

NATIONAL TRANSPORTATION SAFETY BOARD

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



June 9, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 22-014

1. ACCIDENT INFORMATION

Place : Wikieup, Arizona
Date : July 10, 2021
Vehicle : Beech C-90, N3688P
NTSB No. : WPR21FA266
Investigator : Albert Nixon, AS-WPR

2. COMPONENTS EXAMINED

Sections and remnants of wing spar caps

3. DETAILS OF THE EXAMINATION

On July 10, 2021, about 1255 mountain standard time, a Beech C-90 airplane was destroyed in an accident near Wikieup, AZ. The pilot and supervisor were fatally injured. The airplane was operated as a public-use firefighting aircraft in support of the Bureau of Land Management conducting aerial reconnaissance and supervision. The wreckage was consumed by a post-crash fire, with debris scattered over an area of several acres. The left wing was located about 0.79 miles northeast of the main wreckage and had not sustained thermal damage. The wreckage was retained for further examination, and remnants of the wing spars and spar caps were sent to the NTSB Materials Laboratory.

Remnants and sections of the left and right wing spars were received by the NTSB Laboratory. Figures 1 and 2 show the three remnants of the left wing spar, placed in their respective positions. Of note was the flat fracture on the lower spar cap, depicted by the red arrow in both figures—this fracture was later determined to be consistent with fatigue fracture. The upper spar cap exhibited plastic deformation adjacent to its fracture, consistent with downward bending. In contrast, the lower spar cap fracture was flat and perpendicular to the spar direction, with no gross plastic deformation at or near the fracture. The outboard lower spar cap remnant measured 5 inches in length, with the inboard remnant measuring 23.5 inches on the forward side and 28.5 inches on the aft side.

Figure 3 shows the fracture surface of the lower outboard spar cap, which was still constrained by fasteners to the forward and aft tangs of the bathtub fitting, as received. This fracture surface exhibited repeating banded features, consistent with crack arrest

marks from progressive cracking. Figures 4a and 4b, show angled views of the lower outboard spar cap fracture surface. As shown in these figures and in Figure 3, the lower spar cap fracture was located just inboard of the terminal ends of the forward and aft tangs of the bathtub fittings to which it was joined. In addition, while the spar cap fracture was flat and absent local plastic deformation, the nearby fractured components exhibited out-of-plane deformation near the fractures. Located along webs and skins, these erratically oriented fractures were consistent with overstress fractures subsequent to that of the lower spar cap.

Figures 5a and 5b, show oblique and planar underside views of the left outboard spar remnant assembly, and Figure 6a shows the top-down view, as received. These views demonstrate the location of the fractured lower spar cap relative to the ends of the bathtub fitting tangs, as well as the rivets and bolts used to join these components. Figure 6b shows a closer view of the head of the aft side bolt, which was collocated at the lower spar cap crack initiation location (as shown in Figure 3).

To better examine the lower outboard spar cap fracture surface, the assembly was taken apart by removing the rivets and the bolt. Prior to removal, a slight tightening torque was applied to the bolt with a torque wrench. This torque measured 29.5 inch-lbs. The breakaway torque during disassembly measured 18.5 inch-lbs.

The hex-head bolt is shown in Figure 7, including showing the two washers and nut included in the assembly. The head markings were "01DO X", which indicated it had been manufactured by Mac Fasteners, Inc.¹ Using dial calipers, various dimensions of the bolt were measured. These included:

- Shank diameter = 0.1875" (3/16")
- Thread pitch = 33 threads/inch
- Shank length = 1.035"
- Threaded length = 0.345"
- Head height = 0.121"
- Head width = 0.3725" (3/8")
- Grip length = 0.690"

Figure 8 shows the opposite lower and upper sides of the lower inboard spar cap remnant, as received. This spar cap remnant had been separated from any adjacent components, with most of the rivets and fasteners having been removed. The inboard fracture surface, located on the left in the figures, was sectioned two inches from the fracture to facilitate microscopic examination.

Figure 9 shows the sectioned lower inboard spar cap fracture surface. Many of its features mirrored those of the outboard fracture surface (see Figure 3), although this side exhibited more post-fracture damage, apparent on not only the fracture surface but also the upper and lower surfaces. The fracture surface shows convex crack arrest marks,

¹ Mac Fasteners, Inc. is a fastener manufacturer located in Ottawa, KS, now a subsidiary of TriMas Aerospace headquartered in Irvine, CA.

consistent with having emanated from the aft fastener hole where the bolt had been positioned. The hole diameter measured 0.173 inches, and the crack length between fastener holes measured 2.457 inches long. As denoted in Figure 9, and shown in a closer view in Figure 10, the crack appeared to have initiated towards the upper forward side of the bolt fastener hole (upper left corner in Figures 9 and 10).

Figures 11 and 12 show the middle and end of the lower inboard spar cap fracture surface. More pronounced than in Figure 10, there were alternating features of smoother, more reflective bands among rougher, duller bands. As demonstrated in Figures 12 and 13, these features were consistent with overstress 'jumps' that can occur from intermittent higher loads during prolonged crack propagation under cyclic loading.

Figure 14 shows two views of the aft fastener hole, where the lower spar cap crack had originated. Cracks were observed emanating from each side of the hole, having propagated in opposite directions. The aftmost portion of the spar cap remnant and fastener hole had been deformed downward, consistent with deformation subsequent to cracking and fracture. The fastener hole did exhibit several parallel circumferential gouge marks, as highlighted in Figure 14b.

The fracture surface was examined in a field emission scanning electron microscope (SEM) after mild ultrasonic cleaning with acetone. Figure 15 and Figure 16 show typical areas of the lower spar cap fracture surface, exhibiting striations. These striations were consistent with fatigue crack propagation. The striations were not equally spaced, but rather exhibited larger jumps or gaps, with smaller-spaced striations in between. These features, as illustrated in Figure 16, were indicative of crack propagation under spectrum loading.

The areas with overstress 'jumps,' shown in Figures 11 through 13, exhibited a rougher surface with features different than fatigue striations. As demonstrated in Figure 17 and Figure 18, the bands consisted of dimpled rupture, consistent with localized overstress fracture. The presence of intermittent overstress bands was consistent with elevated loading in short durations, such that the remainder of the cap cross section did not completely fracture.

The lower outboard spar cap was disassembled and then sectioned to allow for microscopic examination. This fracture surface had not been deformed or damaged following fracture and was used as a more representative surface for examination once disassembled. Figure 19 shows an overall view of the aft fastener hole where the bolt had been located. This figure was annotated to show the locations of the crack initiation sites for the smaller aft fatigue crack and the main forward-propagating fatigue crack. The main fatigue crack had initiated at a burr at the edge or forward corner of the fastener hole, whereas the aft crack had initiated at two gouges along an indent on the hole bore wall (see Figure 20).

The total length of the main crack, located between the two fastener holes was 2.484 inches, with the smaller crack to the left in Figure 19 being 0.312 inches long. The

width of the crack varied with the thickness of the spar cap, being 0.256 inches near the bolt holes and 0.294 inches near the perpendicular tee. The crack had propagated up the tee to the fastener hole, located 1.594 inches from the bottom surface of the spar cap.

Figure 21 shows a closer view of the aft fatigue crack initiation sites. There were no indications of a materials defect such as a corrosion pit or inclusion. Rather, the feature was an indent at a mechanical gouge. Such a feature would be able to act as a stress concentrator during cyclic loading, initiating a crack. Similarly, Figure 22 shows the crack initiation site of the main fatigue crack, located at the corner with upward-displaced material, consistent with a burr from machining. This exhibited material that had deformed upward and then been folded back under itself, which can act as a stress concentrator.

Figure 23 shows a closer view of the main fatigue crack initiation site, showing fatigue striations emanating from the feature. In addition, the backscattered electron examination showed no dissimilar material, such as an inclusion in the area. Figure 24 shows another view of the crack initiation site, after further cleaning with a proprietary chromic acid-based aluminum cleaner. This figure shows river patterns emanating from the corner, as well as the striations and crack arrest marks consistent with the direction of crack propagation toward the forward direction. In addition, there was a small (~140 μm long) subsurface area with faceted features. Figure 25 shows a closer view of this area, showing the small, rounded facets.

Figure 26 shows a typical area of fatigue striations on the lower outboard spar cap fracture surface. As stated earlier, the surface exhibited regularly spaced smaller striations, and irregularly spaced larger striations. This is shown in Figure 27 from the outboard side. In addition, there were 151 overstress jumps counted along the outboard fatigue crack. These features were quantified in detail as discussed in *Materials Laboratory Addendum Report 22-014B*.

The lower spar cap was cross sectioned in different directions, mounted, and polished. Figure 28 shows the spar cap microstructure from the longitudinal and transverse directions. There were no indications of cracks or intergranular defects or phases in the microstructure. The chemical composition was examined using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The chemical composition was consistent with AA 2014 aluminum alloy. This indicated the bluish constituents in Figure 28 were consistent with copper-rich precipitates typical of this alloy. The hardness was examined per ASTM E18.² The hardness averaged 82 HRBW. The electrical conductivity was examined using ASTM E1004.³ The conductivity averaged 39.2 %IACS. These data were consistent with a T6 or peak-aged temper for this alloy.

Figures 29 and 30 show the right side wing spar components, as received. These include the lower wing spar cap fragments where it was attached to the wing fittings. The

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

³ ASTM E1004 – *Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*. ASTM International, West Conshohocken, PA

location of these components relative to the other right side spar remnants is illustrated in Figure 31. For the most part, the fractures of the skins, webs, and spar pieces exhibited out-of-plane deformation and jagged fracture surfaces. These features were indicative of subsequent fracture of the structure. This lower wing spar cap did not exhibit out-of-plane deformation, but did have a tortuous fracture surface, with some localized flatter areas (see Figure 32). Much of the inboard fracture surface exhibited post-fracture smearing, which was generally absent on the outboard side. Later examination of this fracture surface found only overstress features, with no indications of cracks or fatigue features prior to fracture.

The lower spar cap fragments from the left and right wings were disassembled from their adjacent components by having the fasteners and rivets removed. These spar fragments were examined by fluorescent penetrant inspection (FPI) to determine if other crack indications might be present. The spar and spar cap fragments were cleaned with acetone and dried, then sprayed with Zyglo ZL-27A penetrant with a 30-minute dwell.⁴ The parts were wiped and then applied with Zyglo ZP-9F developer, allowing for a 15-minute dwell.⁵

None of the fastener holes exhibited an indication except for the one location on the outboard right wing lower spar cap, shown on the upper right in Figures 33 and 34. Figure 35 shows the two indications under exposure to ultraviolet (UV) light. These features were isolated by backcutting towards the indications and intentionally overstressing them to reveal any potential subsurface features (laboratory opening). Figure 36 shows one of the mating laboratory-opened fracture surfaces, which did not reveal any fatigue cracking—the features of the opened surface were consistent with overstress. The indications were determined to be cracks in the surface primer, rather than the spar material itself.

In summation, the left wing lower spar cap fractured from a fatigue crack that initiated at the aft bolt fastener hole. The fastener hole exhibited a burr at the corner which served as the crack initiation site for the main fatigue crack. Another, smaller fatigue crack initiated at a gouge in the fastener hole and propagated aftward. The fatigue crack exhibited irregular striation spacing and overstress jumps, consistent with spectrum loading. Visual and FPI examination did not reveal any additional cracks in the other spar cap remnants.

Erik M Mueller
Materials Research Engineer

⁴ ZL-27A is a Type Id-B, Level 3, high-sensitivity post-emulsifiable penetrant designed safety-critical aerospace testing, manufactured by Magnaflux, headquartered in Glenview, IL.

⁵ ZP-9F is a non-aqueous developer made of organic particles to provide an opaque white coating and contrasting background for fluorescent and visible penetrant inspections. The product is manufactured by Magnaflux, headquartered in Glenview, IL.

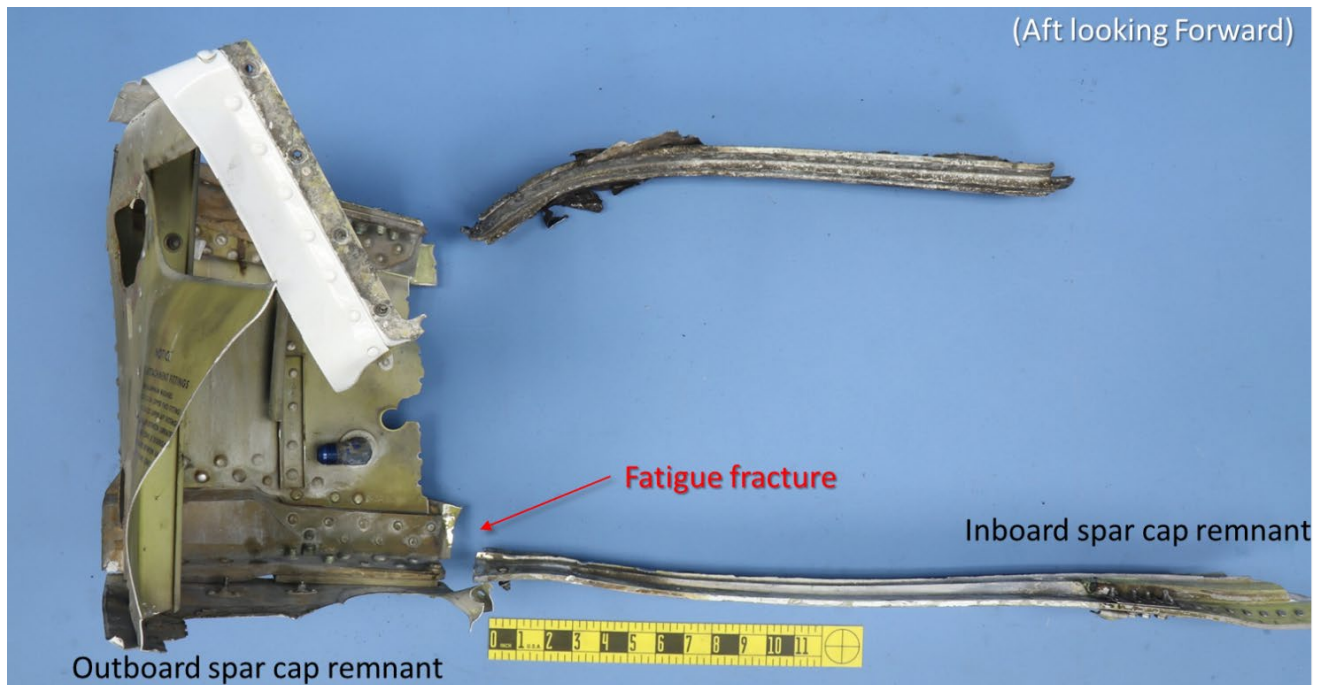


Figure 1 – Reconstruction of pieces of the left wing spar.

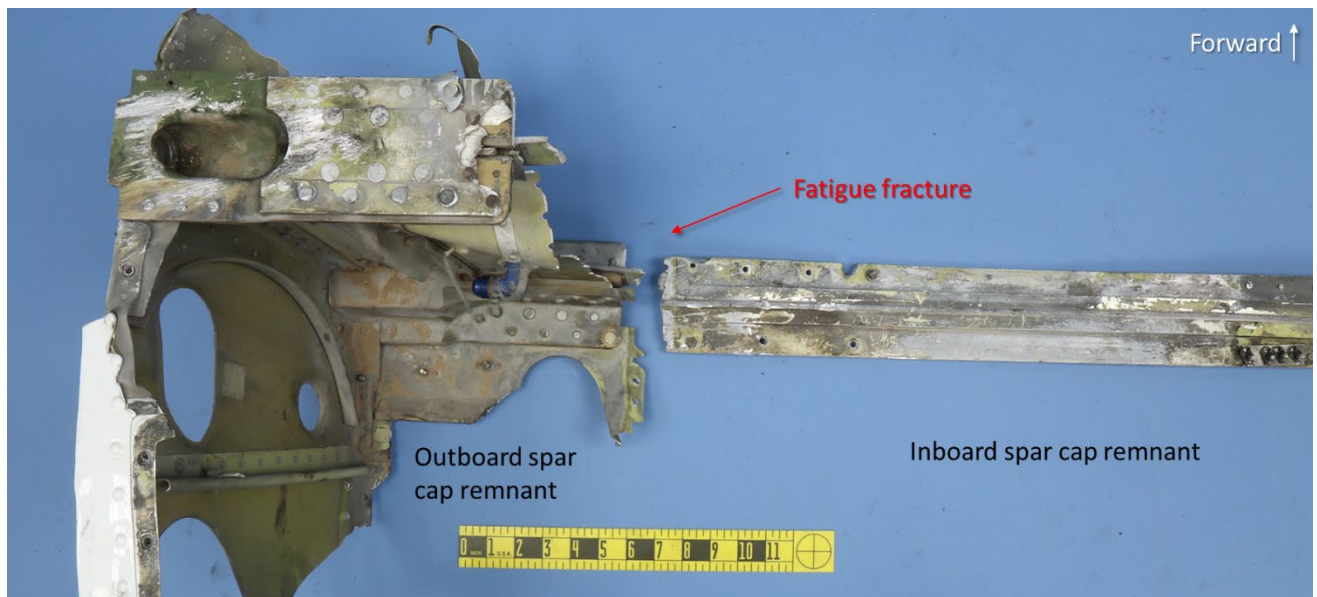


Figure 2 – The left wing lower spar cap reconstruction, viewed from above looking down.



Figure 3 – Fracture surface of the lower outboard spar cap remnant, as received, annotated to show the general crack initiation site and direction of crack propagation.

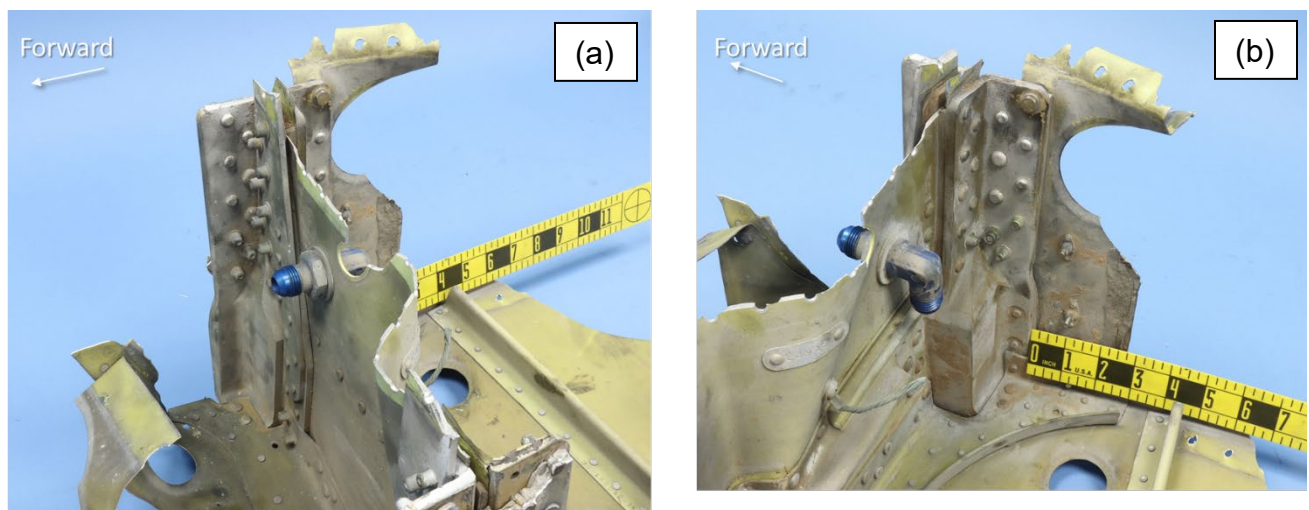


Figure 4 – View of the lower outboard spar cap fracture surface, viewed from an (a) down and aft angle and (b) down and forward angle.

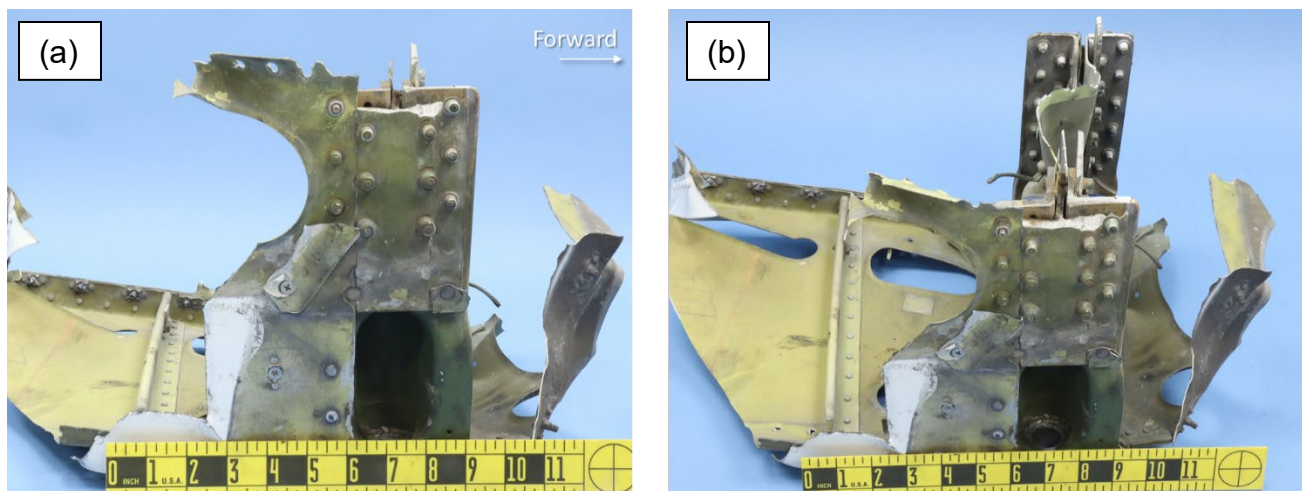


Figure 5 – View of the underside of the lower outboard spar cap fracture looking upward from (a) a planar orientation and (b) an oblique orientation.

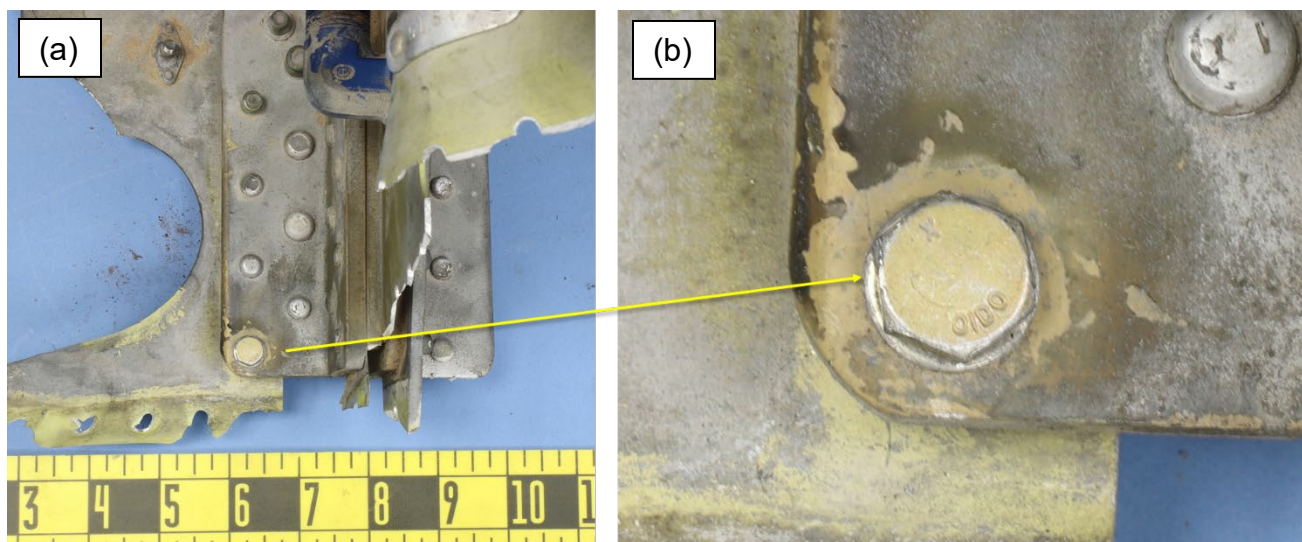


Figure 6 – View of the bolt at the fatigue crack initiation of the lower outboard spar cap fracture surface.

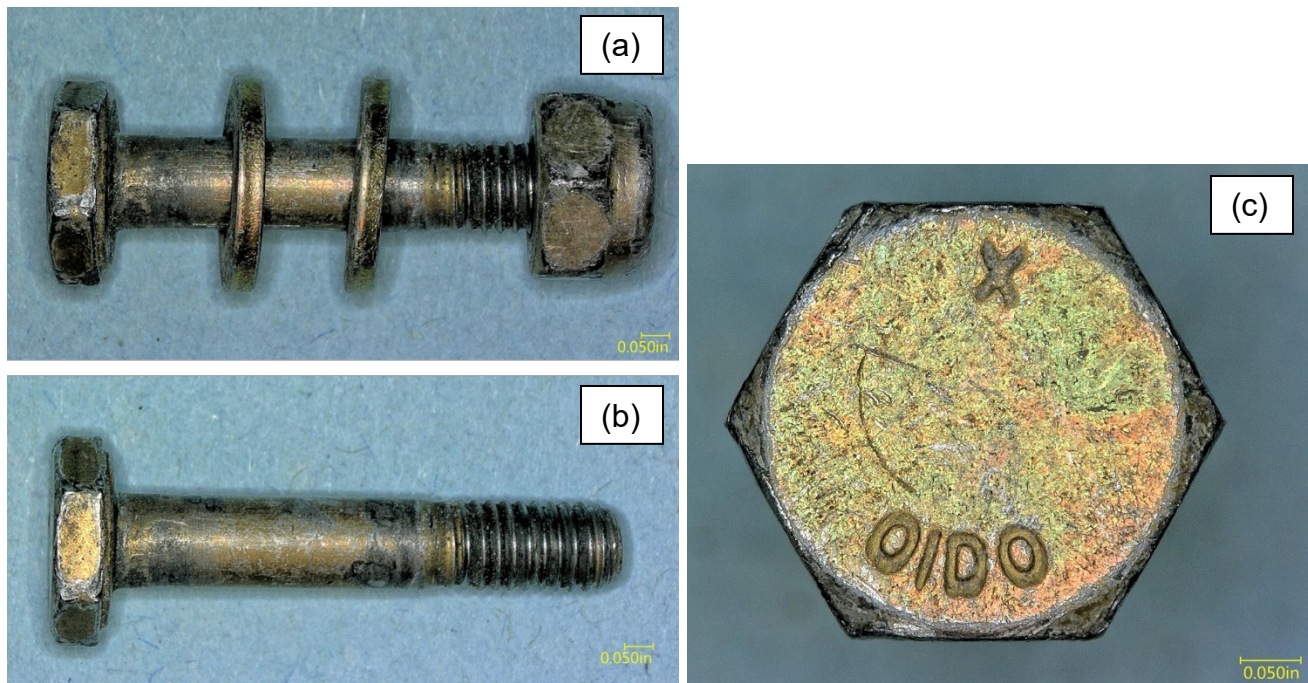


Figure 7 – View of the fastener bolt from Figure 6, after removal (a) showing the two washers and nut (b) from the side, and (c) from the head face.

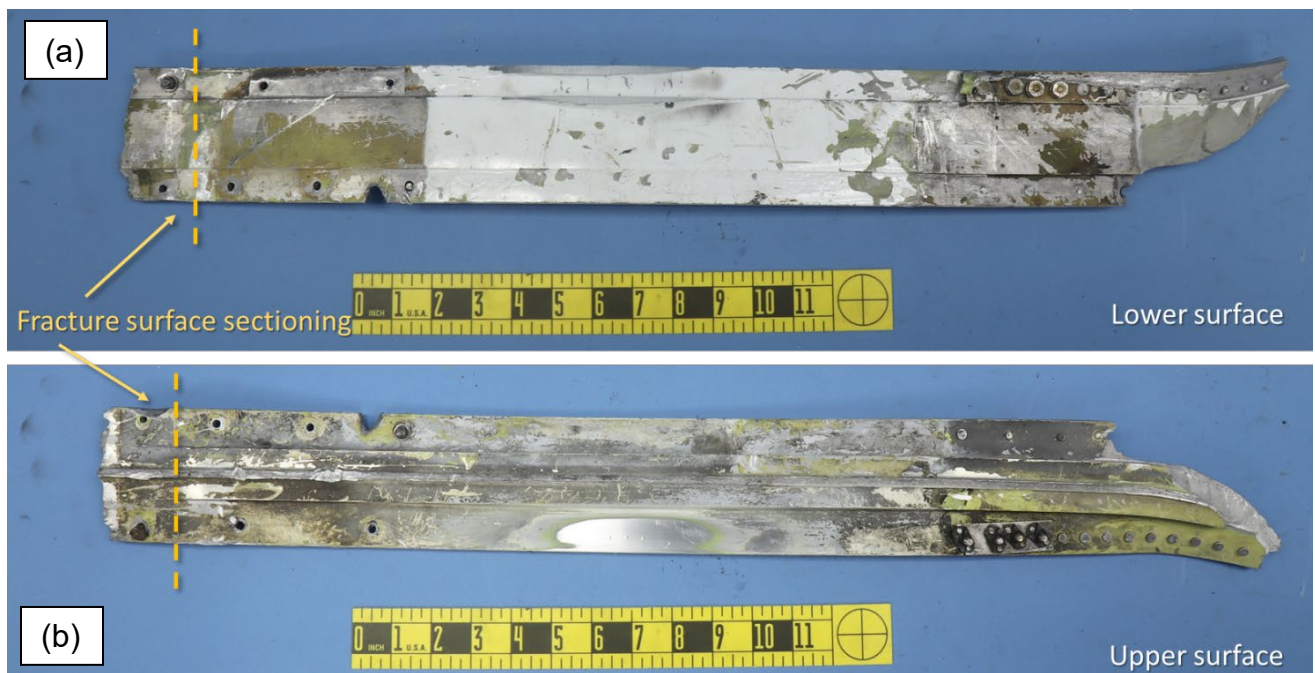


Figure 8 – View of the lower inboard spar cap remnant from (a) the lower and (b) upper surfaces.



Figure 9 – View of the fracture surface of the inboard lower spar cap fracture surface, after sectioning.



Figure 10 – Close view of the inboard lower spar cap fracture surface near the fastener hole initiation site.

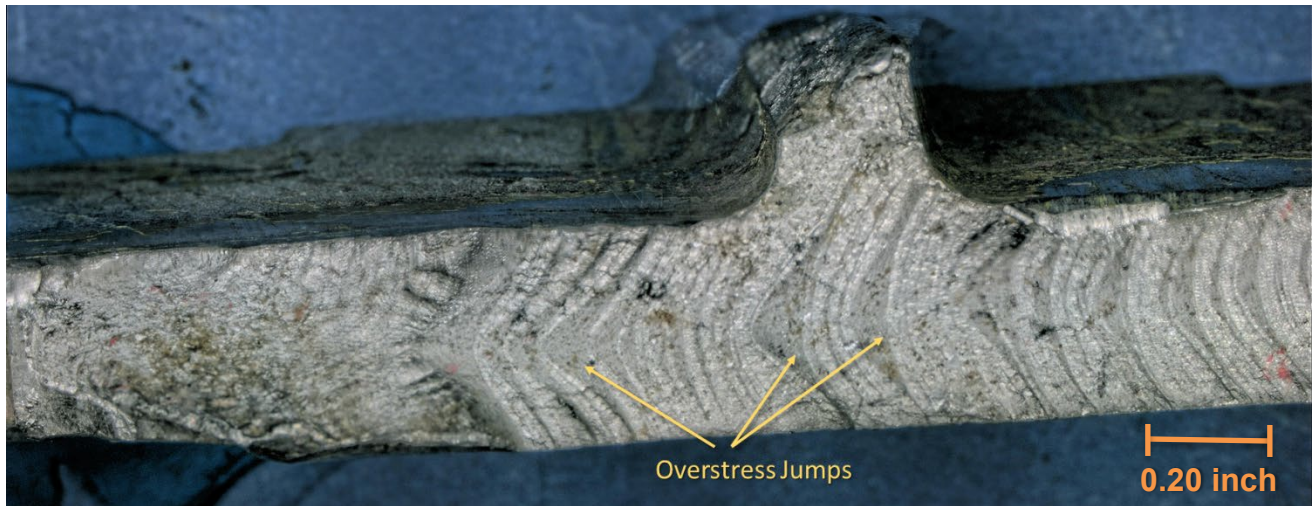


Figure 11 – View of the inboard lower spar cap fracture surface near the T-remnant, showing intermittent overstress jumps along the fatigue crack face.

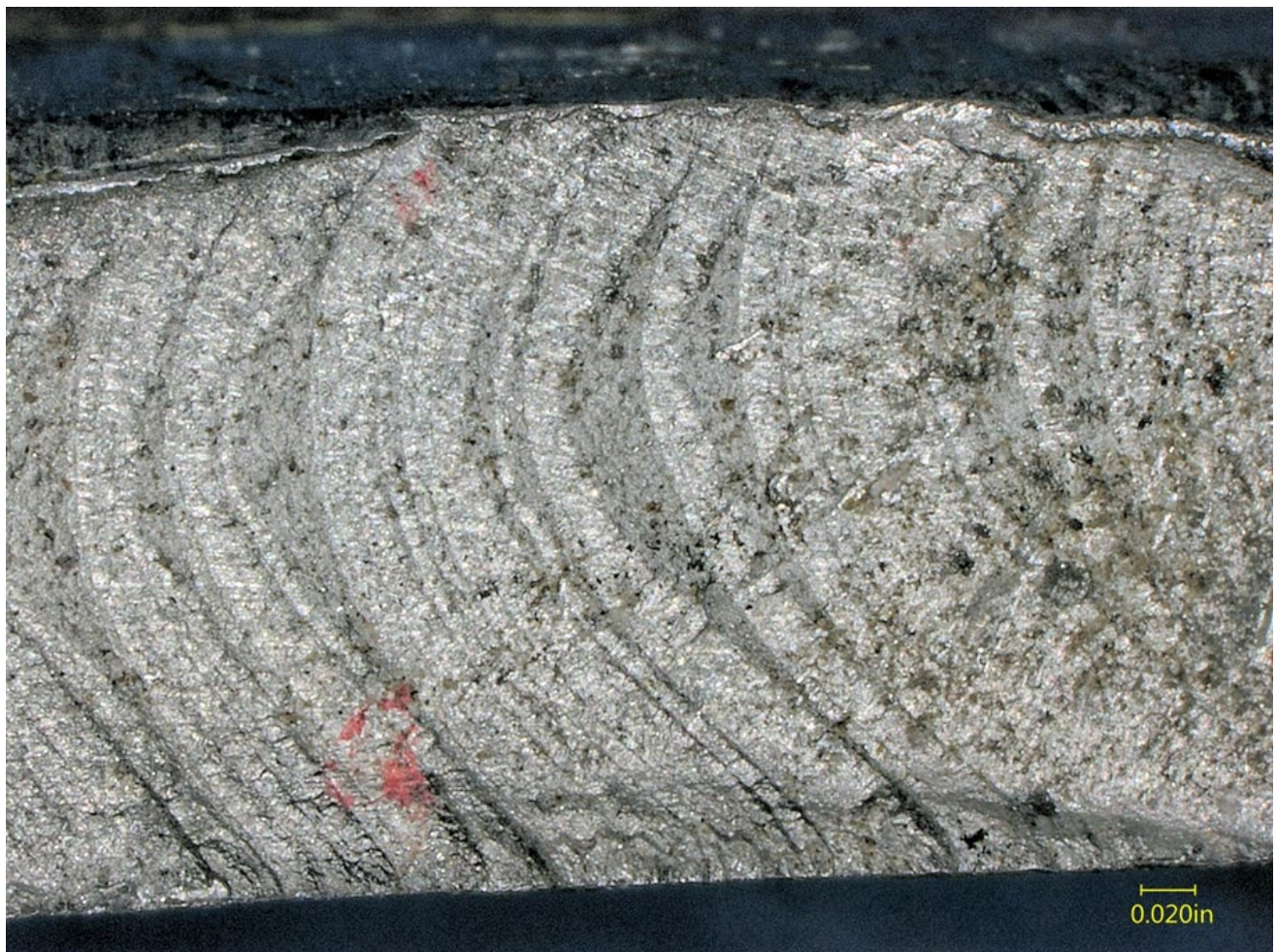


Figure 12 – Fracture surface of the inboard lower spar cap closer to fastener hole.



Figure 13 – Fracture surface of the inboard lower spar cap away from fastener hole

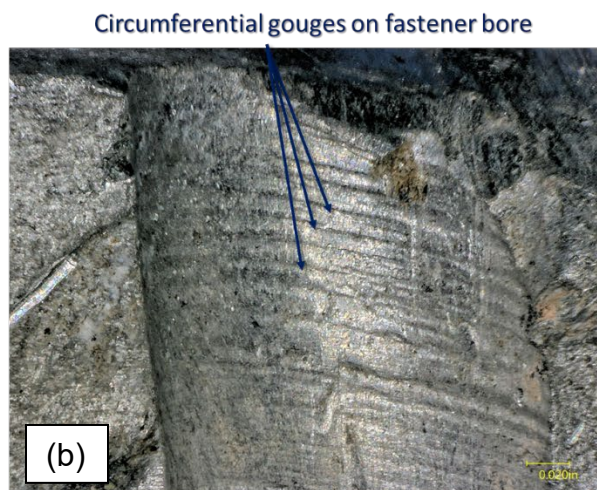


Figure 14 – View of the fastener hole in the inboard lower spar cap (a) overall and (b) closer, showing circumferential gouges on the surface.

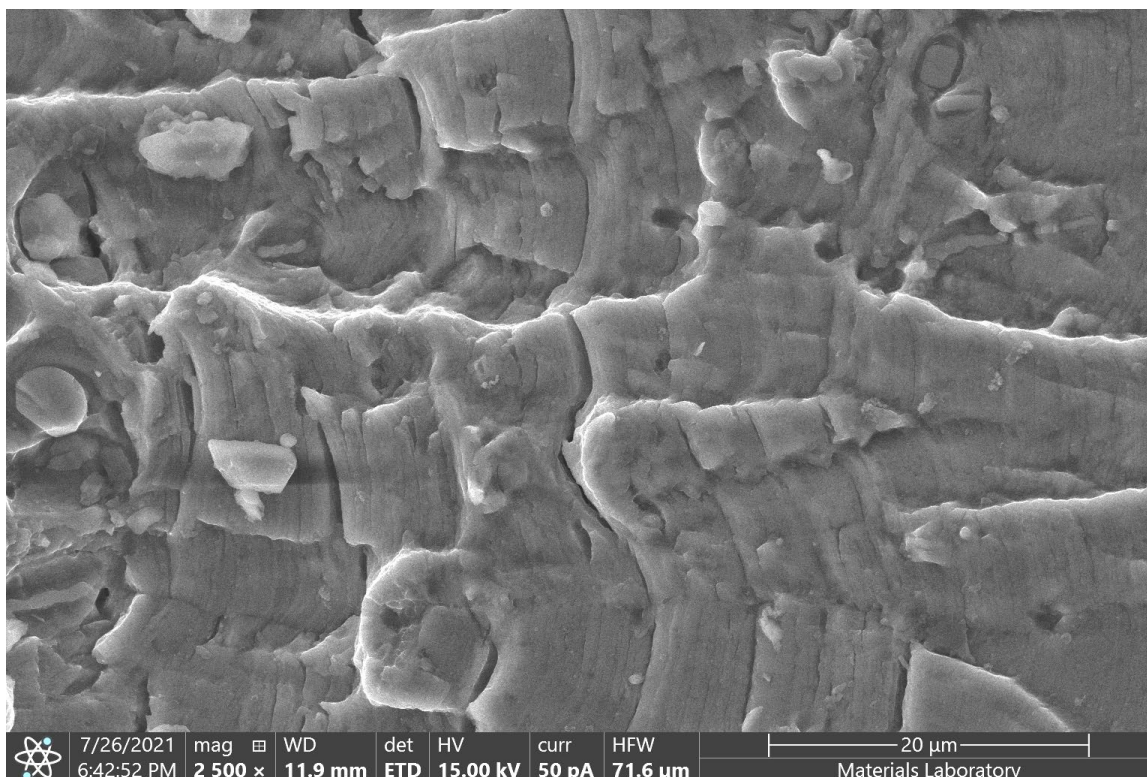


Figure 15 – Secondary electron (SE) micrograph of fatigue striations near the crack initiation site of the inboard lower spar cap fracture in Figure 12.

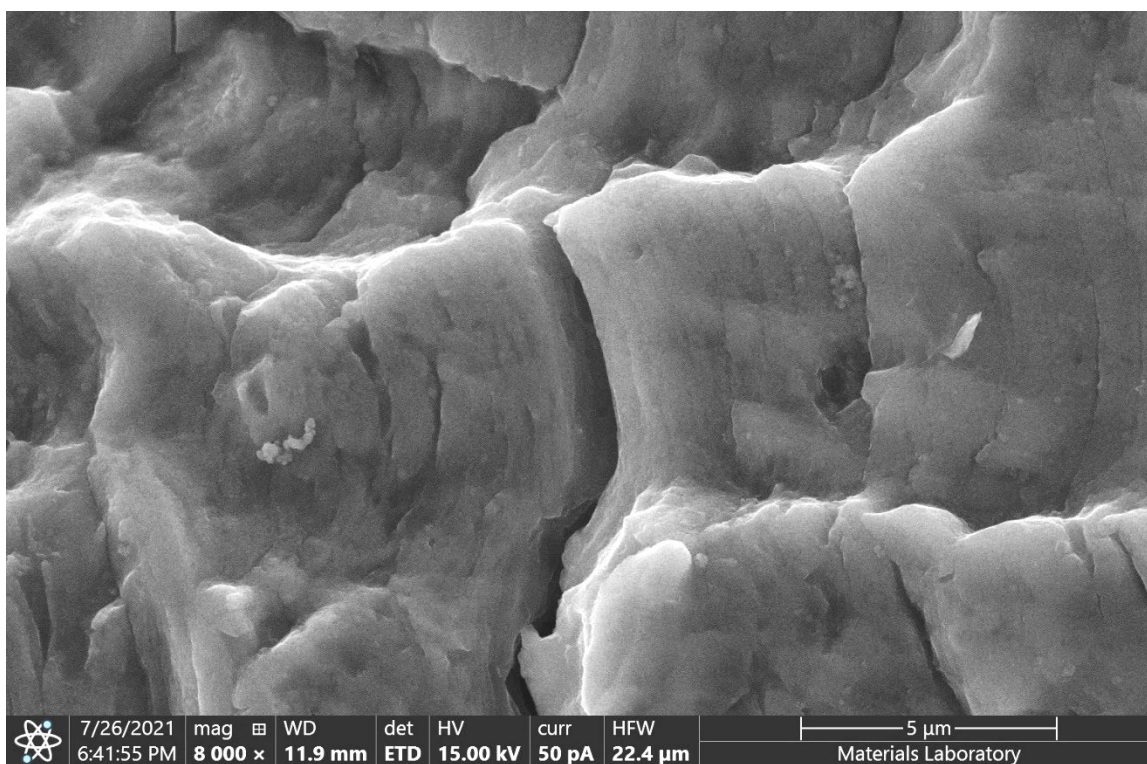


Figure 16 – SE micrograph of striations in Figure 15, showing smaller striations among larger ones along the fracture.

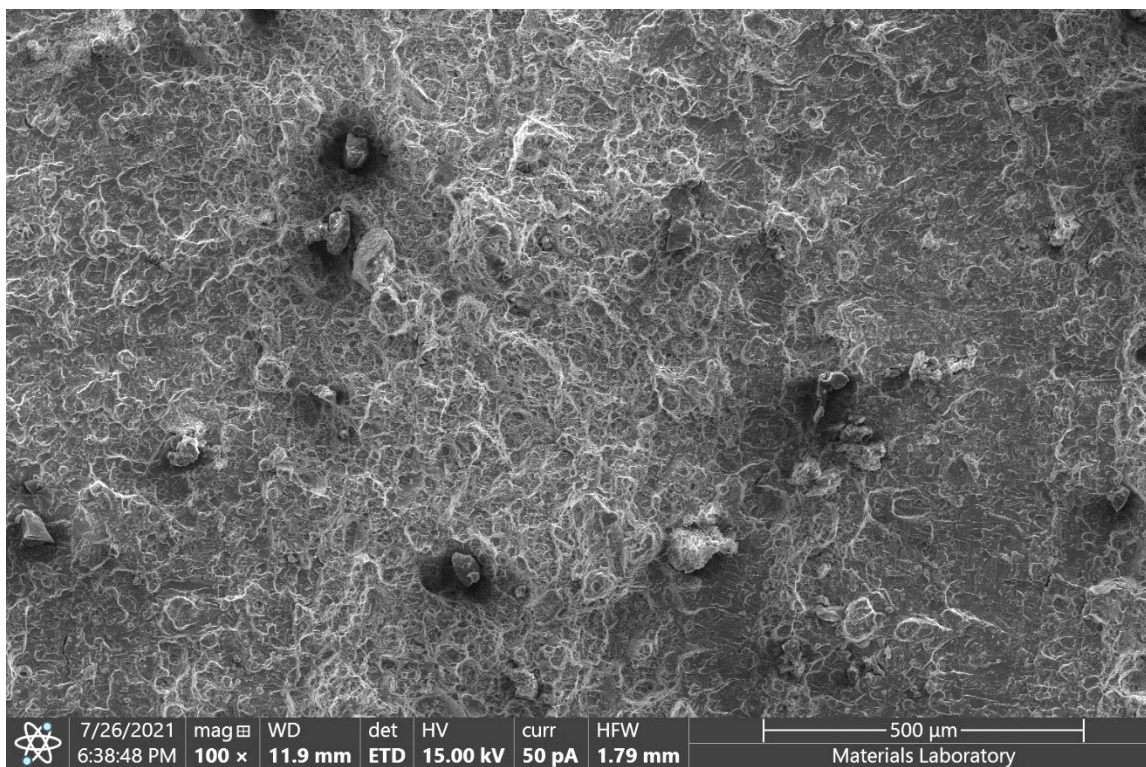


Figure 17 – SE micrograph showing the overall topography of an overstress jump on the inboard lower spar cap fracture surface.

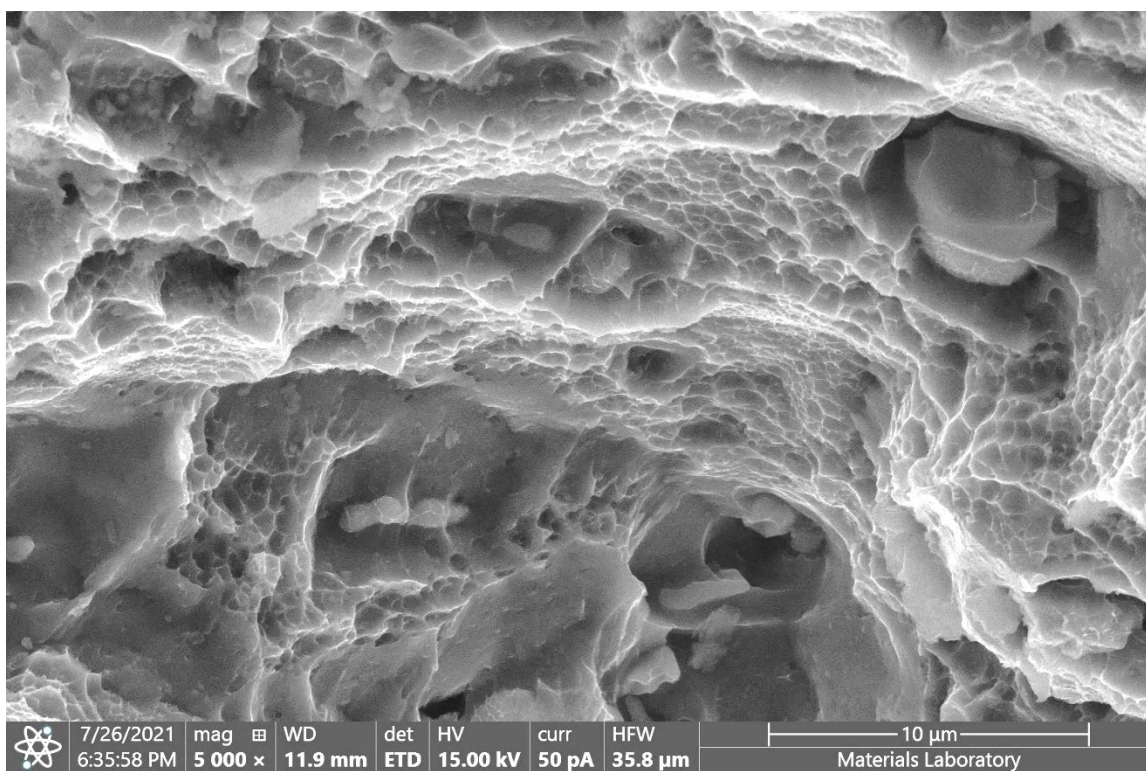


Figure 18 – SE micrograph of typical dimpled rupture features in Figure 17.

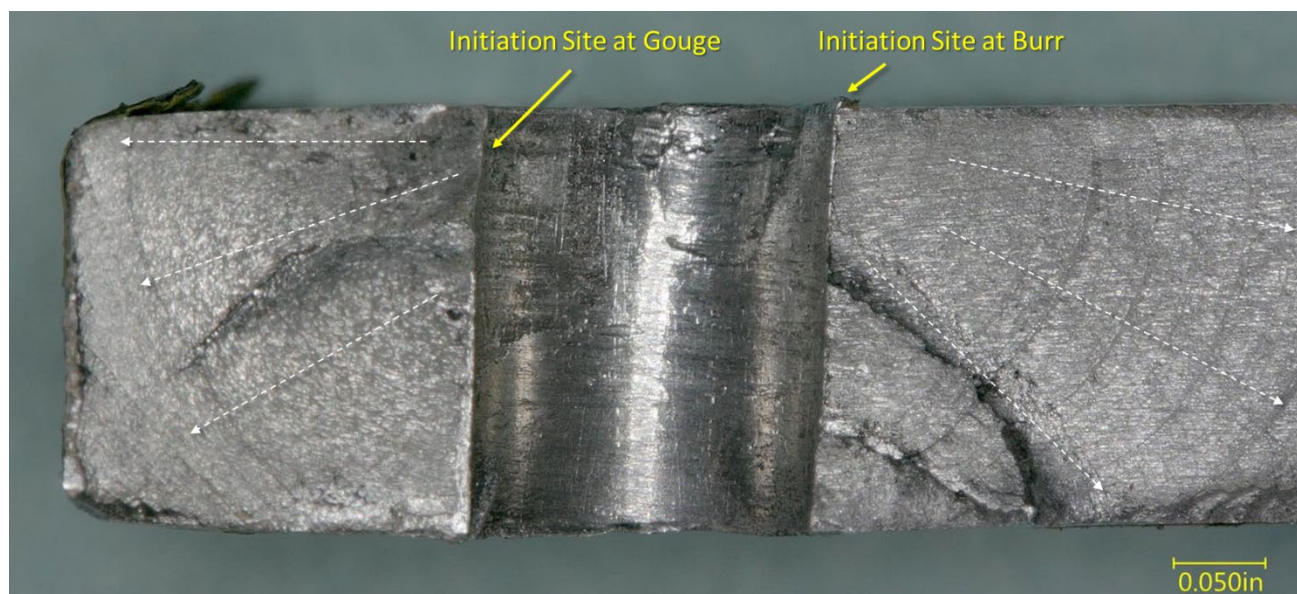


Figure 19 – View of the mating outboard lower spar cap fracture surface near the bolt hole, showing two specific initiation sites on opposite sides.

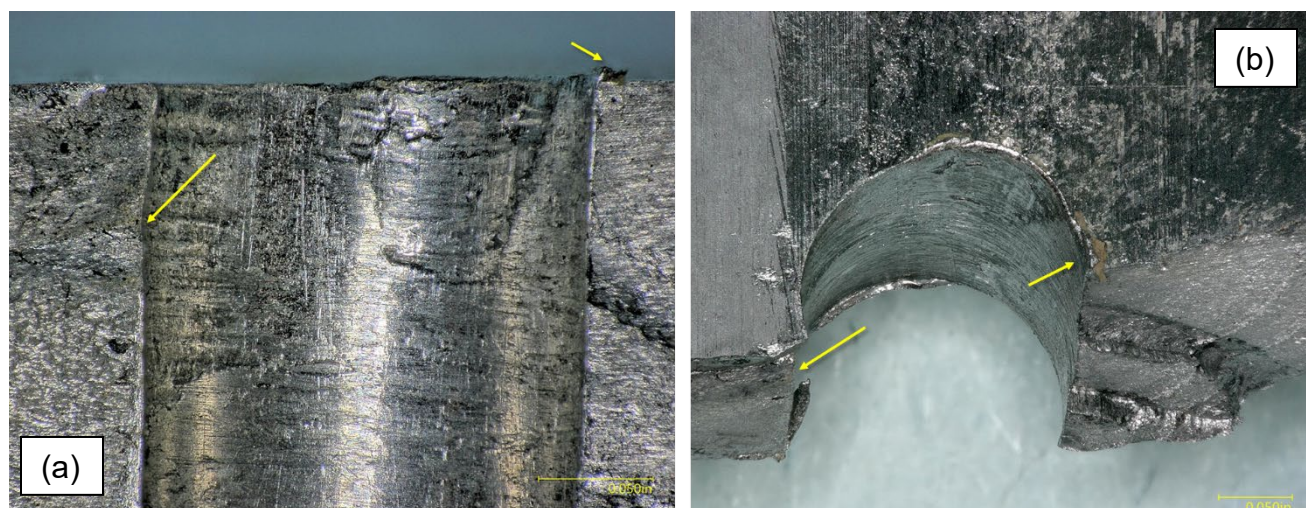


Figure 20 – Closer views of the outboard lower spar cap fracture surface initiation sites around the fastener hole from (a) the fracture surface and (b) the upper surface, showing the upward burr.

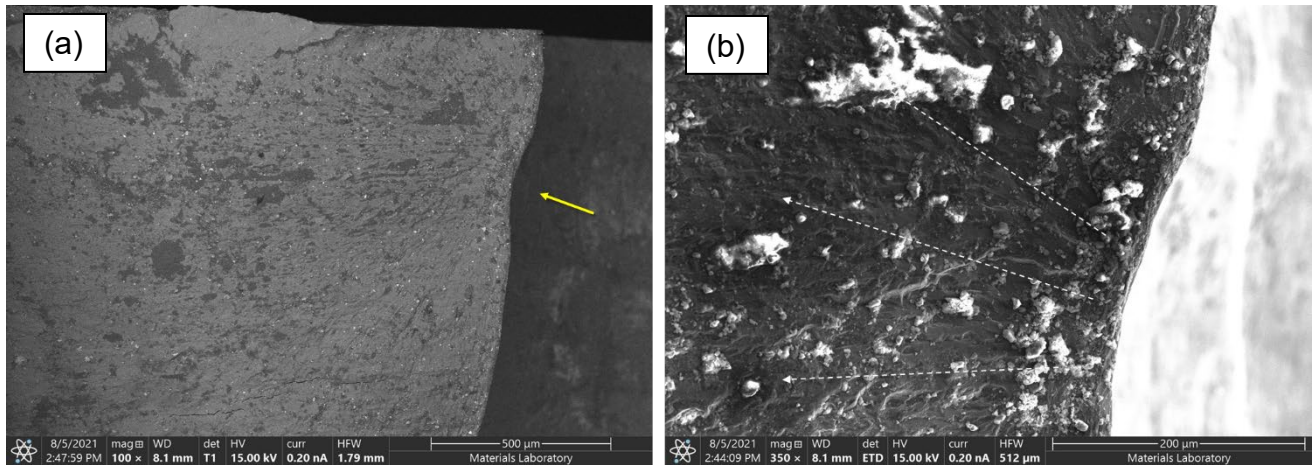


Figure 21 – Views of the aft fatigue crack initiation sites at the fastener bore edge using (a) backscattered mode (BE) and (b) secondary mode (SE). The dashed white arrows demonstrate the crack growth direction and the yellow arrow denotes the initiation site location.

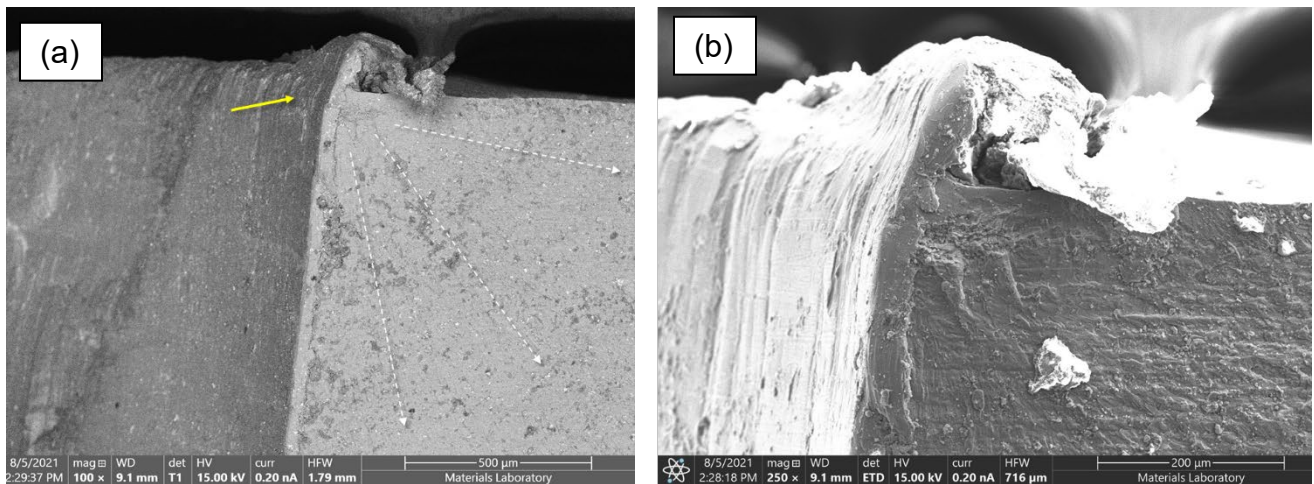


Figure 22 – Views of the forward or main fatigue crack initiation site at the fastener bore corner using (a) backscattered mode and (b) secondary mode. The dashed white arrows demonstrate the crack growth direction and the yellow arrow denotes the initiation site location.

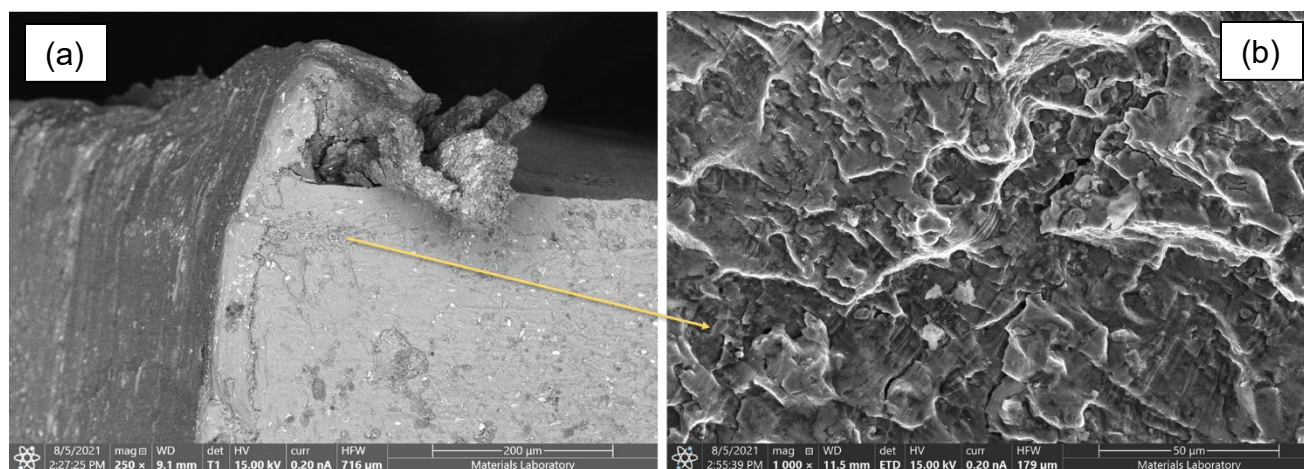


Figure 23 – BE micrograph of the forward crack initiation site, (a) showing a burr at the corner of the fastener bore and surface, with (b) an SE micrograph showing striations adjacent to the surfaces.

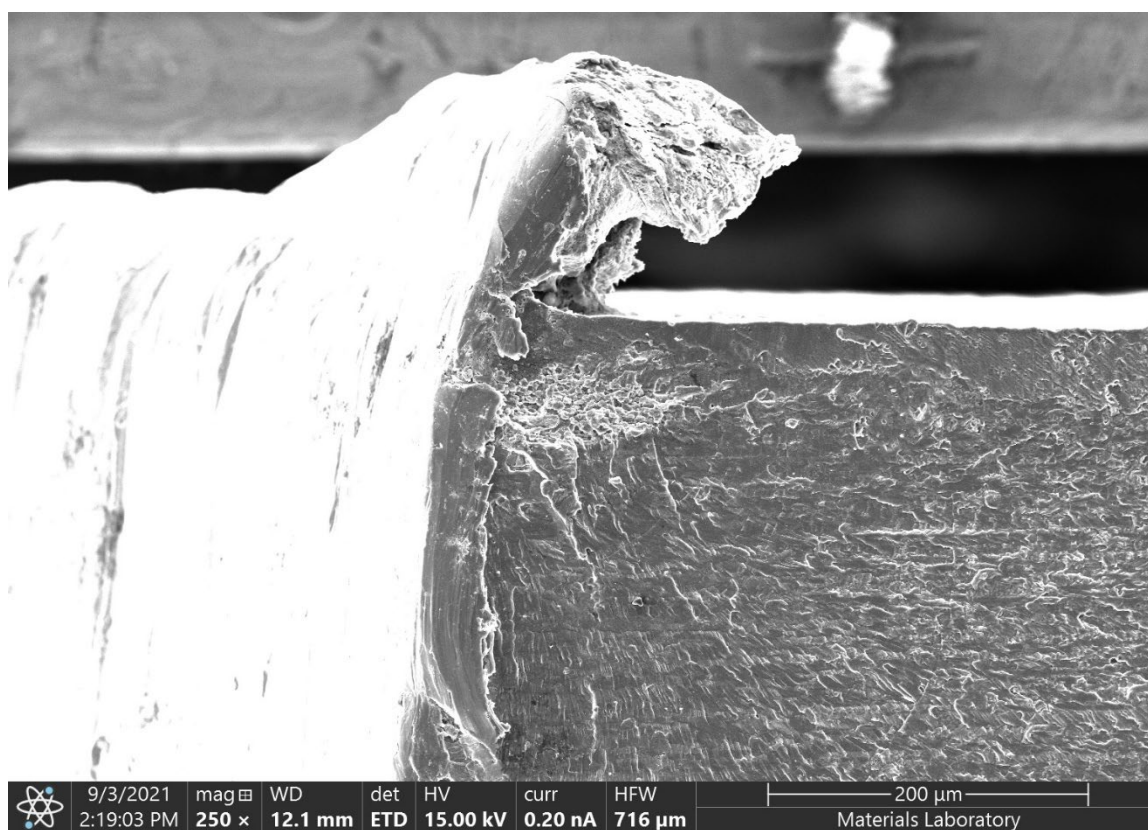


Figure 24 – SE micrograph showing a closer view of the machining burr at the forward fatigue crack initiation site.

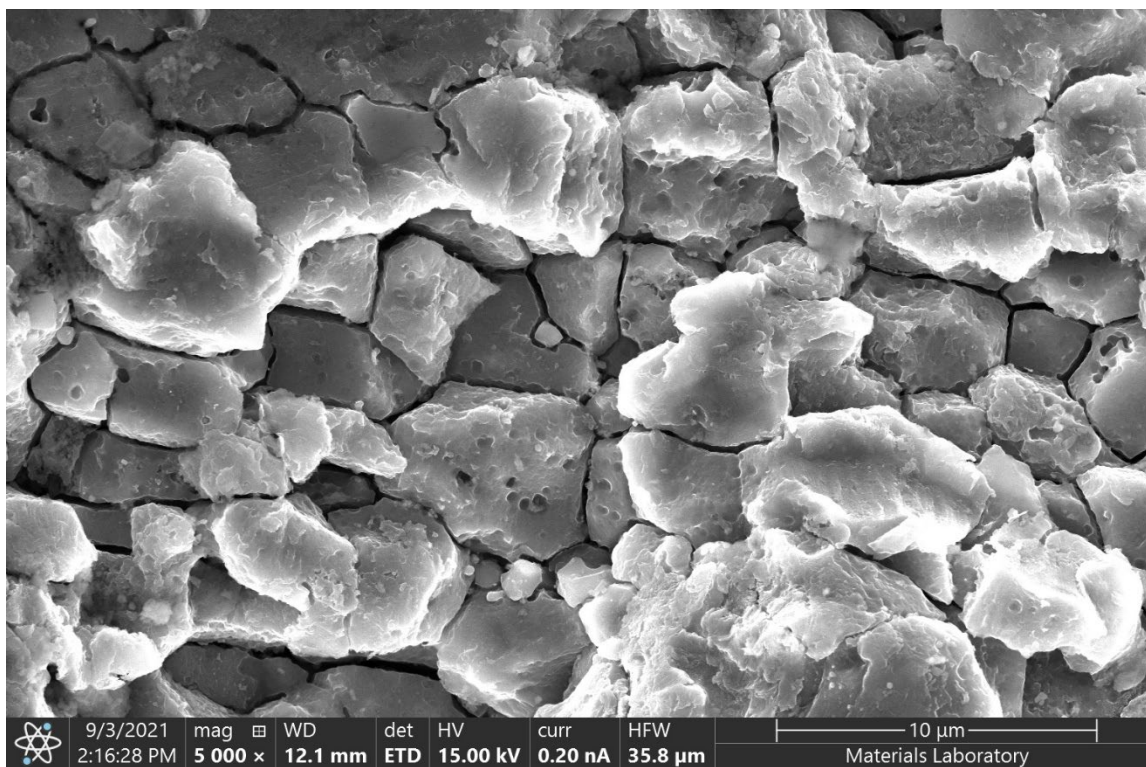


Figure 25 – SE micrograph of intergranular facets at the crack initiation site in Figure 24.

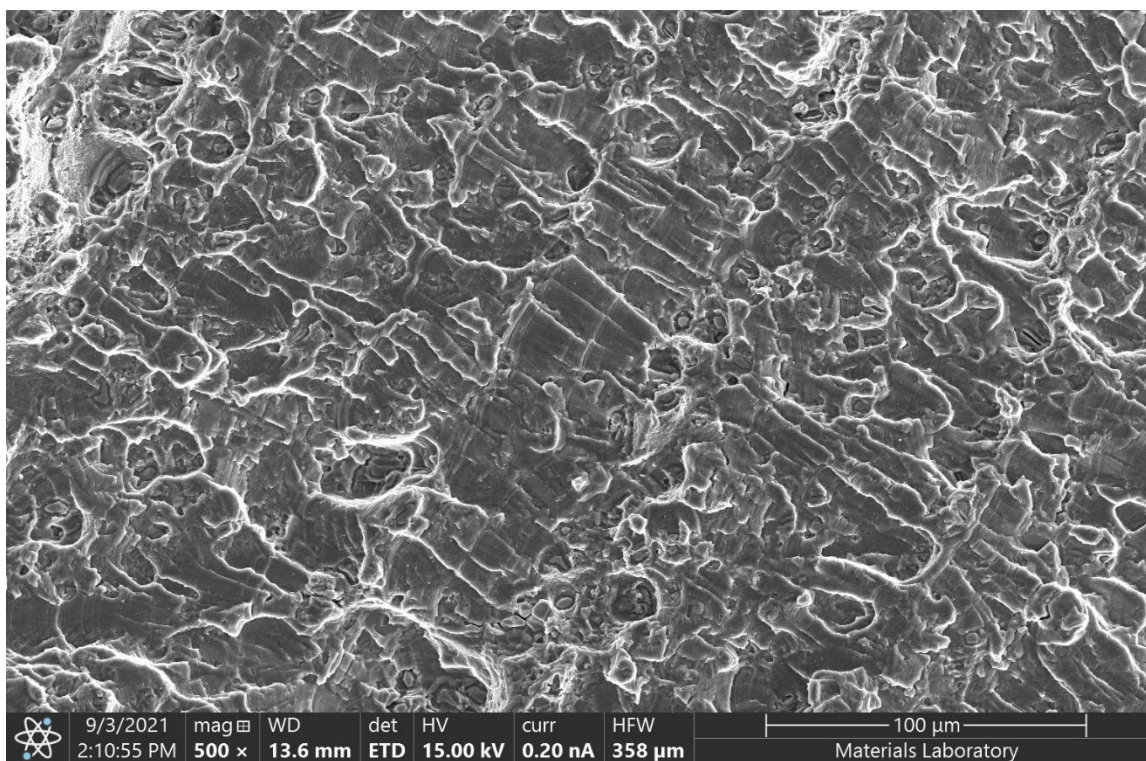


Figure 26 – SE micrograph of fatigue striations on the outboard fracture surface, after cleaning.

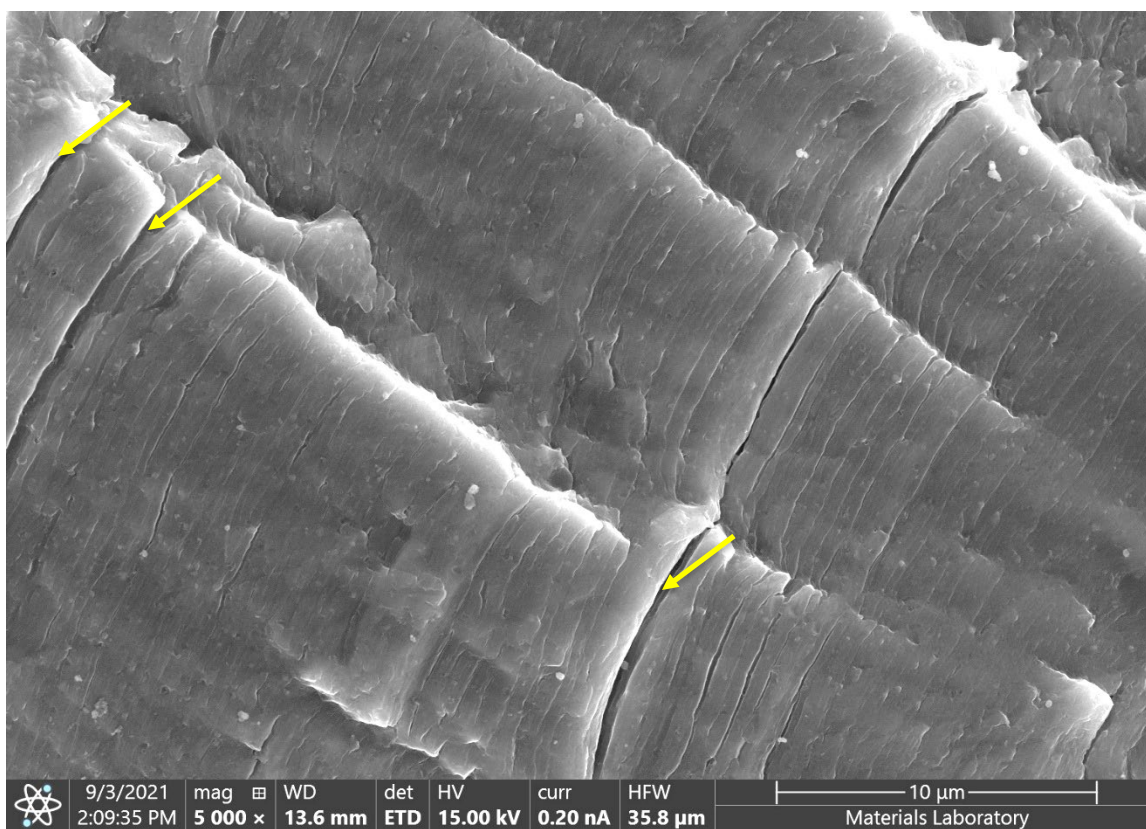


Figure 27 – SE micrograph highlighting the striations in Figure 26, with yellow arrows denoting the larger or deeper features.

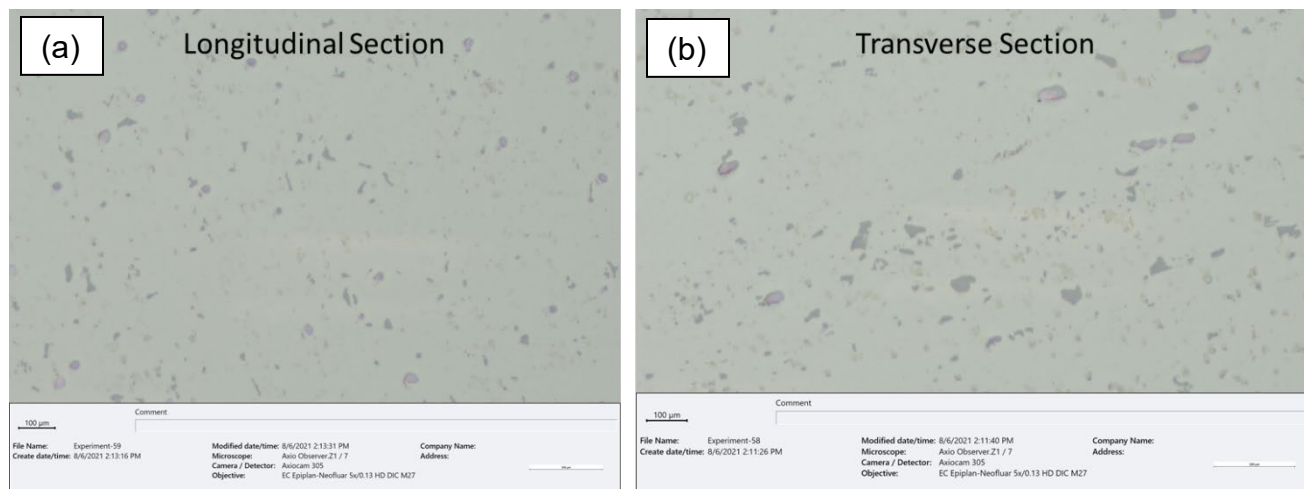


Figure 28 – Bright field (BF) optical micrographs of the wing spar cap cross sectioned through (a) the longitudinal and (b) transverse directions (~1000X, as-polished).



Figure 29 – View of the wing spar components from the right side.



Figure 30 – Reconstruction of the lower wing spar cap and wing fittings.



Figure 31 – Reconstruction of right wing spar fragments.

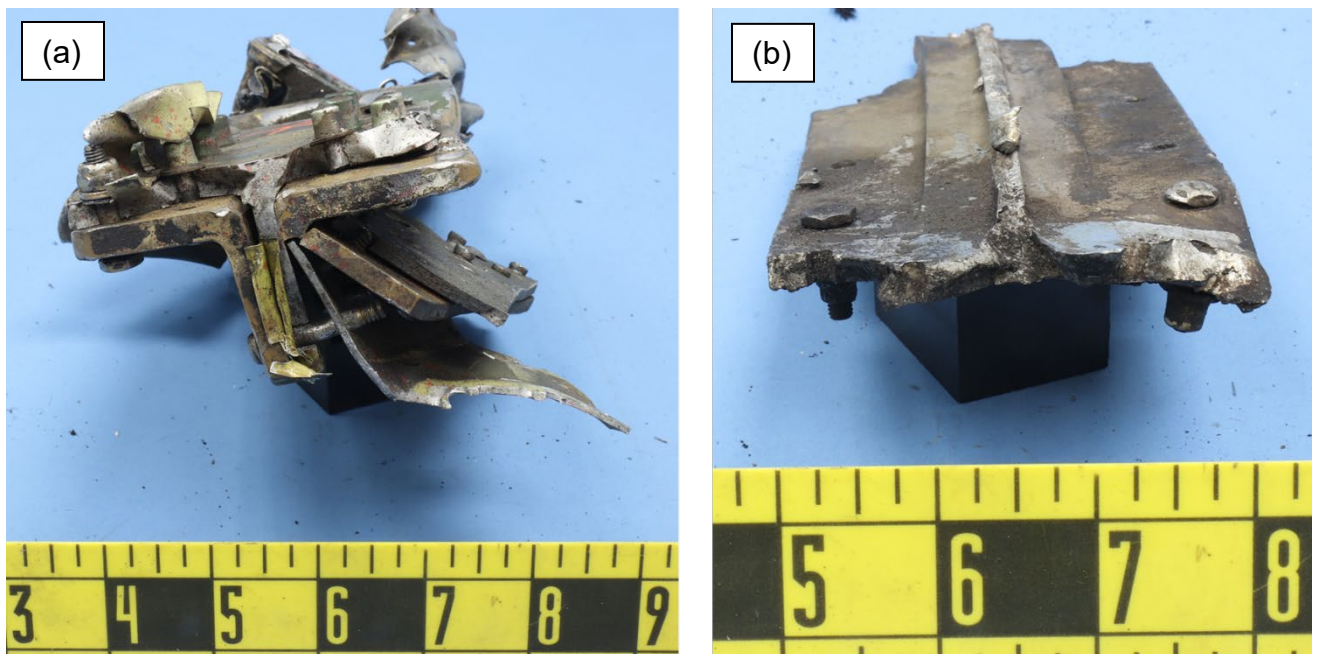


Figure 32 – Views of the fracture surface of the lower spar cap from the right side, showing the fracture from (a) the outboard and (b) inboard sides.

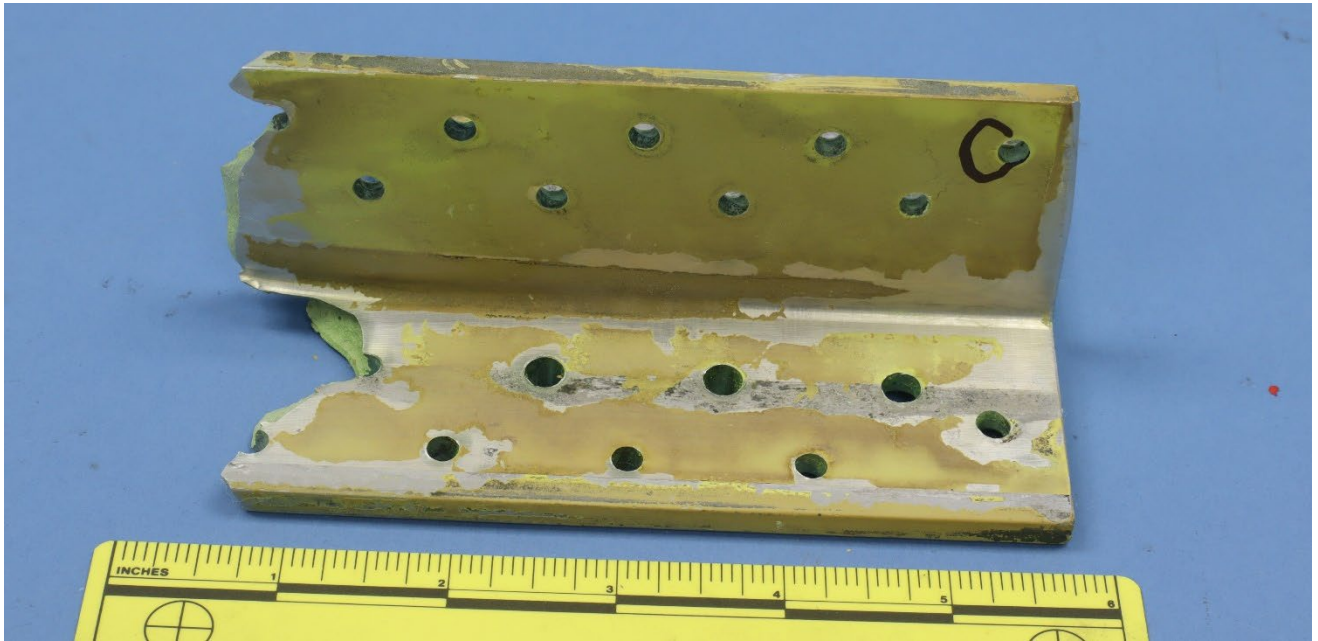


Figure 33 – View of the outboard wing spar cap from the right side after removal of the fasteners and cleaning. The circled area in the upper left exhibited FPI indications.

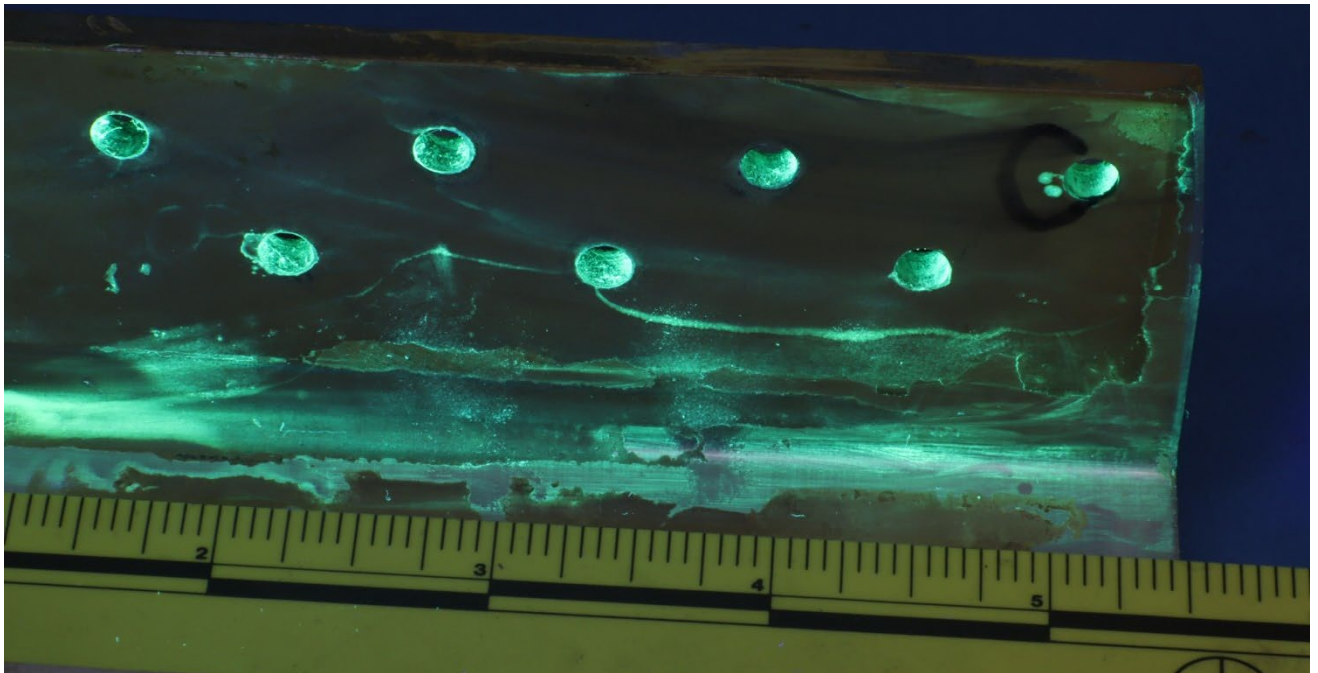


Figure 34 – UV light composite exposure of the spar cap remnant in Figure 33, showing the two indications in the upper right.

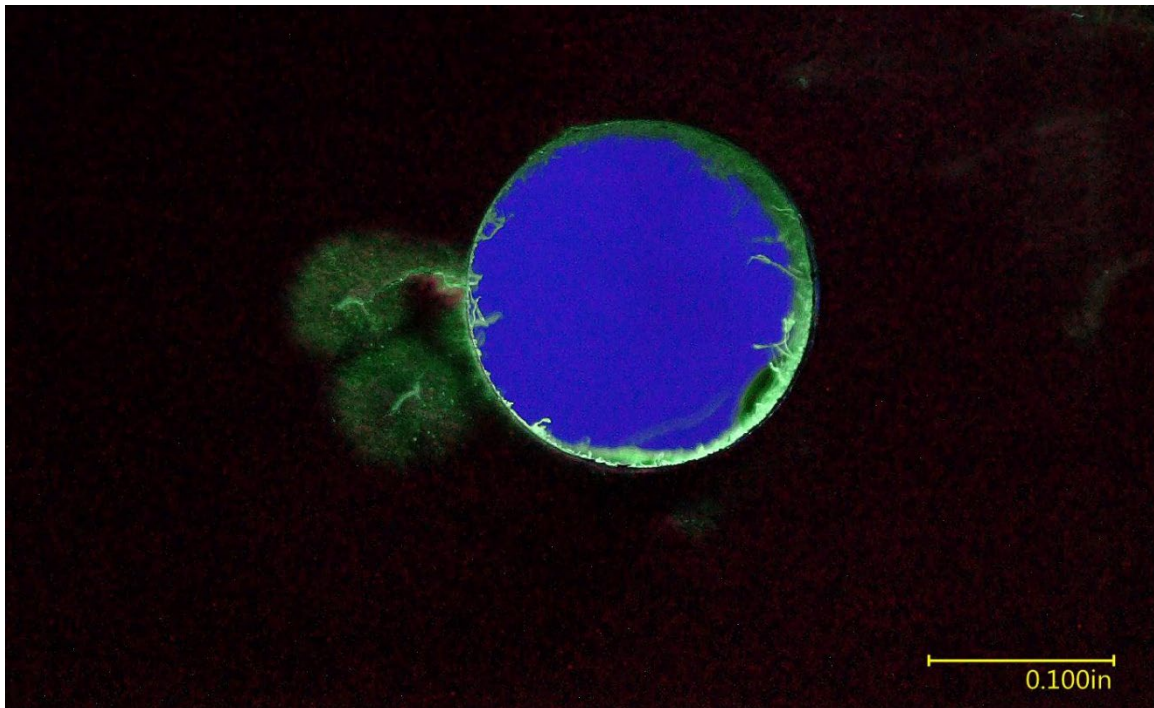


Figure 35 – Closer view of the indications near the fastener hole in Figure 34, under UV lighting.

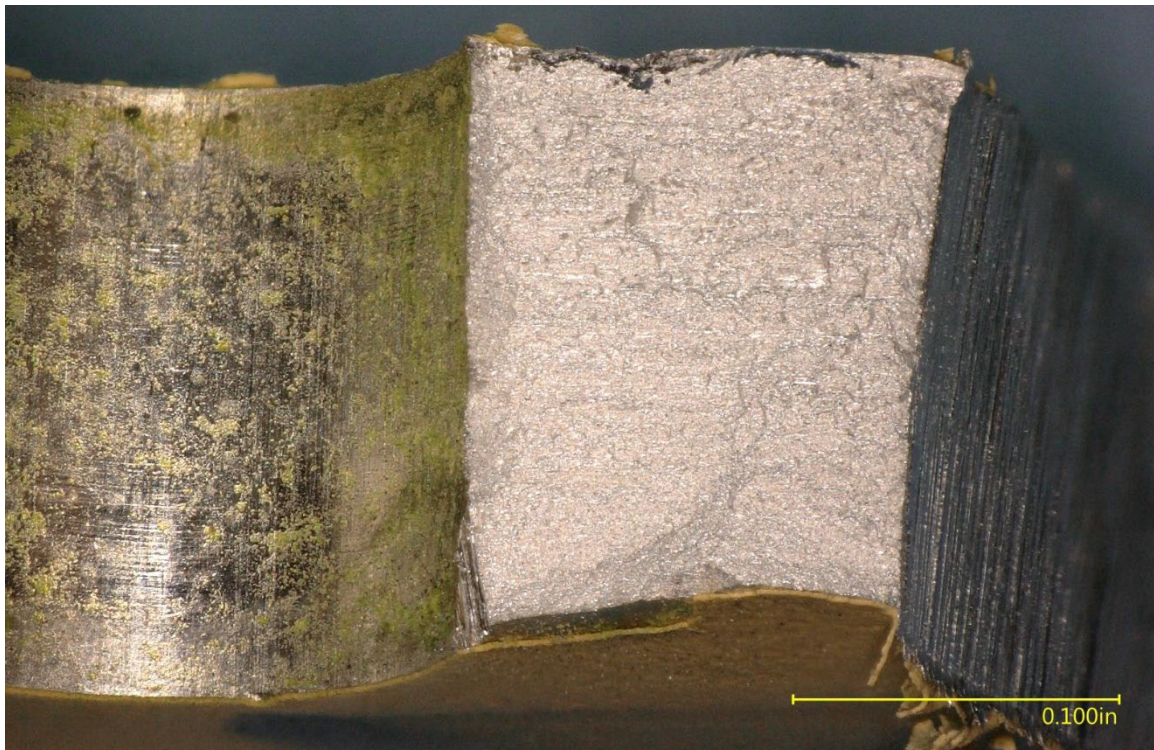


Figure 36 – View of the laboratory-opened indications in Figure 35, revealing no cracks or voids along the surface.