

NATIONAL TRANSPORTATION SAFETY BOARD

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



November 30, 2016

MATERIALS LABORATORY FACTUAL REPORT

Report No. 16-095

1. ACCIDENT

Place : East St. Louis, Illinois
Date : June 6, 2016
Vehicle : Aeronca 7AC, N82694
NTSB No. : CEN16LA218
Investigator : Courtney Liedler, AS-CEN

2. COMPONENTS EXAMINED

Fractured connecting rod
Fractured pieces of piston pin

3. DETAILS OF THE EXAMINATION

On June 11, 2016, about 1200 central daylight time (CDT), an Aeronca 7AC experienced a complete loss of engine power and made an emergency landing on a closed section of highway in East St. Louis, Illinois. The airplane sustained substantial damage to the tail section and wing struts. Several parts from the Continental A65-8 engine (S/N 52068-6-8) were sent to the NTSB Materials Laboratory for further examination.¹

Figure 1 shows the number 2 cylinder assembly, as received. The flange about the opening of the cylinder had been torn and bent. Figure 2 shows the interior of the cylinder, showing the bent flange on the left side of the figure. The piston crown was still present inside the cylinder with a fragment of the connecting rod still attached by the piston pin. The piston crown could be moved up and down slightly, but due to the deformation of the cylinder walls, was trapped inside the cylinder. The sides of the cylinder were sectioned and bent outward so as to remove the piston crown, rod fragment, and the piston pin.

Figure 3 shows the connecting rod fragment removed from the cylinder positioned next to the mating connecting rod. The markings on the connecting rod stated, "ATLAS 10 5561". The rod had fractured approximately 0.58 to 0.79 inches from the piston pin bore. Figure 4 illustrates the condition of the pin bore of the connecting rod. The bore exhibited a small step, as well as material deformation outward with longitudinal wear and chatter marks.

¹ The Continental A65 engine is a variant of the O-170 family of horizontally opposed, air-cooled, four-cylinder reciprocating engines.

The fracture surface on the arm side of the rod had been mostly obliterated, consistent with post-fracture impact damage. However, the piston crown side of the connecting rod had not been similarly damaged, as shown in Figure 5. This fracture surface of the rod exhibited features, such as crack arrest and ratchet marks, consistent with progressive cracking, later determined to be consistent with fatigue.

The nature of the fatigue cracking features was consistent with stresses from reverse bending, originating in four distinct initiation sites at the rod flanges (annotated in Figure 5, and as typified in Figure 6). These cracks grew inward until the remaining rod cross section succumbed to overstress. The relatively large percentage of fatigue features on the fracture surface was suggestive of low-load or high-cycle fatigue.

Two of the crack initiation sites of the rod fracture surface are illustrated in Figures 6 and 7. These initiation sites showed ratchet marks of varying sizes, consistent with smaller fatigue cracks that coalesced as they propagated inward. The crack arrest marks were consistent with the cracks propagating away from these corner initiation sites.

The fracture surface was examined using a scanning electron microscope (SEM). Figure 8 shows a typical area of one of the fatigue cracks, containing fatigue striations. The thin region between the opposing fatigue cracks (as annotated in Figure 5) is highlighted in Figure 9. This region exhibited dimple rupture, consistent with overstress failure.

As observed visually, the crack initiation sites exhibited features consistent with multiple crack initiation sites. One such site is highlighted in Figure 10. For the most part, the crack initiation sites did not exhibit any mechanical or material defects, such as inclusions, pores, or voids, that would lead to premature failure. However, the crack initiation site in Figure 10 did exhibit a pit-like feature with non-conductive material present (see Figure 11). Examination of the non-conductive material using energy dispersive x-ray spectroscopy (EDS) did not reveal any elements typically associated with iron-based corrosion products. The composition of the connecting rod was consistent with a plain carbon steel.

Figure 12 shows the piston pin after removal from the piston crown and cleaning. The pin had fractured inside the connecting rod bore (shown in Figure 4) and was only discovered upon disassembly. The pin fracture location was between 1.37 and 1.59 inches from the shorter stub side. Most of the mating fracture surfaces exhibited smearing damage, consistent with continual rubbing while in contact inside the connecting rod bore. Figure 13 shows the less damaged of the two pin mating fracture surfaces. The fracture surfaces consisted of steps, generally oriented perpendicular to the pin forging direction. The surfaces were relatively flat, particularly around the outer regions (see Figure 14).

Examination of the fracture surface using a SEM found two distinct regions of features on the fracture surface (see Figure 15). The outer region, which extended to a depth of approximately 314 μm (0.012 inch), exhibited intergranular fracture (see Figure 16). The inner regions of the pin fracture surface exhibited dimple rupture, consistent with tensile overstress (see Figure 17).

The pin and the rod were cross sectioned near one of the fracture surfaces, mounted, polished, and etched. Figure 18 and Figure 19 show a cross section of the pin. The pin exhibited visual contrast between the core of the material and the outer layer. This outer layer exhibited a depth of approximately 0.02 inch. The inner core microstructure of the pin exhibited a mostly ferrite structure with darker-colored fine pearlite and manganese sulfide particles (see Figure 20). However, the outer layer was that of tempered martensite and some carbides on the prior austenite grain boundaries (Figure 21). This microstructure was consistent with a resulfurized carbon steel that had been surface hardened, such by carburizing or carbonitriding.² Examination of the surface hardened region on the pin using EDS, found relatively higher amounts of carbon, but did not measure any detectable amounts of nitrogen.

The hardness of the parts was inspected using microindentation hardness per ASTM E384.³ The hardness was plotted using a false color overlay, as depicted in Figure 22. While the hardness in the core regions averaged 93 HRB (195 HV₅₀₀), the hardness in the case hardened region averaged 55 HRC (594 HV₅₀₀). The effective case depth of the case hardened layer was approximately 0.013 inches, consistent with that observed in the metallographic cross section (Figure 19).

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² Carburizing is a type of case hardening that produces an elevated carbon gradient extending inward from the surface, enabling the surface layer to be hardened either by quenching directly or cooling to room temperature and heat treating again. Carbonitriding is a case hardening process at an elevated high temperature in a specific gas atmosphere such that the surface simultaneously absorbs carbon and nitrogen by diffusion, to change the surface properties.

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



Figure 1 – The #2 cylinder, as received. The upper flange was torn and bent on the top of the figure.

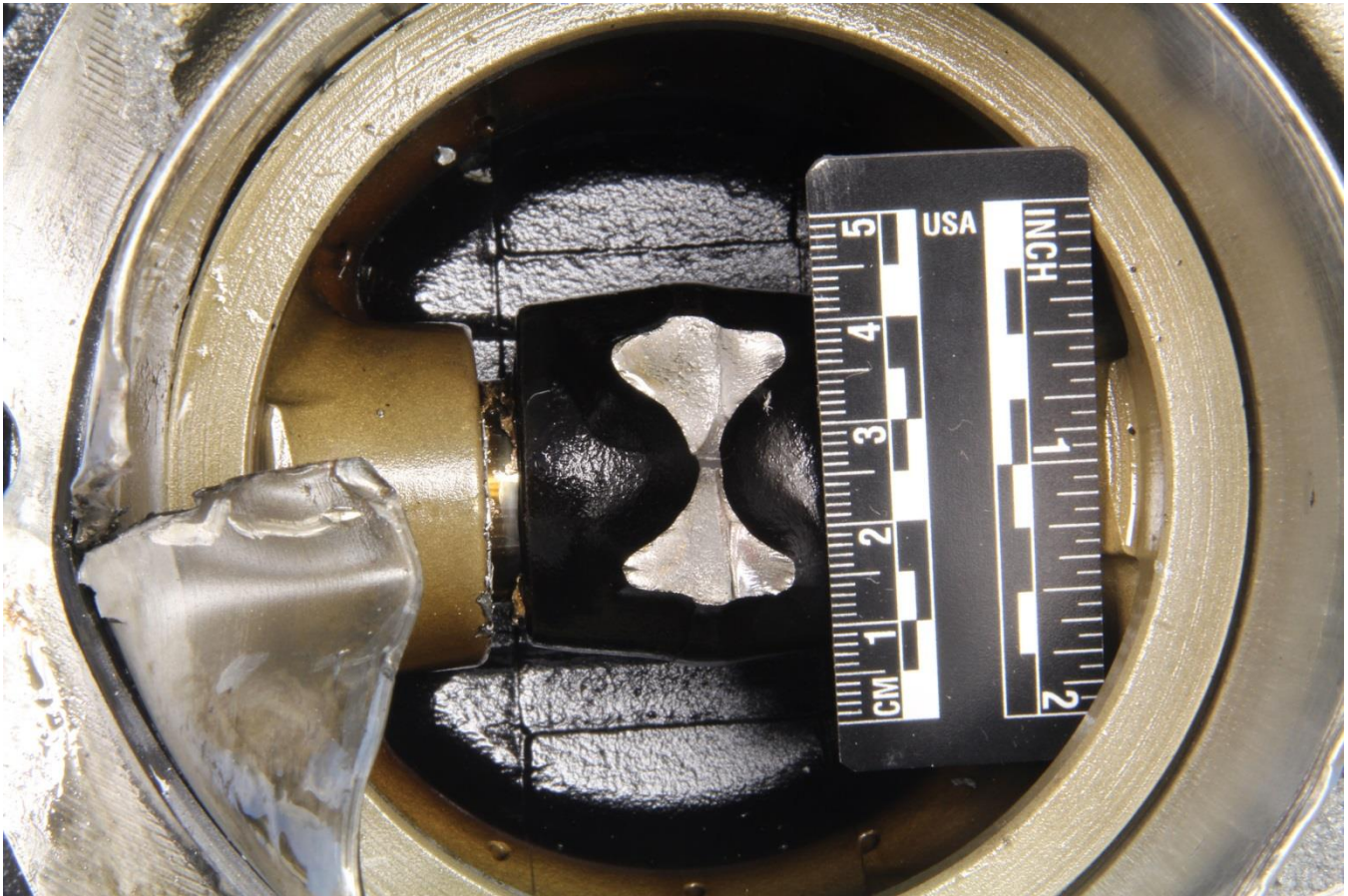


Figure 2 – A closer view of the inside of the cylinder, as-received, showing the fractured fragment of the connecting rod.



Figure 3 – The fractured halves of the connecting rod, shown after removal of the fragment from the cylinder (right).



Figure 4 – Side view of the bearing of the fractured connecting rod, where the fractured pin was located.

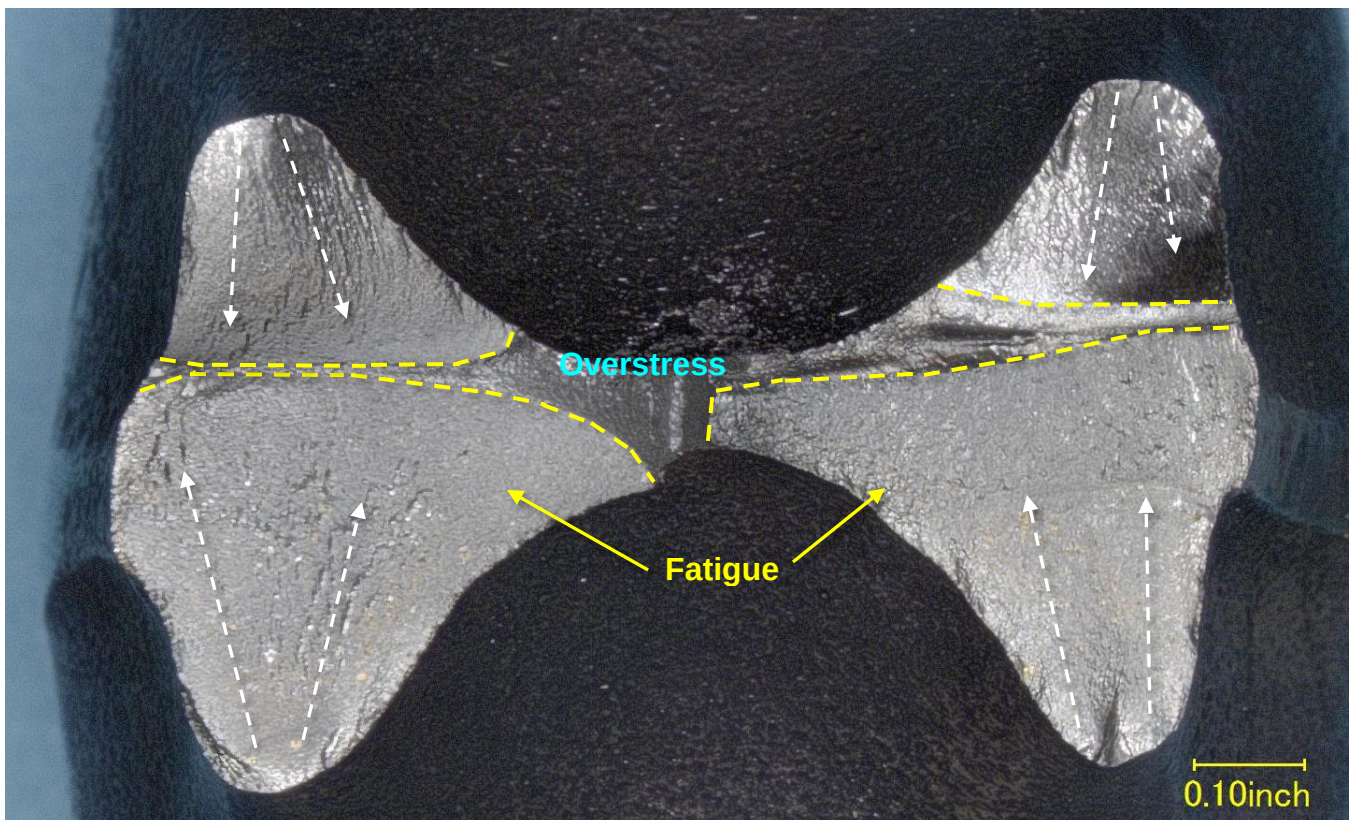


Figure 5 – Closer view of the rod fracture surface (piston side), after removal from the cylinder and cleaning. The different fracture regions are annotated, and the crack growth directions are depicted with white arrows.



Figure 6 – Closer view of the crack initiation site of the lower left side from Figure 5.



Figure 7 – Closer view of the crack initiation site on the lower right side of Figure 5. A ratchet mark was present in the figure.

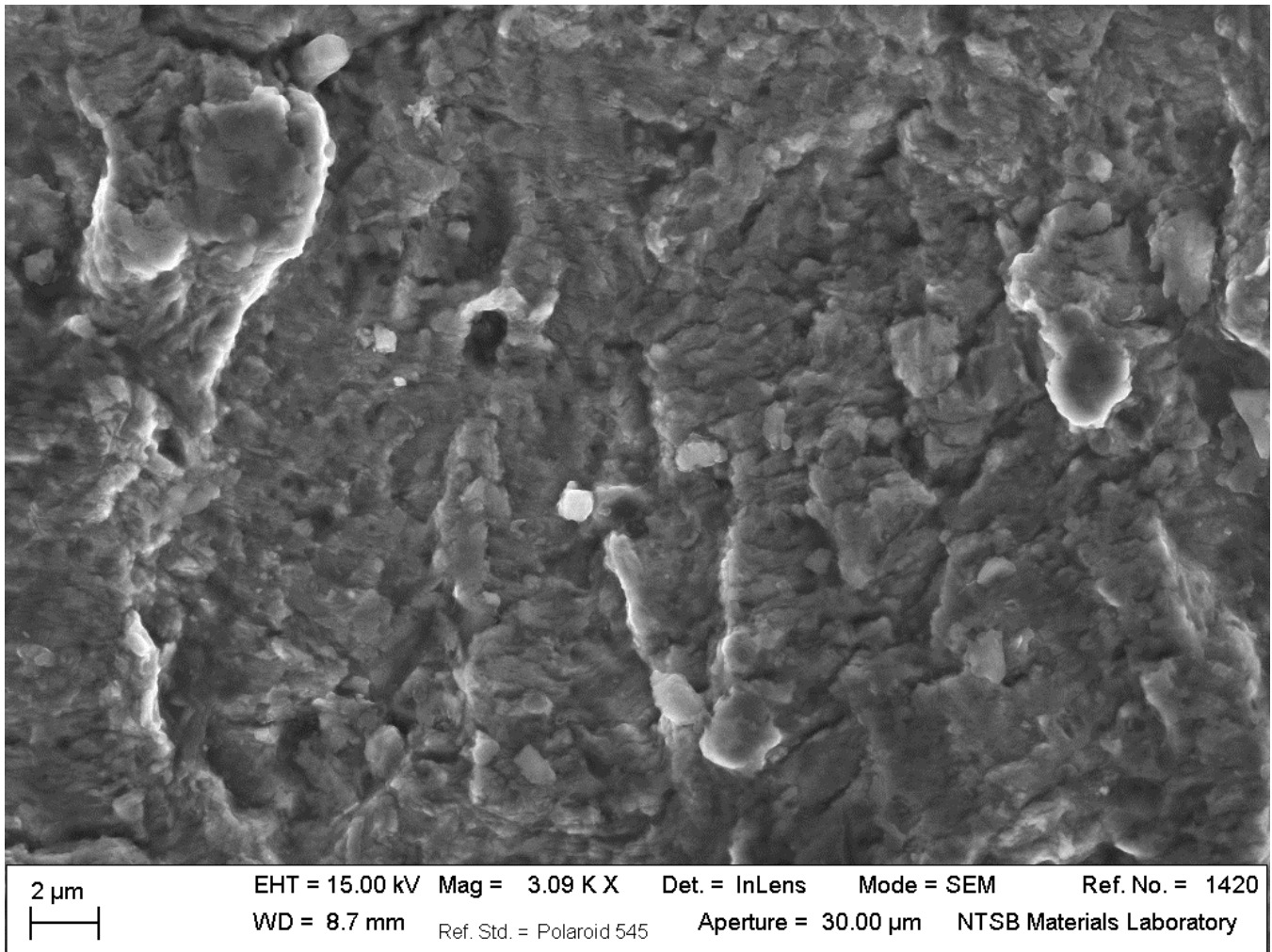


Figure 8 – Secondary electron (SE) micrograph of fatigue striations on the connecting rod fracture surface.

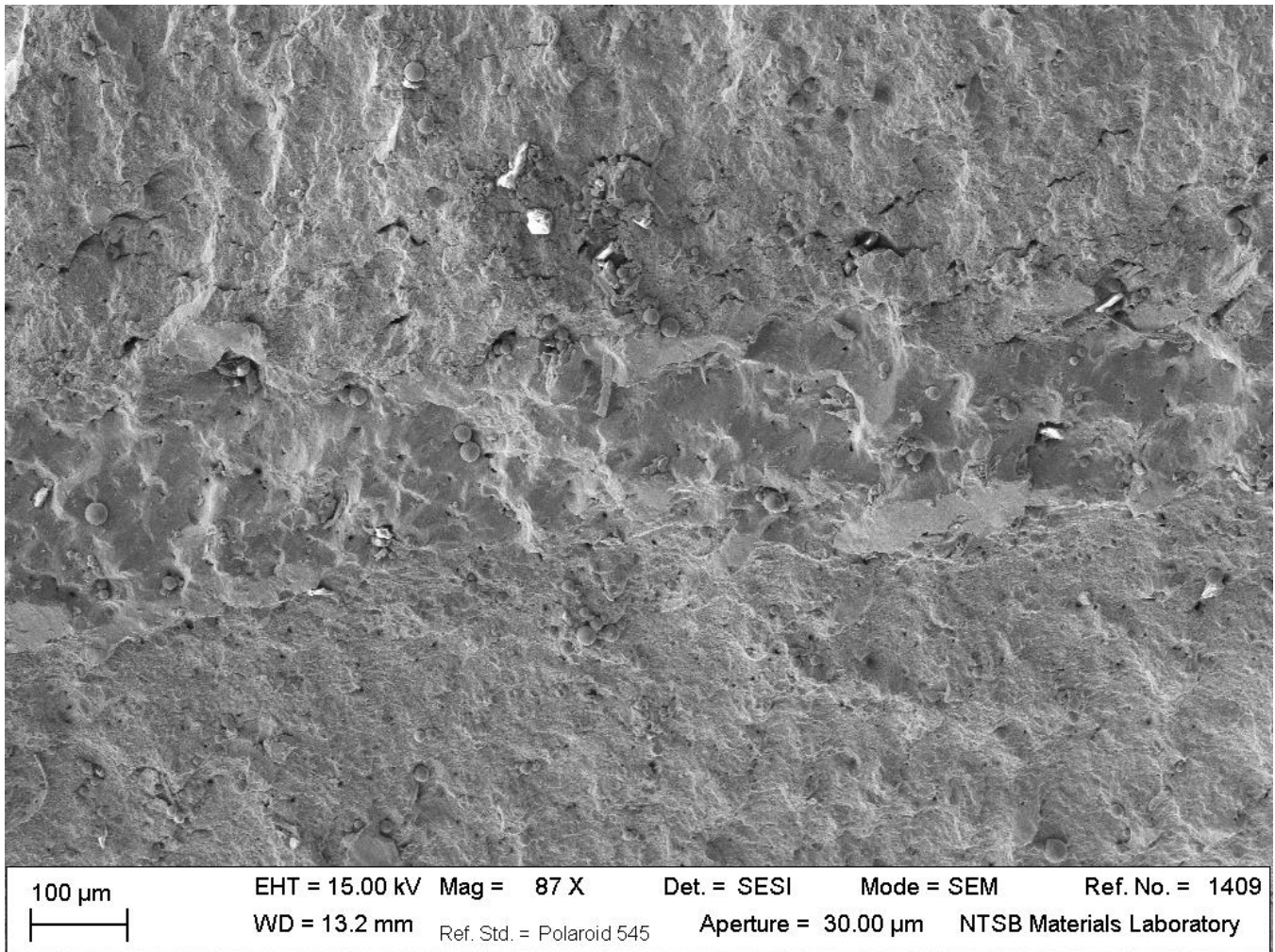


Figure 9 – SE micrograph of the middle of the rod fracture surface, showing the middle overstress fracture between two fatigue crack regions.

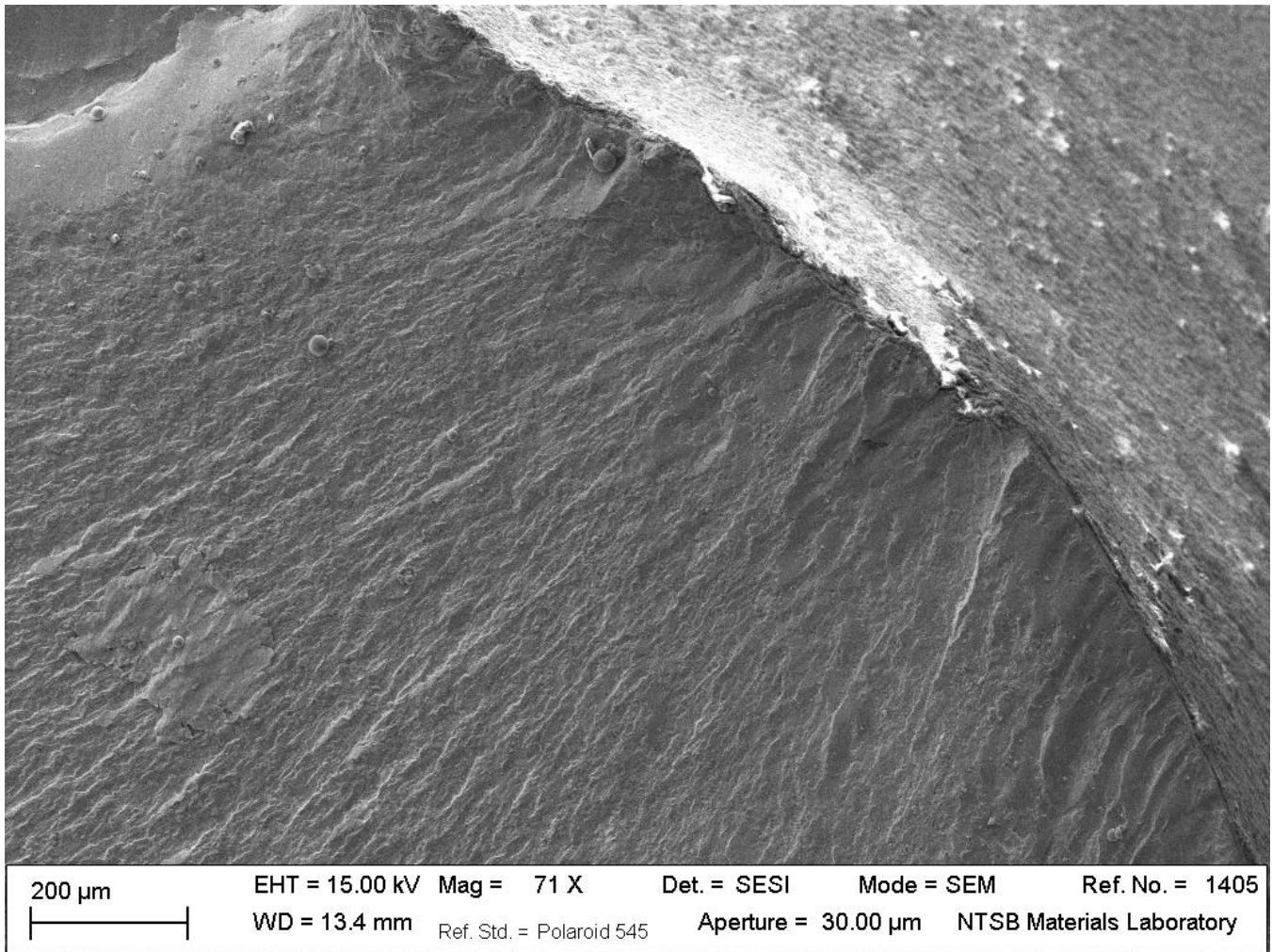


Figure 10 – SE micrograph of one of the fatigue crack initiation sites on the connecting rod.

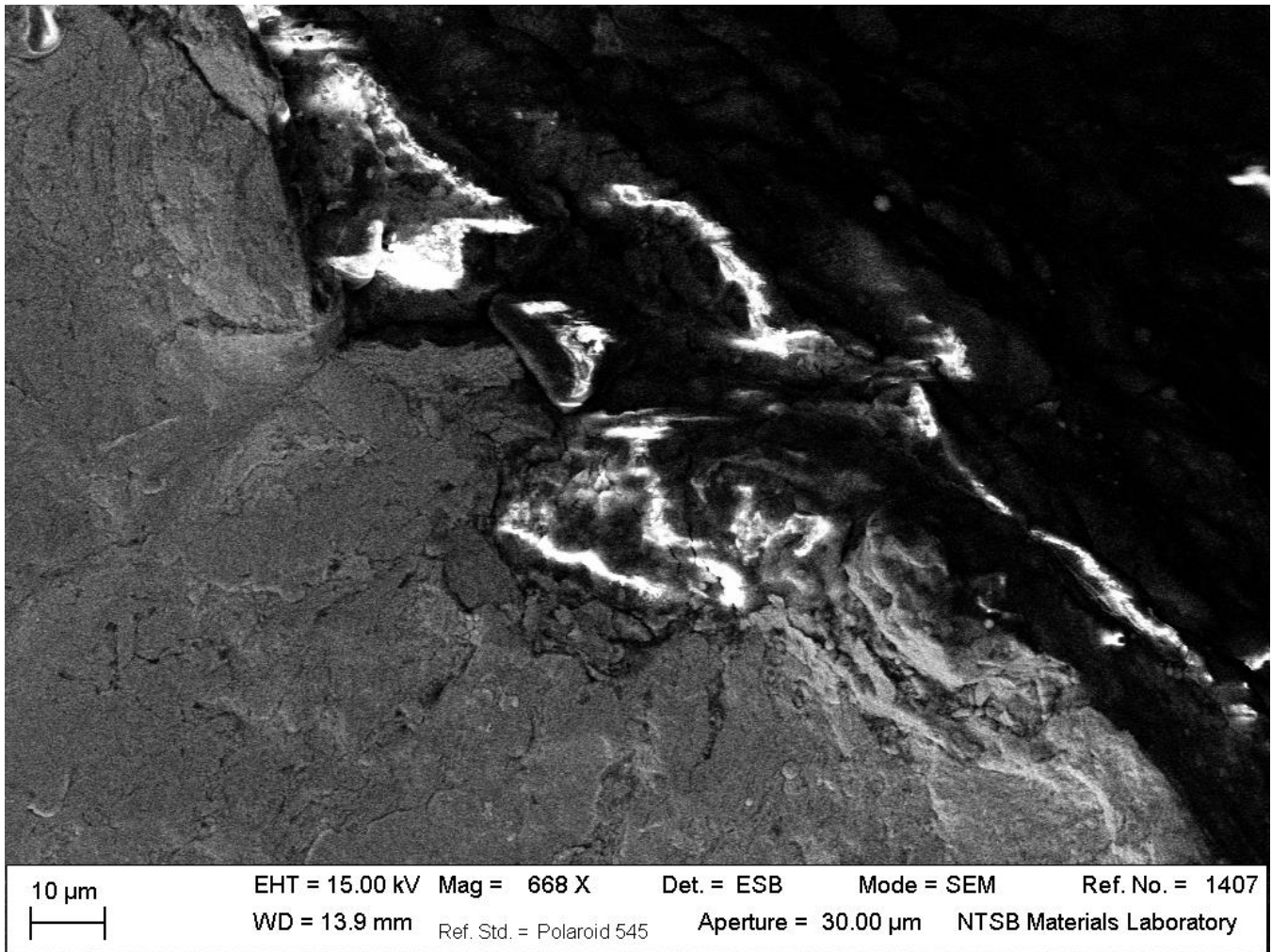


Figure 11 – Backscattered electron (BE) micrograph of one of the initiation sites in Figure 10. The figure shows non-conductive material present at pit-like features at this initiation site.

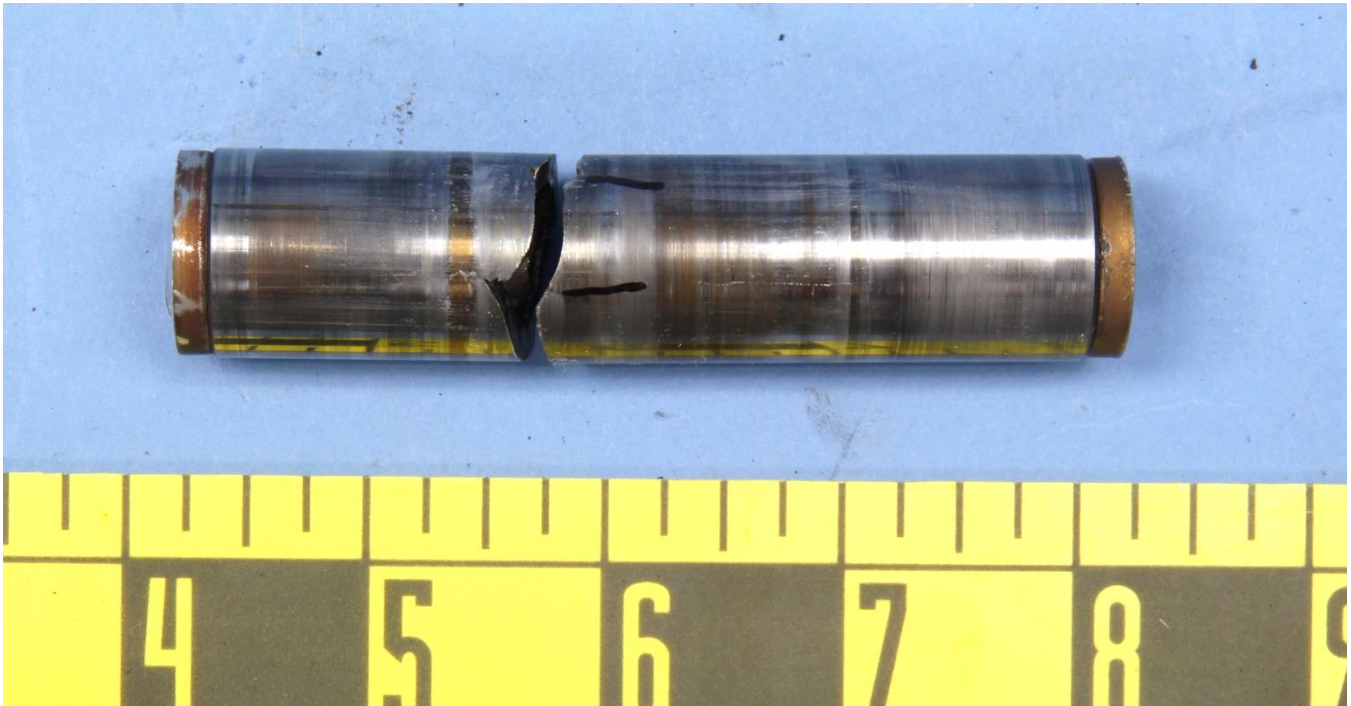


Figure 12 – The fractured piston pin after removal of the connecting rod fragment from the cylinder.



Figure 13 – The less damaged fracture surface of the pin from the connecting rod.

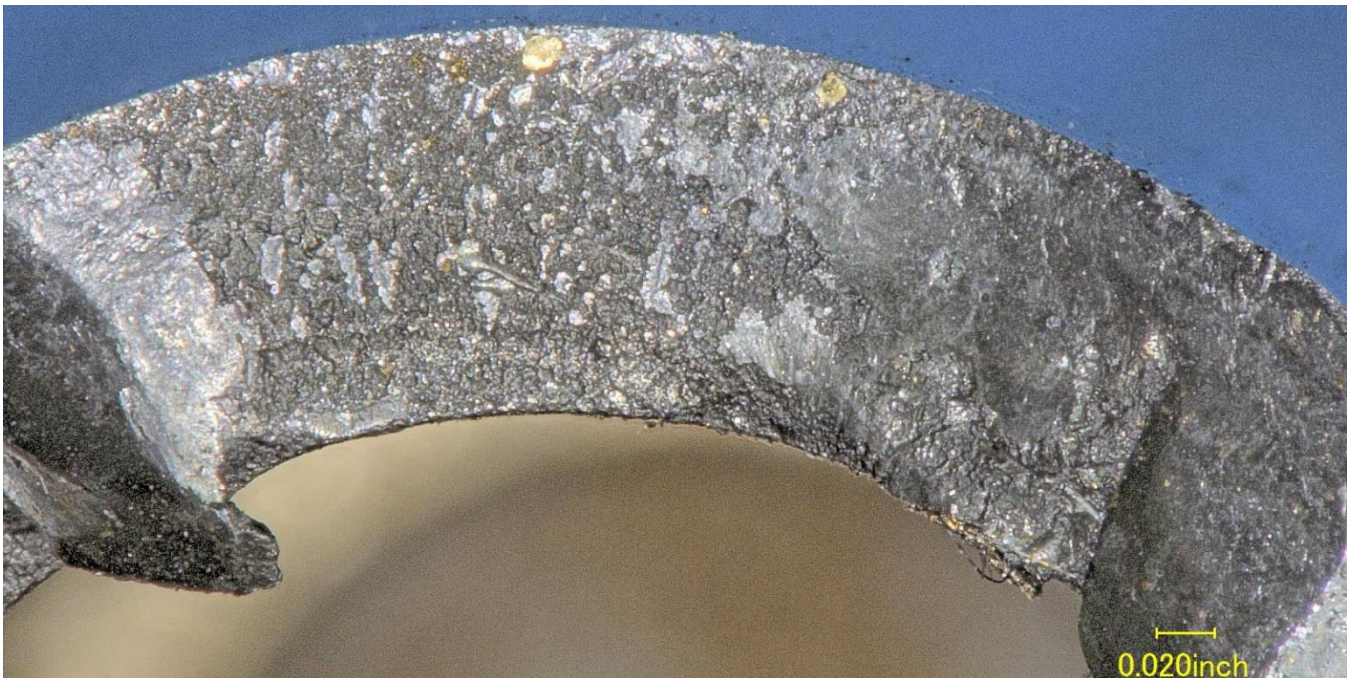


Figure 14 – Closer view of the pin fracture surface, showing relatively flat surface, with rubbing damage present.

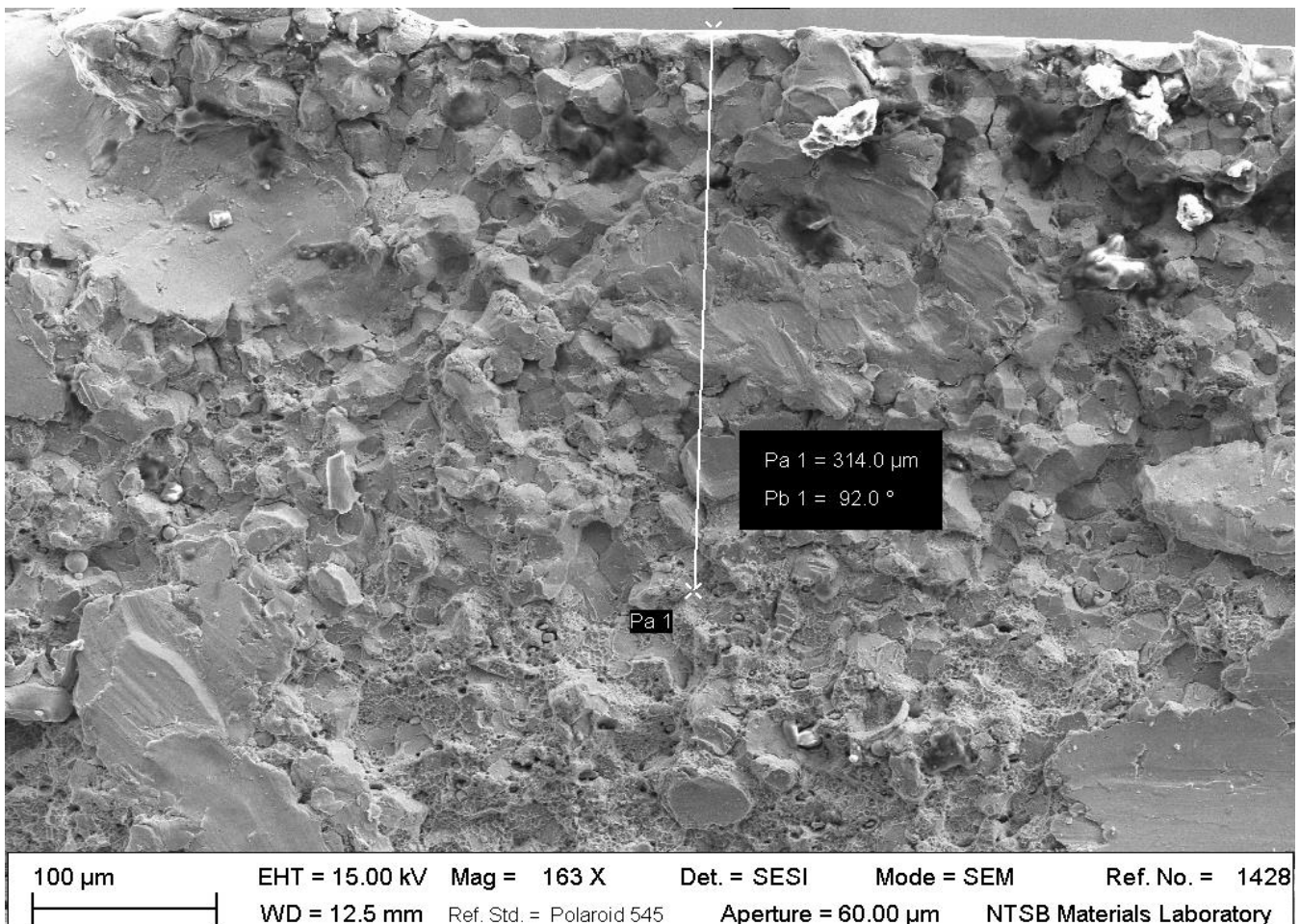


Figure 15 – SE micrograph, showing an outer region of intergranular features, and an inner region of dimple rupture. The depth of the outer intergranular region is annotated on the figure.

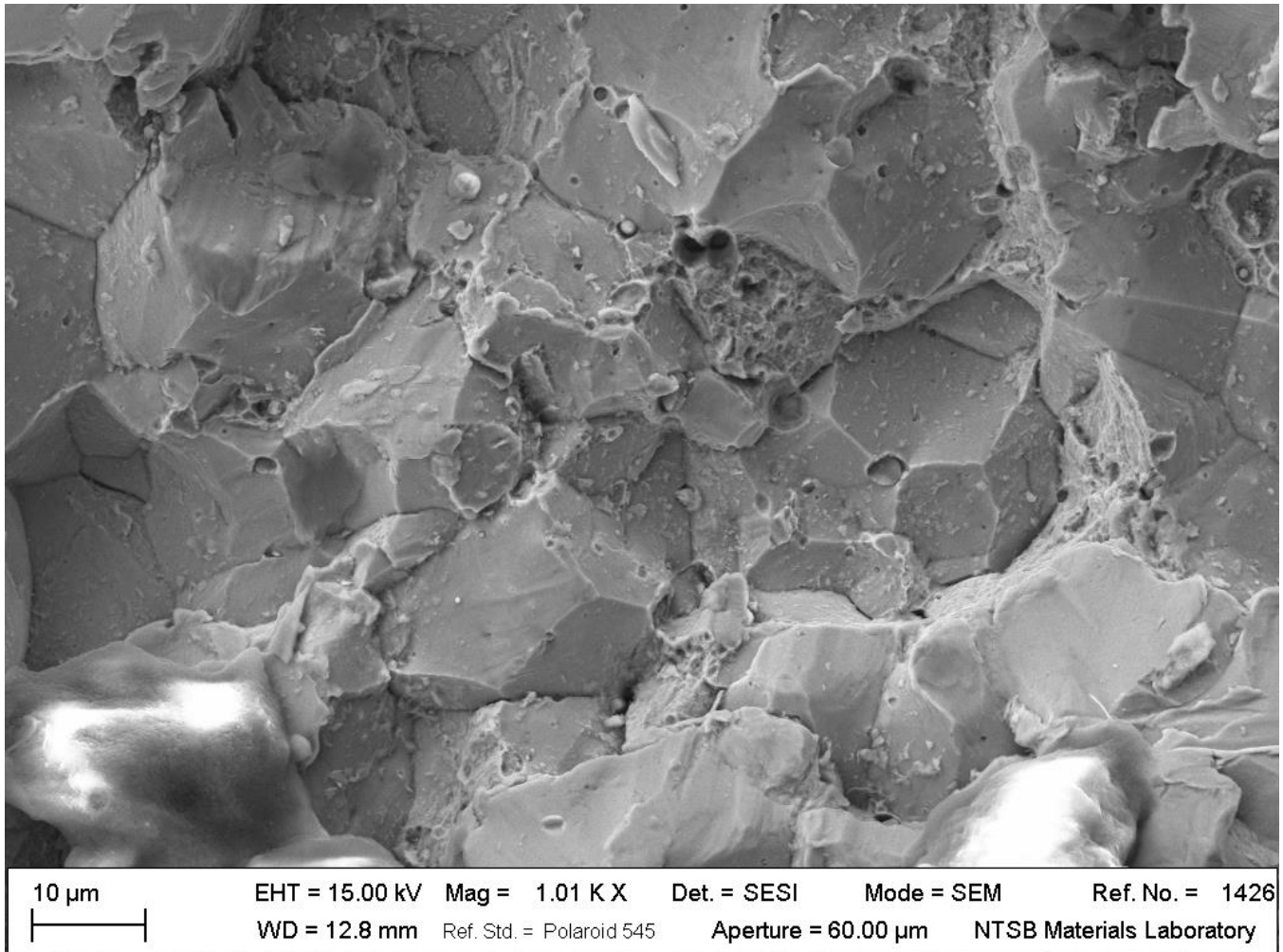


Figure 16 – SE micrograph showing a closer view of the intergranular fracture region of the pin from Figure 15.

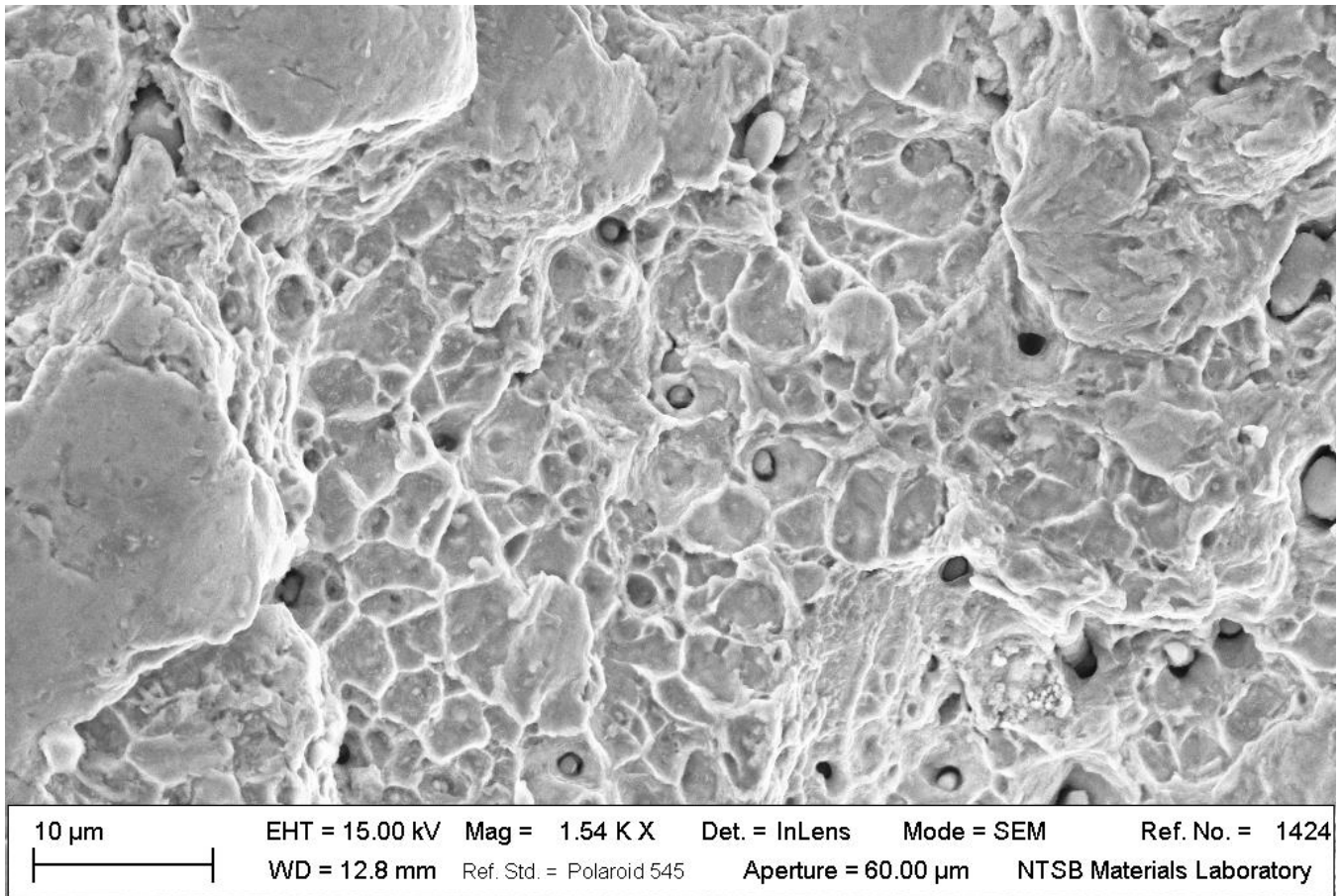


Figure 17 – SE micrograph of the inner dimple rupture features of the pin fracture surface.

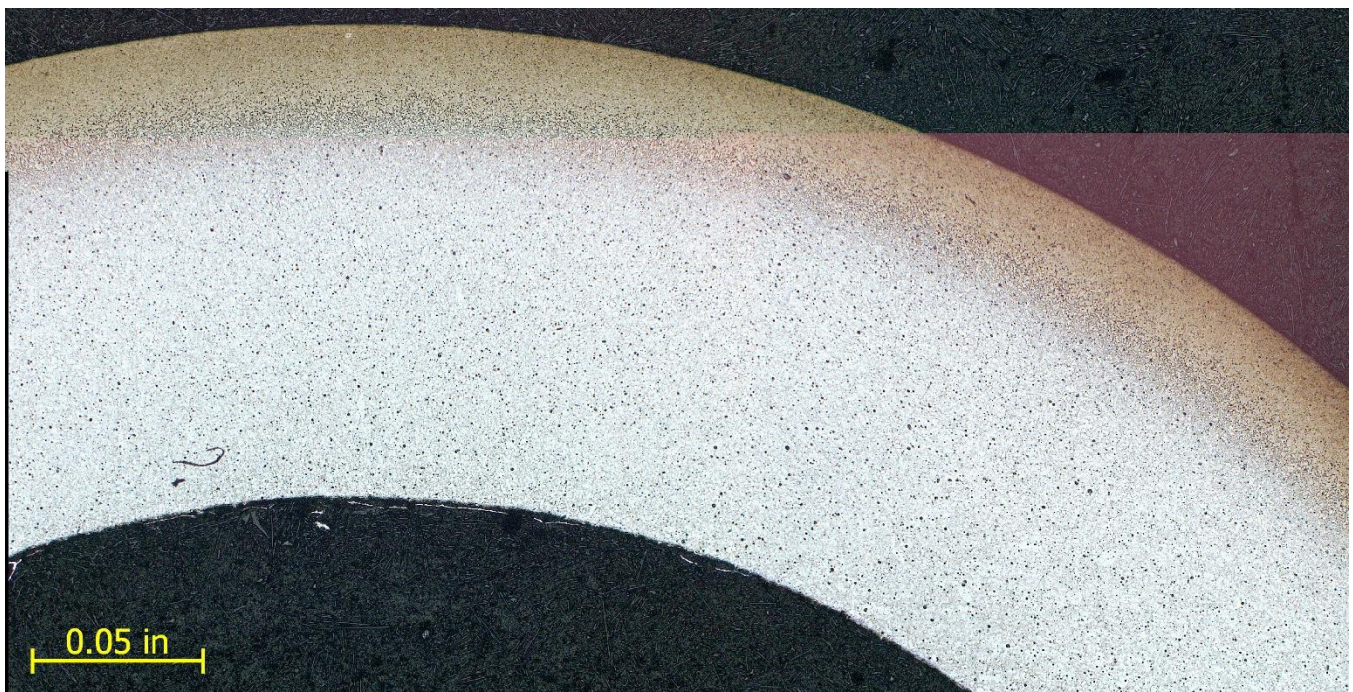


Figure 18 – Montage of micrographs showing a cross section of the pin, with contrast between outer and inner layers (bright field, ~25X, etched 2% Nital).

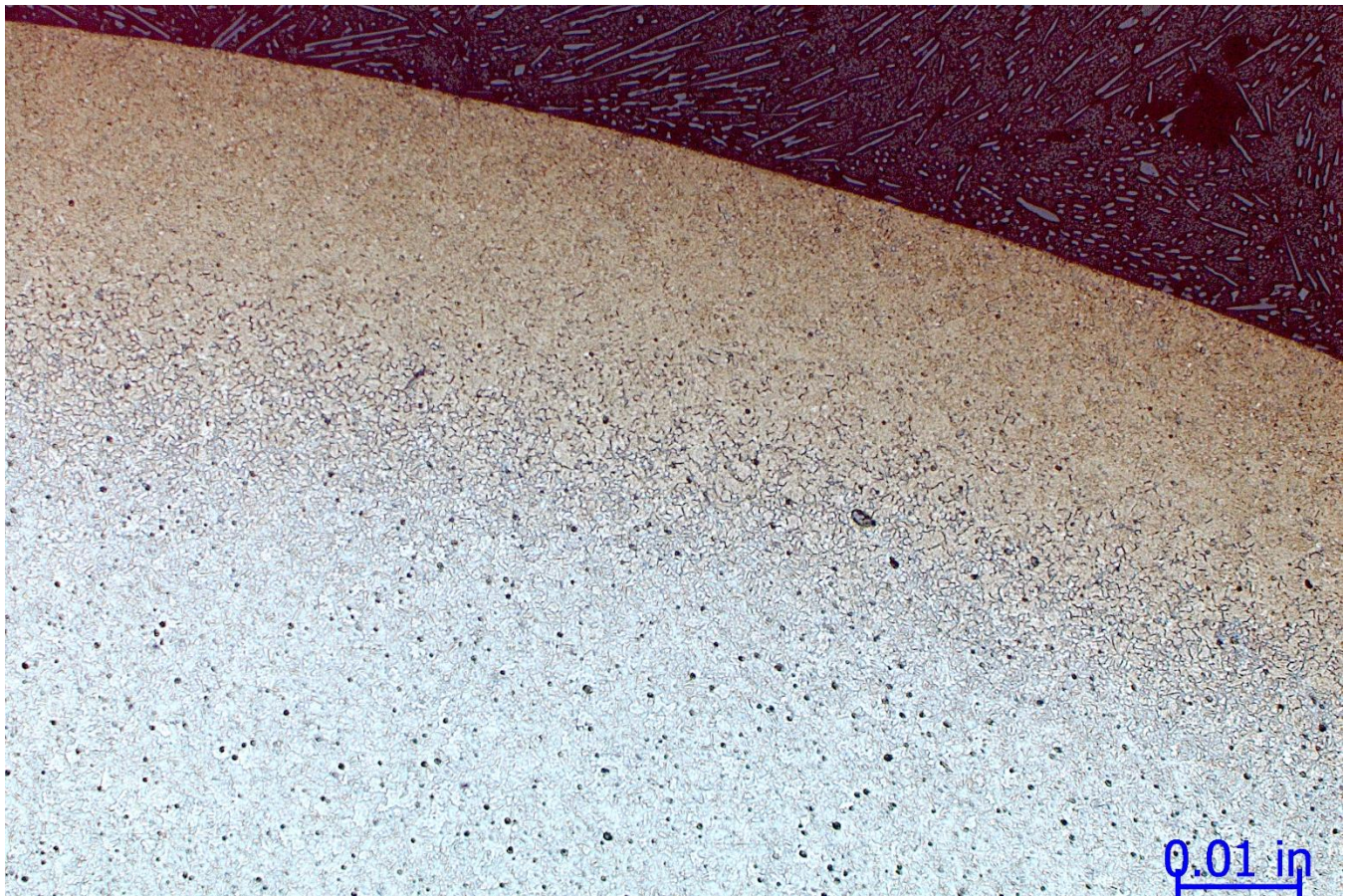


Figure 19 – Bright field (BF) micrograph showing the transition of the outer layer of the pin (~50X, 2% Nital).

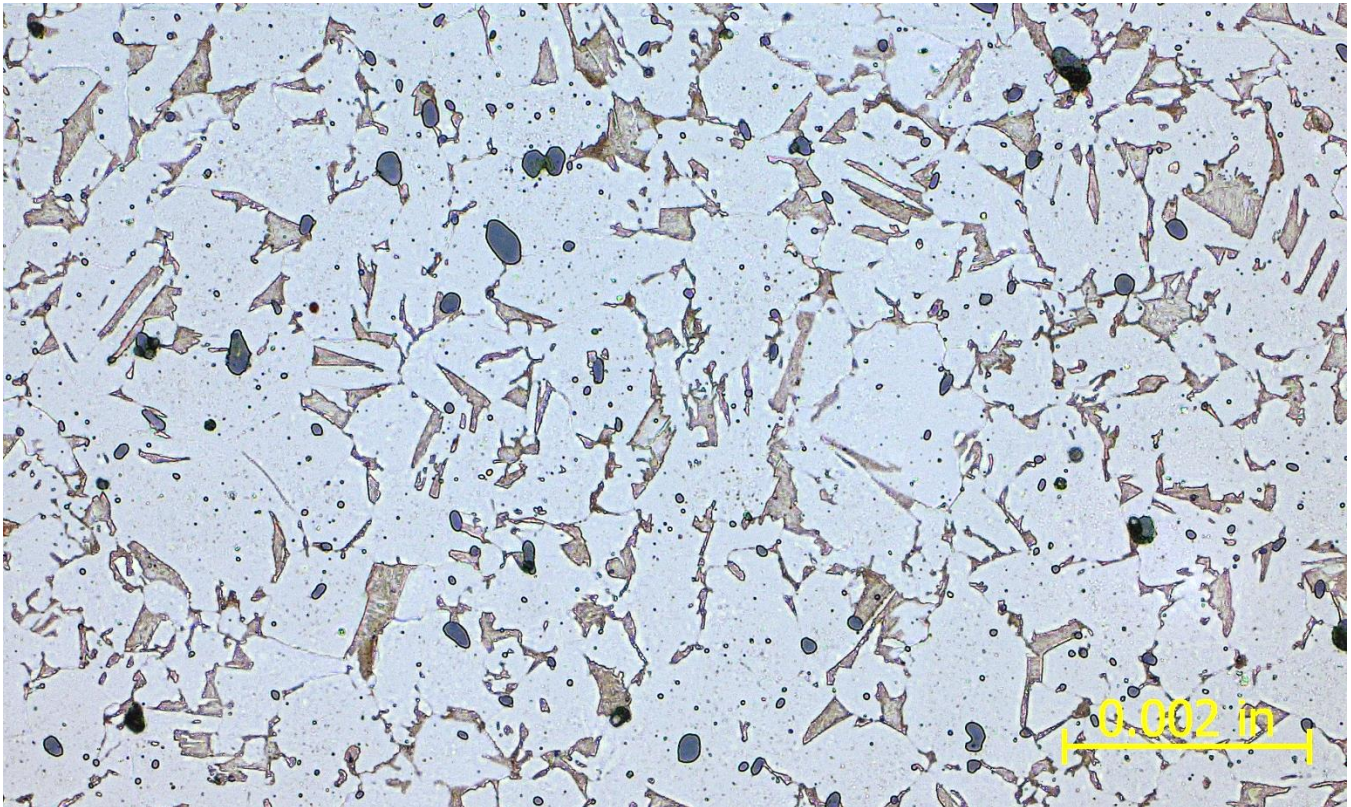


Figure 20 – BF micrograph showing the inner core of the pin cross-section, with a ferrite (lighter phase) and pearlite (darker phase) mixture and dark blue rounded MnS particles (~500X, etched 2% Nital).

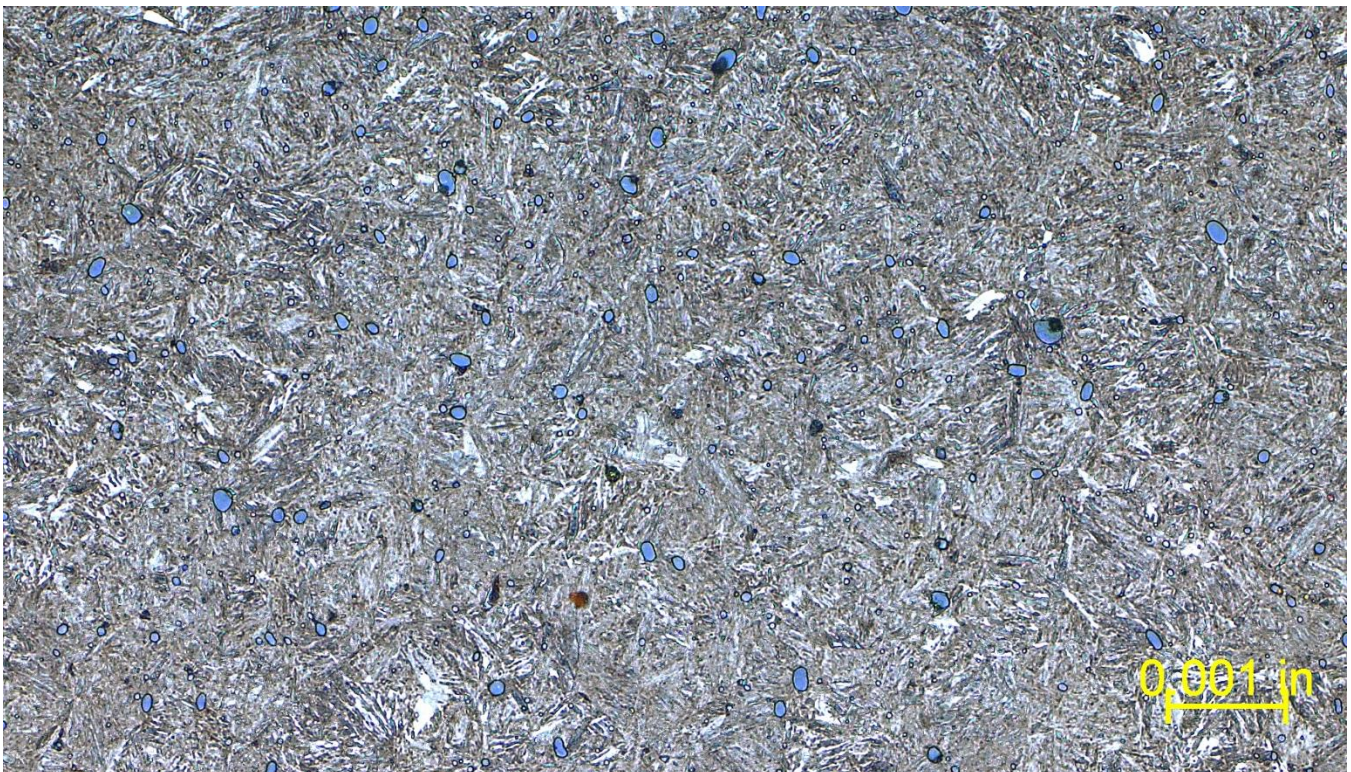


Figure 21 – BF micrograph of the outer case hardened layer, containing tempered martensite not present in Figure 20 (~500X, etched 2% Nital).

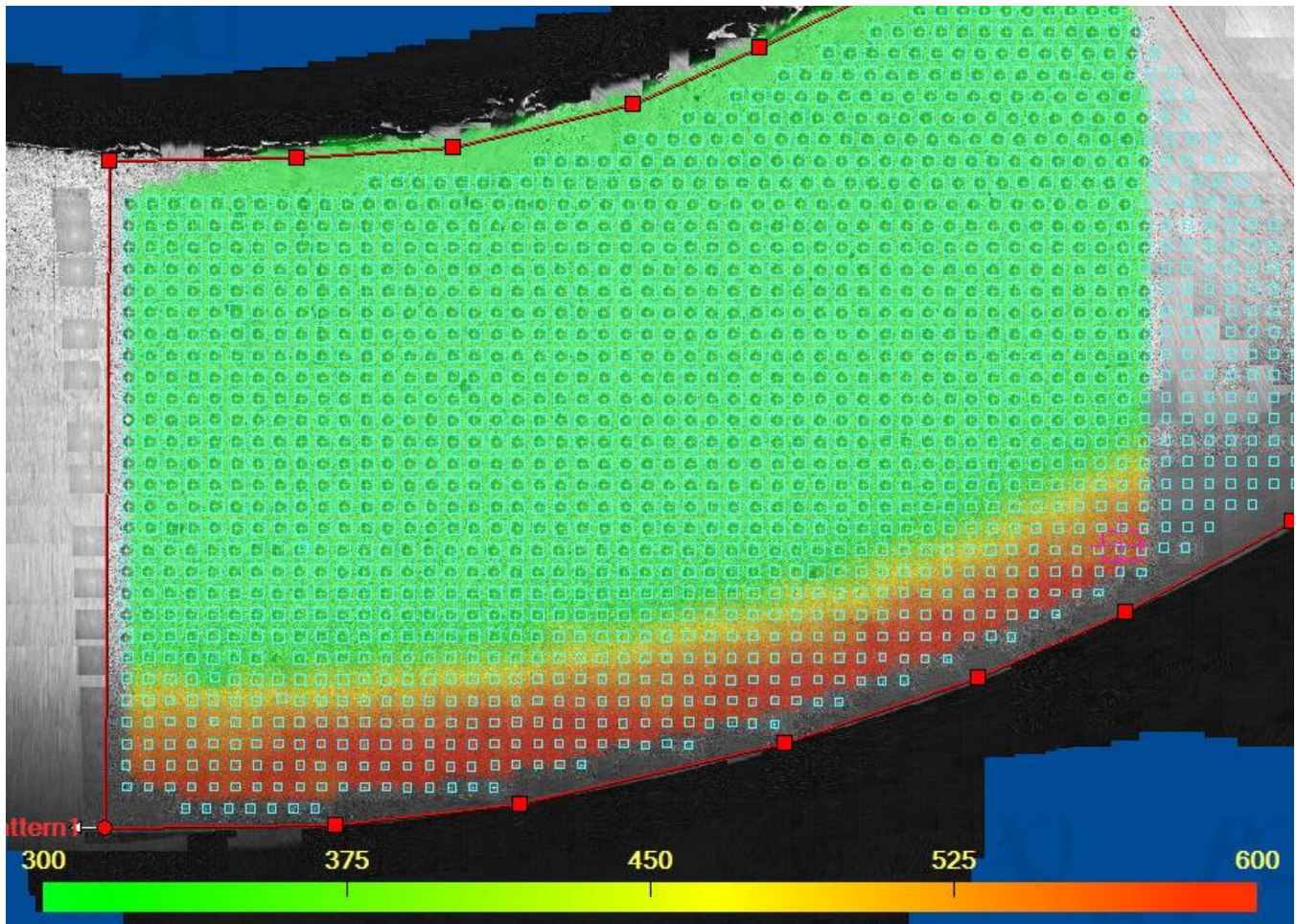


Figure 22 – False color map of microindentation hardness results (in HV500), showing a softer inner core (green, ~300 HV500) and an outer case hardened layer (red, up to 600 HV500). The image is flipped vertically from the Figure 19 orientation.