

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



September 23, 2020

MATERIALS LABORATORY FACTUAL REPORT

Report No. 20-036

1. ACCIDENT INFORMATION

Place : Santa Barbara, California
Date : September 25, 2019
Vehicle : Lockheed C-130A, N119TG
NTSB No. : WPR19LA242
Investigator : Tealeye Cornejo, AS-WPR

2. COMPONENTS EXAMINED

V-band clamp assembly with bleed air duct remnants
Right wing root remnant of bleed air duct
Temperature sensor

3. DETAILS OF THE EXAMINATION

On August 25, 2019, at 2224 Pacific daylight time, a restricted-category Lockheed C-130A, operated by International Air Response (IAR), experienced multiple system failures shortly after takeoff from Santa Maria Public Airport, Santa Maria, CA. The pilot made an emergency landing at the Santa Barbara Municipal Airport, Santa Barbara, CA. The 2 crew and 5 passengers were not injured, but the airplane sustained substantial damage, including fire damage from a post-crash fire.

According to the operator, the airplane had been stationed in Malaysia and had made refueling stops in Hilo, HI and Santa Maria, CA. During the final flight, the crew heard a loud popping noise, and the torque gages signaled fluctuating readings along with fire-warning lights. A crew member in the cargo compartment announced misting hydraulic fluid mixed with smoke. The flight crew lowered and locked the landing gear and then turned off the number 2 and 4 hydraulic pumps. During landing, the right wing began to drop and the airplane drifted to the right, eventually departing the runway. Two Federal Aviation Administration (FAA) inspectors inspected the airplane and identified the number 3 bleed air duct had failed, which when compromised would have blown hot air onto the surrounding electrical wires and hydraulic lines.

The failed parts were sent to the National Transportation Safety Board (NTSB) metallurgical laboratory in Washington, DC. Three components were received by the NTSB Materials Laboratory, including a remnant of a right wing root bleed air duct, V-band

clamp including the flange remnants of said bleed air duct, and a temperature sensor removed from the right wing root area adjacent to the bleed air duct.

Figure 1 shows the temperature sensor from the bleed air duct assembly, as received. This sensor exhibited some darker carbon deposits, consistent with its proximity to the high temperature bleed air gasses. There were no indications of deformation, cracking, or wear on the outside of the sensor. No rattling or oscillating sounds were made when moving or shaking the part.

Figure 2 and 3 show the bleed air duct remnant, as received. The duct remnant had separated from the flange remnant in the V-band clamp, and had been folded over itself, as shown in the figures. The remnant exhibited dark and brownish-orange discolorations on the outer surface, with dark-colored soot present on the inner surface—this soot was easily removed with contact by touch (Figure 3).

The duct was normally cylindrical, but had fractured both circumferentially and longitudinally, as illustrated in Figure 2. In order to examine the duct remnant, it was bent and flattened out, then cleaned using acetone and ethanol. Figure 4 shows the flattened duct remnant from the external surface. The upper circumferential and longitudinal fractures were generally jagged and randomly oriented. The lower circumferential fracture was relatively flat in orientation, with the exception of three downward protruding areas. These areas were consistent with having mated with mirrored areas in the duct flange remnant, shown as received in the V-band clamp in Figure 5.

Most of the flange remnant exhibited protruding portions that were the circumferential fracture surface of the duct. As typified in Figure 6 and Figure 7, these areas exhibited localized necking or thinning deformation adjacent to the fracture surface. There were also indications of localized surface tears, parallel to the fracture surface. The fracture surface, shown in Figure 7, was oriented at approximately 45° towards the duct interior, with a generally rough but reflective surface texture.

The portions of the flange remnant fracture surface that corresponded to the downward protrusions in Figure 4 did not manifest as upward protrusions themselves. Rather, these regions were recessed in location, and appeared flatter, more faceted, and darker in appearance. Figure 8 shows a transition of the flange remnant between a flatter portion of the fracture surface, and the fracture surface on the thin, reflective protrusions.

Figure 9 shows the interior surface of the flattened and cleaned duct remnant, with the three downward protruding portions of the circumferential fracture surface highlighted. The (circumferential) lengths of these areas were 1.149, 0.523, and 0.244 inches, from longest to shortest. The longest one is highlighted in Figure 10. This part of the circumferential fracture was generally flat and rough, exhibiting a darker brown color adjacent to the fracture surface, with vertical perpendicular cracks. This fracture region corresponded to the mating flat fracture area of the flange remnant, shown in Figure 11. Figure 12 and Figure 13 show the mating faces of the circumferential crack between the flattened duct remnant and sectioned flange remnant at the shorter protrusions.

The flange assembly remnant consisted of a remnant of the duct tube (inner part) that was joined to the exterior-facing flange piece. The pieces were joined by a circumferential weld approximately 0.25 inch thick. This was visible as the dark brown ring on the flange fragment in Figures 12 and 13. The fracture surface was located above the circumferential weld in the figures.

Figures 14 and 15 show closer views of the flat fracture regions from the flange remnant. While the thinned elongated fracture areas of the duct were located up to 0.5 inches above the weld boundary, these flatter fractures were located just above the circumferential weld, which joined the inner duct to the outer flange cap. Figure 16 shows the duct remnant region that mated with the flat fracture in Figure 14. This area also exhibited several vertical cracks, oriented perpendicular to the fracture surface. These cracks were consistent with having initiated on the fracture surface and progressing upward in the figure.

The flange remnant was sectioned in several places to allow for optical and electron microscopy examination of the fracture surface. Figure 17 shows a typical view of the largest flat fracture region on the flange remnant as imaged in a scanning electron microscope (SEM). As labeled in the figure, the fracture surface of the duct is located the bottom of the figure and is recessed in this view, while the flange portion on the upper area of the figure protrudes upward towards the reader. The fracture was oriented perpendicular to the duct and flange directions.

Figure 18 shows a typical area of the flat fracture surface. The fracture surface exhibited multiple features, including cleavage facets, porosity, and secondary cracking. In other areas, the features were predominantly dimpled rupture, as illustrated in Figure 19. The dimpled rupture on the flat fracture was primarily oriented in a parallel lamellar manner, consistent with fracture along the elongated grain direction of the rolled duct sheet. On the inside-facing surface of the duct remnant weld region below the fracture surface, the weld exterior exhibited a lenticular surface, as shown in Figure 20. These features were consistent with rumpling of the exterior metal oxide scale that formed during and after the welding process. The surface attains this surface morphology when the weld metal solidifies and cools, causing shrinkage. As these features were located on the exterior weld surface, they were inconsistent with typical progressive cracking features such as striations.

Figure 21 highlights some of the secondary cracking and cleavage features observed on the fracture surface. Secondary cracking means fractures or cracks oriented in directions perpendicular to the fracture surface. These features were consistent with branched cracking in multiple directions. This figure also showed porosity, with tearing near the pores. These features tended to be located toward the exterior surface of the duct remnant (facing downward in Figure 21) and adjacent to the weld location with the flange remnant. The cleavage features were widespread on the fracture surface, as exemplified in Figure 22. Cleavage is a preferential fracture mode along low-energy planes of the metal alloy, consistent with reduced ductility. Since dimpled rupture was observed sporadically

on the fracture surface, the cleavage features indicated localized areas of reduced ductility.

Figure 23 again shows an area of secondary cracking and cleavage fracture, along with more faceted features (center of the figure). Figure 24 highlights the faceted feature observed in the middle of Figure 23. This faceted feature was consistent with an isolated crystalline grain in this area, consistent with intergranular cracking. The sides of the grain facet show intergranular separation with the adjacent material, and some smearing on the right side—this smearing was consistent with movement of this grain along the adjacent material. Figure 25 shows another area of intergranular fracture. In this case, the faceted grains had partially separated from the surrounding material, leaving gaps along the intergranular fracture. Like in Figure 24, part of the separated grain had rubbed against the adjacent material.

Towards the edges of the duct remnant flat fracture surface, localized thinning or necking became more prominent, as illustrated in Figure 26. At these ends of the flat fracture surface, rather than a perpendicular faceted surface, the fracture tapered. Along the right side of the fracture in Figure 26, the duct remnant had narrowed to an edge prior to fracture. Closer examination of these areas revealed equiaxed dimpled rupture, consistent with tensile overstress fracture in these areas.

These features were consistent with pre-existing cracking prior to final circumferential fracture of the duct. This cracking was located adjacent to the welded joint between the flange and the duct. The cracking was manifest as mixed intergranular fracture with cleavage fracture, consistent with lowered ductility. The remainder of the duct remnant fracture was consistent with having plastically deformed and fractured from tensile overstress after the flat fracture regions had separated.

The flat fracture regions were inspected in the SEM using energy dispersive x-ray spectroscopy (EDS) to determine local chemical compositions. The spectra primarily showed peaks consistent with an austenitic stainless steel—Fe, Ni, and Cr. The surface also exhibited high levels of oxygen, consistent with a surface oxide. There were also detectable amounts of S, Na, and Cl present on the fracture surface.

Cross sections were taken through the large flat fracture surface and an area with only overstress fracture. These cross sections were mounted, polished, and etched. Figure 28 shows a cross section of an area of overstress fracture. The left side shows the flange piece and the right side shows the fractured duct remnant, with the overstress fracture facing upward in the top portion of the figure. This area in the figure was above the welded region, and a gap was present between the flange piece and duct remnant. Figure 29 shows a cross-section of the overstress fracture of the duct away from the flange weld, showing grain elongation and localized necking consistent with plastic deformation near the fracture surface.

Figure 30 shows a cross section of the weld between the flange piece and duct remnant, located below Figure 29. The center exhibited columnar grains consistent with

solidification from the outer surfaces inward, typical of localized resolidification after the weld was performed. Some small porosity was present along the centerline, but no cracks were observed in this area.

Figure 31 shows the cross section through the flat fracture region. In this figure, the duct remnant fracture is located in the lower left of the figure, and most of the figure shows the cross section of the flange piece. The flange piece exhibited a horizontal crack on the lower side of the figure, and vertical internal cracking in the upper portion of the figure.

Figure 32 shows a closer view of the flat fracture surface, and the vertical crack in the flange piece. The interior (left-facing) surface of the flange and the duct exhibited pitting, with nonmetallic (gray-colored) compounds. Figure 33 shows a closer view of the horizontal crack. This crack had initiated at a series of surface pits, shown on the left in the figure. There were several smaller parallel cracks that had progressed from the left surface, also initiating at the surface pitting. The crack grew primarily left to right in the figure, but there were multiple vertically-oriented parallel cracks that had branched from the main crack. These branching vertical cracks were consistent with intergranular cracking along the elongated grain direction. The crack interior exhibited nonmetallic compounds along the entire crack interior.

Figure 34 shows a closer view of the flat fracture cross section. In this location, multiple cracks were present, consistent with having developed on a surface and growing inward. There were vertical cracks growing downward in the figure, and horizontal cracks growing from the interior surface (left-facing) in the figure. In all cases, these cracks also contained non-metallic compounds, consistent with corrosion compounds. All these features illustrated were located just about the weld region, which are located at the very bottom of the figure. There were no indications of cracking or extensive porosity in the weld near the flat fracture cross sectioned.

The vertical parallel interior cracking in the top part of the flange piece is highlighted in Figure 35 and 36. These cracks manifest as a layered series of cracks with non-metallic compounds, all parallel to the flange piece interior surface. As shown in Figure 36, many of the interior cracks exhibited needle-shaped morphologies, along with the gray nonmetallic compounds. Both the inward facing flange and duct remnant surfaces exhibited corrosion pitting containing nonmetallic compounds consistent with corrosion products (see Figure 37). In the cross section taken, these pits were located above and below the duct remnant fracture surface and horizontal cracks.

This cross section was examined using a SEM, as illustrated in Figure 38 and 39. The nonmetallic compounds show up as darker gray against the lighter-colored metal alloy in the figures due to the backscattered detector used.¹ EDS examination of the compounds

¹ Backscattered electrons – SEM micrographs produced using backscattered electrons display contrast that is associated with the atomic numbers of the elements in the micrograph. Materials containing elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

found them to be primarily consistent with iron- and chromium-based oxides, consistent with corrosion compounds typical of a stainless steel. The exterior compounds exhibited minor amounts of Na, Cl, Mg, and Si. The interior compounds also exhibited minor amounts of S and Cl.

The chemical composition of the flange and the duct were examined using x-ray fluorescence (XRF) and EDS. The composition was consistent with 321 austenitic stainless steel.²

The sum of these microstructural fracture features, metallographic branch cracking with pits, and interior compounds with sulfur and chlorine were consistent with an environmentally assisted cracking mechanism, specifically stress corrosion cracking (SCC).

Erik M Mueller
Materials Research Engineer

² Type 321 stainless steel is a modified version of the standard 304 austenitic stainless steel alloy with Ti additions to reduce susceptibility to sensitization embrittlement.



Figure 1 – The temperature sensor, as received.

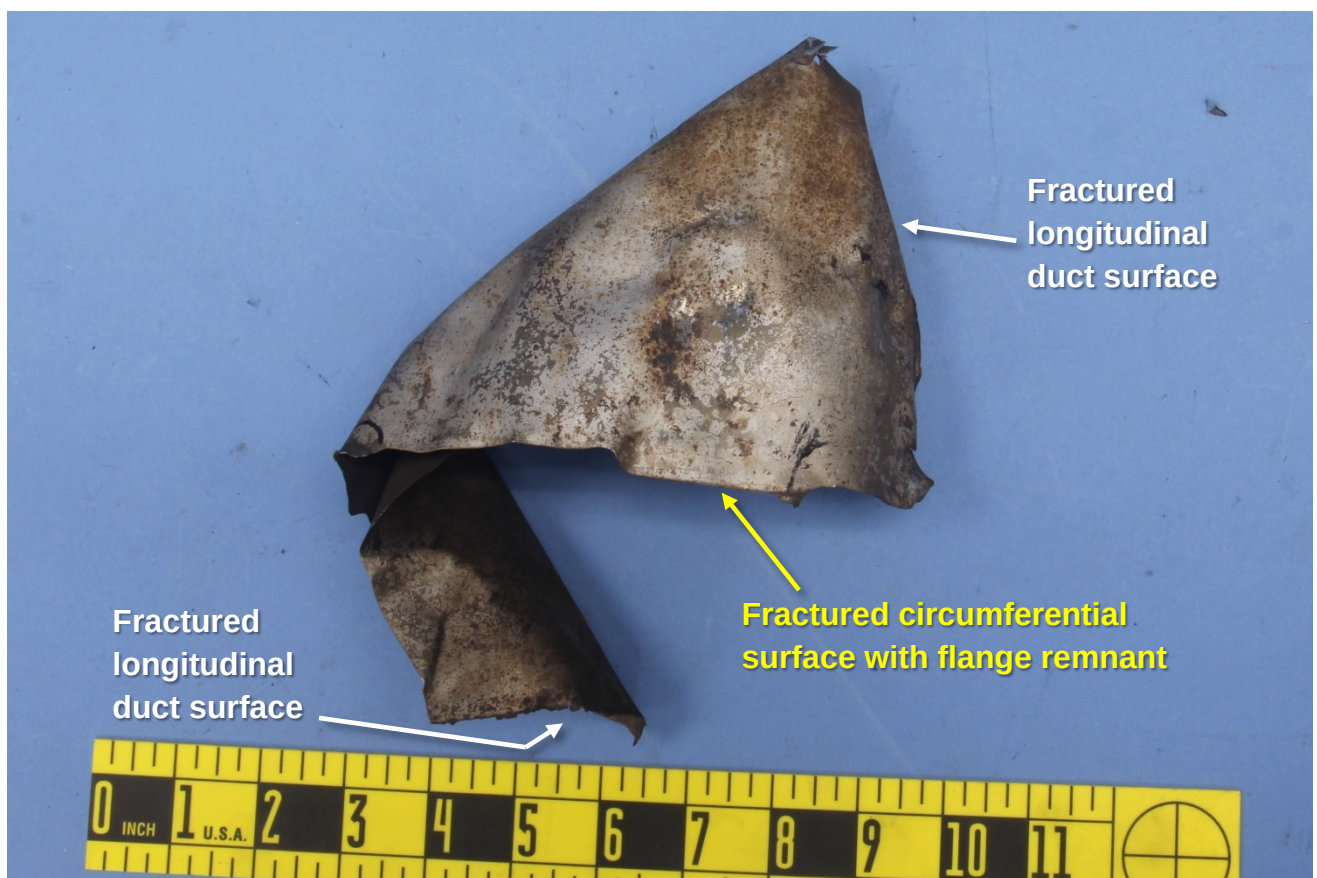


Figure 2 – View of the outer surface of the bleed air duct remnant, as received. The remnant is oriented such that the mating flange remnant would mate on the bottom, with the mating longitudinal fractures on the right and bottom.



Figure 3 – View of the internal surfaces of the bleed air duct remnant.

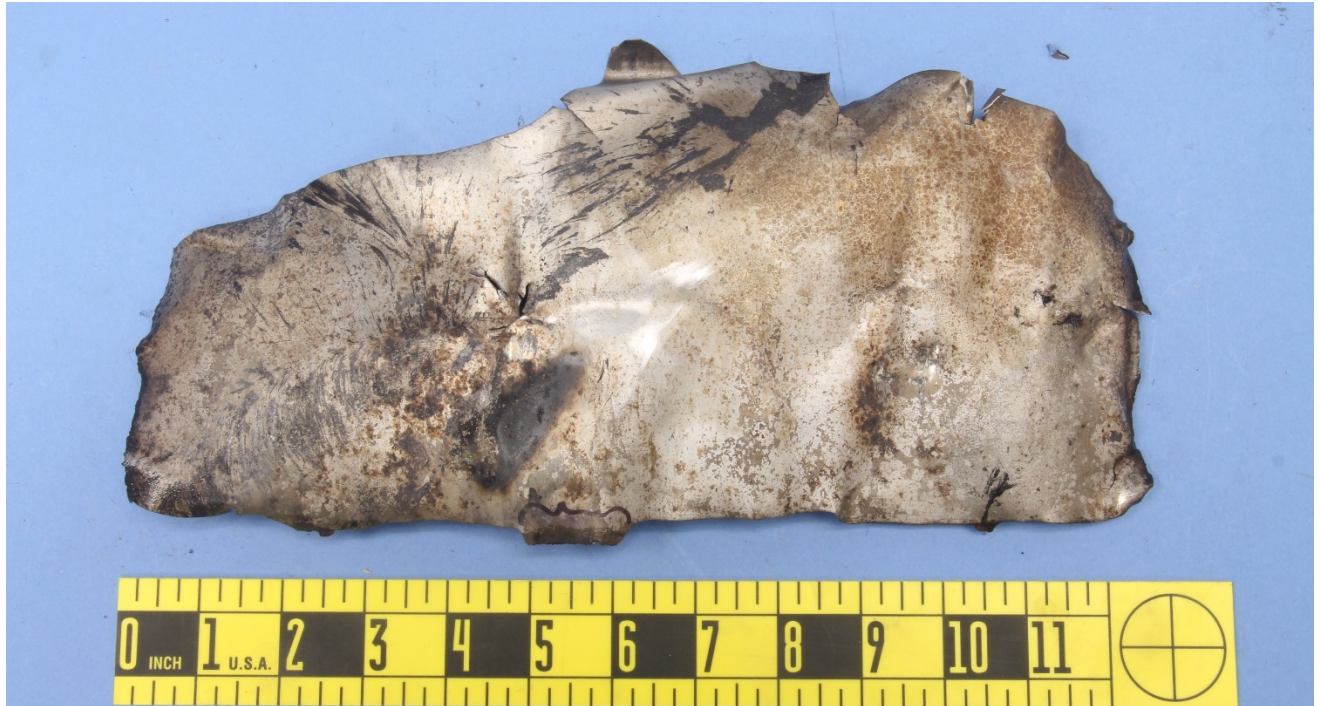


Figure 4 – View of the bleed air duct remnant, after flattening. The fracture surface that mates with the flange remnant on the bottom, with the mating longitudinal fractures on the sides.

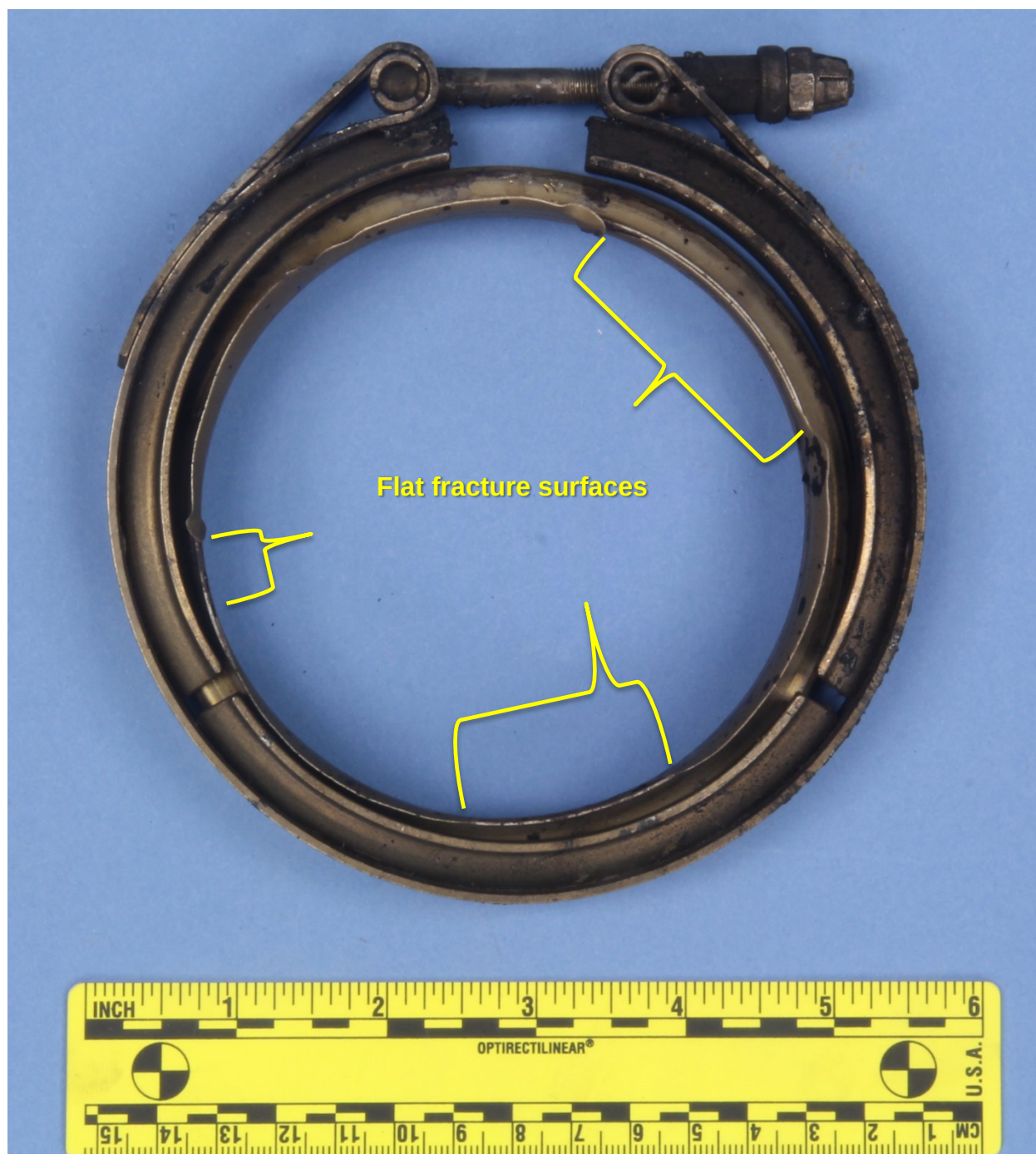


Figure 5 – View of the bleed air duct flange remnant, in the V-clamp, as received. The areas with flat fracture surfaces adjacent to the weld are annotated.

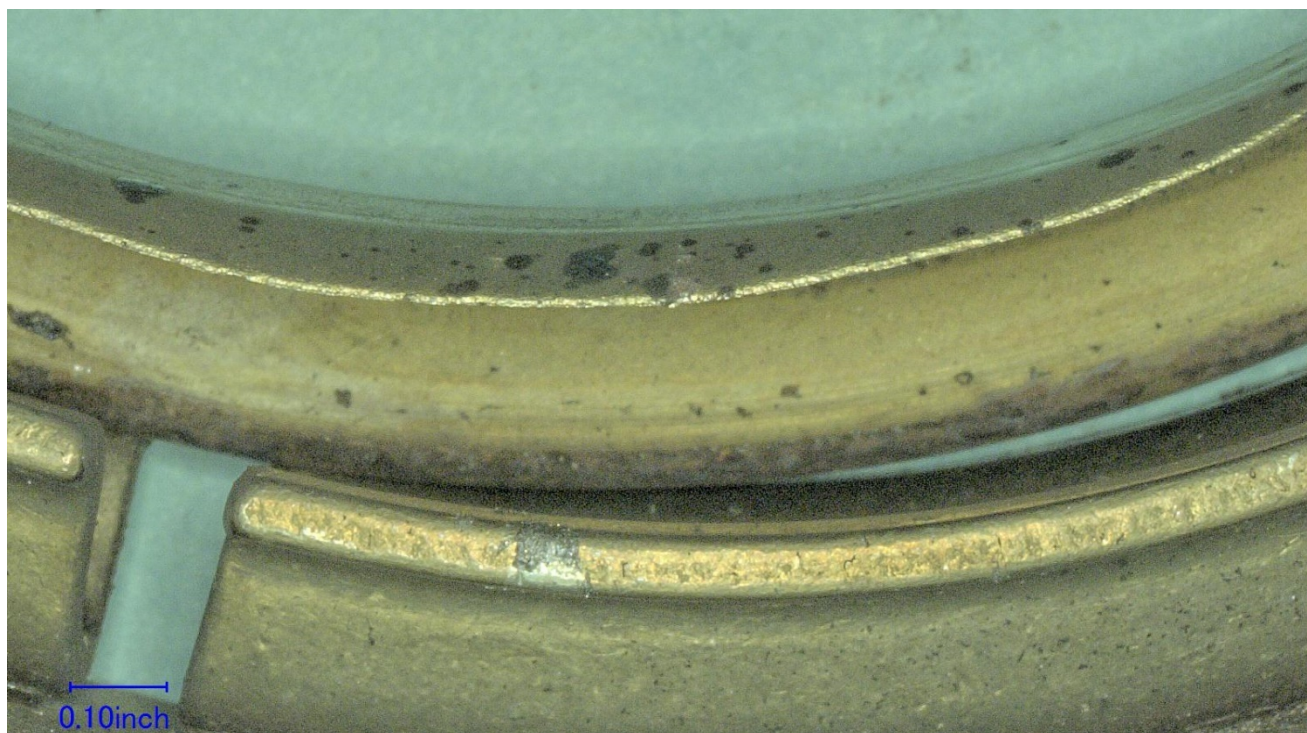


Figure 6 – View of a typical area of the flange remnant fracture surface that was protruding outward.

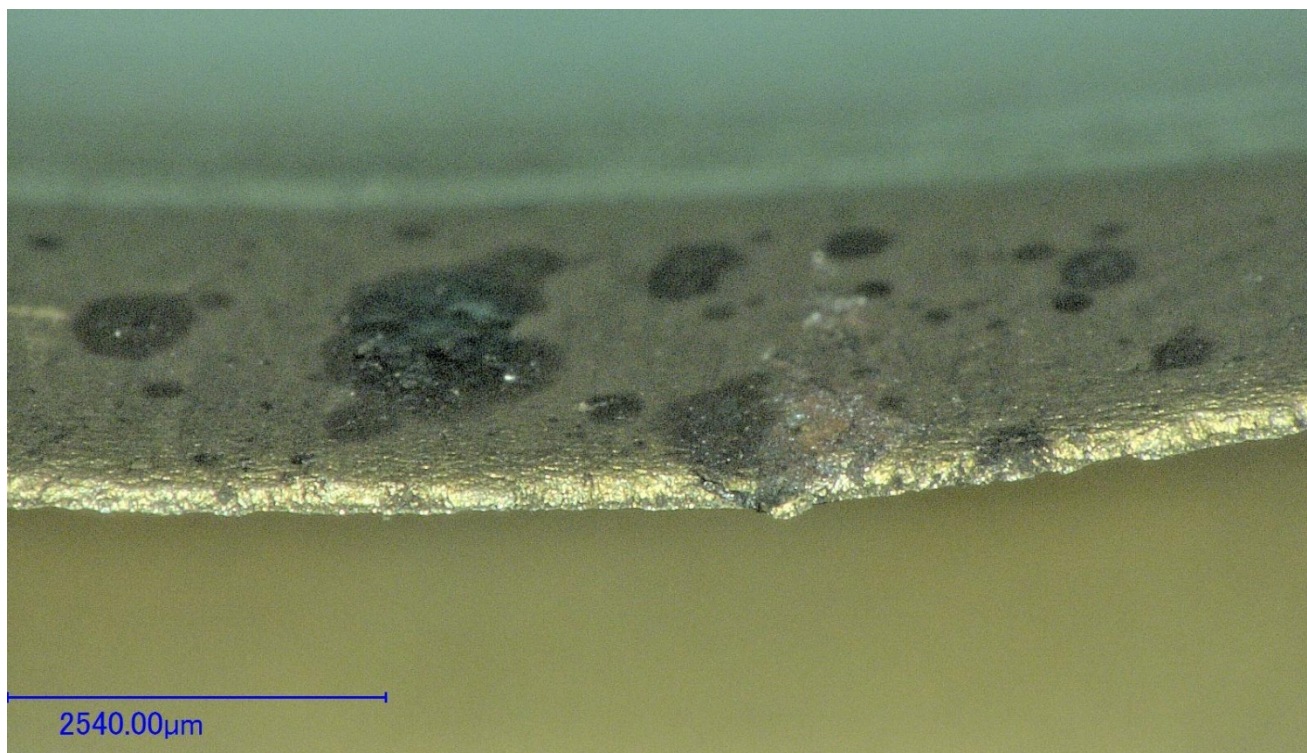


Figure 7 – Closer view of the fracture surface in Figure 6, showing localized thinning and plastic deformation.

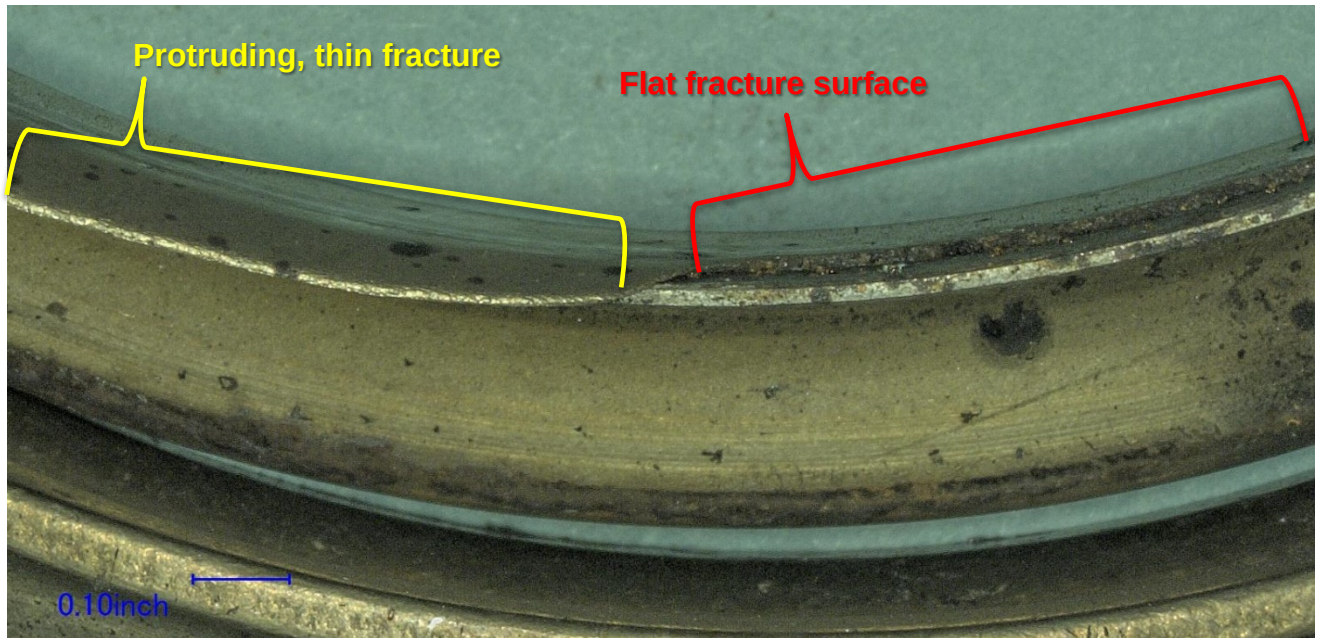


Figure 8 – Section of the flange fracture showing a difference between the protruding, thinned regions (left) and the flatter, rough near-weld fracture (right).



Figure 9 – View of the inside surface of the flattened duct remnant, after cleaning. The fracture surface mating the flange remnants faces downward in the figure.



Figure 10 – The largest area of a downward-protruding portion of the bottom fracture surface of the duct remnant, which mates with the largest flat fracture area on the flange (Figure 11).

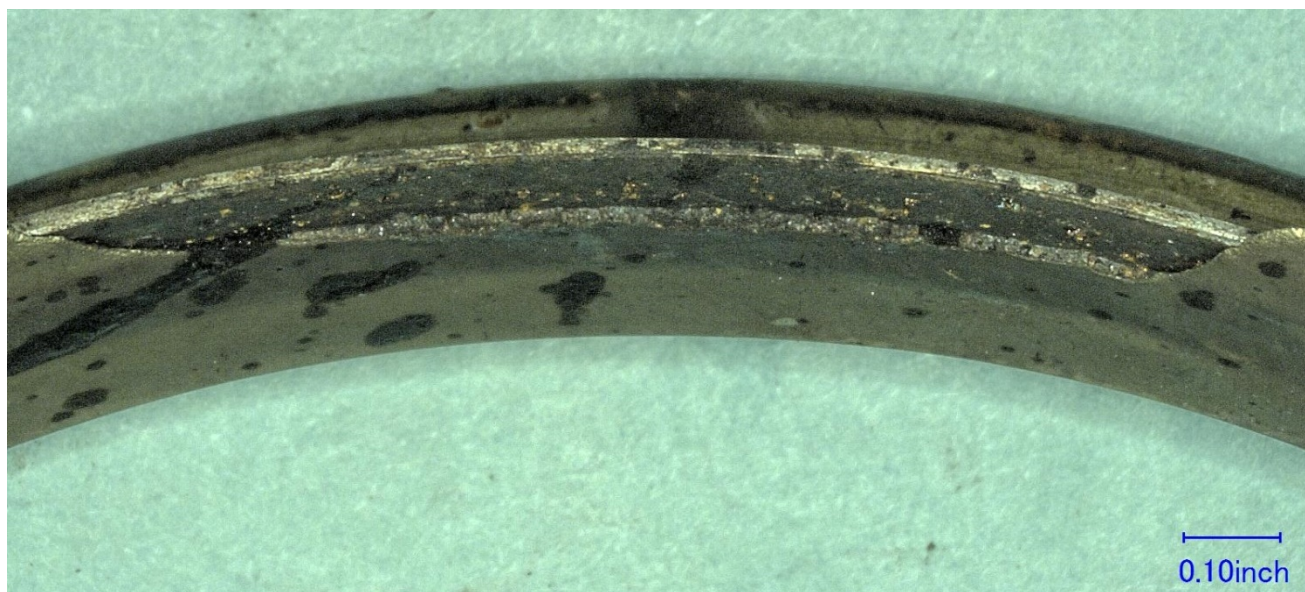


Figure 11 – The flat-fracture surface region near the weld on the duct flange remnant, which mates with the duct fracture section in Figure 10.

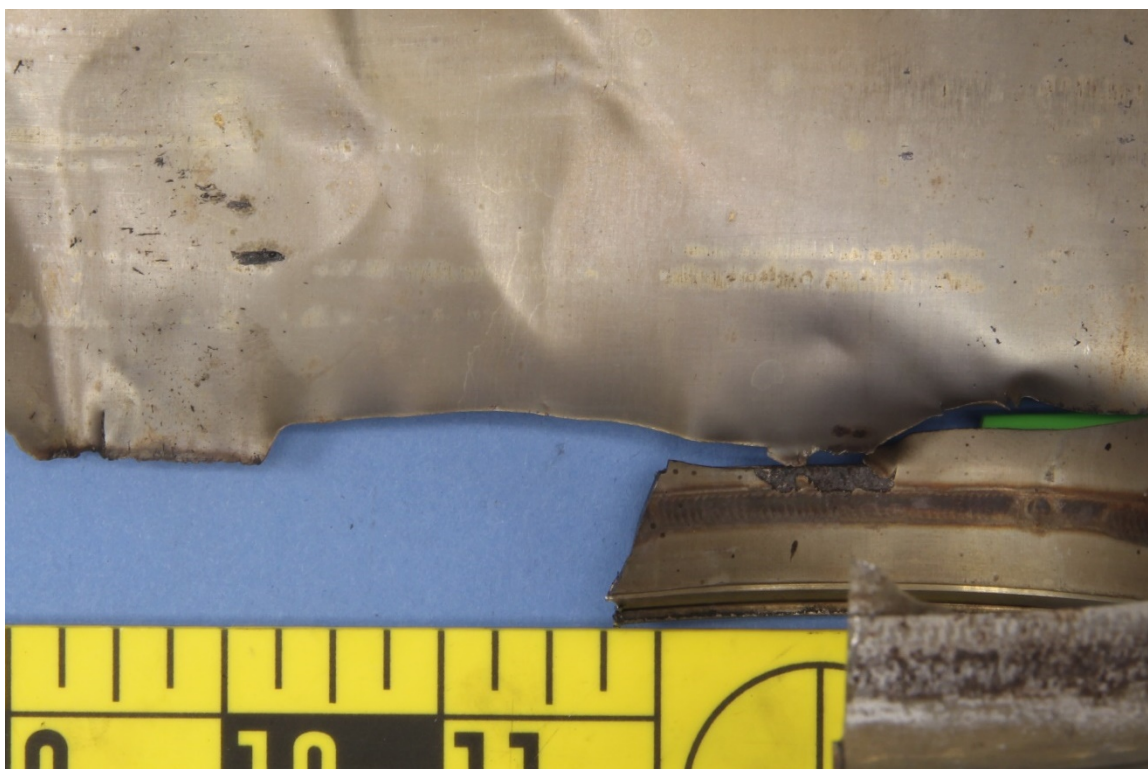


Figure 12 – View of one of the other mating flat-fracture regions of the duct remnants.



Figure 13 – View of one of the other mating flat-fracture regions of the duct remnants.

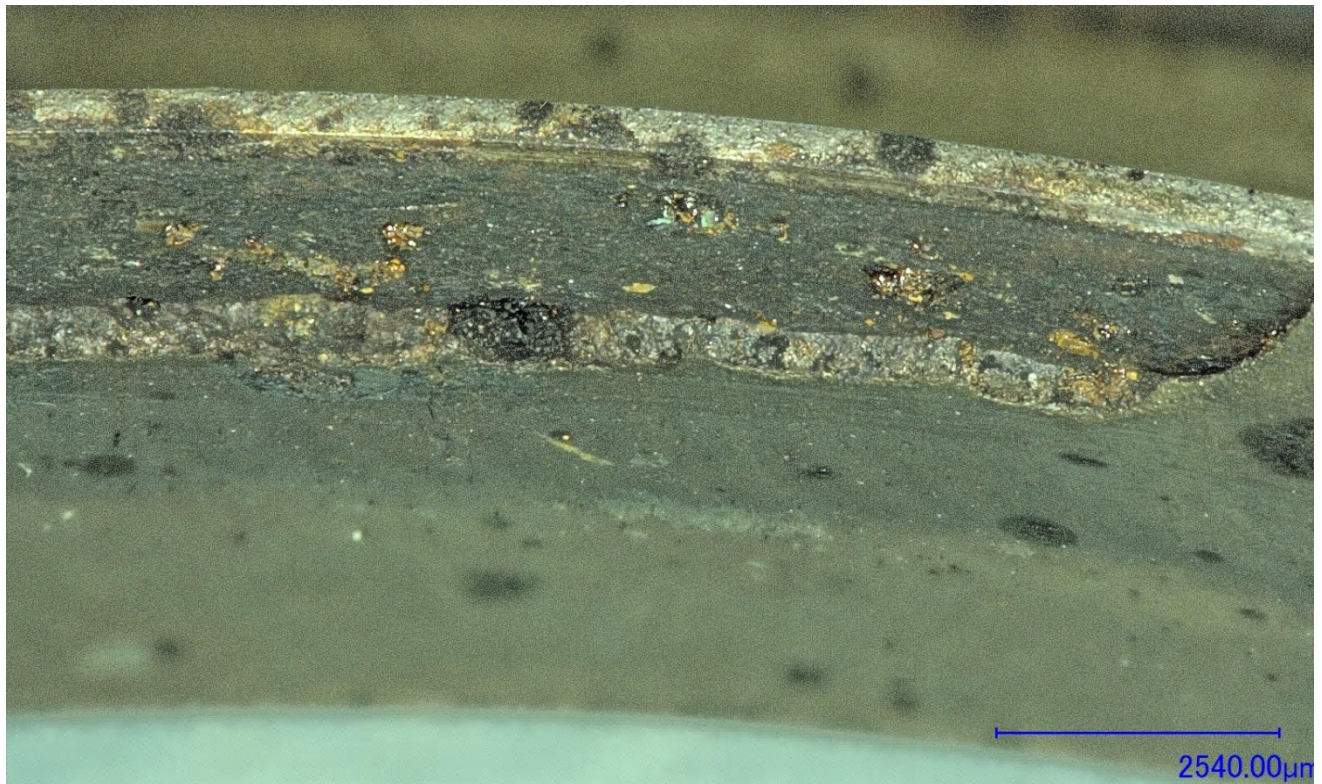


Figure 14 – Closer view of the edge of the flat fracture of the duct flange.



Figure 15 – Closer view of the flat fracture region shown in Figure 13.



Figure 16 – Closer view of the larger flat fracture region of the duct from Figure 10.

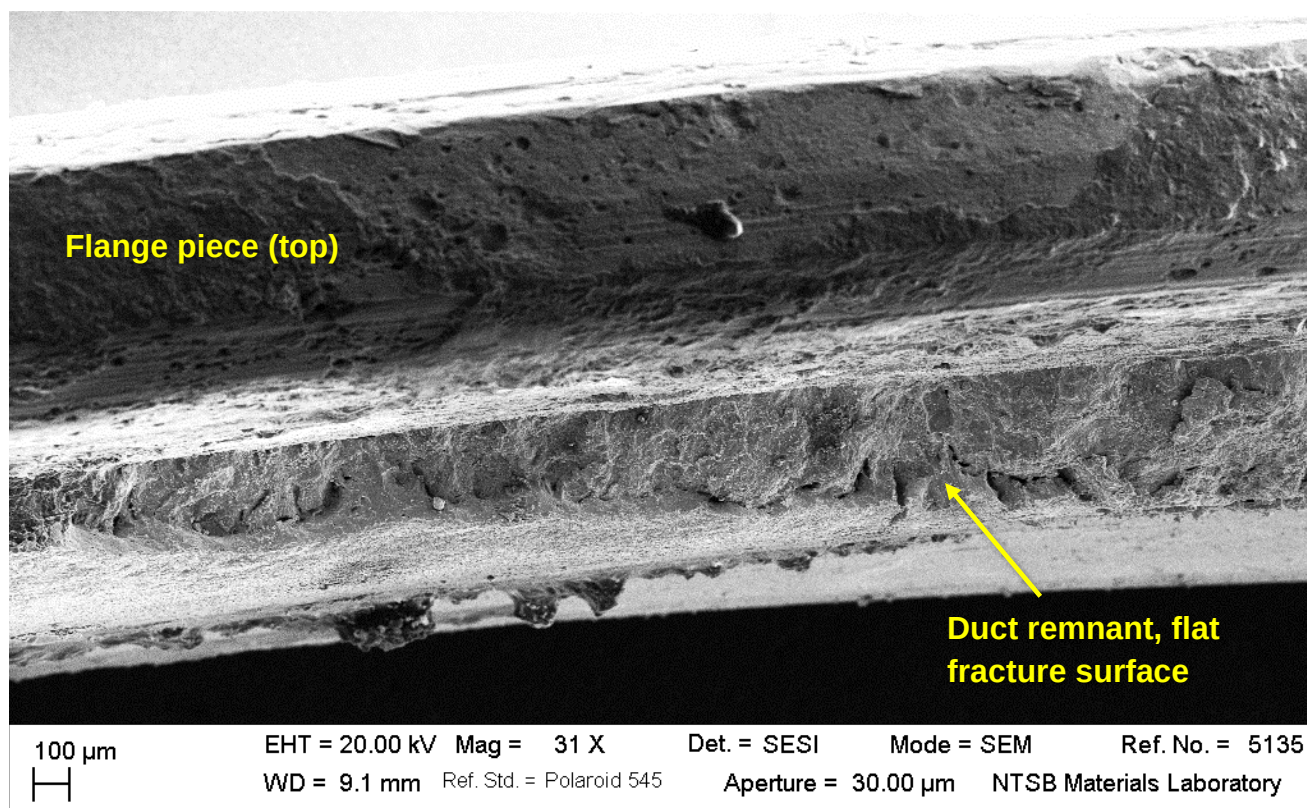


Figure 17 – Secondary electron (SE) micrograph of a typical region of the flat fracture region of the flange remnant shown in Figure 14.

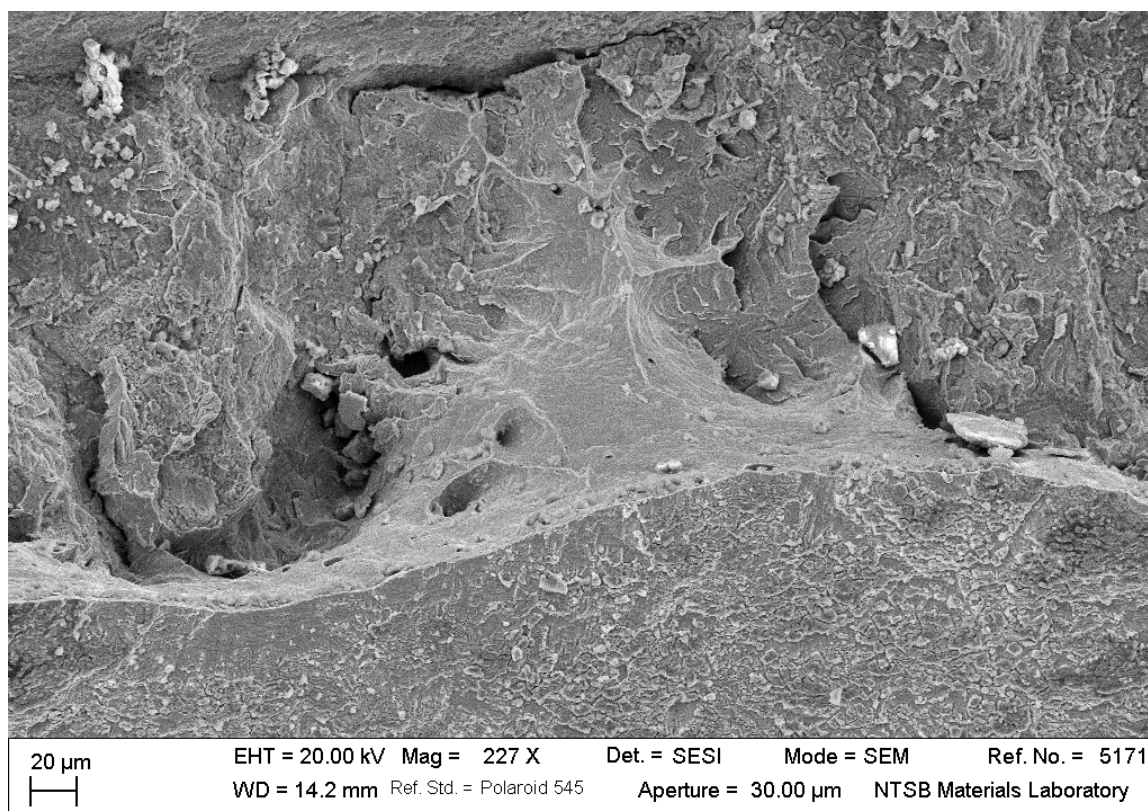


Figure 18 – SE micrograph of the flat fracture showing porosity, cleavage, and secondary cracking.

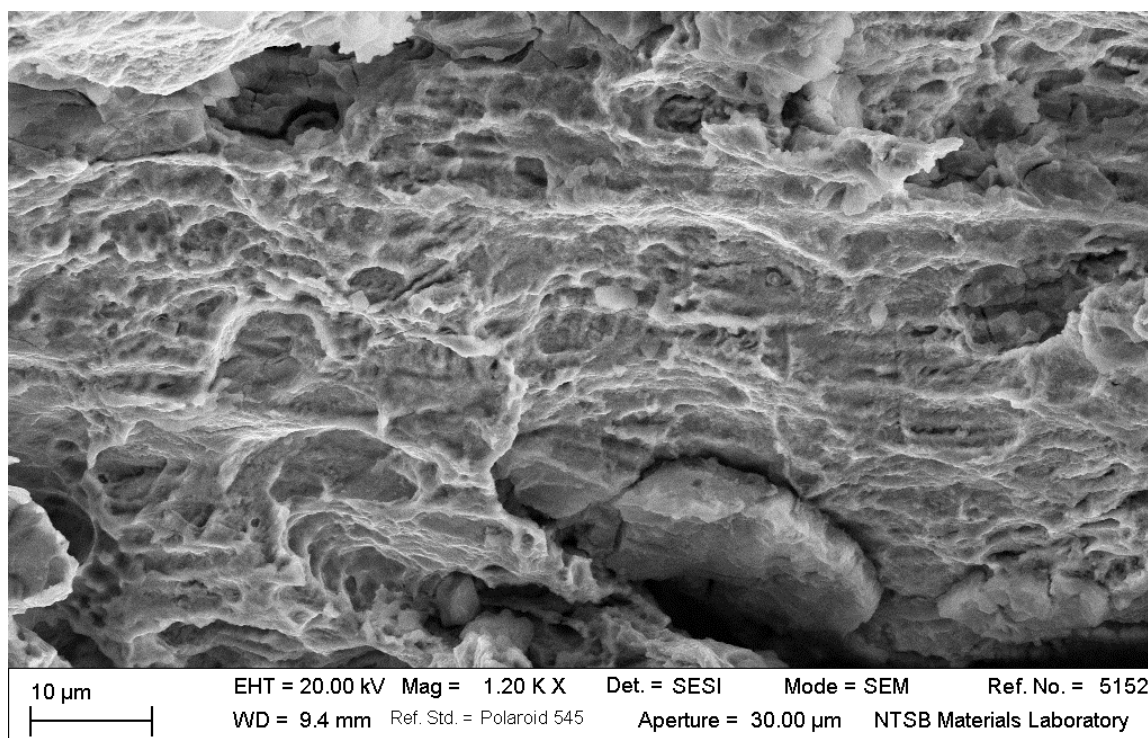


Figure 19 – SE micrograph of an area of the flat fracture showing dimpled rupture.

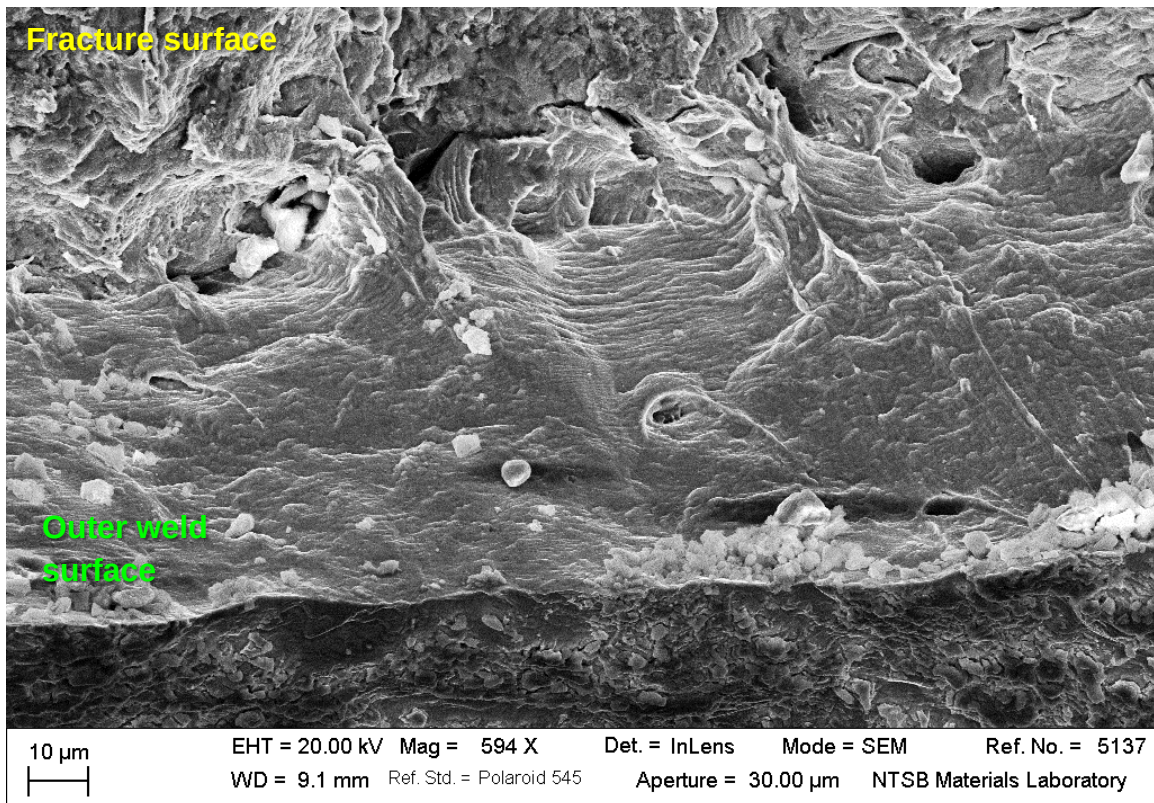


Figure 20 – SE micrograph of a portion of the lenticular weld surface (middle), adjacent the blocky fracture surface features (upper).

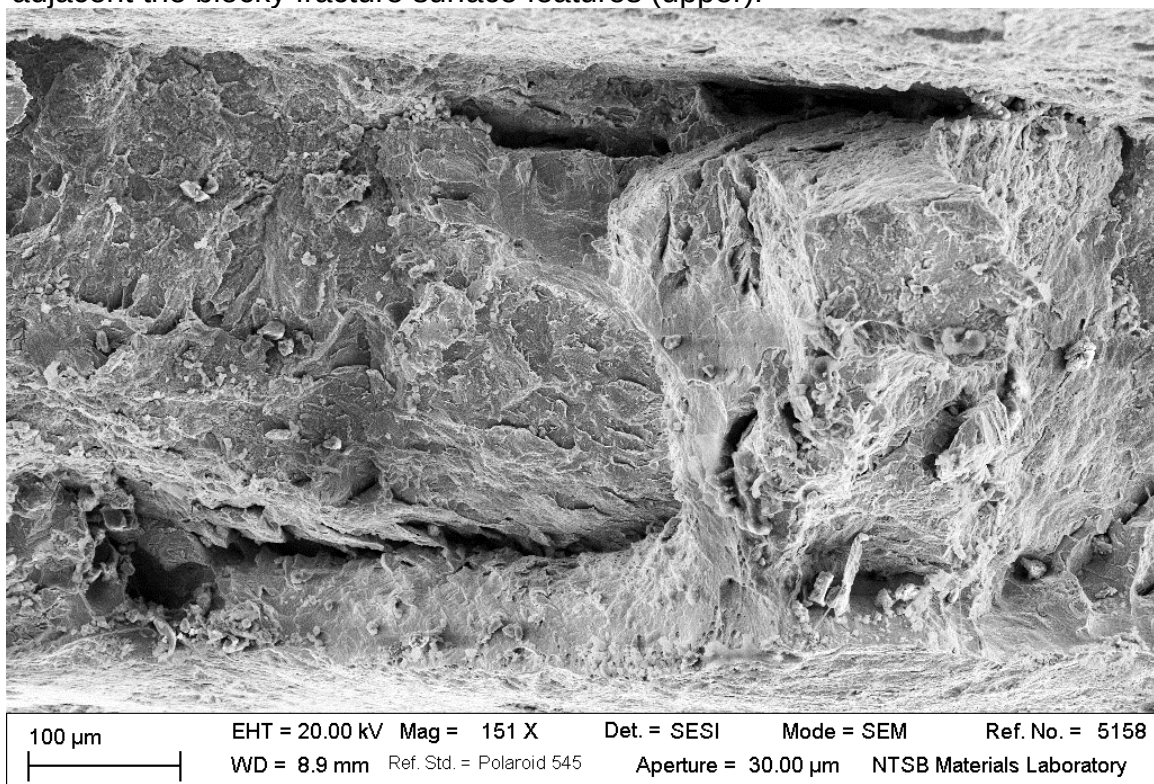


Figure 21 – SE micrograph showing perpendicular tearing in the weld fracture.

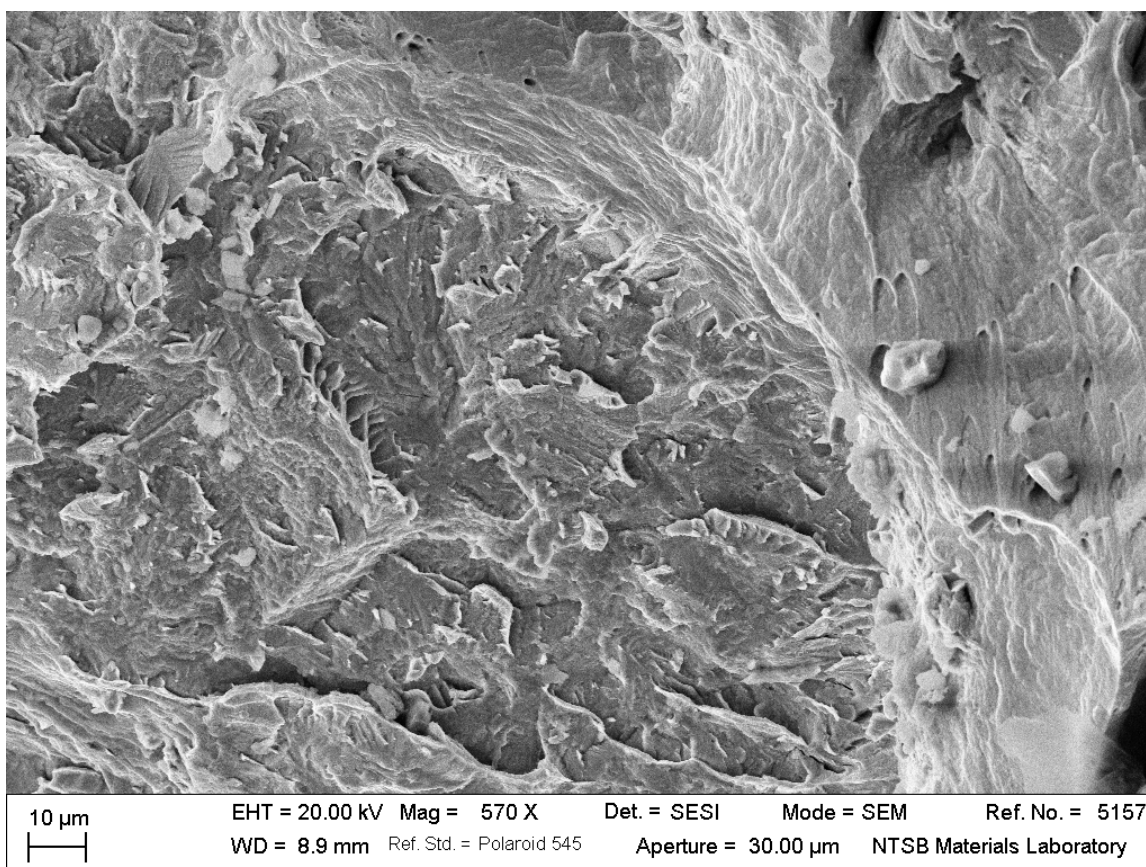


Figure 22 – SE micrograph of cleavage features on the flange flat fracture.

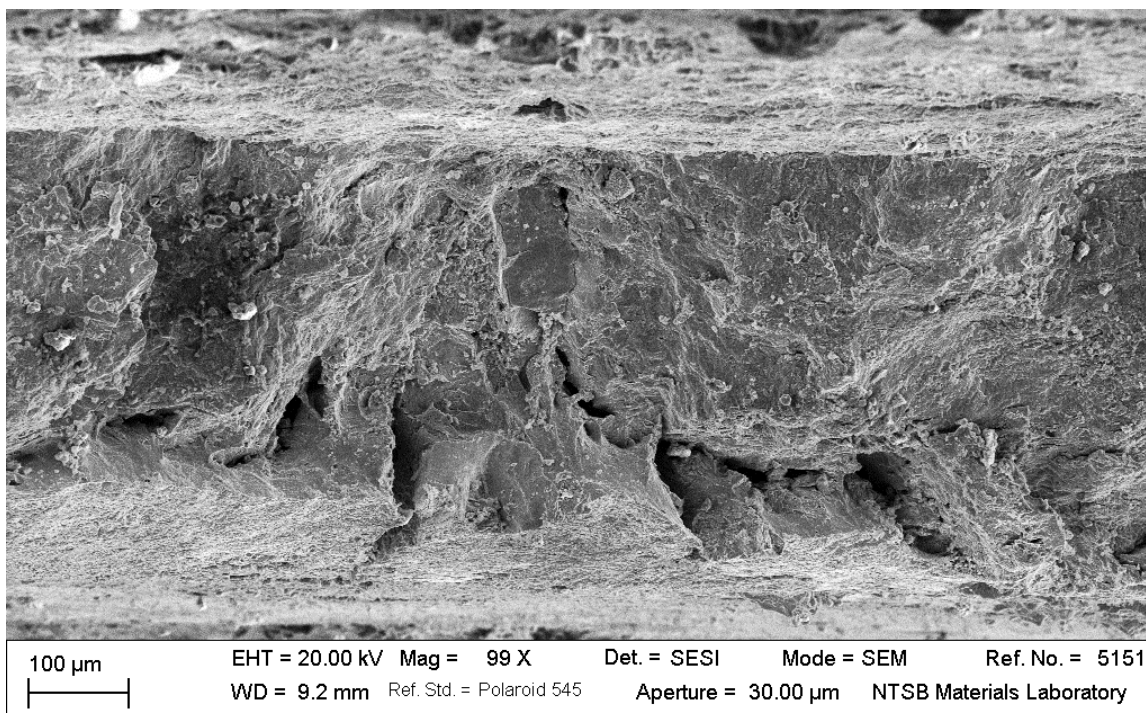


Figure 23 – SE micrograph showing a flatter region of the fracture surface, with secondary cracking, and faceted surface features.

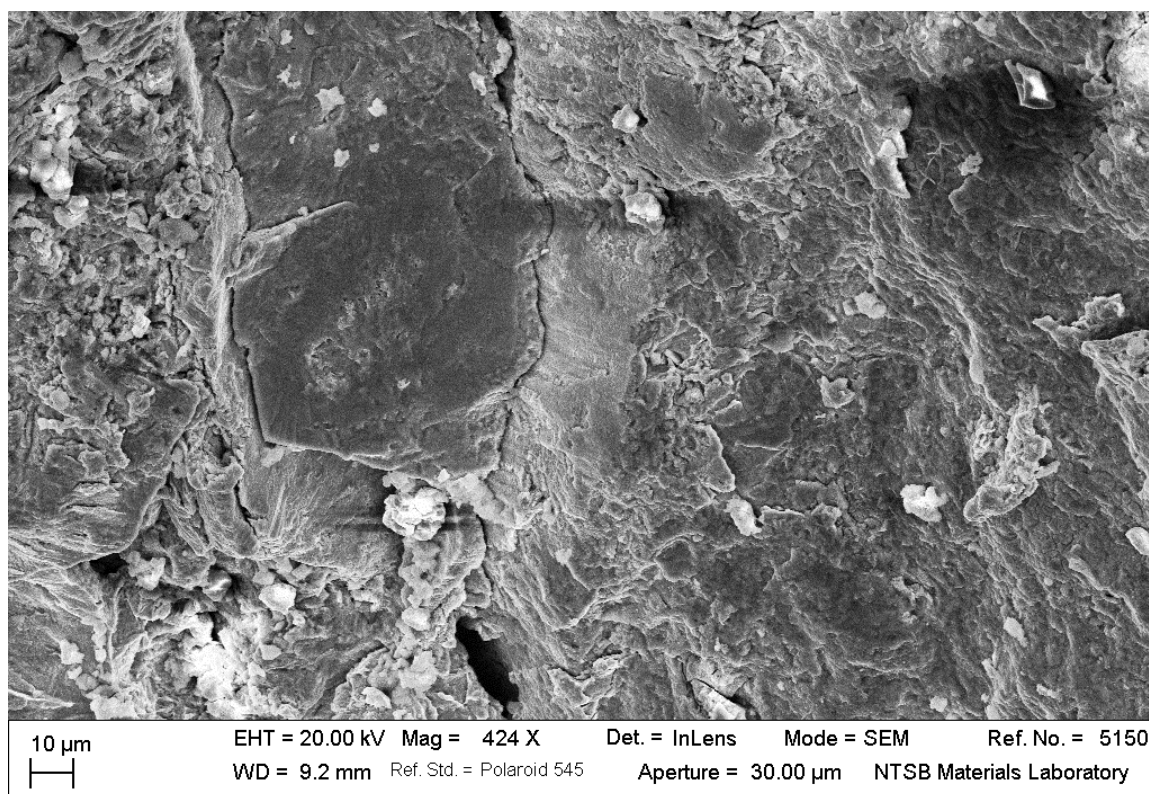


Figure 24 – SE micrograph showing one of the flatter faceted features.

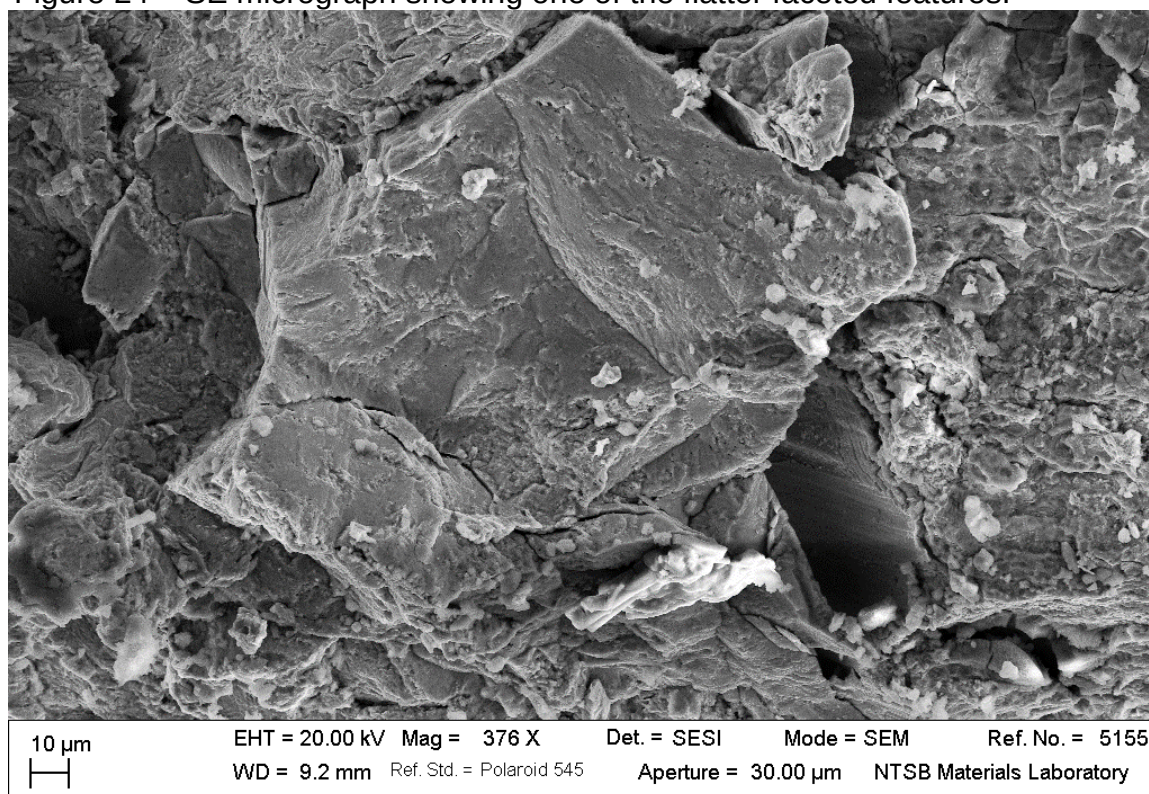


Figure 25 – SE micrograph showing a faceted area with intergranular fracture.

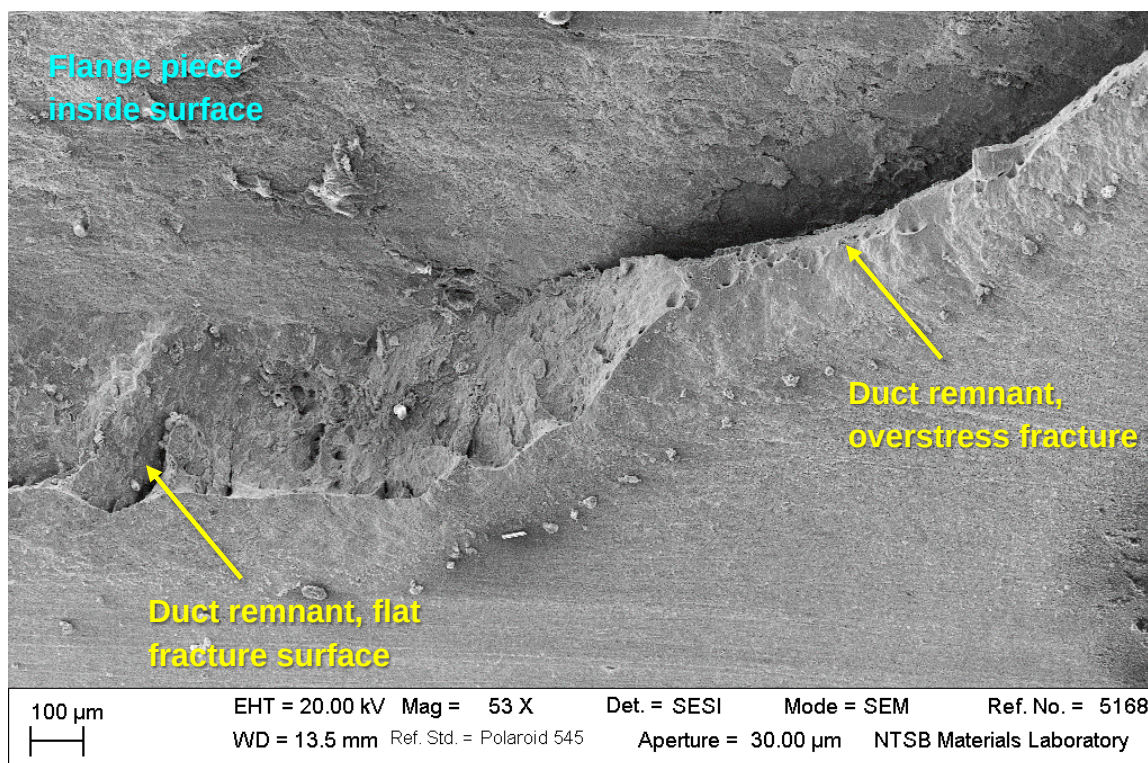


Figure 26 – SE micrograph showing the transition from the flat to necked fracture.

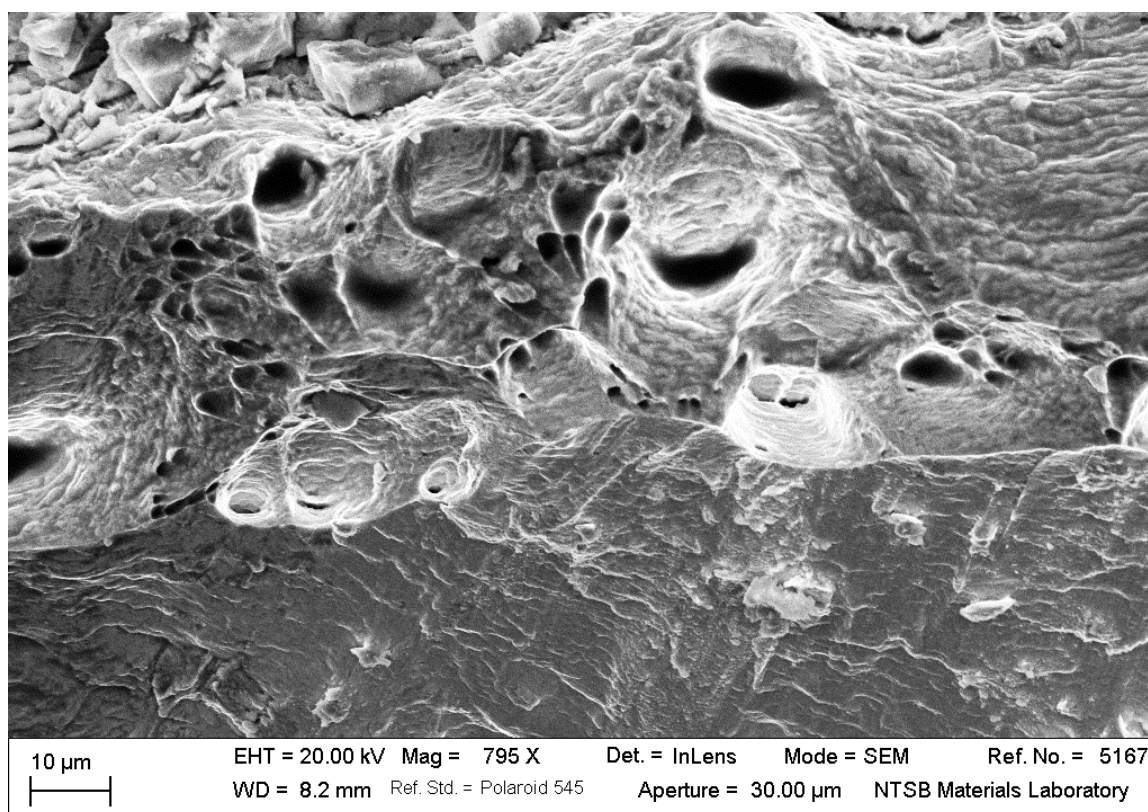


Figure 27 – SE micrograph showing dimpled rupture on the thinned fracture regions of the flange.

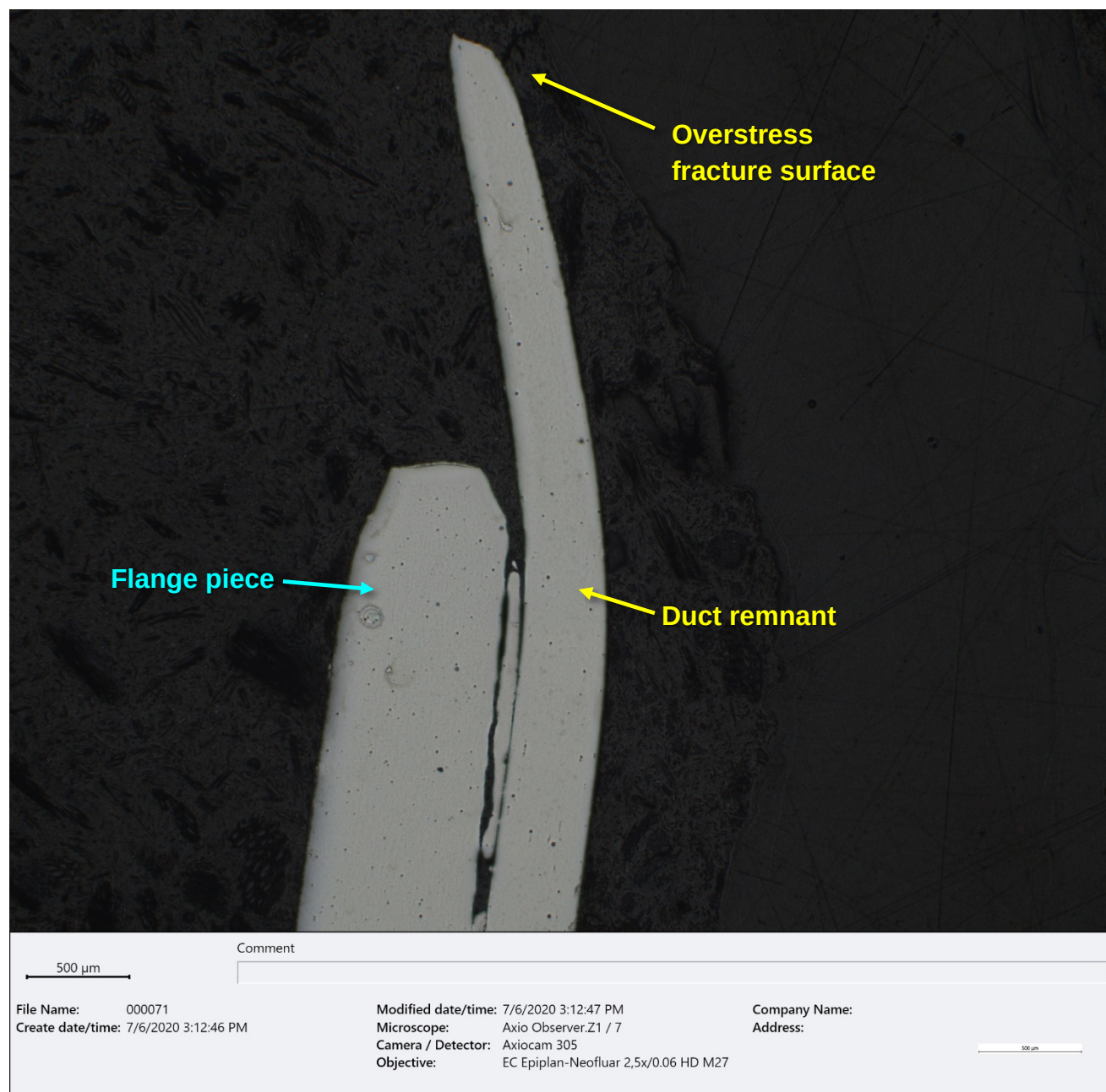


Figure 28 – Bright-field (BF) optical micrograph of a cross section of the flange weld fracture, showing a thin necked area (upper) (~25X, as-polished).

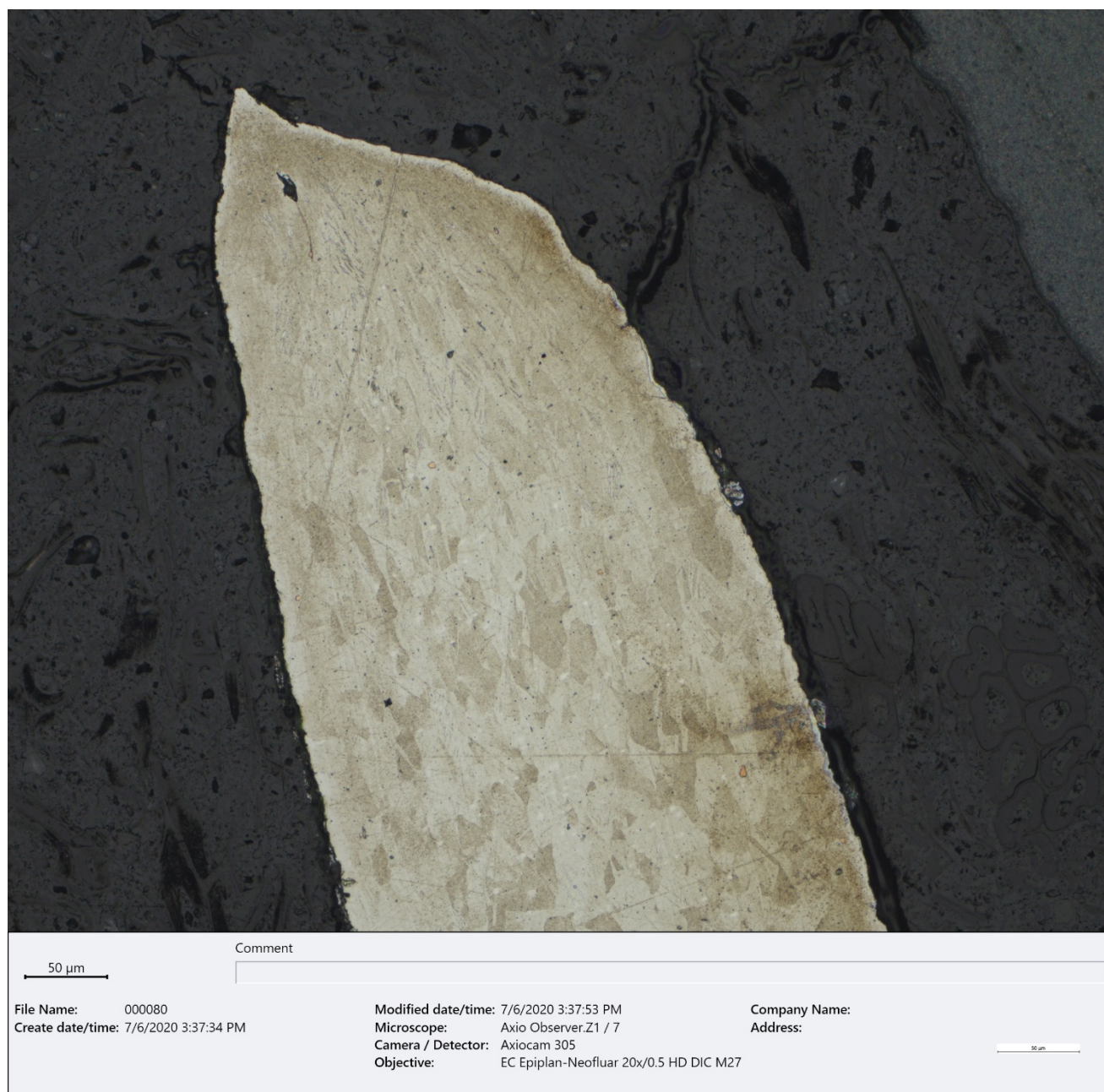


Figure 29 – BF optical micrograph of a cross-section of the thinned fracture of the duct away from the flange weld, showing grain elongation consistent with plastic deformation near the fracture surface (~200X, etched 2% Nital).

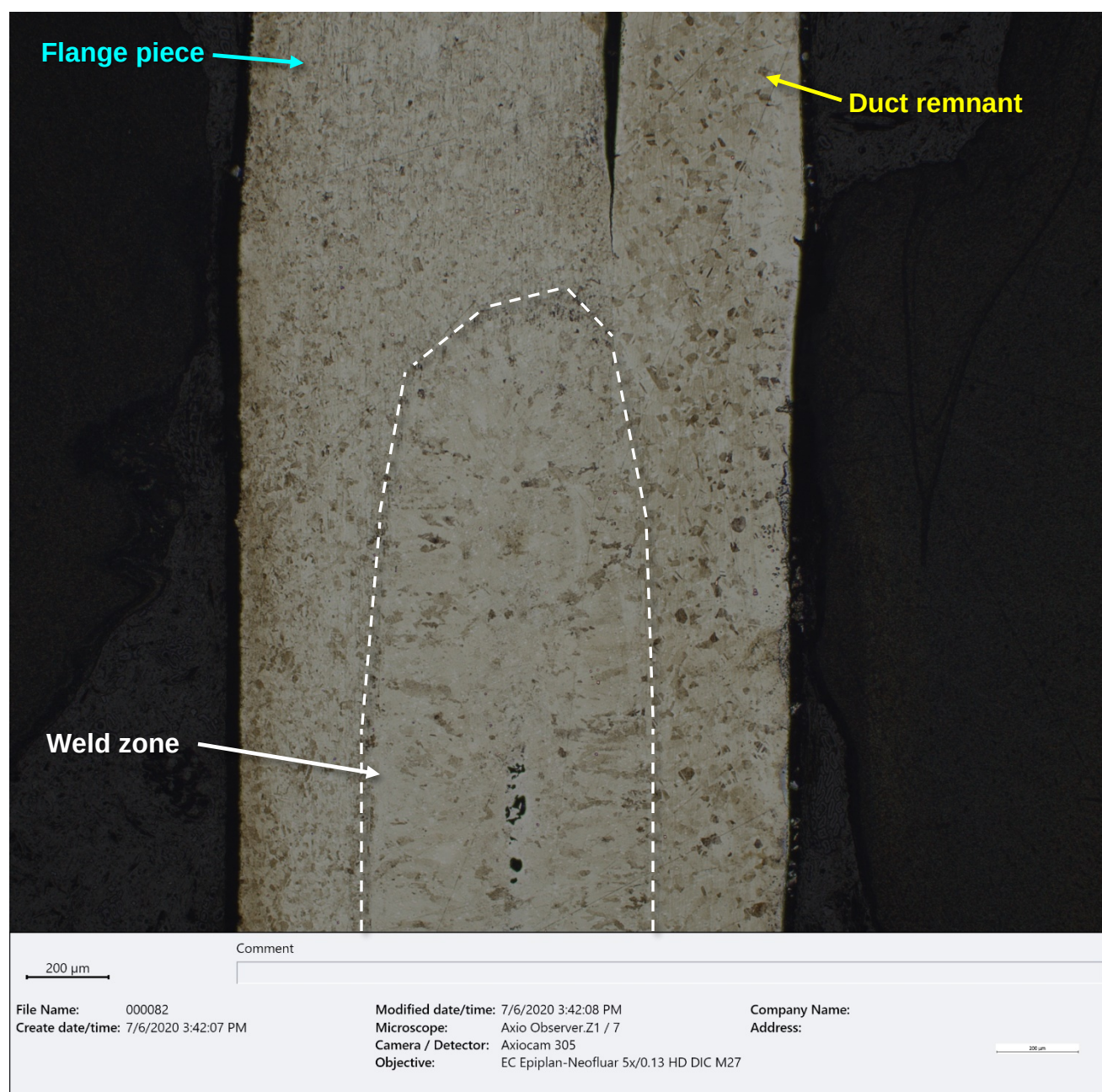


Figure 30 – BF optical micrograph of an intact portion of the duct flange weld, showing horizontal columnar grains and some porosity along the centerline (~50X, etched 2% Nital).

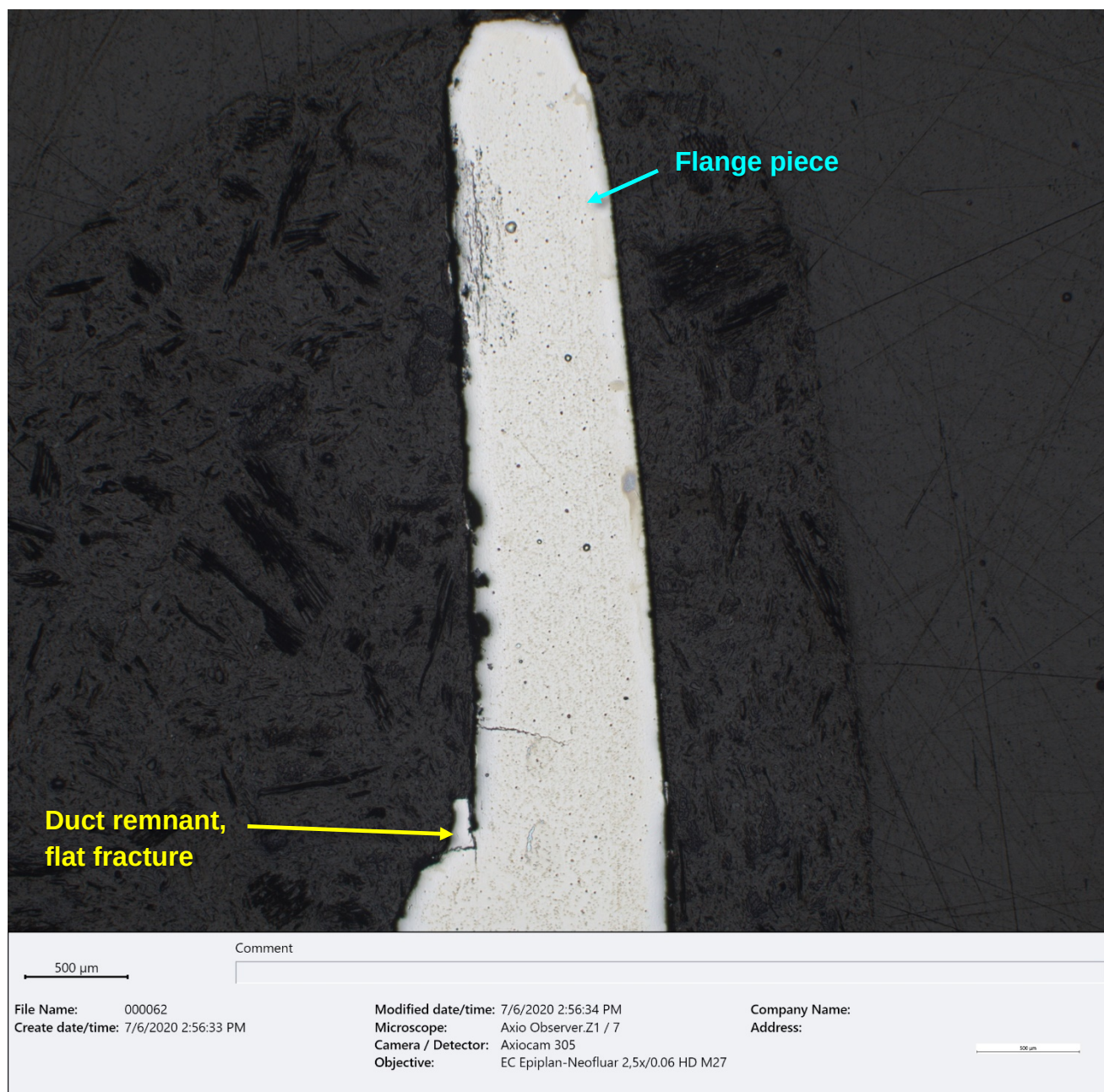


Figure 31 – BF optical micrograph of a cross-section of the flat fracture portion of the flange remnant fracture surface (~25X, as-polished).

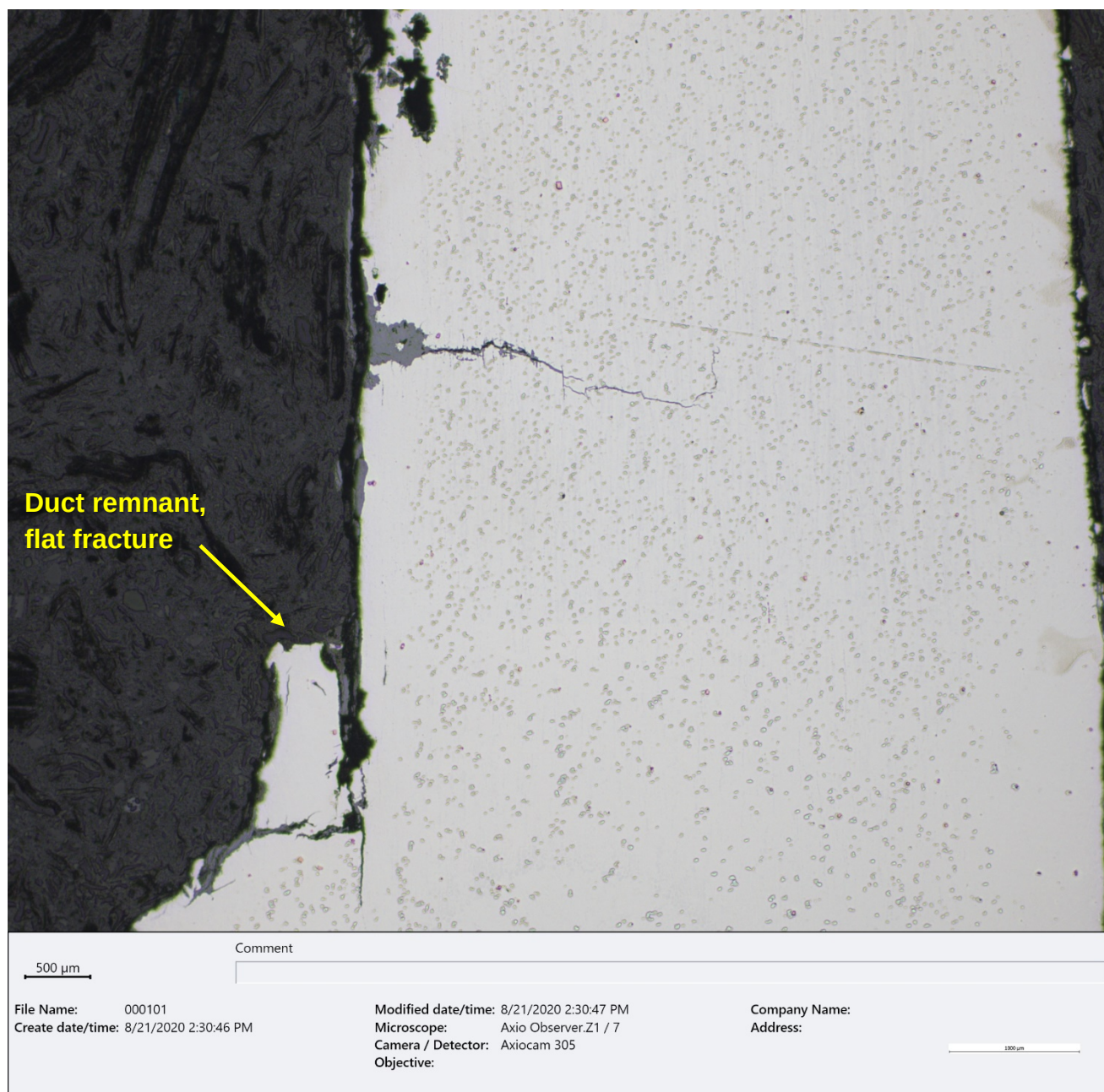


Figure 32 – BF optical micrograph of the flat-fracture region, showing internal horizontal and vertical cracking (~50X, as-polished).



Figure 33 – BF micrograph of the horizontal crack in Figure 32, showing vertical intergranular branching (~500X, as-polished).



Figure 34 – BF optical micrograph showing vertical and horizontal cracking at the flat fracture surface (~200X, as-polished).

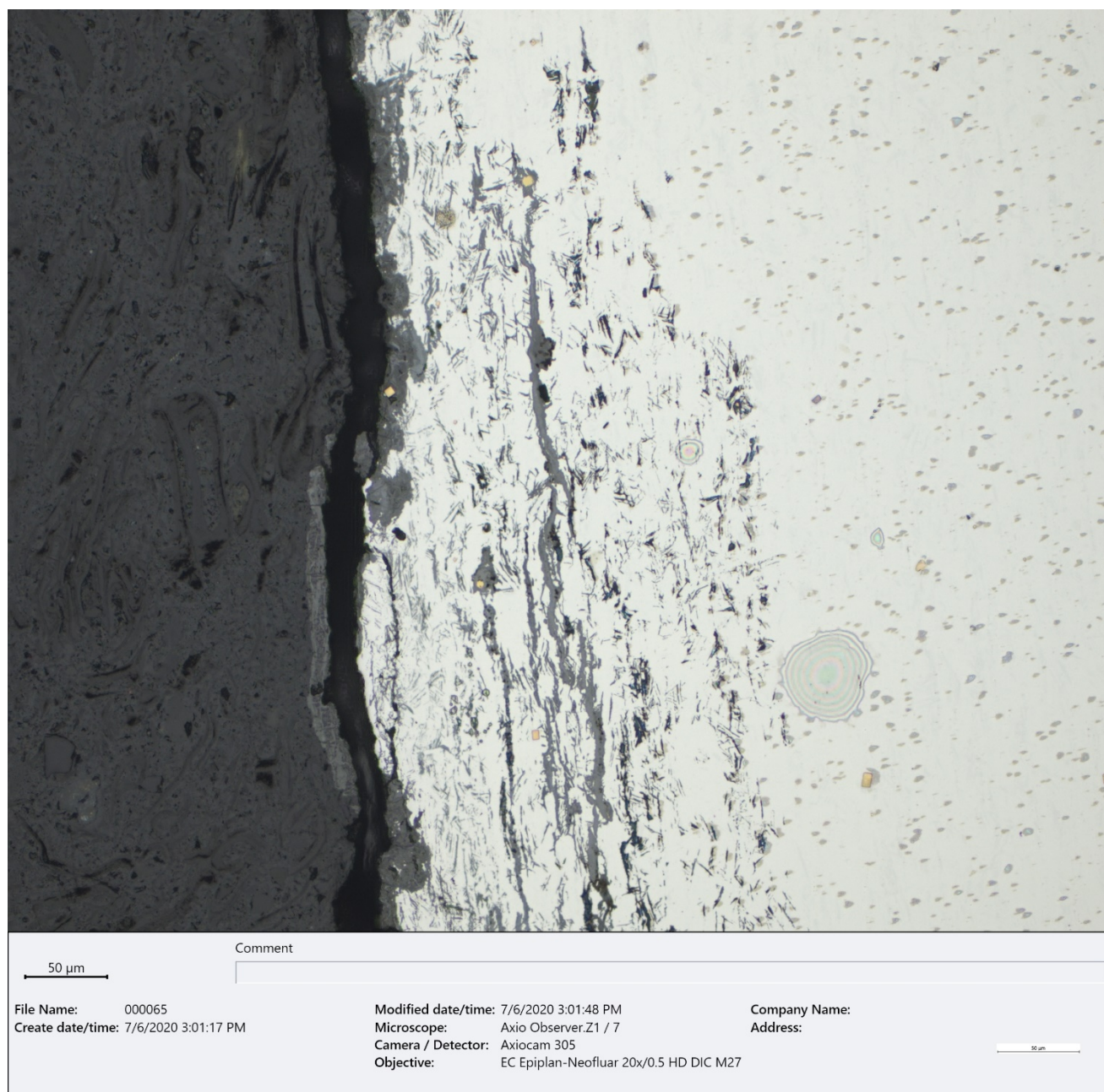


Figure 35 – BF optical micrograph of the layered, parallel internal corrosion compounds in the upper portions in Figure 31 (~200X, as polished).



Figure 36 – BF optical micrograph of a closer look of the layered corrosion compounds in Figure 35 (~500X, as-polished).



Figure 37 – BF micrograph of a surface corrosion pit on the flange piece, with branched cracking (~200X, as-polished).

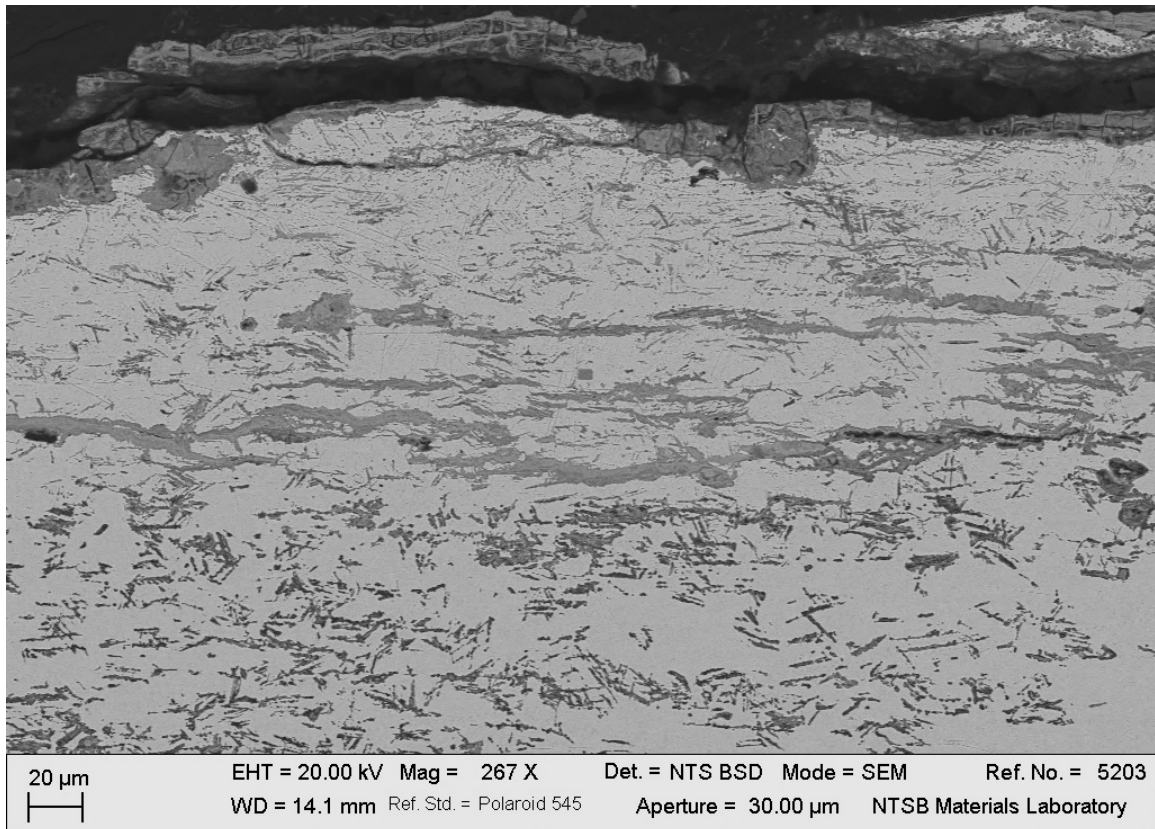


Figure 38 – Backscattered electron (BE) micrograph of the layered internal corrosion (rotated 90° from Figure 35).

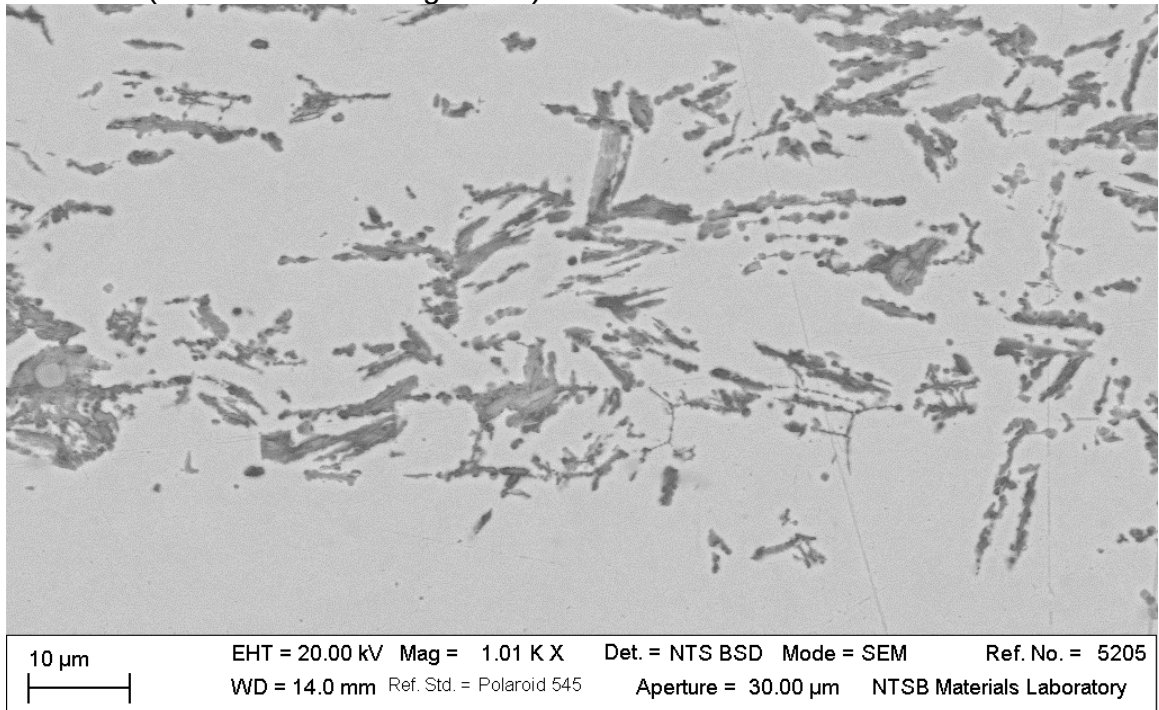


Figure 39 – BE micrograph highlighting the needle-like internal oxidation compounds, ~200 μm under the surface.