

NATIONAL TRANSPORTATION SAFETY BOARD

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



February 11, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-004

1. ACCIDENT INFORMATION

Place : Benson, Arizona
Date : August 19, 2020
Vehicle : Diamond DA-40, N386MA
NTSB No. : WPR20LA290
Investigator : Zoë Keliher, AS-WPR

2. COMPONENTS EXAMINED

Remnants of a nose landing gear fork assembly
Remnants of a nose landing gear welding assembly

3. DETAILS OF THE EXAMINATION

On August 19, 2020, about 2150 mountain standard time, a Diamond DA-40 airplane sustained substantial damage during an accident in Benson, AZ. The flight instructor and pilot were not injured. The flight instructor stated that they heard a loud noise as the nose lowered during landing. The pilot attempted to keep the nose up as the airspeed was slowing, but they stated they heard the strut scraping along the runway. Upon egressing the airplane, they observed that the nose gear had separated at the pivot axle. Components from the nose landing gear assembly were sent to the NTSB Materials Laboratory for additional examination.

Figure 1 shows the nose landing gear (NLG) fork arms, which were still connected to the center fork. Each arm had broken in two places. The fractures were slanted in orientation, with material plastically deformed and exuding towards one side. The fractures themselves were shiny, with streaks parallel to the direction of the aircraft fuselage. These features were consistent with fracture of the arms from scraping along the runway during landing.

Figure 2 shows the remnant from the nose landing gear leg assembly. This leg assembly had fractured at a welded joint with the fork collar insert. There was a stop plate still attached to the collar remnant. The plate had been attached by a series of washers and a self-locking nut.

The leg side of the fractured NLG leg assembly is shown in Figure 3, from the underside looking upward. The tube remnant exhibited several witness marks, the most prevalent being the large, black-colored streak which contrasted against the white paint of the tube. This streak was parallel to the tube direction, consistent with scraping or rubbing against the rotating NLG tire during landing and after fracture.

The aft portion of the leg tube fracture is shown from the side in Figure 4. The underside of the fracture exhibited flattening and deformation toward the back and the upward directions. The upper surface of the tube fracture exhibited buckling consistent with compression. The fracture surface exhibited a generally rough, fibrous texture, with a reddish-color, consistent with post-fracture corrosion of the exposed metal (rusting). These features were consistent with having fractured from overstress in upward bending.

As shown in Figure 2, the NLG leg assembly had also fractured in the forward area, at the weld with the fork collar. Figure 5 shows the mating fracture surface from the fork collar side, as received with the stop plate still attached. This fracture surface exhibited less post-fracture damage than the leg side, and it was therefore the focus of this examination. As can be seen in Figure 5, the fracture surface was located on the hollow cylindrical collar, exhibiting two crescent-shaped fracture features.

The collar remnant was disassembled from the adjacent washers and stop plate. The collar is shown on its side in Figure 6, after disassembly and cleaning with acetone in an ultrasonic cleaner. The collar consisted of a cylindrical section, then a semi-square taper, followed by a threaded portion. The cylindrical section exhibited two areas of circumferential wear, as annotated in Figure 6. These different regions on the collar fragment were measured using calipers, as annotated in Figure 6.

The collar fragment fracture surface, facing leftward in Figure 6, was sectioned for microscopic examination. Figure 7 shows the fracture surface after sectioning. As annotated in the figure, there were three different areas containing different features on the fracture surface—two were crescent-shaped and exhibited a flatter, shinier profile, and a third in the middle that was rougher and dull in luster. The crescent-shaped cracks were later determined to be consistent with fatigue, as described below. For the purposes of this report, the two crescent-shaped cracks were called fatigue Cracks 1 and 2.

Figure 8 and Figure 9 illustrate the largest depths of the cracks for Crack 1 and Crack 2, respectively. Crack 1, which was the larger crack, was approximately 2.0 inches long in circumference with a depth of 0.10 inches at final fracture. The collar thickness was approximately 0.12 inches at this location. As demonstrated by the figures, these regions of the cracks exhibited various types of post-fracture damage, such as from smearing or corrosion. The undamaged regions exhibited ratchet marks and crack arrest marks, consistent with multiple crack initiation sites and progressive crack propagation, respectively (Figure 10). Figure 11 shows the side outer face of part of the fracture surface edge, showing a stepwise morphology, consistent with multiple crack initiation sites. Figure 12 shows several of the crack initiation sites at an angle, consistent with multiple parallel cracks present on the surface (Figure 12). As mentioned earlier, there was extensive post-

fracture damage to these initiation sites, as shown by the edge rounding and smearing in Figure 13.

The fracture surface was examined using a scanning electron microscope (SEM). Figure 14 shows features typical of most areas on the fracture surface cracks—fatigue striations with numerous pock-marked features, consistent with post-fracture corrosion damage after the crack had propagated. Figure 15 shows a transition region at the end of one of the fatigue cracks, showing clearer less-damaged fatigue striations, followed by an area of dimpled rupture (see Figure 16) consistent with the subsequent overstress fracture of the inner regions of the collar.

Figure 17 shows a backscattered SEM micrograph of some of the less-damaged fatigue crack initiation sites and their subsequent ratchet marks.¹ The darker regions on the fracture surface in Figure 17 were indicative of lower atomic number compounds, areas consistent with post-cracking or post-fracture corrosion products. These products were more ubiquitous closer to the initiation sites, suggesting they had been present during the crack propagation prior to final fracture.

Figure 18 shows one of the less-damaged crack initiation sites. While there were radial patterns and striations consistent with initiation at the surface, there were no material defects present such as inclusions, pores, or pits. Figure 19 shows a reverse and angled image of another initiation site, showing parallel cracks in the outer collar surface. Several of these cracks exhibited gaps consistent with parallel progressive cracks. As demonstrated in Figure 20, these initiation sites exhibited surface contamination consistent with post-cracking corrosion products and lubricant derivatives. There were several parallel cracks below this initiation site, as annotated in Figure 19.

These features were consistent with two opposite facing fatigue cracks propagating inward on the collar due to reverse bending, consistent with landing forces and cycles. The cracks propagated until the remaining collar cross section could not withstand the loads on the last landing cycle and succumbed to fracture from overstress. With the collar having separated, the adjacent NLG components would be subject to fracture from overstress.

A portion of the collar was sectioned parallel to the fracture surface, mounted, and polished for metallographic examination. A cross section of the surface is illustrated in Figure 21. The surface exhibited a coating approximately 10 μm (0.0004 inches) thick. The coating was generally uniform in thickness and was adherent, with some small gaps between itself and the substrate. The cross-section was examined using energy dispersive x-ray spectroscopy (EDS), and was found to contain mostly Ni with some P, consistent with elements typical of an electroless nickel coating.

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.

The underlying microstructure revealed equiaxed grains, similar to that found in the core in Figure 22. The chemical composition of the sectioned collar was examined using x-ray fluorescence (XRF) and EDS. From the data obtained using these techniques, the collar was found to be consistent with alloy steel. The hardness was inspected per ASTM E18.² The hardness averaged 99 HRBW.

Another cross section was taken perpendicular to the fracture surface, which was also mounted, polished, and etched. Figure 23 shows a typical view of the cross section. There were secondary cracks present perpendicular to the fracture surface. These cracks were co-located at areas where the Ni-coating was missing. While the parallel cross section showed a mostly adherent coating, the perpendicular coating revealed areas of spalled coating, or areas where the coating was buckled or present with gaps against the substrate (Figures 24 and 25). These features were consistent with cracks having initiated at the surface where the outer coating was cracked, missing, or otherwise compromised.

Erik M Mueller
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² ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

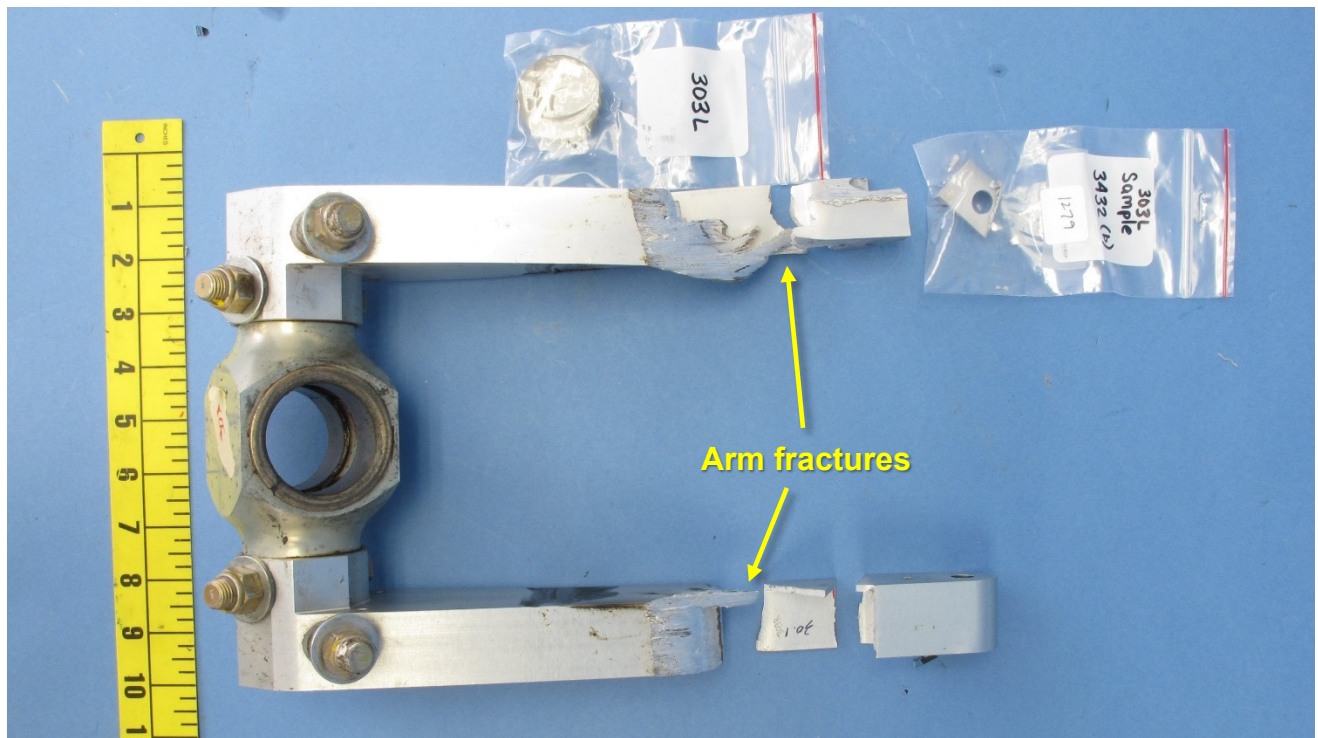


Figure 1 – Closer view of the fractured NLG fork arms, shown connected to the center fork.



Figure 2 – Remnant of the NLG leg welding assembly, which fractured at the fork collar location. The stop plate was still attached to the leg collar remnant.



Figure 3 – View of the leg remnant, showing the collar fracture surface and witness marks on the bottom side.



Figure 4 – View of the side of the leg remnant tube fracture surface, showing buckling on the upper side and tension features on the bottom side, consistent with upward bending in the figure.

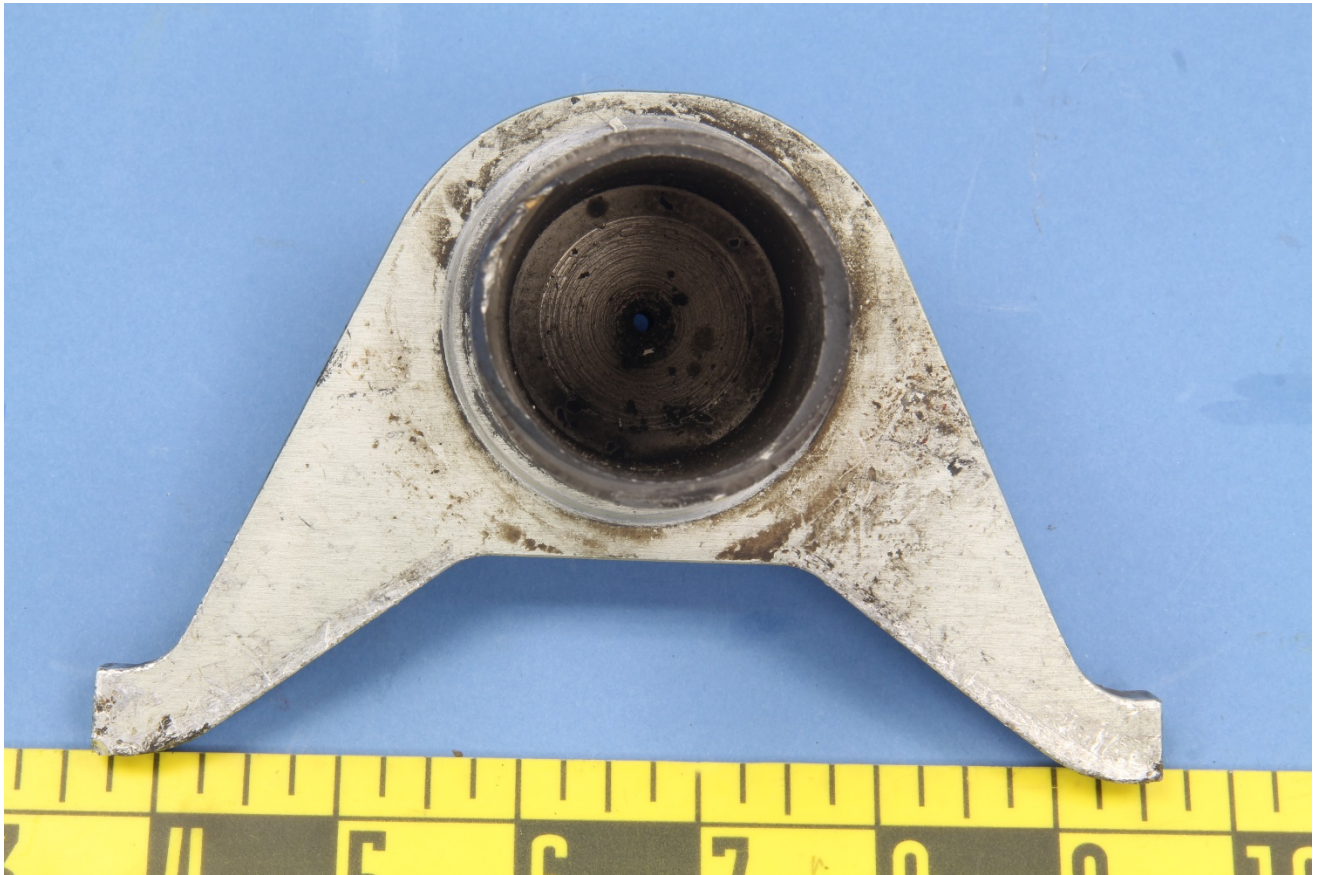


Figure 5 – The fracture surface of the fork collar as received, still attached to the stop plate affixed via bearing washers and a nut.

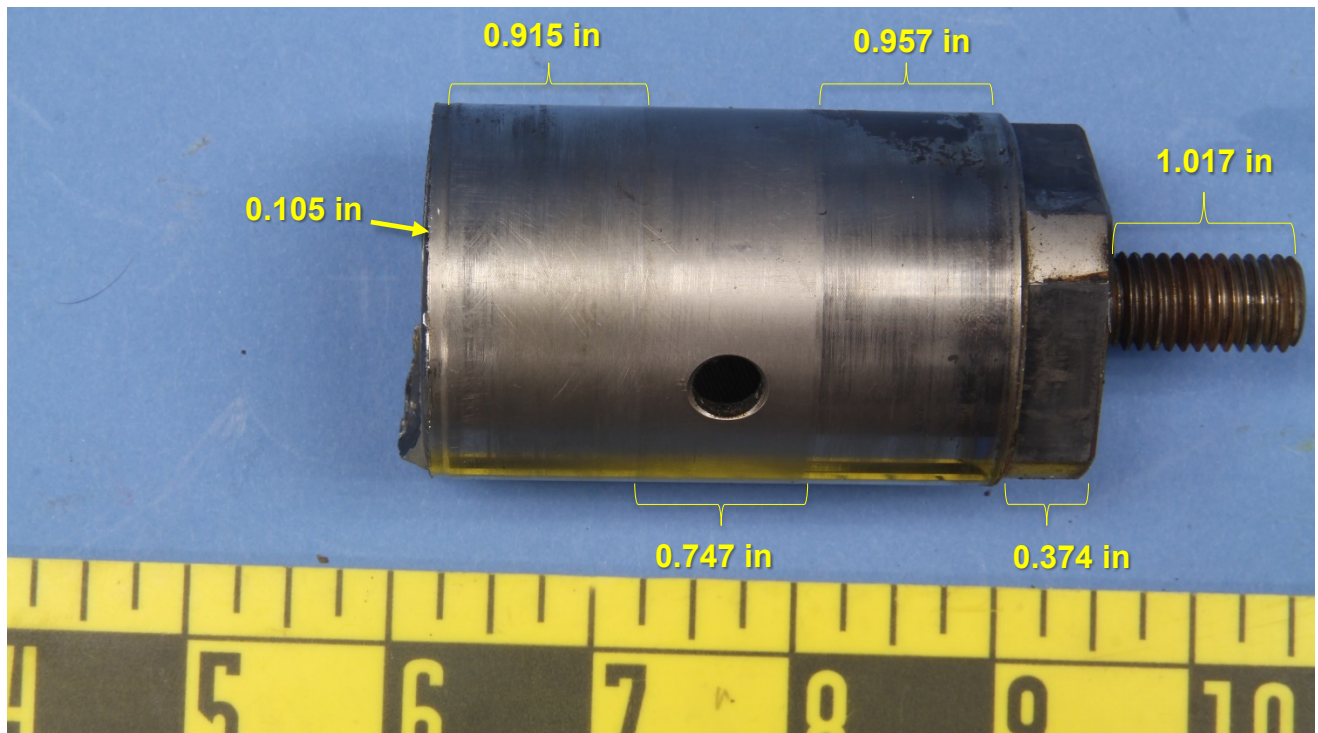


Figure 6 – The collar after removal of the stop plate and adjacent components. Various measurements are annotated on the figure.

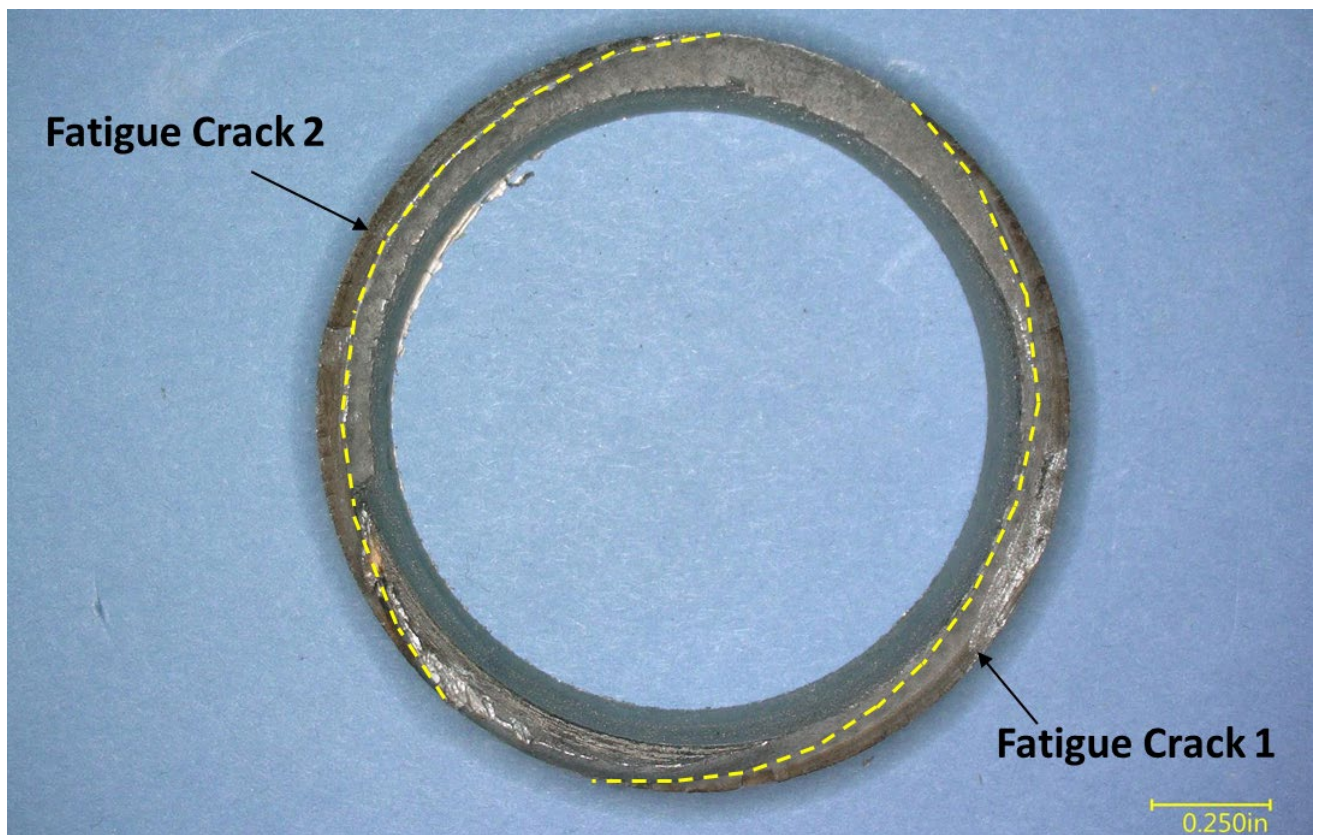


Figure 7 – View of the collar fracture, after sectioning, annotated to show the fatigue areas.

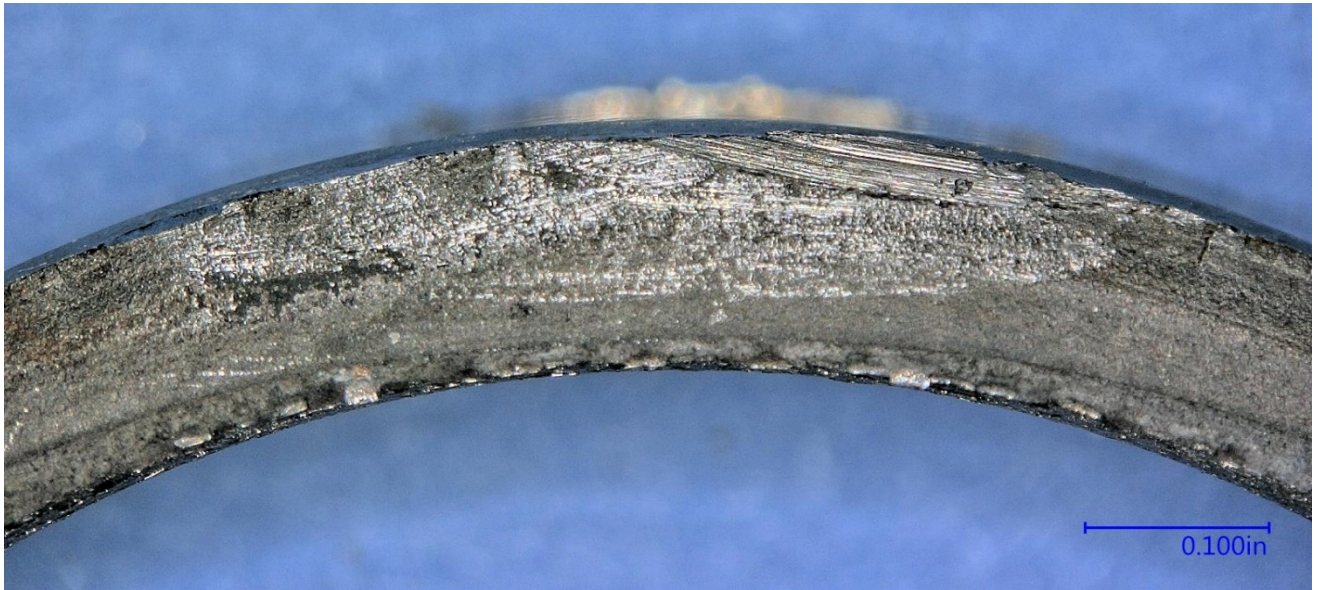


Figure 8 – View of fatigue crack 1, showing the depth of crack propagation, and post-fracture smearing on the surface.



Figure 9 – View of the fatigue crack 2, showing the depth of fatigue crack penetration through the collar cross section.

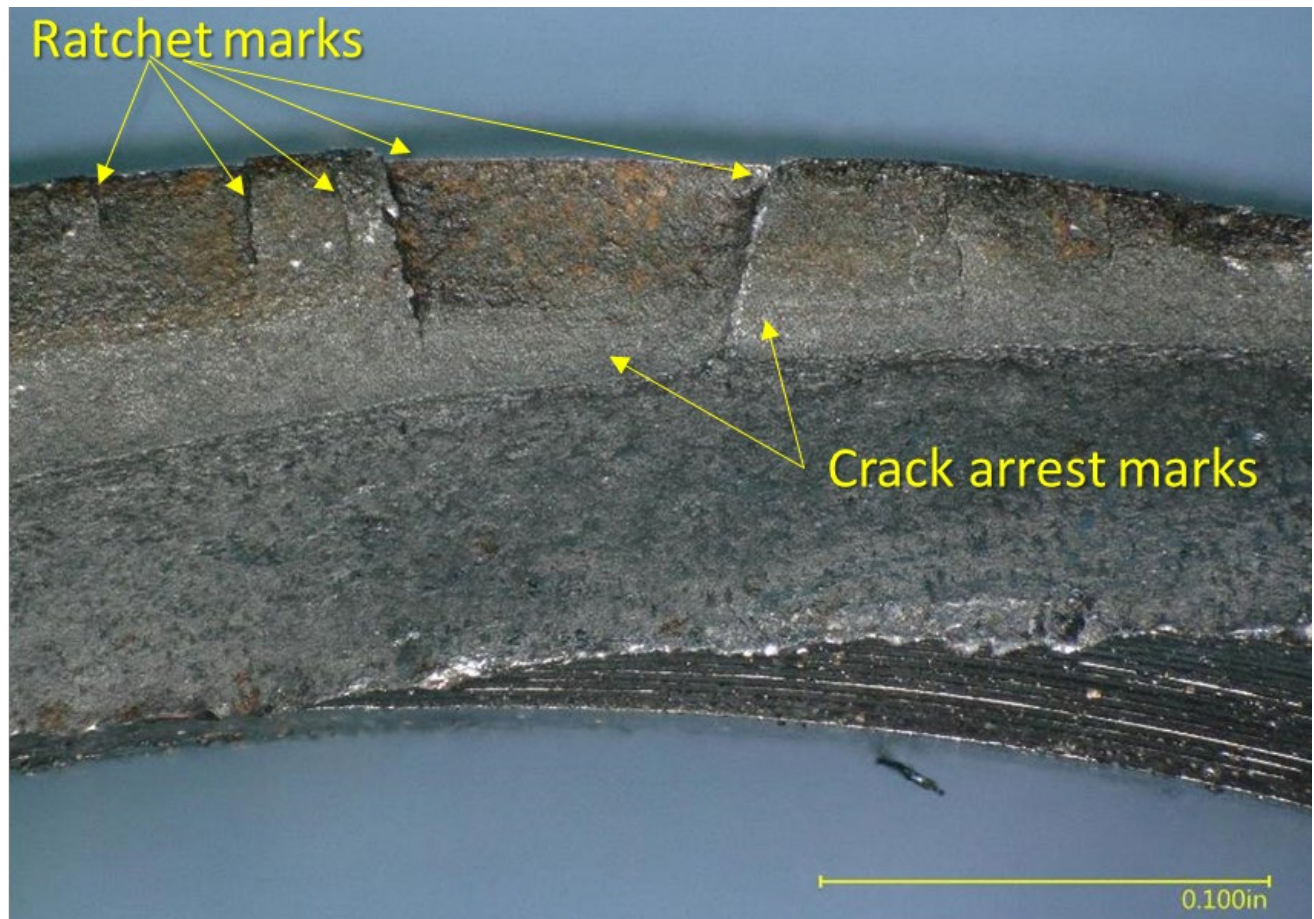


Figure 10 – View of the side of the fatigue crack 1, showing ratchet and crack arrest marks.

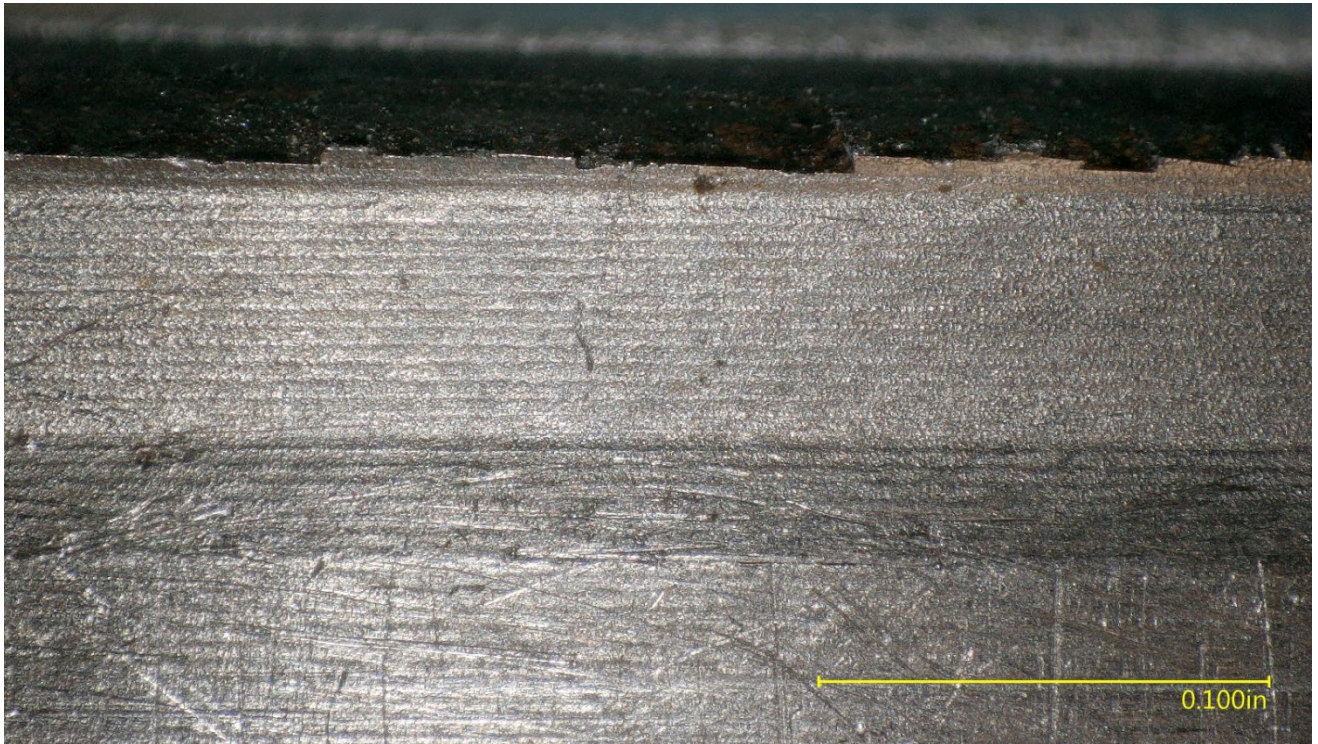


Figure 11 – View of the crack initiation sites on the reverse side from Figure 13.

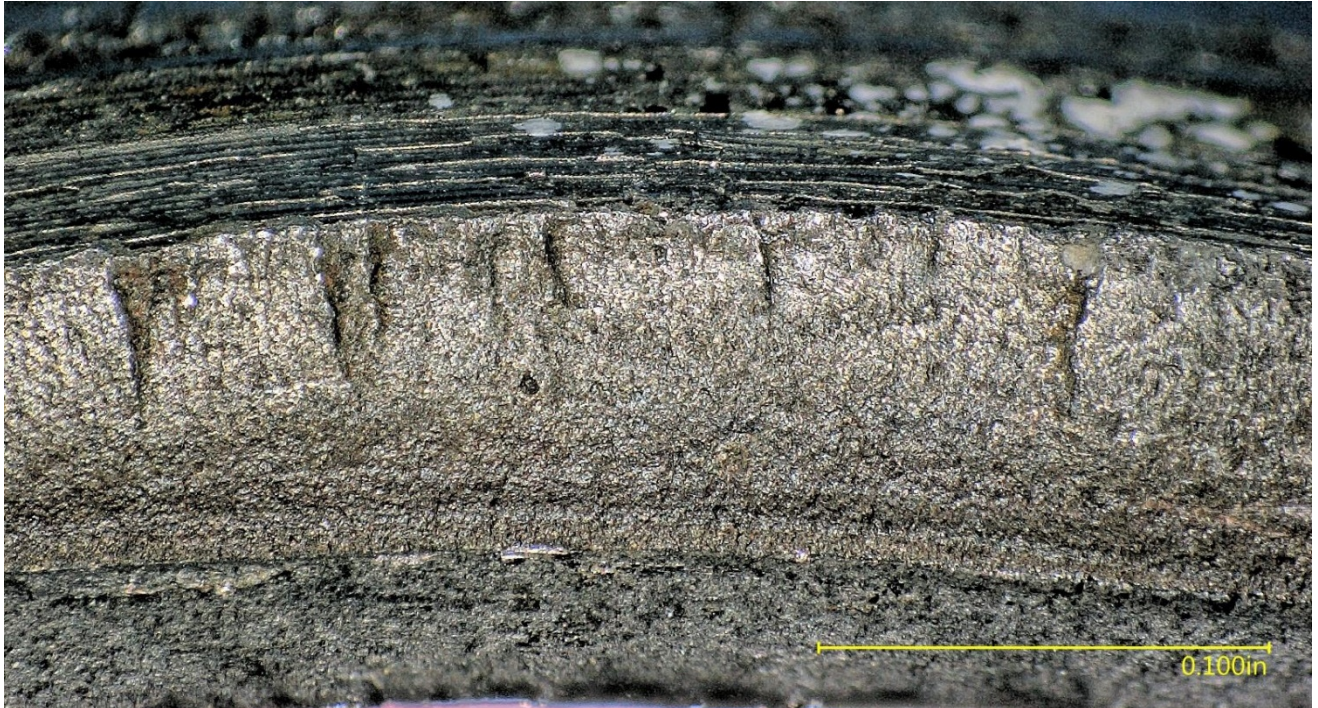


Figure 12 – Angled view of the initiation sites of the fatigue Crack 2, showing wear marks along the outside of the collar.

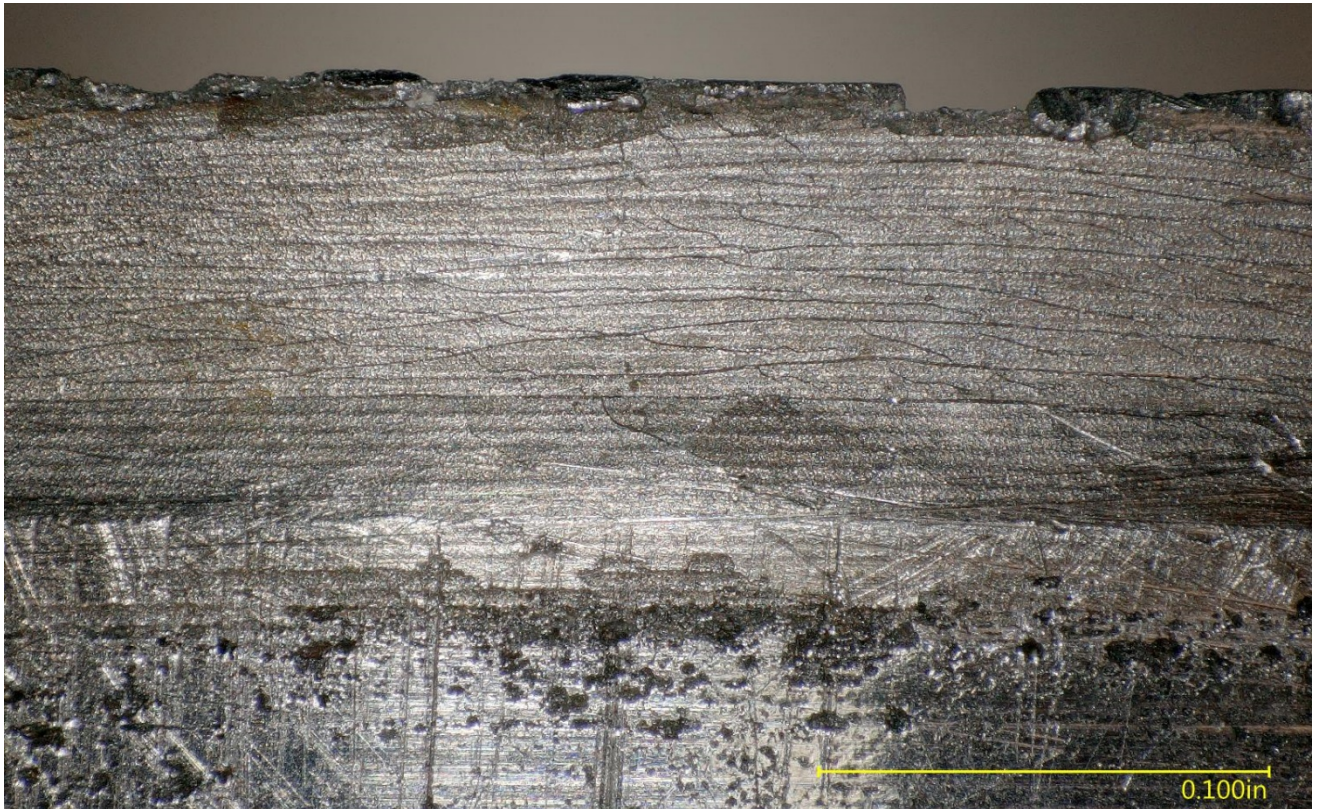


Figure 13 – Closer view of the worn side of the collar below the crack initiation sites.

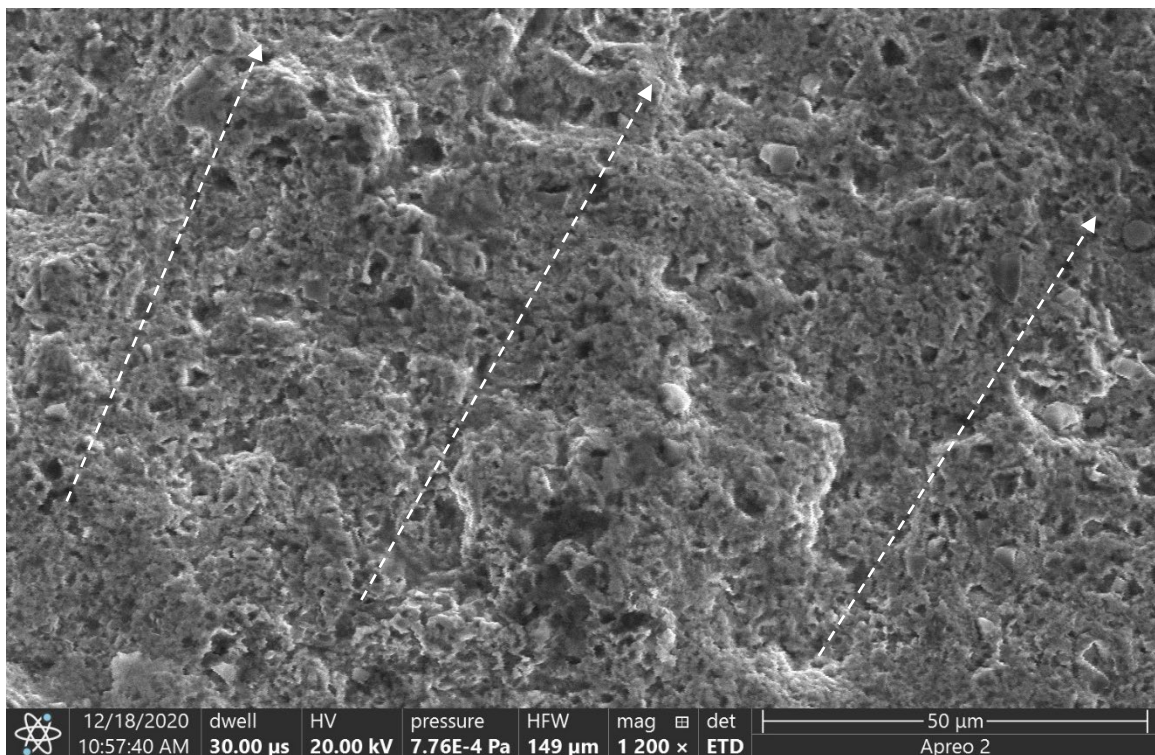


Figure 14 – Secondary electron (SE) micrograph of the fatigue region of the collar fracture surface. The crack propagation direction is denoted by the arrows.

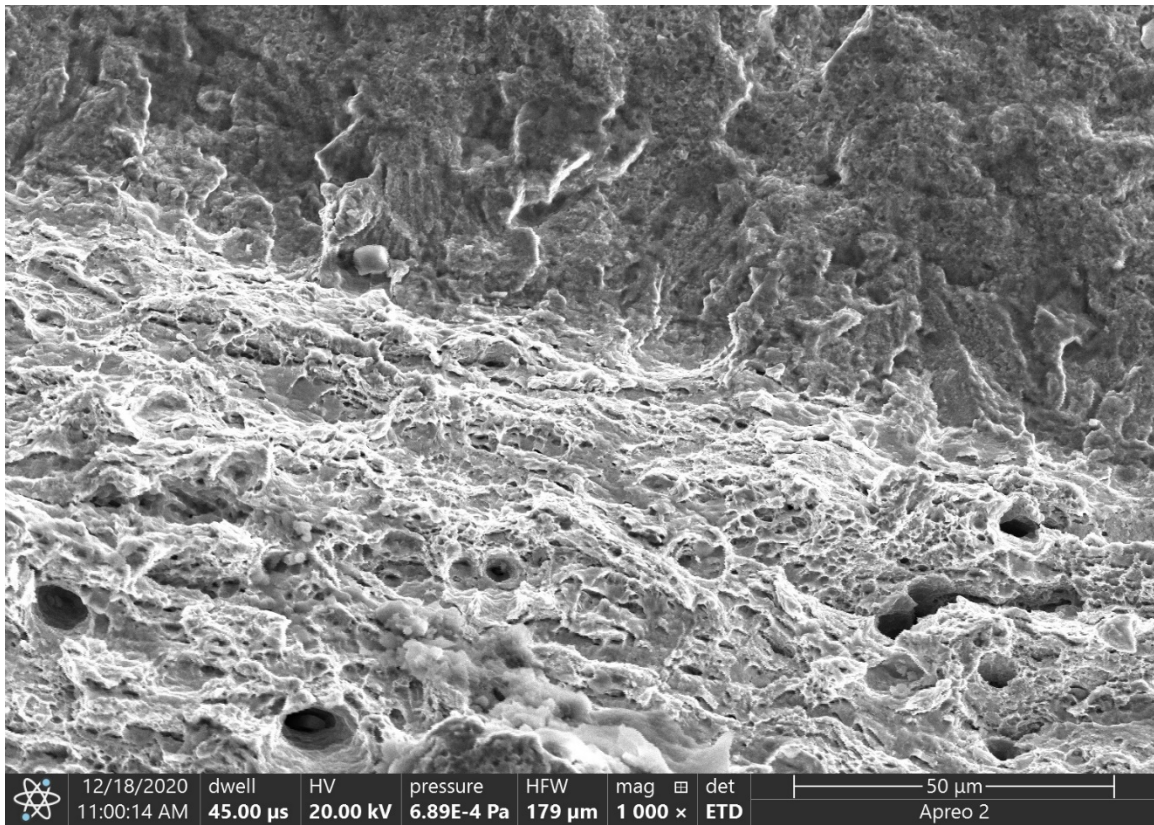


Figure 15 – SE micrograph of the end of one of the fatigue cracks on the collar.

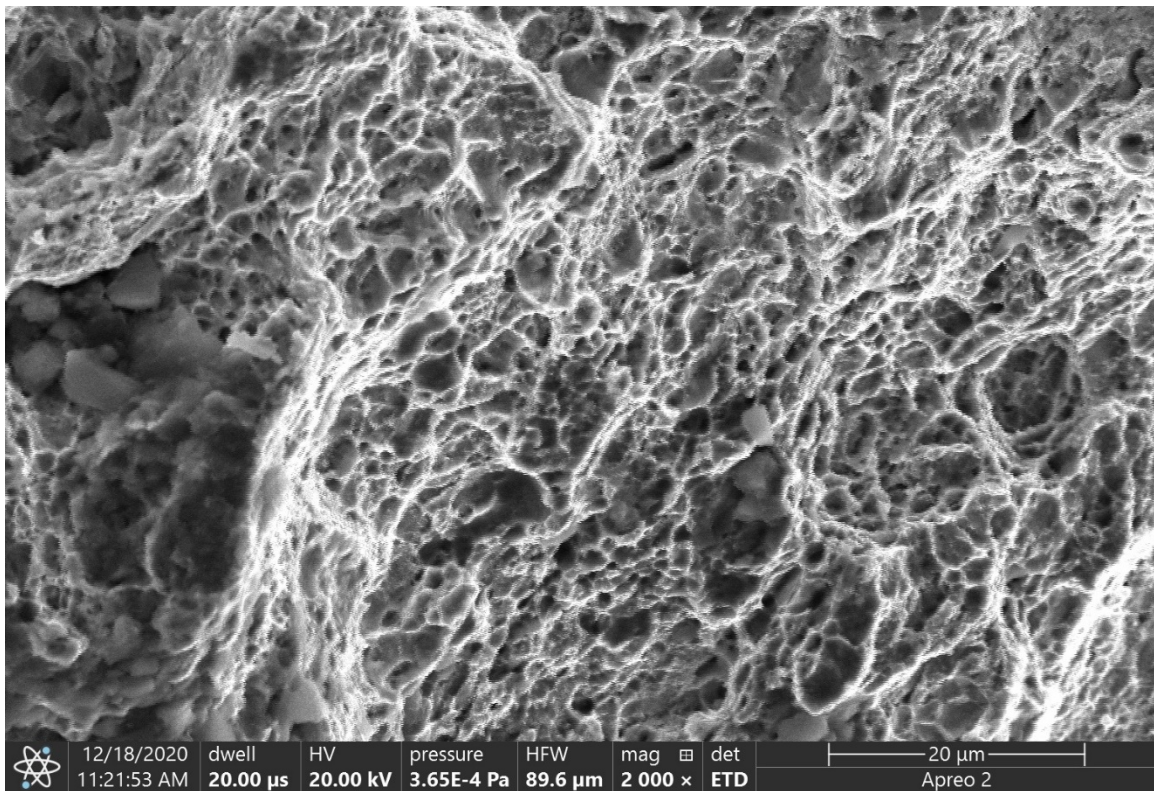


Figure 16 – SE micrograph of dimpled rupture on inner regions of the fracture.

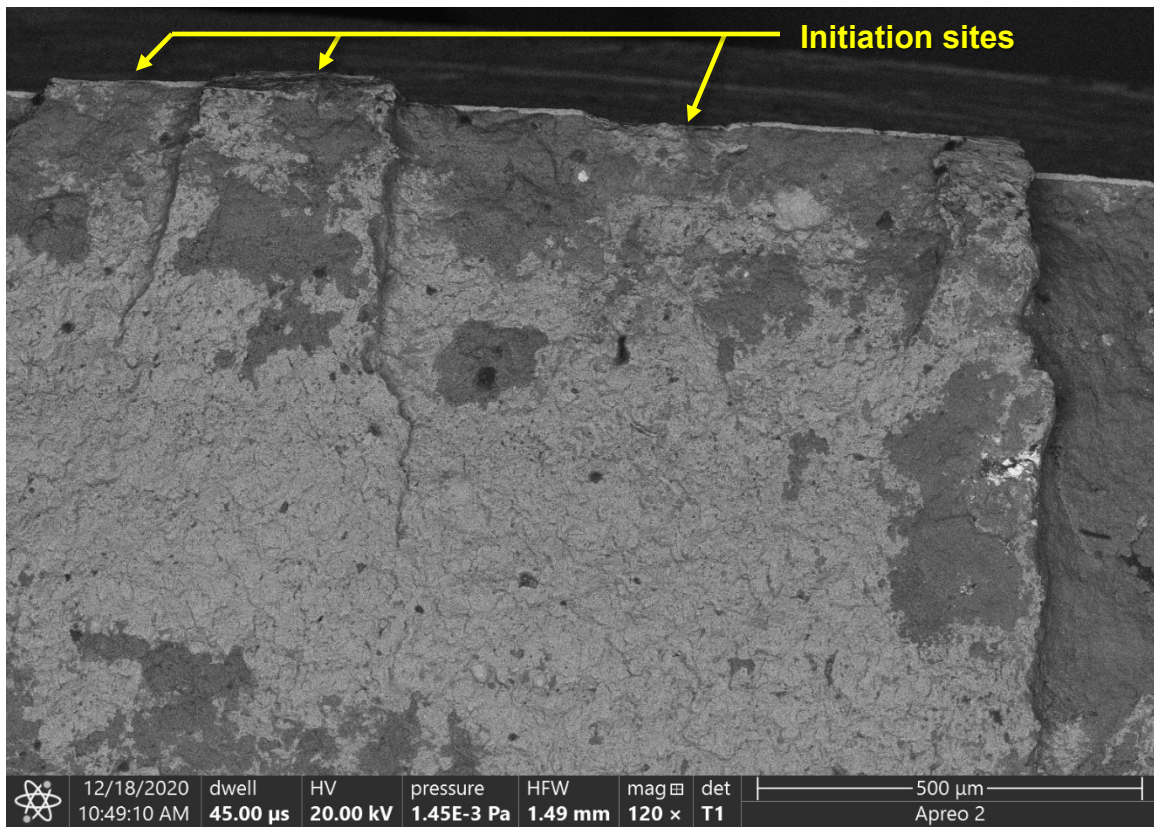


Figure 17 – Backscattered electron (BE) micrograph of the initiation sites of one of the fatigue cracks, showing multiple ratchet marks.

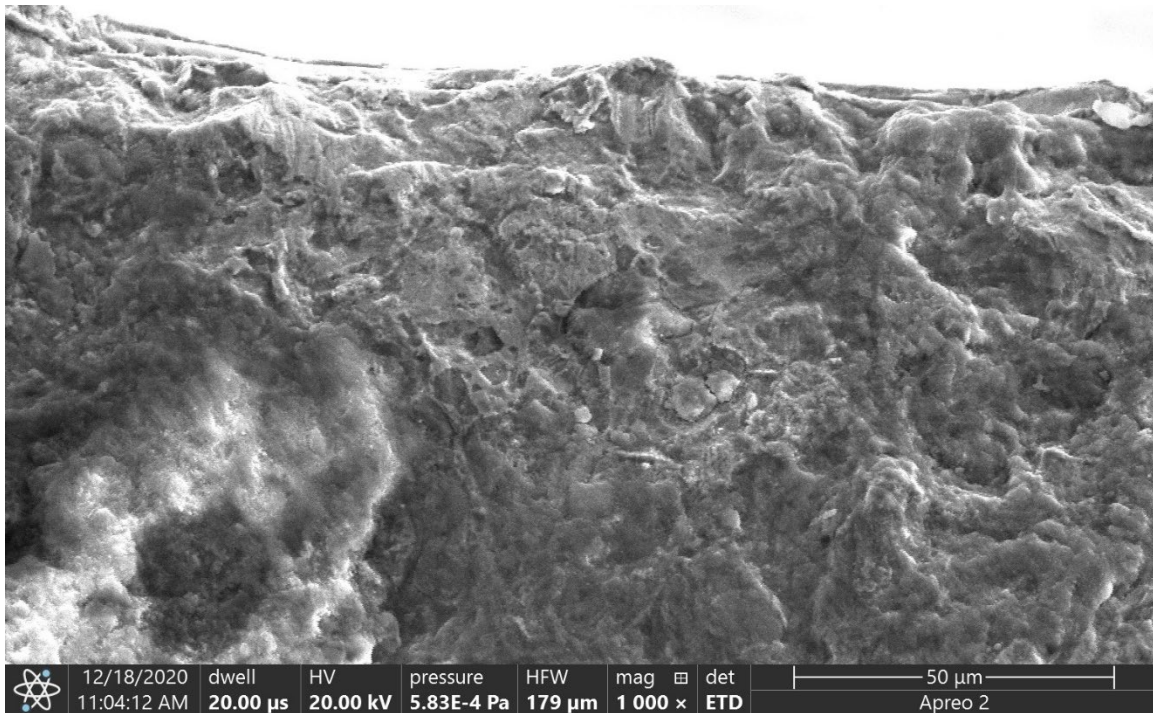


Figure 18 – SE micrograph showing one of the fatigue crack initiation sites.

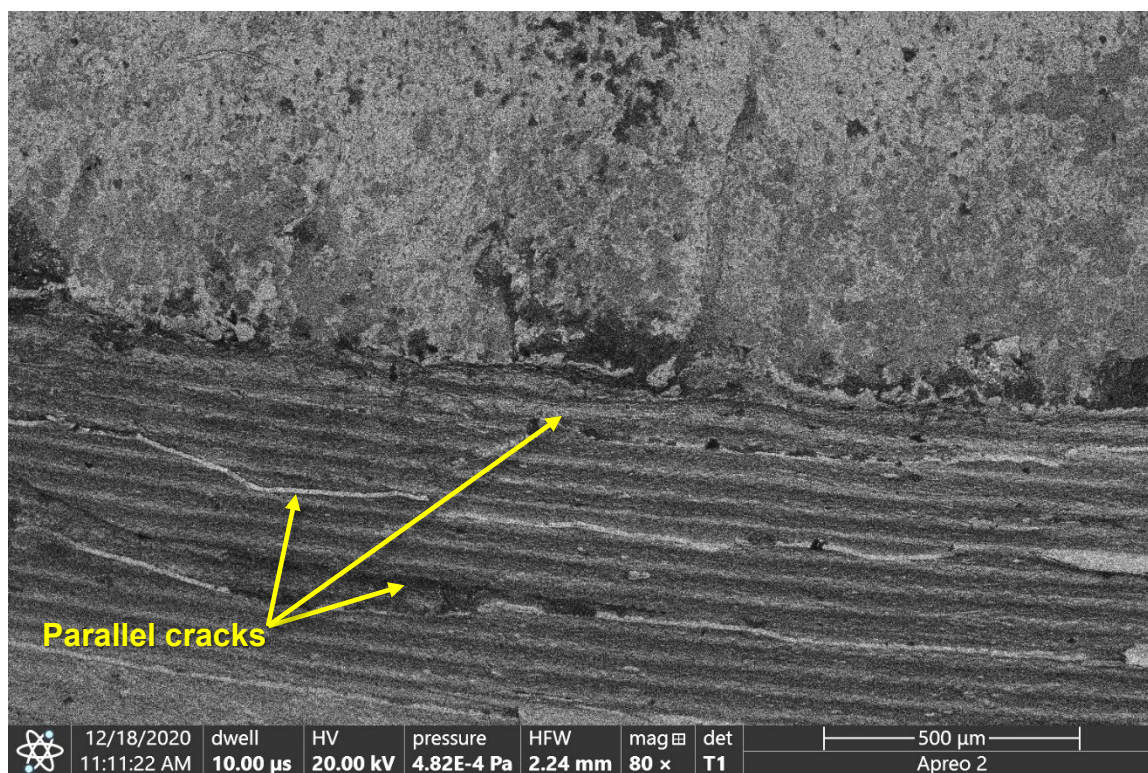


Figure 19 – BE micrograph of an angled view of the crack initiation sites, at a reverse view from Figure 18. The figure shows additional cracks below the fracture.

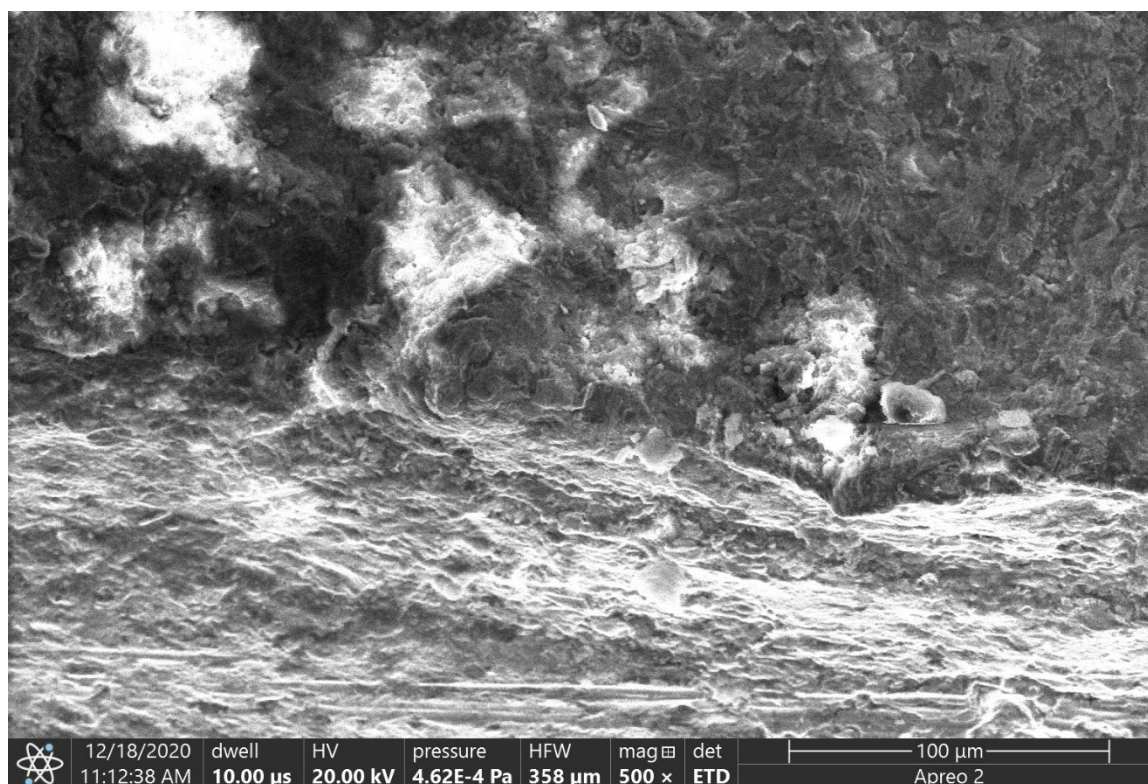


Figure 20 – SE micrograph showing a closer view one of the initiation sites in Figure 19.



Figure 21 – Bright-field (BF) optical micrograph of a cross section of the collar surface, parallel to the fracture surface, showing the adherent surface coating (~200X, etched 2% Nital).

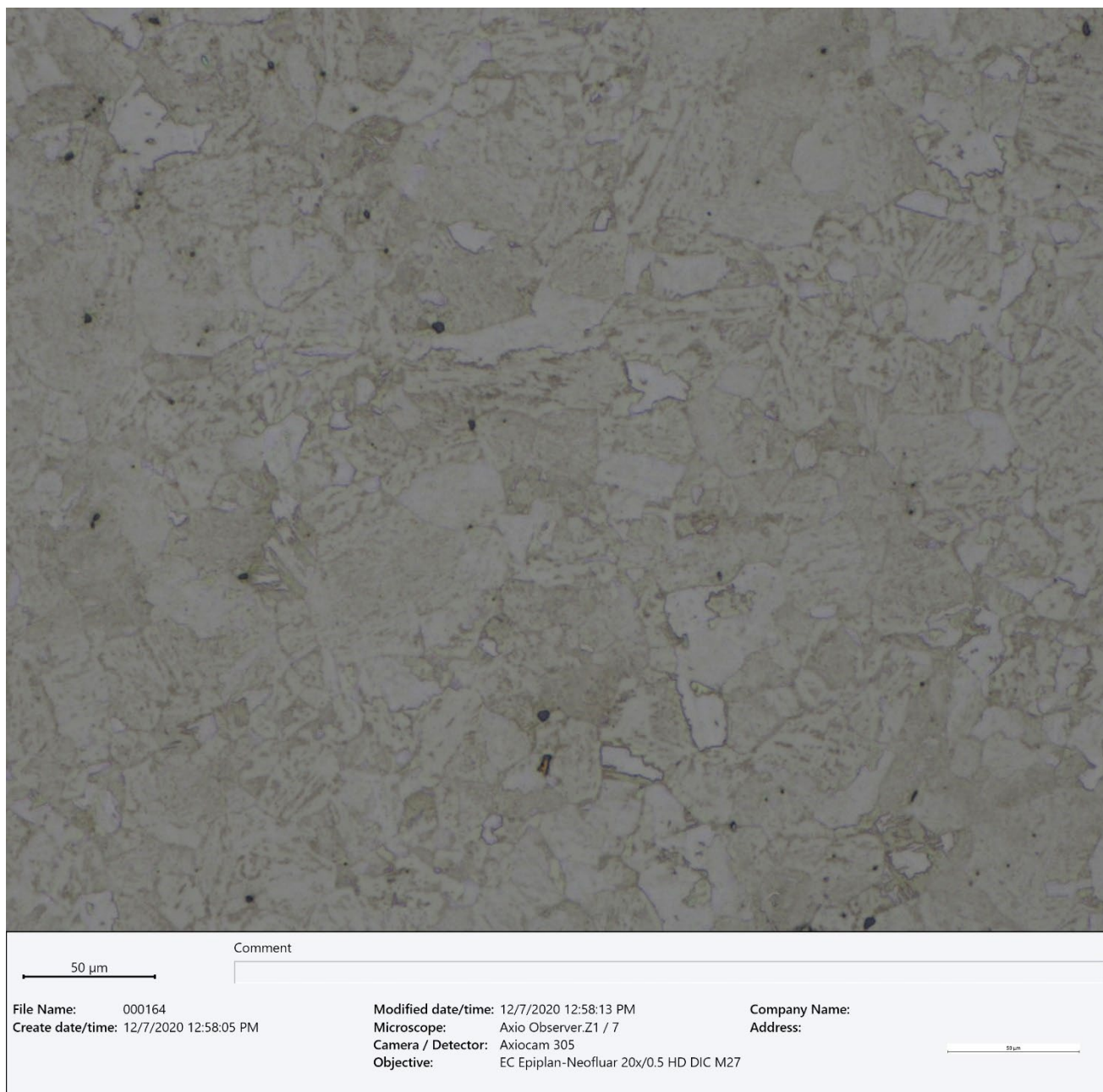


Figure 22 – BF optical micrograph of the core microstructure of the collar cross section (~500X, etched 2% Nital).

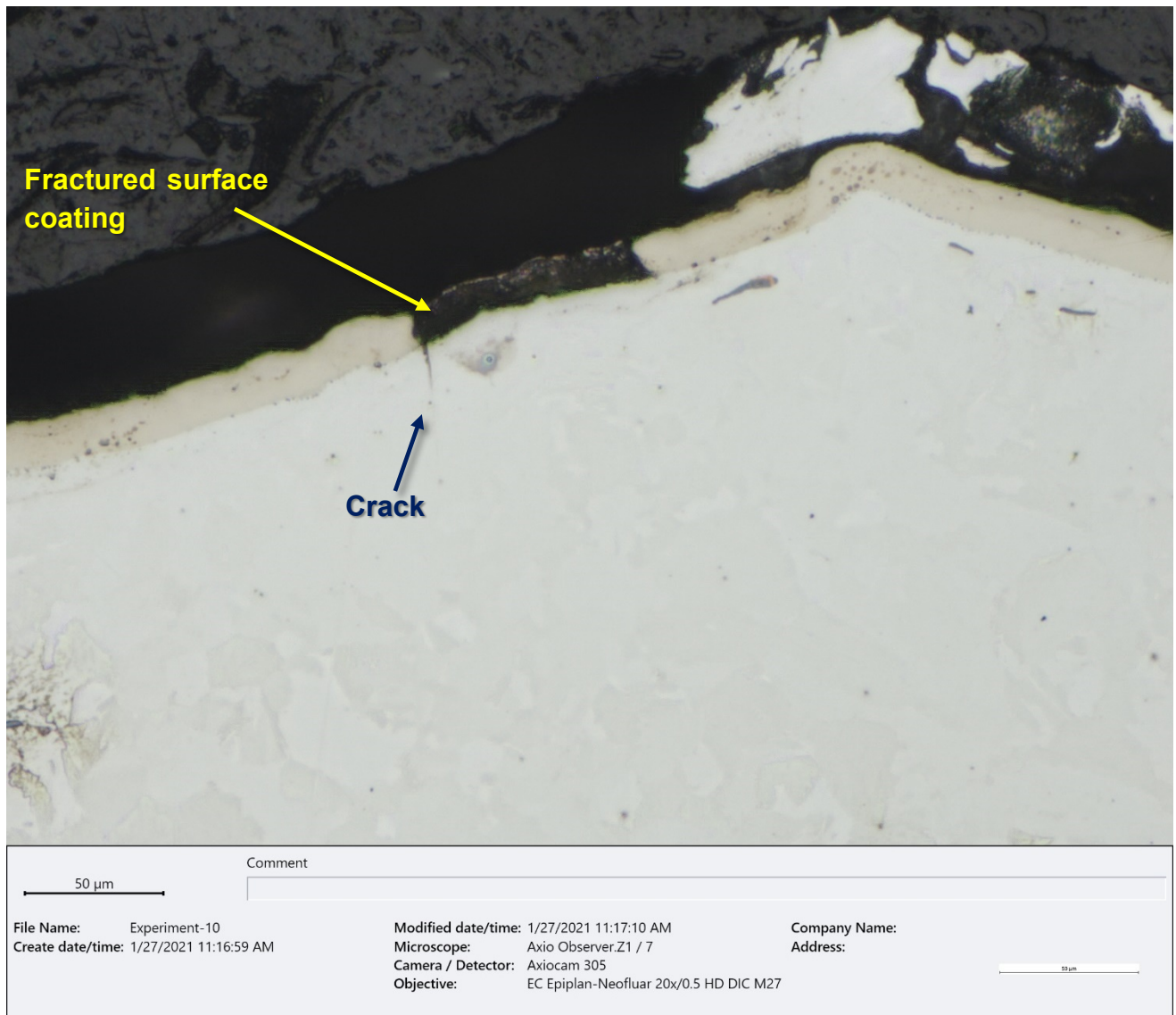


Figure 23 – BF optical micrograph of a perpendicular cross section of the collar below the fracture surface, showing missing Ni coating and a small crack (~500X, as polished).

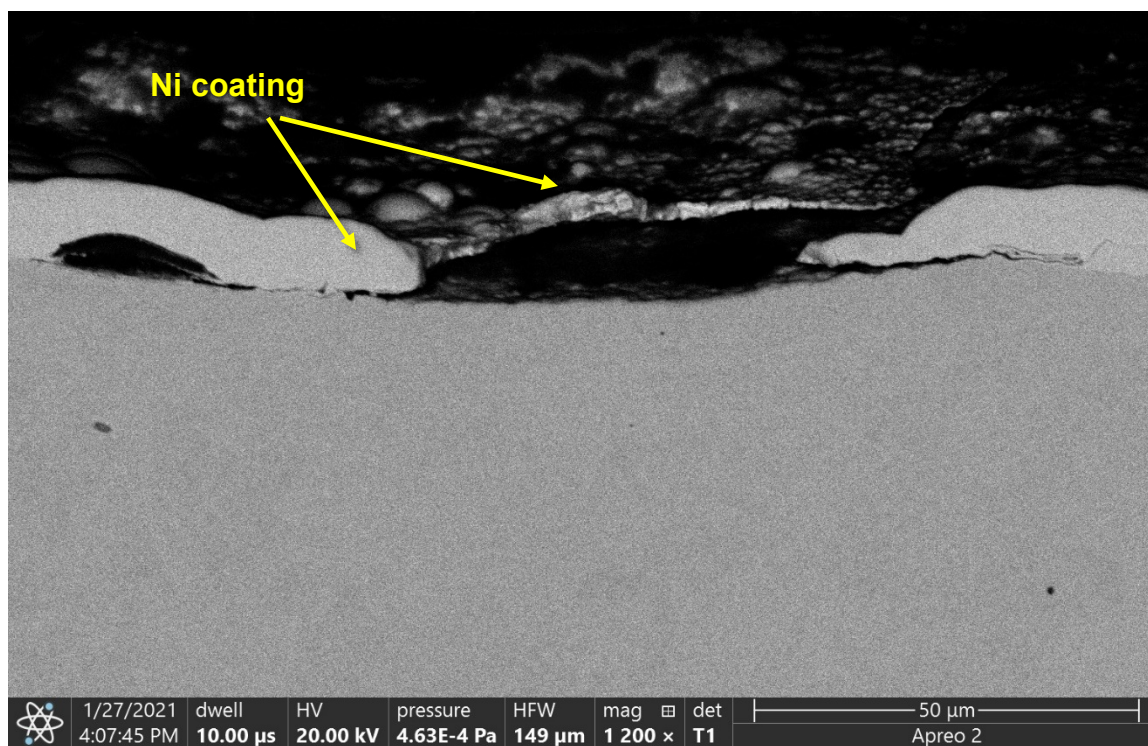


Figure 24 – BE micrograph of a fractured and missing portion of the collar Ni coating, cross-sectioned perpendicular to and below the fracture surface.

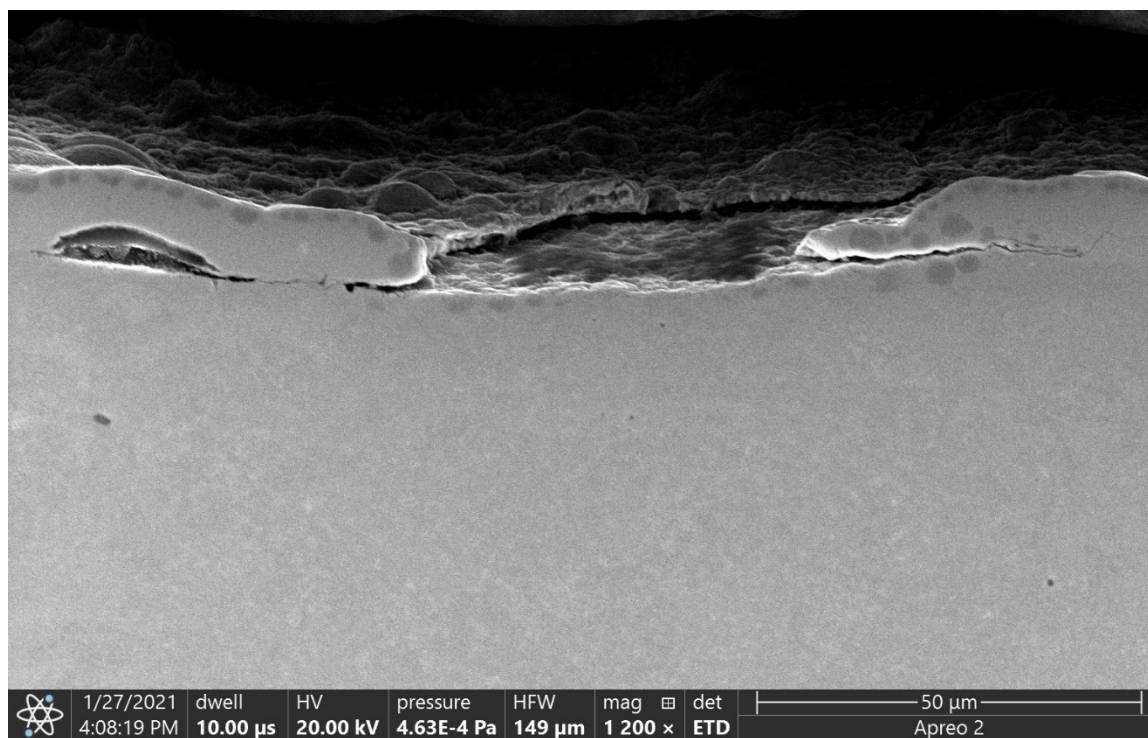


Figure 25 – SE micrograph showing the missing Ni coating in Figure 24.