

NATIONAL TRANSPORTATION SAFETY BOARD

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



May 28, 2020

MATERIALS LABORATORY FACTUAL REPORT

Report No. 20-022

1. ACCIDENT INFORMATION

Place : Waterloo, Illinois
Date : March 12, 2019
Vehicle : Piper PA-32R-300, N750R
NTSB No. : CEN19LA098
Investigator : Tim Sorensen, AS-CEN

2. COMPONENTS EXAMINED

Remainder of the #6 cylinder assembly
Remainder of the #4 cylinder assembly
Remnants of #3 connecting rod and cap assembly
Rod cap remnants
Attachment bolt and nut remnants
Loose debris

3. DETAILS OF THE EXAMINATION

On March 12, 2019, about 1442 central daylight time, a Piper PA-32R-300 airplane was substantially damaged during a forced landing following a loss of engine power near Waterloo, IL.¹ The pilot sustained serious injuries one passenger sustained minor injuries, and the second passenger, a child restrained in a car seat, was not injured. The airframe sustained damage to the nose and forward fuselage, both wings, and empennage.

The last engine overhaul was in February 2008 with a total engine time of 4886.4 hours. The #4 cylinder was replaced in September 2012, 473.4 hours since the 2008 overhaul. The last engine inspection was performed in June of 2018, 944.5 hours after the aforementioned overhaul (5830.9 engine hours total). The total engine time at the accident was 5884.1 hours, which was 997.7 hours since the last overhaul and 53.2 hours since the last inspection.

An engine examination and teardown of the Lycoming IO-540-K1G5D (S/N RL-21770-48A) was performed at Feldpouch Aviation in Vandalia, IL, which was finished on

¹ The Piper PA-32R is a six-seat, high-performance, single engine, all-metal, fixed-wing aircraft produced by Piper Aircraft, headquartered in Vero Beach, Florida.

May 9, 2019.² According to the engine examination report summary, the #4 and #6 connecting rod components were found separated. A connecting rod cap was recovered from the engine, which was deformed and exhibited gouges consistent with secondary mechanical damage. In addition, a portion of a connecting rod cap common to an attachment bolt hole, a second rod cap fragment, two attachment bolt fragments, and two nuts were recovered loose within the engine. These component remnants were retained and sent to the NTSB Materials Laboratory for further examination.

Figure 1 shows the components from the engine, as received. These included the #4 and #6 cylinder assemblies, the #3 connecting rod and its adjacent components, loose connecting rod remnants, and smaller fractured pieces from the engine.

Figure 2 shows the remnants from the #3 connecting rod assembly. Submitted were the rod, cap, two attachment bolts, two nuts, and two bearings. The markings on the connecting rod web stated, "TW 8-5 75484". Relative to the other connecting rod remnants described below, the #3 rod and cap were relatively undamaged—there were no indications of gross plastic deformation or fracture surfaces.

Figure 3 shows the bearings from the #3 connecting rod assembly, viewed from the inside and outside surfaces. While the bearings did not exhibit any gross plastic deformation, there were no visible indications of wear or gouging on the inner surfaces, such as typified with scratching or material spalling. The wear patterns on the inner bearing surfaces showed clustered wear scars, consistent with localized contact and movement. On the exterior surfaces, one of the bearings exhibited three circular-shaped protrusions. These marks matched those on the #3 connecting rod bearing surface, as shown in Figure 4. These marks were consistent with material trapped between the external bearing and connecting rod surfaces.

Figure 5 shows the crankshaft sides of the #4 and #6 cylinder assemblies. These assemblies were intact on the upper portions (where the rockers, retainers, and upper stems of the valves were located), and had not yet been disassembled. The lower portions, facing the reader in Figure 5 through Figure 8, were open. The #6 cylinder flange was connected to a fractured remnant of the engine case (shown in the lower left in Figure 5 and Figure 6).

Both cylinder assemblies had their respective pistons lodged inside the cylinder cavity, and they were unable to be moved. As shown in Figure 5 and Figure 6, the lower skirts of both pistons exhibited gouging consistent with impact damage from smaller parts. The connecting rod remnants were still affixed to their respective pistons by piston pins. The rods could be readily rotated about the pins.

Figure 6 shows the connecting rods moved upward to reveal damage to the lower cylinder skirts. This damage, manifest as plastic deformation and cutting of a portion of the skirt, was proportional to the width of the connecting rods. As demonstrated in Figure

² The O-540 is a family of air-cooled six-cylinder, horizontally opposed fixed-wing aircraft and helicopter engines of made by Lycoming Engines, headquartered in Williamsport, Pennsylvania.

5, the connecting rods fit within the damaged grooves in the skirt flange. This damage pattern was consistent with the rods being forced against the cylinder wall skirt in a rapid manner or impact.

Figure 7 shows a closer view of the #6 cylinder, highlighting the #6 connecting rod bearing surface towards the respective crankshaft journal. On this connecting rod surface, there were no apparent fracture surfaces or areas of missing material. In addition, the bearing surface exhibited some circumferential wear scars and minor (< 0.04 inches or 1 mm deep) impact marks. As shown in Figure 7b, the lower face of the shank of the connecting rod had been inward, consistent with impact with the respective cylinder wall skirt.

Figure 8 and Figure 9 show the intact loose connecting rod cap remnant, from the inner bearing and outer surfaces, respectively. This cap was identified as being from the #6 connecting rod. As shown on the left in both figures, there was a remnant of the attachment bolt still in place in one of the cap bolt holes. The remnant was that of the bolt head. While intact (i.e., not through-fractured), the cap remnant had been flattened, exhibiting vertically-oriented tear marks on the outer surface (Figure 9). The inner (bearing) surface exhibited gouge marks and smearing, consistent with repeated impacts with an adjacent component.

The bolt remnant fracture surface exhibited smearing and deformation on the edges, consistent with post-fracture damage. The small undamaged portion of the bolt fracture surface, along the bolt centerline, exhibited a rough fibrous texture and dull luster. These features were consistent with overstress fracture of the #6 attachment bolt remnant.³

Figure 10 shows the #4 cylinder assembly remnant. As with the #6 cylinder, the cylinder wall skirt exhibited sharp impact damage, consistent with impact from the connecting rod shank face. The left side of the piston skirt in the figures exhibited an angled outward-oriented gouge mark, consistent with an impact in that direction from another component. There was also an upward gouge on the left side of the piston, consistent with the material being pushed upward in Figure 10b.

The #4 connecting bearing surface facing the reader in Figure 10a had fractured through the upper rod yoke. Much of the adjacent material to the connecting rod fracture surface exhibited a darker color and was plastically deformed back towards the bearing surface.

Figure 11 shows two pieces from the #4 connecting rod—one of the bearings and a remnant of the connecting rod cap. The bearing had been deformed exhibiting indications that it had been twisted. The remnant exhibited multiple impact and gouge marks, revealing the underlying copper-based layer. The fracture surface of the cap

³ D.J. Wulpi. "Characteristics of Ductile Fracture." *Understanding How Components Fail*, 3rd. ed. B. Miller, ed. Materials Park, OH: ASM International (2013) pp.102-105

remnant in Figure 11 had been obliterated—plastic deformation of the surface showed material pushed from the outer surface inward, bending over the absent fracture surface.

Figure 12 shows another connecting rod remnant, as well as two fractured pieces from an attachment bolt, along with two nut remnants. Much of the area of one of the remnant fracture surfaces displayed in Figure 12 had been obliterated by smearing, consistent with post-fracture damage. The opposite fracture surface is shown in Figure 13. This surface exhibited a rough-textured, layered fibrous morphology, with a dull luster. These features were consistent with overstress fracture of this remnant surface.

The mating fracture surfaces of the bolt shown in Figure 11 are highlighted in Figure 14 and Figure 15 from the head and nut sides, respectively. The upper fracture surface had been damaged consistent with post-fracture impact, but the lower mating fracture surface was relatively undamaged. This fracture surface exhibited two regions, one flatter and oriented perpendicular to the bolt direction, and an angled, protruding region. Flow lines ran from a damaged edge of the flatter portion towards the angled protruding region. Both regions exhibited a general dull luster and rough surface texture.

The bolt fracture surface was examined using a scanning electron microscope (SEM). Figure 16 shows the damaged edge on the flatter side, showing flow marks emanating from the edge. A closer view of the area revealed dimpled rupture, consistent with overstress fracture (see Figure 17). No features consistent with other fracture modes were found on the bolt. The features on the bolt fracture surface were consistent with overstress fracture in bending.

The #4 cylinder was disassembled, and the piston and connecting rod were removed. The bearing surface of the rod was sectioned 1.25 inches from the bearing surface using an abrasive saw. This rod section is highlighted in Figure 18 from the bearing surface and the side. As shown in Figure 18b, the rod yoke had fractured approximately 0.75 inches from the mating cap surface. The opposite yoke side, shown on the right in Figure 18b, exhibited some outward material deformation, consistent with inward bending of the side (towards the left in the figure).

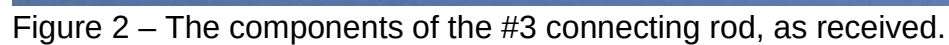
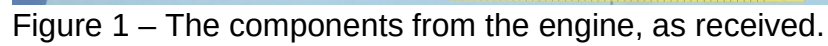
The fracture surface of the sectioned #4 rod is shown in Figure 19, after sectioning and cleaning using acetone. The fracture surface exhibited a banded morphology, with the bands parallel to the outer surface contour. The upper portion of the fracture surface was adjacent to protruding lips. The lower edge exhibited areas of blocky regions, with vertically oriented marks (see Figure 20). This area was examined using a SEM.

Figure 21 shows the edge of the rod fracture surface, revealing a generally rough texture, along with an upward-oriented mottled region in the upper half of the figure. A closer view of the blocky area along the edge revealed it to be an area of missing material (Figure 22). Repeating horizontally tears were present, oriented parallel to the outer rod surface contour. A closer view of this area, shown in Figure 23, revealed dimpled rupture, consistent with overstress fracture. No features consistent with other fracture modes were found in this area of the fracture surface.

The right side of the fracture surface in Figure 19 was examined using a SEM and is shown in Figure 24. The surface exhibited multiple divots or depressions in the fracture surface. As shown in Figure 25, a closer view of this divots revealed them to be ovoid-shaped tears perpendicular to the fracture surface. The only fracture feature observed in this area was dimpled rupture, as typified in Figure 26.

The upper portion of the undamaged rod fracture surface near the protruding lip was examined, as shown in Figure 27. This region exhibited similar characteristics as those examined closer to the exterior edge of the fracture surface. Examination of this portion of the fracture surface revealed dimpled rupture, as typified in Figure 28. No other features consistent with other fracture modes or pre-existing defects were found on the undamaged fracture surfaces of the #4 connecting rod or cap remnants. All other surfaces had been obliterated by post-fracture damage.

Erik M Mueller
Materials Research Engineer



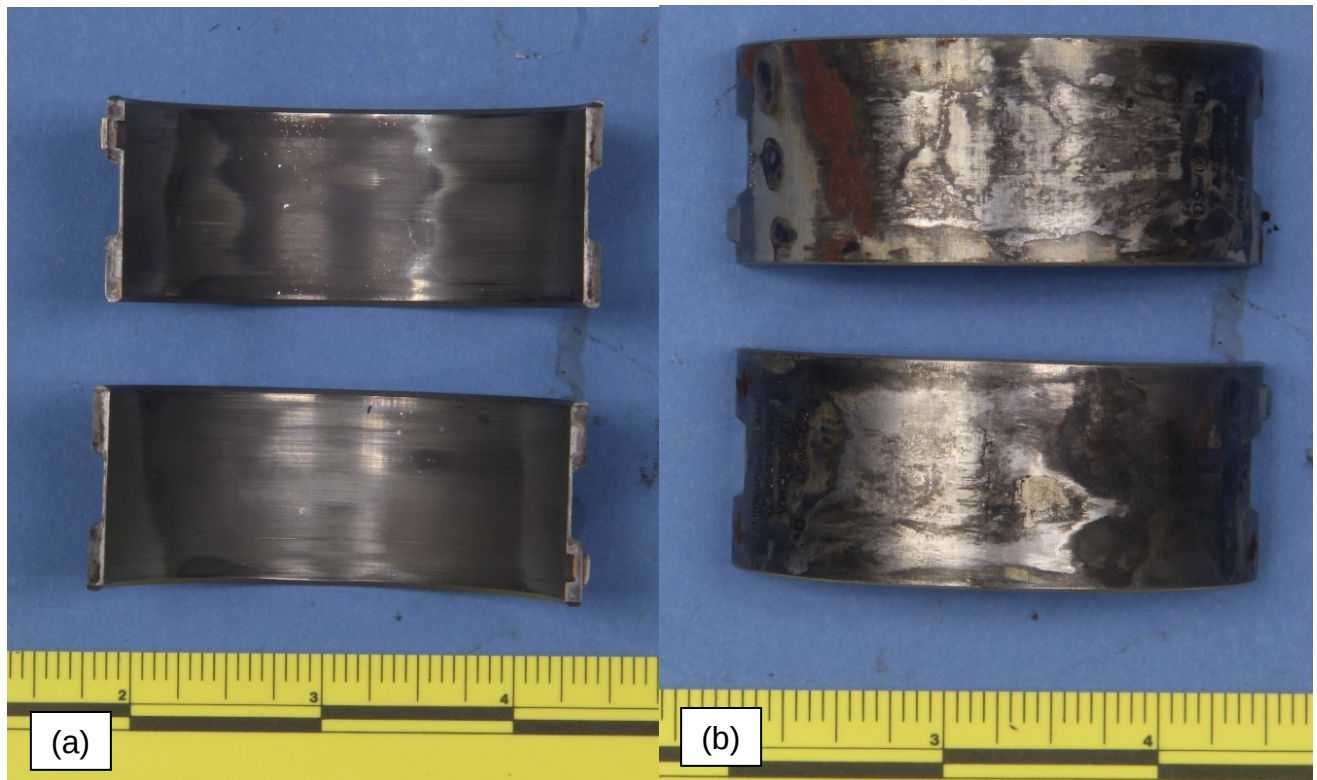


Figure 3 – The (a) inner and (b) outer surfaces of the #3 bearing.



Figure 4 – View of the mating bearing surfaces of the #3 connecting rod surface and the outer bearing surface, showing three matching marks (courtesy Tim Sorensen, AS-CEN).



Figure 5 – View of the connecting rod sides of the cylinder assembly remnants from the #4 and #6 cylinders.



Figure 6 – View of the connecting rod sides of the cylinder assembly remnants from the #4 and #6 cylinders, with the rods moved upward from Figure 4, showing cylinder damage.

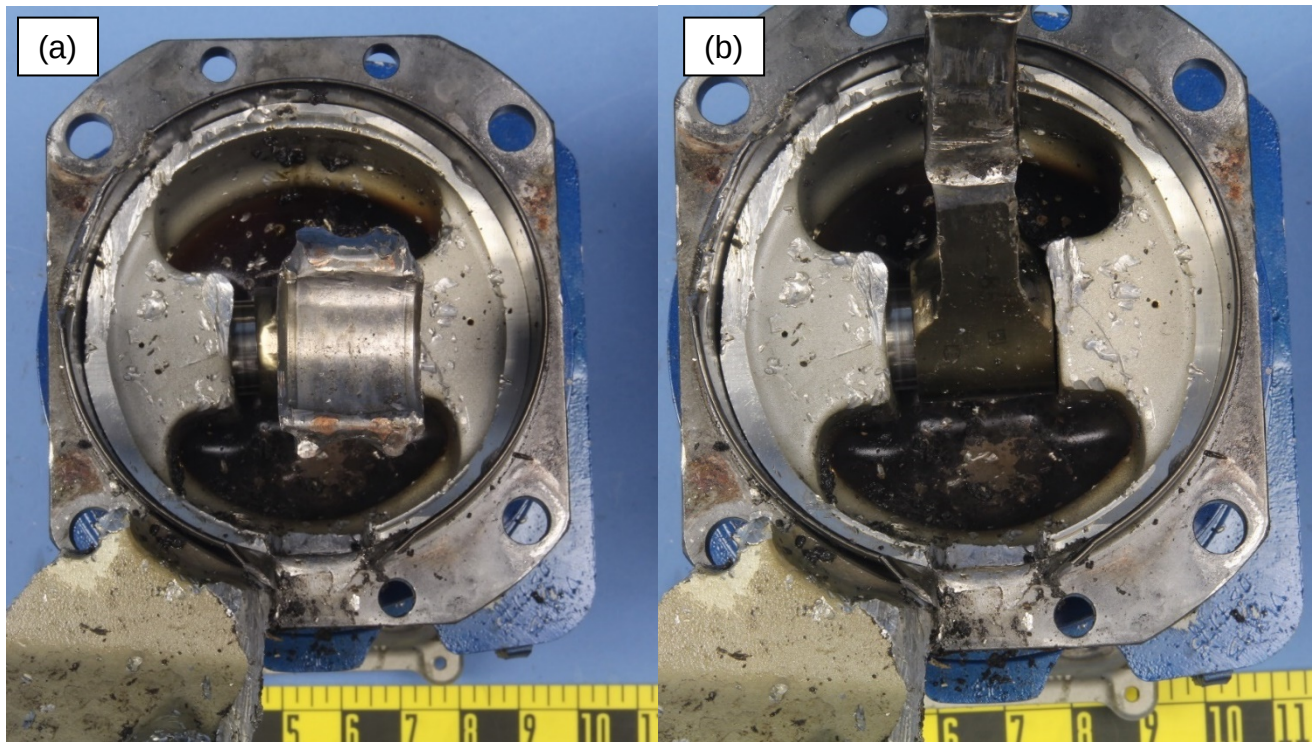


Figure 7 – Closer views of the #6 position assembly remnants showing (a) the rod bearing surface and (b) the rod moved to show the impression in the cylinder wall.



Figure 8 – View of the loose and intact #6 connecting rod cap remnant from the inside surface.



Figure 9 – View of the loose and intact #6 connecting rod cap remnant from the outside surface. There was a bolt remnant in the cap remnant.

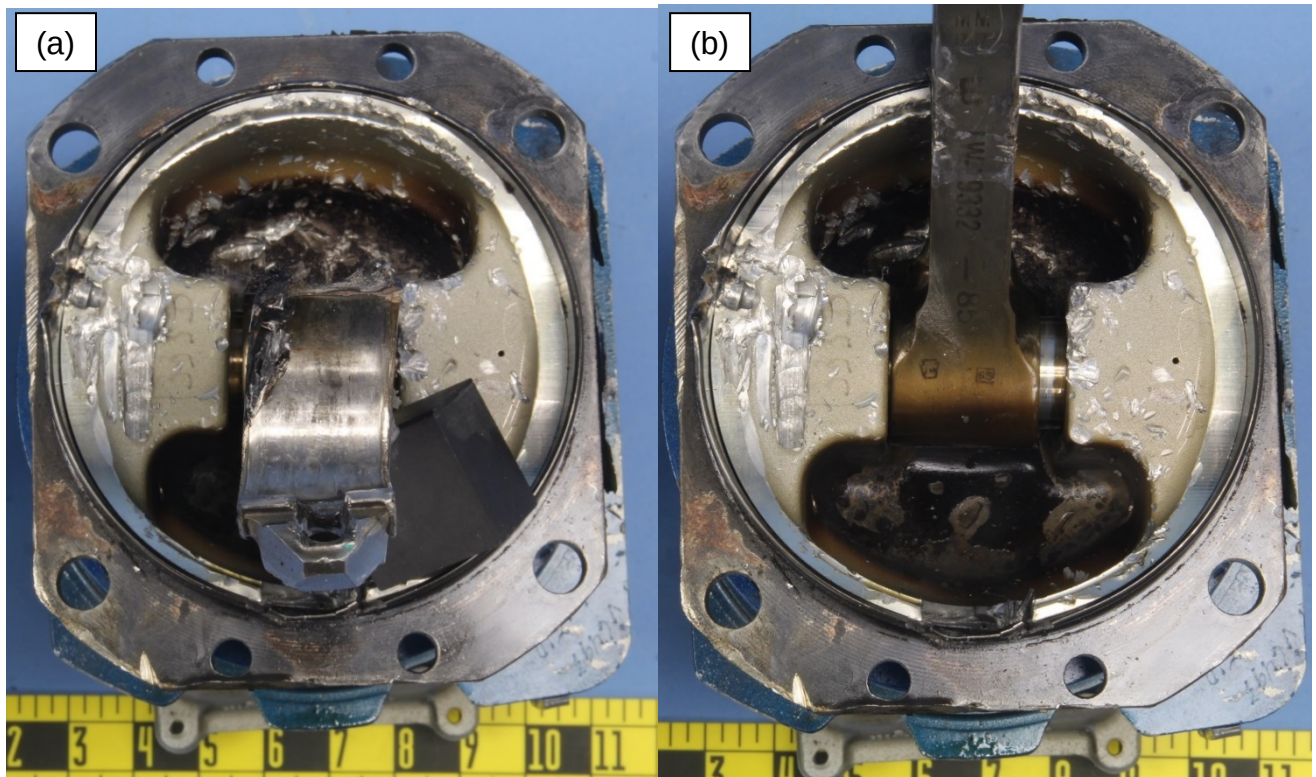


Figure 10 – Closer views of the #4 position assembly remnants showing (a) the rod bearing surface and (b) the rod moved to show the impression in the cylinder wall.



Figure 11 – Remnants of the #4 bearing and a cap fragment viewed from (a) the inner and (b) outer surfaces.



Figure 12 – Remnants of the #4 connecting rod cap, with remnants of an attachment bolt and two nuts.



Figure 13 – View of the undamaged area of the fracture surface from the remnant in Figure 12.



Figure 14 – View of the upper mating face of the bolt fracture surface.

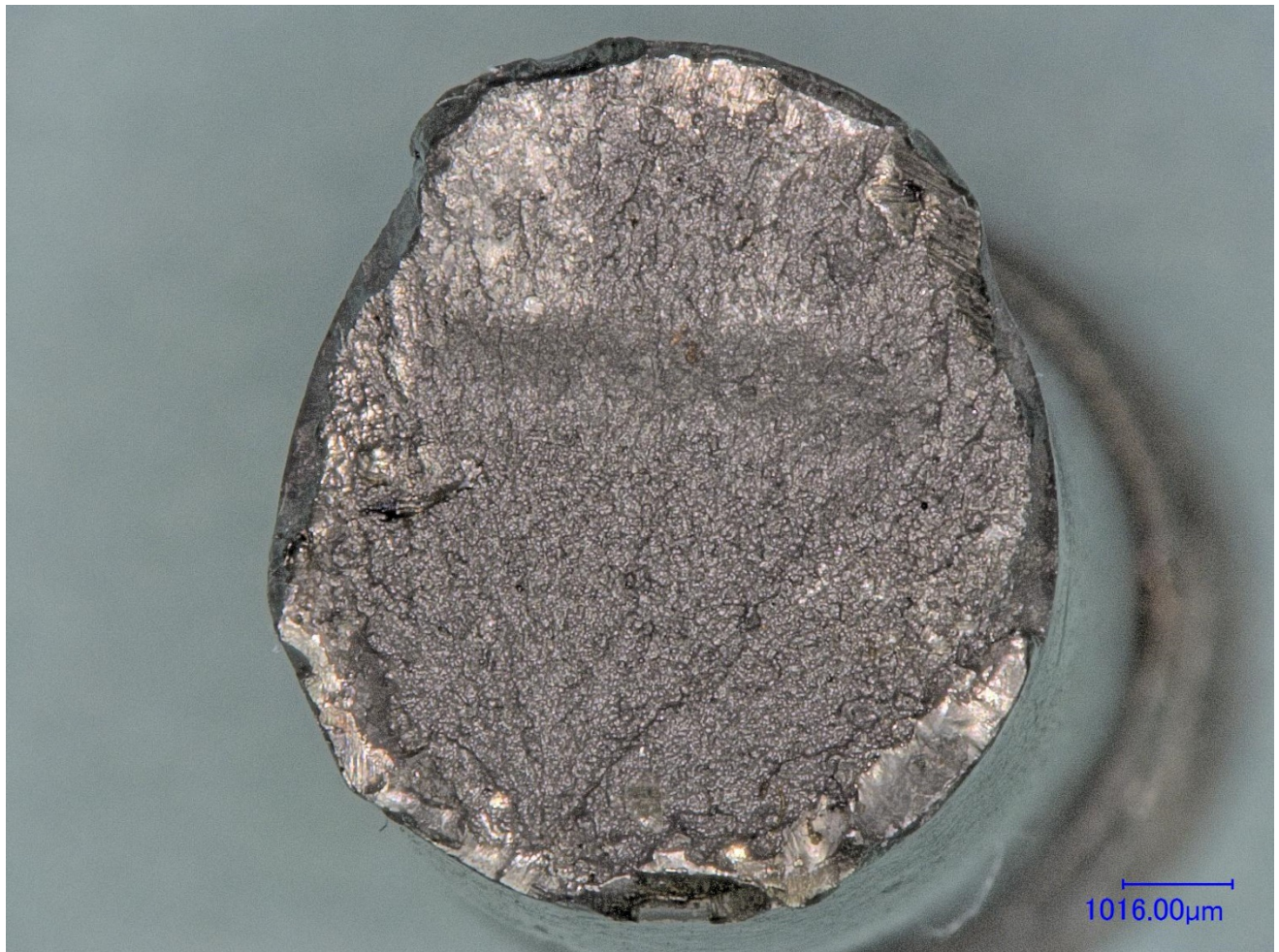


Figure 15 – View of the lower mating fracture surface of the fractured attachment bolt.

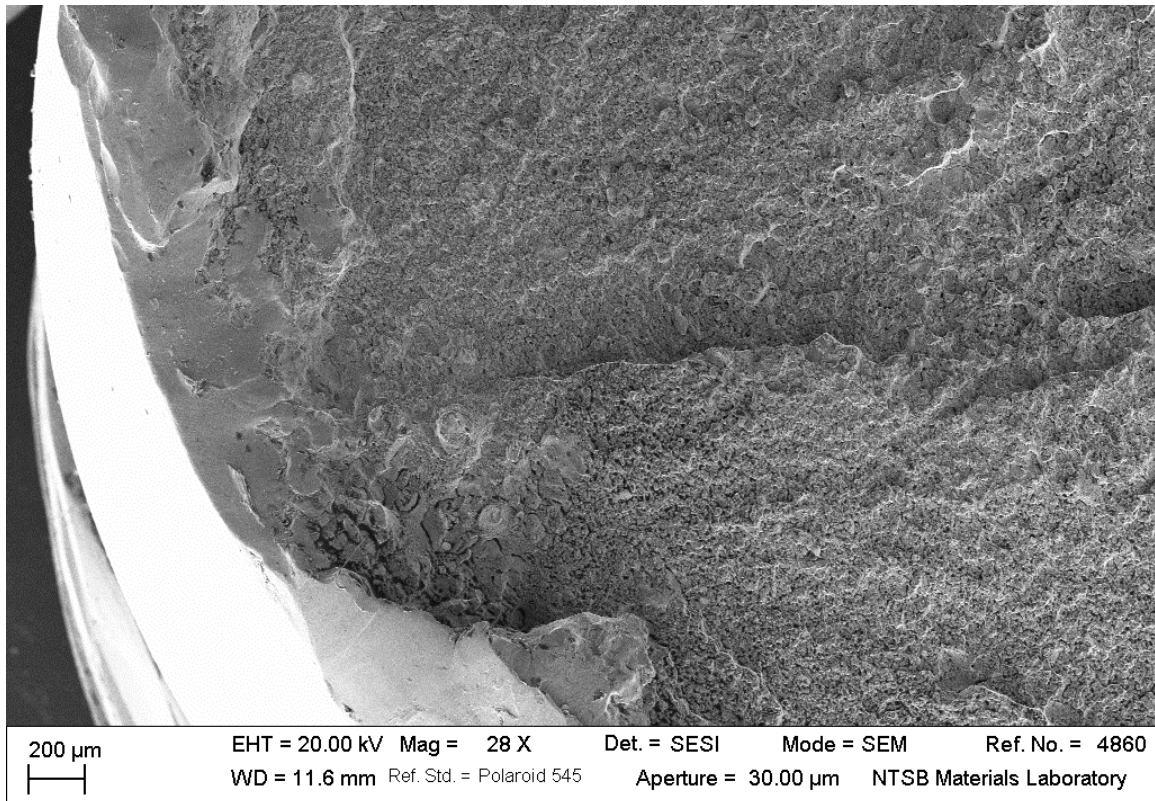


Figure 16 – Secondary electron (SE) micrograph of the beginning of the bolt fracture surface.

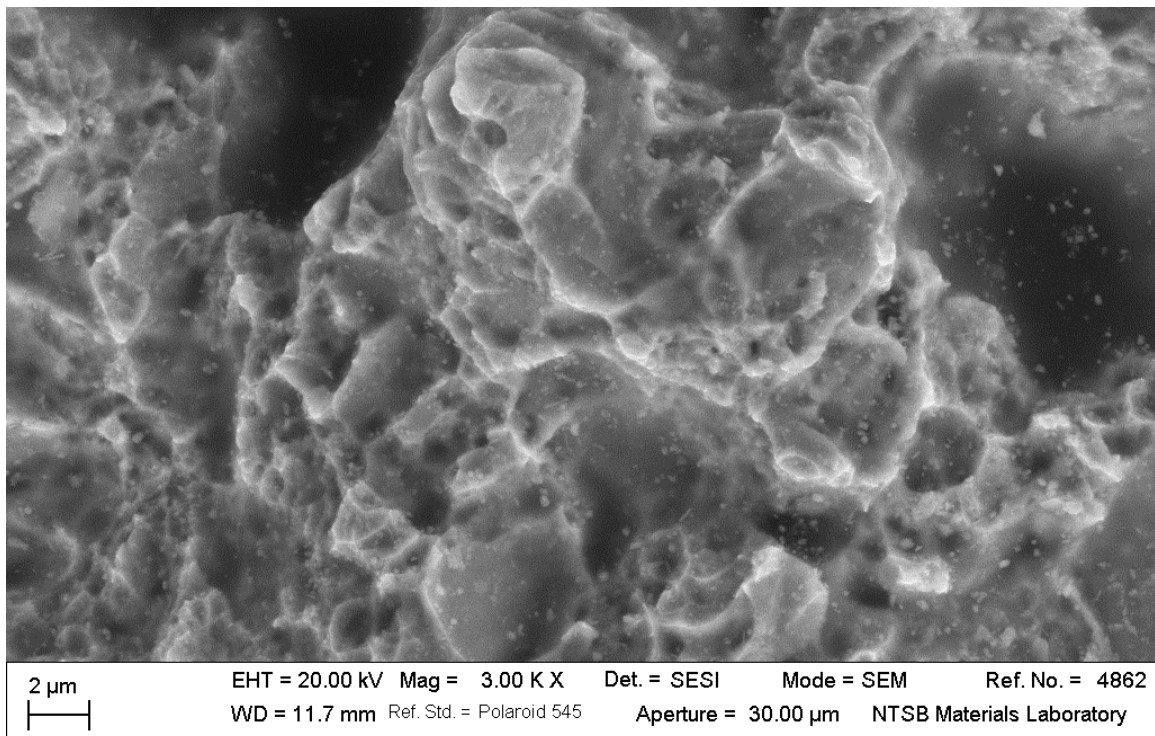


Figure 17 – SE micrograph of a closer view of the bolt fracture surface, showing dimpled rupture.

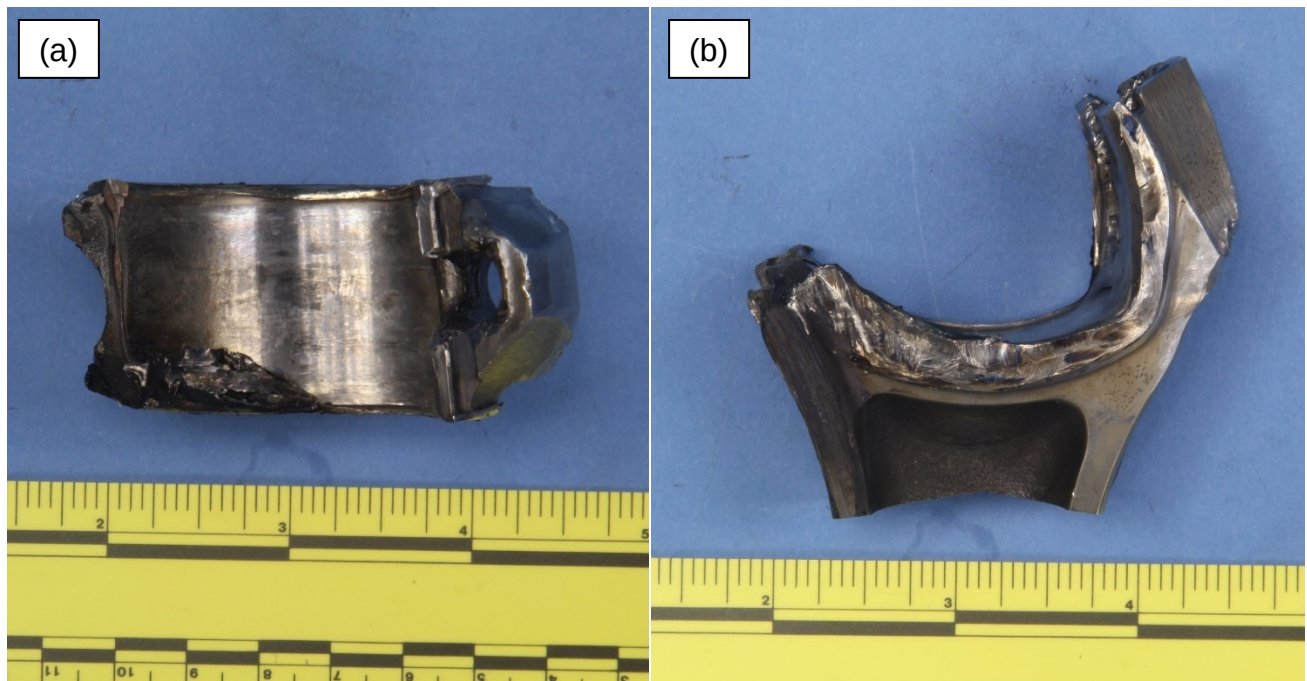


Figure 18 – The sectioned #4 sectioned connecting rod crankshaft-side bearing surface, after sectioning and viewed from (a) the bearing surface and (b) the side.



Figure 19 – View of the less damaged area of the fracture surface of the #4 connecting rod.

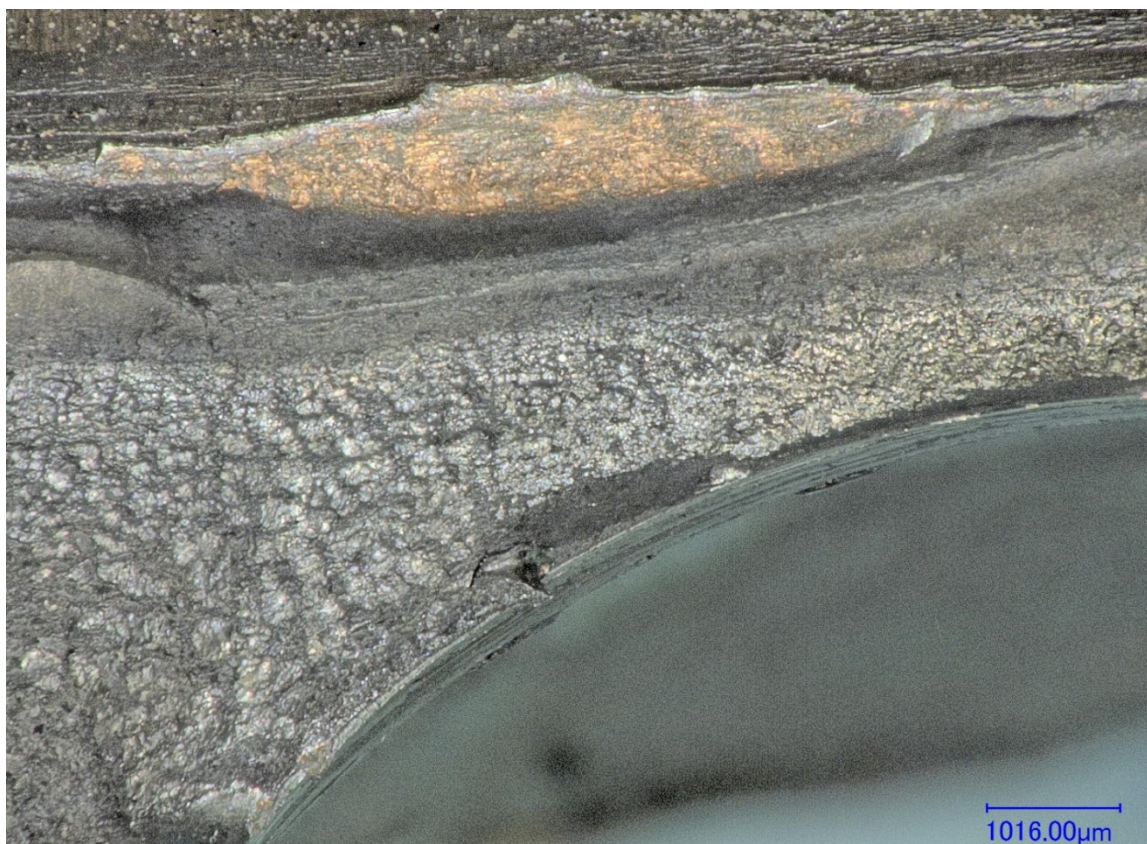


Figure 20 – Closer view of the #4 connecting rod surface in Figure 19.

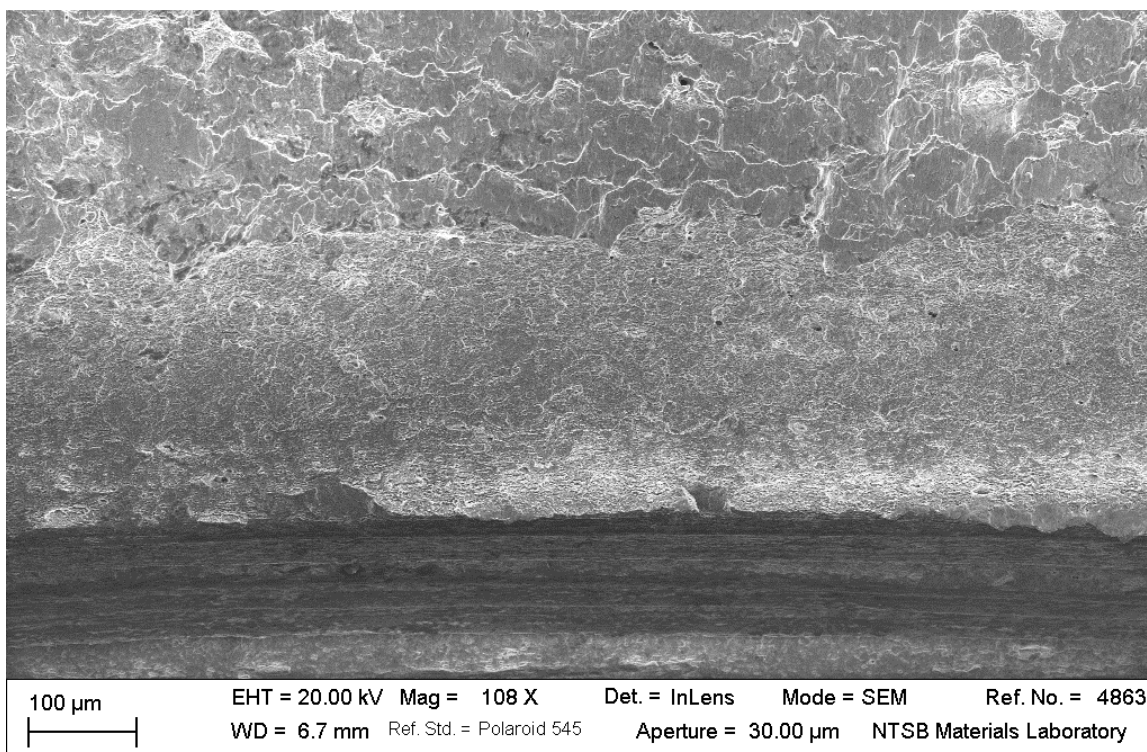


Figure 21 – SE micrograph of a portion of the #4 rod fracture surface edge.

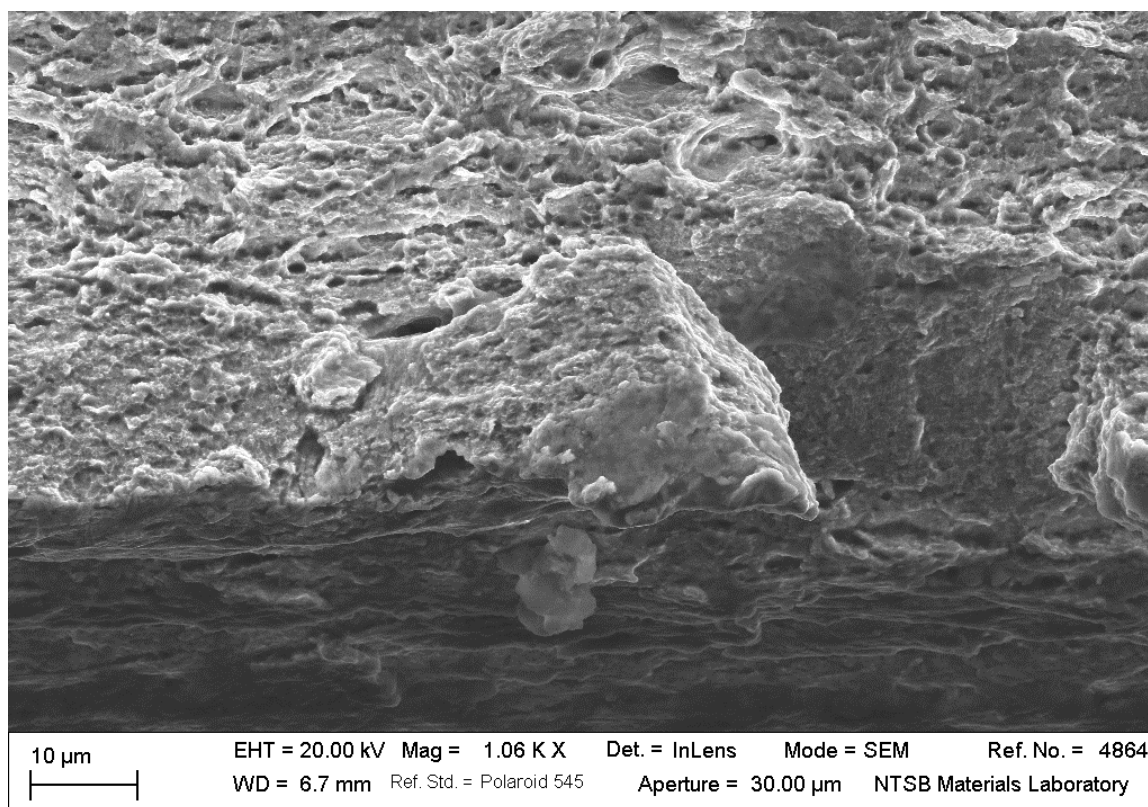


Figure 22 – SE micrograph of a closer view of the stepped edge in Figure 21.

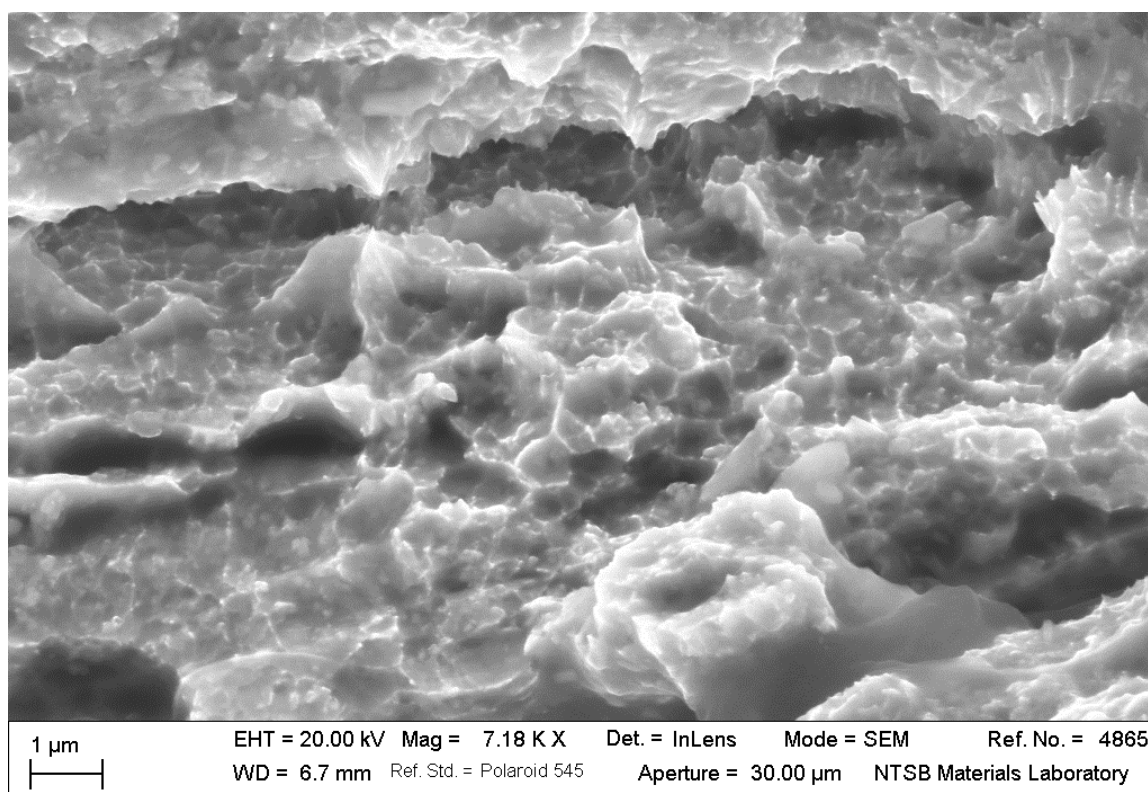


Figure 23 – SE micrograph of edge dimpled rupture of the #4 rod fracture surface.

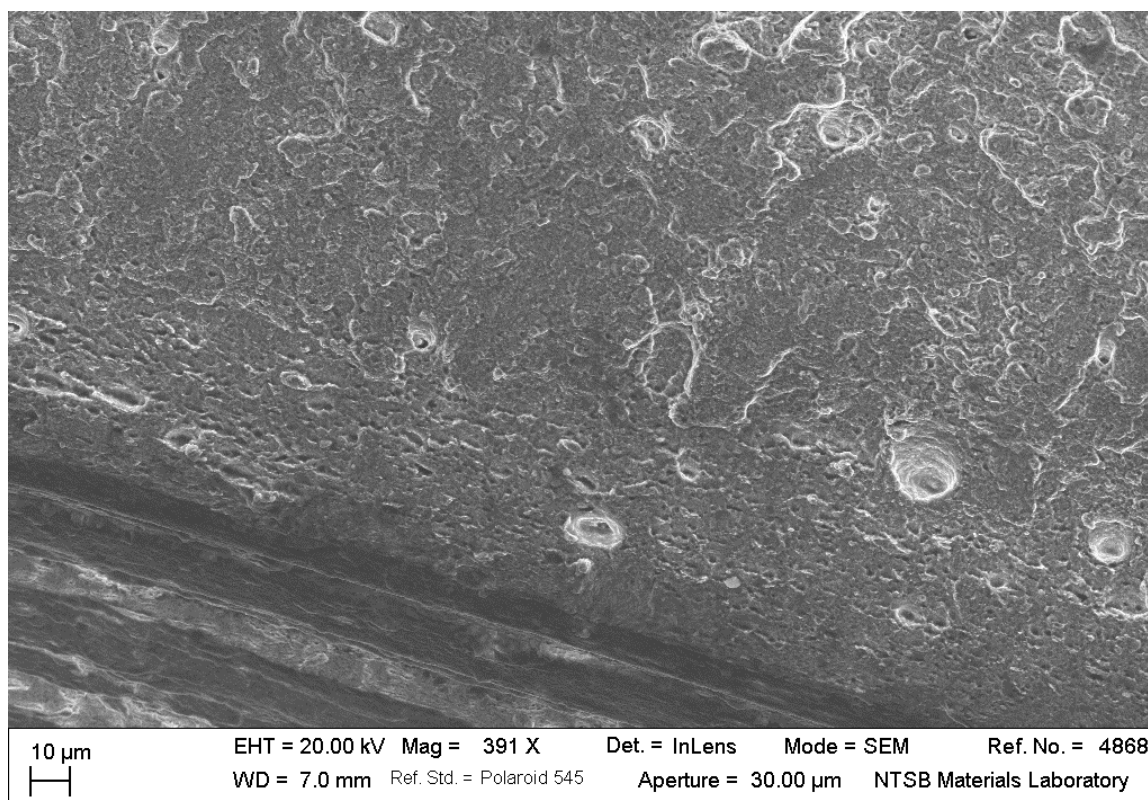


Figure 24 – SE micrograph of the other side of the #4 rod fracture surface.

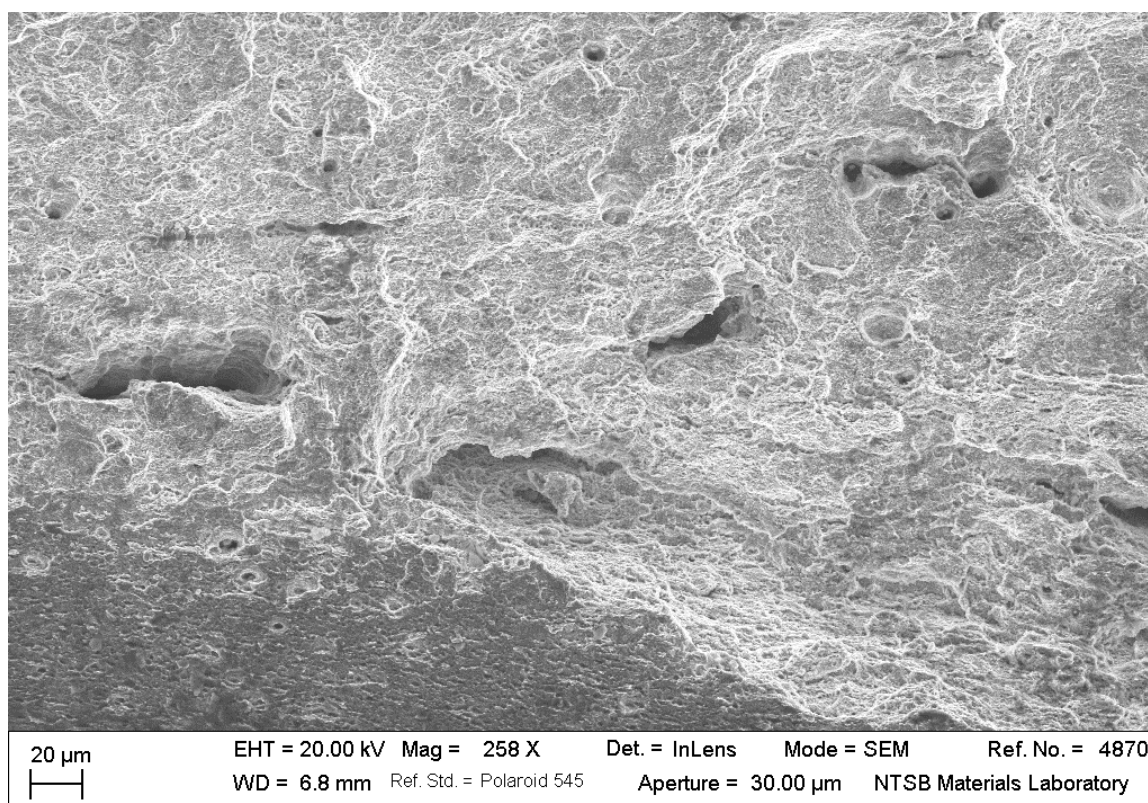


Figure 25 – SE micrograph of divot-shaped tears in the #4 rod fracture surface.

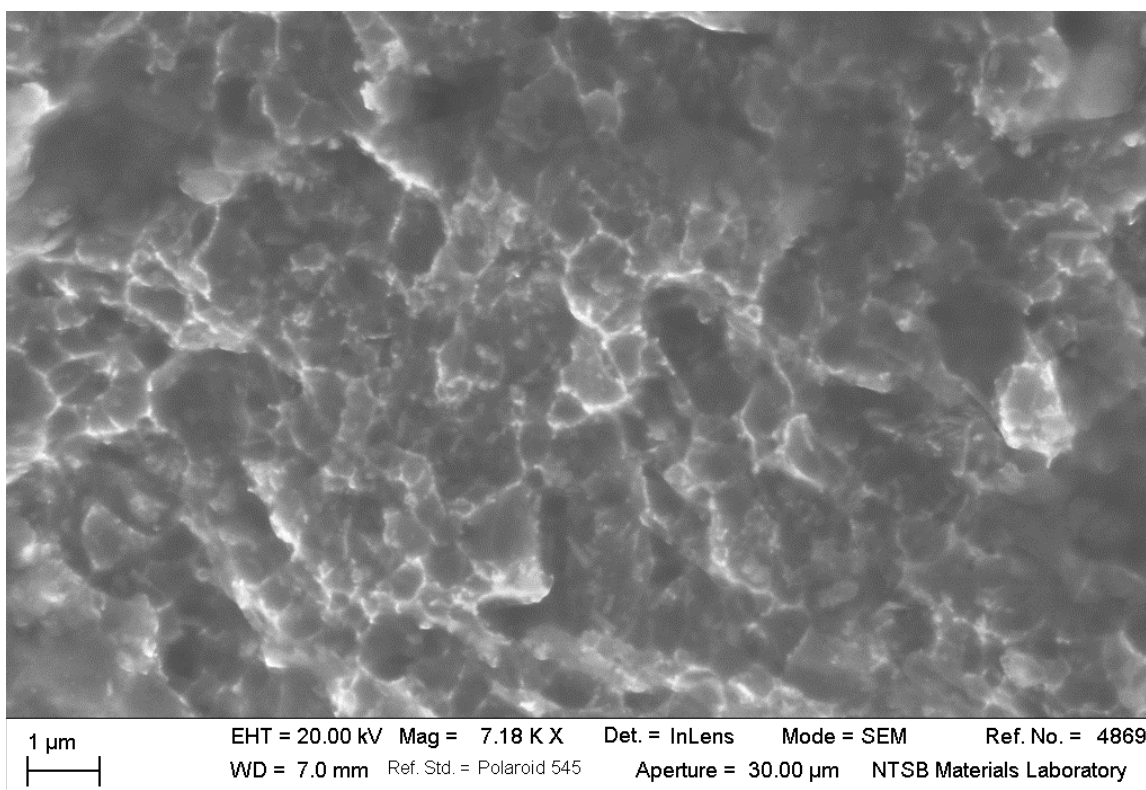


Figure 26 – SE micrograph of dimpled rupture in Figure 25.

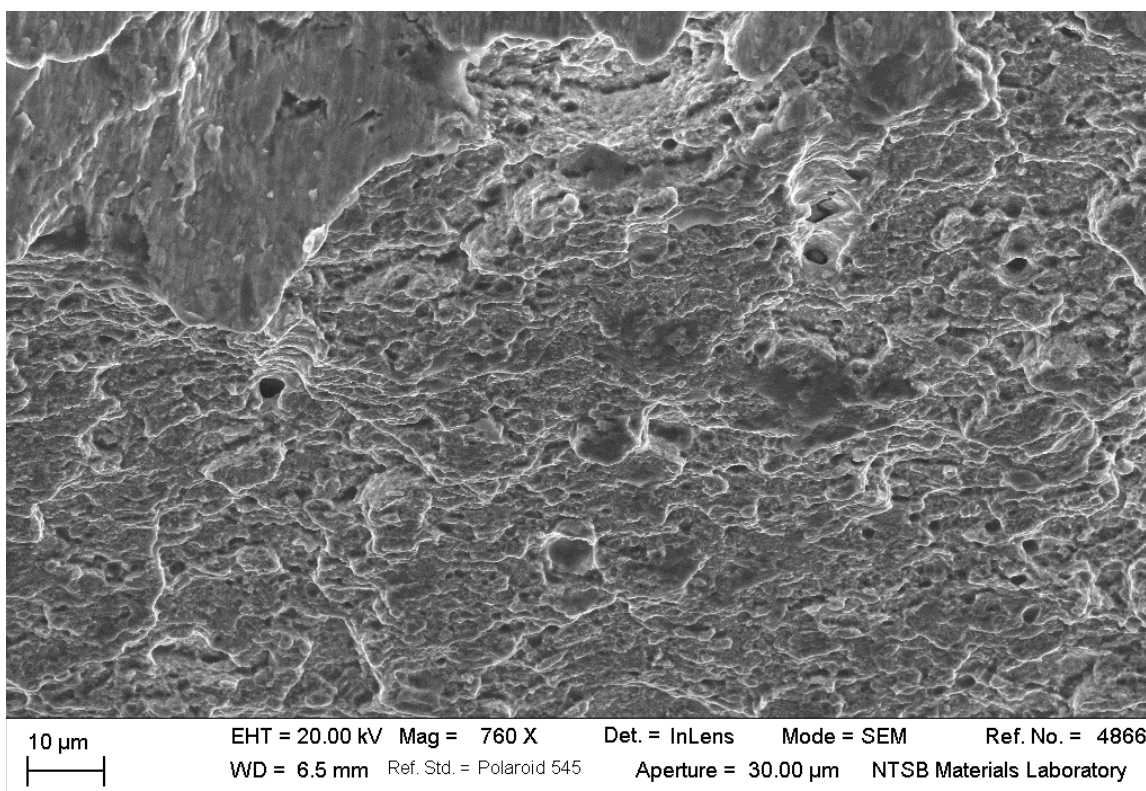


Figure 27 – SE micrograph of the innermost part of the #4 rod fracture surface.

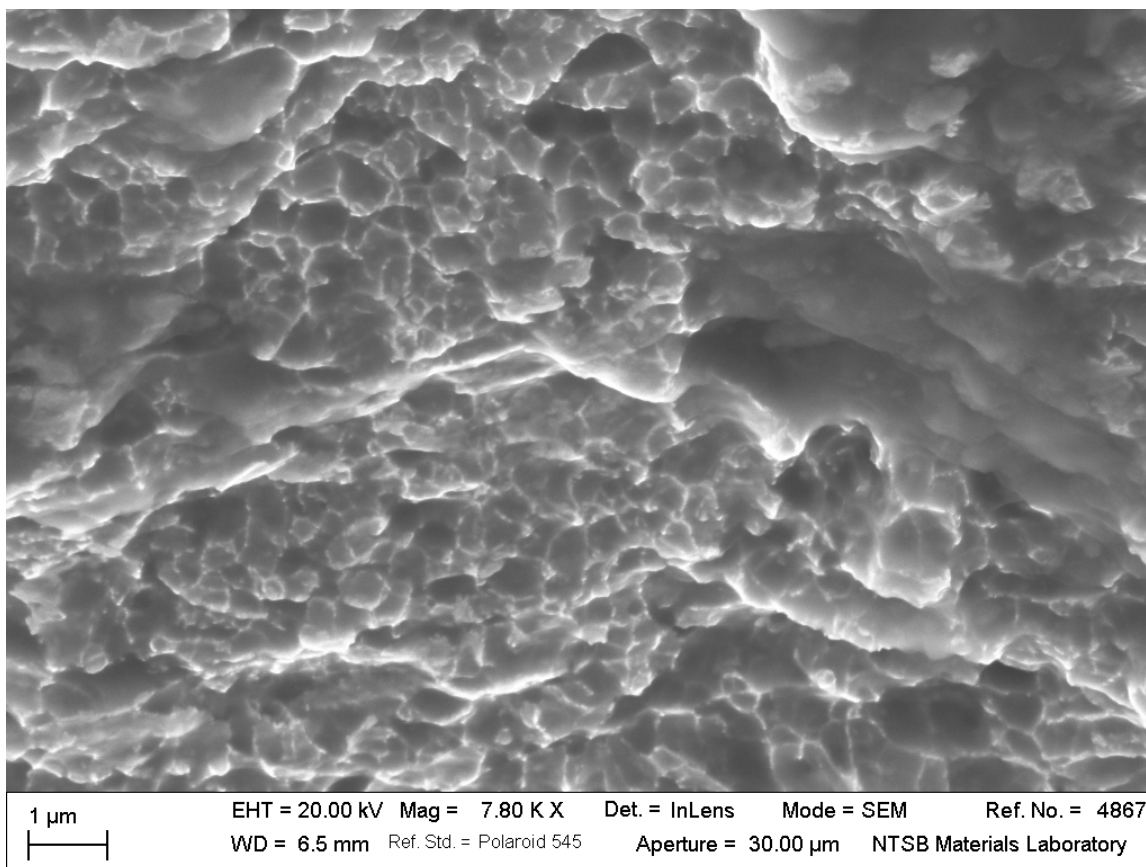


Figure 28 – SE micrograph showing a closer view of dimpled rupture from Figure 27.