

NATIONAL TRANSPORTATION SAFETY BOARD

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



April 30, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-029

1. ACCIDENT INFORMATION

Place : Vinemont, Alabama
Date : February 20, 2021
Vehicle : Piper PA-32RT-300T, N10KV
NTSB No. : ERA21FA133
Investigator : Millicent Hill, AS-WPR

2. COMPONENTS EXAMINED

Pieces of a crankshaft drive gear assembly
Remnants of engine gears

3. DETAILS OF THE EXAMINATION

On February 20, 2021, about 1748 central standard time, a Piper PA-32RT-300T was destroyed when it was involved in an accident near the Cullman Regional Airport (CMD) near Vinemont, AL. The pilot and a passenger were fatally injured. According to airport surveillance video, the airplane impacted terrain after performing a touch-and-go landing. The pilot had stated to first responders that the airplane had “lost power.”

Examination of the accident site revealed that the airplane had come to rest inverted, and a postimpact fire had consumed most of the wreckage. The Lycoming TIO-540-S1AD (S/N L-550-61A) engine was partially separated, having sustained impact and fire damage.¹ Several of the engine gear assembly remnants were sent to the NTSB Materials Laboratory for additional examination.

The parts received included the remnants of five gear assemblies, along with an attachment bolt and lock plate. The parts are shown in Figures 1 through 4, as received. This included the bottom right hand assembly gear (Figure 1), the top left hand assembly gear (Figure 2), and a pair of unlabeled accessory gears (Figure 3). All these gears were intact, with no clear indications of deformation or fracture. These gears did exhibit a thick surface layer of soot and oils, consistent with exposure to fire and elevated temperatures.

¹ The Lycoming TIO-540 is a turbocharged, air-cooled fuel-injected six-cylinder, horizontally opposed fixed-wing aircraft and helicopter engine, manufactured by Lycoming Engines headquartered in Williamsport, PA.

The top left hand gear also exhibited a uniform surface layer of rust. As the layer was uniform and present over wear marks, the rust was consistent with oxidation from exposure to water or air after the accident.

Figure 4 shows the components of the crankshaft drive gear, as received. This consisted of the remnants of the drive gear assembly, the attachment bolt, and the locking plate. The head of the bolt, the teeth of the gear, and the forward backing plate of the gear assembly exhibited a dark color, consistent with oil and soot deposits. These constituents were absent on the aft face of the gear and the threads of the bolt. Of note was one of the gear teeth had fractured and liberated from the gear assembly.

The gear exhibited the following markings on the aft face: "SL13S19649 REV B M23930 FAA-PMA". In the aft looking forward position, the fractured gear was the fifth tooth positioned counterclockwise from the aft tooth face labeled "0".

Figure 5 shows the mating fracture surfaces of the fractured tooth. For the most part, the mating fracture surfaces exhibited a dull, fibrous, light gray surface, contrasting with the surrounding darkened gear surfaces. Figure 6 shows a closer view of the fracture surface on the gear. This fracture exhibited a rough surface texture, along with a general concave orientation, particularly along the edges and periphery. The location of the fracture edges was consistent with the fillet radius between the bottom lands and the adjacent flanks. This geometry is exemplified in the angled view in Figure 7.

Figure 7 also shows the flank and face of an intact tooth adjacent to the fracture surface. There is a longitudinal rectangular wear mark along the width of the tooth, consistent with being the surface interacting with the adjacent gear. This wear was located along the pitch circle location in the middle of the tooth, rather than closer to the upper top land. There were no indications of cracks or fractures on this tooth.

Figure 8 though shows another nearby gear tooth with a smaller rectangular impression along the tooth land. As shown in Figure 9, this impression exhibited localized plastic deformation into the tooth land around the edges. The edges of the rectangular impression exhibited some material spalling and surface cracking.

Also examined was the dowel hole on the forward backing plate of the gear assembly (see Figure 10). The interior of the hole exhibited some circumferential and longitudinal wear marks, consistent with vibration and fretting between the plate and the crankshaft dowel. There was an area on a hole edge with outward plastic deformation, manifest as an impression on the edge. This deformation was present only on the one edge location.

The fractured and liberated gear tooth was cleaned in acetone using an ultrasonic bath. The fracture surface is shown in Figure 11. The surface exhibited a general convex shape, consistent with having mated to the concave shape of the gear fracture. Figure 12 shows the tooth from both lands and faces, whereas Figure 13 shows the tooth from the forward and aft faces. Towards one of the edges, the fracture surface curvature was less

pronounced than along the opposite edge. In addition, this opposite edge exhibited a cantilever curl, along with knife-shaped points exuding outward. These features were consistent with the tooth having fractured in bending, and the bending direction was consistent with the loading and rotation direction of the gear wear marks.

The tooth was examined using a scanning electron microscope (SEM). Figure 14 shows a typical view of the tooth fracture surface. The tooth exhibited a rough texture with parallel elongated regions of flatter surface quality. Closer examination revealed dimpled rupture, consistent with overstress fracture in both of these regions (see Figure 15).

Towards the outside edge of the fracture surfaces on the tooth land and profile width, the fracture surface morphology became more faceted (Figure 16). A closer view of the outer portion of the fracture surface revealed mixed features of faceted and dimpled rupture features, consistent with an additional intergranular fracture mode (Figure 17). Figure 18 shows the local difference of dimpled rupture on one grain facet and tearing on a flatter facet. This intergranular fracture was present on the long edges of the tooth fracture, but not on the short sides, which exhibited only dimpled rupture, as typified in Figure 19.

As the fracture was consistent with overstress in bending, there were no progressive fracture features or initiation sites. However, examination of the driven flank just above the fracture edge on the tensile side revealed secondary cracking above the fracture surface (Figure 20). This cracking was consistent with a partial fracture on one side of the tooth during the overstress event.

The chemical composition of the tooth fracture surface was examined using energy dispersive x-ray spectroscopy (EDS). From the data obtained using these techniques, the remnant was found to be consistent with an alloy steel, such as Type 4340. The outer regions which exhibited intergranular fracture exhibited higher carbon contents than the interior core regions.

The middle of the fractured tooth was sectioned, mounted, polished, and etched using a 2% Nital solution.² A typical view of the tooth microstructure is shown in Figure 20. The microstructure exhibited a fine equiaxed grain structure with lath features, consistent with tempered martensite. Figure 21 shows the fracture edge on the compression side. Figure 22 shows the fracture edge on the tensile side. The tensile side shows additional secondary cracking in the region consistent with the observed intergranular fracture. The compressive side showed three 'spike-shaped' areas, consistent with cross-sectioning through the buckled material on the sides of the tooth fracture. These features were consistent with bending overstress for this part.

The hardness of the tooth cross section was examined using automatic microindentation hardness, per ASTM E384.³ A chart of the individual indent data is shown

² Nital is a mixture of 2% concentrated nitric acid in ethanol.

³ ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA

in Figure 22. The hardness of the tooth peaked at 57 HRC (670 HV₅₀₀) near the surface but did not exhibit a rapid drop in hardness towards the interior, which would be typical of a case hardening surface treatment.

Rather, the hardness decreased slightly to around 47 HRC around 0.03 inches in depth, dropping below 50 HRC around 0.015 inches (0.38 mm). This was consistent with the depth of the intergranular layer on the fracture surface of the tooth, approximately 0.012 inches (0.3 mm).

Erik M Mueller
Materials Research Engineer



Figure 1 – The bottom right hand assembly gear, as received.

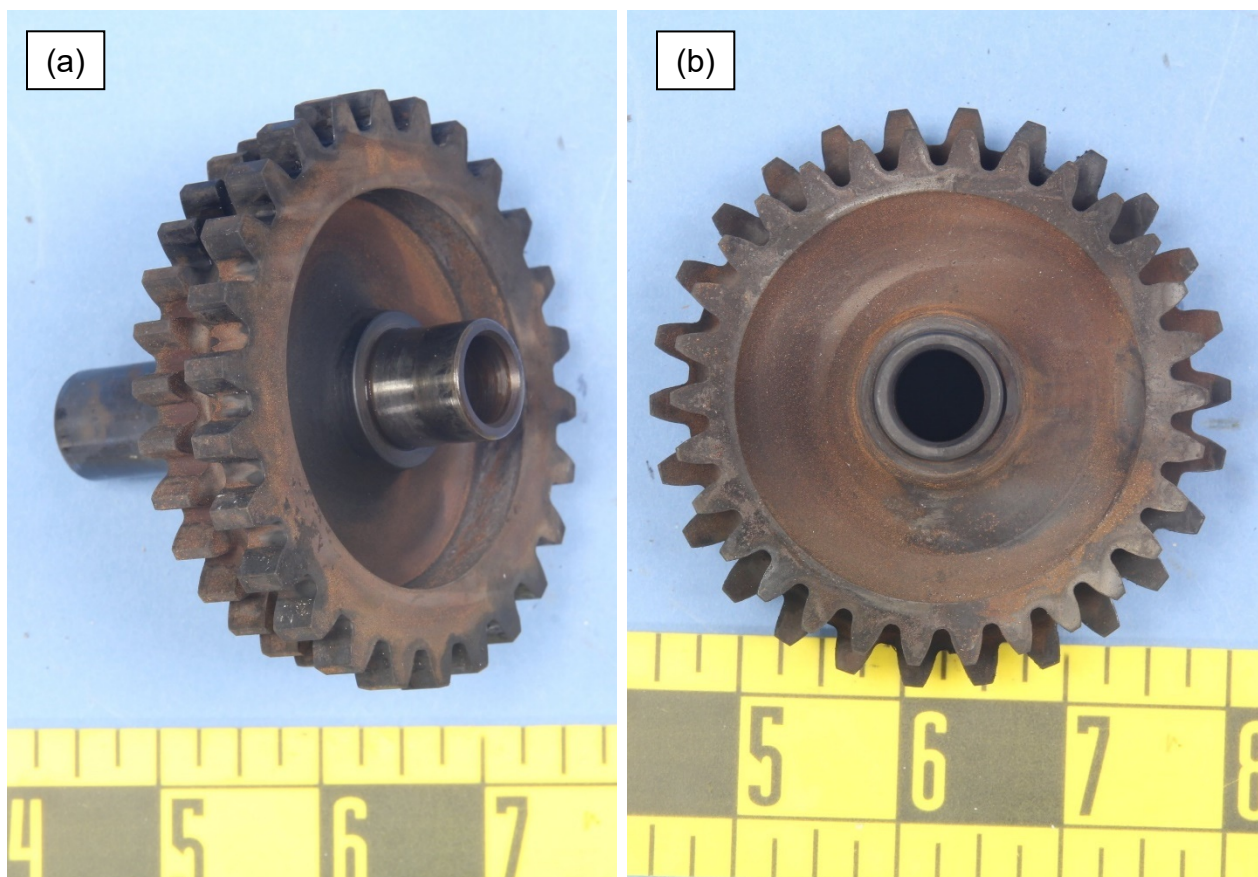


Figure 2 – The top left hand assembly gear, as received.



Figure 3 – The pair of accessory gears, as received; viewed from (a) the sides and (b) the gear faces.

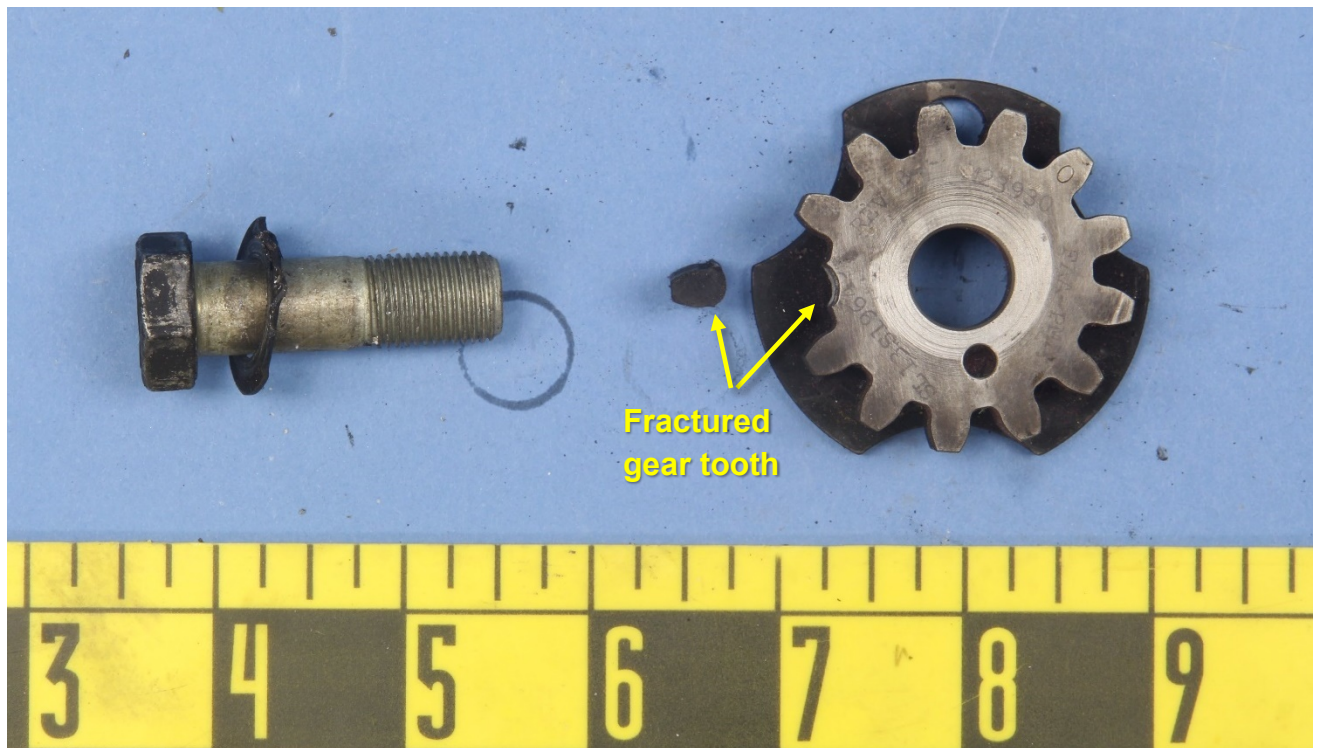


Figure 4 – The crankshaft drive gear and tooth fragment, along with the attachment bolt and locking tab remnant, as received.



Figure 5 – View of the mating fracture surfaces of the drive gear and liberated tooth.



Figure 6 – The fractured tooth surface of the drive gear.



Figure 7 – Angled view of the gear fracture surface, showing the adjacent tooth.

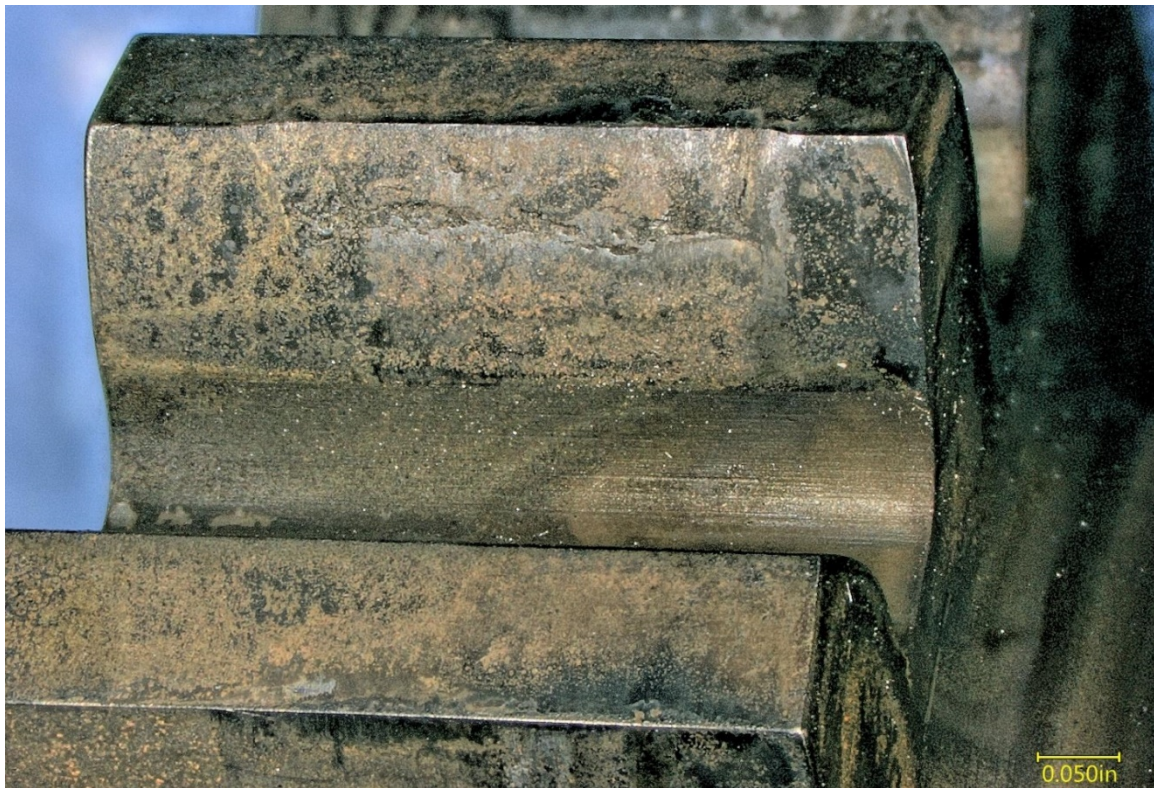


Figure 8 – View of an intact but abraded gear on the driven side.



Figure 9 – Closer view of the imprint on a gear tooth flank in Figure 8.

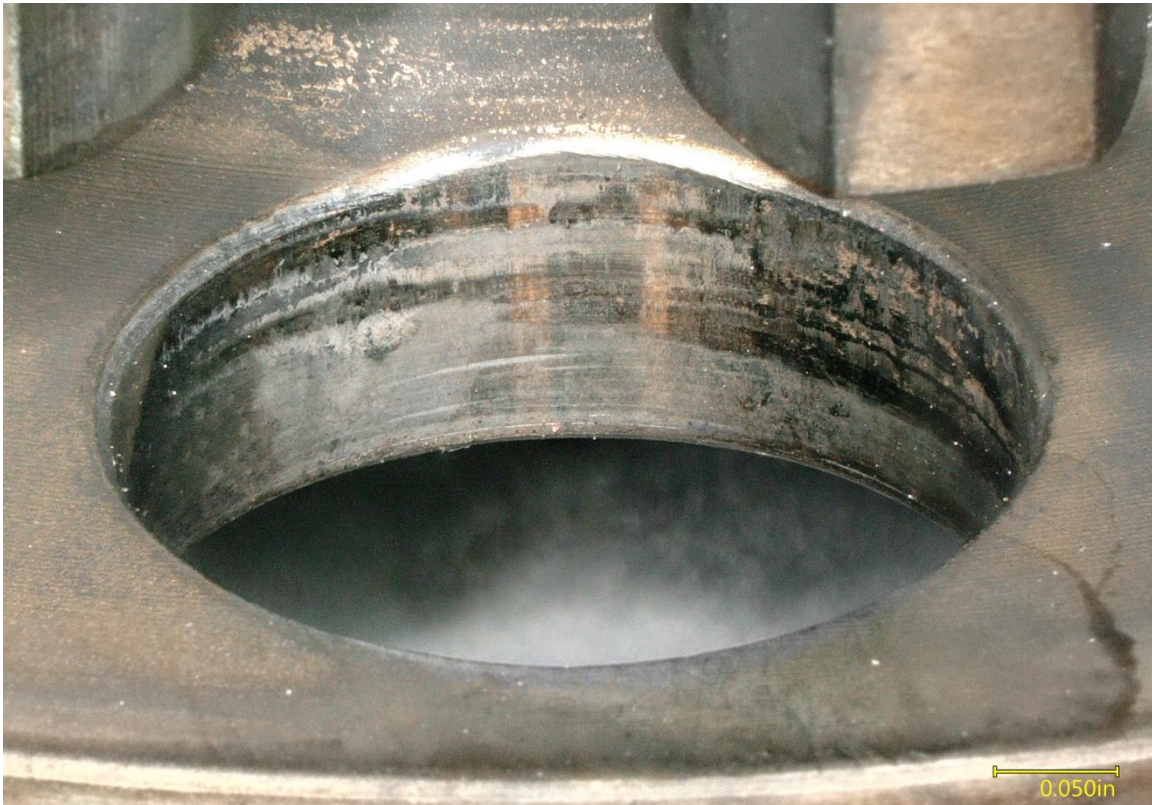


Figure 10 – View of the pin hole on the drive gear backing plate, showing internal wear.



Figure 11 – View of the fracture surface of the fractured drive gear tooth.



Figure 12 – View of the fractured tooth from (a) the lagging face and (b) driven face.

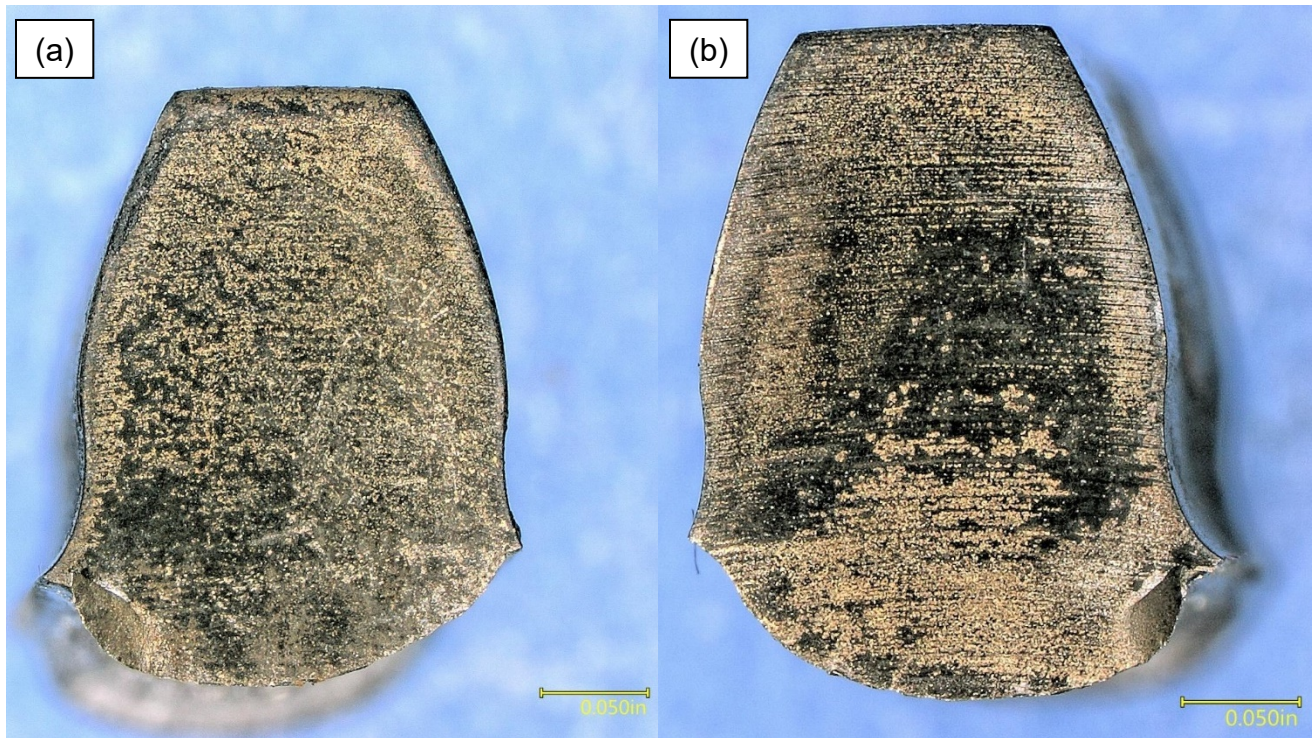


Figure 13 – The sides of the fractured gear teeth from the (a) forward face side and (b) backing plate side.

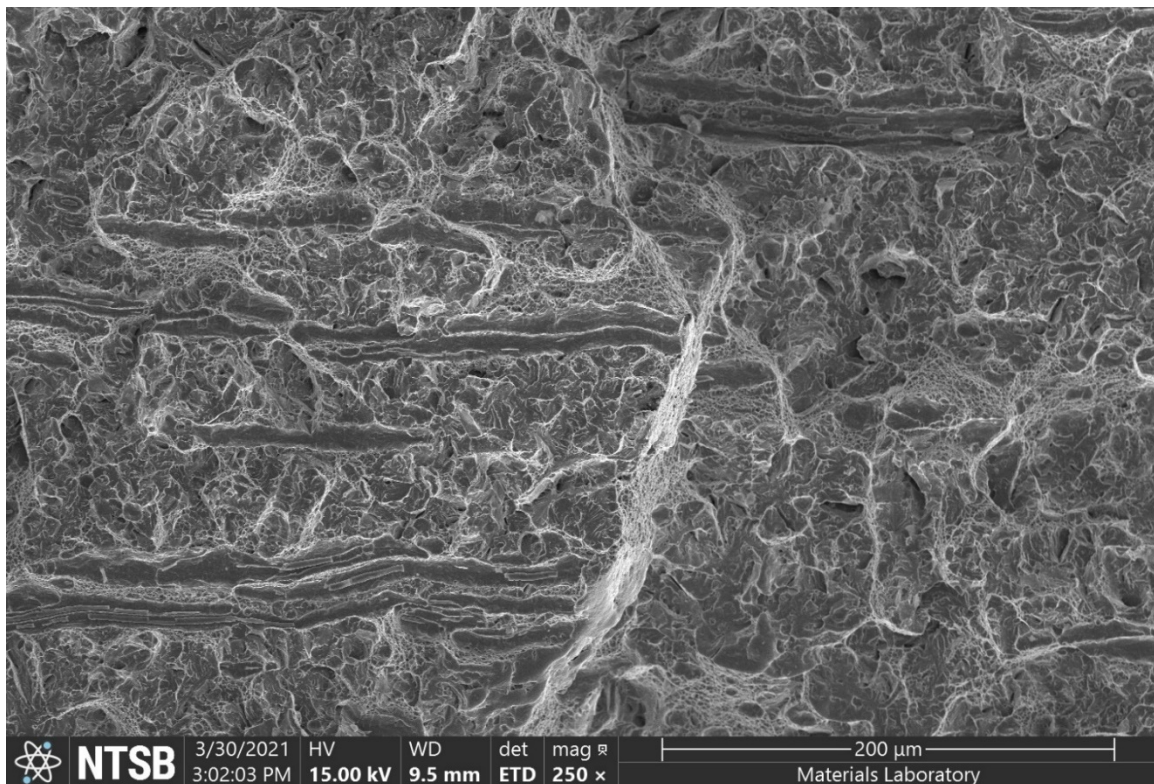


Figure 14 – Secondary electron (SE) micrograph of a typical area of the core fracture surface of the fractured gear tooth.

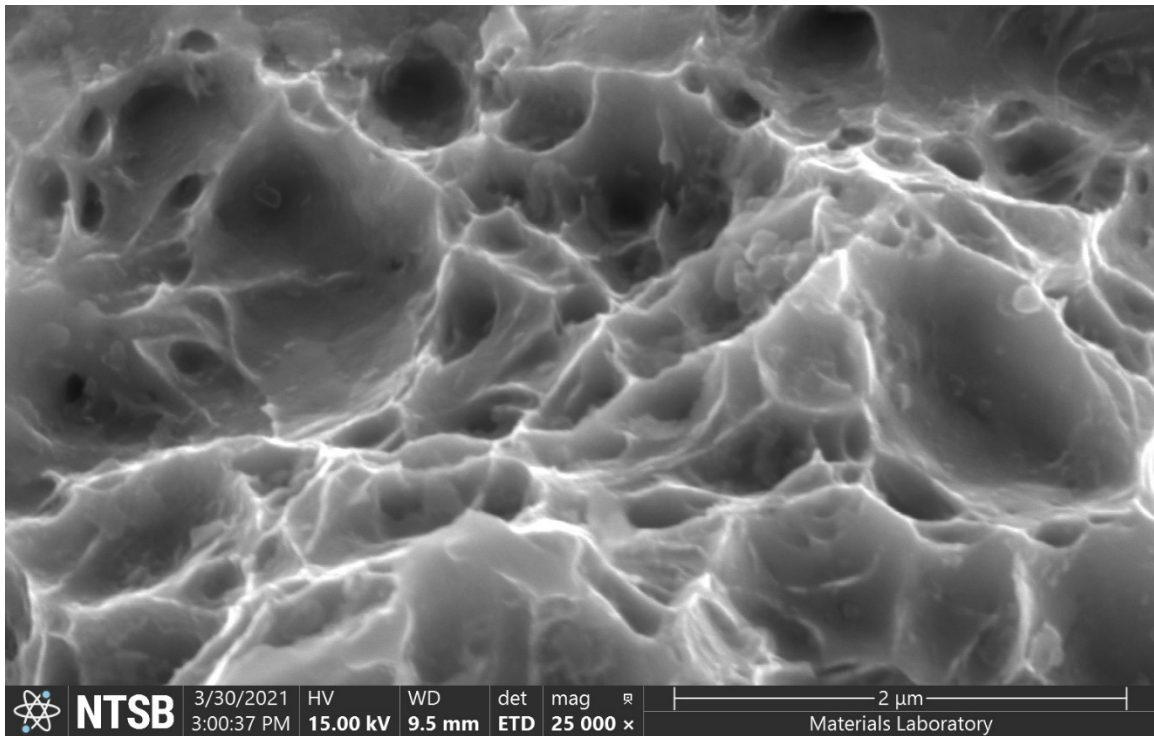


Figure 15 – Closer view of the fracture surface in Figure 14, showing dimpled rupture.

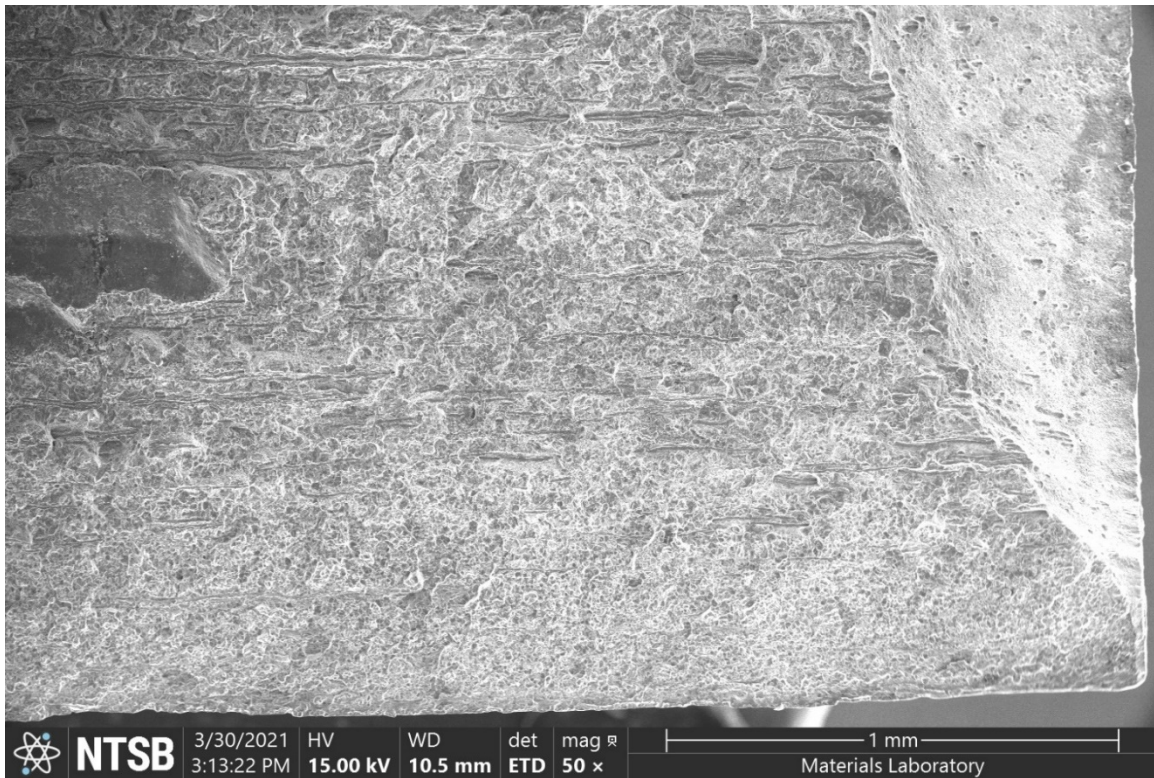


Figure 16 – SE micrograph of the corner of the tooth fracture, showing different regions of fracture features.

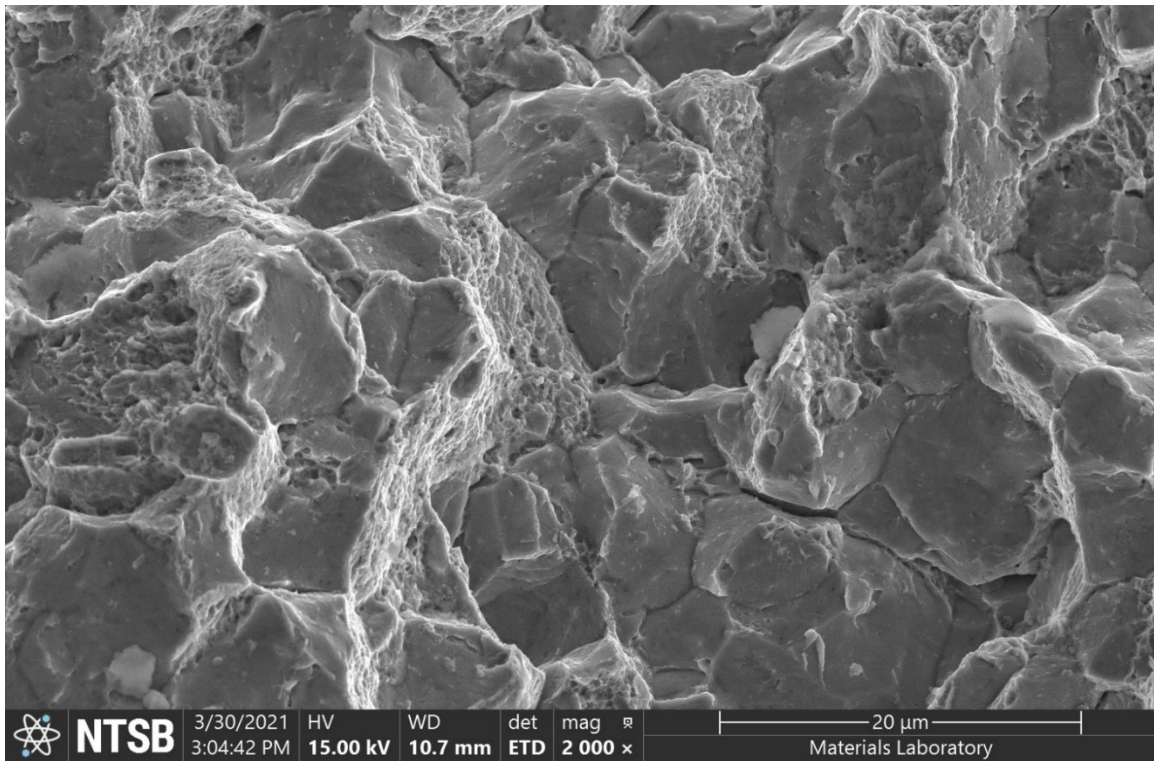


Figure 17 – SE micrograph mixed intergranular and dimpled rupture in the periphery of the tooth fracture.

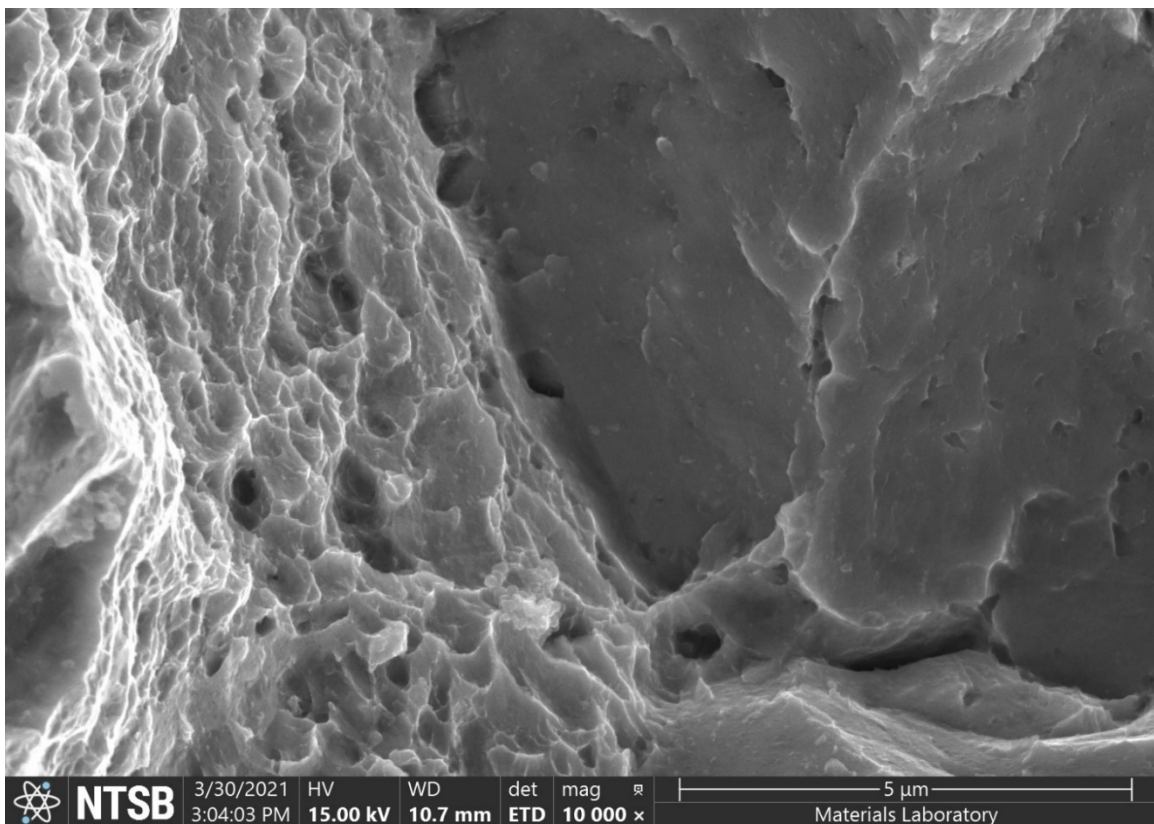


Figure 18 – SE micrograph of dimpled rupture next to a grain facet in Figure 17.

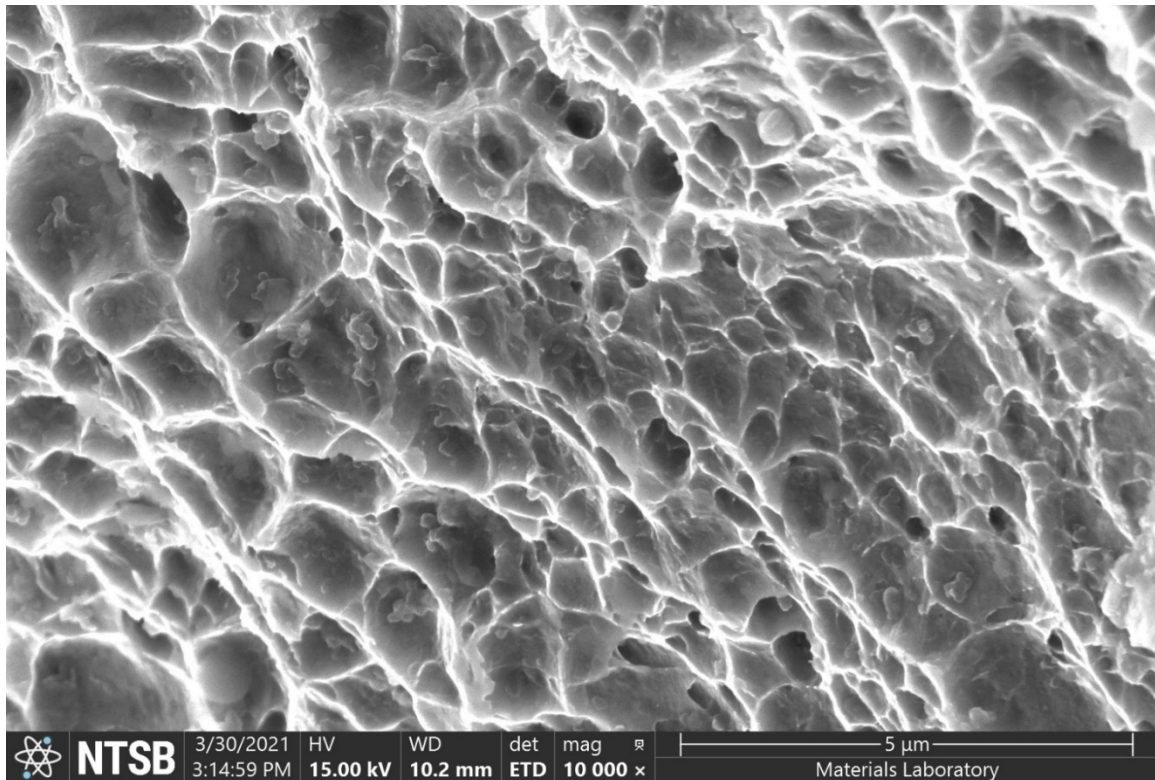


Figure 19 – SE micrograph of dimpled rupture in the shear lip in Figure 16.

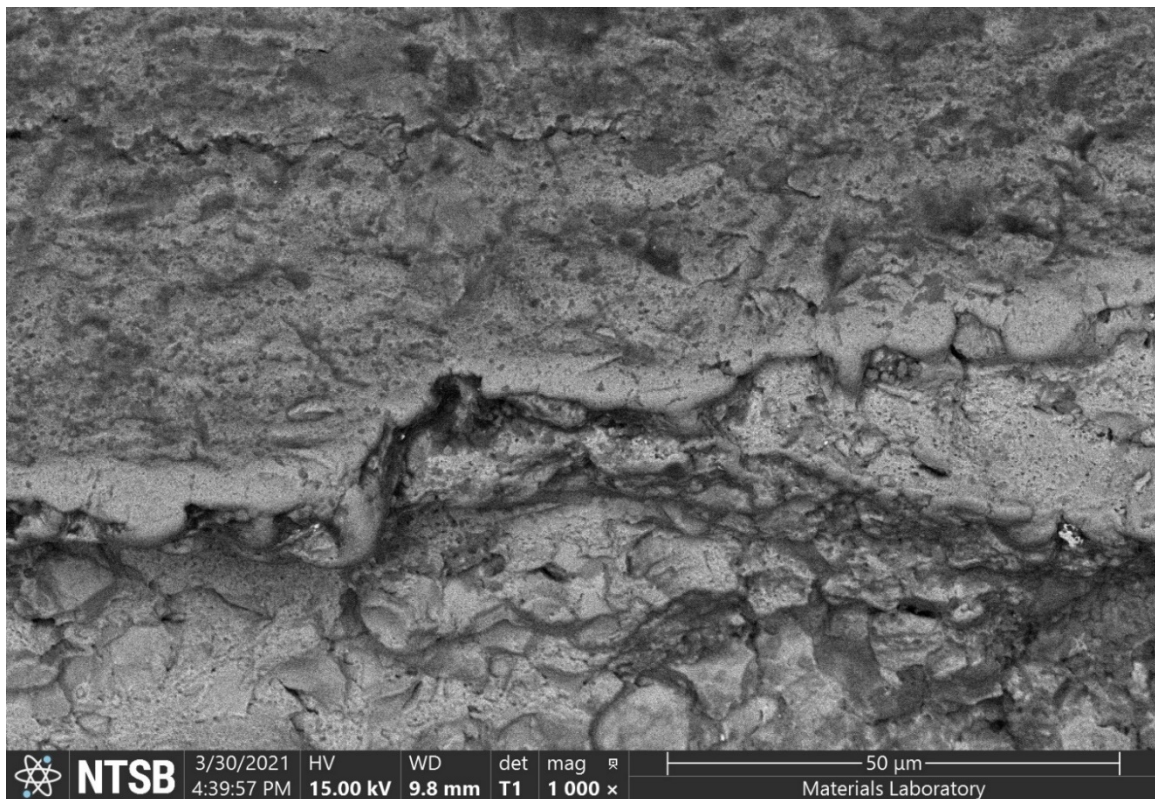


Figure 20 – Backscattered electron (BE) micrograph of the edge of the driven flank, showing secondary cracking on the flank above the fracture surface.

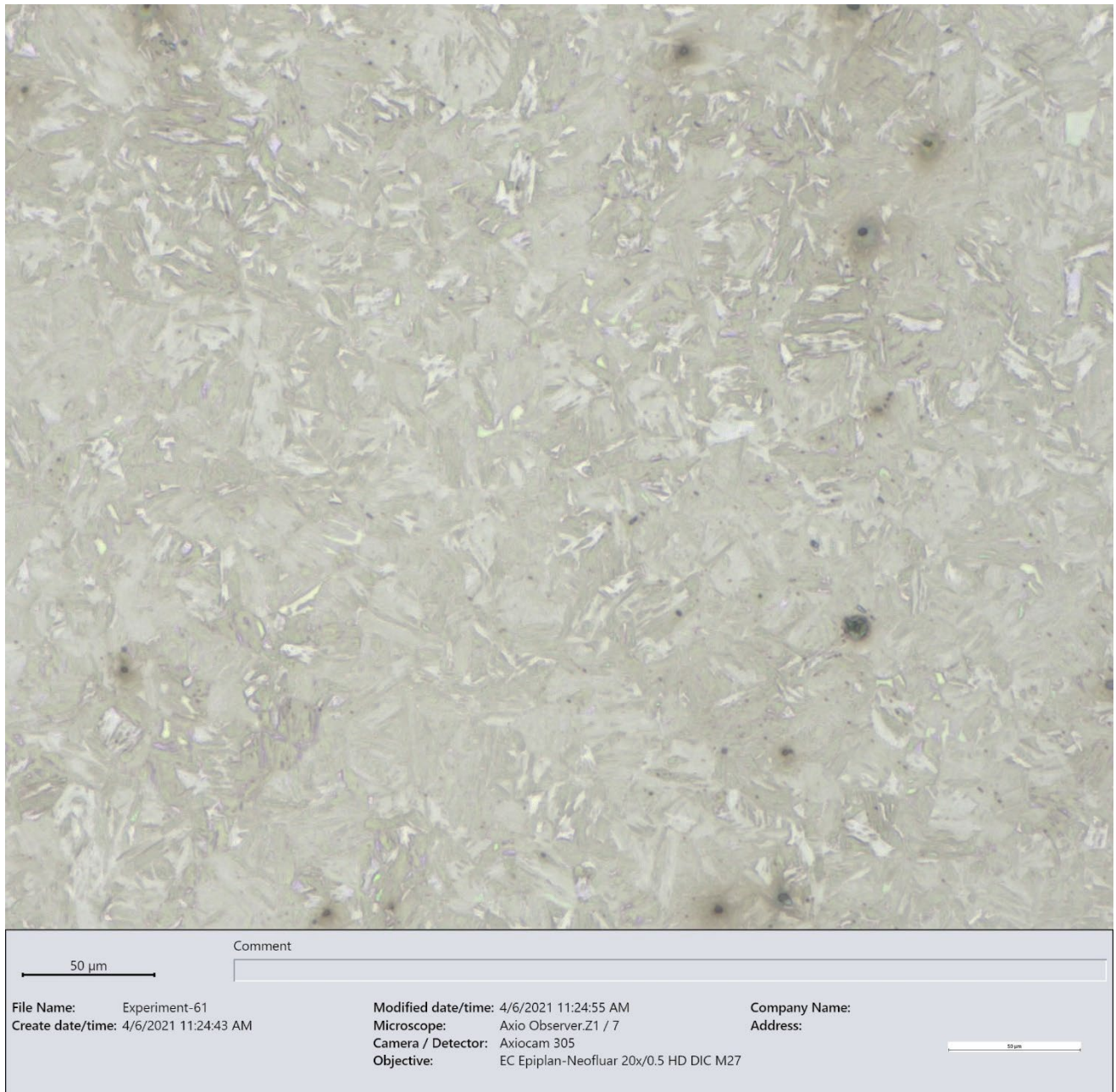


Figure 21 – Bright field (BF) optical micrograph of a typical area of the gear tooth microstructure (~500X, etched 2% Nital).

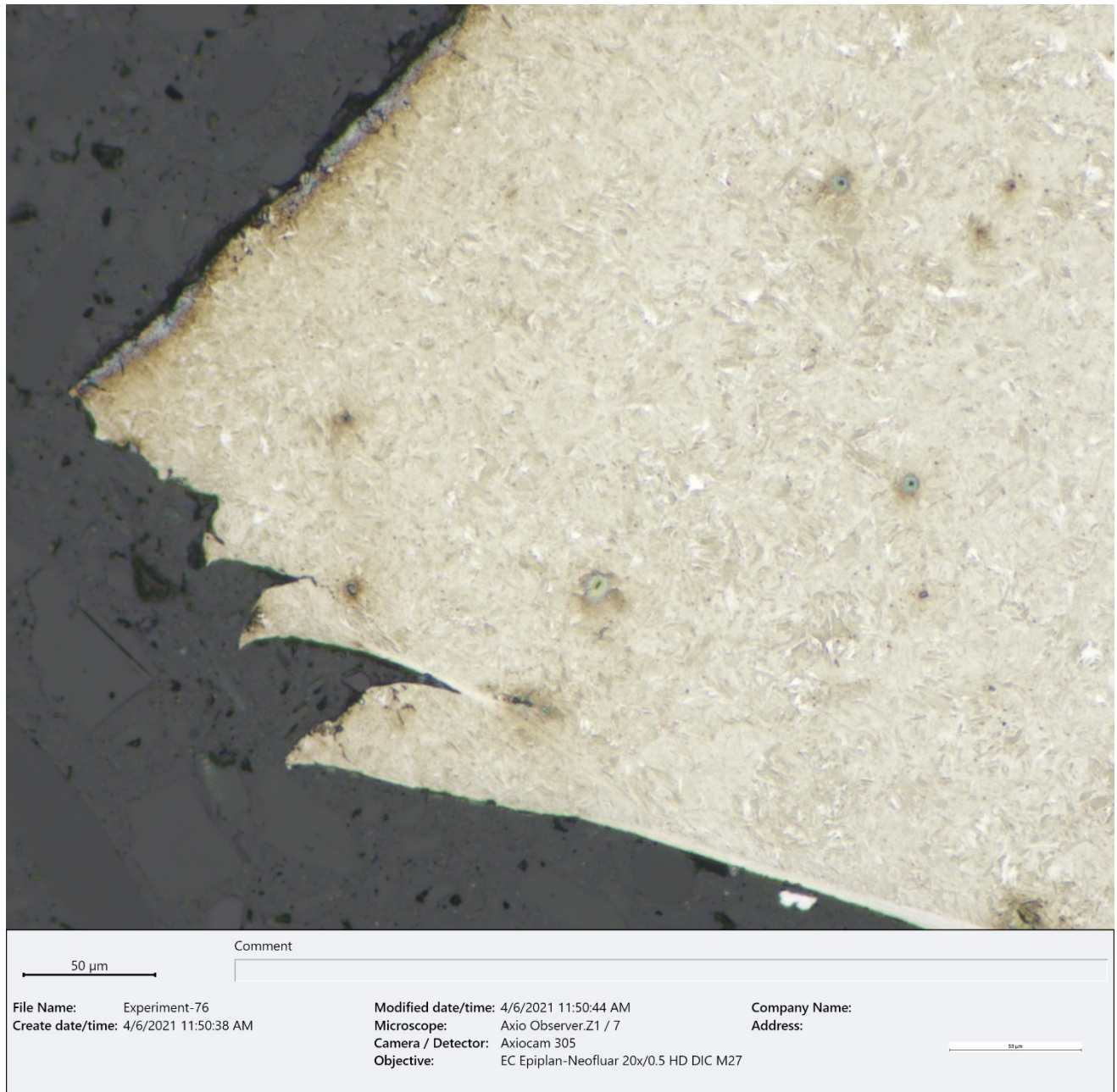


Figure 22 – BF micrograph of the edge of the fracture surface on the compression side (~500X, etched 2% Nital).

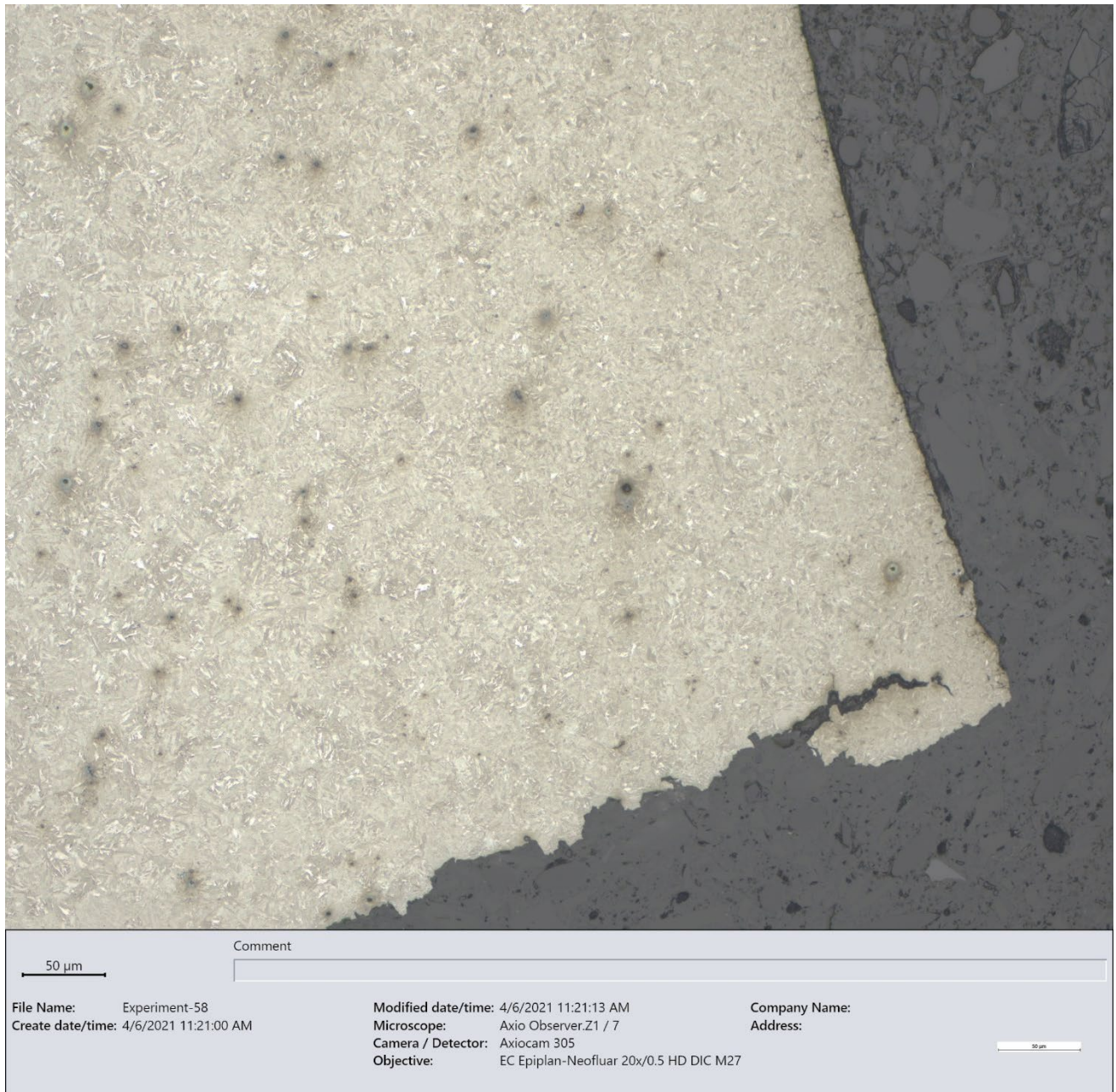


Figure 23 – BF micrograph of the edge of the fracture surface on the tension side (~500X, etched 2% Nital).

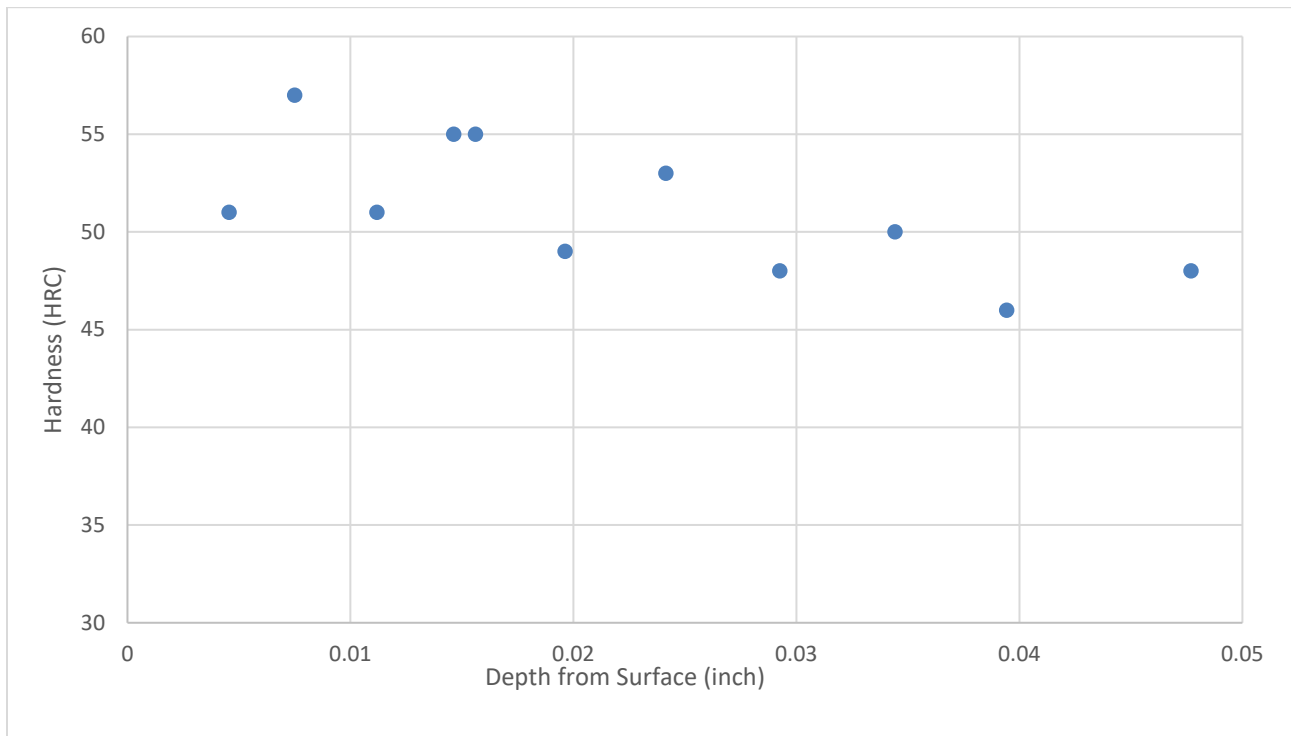


Figure 24 – Microindentation hardness measurements versus depth from the surface, in HRC converted from HV_{500} .