

09 September 2022
66-CB-H220-ASI-19264

Clint Crookshanks
Office of Aviation Safety
Aviation Engineering Division (AS-40)
National transportation Safety Board
4760 Oakland Street, Suite 500
Denver, Colorado 80239



Subject: Boeing Equipment Quality Analysis Report on Right Main Landing Gear – Sun
Country 737-800 N817SY Landing Gear Collapse in Las Vegas 04 February
2022

Dear Mr. Crookshanks:

In support of the US NTSB investigation into the subject event, Boeing's Equipment Quality Analysis Laboratory was asked by the NTSB to perform an examination of the Right Main Landing Gear recovered from the subject airplane. Please find the Boeing EQA Laboratory Report enclosed with this letter.

The information included with this correspondence is controlled under the US Export Administration Regulations (15 CFR Parts 300-799) and has been categorized as ECCN: 9E991.

Please feel free to contact us if you have any questions.

Best regards,



Robert J. McIntosh
Director, Product Safety

Enclosure: Boeing Equipment Quality Analysis Report on Right Main Landing Gear – Sun
Country 737-800 N817SY Landing Gear Collapse in Las Vegas 04 February 2022



Equipment Quality Analysis Report

Boeing Commercial Airplanes



TO: Air Safety Investigations (ASI)

EQA NUMBER: AS13481

DATE: July 18, 2022

MODEL NUMBER: 737-800

AIRPLANE NUMBER: N817SY

SUBJECT: *Right Main Landing Gear Collapse*

IDENTIFICATION: Part name: Main Landing Gear (MLG), Right (RH)
Boeing part number: 161A1118-12

REFERENCE: (a) National Transport Safety Board (NTSB) Aviation Incident Preliminary Report
<https://data.nts.gov/carol-rep/gen/api/Aviation/ReportMain/GenerateNewestReport/104596/pdf>

BACKGROUND:

Per reference (a), 737-800 line number 833, airplane variable number YC082, experienced a right main landing gear collapse during landing on at Harry Reid International Airport (LAS) in Las Vegas, Nevada on February 4, 2022. Airplane YC082 was registered as N817SY and operated by Sun Country Airlines (SCA). The airplane was originally delivered on April 26, 2001 and had accumulated 68,008 flight hours and 26,003 cycles at the time of the event.

The event was under investigation by the United States National Transportation Safety Board (NTSB) with Boeing acting as a technical adviser to the NTSB.

It was reported that the NTSB determined through maintenance record review that the subject MLG Outer Cylinder was originally delivered with 737-800 line number 307, airplane variable number YC473. The part was overhauled at TAP, Rio De Janeiro, Brazil in February 2012 after it had accumulated 20,995 cycles. When the failure event

occurred in 2022, the outer cylinder had accumulated 38,491 total cycles since new and 17,496 cycles since the last overhaul.

Figure 1, shows the right main landing gear outer cylinder after the incident, before parts were removed from the aircraft. The portions were identified as Forward and Aft. The uppermost Forward portion, was sectioned at the point illustrated in Figure 1 during removal from the aircraft. The Forward and Aft portions were sent by the NTSB to Boeing Equipment Quality Analysis (EQA) in Seattle for the next phase of the examination under the direction of the NTSB.

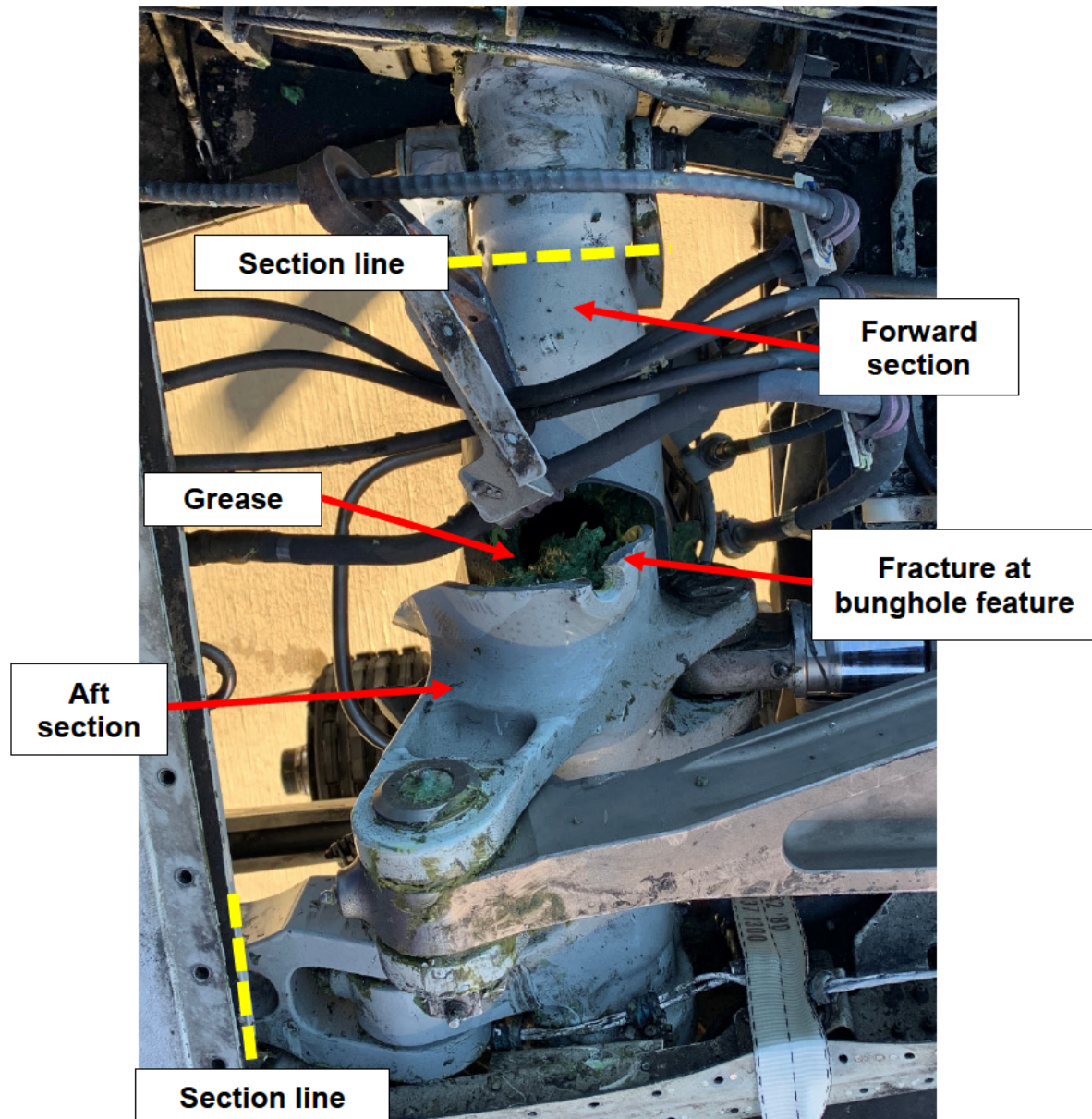


Figure 1: Forward and Aft portions as installed in original configuration

SUMMARY:

The following report documents the sequential steps of the examination performed on each portion of the available part.

Attached as enclosure A is a report of the metallurgical analysis performed by Boeing Research and Technology (BR&T). The BR&T report documents the analysis and its findings.

EXAMINATION, April 26-29, 2022:

The examination at Boeing EQA began on April 26, 2022. The initial exam days were attended by Boeing Air Safety Investigation, BR&T, Landing Gear Structures Engineering, NTSB, Federal Aviation Administration (FAA) and Sun Country Airlines personnel. The subject parts arrived in one crate. Figure 2 shows the crate as received at Boeing EQA. Figure 3 shows the contents of the crate after opening.

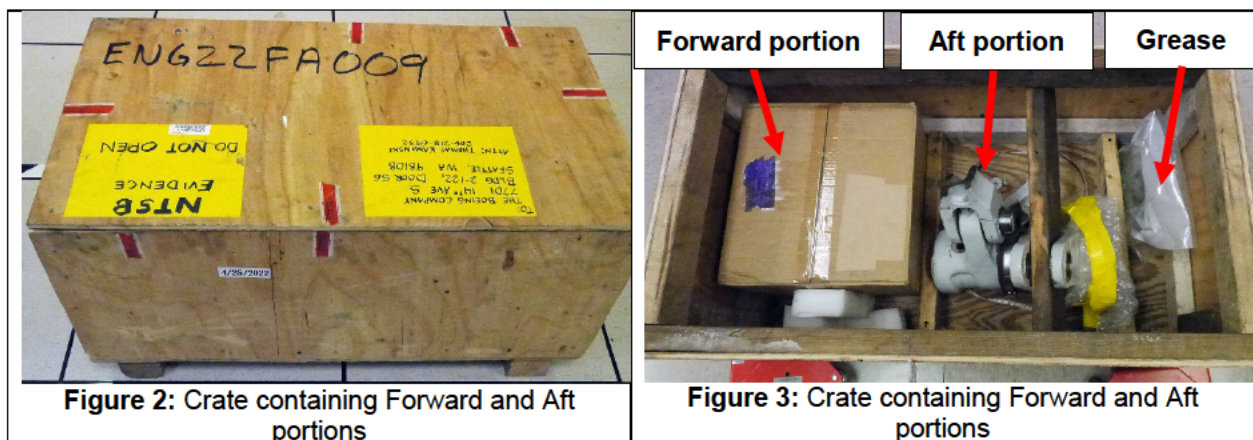


Figure 4 and Figure 5 show the Forward portion during and after unboxing. Figure 5 shows the section line where the outer cylinder was removed from the aircraft.



Figure 4: Box containing Forward portion



Figure 5: Forward portion removed from box

Figure 6 and Figure 7 show the Aft portion removed from the crate. Figure 7 shows where sectioning occurred to remove the outer cylinder from the aircraft.



Figure 6: Aft portion removed from crate

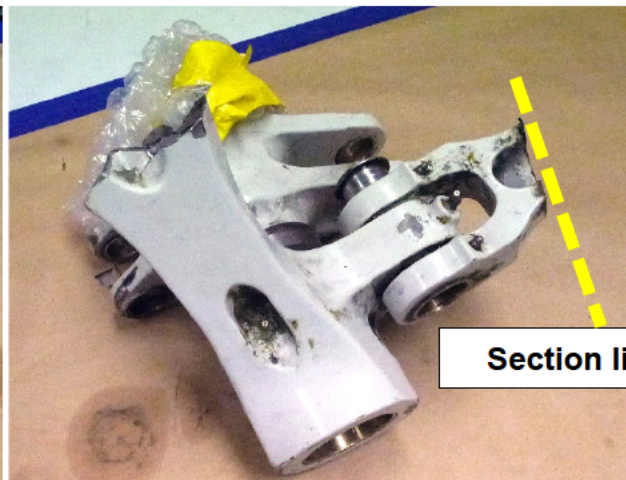


Figure 7: Aft portion removed from crate

The crate contained a quantity of grease double-bagged that had been located in the void behind the bunghole feature. Figure 8 and Figure 9 show the bag and contents. This grease was not evaluated further during this examination.



Figure 8: Grease from outer cylinder, with inner and outer bags



Figure 9: Grease from outer cylinder, inner bag

Aft and Forward fractured areas around the bunghole feature. The parts were previously cleaned of grease and Corrosion Inhibiting Compound by the NTSB before shipment to Boeing, see Figure 10.

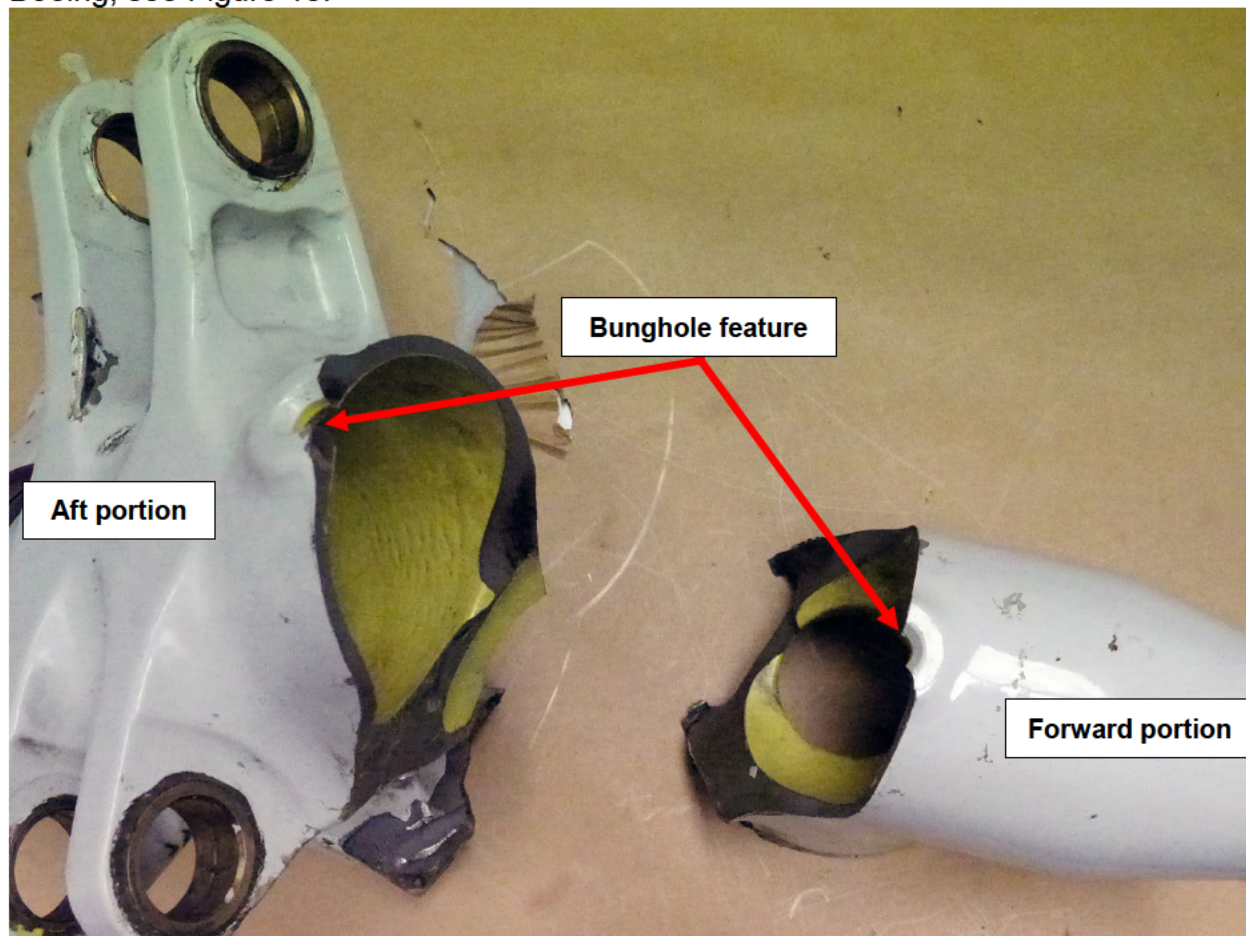
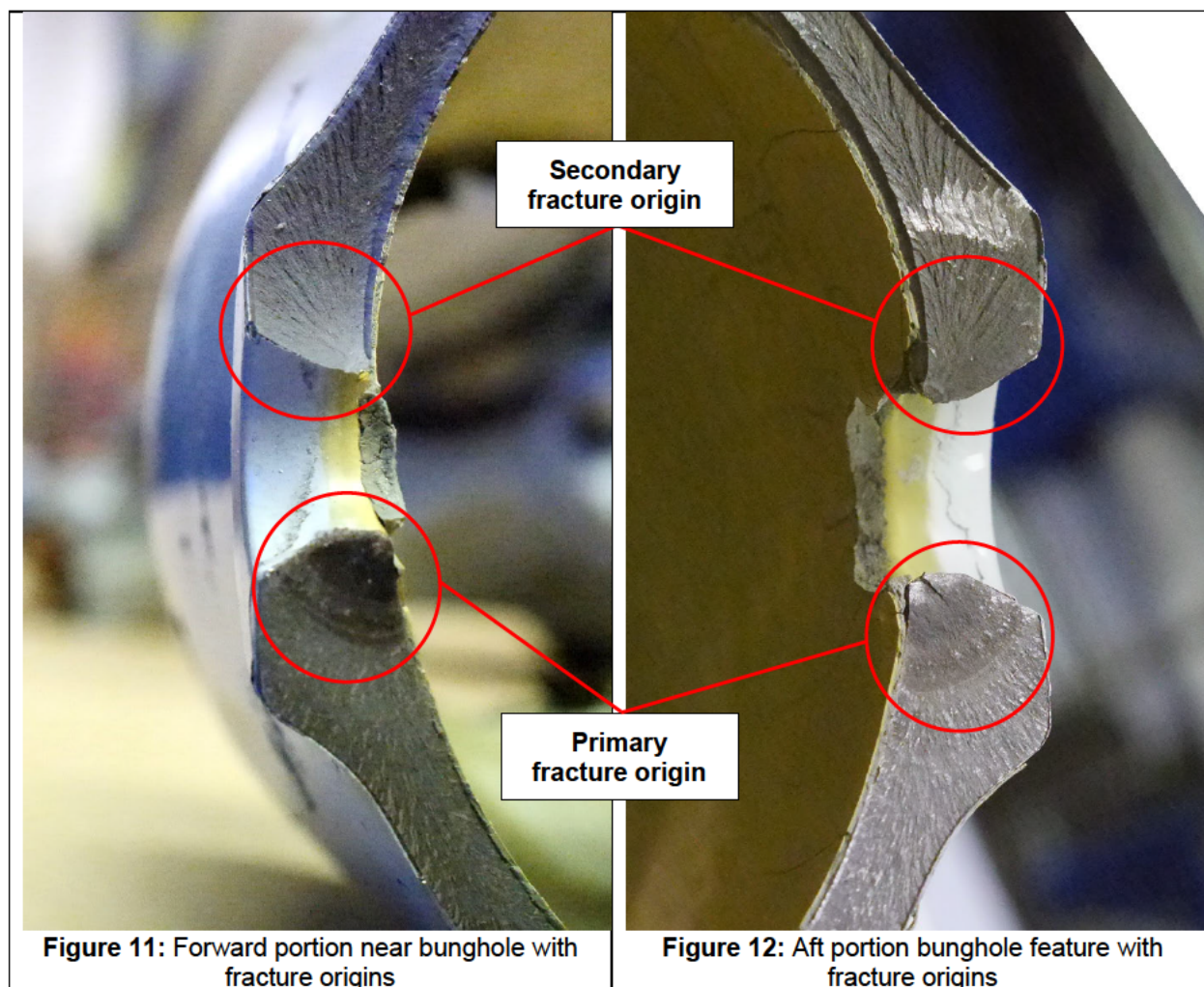


Figure 10: Aft and Forward portions during examination

During the initial examination, BR&T identified the apparent primary and secondary fracture origin thumbnail locations in the bunghole area of the Forward and Aft portions, as shown in Figure 11 and Figure 12.



The examination team decided to cut the areas of interest from the larger parts of the Aft and Forward portions. Arrows indicating the original orientation on the aircraft and cut lines are seen in Figure 13 and Figure 14.

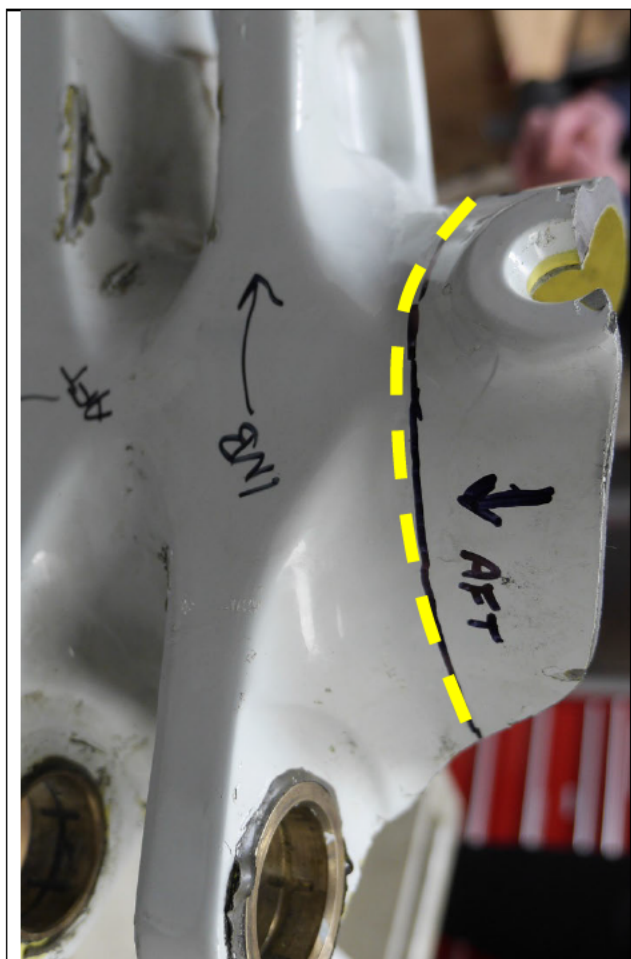


Figure 13: Aft portion with cut line



Figure 14: Forward portion with cut line

The Aft and Forward sections were mounted and sectioned by bandsaw as seen in Figure 15 and Figure 16.



Figure 15: Aft portion mounted during sectioning by bandsaw

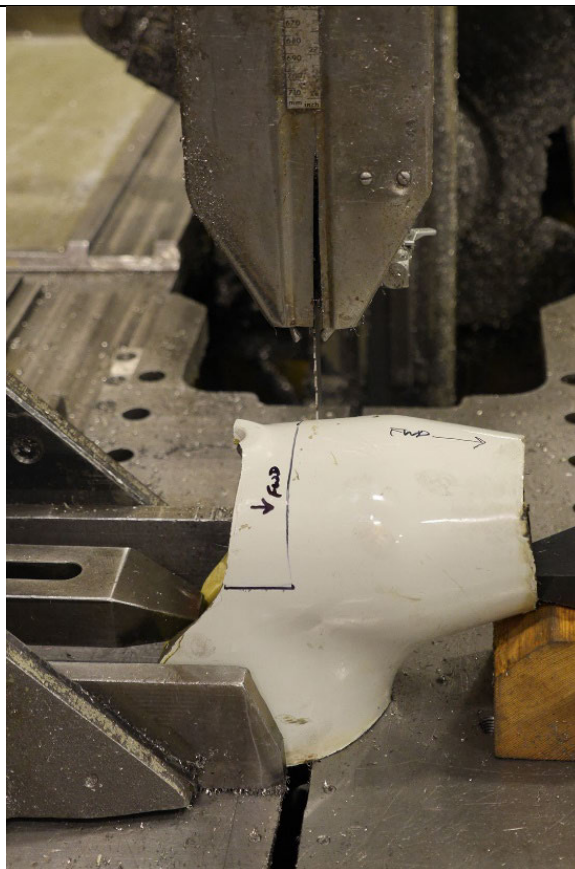


Figure 16: Forward portion mounted for sectioning

The smaller sized samples after sectioning are see in Figure 17 and Figure 18.

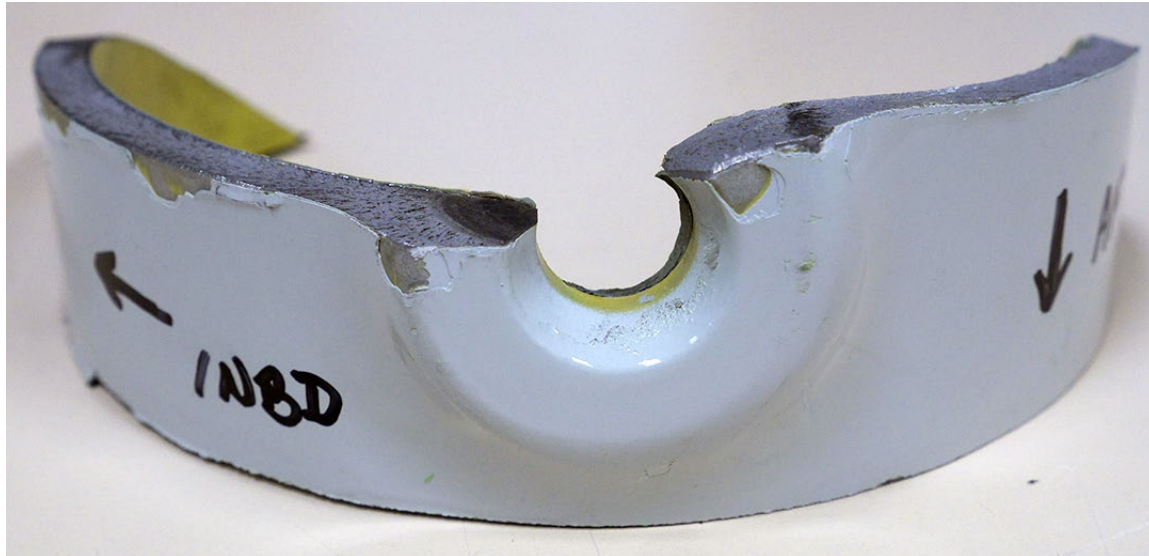


Figure 17: Aft portion after sectioning



Figure 18: Forward portion after sectioning

The parts were ultrasonically cleaned and microscopic images were obtained of the fracture surfaces, see Figure 19 and Figure 20.

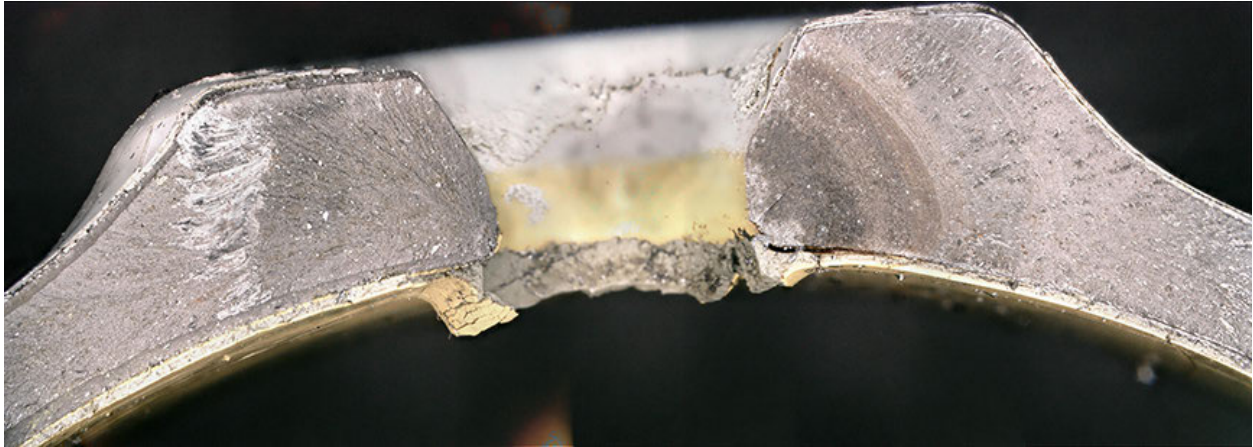


Figure 19: Microscopic image of the Aft fracture face

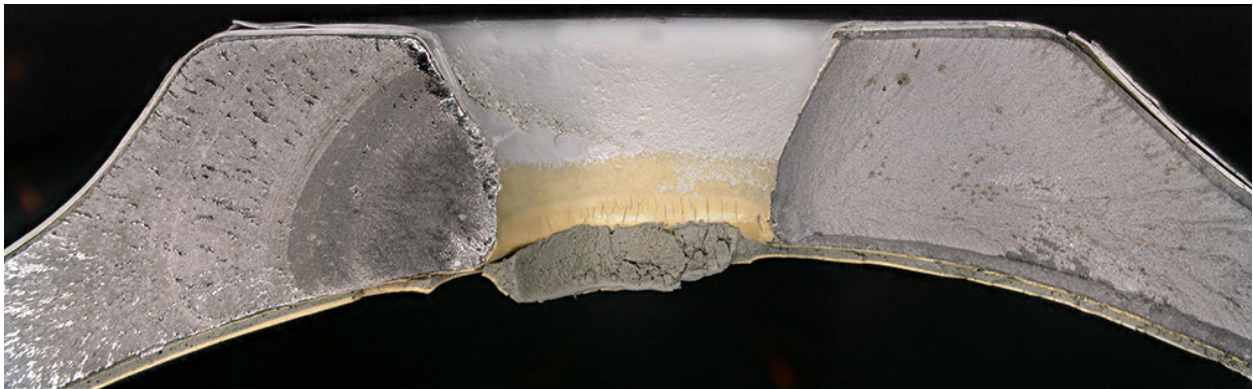


Figure 20: Microscopic image of the Forward fracture face

The Forward and Aft portions were further sectioned to allow detailed examination, Figure 21 and Figure 22. Portions were labeled as seen in the figures.

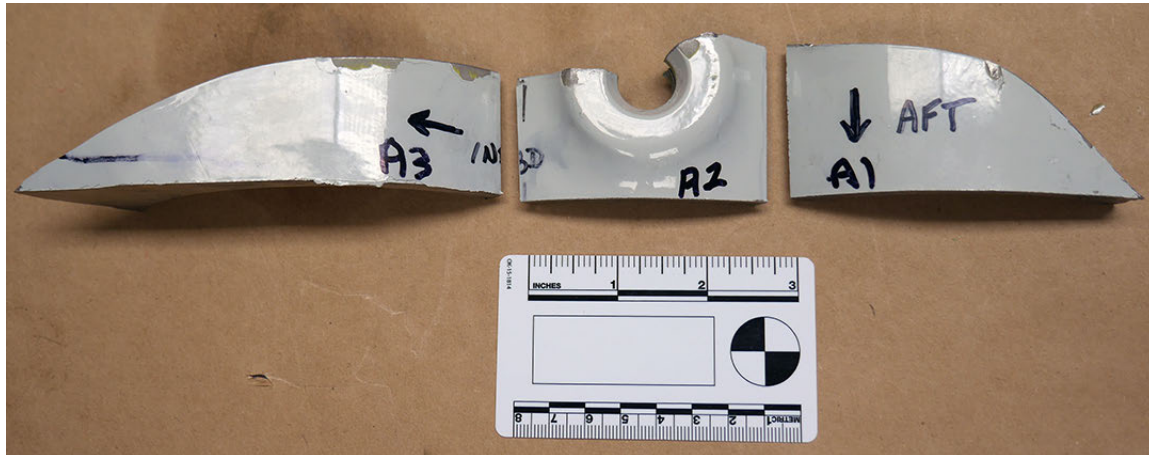


Figure 21: Aft portion sectioned to allow further examination

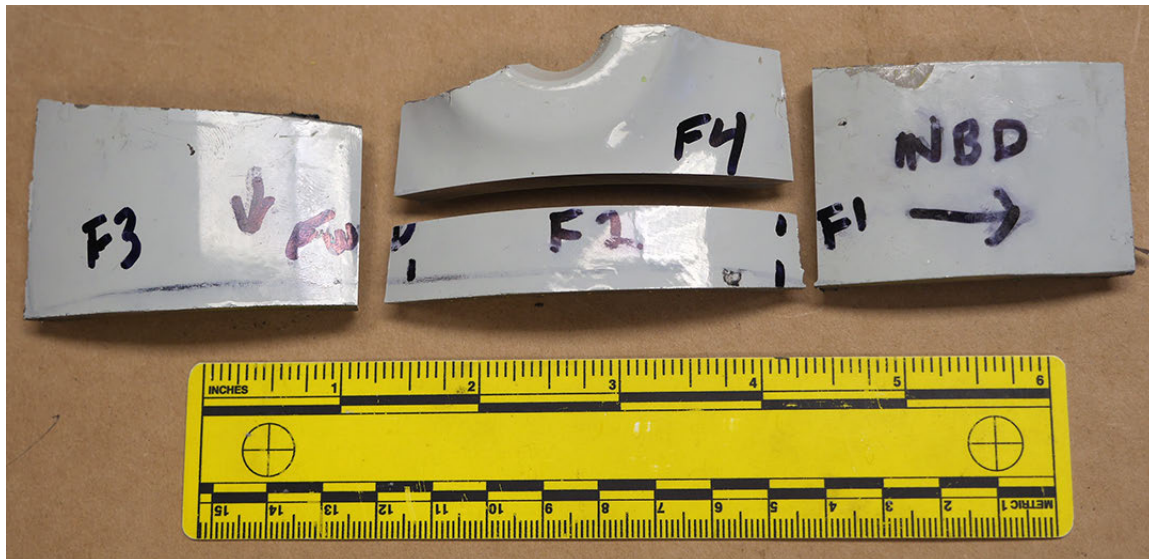


Figure 22: Forward portion sectioned to allow further examination

The A2 portion was stripped of paint and primer at the BR&T paint lab. See Figure 23 and Figure 24.



Figure 23: Portion A2, outer surface, after paint and primer removed

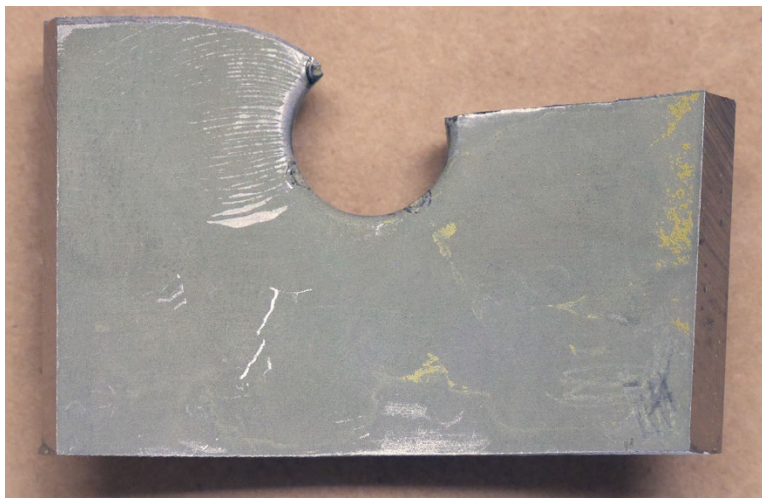
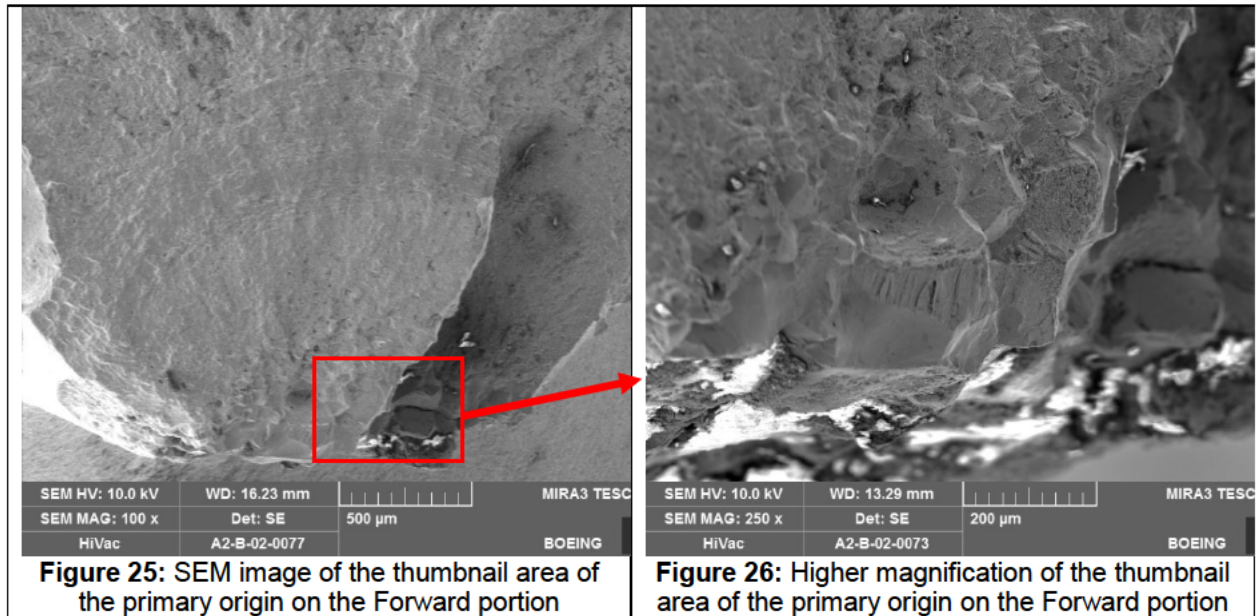


Figure 24: Portion A2, inner surface, after paint and primer removed

BR&T used Scanning Electron Microscopy (SEM) to further evaluate the fracture origins. Figure 25 and Figure 26 show the primary origin on the Forward portion.



SEM examination of the secondary origin are shown in Figure 27, Figure 28 and Figure 29.

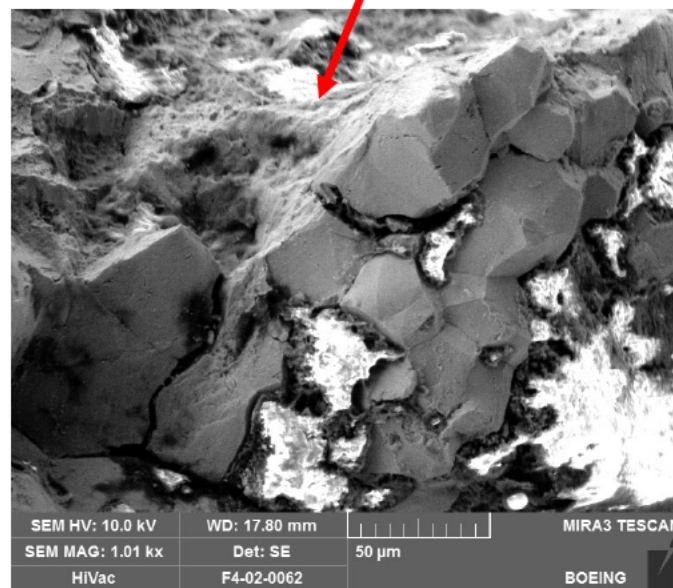
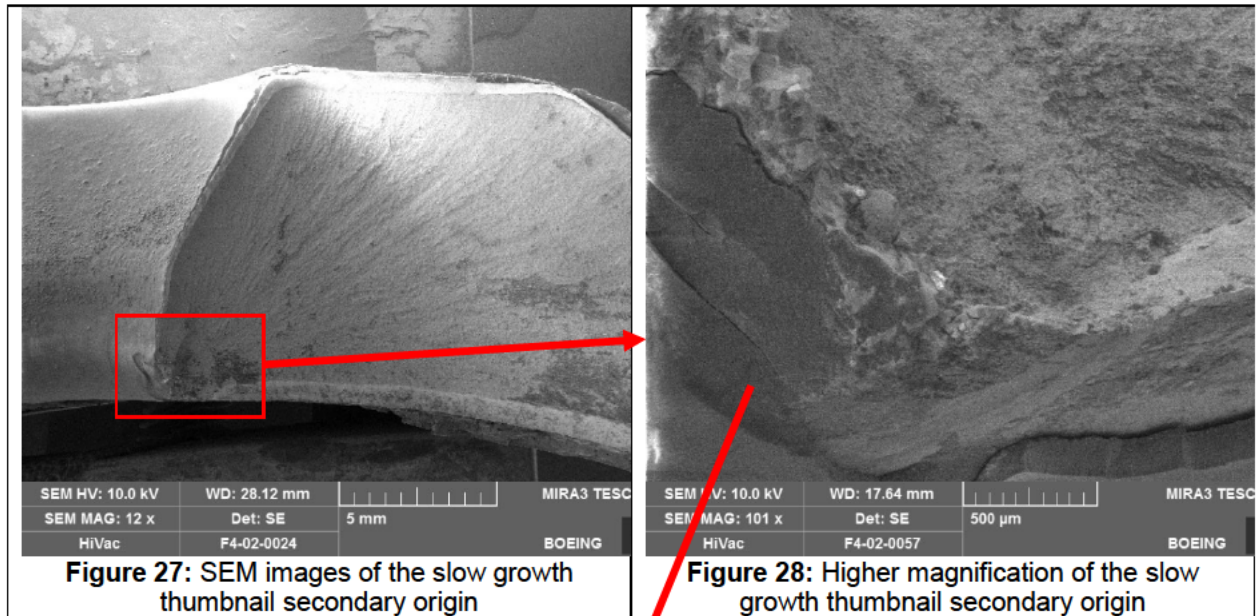


Figure 29: Higher magnification of the slow growth thumbnail secondary origin

During the examination the team discovered spherical anomalies on portion A2, these anomalies are consistent with metal burn damage created by electrical arcing, see Figure 30. Figure 31 shows the possible arc burn at the primary fracture origin

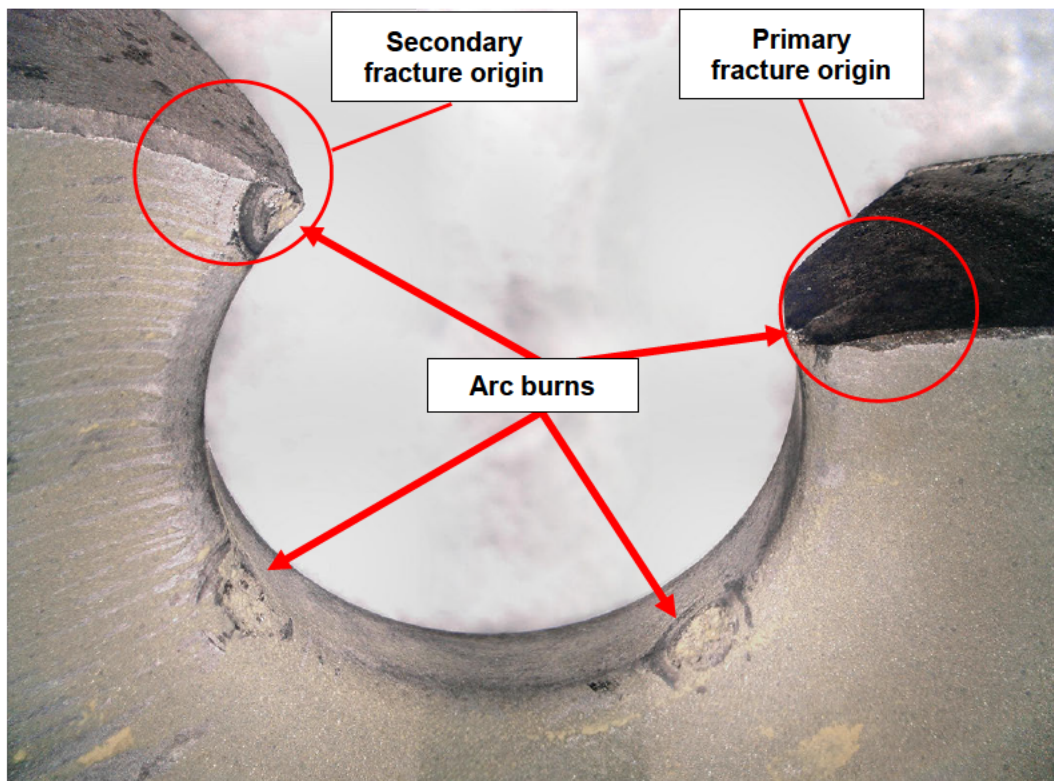


Figure 30: A2 paint and primer removed, possible arc burns

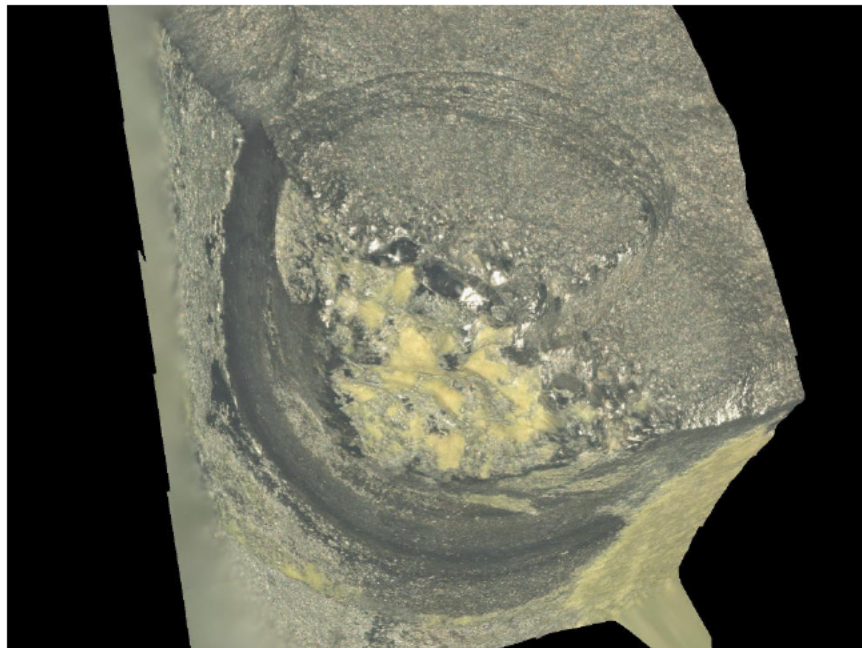


Figure 31: Close up image of possible arc burn at the primary origin

The Aft portion was subjected to magnetic particle inspection (MPI). BR&T found magnetic particle indication at the spherical burn areas and an area showing a linear indication for a crack, see Figure 32.

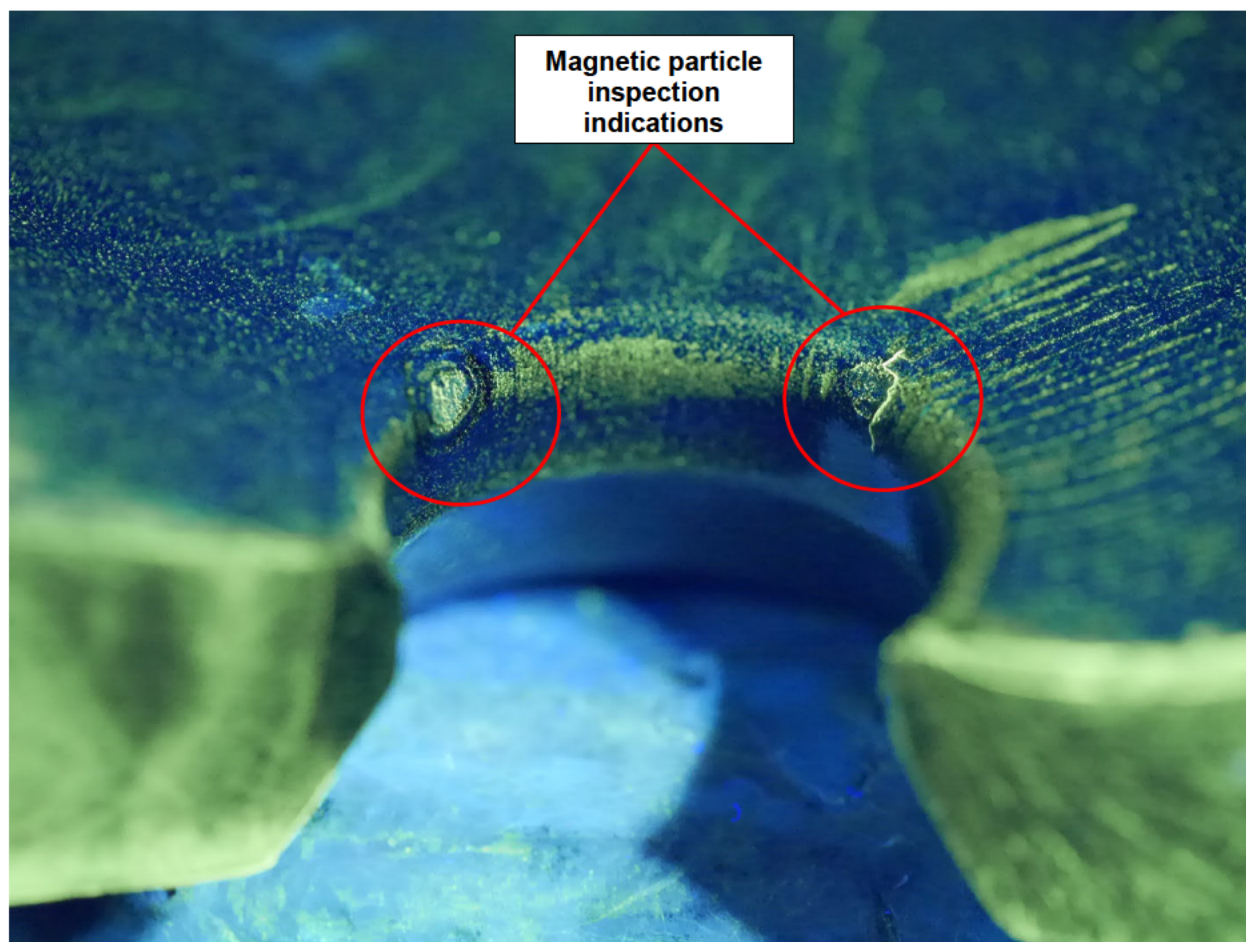


Figure 32: Magnetic particle indications on the Aft portion

To facilitate further examination and testing, the examination team determined that portion A2 was to be cut into smaller sections, see Figure 33.

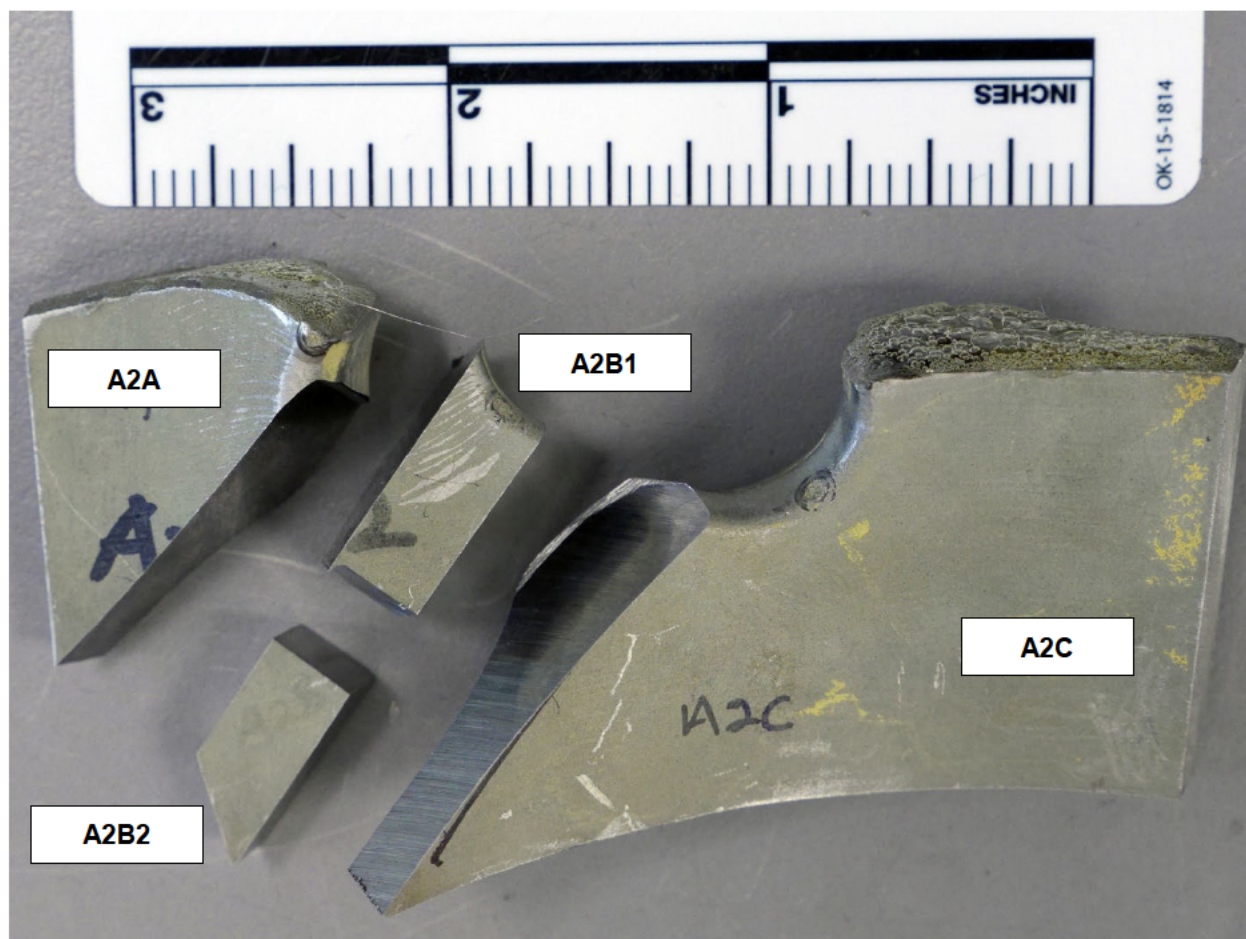


Figure 33: Portion A2 cut into smaller sections to continue the examination

Items A2C and F4 were stripped of paint and primer and subjected to a nitric acid and alcohol (nital) etch inspection, see Figure 34 and Figure 35.



Figure 34: A2C portion after stripping and nital etch



Figure 35: Portion F4 after stripping and nital etch

Nital etch of showed the presence of under-tempered (light colored etching) and over-tempered (dark ring) martinsite, see Figure 36.

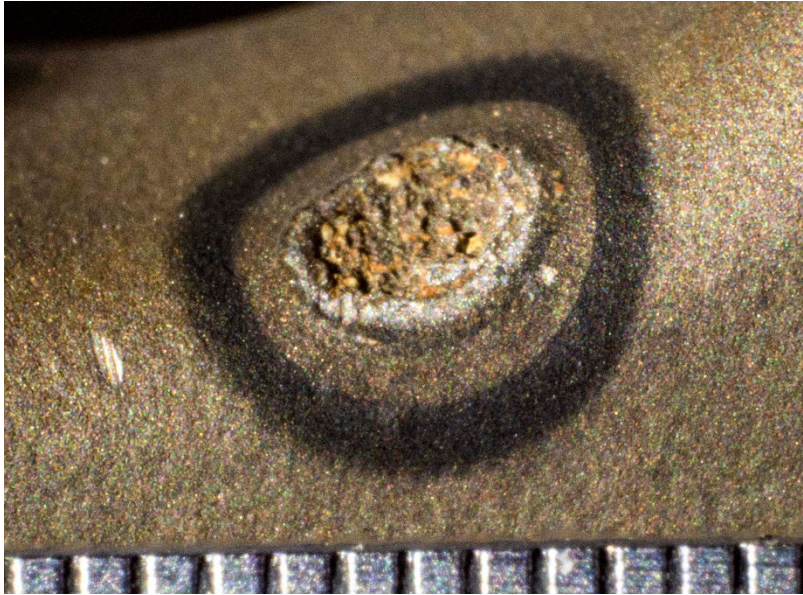


Figure 36: Close up of arc burn after nital etch showing damage consistent with arc burn

The area of interest on portion A2B was mounted and polished for further SEM examination, see Figure 37 and Figure 38

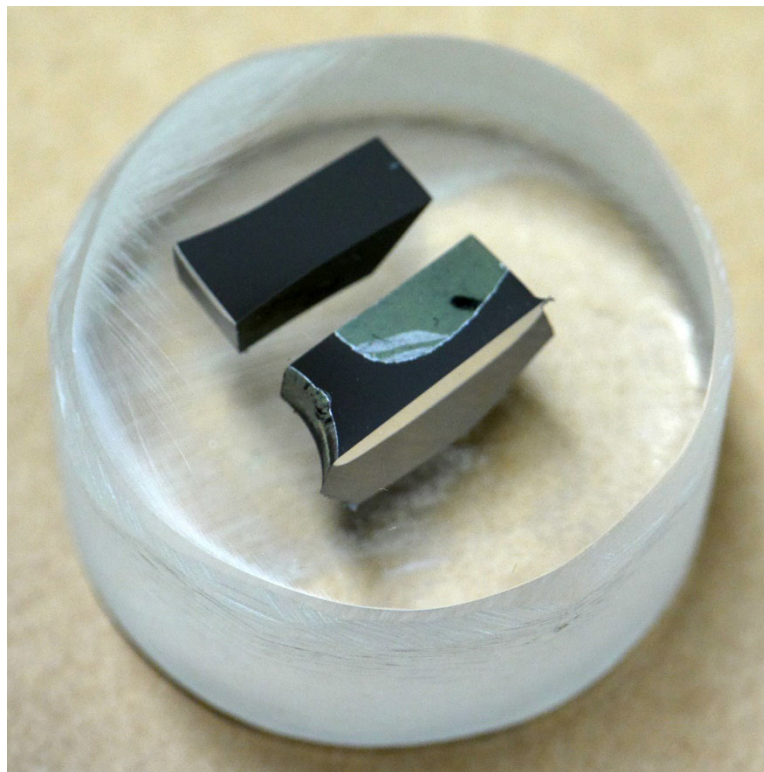


Figure 37: Portions A2B1+A2B2 mounted and polished

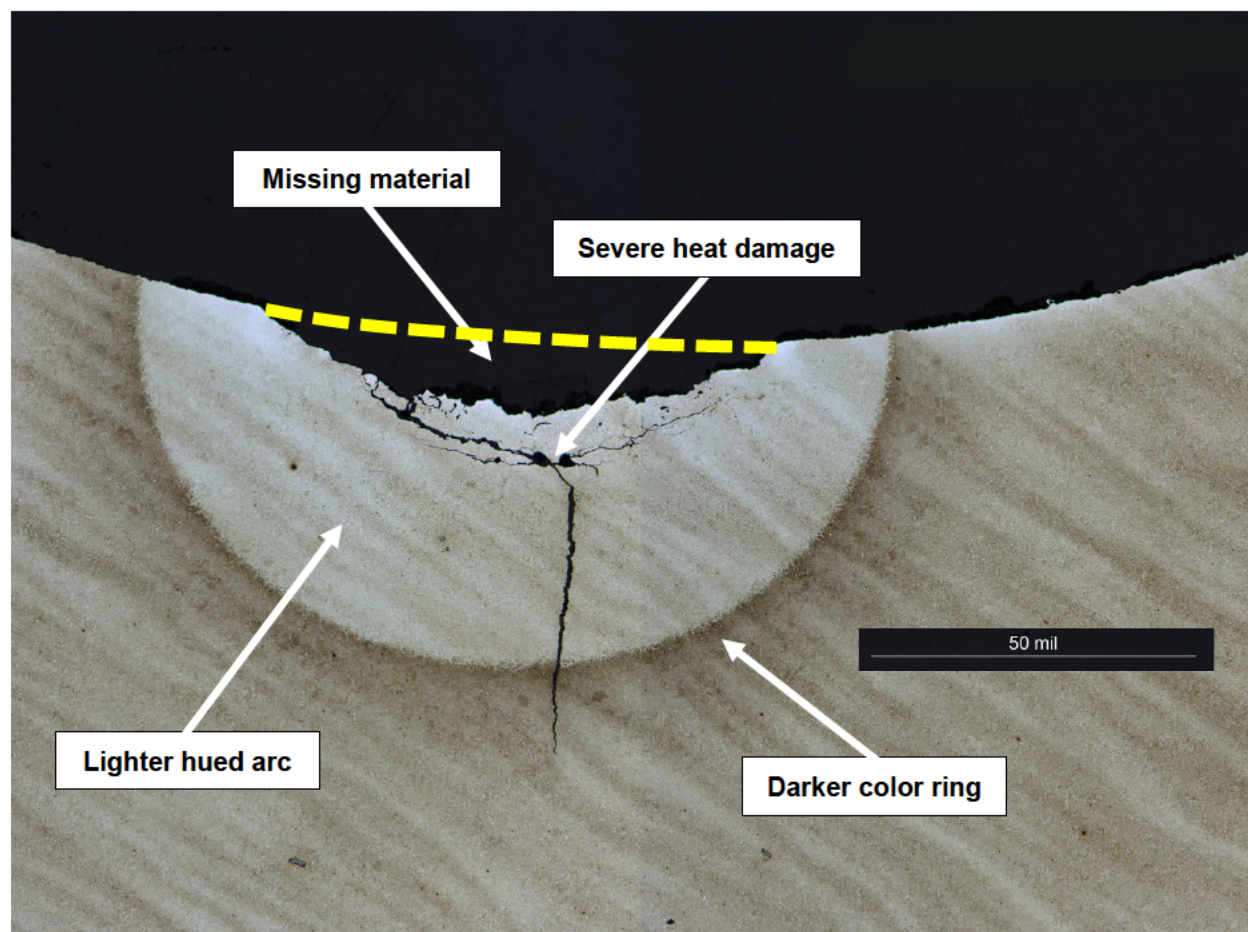


Figure 38: SEM imagery of the arc burn area on portion A2B1

Portion A2A was mounted for further metallographic examination, see Figure 39

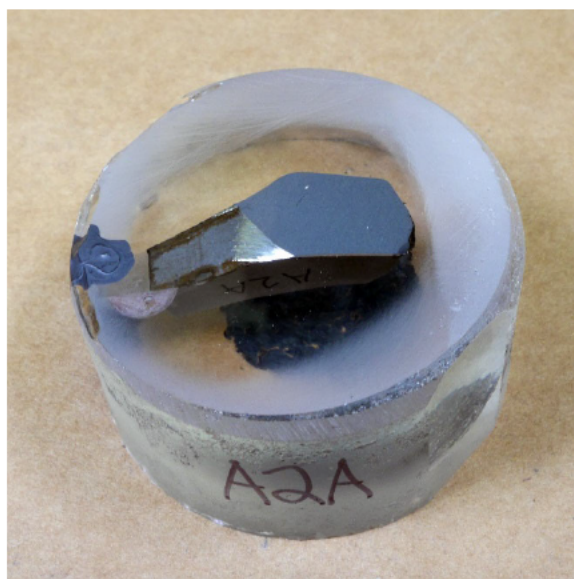


Figure 39: Portion A2A was mounted for further metallographic examination

April 29, 2022 was the last day of the NTSB attended exam at Boeing EQA.
All additional portions from the Aft and Forward portions have been returned to EQA,
see Figure 40.



Figure 40: Aft and Forward portions at EQA

All parts initially received have been returned to the shipping crate as seen in Figure 41
and are currently stored securely at Boeing EQA.



Figure 41: All parts returned to shipping crate at EQA

Refer to enclosure A for details of the BR&T examination and analysis.

DISPOSITION:

The subject component will be conveyed per instruction from Boeing ASI after completion of this analysis.

The preceding information is being submitted for information purposes.

Signature on file.

ENCLOSURE:

A. BR&T Engineering Report No: MS 14149



Engineering Report No: MS 14149

To:

[REDACTED]
[REDACTED]

CC:

[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]
[REDACTED]

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FRACTURE ANALYSIS REPORT

Engineering Report No: MS 14149

Date: June 6, 2022

Lab BLIS Number(s): 2022506, 2022134

Part Information:

Design Drawing Part Name: Right Main Landing Gear Outer Cylinder

Part Number: 161A1118-12

Serial Number (if applicable):

ATA Index: 32

Responsible Design Group: Landing Gear Design

Airplane Information:

A/P Customer: Sun Country

A/P Model: 737- 800

Registry No: N817SY

Line Position No: 833

Flight Hours: 68,008

Material Information:

Material: 4340M

Heat Treat: 275 – 300 ksi

Material Specification: BMS7-26

Finish:

Outside Diameter:

Cadmium-titanium alloy plate and apply chromate treatment.

Apply two coats of Primer.

Apply gloss enamel

Inside Diameter:

Cadmium-titanium alloy plate and apply chromate treatment

Apply one coat of primer.

Apply Sprayable Sealant

Apply one coat of primer.

Coat the interior surface of tubular and hollow parts with CIC

Other Applicable Information:

GROUP INDEX: Landing Gear Design Center

SUBJECT: Metallurgical Fracture Analysis of Main Landing Gear Outer Cylinder

BACKGROUND:

Soon after takeoff from Harry Reid International Airport (LAS) Sun Country Airlines flight 110 received a red warning light for the right main landing gear (RMLG). After subsequent actions in the cockpit, the crew declared an emergency and returned to LAS. During landing, about 3 seconds after touching down, the RMLG collapsed.

The RMLG was removed from the airplane and the fracture surfaces were excised. The RMLG fractures were submitted to the National Transportation Safety Board (NTSB) for investigation. The NTSB shipped the parts to Boeing and supervised the Equipment Quality Analysis (EQA) and BR&T investigations at Boeing. Figure 1 shows the as-received parts in the shipping crate. The smaller, forward section is in the cardboard box.

The Right Main Landing Gear Outer Cylinder was originally delivered with A/C YC473/29918. The Right Main Landing Gear was overhauled at TAP, Rio de Janeiro, Brazil in February 1, 2012 after 20,995 Flight Cycles. No details were provided as far as what processes were performed during this overhaul.

EXPERIMENTATION AND RESULTS:

After the fractured parts were removed from the shipping container and photographed, under the direction of the NTSB, the parts were cut into sections manageable for further dissection in the metallographic laboratory and labeled consistent with their orientation on the landing gear. (Figure 2, 3a and 3b.)

The subject right main landing gear outer cylinder had fractured through the trunnion of the outer cylinder, through the bung hole (a tooling hole).

The fracture faces were well preserved and visual examination revealed the presence of slow crack growth thumbnail features on both sides of the hole (Figure 4 and 5). The fracture appearance in these regions was consistent with fatigue crack propagation. SEM microscopy confirmed the origin of both fractures was located at the corner created by the intersection of the bung hole and the inner surface of main landing gear outer cylinder trunnion (Figure 6a). The fatigue cracking propagated from intergranular regions that were present at the corner (Figure 6b). The intergranular fracture portion had unusual particles on grain faces and boundaries (Figure 6c). EDS of the particles revealed that they were essentially pure cadmium as shown in figure 6d, indicating that the intergranular portions of the fracture were possibly the result of cadmium embrittlement. The secondary origin exhibited intergranular fracture features with cadmium at the grain boundaries that were similar to those at the primary origin (Figures 7a, b, and c). At the primary origin, the intergranular fracture mode extended to a depth of approximately 0.02 inches prior to transitioning to transgranular fatigue cracking to a depth of approximately 0.42 inches (Figure 8a). At the secondary origin, the slow growth fatigue fracture growth extended to a depth of 0.07 inches (figure 8b).

The section containing the Aft Fracture Face was chemically stripped and lightly grit blast to aid in removal of the finishes (the fracture faces were protected during these operations to prevent damage). When the finishes were removed, the presence of four spherical anomalies approximately 0.1 inches in diameter were revealed. These spherical artifacts were centered on the intersection of the inner diameter of the bung hole and the inner diameter of the outer cylinder trunnion. The spherical features were consistent with base metal burn damage created by electrical arcing. Two of these were coincident with the fracture origins. Figure 9a and 9b show the arc burn that was present at the primary fracture origin.

Magnetic particle inspection was performed on the stripped Aft Fractured part and magnetic particle indications were coincident with the spherical burn areas on the radius, with one of these areas also showing a linear indication for a crack (Figure 10). This piece was further sectioned to enable cross-sectioning of one of the arc burns for metallographic examination and nital etch inspection (Figure 11). Two dark etched rings were present on the intersection of the inner diameter of the cylinder and the bung hole feature (Figure 12a and b). These indications were coincident with the locations that had magnetic particle inspection indications. These darker etched areas were characteristic of overtempered martensite (OTM) and consistent with heat damage created during arc burning. Figure 13 shows a magnified image of an arc burn observed on the bung hole.

The arc burn selected for cross-sectioning was mounted and prepared for metallographic examination. The inner most region was missing material. Four regions of interest were observed (Figure 15). Hardness measurements

were made from the surface into the matrix of the three regions present. The surface was approximately 56 Rc, consistent with undertempered martensite, the next region was approximate 45 Rc, consistent with overtempered martensite, and the matrix was approximately 56 Rc, which is typical of the proper 275-300ksi temper for 4340M (Figure 15a and b). The microstructural modifications and hardness values were consistent with heat damage that occurs during electrical arcing events. The second layer was a porous area that did not have a typical wrought metallic microstructure and was consistent with pronounced, localized base metal heat damage (Figure 16).

Additional SEM work was done to further characterize the burn. The mount was coated with Au-Pd (Gold Palladium) enabling EDAX to be performed. The porous area in the subsurface of the indication was located using the SEM, and the spectrum showed Cd present in the region of the arc burn that had severe heat damage (Figure 17a and b). The presence of Cadmium was also detected in a crack emanating from the arc burn (Figure 18a and b).

CONCLUSIONS:

The main landing gear outer cylinder fractured at the bung hole in the trunnion area 17,496 cycles after its first overhaul which was accomplished in February 2012.

The fracture originated at two locations along the corner feature that is formed between the inner diameter of the bung hole and the inner surface of the trunnion. The initiation occurred by an intergranular separation mechanism characteristic of cadmium embrittlement to a depth of .02 inches.

Beyond the intergranular fracture area, the growth mechanism changed to fatigue crack propagation to a final depth of 0.42 inches before final fracture occurred.

Metallurgical evaluation revealed that primary and secondary origins were coincident with arc burns which created base metal heat damage.

After all finishes were removed, Cadmium was detected in the porous surface layer and within secondary cracks that emanated from the arc burns indicating that Cadmium plating was present when the arc burns occurred. Possible sources for the arcing damage are during post –plate magnetic particle inspection, or more likely, during a stylus cadmium plating operation.

The protective finishes in the area of the fracture initiation were in accordance with CMM requirements and the material exhibited hardness values consistent with the required 275-300ksi heat treat condition.

Prepared by:

Approved by:

Approved by:





ACKNOWLEDGEMENTS:

██████████ – Metallography
██████████ – Metallography
██████████ – Metallography
██████████ – Scanning Electron Microscopy
██████████ – Nondestructive Inspection
██████████ – Chemical Lab



Figure 1. The opened shipping container with the aft section of the main landing gear outer cylinder submitted for fracture analysis. The enclosed cardboard box contained the forward section of the trunnion.

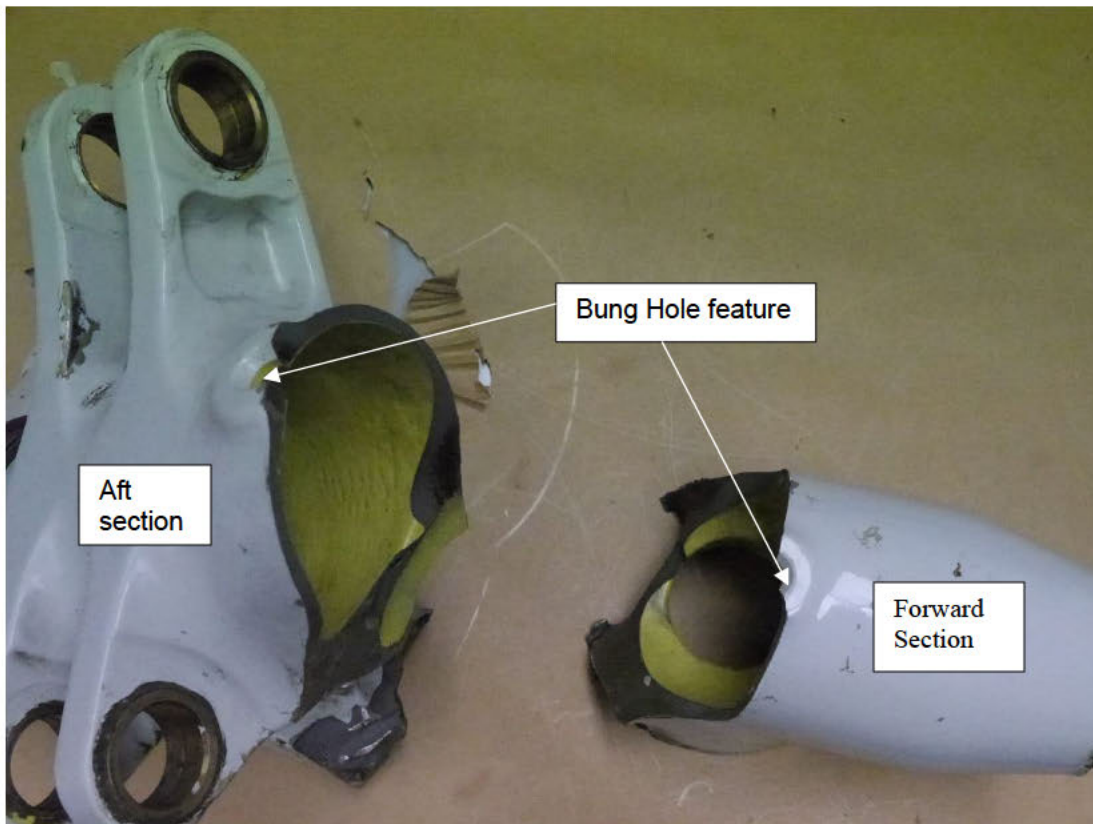


Figure 2. Fractured parts showing Bung Hole that fractured. The parts had been cleaned of grease and Corrosion Inhibiting Compound by the NTSB prior to shipping to Boeing.

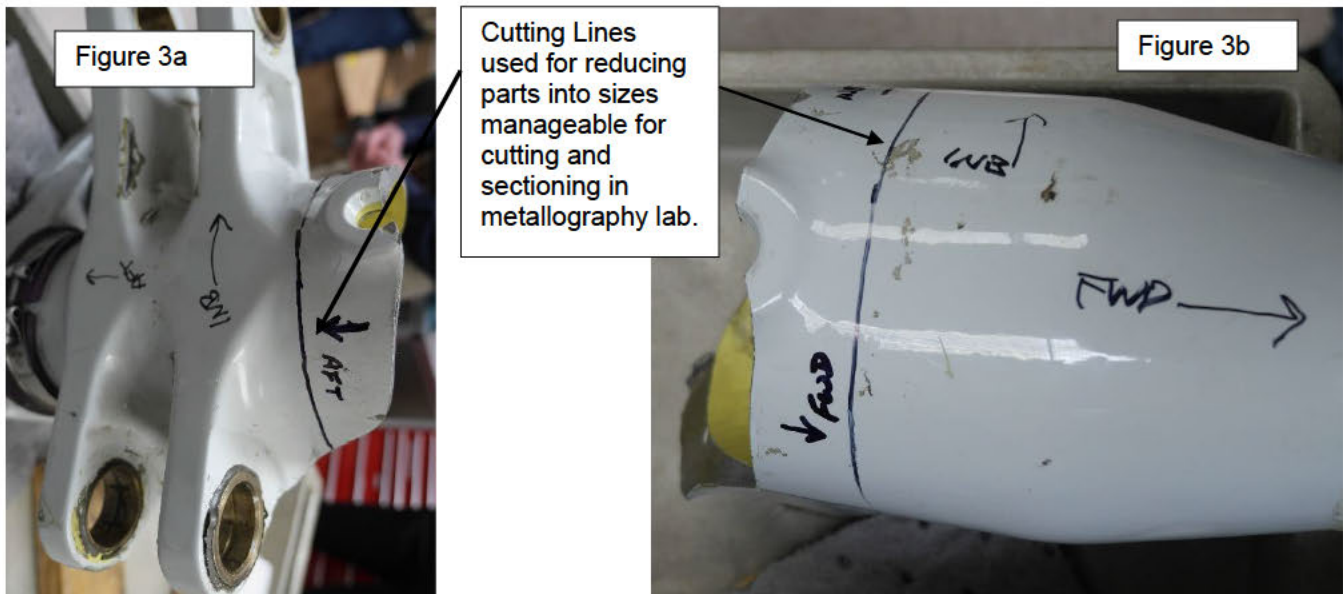


Figure 3a and b. Sections identifying of their orientation on the airplane as well as showing locations for sectioning.

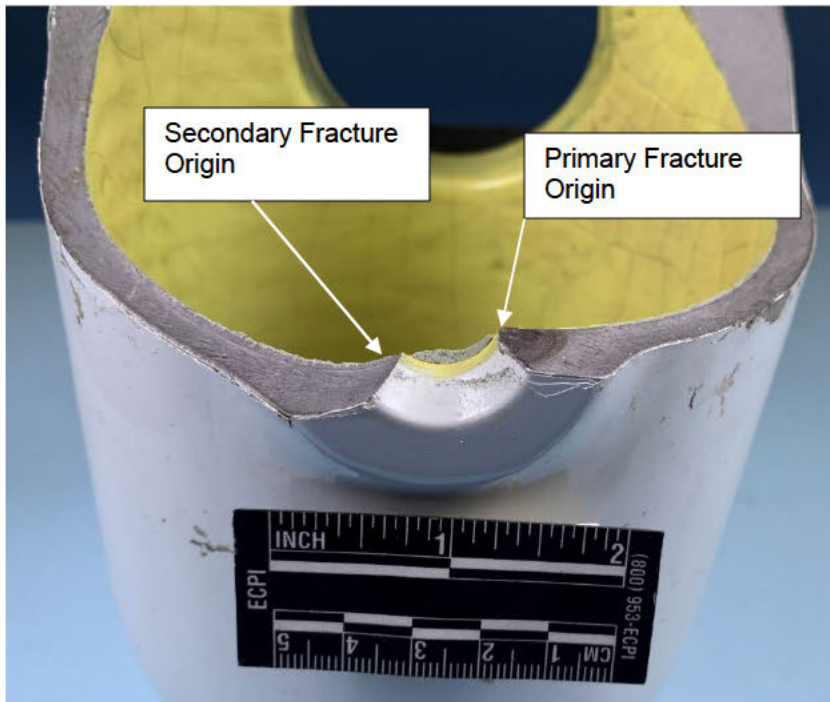


Figure 4. Fracture face on the forward side of the trunnion with respect to the bung hole. Due to the slope of the fracture, the secondary origin cannot be seen in this photograph. The thumbnail features consistent with fatigue crack propagation.

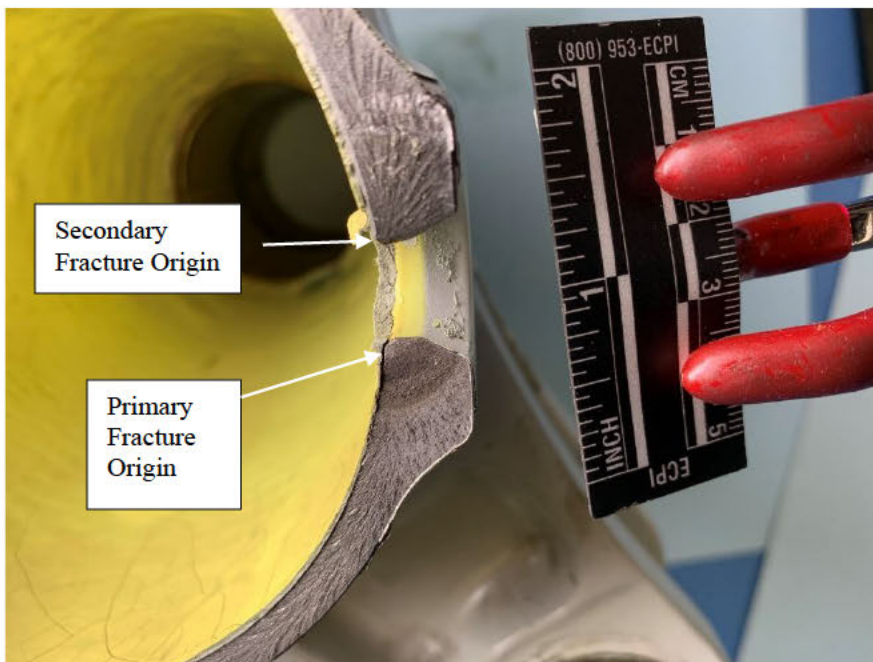


Figure 5. Fracture faces on the aft side of the trunnion with respect to the bung hole. Both the primary and secondary origins can be seen with the primary showing several growth regions.

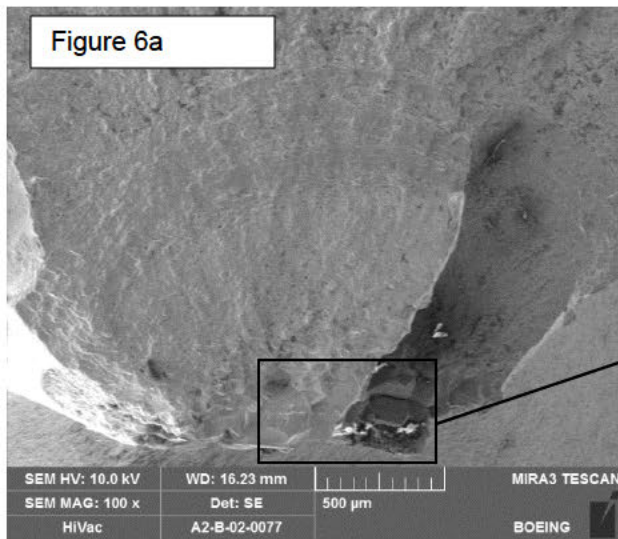


Figure 6a.

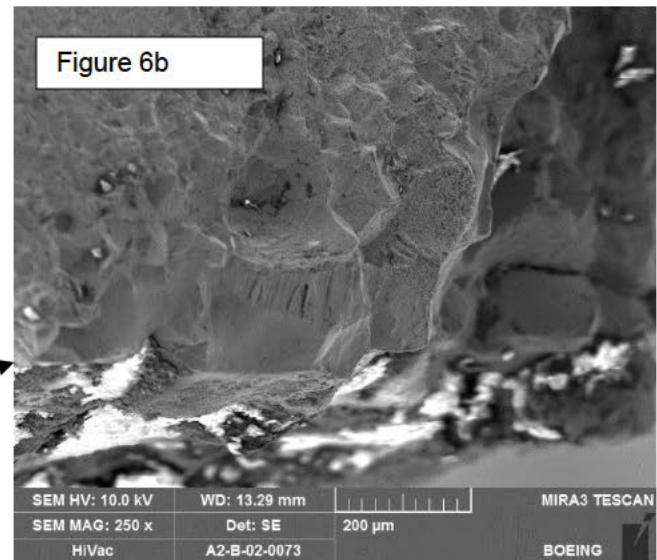


Figure 6b.

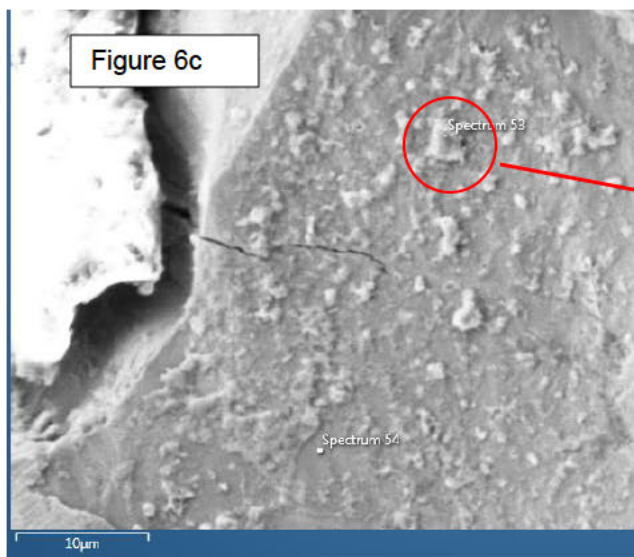


Figure 6c.

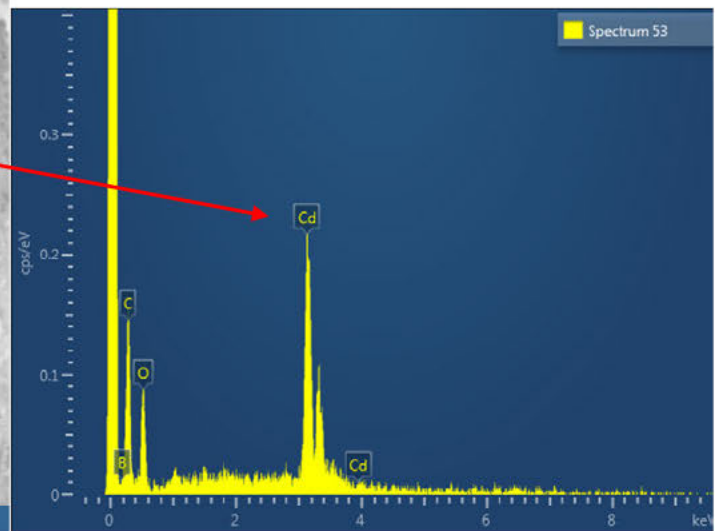


Figure 6d.

Figure 6a. SEM image of the thumbnail area at the primary origin located on the Forward portion. Figure 6b is a higher magnification photo of the intergranular initiation site boxed in photograph 6a. Photograph 6c shows the particles present on the intergranular facets. It is noteworthy that the facets were free of corrosion.

Figure 6d: EDS spectrum of typical particle on the intergranular facets shown in the red circle of figure 6c. The particles were essentially pure cadmium

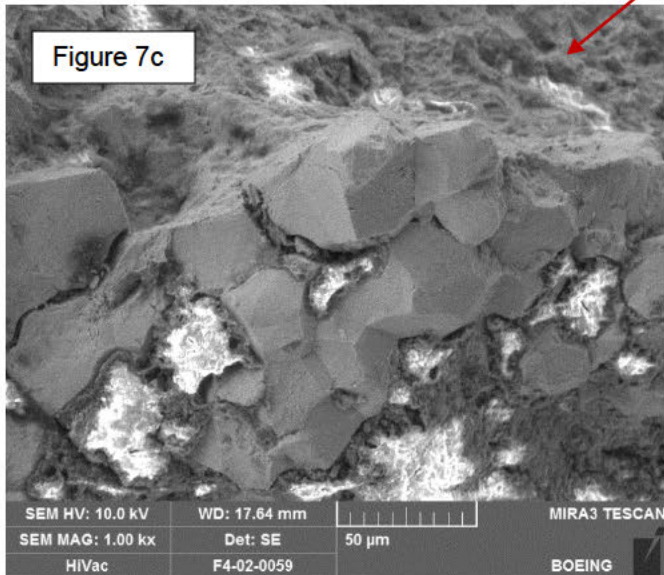
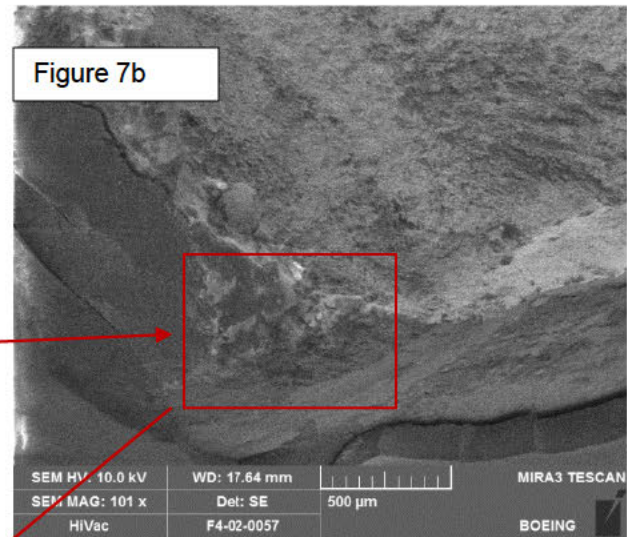
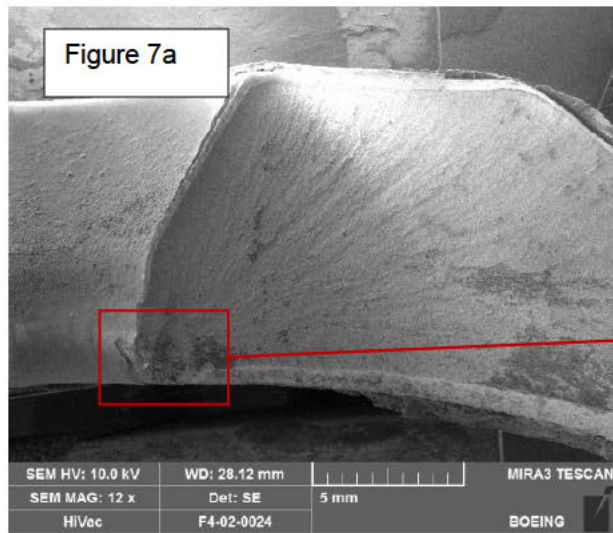


Figure 7a,b. and c. Scanning electron microscope images of the slow growth thumbnail area of the secondary origin, showing that the initial stages of cracking occurred at the surface where the bung hole meets the inner diameter of the Main Landing Gear Outer Cylinder and cracking origin morphology was consistent with intergranular fracture.

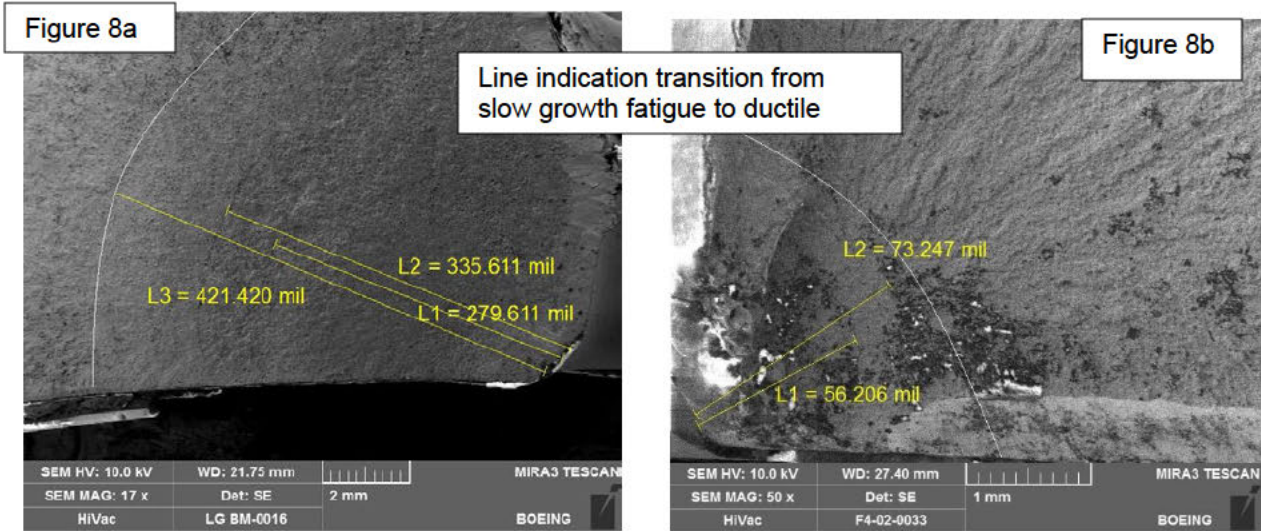


Figure 8a and b. Crack origin areas showing length of fatigue crack growth prior to transition to ductile separation at the primary (Figure 8a) and secondary origin (Figure 8b).

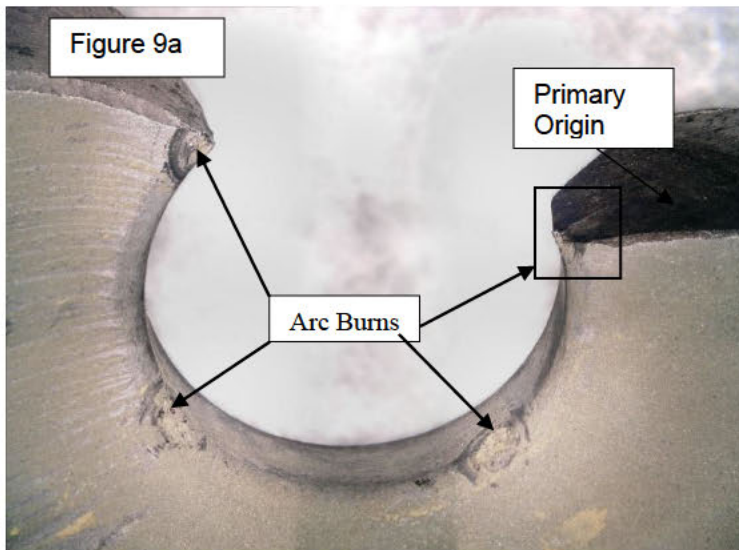


Figure 9a. Partially stripped Aft section showing 4 arc burns. Figure 9b shows a close up view of the primary origin outlined by the boxed area in Figure 9a.

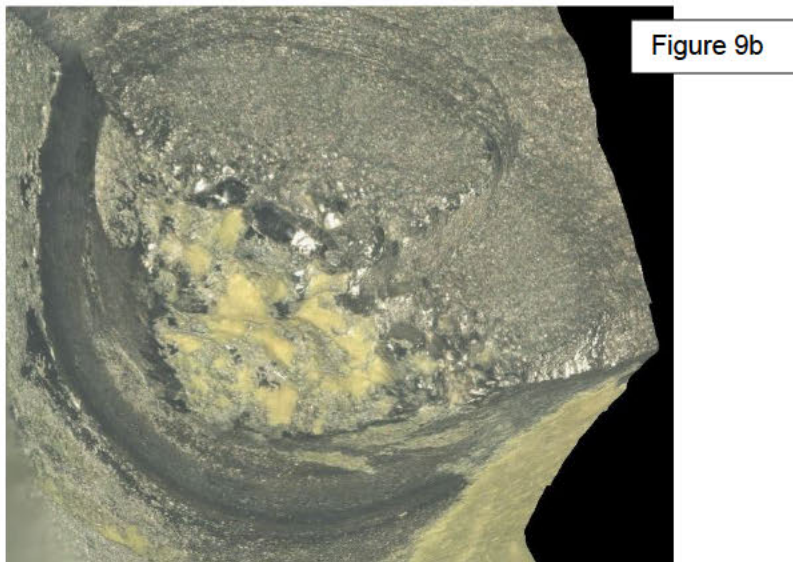


Figure 9b. Close up of the arc burn detected at the primary origin prior to stripping all finishes.

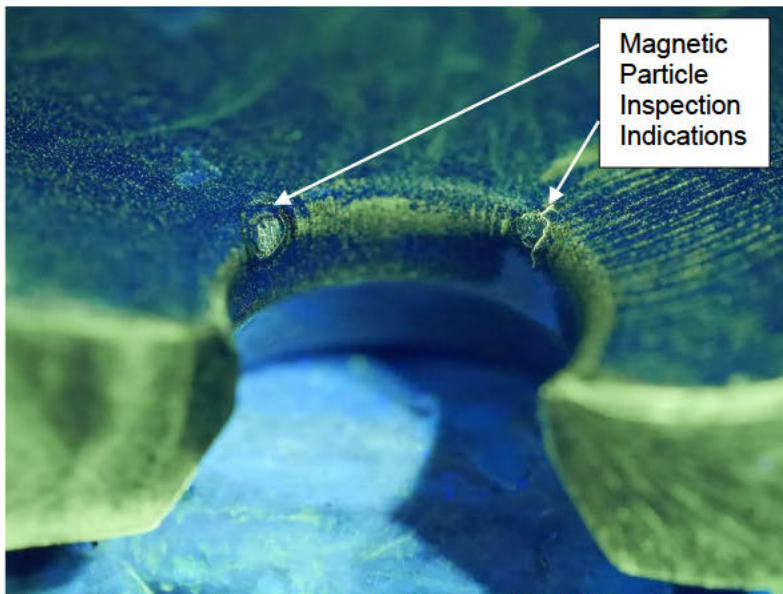


Figure 10. Magnetic particle indications on the Aft Fracture part after all finishes had been removed.

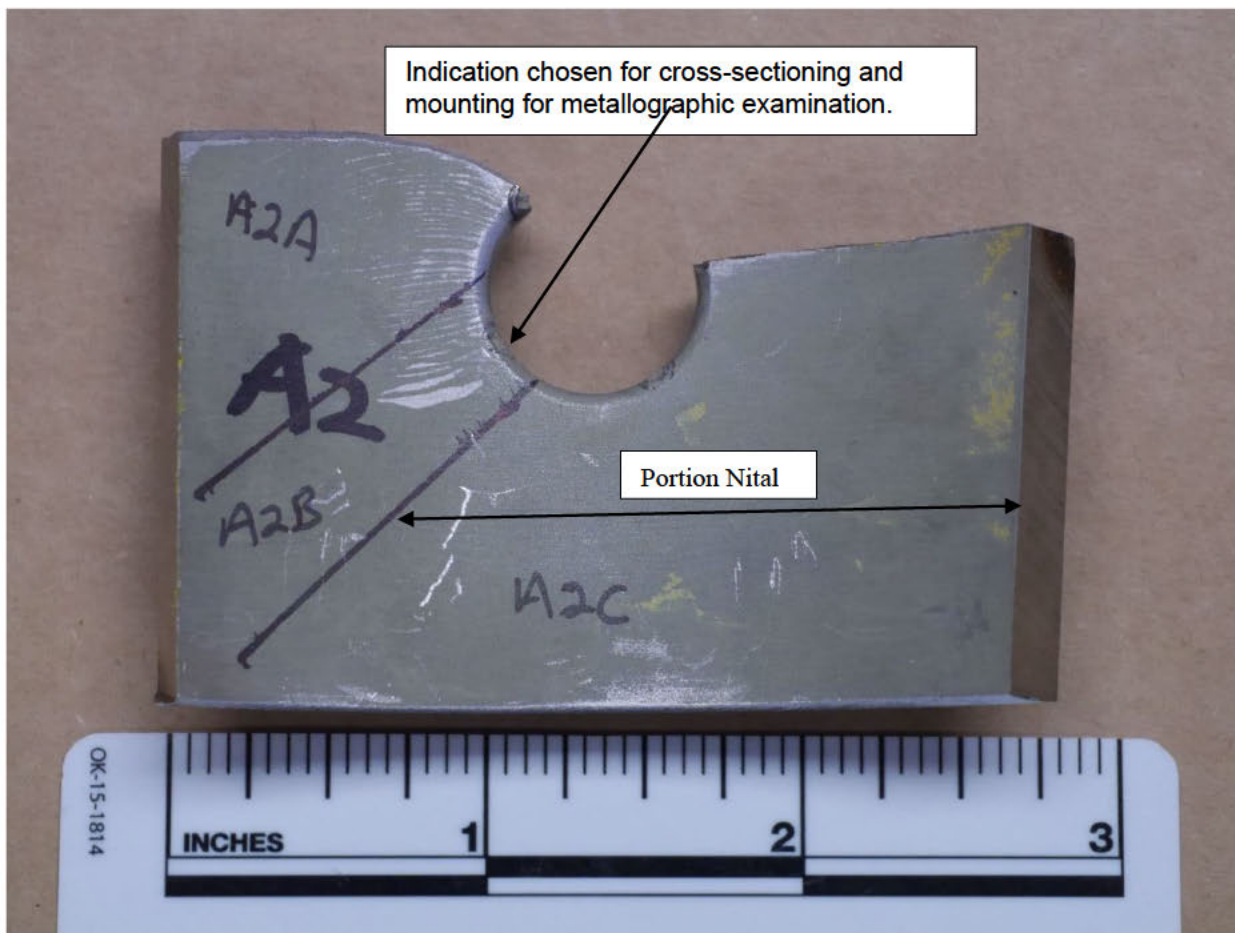


Figure 11. Sectioning plan for Aft section of fracture.



Figures 12a and 12b. Nital Etch inspection of section Aft section A2b (from cut out shown above) and the Forward section showing presence of under tempered (light etching at the center of the indication) and overtempered martensite (dark etching rings). (Close up of etch inspection indication shown in Figure 13)

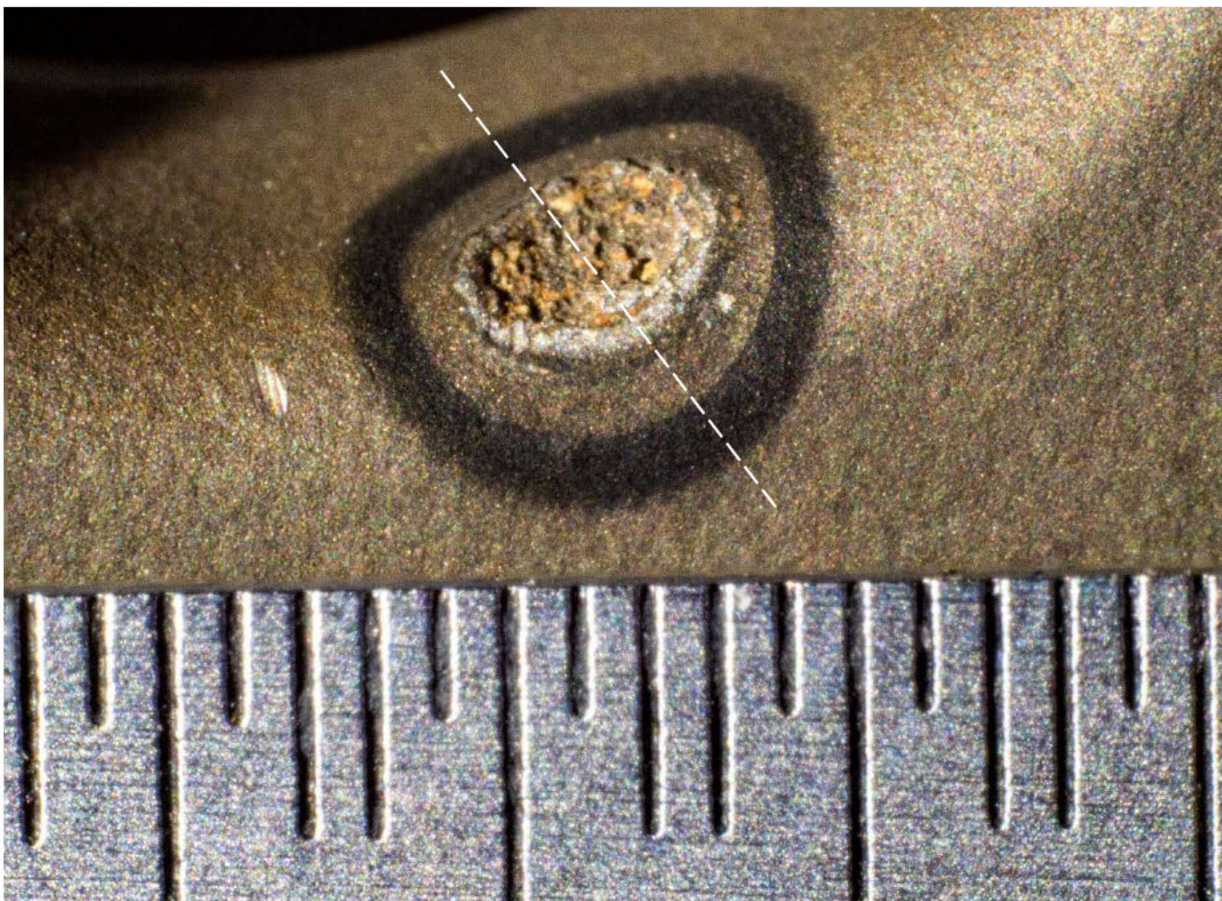


Figure 13. Close up of etch inspection indication showing presence of under tempered (light etching around the porous region) and over tempered martensite (dark etching ring). Dashed line indicates example of location of cross section in photos below.

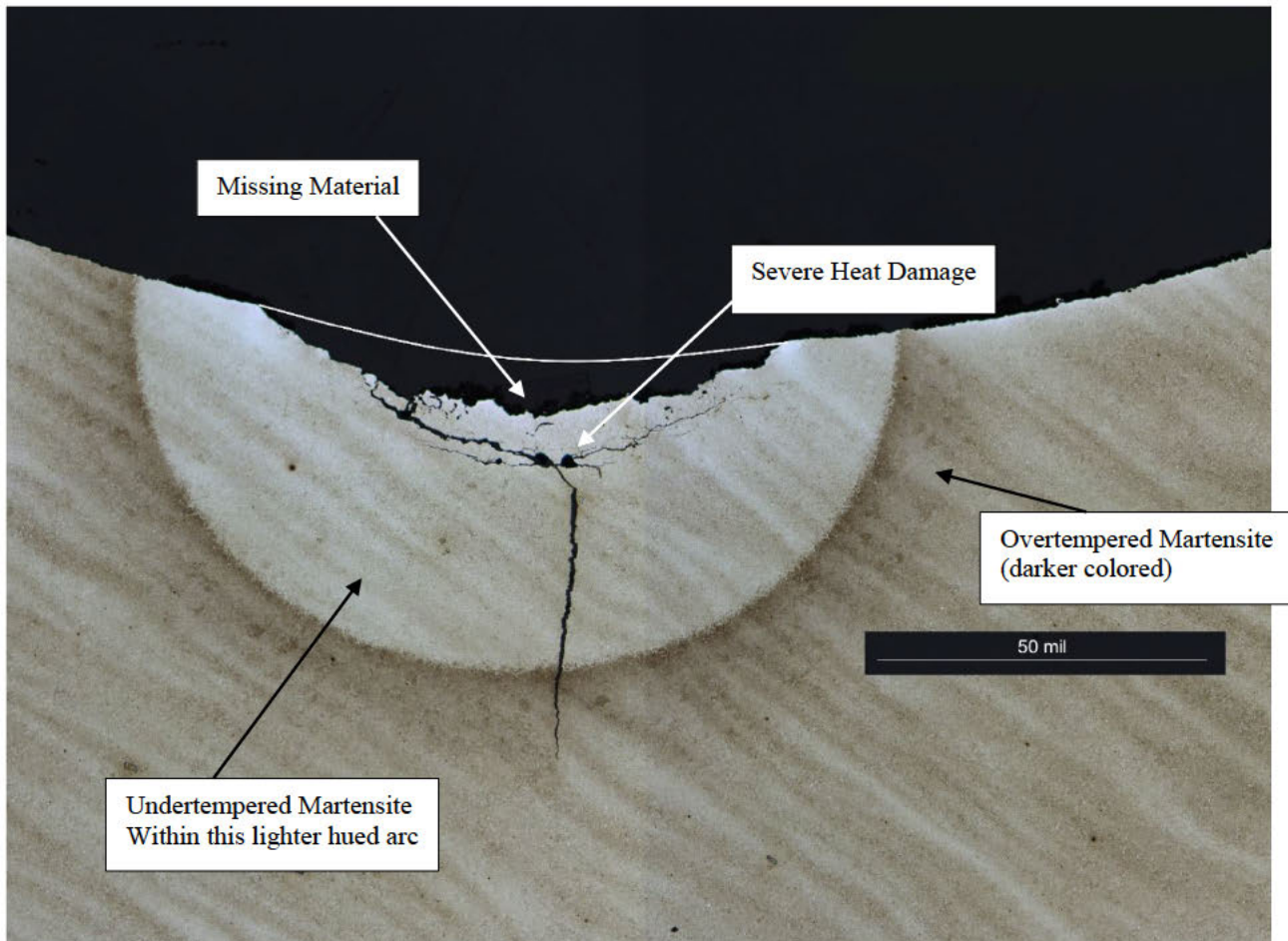


Figure 14 showing the 4 regions present in the microstructure under the arc burn.

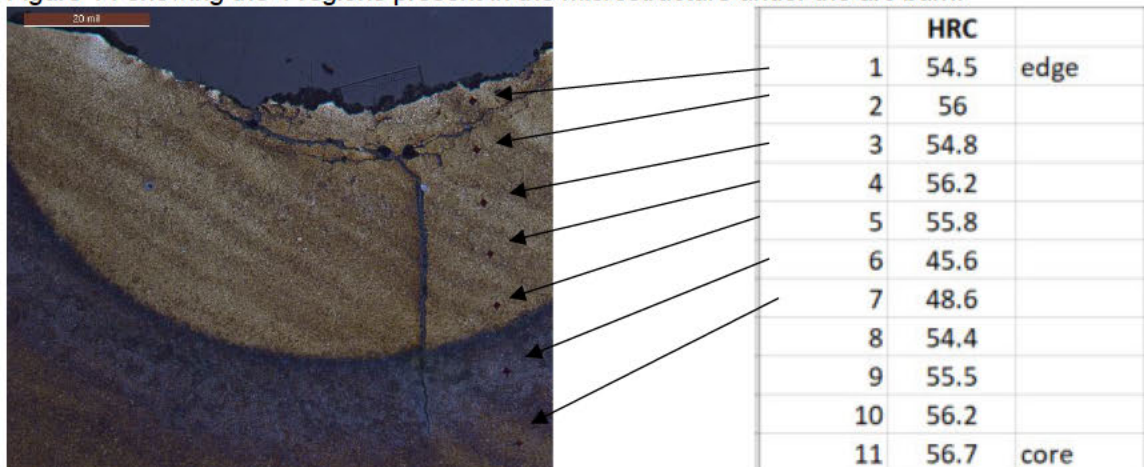


Figure 15. Metallographic mount showing indentations from hardness measurements and the 7 most inner measurements.

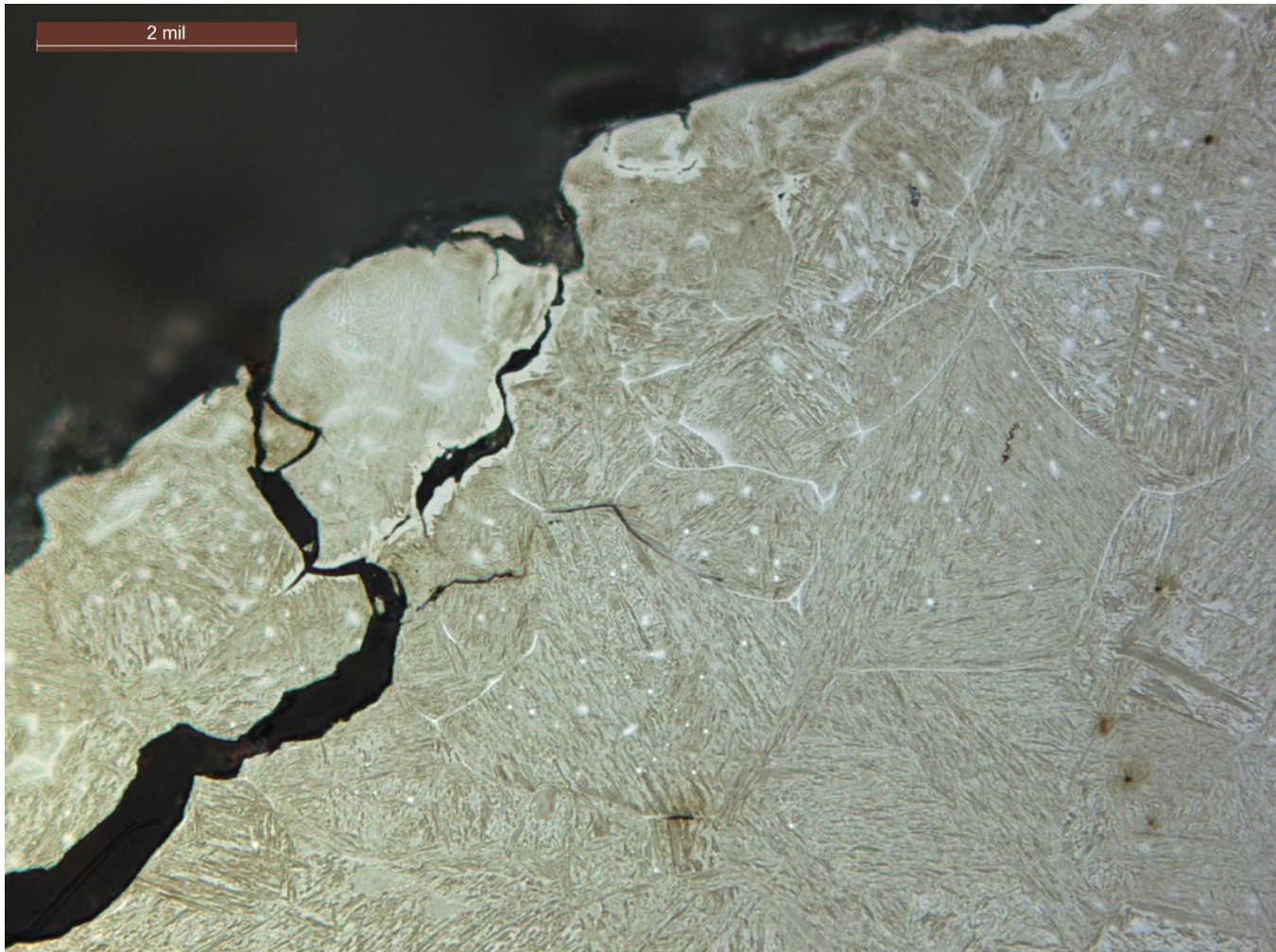


Figure 16. 500x photograph of area at the surface of the cross-section of the cross-sectioned arc burn. Note the difference in the grain morphology at the surface.

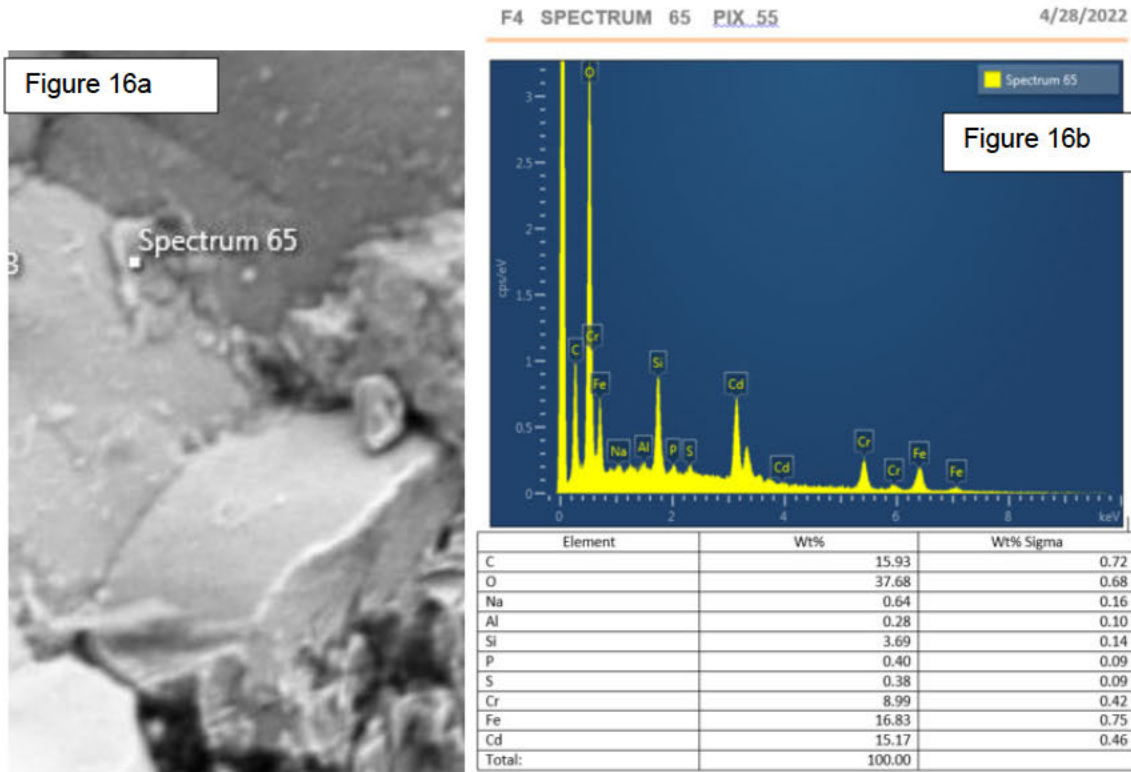


Figure 17a and b. EDX scan at fracture surface of particulate found in intergranular cracking morphology. Scan at location "Spectrum 65" showed high level of Cadmium present.

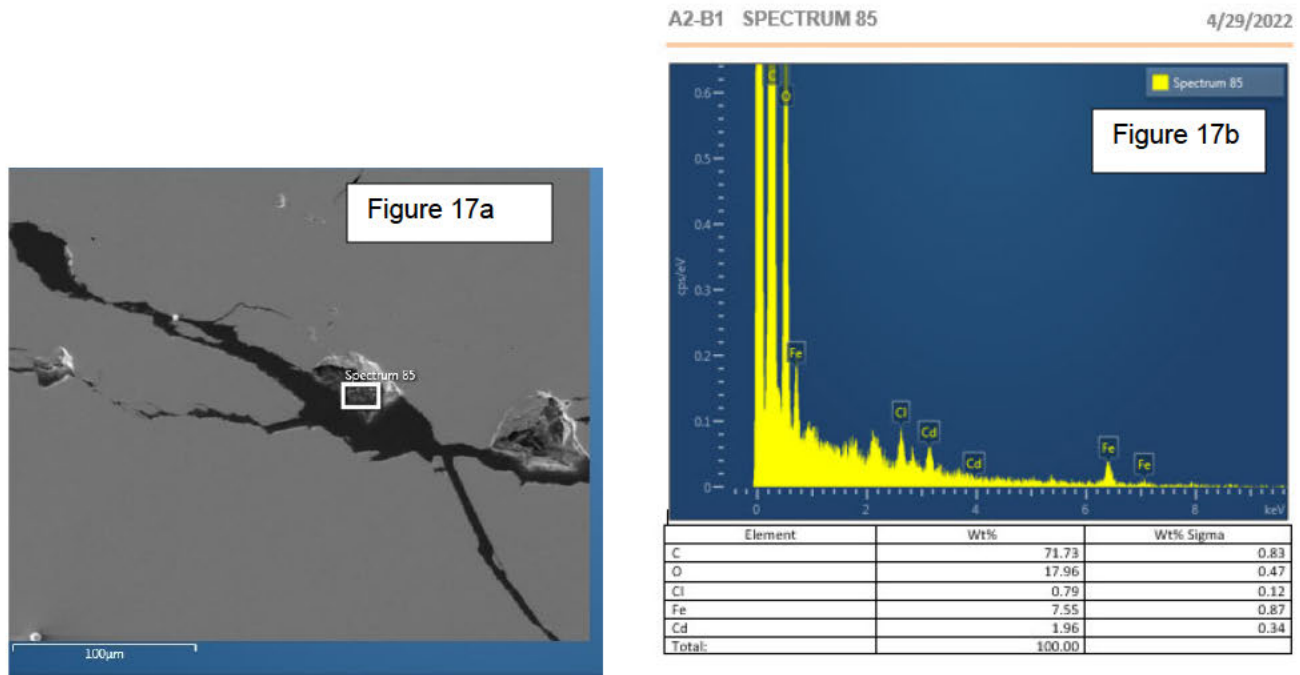


Figure 18a and b. EDX scan within the crack of the metallographic mount revealed the presence of Cadmium in cracking emanating from the arc burn.