

# NATIONAL TRANSPORTATION SAFETY BOARD

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



September 5, 2018

## MATERIALS LABORATORY FACTUAL REPORT

Report No. 18-057

### 1. ACCIDENT INFORMATION

Place : Alexandria, Louisiana  
Date : April 20, 2018  
Vehicle : Boeing MD-83, N807WA  
NTSB No. : DCA18FA144  
Investigator : Lorenda Ward, AS-10

### 2. COMPONENTS EXAMINED

Fractured remnants of a main landing gear assembly

### 3. DETAILS OF THE EXAMINATION

On April 20, 2018, at about 1420 CDT, a Caribbean Sun Airlines (doing business as World Atlantic Airlines) MD-83, S/N 53093, experienced a right main landing gear collapse during landing at Alexandria Airport (AEX) near Alexandria, LA. This collapse caused the right wing to contact the runway, leading to fuel and hydraulic fluid leaking. The 94 passengers and 7 crew were evacuated, and no injuries were reported. The flight was contracted by the United States Immigration and Customs Enforcement (ICE) agency but operated under Part 121 regulations. The airplane was substantially damaged.

According to the applicable service bulletin (SB) for this part, SB MD80-32A344, the forward side of the landing gear was to be inspected every 450 flight cycles (landings).<sup>1</sup> The last inspection was 218 flight cycles prior to the accident.

#### 3.1. Visual Examination and Measurements

The fractured landing gear was removed, crated, and sent to Boeing's facility in Huntington Beach, CA for group examination from May 1 to May 5, 2018. The parts are shown as received in Figure 1 and Figure 2. The right main landing gear outer cylinder had fractured circumferentially with one pair of mating fracture surfaces. The fracture was oriented perpendicular to the gear's longitudinal direction and had progressed around the

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<sup>1</sup> Boeing MD-80 Service Bulletin MD80-32A344 details inspection requirements for the main landing gear shock strut cylinder, last revised December 20, 2006.

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entire cross section of the cylinder. The fracture was located 20.4 inches from the topmost point of the gear and 29.9 inches from the bottom of the gear cylinder.

The gear assembly was originally manufactured by Douglas.<sup>2</sup> The assembly metal tag stated the part number was 5935355-501, with serial number S1017. Other part information was chemically etched on a flat face in the lower part of the landing gear cylinder. After chemically stripping the paint in that area, the markings stated "SPCL GLANDNUT", "5935348-7", "CPT I370".

The macroscopic features were mirrored on each mating face of the fracture surface. Most of the fracture surface exhibited a dull, gray luster, with a rough surface texture (see Figure 3). Shear lips were present on the edges of the fracture surface on the outward and inward surfaces. The primary fracture feature on both fracture surfaces were chevron marks and river patterns, consistent with having emanated from the forward face of the cylinder, advancing circumferentially through the cylinder cross-section around to the aft.

The forward face of the exterior of the fractured landing gear is shown in Figure 4. This area exhibited a rectangular-shaped area that measured 4 inches longitudinally and 5 inches circumferentially. The outlines of this area are highlighted in Figure 5 and Figure 6, which show the forward sides of the upper and lower cylinder fracture surface, respectively. After partial chemical stripping of the paint and primer from this area, the material was tested using Fourier Transform Infrared (FTIR) spectroscopy to determine if it was consistent with a protective tape or with paint.<sup>3</sup> The material examined was found to be consistent with paint, and no indications of material consistent with a prescribed (but optional) tape were found.

The mating sides of the fracture surface were sectioned from the larger cylinder assembly, and then again sectioned about the initiation site to facilitate microscopic examination. Figure 7 shows the portion of the upper fracture surface, after sectioning and before removal of paint and primer.

Figure 8 shows the fracture surface, which exhibited chevron marks emanating from a small thumbnail crack on the forward side of the cylinder exterior (bottom of Figure 8). The thumbnail crack is highlighted from a planar view in Figure 9 and Figure 10, and at an oblique angle in Figure 11. The thumbnail crack exhibited crack arrest, or beach, marks, consistent with progressive fracture, later determined to be fatigue. The thumbnail crack measured 0.035 inches (0.89 mm) in depth, and 0.072 inches in length (1.84 mm). No

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<sup>2</sup> The MD-83 is a variant of the MD-80 manufactured by McDonnell Douglas, which first entered service in January 1988. McDonnell Douglas merged with The Boeing Company (currently headquartered in Chicago, IL) in August 1997.

<sup>3</sup> FTIR is an infrared spectroscopy technique that measures the molecular structure of organic and inorganic compounds by identifying the rotational and vibrational energy levels as they interact with infrared electromagnetic radiation. The data are Fourier transformed to display an amplitude versus wavelength spectrum.

shear lips or chevron marks were located at this thumbnail crack. The area on the cylinder exterior exhibited features consistent with smearing.

### 3.2. Scanning Electron Microscopy Examination

Selected sections of the landing gear near the fracture surface were examined using scanning electron microscopes (SEM). The fracture surfaces were successively cleaned using ethanol, acetone, and Alconox to remove oxide and corrosion products on the fracture surface.<sup>4</sup>

Figure 12 shows the thumbnail crack on the upper fracture surface. Consistent with what was observed in Figure 11, the crack initiation site had been damaged by smearing (see Figure 13 and Figure 14). As shown in Figure 13b, much of the fracture surface exhibited dark pock-marked features, consistent with oxide on a metal surface.<sup>5</sup> This fracture surface oxidation was consistent with oxidation that occurs on an exposed metal surface after crack initiation and/or fracture.

The exterior of the cylinder near the fracture surface also exhibited secondary cracks, oriented parallel to the fracture surface fatigue crack. A typical example is shown in Figure 15. The largest of these cracks near the upper fracture surface was 0.013 inches (0.33 mm) in length.

The chemical composition of the cylinder material was inspected using energy dispersive x-ray spectroscopy (EDS). The composition was consistent with 300M, the material prescribed for the landing gear cylinder.<sup>6</sup> The hardness was inspected per ASTM E18.<sup>7</sup> The hardness averaged 55 HRC, which was consistent with the typical hardness of many heat treatments for 300M.<sup>8</sup>

As described earlier, the elevated area on the forward side of the cylinder around the fracture surface was found by chemical analysis to be consistent only with the paint and primer, not with a protective tape. After chemical stripping of paint and primer in the area, no other coating or material was found on the cylinder surface. The region surrounding the fracture surface was absent of any indication of a cadmium (Cd) layer. The surface texture exhibited scratch marks consistent with mechanical grinding. Outside of this region, evidence of a Cd electroplated coating was present (see Figure 16).

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<sup>4</sup> Alconox is a powdered cleaning detergent, containing primarily sodium bicarbonate and sodium alkylbenzene sulfonate, manufactured by Alconox, Inc., White Plains, NY.

<sup>5</sup> Backscattered electrons: SEM micrographs produced using backscattered electrons display contrast that is associated with the atomic numbers of the elements in the micrograph. Materials containing elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

<sup>6</sup> 300M is a modified alloy of Type 4340 alloy steel, typically containing higher silicon content.

<sup>7</sup> ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

<sup>8</sup> HRC – Hardness, Rockwell C scale. An indentation method of determining the hardness of harder metal alloys using a conical diamond indenter and 150 kg load.

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Inspection of the cylinder exterior with Cd found that this portion of the coating was porous and incomplete.

Later inspection of both these areas by EDS found no Cd electroplating near or around the fracture surface, but Cd was present outside this area. Therefore, the area around the fracture surface was consistent with having been masked, stripped of paint and primer, removing the Cd electroplating by mechanical means, and then re-primed and painted.

The lower fracture surface was inspected using a SEM. The thumbnail crack on this mating side exhibited less oxidation and contamination than the upper fracture and is shown in Figure 17. The end of the thumbnail crack is shown Figure 18. Closer examination of the thumbnail crack revealed fatigue striations, consistent with fatigue crack propagation (Figure 19).

Outside the crack, dimple rupture was found—this was consistent with subsequent overstress fracture of the gear cylinder on the landing at the time of the accident. Later examination of the lower fracture thumbnail crack revealed three overstress bands or “jumps.” These were 0.022 inch (0.56 mm), 0.030 inch (0.76 mm), and 0.033 inch (0.83 mm) from the origin of the crack (the total crack depth was 0.035 inch [0.89 mm]).

Unlike the upper fracture surface, the fatigue crack initiation site was relatively undamaged on the lower fracture (see Figure 20 and Figure 21). There were corrosion pits adjacent to the fatigue crack initiation site as deep as 6  $\mu\text{m}$  ( $2.36 \times 10^{-4}$  inch), but there were none located at the initiation site.

### 3.3. Additional Testing and Examinations

A portion of the upper fracture surface section was mounted, polished, and etched. Figure 22 reveals a typical area of the microstructure of the cylinder. The microstructure was consistent with tempered martensite with equiaxed prior-austenite grain boundaries, typical for this alloy and hardness.

The interior surface of the cylinder exhibited chatter marks consistent with grinding operations. The external surface was Barkhausen magnetic noise tested to examine for excessive mechanical damage.<sup>9</sup> No indications of magnetization change severe enough to indicate grinding damage to the cylinder were found (readings were written directly on segment shown in Figure 23). The exterior cylinder surface of the upper fracture surface was etched using a Nital solution.<sup>10</sup> No indications of color change, consistent with the

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<sup>9</sup> Barkhausen noise testing is a method of testing ferromagnetic materials where measured variations in magnetic flux over changing magnetization can be used to identify grain and microstructure change, indicative of heat input from excessive grinding.

<sup>10</sup> Nital is a solution of 2-10% nitric acid with ethanol. In this instance, the Nital etch was used to identify the visual changes consistent with microstructure changes indicative of heat input from excessive grinding.

effects excessive grinding or mechanical abuse, were observed visually from the etching examination (see Figure 24).

An area near the fracture surface was inspected using microindentation hardness tests to determine if there was an appreciable change in local hardness between the cylinder surface and cylinder interior. A section of the cylinder was mounted and polished, and the microindentation hardness was tested per ASTM E384.<sup>11</sup> The values were converted per ASTM E140.<sup>12</sup> As demonstrated in Figure 25, the hardness of the surface of the material was consistent with that obtained further inward. The highest hardness value measured was 57 HRC (627 HV<sub>500</sub>) 0.007 inch from the surface, and the lowest values of 55 HRC (594 HV<sub>500</sub>) were obtained 0.024 inch and 0.040 inch from the surface. These data were not consistent with a layer of decarburization or areas of excessive hardness on the surface.

### 3.4. Maintenance Prescribed by Service Bulletin and Maintenance History

The procedure outlined in SB MD80-32A344 directs an inspection in the area on the cylinder where this fracture initiated. In summation, the inspection procedure from the applicable service bulletin states to chemically strip the topcoat paint and primer off, and then perform fluorescent penetrant inspection (FPI) or magnetic particle inspection (MPI) on the region. If no crack indications were found, the area was to be prepared for return to service as stated below. There was no direction stating to inspect for the presence of an electroplated layer in the instance of no crack indications found.

If a crack indication was found from the inspection, the underlying Cd electroplating was to be removed, followed by a second FPI or MPI inspection. If the crack indication was confirmed, the part was to be scrapped. If there were no further indications of cracks, however, the area was to be brush Cd electroplated (without a post-electroplating baking procedure).

After the brush Cd application (or if no indications were found to begin with), the area can undergo one of three preparation steps:

- The area can be primed and painted again
- The area can be coated with Cor-Ban 27L and then have a protective boot applied
- The area can be coated with Cor-Ban 27L and then a protective tape applied.<sup>13</sup>

<sup>11</sup> ASTM E384 – *Standard Test Method for Knoop and Vickers Hardness of Materials*. ASTM International, West Conshohocken, PA

<sup>12</sup> ASTM E140 – *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*. ASTM International, West Conshohocken, PA

<sup>13</sup> Cor-Ban 27L is a non-toxic, non-drying paste compound designed to provide corrosion protection at ambient temperature under ultraviolet exposure.

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As stated previously, there were no indications of a protective tape, corrosion inhibitor, or cadmium electroplating on the area around the cylinder fracture.

According to records obtained in this investigation, the airplane had undergone 43724 flight hours, or 39539 cycles (landings) at the time of the accident. The airplane was under the World Atlantic Airlines certificate, which was obtained on August 26, 2015. The last inspection performed on this main landing gear cylinder was November 16, 2017, where the airplane had undergone 43298 hours and 39321 cycles. At the time of the accident, the airplane had accrued 426 hours or 218 cycles since the November 2017 inspection. All the inspections performed under the World Airlines certificate were:

- November 16, 2017 – 43298 hours and 39321 cycles (279 cycles since last)
- March 30, 2017 – 42733 hours and 39042 cycles (294 cycles since last)
- November 1, 2016 – 42062 hours and 38748 cycles (427 cycles since last)
- February 29, 2016 – 41147 hours and 38321 cycles (414 cycles since last)

The nondestructive testing was performed by AMS, Inc. on the February 29, 2016, March 30, 2017, and November 16, 2017 dates.<sup>14</sup> Another company, Miami NDT, performed the nondestructive testing on November 1, 2016.<sup>15</sup> The inspection performed in February 2016 was the first under the World Atlantic Airlines certificate; the previous inspection 414 cycles prior was under another certificate holder.

### **3.5. Site Visit to Landing Gear Maintenance Facility**

The investigators for this accident visited the facilities of the operator, World Atlantic Airlines, in Miami, FL. The operator demonstrated the inspection procedures performed on the portion of the landing gear as prescribed in SB MD80-32A344. This inspection was performed on another MD-83 owned by the operator. The operator contracted Miami Tech, Inc. to prepare this landing gear for nondestructive inspection, and then to prepare the landing gear for return to service.<sup>16</sup> The nondestructive evaluation was performed by AMS, Inc.<sup>14</sup>

The preparation contractor, Miami Tech, began the procedure by masking off the area to be inspected with metallic tape, specifically designed for aerospace applications. This tape was placed about a 5-inch circumferential and 4-inch longitudinal section. Chemical stripping agents were placed on the isolated section of the forward landing gear exterior to initiate the paint and primer removal. These compounds were allowed to dwell, giving time for the paint to spall from the landing gear surface. After this dwell time, the area was wiped with a cloth using isopropyl alcohol. Any remnants of paint and primer were removed with a soft plastic scraper.

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<sup>14</sup> Aerospace Maintenance Supplies and Services, Inc. (AMS Inc.) is an FAA approved nondestructive testing facility located in Medley, FL.

<sup>15</sup> Miami NDT, Inc. is an FAA approved nondestructive testing facility located in Doral, FL.

<sup>16</sup> Miami Tech Aircraft Maintenance is a privately owned and operated maintenance, repair, and overhaul (MRO) facility, located in Miami, FL.

After preparation, the area was inspected using magnetic particle inspection by AMS. During the witnessed procedure, the inspection team employed three employees—one an ASNT Level II certified inspector and one an ASNT Level III certified inspection in fluorescent magnetic particle testing (MPI).<sup>17</sup> The certified operators stated they had experience with inspection of these landing gears and carried their certification documents on hand.

Prior to inspection, the operators placed cloths or rags around the sides and bottom of the masked area. The operators then sprayed the area with a ScotchNeck SKC-M solvent cleaner/remover.<sup>18</sup> This was wiped from the surface. After this, the operators applied Magnaglow Aerosol 14AM oil-based fluorescent magnetic particle suspension liquid.<sup>19</sup> Under operation with an AC or DC current that induces a magnetic field, the particles in the suspension are pulled to any surface or subsurface feature that interrupts the field (such as a crack).

During the inspection, the Level II and Level III operators witnessed the inspection from the forward side of the landing gear, while the third employee positioned behind the gear to hold a black cloth. The black cloth was used to shield the inspectors from outside light. The inspection was performed just prior to midday. During the inspection, the operators would apply a handheld U-shaped electromagnetic coil to the surface around the inspection area.

Applying DC current, the inspectors positioned the handheld coil parallel to the gear longitudinal direction (90°), as well as two 45° angles. During these inspections, the operators would apply additional magnetic particle suspension as needed, while using a UV black light to view the area. At the time of this inspection, no crack indications were identified. The operators stated they would be able to identify an indication of 0.050 inches, the minimum stated in the applicable service bulletin. After the inspection, the operator cleaned the area with the solvent cleaner and a cloth. The area was then demagnetized using multiple degaussing passes with the handheld U-shaped coil using AC current. After the inspection, the operators certified the inspection was performed per the service bulletin with no cracks found.

As per the instructions in the SB, after the inspection, if no cracks were found, Miami Tech would apply a Cd electroplating if it had been removed, reapply paint and primer to the area, remove the masking tape, and continue preparations to return the airplane to service. Miami Tech demonstrated the procedure by performing a brush Cd electroplating. The previously inspected surface was cleaned, and yellow cloths were

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<sup>17</sup> The American Society for Nondestructive Testing (ASNT) certifies operators on Levels I through III, based on experience and testing ability. Level III is the highest level of certification, and Level II is the intermediate operator level—both are certified to interpret, evaluate, and report results.

<sup>18</sup> ScotchNeck SKC-S is an NDT-approved solvent cleaner/remover for pre-cleaning before non-destructive testing and for removing excess surface penetrant from an inspection area before applying developer during liquid penetrant testing. This product is manufactured by Magnaflux, headquartered in Glenview, IL.

<sup>19</sup> Magnaglow Aerosol 14AM is a magnetic particle suspension liquid for designed to locate fine discontinuities in critical parts and applications by providing fluorescent green indications for inspection quality and accuracy. This product is manufactured by Magnaflux, headquartered in Glenview, IL.

applied around the masked area. A grounding/negative cable was attached to a side linkage connected to the landing gear. All other surrounding areas that might come in contact with the probe were masked with yellow masking tape.

The operators used a cloth-tipped probe, which was dipped into the brush Cd electroplating solution, to apply the solution to the cylinder surface, using small circular motions. The operator would initially use a voltage up to 20 V DC, but then reduce the voltage to 8 to 12 V as the Cd electroplating was successfully applied. The operator looked for a visual color change during application to ensure that the electroplating was adhering. After several minutes of this repeated application, the operators checked the electroplating thickness using an ultrasonic thickness probe. Upon reaching the desired thickness of at least 0.0005 inches, the surface would exhibit a golden color. After this procedure, the repair facility would then apply the paint and primer, then and prepare the airplane for return to service.

Erik M Mueller  
Materials Research Engineer



Figure 1 – The fractured right main landing gear, as received.

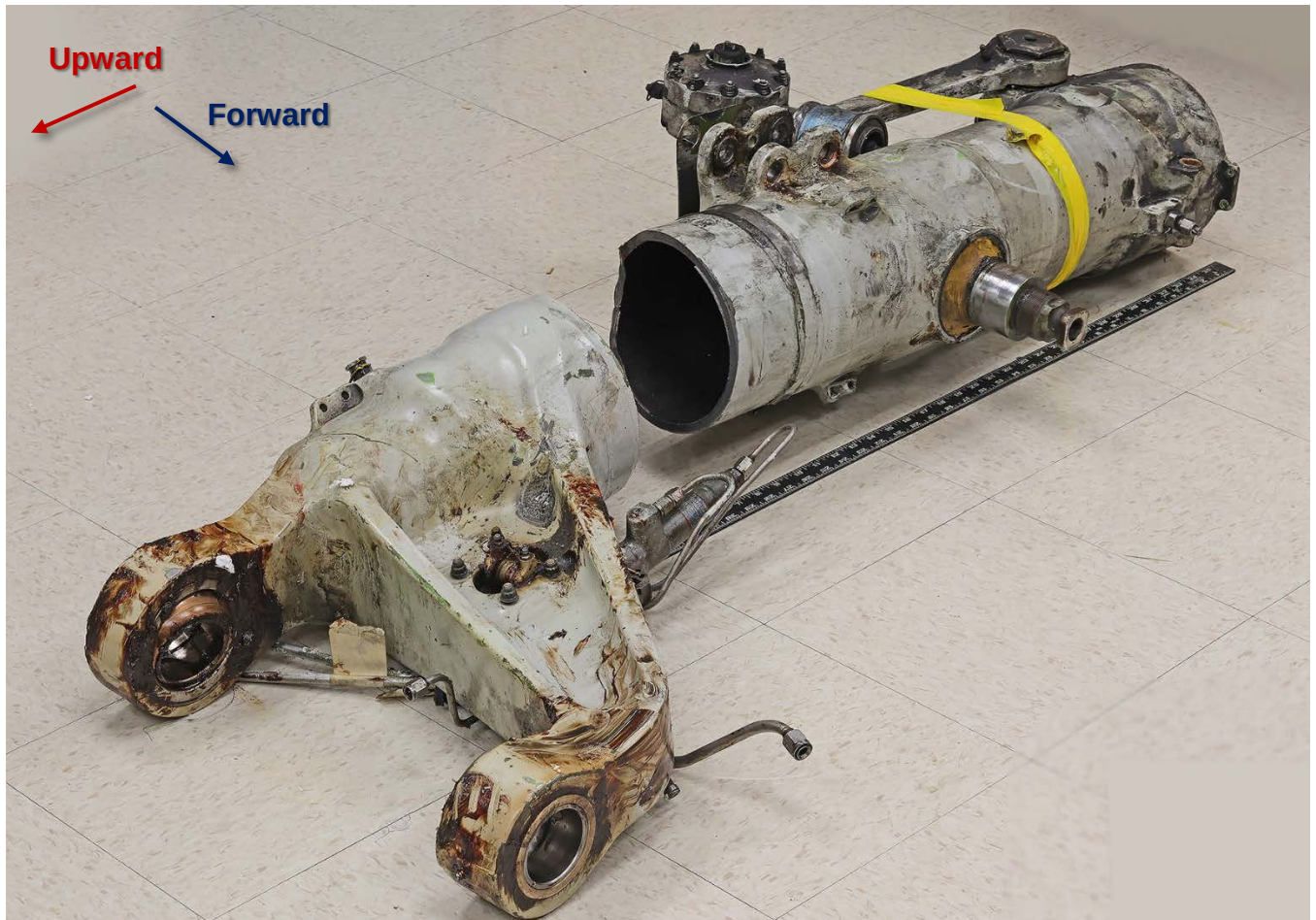


Figure 2 – An angled view of the landing gear cylinder, as received.

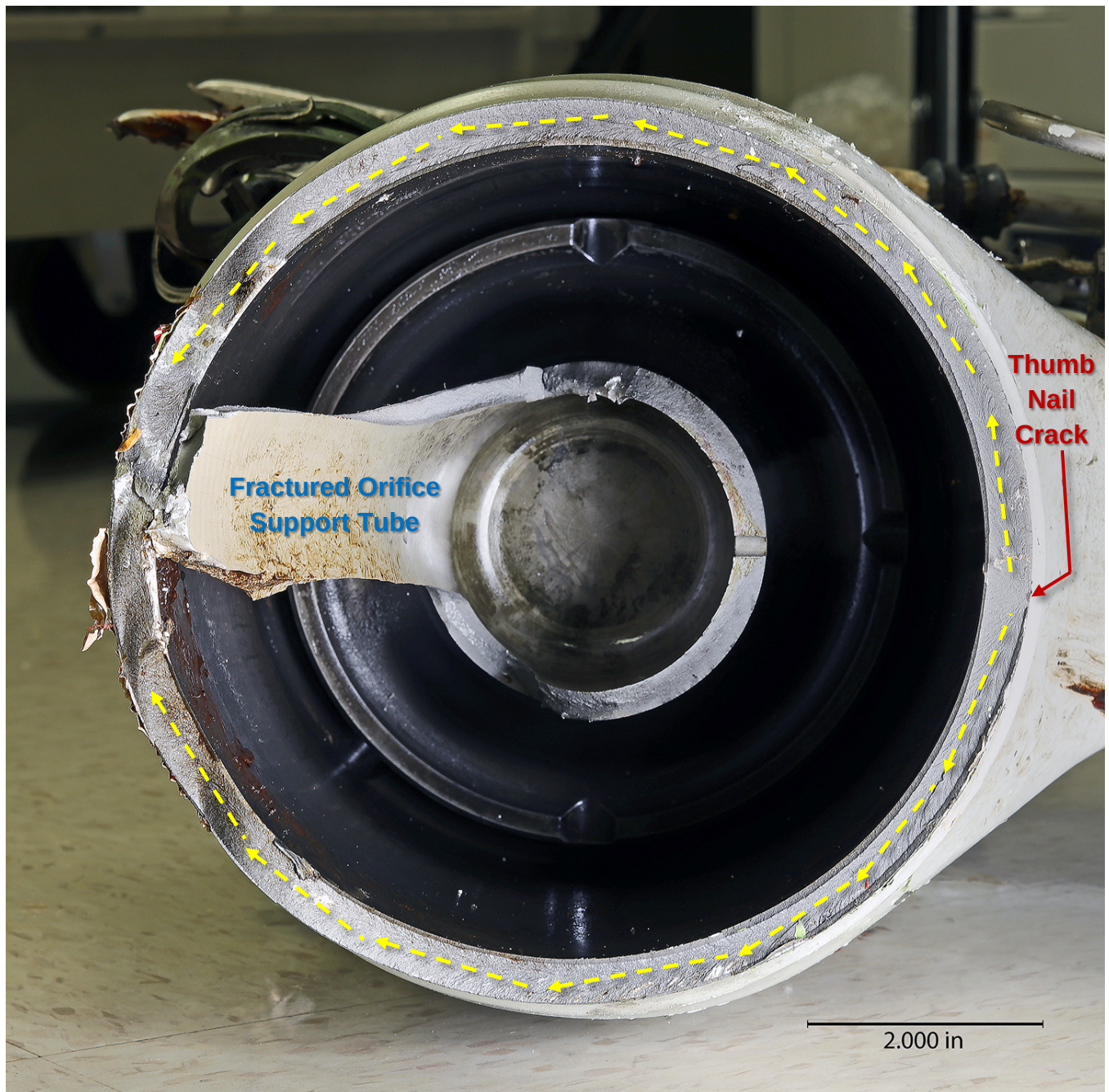


Figure 3 – View of the upper fracture surface of the cylinder. The dashed arrows show the general fracture direction, from the thumbnail crack on the forward side to the aft side.



Figure 4 – Closer view of the forward side of the fractured landing gear, showing the area of fracture initiation on the forward side (white boxed area).



Figure 5 – View of the upper fracture surface, viewed from the forward side. The boxed area highlights the masked and repainted area.



Figure 6 – View of the lower fracture surface, after some paint stripping. The boxed area highlights the masked and repainted area.

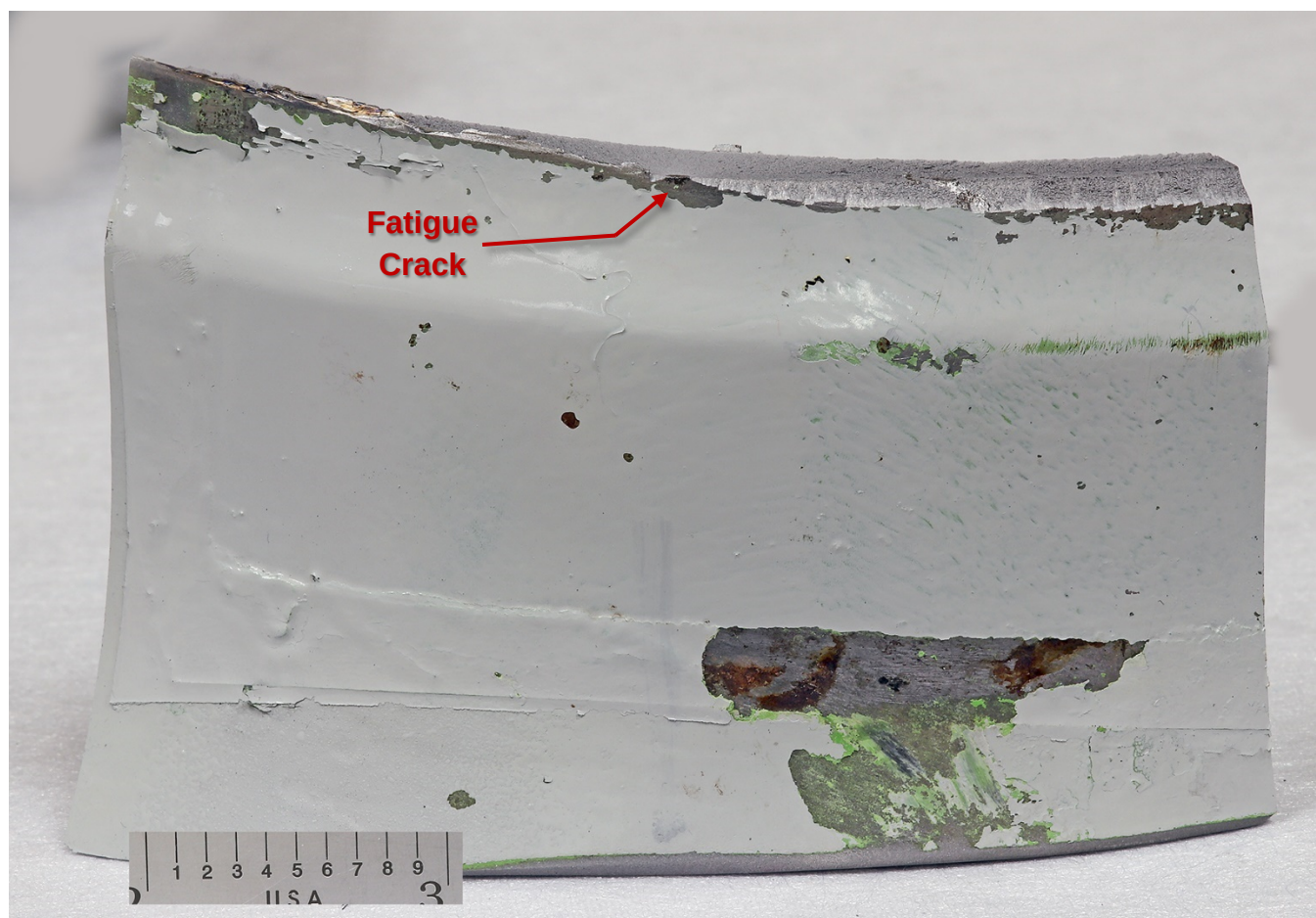


Figure 7 – Section of the upper fracture surface, after sectioning.

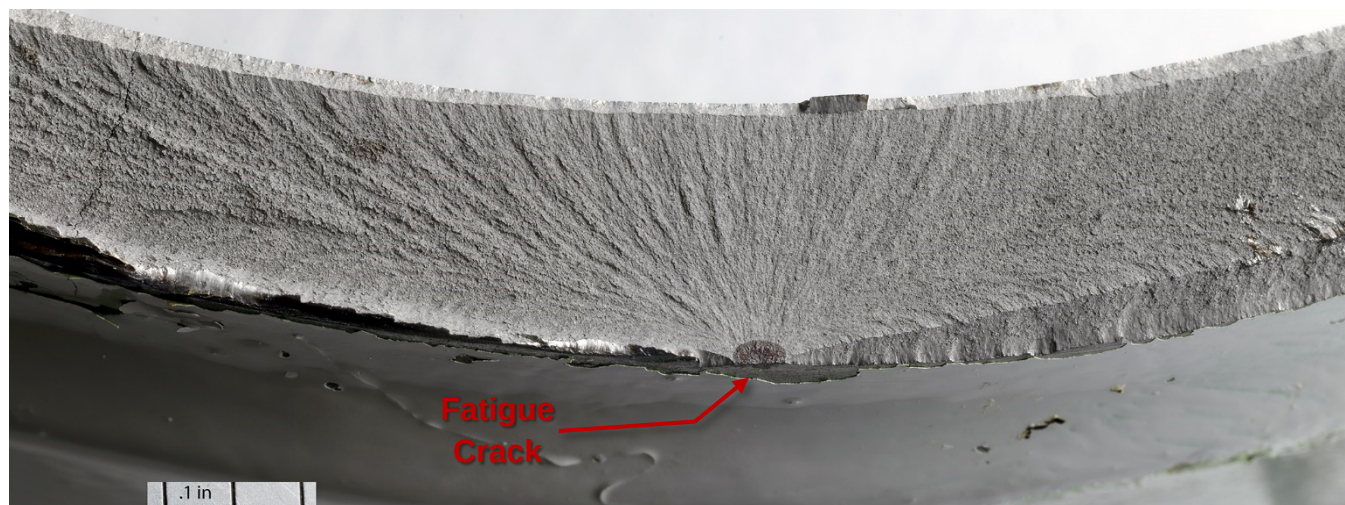


Figure 8 – Closer view of the crack initiation site on the upper fracture surface.

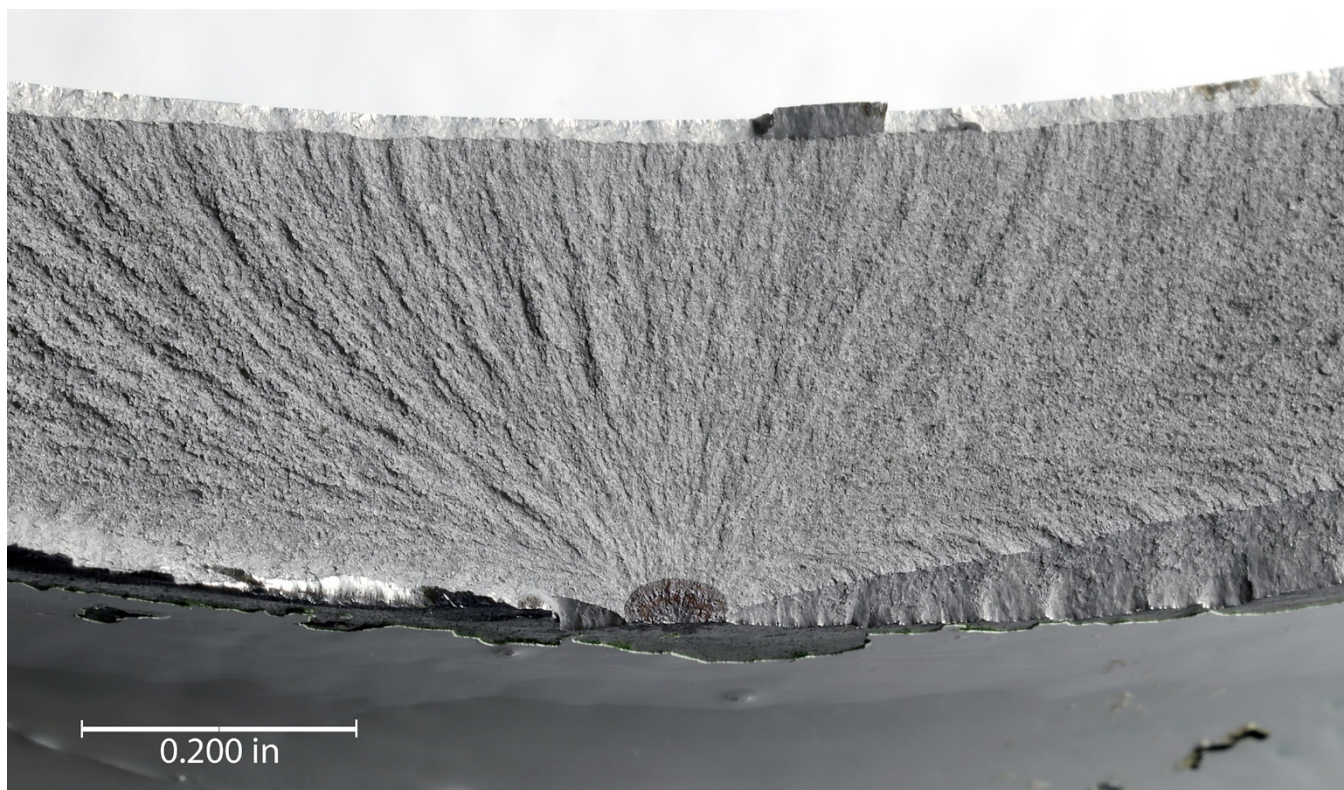


Figure 9 – Closer view of the crack initiation site, showing the thumbnail crack.

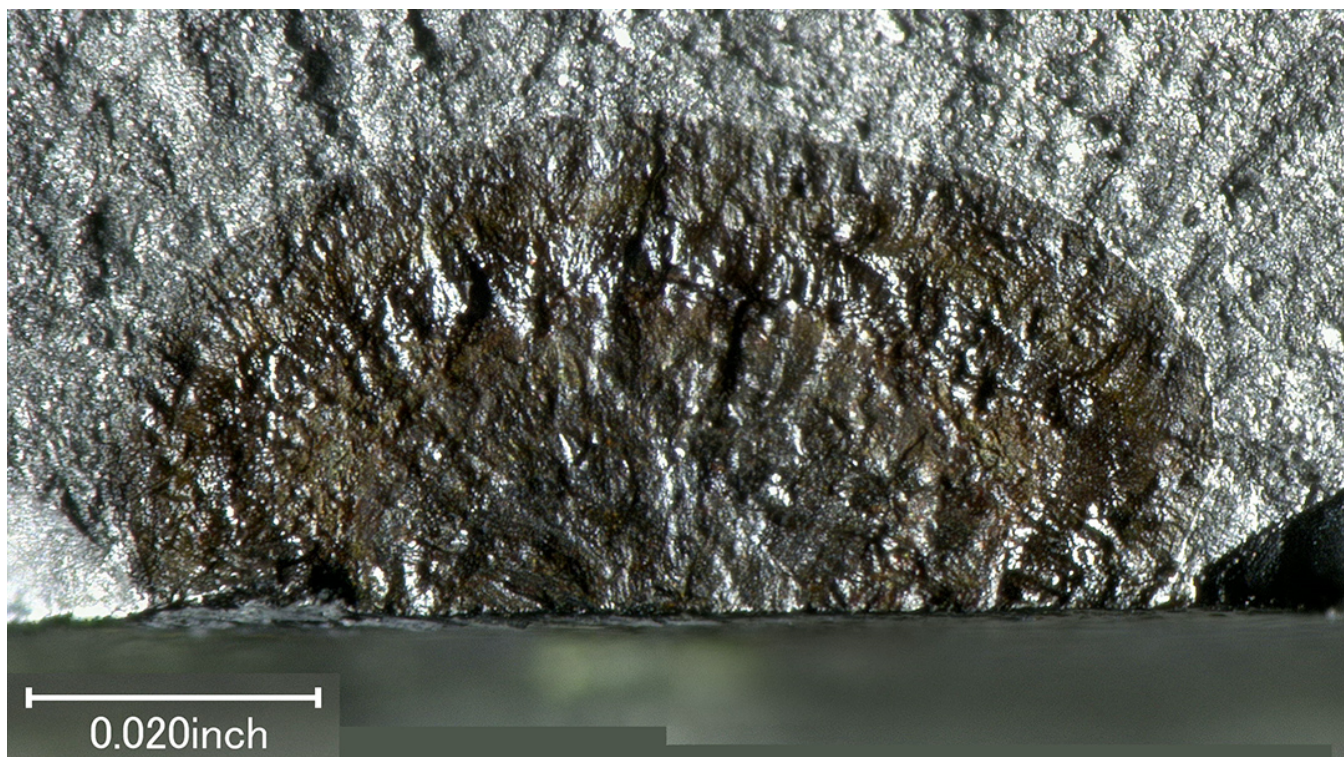


Figure 10 – The thumbnail crack on the upper fracture surface, as received.



Figure 11 – The thumbnail crack in Figure 10, shown at an angle to show the exterior of the cylinder.

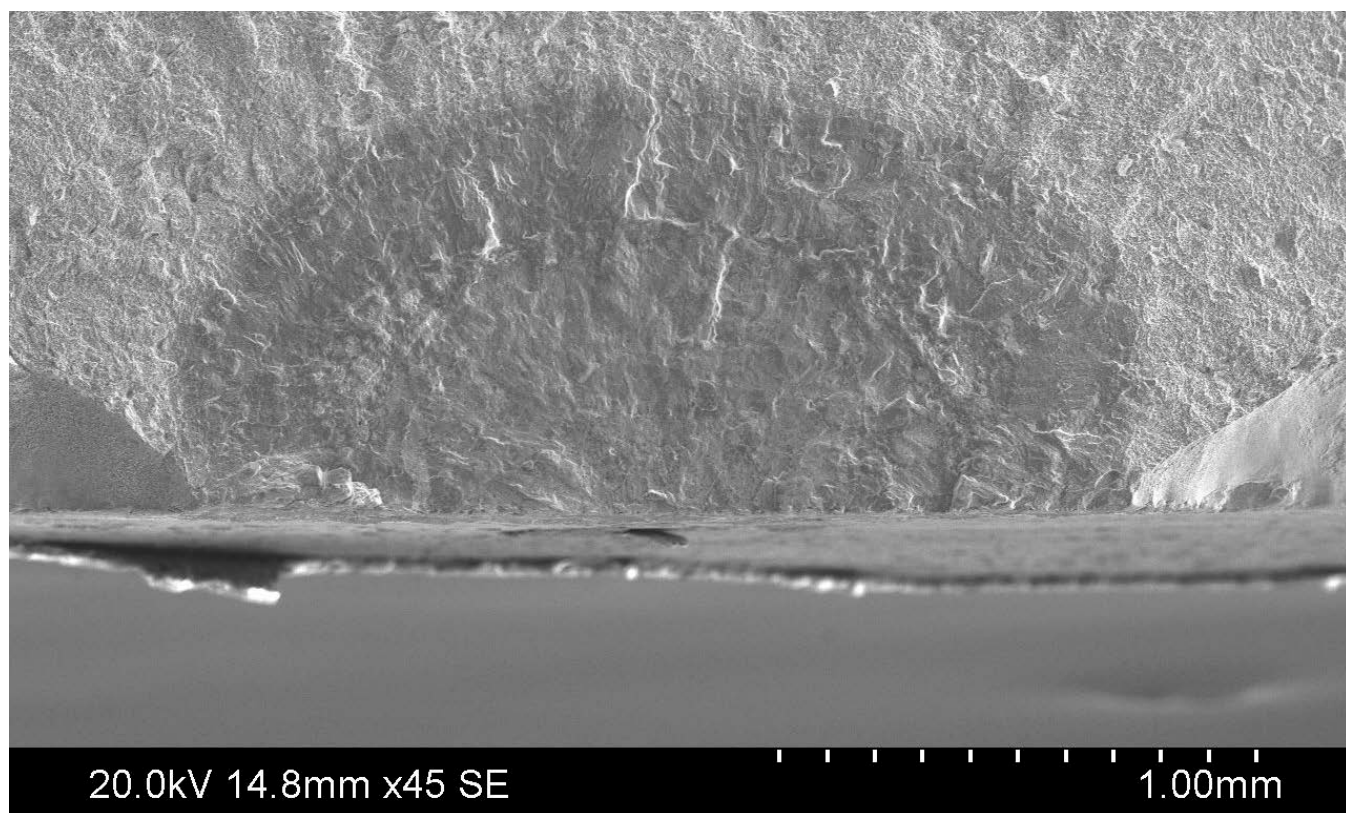


Figure 12 – Secondary electron (SE) micrograph of the fatigue crack on the upper fracture.

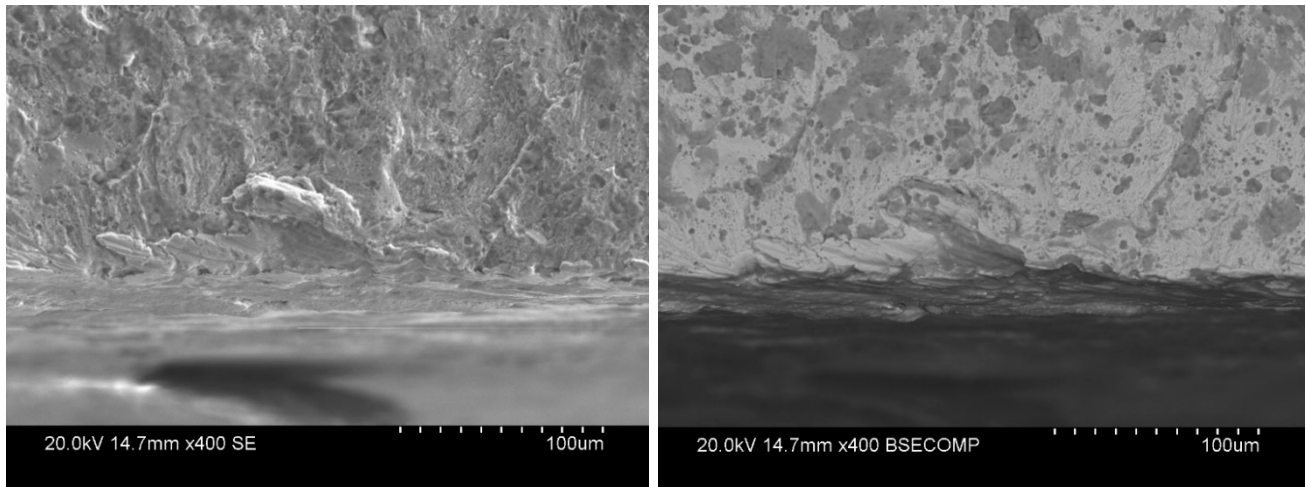


Figure 13 – The fatigue crack initiation site of the upper fracture, which had been damaged by post-fracture smearing view with (a) secondary electrons and (b) backscattered electron (BE).

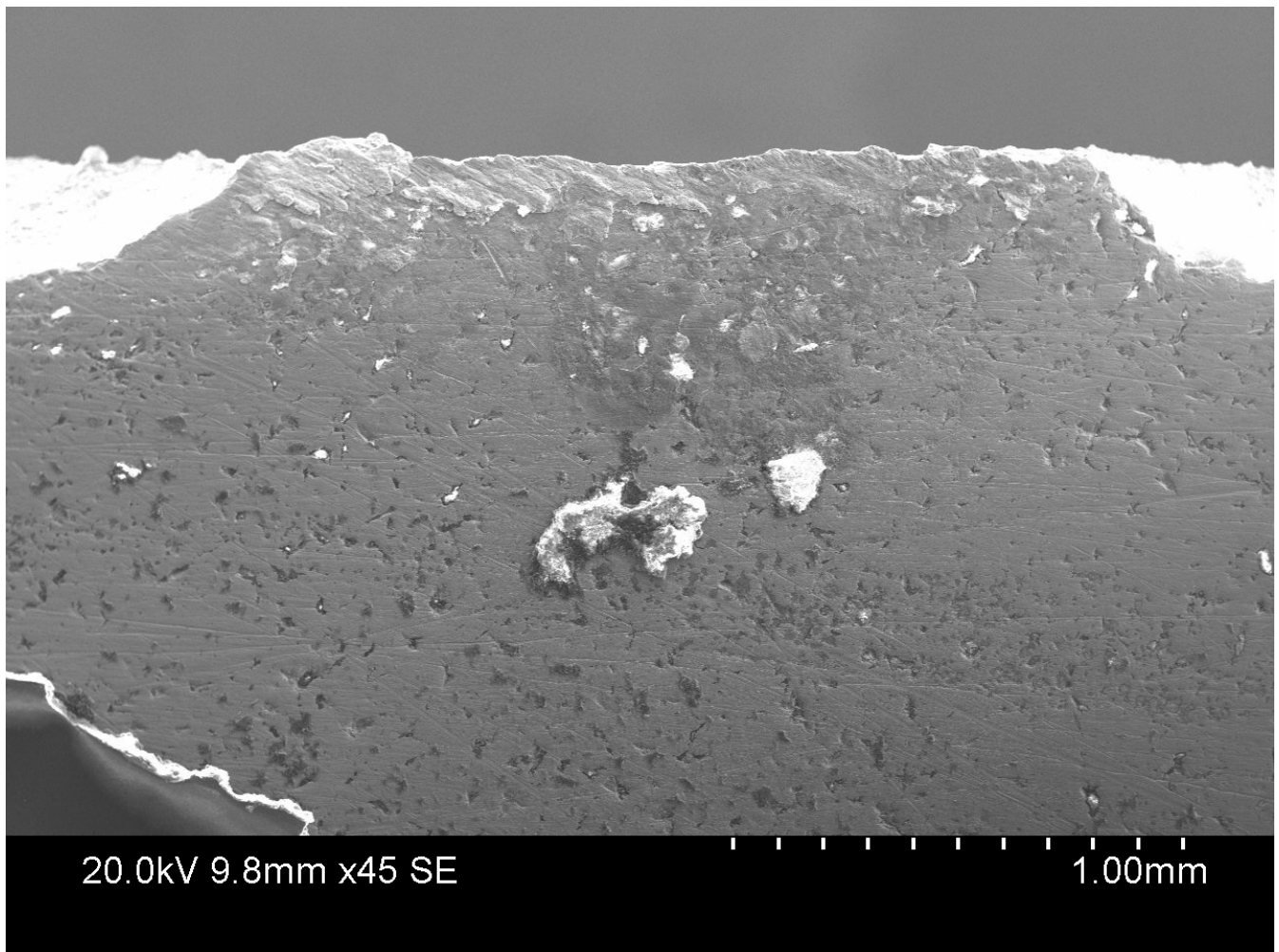


Figure 14 – SE micrograph of the cylinder exterior at the fatigue crack initiation site, showing smearing.

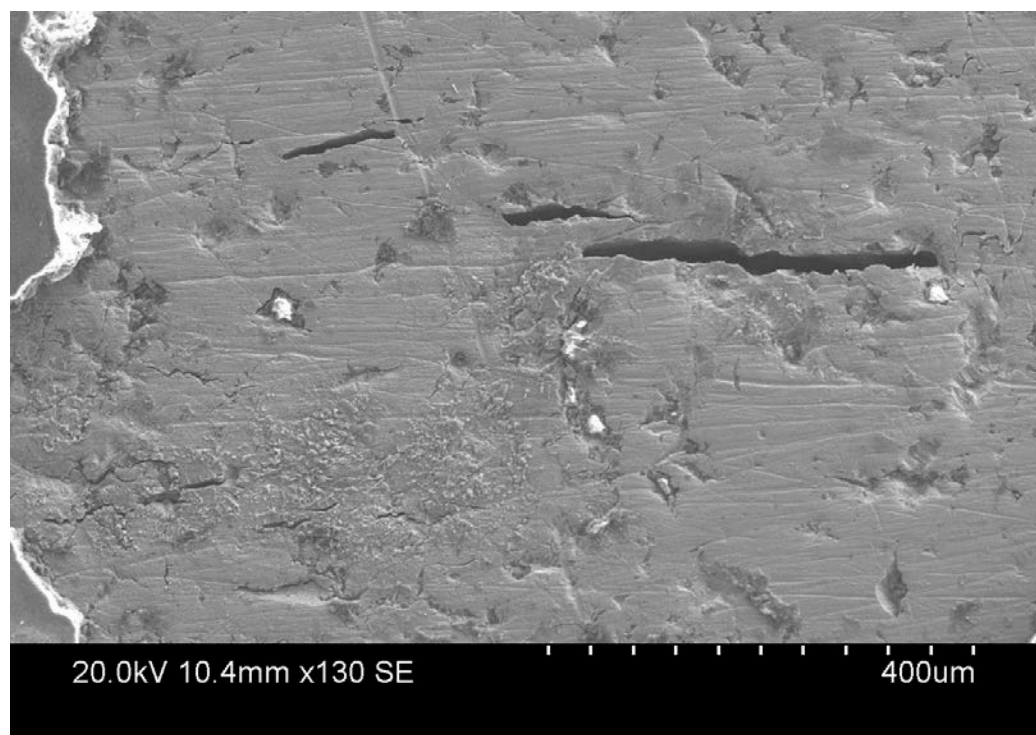


Figure 15 – SE micrograph of secondary cracks near the upper fracture surface.

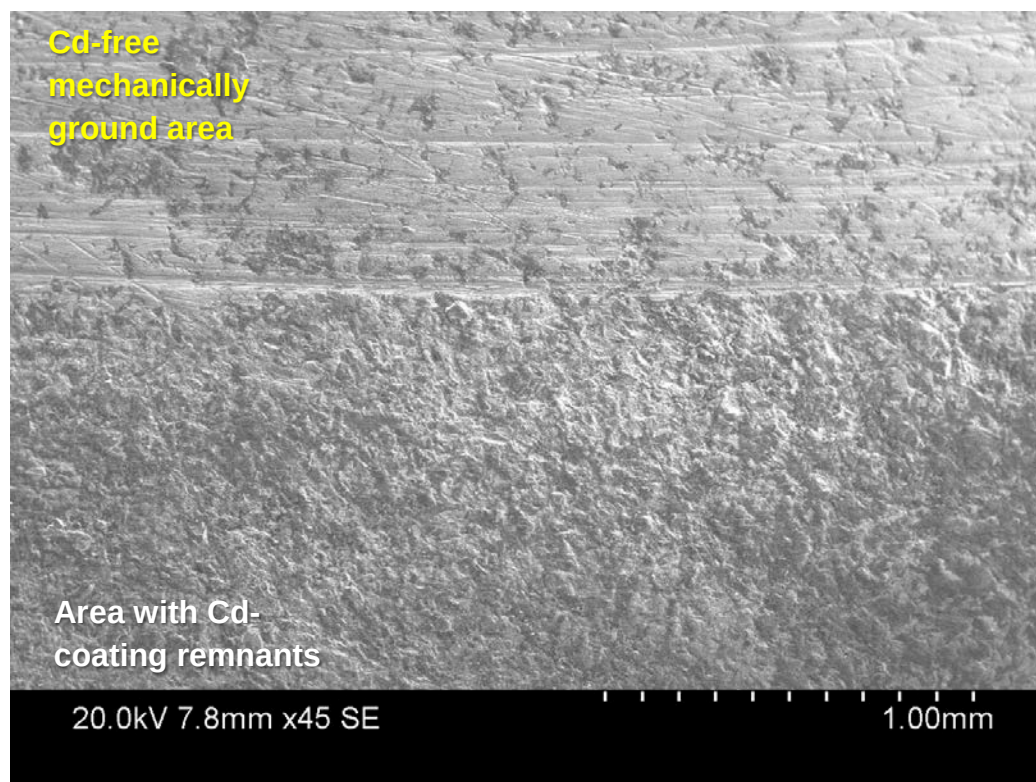


Figure 16 – SE micrograph of the cylinder exterior near the upper fracture surface, showing the region with and without Cd coating.

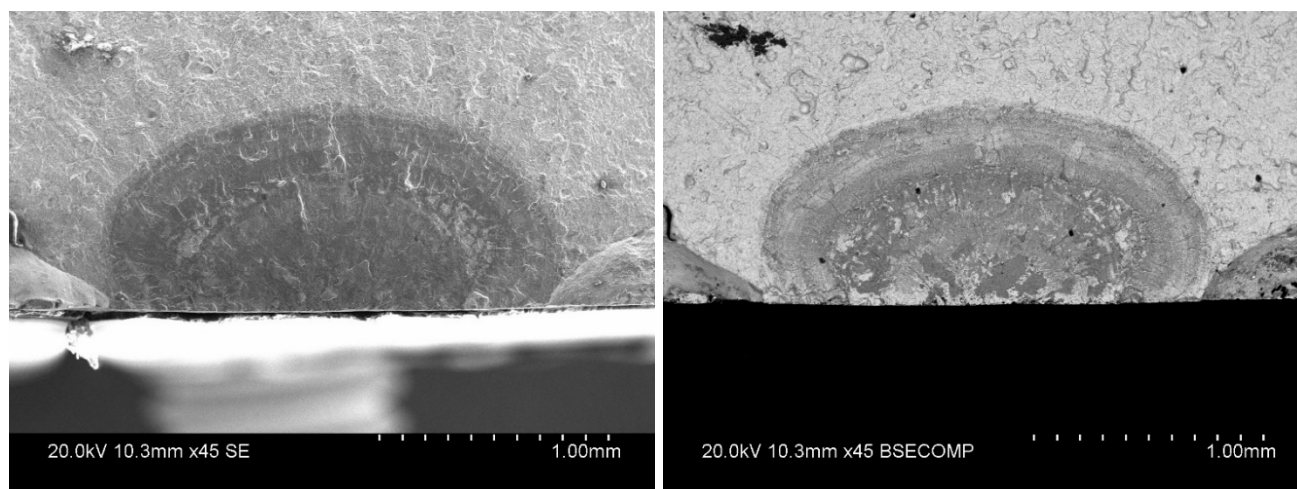


Figure 17 – The fatigue thumbnail crack on the lower fracture surface, viewed in (a) SE and (b) BE modes.

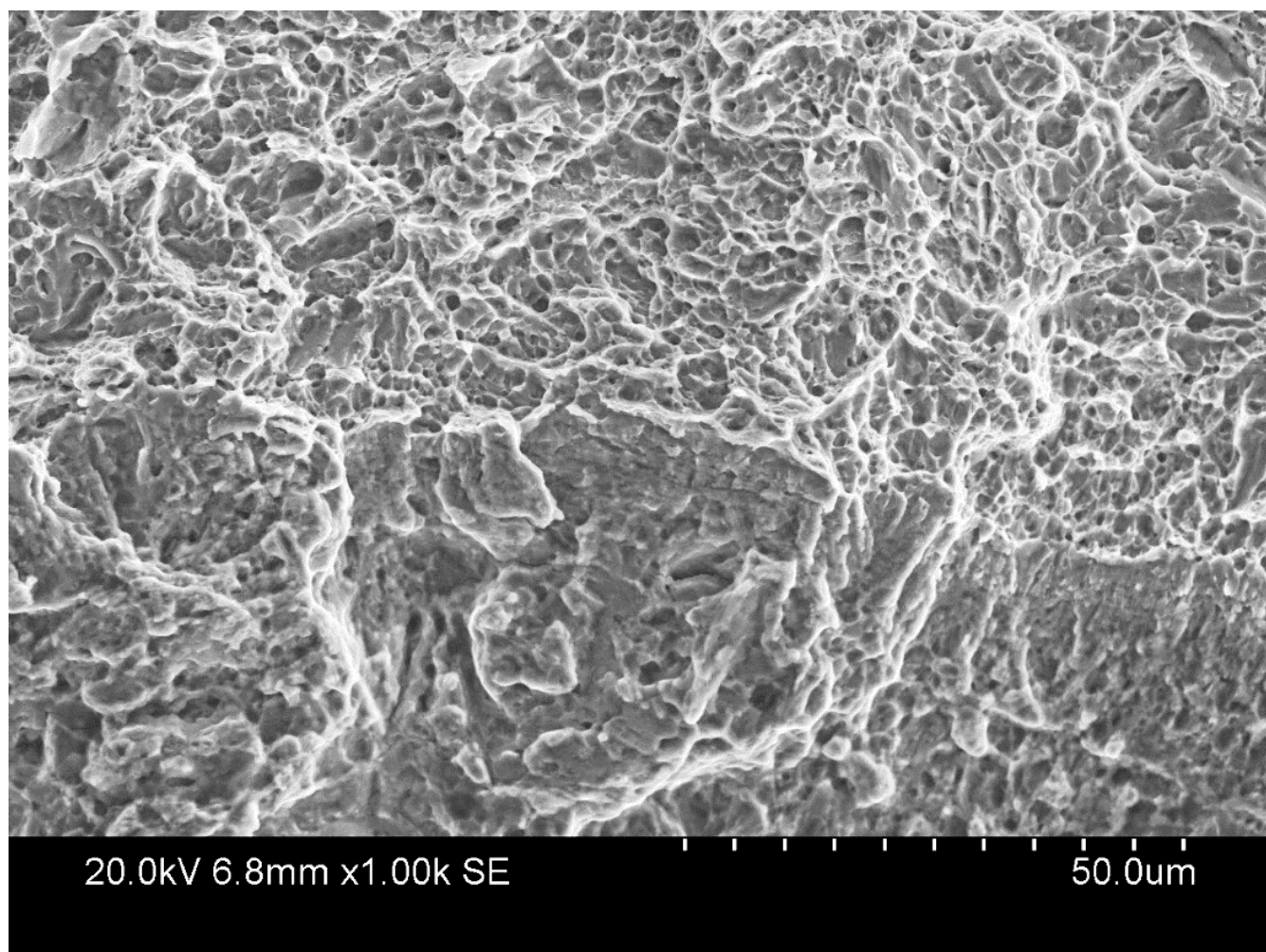


Figure 18 – SE micrograph of the end of the fatigue crack on the lower fracture.

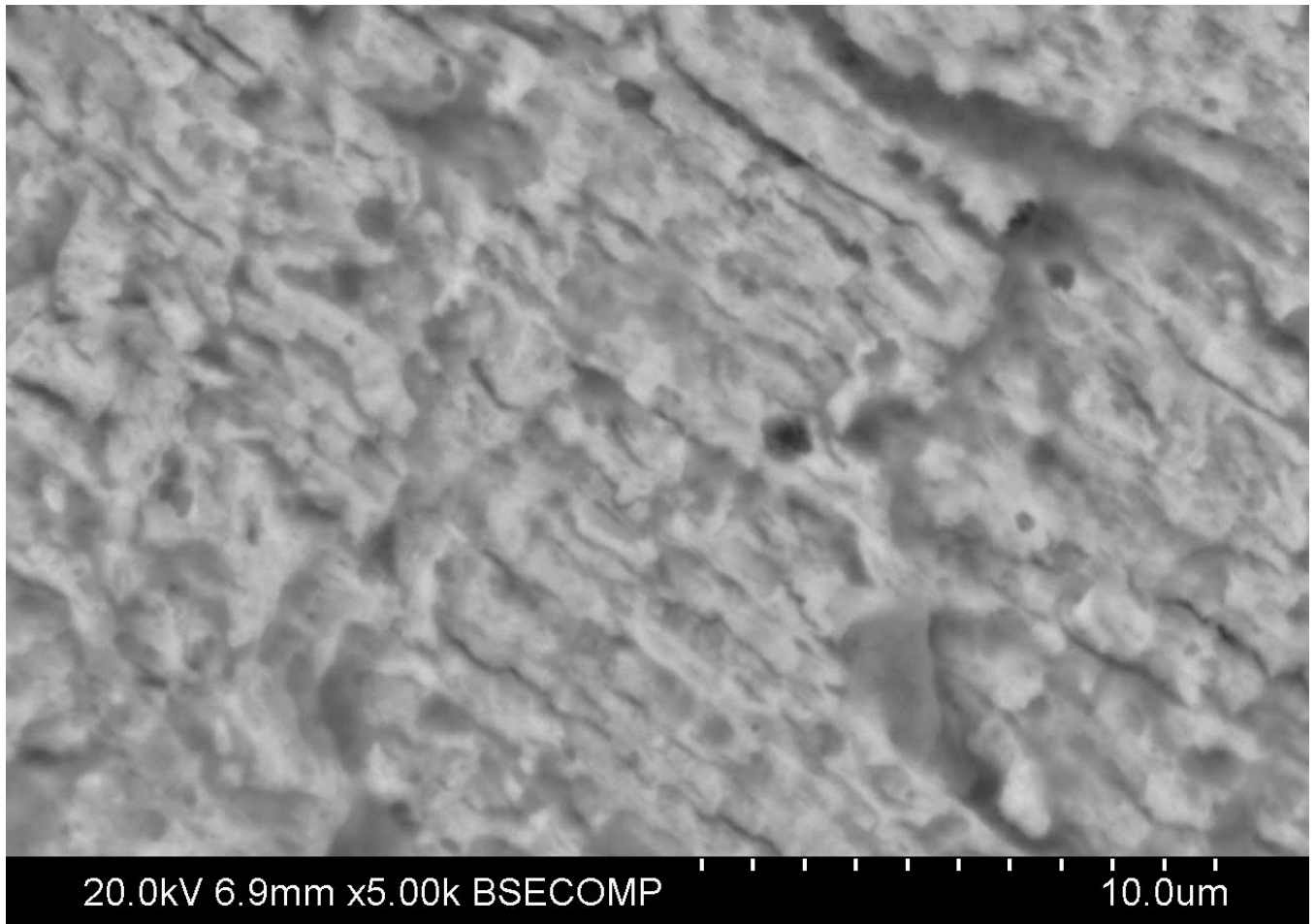


Figure 19 – BE micrograph of fatigue striations on the lower fracture thumbnail crack.

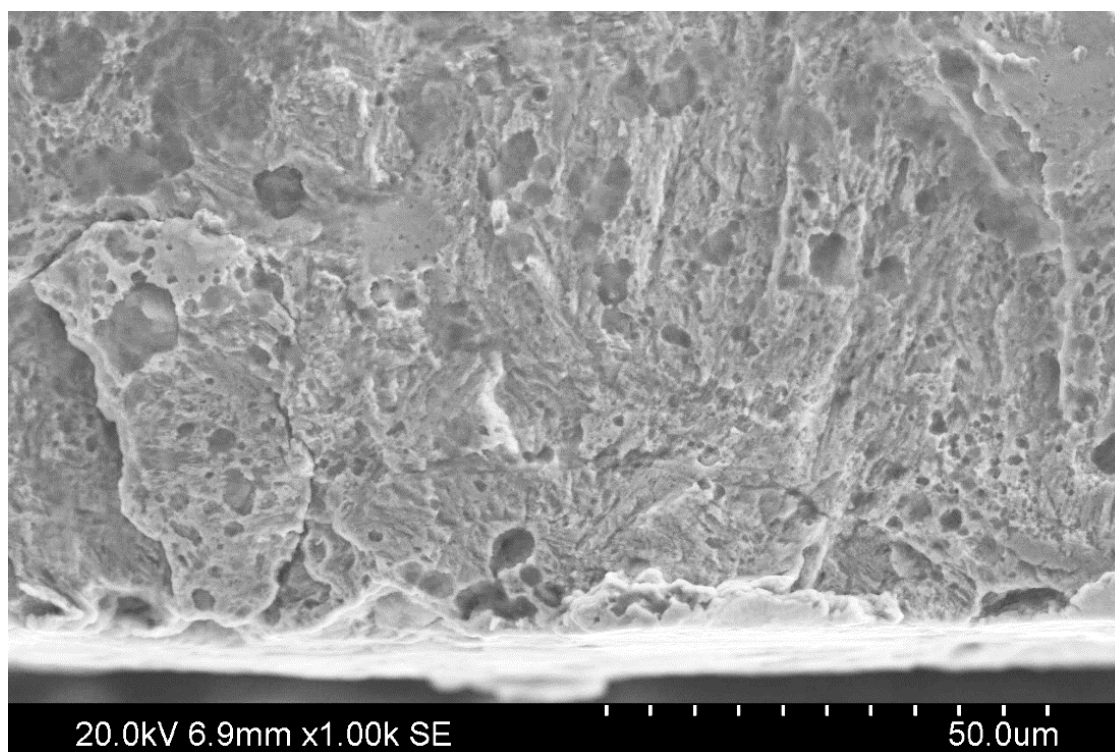


Figure 20 – SE micrograph of the fatigue crack initiation site on the lower fracture surface.

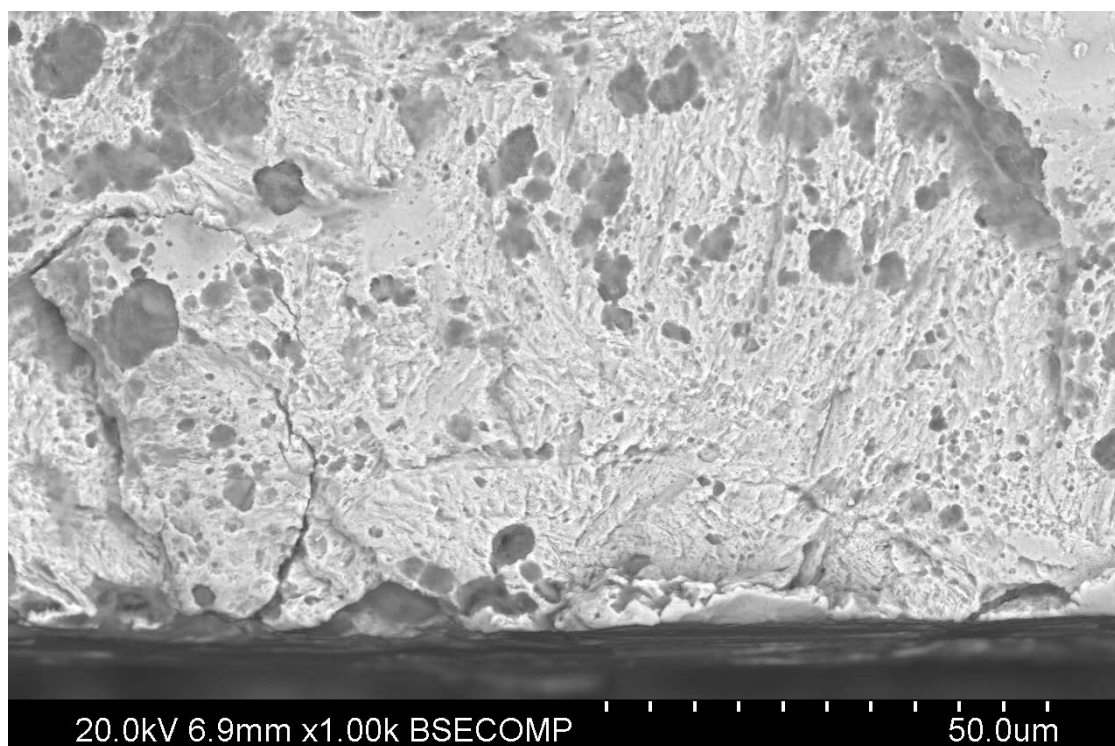


Figure 21 – BE micrograph of the fatigue crack initiation site on the lower fracture surface.

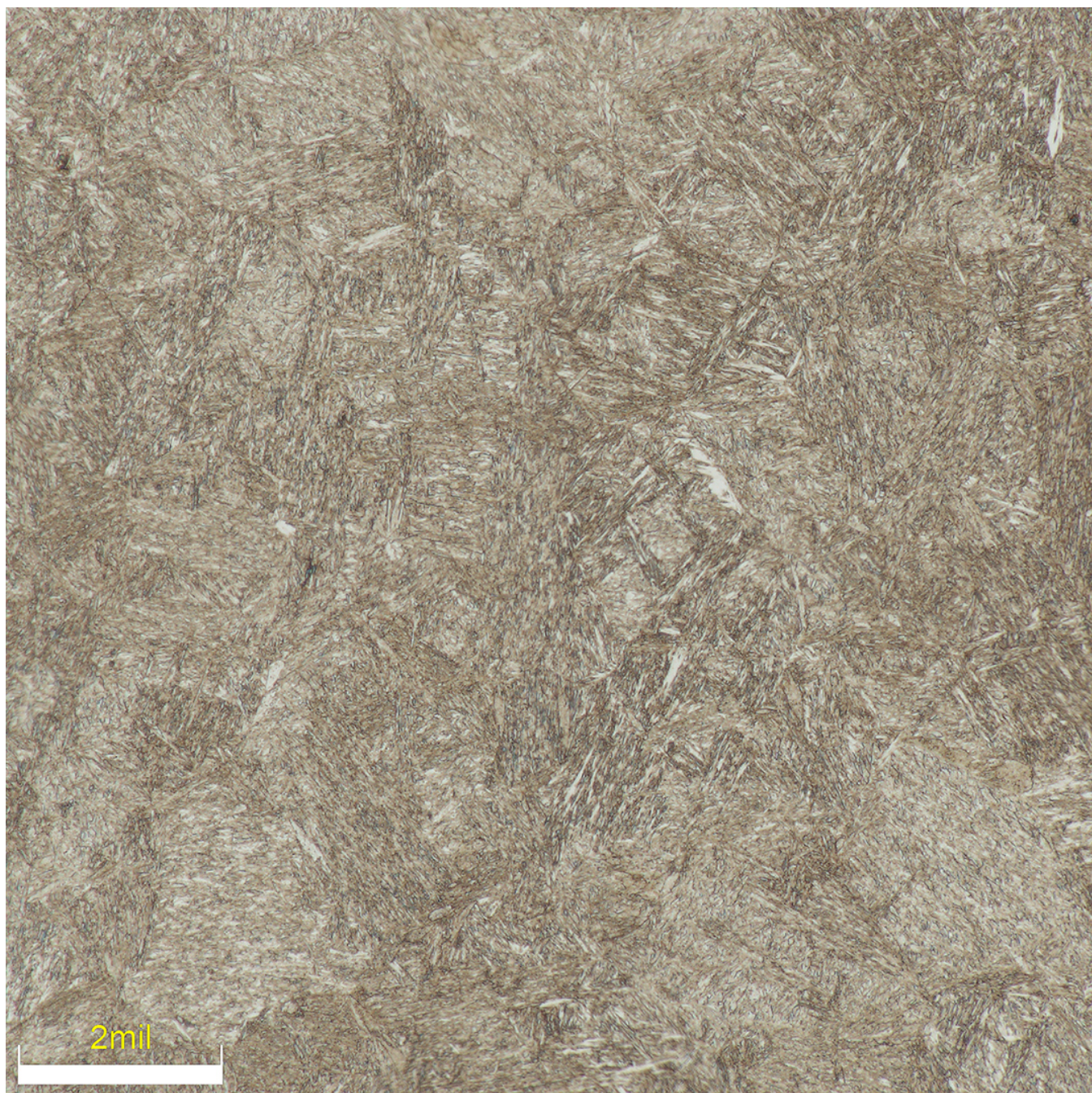


Figure 22 – Bright field (BF) optical micrograph, showing a typical area of the cylinder microstructure, showing tempered martensite (~500X, etched 2% Nital).

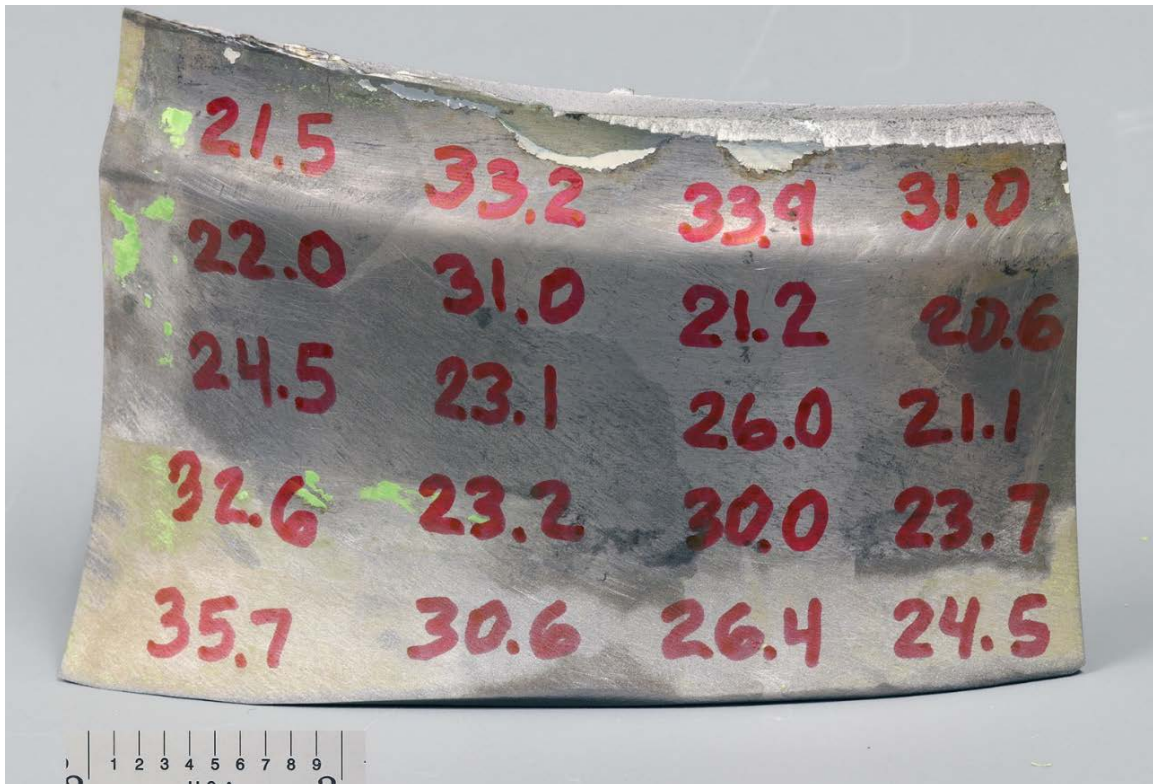


Figure 23 – The Barkhausen magnetic noise results, written on the section containing the upper fracture (values represent magnetoelastic parameter change with increasing magnetization).

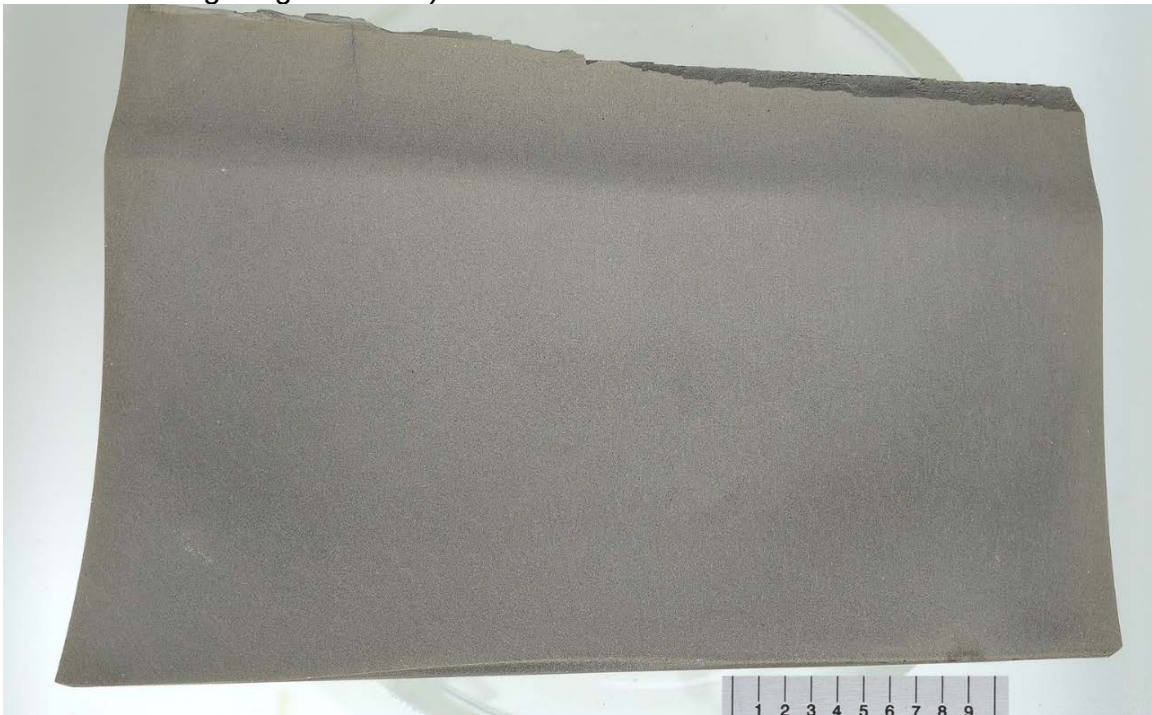


Figure 24 – The section of the upper fracture surface exterior, after Nital etching the surface. There were no areas consistent with excessive darkened or lightened surface color.

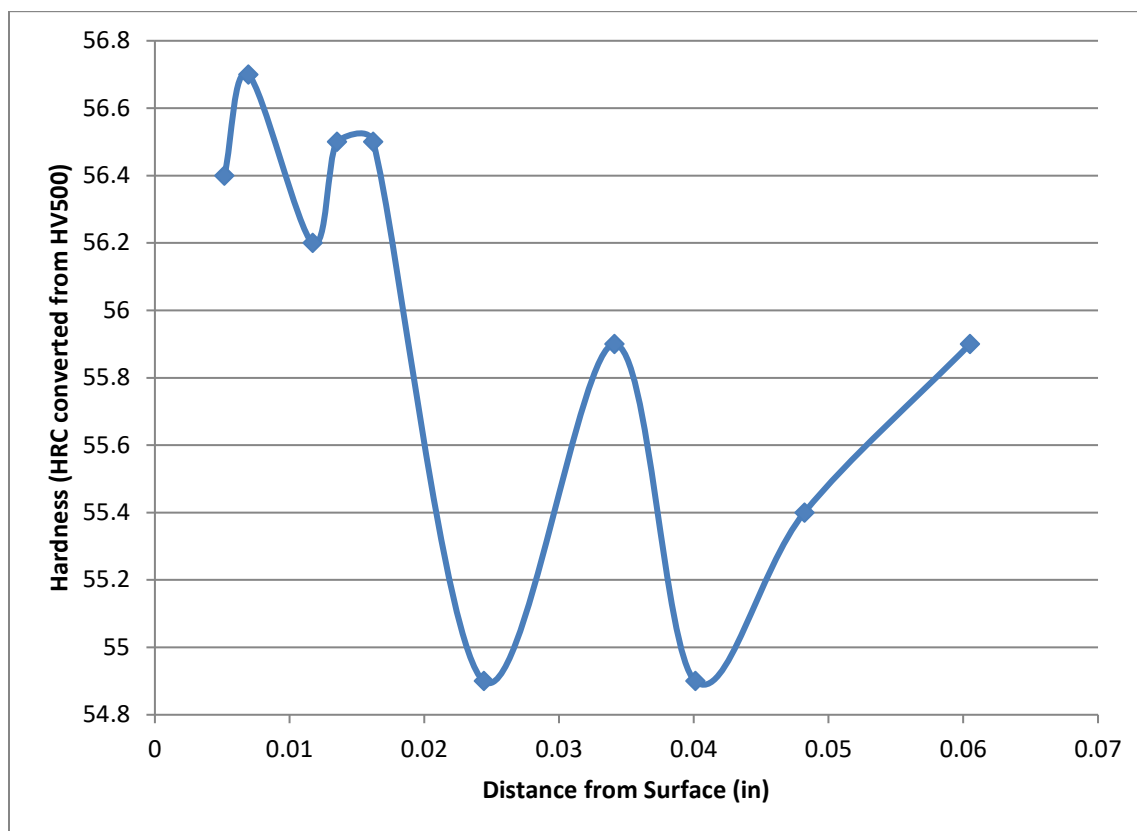


Figure 25 – Chart of hardness results from the exterior surface of the cylinder near the fracture surface, in HRC (converted from HV<sub>500</sub> per ASTM E140).