

NATIONAL TRANSPORTATION SAFETY BOARD

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



January 12, 2021

MATERIALS LABORATORY FACTUAL REPORT

Report No. 20-047

1. ACCIDENT INFORMATION

Place : Fletcher, North Carolina
Date : December 28, 2019
Vehicle : Piper PA-32RT-300, N27GB
NTSB No. : ERA20LA062
Investigator : Todd Gunther, AS-ERA

2. COMPONENTS EXAMINED

Remnants of an oil pump case and impellers
Remnants of an oil pump drive gear

3. DETAILS OF THE EXAMINATION

On December 28, 2019, about 1735 eastern standard time, a Piper PA-32RT-300 was destroyed during an emergency landing in Fletcher, NC after it experienced a partial loss of engine power during the initial climb from Asheville Regional Airport (AVL), Asheville, NC. The private pilot and four passengers were not injured. The pilot stated that during climb, the airplane experienced a loss of engine power and turned back to the airport. During an emergency landing towards a nearby parking lot, the pilot noted the oil pressure gauge was in the "yellow."

The Lycoming IO-540-K1G5D engine had been examined after the accident.¹ According to the teardown report, the #4 connecting rod was reported as having "disintegrated," and the remains of the bearing, cap end, crankshaft and journal all exhibited thermal damage consistent with a lack of lubrication. The oil pump was unable to be actuated prior to disassembly. Components from the oil drive pump assembly were removed from engine and sent to the NTSB Materials Laboratory for additional examination.

The previous overhaul was noted as having occurred on November 5, 2013, with the engine having accrued 364.81 hours since overhaul (at the last inspection). The airplane's most recent annual inspection was completed on May 6, 2019. At the time of

¹ The IO-540 is a family of air-cooled fuel-injected, six-cylinder, horizontally opposed reciprocating engines, manufactured by Lycoming Engines, headquartered in Williamsport, PA.

the inspection, the airplane had accrued about 4082 total hours of operation, and the engine had accrued about 365 hours since the overhaul.

Figure 1 and Figure 2 show the oil pump components, as received. These include half of a pump case, two impeller gears, one larger gear with a shaft, and the drive gear, which was comprised of a shaft with a gear on one end. Two of the teeth of the drive gear had fractured and are pictured in Figure 2.

There were multiple markings on the exterior surface of the case. One embossed marking stated, "LW-1034". Etched markings on the side stated, "LW-10343-DET 9972 LW-10344-ASSY 3213". A vibroetched marking on the opposite side stated "2582A03".

The inner surfaces of the pump case are shown in Figures 3 through 5. The surfaces were smoothed and generally reflective, consistent with having been machined. Many of these surfaces exhibited circumferential wear marks, consistent with rotational wear of the internal impeller gears. The position of these gears is shown inside the case in Figure 6. The wear marks present on the internal surfaces of the case half were consistent with typical rotational wear under lubricated conditions—there were no indications of abrasive wear, spalling, galling, or gouges on the faying surfaces.

Figure 7 and Figure 8 show the larger gear from the oil pump, viewed from the opposite faces and the gear teeth. The gear exhibited a brownish-red color. However, as shown in Figure 8, this color had been mostly worn away on the gear teeth top lands—this color was consistent with a coating such as a paint on the gear surface. This gear also had a hollow cylindrical shaft attached to it through the center, as shown in Figure 8. The teeth of this gear were intact, and they did not exhibit any indications of plastic deformation.

Figure 8 also shows the contact areas on the faces of many of the large gear teeth. While the teeth lands did exhibit a lack of paint consistent with rotational wear, there were still paint remnants present, which would be inconsistent with severe wear conditions. Likewise, the faces of the gear teeth exhibited some longitudinal wear marks and rectangular reflective regions, consistent with contact with mating gear teeth. None of this wear was severe enough to manifest as gouging, deformation, or material loss on the gear, and was consistent with typical contact between gear teeth.

Figures 9 and 10 show one of the impeller gears. This gear exhibited a hollow slotted center, such that the flat portion of the shaft of the drive gear fit inside. One of the faces, shown in Figure 9a, exhibited markings. One marking was a stamp on the gear stating "N", and the other was a stamp located around the gear face stating, "51B232/4 V6498 48/12".

Figures 10 and 11 show several of the slotted impeller gear teeth from an oblique and angled view, respectively. While the contact faces of the teeth did exhibit imprints, these were consistent with typical contact marks with the mating teeth of the other gear. There were no indications of severe wear, missing material, or plastic deformation. The edges and rounded surfaces of the internal slot did exhibit longitudinal wear marks and

some deformation on the edge. These were consistent with the sliding against the flat shaft surfaces of the drive gear (as illustrated in Figure 12). However, in the position displayed in Figure 12, there was no indication of a loose fit or rotational slippage, indicating the wear to be typical of service conditions.

Figure 13 and Figure 14 show the other impeller gear, which exhibited a circular hollow bore that was not slotted. This component exhibited few indications of damage, except for the face shown in Figure 13b. This face had been marked with “C” on one of the teeth. The face of the impeller on this side exhibited circumferential wear marks in a ring pattern significant enough to darken part of the face, consistent with material loss and wear. There were no indications of wear or material loss on the teeth of the gear.

Figure 15 shows the drive gear shaft from three different angles, representing the damage to the part. Of note was the fracture of two gear teeth, as highlighted in Figure 16. There were also witness marks along the slotted portion of the shaft, shown Figure 15b and 15c. There were a variety of markings on the part, as shown on the gear face in Figure 16a: “LW-10318 ASSY MFR30620”. The other markings were on the shoulder of the shaft, stating, “LW-10317-DET 7189 46/01”.

Figures 17 and 18 highlight the fracture surfaces of the gear teeth, from the gear side. The fractures were generally flat, although they were actually somewhat concave when viewed from the side. The fractures were located near the roots of the gear teeth, above the fillet radii, generally along the clearance circle.

The fracture surfaces themselves were generally dull, rough, and fibrous in nature. The fracture surfaces in Figures 17 and 18 both exhibited shinier, smoother regions on the left of the figures, consistent with post-fracture damage such as smearing. The fractures in Figure 18 can be contrasted with the intact teeth adjacent to the fractured teeth, shown in Figure 19. The left tooth face in Figure 19 displayed wear marks, consistent with the driven side of the gear (see Figure 20). The worn areas of the teeth exhibited upward-oriented wear marks on the upper quarter of the tooth, with more randomly oriented marks along the curved part of the tooth face. The fracture surfaces and the wear marks on the intact teeth were consistent with gear rotation from right to left in Figures 18 and 19.

Besides the wear marks on the gear teeth faces, the flat portion of the shaft on the gear drive exhibited a rectangular impression, consistent with adhesive wear against an adjacent faying surface—the interior bore of the slotted impeller. The wear marks, present but reversed on the opposite side, were consistent with the rotation direction of the gear. There were also some rotational marks on the smooth rounded side of the shaft adjacent to the flattened area. These areas exhibited indications of a brownish-colored compound, consistent with iron oxide. None of these surfaces exhibited damage in the form of abrasion, material loss, or deformation.

Figures 22 through 25 show the two fractured and liberated gear teeth from different views. The gear teeth had fractured near the roots above the fillet radii, consistent with the mating fracture surfaces from the drive gear. The driven faces of the teeth exhibited similar

wear patterns as the intact gear tooth shown in Figure 20. One of the gear teeth exhibited local plastic deformation on the face, shown in Figure 23 and 24. This deformation was oriented outward and horizontal to the flank direction in the figure. In addition, Figure 23 shows a small corner indentation near the tooth top land. These damage features were consistent with post-fracture impact damage, typical of liberated pieces impacting rotating metallic components.

Figure 26 shows a closer view of the less damaged gear tooth fracture surface from the gear drive side. The central region of the fracture surface exhibited a fibrous morphology, with features oriented in a parallel, horizontal manner in the figure. The outer portions, though, exhibited a finer morphology. This gear was examined using a scanning electron microscope (SEM) as illustrated in Figure 27. This figure demonstrates the difference in fracture surface morphologies between the outer and core regions.

Figure 28 shows a closer view of a typical area of the core region of the fracture surface. The features were consistent with dimpled rupture, typical of overstress fractures of ductile materials. The outer region is typified in Figure 29, showing intergranular fracture features. Some areas of the outer, intergranular region adjacent to the surface edge exhibited a darker contrast in the SEM, as typified in Figure 30.

These regions were examined using x-ray mapping from energy dispersive x-ray spectroscopy (EDS). As shown in the maps in Figure 31, the intergranular regions of the fracture surface corresponded to areas of higher carbon content. These features were consistent with a carburizing surface treatment of the gear. Figure 32 shows a closer view of the carbon-rich region, again exhibiting intergranular fracture, with some limited areas of dimpled rupture along the grain boundaries. All these features were consistent with overstress fracture of the two gear teeth during rotation.

One of the fractured gear teeth was mounted, polished, and etched for metallographic examination. Of note was the area closest to the surface, as illustrated in Figure 33. The region 20 μm (8×10^{-4} inches) closest to the surface exhibited intergranular cracking, as demonstrated by the dark regions in Figure 33. This cracking was present along the prior austenite grain boundaries along the cross sectioned faces, flanks, and land surfaces. No cracking was seen in other areas away from the surface, or along the fracture surface.

Figure 34 shows an area of the corner of the cross-sectioned gear tooth, after etching with a 2% Nital solution.² There was a clear visual contrast between the outer areas near the surface and the core regions. Figure 35 shows a closer view of the core microstructure, which was consistent with a tempered martensitic microstructure exhibiting a general lath morphology. This area did not exhibit any incipient spheroidal carbides or similar constituents. In contrast, the surface microstructure, shown in Figure 36, exhibited a martensitic structure with a more plate-like morphology, consistent with higher carbon content. There was no visual evidence of retained austenite in the surface region.

² Nital is a mixture of 2% nitric acid (HNO_3) mixed with ethanol.

The chemical composition of the drive gear was examined using x-ray fluorescence (XRF) and EDS. From the data obtained using these techniques, the gear was found to be consistent with an alloy steel, such as Type 8620.

Hardness data were taken on the cross sectioned and polished gear specimen from the surface to the core using microindentation hardness testing per ASTM E384.³ The hardness data exhibited a change in hardness dependent on the depth from the surface, consistent with a case hardening such as carburization. The core hardness was 47 HRC (474 HV₅₀₀), with an effective case depth of 0.037 inches. The highest hardness at the surface was found to be 66 HRC (850 HV₅₀₀). Figure 37 shows a graph of the hardness data.

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



Figure 1 – The oil pump case half, impellers, and large gear, as received.

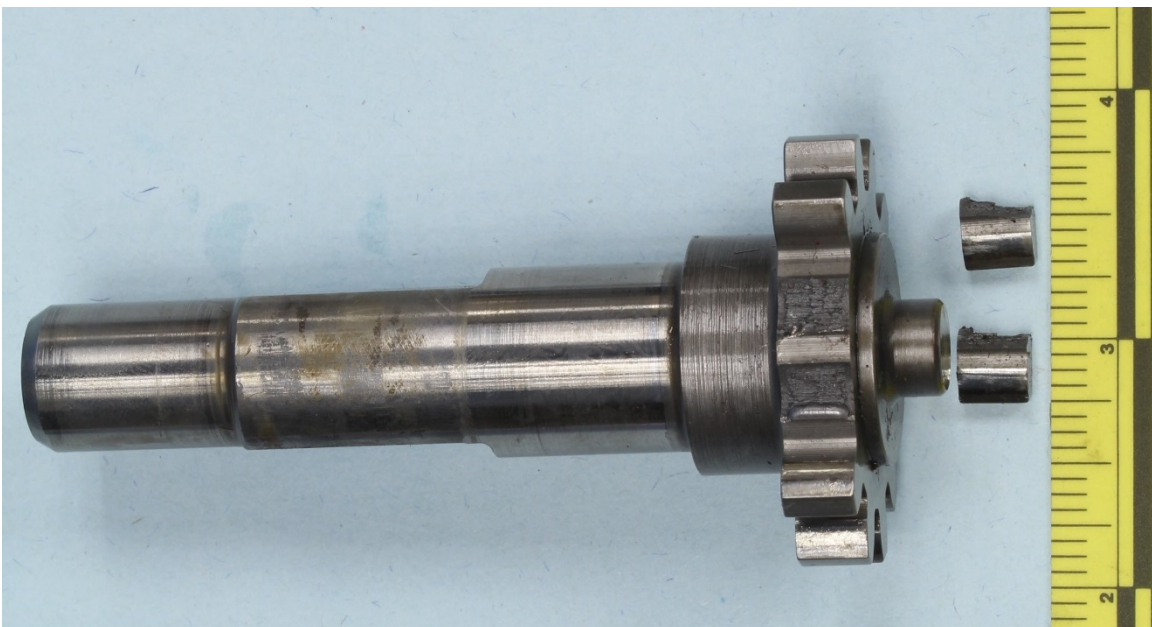


Figure 2 – The geared drive shaft with two fractured gear teeth, as received.

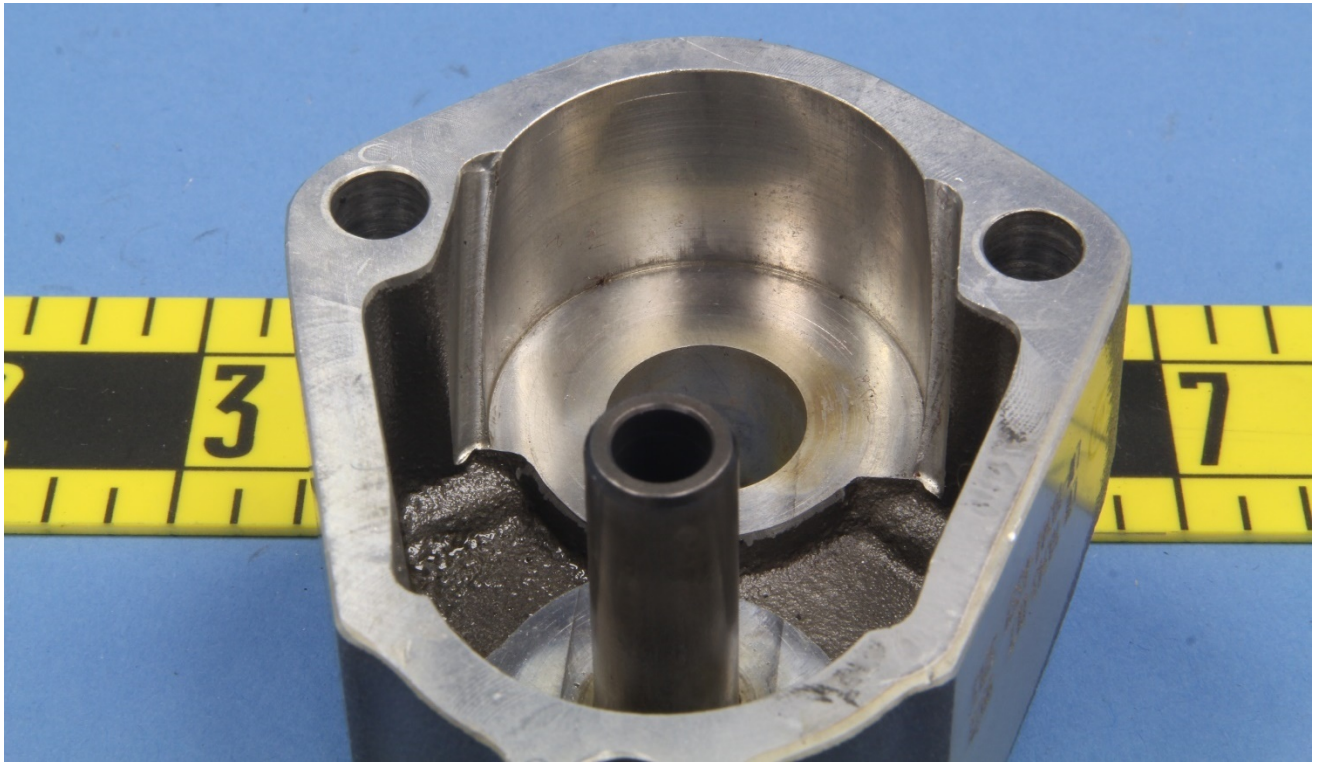


Figure 3 – View of the internal impeller surfaces of the case.

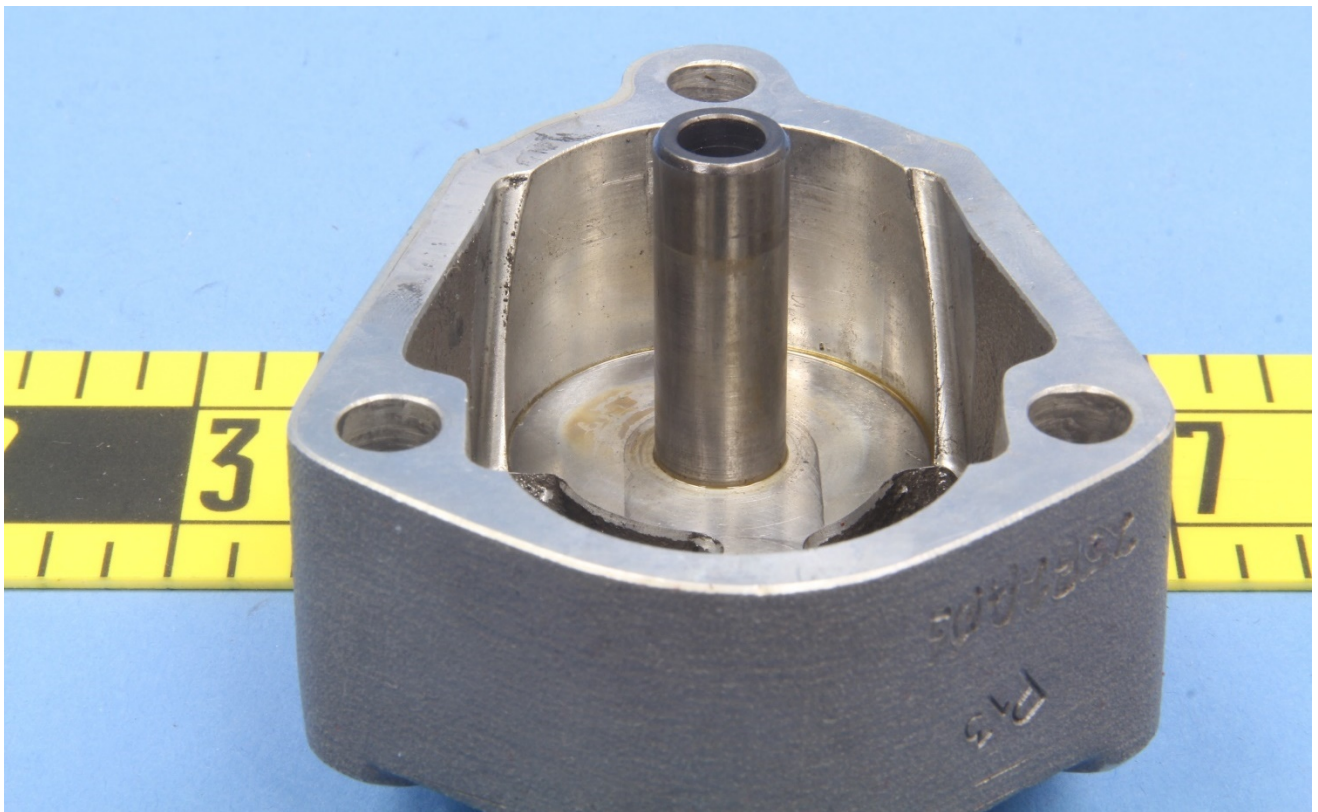


Figure 4 – View of the internal impeller surfaces of the case, opposite side from Figure 3.

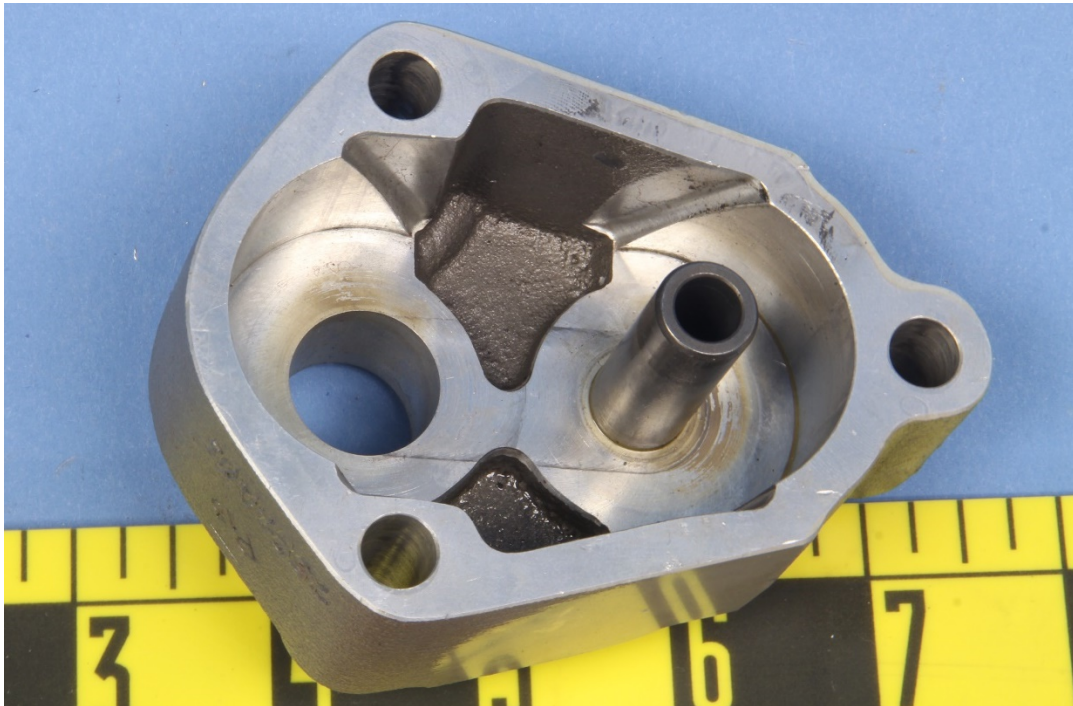


Figure 5 – View of the internal surfaces of the oil pump case.

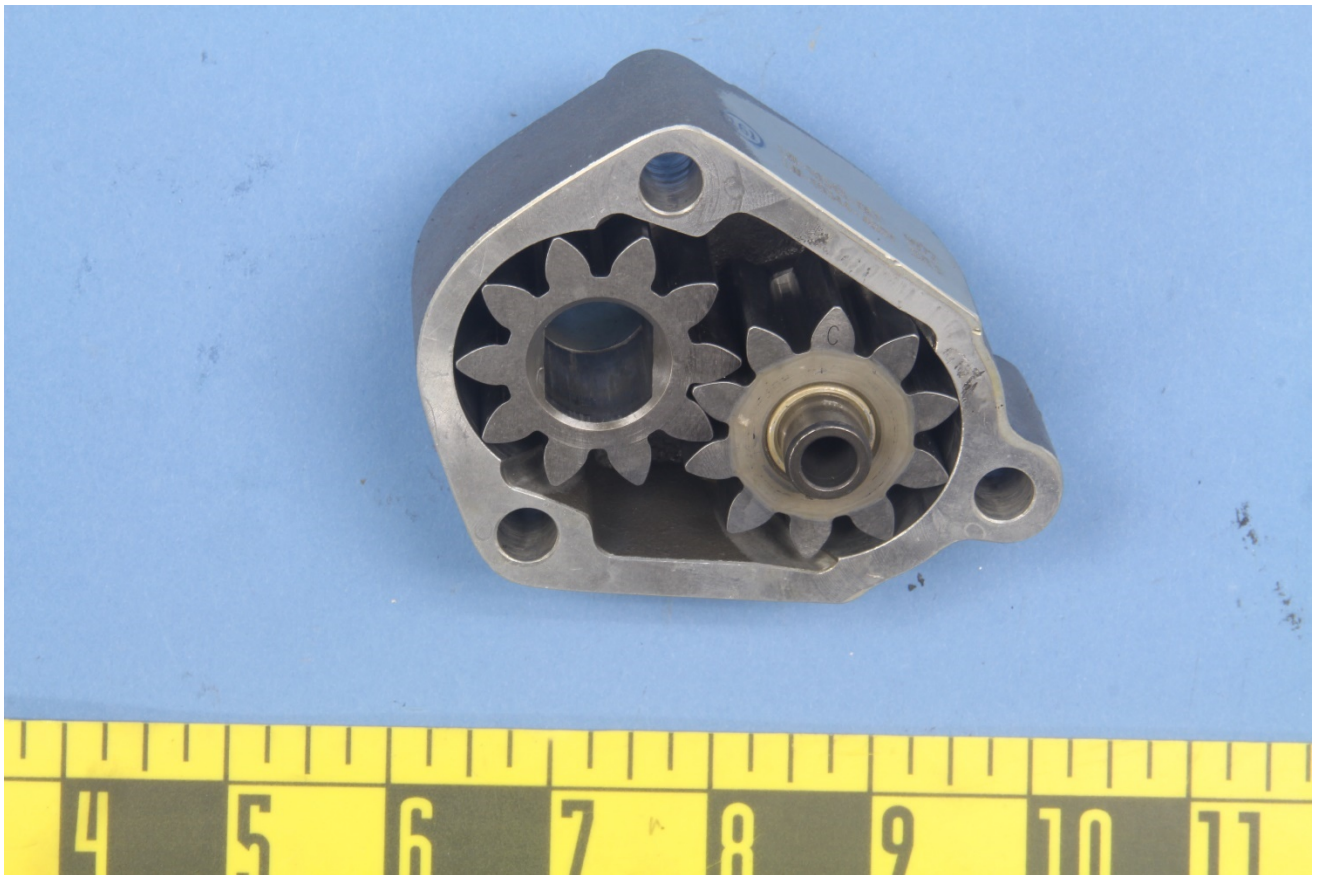


Figure 6 – View of the interior of the pump case, with the impellers reinstalled.

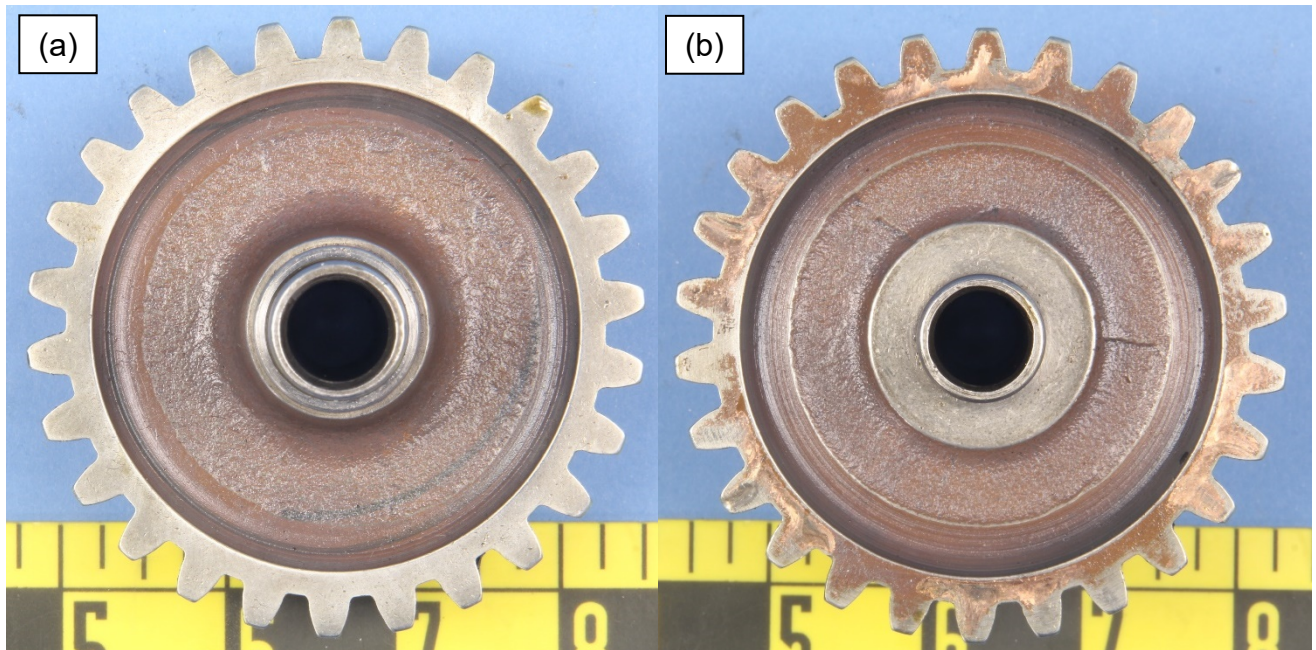


Figure 7 – View of the faces of the large gear from (a) the necked shaft side and the (b) flat shaft side.

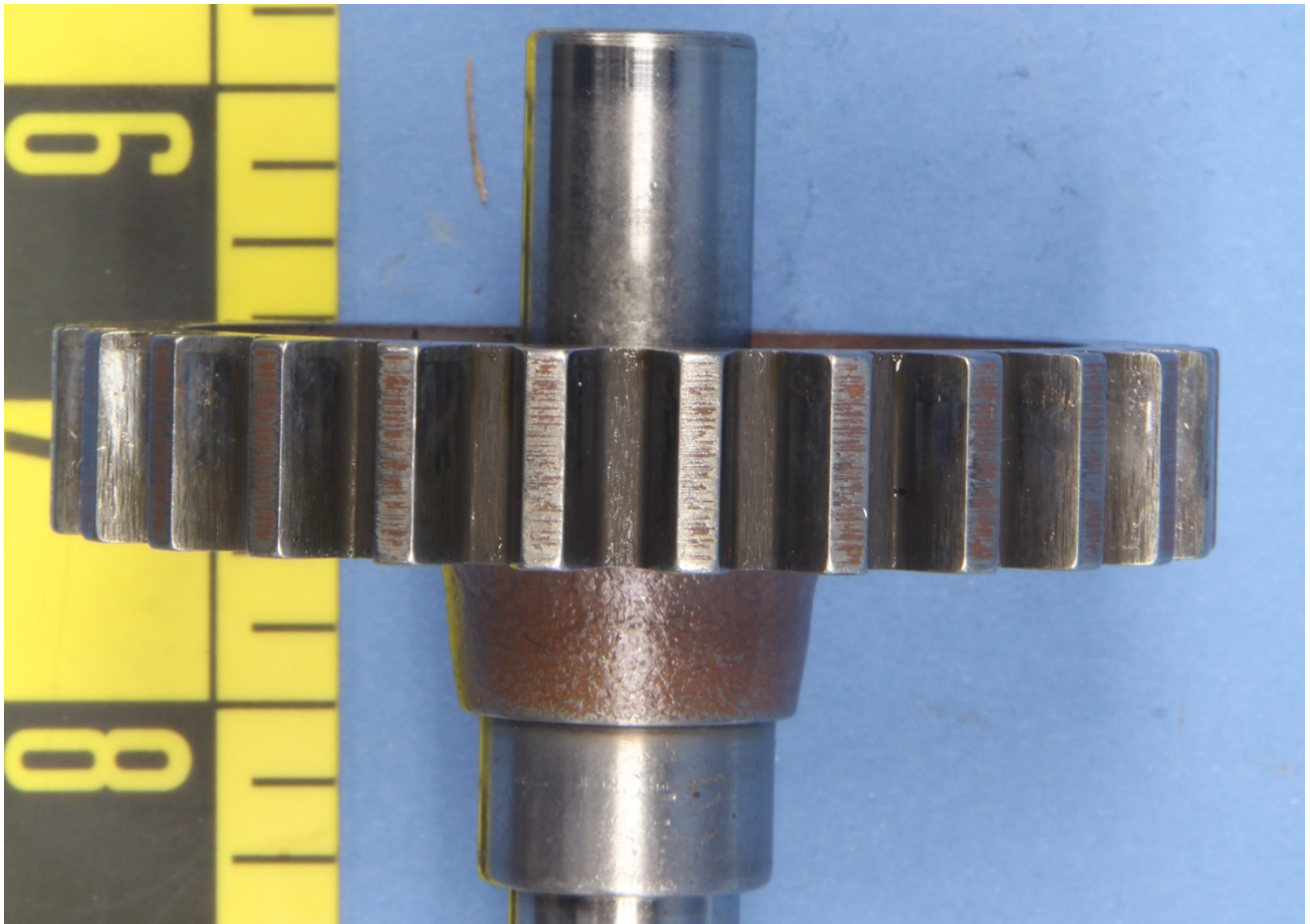


Figure 8 – Typical view of the gear teeth and roots from the side of the large gear.

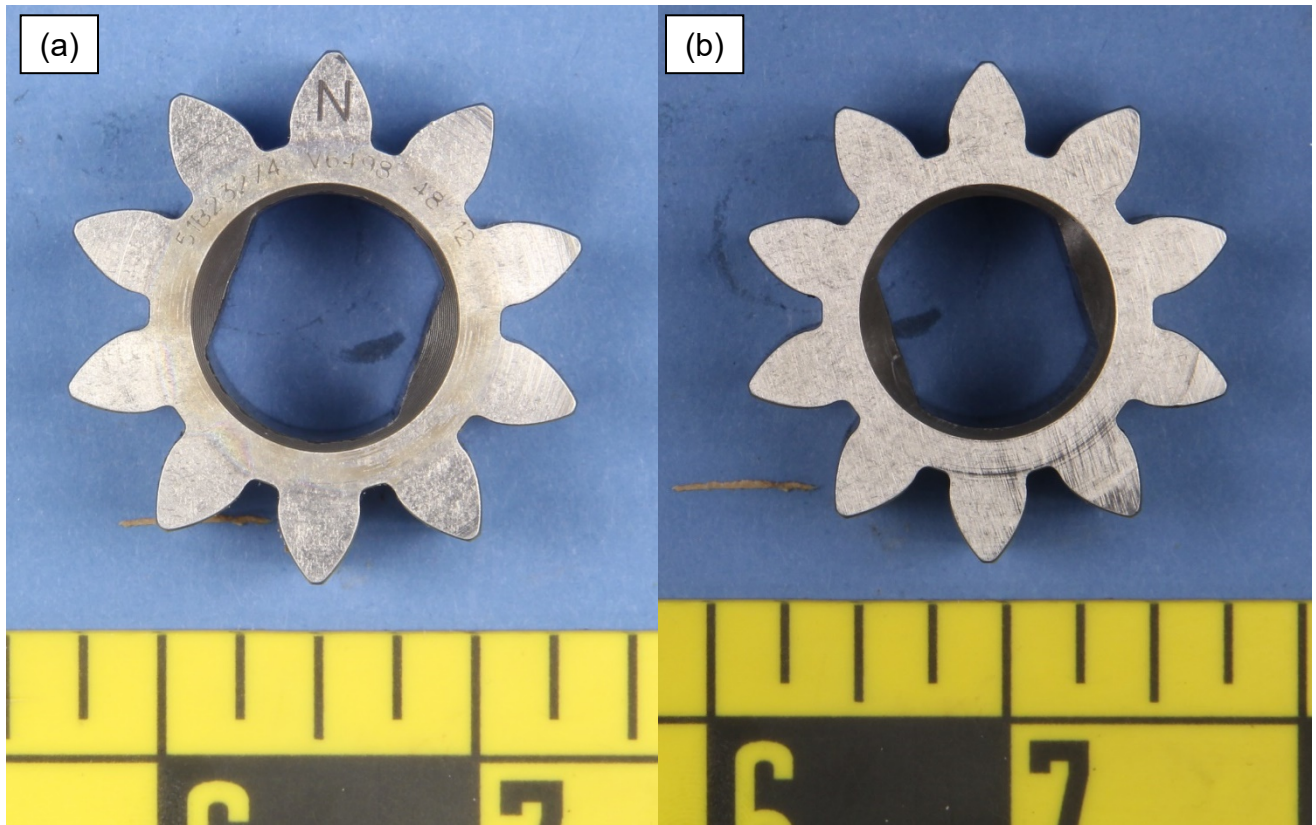


Figure 9 – The (a) marked and (b) unmarked faces of the slotted impeller gear.

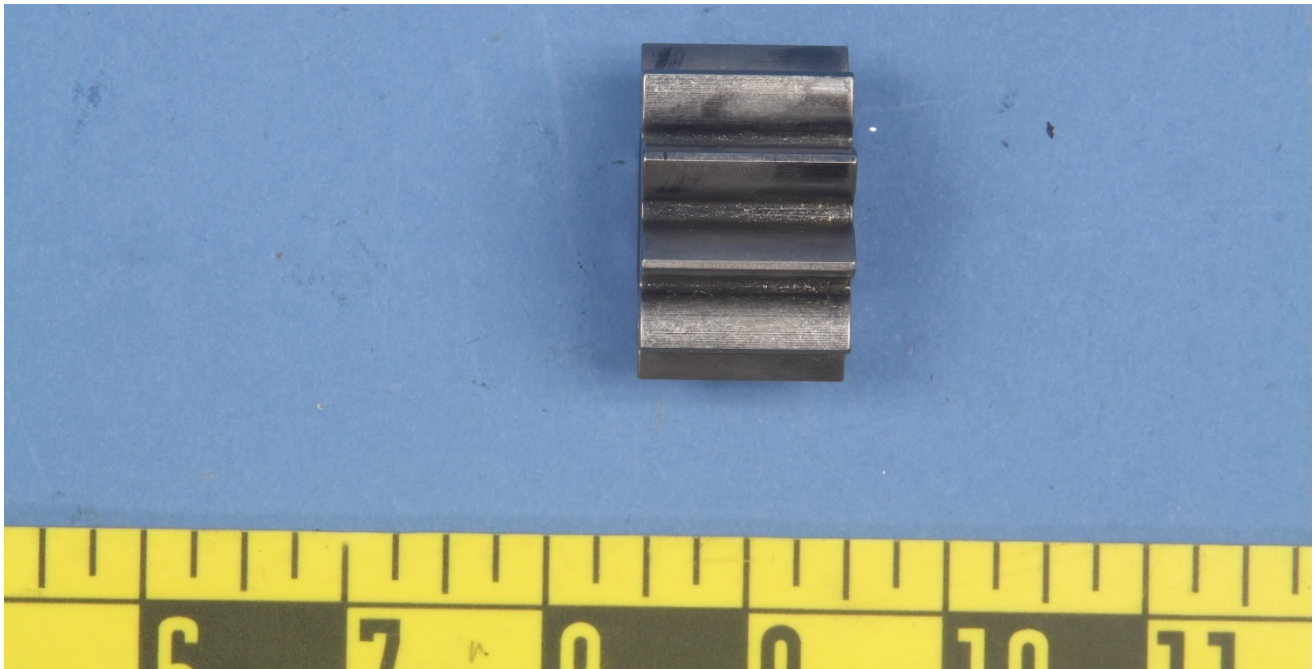


Figure 10 – View of the impeller gear teeth, from the side.



Figure 11 – Angled view of the marked face, teeth, and internal cavity of the slotted impeller gear.

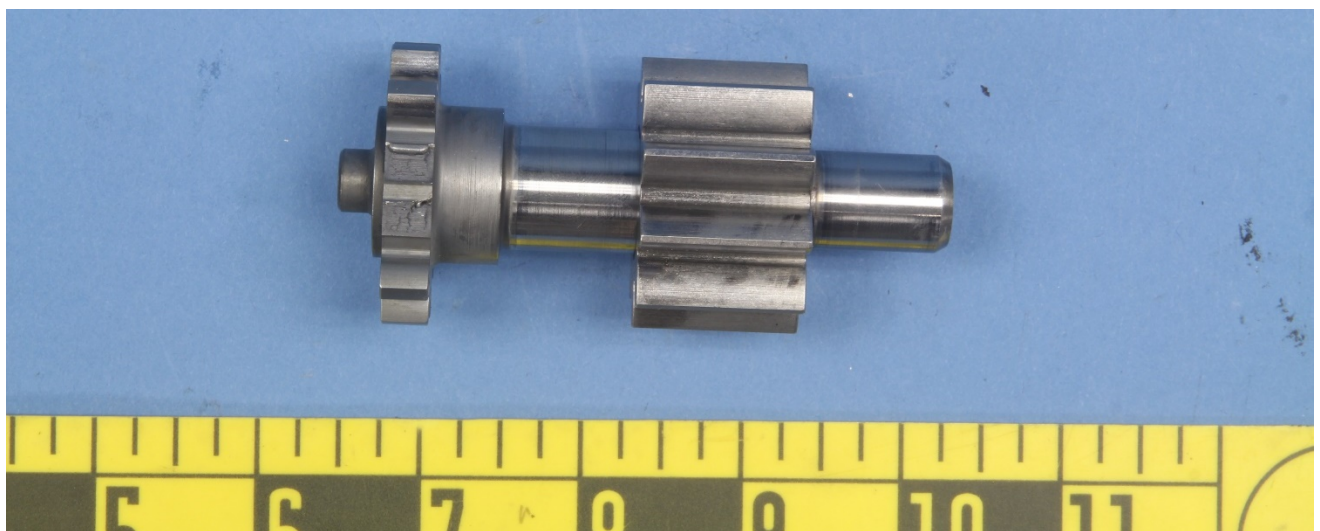


Figure 12 – Repositioning of the slotted impeller gear on the gear drive shaft.

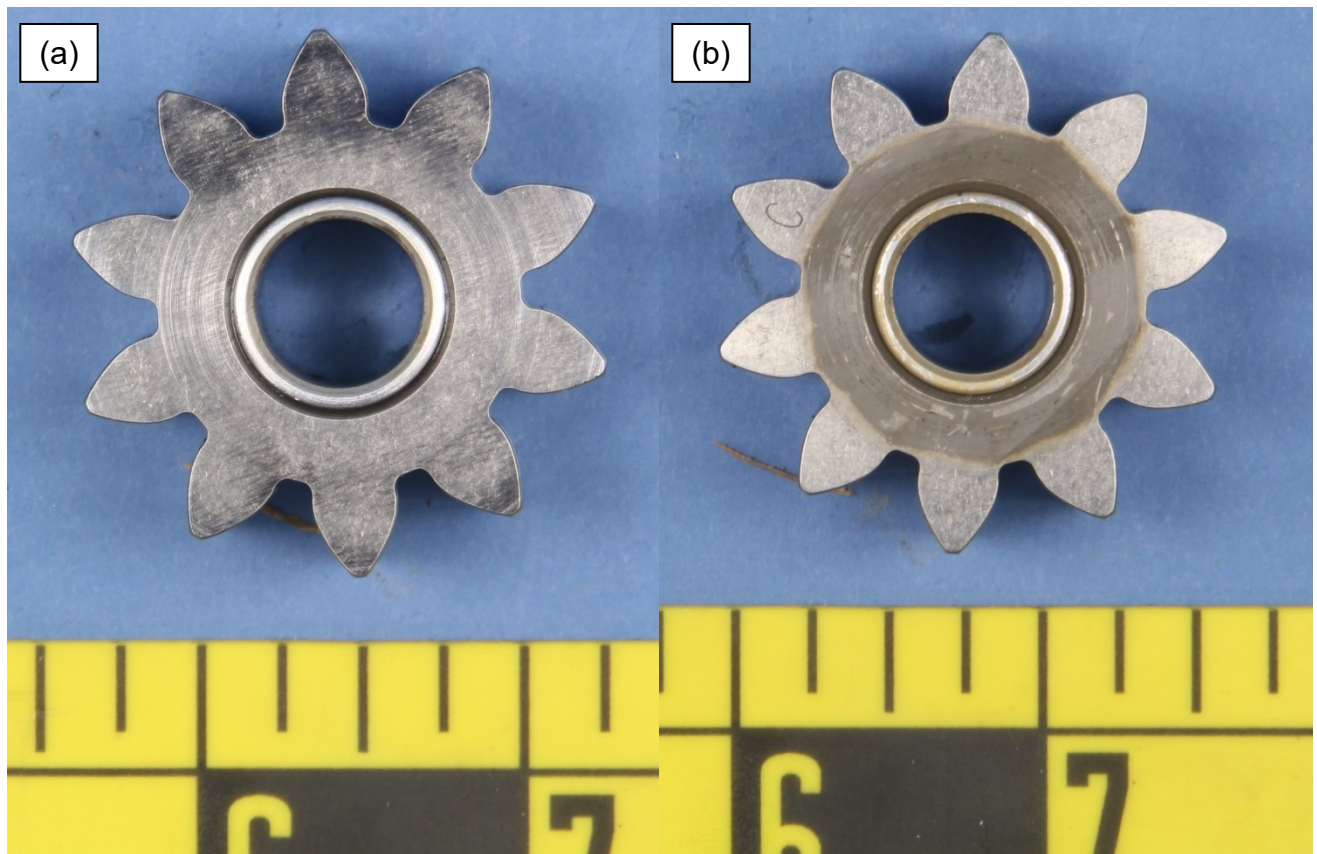


Figure 13 – The (a) unmarked and (b) marked faces of the circular impeller gear.

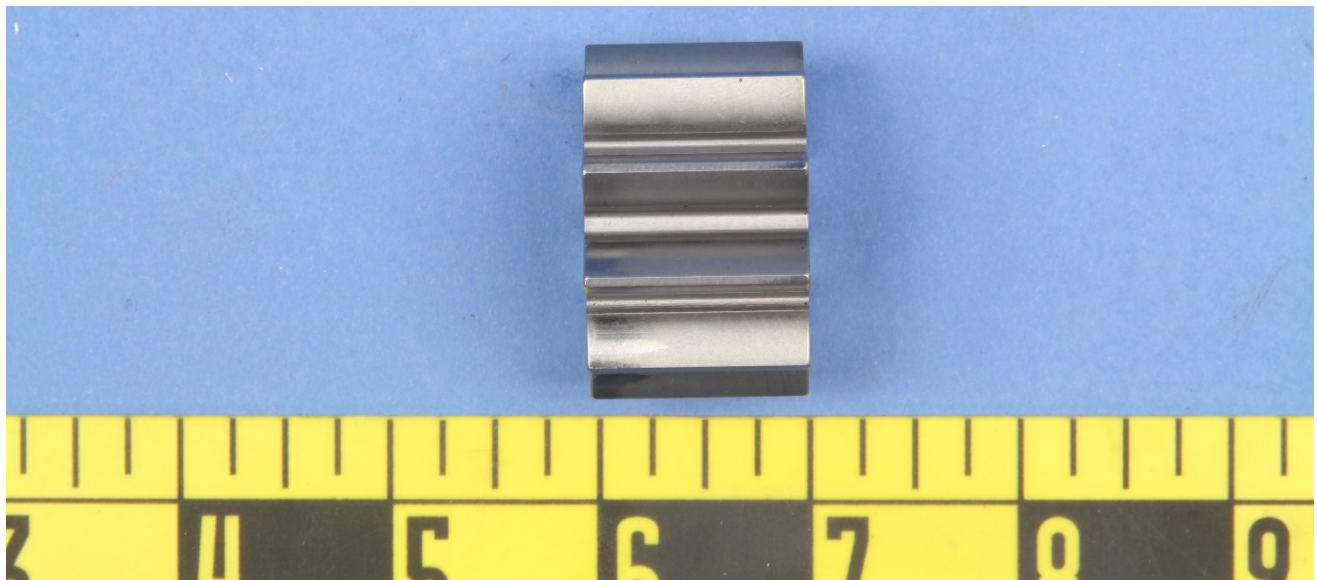


Figure 14 – View of the circular impeller gear teeth, from the side.

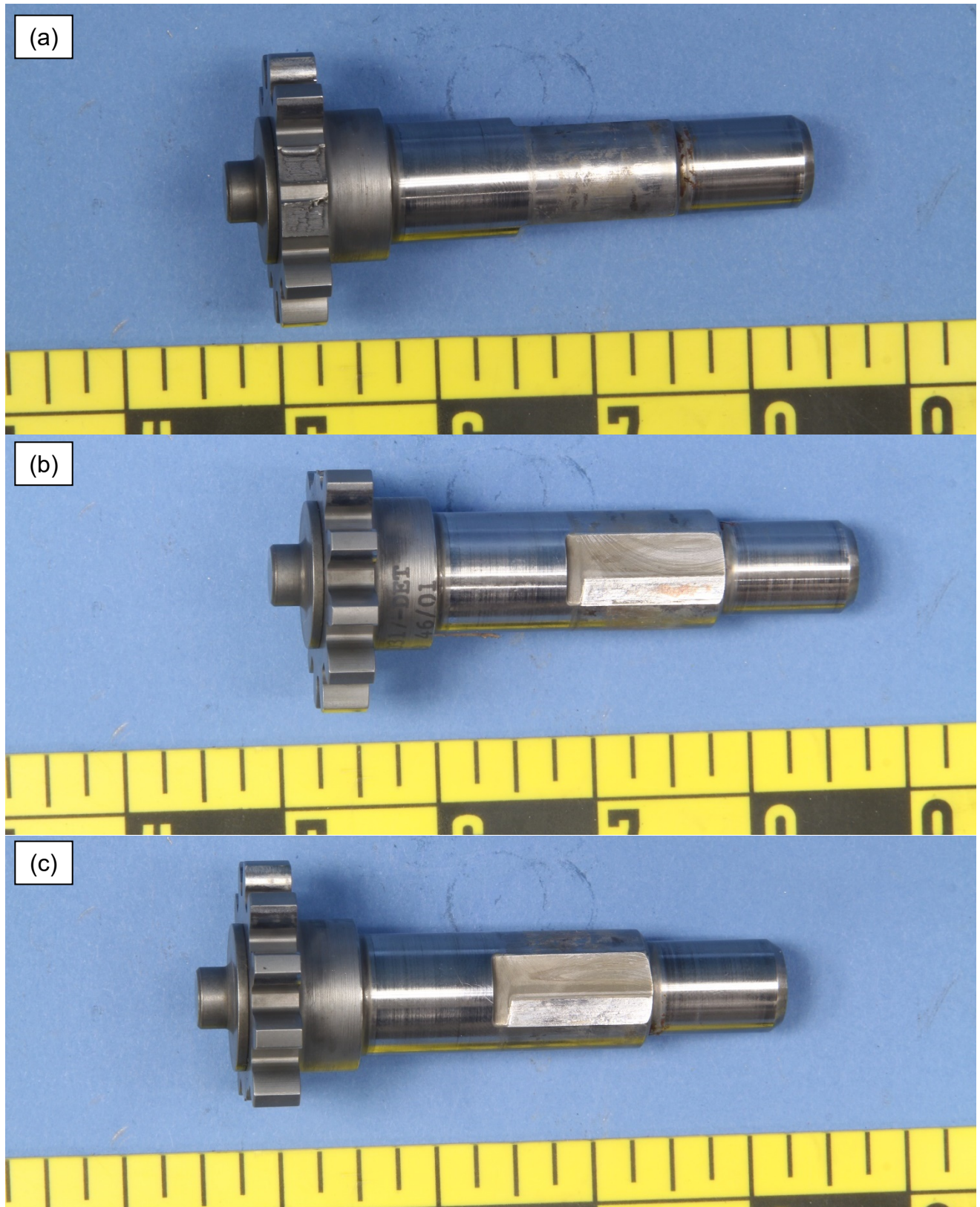


Figure 15 – View of the fractured drive gear shaft from (a), (b), (c) three sides, rotated $\sim 60^\circ$.

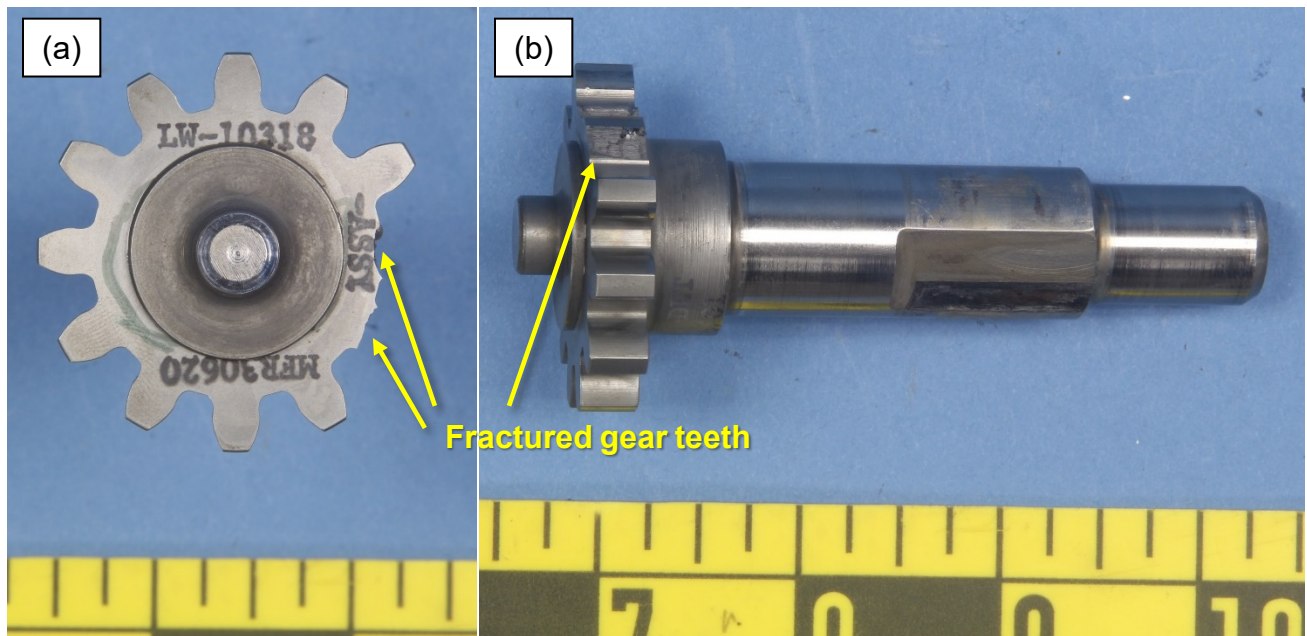


Figure 16 – The drive gear shaft from (a) the gear face with markings and (b) from an angled side view.

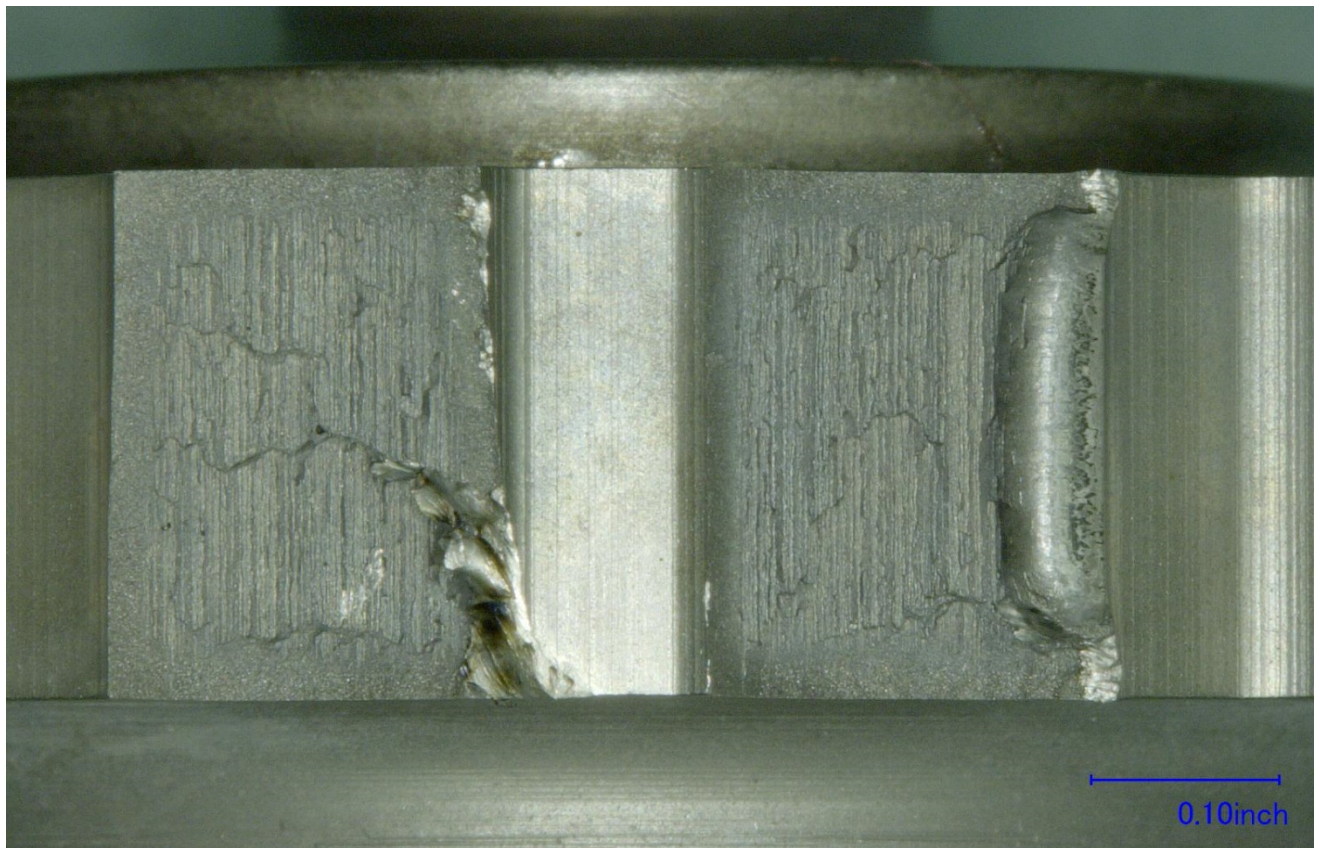


Figure 17 – View of the fractured gear teeth from the gear drive side.



Figure 18 – Angled view of the fractured gear teeth from the drive gear.

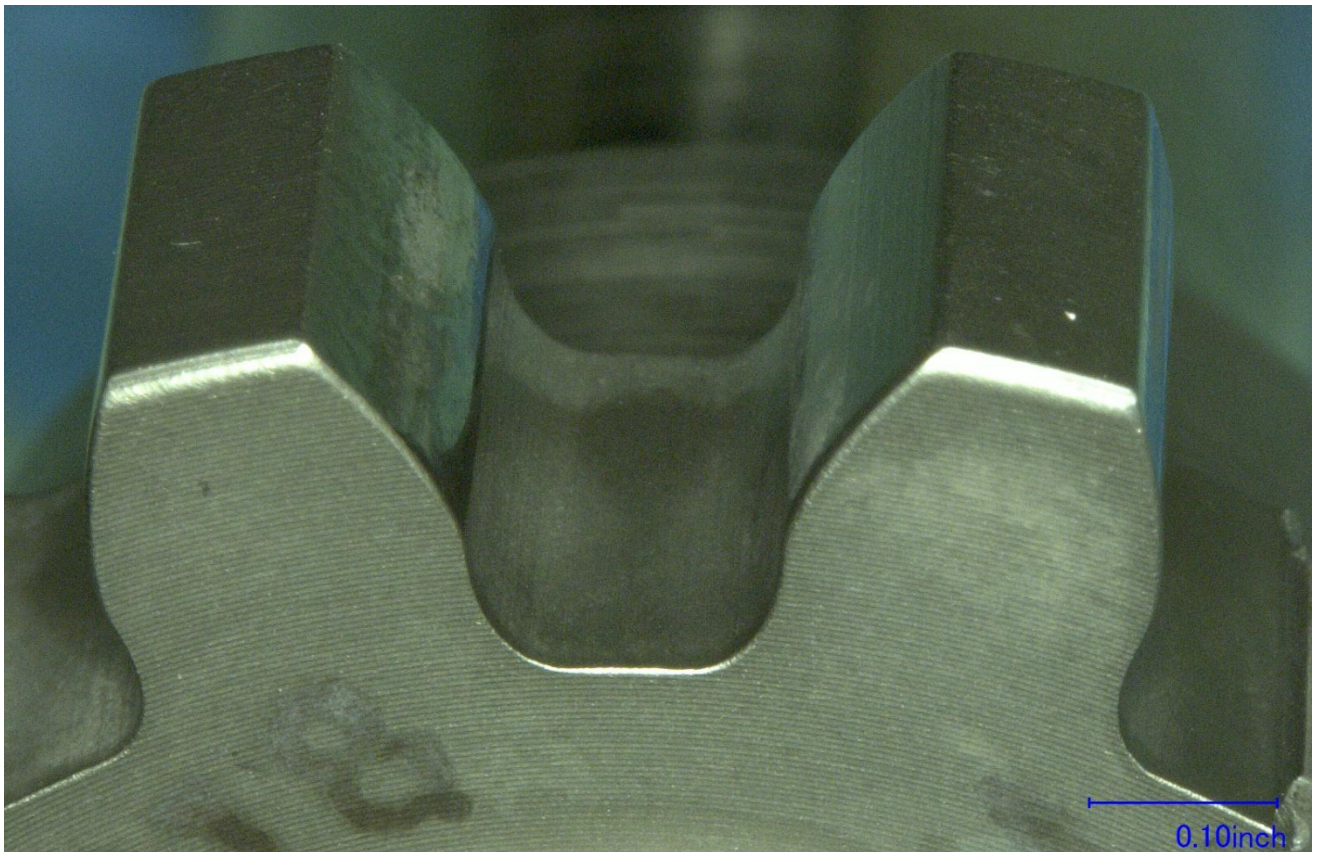


Figure 19 – View of the intact gear teeth from the drive gear, shown in the same orientation as the fractured teeth in Figure 18.

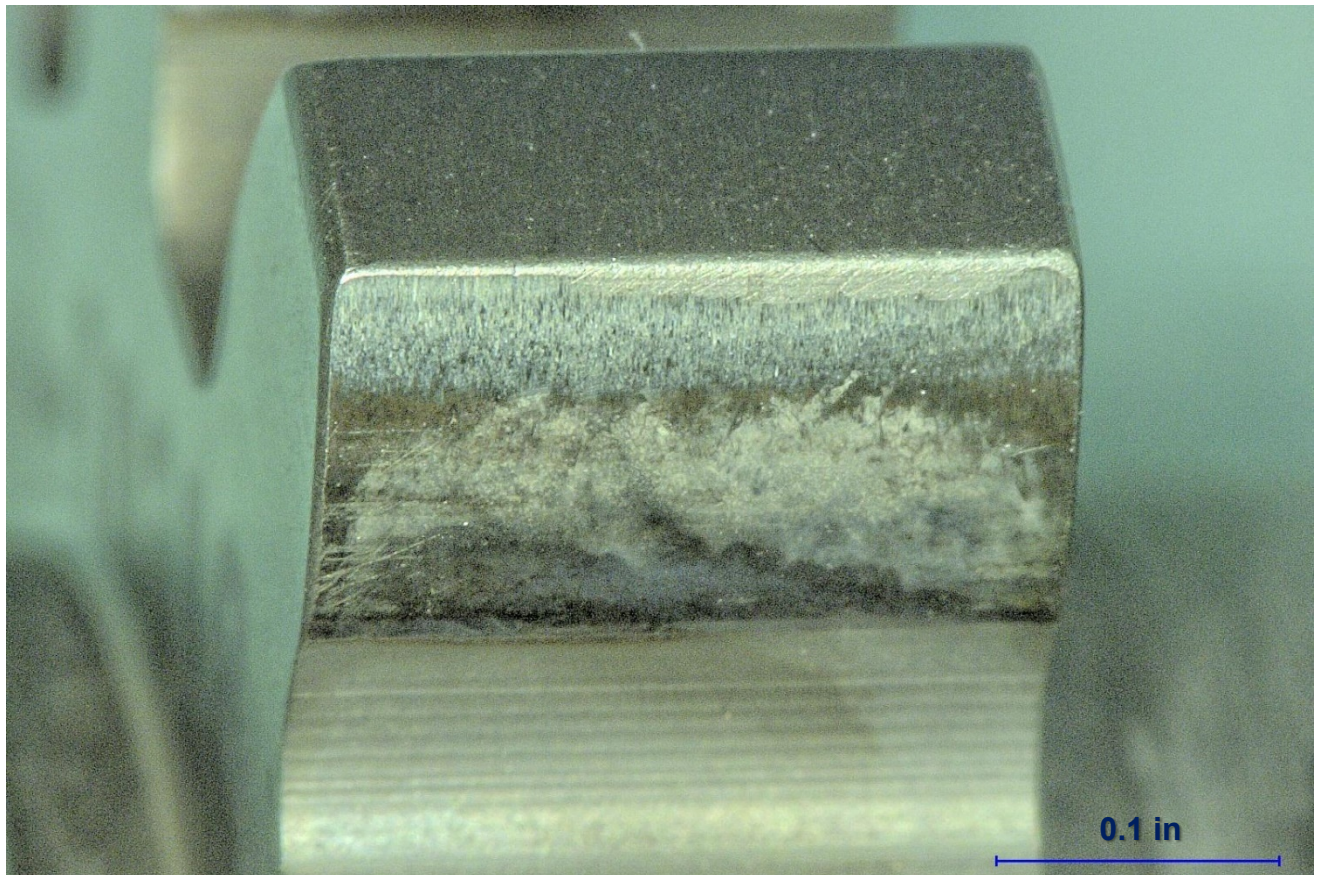


Figure 20 – View of the contact areas of the gear teeth adjacent to the fractured teeth on the drive gear.

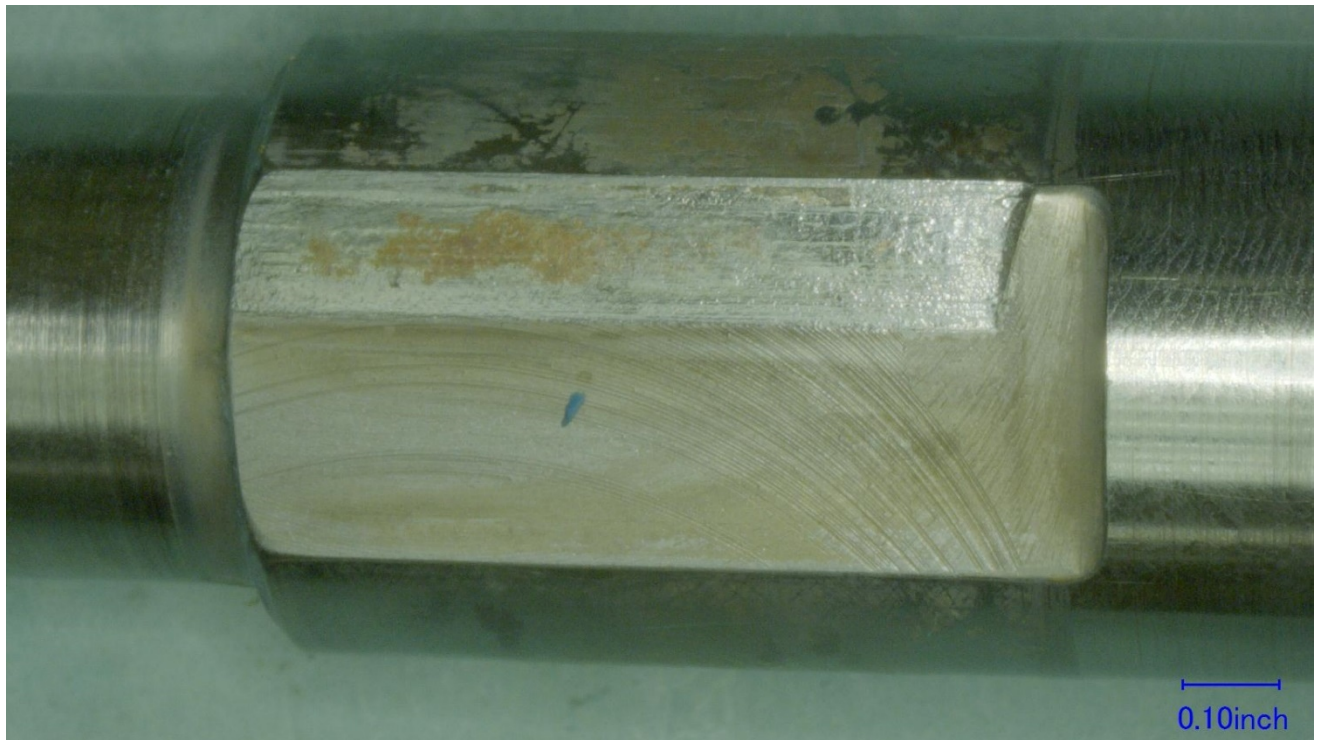


Figure 21 – View of the wear patterns on the contact face of the drive gear shaft.

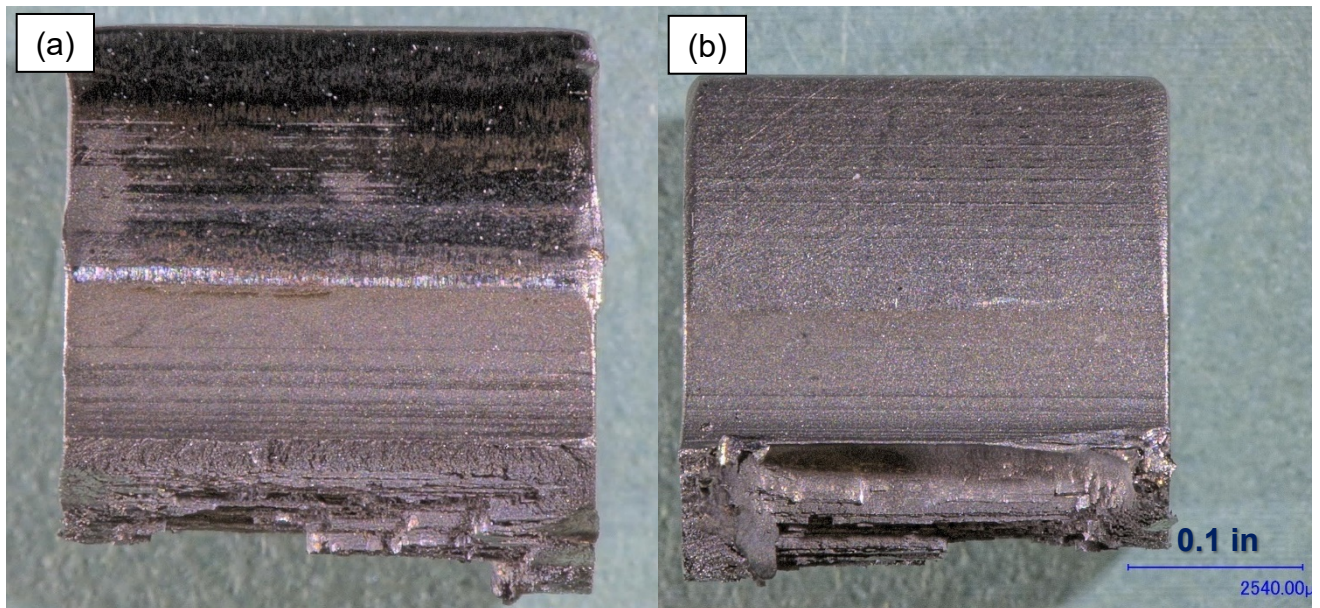


Figure 22 – View of one of the fractured gear teeth from (a) (b) each side.

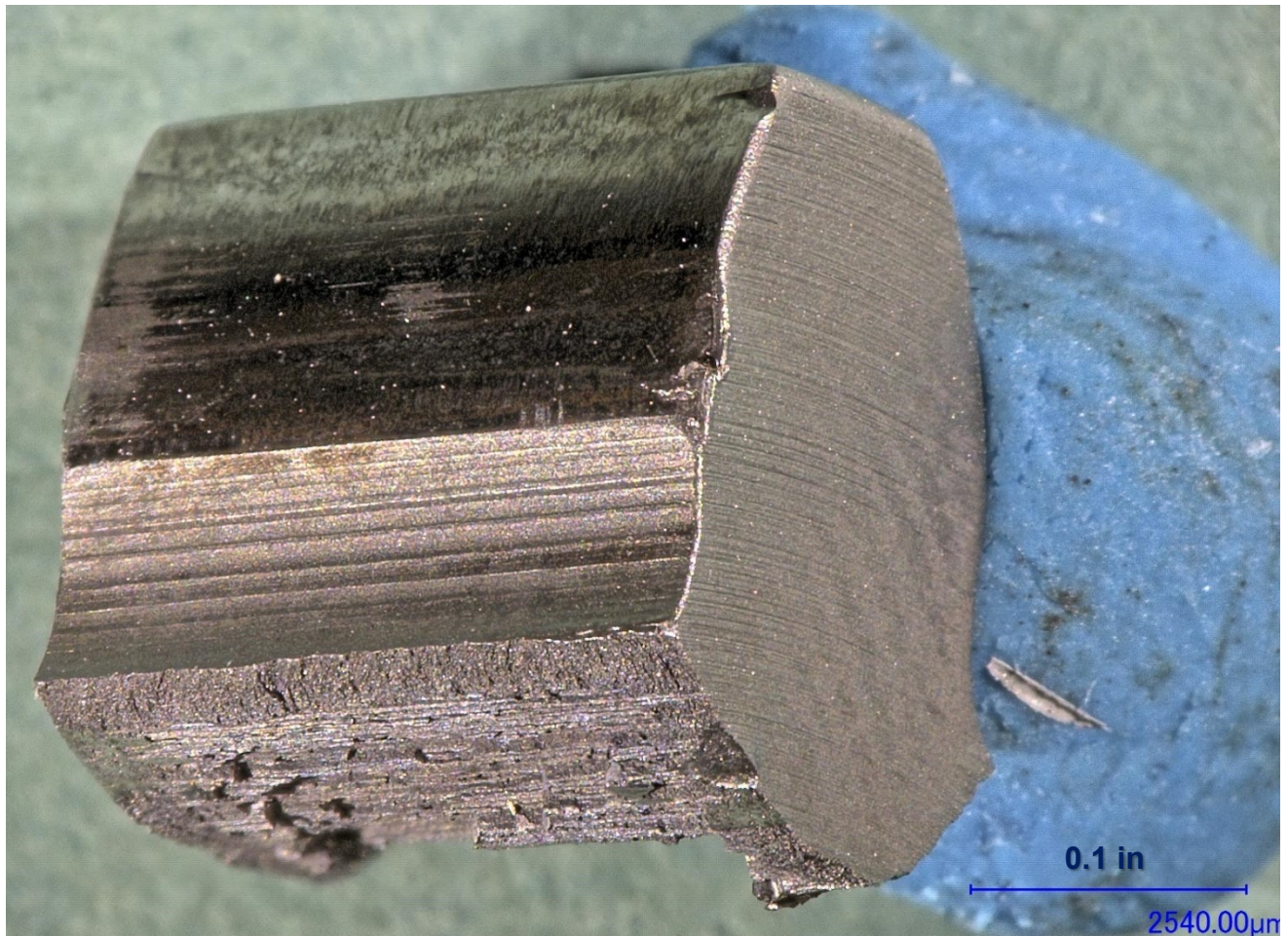


Figure 23 – Angled view of one of the fractured view, showing the fracture surface, the contact surfaces and the edges.

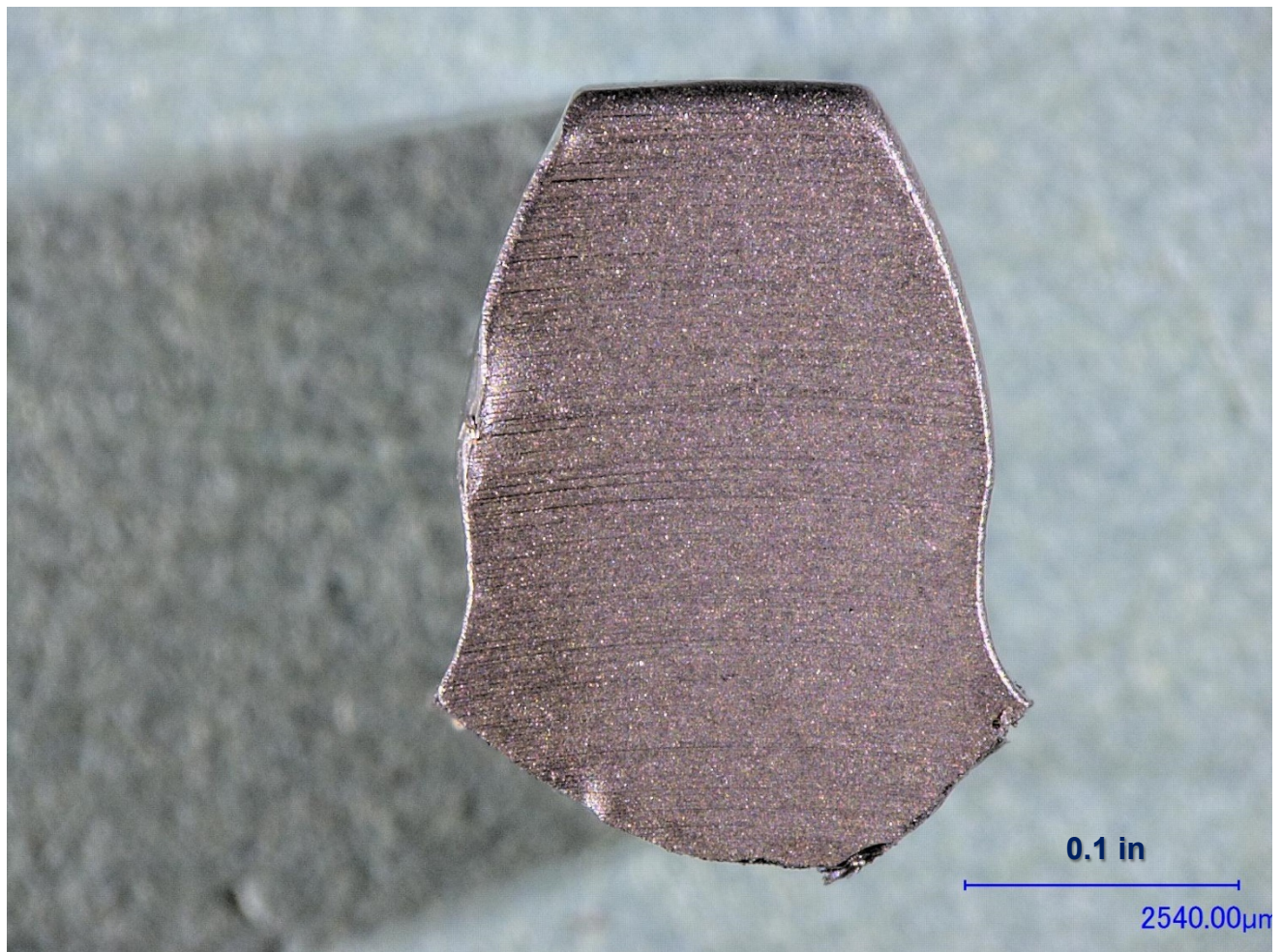


Figure 24 –The flat face of the fractured gear tooth.

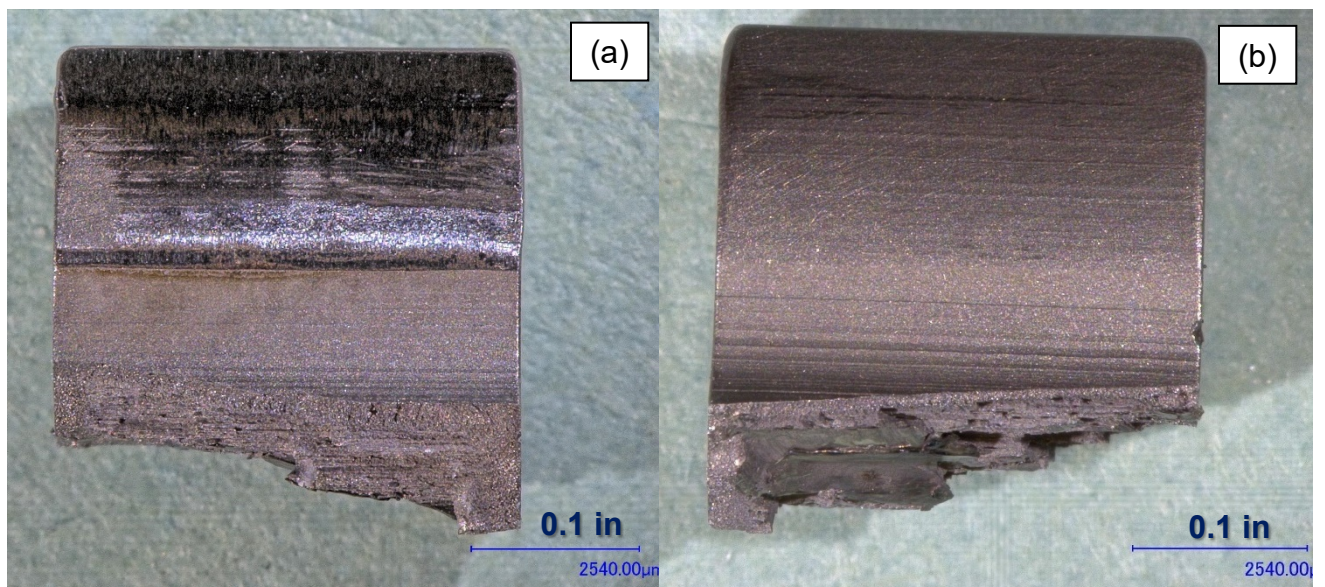


Figure 25 – Opposite views of the other fractured gear tooth.

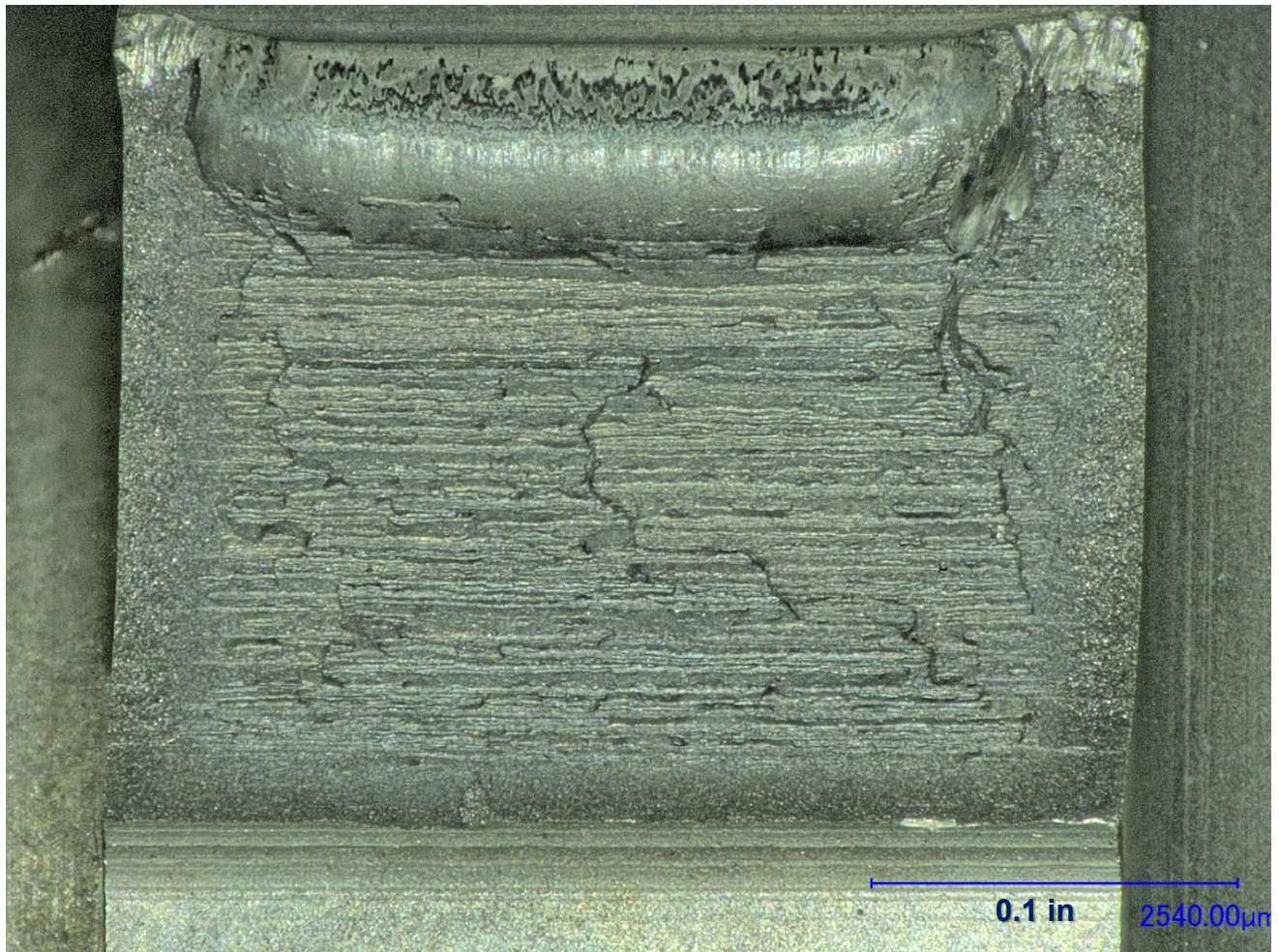


Figure 26 – Closer view of one of the fractured gear tooth fractured surfaces from the drive gear.

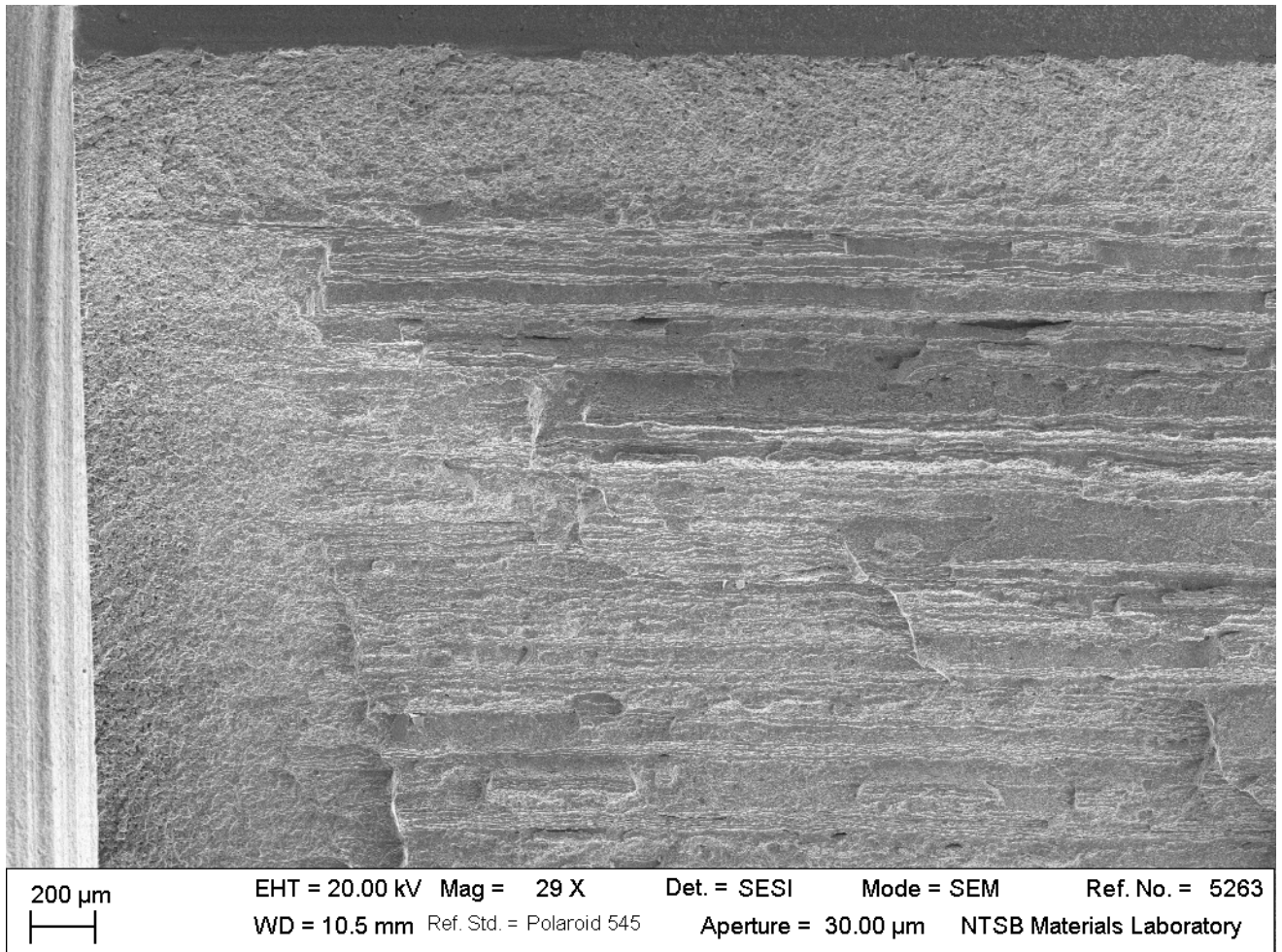


Figure 27 – Secondary electron (SE) of the corner of the gear tooth fracture surface, showing two distinct fracture regions.

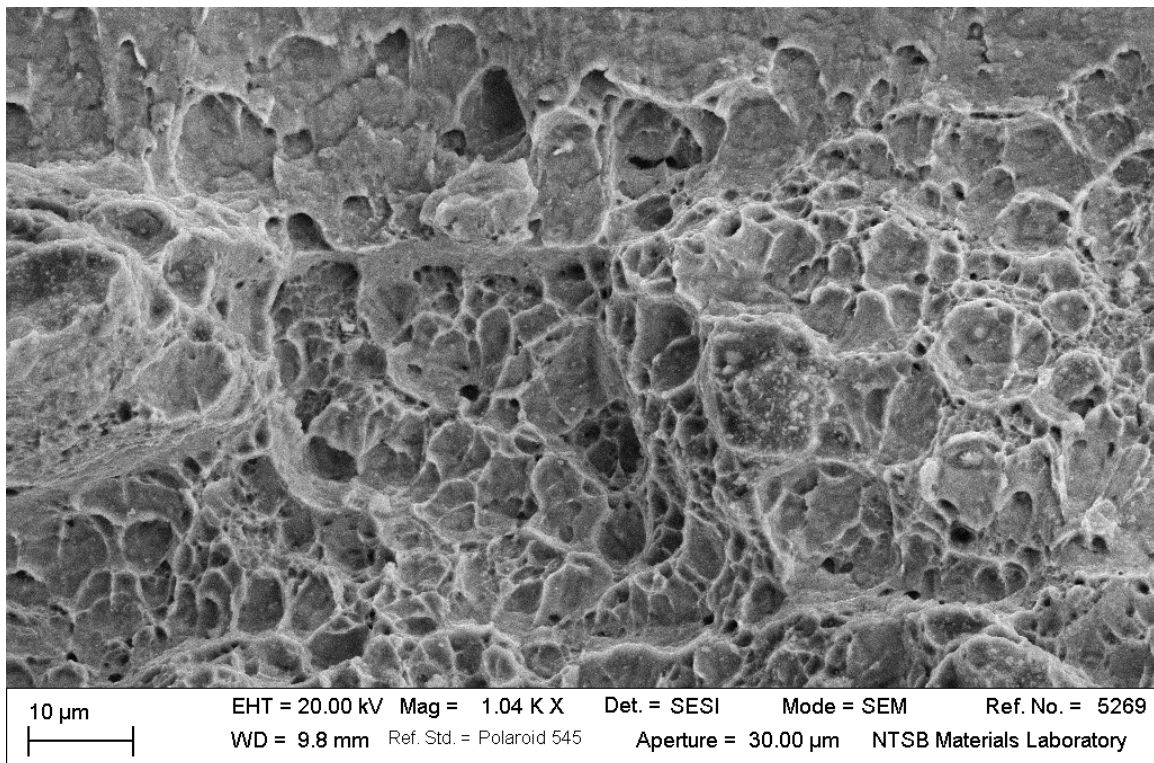


Figure 28 – SE micrograph of dimpled rupture on the interior of the fracture surface.

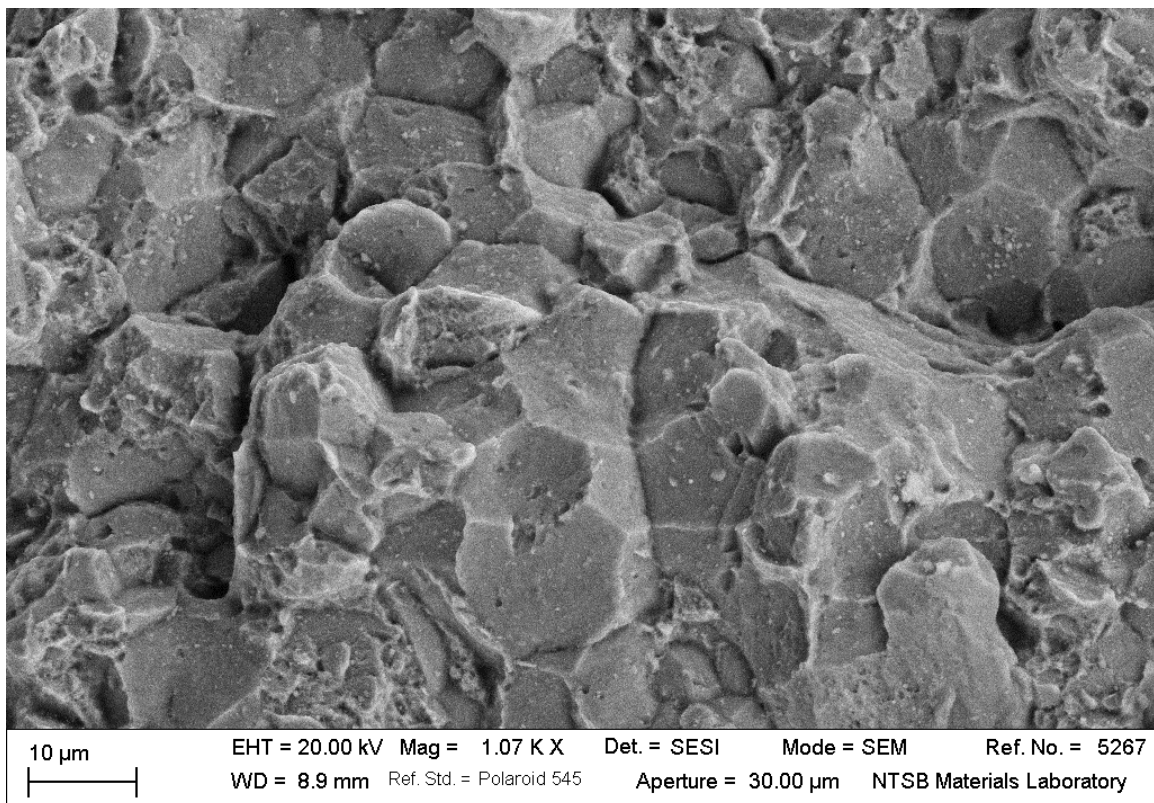


Figure 29 – SE micrograph of intergranular fracture on the periphery of the fracture surface.

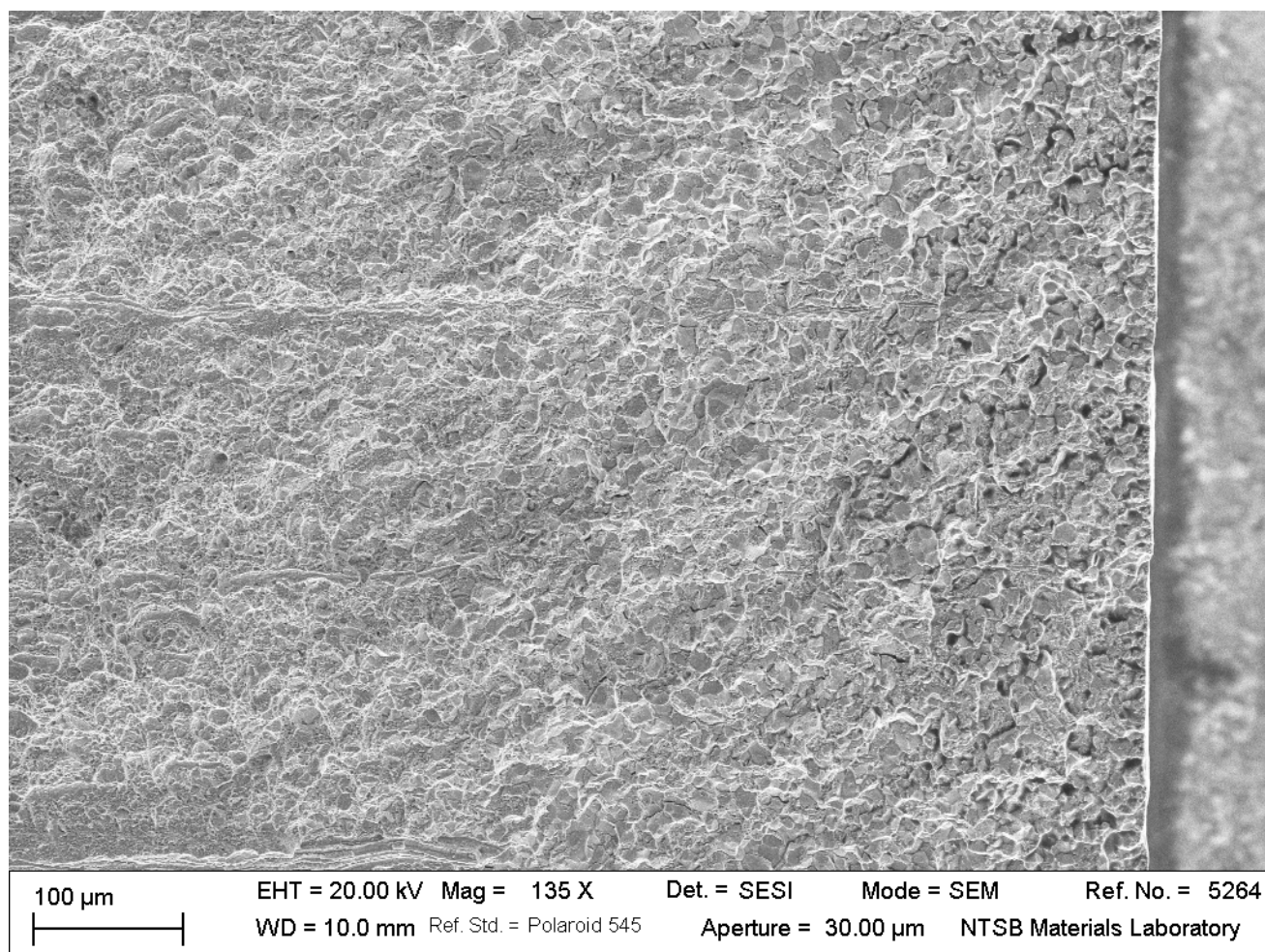


Figure 30 – SE micrograph of the exterior of the intergranular regions of the fracture.

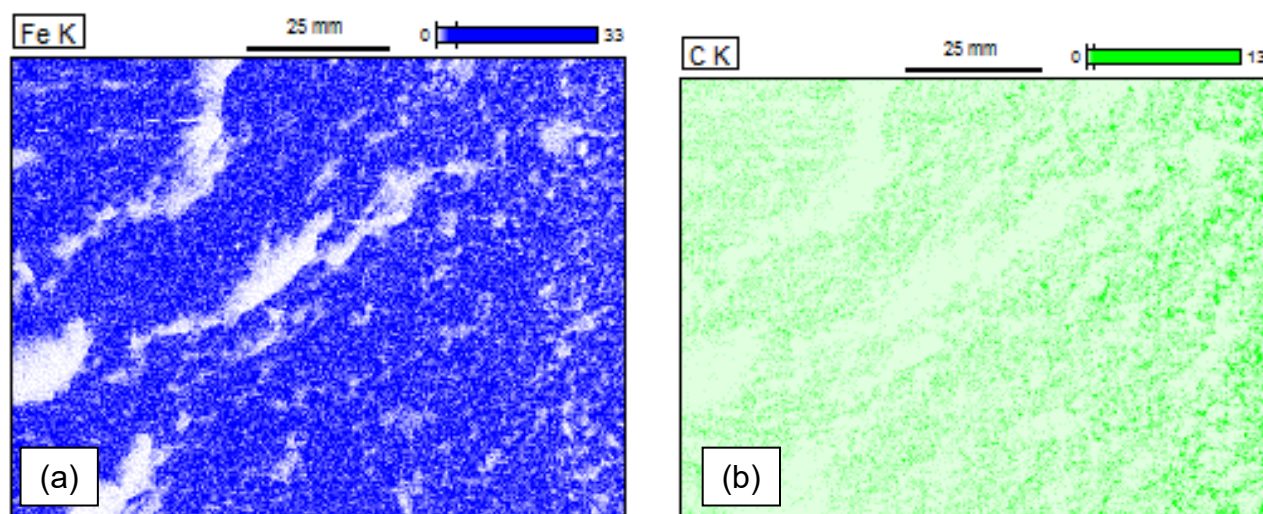


Figure 31 – X-ray maps of Figure 30, showing (a) high levels of Fe and (b) high levels of C.

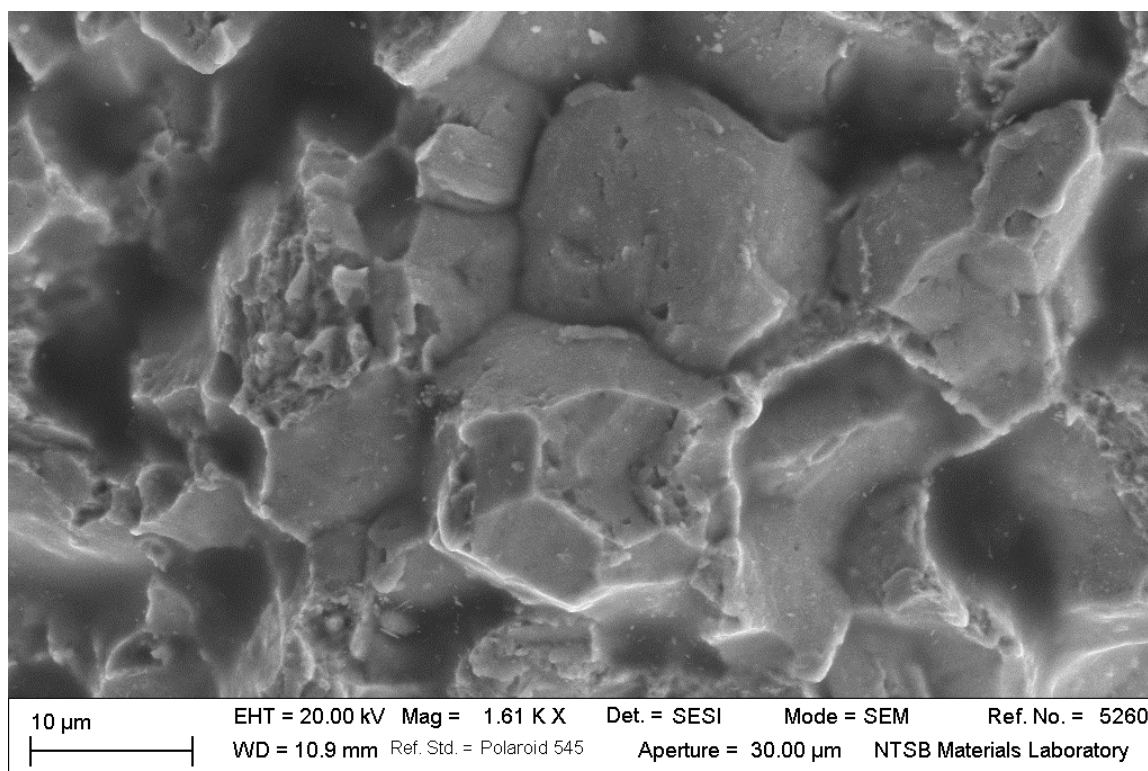


Figure 32 – SE micrograph of intergranular fracture in the area of highest C in Figure 30.

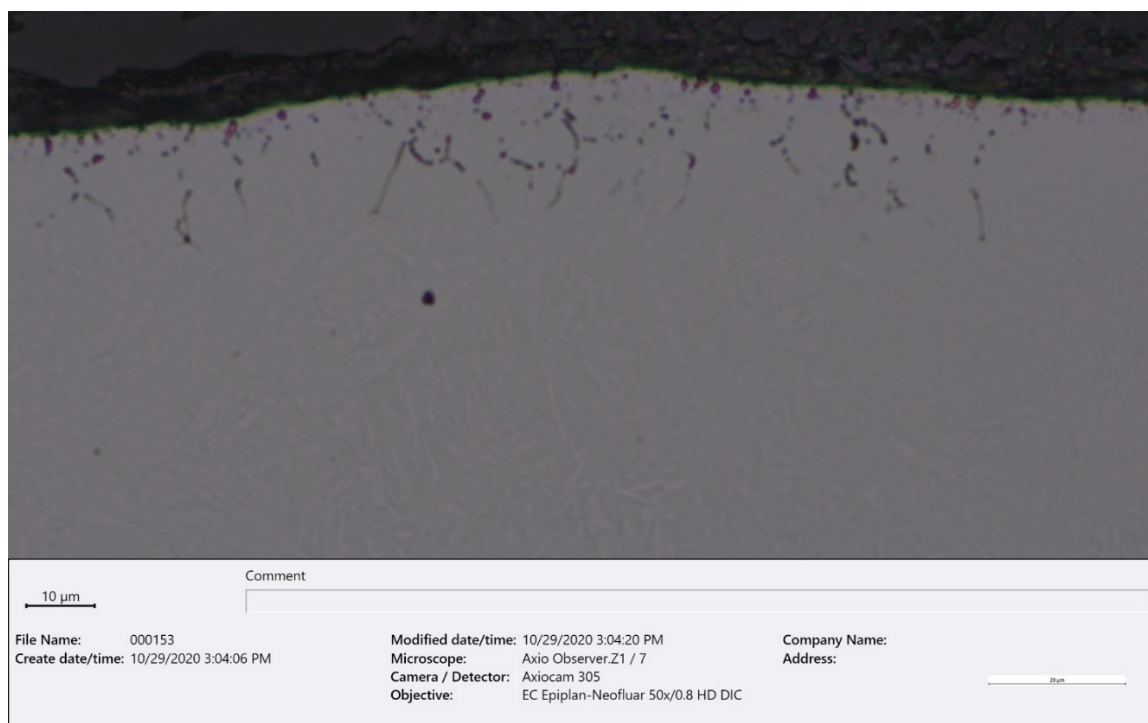


Figure 33 – Bright-field (BF) optical micrograph of the surface of the cross-sectioned fractured gear tooth, showing intergranular cracks (~1000X, as-polished).



Figure 34 – BF optical micrograph of the surface corner of the cross sectioned fractured gear tooth, showing a different etching response from the surface and core regions (~25X, etched 2% Nital).

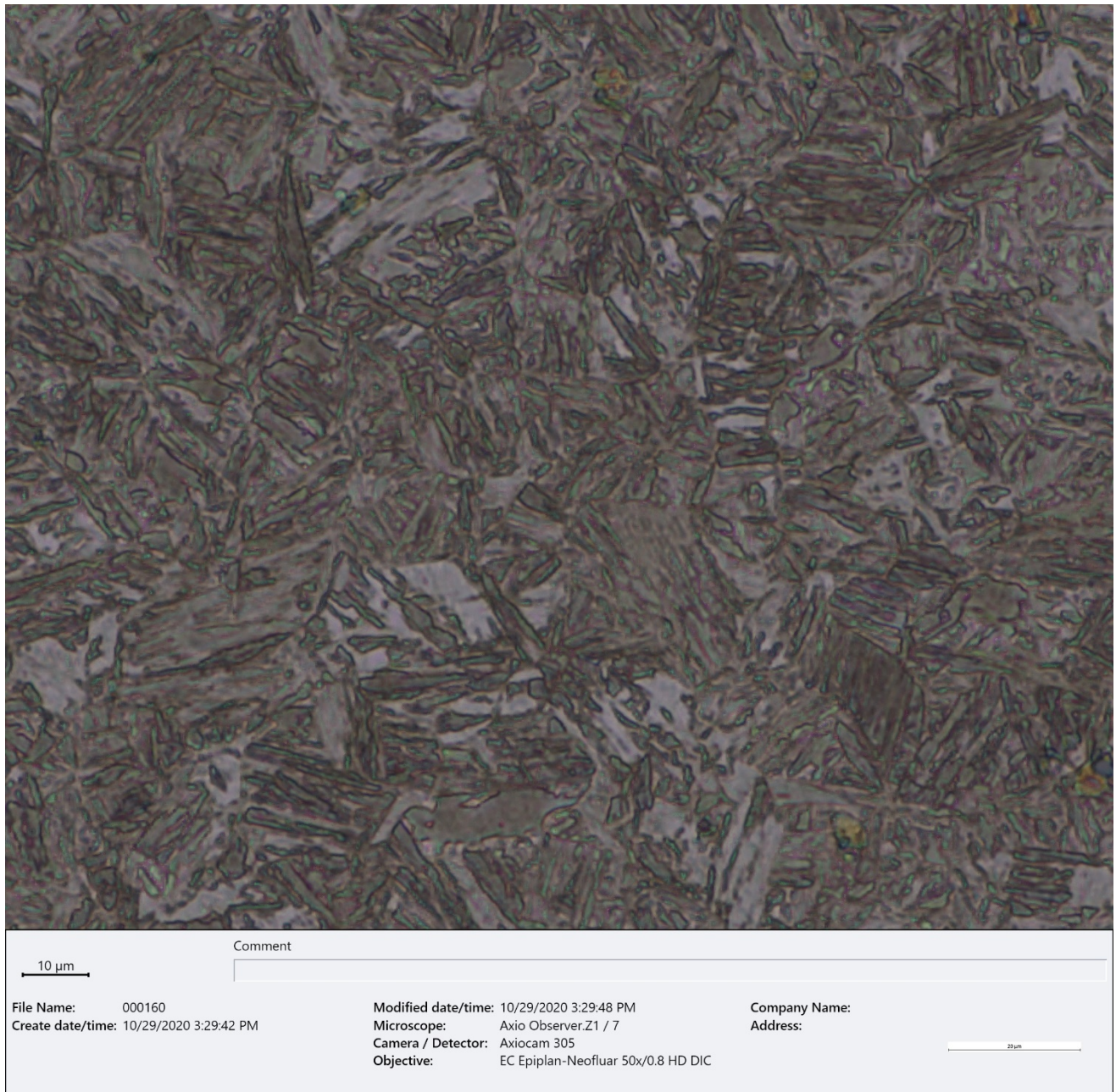


Figure 35 – BF optical micrograph of the core microstructure of cross sectioned fractured gear tooth (~1000X, etched 2% Nital).



Figure 36 – BF optical micrograph of the surface microstructure of cross sectioned fractured gear tooth (~1000X, etched 2% Nital).

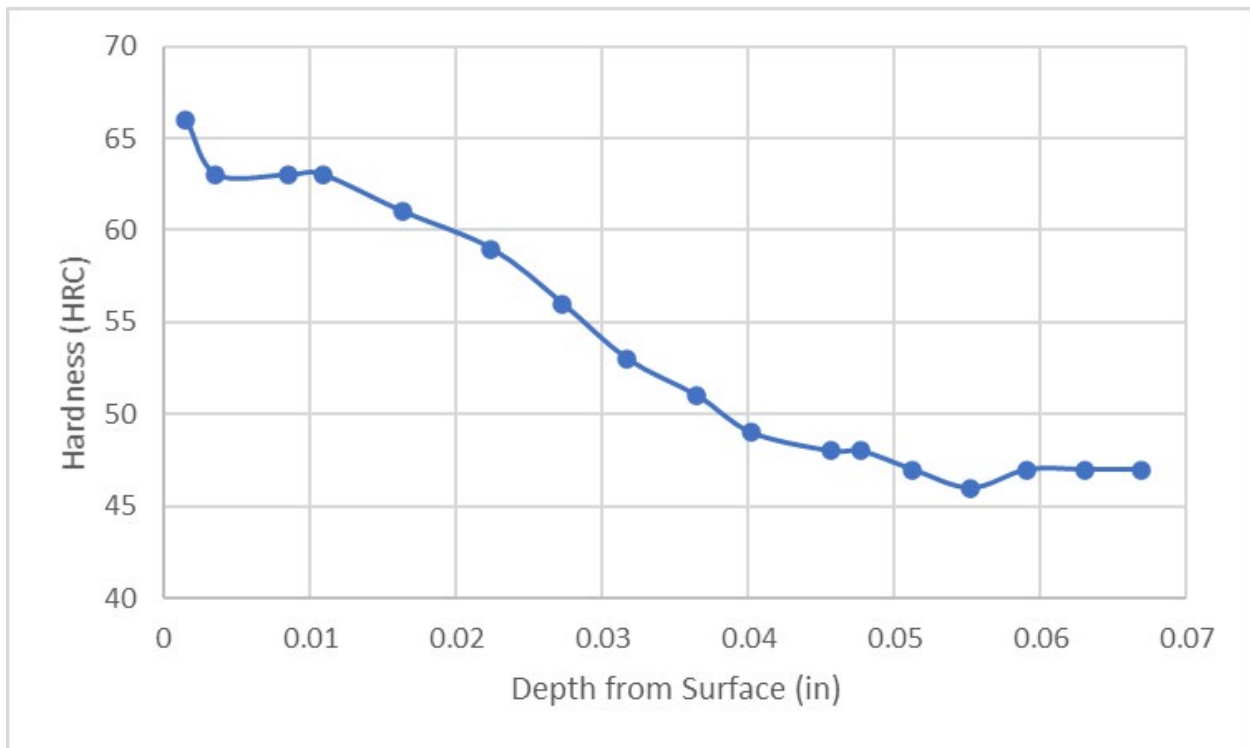


Figure 37 – Graph of the microindentation hardness data (in HRC converted from HV500) from the surface inward of the mounted and polished fractured gear tooth.