

NATIONAL TRANSPORTATION SAFETY BOARD

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



January 28, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 18-097

1. ACCIDENT INFORMATION

Place : Pearsall, Texas
Date : August 24, 2017
Vehicle : Air Tractor AT-401, N4532F
NTSB No. : CEN17LA330
Investigator : Andrew Todd Fox, AS-CEN

2. COMPONENTS EXAMINED

No. 9 engine cylinder

3. DETAILS OF THE EXAMINATION

On August 24, 2017, about 1000 central daylight time, an Air Tractor AT-401 sustained substantial damage during a forced landing near Pearsall, TX. The commercial pilot was not injured. The pilot reported that the airplane experienced a partial loss of engine power during a low altitude spray run over a peanut field, noting that the engine was surging and unable to regain “normal engine operation.”

A post-accident examination of the engine, a Pratt & Whitney R-1340 (S/N 41-12807), revealed that the No. 9 cylinder head had fractured.¹ The cylinder was removed and sent to the NTSB Materials Laboratory for additional examination. The engine had accumulated 8899.2 hours since new and 1310.1 hours since the last overhaul on May 2, 2009. The cylinder had not been replaced or repaired during that 2009 overhaul.

Figure 1 and Figure 2 show the components of the engine cylinder assembly, as received. The markings on the side of the cylinder housing stated, “S/N 4 4HN52 L215”. Some of the components exhibited plastic deformation, consistent with impact or compression damage. Figure 3 shows this damage to the tubes on the forward side that contained the pushrods. The inboard tube openings had buckled inward. Likewise, the forward side spark plug exhibited inward buckling deformation, shown in Figure 4.

¹ The Pratt & Whitney R-1340 Wasp is a single-row, nine-cylinder, air-cooled, radial reciprocating aircraft engine first used in 1925. Pratt & Whitney, a subsidiary of United Technologies (UTC), is an American aerospace manufacturer headquartered in East Hartford, CT.

Of note on the cylinder was a large circumferential crack through the housing. The crack is displayed in a series of figures, from Figure 4 through Figure 7. The crack was generally located at the valley between two air cooling fins, although the crack was also located through the forward spark plug hole (Figure 6). The crack was measured circumferentially as 26.3 inches long, with approximately 5.6 inches of the remaining circumference uncracked. One end of the crack terminated at the aft spark plug hole (Figure 4), and the other end was located between two cooling fins 5.6 inches away (Figure 7). The widest opening of the crack, shown in Figure 5, was located 8.5 inches from the bottom side of the inboard flange, and 10.5 inches from the bottom opening of the cylinder.

The remaining intact 5.6 inches of the cylinder between the crack tips was backcut and intentionally overstressed (laboratory opened) to reveal the mating crack faces, or fracture surfaces. These mating fracture surfaces are shown in Figure 8, after opening. As shown in the figure, the fracture surfaces exhibited distinct colors, consistent with exhaust and combustion gasses blowing past the surfaces for different lengths of time. The parts of the fracture surfaces in the middle of the figure exhibited a dark, dull soot color, whereas the rest of the fracture surfaces exhibited a lighter color with white deposits.

Figure 9 shows the outboard side of one of the laboratory-opened fracture surfaces. Macroscopically, the fracture features differed between the darker and lighter areas on the fracture surface. The lighter areas of the fracture surface exhibited a general rough and tortuous morphology, whereas the darker areas exhibited a generally flatter surface morphology. Figure 10 shows this portion of the fracture surface when viewed using oblique lighting. This region of the fracture surface exhibited crack arrest marks and ratchet marks, consistent with progressive cracking from multiple crack initiations sites.

The valve faces and the inner surface of the cylinder, shown in Figure 9, exhibited flat, flaky compounds that adhered to all the inner surfaces. These compounds exhibited a brownish-yellow color, with a waxy luster. Samples of these compounds were examined using energy dispersive x-ray spectroscopy (EDS). The EDS data found these flaky compounds to be consistent with lead oxides and lead bromide, as typified in Figure 11. These compounds were consistent with compounds that form after combustion of tetraethyl lead and 1,2-dibromoethane—the typical anti-knocking and lead-scavenging additives in aviation gasoline (avgas).²

Likewise, the mating outboard fracture surface exhibited a darker-colored region consistent with progressive cracking, and a lighter-colored area with a rougher surface morphology (Figure 12). Figure 13 shows the progressive region of the fracture surface, which exhibited crack arrest marks and multiple ratchet marks. The nature of these features was consistent with crack propagation from outer cylinder surfaces towards the inside.

² Lead II oxide, or PbO, has two polymorphs. The tetragonal structure has a red color, with a greasy, dull luster. The orthorhombic structure is yellow with a red tint, having a greasy, dull luster. At the temperatures found in internal combustion engines, $(\text{CH}_3\text{CH}_2)_4\text{Pb}$ decomposes into lead and lead oxides as well as combustible ethyl radicals.

Figure 14 and Figure 15 show some of the crack initiation sites on the outboard fracture surface. These areas exhibited the aforementioned ratchet and crack arrest marks. There were no discernible discrepancies, such as corrosion pits, wear marks, or machine marks, present at these initiation sites.

A section of the outboard fracture surface was sectioned, cleaned with acetone, and examined using a scanning electron microscope (SEM). A typical area of the progressive region of the fracture surface is illustrated in Figure 16. This portion of the fracture surface exhibited fatigue striations, consistent with fatigue cracking. Even with acetone cleaning, the fracture surface still exhibited oxidation, consistent with metal exposure to oxidative conditions at elevated temperatures. This oxidation obscured some of the details of the underlying fatigue striations (Figure 17).

The presence of multiple ratchet marks on the fracture surface was consistent with multiple fatigue cracks that coalesce as they propagated from their individual initiation sites. As typified in Figure 18, these initiation sites were located on the outer surface of the cylinder in a root between two cooling fins. There were no discernible features at the crack initiation sites, such as corrosion pits, inclusions, or mechanical damage marks, that would have led to early fatigue crack initiation. As shown in Figure 18, solidification voids were present throughout the fracture surface. However, in examining the orientation of the fatigue striations near the initiation sites (Figure 19), they were not consistent with crack initiation at the voids.

Outside the fatigue crack region, the fracture surface exhibited dimple rupture and ductile tearing, shown in Figure 20. The dimple rupture and tearing features were consistent with those present in the intentional overstressed areas (Figure 21). The areas outside of the fatigue cracking were consistent with subsequent overstress fracture.

One of the cooling fins near the fracture surface was sectioned, mounted and polished. The chemical composition of the cylinder was inspected using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). A typical EDS spectrum is shown in Figure 22. The composition was consistent with an AA 200-series aluminum casting alloy.

Figure 23 and Figure 24 show a typical area of the microstructure, as polished. The microstructure was dendritic, typical of cast parts. The interdendritic phases, shown as darker gray in the figures, were consistent with the last material to freeze during the casting process.

As shown in Figure 23, there were dark, globule-shaped areas along the interdendritic regions, consistent with solidification porosity. While examination of the fracture surface did not find any indications that the porosity acted as fatigue crack initiation sites, some subsurface cracking was found in the metallographic examination of the cylinder microstructure. Figure 25 shows cracking below the surface of the cooling fin. This cracking was located along the interdendritic regions, where some of the second phases had fractured locally, and/or where solidification porosity was located.

The hardness of the cylinder fin cross section was inspected per ASTM E384.³ The hardness averaged 68 HV₅₀₀. The electrical conductivity was inspected per ASTM E1004, and averaged 41.1 %IACS.⁴ These data were consistent with those typical of this alloy having been in the as-fabricated (or as-cast) condition.

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

⁴ ASTM E1004 – *Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*. ASTM International, West Conshohocken, PA



Figure 1 – The No. 9 engine cylinder viewed from the aft side, as received.

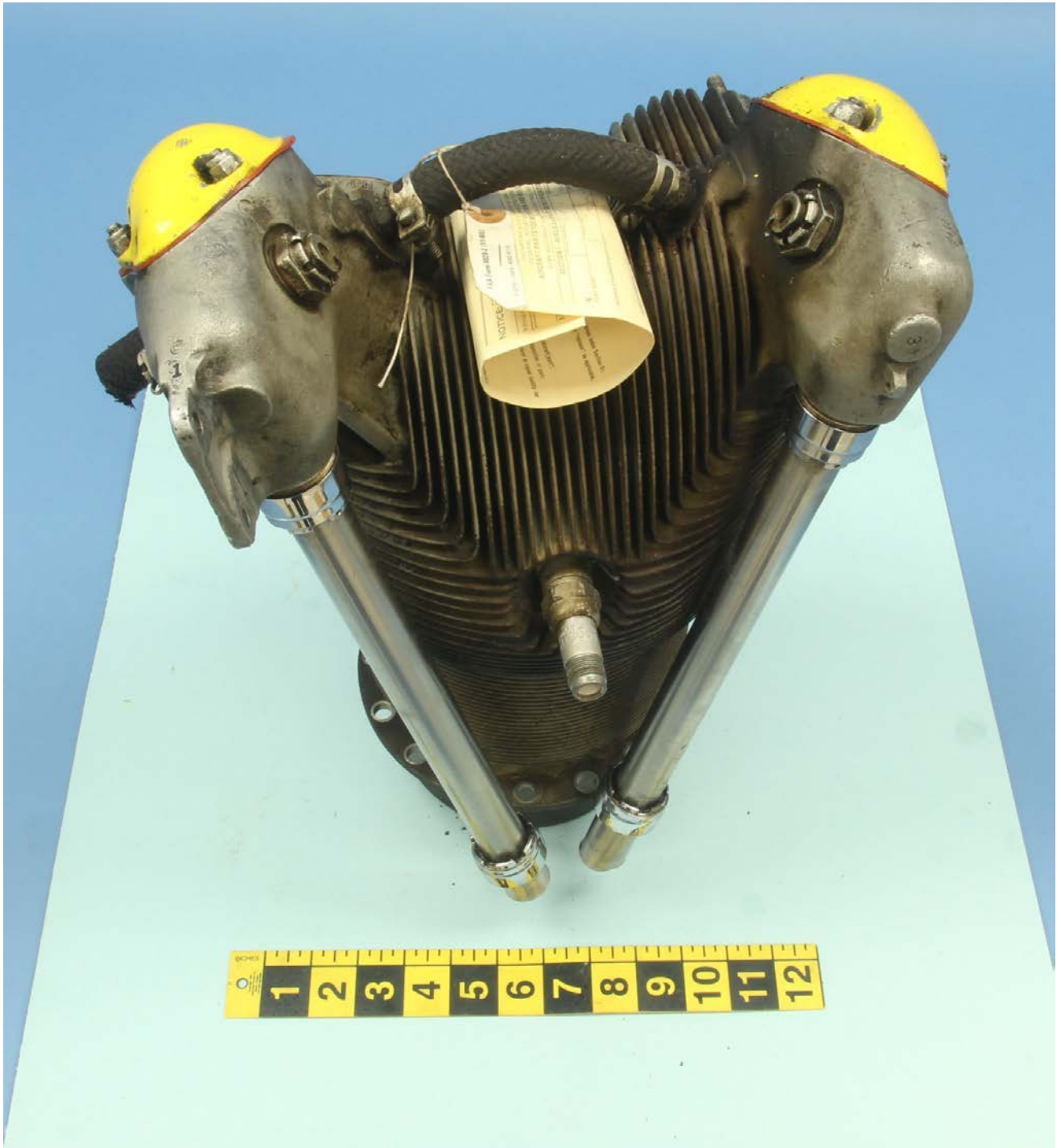


Figure 2 – The No. 9 engine cylinder viewed from the forward side, as received.



Figure 3 – The pushrod tubes on the forward side of the engine, showing denting damage.



Figure 4 – View of the aft spark plug, showing denting damage and the end of the crack between two cooling fins.



Figure 5 – The crack in the cylinder, rotated 90 from Figure 4, showing the largest opening.



Figure 6 – The cylinder crack, viewed from the forward side (or rotated 90 from Figure 5).



Figure 7 – View of the other end of the cylinder crack, rotated 90° from Figure 6.



Figure 8 – View of the fracture surfaces of the cylinder crack, after laboratory opening.



Figure 9 – The outboard mating fracture surface, annotated to show the different fracture regions.



Figure 10 – The progressive area of the outboard fracture surface, using oblique lighting.

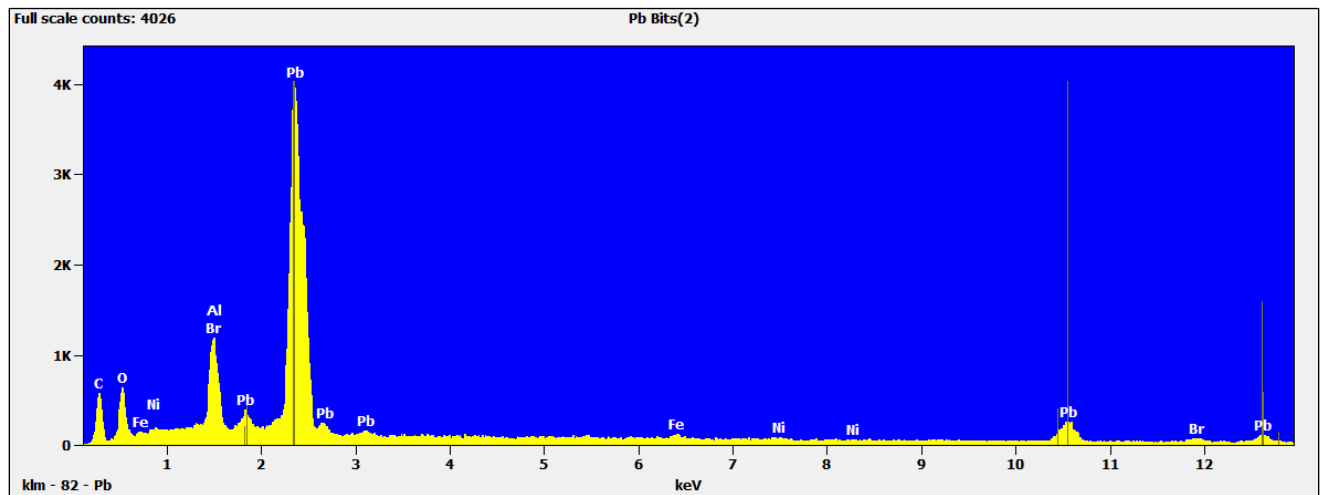


Figure 11 – EDS spectrum of the flaky compounds in the cylinder surface in Figure 10.

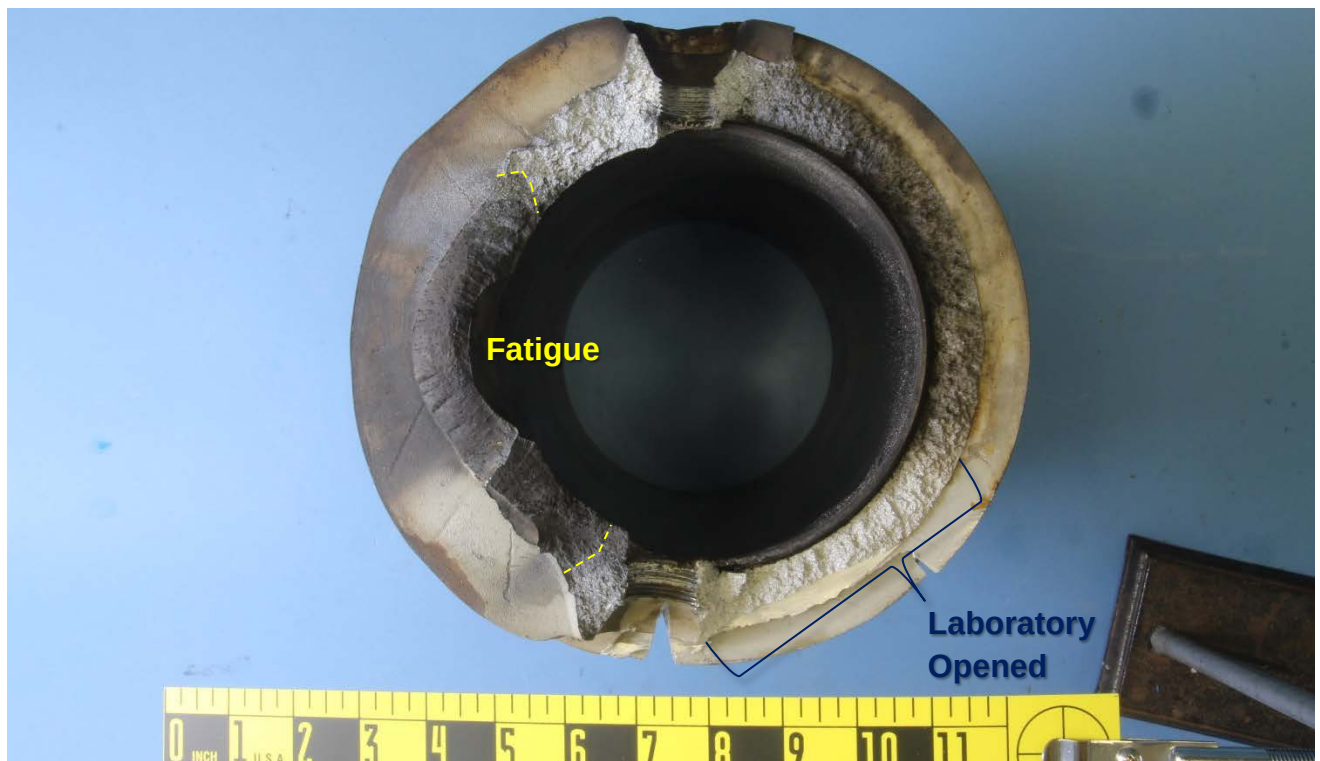


Figure 12 – The inboard mating fracture surface, annotated to show the different fracture regions.



Figure 13 – The fatigue area of the outboard fracture surface, using oblique lighting.



Figure 14 – Closer view of the crack initiation sites, showing ratchet marks and crack arrest marks.



Figure 15 – Closer view of the crack initiation sites tilted at an angle, showing the cooling fin valley.

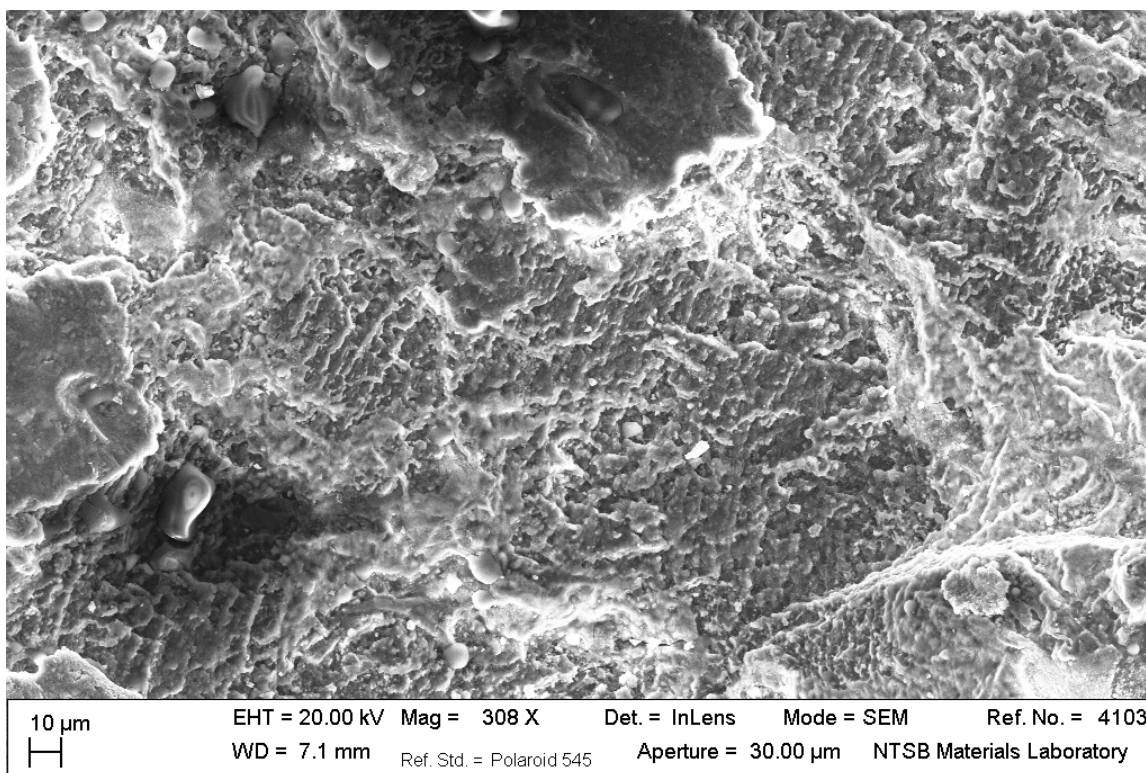


Figure 16 – Secondary electron (SE) micrograph of fatigue striation on mid-distance of the inboard fracture surface.

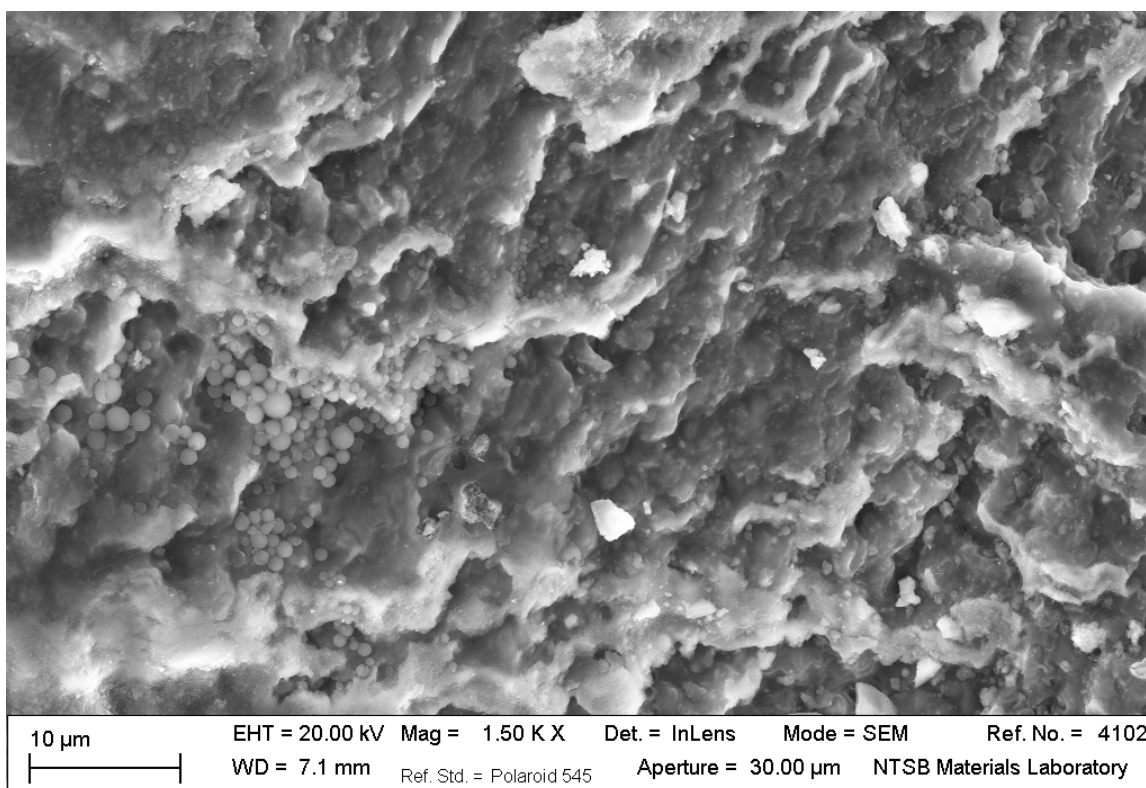


Figure 17 – SE micrograph showing a closer view of the striations in Figure 16.

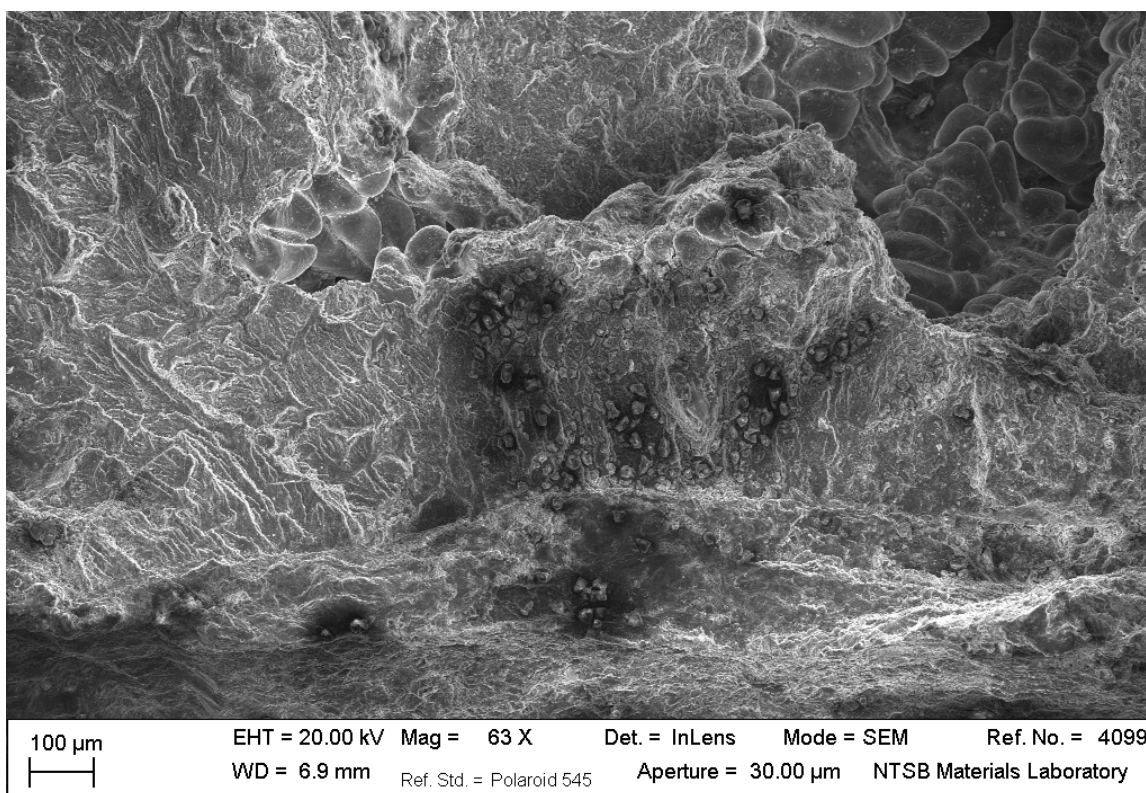


Figure 18 – SE micrograph of one of the fatigue crack initiation sites.

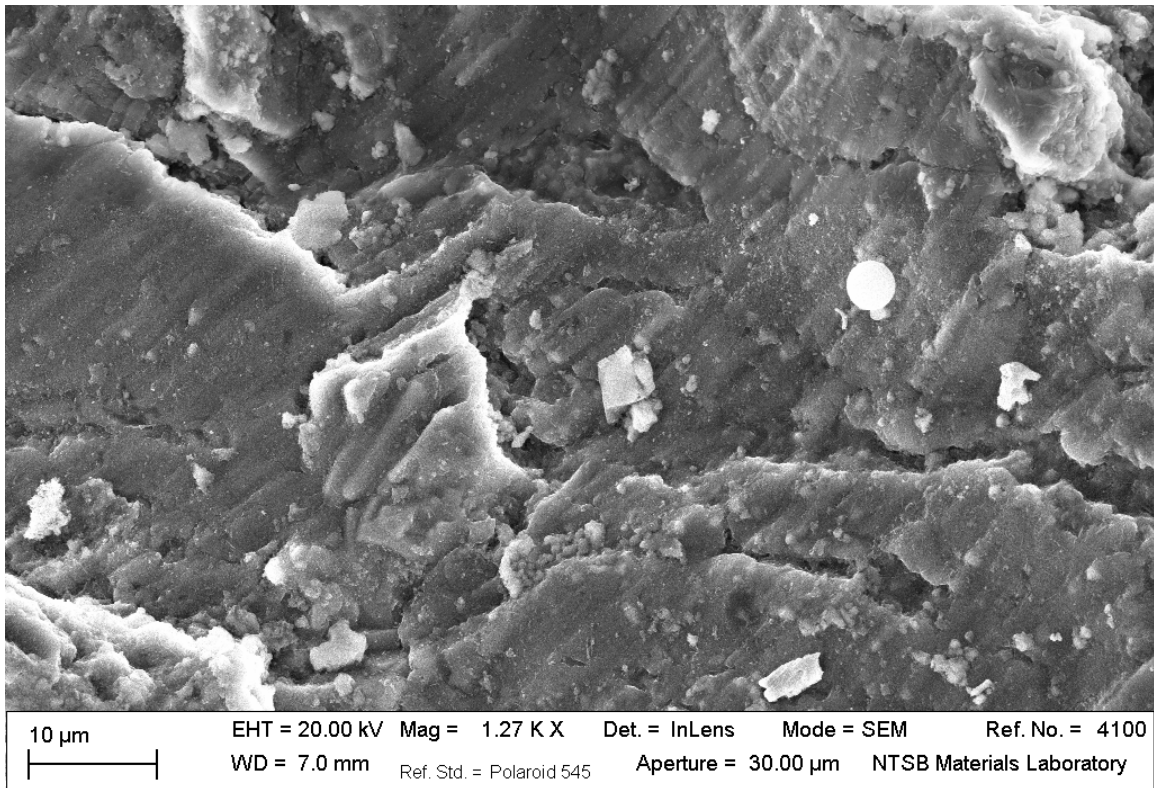


Figure 19 – SE micrograph of fatigue striations near a crack initiation site.

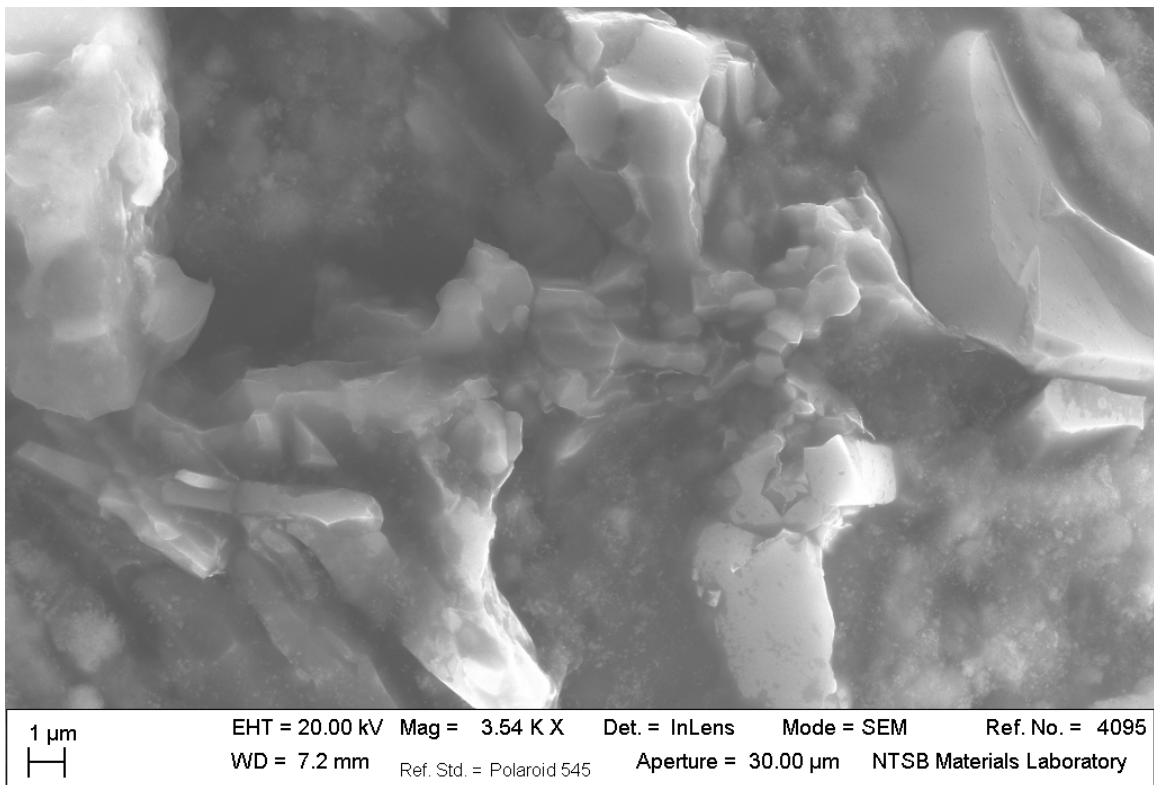


Figure 20 – SE micrograph showing dimple rupture and tearing on the fracture surface outside the fatigue cracking region.

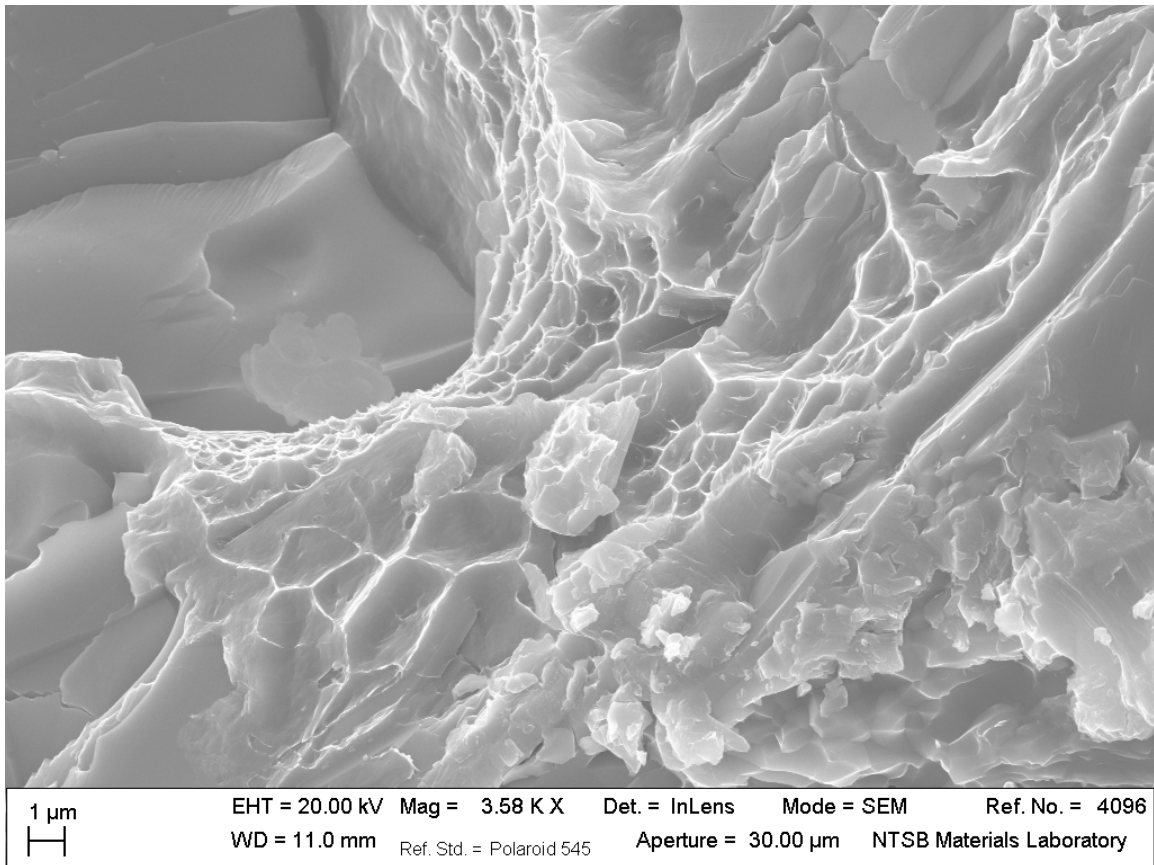


Figure 21 – SE micrograph dimple rupture in the laboratory-opened part of the fracture surface.

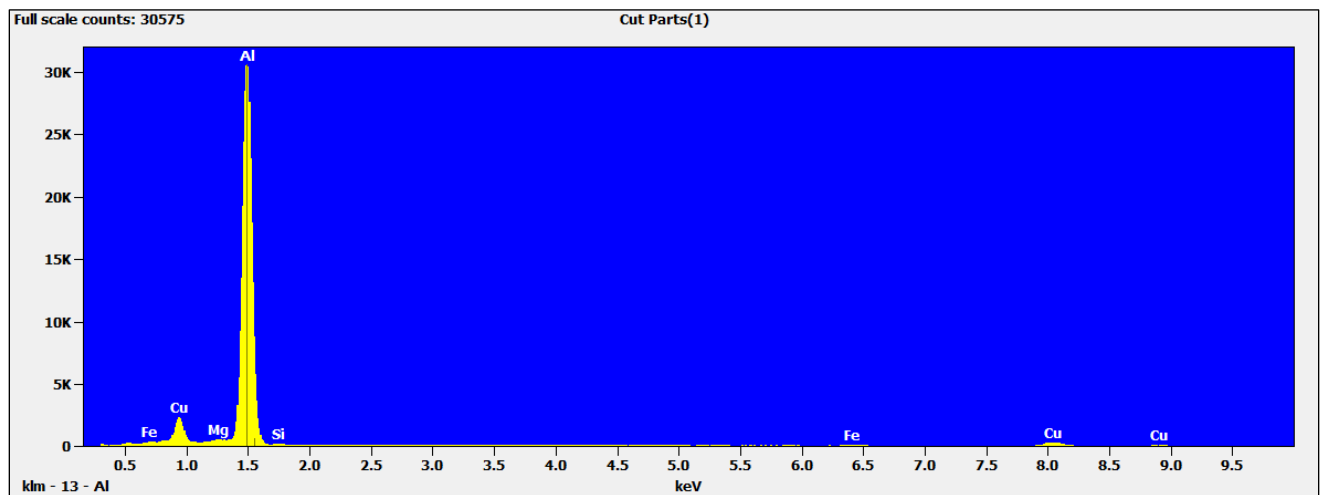


Figure 22 – EDS spectrum of a typical area of the cylinder outer housing.

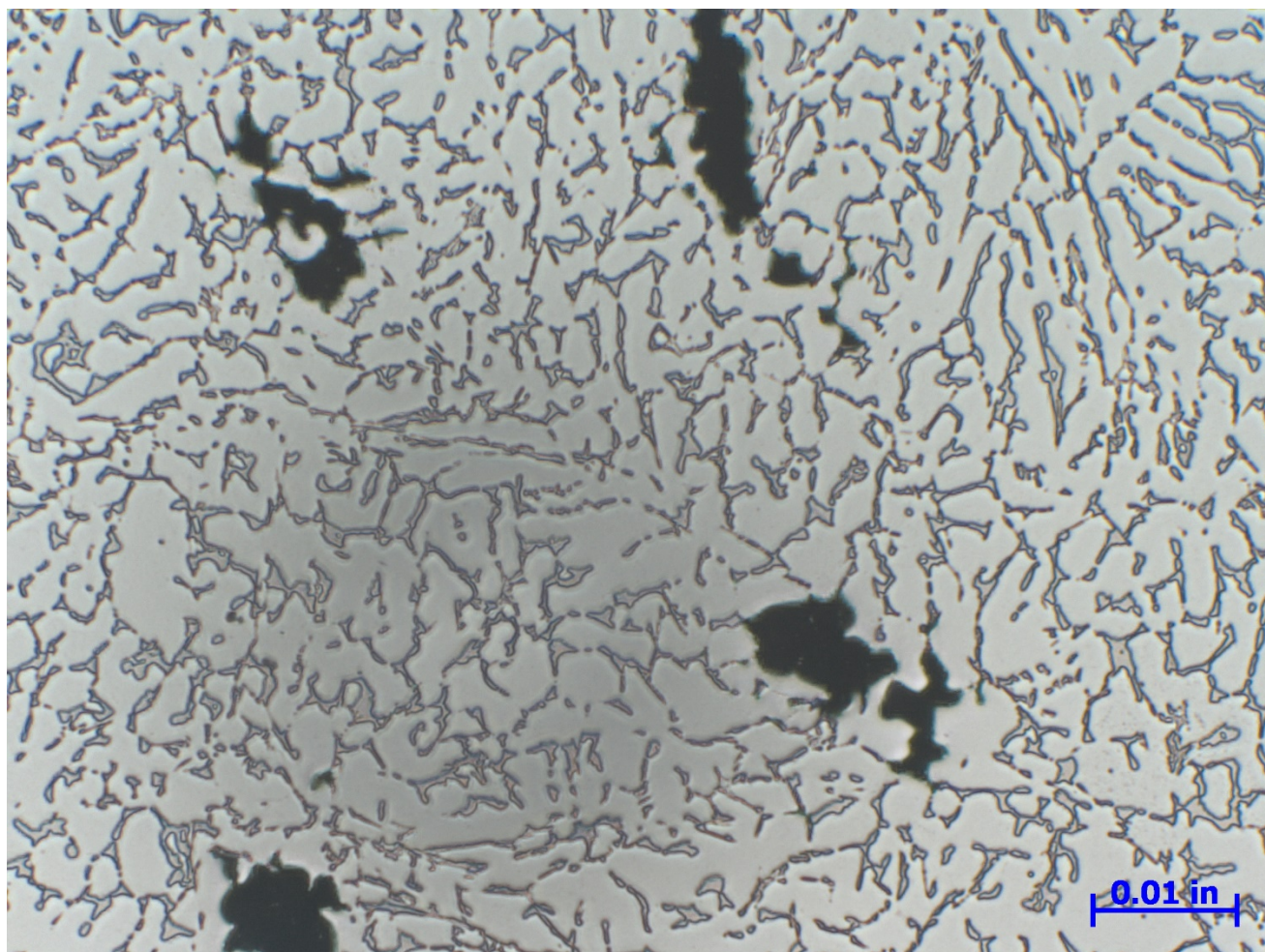


Figure 23 – Bright field (BF) optical micrograph of a typical area of the cylinder housing microstructure, showing a typical casting dendritic structure with some solidification voids (black) (~50X, as-polished).

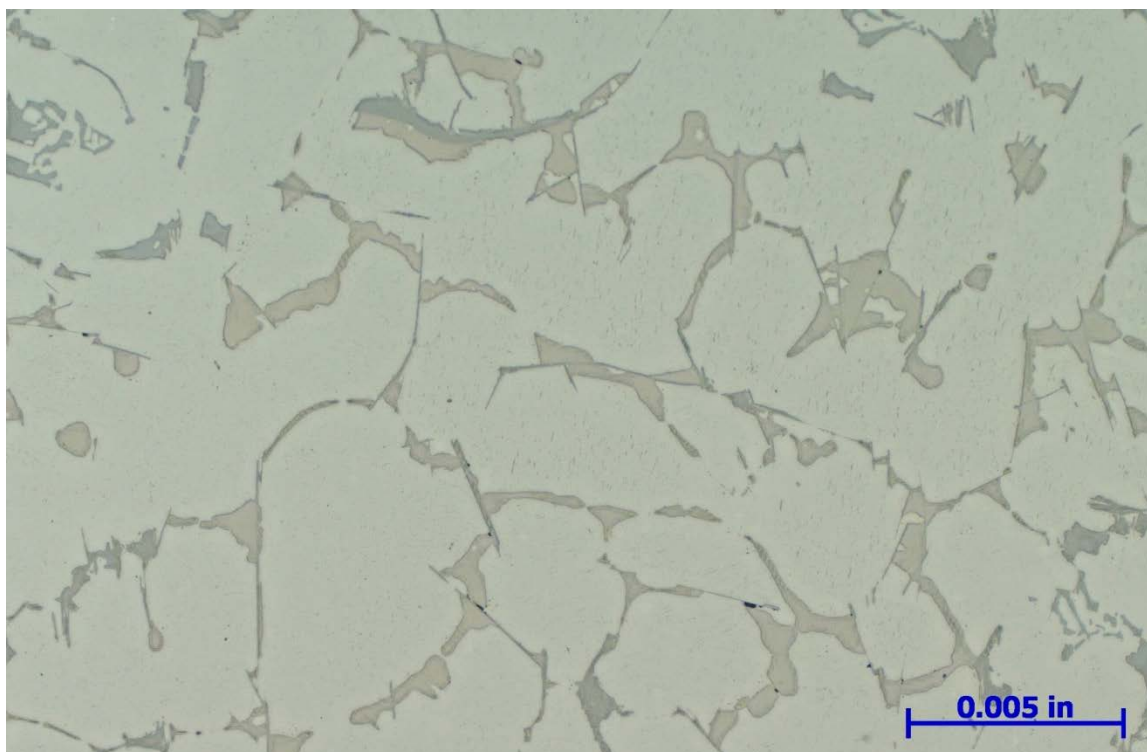


Figure 24 – BF optical micrograph the cylinder housing microstructure, showing the interdendritic phases (darker gray) (~500X, as-polished).

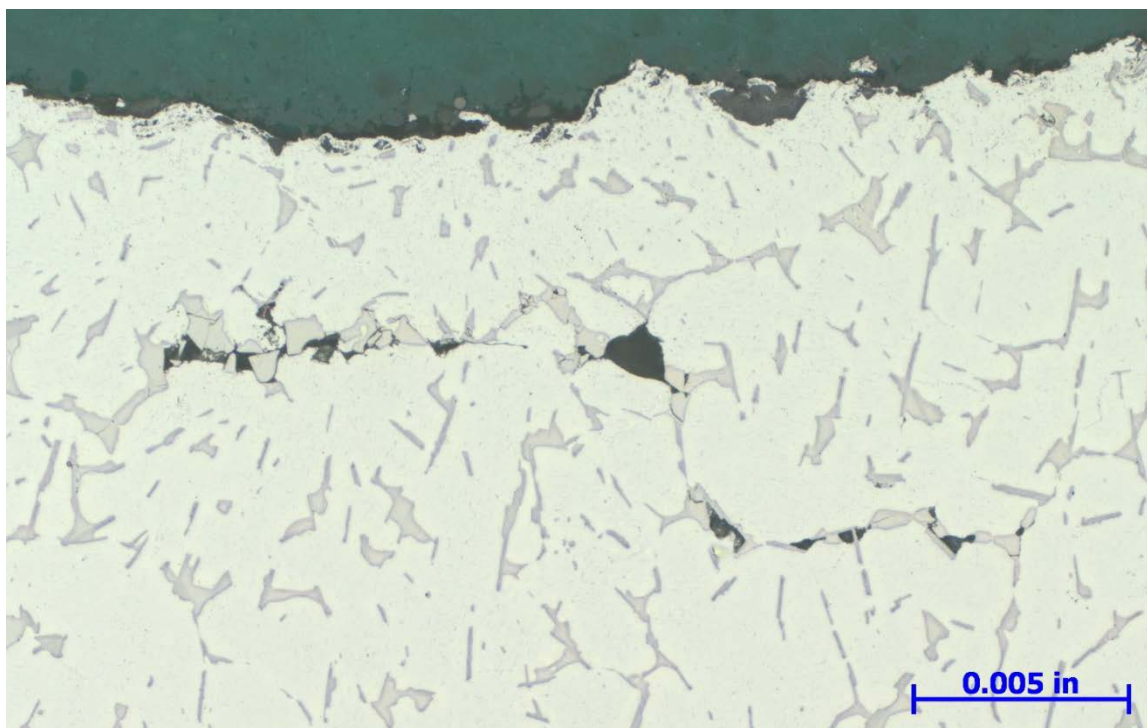


Figure 25 – BF optical micrograph, showing subsurface interdendritic cracking with some surface corrosion (~500X, as-polished).