NATIONAL TRANSPORTATION SAFETY BOARD

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

December 4, 2019

MATERIALS LABORATORY FACTUAL REPORT   Report No. 19-070

1. ACCIDENT INFORMATION

Place	:	Adrian, Michigan
Date	:	January 13, 2019
Vehicle	:	Piper PA-32R-300, N8892E
NTSB No.	:	CEN19LA066
Investigator	:	Mitchell Gallo, AS-CEN

2. COMPONENTS EXAMINED

Crankshaft bolt fragments
Crankshaft gear

3. DETAILS OF THE EXAMINATION

On January 13, 2019, at 1746 eastern daylight time, a Piper PA-32R-300 experienced a total loss of engine power during a visual approach to Lenawee County Airport in Adrian, MI. The airplane impacted a fence and terrain short of the runway and sustained substantial damage. The private pilot received minor injuries. Post-accident examination of the engine, a Lycoming IO-540-K1G5D (S/N L-13642-48A), revealed that the crankshaft gear bolt (P/N 13S19649) had was fractured.[1] A logbook entry dated August 24, 2013, at a tachometer time of 3,399.87 hours and a time since overhaul of 0 hours, stated that the engine was disassembled, and an AN8-14 bolt was installed. The illustrated parts catalog and mandatory service bulletin 475C for the engine specified an AN8-14A bolt. The tachometer time at the time of the accident was about 3,466 hours (66 hours since overhaul). The fractured bolt, along with a gear and spacer from the engine were sent to the NTSB Materials Laboratory for examination.

Figure 1 shows the gear from the engine, as received. The gear face is shown in Figure 1a and the backing plate face is shown in Figure 1b. As shown in Figures 2 and 3, the gear face displayed vibroetched markings. The markings stated, “L-71974” and “13519649”.

[1] The IO-540 is a family of air-cooled, horizontally opposed, six-cylinder fuel-injected engines with 541.5 cubic inch (8,874 cc) displacement, made by Lycoming Engines, headquartered in Williamsport, PA.

The gear teeth exhibited damage consistent with impact and wear with an adjacent geared component. These included rectangular-shaped impact marks, shown in Figure 3. The impact marks were located on the edge of top lands of several teeth (upwards in Figure 4). Most of the faces of the gear teeth exhibited pock marks and missing material, as shown in Figures 5 and 6. This missing material was located above the flanks on the faces, which was consistent with locations where surfaces contact between geared components. These features were consistent with spalling wear of the gear.

Figure 7 illustrates the submitted spacer from both sides. Overall, the shape of the spacer remnant was a U-shape. The bottom portion of the spacer was missing. The upper portion in the figures had been bent over from one side to the other. The face displayed in Figure 7b exhibited circular impressions, consistent with batter marks. These features were consistent with repeated impacts with an adjacent component.

Figure 8 shows the two halves of the fractured crankshaft bolt, as received. The figure is annotated to show several measurements. The grip length, or length from under the head to the threaded transition, was 0.816 inches. The thread length was 0.784 inches, with the total length being 1.910 inches long. The shank diameter was 0.495 inches. The head of the bolt exhibited raised markings, “A F C” with an “X” on the bottom (see Figure 8, right side).

According to the dimensions for both AN8-14 and AN8-14A bolts, the grip length total length should be 1.59375 inches, the grip length should be 0.8125 inches, the threaded length should be a minimum 0.781 inches, and the diameter should be 0.500 inches in diameter. The (A) designation on the bolt part number indicates there should be no drilled hole in the shank. The fractured bolt measurements were consistent with the above dimensions and contained no drilled hole in the shank. Therefore, the submitted bolt was consistent with an AN8-14A.

The bolt had fractured 1.038 inches below the bolt head. The fracture surface is shown in Figure 9. Examination using visual and scanning electron microscopy (SEM) found features consistent with fatigue crack propagation and subsequent overstress. These regions on the fracture surface are annotated in Figure 10. As shown in Figures 9 through 12, there were two smaller thumbnail cracks present on opposite 180° sides of the fracture surface. Figure 11 shows the thumbnail crack feature of the larger crack—this crack was located near the bottom of a thread root.

Figure 12 and Figure 13 show the smaller thumbnail crack side, at an angled and planar view, respectively. As illustrated in the figures, the smaller thumbnail crack exhibited crack arrest marks and ratchet marks, consistent with crack initiation at the thread root and propagation inward.

Figure 14 shows a typical area of the larger fatigue crack in the initial thumbnail area. The figure shows fatigue striations, consistent with fatigue crack propagation. Figure 15 shows a typical area of the fatigue crack in the larger, flatter area. This region also exhibited fatigue striations. The smaller opposite thumbnail crack also exhibited fatigue striations. In both thumbnail cracks, the striations were oriented consistent with the propagation from the outside surface inward. The small middle region exhibited dimple rupture, as shown in Figure 16. These features were consistent with subsequent overstress.

As shown by the ratchet marks in Figure 11 and 13, both fatigue cracks exhibited multiple crack initiation sites. Figure 17 shows some of these initiation sites, with intermediate ratchet marks. As illustrated in Figure 18, there were no features consistent with material or mechanical defects, such as corrosion pits, pores, and voids.

The threaded portion of the fractured bolt was sectioned, mounted, and polished. Figure 19 shows a thread root and two teeth adjacent to the fracture surface (off figure to the right in Figure 19). A small crack was present emanating inward from the thread root. Figure 20 shows the same thread root after etching with a 2% Nital solution.[2] The root exhibited grain flow around the radius, which was consistent with rolled threads.

The above bolt features were consistent with fatigue cracking that initiated at multiple sites near the bottom of a thread root. These smaller cracked coalesced and propagated inward through more than half the crack section of the bolt. The bolt began to cycle under reverse bending, which initiated fatigue cracking at multiple sites along the thread root on the opposite side. Once both cracks had propagated inward to the extent present on the fracture surfaces, the remaining cross section of the bolt fractured from overstress.

The composition of the bolt was examined using energy dispersive spectroscopy (EDS). The composition was consistent with an alloy steel. Figure 21 shows a typical area of the bolt microstructure. The microstructure was consistent with tempered martensite. The hardness of the core of the bolt was inspected using microindentation hardness per ASTM E384.[3] The hardness for the part averaged 31 HRC (308 HK_{500}), which exceeded a stated minimum of 26 HRC. These data were consistent with the alloy and microstructure observed.

Erik M Mueller
Materials Research Engineer

[2] Nital – a solution of 2% concentrated nitric acid (HNO_3) in ethanol.
[3] ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA

Figure 1 – The crankshaft gear, viewed from opposite faces, as received.

Figure 2 – The markings on the face of the gear side of the crankshaft gear.


Figure 3 – Vibroetched markings on the gear face, 180° opposite of those in Figure 2.

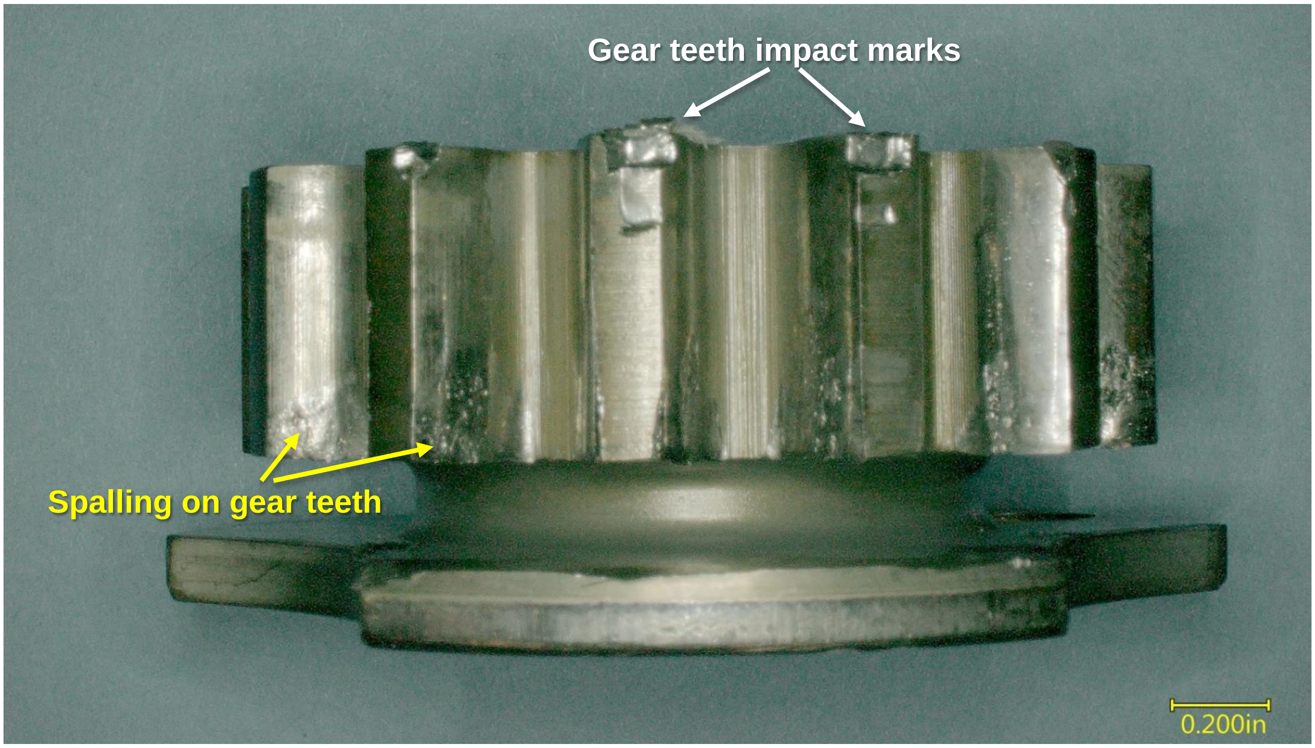

Figure 4 – View of the gear from the teeth side, showing rectangular impact marks from an adjacent geared component.

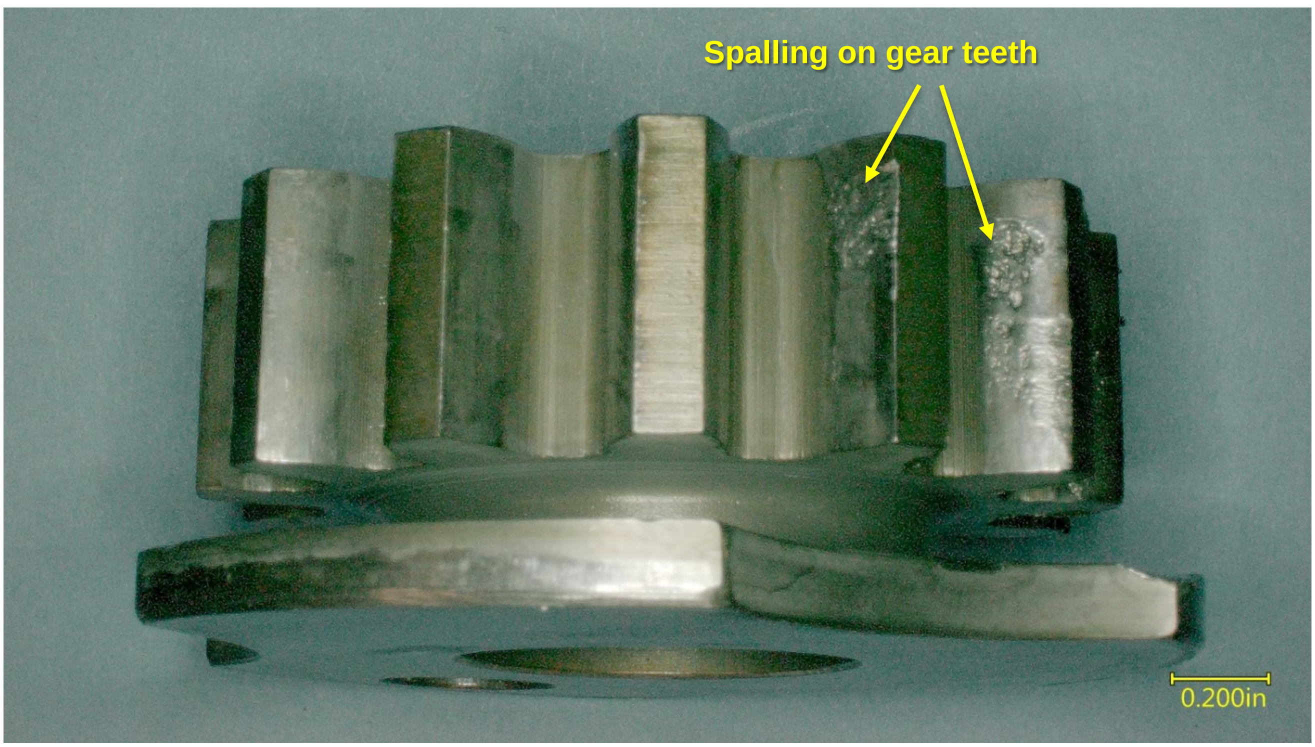

Figure 5 – View of the gear teeth, rotated approximately 90° from Figure 4, showing spalling on the teeth contact faces (arrows).

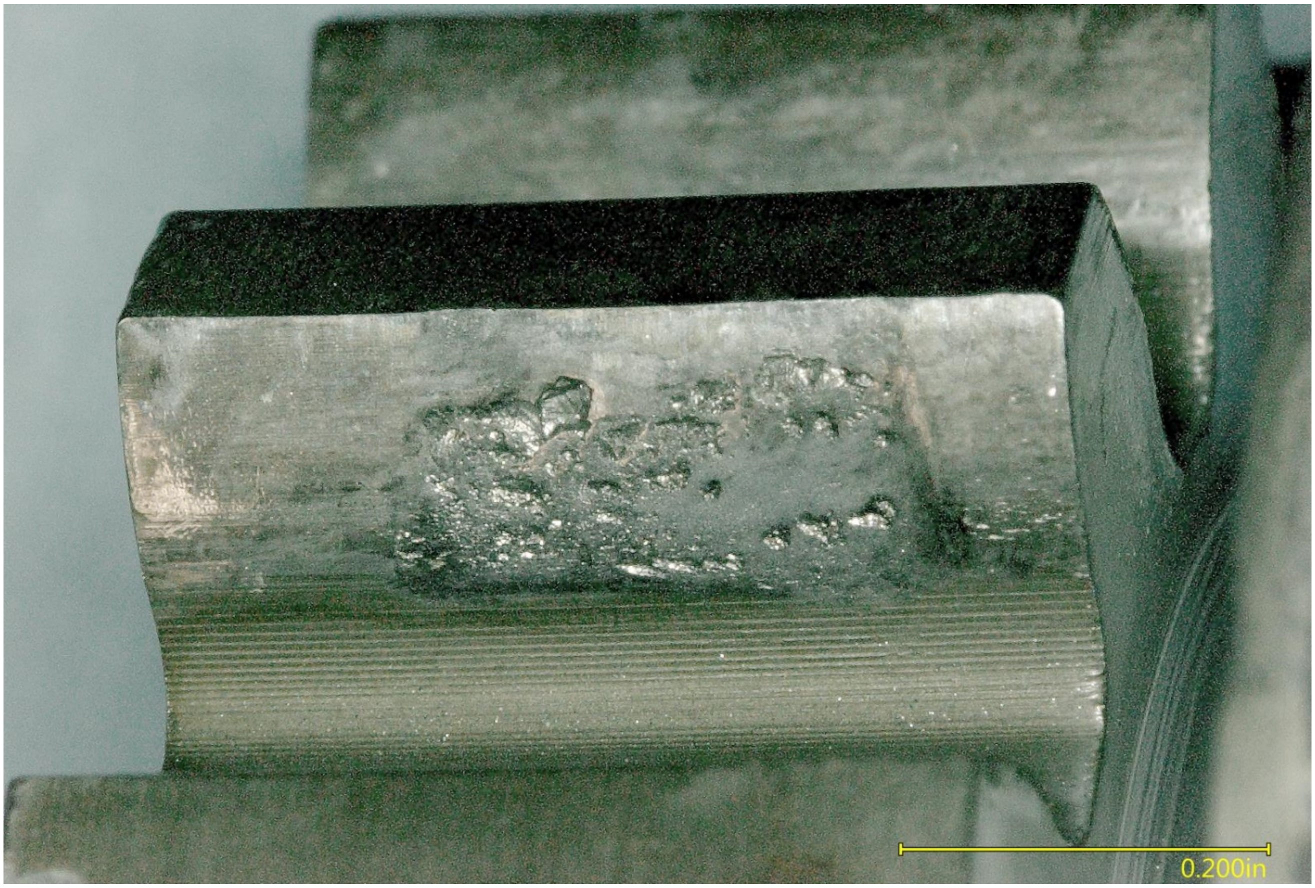

Figure 6 – Closer view of the spalling on a gear tooth face.

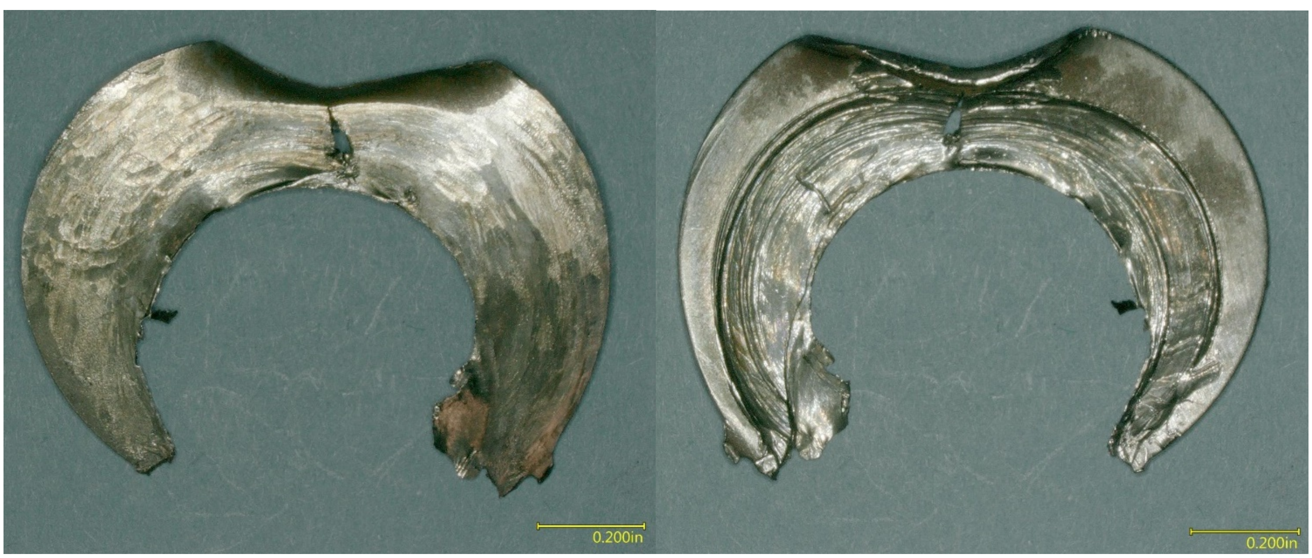

Figure 7 – Deformed spacer, viewed from (left) the flatter and (right) the reverse side, as received.

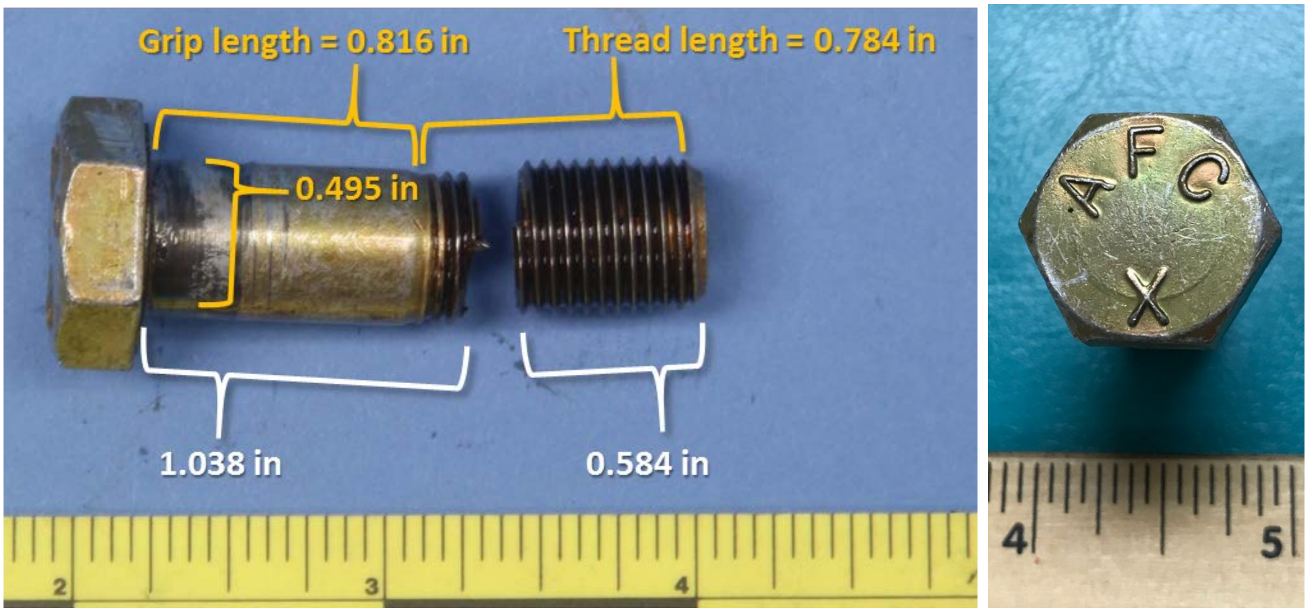

Figure 8 – View of the two fractured halves of the crankshaft bolt, as received on the left figure. The top of the bolt head is shown on the right.

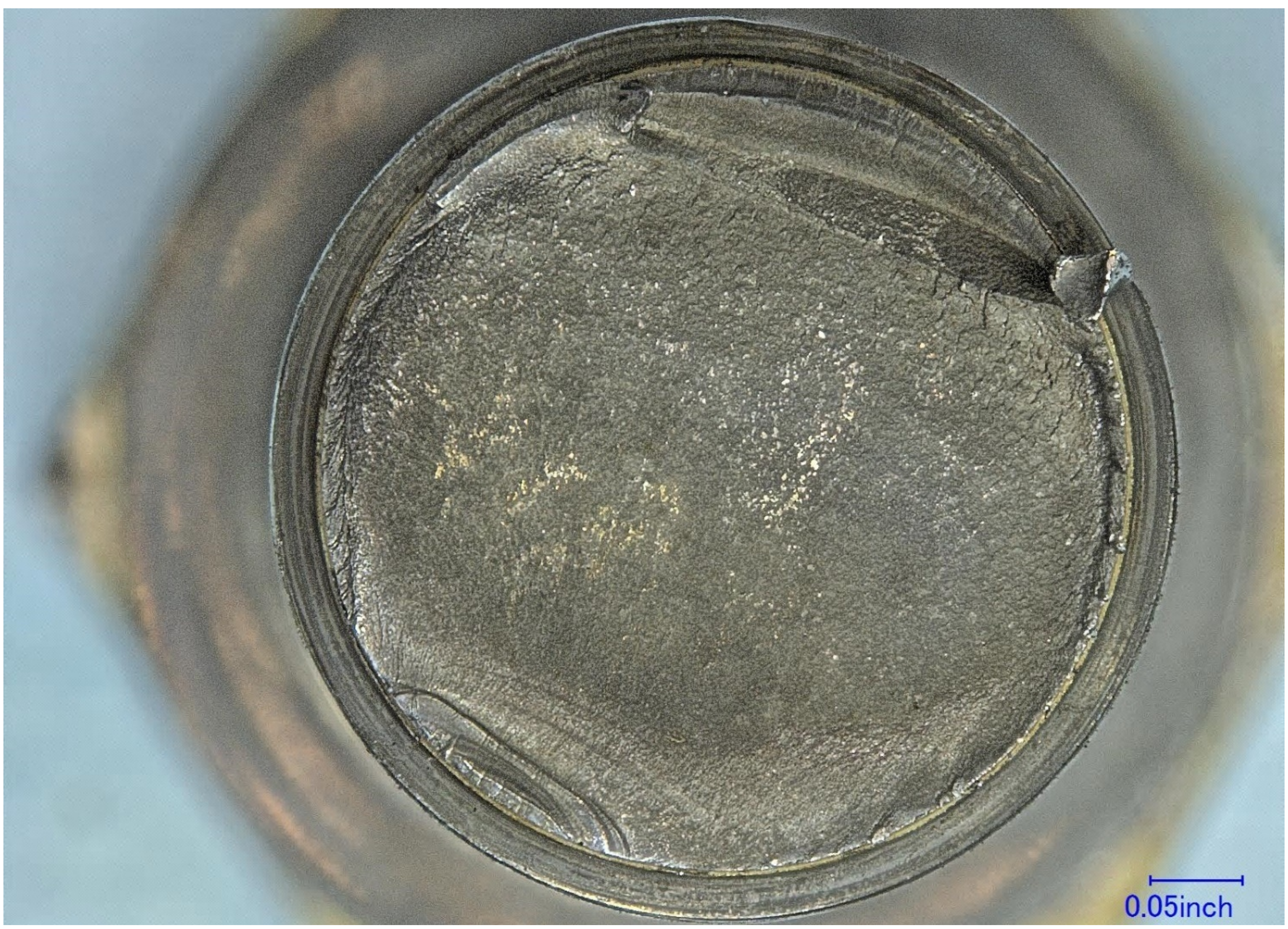

Figure 9 – The bolt shank fracture surface, showing crack arrest and ratchet marks.

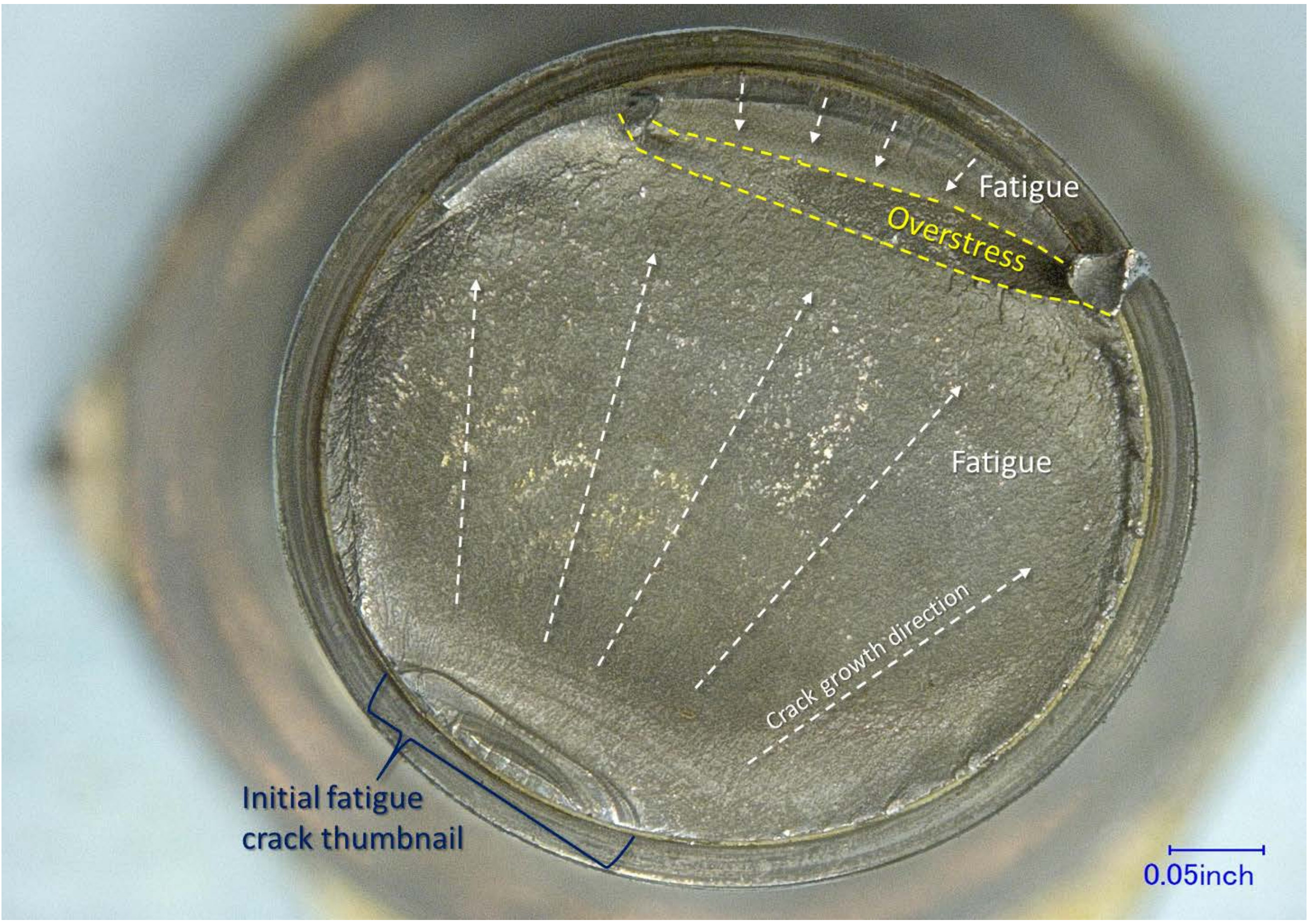

Figure 10 – The bolt fracture surface, annotated to show the different fracture regions on the surface.

Figure 11 – Angled view of the initial thumbnail on the fatigue crack of the bolt fracture.

Figure 12 – Angled view of the smaller thumbnail crack and the overstress region on the bolt.

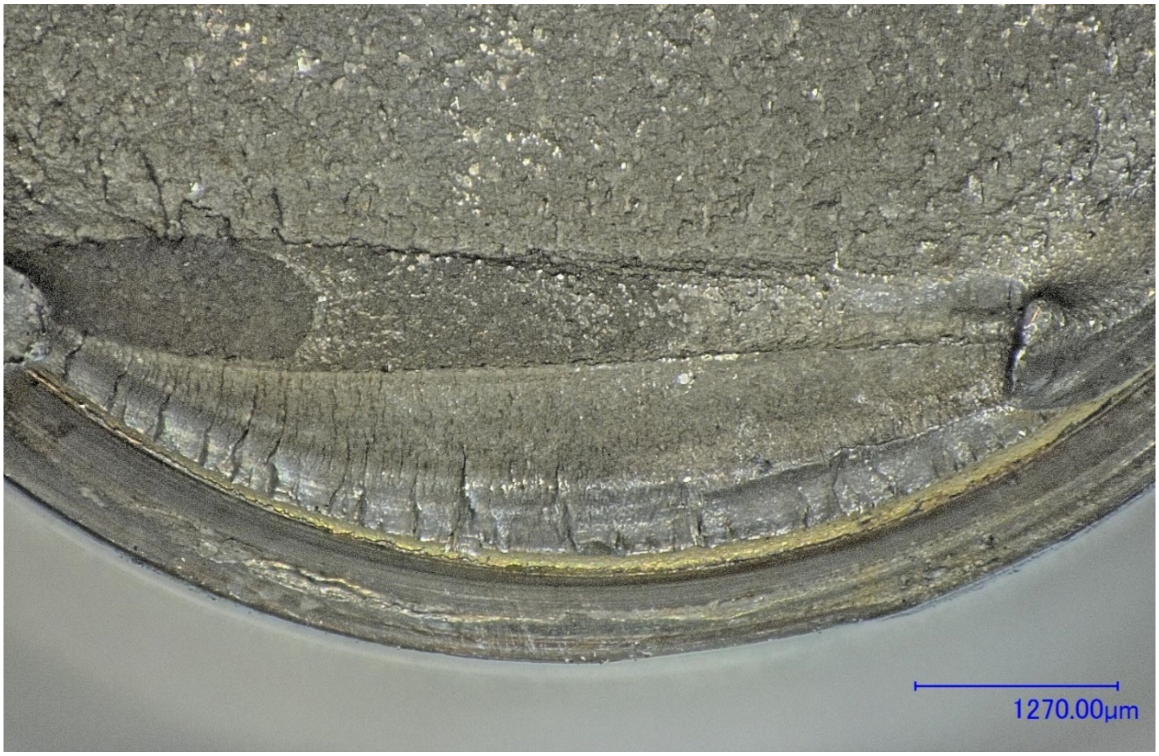

Figure 13 – View of the area of overstress and the smaller fatigue crack on the fractured bolt.

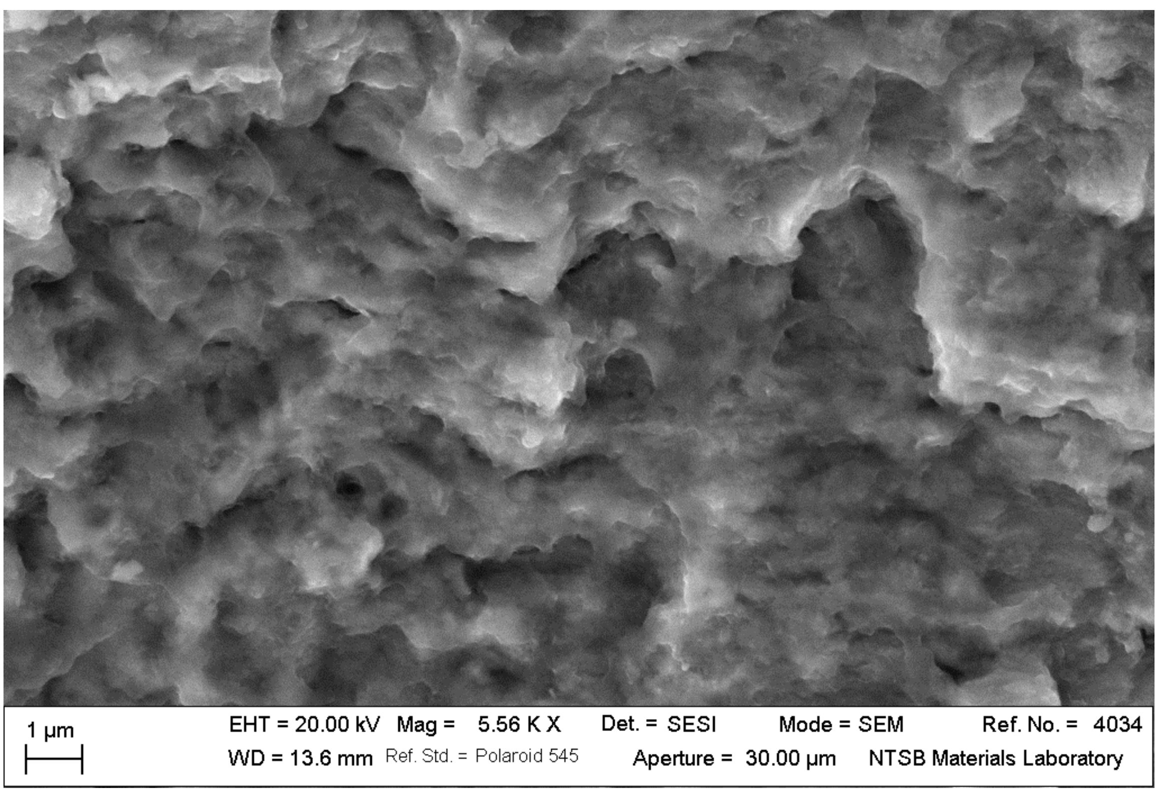

Figure 14 – Secondary electron (SE) micrograph of fatigue striations near in the initial thumbnail area of the bolt fracture surface.

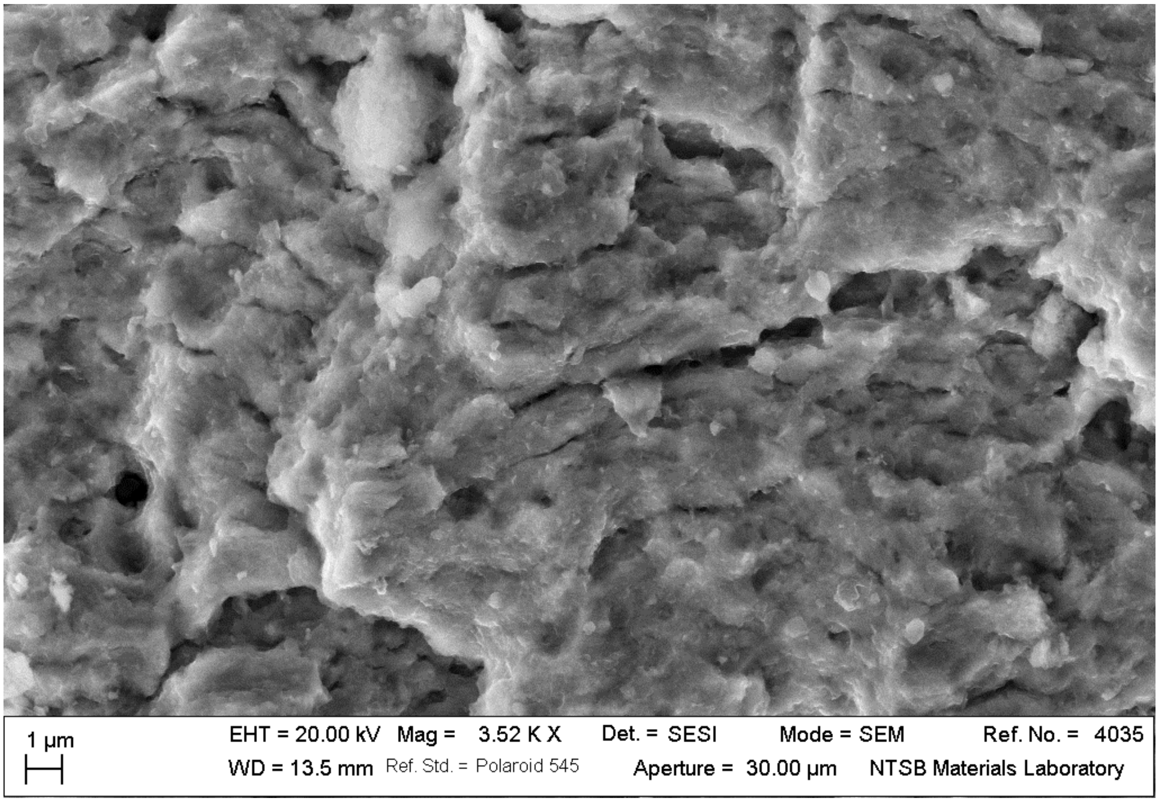

Figure 15 – SE micrograph of fatigue striations at the end of the large fatigue crack on the bolt fracture surface.

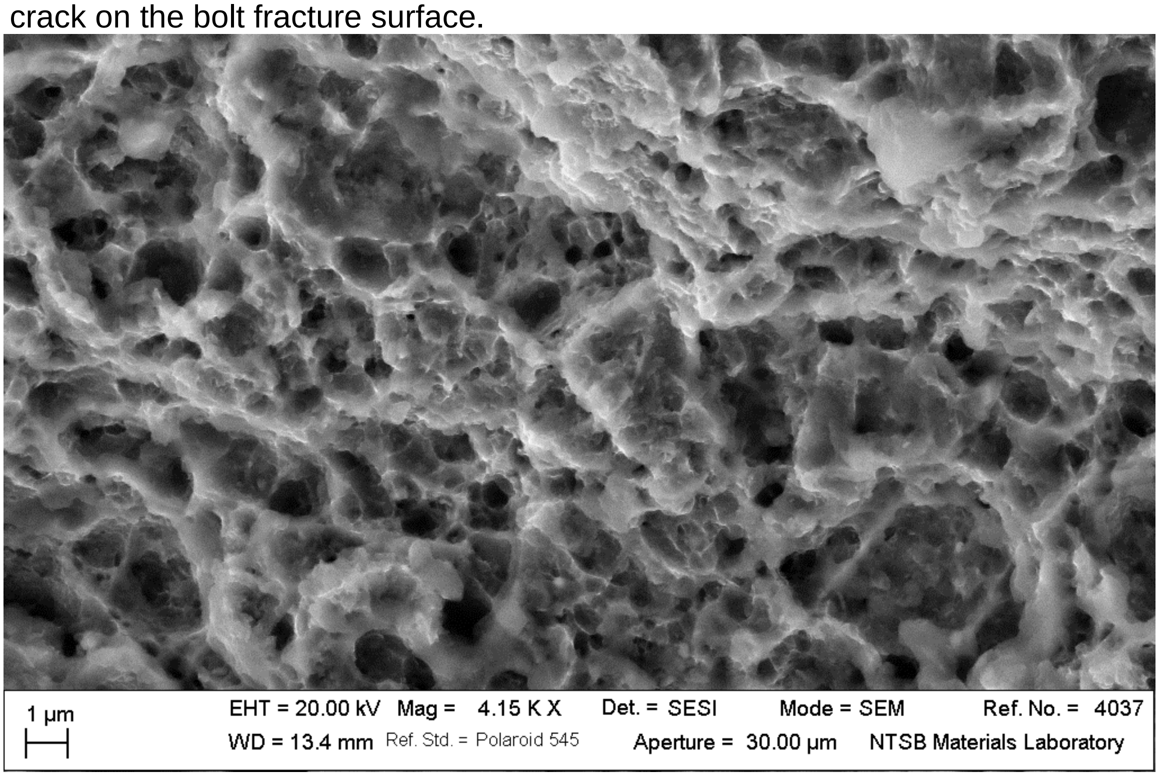

Figure 16 – SE micrograph of dimple rupture in the overstress area on the bolt fracture surface.

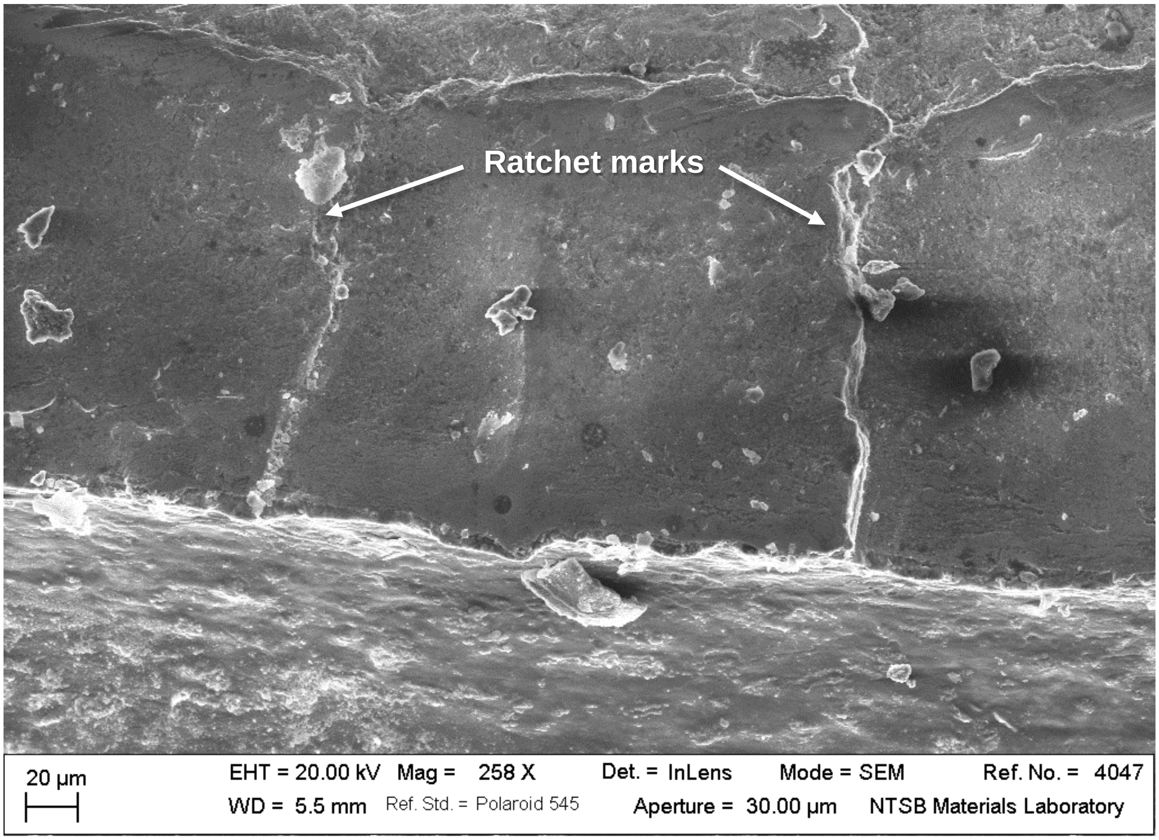

Figure 17 – SE micrograph of multiple crack initiation sites, with ratchet marks highlighted.

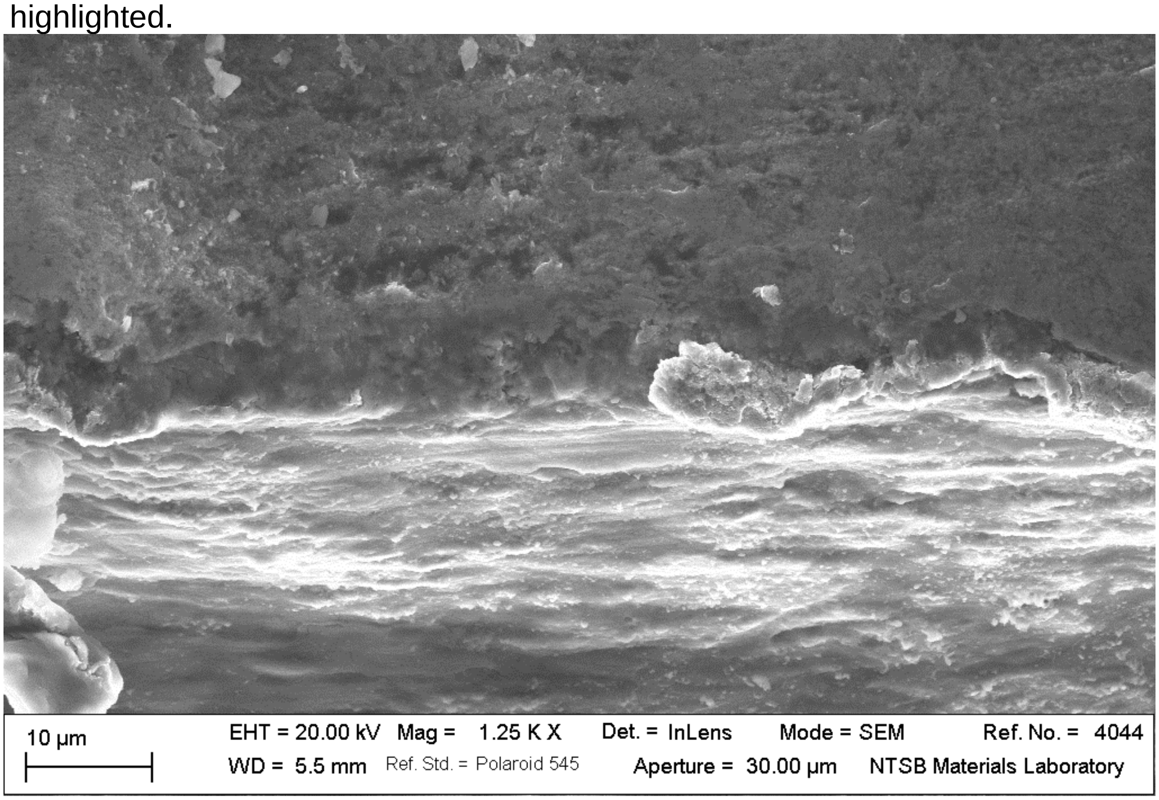

Figure 18 – SE micrograph of the middle initiation site in Figure 17.

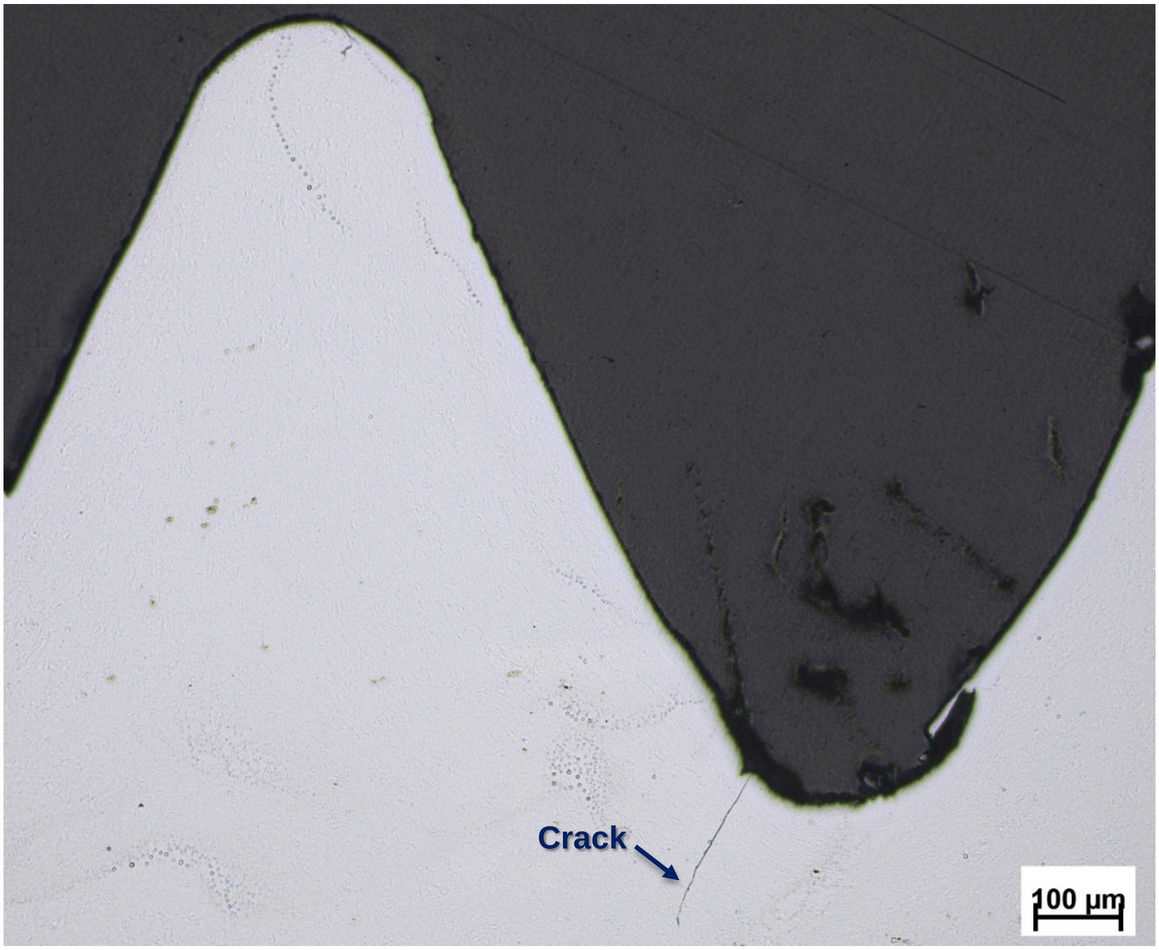

Figure 19 – Bright-field (BF) optical micrograph of a cross-section of the threaded bolt section, near the fracture surface. A small crack was present in the thread root (arrow) (~100X, as polished).

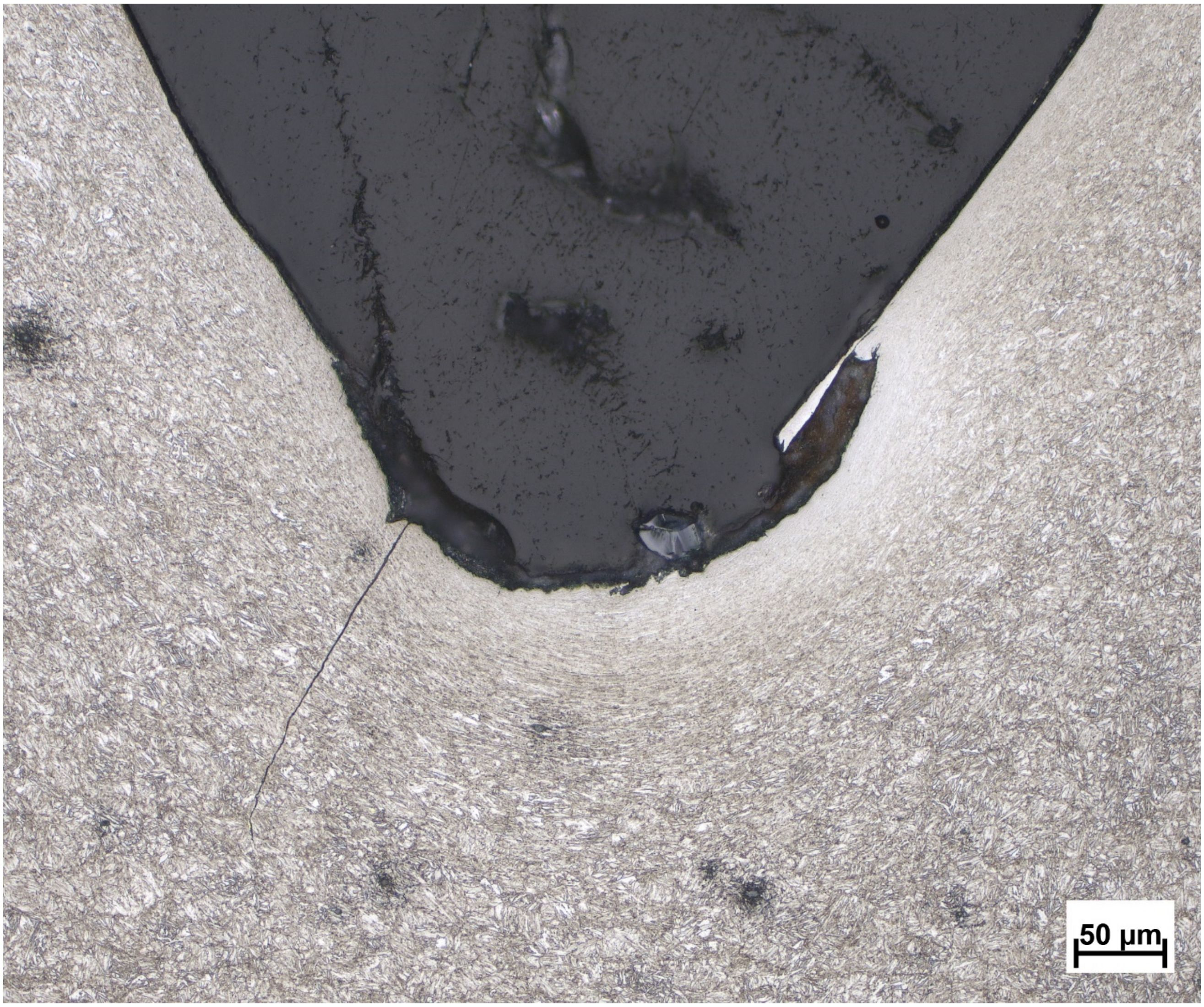

Figure 20 – BF micrograph of cracked thread root adjacent the fracture surface in Figure 19, showing grain flow around the thread and the crack (~200X, etched 2% Nital).

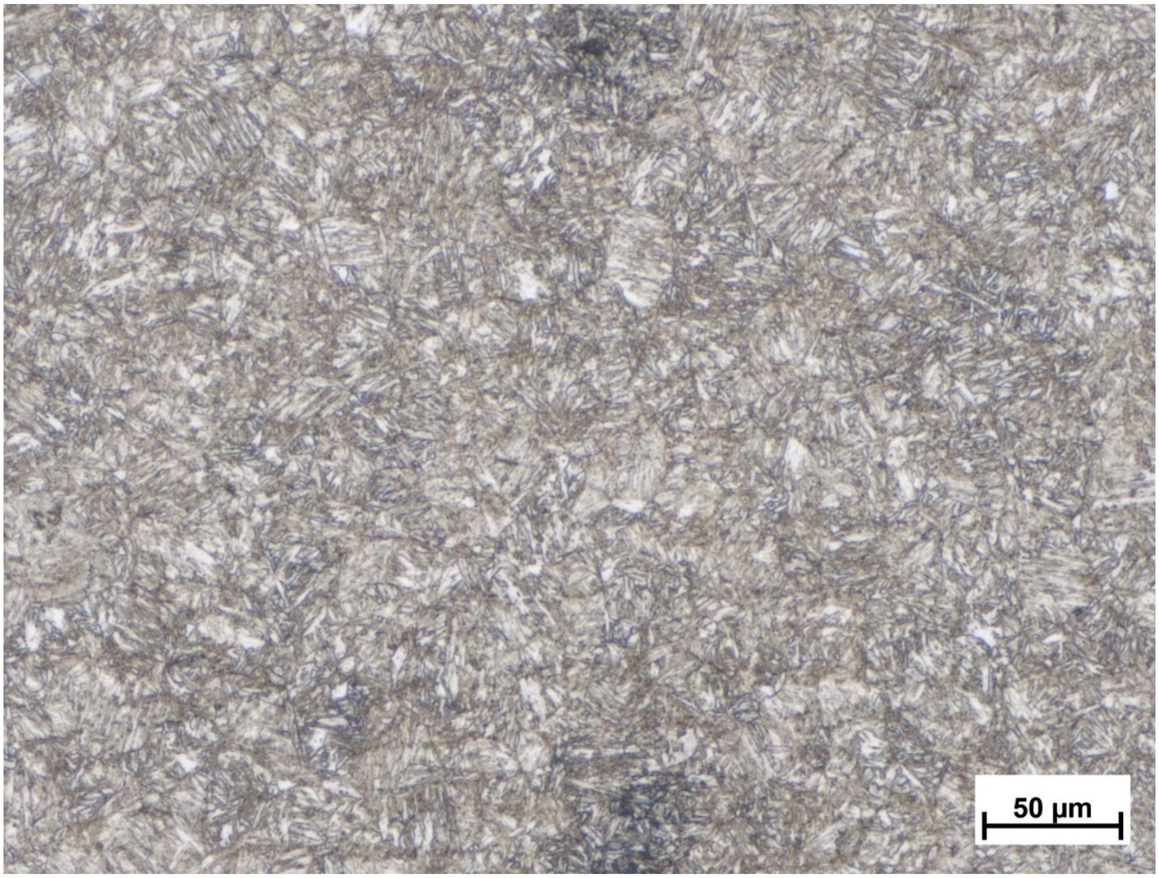

Figure 21 – BF optical micrograph of a typical area of the bolt microstructure, showing tempered martensite (~500X, etched 2% Nital).