

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



DCA25LA061

MATERIALS LABORATORY

Factual Report 25-056

February 2, 2026

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A. ACCIDENT INFORMATION

Location: St. Mary's, Alaska
Date: December 18, 2024
Vehicle: Lockheed 382G-44K-30, N403LC
Investigator: Clinton Crookshanks, AS-40

B. COMPONENTS EXAMINED

Portion of fractured bulkhead web

C. EXAMINATION PARTICIPANTS

Group Chair Michael Meadows
National Transportation Safety Board
Washington, District of Columbia

Specialist Clinton Crookshanks
National Transportation Safety Board
Aurora, Colorado

Group Member Hank Pszcola
Lockheed Martin
Marietta, Georgia

Group Member Fred Caplan
Federal Aviation Administration
Atlanta, Georgia

D. DETAILS OF THE EXAMINATION

On December 18, 2024 at about 1600 Alaska standard time, Lynden Air Cargo LLC flight LYC141, operating under the provisions of Title 14 Code of Federal Regulations Part 121, experienced a rapid decompression while climbing through FL220 (22,000 ft). An emergency landing was performed with no injuries. A post-accident inspection by maintenance personnel revealed a crack in the forward pressure bulkhead. The fracture was harvested by maintenance personnel and shipped to the NTSB Materials Laboratory for further examination.

The submitted portion of the fractured bulkhead web was initially examined by the participants listed above at the NTSB Materials Laboratory (Washington, DC) from April 15 - 17, 2025. Results of the examination and subsequent follow-on work are documented throughout this report.

Figure 1 shows both forward and aft sides of the portion of fractured bulkhead web as received.¹ The specimen was approximately 17 inches long and just over 2.5 inches wide with a vertical row of 23 approximately fastener holes evenly spaced by 0.75 inch and centered along the length of the specimen.² The fasteners had been removed prior to receipt. For convenience, the holes were numbered sequentially from 1 - 23 starting at the upper end and given an "H" prefix. A 14.4 inch vertically oriented through-crack was observed right-adjacent to the line of fastener holes between holes 3 and 23. The upper end of the crack intersected a circular cut-out feature which extended to the free edge of the specimen.³ The lower end of the crack terminated between holes 22 and 23 and a ligament of intact web material remained attached to the free edge of the specimen. The overall profile of the crack was relatively flat and straight relative to the line of fastener holes but exhibited localized steps in between many of the fastener holes. The crack path deviated toward the right at the upper and lower ends near hole 4 and between holes 22 and 23, respectively.

Additional vertically oriented cracks were observed above and below the primary crack right-adjacent to holes 1 - 2 and 23, respectively, as shown in figure 2. Similar crack patterns were observed on both the aft and forward (FWD) surfaces, however cracking was more visible and extensive on the aft surface at these locations. A green coating had locally flaked off the forward surface where these cracks were observed. The crack nearest hole 1 (H1) intersected the upper edge of the specimen.

The forward surface had a green coating with a satin finish. Circular witness marks were observed around each fastener hole, consistent with the presence of a rivet/fastener head. The aft surface had a lighter green/brownish coating with a matte finish and a lighter green band which extended along the fastener line, consistent with the footprint of a stiffener element which had been attached before the fasteners were removed.

To completely expose the fracture surface, a saw cut was made from the lower free edge of the specimen toward the lower end of the crack tip, indicated by a dashed line in figure 3, which shows an overall section cut map of the bulkhead web. Prior to intersecting the crack tip, the remaining intact ligament was fractured in the laboratory which allowed for separate and closer examination of the mating left and right fracture surfaces.

¹ Directional descriptions refer to the bulkhead configuration as installed on the aircraft from the perspective of looking forward.

² Fastener holes were evenly spaced except the top hole (H1) was approximately 0.90 inch from the next adjacent hole (H2).

³ The circular cut-out feature resembled other similar features at each corner of the specimen which were presumably used to aid in harvesting the specimen from the larger bulkhead web.

Both the left and right fracture surfaces were examined under magnification (4X - 80X stereomicroscope) and various lighting conditions. The visual exam revealed features resembling ratchet marks emanating from the aft and forward surfaces between holes 4 - 22, which appeared more prominent along the aft surface.⁴ The fracture surface was generally oriented perpendicular to the adjacent bulkhead web surfaces on many offset planes in this region and exhibited a relatively shiny appearance. Several curved thumbnail shaped regions were observed to radiate from the aft and forward sides, consistent with crack arrest marks. These features were all consistent with progressive cracking (later confirmed to be fatigue cracking) from multiple initiation sites. Several areas exhibited black/brown and greenish deposits on the fracture surface. The upper and lower ends of the fracture between holes 3 - 4 and holes 22 - 23, respectively, where the fracture path deviated away from the fastener row, exhibited a relatively rough morphology, matte appearance, and was slanted through the bulkhead web thickness, consistent with overstress separation.

The left side of the fracture was progressively cleaned using acetate replica tape to remove debris from the surface, followed by acetone with ultrasonic agitation. Cracks originating from the aft surface generally appeared to initiate near fastener hole locations without intersecting the hole features. The cracks grew through the thickness of the web and spanwise until they intersected cracks that were growing from adjacent fastener holes, forming a series of intersecting cracks. Approximate crack region lengths were measured along the aft surface using a 4x - 80x zoom stereomicroscope and calipers. Ratchet mark, radial mark, and curved crack arrest mark patterns were used to measure approximate crack boundaries.⁵ Measured crack region lengths ranged from 0.59 inch to 1.02 inches with an average length of 0.74 inch. Table I shows the measured length of each crack with respect to the nearest fastener hole location.

To facilitate closer examination of the fracture and adjacent surfaces using digital/optical and scanning electron microscopy (SEM), additional section cuts were made at locations indicated by dashed lines in figure 3. Yellow brackets indicate locations and orientations of metallurgical cross sections that were excised after detailed fractographic examination. All crack regions exhibited similar features which are discussed in more detail below. The detailed fractographic examination described below focused on cracks located at H13 and H20, the two largest fatigue crack regions.

⁴ Ratchet marks are slight vertical steps in the fracture that link slightly offset planes of fatigue cracking at a fatigue origin area. Ratchet marks generally are aligned in the direction of cracking and taper off as distance from the origin is increased and a unified crack front is produced.

⁵ Radial marks are Lines on a fracture surface that radiate from the fracture origin and are visible to the unaided eye or at low magnification.

Figure 4 shows digital microscope images of the left fracture surface between holes 12 - 14. A closer view of the fracture surface near hole 13 along with the mating right side of the fracture is shown at the bottom of the figure. Ratchet mark features emanating from the aft surface are indicated by blue arrows. Curved features consistent with crack arrest marks emanating from H13 and H14 are indicated by yellow and red dashed lines, respectively. A closer view of the area indicated on the mating right fracture surface is shown in figure 5 where green deposits were observed embedded on the fracture surface. These deposits were consistent in appearance with the coating material on the adjacent surfaces.

Figure 6 shows scanning electron microscope images of the region identified in figure 4. The general direction of fatigue crack growth was from the aft surface toward the crack arrest marks (yellow and red dashed lines), as indicated by black arrows. At these arrest marks, the fracture morphology changed from a flatter feathery appearance near the aft surface, to a rougher appearance between the arrest marks and a slanted fracture plane at the forward surface. A closer view of the rougher fracture morphology is shown in the right image where dimpled fracture features were observed, consistent with overstress separation.

Figure 7 shows a scanning electron microscope image of the left fracture surface near H13. A region of intergranular (IG) features was observed at the aft surface which extended approximately 0.003 inch through the material thickness.⁶ Feathery fracture features extended from the IG region over many offset planes toward the forward surface, as indicated by black arrows. Several small, curved thumbnail shaped regions (later to be confirmed fatigue cracks) were observed extending from the forward surface through approximately 10% of the material thickness. Secondary cracks were also observed along the fracture surface, some examples of which are indicated by red arrows.

Figure 8 consists of tilted views of the previous figure to show the adjacent aft surface relative to the fracture surface with the edge of H13 visible at the bottom of the image. The upper portion of the fracture surface undercut the lower portion along the aft surface as indicated by the bracket in the left image. The right image shows a closer view of the intergranular cracking features which extended from the aft surface. Transgranular fatigue fracture was observed emanating from the intergranular region as indicated by black arrows.⁷

Figure 9 shows scanning electron microscope images of the transgranular fatigue cracking region where striations (oriented horizontally) of varying intensity

⁶ Intergranular refers to cracking or fracturing that occurs between the grains or crystals in a polycrystalline material which often resembles a "rock candy" appearance.

⁷ Transgranular refers to cracking or fracturing that occurs through the grains or crystals in a polycrystalline material.

were observed. The direction of crack growth is upwards in this image (aft to forward).

Figure 10 shows scanning electron microscope images of the boundary between intersecting fatigue cracks emanating from the aft surface and forward surface, indicated by the yellow dashed line. Aft to forward crack growth direction is indicated by black arrows and forward to aft crack growth direction is indicated by white arrows. Higher magnification views of the cracking from the forward surface are shown in figure 11 where similar fatigue striations (oriented horizontally) were observed. The direction of crack growth is downward (forward to aft). The cracking that formed along the aft surface grew through more of the web thickness, progressing between 85% and 95% before intersecting the cracking that formed along the forward surface at the largest fatigue crack networks.

Figure 12 shows a digital microscope image of the left fracture surface at H20. Similar ratchet mark features (blue arrows) and curved arrest marks (yellow dashed lines) were observed extending from the aft surface. The fatigue crack region extending from the aft surface is indicated by the bracket. A closer view of the boxed area indicated is shown in figure 13 where regions of intergranular cracking were observed at the aft surface to a depth of approximately 0.003 inch. Feathery fracture features emanated from the IG regions and aft surface towards the forward surface through approximately 90 - 95% of the material thickness with local growth directions indicated by black arrows. Curved thumbnail shaped crack regions were observed extending from the forward surface as indicated by white arrows. Secondary cracks were also observed on the fracture surface with some prominent examples indicated by red arrows.

Closer views of typical fracture initiation sites in the H20 fatigue crack region are shown in figure 14. Intergranular cracking was observed at both the aft and forward surfaces with feathery transgranular fatigue features and curved arrest marks extending from the intergranular features in the directions indicated by the arrows. The right image shows the boundary between fatigue cracking growing from the aft surface and the forward surface and is indicated by a dashed yellow line.

Chemical analysis was performed using energy dispersive x-ray spectroscopy (EDS) at several of the fracture initiation sites along the aft surface. Figures 15 and 16 show representative SEM images and EDS spectra associated with the boxed areas. Major peaks of aluminum and zinc were identified in all areas, consistent with a 7XXX series aluminum alloy material. Other elements were detected as shown by weight percentage. The presence of chlorine was detected near the edge of the fracture at the adjacent aft surface.

Figures 17 and 18 show scanning electron microscope images of the upper and lower ends of the fatigue cracking regions emanating from the aft surface near

H4 and H22, respectively, where the fracture mechanism transitions abruptly from fatigue (below the dashed yellow line) to overstress (above the dashed yellow line).

The aft and forward surface coatings were removed locally around some of the fastener holes to examine the base metal surfaces more closely. A commercial chemical paint stripper was used. Figure 19 shows the before (upper images) and after (lower images) condition at H17. A gold iridescent finish was observed on the aft and forward surfaces following coating removal, consistent with the application of a chemical conversion coating. Figure 20 shows a closer view of the aft surface between the edge of H20 and the fracture surface prior to coating removal. The green coating appeared flaked off in some locations which exposed the underlying gold iridescent coating and small cracks oriented parallel to the primary fracture surface were observed in these regions, several examples are indicated by yellow arrows.

Figures 21 and 22 show closer views of the area between the edge of H17 and the primary fracture surface on the aft and forward surfaces, respectively. The left images are digital microscope images with higher magnification SEM images shown on the right. Multiple small cracks oriented parallel to the primary fracture surface were observed. Scratch-like features running perpendicular to the fracture plane and some surface pits were also observed. On the forward surface (figure 22), a circular witness mark centered about the fastener hole was observed as indicated by brackets, which was consistent with the presence of a fastener head.

Metallurgical cross section cuts were taken from the left side of the fracture adjacent to H6 and through H15, transverse to the length of the fracture surface. Figure 23 shows micrographs of the mounted, polished, and etched specimens from adjacent to H6 (left) and through H15 (right). Cracks were observed extending from the aft surface below the fracture surface and branching from the primary fracture surface in both specimens. Cracks were also observed extending from the forward surface below the fracture surface in the specimen taken through H15. Some of these surface initiated cracks were confined to the clad layer (lighter etched band along the forward and aft surfaces) while others continued through the base metal. Examples of surface-initiated cracks and branched cracks are indicated by yellow arrows and brackets in figure 23.

Representative cross sections were taken, prior to coating removal, from excess bulkhead web material away from the fracture. These specimens were mounted and polished for metallographic examination. Figure 24 shows representative views of the forward surface (left) and aft surface (right) in the as-polished (upper) and etched (lower) condition.⁸ The coating layers were observed as

⁸ Specimens were etched using Keller's reagent, a solution of 1% Nitric acid, 1.5% Hydrochloric acid, 3.5%Hydrofluoric acid in Distilled water.

a green band along the forward and aft surfaces on the far left and far right in each image respectively. Etching revealed a distinct clad layer on each side of the base metal, shown as a homogenous lighter band beneath the coating layers. The etched microstructure of the base material exhibited elongated grains, consistent with rolled aluminum sheet stock. The coating thickness on the aft surface ranged from 0.0006 - 0.0012 inch and averaged 0.0008 inch. The coating thickness on the forward surface ranged from 0.0019 - 0.0025 inch and averaged 0.0022 inch. The clad layer thickness on each surface ranged from 0.0018 - 0.0024 inch and averaged 0.0021 inch. The overall material thickness, with coating removed, was measured to be approximately 0.047 inch.

The material composition was analyzed using X-ray fluorescence spectroscopy (XRF). The clad layer was identified as predominantly aluminum with a small amount of zinc with other trace elements. The base metal was identified as being consistent with 7075 aluminum alloy. Electrical conductivity was measured to be 33.7 %IACS with the clad layer intact and 34.7 %IACS with one side of the clad layer removed.⁹ Microhardness indentation measurements were obtained on a sample of bulkhead web material with the coating and clad layer removed and results ranged from 163 - 185 HV and averaged 174 HV.¹⁰ The microhardness indentation value of 174 HV corresponds to approximately 87 HRB.¹¹ The hardness and electrical conductivity values measured were consistent with those expected for 7075 aluminum alloy in peak aged (T6) condition.

Submitted by:

Michael Meadows
Materials Engineer

⁹ Electrical conductivity is expressed in percent International Annealed Copper Standard (%IACS), at 20°C by definition, where copper = 100 %IACS.

¹⁰ HV corresponds to the Vickers hardness scale and is an indentation hardness measurement unit. The test was done by applying a 500-gram load to a diamond indenter and measuring the size of the resulting impression. Higher numbers indicate harder materials.

¹¹ HRB corresponds to the Rockwell B hardness scale. The approximate HRB value was derived from ASTM E140 Standard Hardness Conversion Tables for Metals - Table 9 for wrought aluminum products.

Table I: Aft Surface Fatigue Crack Lengths

Relative Fastener Hole Location	Crack Length (in.)
H4	0.70
H5	0.72
H6	0.65
H7	0.79
H8	0.72
H9	0.79
H10	0.74
H11	0.67
H12	0.59
H13	1.02
H14	0.59
H15	0.78
H16	0.71
H17	0.84
H18	0.68
H19	0.67
H20	1.01
H21	0.69
H22	0.66

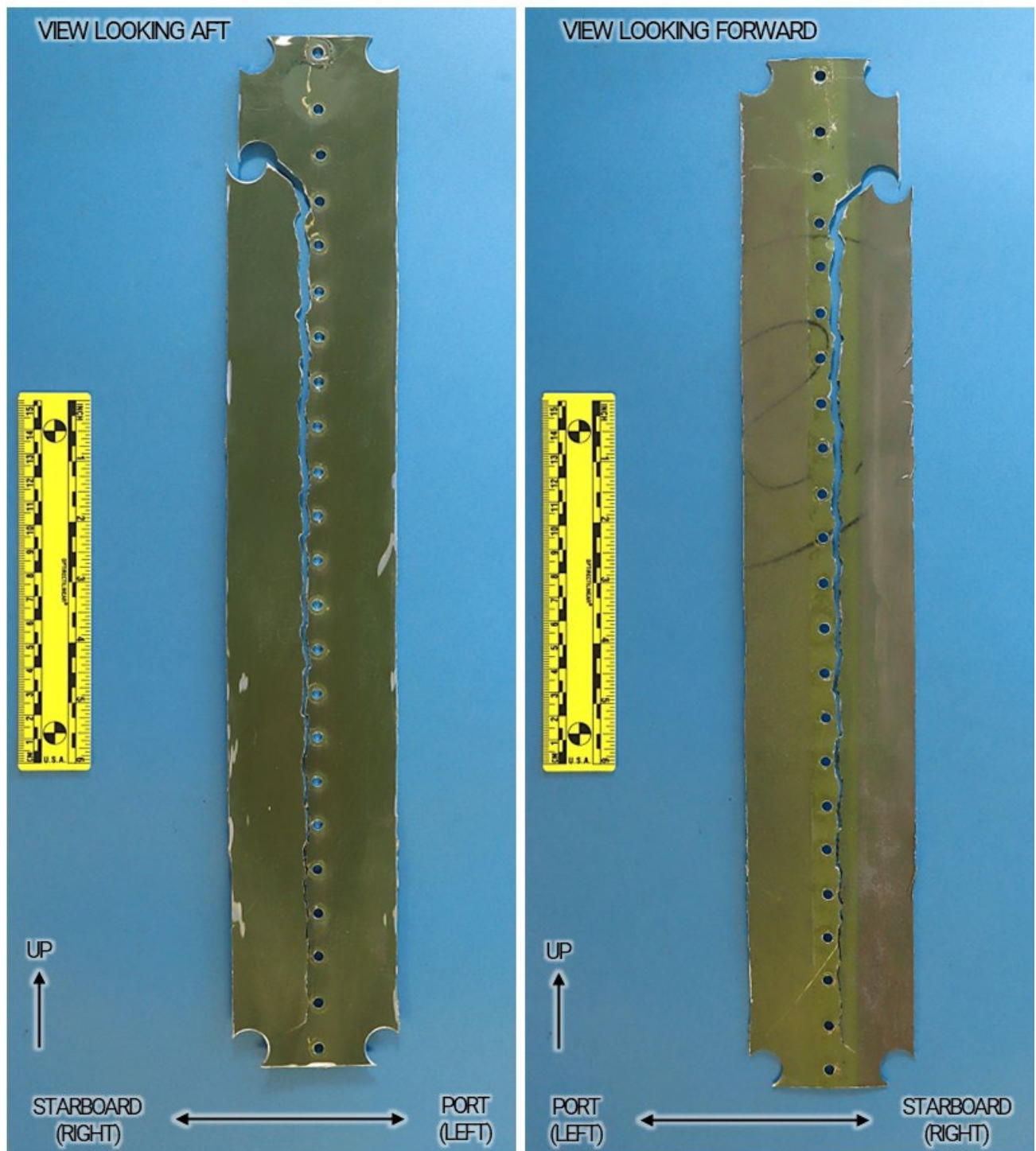


Figure 1. Photographs of the forward surface (left) and aft surface (right) of the portion of the bulkhead web as received.

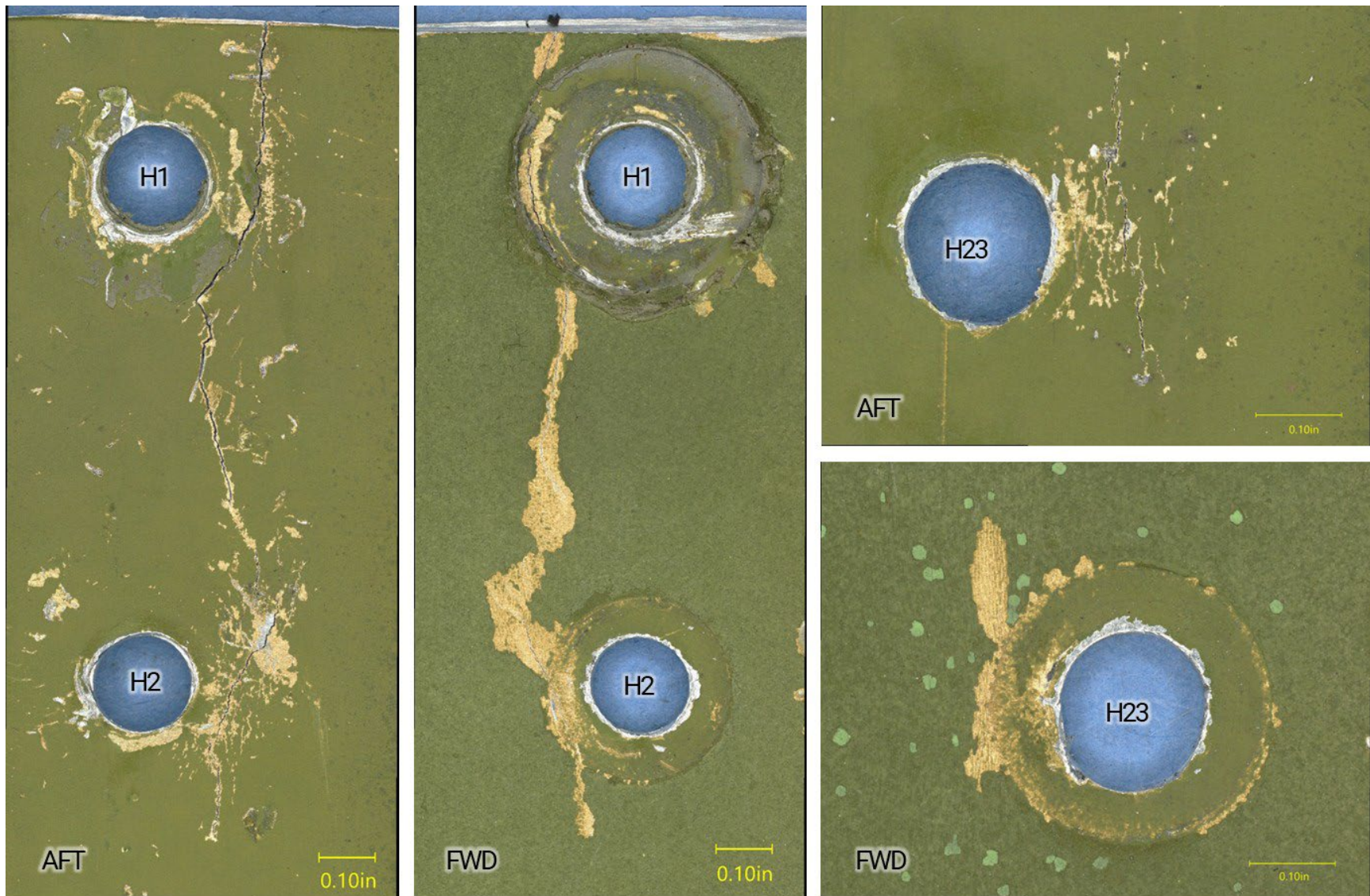


Figure 2. Closer views of the aft and forward surfaces of the bulkhead web near holes 1, 2, and 23 where vertically oriented cracks were observed adjacent to the holes.

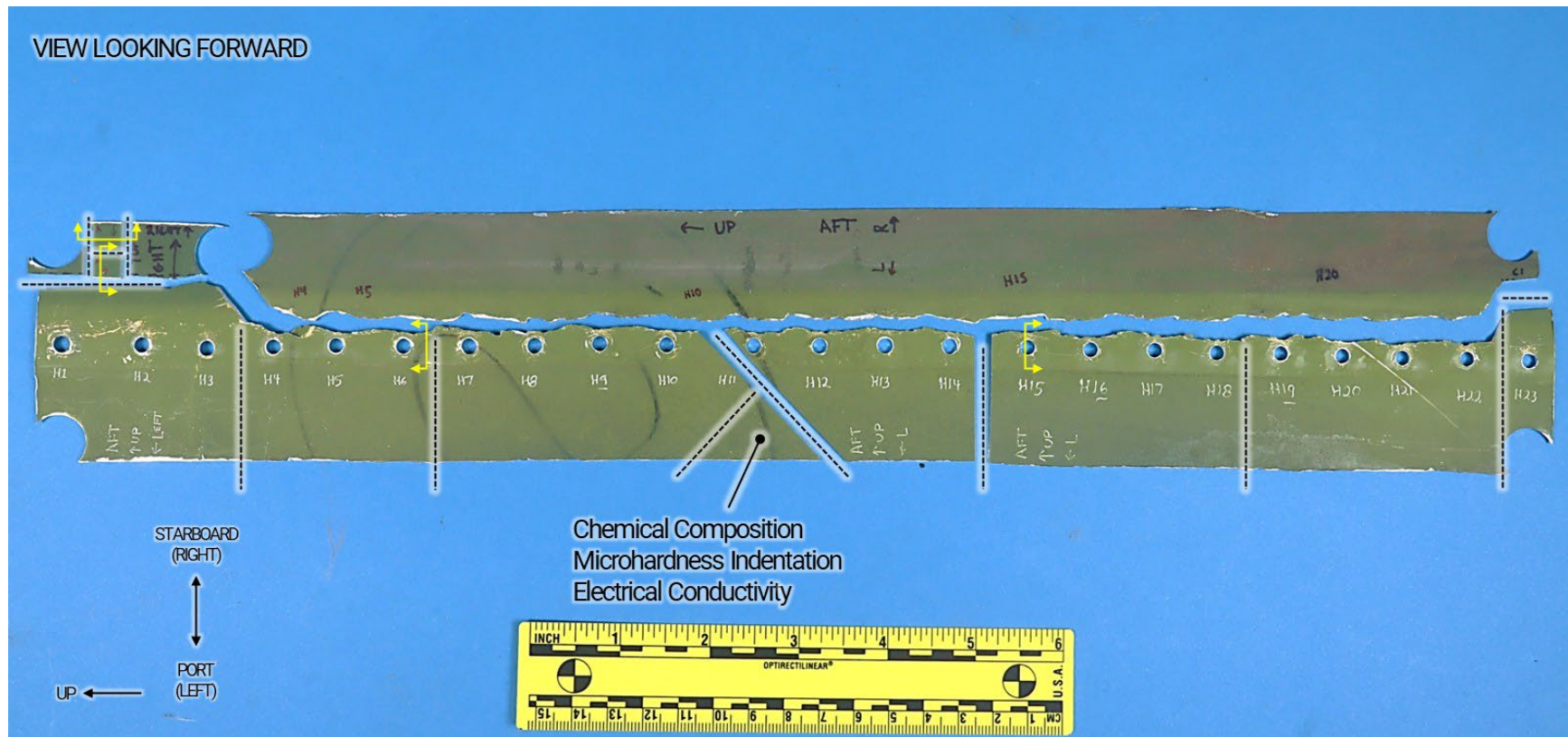


Figure 3. A specimen map of the bulkhead web showing locations where cuts were made in the laboratory (dashed lines) to facilitate handling, closer examination, and testing. Metallurgical cross-sections were excised from locations indicated by yellow brackets.

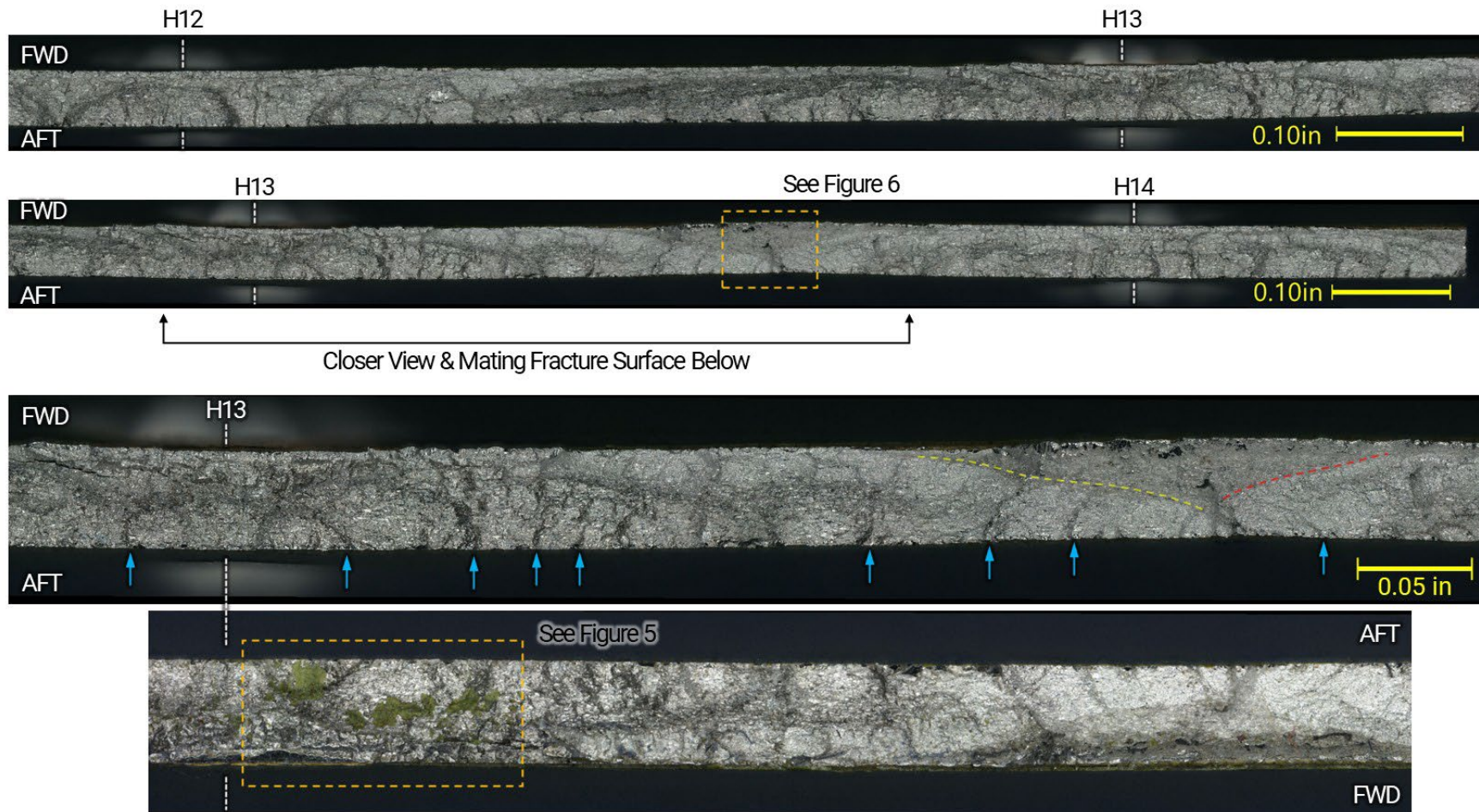


Figure 4. Closer views of the fracture surface between H12 - H14 shown above with a zoomed in view between H13 and H14 below. Curved crack arrest marks emanating from H13 and H14 are indicated by yellow and red dashed lines, respectively. Typical ratchet mark features observed along the aft surface are indicated by blue arrows. The bottom image shows the mating (right side) fracture surface between H13 and H14 showing green deposits on the fracture surface.

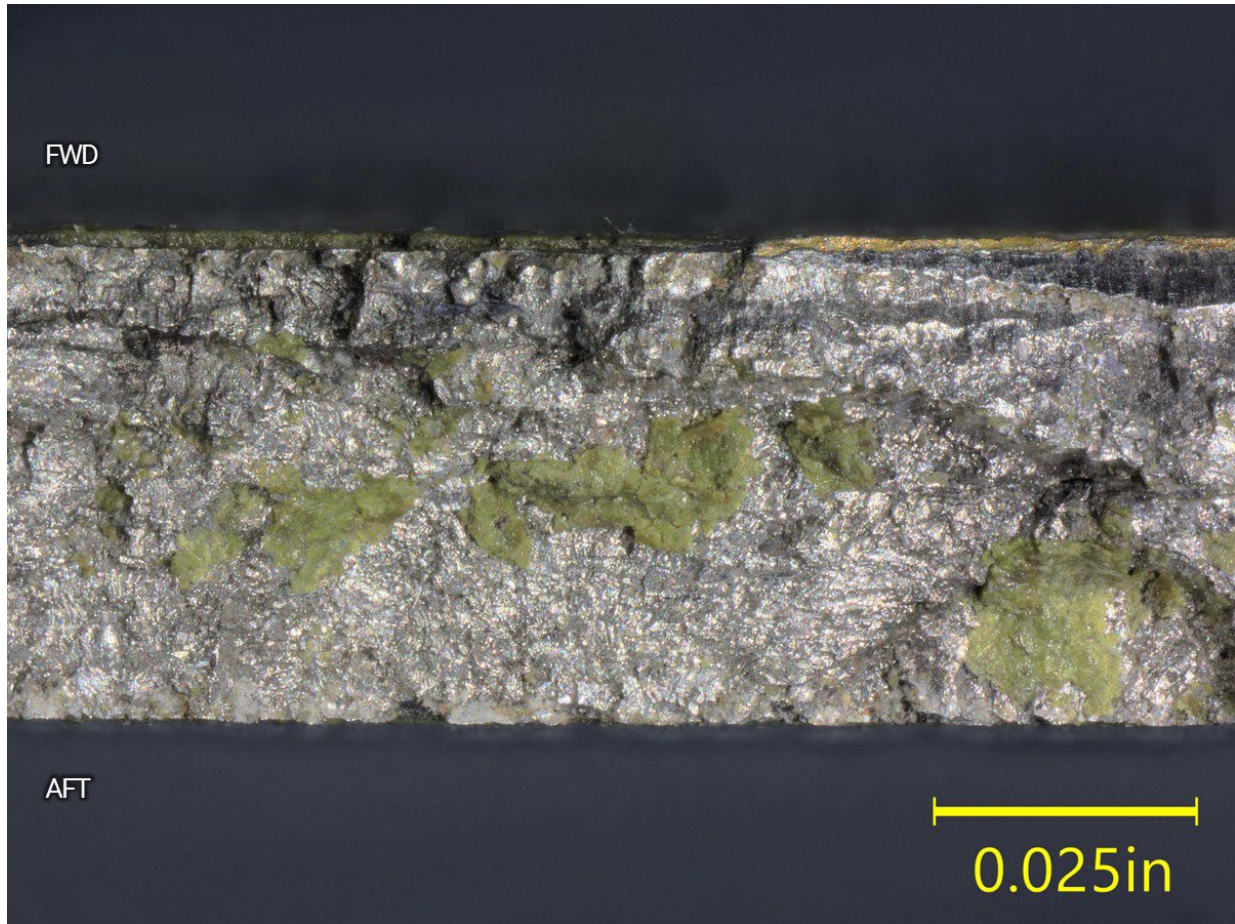


Figure 5. A closer view of the right fracture surface indicated in the previous figure showing green deposits embedded on the fracture surface.

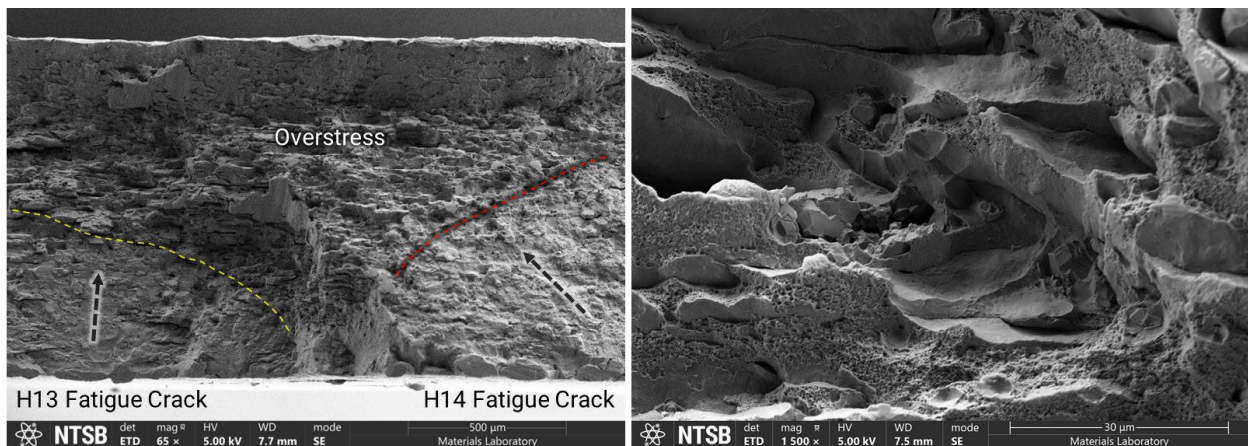


Figure 6. SEM images of the region identified in figure 4. The extent of fatigue cracking from the aft surface (growth direction indicated by arrows) from H13 and H14 is indicated by yellow and red dashed lines, respectively. The right image shows a closer view of the overstress region where dimpled fracture features were observed.

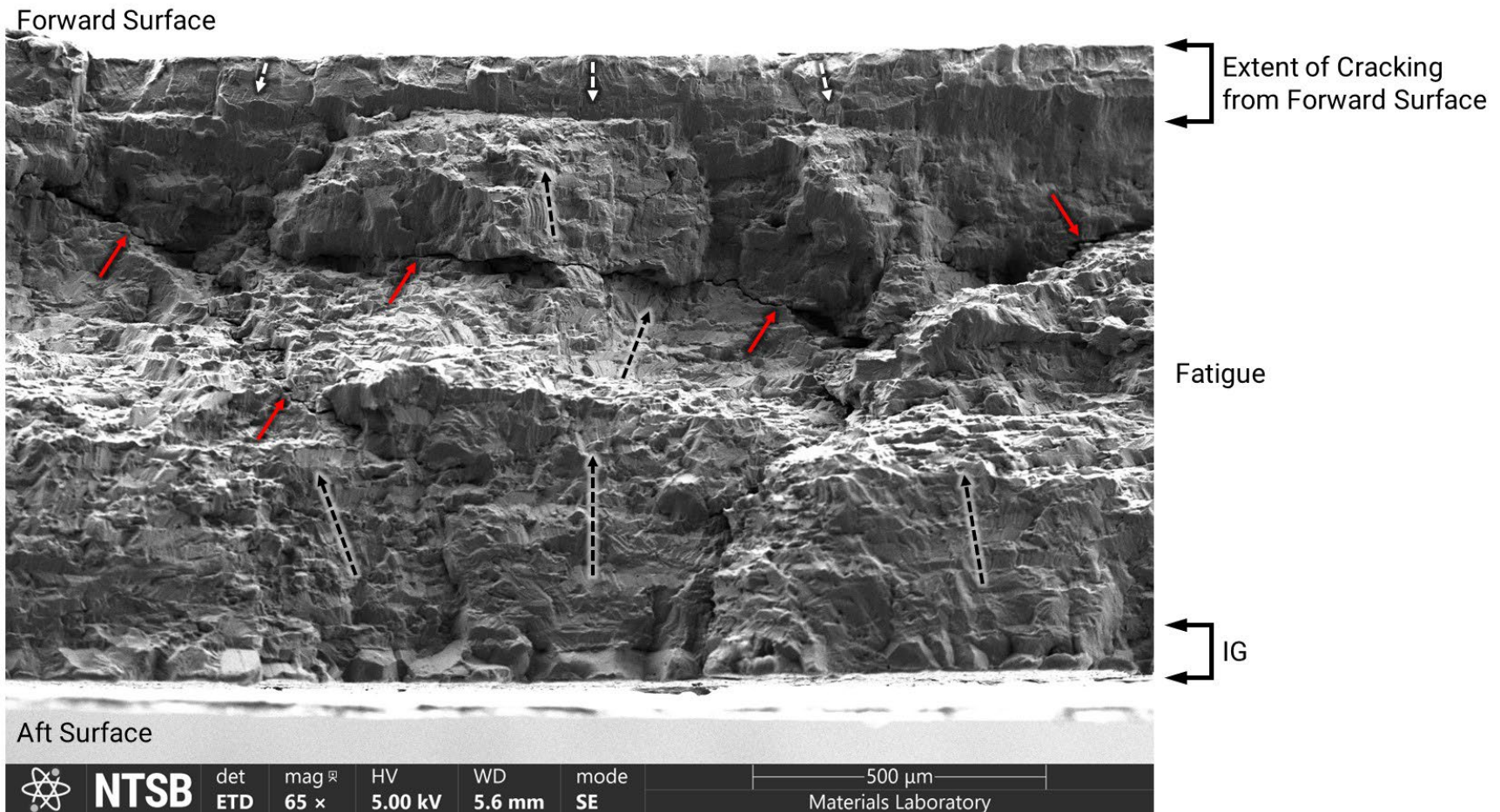


Figure 7. An overall SEM image of the left fracture surface at H13 showing an intergranular (IG) region at the aft surface from which fatigue cracking extended through the material thickness as indicated by black arrows. Curved thumbnail shaped crack regions extended from the forward surface as indicated by white arrows. Secondary cracks were observed branching from the primary fracture surface with typical examples indicated by red arrows.

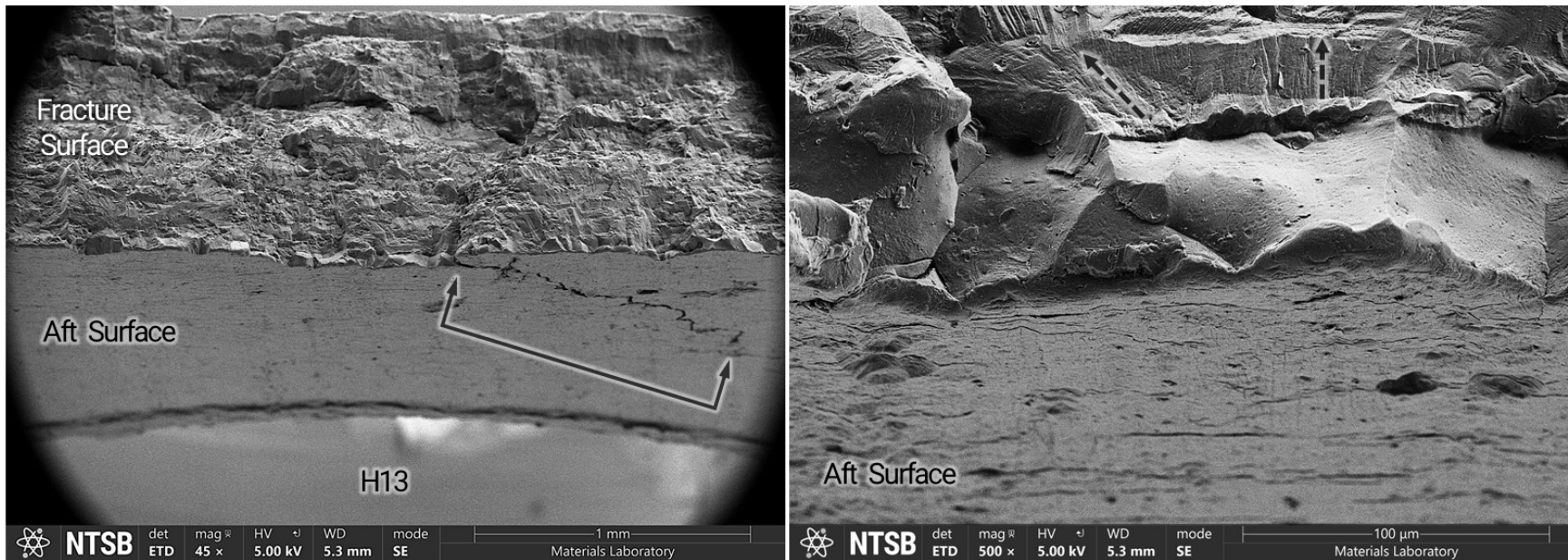


Figure 8. Tilted SEM images of the same region in the previous figure showing the adjacent aft surface. The bracket in the left image indicates a crack in the aft surface undercutting the adjacent fracture surface. The right image shows a closer view of intergranular features at the aft surface from which fatigue cracking progressed from as indicated by black arrows.

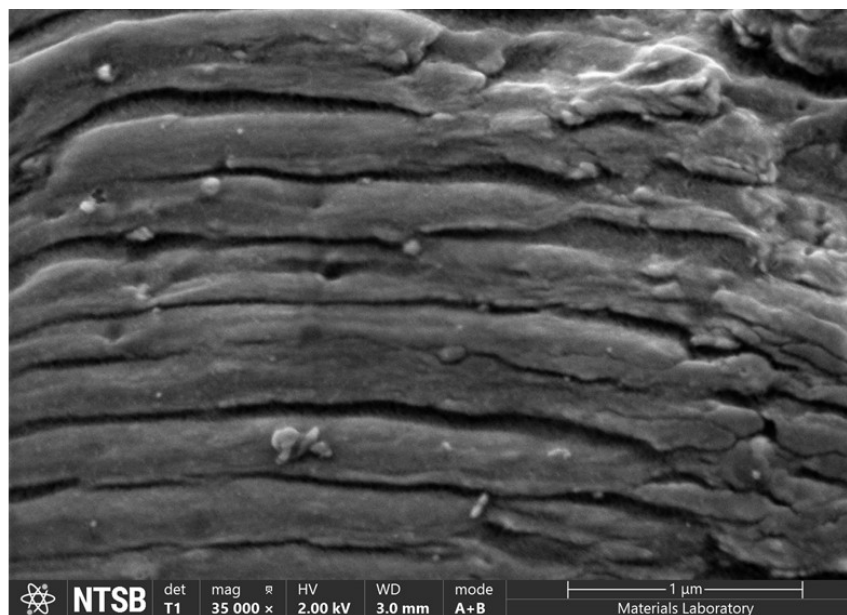
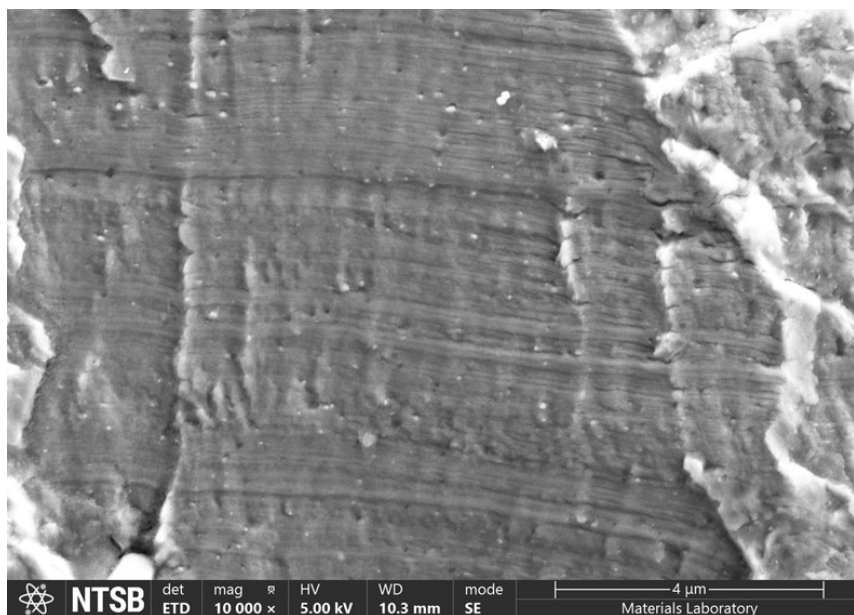


Figure 9. SEM images at different magnification levels of typical fatigue striations observed along the H13 fatigue crack growing from the aft surface. The crack growth direction is upwards in these images.

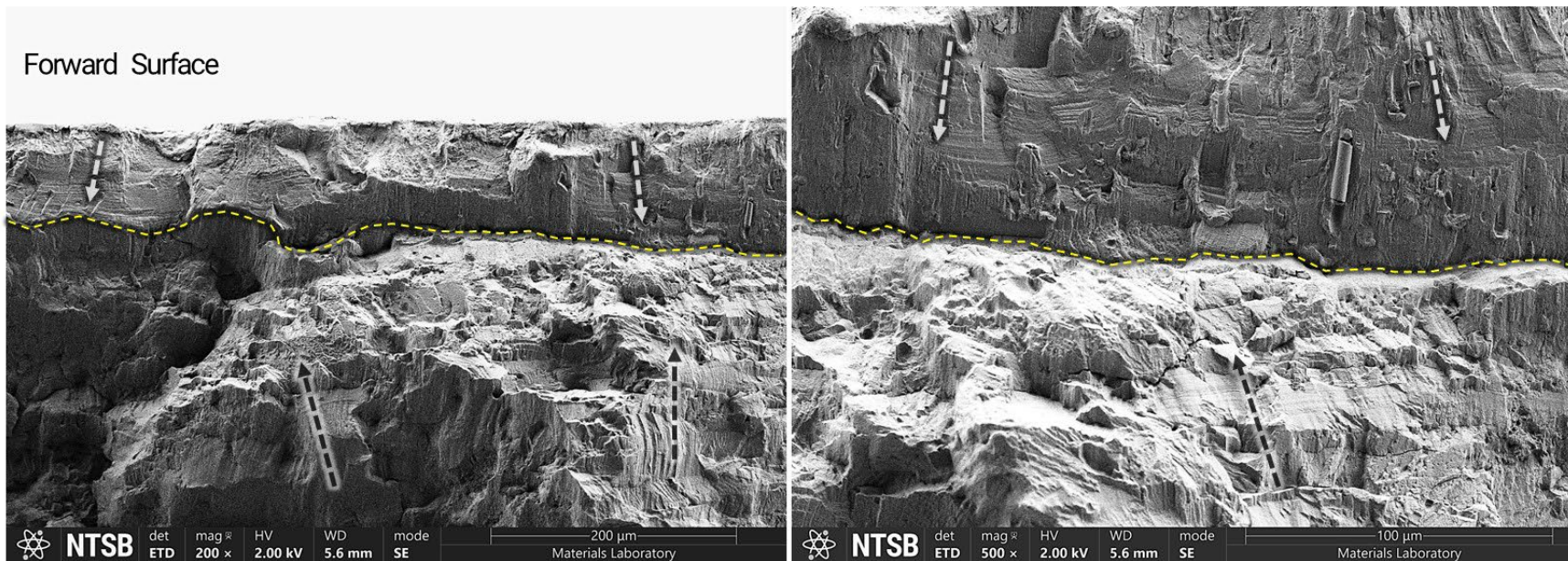


Figure 10. SEM images showing closer views of fatigue cracking extending from the forward surface at H13 (in the direction of the white arrows). The boundary between fatigue cracking extending from the aft surface (in the direction of the black arrows) is indicated by a yellow dashed line.

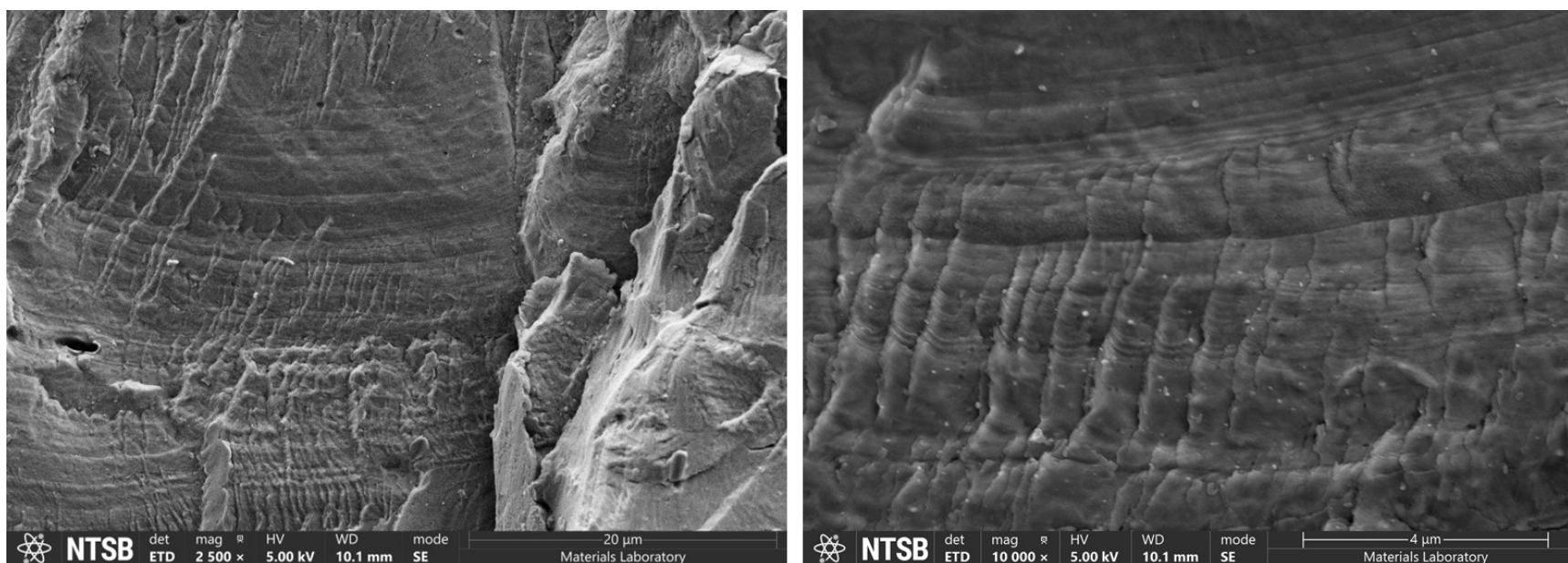


Figure 11. SEM images at different magnification levels of typical fatigue striations observed along the H13 fatigue crack growing from the forward surface. The crack growth direction is downwards in these images.

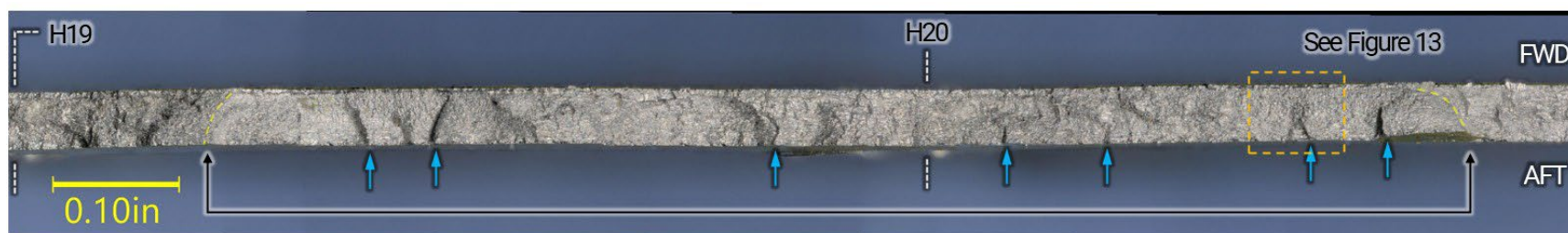


Figure 12. Closer view of the fracture surface between H19 - H21. Curved crack arrest marks emanating from H20 (bracketed region) are indicated by yellow dashed lines. Typical ratchet mark features observed along the aft surface are indicated by blue arrows.

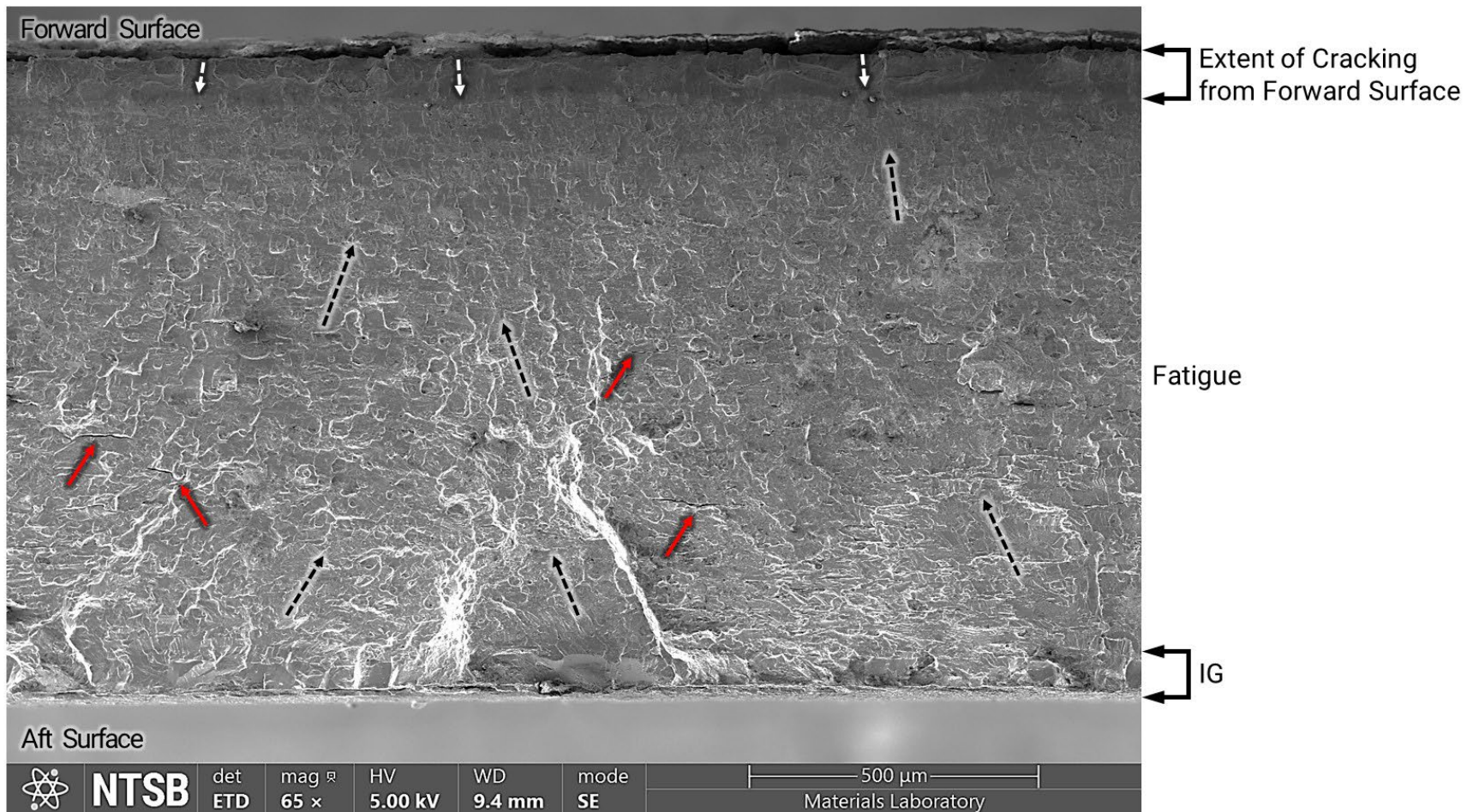


Figure 13. An overall SEM image of the left fracture surface at H20 showing a region with intergranular (IG) features at the aft surface from which fatigue cracking extended through the material thickness as indicated by black arrows. Curved thumbnail shaped crack regions extended from the forward surface as indicated by white arrows. Secondary cracks were observed branching from the primary fracture surface with typical examples indicated by red arrows.

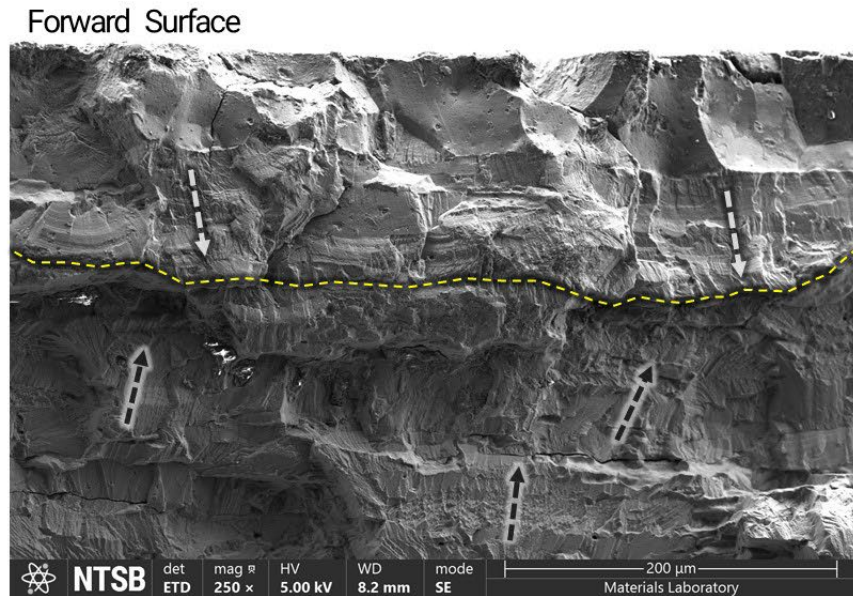
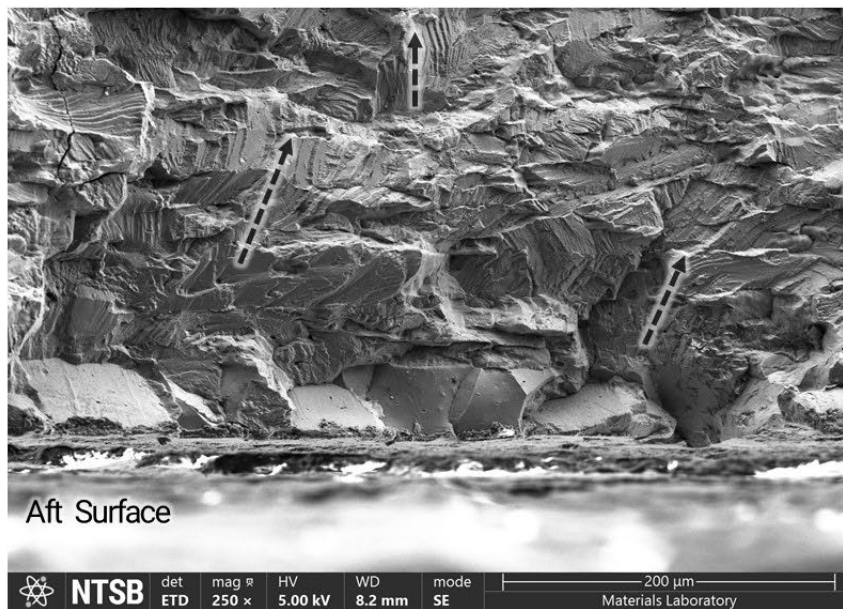


Figure 14. Closer SEM images of fracture initiation sites at the aft surface (left) and forward surface (right). Intergranular features with fatigue cracking features emanating from them were observed at both surfaces with black arrows indicating crack growth direction from the aft surface and white arrows indicating crack growth direction from the forward surface. The right image shows the boundary between the aft and forward fatigue cracks indicated by a yellow dashed line.

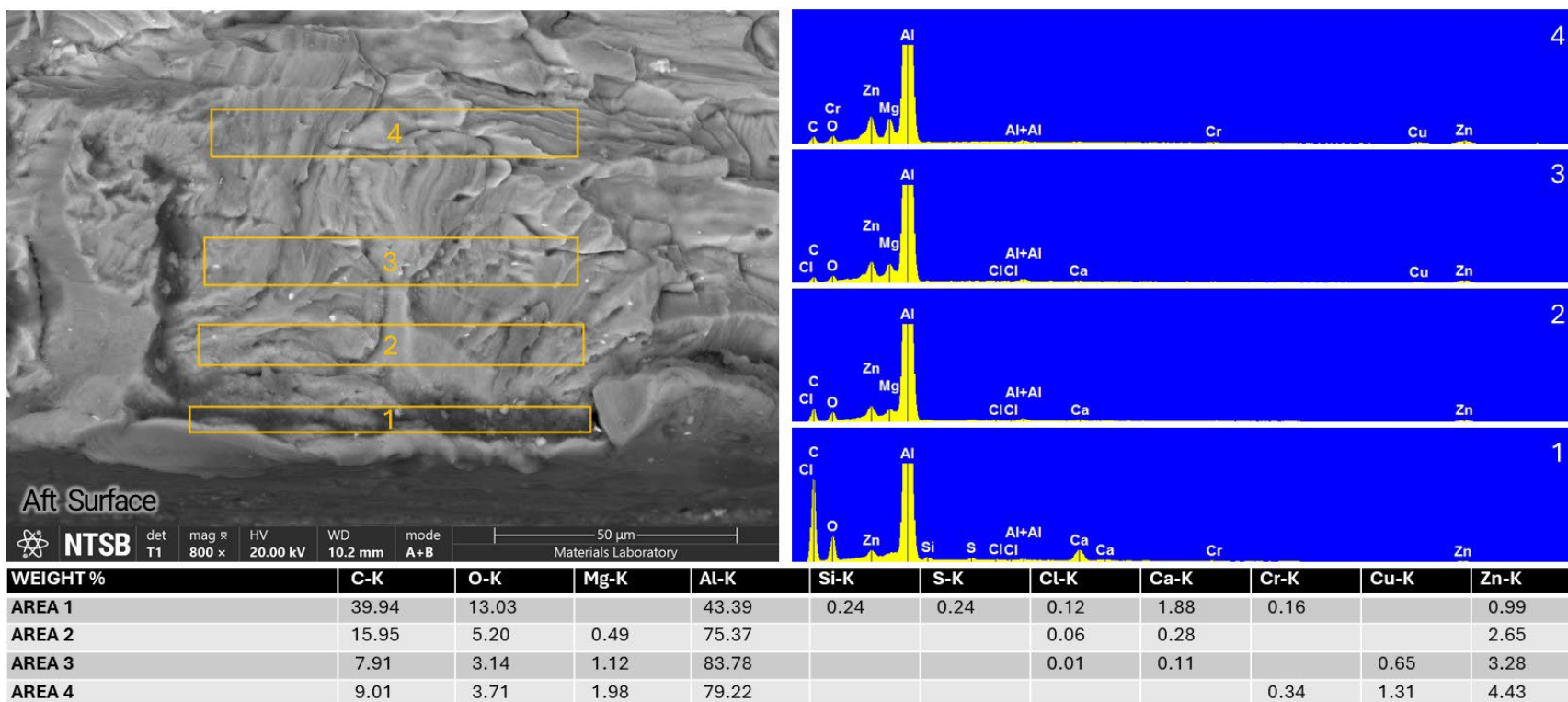


Figure 15. Energy dispersive spectroscopy (EDS) results at several regions near a fracture initiation site at the aft surface. The presence of chlorine (Cl) was detected near the surface.

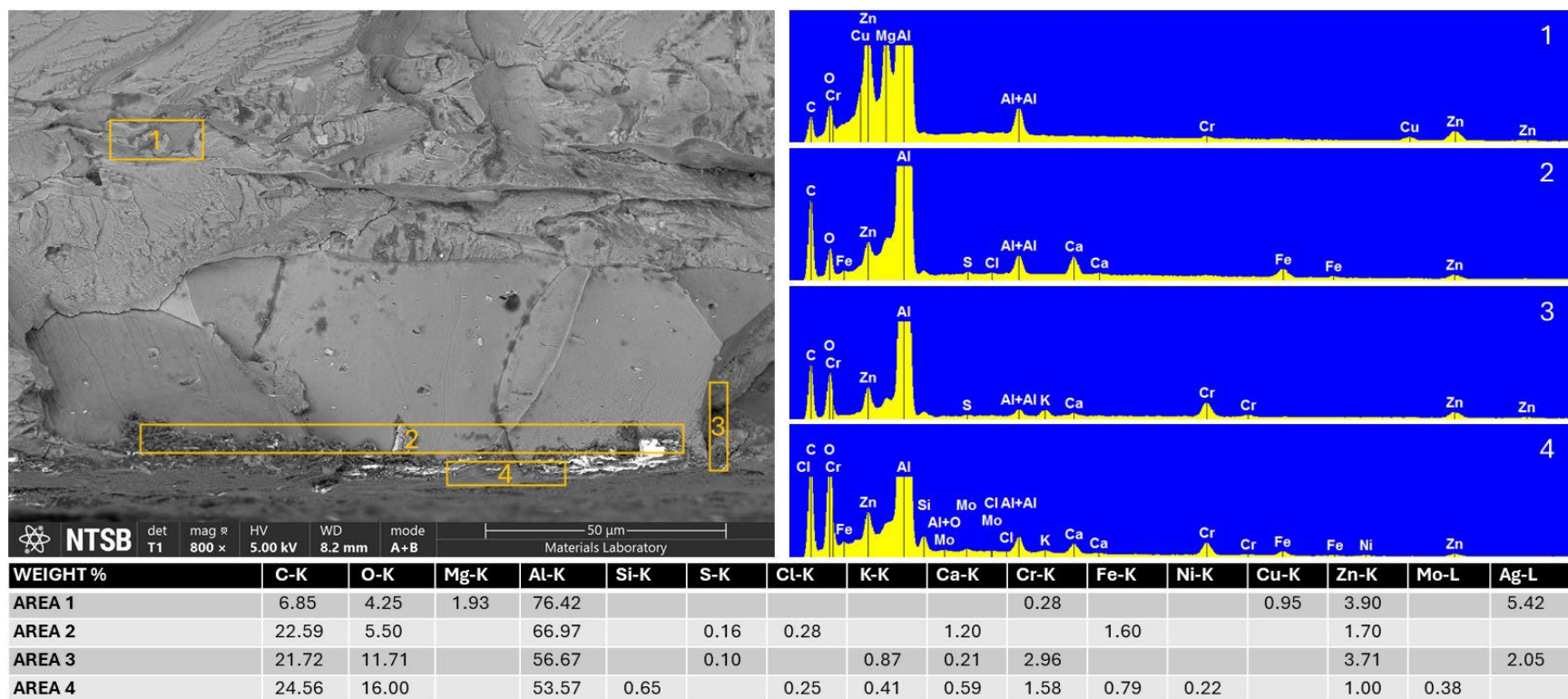


Figure 16. Energy dispersive spectroscopy (EDS) results at several regions near an intergranular fracture initiation site at the aft surface. The presence of chlorine (Cl) was detected near the surface.

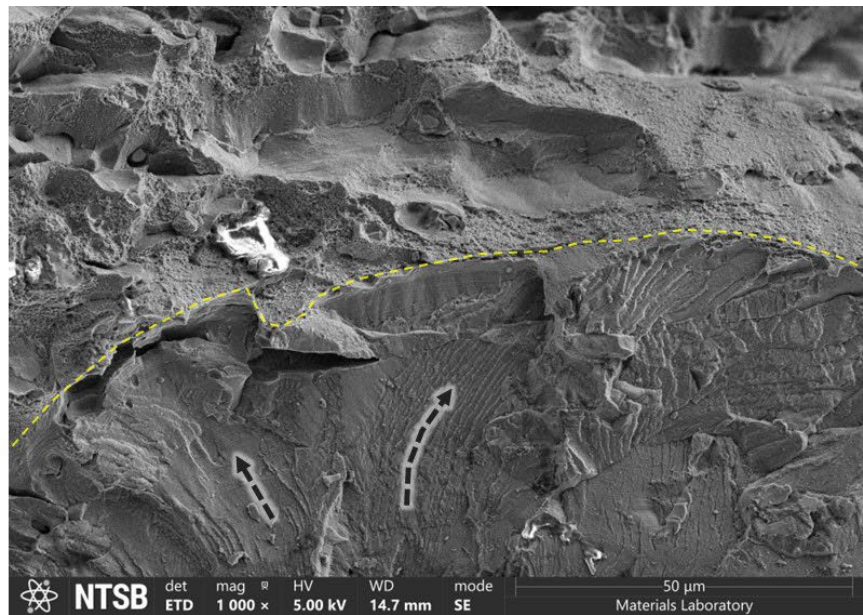
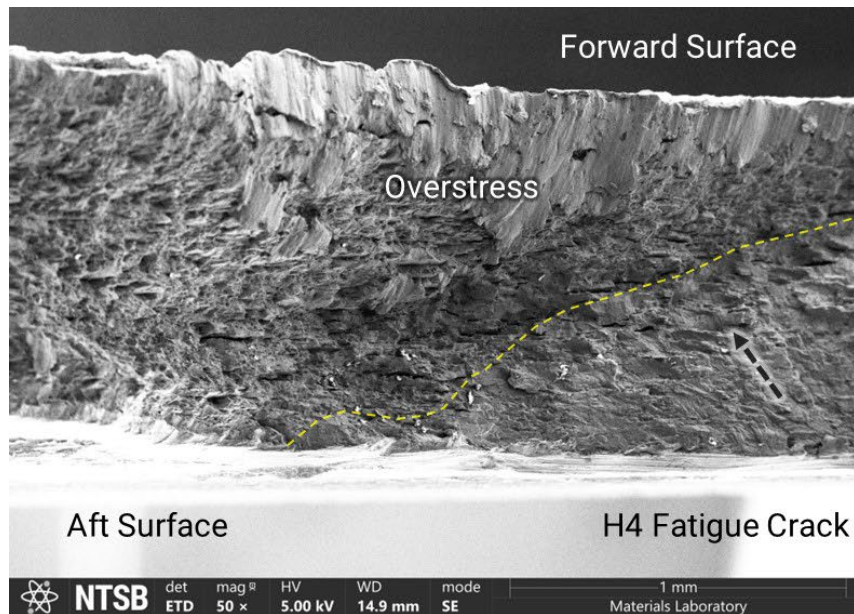


Figure 17. SEM images at different magnification levels of the upper end of the bulkhead web fracture surface near H4 showing the edge of the fatigue cracking (yellow dashed line) growing from the aft surface in the direction of the black arrows. The region above and to the left of the yellow dashed line was consistent with overstress fracture.

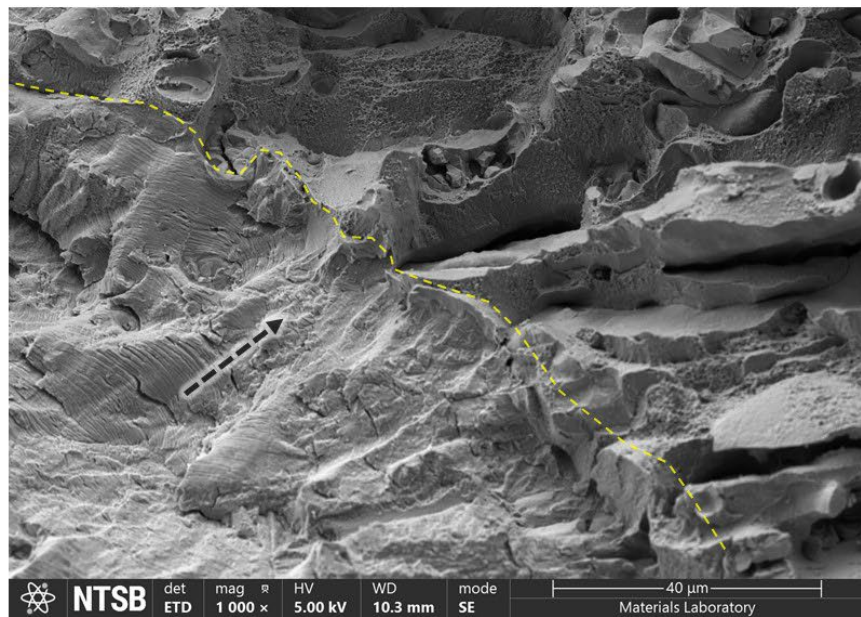
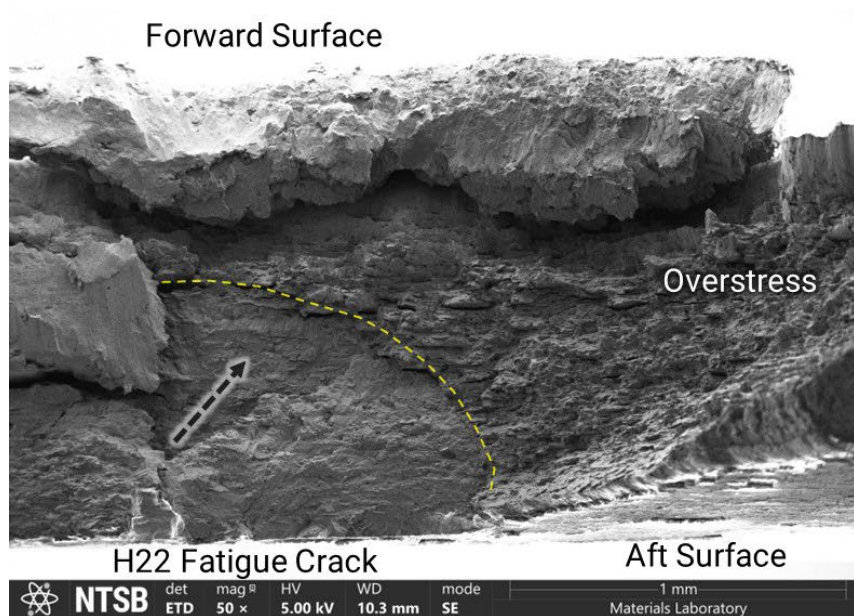


Figure 18. SEM images at different magnification levels of the lower end of the bulkhead web fracture surface near H22 showing the edge of the fatigue cracking (yellow dashed line) growing from the aft surface in the direction of the black arrows. The region above and to the right of the yellow dashed line was consistent with overstress fracture.

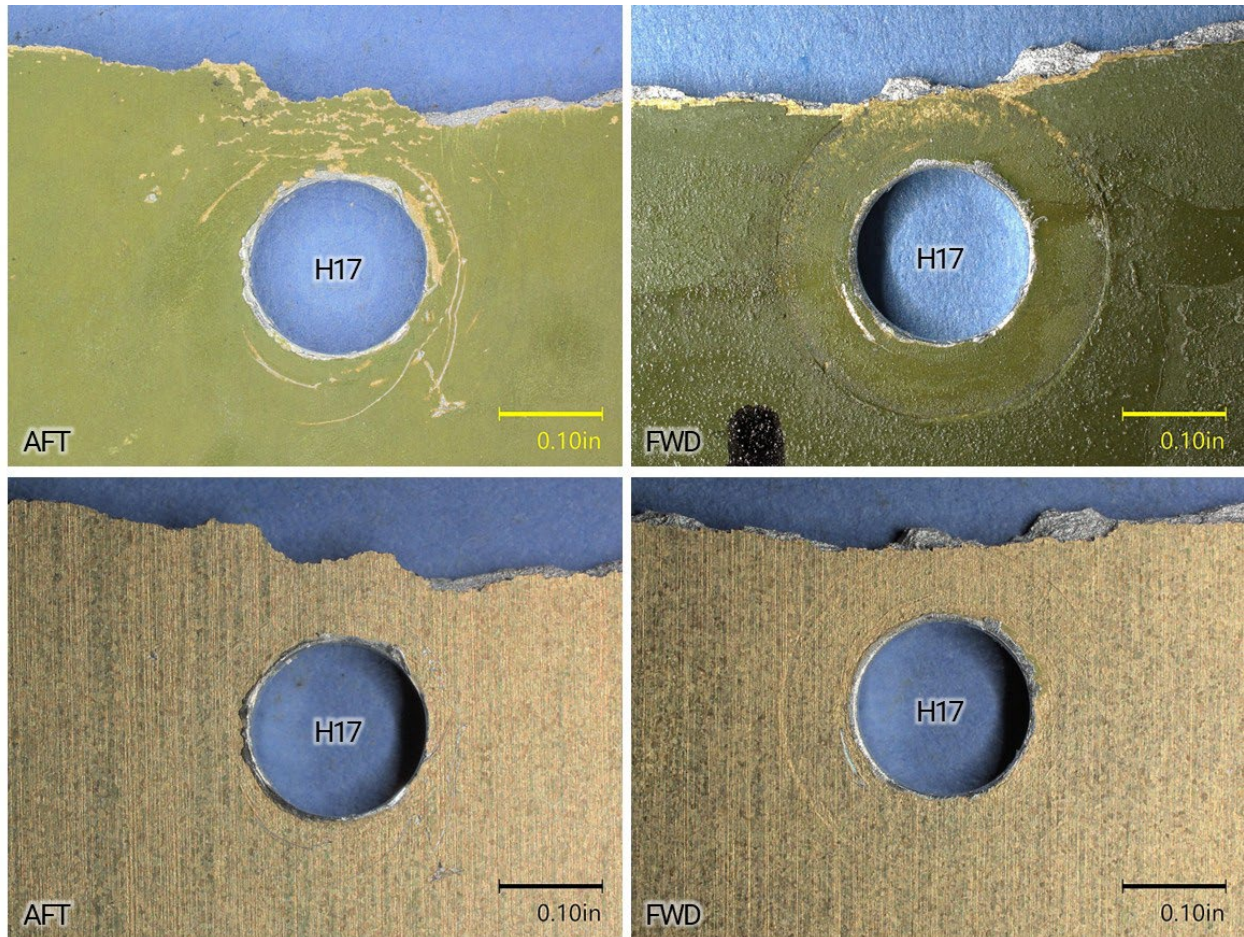


Figure 19. Digital microscope images of both surfaces of the bulkhead web at H17 before (above) and after (below) coating removal (chemical stripping).

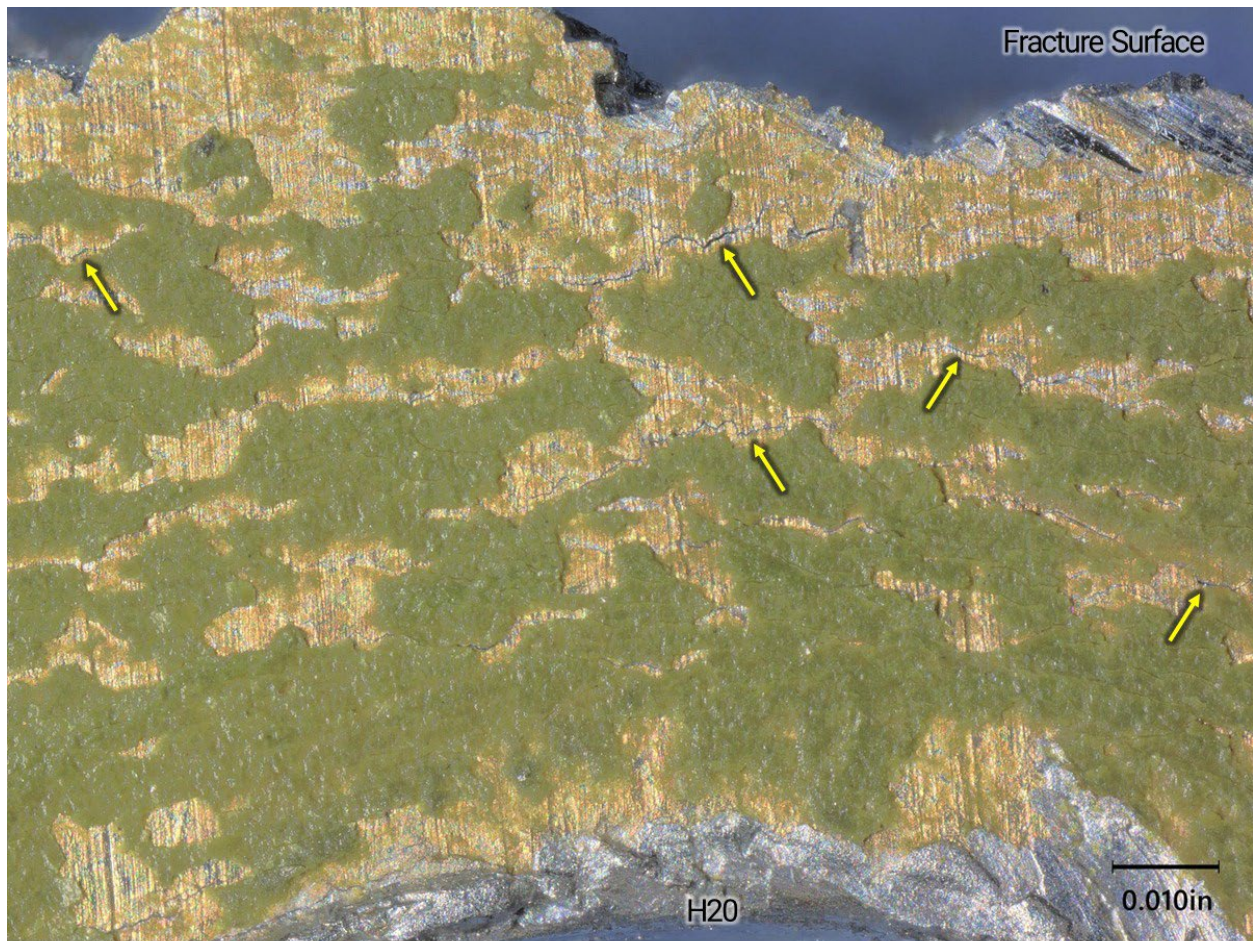


Figure 20. A representative view of the aft surface (prior to coating removal) between a fastener hole edge and the fracture surface. Small cracks oriented parallel to the primary fracture surface were observed in the vicinity of the fastener holes with typical examples indicated by yellow arrows.

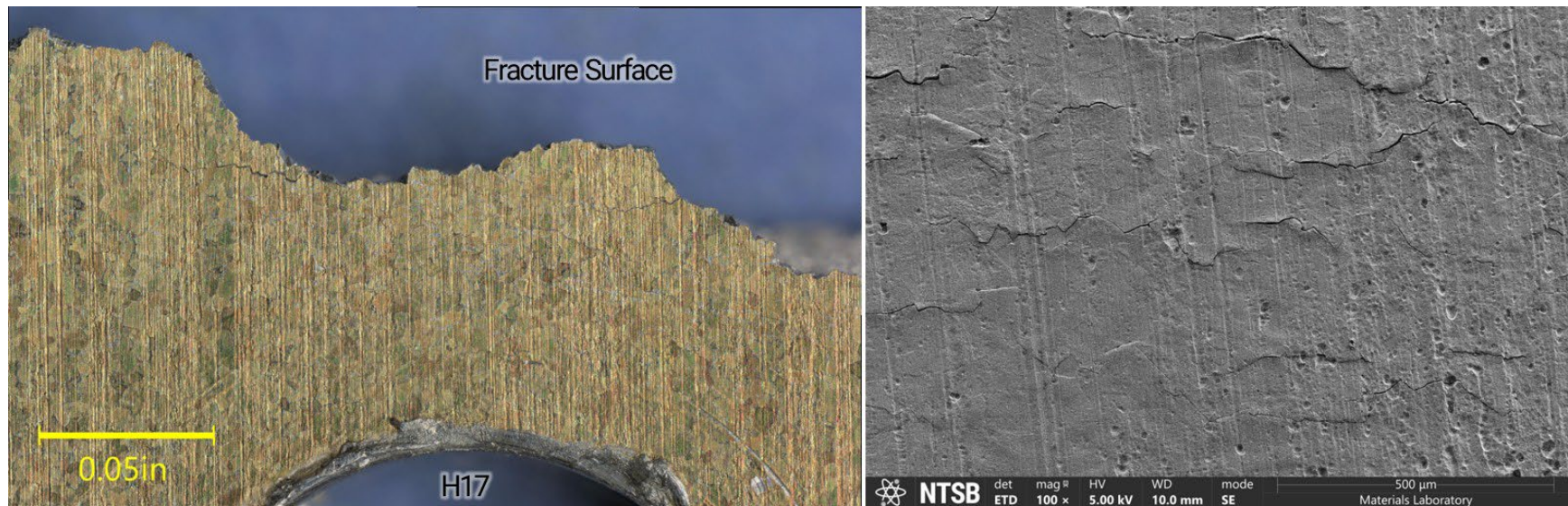


Figure 21. Representative views of the aft surface (after coating removal) between a fastener hole edge and the fracture surface. A digital/optical image is shown on the left and a higher magnification SEM image on the right. Small cracks oriented parallel to the primary fracture surface were observed in the vicinity of the fastener hole. Scratch-like features (oriented vertically in these images) running perpendicular to the fracture plane and some surface pits were also observed.

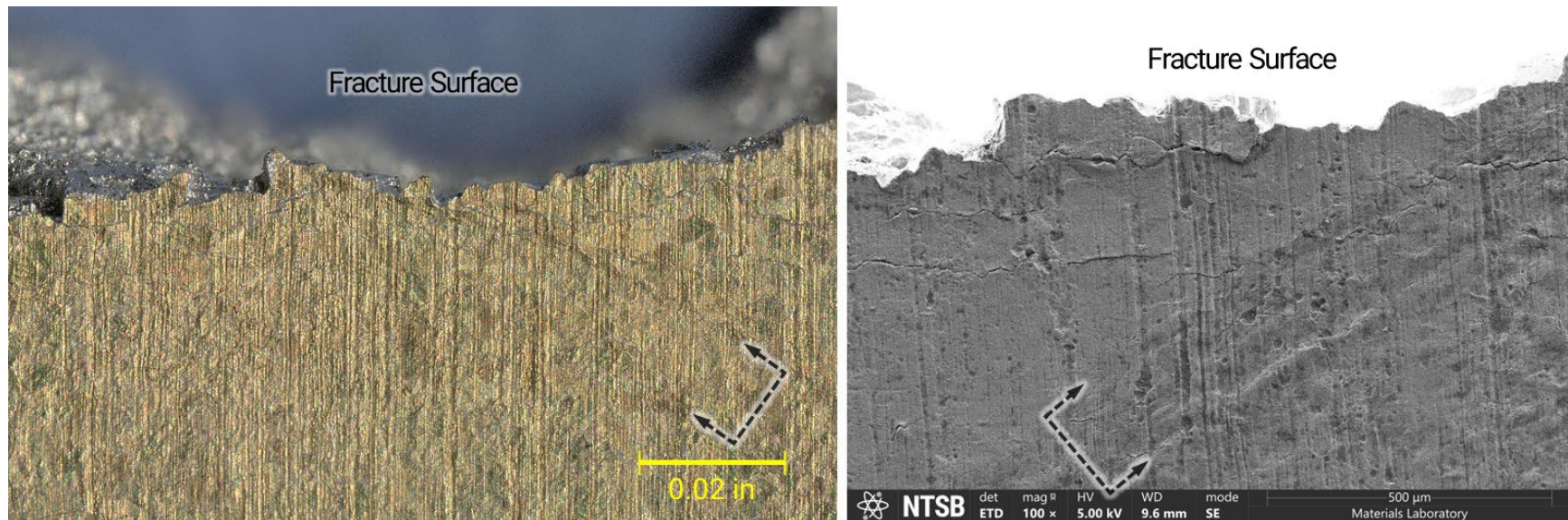


Figure 22. Representative views of the forward surface (after coating removal) between a fastener hole edge and the fracture surface. A digital/optical image is shown on the left and a higher magnification SEM image on the right. Small cracks oriented parallel to the primary fracture surface were observed in the vicinity of the fastener hole. Scratch-like features (oriented vertically in these images) running perpendicular to the fracture plane and some surface pits were also observed. The bracketed region indicates a circular witness mark consistent with the presence of a fastener head.

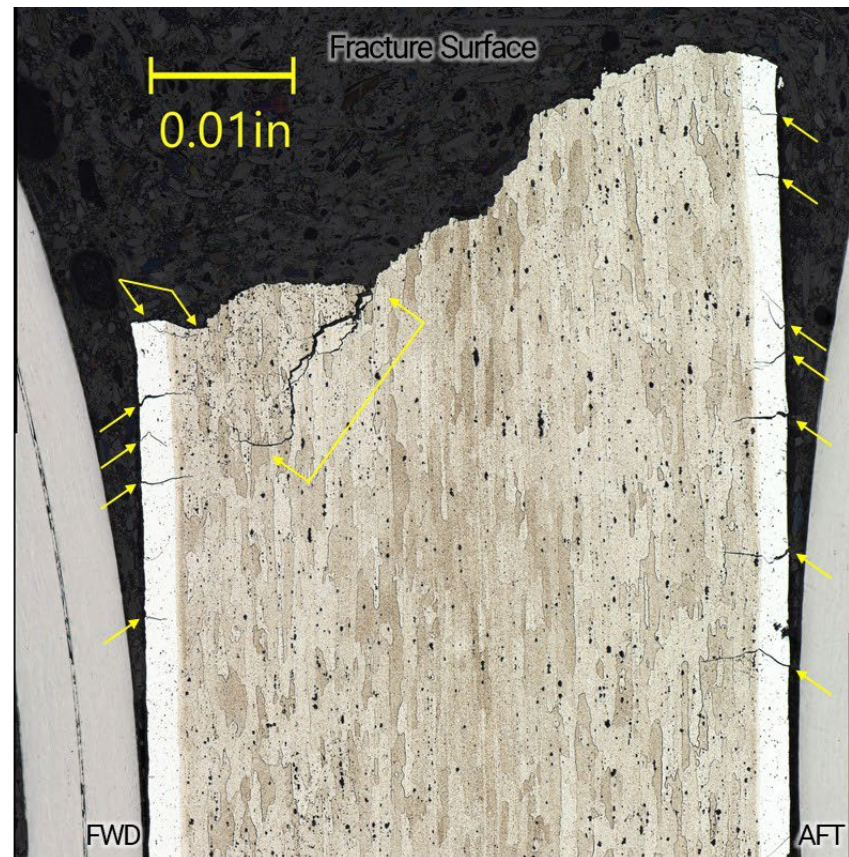
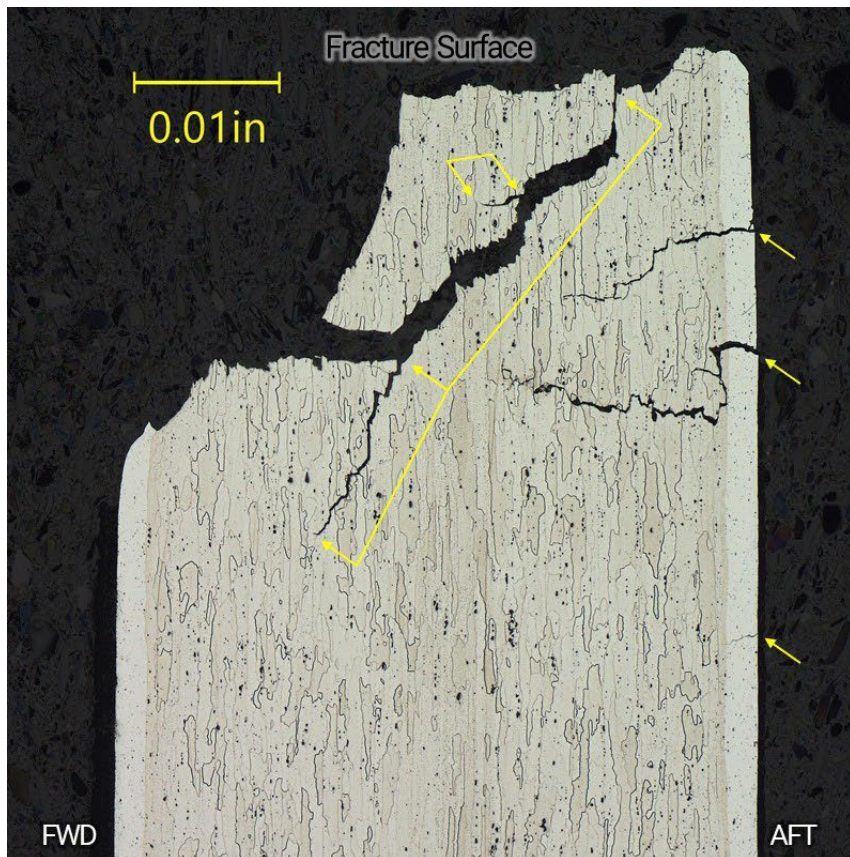


Figure 23. Metallurgical cross section views taken between H6 - H7 (left) and through H15 (right). Surface cracks were observed extending through the lighter etched clad layer and into the base metal as indicated by arrows. Bracketed regions indicate branching cracks. Bright Field Images, Keller's Etch.

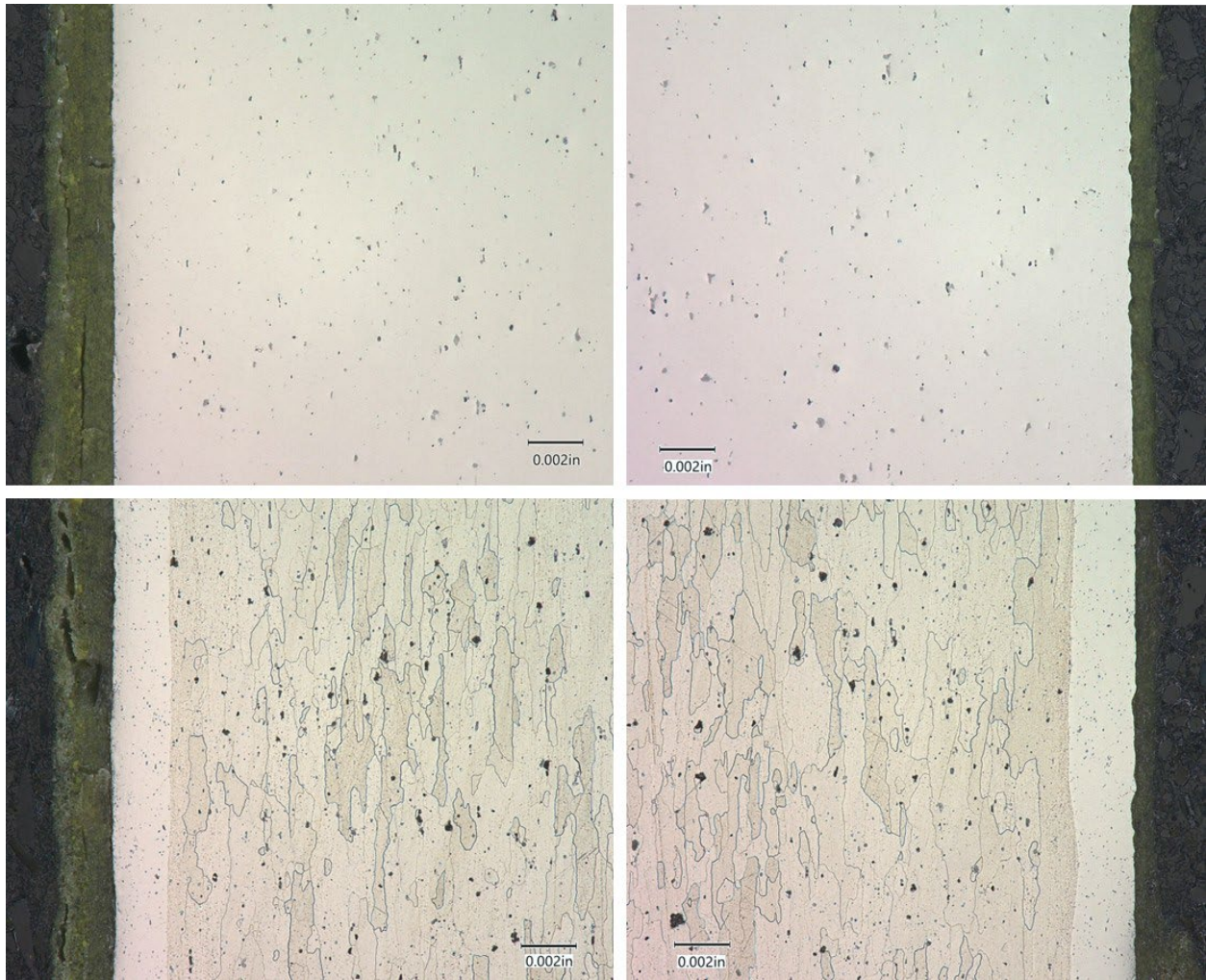


Figure 24. Metallurgical cross section views near the forward surface (left) and aft surface (right) taken from bulkhead web material away from the fracture surface. The as-polished condition is shown above, and the etched condition is shown below. Bright Field Images, Keller's Etch.