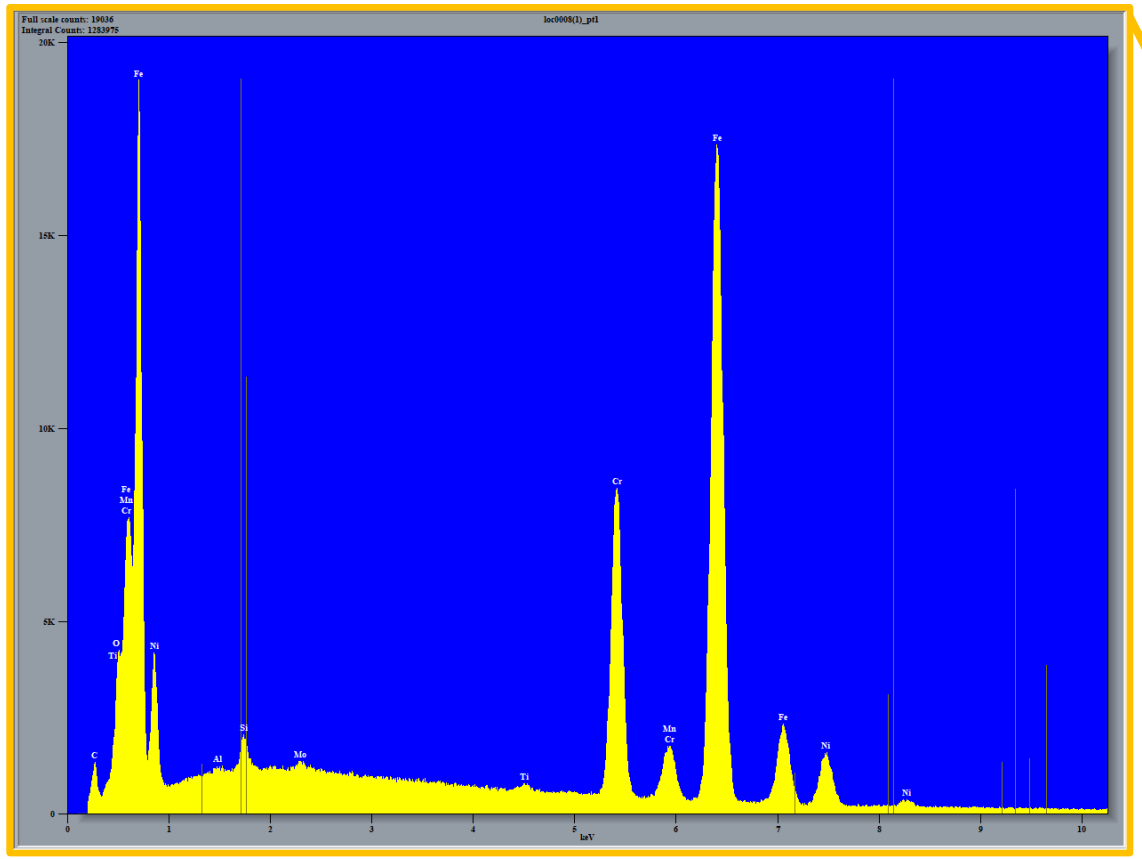



Location 9

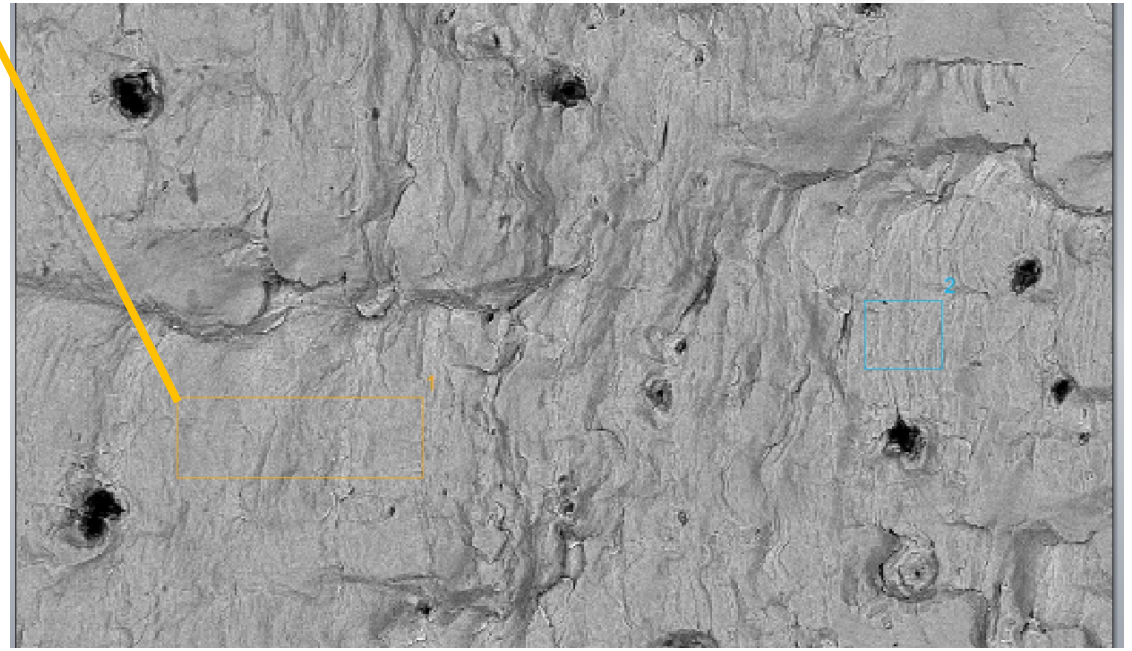


# FIGURE 13: SEM EXAMINATION OF CP09 CRACK SURFACE EDS EVALUATION NEAR LOCATION 9

EDS Spectra of sub-region 1 (sub-region 2 was very similar). Composition was similar to the composition specified for tube, AMS 5557 321 SS.

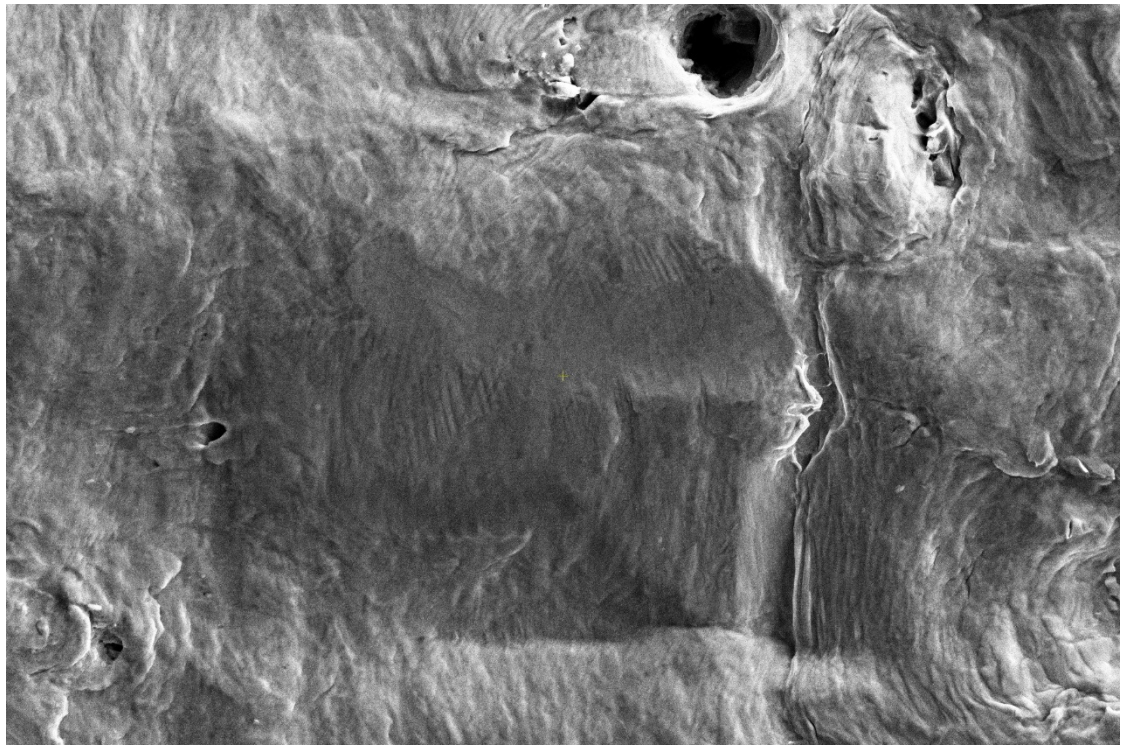



Backscatter image

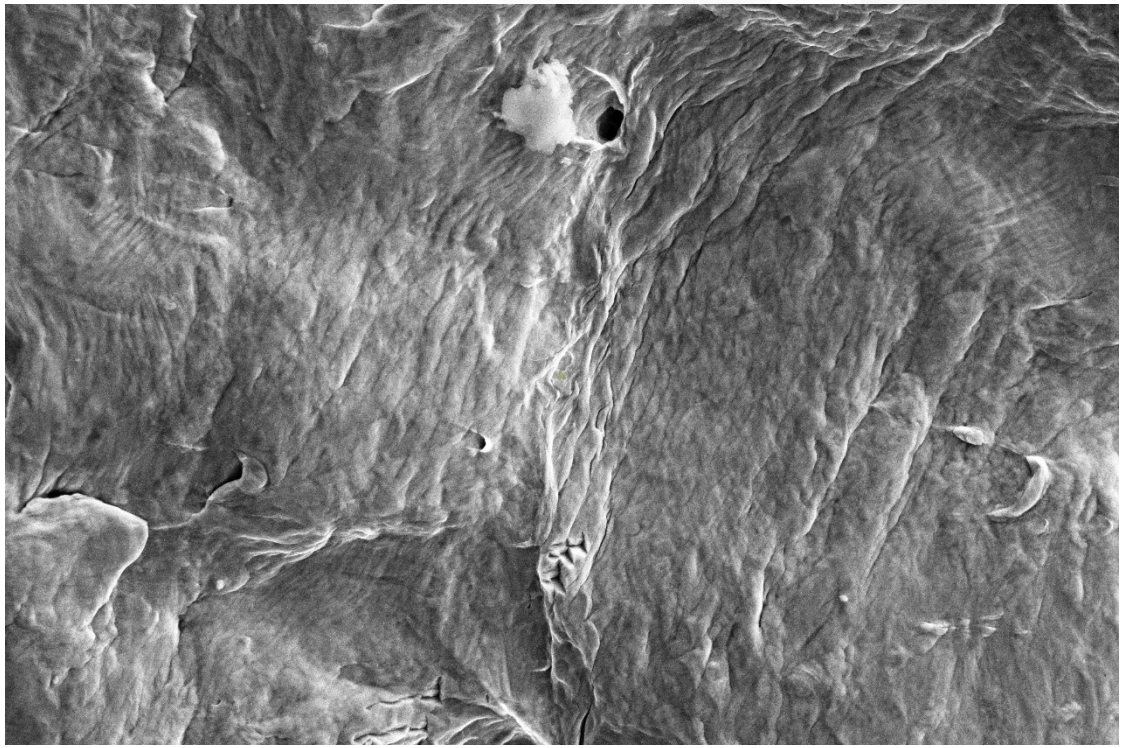


# FIGURE 14: SEM EXAMINATION OF CP09 CRACK SURFACE LOCATIONS 11 AND 12

Location 12

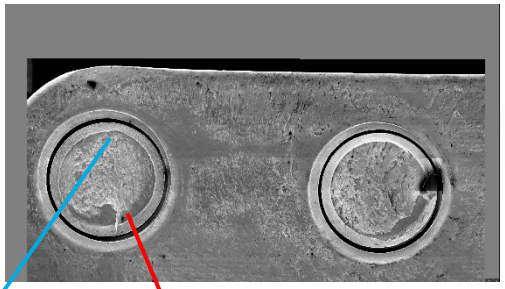


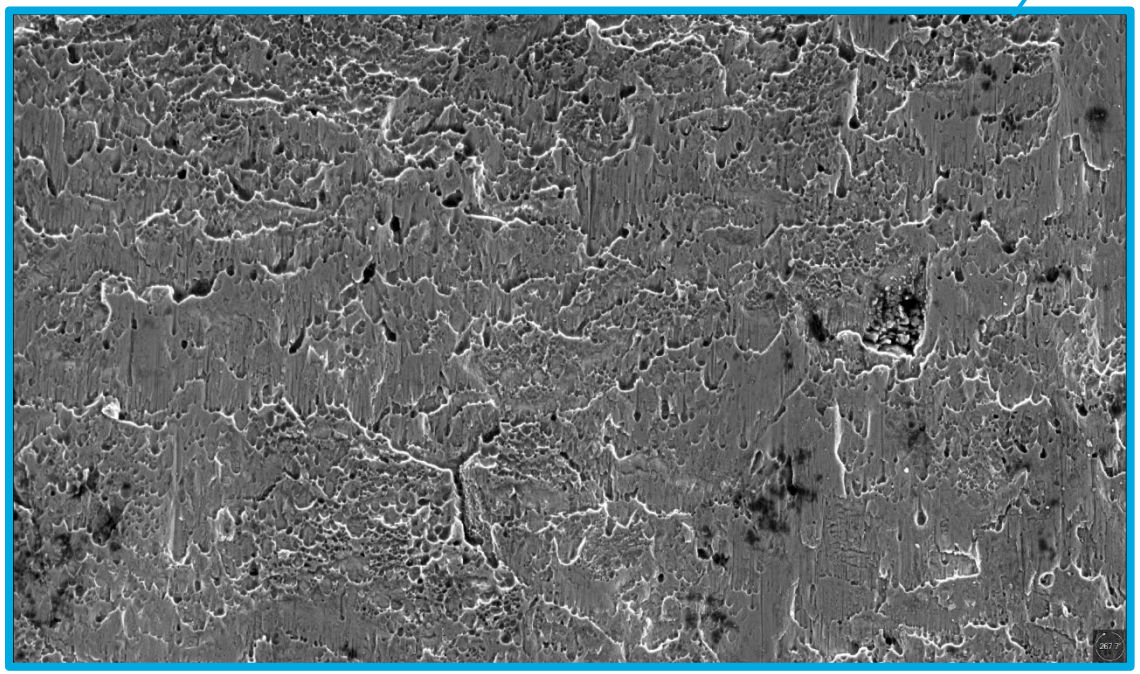
Location 11

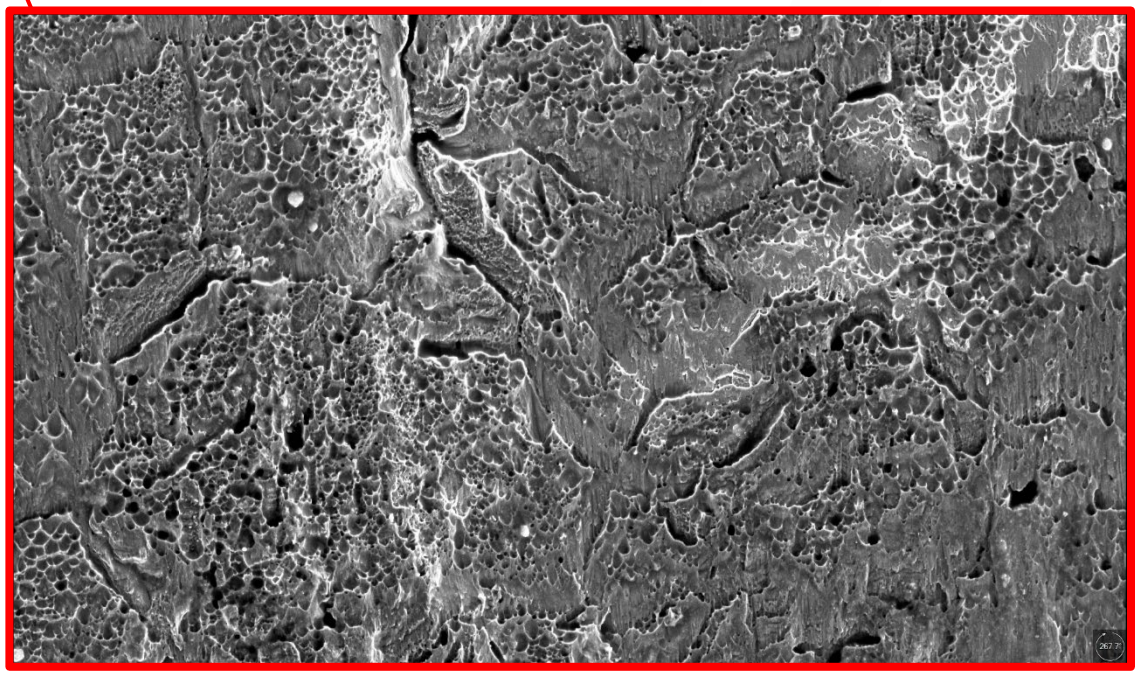


# FIGURE 15: PN 5318316-01 TMS LOWER AFT CASE MOUNT – CLOSE-UP VIEW OF FRACTURED BOLTS AND SECONDARY DAMAGE

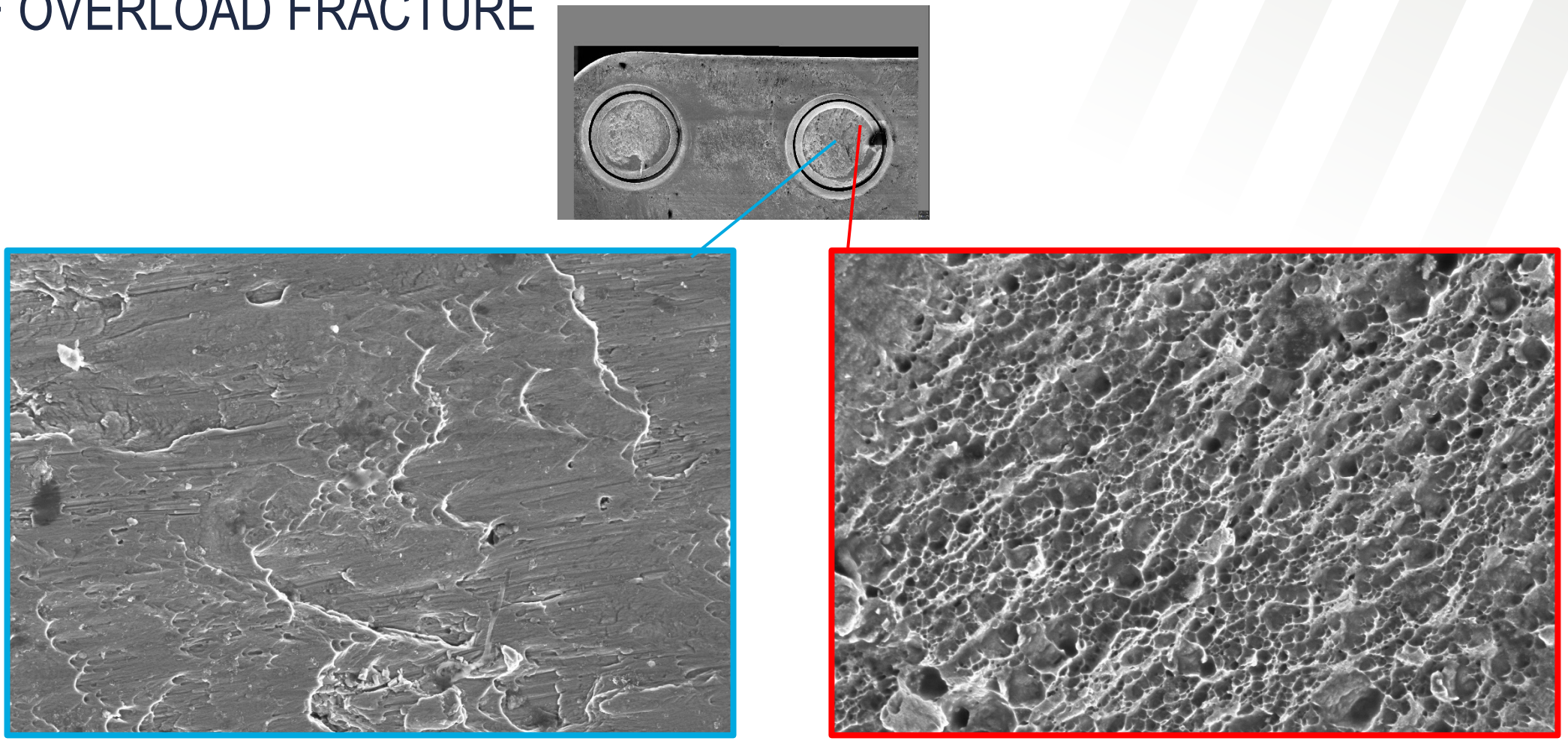
# FIGURE 16: PN 5318316-01 TMS LOWER AFT CASE MOUNT – SEM OF FRACTURED CORNER BOLT REVEALED DIMPLES INDICATIVE OF OVERLOAD FRACTURE



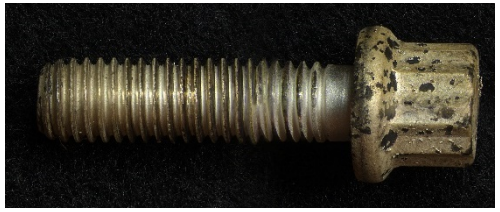




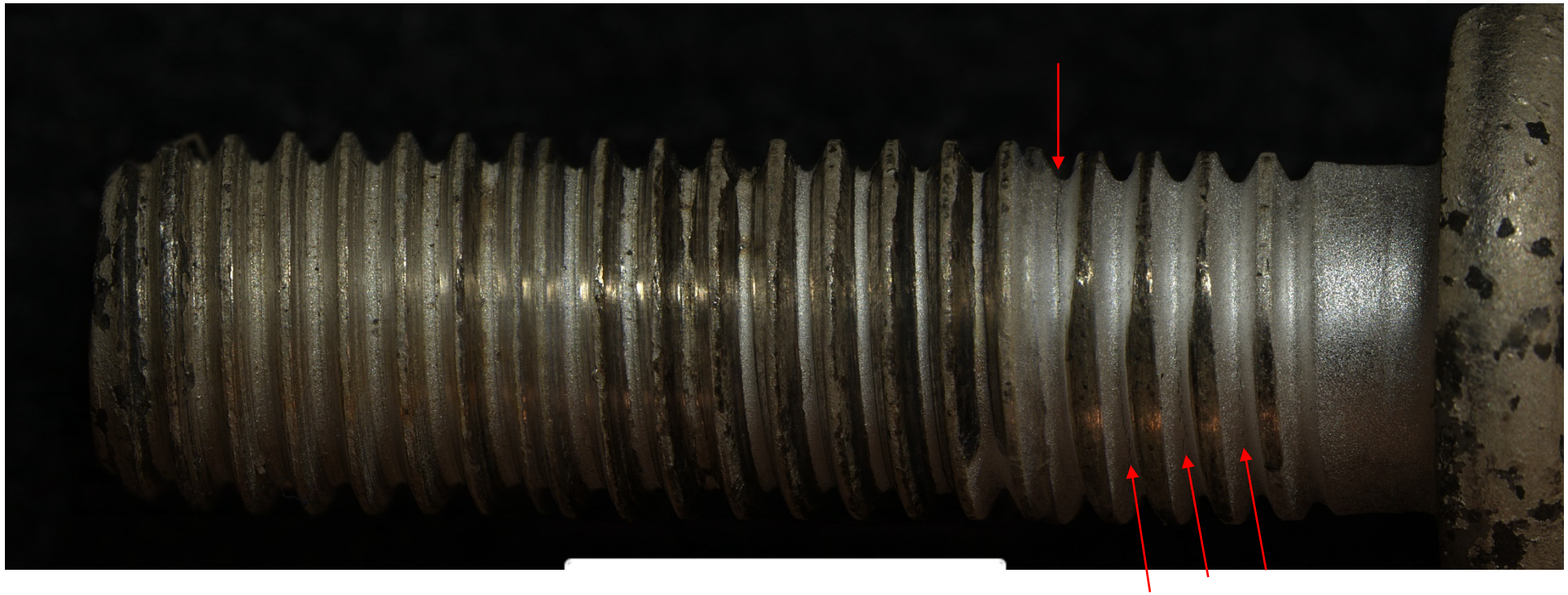
# FIGURE 17: PN 5318316-01 TMS LOWER AFT CASE MOUNT – SEM OF FRACTURED CENTER BOLT REVEALED DIMPLES INDICATIVE OF OVERLOAD FRACTURE



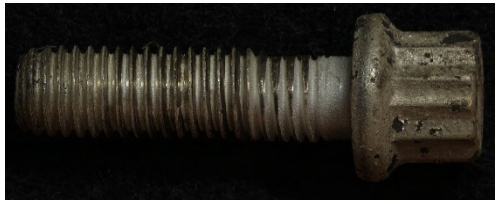
# FIGURE 18: PN 5318316-01 TMS LOWER AFT CASE MOUNT; CLOSE-UP VIEWS OF CRACKED BOLT

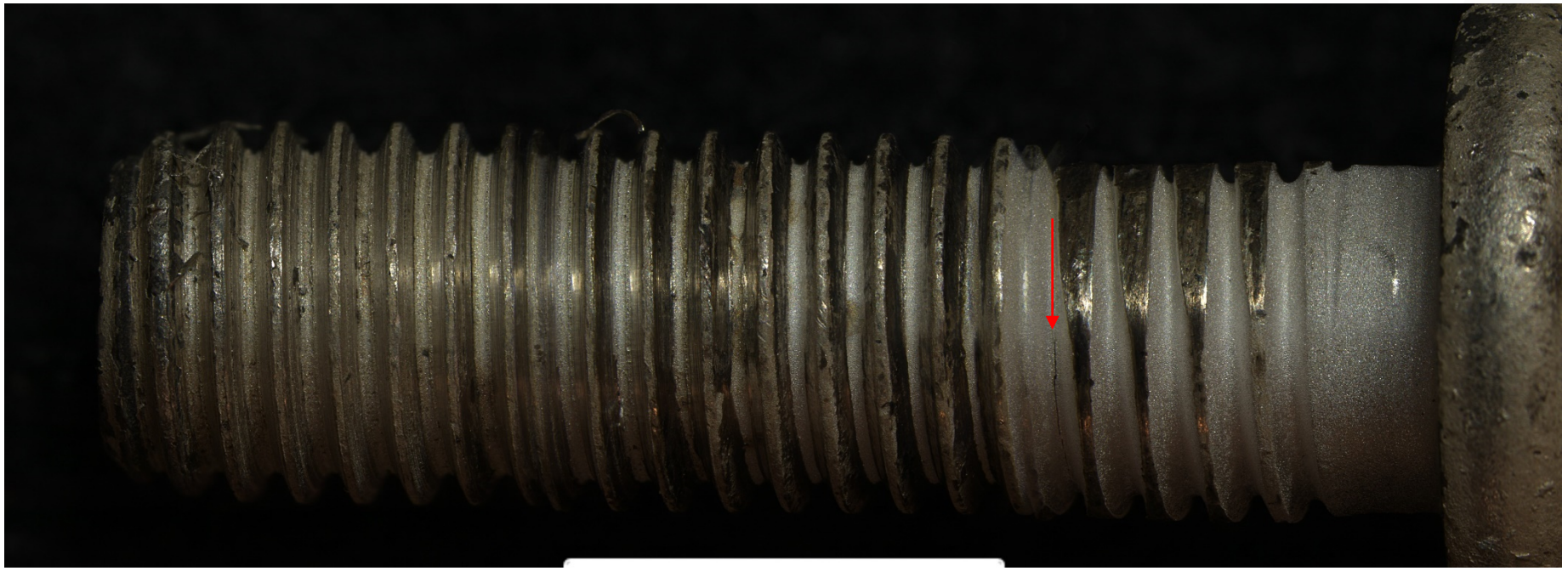


# FIGURE 19: PN 5318316-01 TMS LOWER AFT CASE MOUNT; CLOSE-UP VIEWS OF CRACKED BOLT

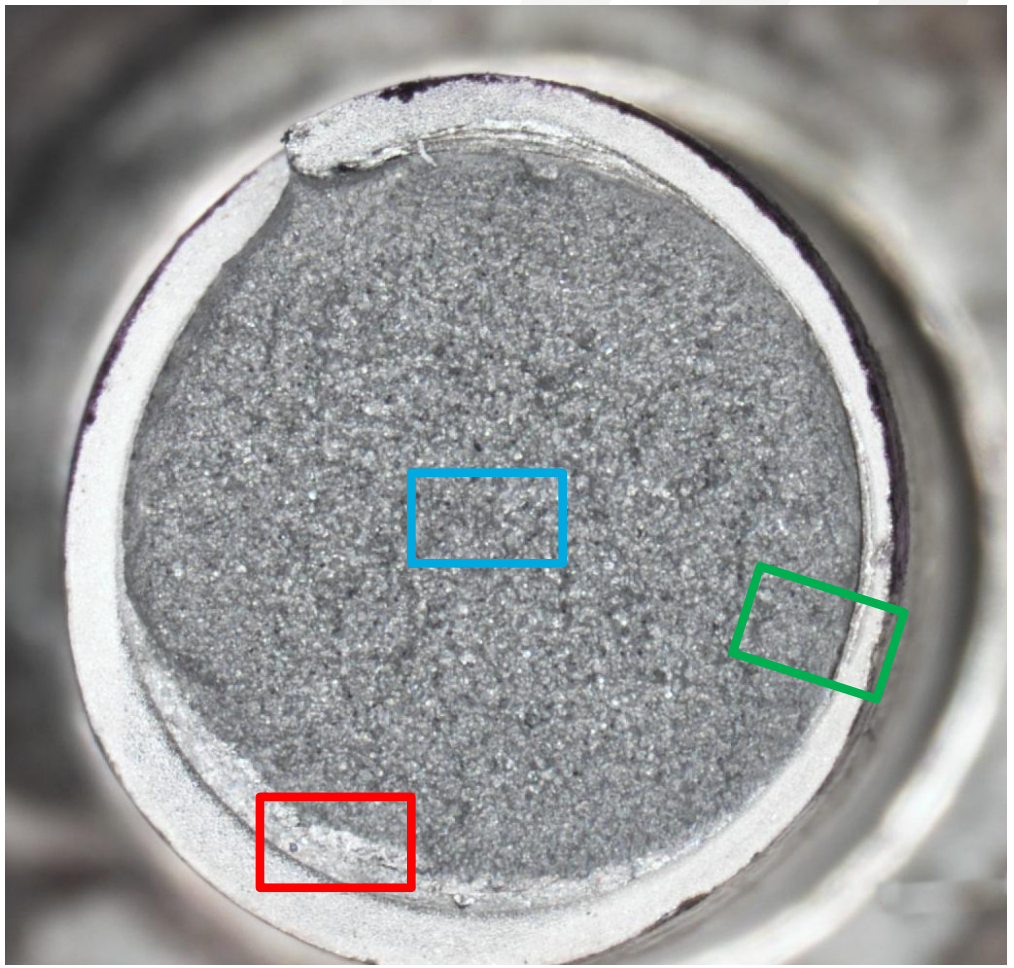


# FIGURE 20: PN 5318316-01 TMS LOWER AFT CASE MOUNT; CLOSE-UP VIEWS OF CRACKED BOLT



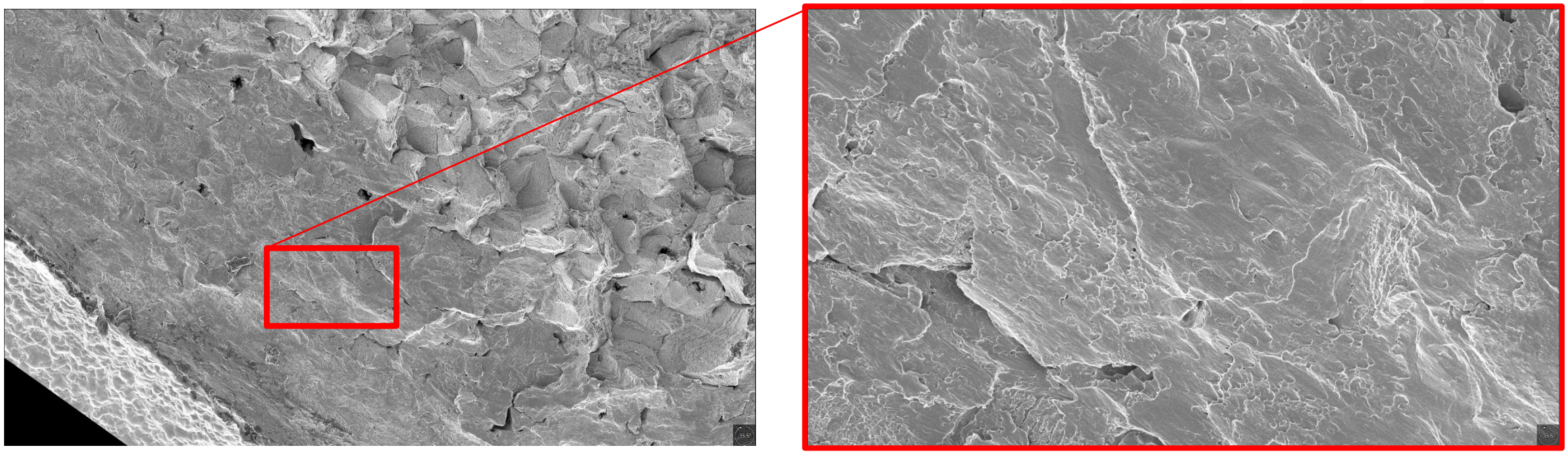


# FIGURE 21: PN 5318316-01 TMS LOWER AFT CASE MOUNT; CLOSE-UP VIEWS OF OPENED CRACK SURFACE



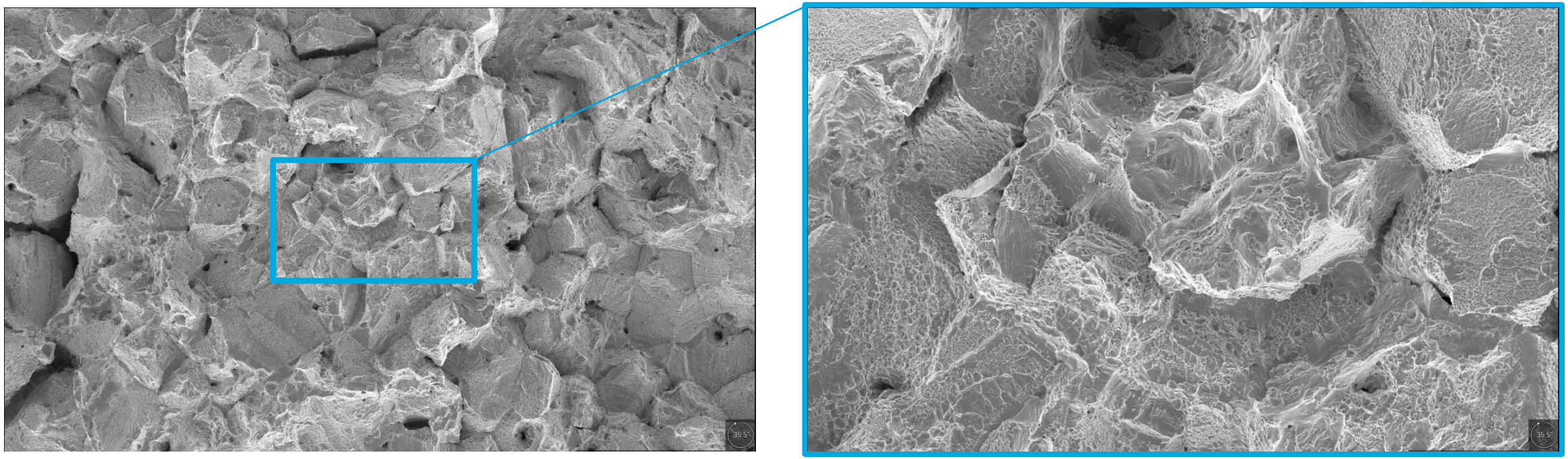
Close up views of the indicated region follow.

# FIGURE 22: PN 5318316-01 TMS LOWER AFT CASE MOUNT; SEM VIEWS OF OPENED CRACK SURFACE



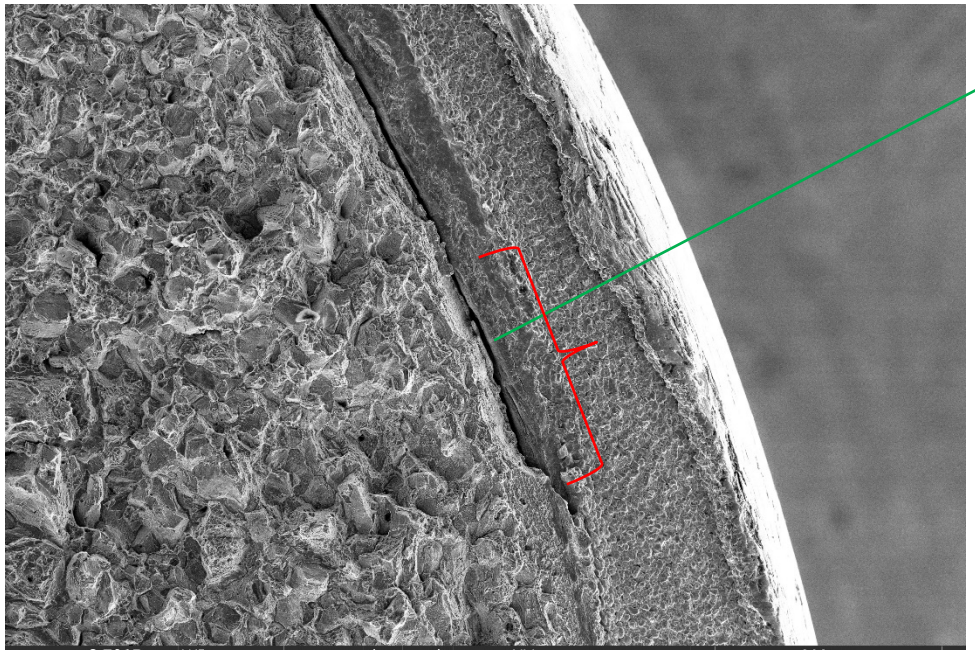
This region exhibits secondary damage of overstress (dimpled) features.

# FIGURE 23: PN 5318316-01 TMS LOWER AFT CASE MOUNT; SEMP VIEWS OF OPENED CRACK SURFACE

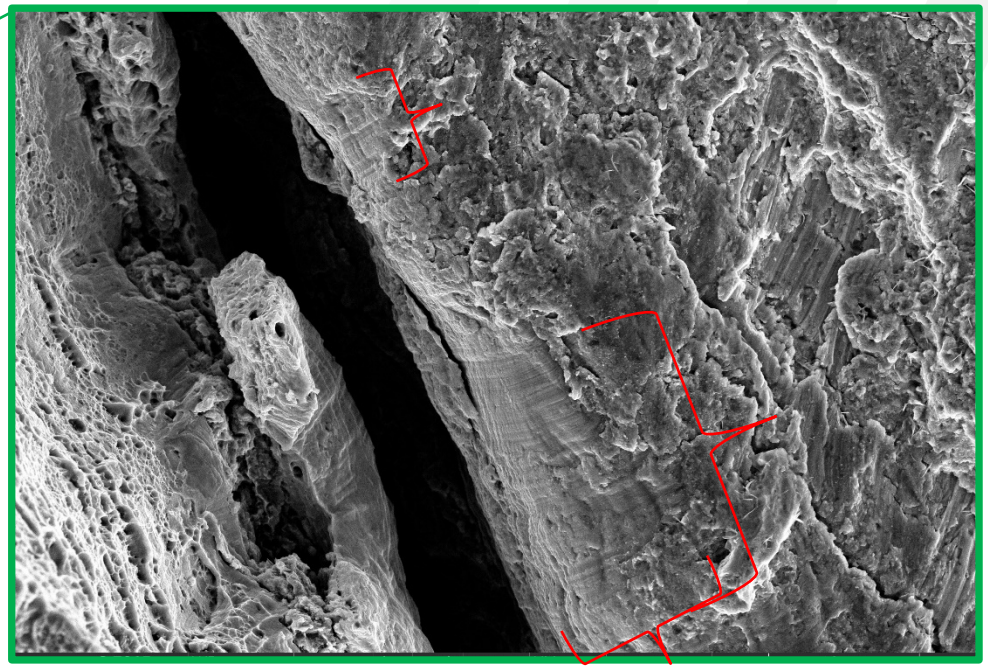


This region exhibits secondary damage of overstress (dimpled) features.

# FIGURE 24: PN 5318316-01 TMS LOWER AFT CASE MOUNT; SEM VIEWS OF OPENED CRACK SURFACE

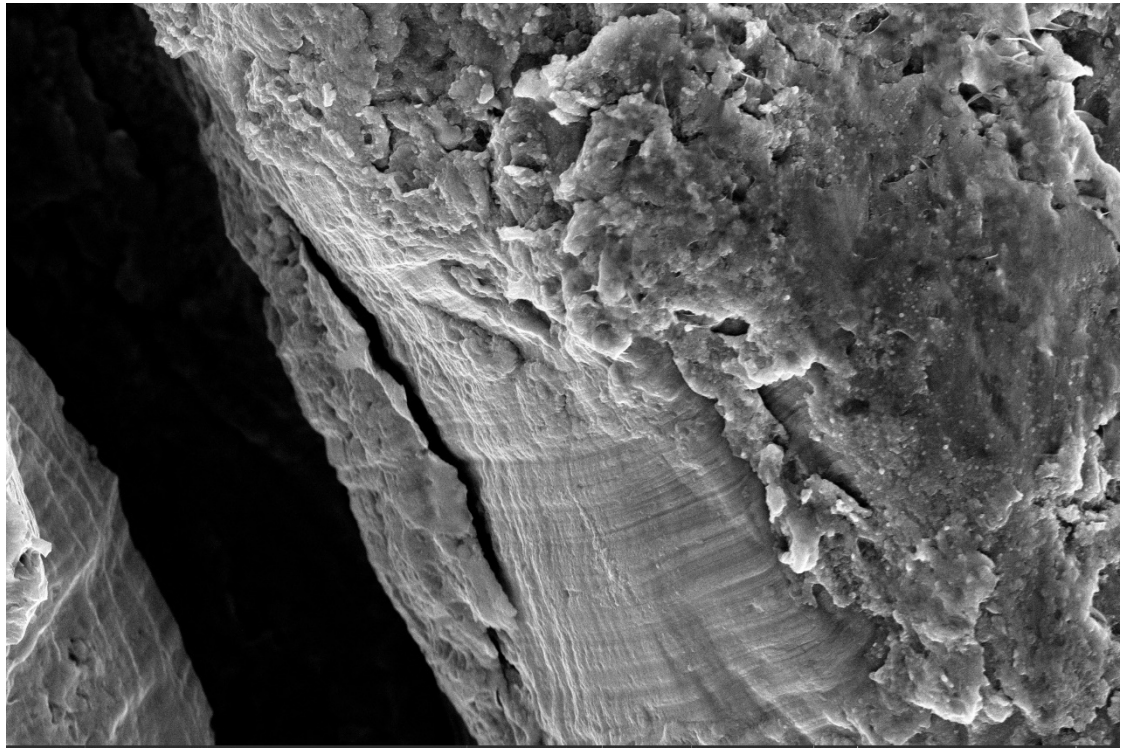


A shallow band of fatigue was observed in the region indicated with a brace.

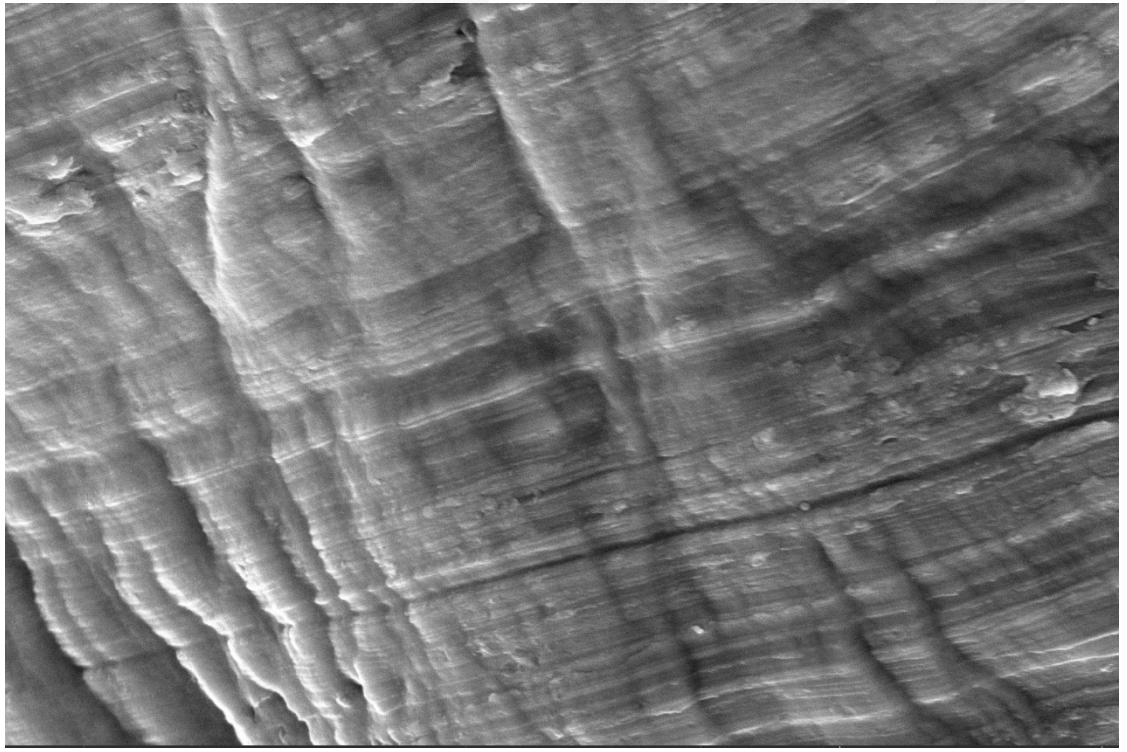


Braces indicate fatigue; close-up images follow

# FIGURE 25: PN 5318316-01 TMS LOWER AFT CASE MOUNT; SEM VIEWS OF OPENED CRACK SURFACE

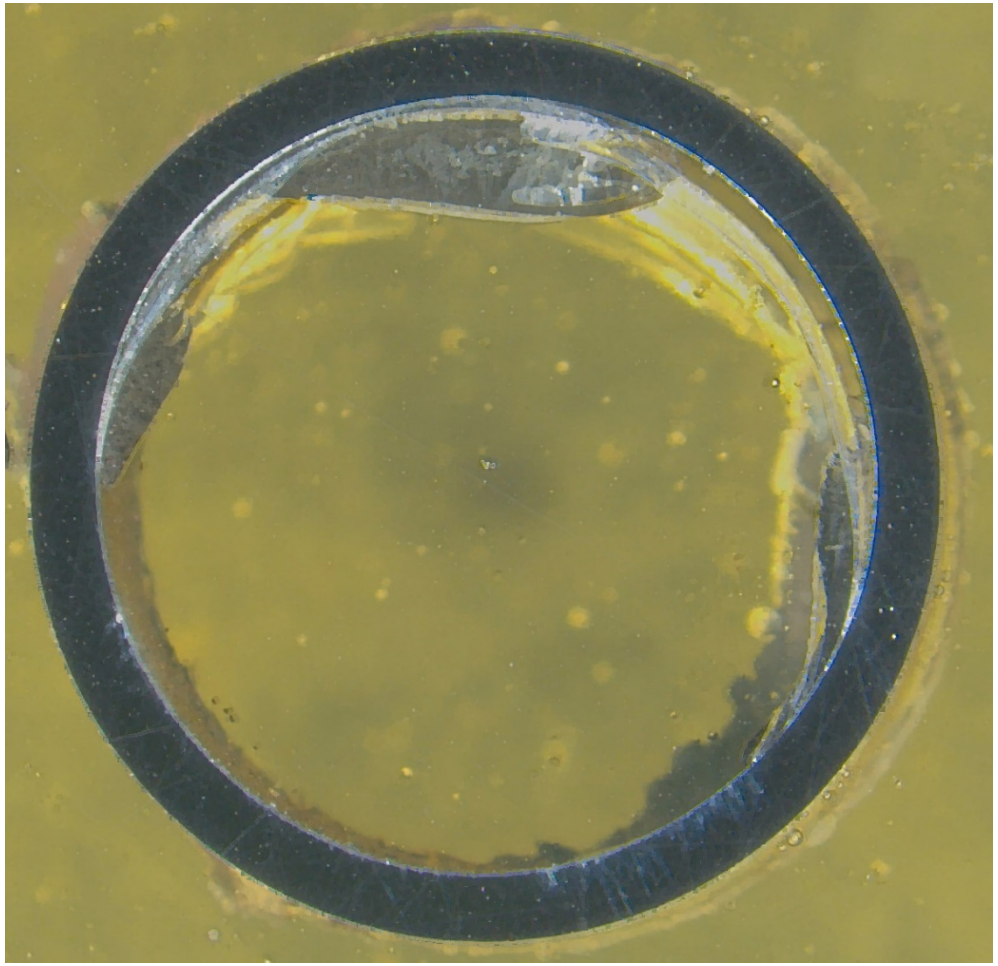


Striated fatigue origin region



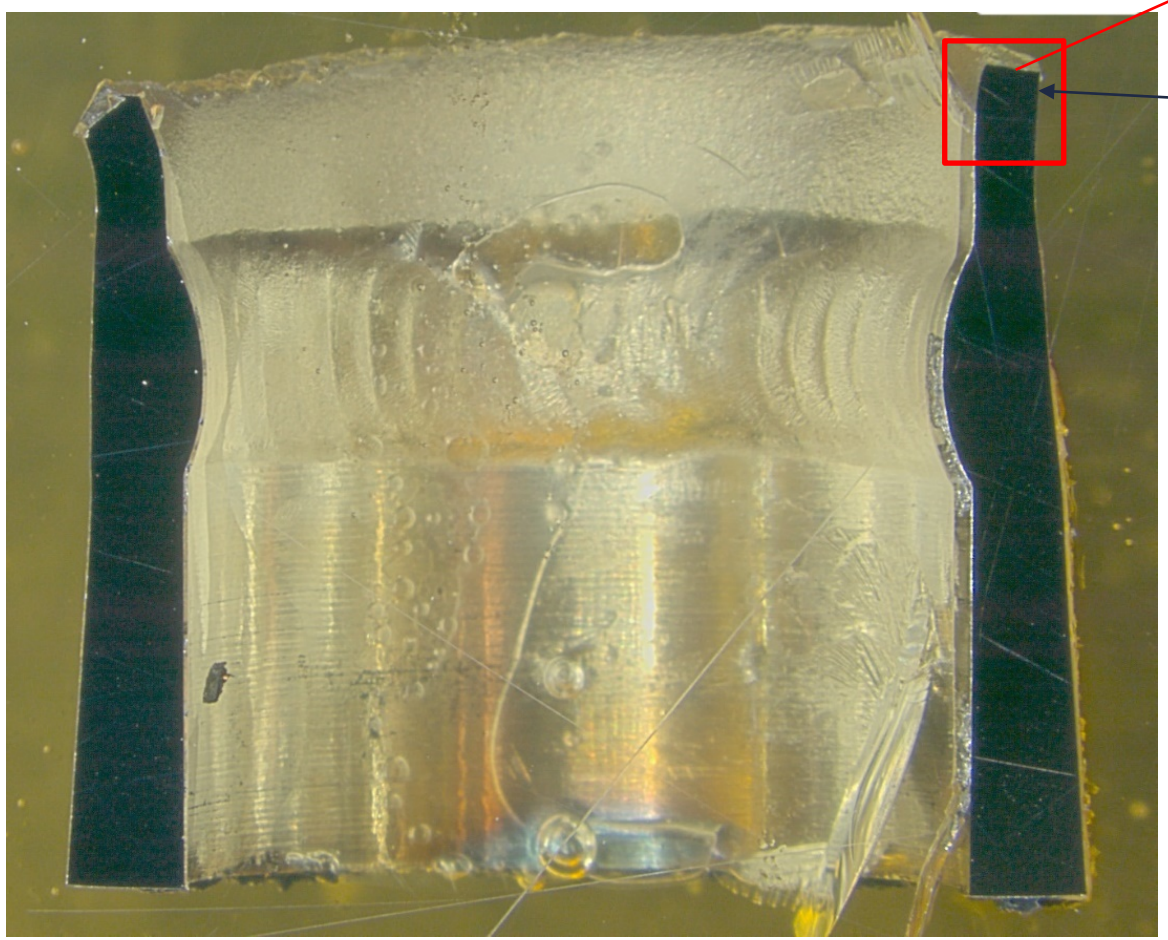
Striated fatigue near the end of fatigue progression.

# FIGURE 26: METALLOGRAPHIC SECTION THROUGH STRAIGHT REGION OF CP09 TUBE



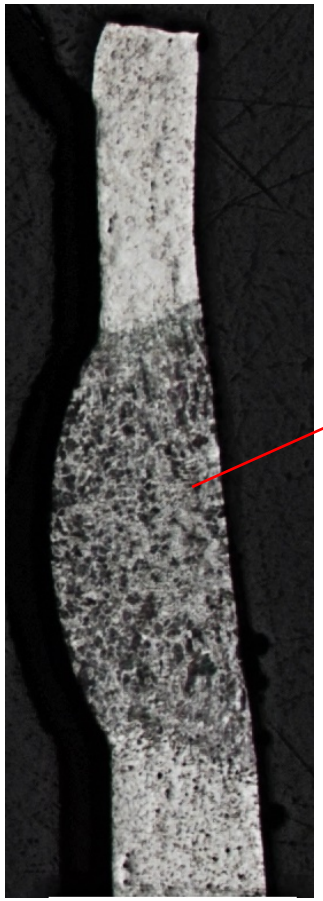
Wall thickness was measured at 8 locations around the circumference and was within 0.001 inch of nominal thickness.

# FIGURE 27: METALLOGRAPHIC SECTION THROUGH ORIGIN REGION OF CP09 TUBE FRACTURE SURFACE

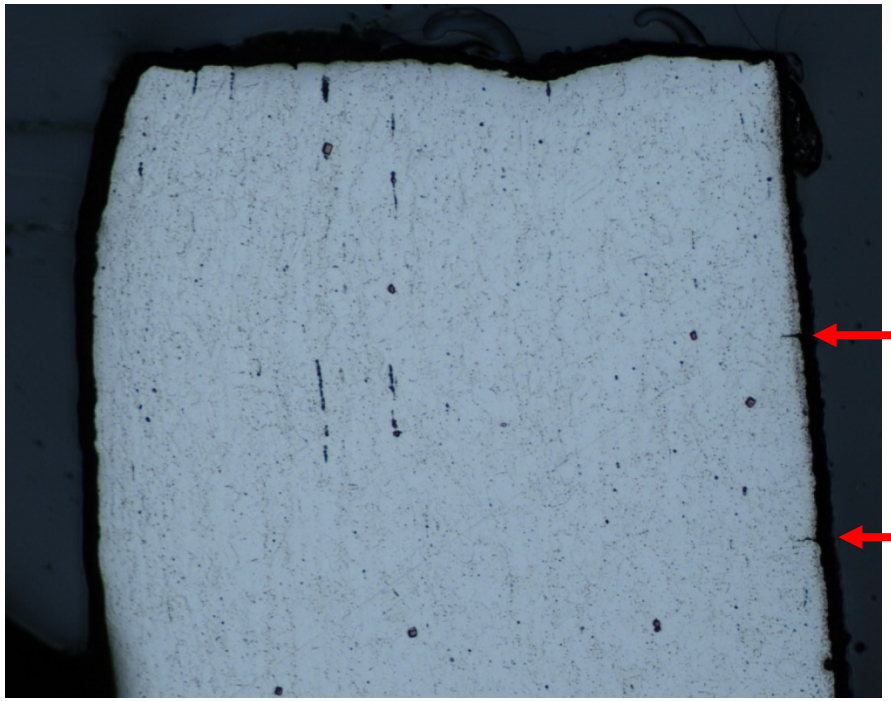


# FIGURE 28: ETCHED METALLOGRAPHIC SECTIONS FROM CP09 TUBE

Fracture surface

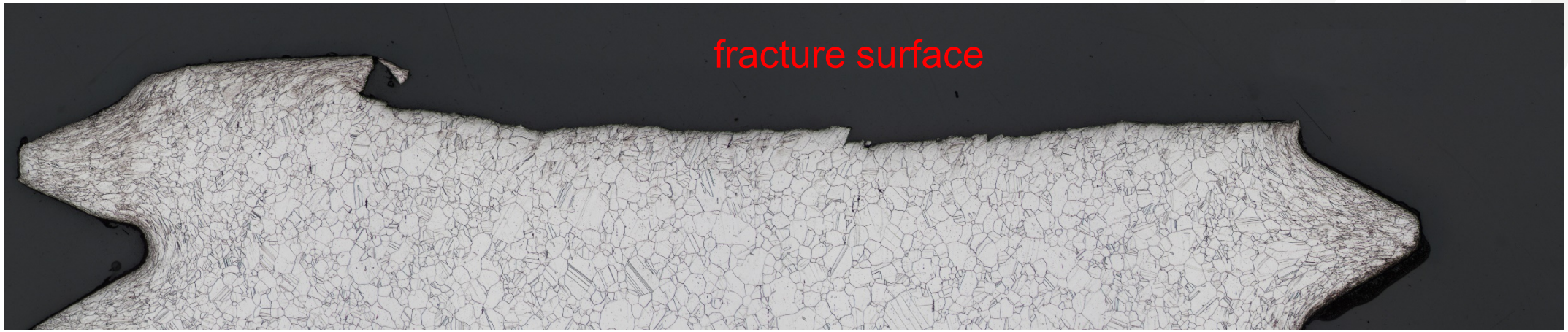



Fracture surface



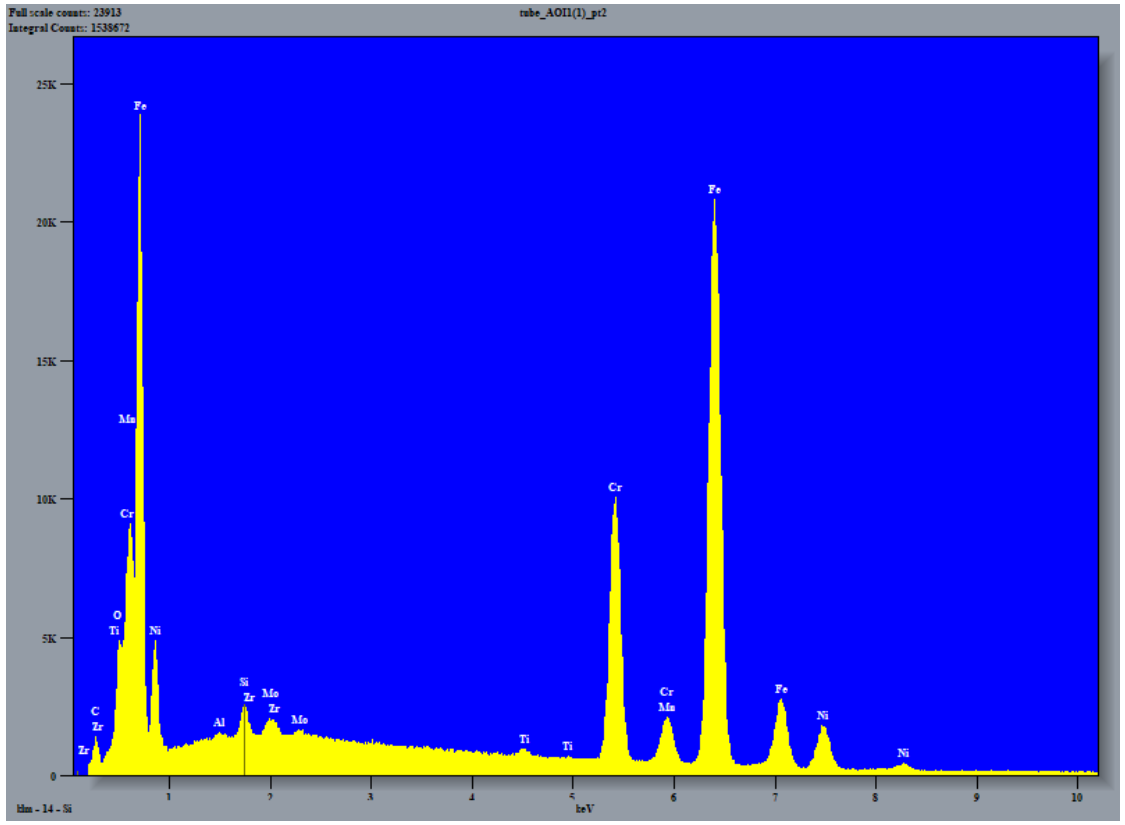
Two parallel secondary cracks were apparent at the indicated locations. Grain size was 9.

# FIGURE 29: ETCHED METALLOGRAPHIC SECTION THROUGH A ST1503-12 BOLT FRACTURE SURFACE

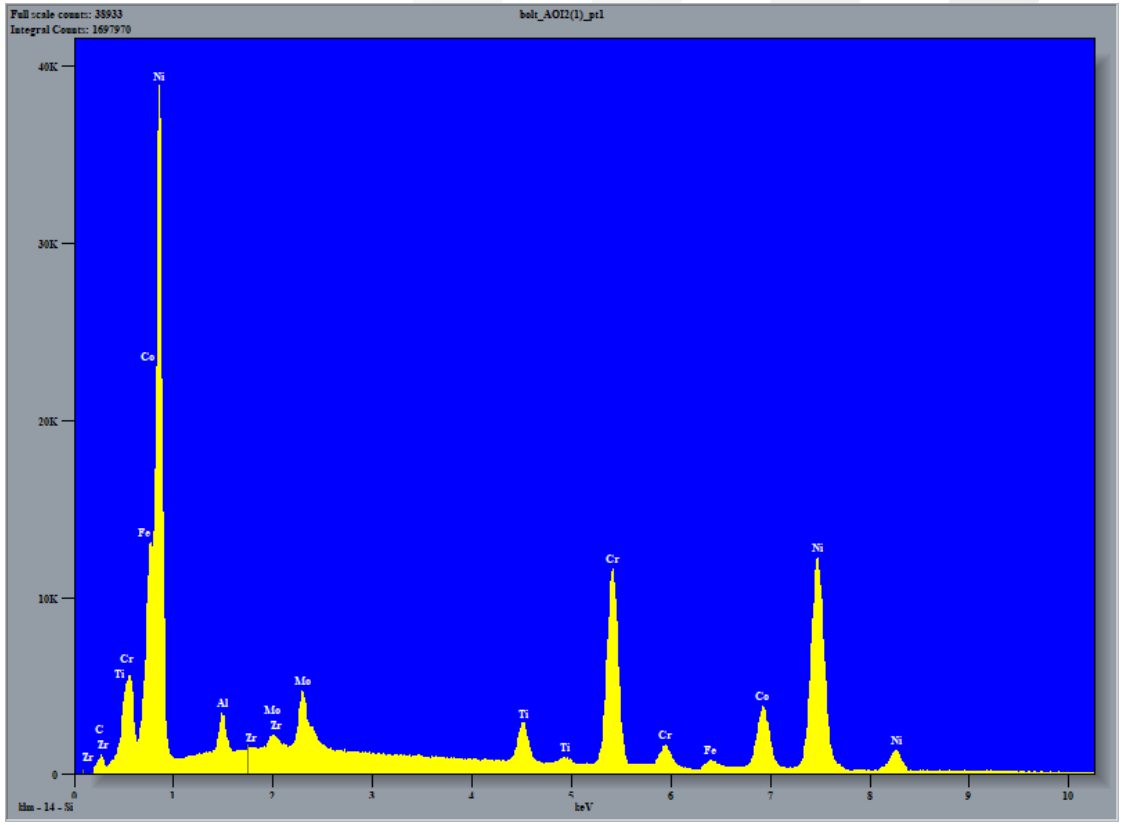



Grain size of the bolt was 6, which conformed to the AMS 5708 requirement of 3 or finer. Fracture surface was predominantly intergranular.

# FIGURE 30: EDS SPECTRA, TUBE AND BOLT




EDS Spectrum from Tube revealed a similar composition to AMS 5557.




EDS Spectrum from a bolt revealed a similar composition to AMS 5508.