

NATIONAL TRANSPORTATION SAFETY BOARD

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



April 17, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 18-024

1. ACCIDENT INFORMATION

Place : Beckville, Texas
Date : August 14, 2017
Vehicle : Piper PA-22-135, N2591A
NTSB No. : CEN17LA317
Investigator : Tim Sorensen, AS-CEN

2. COMPONENTS EXAMINED

Parts from No. 3 cylinder assembly
Fractured remnants of No. 3 piston
Remnant of No. 3 exhaust valve
Piston pin
Spark plug

3. DETAILS OF THE EXAMINATION

On August 14, 2017, about 1017 central daylight time, a Piper PA-22-135 was substantially damaged during a forced landing following a partial loss of engine power near Beckville, Texas. The pilot sustained minor injuries. The pilot stated that the engine partially lost power after about 2 hours into the flight. His efforts to restore full power were unsuccessful, and the pilot executed a forced landing in a pasture. A detailed examination of the airplane occurred after recovery from the accident site. Several components from the Lycoming O-290 series engine were sent to the NTSB Materials Laboratory for further examination.¹

Figure 1 through Figure 3 show the #3 cylinder assembly from the accident engine, as received. As shown in upper left of Figure 1, the areas in and around the exhaust port, such as the cooling fins, exhibited white-colored coking deposits. These were consistent with exposure to elevated temperatures. Several components had already been removed or disassembled, notably the rocker box cover and pushrods, as seen in Figure 2. There was no observable plastic deformation or wear with the rocker arms or shaft, and all the components appeared to be coated with engine oil.

¹ The O-290 is a family of dual ignition, four-cylinder, air-cooled, horizontally opposed aircraft engines, manufactured by Lycoming Engines, headquartered in Williamsport, PA.

The interior combustion chamber of the #3 cylinder is shown in Figure 3 and Figure 4. These interior surfaces exhibited severe batter, scraping marks, and gouging on the one of the cylinder side walls. Many of these batter and impact marks were semi-circular or curved, consistent with the size and shape of the exhaust valve head (shown later in Figure 11a and Figure 11b). As shown in Figure 4, regions of white- and yellow-colored deposits, consistent with lead-based compounds, were present on the corners of the cylinder and the face of the intake valve.

The intake valve was intact and still in place, along with the stem of the exhaust valve. However, the head of the exhaust valve had fractured from the exhaust valve stem. Figure 4 shows a closer view of the fracture surface of the exhaust valve stem, in position in the valve guide within the valve seat. The valve seat recess showed indications of deformation on the edges, as well as the white- and yellow-colored compounds, consistent with lead-based compounds.

Figure 5 shows the piston pin, as received. The pin exhibited two darker circumferential marks, consistent with the position of the connecting rod pin bore (not received). The pin did not exhibit any other features consistent with significant sliding wear or damage prior to or during the accident.

Figure 6 shows the spark plug removed from the #3 cylinder, as received. The spark plug exhibited dark viscous oil deposits on the side and the head. The side electrode tip of the spark plug appeared shiny and reflective, consistent with impact damage from an adjacent component. There was no other damage present on the either electrode of the spark plug.

Figure 7 and Figure 8 show the parts of the piston assembly, as received. The piston had fractured in several locations, as shown in Figure 7a and Figure 7b. These fracture surfaces were dull in luster and rough in texture—features consistent with overstress fracture. The fractures were primarily located about the piston pin bore. A separate fragment submitted with the pin also exhibited fracture features consistent with overstress (Figure 8). Two fragments of one of the oil guide rings were received with the piston, both of which exhibited features consistent with overstress fracture. No features consistent with pre-existing cracking were observed on the piston or other components of the piston assembly.

The crown of the piston, shown in Figure 7b, exhibited multiple batter and impact marks. Like the combustion chamber of the cylinder, the impact marks were semicircular in shape, with one mark severe enough to penetrate the thickness of the piston crown. These marks were consistent with batter from the fractured exhaust valve head, shown in Figure 9 through Figure 11.

The fractured halves of the exhaust valve are shown in Figure 9 and Figure 10 after disassembly and removal from the cylinder assembly. The exhaust valve had fractured where the head geometry transitioned to the stem. Both fractured fragments exhibited dark coloring consistent with engine deposits. Figure 11 shows a closer view of the fractured

exhaust valve head from both sides. Three distinct portions of the exhaust valve head were severely deformed or missing. The face of the fractured valve head exhibited circular marks, consistent with impacts with the intake valve and/or the exhaust valve seat recess in the cylinder. These features were consistent with post-fracture batter inside the cylinder combustion chamber.

Due to the post-fracture batter damage, the fracture surface on the separated valve head was obliterated (see Figure 11a). However, the mating fracture surface on the stem was relatively undamaged and exhibited macroscopic fracture features. As shown in Figure 12 and Figure 13, the stem was found tapered or necked adjacent to the fracture surface—this tapering was not consistent with the design geometry of the part. The area of the valve stem adjacent to the tapered area exhibited dark and light non-metallic deposits. The fracture surface, shown in Figure 14, exhibited a rough texture and dull luster, with several ridges. The ridges exhibited a general radial pattern from the center outward. The orientation of these ridges was consistent with torsional loading at fracture.

The valve stem fracture surface was sectioned, cleaned, and examined using a scanning electron microscope (SEM). A typical area of the fracture surface is illustrated in Figure 15. Much of the fracture surface was non-conductive as evidenced by the charging effects witnessed in the SEM, consistent with post-fracture oxidation. Many of these oxides were small blocky-shaped deposits (see Figure 16). Portions of the fracture surface exhibited interconnected voids open to the surface (Figure 17). These voids, along with the tapered region of the stem near the fracture surface, were consistent with high-temperature deformation under stress.

The chemical composition of the exhaust valve was examined using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The chemical composition of a cross-sectioned polished portion of the valve stem was consistent with a stainless steel alloy. The fracture surface compounds (shown in Figure 16) were examined using EDS, with a typical spectrum illustrated in Figure 18. These deposits had elevated levels of lead (Pb), bromine (Br), along with phosphorus (P) and chlorine (Cl). The high lead and bromine contents were consistent with deposits from oxidation of anti-knocking compounds added to aviation fuel. The deposits on the outside of the valve stem were also examined using EDS, with a typical spectrum shown in Figure 19. This spectrum had elevated levels of chromium (Cr), iron (Fe), and nickel (Ni), which were the primary constituents of the valve alloy. This spectrum also exhibited elevated levels of lead, bromine, and phosphorus.

The valve stem was cross sectioned through the fracture surface and tapered end, mounted and polished. A typical region of the microstructure away from the fracture surface and the tapered end is shown in Figure 20 and Figure 21. The microstructure exhibited general grain flow in the direction of the stem direction, with general equiaxed-shaped grains. The grain boundaries did exhibit high carbide formation, consistent with exposure to elevated temperatures in excess of 800 °F (425 °C). Figure 22 and Figure 23 show a typical area of the microstructure adjacent to the fracture surface. As shown in Figure 22, the fracture surface exhibited intergranular oxidation and excessive grain flow.

A closer examination of the microstructure in this area (Figure 23) showed a different structure than in Figure 22, with larger grains and large blocky chromium carbides in an austenitic matrix, consistent with exposure to even higher temperatures.

Portions of the valve stem surface away from the fracture surface exhibited subsurface bulk oxidation, as illustrated in Figure 24. This oxidation penetrated 0.005 to 0.010 inches into the surface of the valve (shown dark in Figure 24 and Figure 25). The portions of the valve alloy material adjacent to the surface oxidation exhibited subsurface oxidation and porosity, concentrated along the grain boundaries. These features were consistent with high-temperature oxidation processes over an extended period.

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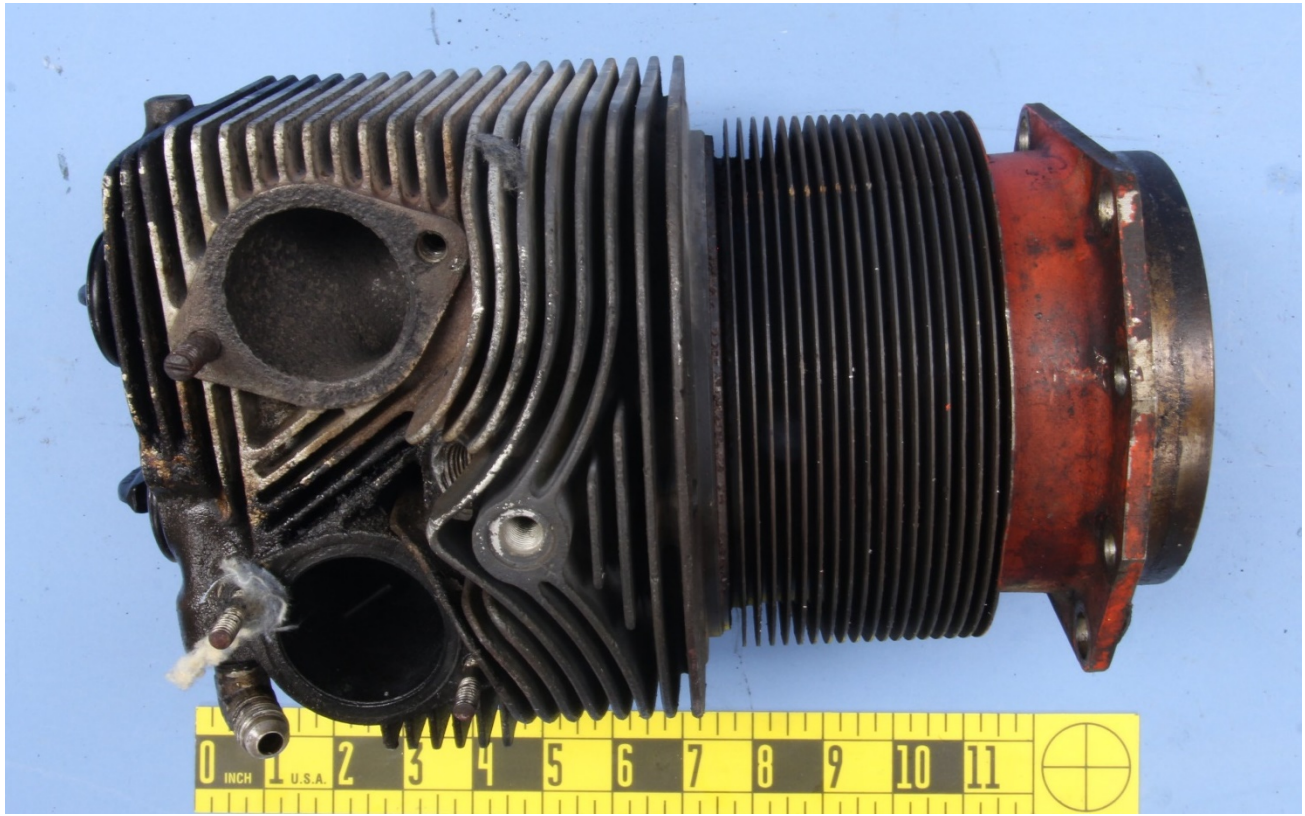


Figure 1 – The #3 cylinder, as received, viewed from the side. The engine valve rocker cover had been removed prior to receipt.

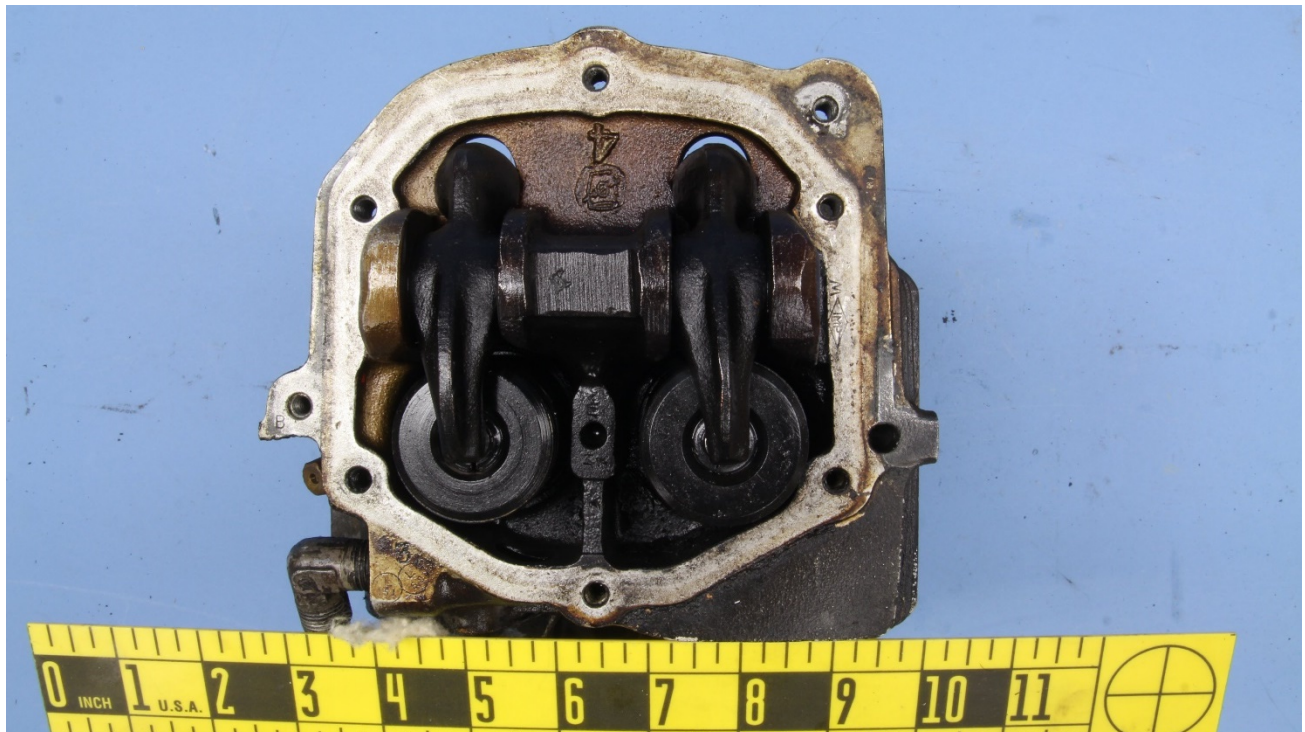


Figure 2 – The rocker section of the #3 cylinder, as received.



Figure 3 – The piston chamber of the #3 cylinder, as received, showing the exhaust valve stem fragment on the right.



Figure 4 – A closer view of the piston chamber of the cylinder, showing the exhaust valve stem fracture surface on the bottom.

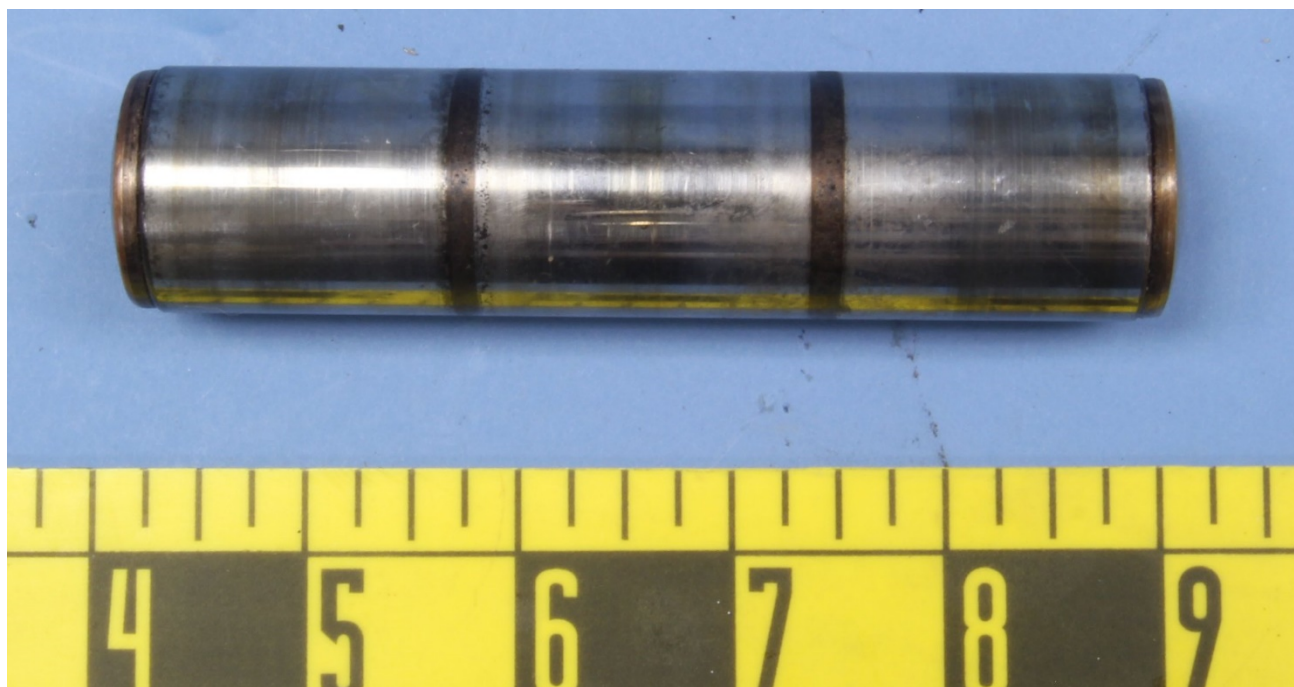


Figure 5 – The piston pin from the #3 piston, as received.



Figure 6 – One of the spark plugs from the #3 cylinder, as received, viewed from (a) the side and (b) from the electrode side.



Figure 7 – The remanats of the piston, as received, viewed from (a) the skirt underside and (b) the crown.

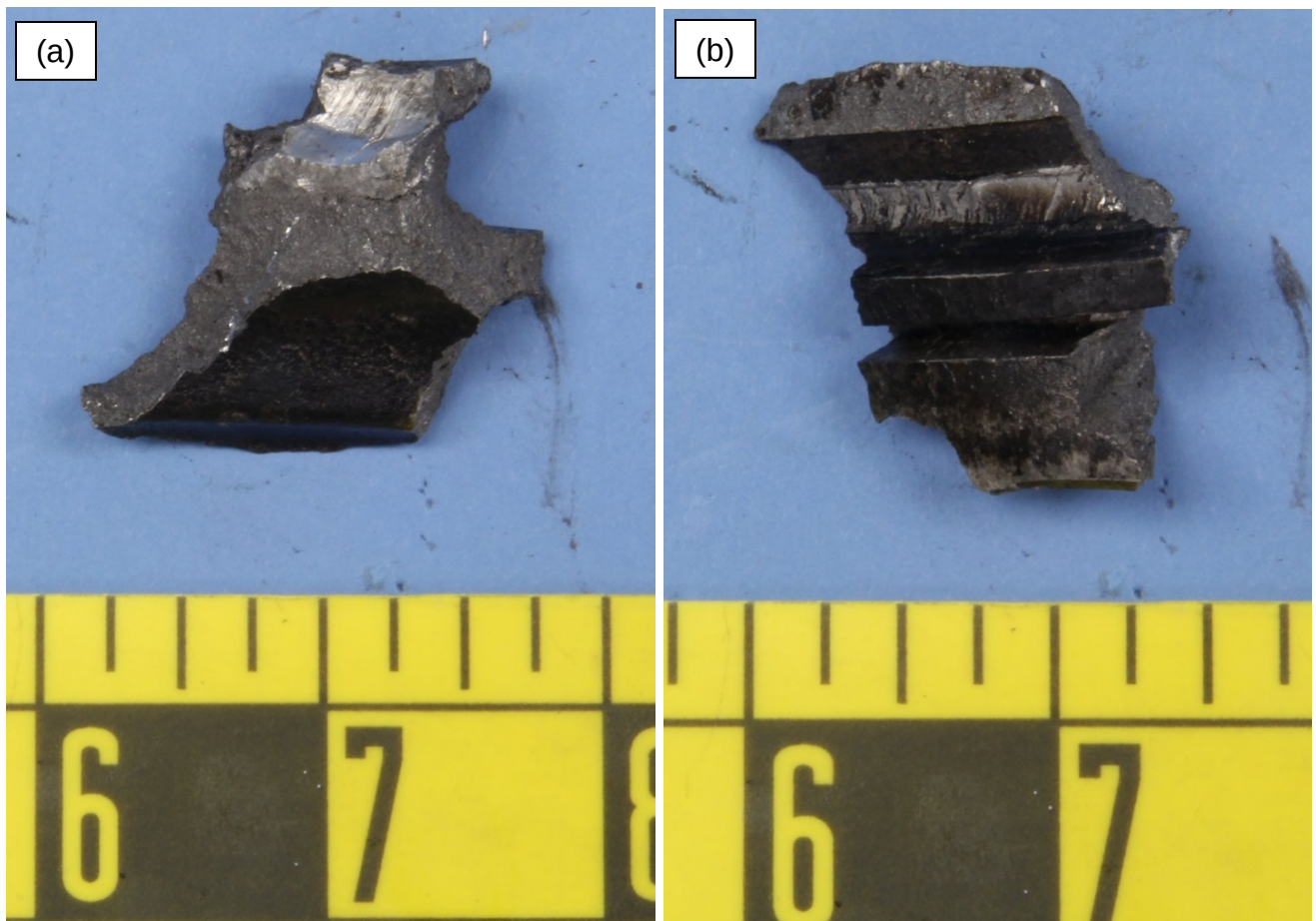


Figure 8 – The piston fragment viewed from (a) the fracture surface and (b) the reverse side.



Figure 9 – The exhaust valve stem and exhaust valve head, after removal from the cylinder assembly, viewed from the fracture surface on the head.



Figure 10 – The exhaust valve parts, shown on the side with the mating fracture surfaces facing each other.

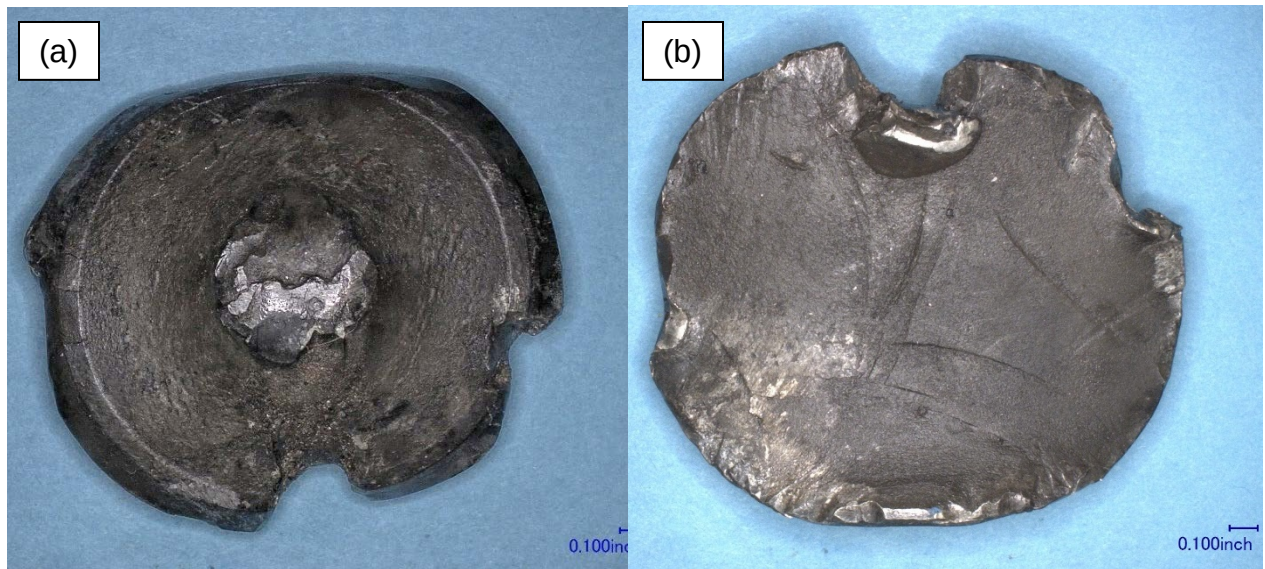


Figure 11 – The exhaust valve head viewed from (a) the fractured stem side and (b) the cylinder chamber side.



Figure 12 – Closer view of the exhaust valve stem fracture from the side, showing a tapered geometry near the fracture and dark non-metallic compounds on the surface.



Figure 13 – The exhaust valve stem fracture from the side, rotated 180° from Figure 12.



Figure 14 – Closer view of the exahust valve stem fracture surface, after sectioning.

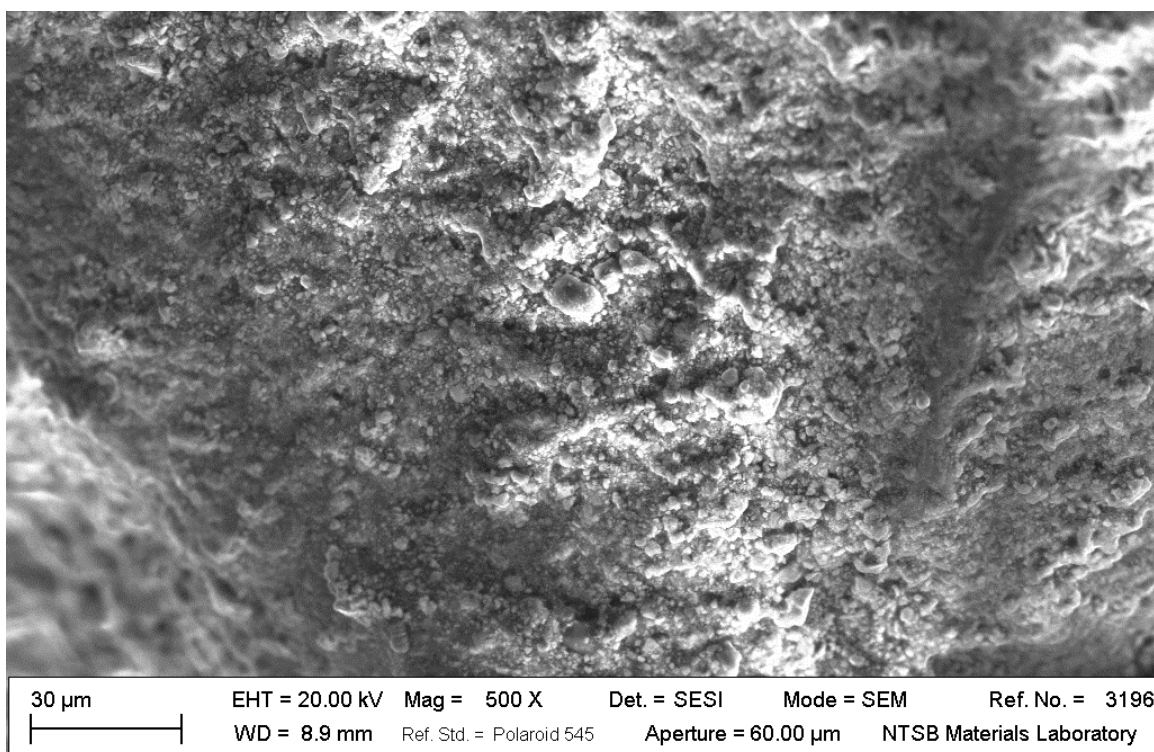


Figure 15 – Secondary electron (SE) micrograph of a typical area of the exhaust valve fracture surface.

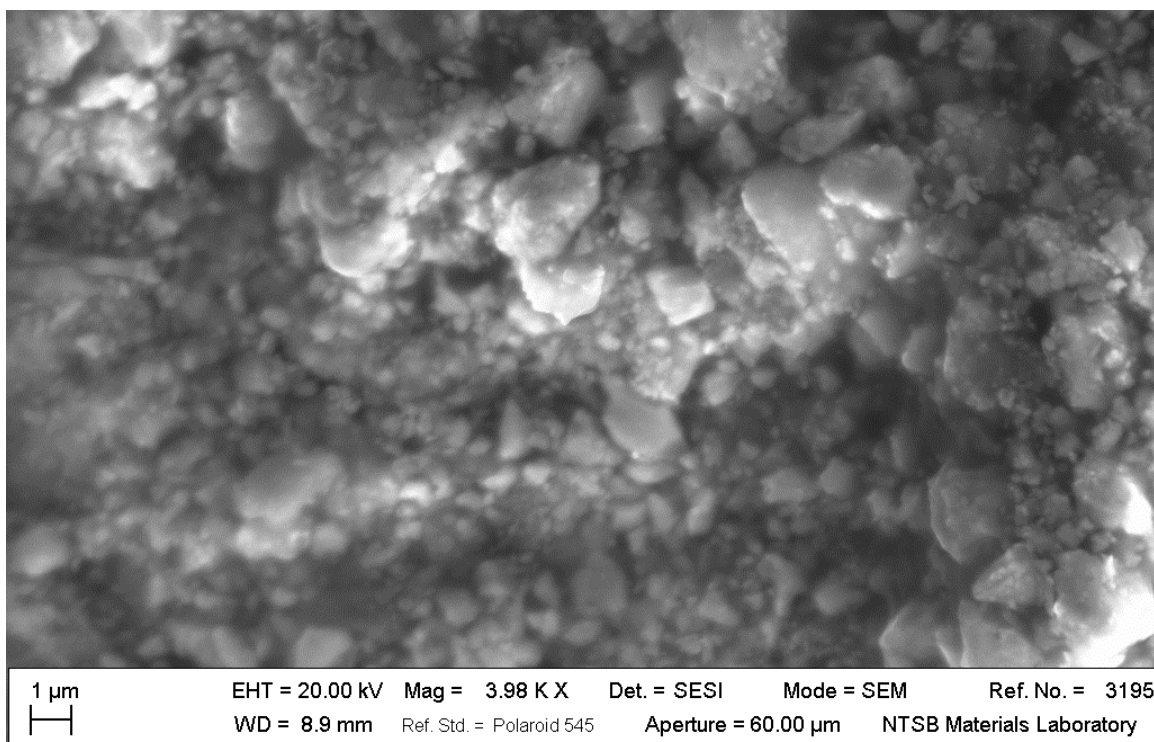


Figure 16 – SE micrograph of a closer area of Figure 15, showing small compound particles.

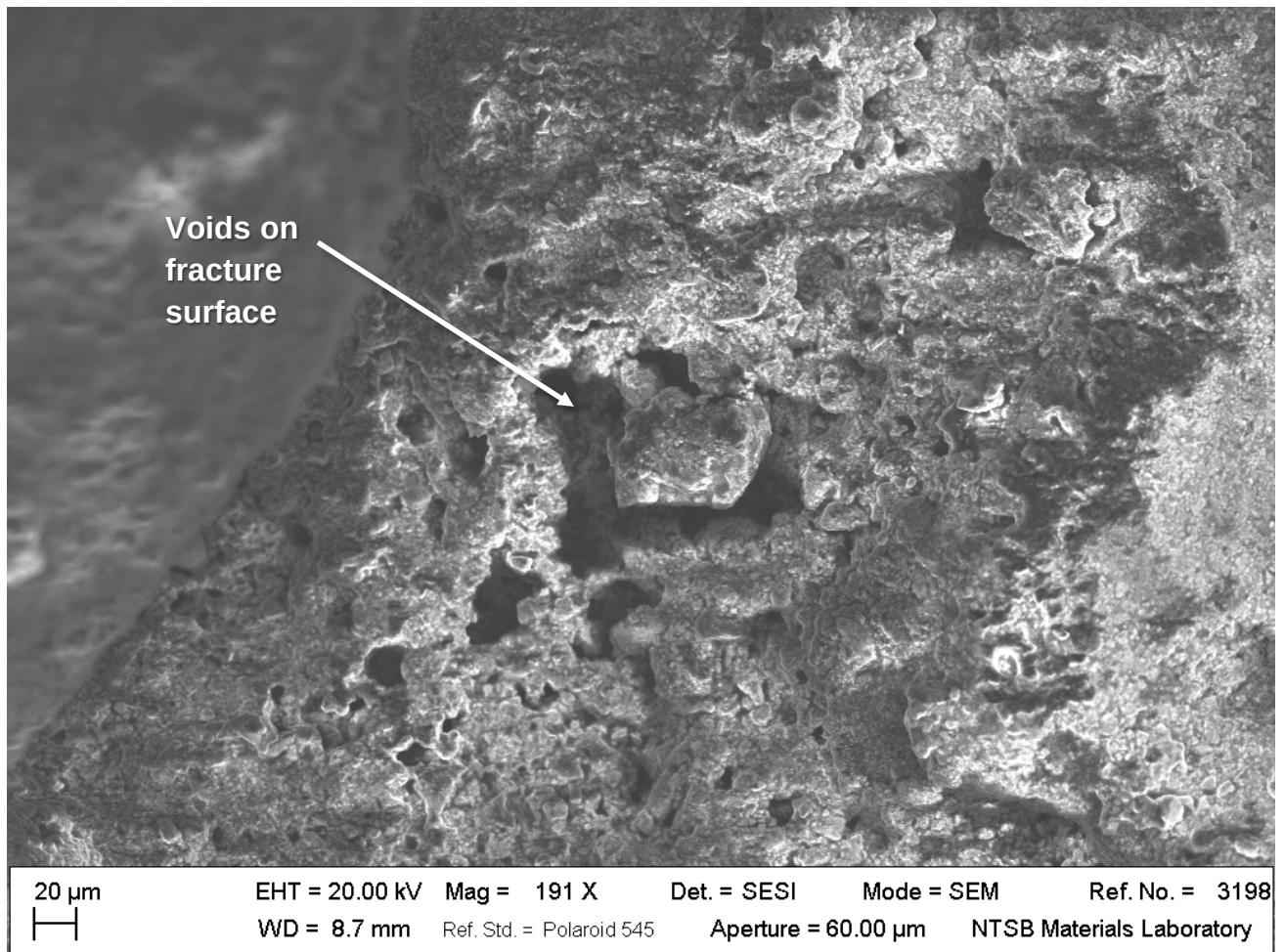


Figure 17 – SE micrograph showing voids (dark) on the valve stem fracture surface.

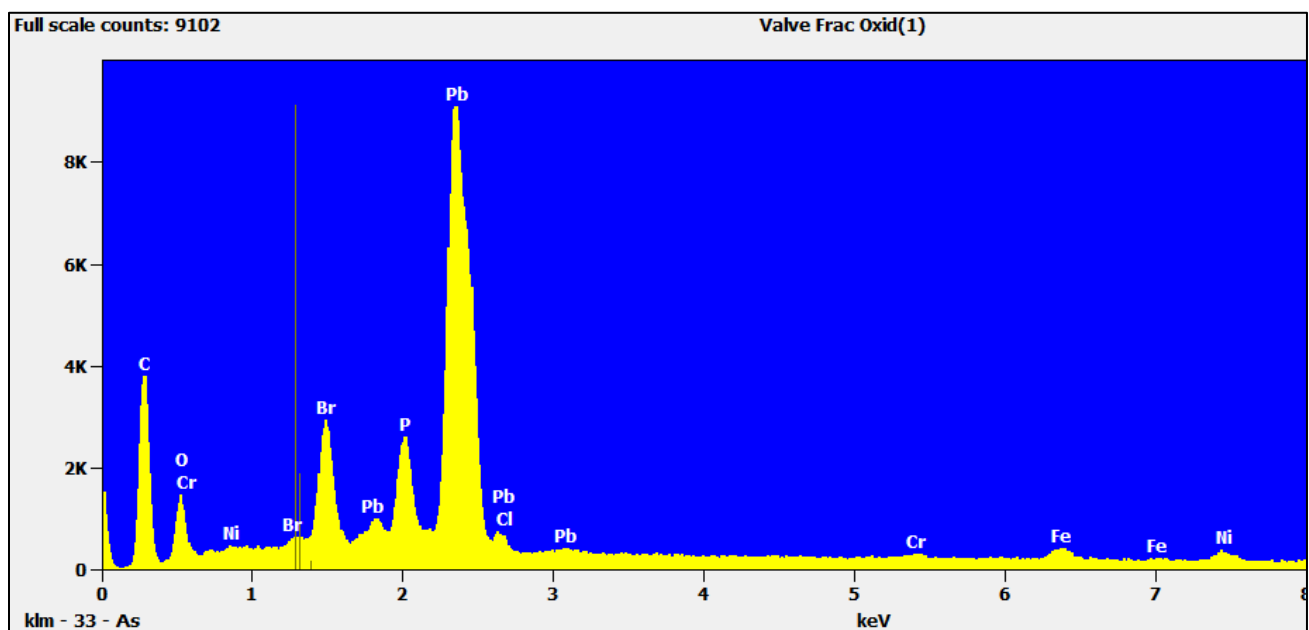


Figure 18 – EDS spectrum of the exhaust valve fracture surface (from Figure 16).

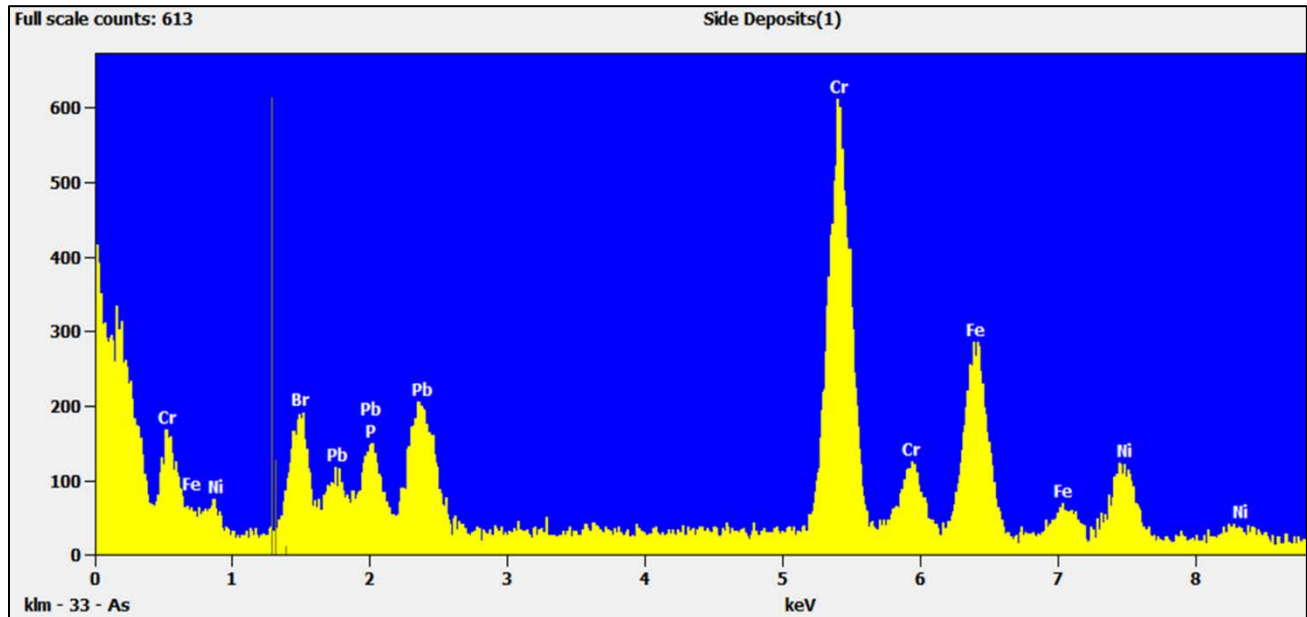


Figure 19 – EDS spectrum from deposits on the exhaust valve stem.

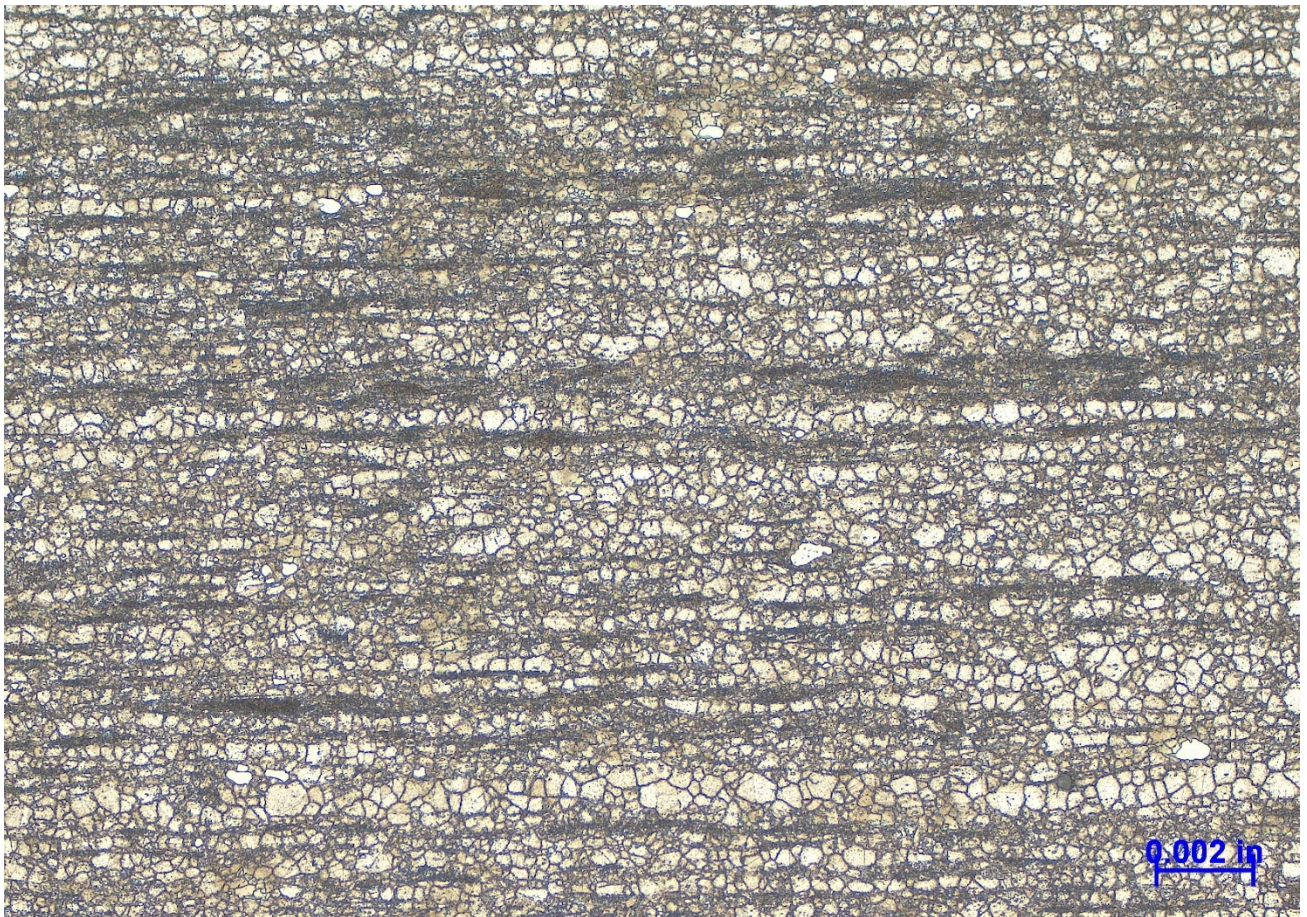


Figure 20 – Bright field (BF) optical micrograph of a typical area of the exhaust valve microstructure away from the fracture surface (~200X, etched Fry's Reagent).

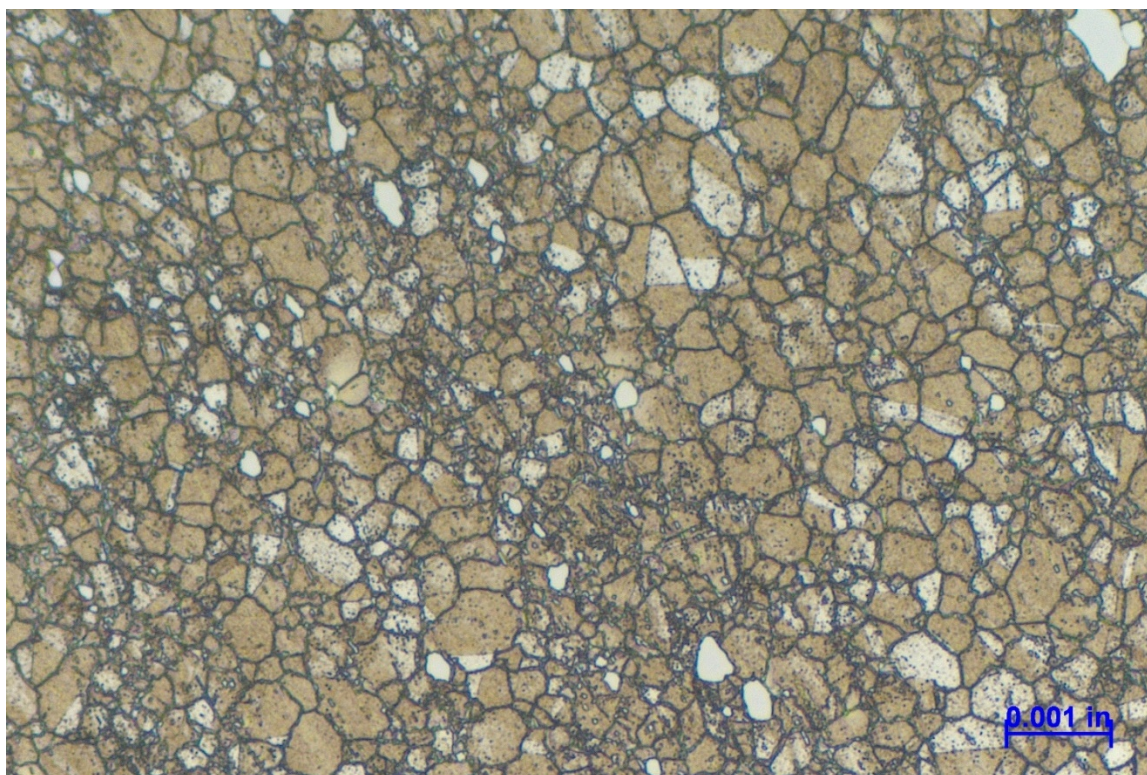


Figure 21 – BF optical micrograph of a typical area of the exhaust valve microstructure away from the fracture surface (~500X, etched Fry's Reagent).



Figure 22 – BF optical micrograph of an area of the exhaust valve fracture surface, showing internal oxidation along grain boundaries (~100X, etched Fry's Reagent).

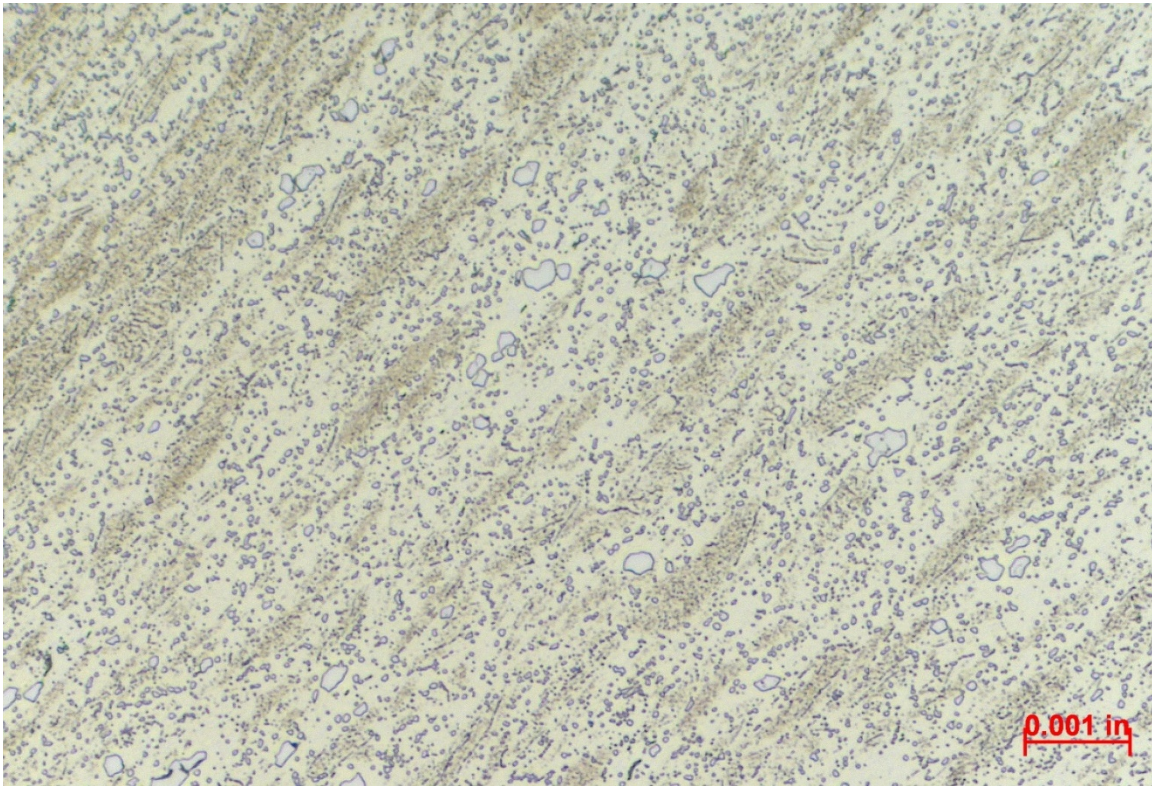


Figure 23 – BF optical micrograph of a typical area of the exhaust valve microstructure adjacent to the fracture surface (~500X, etched Fry's Reagent).

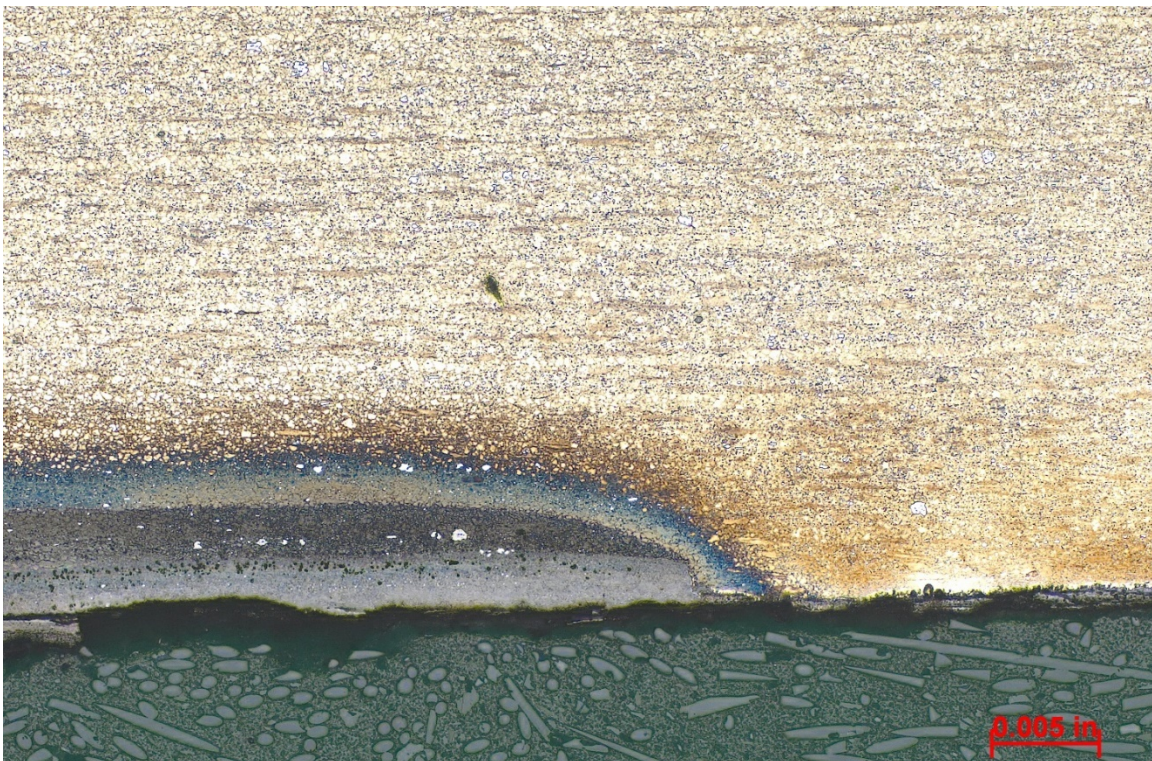


Figure 24 – BF optical micrograph of an area of the exhaust valve stem surface showing an area of oxidation and porosity (~100X, etched Fry's Reagent).

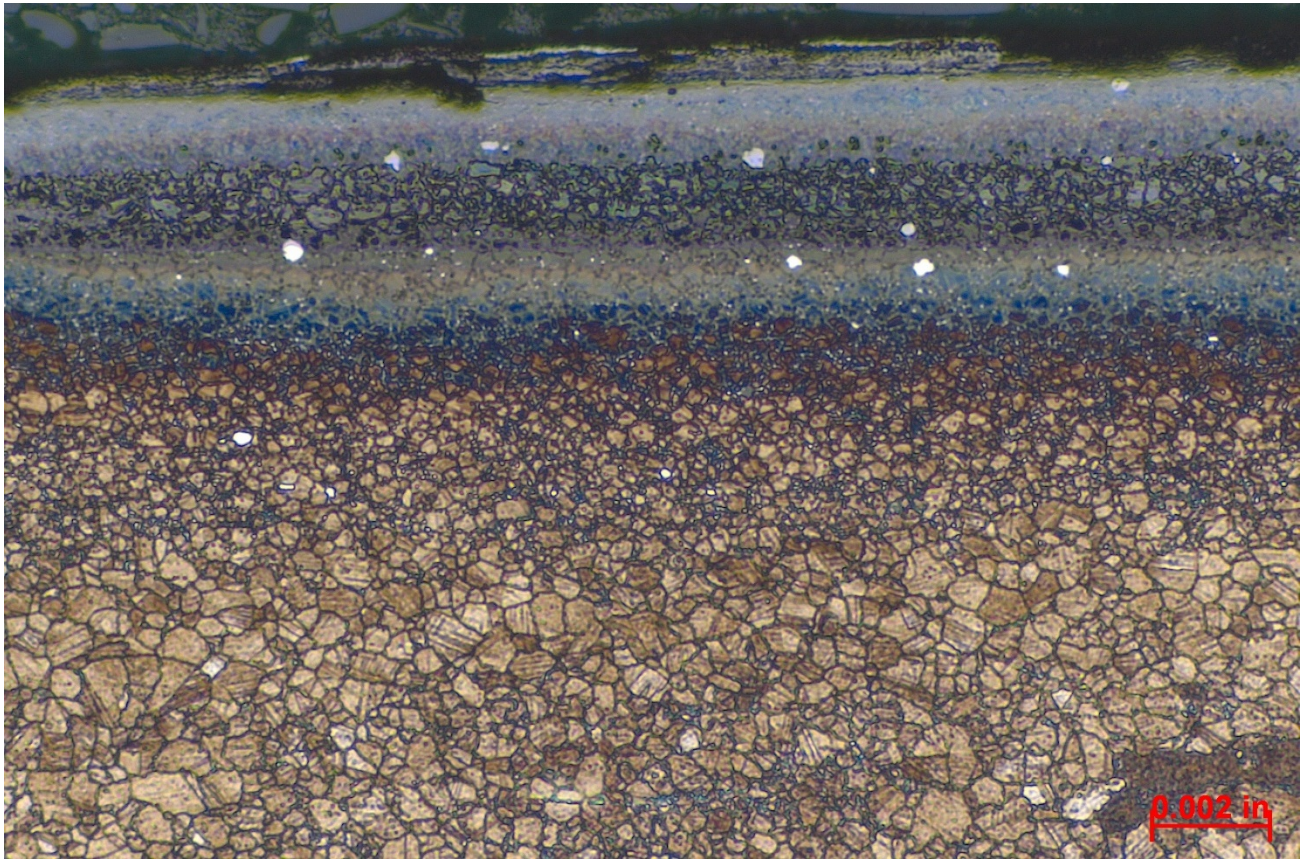


Figure 25 – BF optical micrograph of an area of the exhaust valve stem surface showing an area of oxidation and porosity (~200X, etched Fry's Reagent).