

NATIONAL TRANSPORTATION SAFETY BOARD

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



January 7, 2020

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-081

1. ACCIDENT INFORMATION

Place : Georgetown, South Carolina
Date : September 22, 2018
Vehicle : Beech V35, N435RB
NTSB No. : ERA18LA258
Investigator : Leah Read, AS-ERA

2. COMPONENTS EXAMINED

Pilot's left-hand rudder pedal lower arm sections
Rudder pedal push rod tube
Forward rudder control pulley with fractured pieces
Forward rudder pedal bellcrank

3. DETAILS OF THE EXAMINATION

On September 22, 2018, about 1515 eastern daylight time, a Beech V35 airplane was substantially damaged when it collided with trees on landing at the Georgetown County Airport in Georgetown, SC. The flight instructor and the private pilot sustained minor injuries. The airplane was registered to and operated by DAH Aircraft LLC. According to the flight instructor, the airplane began to yaw and roll to the right without pilot input. The instructor was able to maintain some control of the airplane by applying the left rudder, left aileron, and forward elevator pressure. During landing, the instructor noted the yaw increasing to the right as the speed decreased. As the airplane slowed over the runway, it drifted to the right onto the grassy area adjacent to the runway. After touching down, the airplane veered to the right and collided with trees, resulting in substantial damage to the fuselage and wings.

The pilot stated he heard a "pop" and felt a "bump" in the airplane, after which the instructor then noticed a flight control problem and announced that he was keeping the controls. The pilot looked out the window and noticed the control surface of the right ruddervator was not moving. The airplane wreckage was retained for further investigation.

Figure 1 shows the components from the rudder control system, as received by the NTSB Materials Laboratory. The components included a bellcrank, a control pulley, push rod tube, and a lower arm. The pulley and arm assemblies had fractured in multiple

locations. The push rod bolt still had a portion of the lower arm clevis attached to the forward attachment bolt.

Figure 2 shows a reconstruction of the push rod and the lower arm from the left-hand rudder. The clevis of the lower arm had attached to the forward side of the push rod tube assembly, as shown in Figure 2. The outboard clevis remnant of the arm was still attached with a bolt and nut. The outboard clevis remnant had fractured at the corner. The inboard clevis had fractured in three locations. The push rod tube, as depicted in Figure 3, did not exhibit any indications of damage. The fisheye bearings on both the forward and aft sides of the push rod tube assembly were able to be moved and did not exhibit any contamination or corrosion.

Figure 4 through Figure 7 show the fractured pieces of the clevis fragments that were not attached to the push rod bolt, positioned in their respective places on the pedal arm main remnant. The inboard clevis had fractured radially about the bolt hole in three locations. In contrast, the outboard clevis had fractured at the corner with the pedal body. The inside surfaces of the inboard clevis fragment exhibited missing paint, as shown in Figure 4. The bolt hole surfaces of these pieces also exhibited some wear, consistent with rubbing against the mating bolt shank.

As shown in Figure 7 and Figure 8, the inboard clevis fragment fracture surfaces, and the mating inboard fracture surface on the pedal arm, exhibited a dark color. This was in contrast to the lighter, shiny fracture surfaces of some of the fractures on the pedal arm, and the outboard clevis fragment, shown in Figure 9.

As shown from the slant toward the outboard direction on the outboard clevis fracture on the pedal arm (Figure 8) and the fractured clevis (Figure 9a), the direction of fracture was consistent with bending toward the outboard direction. In examining the fracture surfaces, no indications of plastic deformation or localized ductility were observed. The material adjacent the fracture surfaces was not deformed, consistent with a lack of ductility at fracture of the pedal arm.

Figure 10 shows the outboard side of the fractured clevis locations. The intact clevis piece that fractured exhibited a slant with the fracture surface facing outboard (see Figures Figure 8 and Figure 10). These features were consistent with the intact clevis piece having fractured in an outboard bending direction.

Figure 11 shows the side bore of the smallest fractured clevis fragment from the inboard side. The bore surface exhibited cracking, consistent with the radial orientation of the fracture surfaces on the left and right in the figure. Figure 12 shows one of the fracture surfaces of the fragment. Half of the fracture surface exhibited a shiny appearance, while the other half exhibited a darker color. Figure 13 shows a closer view of the divide on the fracture surface. Both sides were rough with high peaks and valleys. The shiny region of the fracture surface exhibited some flat facets, which were light blue in color.

The fracture surfaces of the clevis fragments were examined using a scanning electron microscope (SEM). Figure 14 shows a typical area of one of the fracture surfaces. The surface was tortuous with varied heights. The surface exhibited areas with rounded features and sharper jagged areas.

Figure 15 shows some of these sharper features. They consisted of cleavage steps with localized tearing (right side on Figure 15). These features were consistent with fracture of the microscopic precipitates and secondary phases typical of a casting. The fracture surface also exhibited fine dimple rupture features (Figure 16). These features were consistent with ductile overstress fracture of the matrix constituent of the microstructure of the arm.

Figure 17 shows a closer view of the rounded features of the fracture surface. These regions typically consisted of deep valleys containing nonconductive material—this material charges in an electron microscope, leaving under- or overexposed areas in micrographs taken with an SEM. Figure 18 shows a closer view of the rounded features. The surfaces typically exhibited a nonconductive (or less conductive) layer. This surface layer exhibited branched microcracking along the surface. The rounded features were consistent with the surfaces of dendrites from the initial casting process. The microcracked surface material on these layers was consistent with surface oxide that formed during the casting process.

Figure 19 shows the side of one of the fractured clevis fragments, from the inside bore of the bolt hole. As illustrated in the figure, multiple cracks were open to the surface. These cracks were radial in orientation and were parallel to the fracture surface (left in the figure).

One of the fragments was vacuum mounted, polished, and etched. Figure 20 shows a typical cross section of this fragment, oriented with the fracture surface pointing downward in the figure. The figure shows a tortuous fracture surface. The light and darker colors were consistent with microstructure constituents of the clevis casting. The darker regions were areas with non-conductive material or empty space that had filled with epoxy during the mounting process. Figure 21 shows a closer view of the fracture surface. As shown in the figure, there were large gaps in the interdendritic regions, consistent with shrinkage voids from incomplete casting. Figure 21 also shows cracks emanating from these voids and interdendritic regions.

Figure 22 shows the mounted and polished clevis specimen as viewed using a scanning electron microscope at low magnification. This cross section showed voids as large as 1.2 mm (0.05 inches). Figure 23 shows a typical pore in the interdendritic region. This area was examined using energy dispersive x-ray spectroscopy (EDS) in mapping mode (x-ray maps). The composition of the clevis casting was inspected using EDS probes. The composition was consistent with a magnesium casting alloy, such as AZ91.

Some of the results of the mapping are depicted in Figure 24. In these figures, areas that are white were absent a particular element and areas that were colored exhibit higher

amounts of that element. As shown in the figures, areas outside the pore were high in magnesium (Mg), and areas inside the pore were high in carbon (C). The areas of the casting surrounding the pore were higher in oxygen (O), consistent with a magnesium oxide (MgO) layer. Figure 25 shows a closer view of the MgO layer surrounding a pore. As shown in the figure, small cracks were present emanating from the pore and surrounding oxide layer.

According to the part drawing for the pilot's rudder pedal lower arm (P/N 35-524300), the part was to be made from a rough casting (drawing 35-524143-999). That drawing stated that the part was to be made from a rough sand casting of AZ91 magnesium alloy per QQ-M-56, with a "TEMPER-HTA." This casting was to be straightened at the foundry, with a "radiographic and/or visual inspection." Afterward the arm was machined, the part was to be corrosion proofed per AN-M-12, Type III, which is a dichromate treatment.

Overall, the fracture features observed were consistent with fracture of the clevis from cracks and voids created during the casting process. The presence of voids, cracks, and oxide layers would reduce the cross-sectional area that could withstand the force applied over the pedal arm clevises. Once a high enough load input was applied to the pedal arm, the remaining material fractured in overstress.

Figure 26 and Figure 27 show the bellcrank assembly, as received. The bellcrank was intact, with no discernible fractures or cracks. Figure 28 shows the rudder cable tracks for the bellcrank. As shown in this figure, there were angled depressions along the cable groove. These were consistent with the adjacent cable being impressed into the groove paint while static (not moving or sliding).

Figure 29 shows the rudder control pulley, viewed from the flange that had fractured in multiple places. These fracture surfaces were slanted downward at an angle, with the fracture surface facing away from the pulley cable groove (Figure 30). The fracture surfaces exhibited river marks and hackles which fanned out away from the cable groove. These features were consistent with the pulley flange being bent outward, and the groove fracturing in multiple locations from overstress.

Erik M Mueller
Materials Research Engineer



Figure 1 – The components from the pilot rudder system, as received.



Figure 2 – The pilot left pedal from the outboard side, repositioned with the push rod tube to show placement of the fractured clevis attached to the rod bolt.

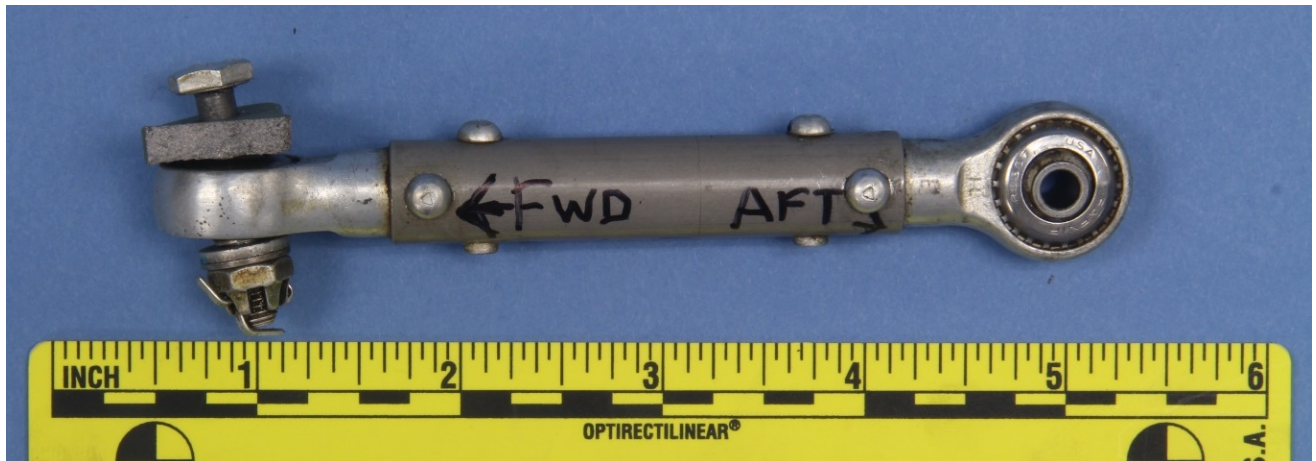


Figure 3 – The push rod tub, viewed showing the fractured clevis from the pedal lower arm.



Figure 4 – The left pilot pedal arm from the outboard side, with the pieces of the fractured clevis positioned in their placement at fracture.



Figure 5 – The fractured pieces of the left pilot pedal arm from the inboard side.



Figure 6 – The fractured pieces of the left pilot pedal arm from the aft side.



Figure 7 – View of the fractured clevis fracture surfaces, positioned to face the reader.



Figure 8 – The left pilot pedal arm from the forward side, tilted to show the clevis fracture surfaces.



Figure 9 – View of the whole fractured clevis from (a) the side and (b) the fracture surface.

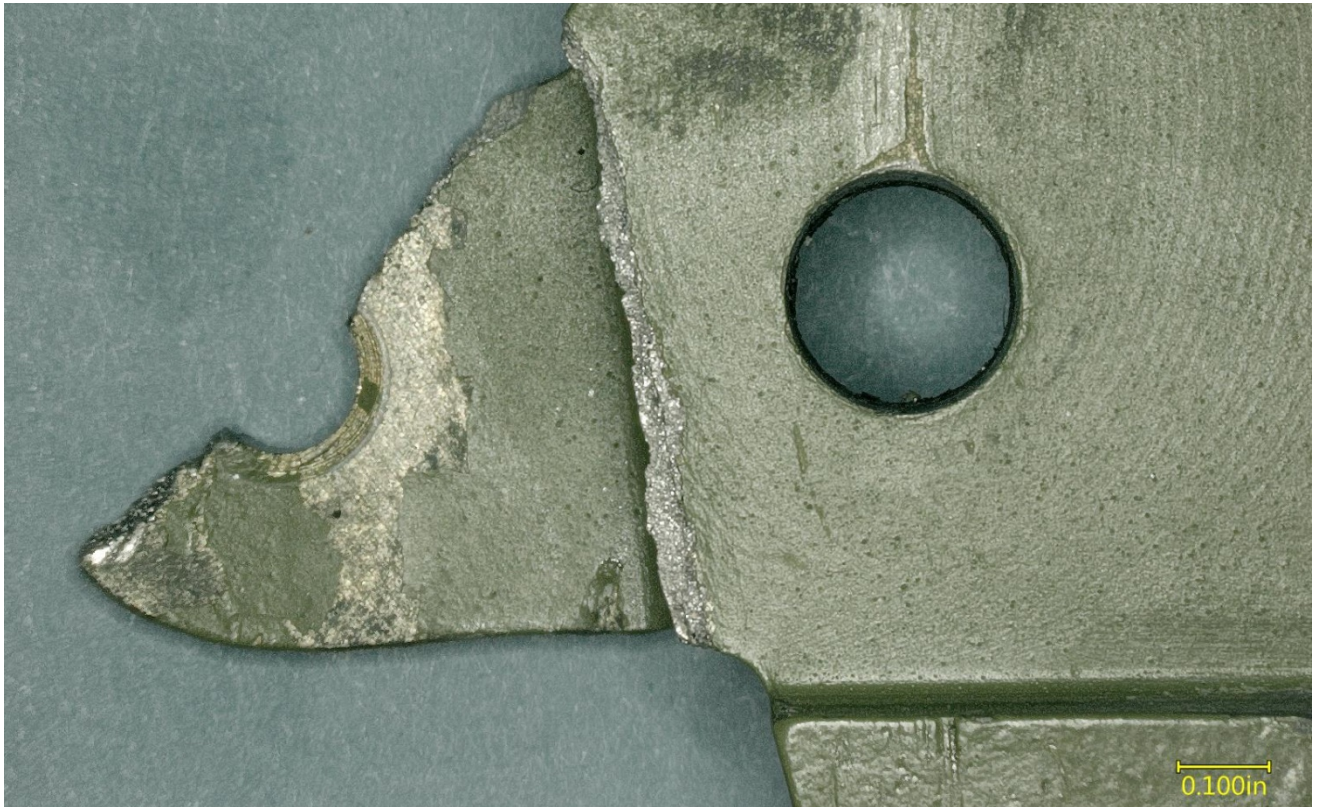


Figure 10 – Closer view of the fractured clevises from the outboard side.

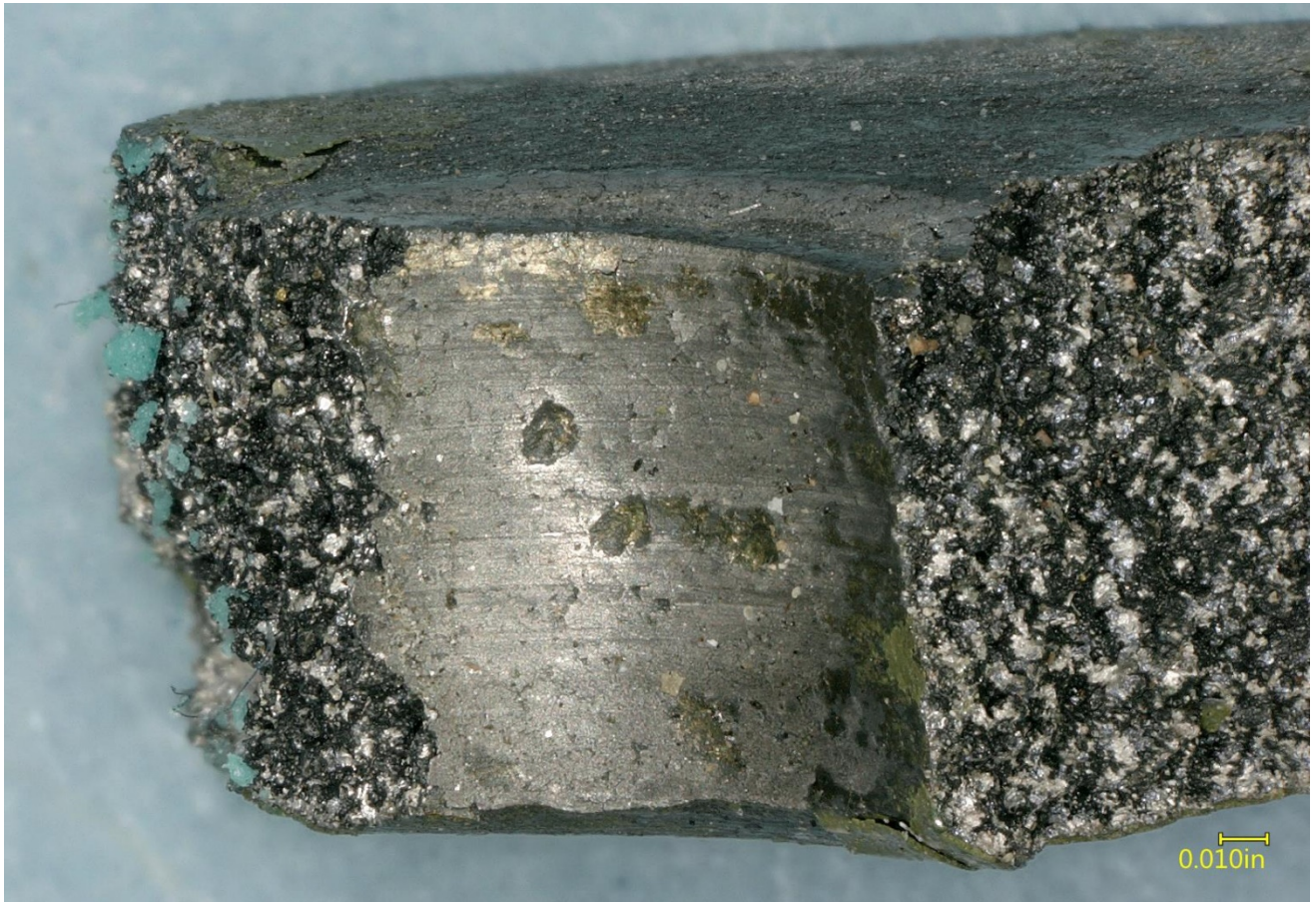


Figure 11 – View of the bore hole of the smallest clevis fragment, showing cracking and missing material.



Figure 12 – Flat view of the fracture surface of the clevis fragment in Figure 11, showing dark and light regions.



Figure 13 – Closer view of the fragment fracture surface, showing a dark surface material.

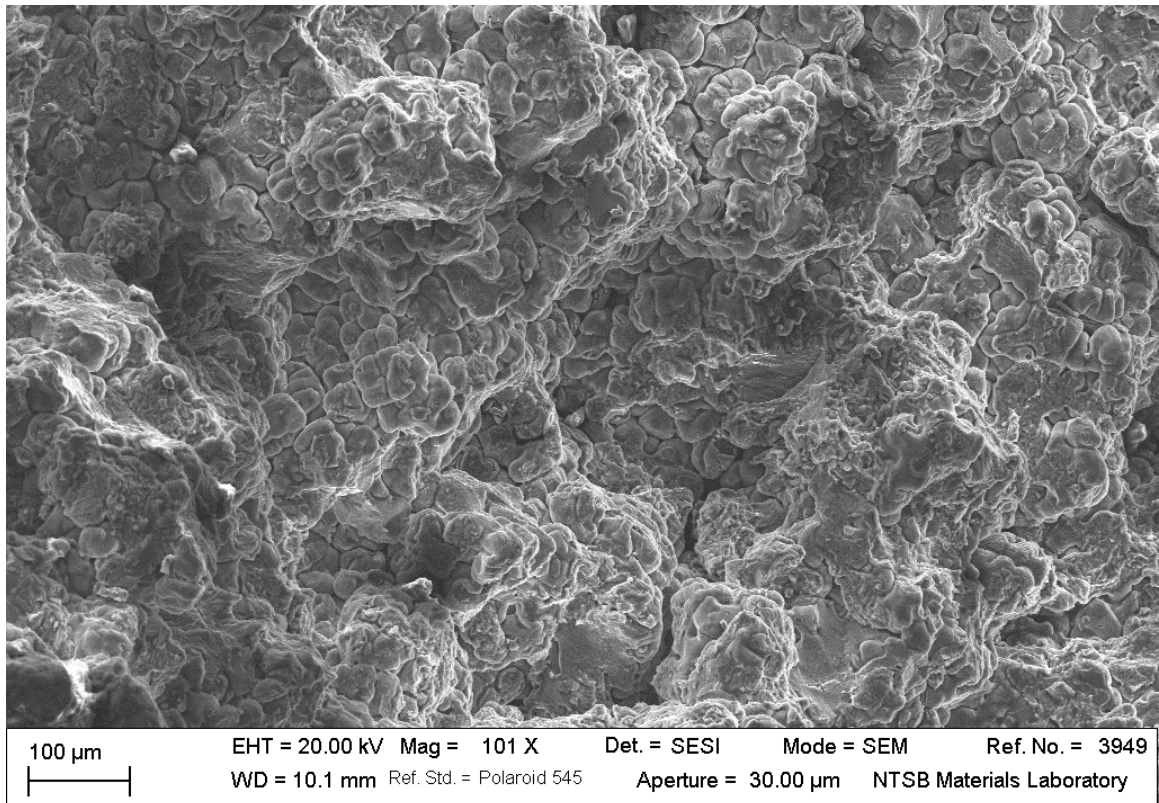


Figure 14 – Secondary electron (SE) micrograph of a typical area of the pedal arm clevis fracture surface.

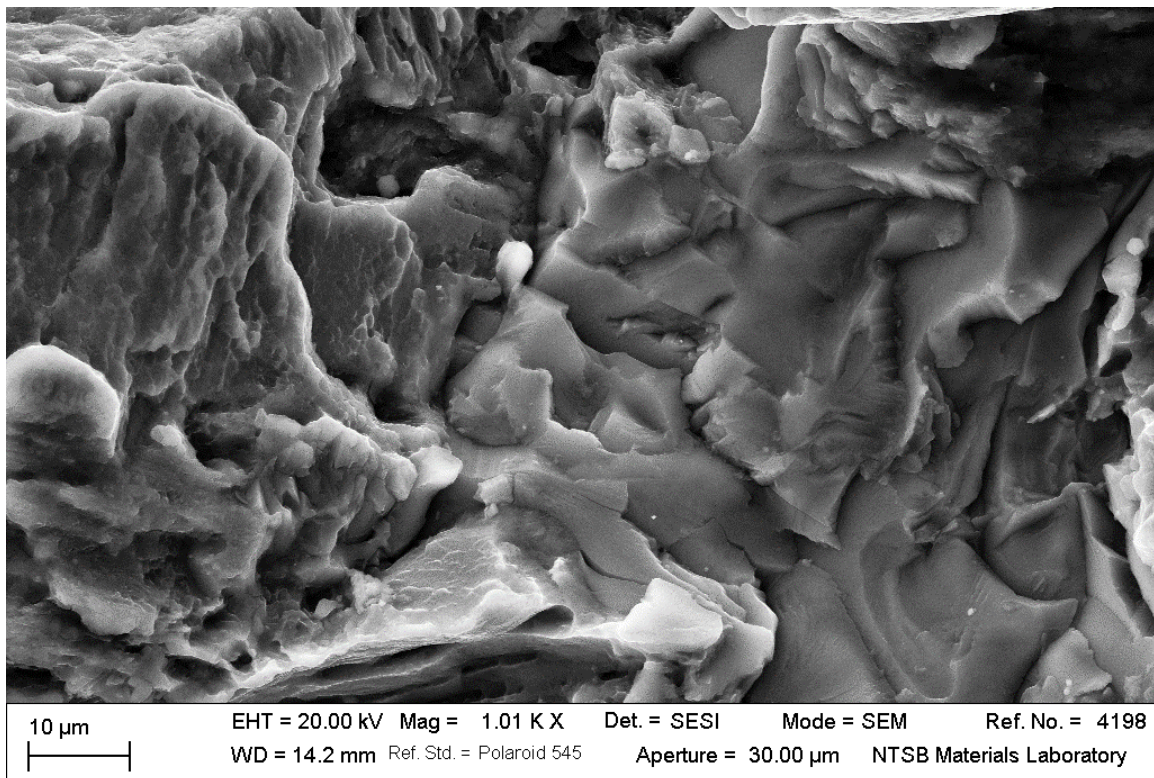


Figure 15 – SE micrograph of a typical area of the fracture surface exhibiting overstress fracture features.

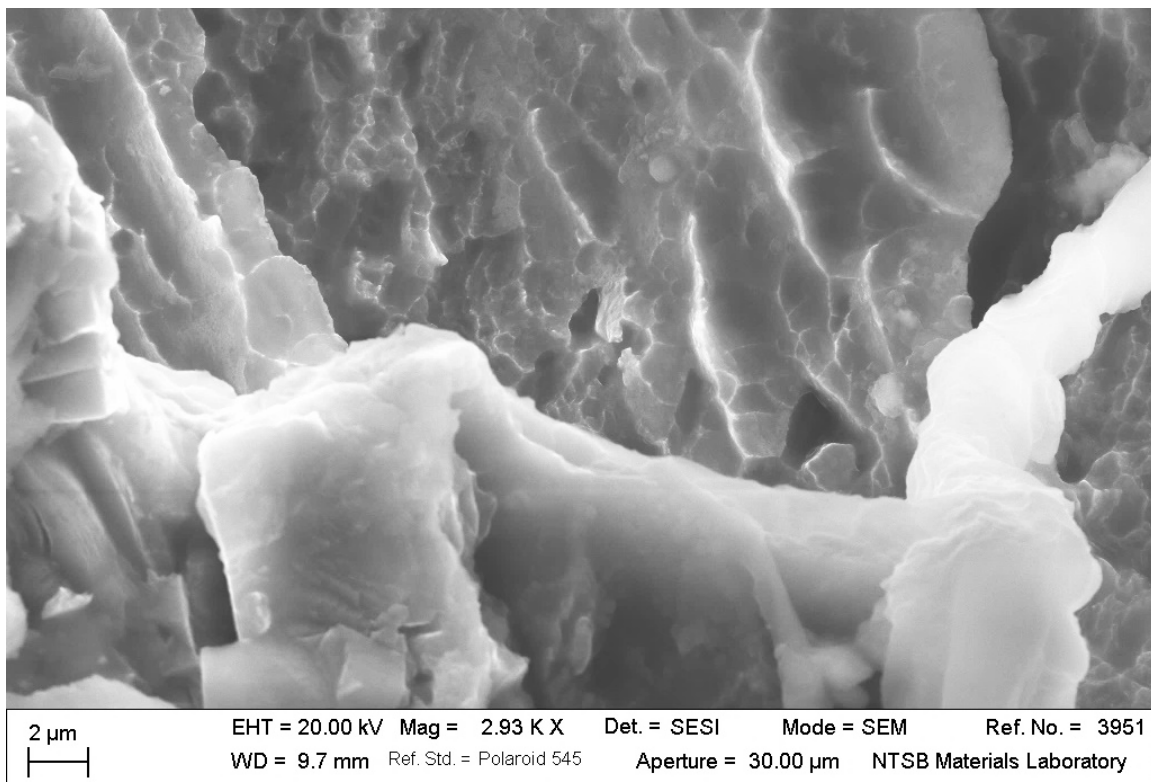


Figure 16 – SE micrograph of dimple rupture on the pedal arm clevis fracture in Figure 15.

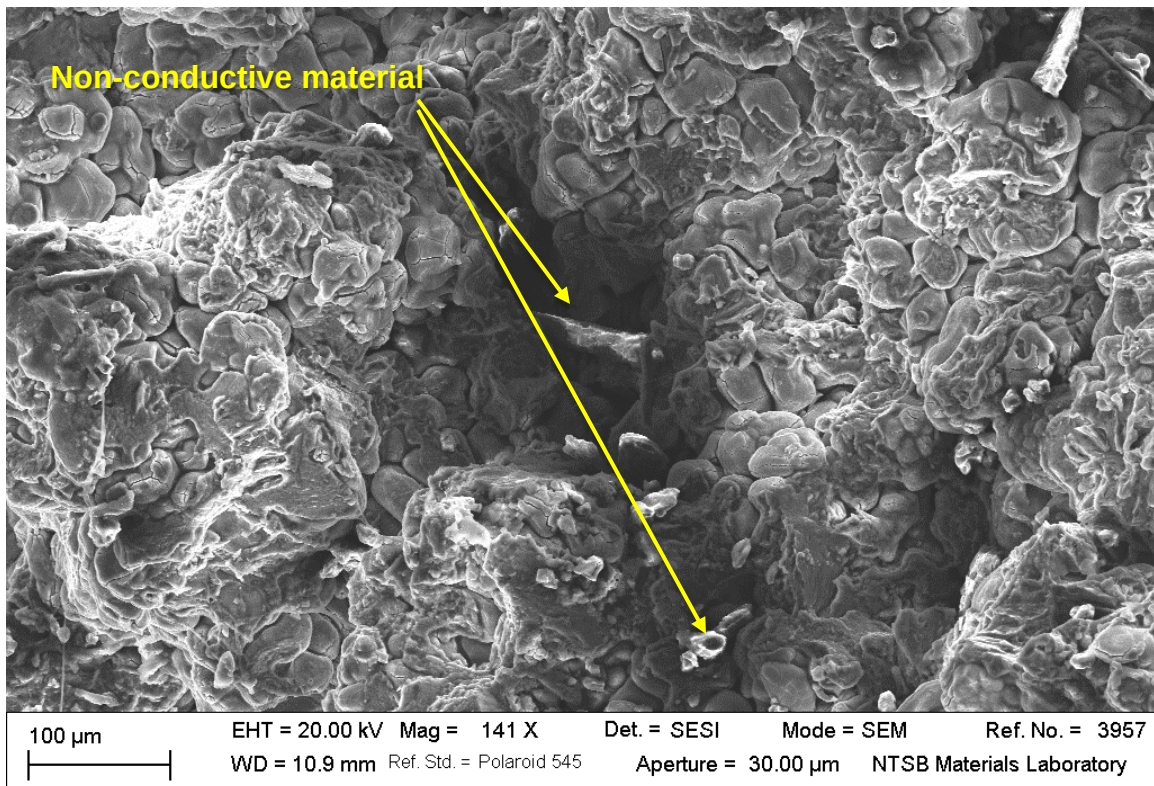


Figure 17 – SE micrograph of a rounded area of the clevis fracture, exhibiting non-conductive material.

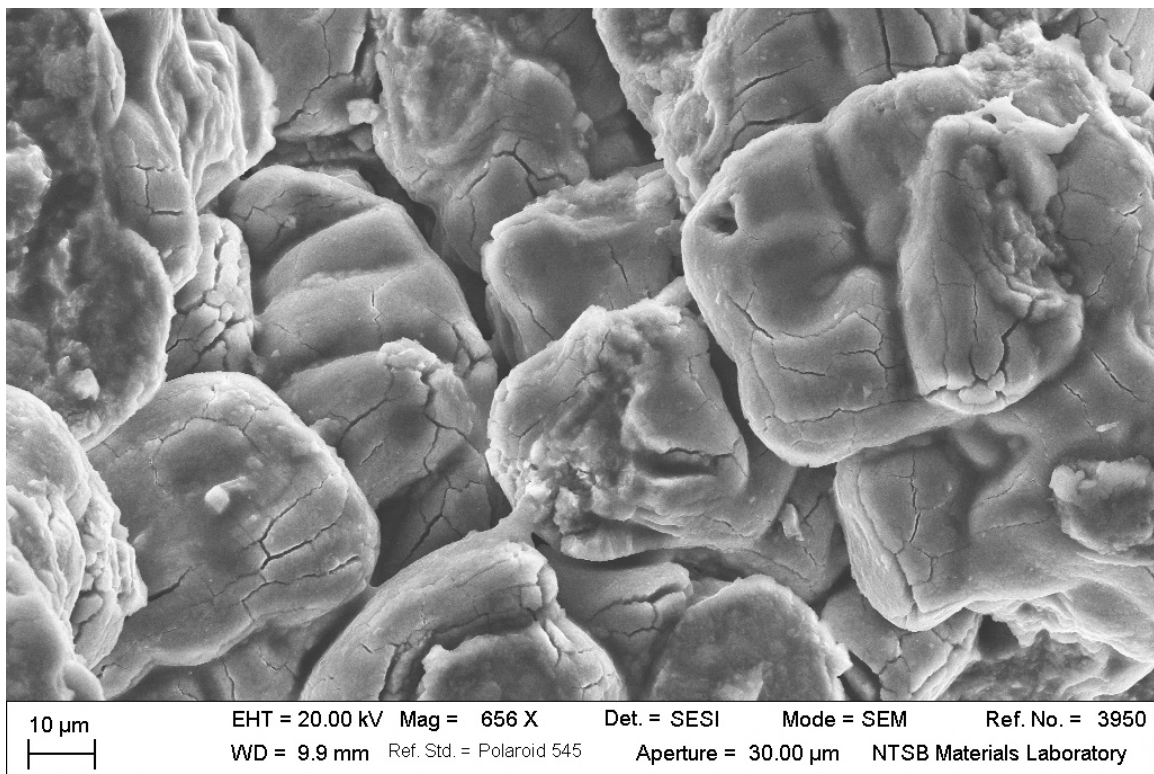


Figure 18 – SE micrograph of the rounded fracture surface areas, showing a microcracked surface layer.

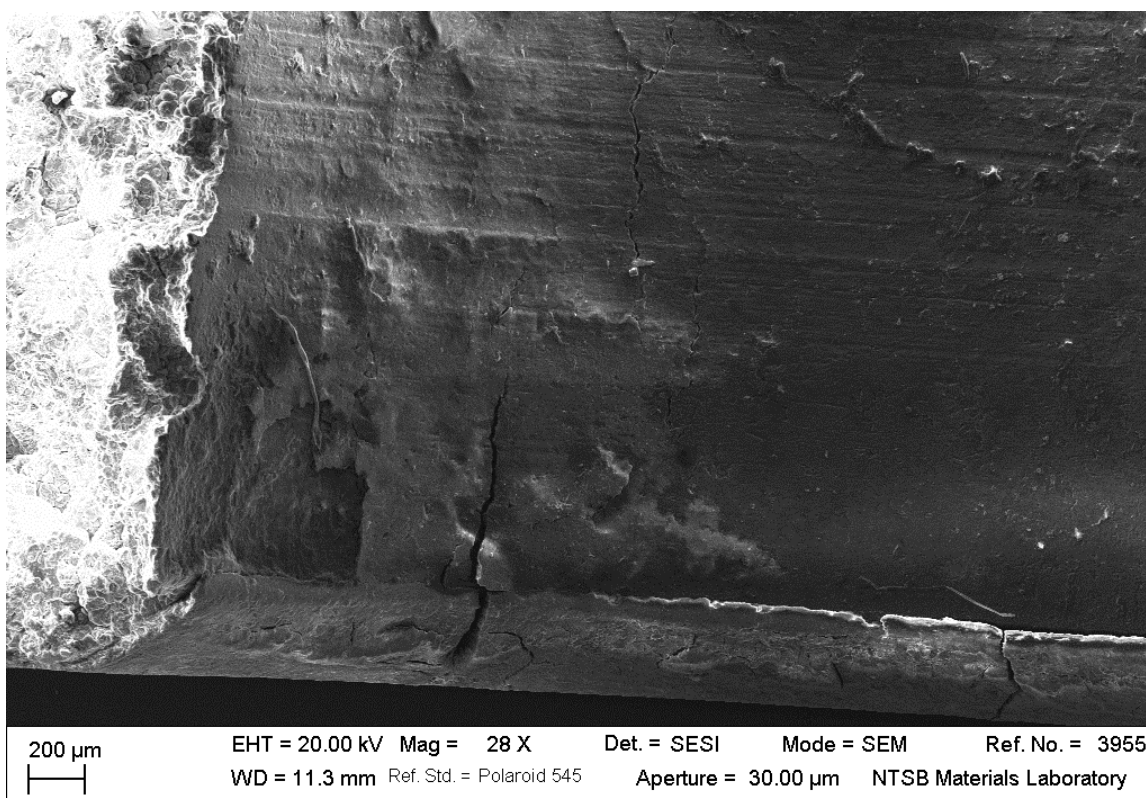


Figure 19 – SE micrograph of the side of the fractured clevis piece, showing multiple cracks parallel to the fracture surface.

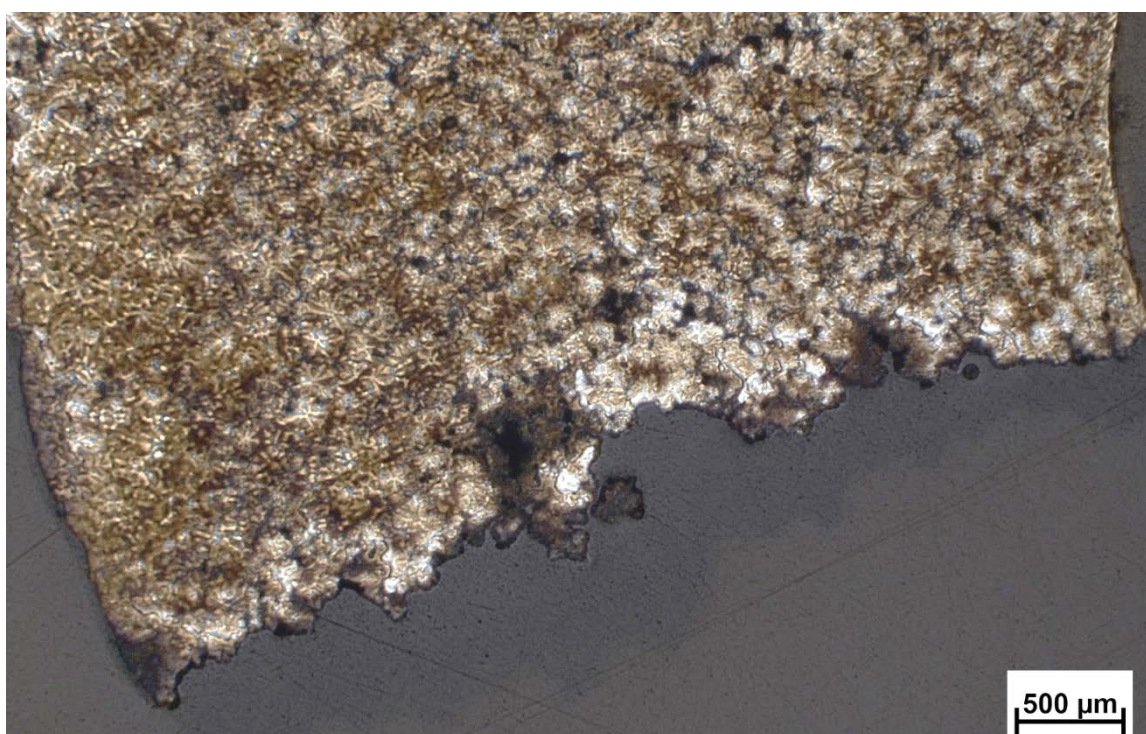


Figure 20 – Bright-field (BF) optical micrograph of the clevis fracture surface (~25X, etched from tap water).

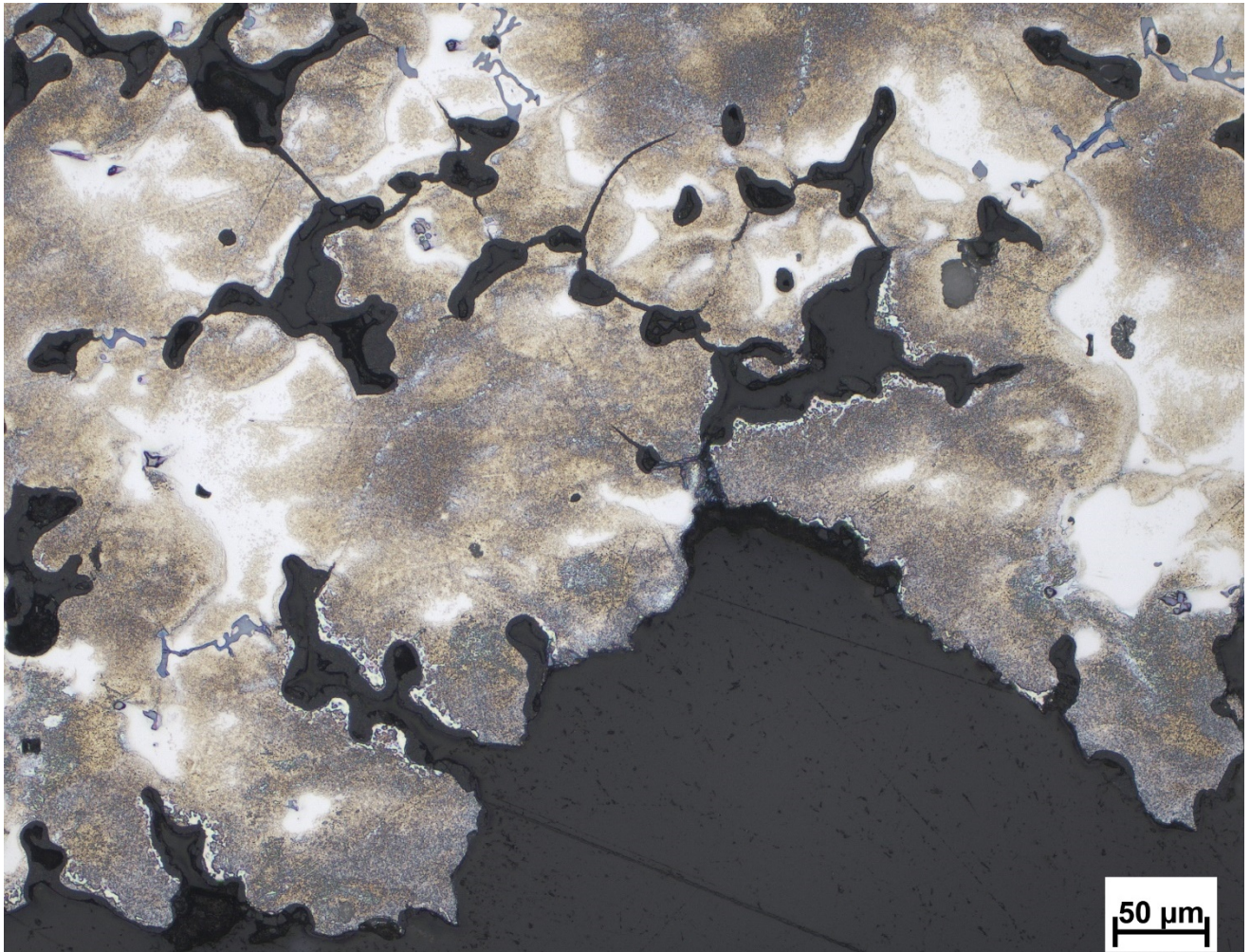


Figure 21 – BF optical micrograph of the fracture surface cross section, showing porosity, internal contamination and subsurface cracking (~200X, etched from tap water).

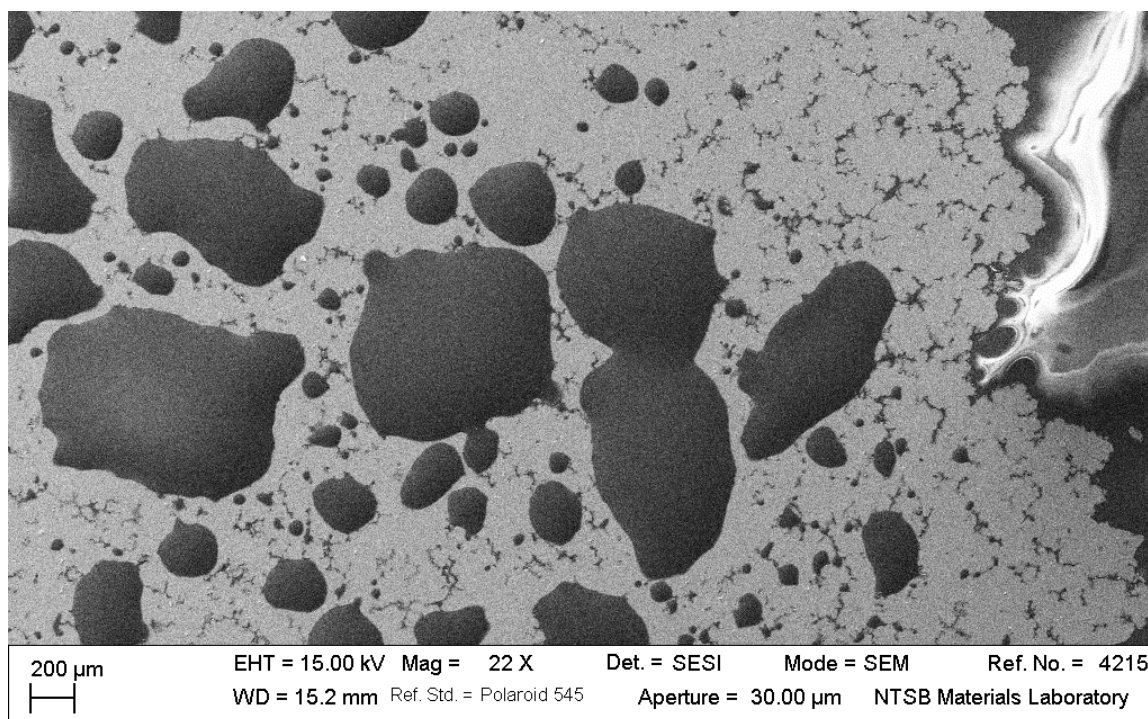


Figure 22 – SE micrograph of the cross-sectioned clevis fracture surface, showing large subsurface porosity.

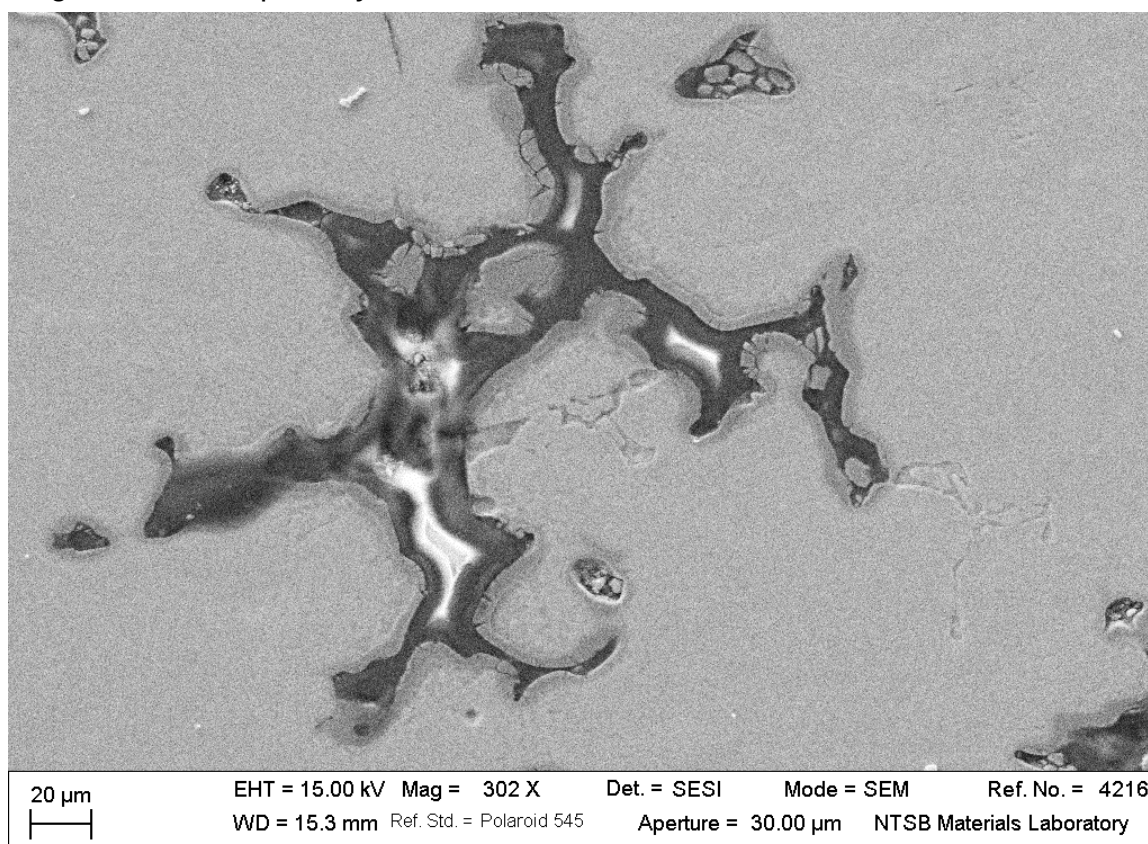


Figure 23 – SE micrograph of one of the interdendritic pores, showing non-conductive material inside.

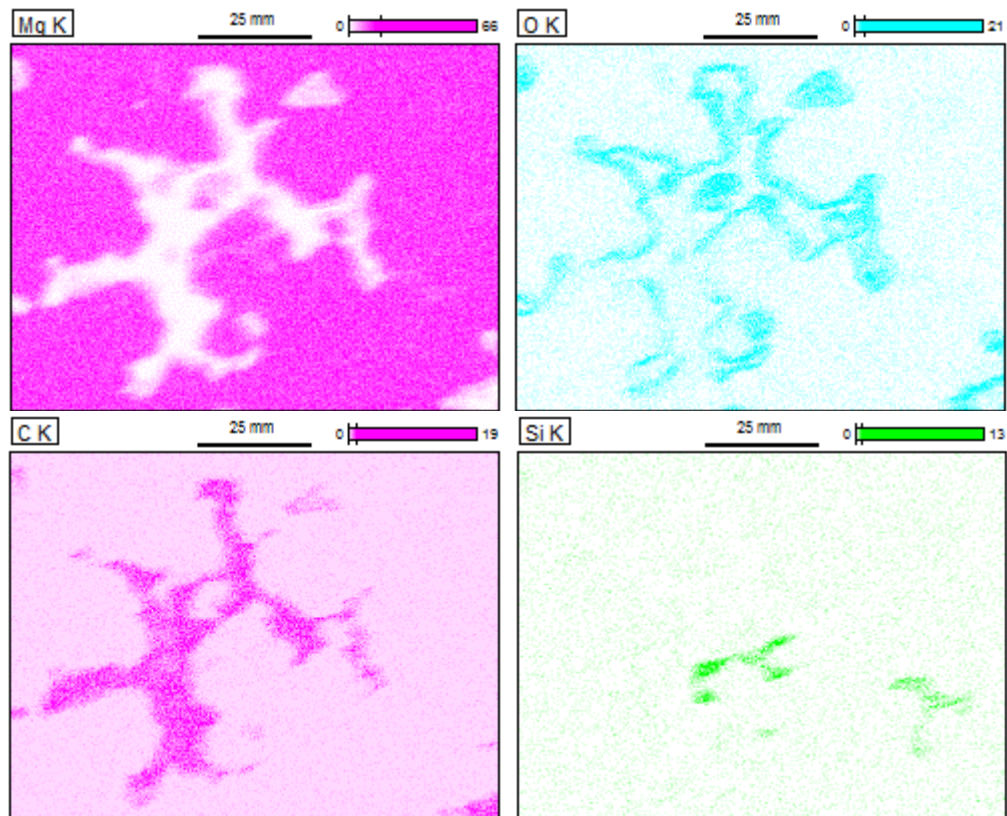


Figure 24 – X-ray maps of selected elements from Figure 23, highlighting elevated concentrations of Mg, O, C, and Si.

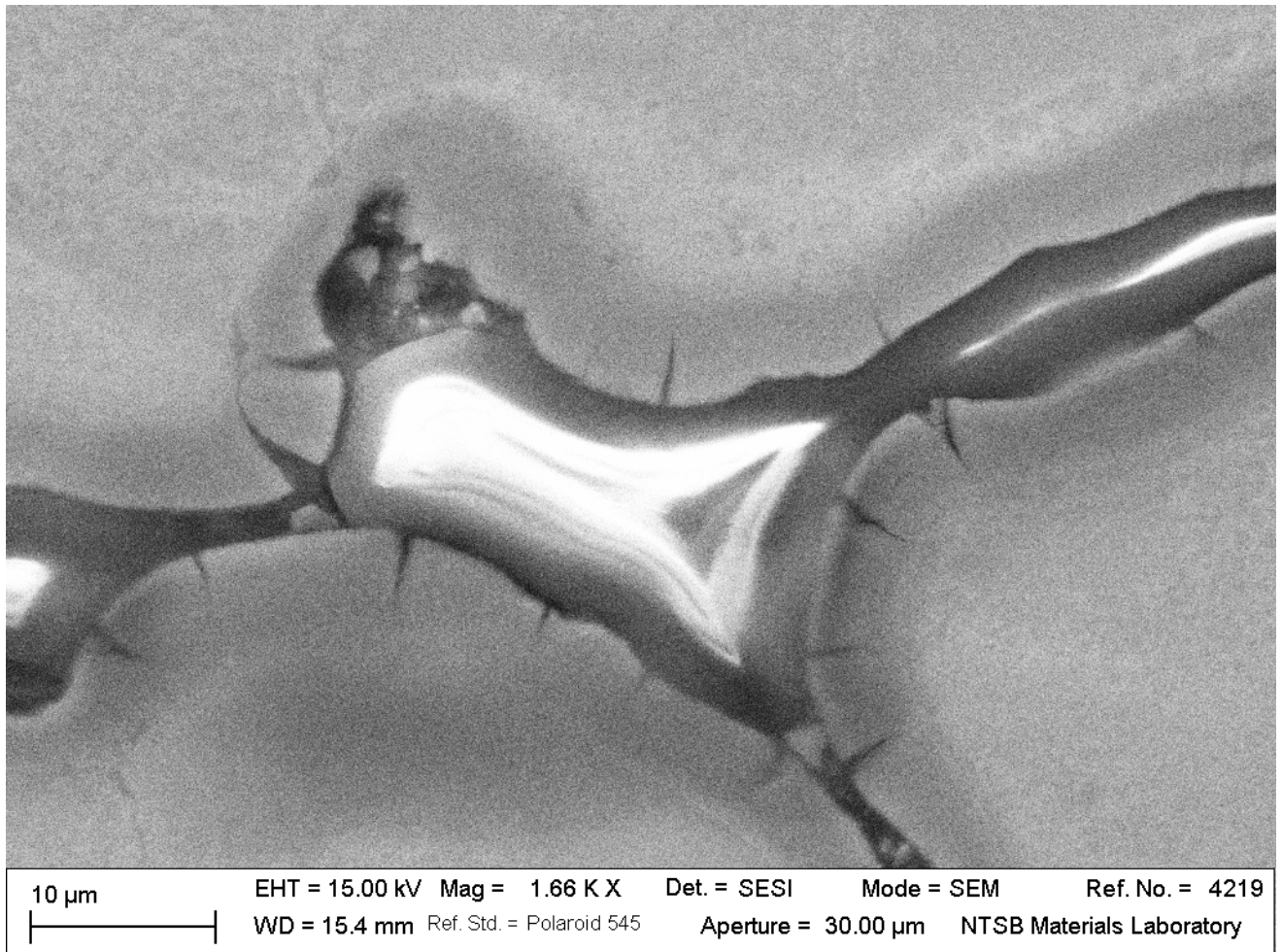


Figure 25 – SE micrograph of a pore, showing cracking in the oxide layer adjacent the pore.



Figure 26 – View of the bellcrank assembly from the arm side, as received.



Figure 27 – View of the bellcrank from the side opposite Figure 26.



Figure 28 – View of the cable track of the bellcrank, showing impressions.



Figure 29 – The control pulley, as received.



Figure 30 – View of the fracture surfaces of the pulley, as received.