

Metallurgical Investigation Final Report



Subject: Metallurgical Investigation of Fuel Triplet and Fuel Nozzle from PW4168 Engine P733619

Date: December 1, 2016

Summary and Conclusions:

An undercowl fire was attributed to a fuel leak from a crack in the fuel triplet that originated from the run out of the braze fillet around the toe of a ball tack weld. Analysis of the fracture surface revealed that the cracks were due to high cycle fatigue. No defects or anomalies were found to be associated with the crack. X-ray examination as well as a metallographic cross-section through the fatigue origin found full braze coverage with very little porosity. The tube, braze and elbow were confirmed to be similar in composition to the applicable material specifications. The tube thickness near the crack surface conformed to drawing requirements.

1.0 Details of Examination

The fuel triplet and fuel nozzle were received in well-packed shipping containers that did not exhibit any handling damage. An installation schematic showing the relative positions of the fuel triplet component in an engine is shown in Figure 2. The fuel triplet was received with one end cut off and the fuel nozzle still attached as it was at the time of the event. It was reported that it had been cut to facilitate disassembly from the engine without disturbing the b-nut connection to the fuel nozzle. Images of the triplet hardware as-received are shown in Figure 2. The remainder of the triplet attached to the fuel nozzle is shown in Figure 3. A close examination of the tube at the brazed joint to the fitting revealed a crack. The crack was approximately aligned with the center of a tack weld, but not in the tack weld. A gouge was apparent on the nut, however, the source of this damage could not be determined.

The fuel triplet was ultrasonically cleaned in a mild solution of *BLUE GOLD*¹. After cleaning, part markings were documented as shown in Figures 4-6. The part was then submitted for radiographic inspection. X-ray of the brazed joints on the fuel triplet found full braze coverage (Figure 7). The only crack observed was the crack previously shown in Figure 3.

The crack was fractured open and examined using a binocular microscope. Examination found a thumbnail shaped region of fatigue that progressed through wall from an origin on the outer diameter surface of the tube, approximately in line with the toe of a ball tack weld. This region was approximately 0.1” along the circumference, and fatigue in this region progressed predominantly toward the center of the tube. Outside of this region, the fatigue progressed circumferentially (Figure 8). The total fatigue crack is shown in Figure 9.

The crack surface was examined using a field emission scanning electron microscope (FESEM). Examination of the origin region revealed no defects or anomalies (Figure 10). Also, no overstress features were apparent (Figure 11). Examination of the surface at higher magnification found finely spaced, difficult to resolve striations indicative of HCF (Figures 12-14). It was noted that the fatigue features became increasingly banded toward the extremities of the progression.

Metallographic section A-A was prepared transversely through the half of the crack that also had the tack weld, as sketched in Figure 8. Review of the section in the as-polished condition revealed full braze coverage with minimal porosity. The section was then etched with a solution of 10% oxalic acid, which revealed a tube microstructure that was typical of properly processed 321 stainless steel. The tube thickness at this location conformed to drawing requirements (Figure 15).

¹ *BLUE GOLD* is an industrial liquid concentrate used for cleaning and degreasing; additional information is available at <http://www.bluegold.org/index.asp>

1.0 Details of Examination (continued)

Section A-A was re-polished to remove the etched affect. It was then carbon coated for enhanced conductivity and examined using a FESEM. As with the optical review, no defects or anomalies were found. Energy dispersive spectrometry (EDS) was used to examine the composition of the mounted section. An x-ray map showed that the tube and elbow were similar materials, with the braze and the tack weld having significantly different compositions. Quantitative EDS analysis found the tube composition to conform to AMS 5557 (321 stainless steel). The elbow was similar to 347 stainless, the tack weld was similar to Inconel 625, and the braze was gold nickel.

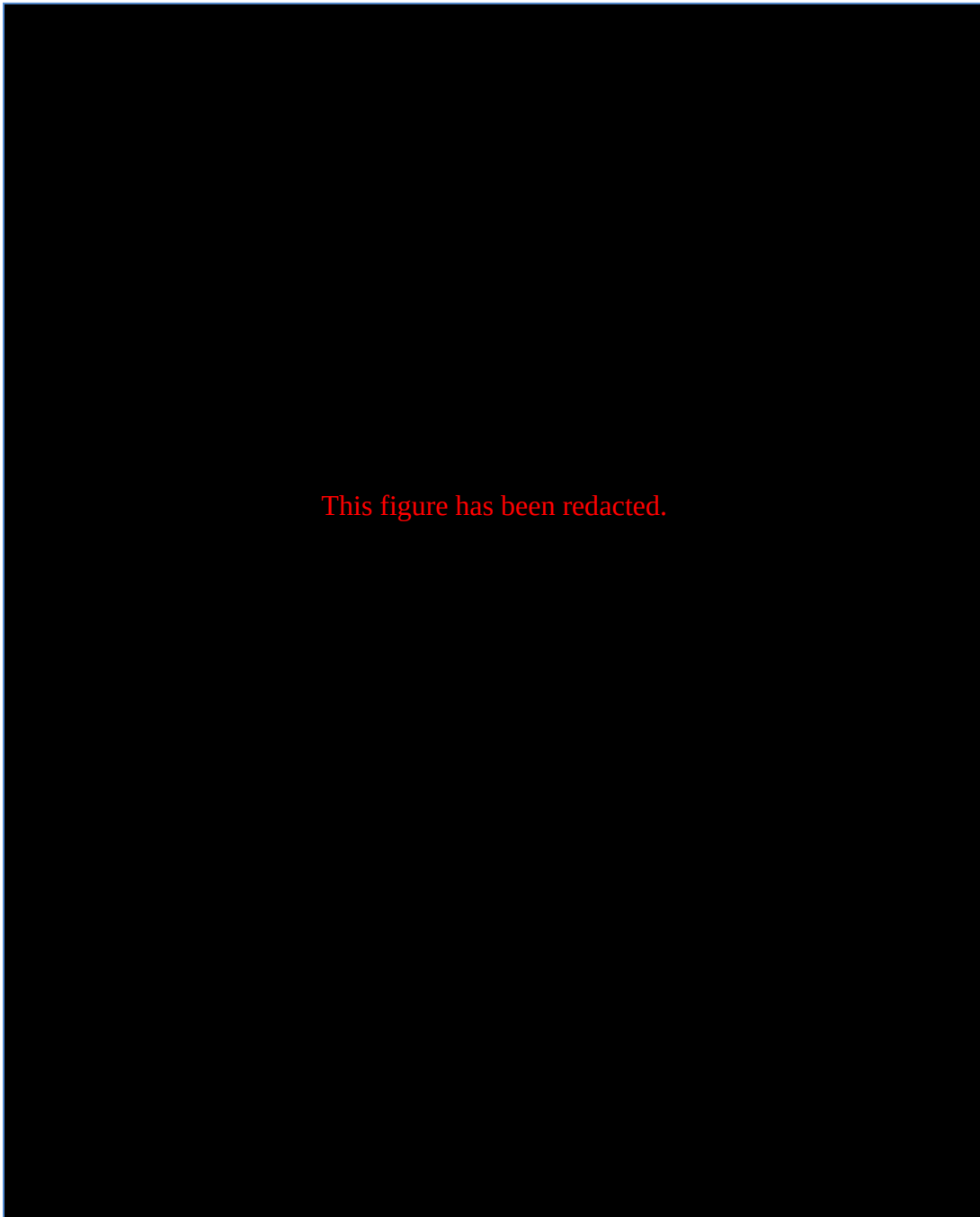


Figure 1: Schematic diagram of fuel nozzle supply manifold assemblies around the engine. The manifold of interest is item 20.

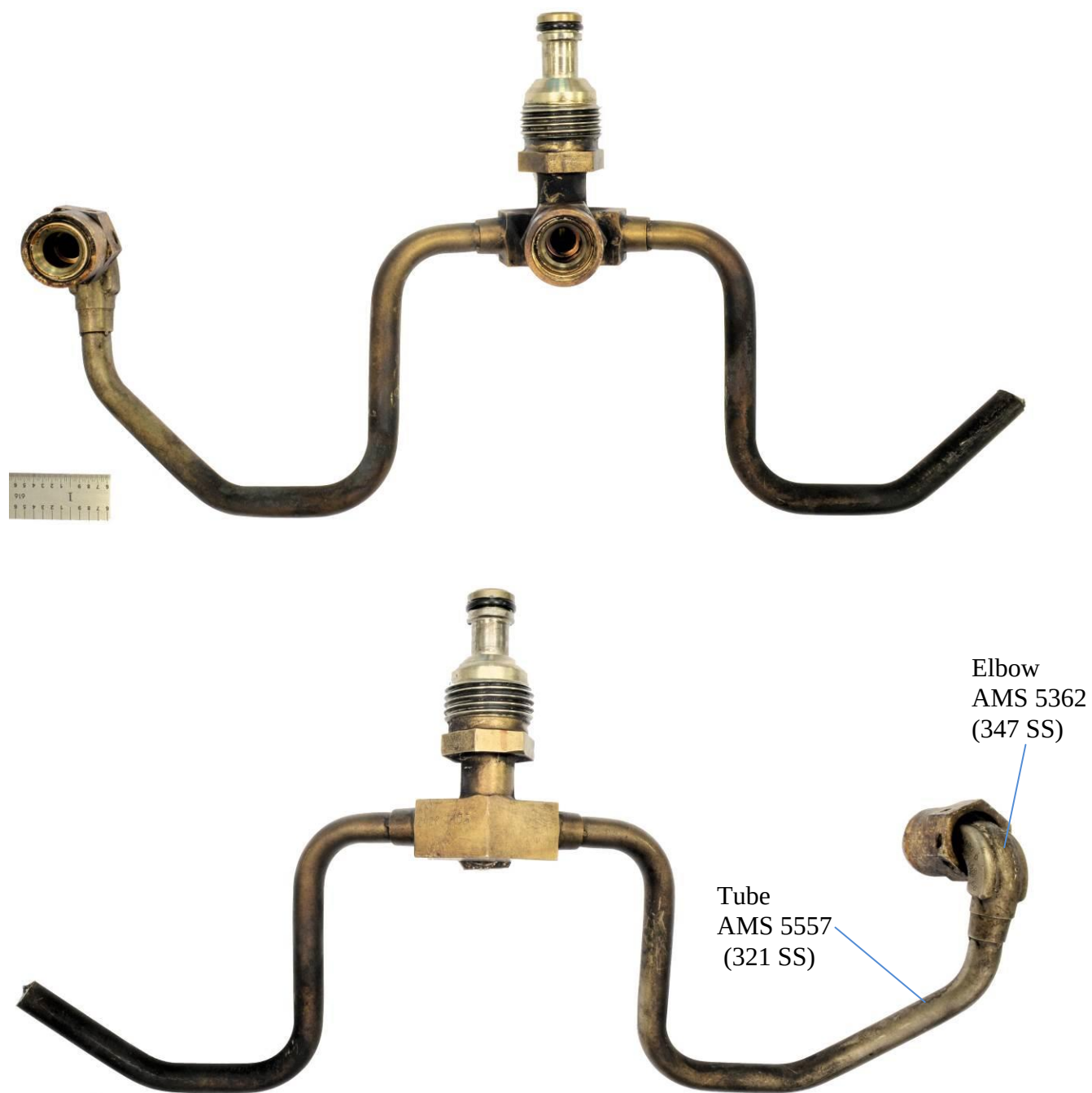


Figure 2: Condition of the fuel triplet as-received. Note that it was cut prior to submission for this investigation to facilitate disassembly.

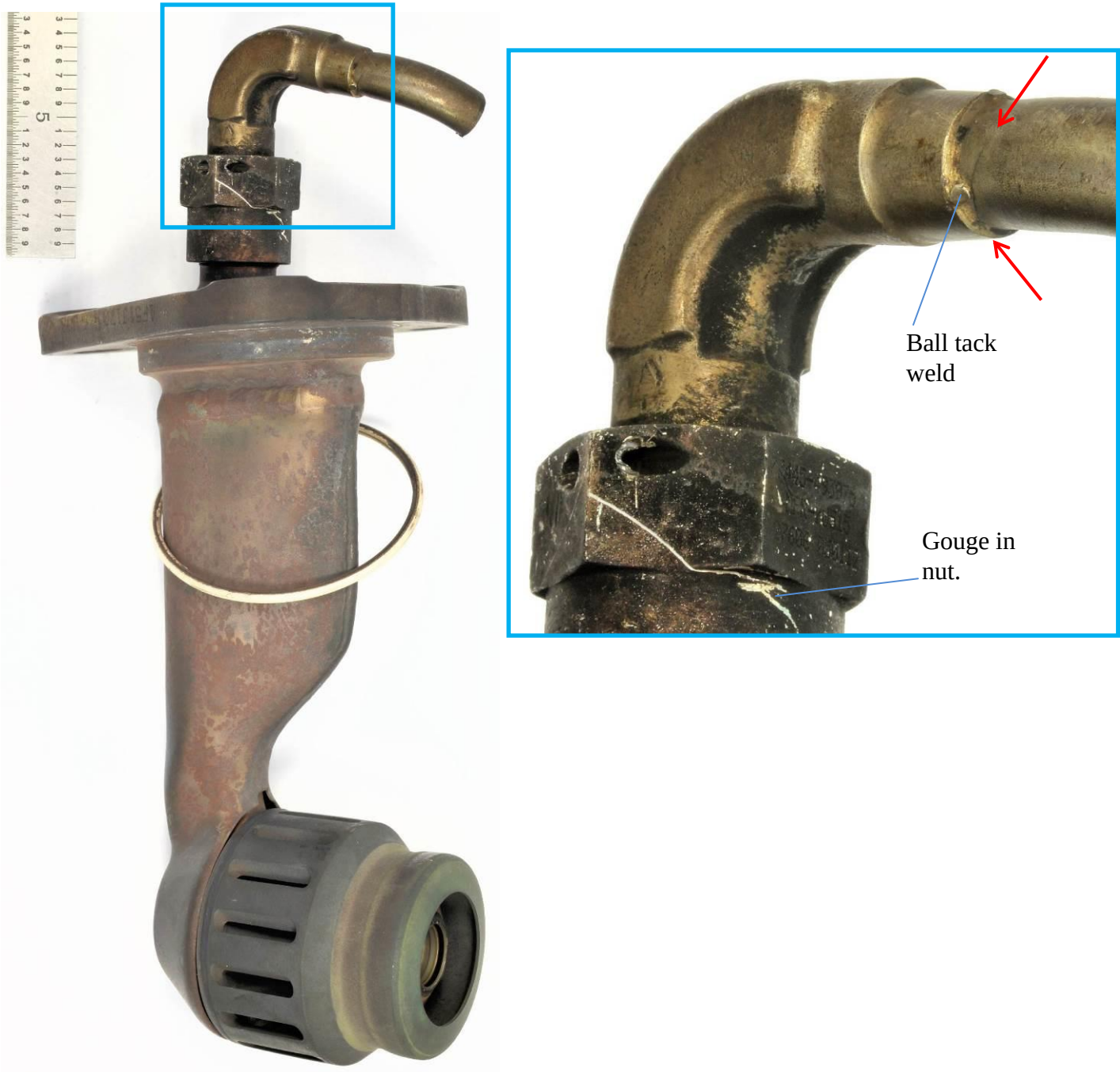


Figure 3: Sectioned piece of fuel triplet attached to fuel nozzle. The cracked location was at a brazed joint between an elbow and a tube, as indicated.

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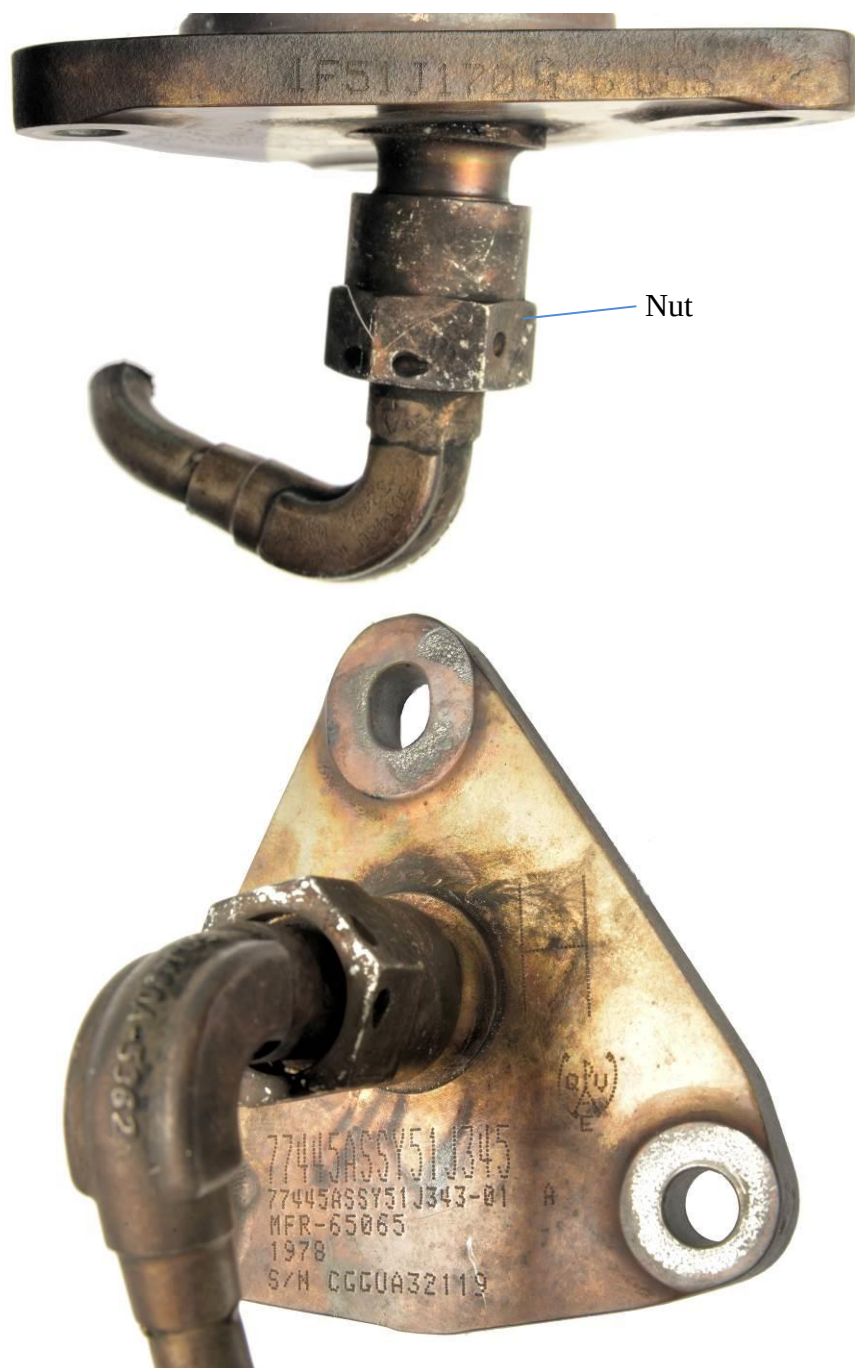


Figure 4: Fuel Triplet Part Markings

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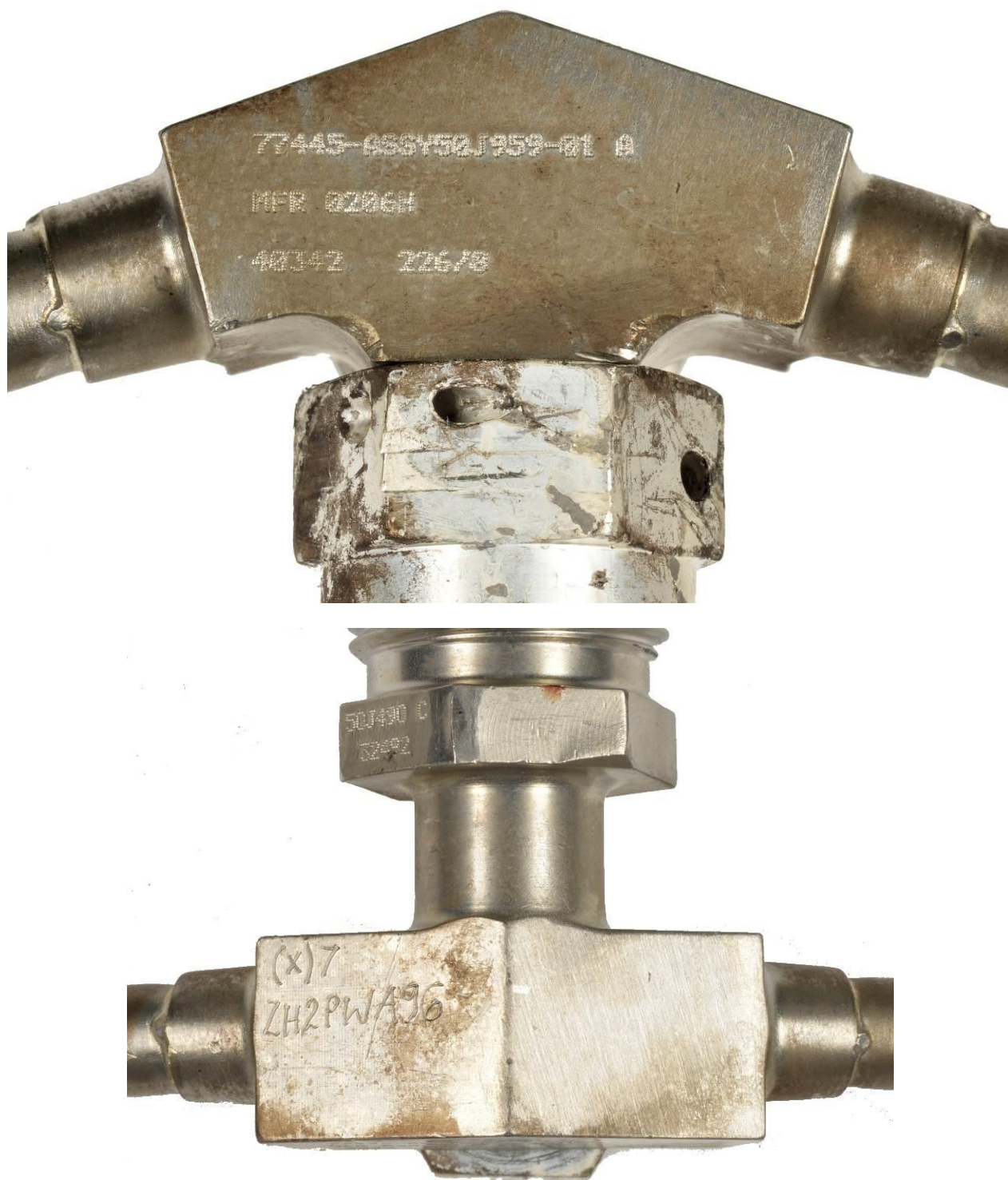


Figure 5: Fuel Triplet Part Markings



Figure 6: Fuel Triplet Part Markings

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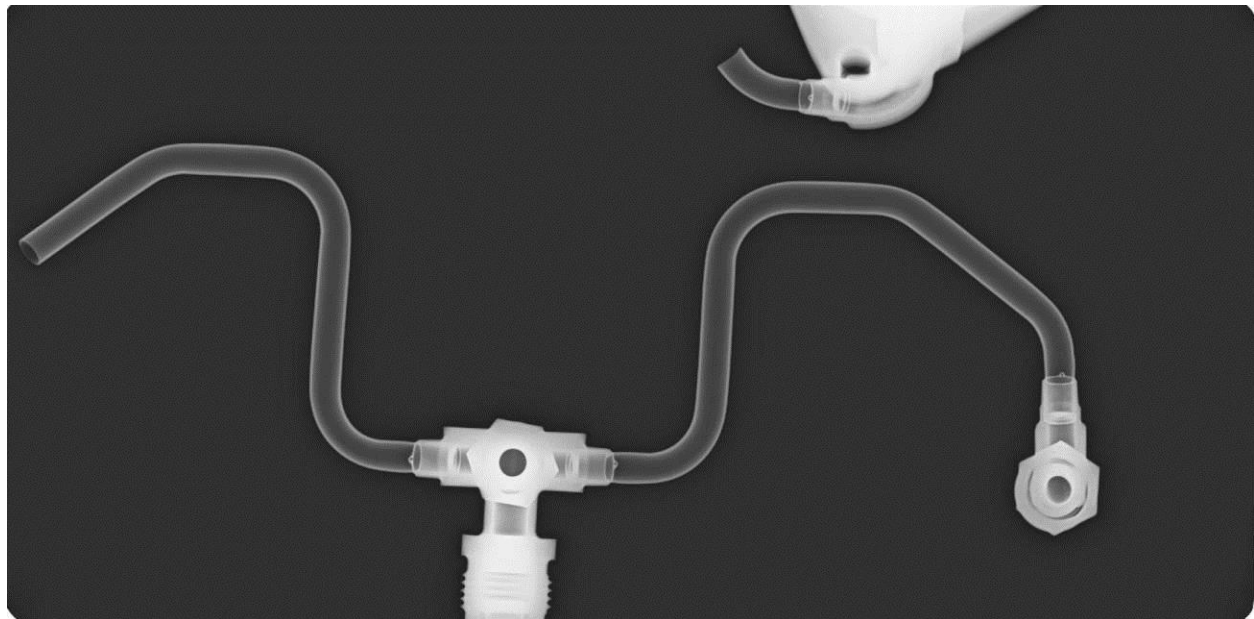
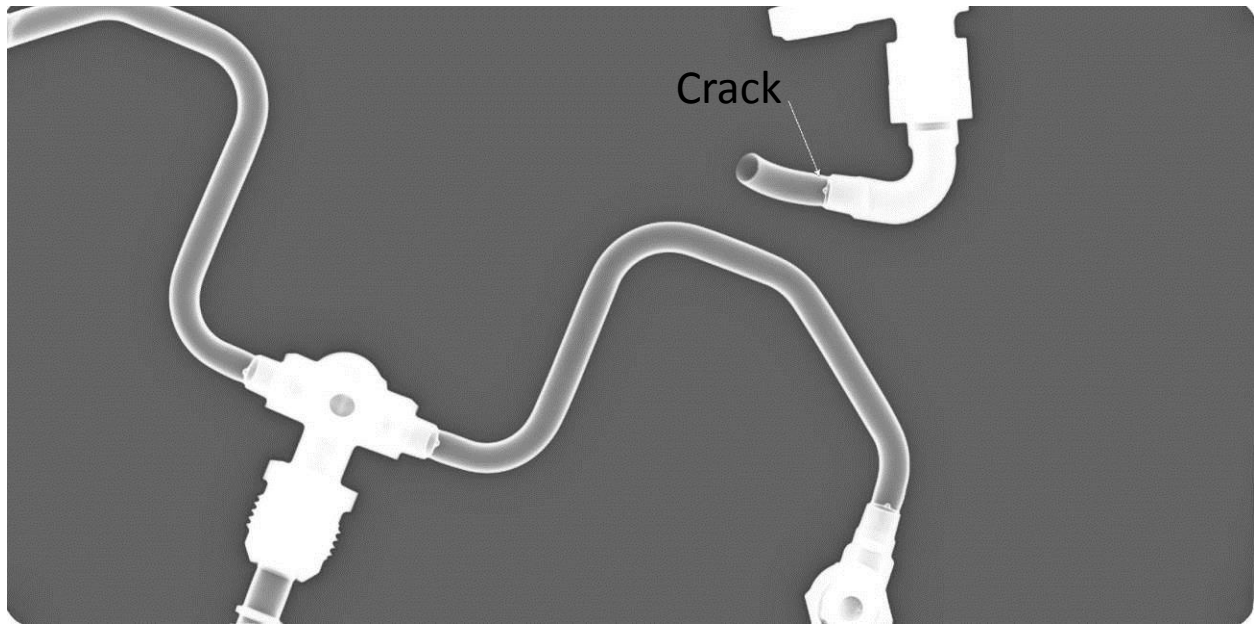


Figure 7: X-ray inspection found full braze coverage at all brazed joints.

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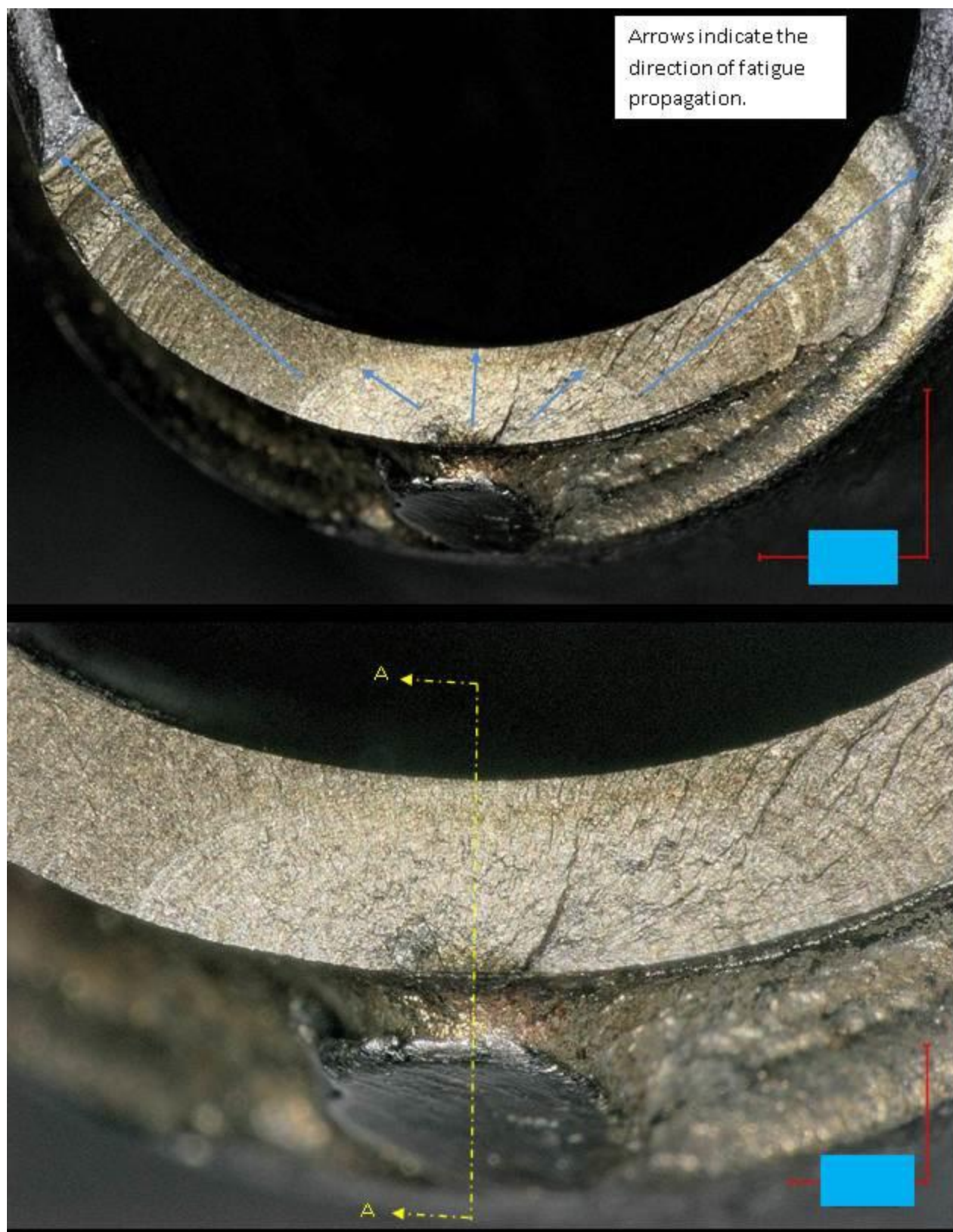


Figure 8: Fatigue origin was aligned with a tack weld.

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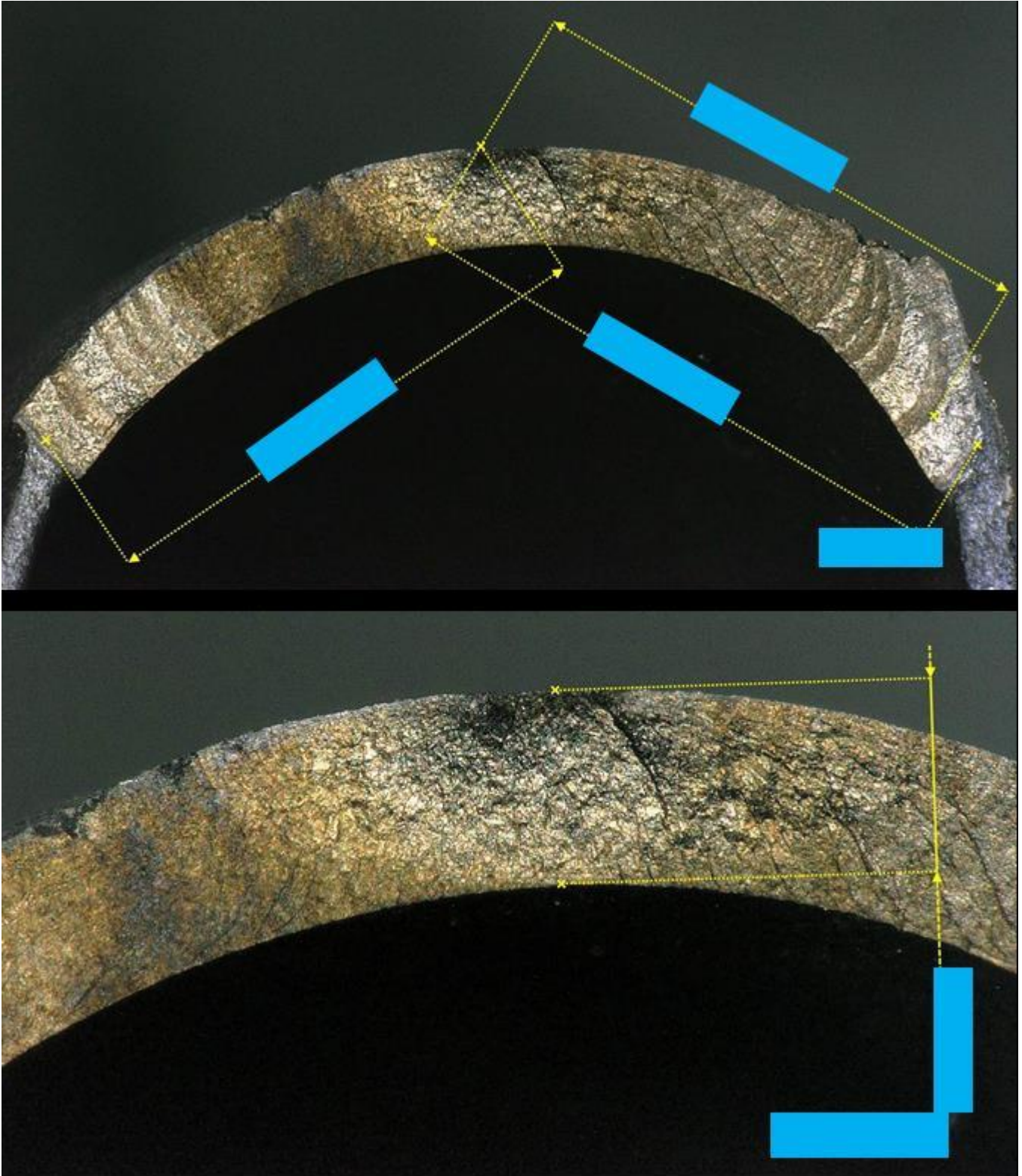


Figure 9: Opposite side of the crack surface. Fatigue progression was [REDACTED] along the circumference and the tube wall was [REDACTED] thick at the fatigue origin.

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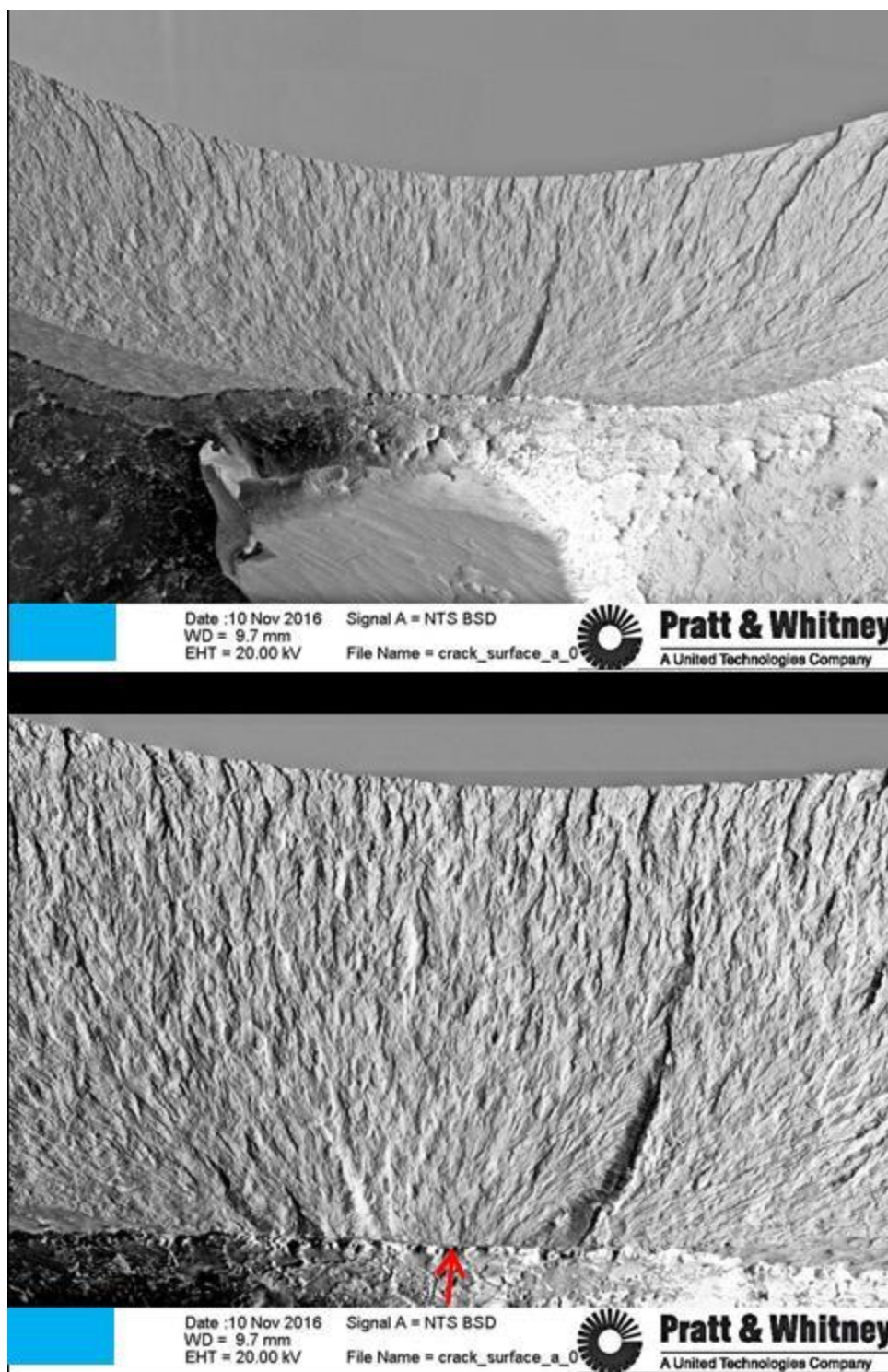


Figure 10: Backscatter SEM images of the fatigue origin, which is indicated with an arrow. No defects or anomalies were apparent at low magnification.

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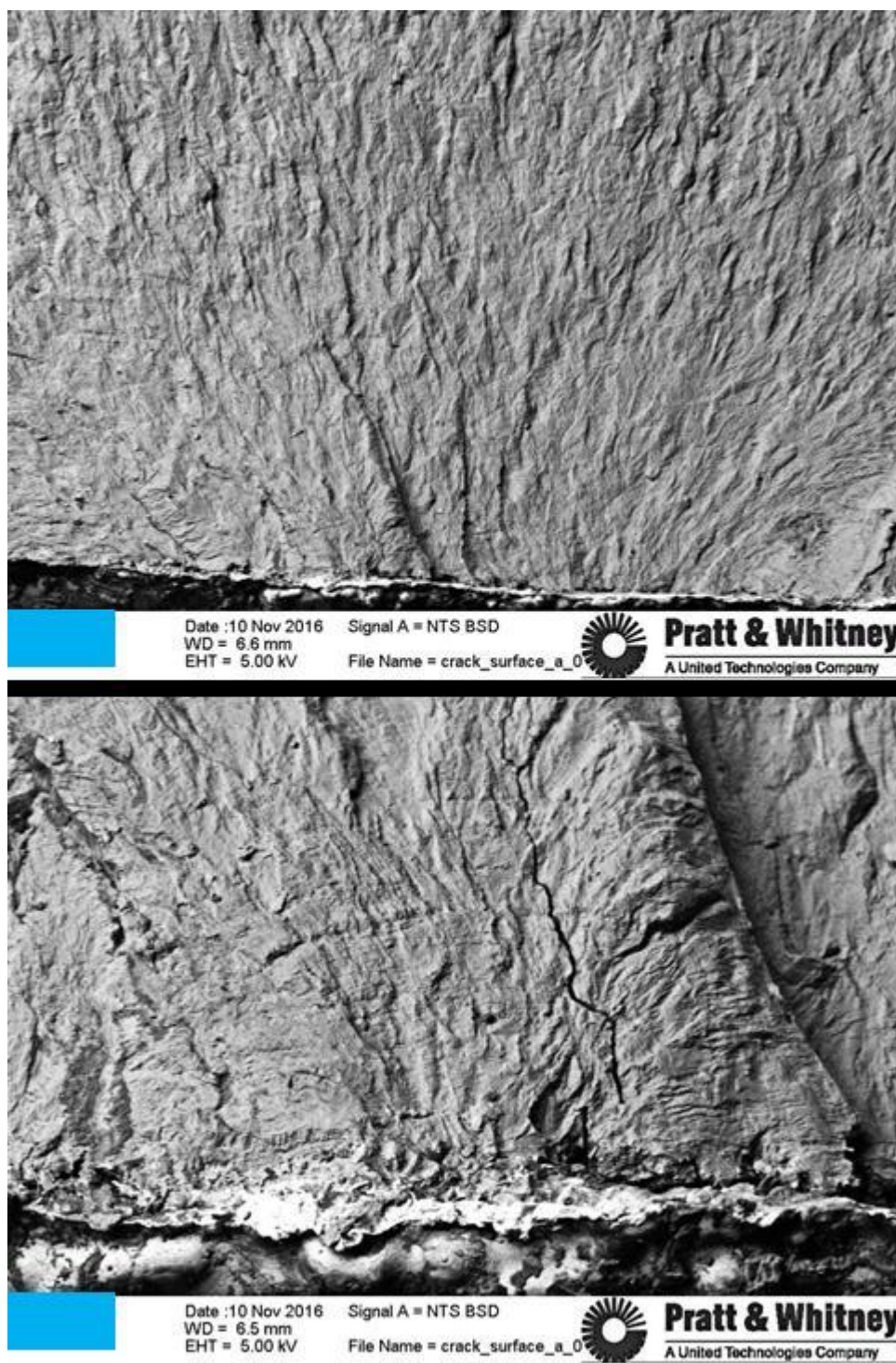


Figure 11: Backscatter SEM images of origin region at higher magnification. No overstress region was apparent at the surface and no defects were observed.

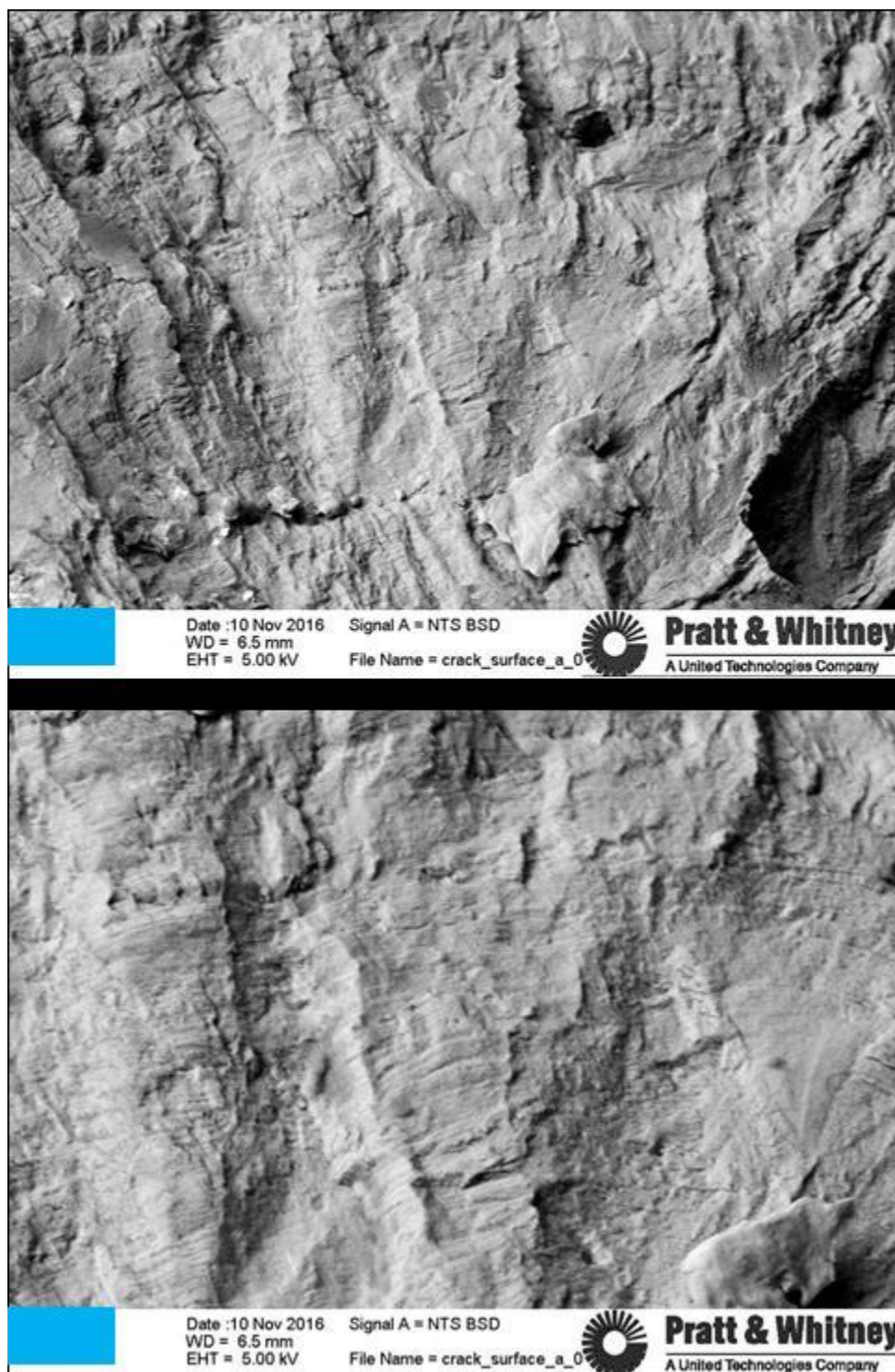


Figure 12: Finely spaced fatigue striations indicative of High Cycle Fatigue progression.

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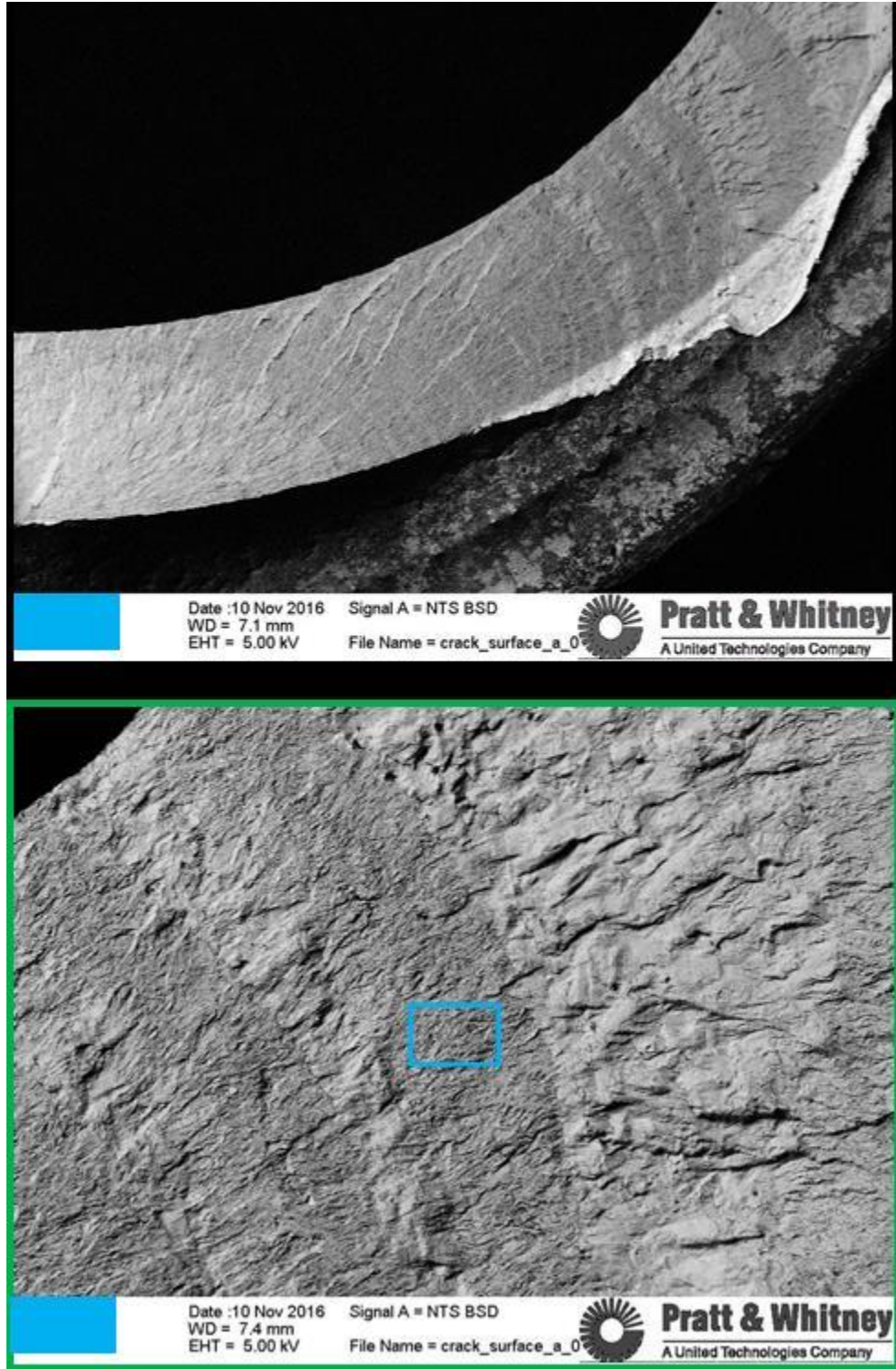


Figure 13: Banded HCF progression moving circumferentially away from the fatigue origin.

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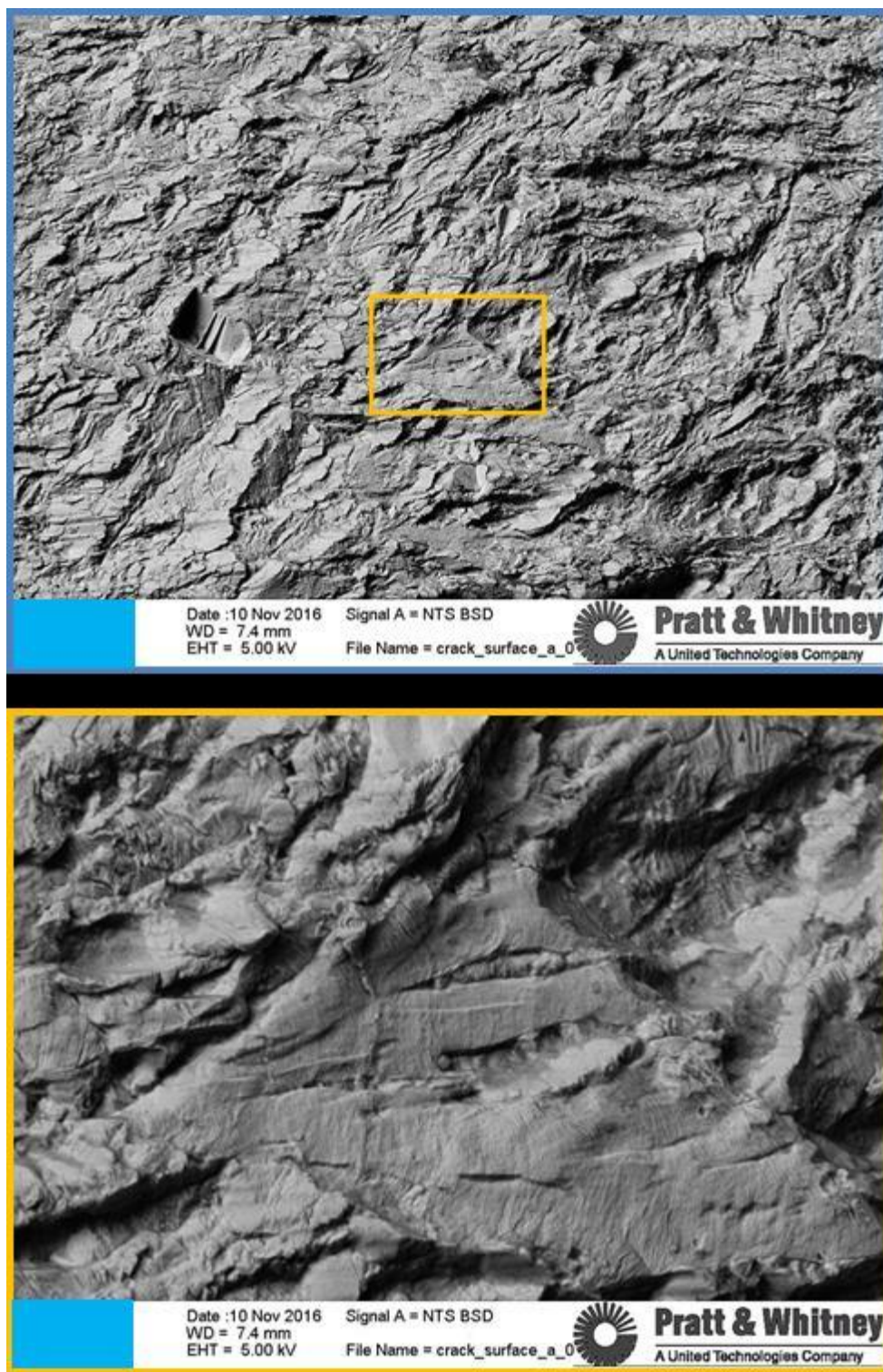


Figure 14: Finely Spaced HCF striations near extremity of crack progression.

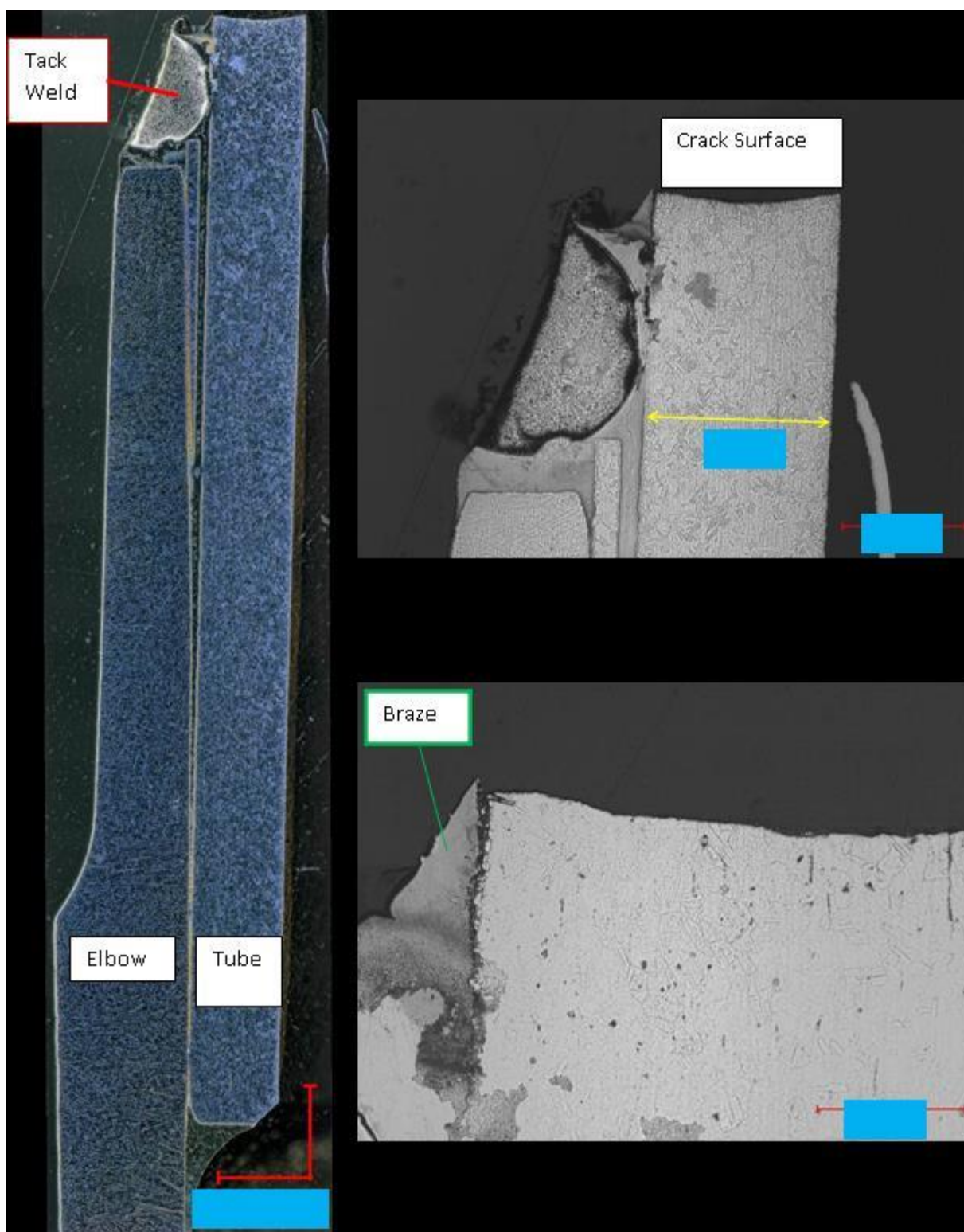


Figure 15: Optical metallographic examination of section A-A (reference Figure 8).

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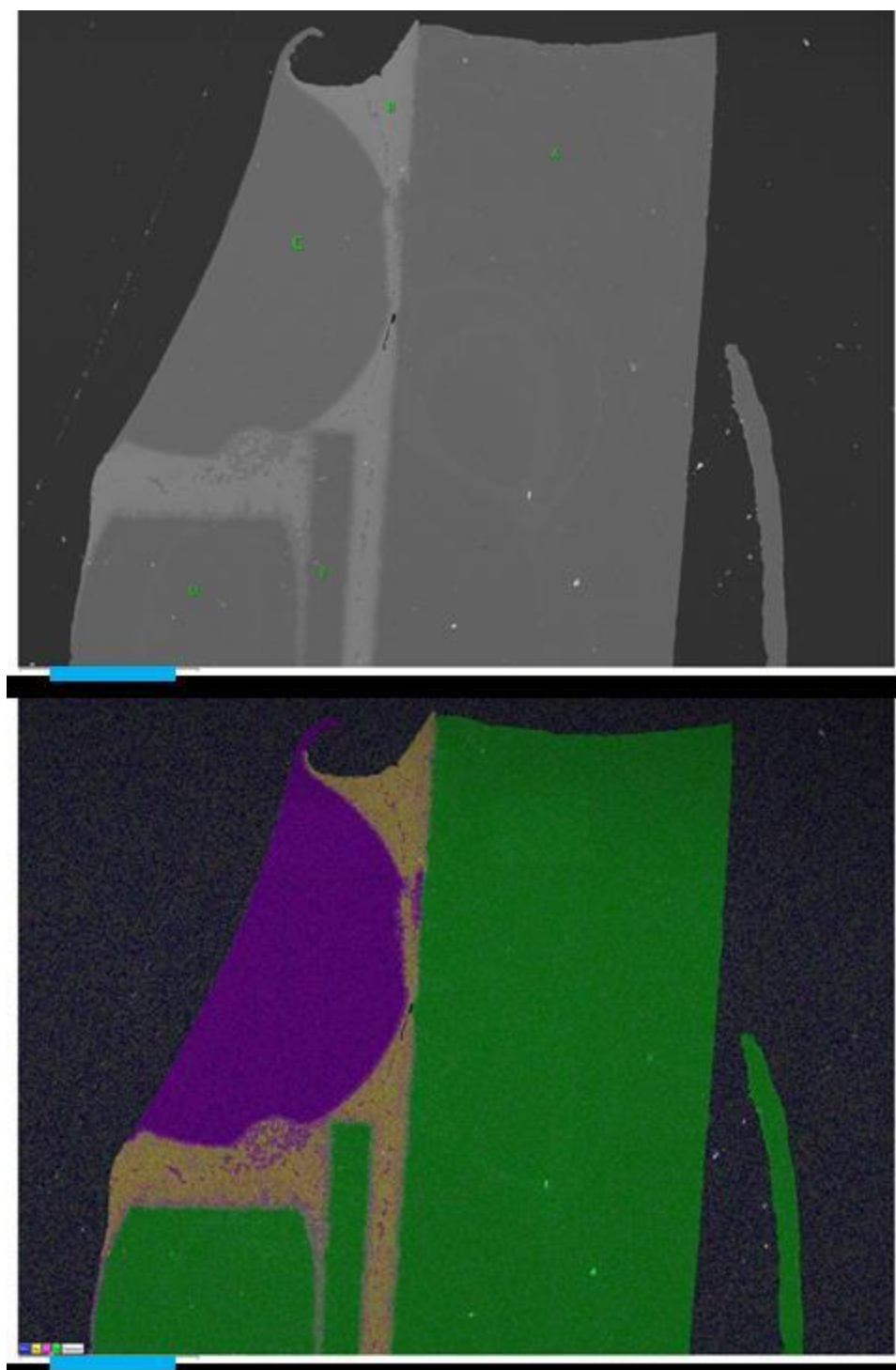


Figure 16: SEM image of section A-A (top) and layered x-ray map (bottom) showing compositional differences.

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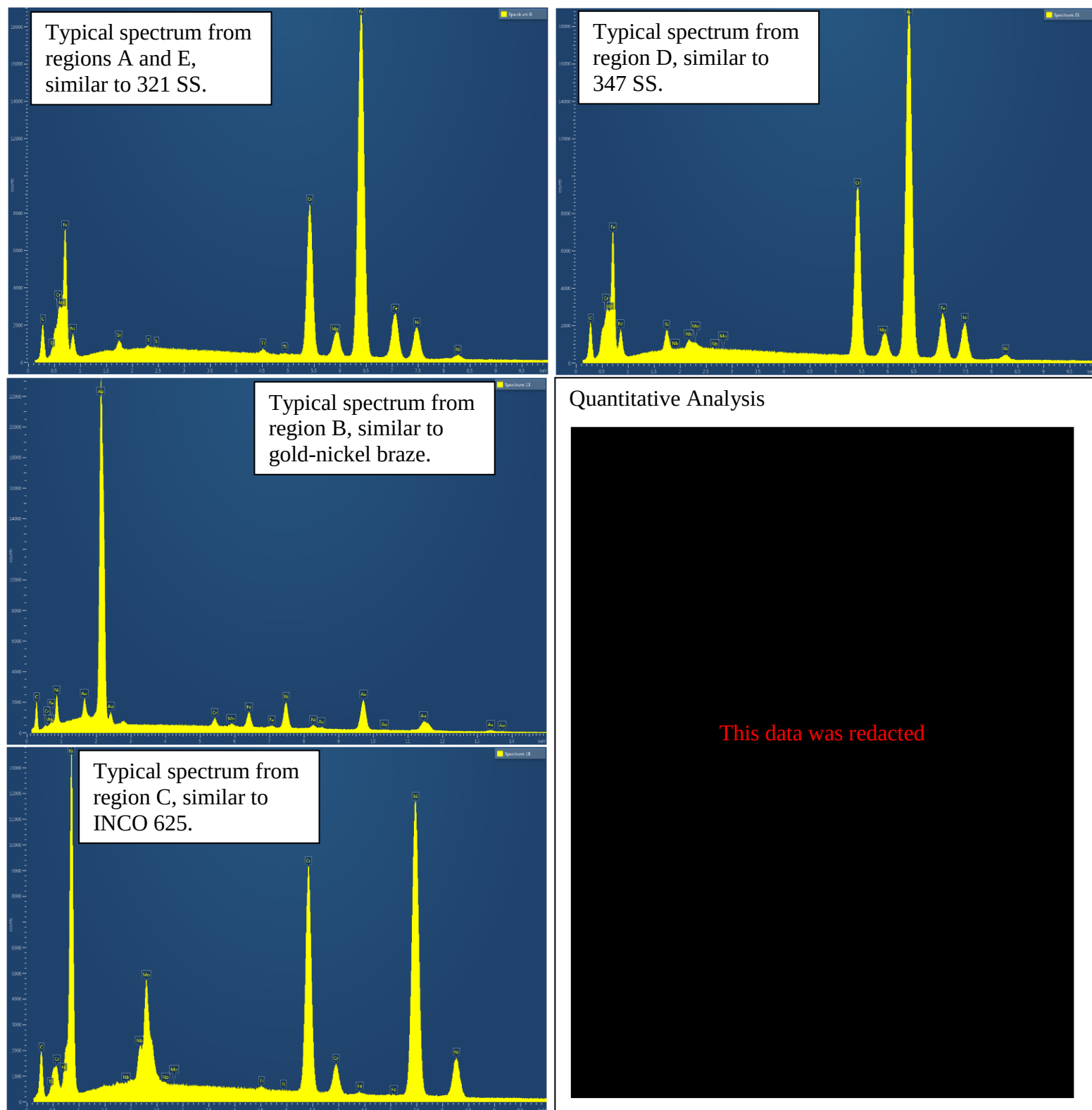


Figure 17: EDS analysis of elemental composition of materials in section A-A.

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