

NATIONAL TRANSPORTATION SAFETY BOARD

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



March 22, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-008

1. ACCIDENT INFORMATION

Place : Phoenix, Arizona
Date : May 13, 2020
Vehicle : Mooney M20J, N201HH
NTSB No. : WPR20LA144
Investigator : Stephen Stein, AS-WPR

2. COMPONENTS EXAMINED

Remnants of #3 and #4 connecting rod parts
Crankshaft remnant with counterweights
Remnants of attachment bolts

3. DETAILS OF THE EXAMINATION

On May 13, 2020, about 0842 mountain standard time, a Mooney M20J airplane was substantially damaged during an accident near Phoenix Deer Valley Airport (DVT). The commercial pilot and passenger were not injured. According to the pilot, the purpose of the flight was to observe the airplane's performance following a propeller overhaul that was completed about 2 weeks prior. The pilot stated that during the accident flight the engine increased in rpm without any pilot input. The pilot retarded the propeller lever, and while the engine continued to function, it sounded erratic and could not be manipulated by throttle movement. After encountering catastrophic engine failure, the pilot performed an emergency landing in an area with minimal vegetation. The airplane landed and came to rest in a shallow gully. The airplane and engine were recovered for examination. After the engine teardown, several components from the Lycoming IO-360-A1B6D engine were sent to the NTSB Materials Laboratory for additional examination.¹

Figure 1 shows the crankshaft from the accident airplane engine, as received. This crankshaft had four connecting rod journals, identified as C1 through C4 from forward to aft. Overall, the crankshaft was intact, exhibiting no fractures, large cracks, or signs of gross plastic deformation.

¹ The IO-360-A1B6D, from the Lycoming family of O-360 engines, is a fuel-injected, four-cylinder, direct-drive, horizontally opposed, air-cooled, piston aircraft engines manufactured by Lycoming Engines, headquartered in Williamsport, PA.

The C3 and C4 journals did exhibit severe damage, as shown in Figure 2 and Figure 3, respectively. Each of the journals exhibited a dark, flat color, with areas of journal flattening, smearing, and localized plastic deformation. The C3 journal exhibited an area of missing material around the oil hole (Figure 2a). Both the journals had been smeared, although the smearing was more pronounced on the C4 journal (see Figure 3a). In addition, the webs and adjacent counterweight exhibited gouge marks, consistent with impact batter against other adjacent or loose components.

Both the crankshaft counterweights between the C3 and C4 positions were still attached on that web flange. The counterweights are shown in the overall crankshaft pictures in Figure 1. One of the counterweights can be seen, as received and still attached, in Figure 4 and Figure 5. The counterweight exhibited some streaks and impact marks on the outer edges, consistent with contact with adjacent parts. The markings on the aft face of part stated, "LW-19227-ASSY 6495 3804 REV N".

The counterweights were disassembled by removing the circlips, washers, and bearings. Figure 6 and Figure 7 show these parts from the counterweight assembly laid out in their as-assembled positions, from the outer-facing and inner-facing surfaces, respectively. The left side washer on forward side was unable to be removed without damaging it, since this counterweight had exhibited smearing damage over the hole. This washer can be viewed in Figure 5. Three of the washers exhibited the same markings on the outer surface, "71907 6495 12-14". The washer in the lower right in Figure 6 and Figure 7 (left washer on aft face) stated, "71907 6495 11-14". Both roller bearings exhibited the following markings on one face: "1014 V7269". The lower one depicted in Figure 6 and Figure 7 also showed "72797" on the opposite face.

The rollers exhibited two circumferential wear marks on the cylindrical surfaces. These marks were consistent with wear typical of rotational contact with the counterweight and the web flange (Figure 8). No indications of gouging, deformation, or material loss were found on the bearings. On the faces, there were circular discolorations (Figure 7). These features were consistent with the three holes on the adjacent washers, which would leave these areas of the bearing faces exposed to elevated engine temperatures and oil residues. In addition, the peripheries of the washer faces were lighter in color than the rest of the faces, consistent with either the positions of the circlips on the outer-facing surfaces, or the counterweight seats on the inner surfaces.

The other counterweight is shown, as received and still attached, in Figure 9 and Figure 10. The counterweight exhibited some streaks and impact marks on the outer edges, consistent with contact with adjacent parts. The markings on the aft face of part stated, "LW-19227-ASSY 6495 2908 REV N".

The disassembled counterweight parts are illustrated in Figure 11 and Figure 12, laid out in their as-assembled positions, from the outer-facing and inner-facing surfaces, respectively. All four washers exhibited the same markings on the outer surface, "71907

6495 12-14". Both roller bearings exhibited the marking, "1613 V7269" on one face and "14W21696" on the opposite face.

Like the previous disassembled counterweight components, the rollers exhibited two circumferential wear marks on the cylindrical surfaces, consistent with wear typical of rotational contact with the counterweight and the web flange (Figure 13). No indications of gouging, deformation, or material loss were found on the bearings. On the faces, there were also the triad of circular discolorations (Figure 12), consistent with the three holes on the adjacent washers. The outside circumferential areas of the washer faces were lighter in color than the rest of the faces, consistent with either the positions of the circlips on the outer-facing surfaces, or the counterweight seats on the inner surfaces.

Figure 14 shows the attachment bolt remnants from the connecting rods from C3 and C4, after disassembly and staging. Both bolts from the C3 position had fractured—one exhibited necking adjacent to the fracture surface, with a cup and cone morphology, and the other exhibiting a slanted fracture surface. Both fracture surfaces were dull in luster, with a rough, fibrous surface appearance. These features were consistent with the bolts having fractured in tensile overstress.

The attachment bolts from the C4 position, shown in Figure 14b, had also fractured along the shafts. These remnants exhibited more impact marks and batter, consistent with post-fracture impact damage. Both fractures exhibited a general cup-and-cone shape, with necking adjacent to the fracture surfaces. The fracture surfaces were dull in luster, with a rough, fibrous texture. These features were consistent with fracture from overstress. One of the bolt fragments also exhibited an angled bend, with a nut remnant that had fractured—it could not be determined if these fractures and deformations were consistent with post-fracture damage.

Figure 15 shows the fractured remnants of the C3 connecting rod cap and a remnant of the connecting rod journal yoke. The cap had fractured near the midpoint, with material thinning and twisting significant enough to obscure any potential fracture features. Both these pieces exhibited sharp gouge marks, deep enough to deform material outward. The edges of the pieces had been battered and torn, particularly around the bolt holes. These features were consistent with post-fracture impact damage.

Figure 16 and Figure 17 show some of the inner surface of the C3 cap piece. Multiple deep gouges are shown in Figure 16, consistent with impacts with adjacent components severe enough to plastically deform the surrounding material. As shown in Figure 17, there were multiple features consistent with deep cracks, generally oriented perpendicular to the cap rotation direction.

Figure 18 shows the remnants of the C4 connecting rod cap, as received. While had also fractured in the middle, in contrast to the C3 cap remnants, these pieces exhibited a relatively flat fracture, oriented perpendicular to the cap direction. Figure 19 illustrates the flat fracture surface of the C4 cap remnant, oriented toward the reader. The figure was annotated to show several of the prominent features of the surface. Much of the surface

exhibited reflective regions and rounding with vertical streaks (as depicted in the figure). These features were consistent with post-fracture smearing damage. The surface also exhibited ridges (oriented vertically), consistent with ratchet marks, indicative of multiple crack initiation sites.

Figure 20 shows a closer view of the inner surface edge between two ratchet marks. This region exhibited crack arrest marks, consistent with crack propagation. These features were consistent with having emanated out from an initiation site, highlighted on the lower edge in Figure 20. The fracture surface was examined using a scanning electron microscope (SEM). The regions with crack arrest marks exhibited fatigue striations, consistent with fatigue crack propagation (see Figure 21).

Figure 22 shows a closer view of one of the fatigue crack initiation sites, viewed from the edge. As shown in the figure, this edge had been rounded, consistent with post-fracture damage. Fatigue striations were observed propagating from the site at this location, denoted by the yellow-dashed arrows. A vertical-oriented crack on the inner surface was co-located at the crack initiation site.

Figure 23 is a backscattered electron micrograph of the area in Figure 22.² The figure shows a darker-colored material along the inner surface of the cap remnant. This material, which had lower average atomic number, was consistent with a surface layer or compound different in composition than the underlying metal alloy. The lack of this layer, along with the rounding along the edge, were consistent with material lost along these surfaces. The figure also shows fatigue striations emanating from the initiation site, collocated with a vertical crack. More severe damage was found along the fracture surfaces edges on the sides of the cap, as typified in Figure 24. This figure shows not only the vertically oriented cracks, but additional horizontal-oriented cracks. These coincided with missing chunks of material and other fractures.

Figure 25 shows a macroscopic view of the fractured C4 cap inner surface. This figure shows multiple secondary cracks below the fracture surface—these cracks were oriented parallel to the fracture surface (or perpendicular to the cap direction). The inner surface also exhibited streaks and bluing, oriented along the rotation direction (or perpendicular to the fracture surface and cracks). These streaks were associated with areas of missing or spalled material, located farther away from the fracture surface, as demonstrated in Figure 26.

Figure 27 shows a closer view of the spalled areas along the inner race or surface of the C4 cap remnant. These elongated dark regions were consistent with missing material. Their jagged nature was consistent with material spalling from abrasive wear. Figure 28 shows a closer view of the inside of the larger spalled region in the lower middle

² Backscattered electrons – SEM micrographs produced using backscattered electrons display contrast that is associated with the atomic numbers of the elements in the micrograph. Materials comprised of elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

of Figure 27. This revealed a faceted morphology, consistent with an intergranular surface quality. There was also some smearing and deformation, consistent with wear.

Figure 29 shows a microscopic view of one of the parallel cracks seen in Figure 25 and Figure 26. As demonstrated in Figure 29, the cracks were associated with a lack of or missing surface material, which was consistent with a material of lower average atomic number. The fracture patterns in the missing material were consistent with wear or spalling of the surface layer with the crack development seen in the figure. The cracking was primarily horizontal in the figure (oriented parallel to the fracture surface), with branching secondary cracks along the rotation direction of the inner race. The cracks penetrated into the underlying cap alloy.

A cross-section of the C4 cap was sectioned, mounted, and polished to facilitate metallographic examination. Figure 30 shows a typical view of cracks observed penetrating from the surface. As shown in the figure, the cracks were consistent with having initiated at the inner surface (bottom of figure) and having propagated into the cap material in an intergranular path. These cracks were located with non-metallic material, shown as dark gray areas near the surface.

While the cracks in Figure 30 had propagated into the cap material perpendicular to the surface, multiple cracks were found that were oriented generally parallel to the surface, as illustrated in Figure 31. Typical of the cracks witnessed, these cracks exhibited branching in multiple directions.

Overall, the microstructure of the cap was fairly uniform, even near the surface where the cracks were observed in Figure 30 and Figure 31. However, toward the edges, the microstructure was found to have changed, along with cracking and spalling/flaking of material. Figure 32 demonstrates an area along the edge, and Figure 33 highlights the damaged region. The damaged area exhibited a lighter color when etched, along with larger grains closer to the surface and resolutioning of second phase constituents. This damaged layer exhibited cracking parallel to the surface. In contrast, the core microstructure exhibited a microstructure consistent with tempered martensite (Figure 34).

The chemical composition of the sectioned tube was examined using x-ray fluorescence (XRF) and energy dispersive x-ray spectroscopy (EDS). From the data obtained using these techniques, the propeller was found to be consistent with an alloy steel such as Type 4130. The hardness was inspected per ASTM E18.³ The hardness averaged 33 HRC. These data were typical of this alloy and microstructure.

Figure 35 and Figure 36 show backscattered electron micrographs of the cross-sectioned cracks in the C4 cap. These cracks exhibited darker-contrast material. Examination using EDS found this material to be consistent with an iron oxide. Figure 37 shows the cracks seen optically in Figure 30. Consistent with the gray-colored material in that figure, the micrograph in Figure 37 shows the material was non-metallic (see Figure

³ ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

38). EDS examination of this material found it to be an iron oxide with minor amounts of Na, Ca, and P.

Figure 39 shows a cross section of the inner surface, at an area where the surface material shown in Figure 29 was still adherent. Figure 39 shows a darker middle layer, just above the metal substrate, and an outer lighter layer with white-colored particles. EDS examination of the middle layer found it to be consistent with an iron oxide with minor amounts of Na, Ca, and P. The outer layer consisted of iron and oxygen, but also high levels of Pb and Br, with minor amounts of Cu, S, P, and Ca. This outer layer was consistent with the lead-based oxide deposits that occur in reciprocating engines due to the use of tetraethyllead in avgas fuel.

Erik M Mueller
Materials Research Engineer



Figure 1 – A view of the crankshaft, as received.

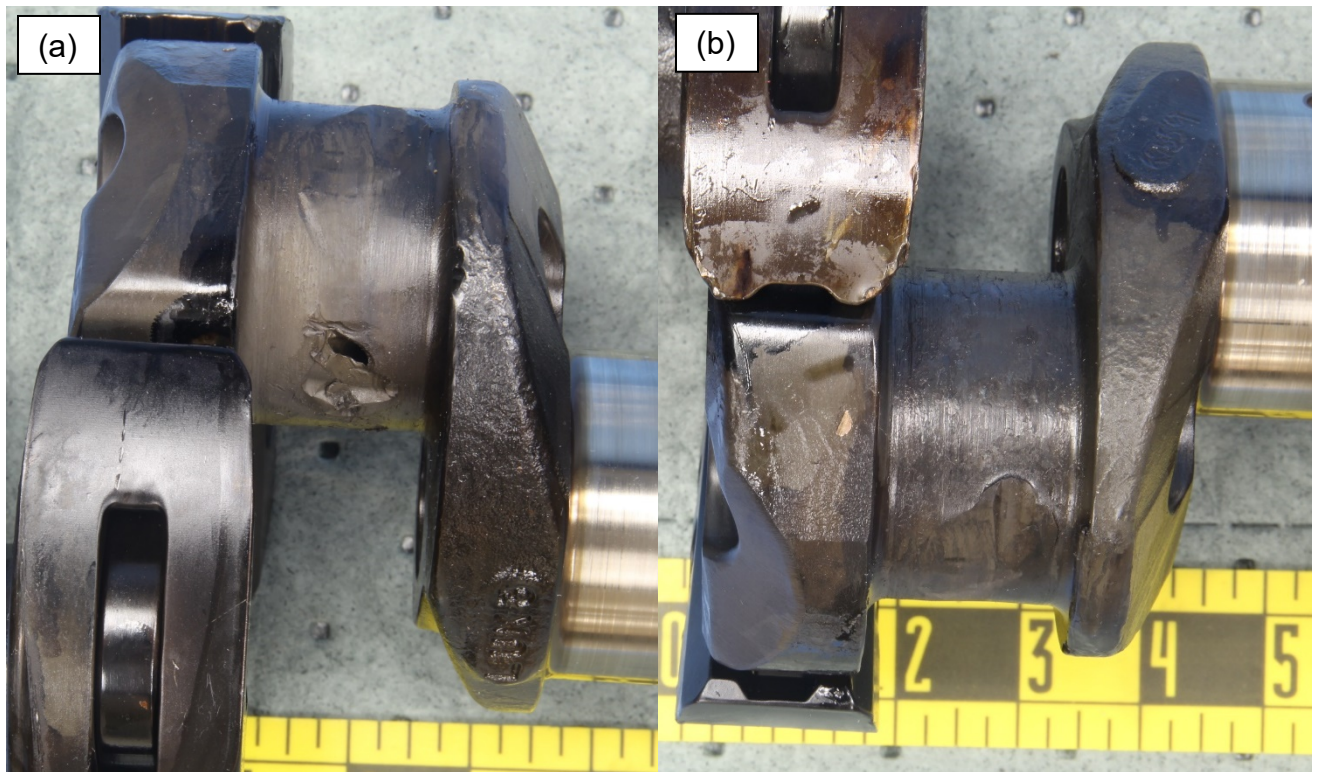


Figure 2 – View of the damaged C3 journal from (a) the top view and (b) a side view.

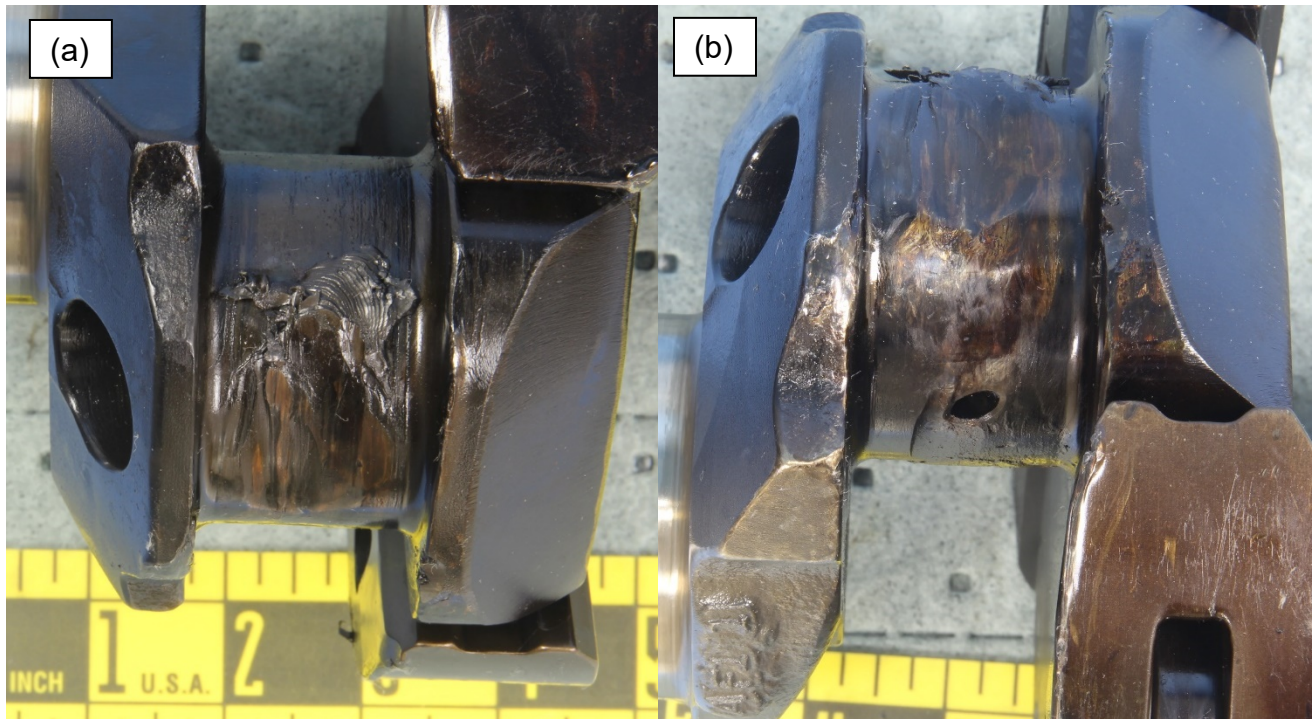


Figure 3 – View of the damaged C4 journal from (a) the top view and (b) a side view.

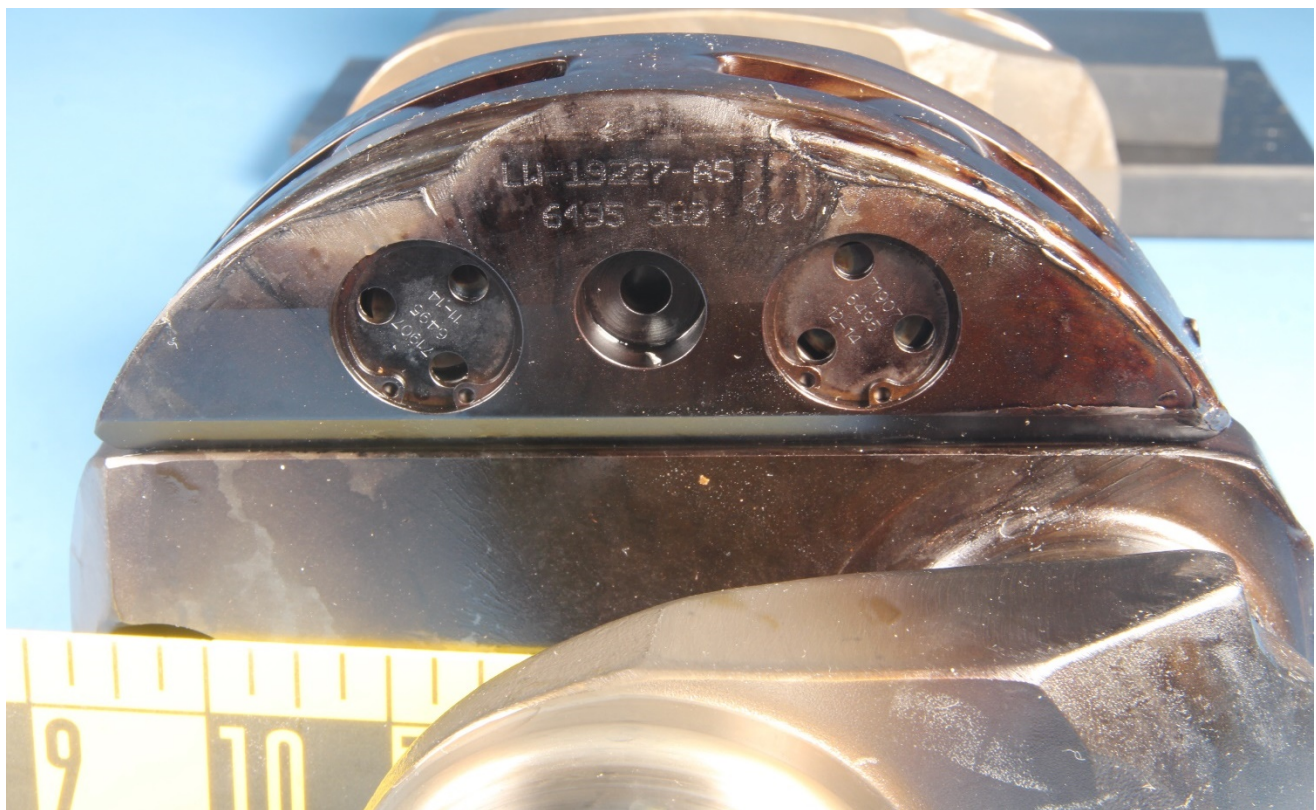


Figure 4 – View of one of the counterweights, as attached to the crankshaft, viewed aft looking forward.



Figure 5 – The counterweight in Figure 4, viewed forward looking aft.

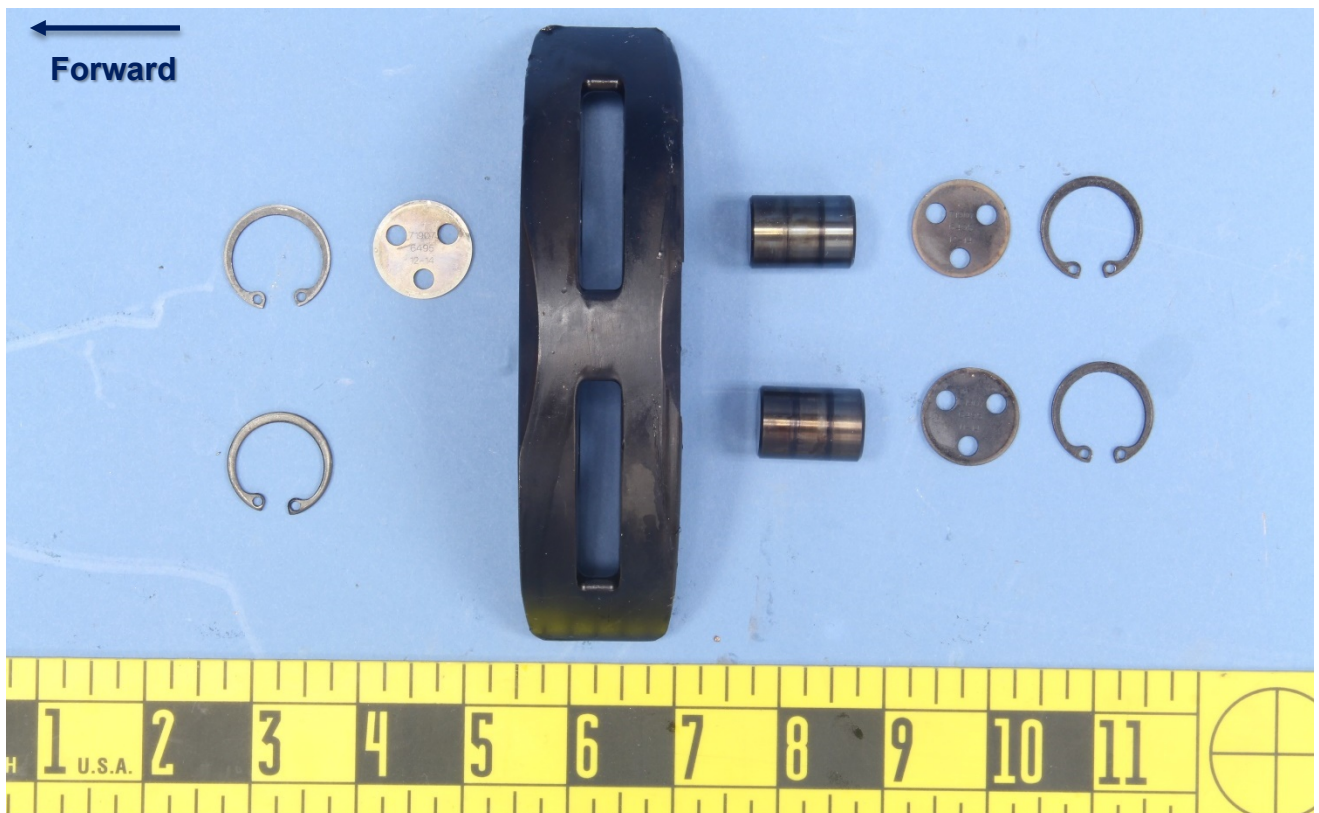


Figure 6 – View of the components of the counterweight in Figure 5, after disassembly. The washers and circlips are viewed from the outside, and the bearings are viewed on the side.

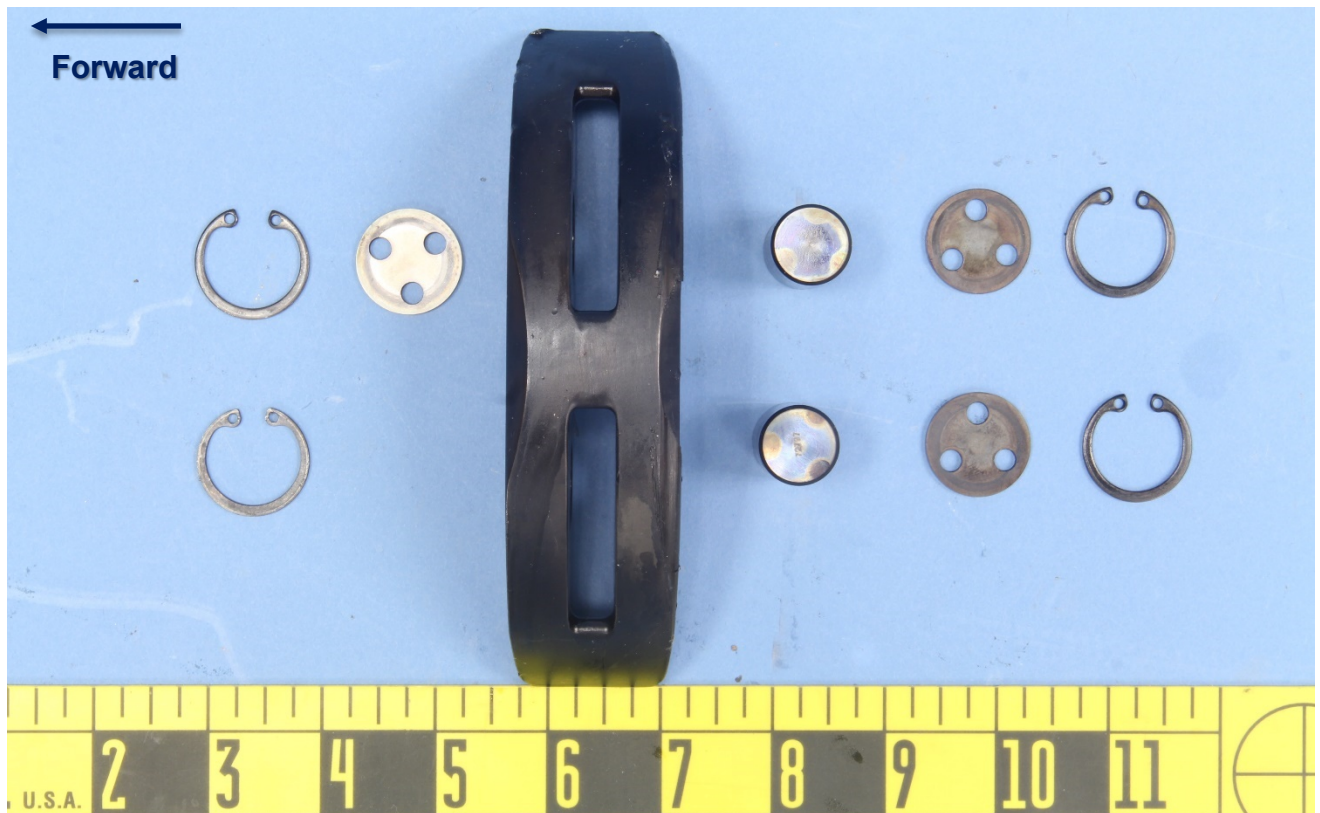


Figure 7 – The counterweight components in Figure 6, viewed from the inside surfaces with the bearings viewed from the side.



Figure 8 – View of (a) the aft circlips and washers with the bearings and (b) the forward circlips and washer.



Figure 9 – View of the other counterweight, as received, viewed aft looking forward.



Figure 10 – The counterweight in Figure 9, viewed forward looking aft.



Figure 11 – View of the components of the counterweight in Figure 10, after disassembly. The washers and circlips are viewed from the outside, and the bearings are viewed on the side.



Figure 12 – The counterweight components in Figure 11, viewed from the inside surfaces with the bearings viewed from the side.



Figure 13 – View of (a) the aft circlips and washers with the bearings and (b) the forward circlips and washer.

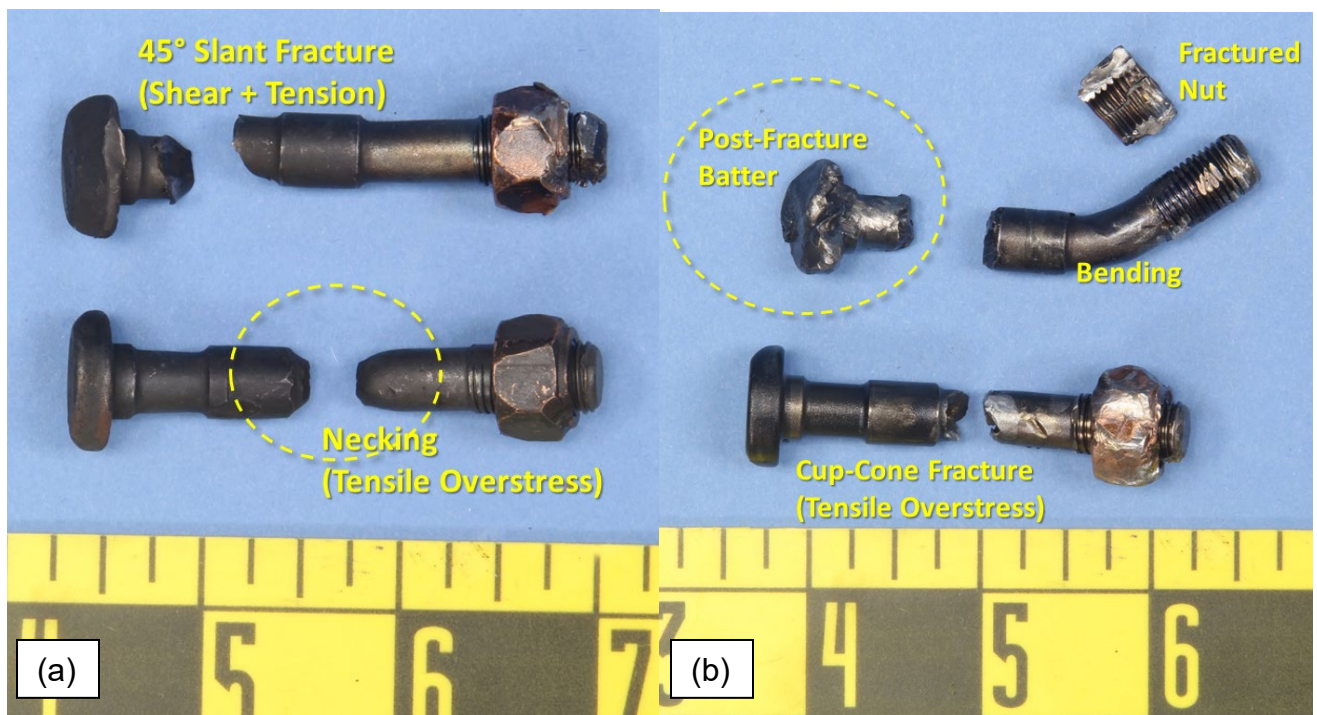


Figure 14 – View of the fractured attachment bolts from (a) the C3 connecting rod remnants and (b) the C4 connecting rod remnants, annotated to show fracture and damage features.



Figure 15 –The remnants of the C3 connecting rod cap (upper part of figure) and a piece of the connecting rod (lower).



Figure 16 – View of the inner surface of the C3 cap remnant, showing gouges and rumpling near the fracture.



Figure 17 – View of the inner surface of fractured C3 cap remnant, showing a series of cracks parallel to the fracture surface.

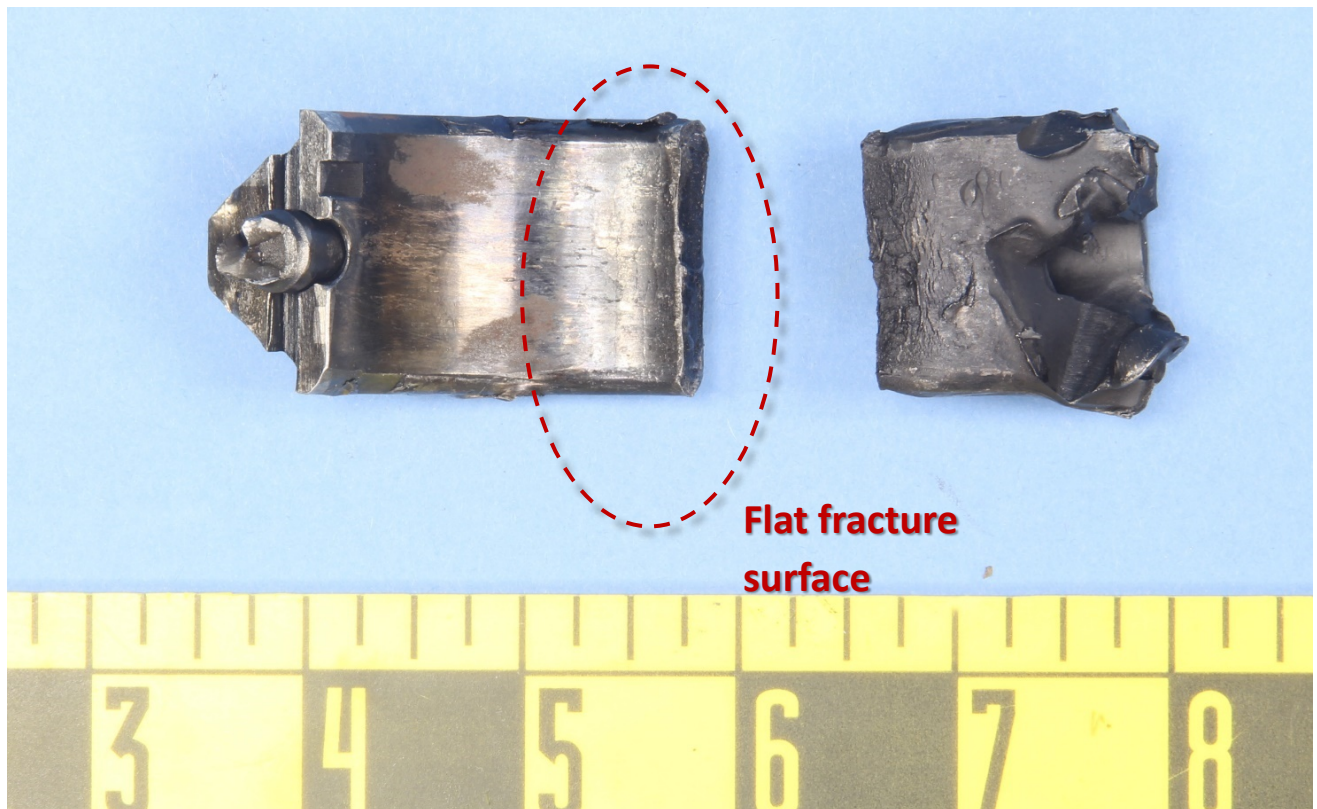


Figure 18 – The remnants of the C4 conrod cap, showing a flat fracture highlighted in Figure 19.

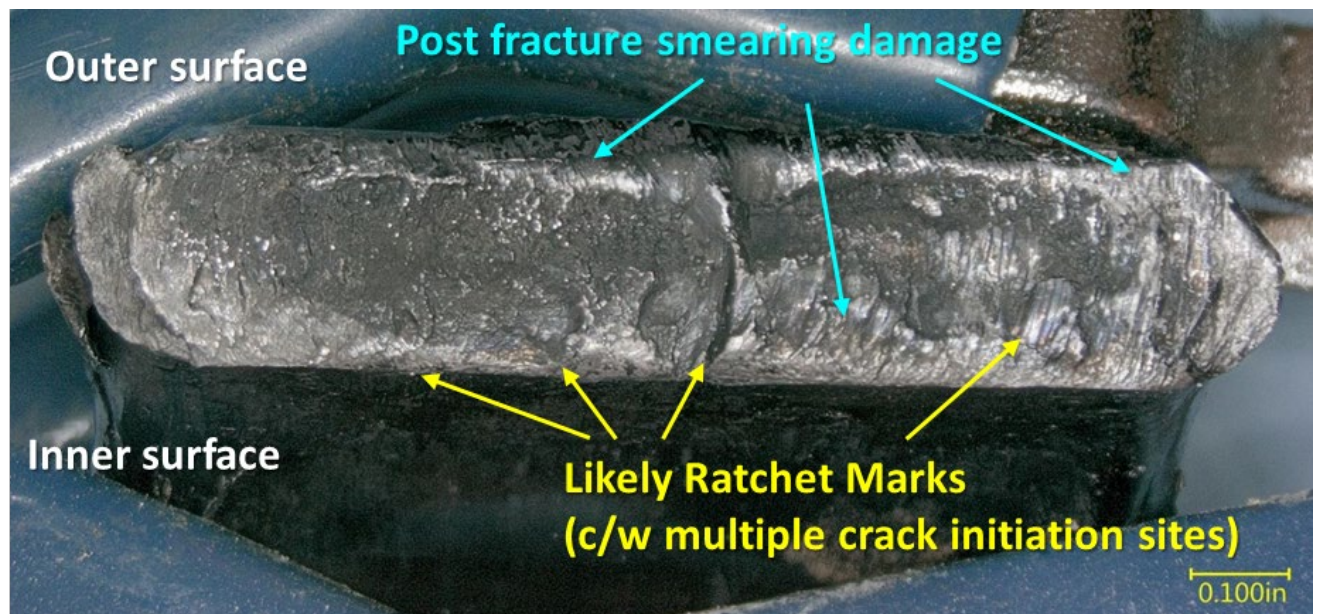


Figure 19 – View of the fracture surface of the C4 cap remnant with features annotated.

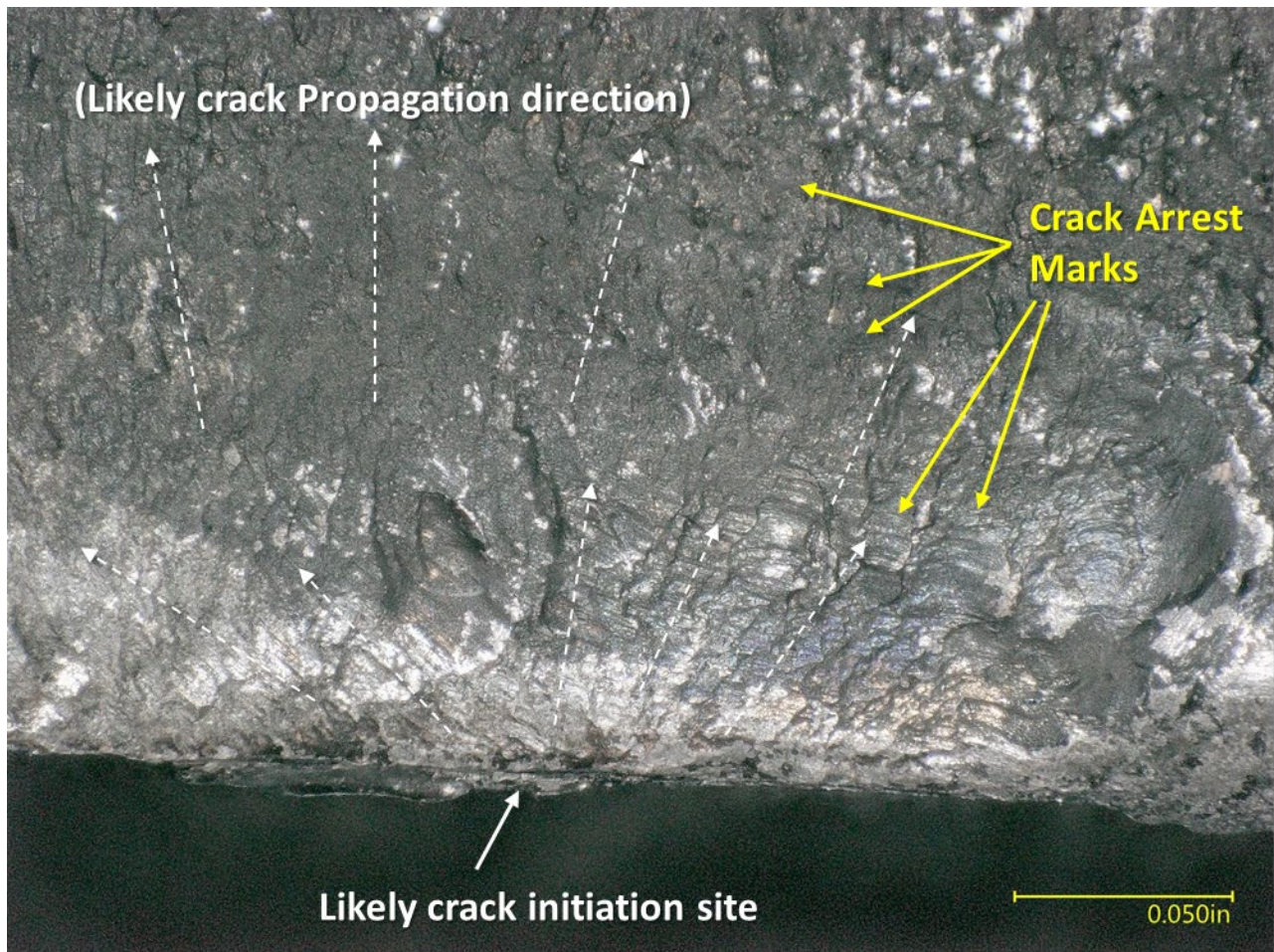


Figure 20 – View of a likely crack initiation site on the C4 cap fracture surface.

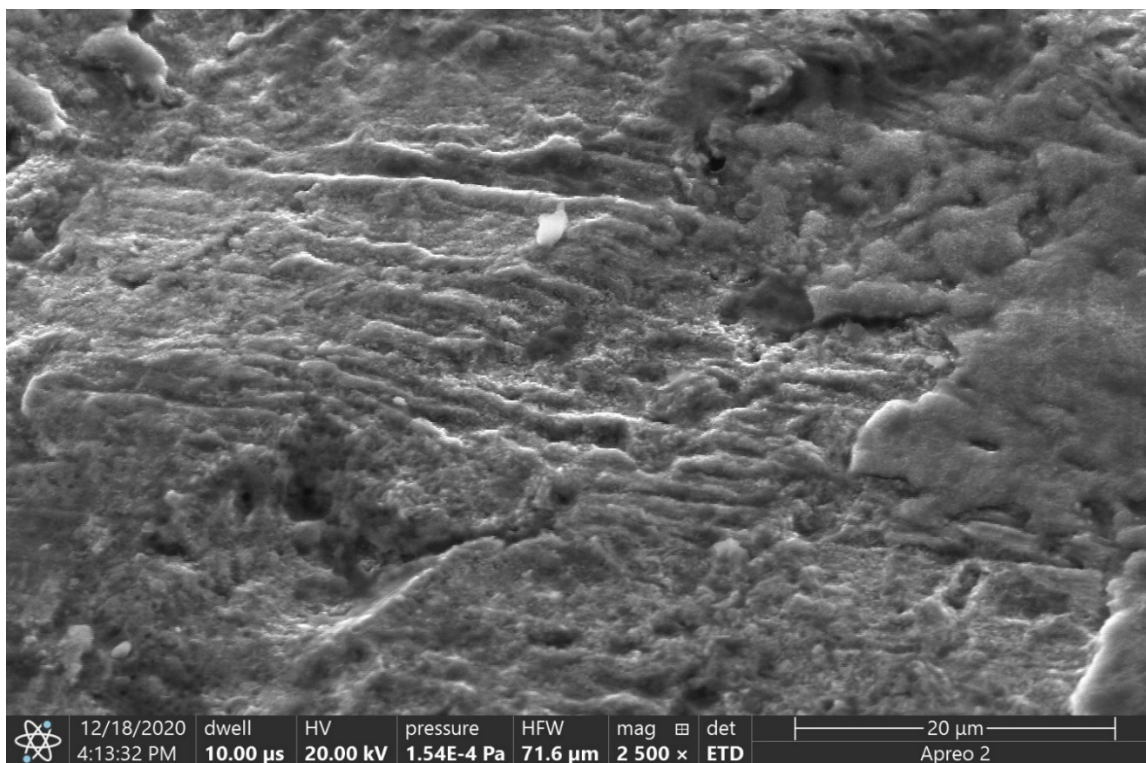


Figure 21 – Secondary electron (SE) micrograph view of the C4 cap fracture surface, showing fatigue striations.

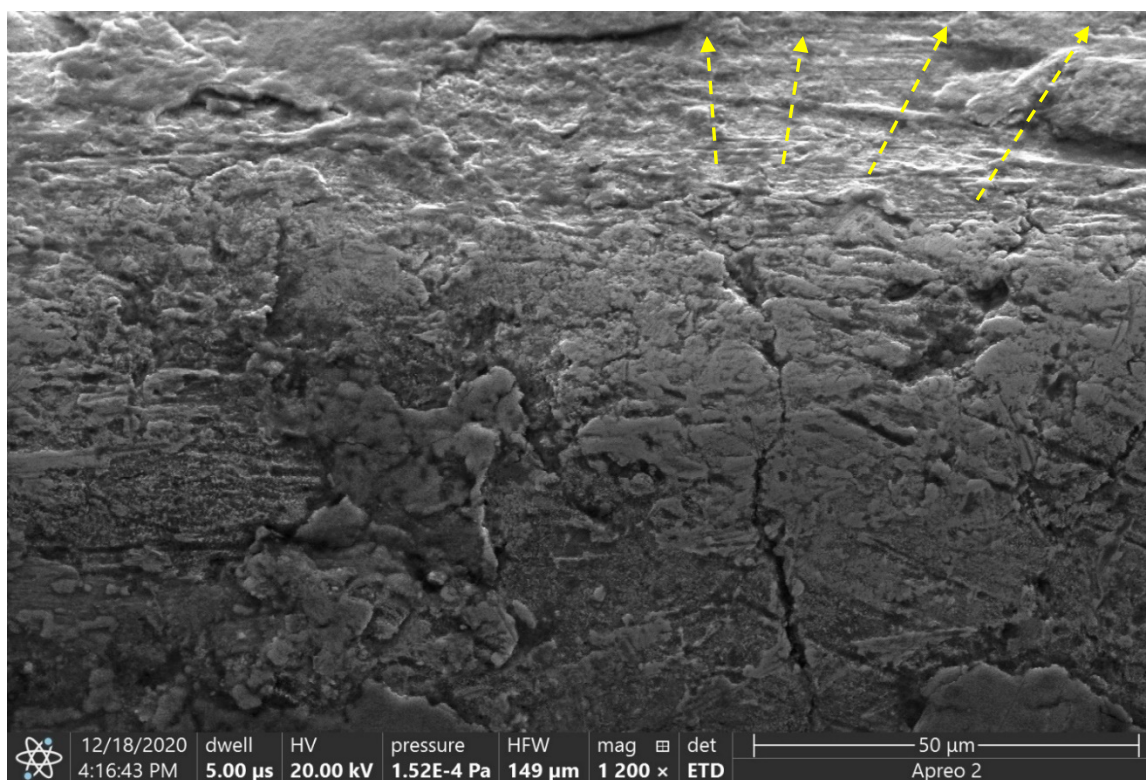


Figure 22 – SE micrograph of the rounded edge of the C4 cap fracture surface, showing fatigue striations emanating upward (arrows).

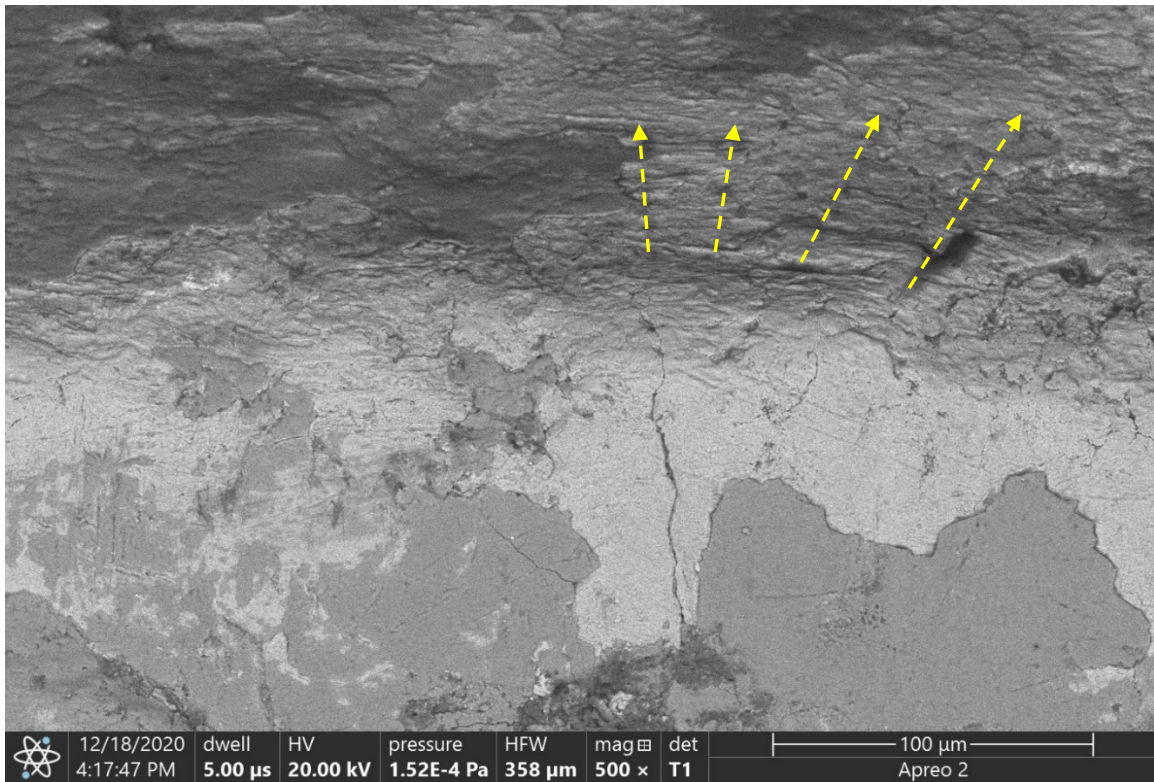


Figure 23 – Backscattered electron (BE) micrograph of the edge in Figure 22.

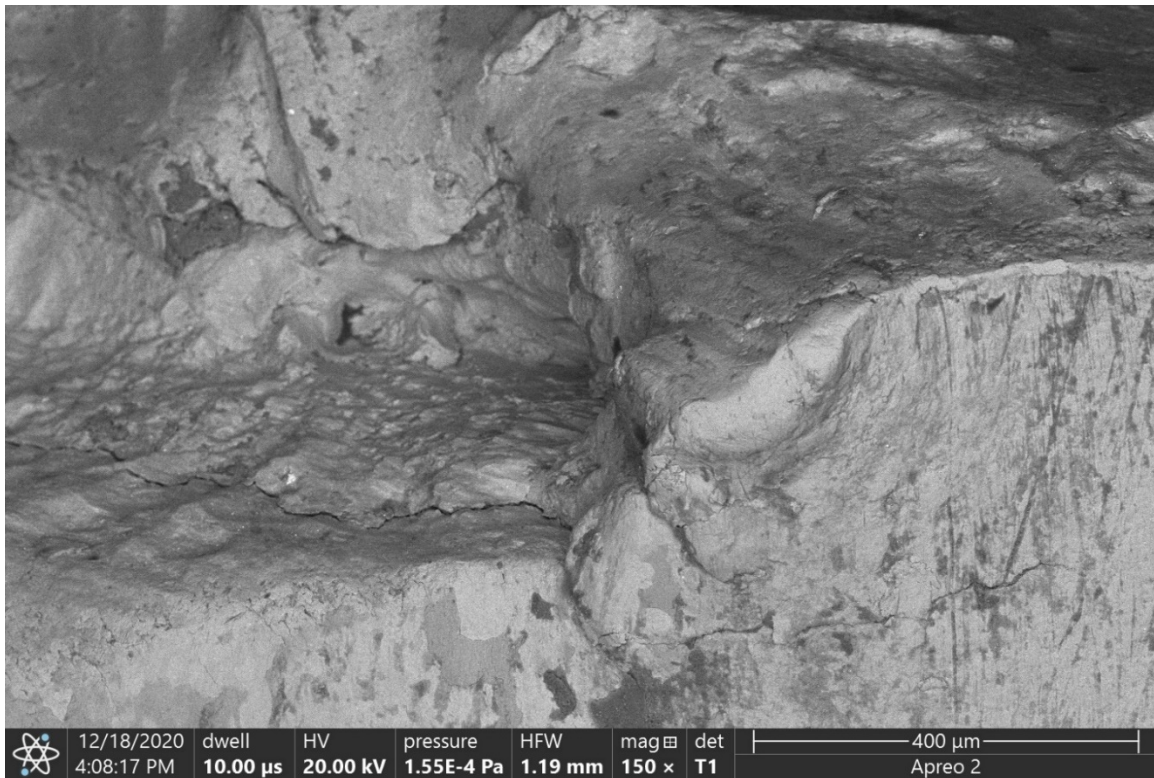


Figure 24 – BE micrograph of spalled material and cracking on the side edge of the cap remnant fracture.



Figure 25 – Angled view of the inner surface of the C4 cap, showing parallel cracks below the fracture surface.



Figure 26 – Oblique view of the inner surface of the C4 cap, showing cracks and spalled material.



Figure 27 – Closer view of the spalled material on the inner surface of the C4 cap remnant.

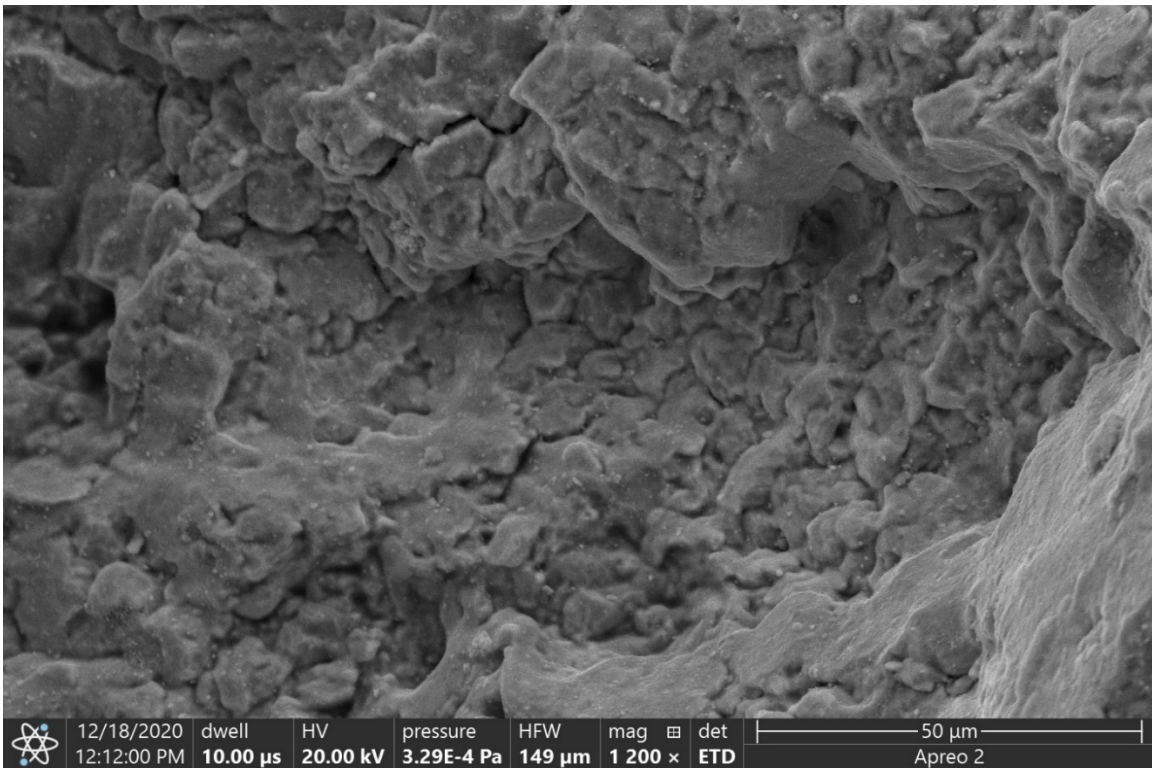


Figure 28 – SE micrograph of the inside of a spalled material streak in Figure 27.

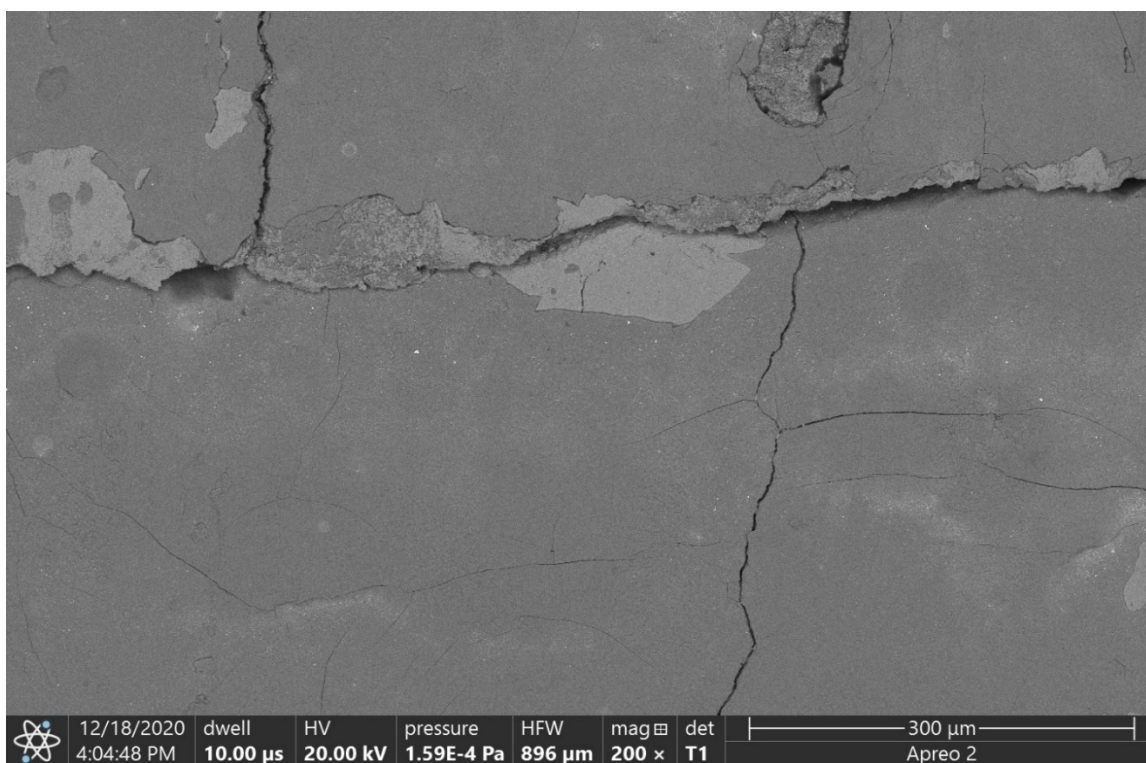


Figure 29 – BE micrograph of one of the parallel cracks on the C4 inner surface.



Figure 30 – Bright-field (BF) optical micrograph of a cross section through the C4 inner surface, showing multiple cracks (~200X, etched 2% Nital).



Figure 31 – BF optical micrograph of cracks perpendicular and parallel to the inner surface of the C4 cap remnant (~200X, etched 2% Nital).

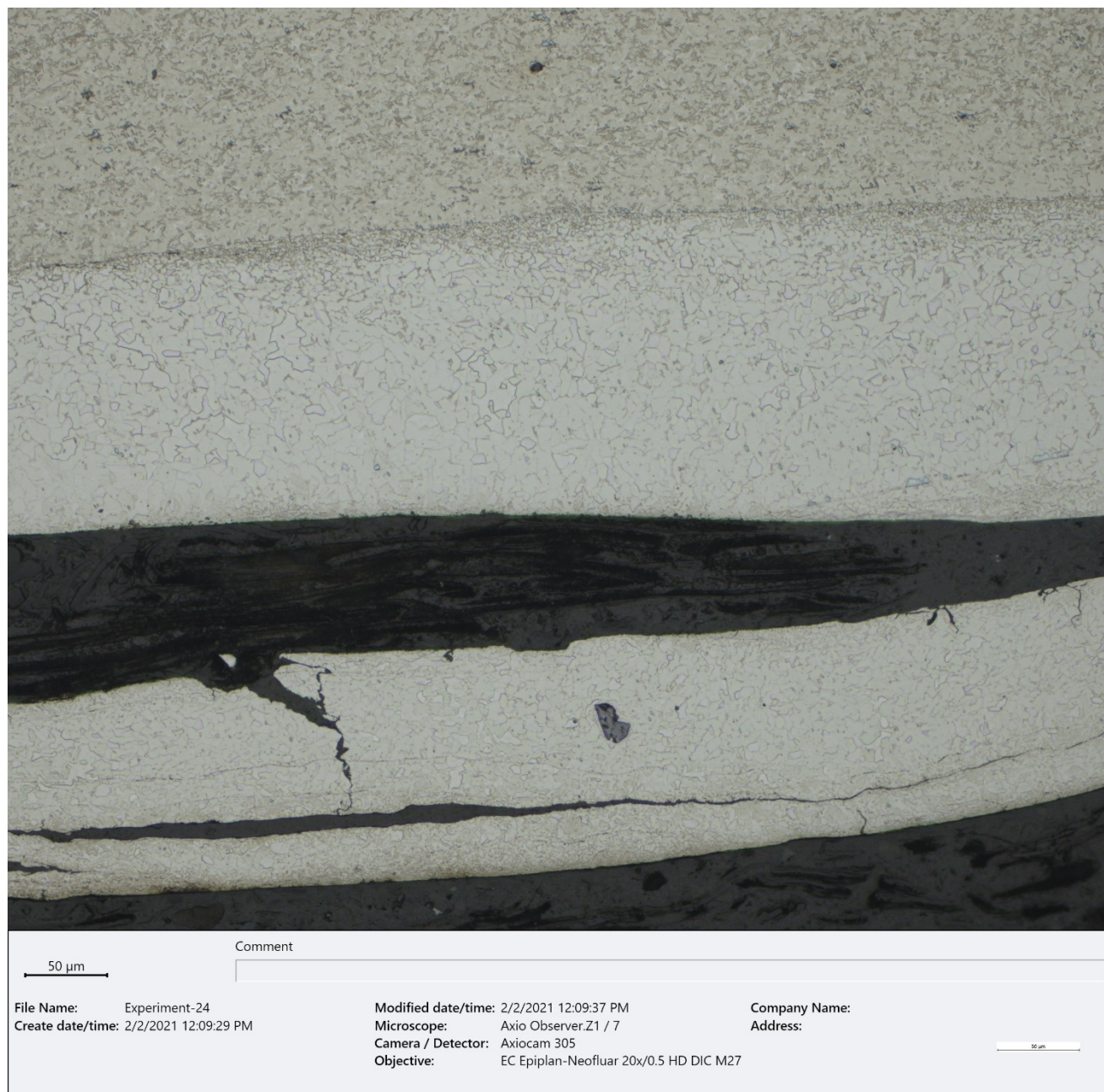


Figure 32 – BF optical micrograph of spalled and heat-damaged inner surface regions of the C4 cap remnant (~200X, etched 2% Nital).

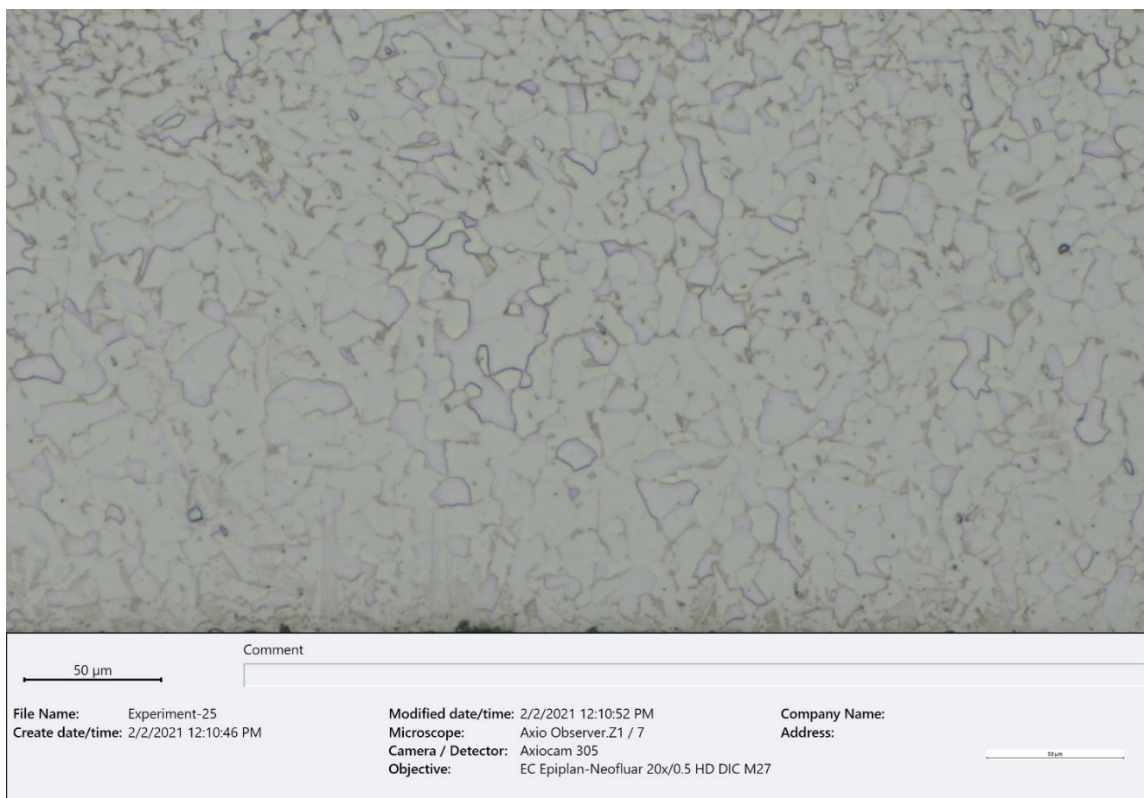


Figure 33 – BF optical micrograph of the heat damaged surface region in Figure 32, showing larger equiaxed grains (~500X, etched 2% Nital).



Figure 34 – BF optical micrograph of a typical region of the cap core microstructure (~500X, etched 2% Nital).

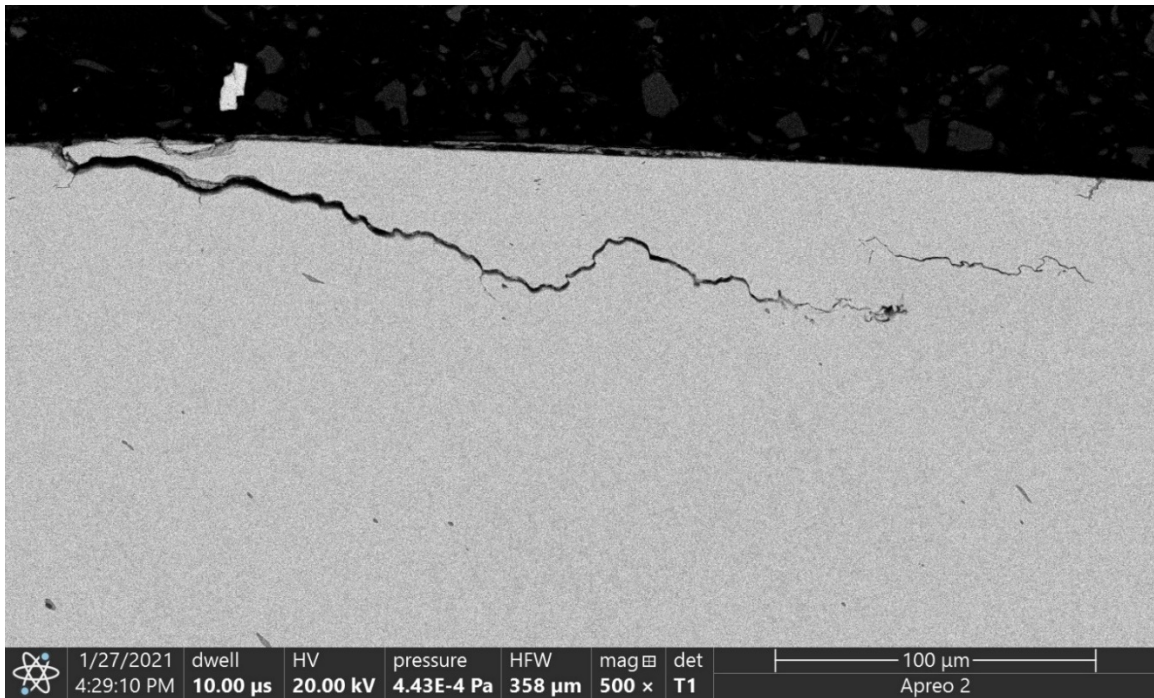


Figure 35 – BE micrograph of one of the inner parallel-oriented surface cracks.

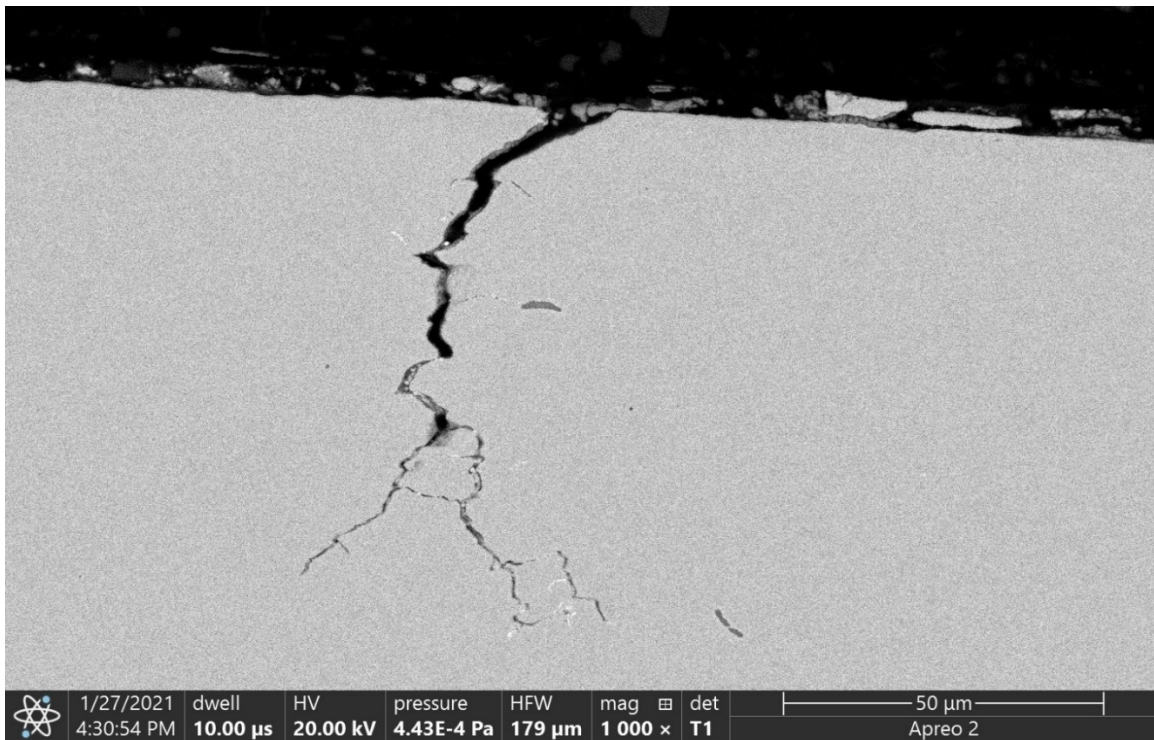


Figure 36 – BE micrograph of one of the perpendicular-oriented cracks, showing intergranular quality.

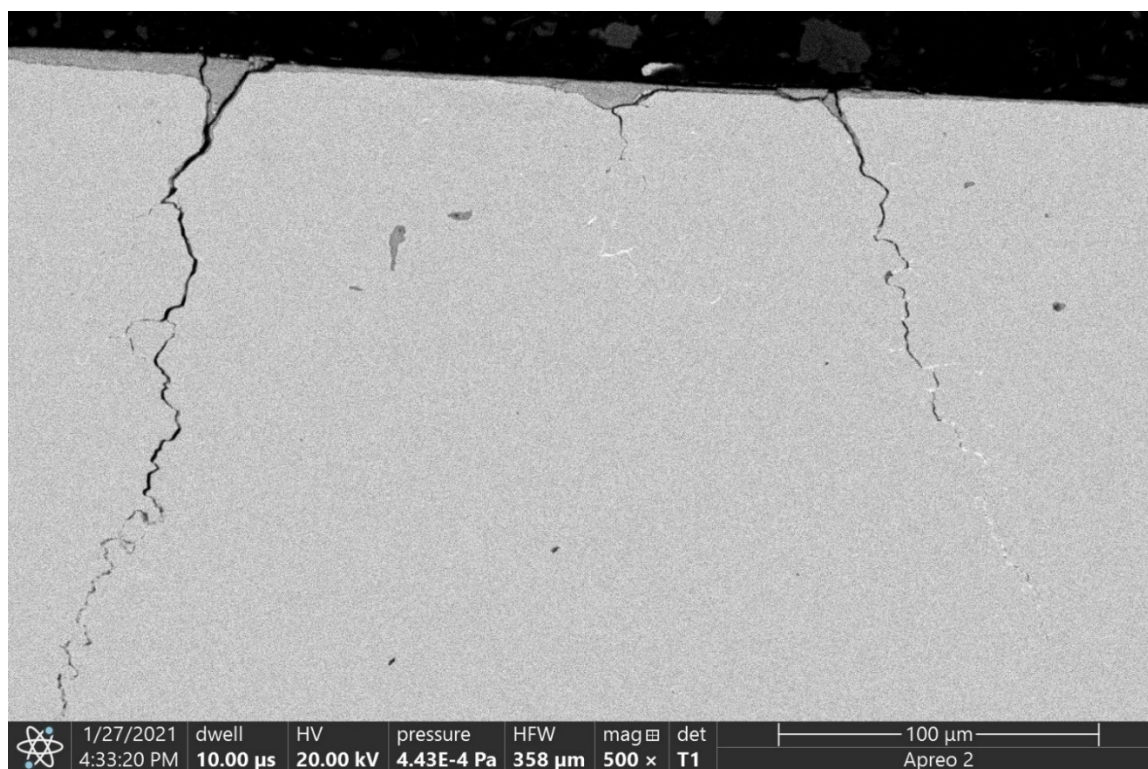


Figure 37 – BE micrograph of the cracks in Figure 30, showing lower-Z materials along the cracks.

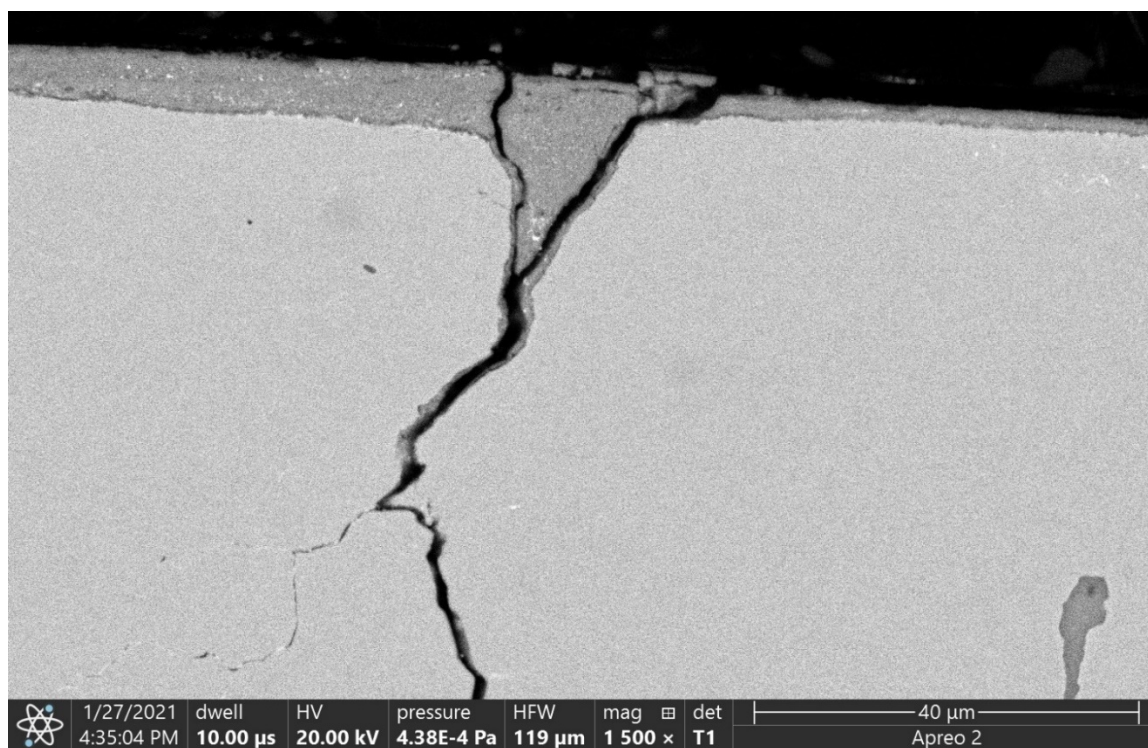


Figure 38 – BE micrograph showing the surface intersection of the left crack in Figure 37.

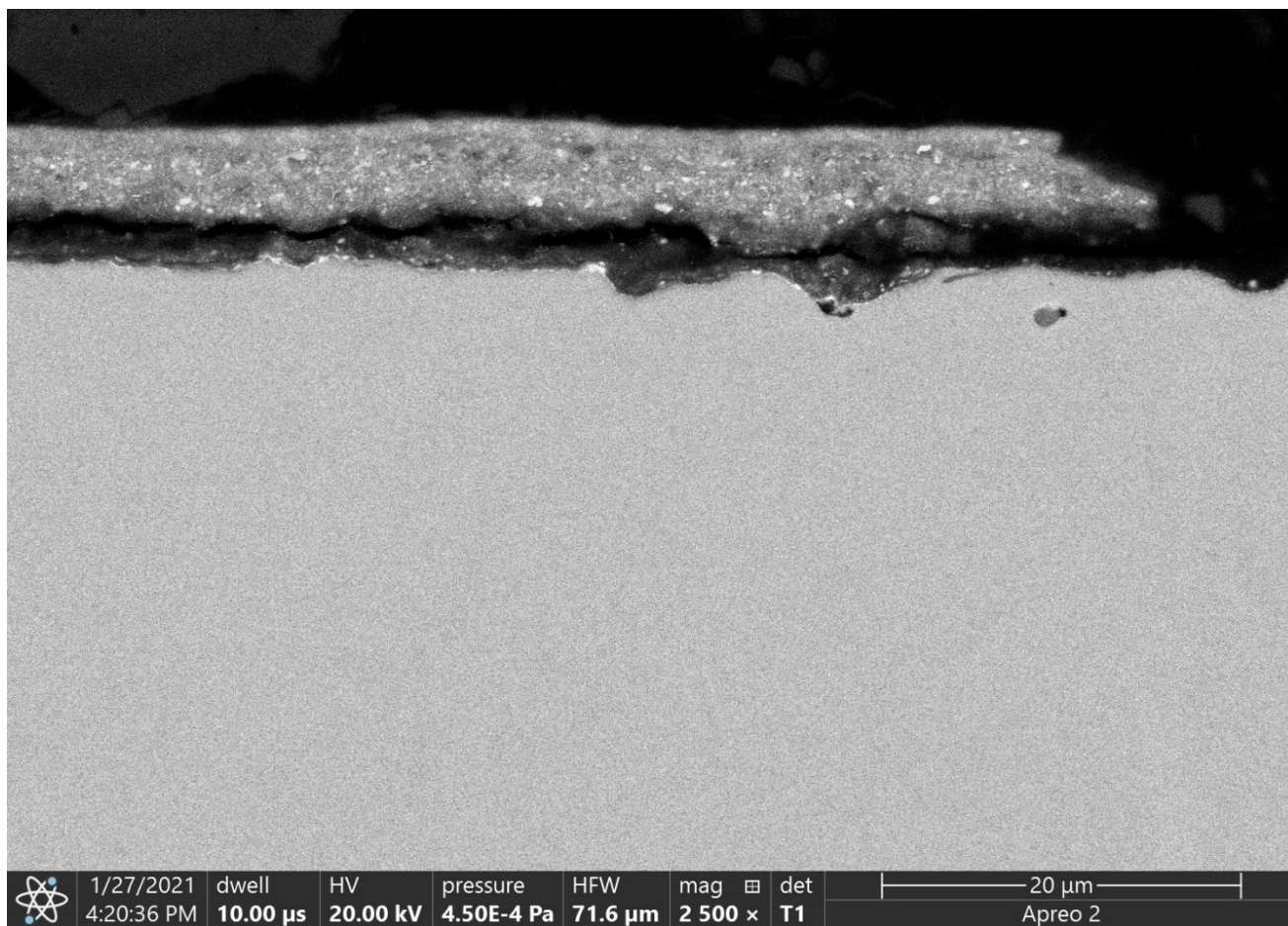


Figure 39 – BE micrograph of a cross section of other material layers along the inner surface of the C4 cap remnant.