

NATIONAL TRANSPORTATION SAFETY BOARD

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



November 14, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 18-085

1. ACCIDENT INFORMATION

Place : Farmington, Pennsylvania
Date : January 29, 2018
Vehicle : Cessna P210N, N34VF
NTSB No. : ERA18LA072
Investigator : Aaron McCarter, AS-ERA

2. COMPONENTS EXAMINED

Crankshaft drive gear
Camshaft
Fragments of gear teeth

3. DETAILS OF THE EXAMINATION

On January 29, 2018, about 1650 eastern standard time, a Cessna P210N was substantially damaged after a loss of engine power and subsequent forced landing near Farmington, PA. The commercial pilot received minor injuries. During final approach, the airplane struck several trees and a power line, shearing off part of the left wing before the airplane struck the ground and skidded to a stop. The airplane came to rest upright. The fuel tanks were breached during the collision, which resulted in a fire that enveloped the airplane as the pilot evacuated.

The pilot reported that while in cruise flight, the airspeed decreased while the engine rpm fell to zero. The pilot attempted to restart the engine, but power could not be restored. According to Federal Aviation Administration (FAA) records, the airplane was equipped with a Continental Motors TSIO-520-P5B, 325 hp engine, manufactured in 1979.¹ At the time of the accident, the airplane had accumulated 4268 airframe total hours, and the engine had accumulated 750 total hours since overhaul. The airplane had flown for 21 hours since its most recent annual inspection that was completed on November 17, 2017.

¹ The Continental TSIO-520-P5B is a six-cylinder, horizontally opposed aircraft engine produced by Teledyne Continental Motors. First run in 1963 as a development of the IO-346, it has been produced in versions incorporating fuel injection (IO-520), turbo-charging (TSIO-520).

Figure 1 shows the parts from the engine, as received. This included a camshaft assembly, complete with a forward governor bevel gear and an aft timing gear. The camshaft had been stamped with "TCM 655384 B". As shown in Figure 2, the aft timing gear assembly consisted of two gears (one smaller on the aft side and one larger forward). These gears were attached to the camshaft mount flange by four bolts secured with safety wire. While the smaller aft gear did not exhibit any indications of damage, the teeth of the larger timing gear did. All these teeth were deformed, consistent with rotational contact by an adjacent gear. However, the direction of the deformation varied from one gear tooth to the other, either being in one direction or both in some circumstances.

Six attachment bolts were received. These bolts had already been removed from their previous locations. As shown in Figure 4, the attachment bolts did not exhibit any plastic deformation, wear, or other notable damage.

The journals and cam lobes of the camshaft are shown in Figures 5 through 10, organized from aft to forward positions. The journal surfaces all exhibited rotational wear marks typical of camshafts in reciprocating engines after time in service. The cam lobes exhibited S-shaped swirling wear marks on all the surfaces. The bevel gear on the forward side of the camshaft is shown in Figures 11 and 12. The gear was vibroetched with the following marks: "534655 AB PG 34/01". No indications of wear or damage were observed on this gear.

Figure 13 shows the crankshaft drive gear. The figure shows the gear after sectioning of a quadrant for later examination. The flat gear face exhibited the following vibroetched markings: "653631 F 09/02 PG". None of the gear teeth were on the drive gear. Of the missing gear teeth, 10 had fractured, and 20 had been worn and smeared. Two of the teeth, annotated in Figure 13, exhibited features such as crack arrest marks and heat tinting, consistent with progressive cracking prior to fracture.

The gear teeth fracture surfaces of note are illustrated in Figures 14 and 15. One of the fractured teeth was an isolated fracture surface, surrounded by worn and smeared gear teeth remnants (Figure 14). Located 180° on the opposite side were a cluster of four gear teeth fracture surfaces (Figure 15). The second fracture surface from the left in Figure 15 exhibited a progressive crack that comprised approximately 60% of the surface area. This progressive region exhibited crack arrest marks which were oriented consistent with the crack propagation from the tooth edge located near the thread root, as shown in Figure 16. Ratchet marks were present near the initiation side of the crack, consistent with multiple crack initiation sites.

This section of the drive gear was examined using a scanning electron microscope (SEM). As shown in Figures 17 and 18, the progressive region of the fracture surface exhibited fatigue striations, consistent with fatigue crack propagation. Outside this region, the fracture surface exhibited dimple rupture, consistent with subsequent overstress fracture of the tooth (Figure 19).

The gear tooth located 180° from the one in Figure 16 is highlighted in Figures 20. This fracture surface was examined in a SEM, and the fracture surface revealed fatigue stations (see Figure 21). As shown in the micrographs, the fracture surfaces were heavily damaged and contained embedded particles, consistent with post-fracture damage, oxidation, and contamination. All the fatigue crack initiation sites had been obliterated by post-fracture smearing damage, as typified in Figure 22.

A section of the drive gear was mounted, polished, and etched. An area of the cross section through two of the tooth fracture surfaces and a gear tooth valley is shown in Figure 23. While the microstructure adjacent to the fracture surfaces of the missing teeth on the left and right of the figure were consistent with the microstructure further inward, the microstructure near the undamaged thread root valley exhibited a more uniform, darker morphology. The core microstructure, highlighted in Figure 24, exhibited globular ferrite (colored white) surrounded by higher carbon constituents, such as fine pearlite and/or bainite (brown colored).^{2,3,4} In contrast, the microstructure near the thread root valley, shown in Figure 25, did not exhibit the large ferrite, instead consistent with higher carbon phases such as fine pearlite, bainite, and/or tempered martensite. This microstructure was consistent with a case hardening surface treatment, typical in gear manufacturing.

The chemical composition of the drive gear was inspected using x-ray fluorescence (XRF) and energy-dispersive x-ray spectroscopy (EDS). The composition was consistent with a Type 8740 alloy steel. When examined using EDS, the surface regions exhibited higher carbon content, but no indications of additional nitrogen.

This aforementioned cross section at the thread root was hardness tested using microindentation hardness per ASTM E384.⁵ Figure 26 shows the data from the microindentation hardness tests. The hardness peaked at 58 HRC (686 HK₅₀₀), 0.009 inches from the surface. The average hardness of the core was 32 HRC (324 HK₅₀₀). The effective case depth was 0.022 inches. These data were typical for a case-hardened alloy steel.

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² Ferrite is the lower temperature body-centered cubic iron-based phase that comprises steel microstructures, with very low solubility for carbon.

³ Pearlite is a metastable lamellar aggregate of ferrite and cementite (Fe₃C) resulting from transformation of higher temperature face-centered cubic austenite at temperatures above the stable range for bainite.

⁴ Bainite is a metastable aggregate of ferrite and cementite resulting from rapid transformation of higher temperature austenite at temperatures below the pearlite range but about the martensite start temperature.

⁵ ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA



Figure 1 – The components from the camshaft assembly and drive gear, as received.

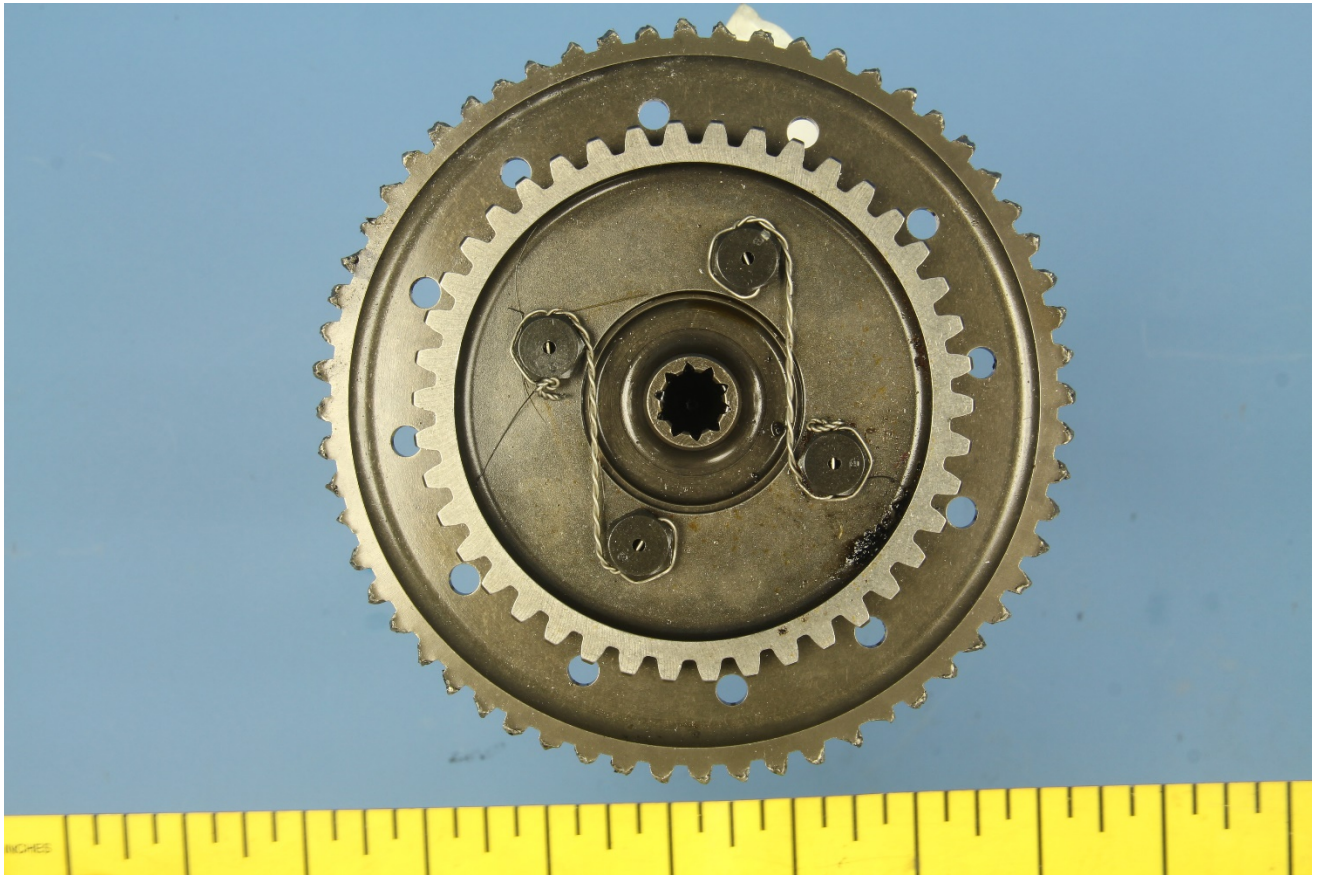


Figure 2 – View of the camshaft assembly from the timing gear, showing the attachment bolts to the mount flange in place with safety wire.

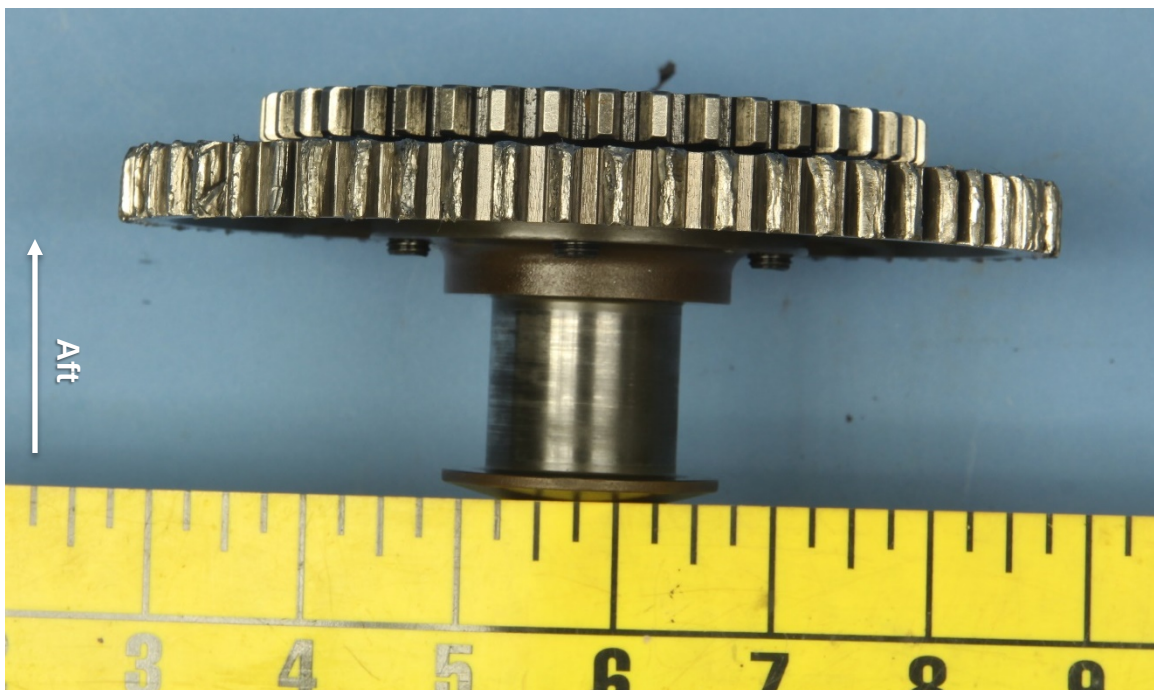


Figure 3 – View of the timing gear, showing the worn gear teeth.



Figure 4 – The loose six attachment bolts, after cleaning to remove oils and particles.

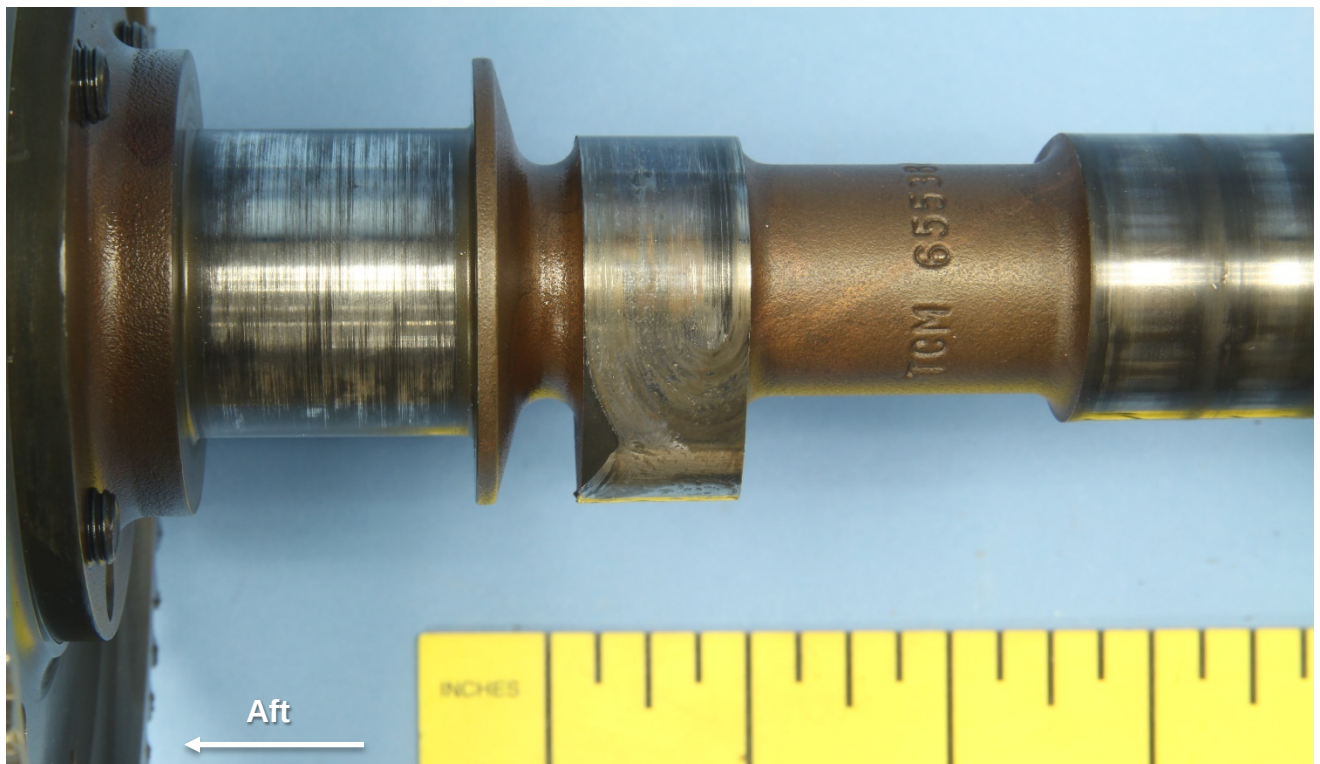


Figure 5 – The aftmost part of the camshaft, showing the journal bearings and lobes.

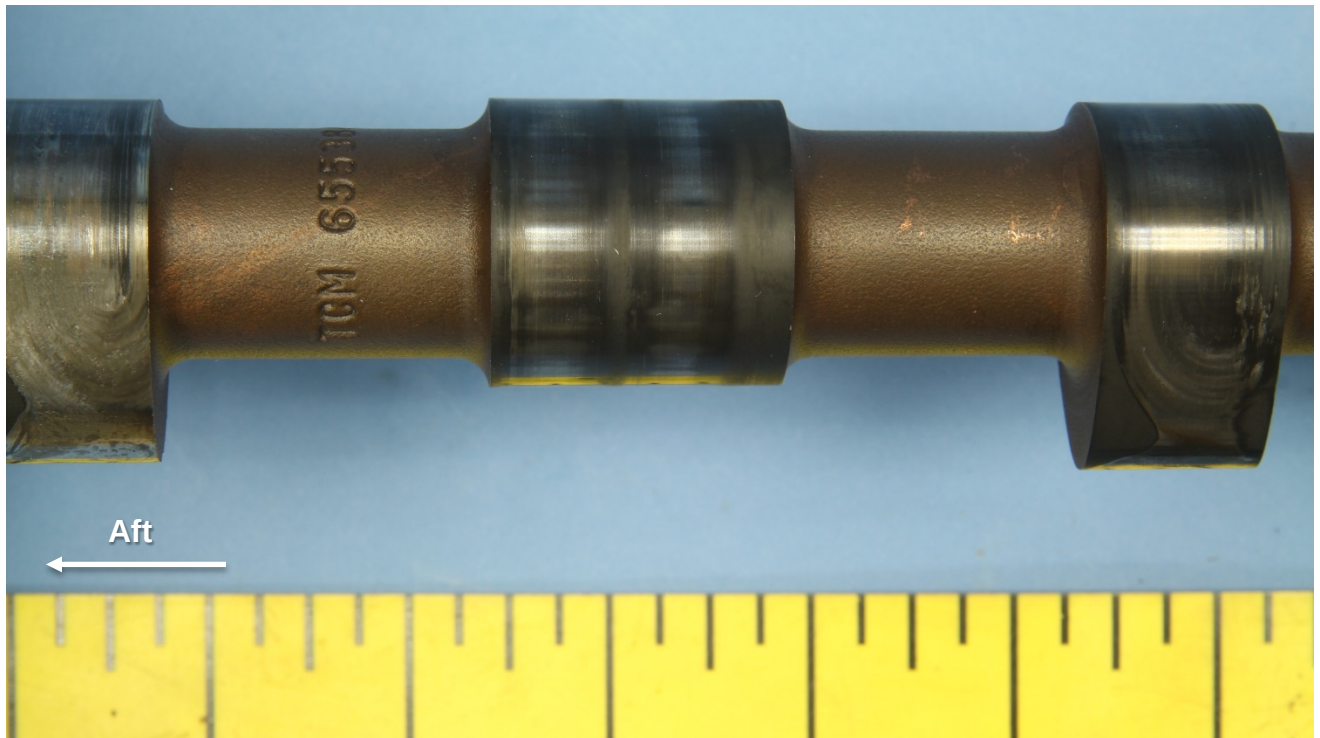


Figure 6 – Some of the journal bearings and lobes of the camshaft, viewed forward of the position in Figure 5.

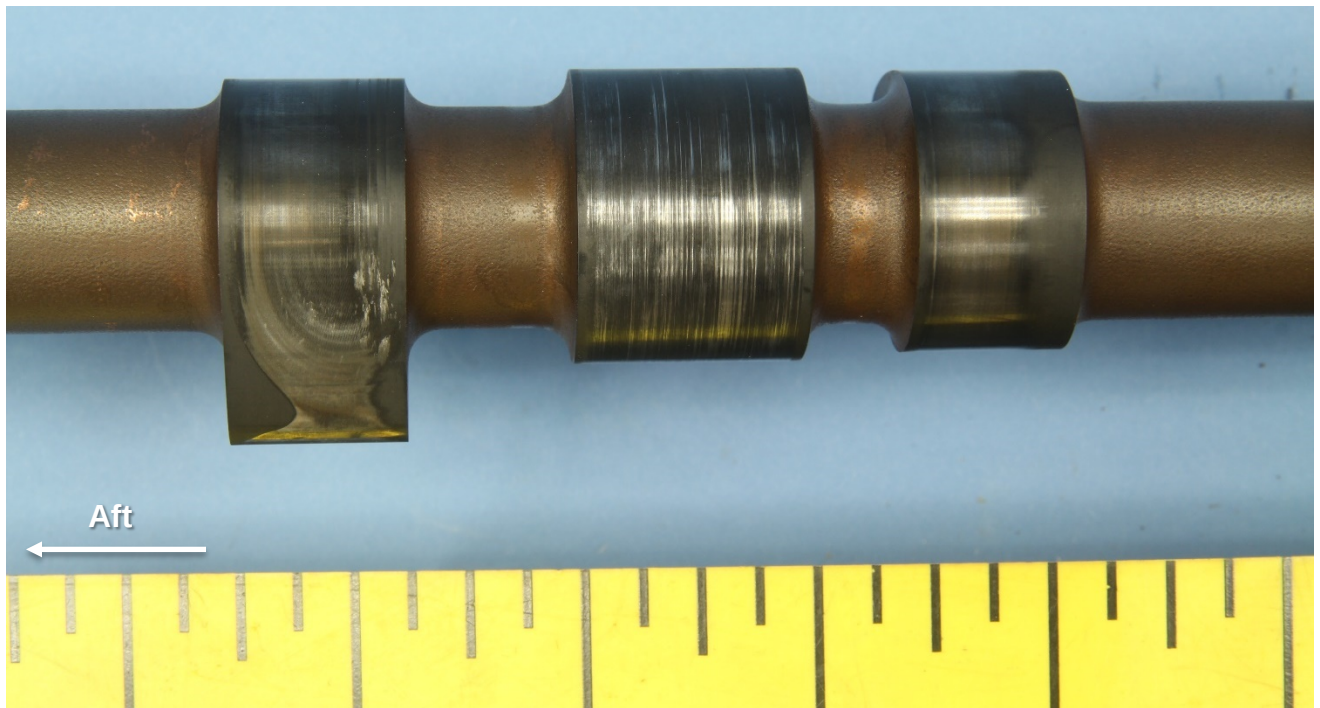


Figure 7 – Some of the journal bearings and lobes of the camshaft, viewed forward of the position in Figure 6.

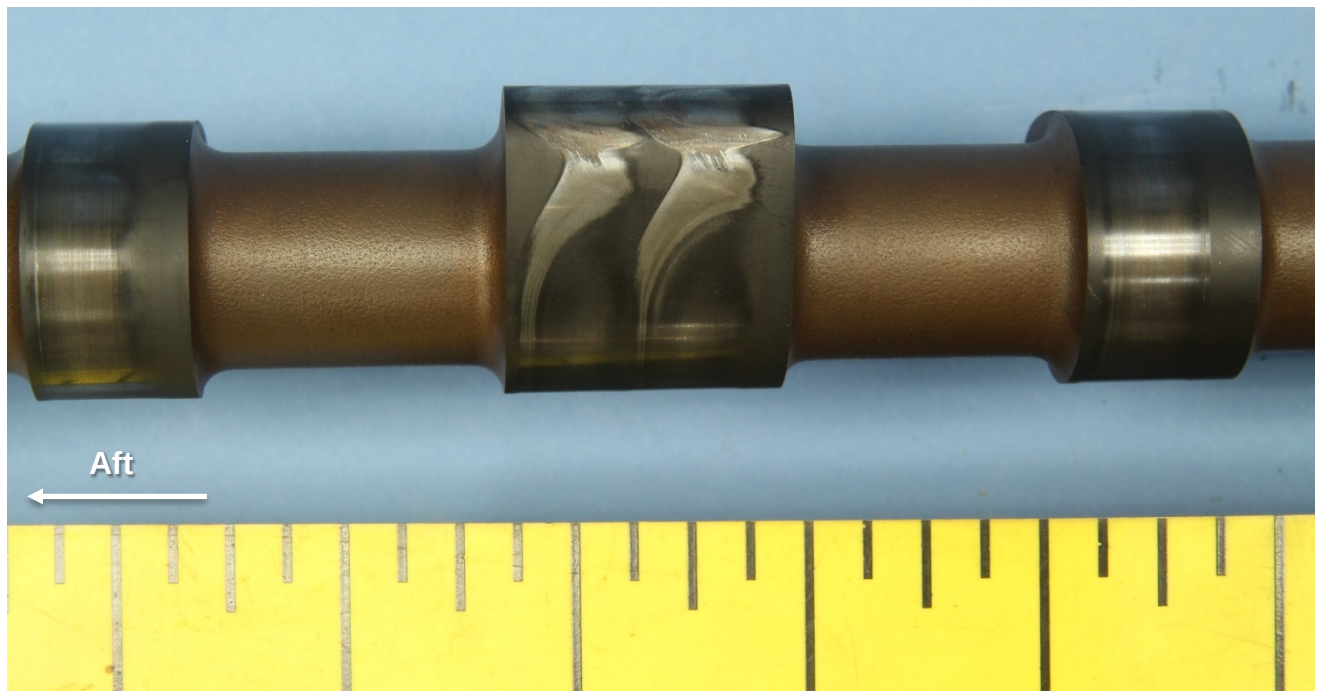


Figure 8 – Some of the journal bearings and lobes of the camshaft, viewed forward of the position in Figure 7.



Figure 9 – Some of the journal bearings and lobes of the camshaft, viewed forward of the position in Figure 8.



Figure 10 – Some of the journal bearings and lobes of the camshaft, viewed forward of the position in Figure 9.



Figure 11 – Some of the journal bearings and lobes of the forwardmost part of the camshaft, including the governor bevel gear.



Figure 12 – The bevel gear from the forward side of the camshaft assembly, after removal from the camshaft.

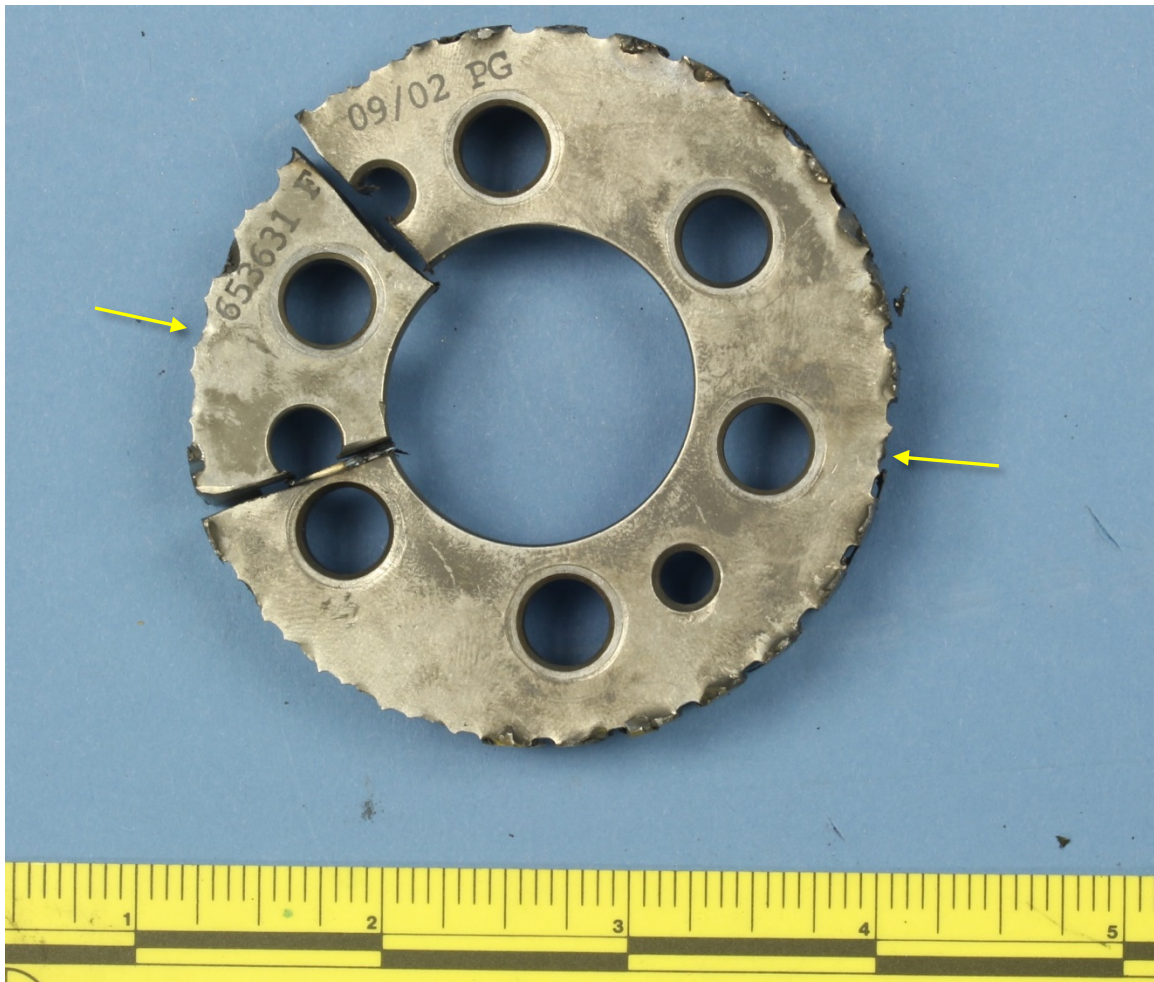


Figure 13 – The drive gear, from the flat side, after sectioning. The fractured teeth remnants later found to be fatigue are annotated with yellow arrows.

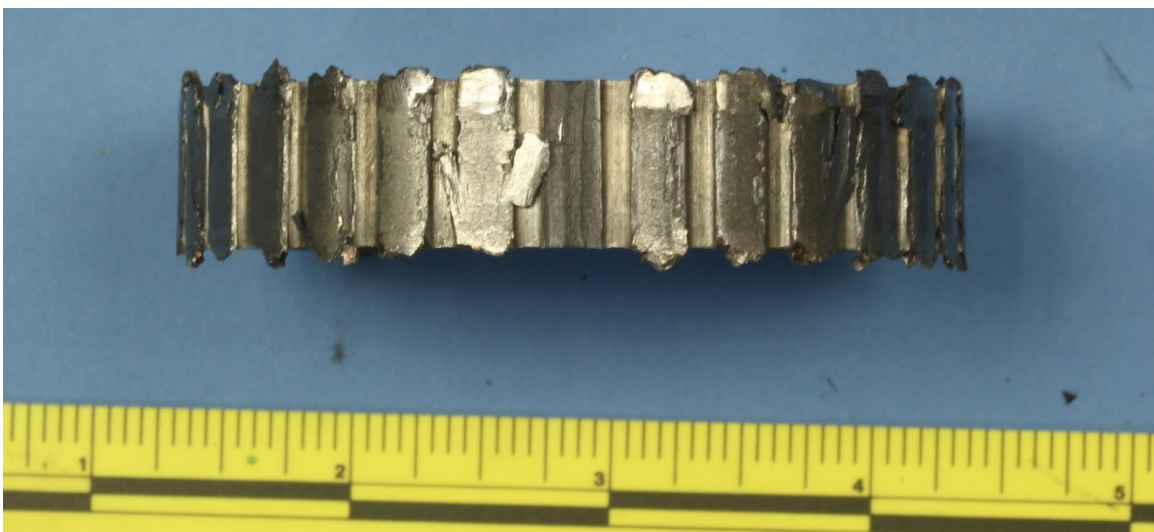


Figure 14 – View of the drive gear teeth, showing fractured and smeared teeth remnants.

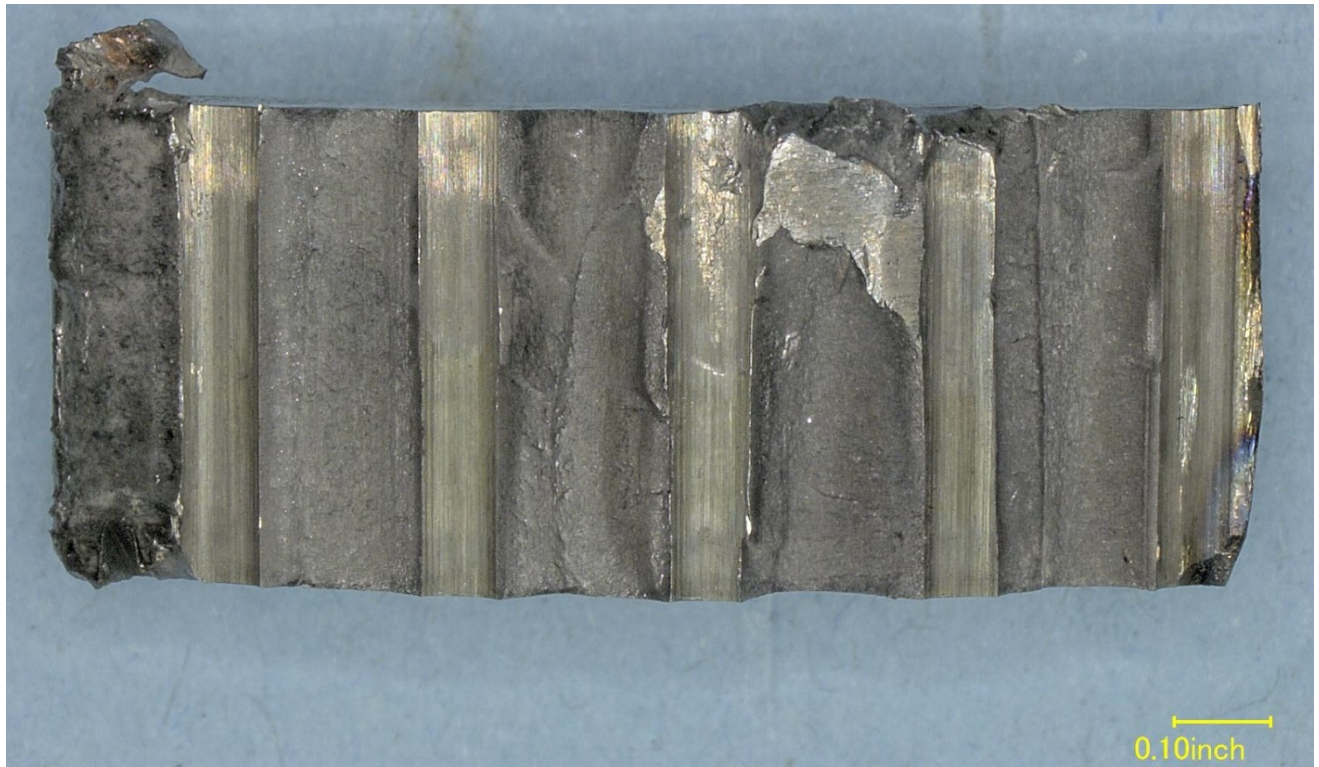


Figure 15 – View of the series of fractured teeth on the drive gear, sectioned from the part.



Figure 16 – Closer view of the fractured tooth exhibiting progressive cracking, later determined to be fatigue.

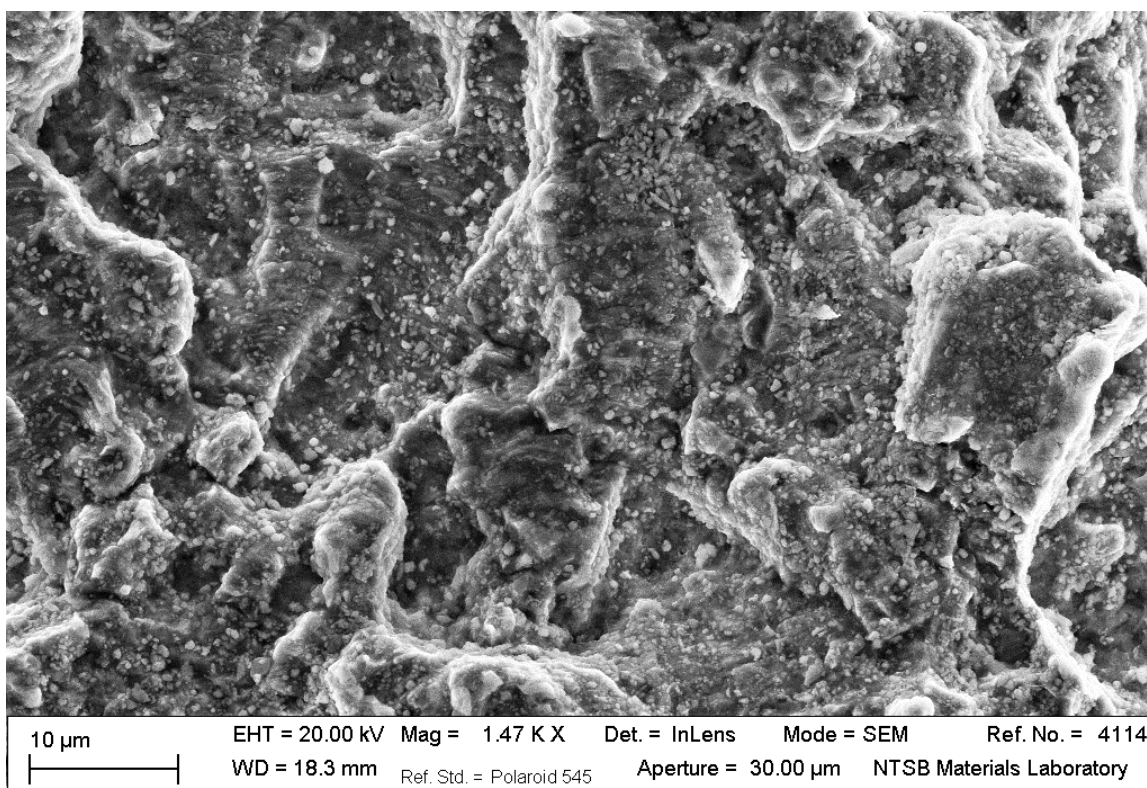


Figure 17 – Secondary electron (SE) micrograph of the progressive region of the tooth in Figure 16, showing fatigue striations.

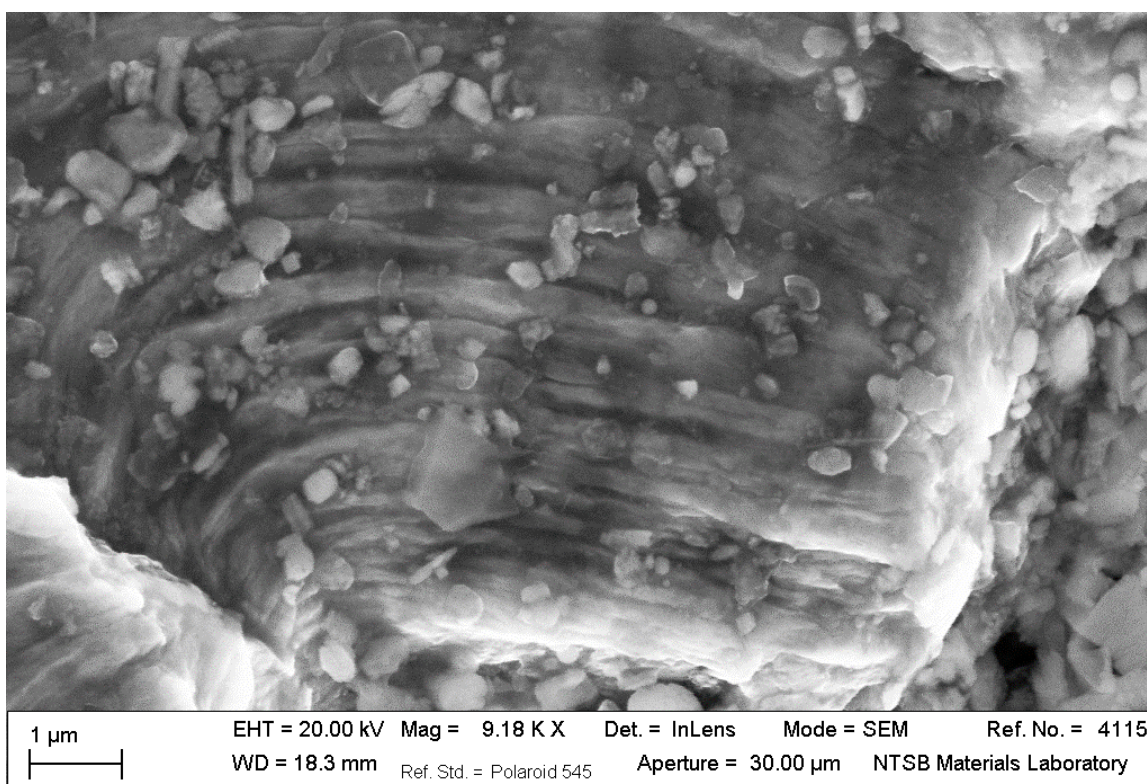


Figure 18 – SE micrograph showing a closer view of the striations in Figure 17.

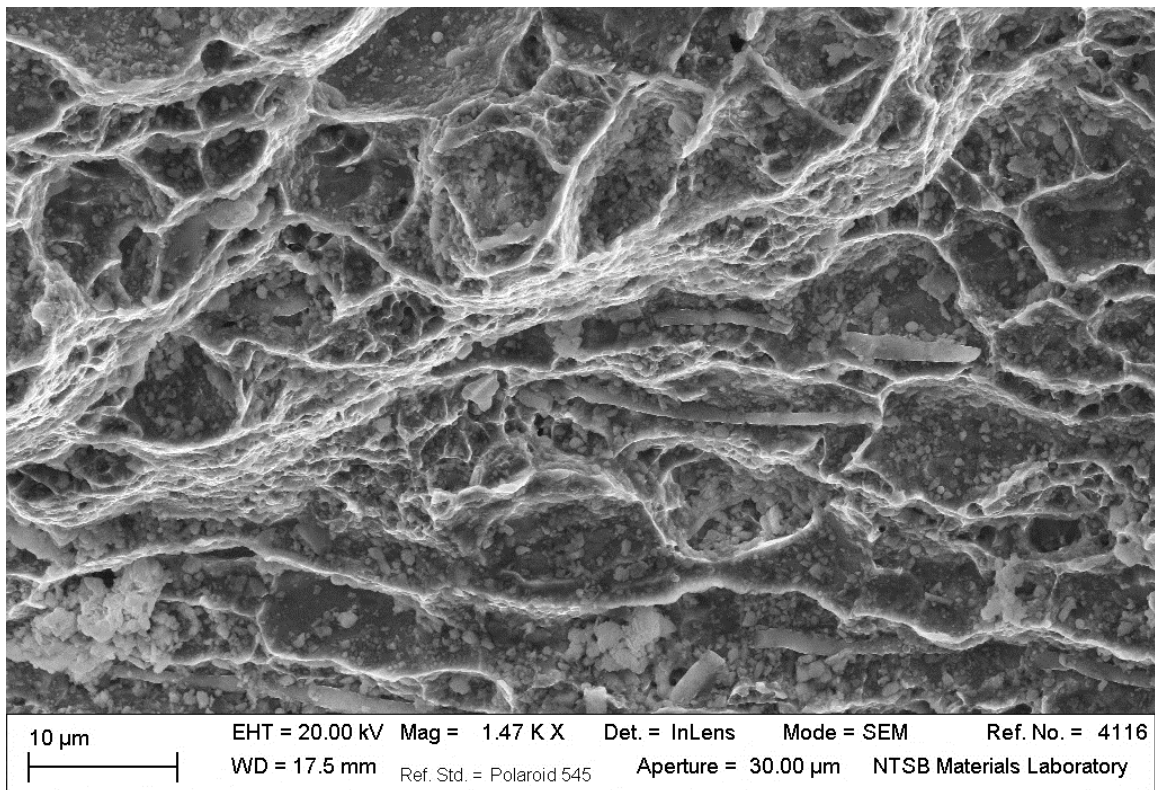


Figure 19 – SE micrograph of dimple rupture on the fractured tooth in Figure 16.



Figure 20 – View of the fractured gear tooth in Figure 14, located 180° opposite of the fractured teeth in Figure 15.

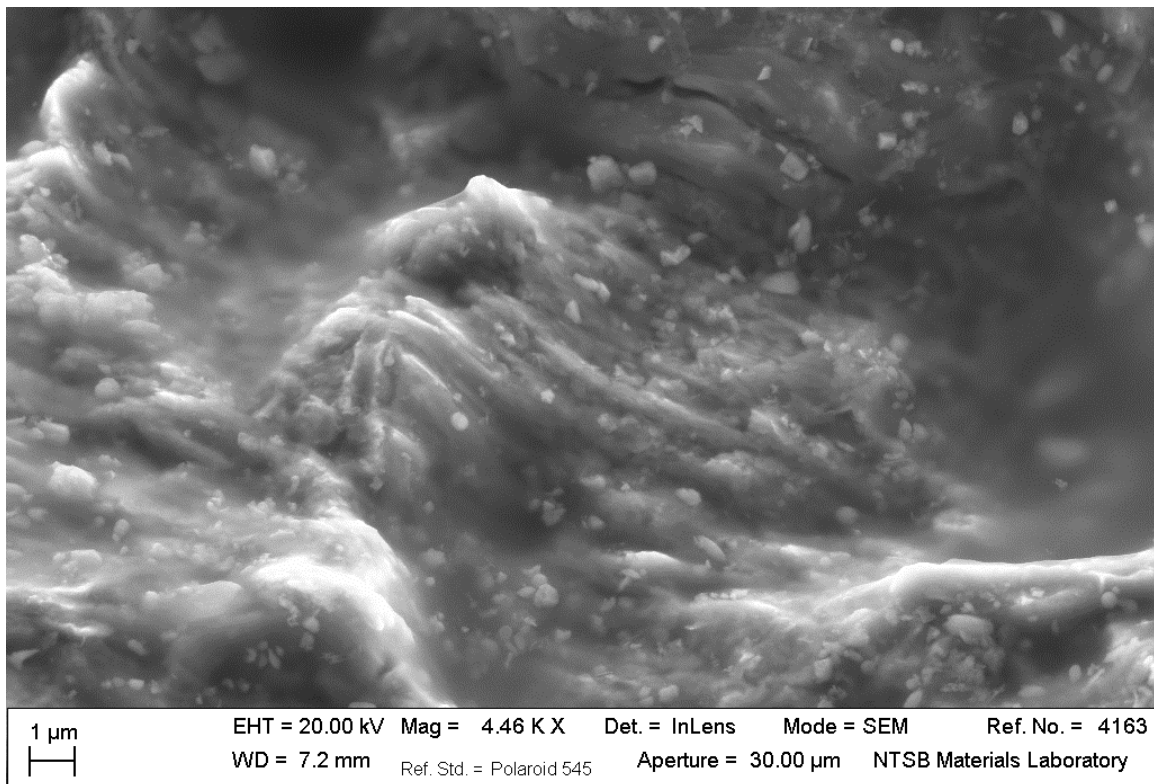


Figure 21 – SE micrograph of fatigue striations on the fractured tooth in Figure 20.

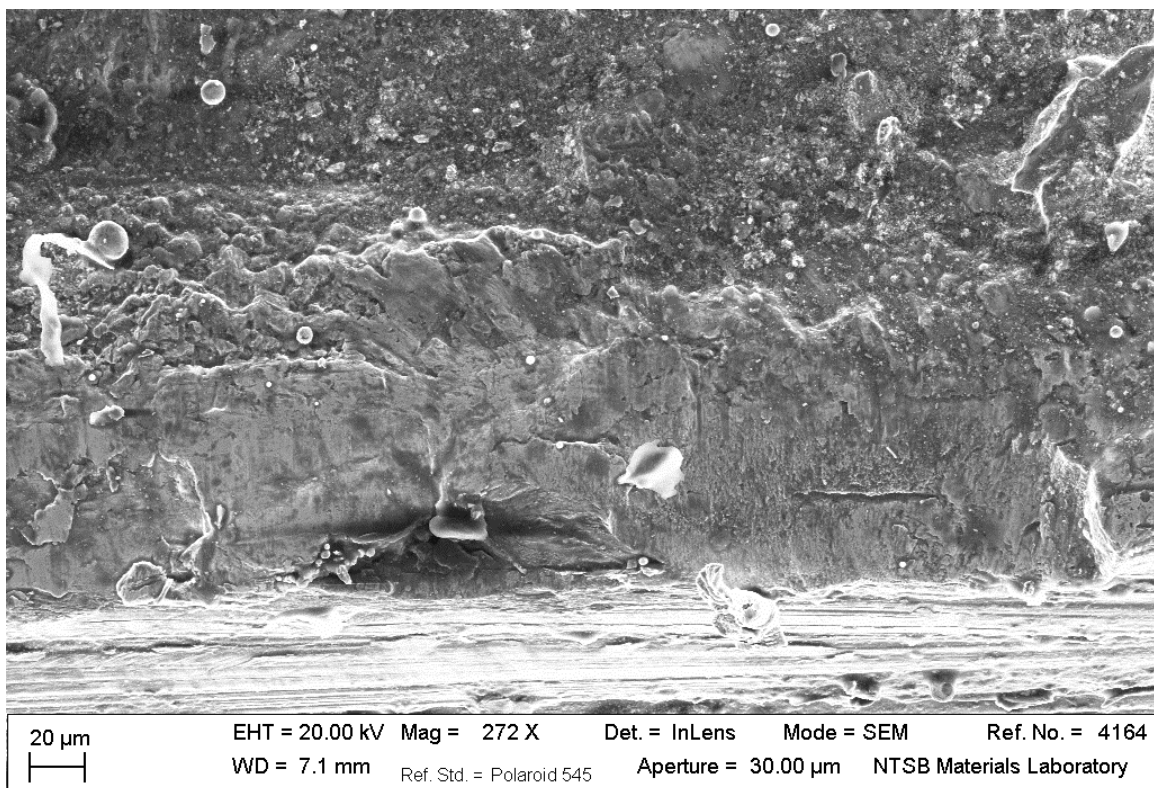


Figure 22 – SE micrograph of a fatigue crack initiation site, showing smearing.

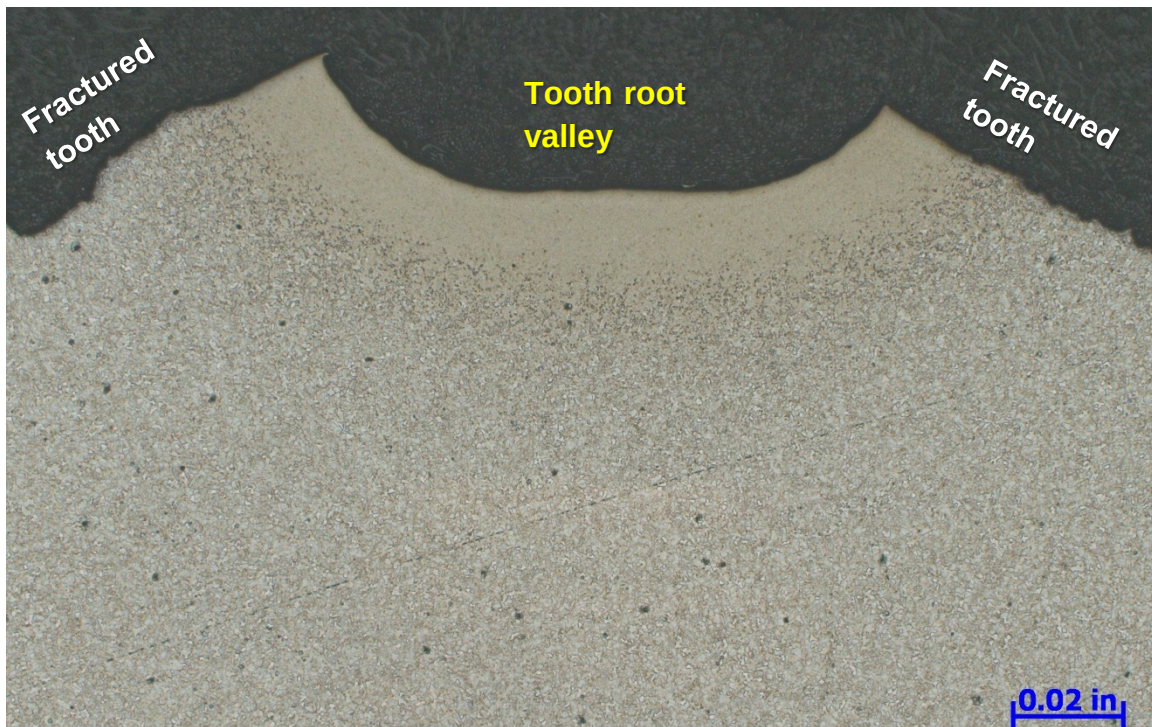


Figure 23 – Bright-field (BF) optical micrograph of fractured gear teeth cross-section, showing the surface modification in the undamaged thread valley (~25X, etched 2% Nital).

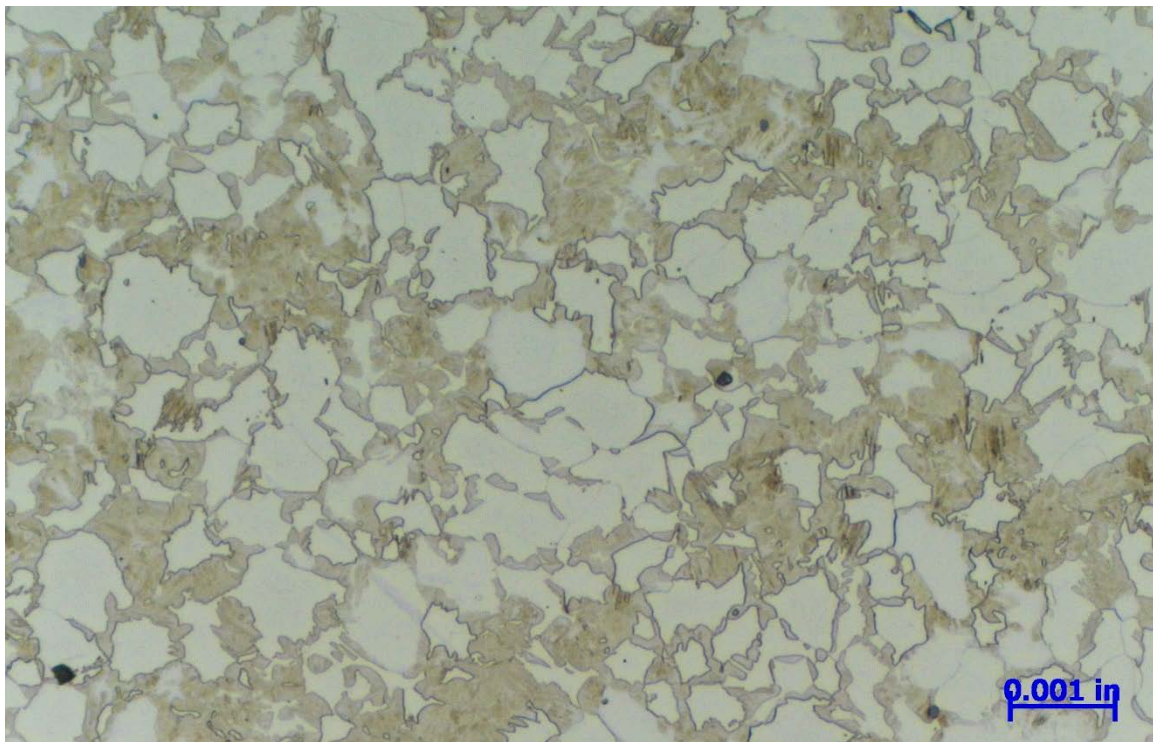


Figure 24 – BF optical micrograph showing a typical area of the core microstructure showing ferrite (light) surrounded by higher carbon phases (brown) (~500X, etched 2% Nital).



Figure 25 – BF optical micrograph showing a typical area of the surface microstructure showing high carbon phases (~500X, etched 2% Nital).

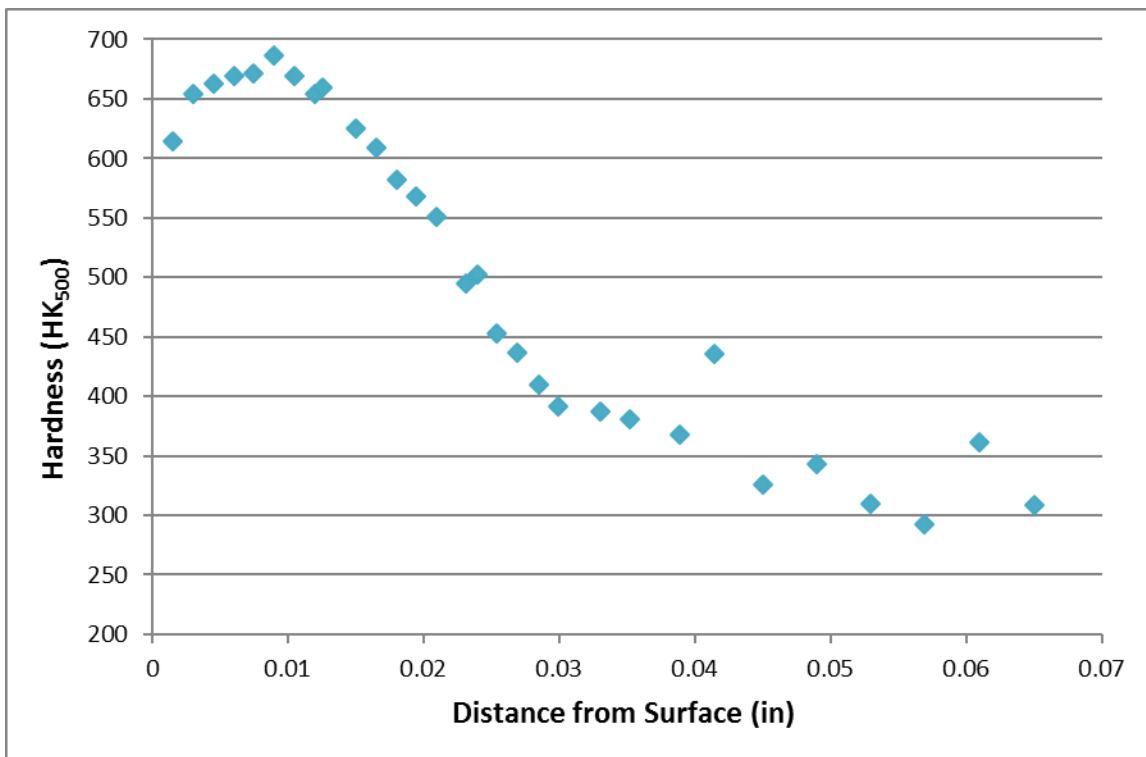


Figure 26 – Chart showing the microindentation hardness data (in HK₅₀₀) relative to surface depth (in inches) of the gear tooth valley cross section in Figure 23.