

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN22FA405

MATERIALS LABORATORY

Factual Report 22-069

November 2, 2022

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A. ACCIDENT INFORMATION

Location: Tomball, Texas
Date: September 1, 2022
Vehicle: Cirrus SR22, N420SS
Investigator: Andrew Todd Fox, ASI-CEN

B. COMPONENTS EXAMINED

Brazed 90° elbow fitting, separated into two (2) pieces.
Braided stainless steel fuel line.
Exemplar fuel pump.

C. EXAMINATION PARTICIPANTS

Specialist Donald Kramer, Ph.D.
National Transportation Safety Board
Washington, DC

D. DETAILS OF THE EXAMINATION

A 90° elbow fitting, separated into two pieces, and a flexible fuel line were submitted to the NTSB Materials Laboratory for examination as shown in figure 1. One segment of the elbow fitting was still connected to a B-nut at the end of a flexible fuel line. The other segment was free-standing. The fitting was part of the engine fuel system, with one end connected to the fuel boost pump inlet and the other end connected to the flexible fuel line. For reference, an exemplar boost pump with attached inlet and outlet fittings is shown in figure 2, with the inlet fitting indicated by red rectangles. According to an engineering drawing from the aircraft manufacturer, the specified fitting was MS51527-B8ZC, a nominal ½" diameter fitting made from plain carbon steel with a zinc-plate finish. The end connected to the fuel pump was straight threaded with an O-ring backed by a washer and compression nut. The other end was a straight-threaded tube with a 37° flared end for the B-nut connection to the flexible fuel line. The fitting was first examined on September 7, 2022 and September 8, 2022 with a representative from Cirrus Design Corporation dba Cirrus Aircraft in attendance, with additional examination occurring thereafter.

1.0 Examination of fitting separation

The fitting had separated into two pieces, as shown in figure 1. Visual examination indicated that the separation had occurred at a brazed joint as seen in figures 3a and 3b. The socket-side of the joint, shown in figure 3a, was on the segment connected to the boost pump inlet while the tube-side of the joint, shown in figure 3b, was on the segment connected to the B-nut. For convenience, the socket and tube were assigned clock positions as if the fitting and pump were installed on

the aircraft and were viewed from the aft direction looking forward, with 12 o'clock located at top-dead-center (see figure 2 for the orientation of the installed pump). As indicated in figure 3b, a blue adhesive torque stripe had previously been applied to the tube, B-nut, and fuel line transition elbow along the 3:00 position. The torque stripe had fractured in two locations: one at the transition from the tube to the B-nut, and the other at the transition from the B-nut to the transition elbow. As indicated in figure 3b, the torque stripe at the later location was displaced in the circumferential direction, consistent with a rotation of the transition elbow relative to the B-nut. The displacement, measured on a calibrated image was approximately 0.075 inch. The rotation, viewed from the forward direction looking aft, was in the counterclockwise direction or from the 9:00 position toward the 12:00 position in the clock coordinate system of the brazed joint. When viewed at higher magnification, a small rotational offset of approximately 0.006 inch was also observed at the crack between the B-nut and tube, with the B-nut similarly rotating in the counterclockwise direction (viewed forward looking aft).

Both sides of the joint exhibited plastic deformation consistent with an applied moment causing the tube to lever out of the socket, with the pivot point at approximately the 10:00 position. At that position and near the butt-end of the joint, the tube material was deformed axially upward and outward, as indicated in figures 4 and 5, respectively. At the same clock position but at the top opening to the joint, the tube material was similarly displaced axially upward but was deformed radially inward. At approximately the 4:00 position (180° around the circumference of the tube) the sidewall was deformed radially inward (a comparatively small amount) near the butt-end of the tube. On the socket-side, the braze metal at the base of the joint exhibited a comparatively flattened and smeared appearance over an approximately 70° angle that was centered nominally about the 10:00 position, as indicated by the yellow-dashed region shown in figure 6. Centered about the same clock position, the sidewall at the opening to the socket was deformed as shown in figure 7.

2.0 Characterization of brazed joint

The brazed joint on the separated fitting was compared to a similar joint taken from an exemplar boost pump. The exemplar fitting was sectioned in the radial axial plane of the tube, passing through the 10:00 and 4:00 positions. One of the sectioned sides was mounted in diallyl phthalate resin, ground using silicon carbide papers, and polished on a cloth loaded with a 3 µm diamond suspension. The resulting cross section through the joint at the 4:00 position is shown in figure 8. The socket was approximately 0.146-inch deep and the tube extended approximately 0.136 inch into the socket. The gap between the end of the tube and the base of the socket was filled with copper braze metal. A region of porosity in the braze metal, approximately 0.013 inch in width, was observed close to the internal passage. The rest of the braze metal appeared to be well-consolidated. A fillet of braze metal was also observed along the external surface where the tube entered the socket. The

sidewall between the base and opening of the socket exhibited regions where the socket and tube surfaces were in direct contact with one another, with no apparent gap or braze metal in between. Elsewhere along the sidewall, small gaps between the tube and socket were observed, the widest of which measured approximately 0.0005 inch across. Some of the gaps were filled with braze metal while others were not.

The separated fitting from the accident aircraft exhibited similar features on the sidewall of the socket and tube, with some apparent copper-colored and some bare-steel regions, as seen in figures 7 and 4, respectively. Similarly, braze metal was generally observed covering the base of the socket and the butt-end of the tube, seen in figures 3a and 5, respectively, except near the 3:00 position, where a gap in coverage was observed.

The tube- and socket-sides of the joint were scanned using a structured-light 3D scanner and the models were used to estimate their outer- and inner-diameters, respectively, as shown in figures 9a and 9b. Regions that exhibited plastic deformation were excluded from the diameter measurements. The tube and socket both measured 0.626 inch for the outer- and inner-diameter, respectively.

Anomalies were observed on the separated joint. As indicated in figure 5 and shown by scanning electron microscope in figures 10a and 10b, at the 2:00 and 4:00 positions, the braze metal between the butt-end of the tube and the base of the socket exhibited a porous, unconsolidated appearance. In between these regions, at the 3:00 position, was a region without copper braze metal fill, indicated in figure 5. As seen in figure 4, the zinc plated surface outside the joint and near the 1:00 position exhibited dark staining at two locations.¹ Thumbnail-shaped regions of staining were also observed within the joint space adjacent to the surface staining. A backscatter electron image of one of those locations is shown in figure 11a. The thumbnail-shaped region had a dark appearance in the backscatter image. A higher magnification image near the bottom edge of the thumbnail region (a region furthest from the opening of the joint) is shown in figure 11b, also indicated in part a. The dark-colored material appeared to be deposited over the light-colored regions, which exhibited a smeared appearance. The compositions of the dark- and light-colored regions were examined by energy-dispersive X-ray spectroscopy (EDS), as shown in figures 12a and 12b, respectively. The spectrum from the dark-colored region consisted primarily of iron (Fe), copper (Cu), zinc (Zn), and oxygen (O). By comparison, the spectrum from the light-colored region consisted primarily of Fe and Cu. Zinc and oxygen were detected by EDS at two additional locations: One location was in an adjacent stained region, shown in figures 4 and 13a, and the second

¹ Prior to cleaning, these regions were covered by a white residue, which can be seen for one of the regions in figure 3b.

location was observed on the end face of the tube near the 5:00 position, as shown in figures 5 and 13b.

3.0 Residue on fitting external surface

Visual examination of the separated fitting's socket-side revealed a residual film of unknown origin. The film was observed on the flat face of the socket near the opening to the joint, as indicated in figure 14. Yellow arrows in the figure demarcate the boundary of the film, which extended from the 12:00 position to the 6:00 position by way of 9:00. The film was clear toward 12:00, but exhibited a blue tint, consistent with fuel dye, toward the 6:00 position. An excerpt from a photo taken during the wreckage exam, seen in figure 15 and showing the socket-side of the joint, indicated the film was present at that time. Multiple spots of blue dye were also observed on that part of the fitting. Within the boundary of the film, the spots of dye exhibited comparatively discrete boundaries as compared to their condition at the time of the lab examination.

The tube-side of the joint was examined and a clear film was observed on the zinc-plated sidewall adjacent to the joint opening, also centered about the 9:00 position, but with no blue staining from fuel dye. The boundary of the film is indicated by yellow arrows in figure 16a and a region of the film is shown in the scanning electron microscope image in figure 16b. The chemical composition of the film was identified by EDS. As shown in figure 17a, a spectrum from a region at the edge of the film consisted primarily of silicon (Si), oxygen (O), and carbon (C), consistent with a silicone-based material, along with a trace of Zn and a possible trace of lead (Pb). A spectrum taken outside the boundary of the film, shown in figure 17b, consisted primarily of Zn, Fe, Cr, O, and C with traces of additional elements. An EDS spectrum from the film on the socket-side of the fitting (not shown) produced a similar spectrum as shown in figure 17a, consisting primarily of Si, O, and C.

E. REFERENCES

SAE International (2004). "Surface Vehicle Standard J514 - Hydraulic Tube Fittings - REV. SEP2004." SAE International, Warrendale, PA.

F. ATTACHMENTS

Attachment 1 - MS51527E - Detail Specification Sheet - Fittings, Hydraulic Tube, Flared, 37 degree and flareless, steel; elbow, tube to boss, 90 degree, O-ring, 37 degree flared.

Attachment 2 - MIL-DTL-18866K - Detail Specification - Fittings, Hydraulic Tube, Flared, 27 Degree and Flareless, General Specification for.

Attachment 3 – Excerpt from “Aviation Fuels: Technical Review,” Chevron Products Company, 2007.

Submitted by:

Donald Kramer, Ph.D.
Senior Materials Engineer

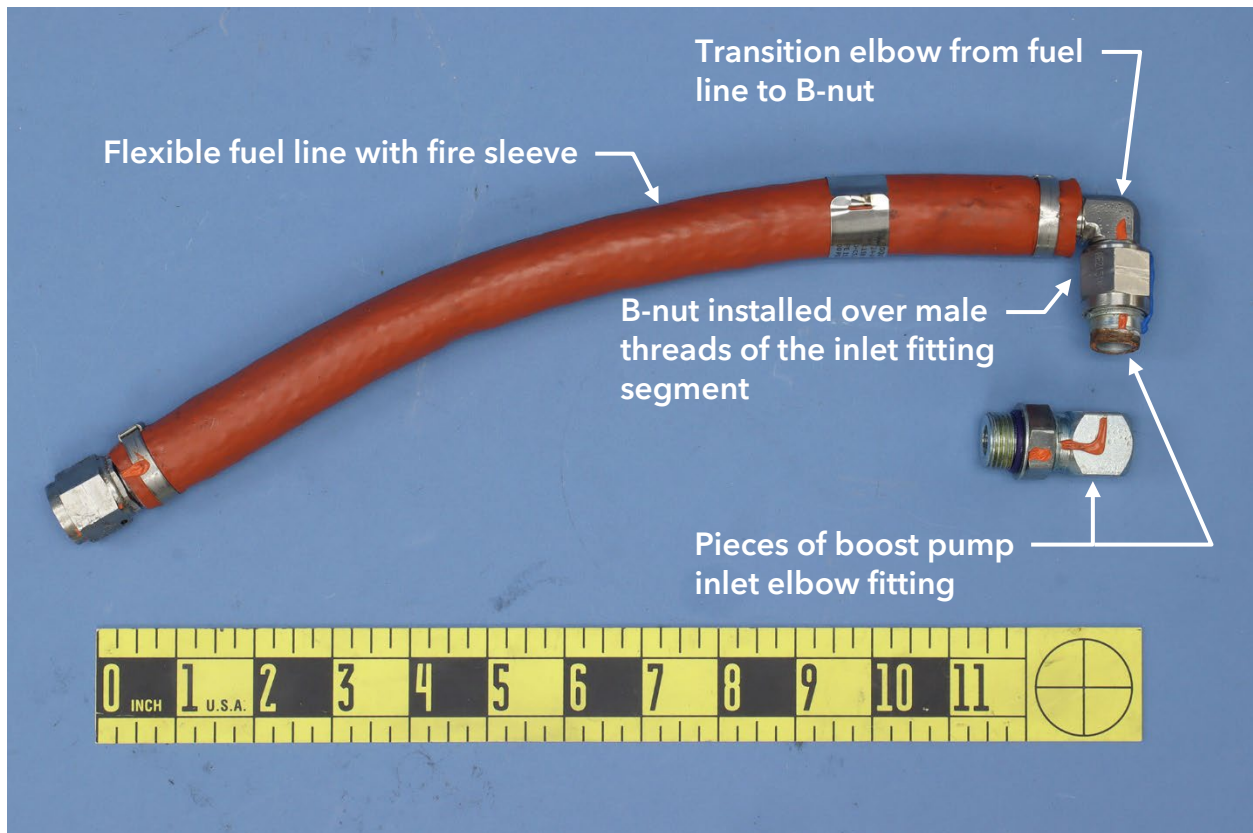


Figure 1. Image of the as-received separated elbow fitting and flexible fuel line.

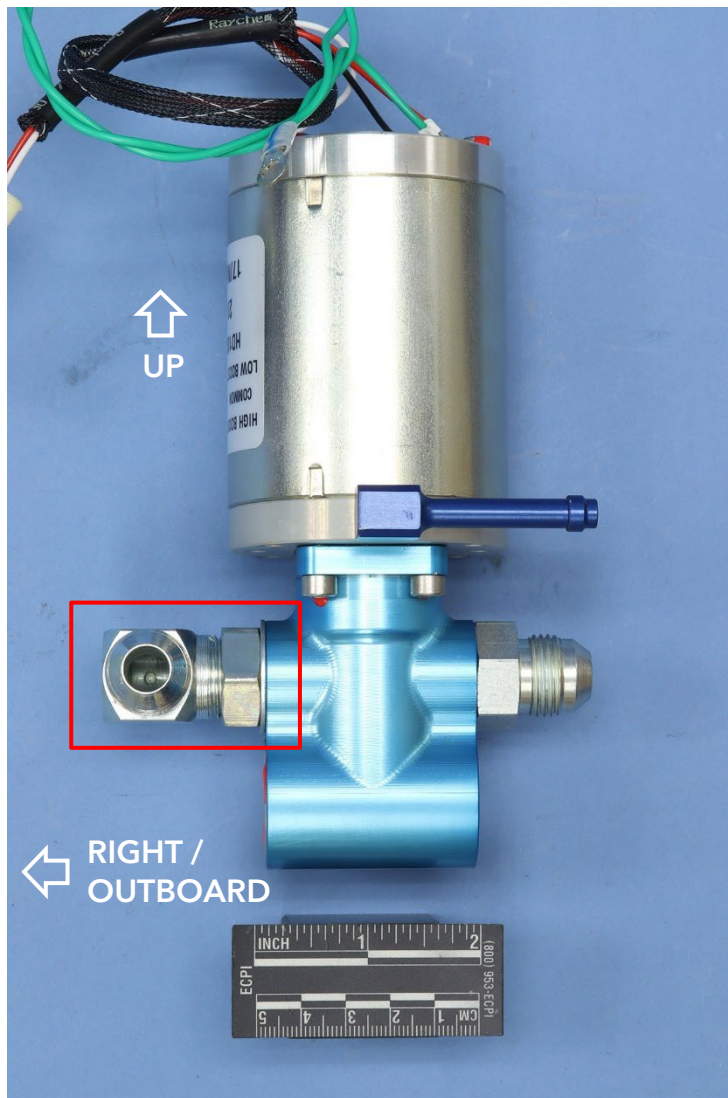


Figure 2. Two images showing different views of an exemplar fuel boost pump with red rectangles highlighting the 90° elbow fitting. The pump is installed on the right side of the aircraft. The left image shows the forward-facing side of the pump and the right image shows the right and top sides of the pump.

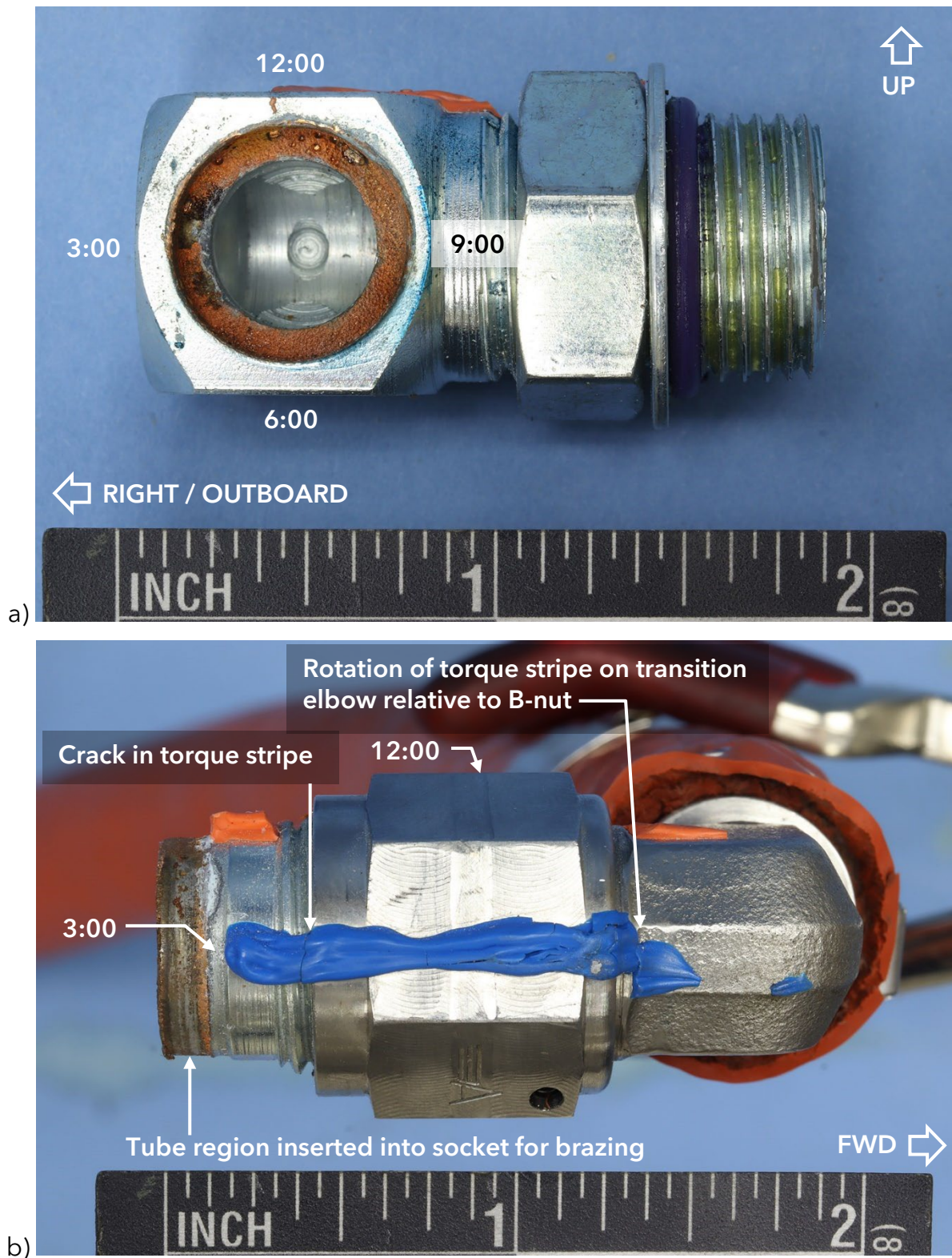


Figure 3. Images of the separated fitting; a) socket side and b) tube side with cracked and rotated blue torque striping.

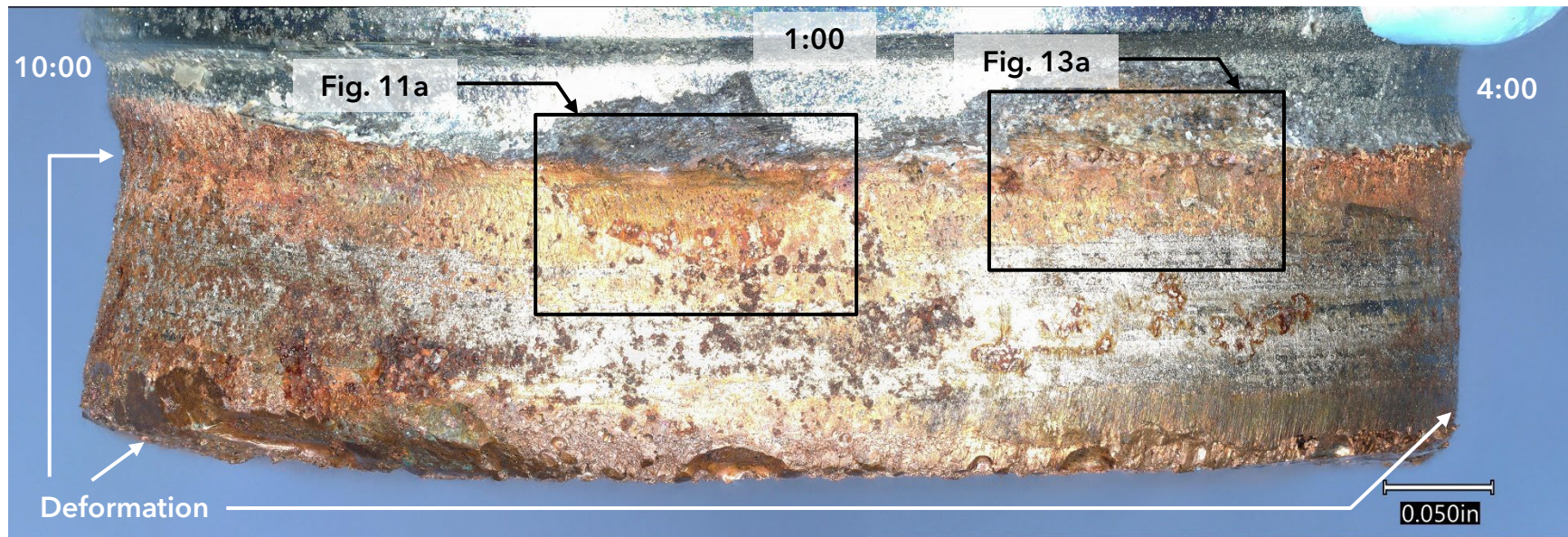


Figure 4. Image showing the sidewall of the brazed portion of the tube at approximately the 1:00 position. The tube was deformed in the axial direction at approximately the 10:00 position (upward in the image) and was deformed radially outward, also at the 10:00 position, at the butt-end of the joint. The tube was deformed radially inward near the butt-end of the joint at the 4:00 position and at the opening to the joint around the 10:00 position. Staining was also observed at two locations on the zinc-plate and copper braze surfaces.

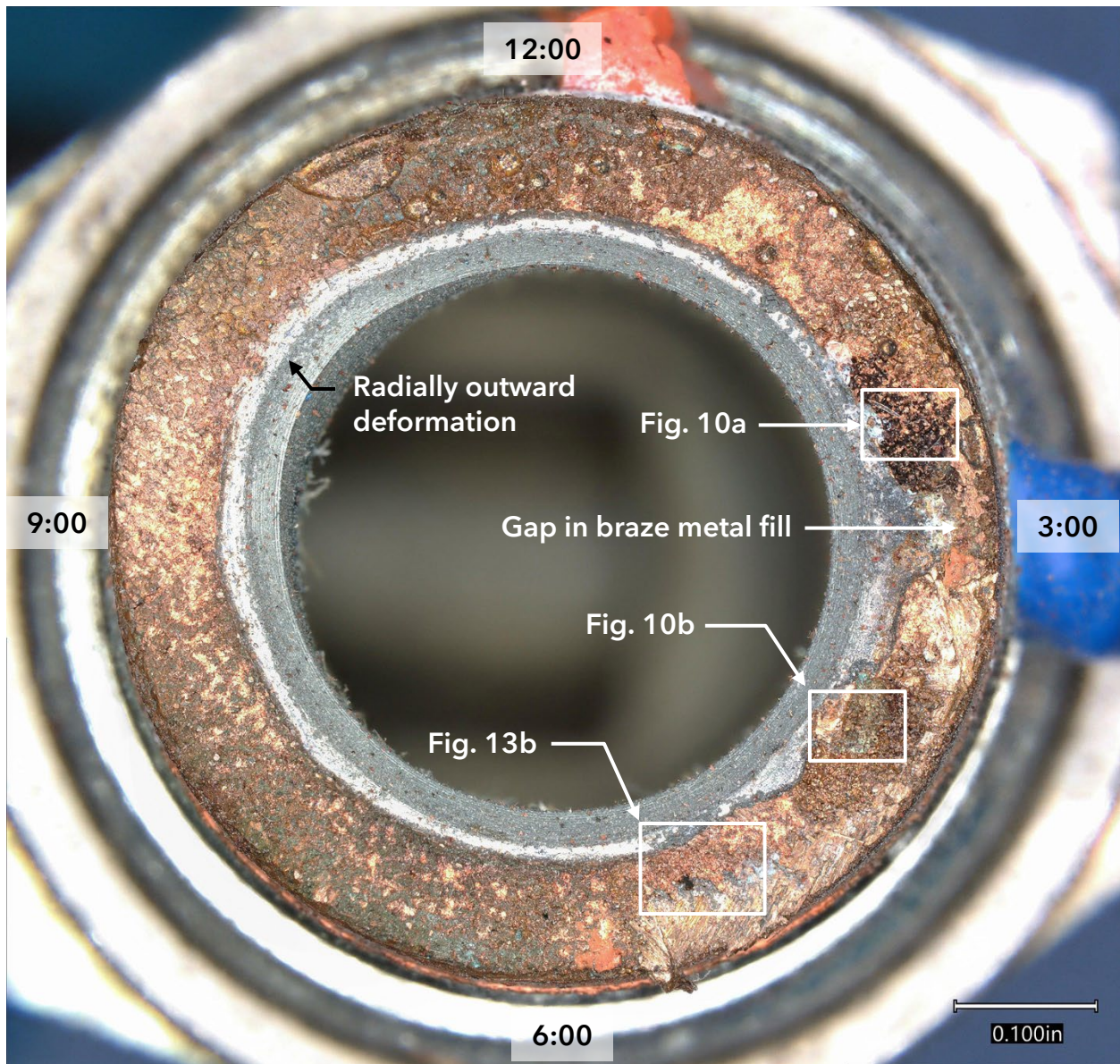


Figure 5. Image showing the brazed end of the tube.

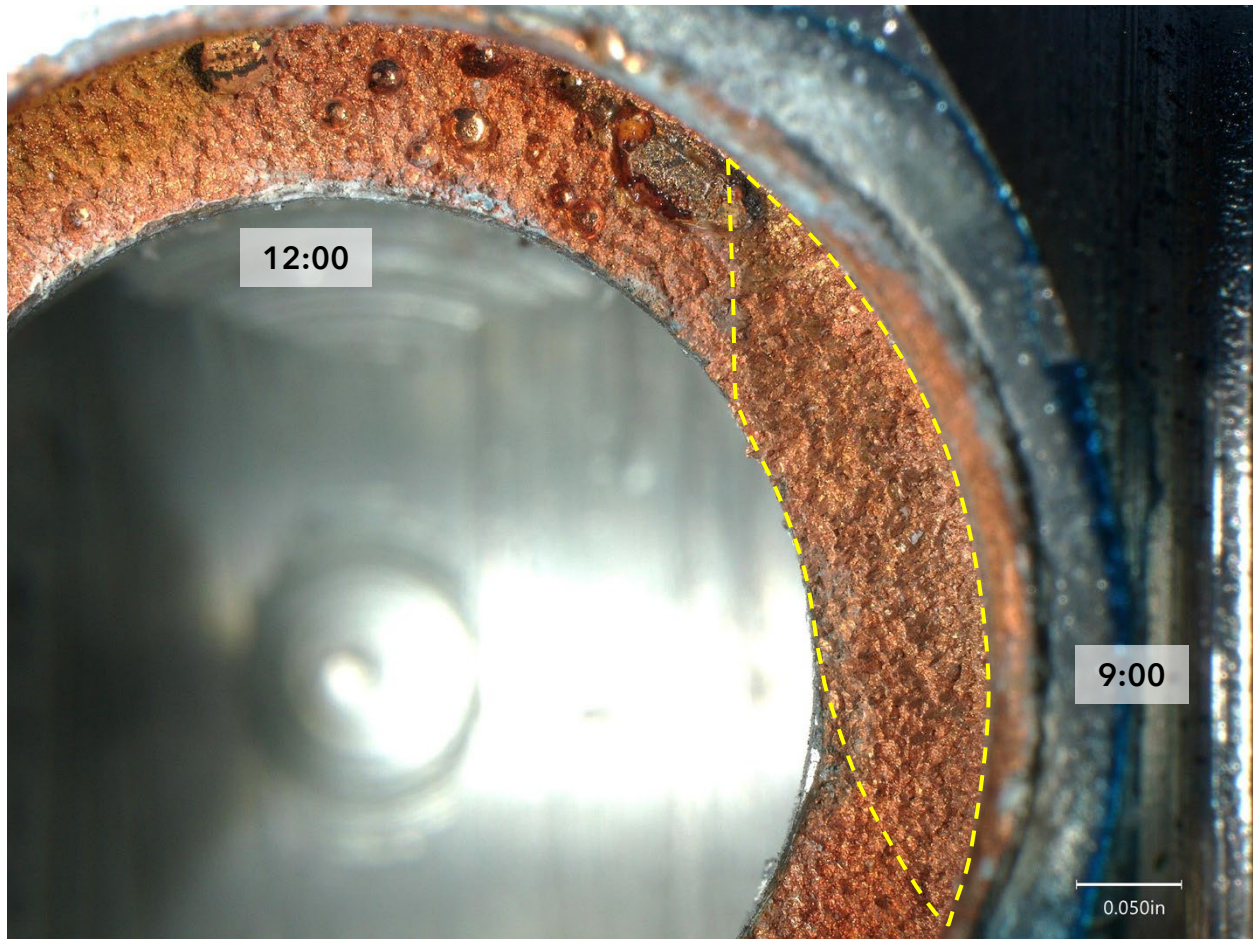


Figure 6. Image of the socket base between the 9:00 and 12:00 positions. A region of the base is indicated by the yellow dashed line where the braze metal surface was comparatively flattened and smeared. The region spanned an approximately 70° arc centered nominally about the 10:00 position.



Figure 7. Image of the socket sidewall centered about the 10:00 position with an indicator pointing to deformation of the sidewall edge at the entrance to the joint.

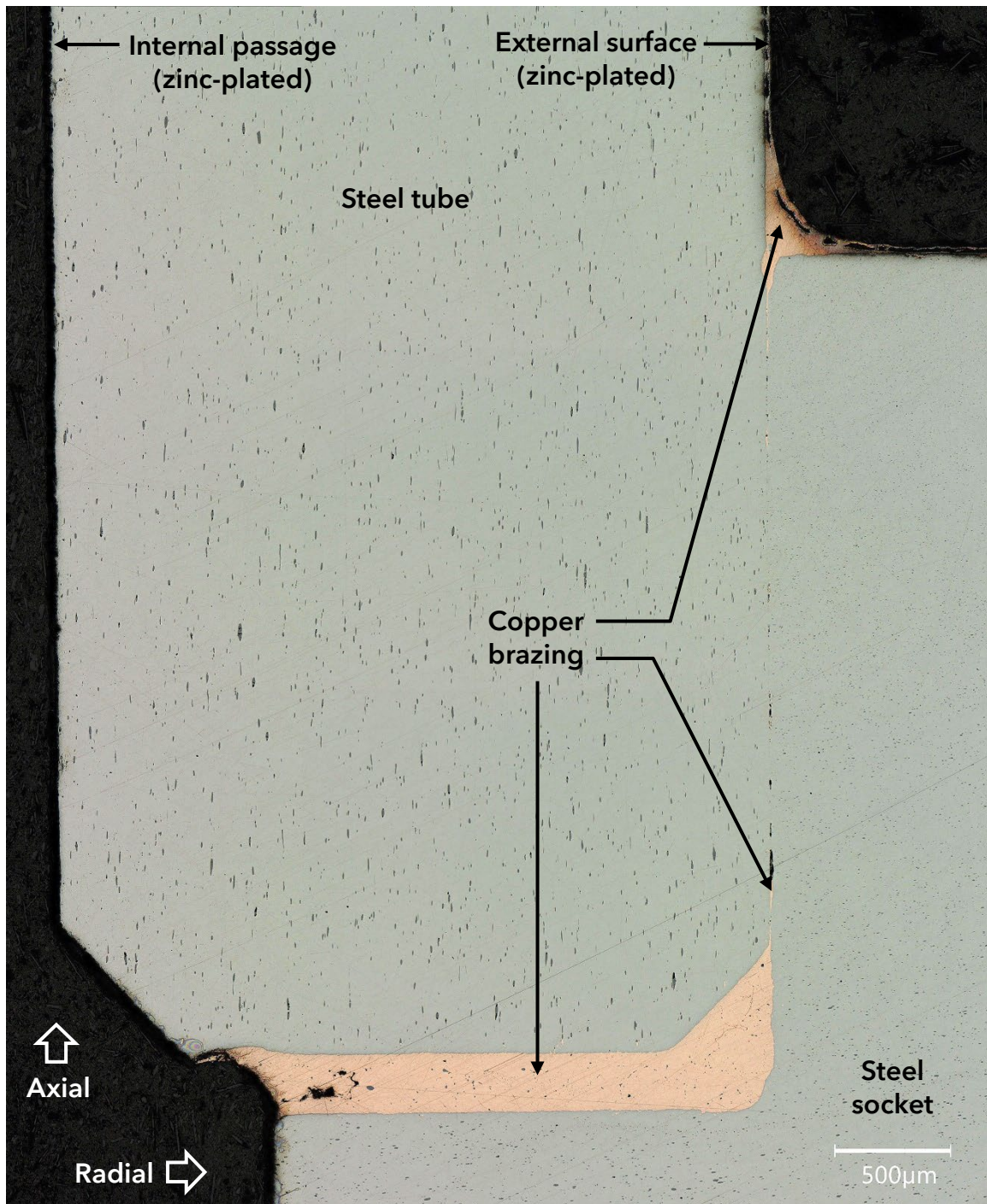


Figure 8. Cross section through exemplar fitting at approximately the 4:00 position.



Figure 9. 3D models generated using a structured-light 3D scanner; a) tube-side of joint and b) socket-side of joint.

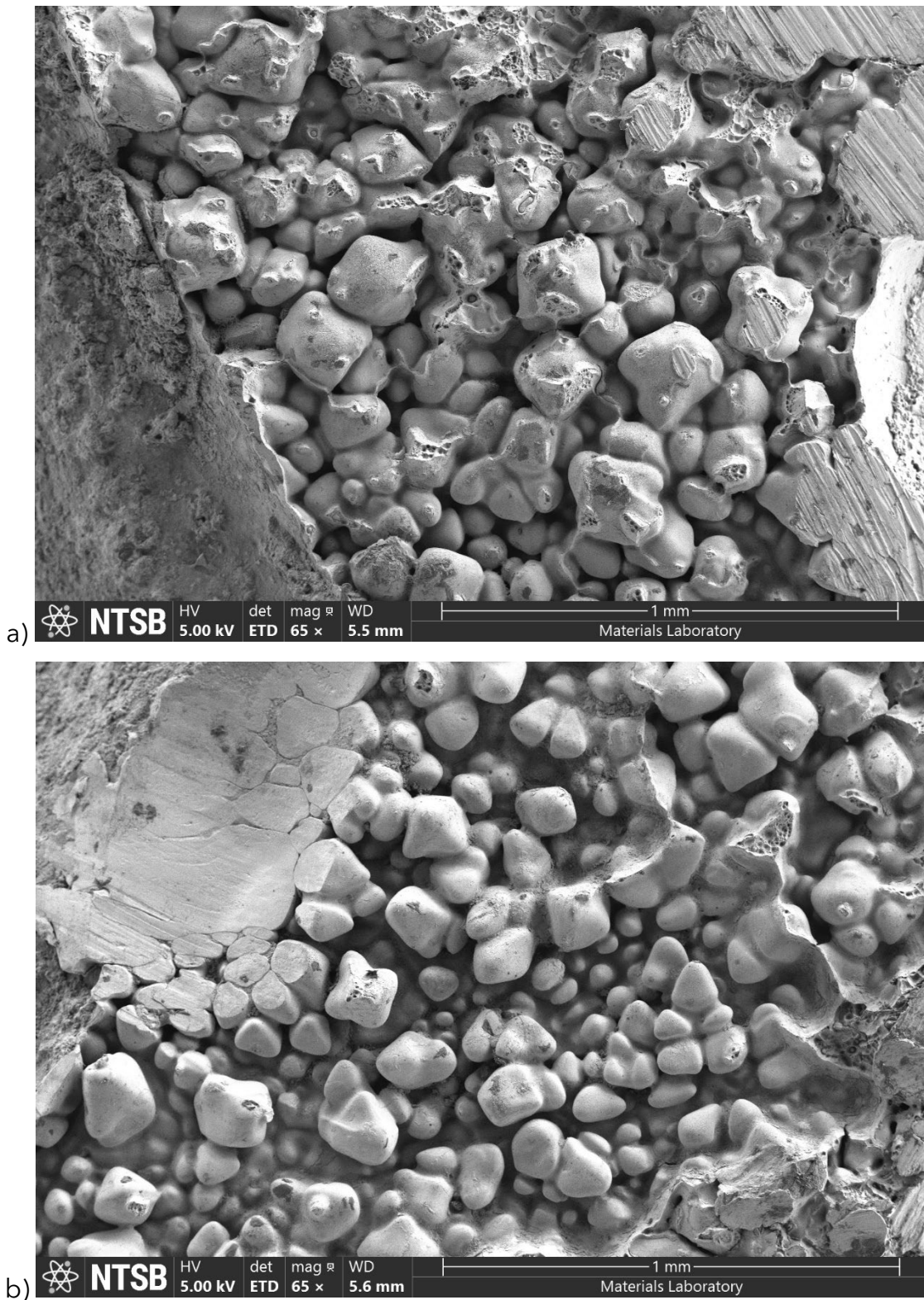


Figure 10. End face of brazed tube showing unconsolidated copper braze metal. See figure 5 for clock positions; a) near the 2:00 position and b) near the 4:00 position.

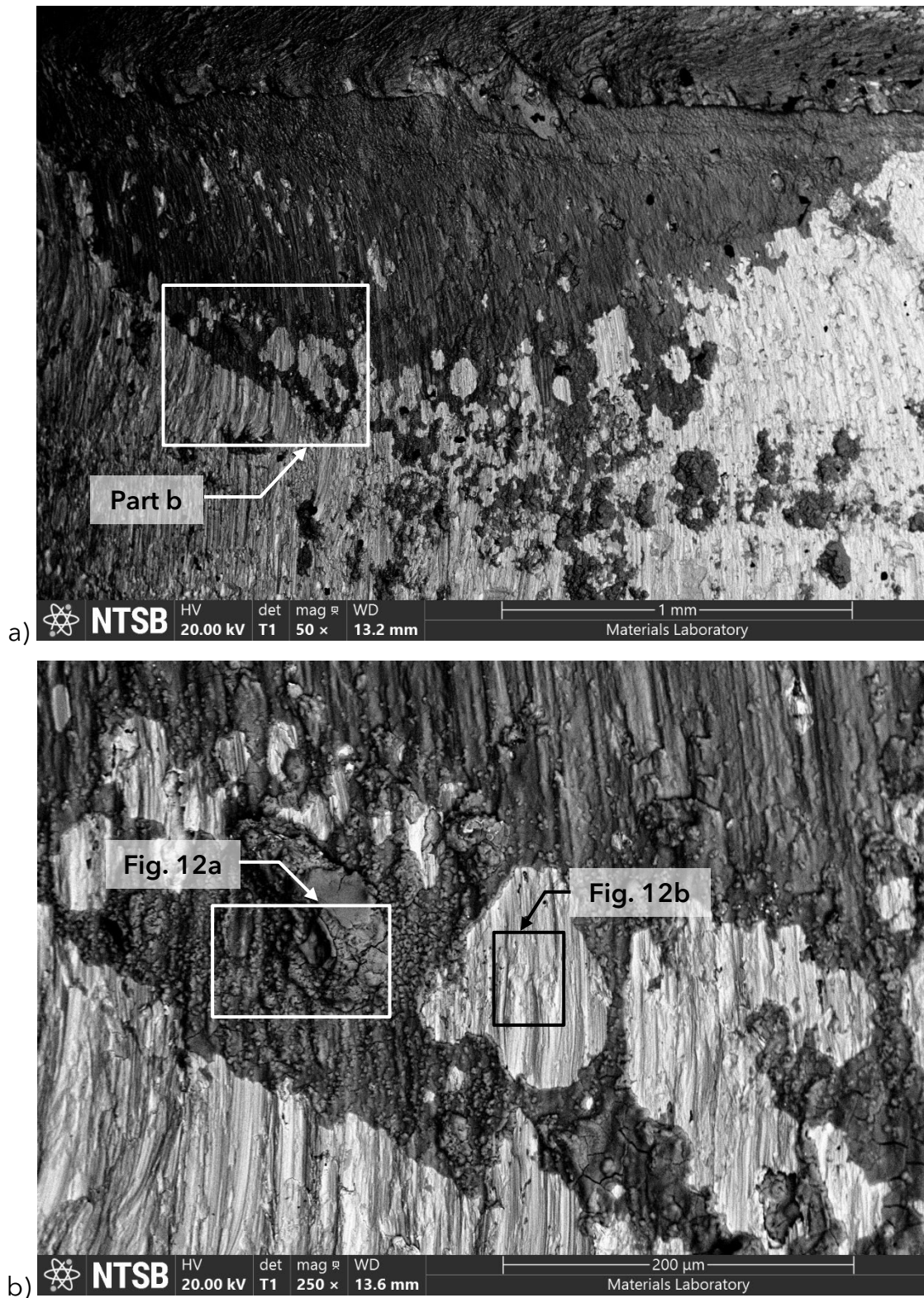


Figure 11. Backscatter electron images on the sidewall of the brazed tube near the 1:00 position and at the opening to the joint. See figure 4; a) Low magnification image of a thumbnail-shaped region and b) higher magnification image at the location indicated in part a.

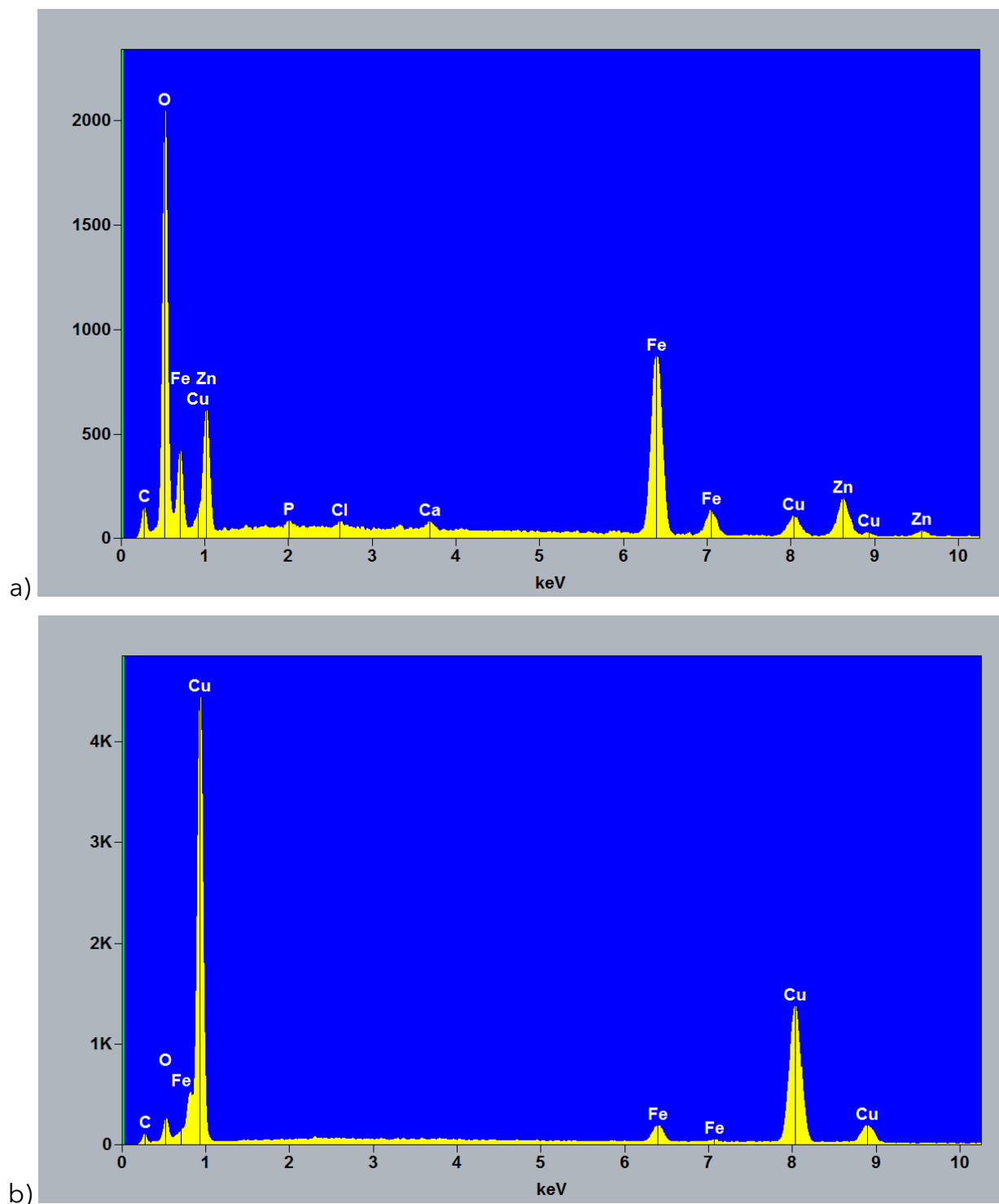


Figure 12. EDS spectra from the regions indicated in figure 11; a) spectrum for dark-colored region exhibiting primarily iron (Fe), copper (Cu), zinc (Zn), and oxygen (O) and b) spectrum from the light-colored region exhibiting primarily Fe and Cu.

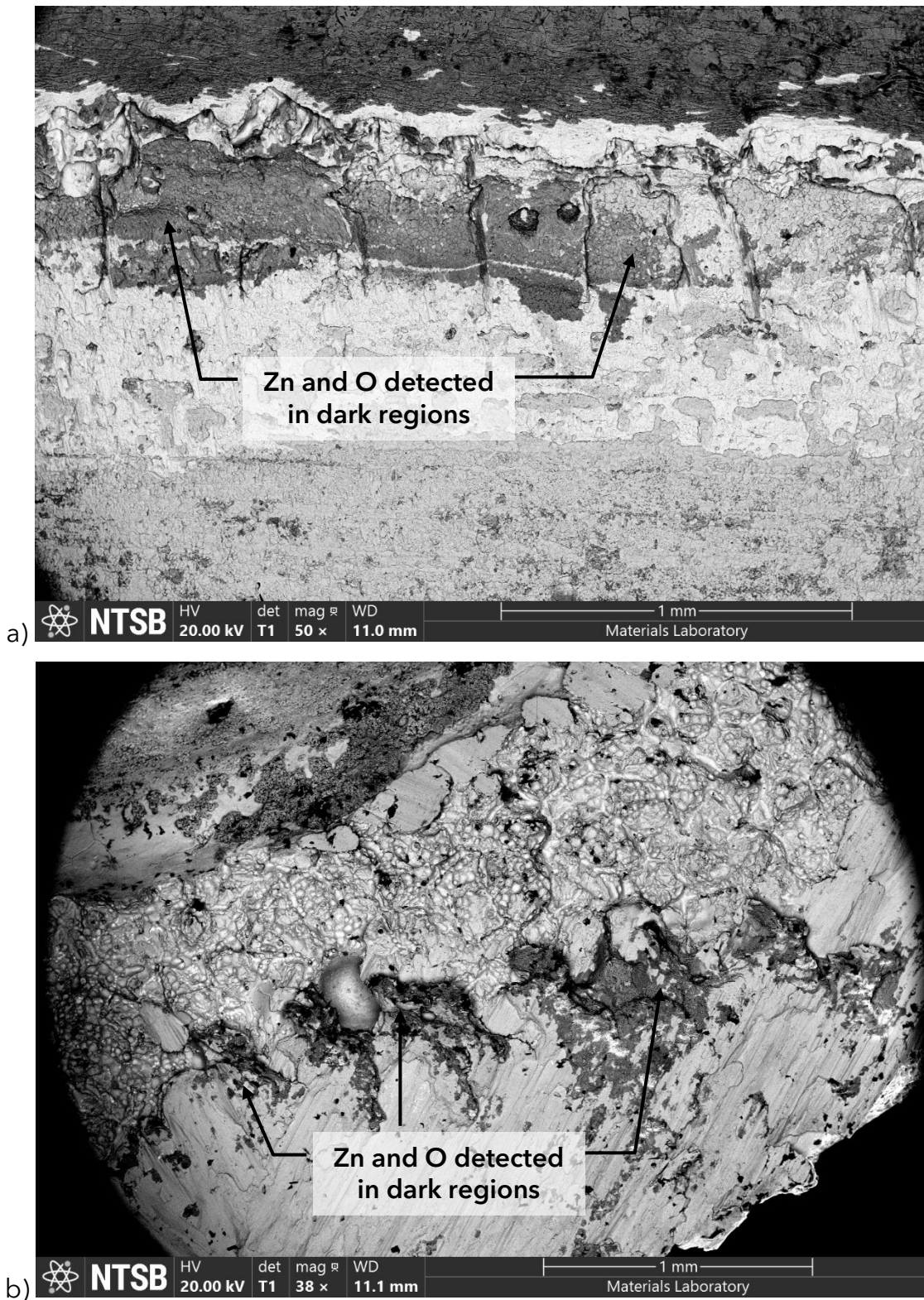


Figure 13. Images of additional regions exhibiting Zn and O in EDS spectra; a) region along sidewall of tube at opening to joint near 1:00 position (see fig. 4) and b) region on end-face of tube near the 5:00 position (see fig. 5).

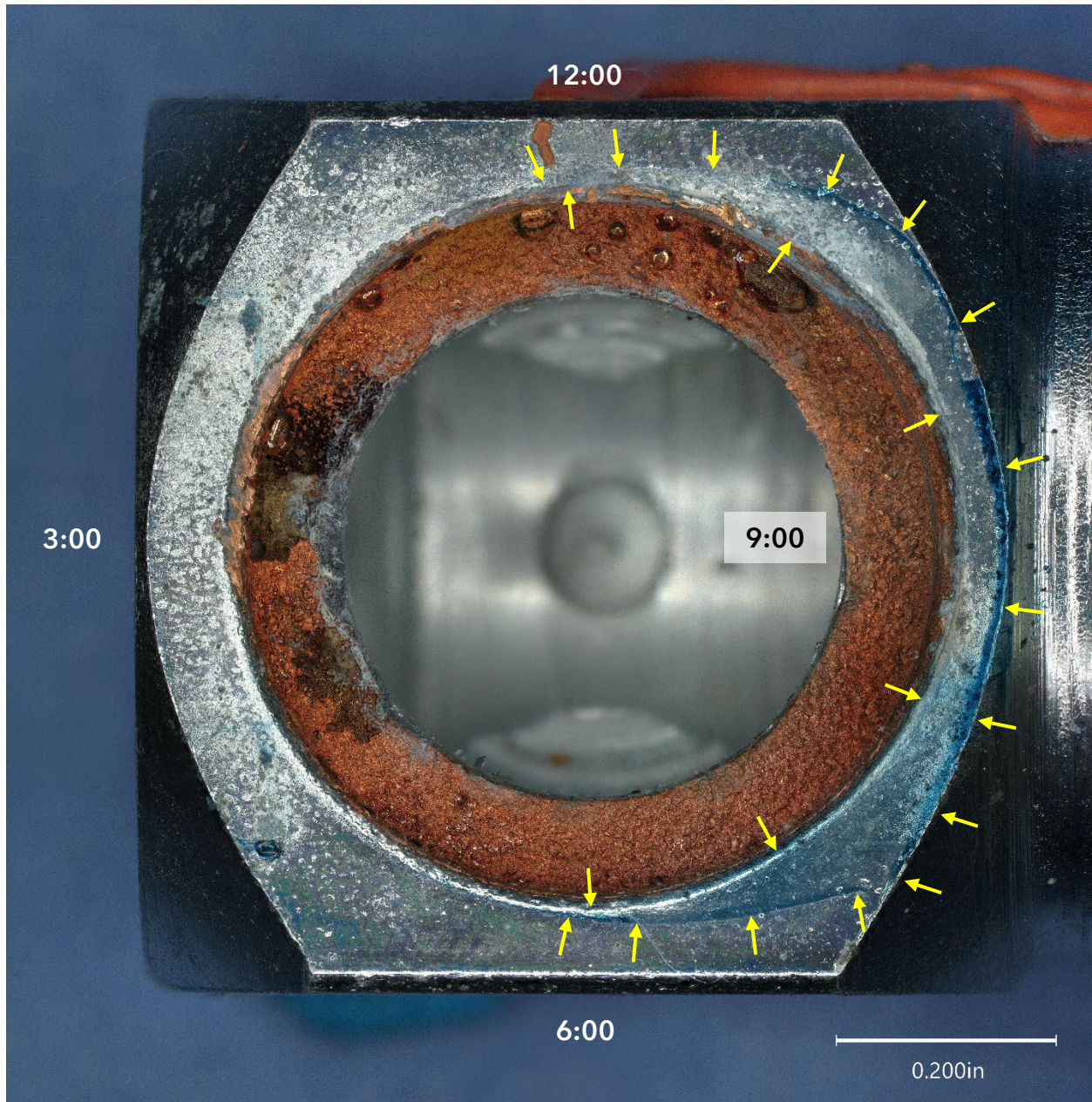


Figure 14. Image of the socket with yellow arrows indicating the extent of a translucent film on the flat face around the entrance to the joint. The film extended from approximately the 12:00 position to the 6:00 position by way of the 9:00 position.



Figure 15. Excerpt of a photo taken during the wreckage exam showing the condition of the socket and surrounding surfaces at that time. Image courtesy of the investigator-in-charge.

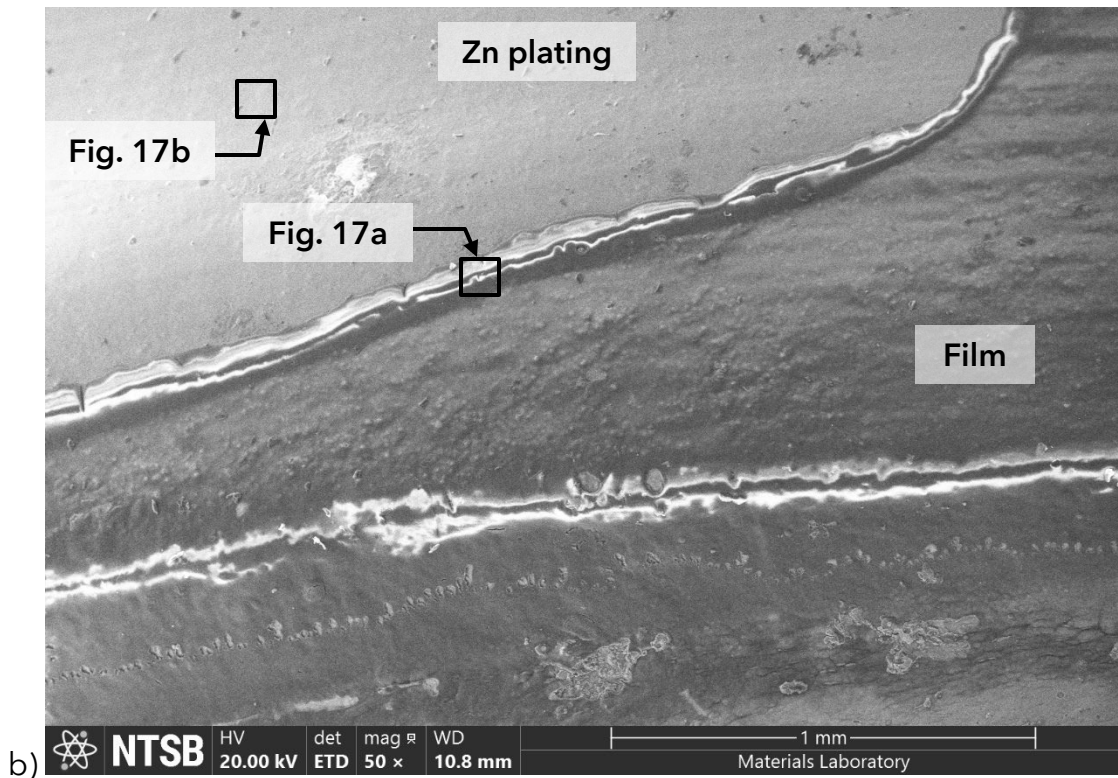
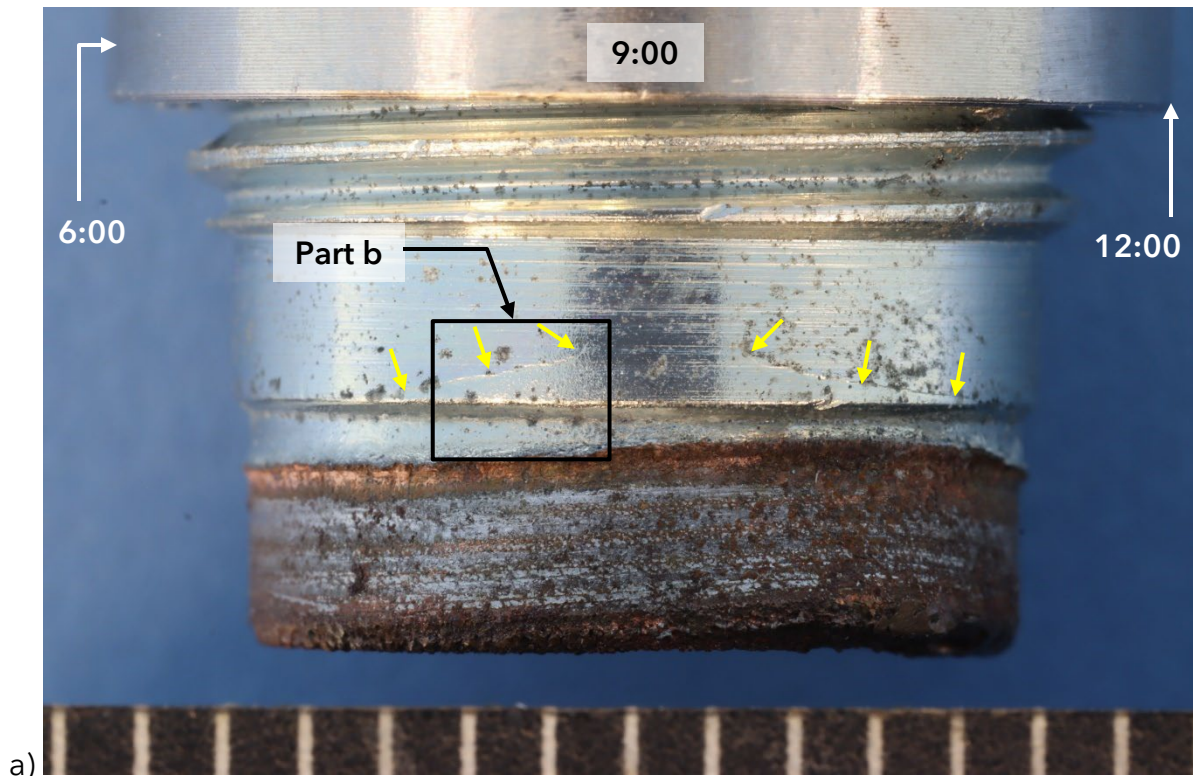


Figure 16. a) Image of the tube at the 9:00 position with the boundary of the translucent film indicated by yellow arrows and b) SEM image as indicated in part a showing the film boundary.

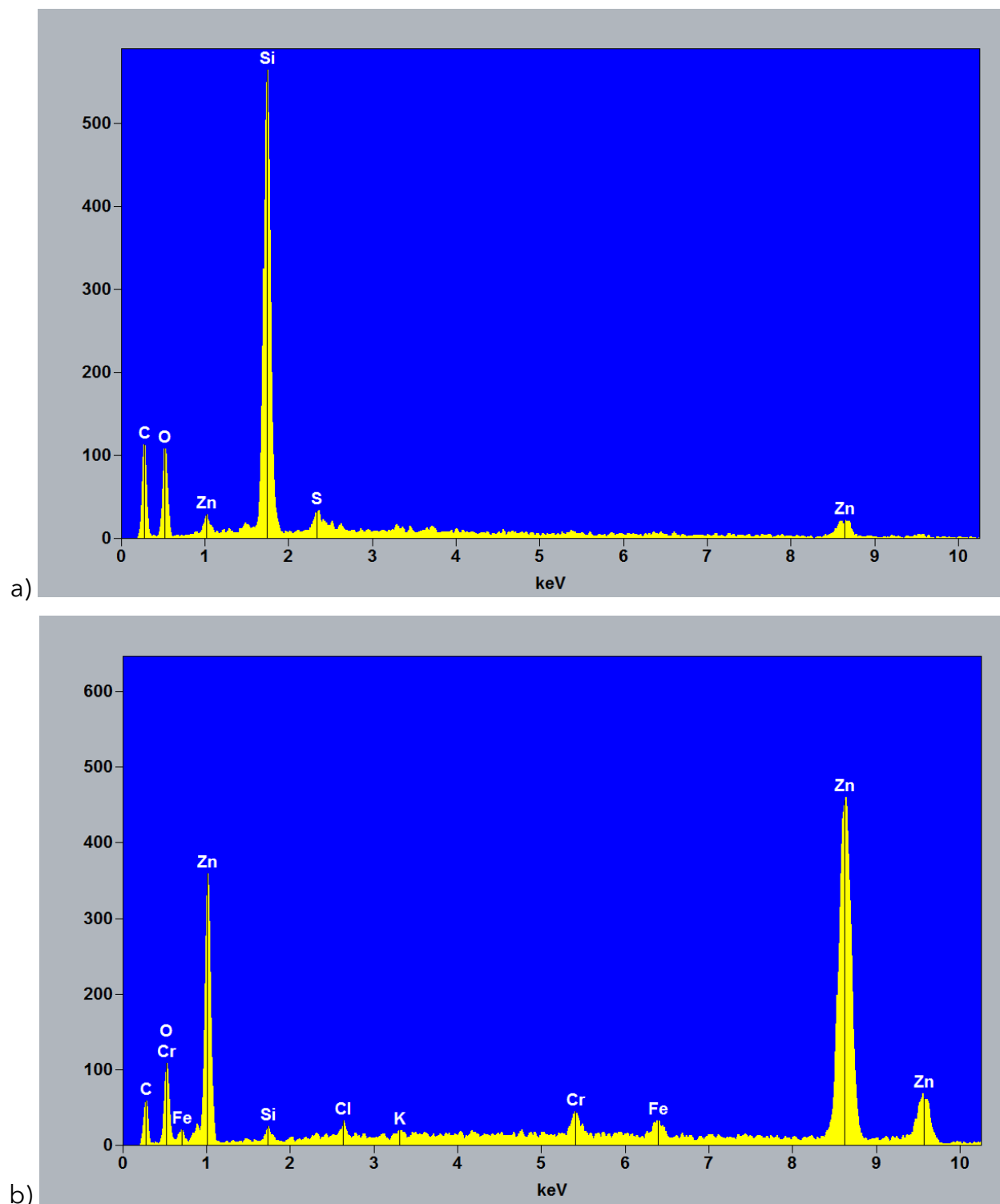


Figure 17. EDS spectra at the locations indicated in figure 16b; a) spectrum at the edge of the film exhibiting silicon (Si), oxygen (O), and carbon (C) with a trace of zinc (Zn) and b) spectrum outside the film exhibiting primarily Zn, iron (Fe), chromium (Cr), O, and C.