NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

April 3, 2015

MATERIALS LABORATORY FACTUAL REPORT Report No. 15-021

A. ACCIDENT INFORMATION

Place	:	Bedford, Massachusetts
Date	:	May 31, 2014
Vehicle	:	Gulfstream IV
NTSB No.	:	ERA14MA271
Investigator	:	Adam Huray (AS-40)

B. COMPONENTS EXAMINED

Gust lock handle, elevator hook & roller, sunglasses, pedestal switch panel, and elevator input bungee.

C. DETAILS OF THE EXAMINATION

Gust Lock Handle:

The gust lock handle was submitted assembled, as shown in Figure 1. Labelling in Figure 1 indicates the directionality of the gust lock handle as-installed on the aircraft. The surfaces on the link of the gust lock handle had dark-colored deposits consistent with soot, and charred, peeling coating was observed on the external surfaces of the body. Red/brown rust-like deposits consistent with corrosion were also observed on some areas of the body, link, and slider assembly.

The gust lock handle was x-rayed in the as-received condition, and the internal spring appeared intact. However, the internal spring did not return the slider assembly to the locked position during manual operation of the handle.

Figure 2 and Figure 3 show that the lock pin that mated with the link was fractured within the gust lock handle assembly. One piece of the lock pin was recessed into the mating slider assembly bracket; another piece of the lock pin on the opposite side of the gust lock handle protruded past the slider assembly bracket and contacted the side of the link. The recessed lock pin piece was on the inboard side of the gust lock handle and fell out of the inboard bracket of the slider assembly during examination. The protruded lock pin piece was on the outboard side of the gust lock handle and remained in the outboard bracket of the slider assembly during examination. The recessed lock pin piece on the inboard side is shown in Figure 4; the protruded lock pin piece on the outboard side is shown in Figure 5. Deposits consistent with corrosion were observed on the majority of the fracture surface of the inboard lock pin piece, while the fracture surface of the outboard lock pin piece had notably fewer deposits. Manual manipulation of the gust lock handle revealed that the protruding outboard lock pin piece contacted the outboard side of the link when the link was rotated, as illustrated in Figure 6. The green arrows in Figure 7 point to circumferential marks on the outboard surface of the link in the area where the protruded outboard lock pin piece made contact.

The gust lock handle was disassembled. The outboard piece of the lock pin was pushed out of the hole in the outboard bracket of the slider assembly using a punch.

There was damage and corrosion around the entire circumference of the outboard lock pin piece. Some of the material had been pushed towards one side, which gave the outboard lock pin piece a wedge-shaped appearance when viewed in profile, as shown in Figure 8. The as-received orientation of the wedge-shaped outboard lock pin piece was determined to have the short end towards the top/aft side of the gust lock handle and the longer end with the smeared lip of material towards the bottom/forward side of the gust lock handle. Damage was also observed on the bottom surface of the outboard lock pin piece, as shown in Figure 9. The damaged areas were silver in color and had a smeared appearance. Gold-colored material was observed on the undamaged areas around the circumference and on the bottom surface of the outboard lock pin piece.

The fracture surface of the inboard lock pin piece was flat. Because the inboard lock pin piece was recessed within the mating slider assembly bracket and did not appear to contact the mating inboard link surface during manual manipulation of the gust lock handle, the fracture surface of the inboard lock pin piece was examined using a Scanning Electron Microscope (SEM) in the as-received condition prior to cleaning. Heavy corrosion deposits obscured the fracture surface features on the uncleaned inboard lock pin piece, as shown in Figure 10. The inboard lock pin piece was cleaned using Evapo-Rust™ (Harris International Labs, Springdale, AR) and an acetone rinse and, as seen in Figure 11, some shiny areas consistent with contact damage were observed on the fracture surface. Reexamination of the cleaned inboard lock pin piece fracture surface in the SEM did not reveal any distinguishing features. Instead, the fracture surface of the cleaned inboard lock pin piece had flattened and smeared areas, with some residual corrosion products. Exemplar SEM images of the cleaned inboard lock pin piece fracture surface are shown in Figure 12.

SEM examination of the outboard lock pin piece fracture surface showed it was covered in corrosion products, and had features that were mostly flattened. There were numerous areas with smearing damage on the fracture surface, with the smearing damage having pushed the pin material towards one side of the gust lock handle. The fracture surface appeared to consist of multiple flattened planes, with a distinct step visible between the two largest planes, as indicated by the yellow dotted line in Figure 13. Some layers of peeling material (green arrows in Figure 13) were observed on the outer diameter (OD) of the outboard lock pin piece in one area.

Standard-less semi-quantitative Energy Dispersive X-Ray Spectroscopy (EDS) analysis of the outboard lock pin piece fracture surface showed it had constituents consistent with steel, as seen in the representative spectrum shown in Figure 14. The EDS spectrum also showed evidence of corrosion products and cadmium plating.

A cross-section was prepared through the outboard lock pin piece. The cross-section showed the wedge-shaped appearance of the outboard lock pin piece, as well as the non-flat bottom surface and the irregular OD. An overall image of the cross-section was shown in Figure 15. An external layer was observed on the edges of some areas of the outboard lock pin piece, as indicated by the red arrows in Figure 16. The external layer was noted in the locations of the undamaged gold-colored material observed during the initial visual examination on the circumference and bottom surface of the outboard lock pin piece. Standard-less semi-quantitative EDS analysis confirmed the external layer was cadmium-rich, as seen in the EDS spectrum shown in Figure 17.

Per Gulfstream personnel, the lock pin (Part Number (P/N) 43906-463) assembled within the gust lock handle assembly (P/N 43083-402-1) is supposed to be made from drill rod material. A representative of Rockwell Collins, the manufacturer of the gust lock handle assembly, reported the drill rod material should have been Type A2 tool steel that met the requirements of ASTM A681, according to the Rockwell Collins material supplier. A standard-less semi-quantitative EDS analysis revealed that while the composition could meet the parameters for drill rod, it did not meet the ASTM A681 specification for Type A2 tool steel. An EDS spectrum representative of the base material is shown in Figure 18. The hardness was measured on the cross-section through the outboard lock pin piece using a LECO automatic microindentation hardness tester per ASTM E384.[1] The hardness of the outboard lock pin piece averaged 30 HRC (302 HV_{500}), which indicates the material was not quench hardened and tempered. The microstructure of the outboard lock pin piece material, shown in Figure 19, consisted of spheroid carbides in a ferrite matrix, which is consistent with steel in a spheriodized condition.

A band of wear with distinct material loss and rolled material along the edges was observed around the entire circumference of the spacer. The wear band was notably heavier around one half of the circumference.

The disassembled gust lock body, link and slider assembly are shown in Figure 20. There was a distinct linear soot mark visible on the faces of the link. The link was inserted into the gust lock body with the soot mark in-line with the gust lock body edge. The angle between the link and the gust lock body measured 16 degrees, as shown in Figure 21. Gulfstream indicated this position was consistent with the gust lock handle in the stowed position.

There were contact marks on most of the inboard surface of the link; similar contact marks were observed on the outboard side of the link, but the marks were confined to between the up and down slots and just past the other side of the down slot. The contact marks on the inboard and outboard link surfaces are shown in Figure 22. The majority of the contact marks were circumferential, and were in the direction the link rotated.

[1] ASTM E384 – Standard Test Method for Knoop and Vickers Hardness for Materials.

The center and the top side of the down slot surface was undamaged and had a gold-colored plating visible on it; some damage was noted on the bottom side of the down slot surface. The entire down slot surface appeared relatively corrosion-free. The down slot surface is shown in Figure 23. Damage was observed on the bottom side and on part of the center of the up slot. The other part of the center and the top side of the up slot had heavy corrosion. The up slot surface is shown in Figure 24. Adjacent to the center flat of the up slot, there was material rolled off the outboard face of the link into the slot; the rolled material is indicated by the red dotted circle in the center image of Figure 24. Adjacent to the top side of the up slot, there was material deposited onto the outboard face of the link, as indicated by the red arrows in Figure 25. A Keyence 3D Macroscope confirmed that there was material deposited onto the outboard face of the link, rather than a portion of the link surface worn away.

Elevator Hook & Roller:

Figure 26 and Figure 27 show that all of the surfaces of the elevator hook, including within the slot, were covered in red/brown rust-like deposits consistent with corrosion. L-shaped areas with little to no corrosion deposits were observed on the ends of the slot, as seen on the representative end shown in Figure 28. Shiny, deformed areas were visible around the elevator hook slot edges adjacent to the L-shaped areas.

The elevator hook was cleaned using Evapo-Rust™ (Harris International Labs, Springdale, AR) and an acetone rinse. After cleaning, the L-shaped areas on the ends of the slot were observed to be consistent with burnished material. Linear marks were visible on the ends of the elevator hook slot and at the corners of the slot bottom in-line with the slot sides/flats, as indicated by the green arrows in Figure 27-Figure 29. The marks were observed as parallel to the edges of the slot ends. The shiny, deformed areas on the hook slot edge were revealed after cleaning to be material that had been rolled out of the slot ends adjacent to some of the linear marks. Circumferential lines consistent with machining were observed in the bottom of the elevator hook slot. No obvious deformation or witness marks were observed within the elevator hook slot.

The elevator roller was covered in dark-colored deposits. The deposits were non-uniform and appeared to be heavier around one half of the roller circumference. Circumferential markings through the dark-colored deposits were observed around the OD of the roller, as indicated by the blue brackets in the top images of Figure 30.

The dark-colored deposits were cleaned from the roller surfaces using a sodium hydroxide solution. After cleaning, a shiny band, indicated by the blue bracket in the bottom image of Figure 30, was observed coinciding with the location of the circumferential markings through the dark-colored deposits. The shiny band was consistent with wear, and extended around the entire circumference of the roller. The band was located offset from the center of the roller width. The width of the band measured roughly the same as the width of the mating elevator hook slot.

Sunglasses:

The sunglasses were submitted with the right lens still assembled inside the frames and the left lens missing. Broken pieces of the left lens were also submitted. It was reported that one of the pieces was further broken into two pieces during recovery. The sunglasses as-submitted are shown in Figure 31. The right lens and most of the exterior surfaces of the frame were covered in a black-colored substance consistent with soot; some areas on the interior surfaces of the frame, particularly near the nosepieces, did not appear to have soot. The following markings were visible on the inner surface of one of the stems: “SERENGETI” and “5134”.

Soot was also observed on the broken pieces of the left lens. The soot was observed on the flats and most of the edges of the lens pieces. Two pieces had one shiny, soot-free edge that was noticeably different in appearance from the other edges, as shown in Figure 32.

The frames of the sunglasses were deformed; the left stem had twisted downwards and the left eyepiece was bent. No pinched areas were observed on the frames.

Pedestal Switch Panel:

The pedestal switch panel was submitted with the following switches still assembled: Anti-Skid Test, Nutcracker Switch Test, Ground Spoiler Test, Thrust Reverser Emergency Stow, Ground Spoiler, Anti-Skid, and Stall Barrier. Portions of the front panel and switch covers were warped and melted, consistent with fire damage. All of the surfaces of the pedestal switch panel were covered in soot and debris consistent with fire suppression agents, as shown in Figure 33.

The four non-test switches were manually disassembled from the switch assembly and x-rayed in the as-submitted position. The Thrust Reverser Emergency Stow, Ground Spoiler, and Anti-Skid switches had similar connections, while the Stall Barrier switch had different wiring. Radiographs of the Thrust Reverser Emergency Stow, Ground Spoiler, Anti-Skid, and Stall Barrier switches are shown in Figure 34-Figure 37, respectively. Unused exemplar switches that represented each wiring scheme were provided by Gulfstream for comparison, and were also x-rayed. The exemplar switches were examined in both the depressed and extended positions. Figure 38 and Figure 39 show radiographs of the first wiring scheme in the depressed and extended positions, respectively, while Figure 40 and Figure 41 show radiographs of the other wiring scheme in the depressed and extended positions, respectively.

By comparing the positions of the incident switches to the exemplar switches in their known positions, it was determined that at the time of the incident the Thrust Reverser Emergency Stow, Ground Spoiler, and Anti-Skid switches were in the extended position, and the Stall Barrier switch was in the depressed position.

Elevator Input Bungee:

The elevator input bungee was submitted assembled, with most of the external surfaces coated in soot and corrosion deposits. The elevator input bungee is shown as-received in Figure 42.

The spring within the chamber of the load relief bungee of the elevator input bungee was x-rayed. One side of the elevator input bungee was examined in the as-submitted position; the resulting radiographs are shown in Figure 43. The spring inside the load relief bungee chamber was compressed and released multiple times, then returned to neutral position, and the opposite side of the elevator input bungee was x-rayed. Radiographs of the opposite side of the elevator input bungee are shown in Figure 44. The spring inside the load relief bungee chamber of the elevator input bungee appeared intact in all of the radiographs, and no anomalies were observed.

Adrienne V. Lamm
Materials Engineer

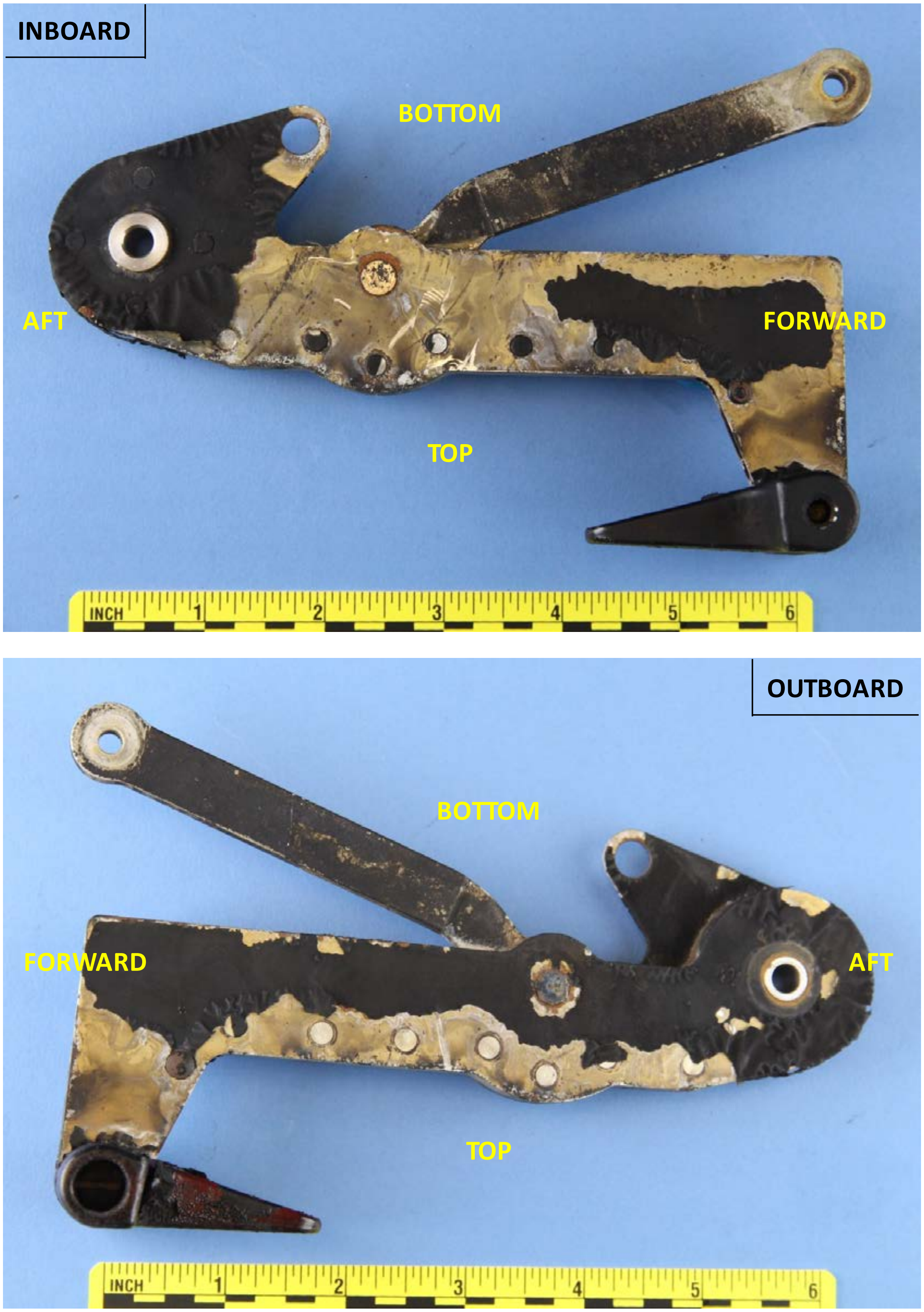


Figure 1: Overall photos of the submitted gust lock handle.

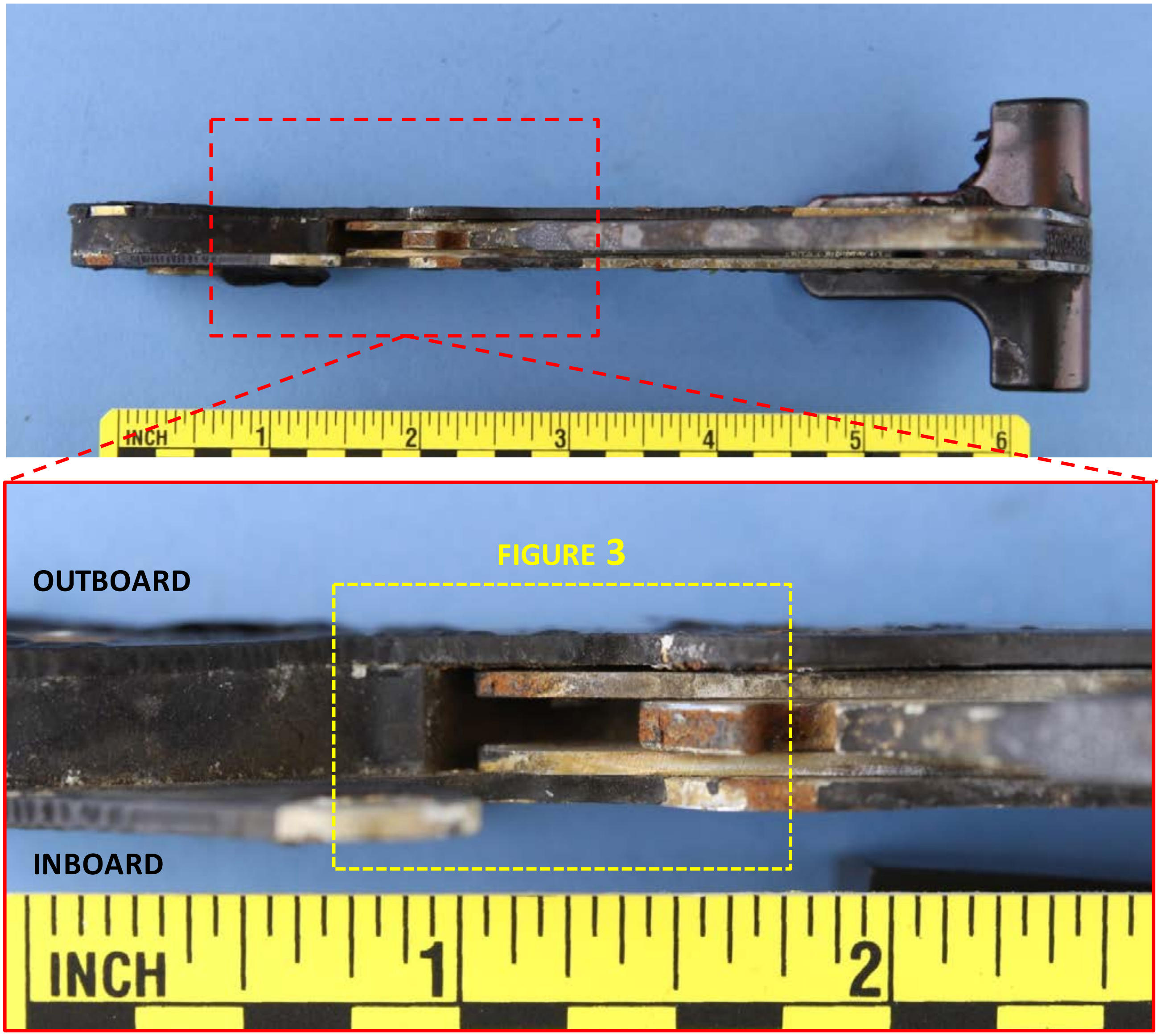


Figure 2: Close-up photos showing the lock pin that mated with the link was fractured within the gust lock handle assembly.

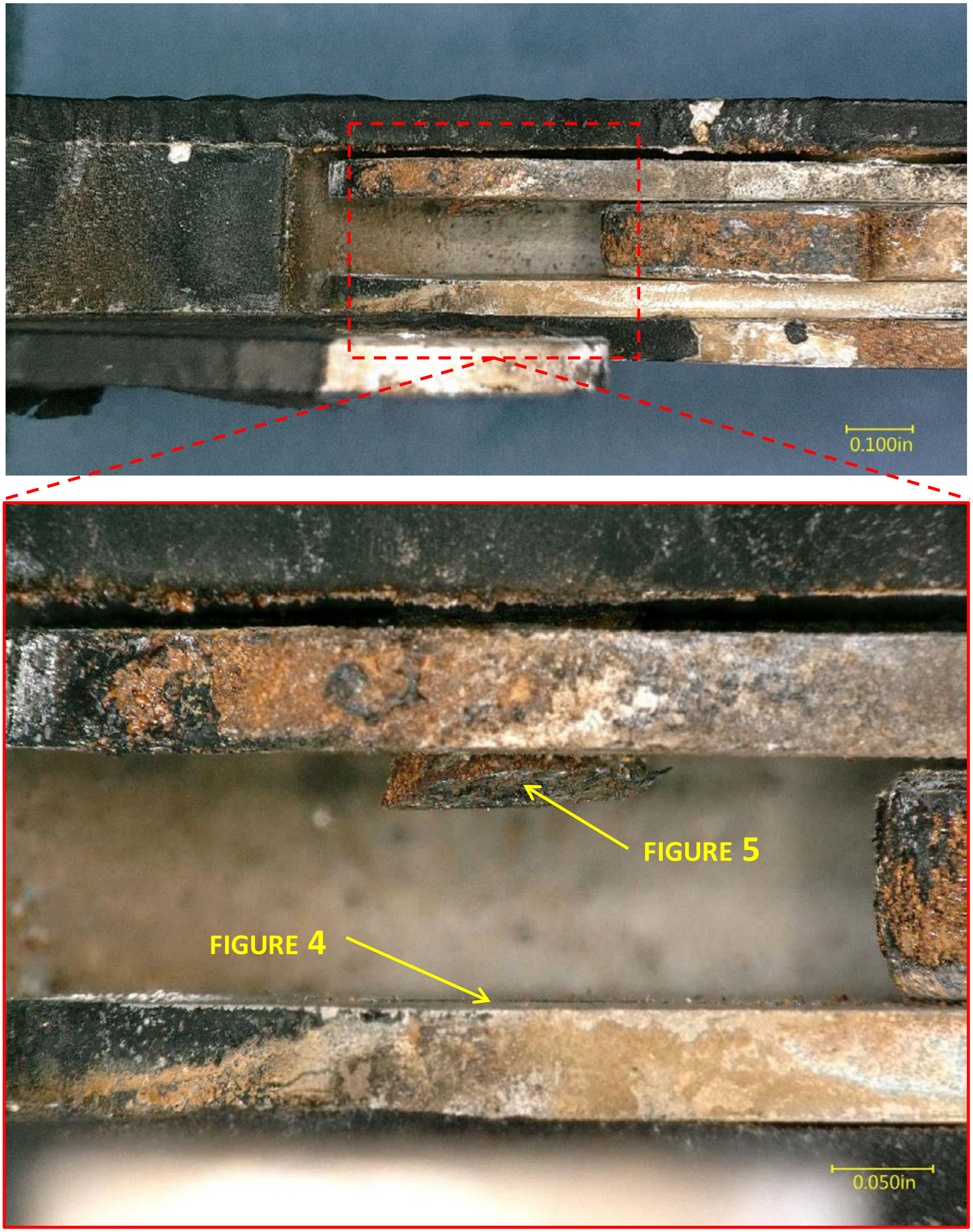


Figure 3: Digital microscope photos showing the lock pin that mated with the link was fractured within the gust lock handle assembly**.**

Figure 4: Digital microscope photos of the recessed lock pin piece on the inboard side of the gust lock handle.

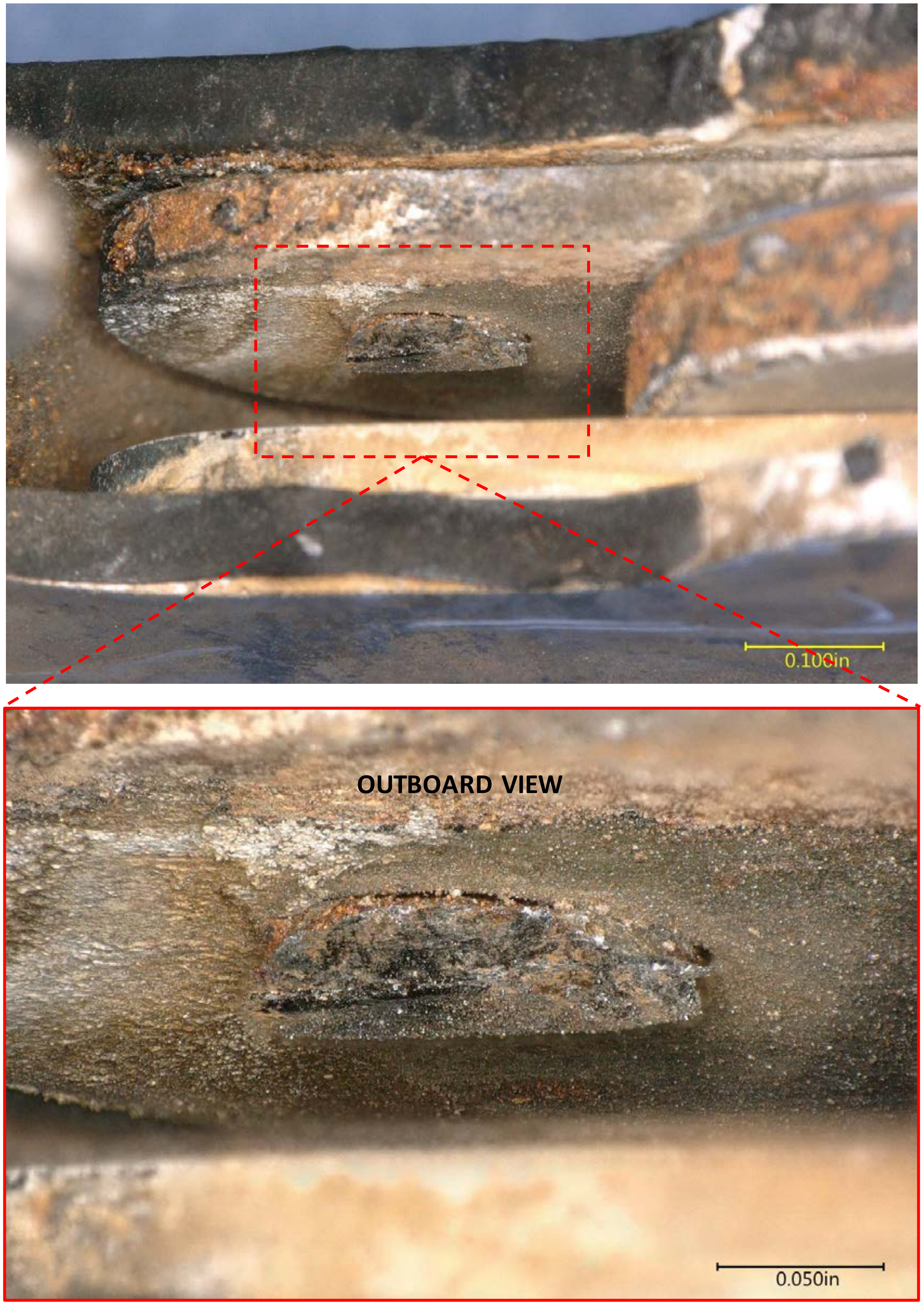


Figure 5: Digital microscope photos of the protruded lock pin piece on the outboard side of the gust lock handle.

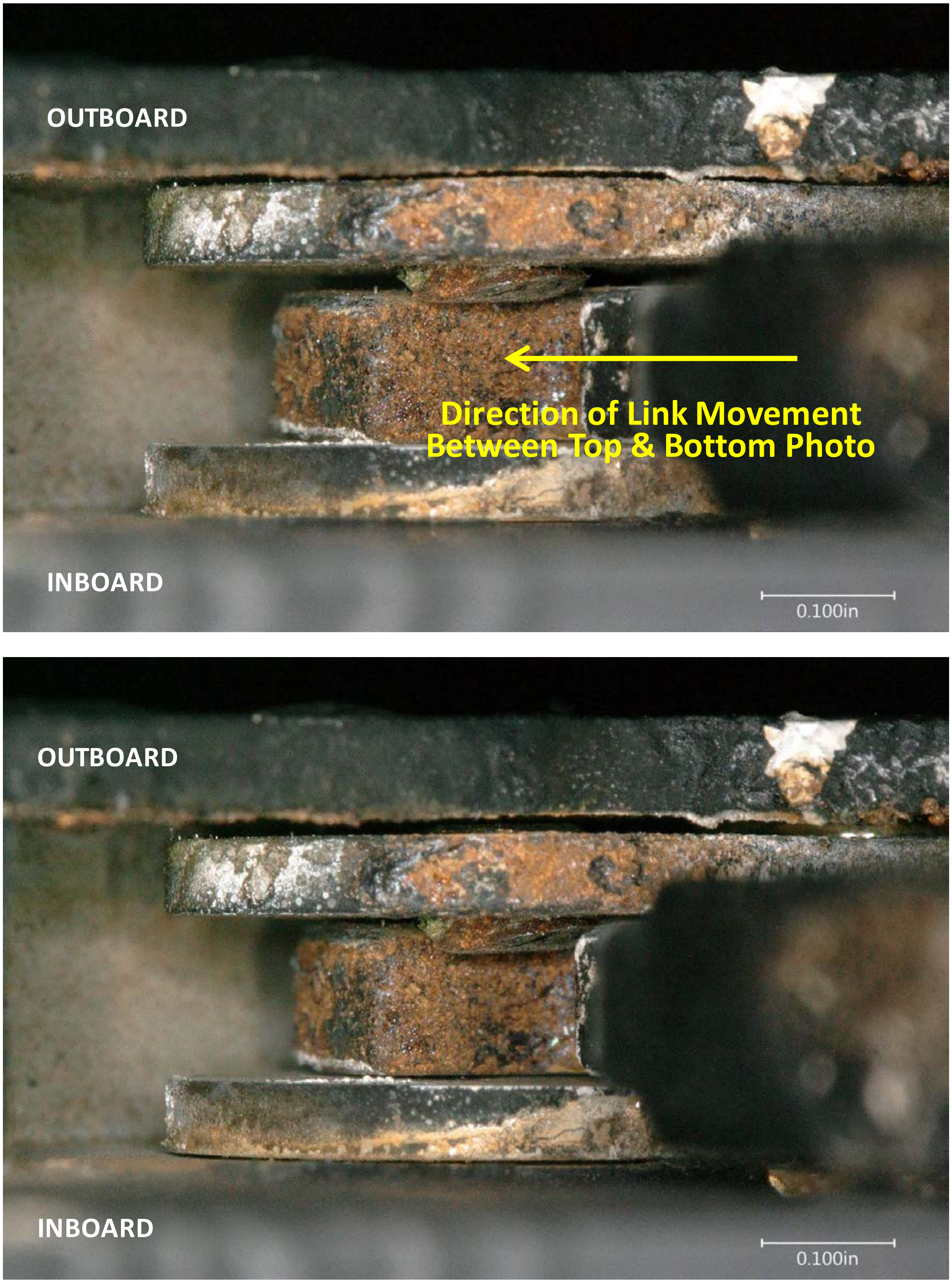


Figure 6: Digital microscope photos showing the protruding outboard lock pin piece contacted the outboard side of the link when the link was rotated within the gust lock handle.

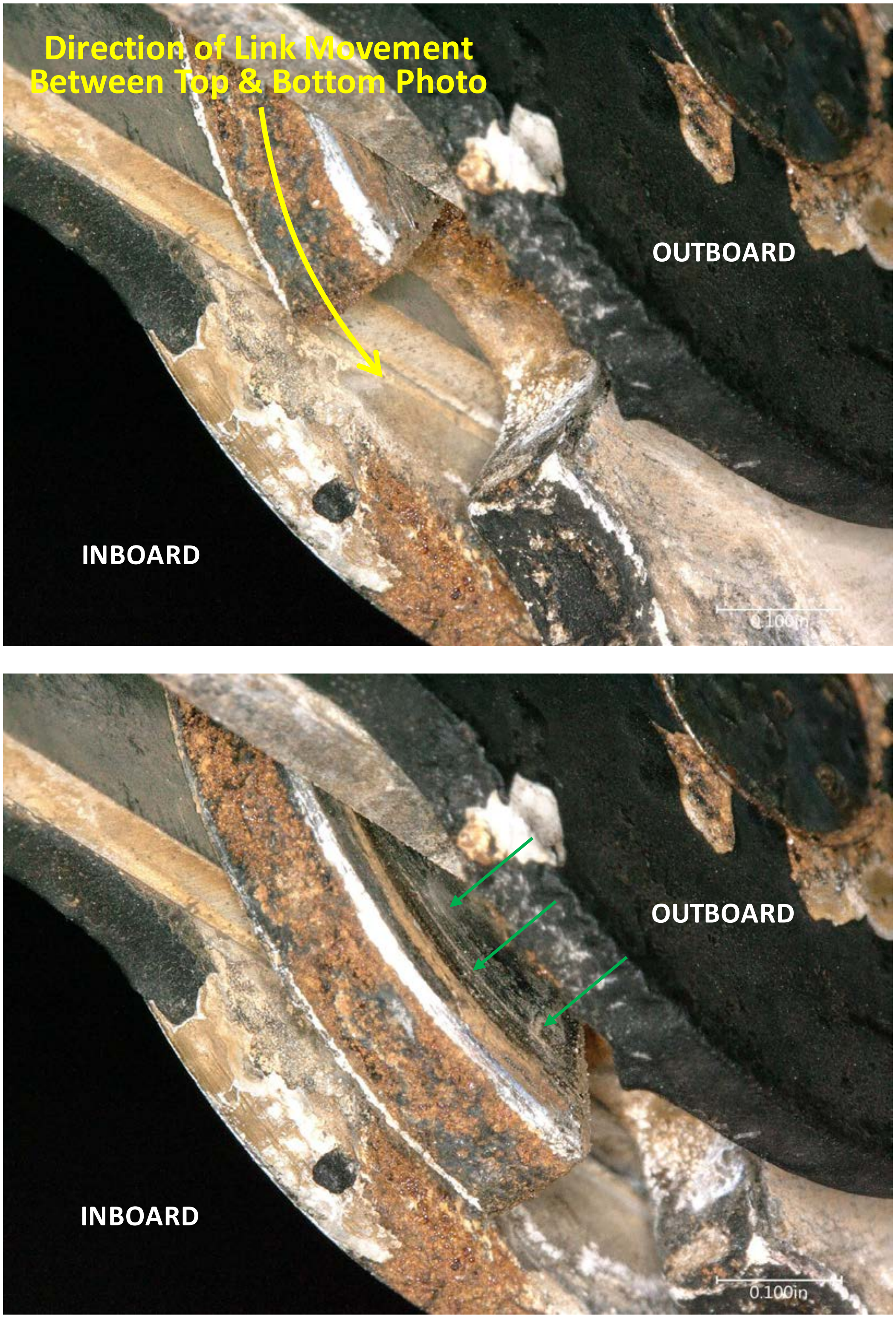


Figure 7: Digital microscope photos of circumferential marks (green arrows) on the outboard surface of the link in the area where the protruded outboard lock pin piece made contact when the link was rotated within the gust lock handle.

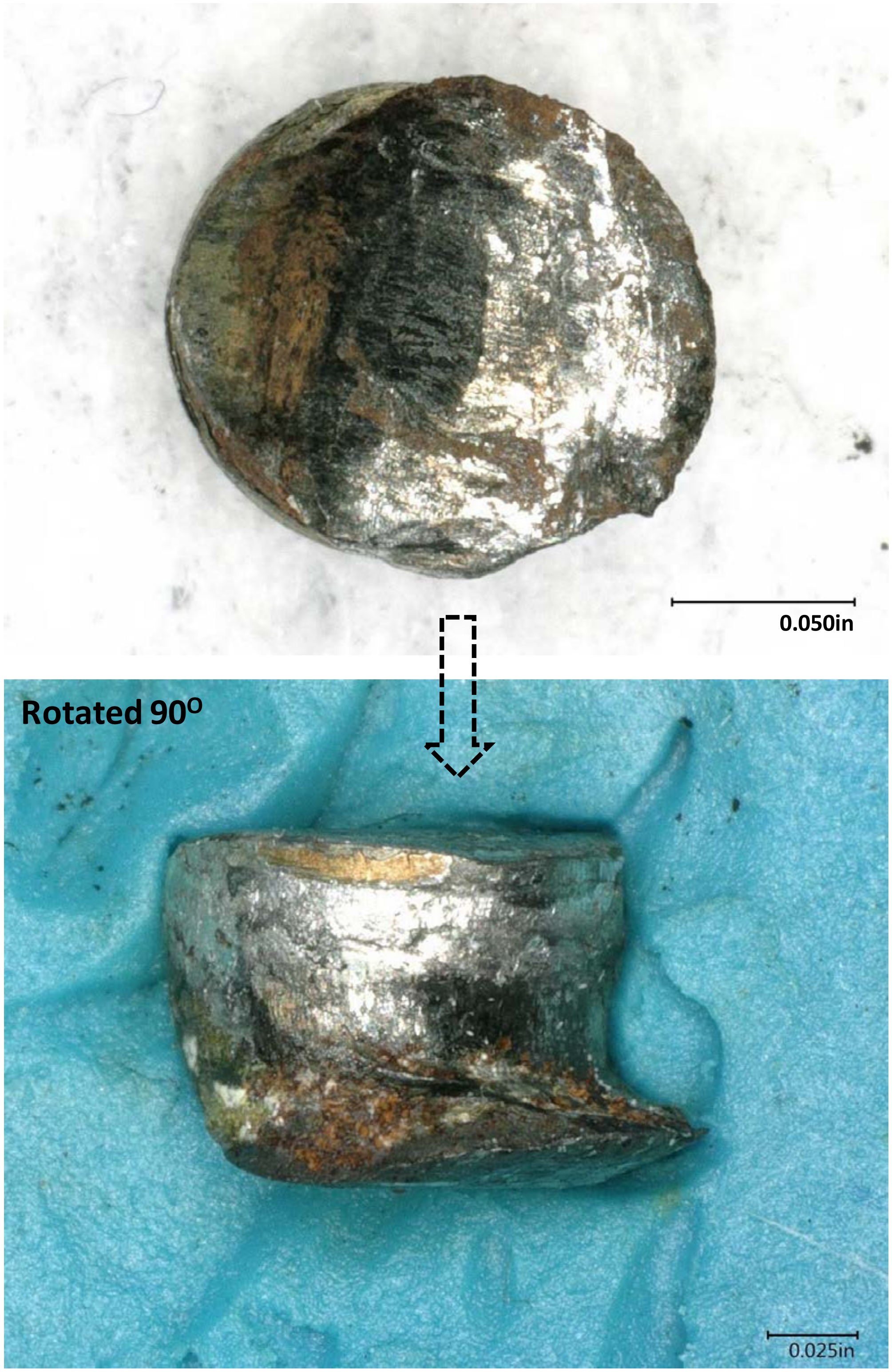


Figure 8: Digital microscope photos of the fracture surface (top) and profile (bottom) of the outboard lock pin piece from the gust lock handle.

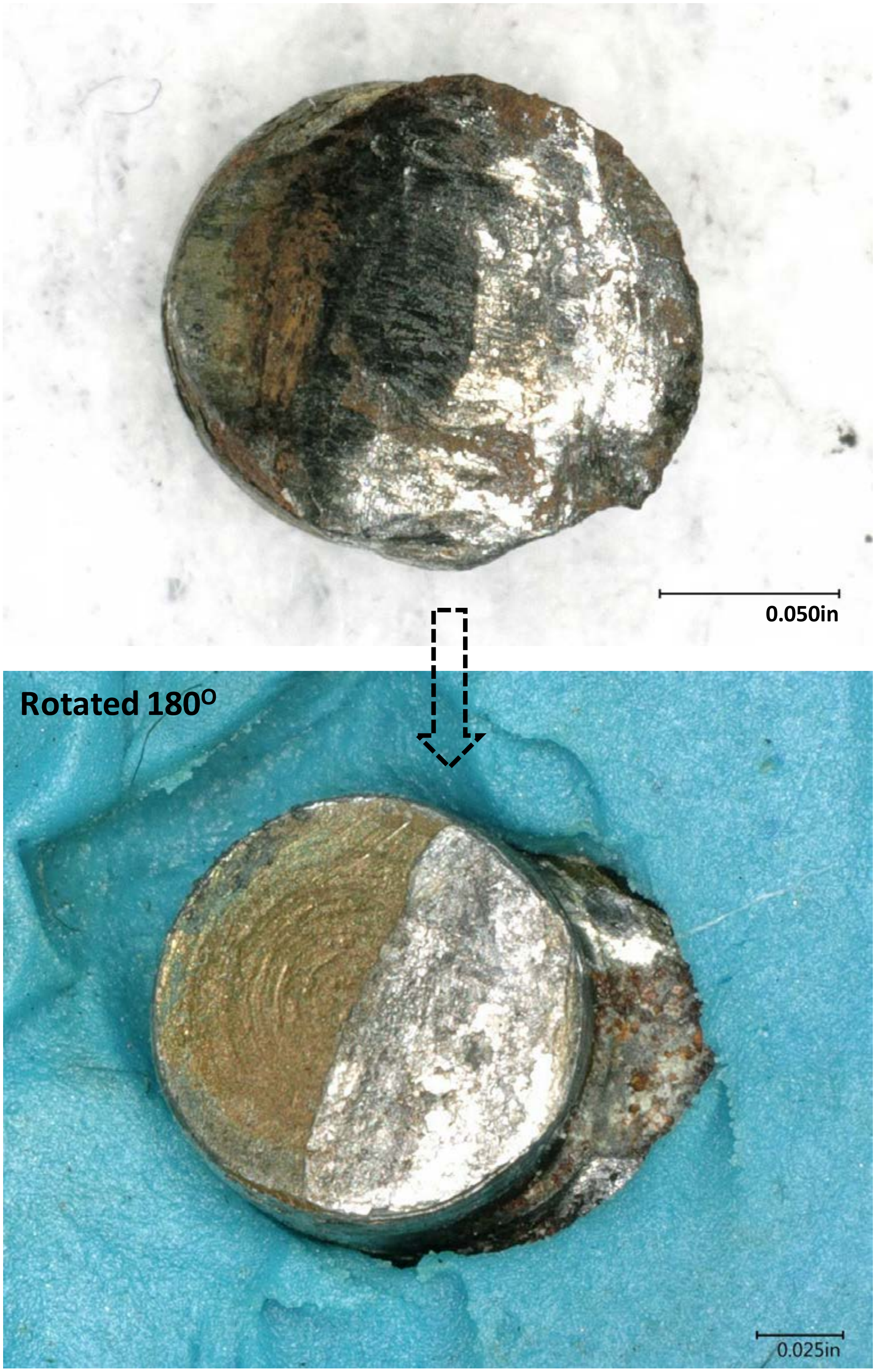


Figure 9: Digital microscope photos of the fracture surface (top) and bottom surface (bottom) of the outboard lock pin piece from the gust lock handle**.**

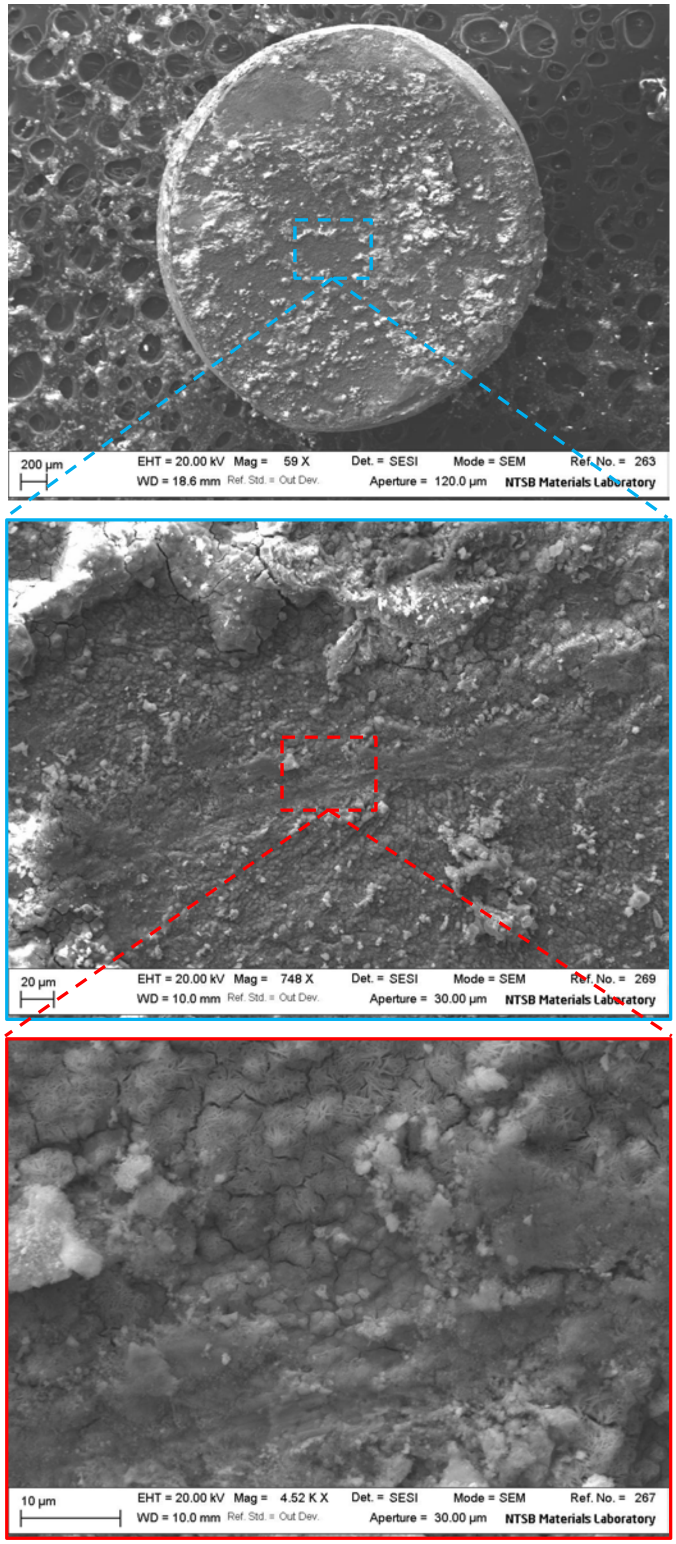


Figure 10: SEM images of the fracture surface on the inboard lock pin piece from the gust lock handle prior to cleaning.

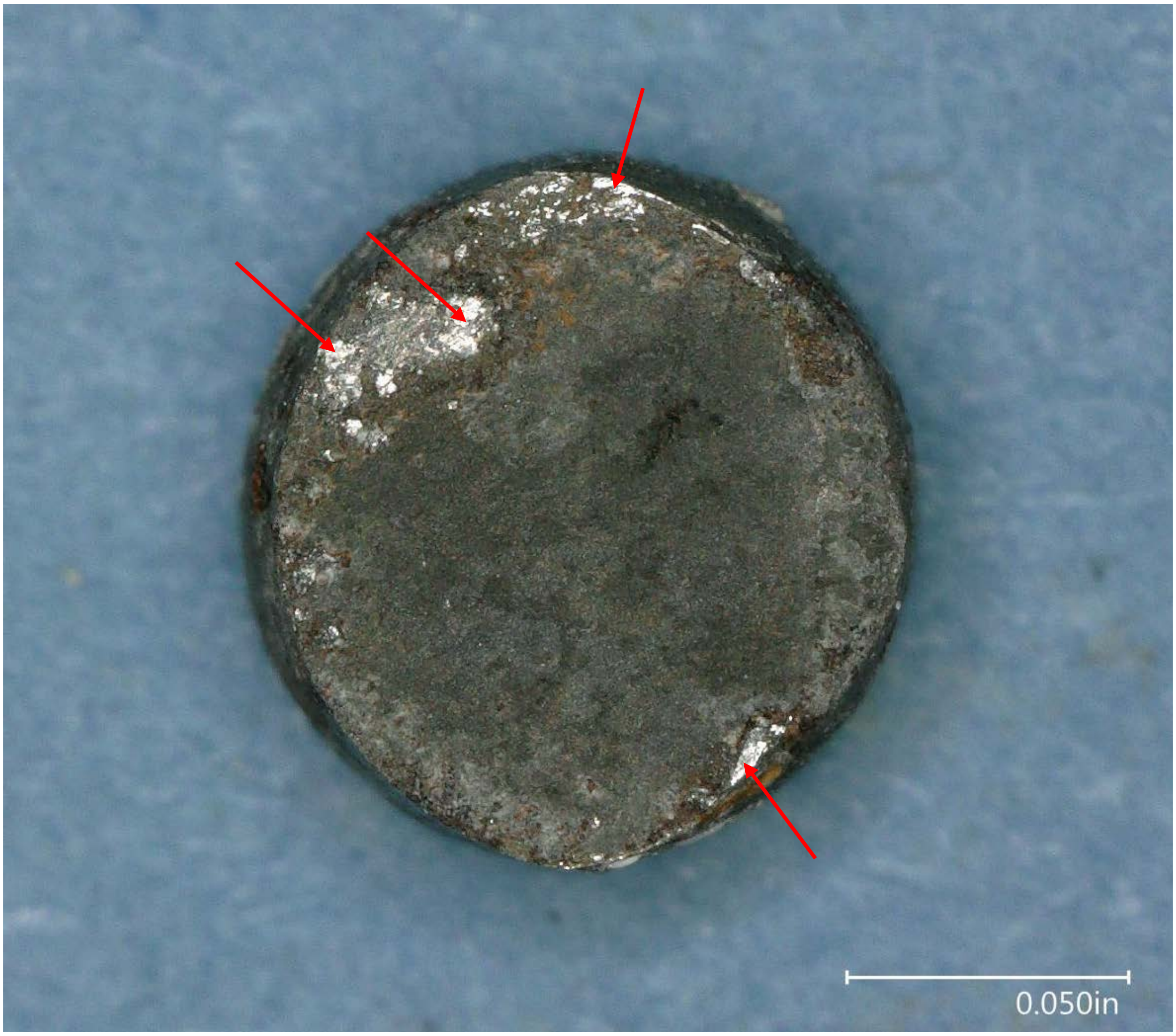


Figure 11: Digital microscope photo of the fracture surface on the inboard lock pin piece from the gust lock handle after cleaning. The red arrows point to shiny areas visible on the fracture surface.

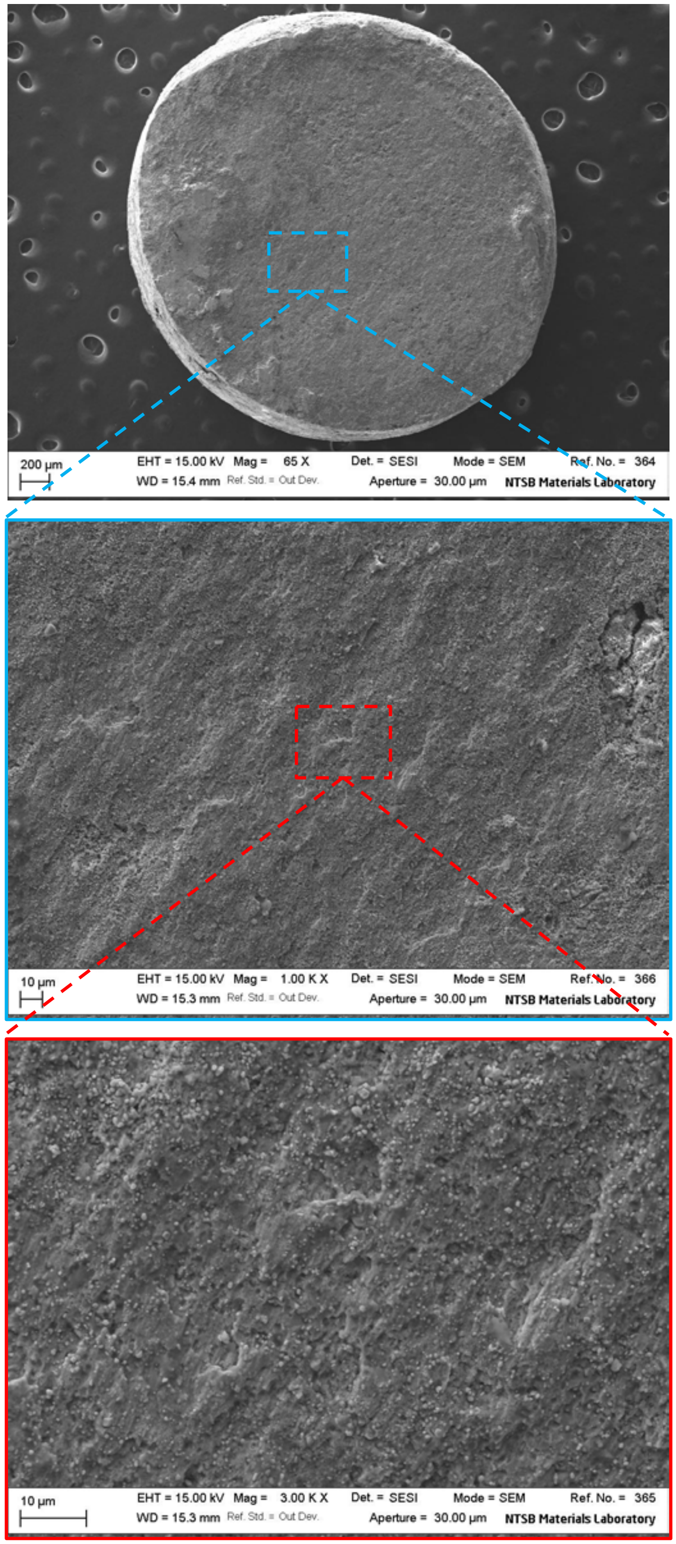


Figure 12: SEM images of the fracture surface on the inboard lock pin piece from the gust lock handle after cleaning.

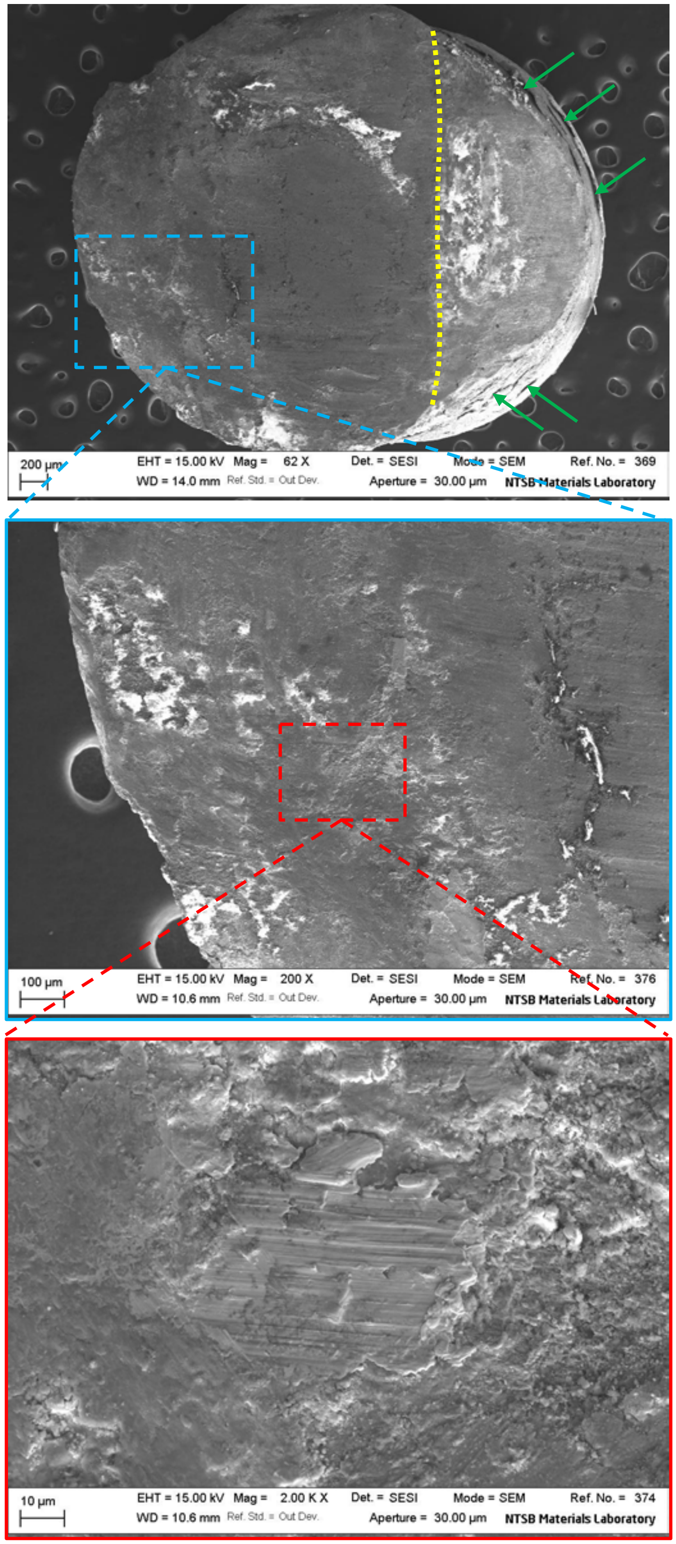


Figure 13: SEM images of the fracture surface on the outboard lock pin piece from the gust lock handle. The yellow dotted line traces a distinct step visible between the two largest flattened planes on the fracture surface. Layers of peeling material (green arrows) were observed in one area on the OD of the outboard lock pin piece.

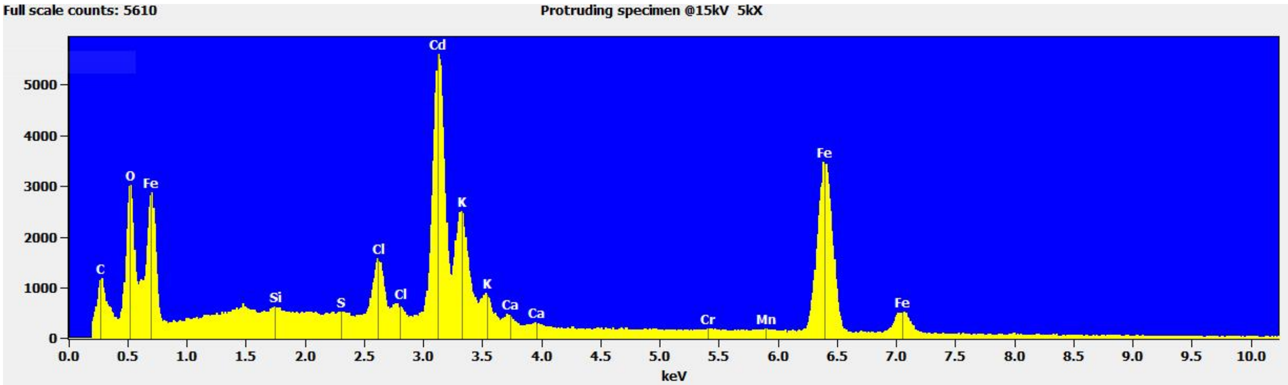


Figure 14: Semi-quantitative EDS spectrum of the fracture surface on the outboard lock pin piece.

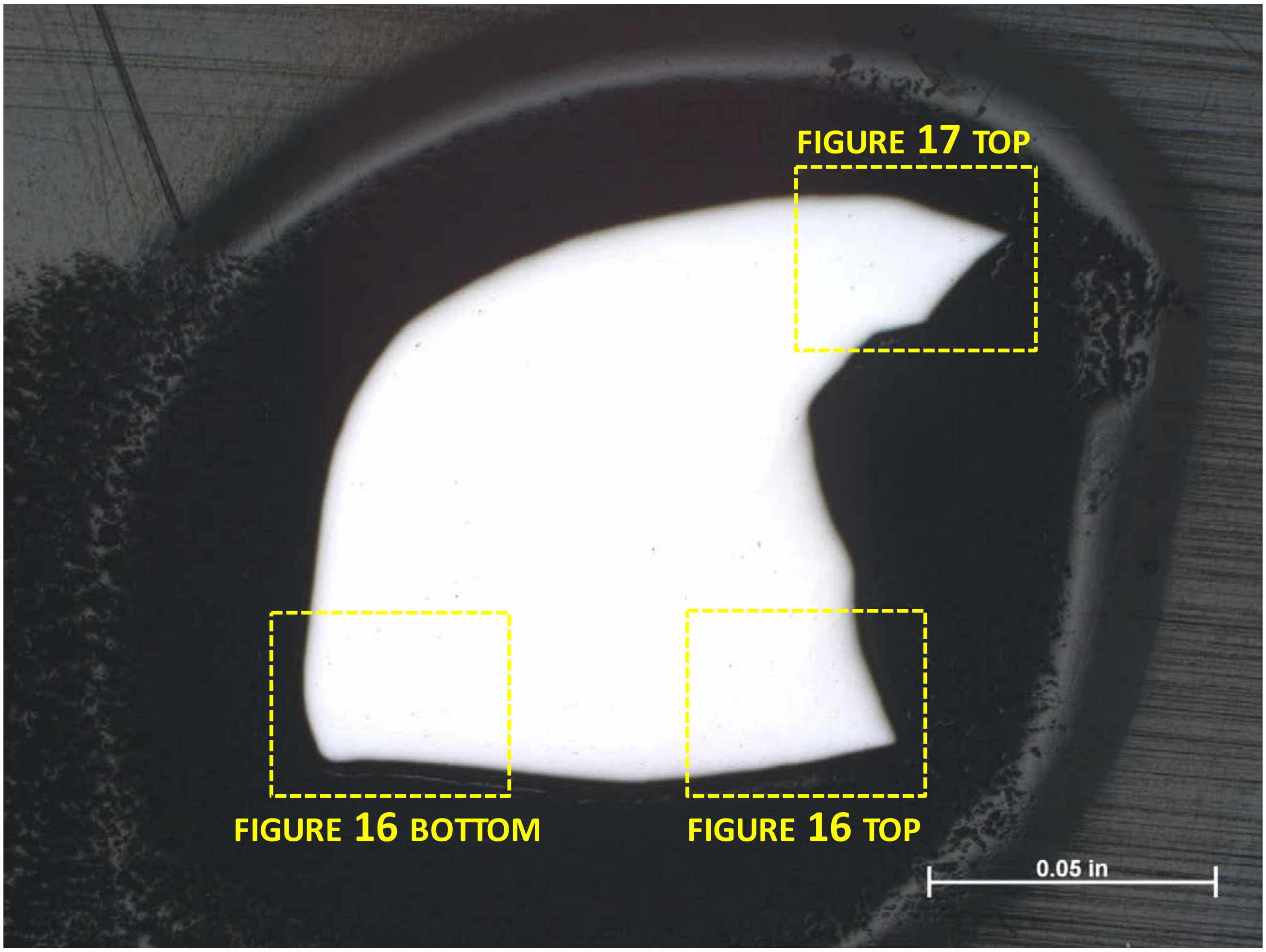
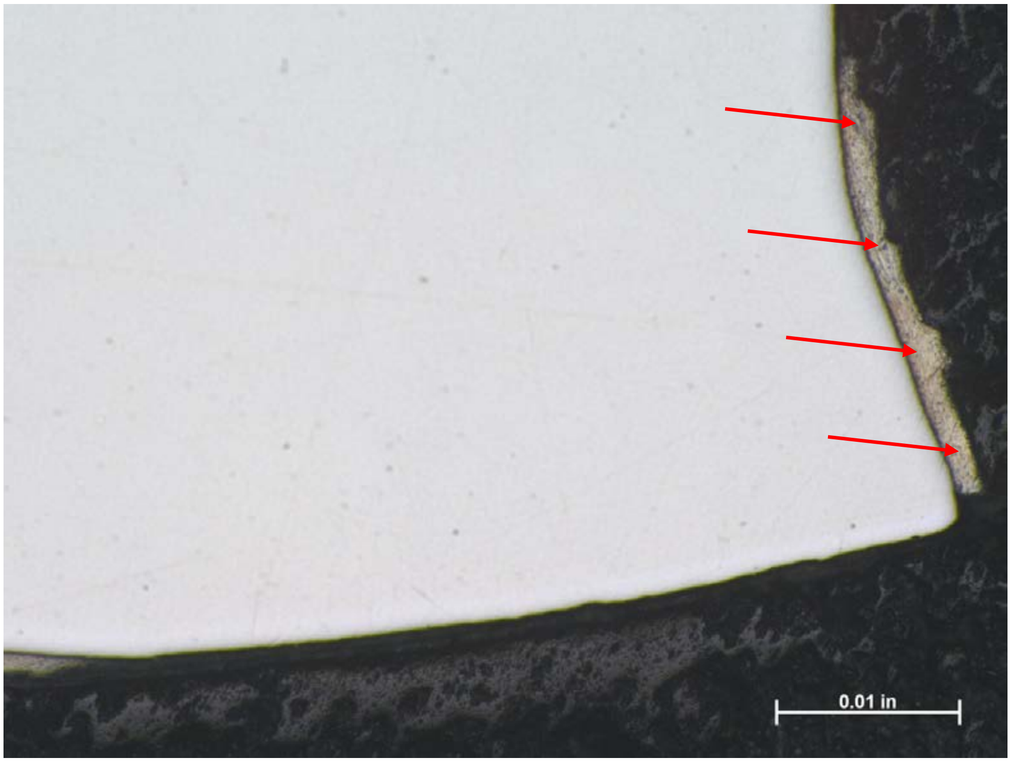


Figure 15: Metallographic image of the cross-section prepared through the outboard lock pin piece from the gust lock handle. (Unetched)



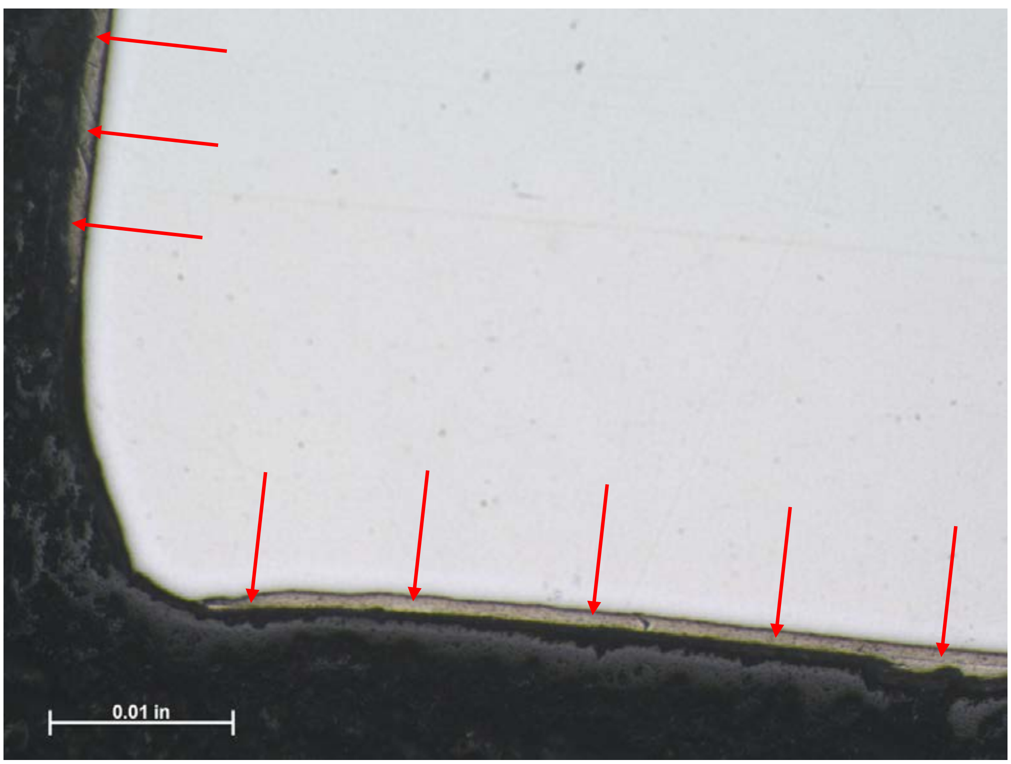


Figure 16: Metallographic images the external layer (red arrows) observed on the edges of some areas of the cross-section prepared through the outboard lock pin piece from the gust lock handle. (Unetched)

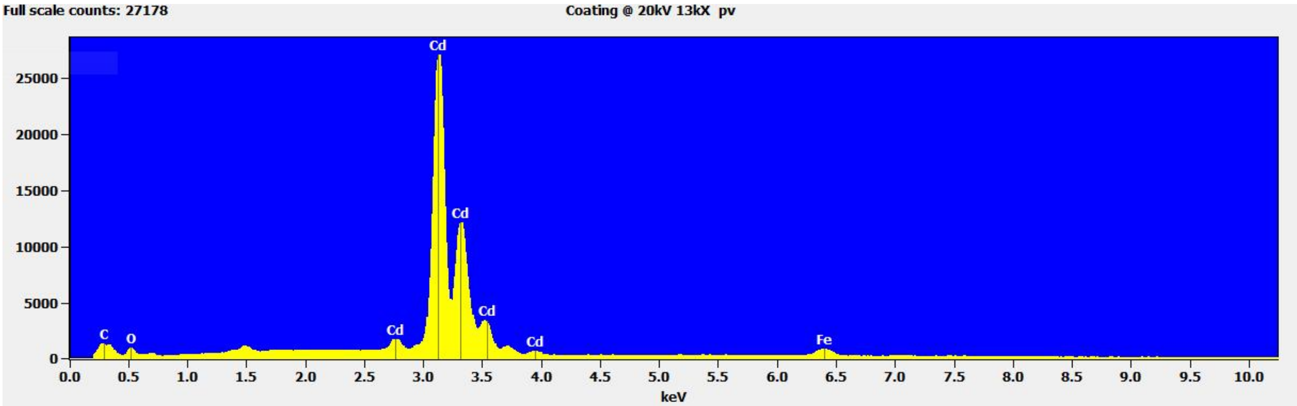


Figure 17: Semi-quantitative EDS spectrum of the external layer around the edges of areas on the cross-section through the outboard lock pin piece**.**

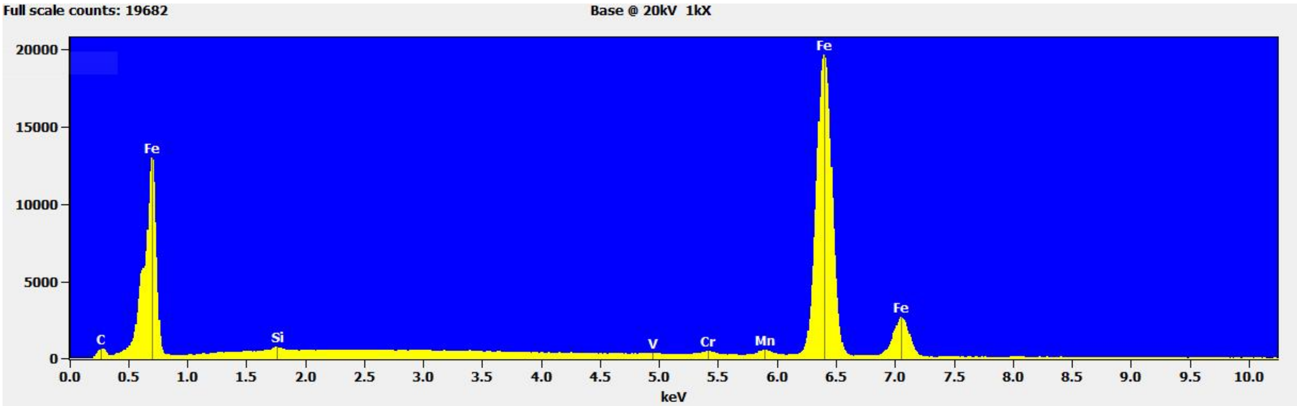


Figure 18: Semi-quantitative EDS spectrum of the base material of the outboard lock pin piece**.**

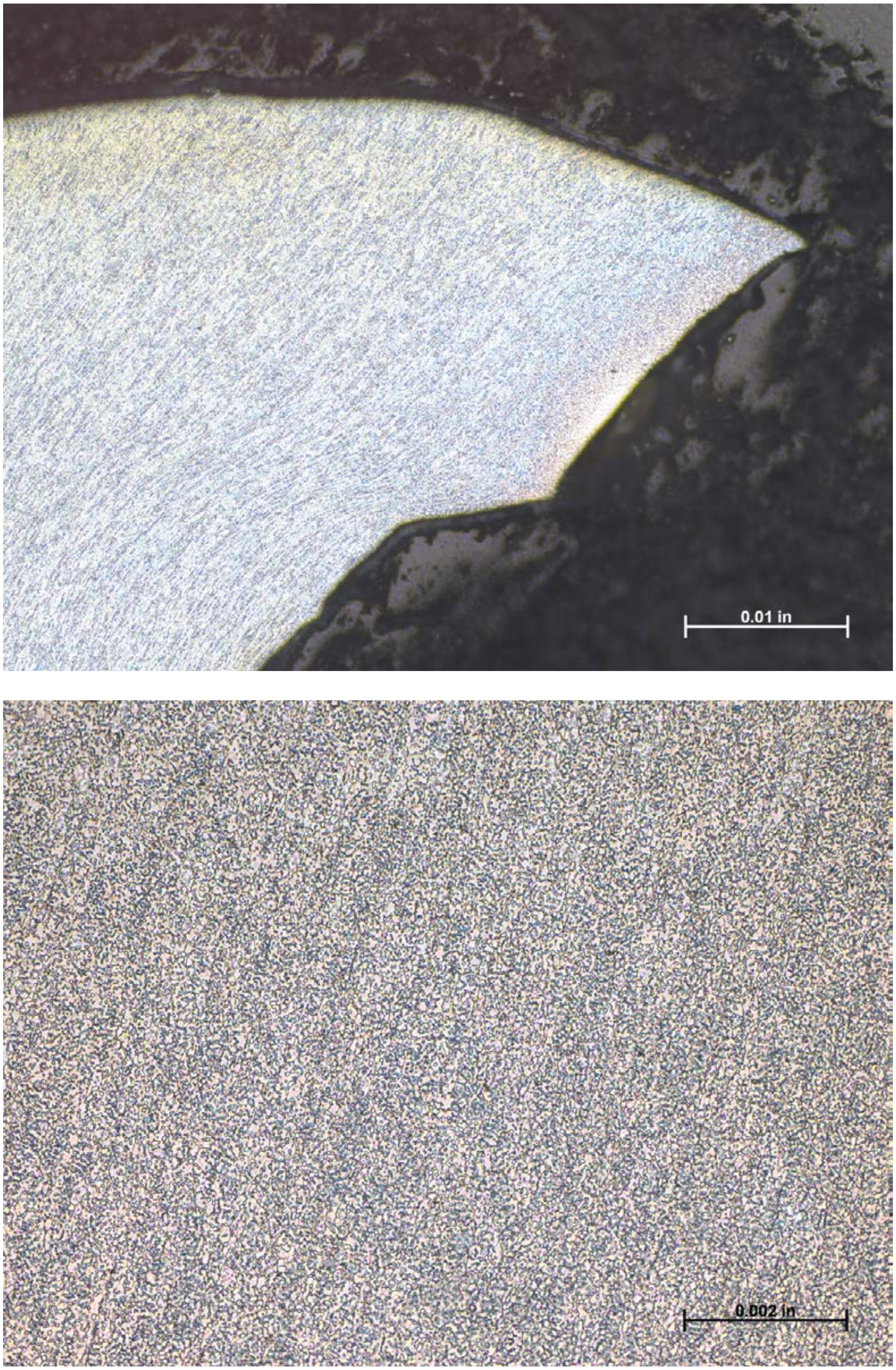


Figure 19: Metallographic images showing the microstructure of the base material of the outboard lock pin piece cross-section. (2% Nital etch)

Figure 20: Overall photos of the disassembled gust lock body, link and slider assembly from the gust lock handle.

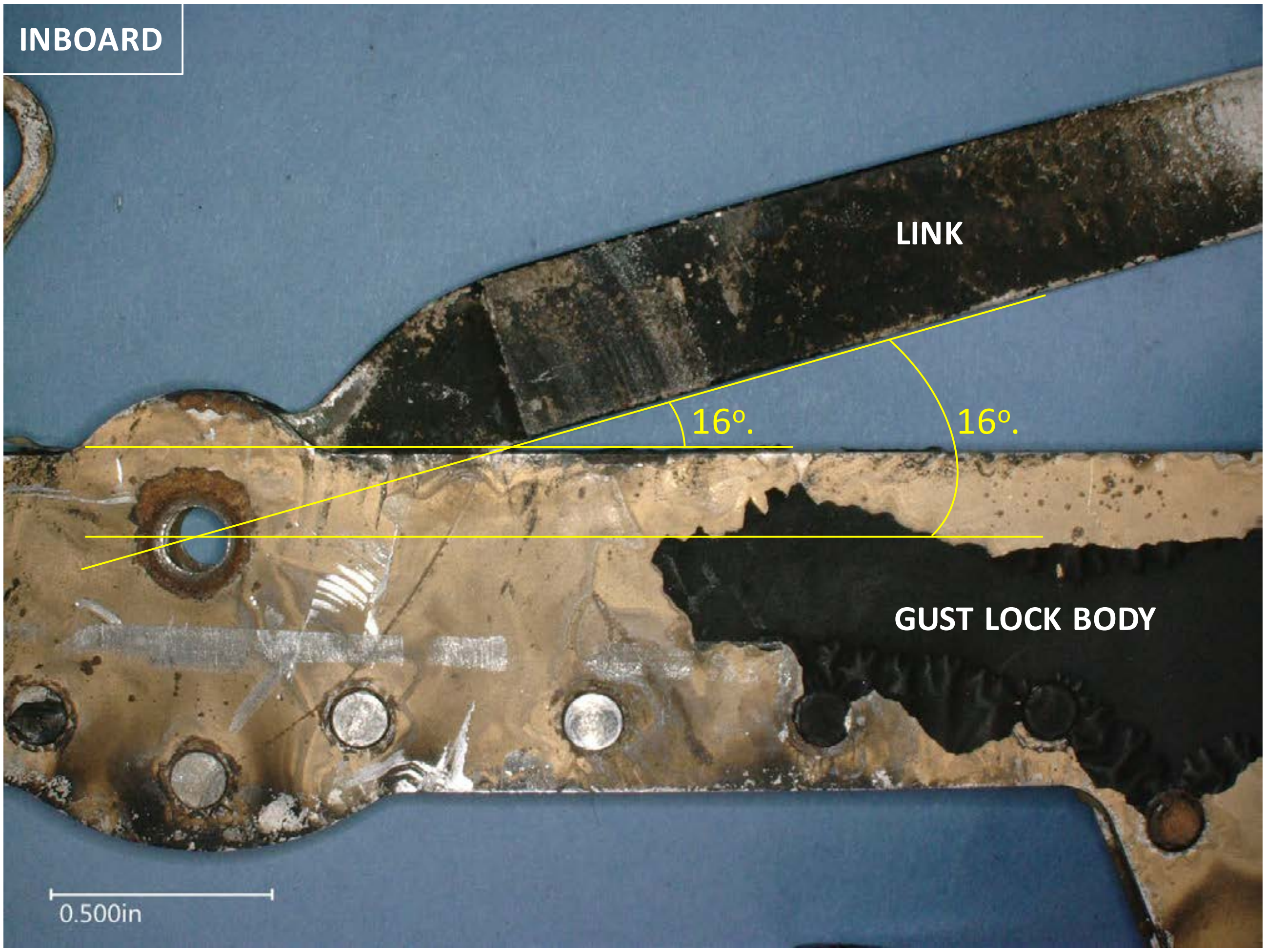


Figure 21: Digital microscope photo showing the angle between the gust lock handle components when the link was inserted so the soot mark on the link surface was in-line with the gust lock body.

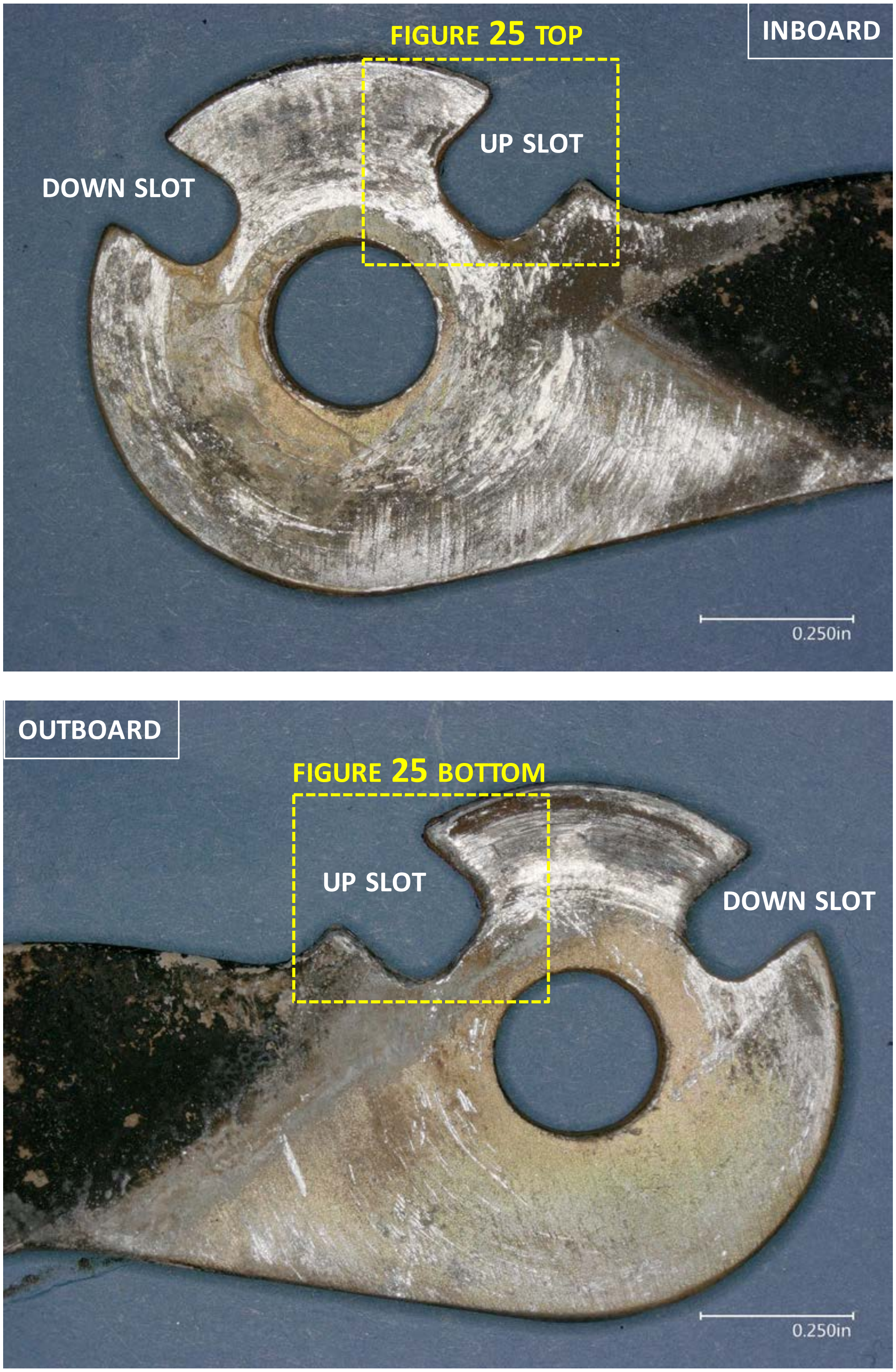


Figure 22: Digital microscope photos showing the contact marks on the inboard and outboard surfaces of the link from the gust lock handle**.**

Figure 23: Digital microscope photos showing the down slot surface on the link from the gust lock handle.

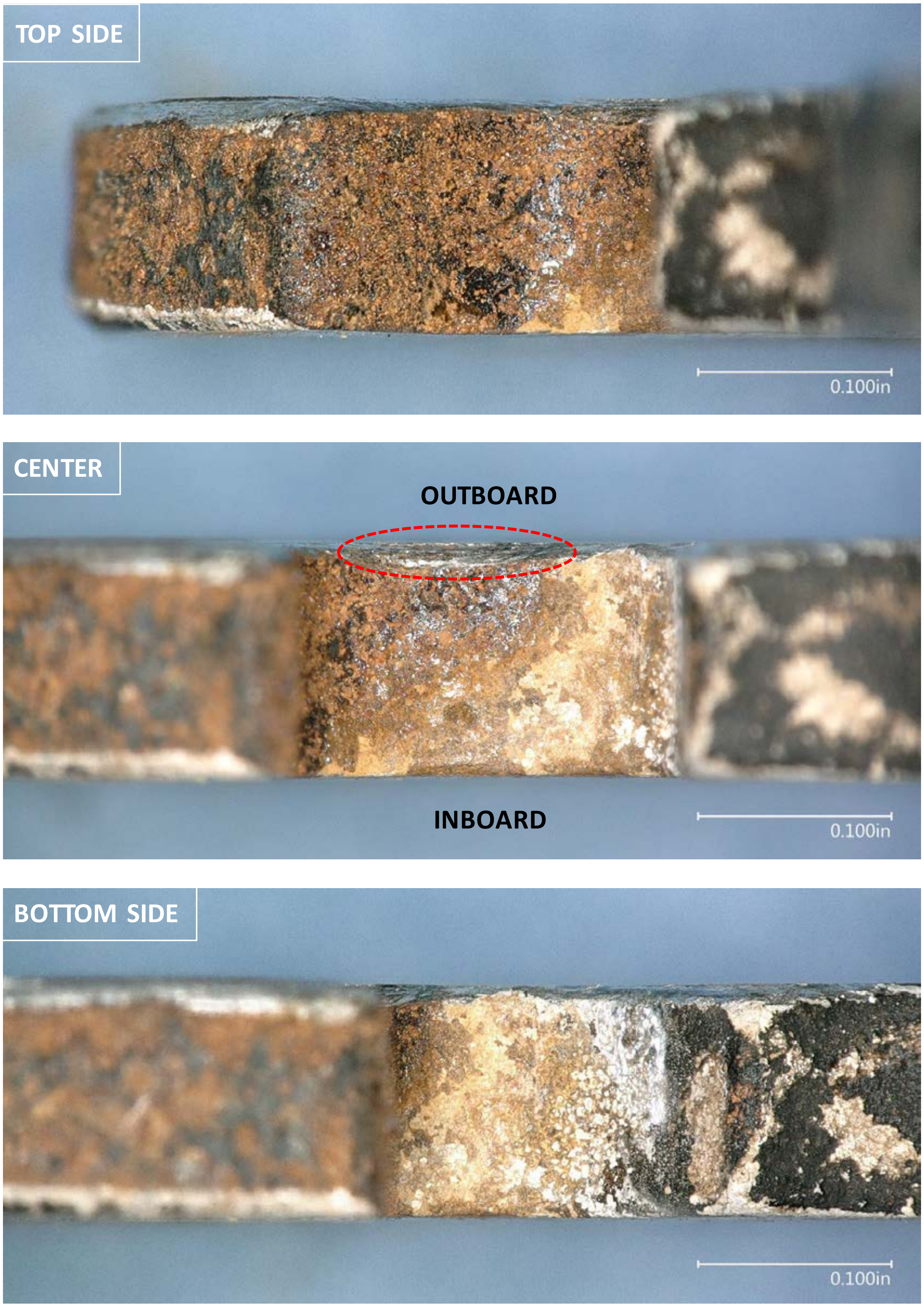


Figure 24: Digital microscope photos showing the up slot surface on the link from the gust lock handle. The red dashed line encircles material rolled off the outboard face of the link into the slot.

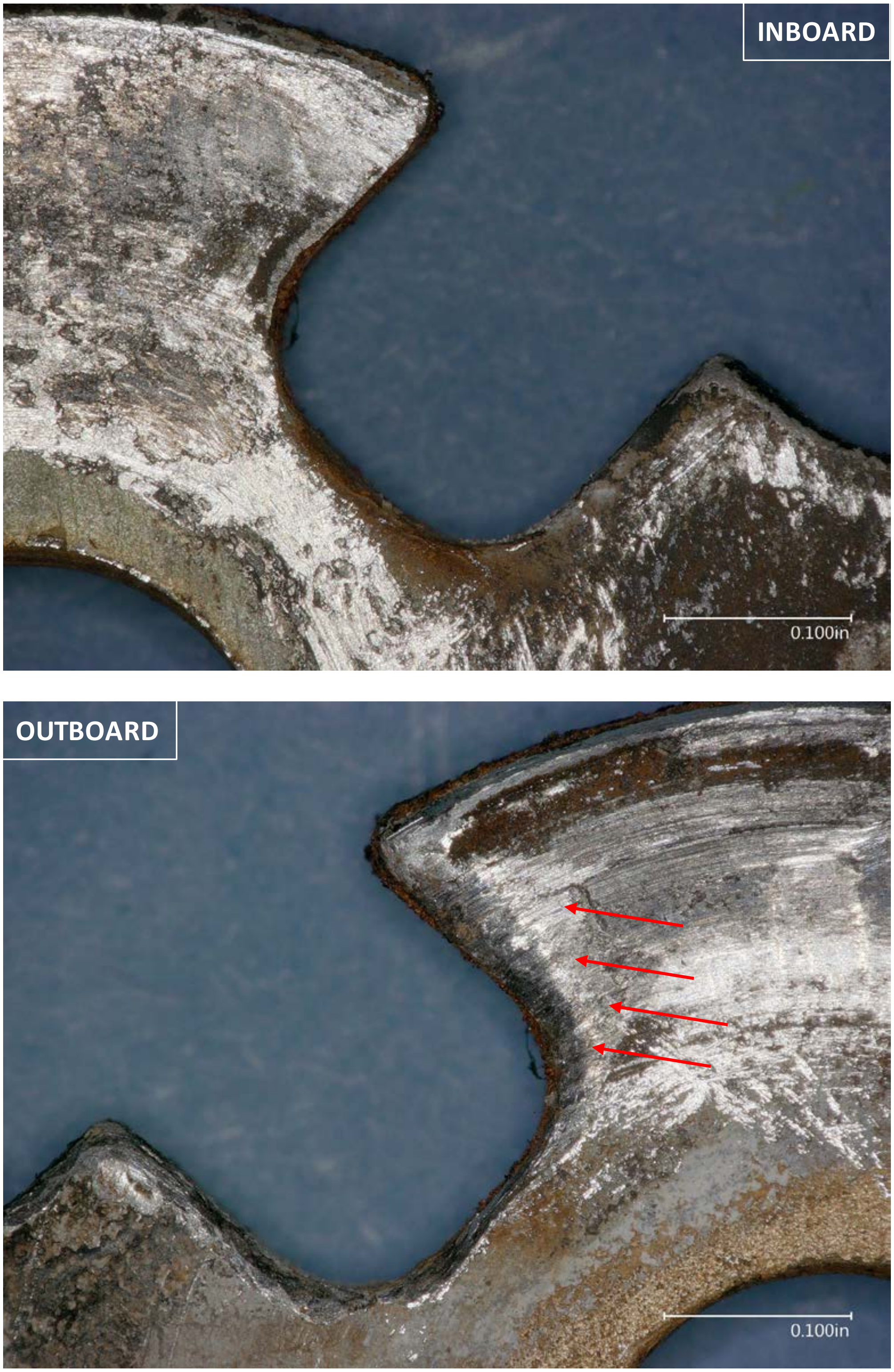


Figure 25: Digital microscope photos showing the contact marks surrounding the up slot on the inboard and outboard surfaces of the link from the gust lock handle. Material deposited onto the outboard face of the link is indicated by the red arrows.

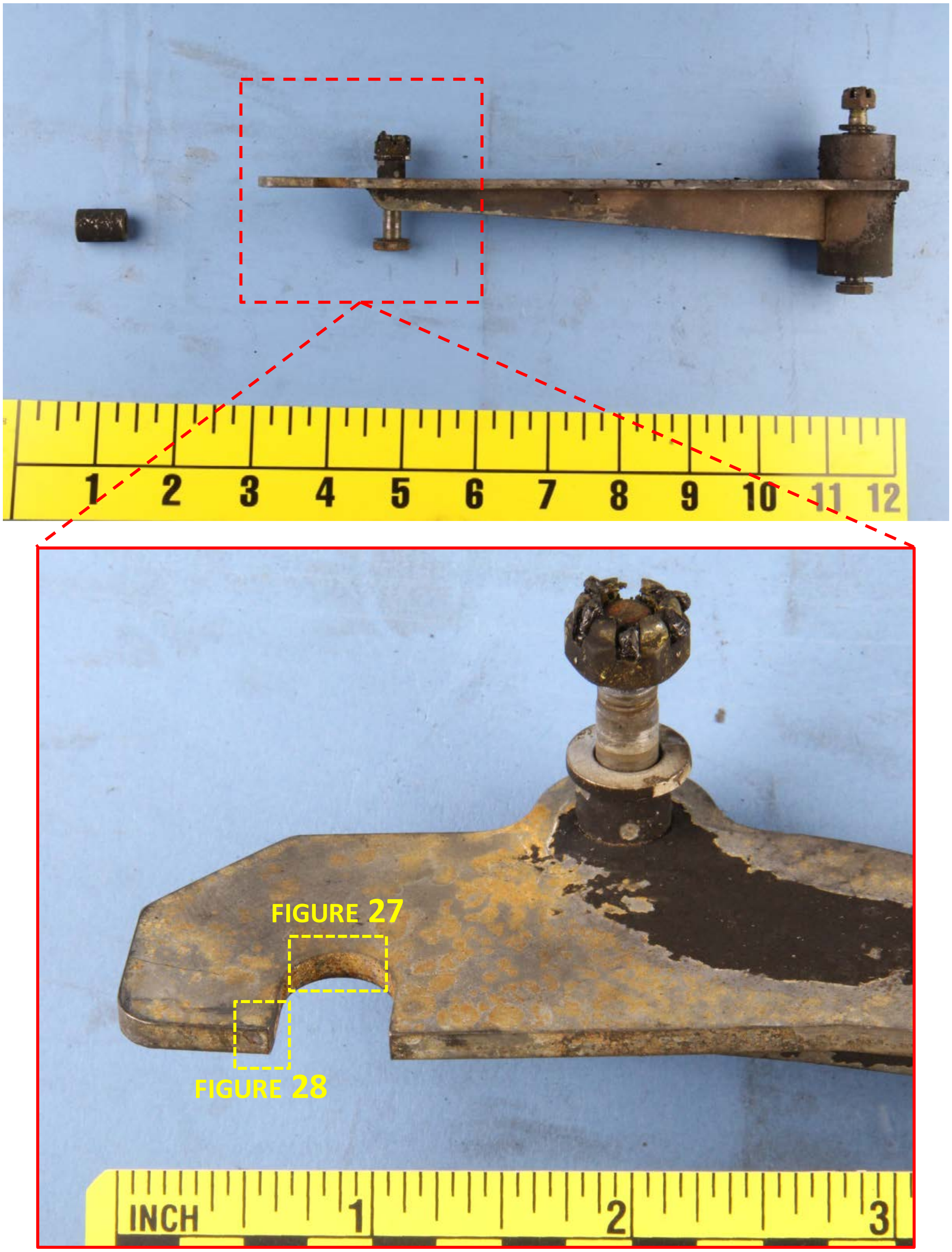


Figure 26: Overall photo of the elevator hook and roller (top), and close-up photo of the elevator hook slot (bottom).

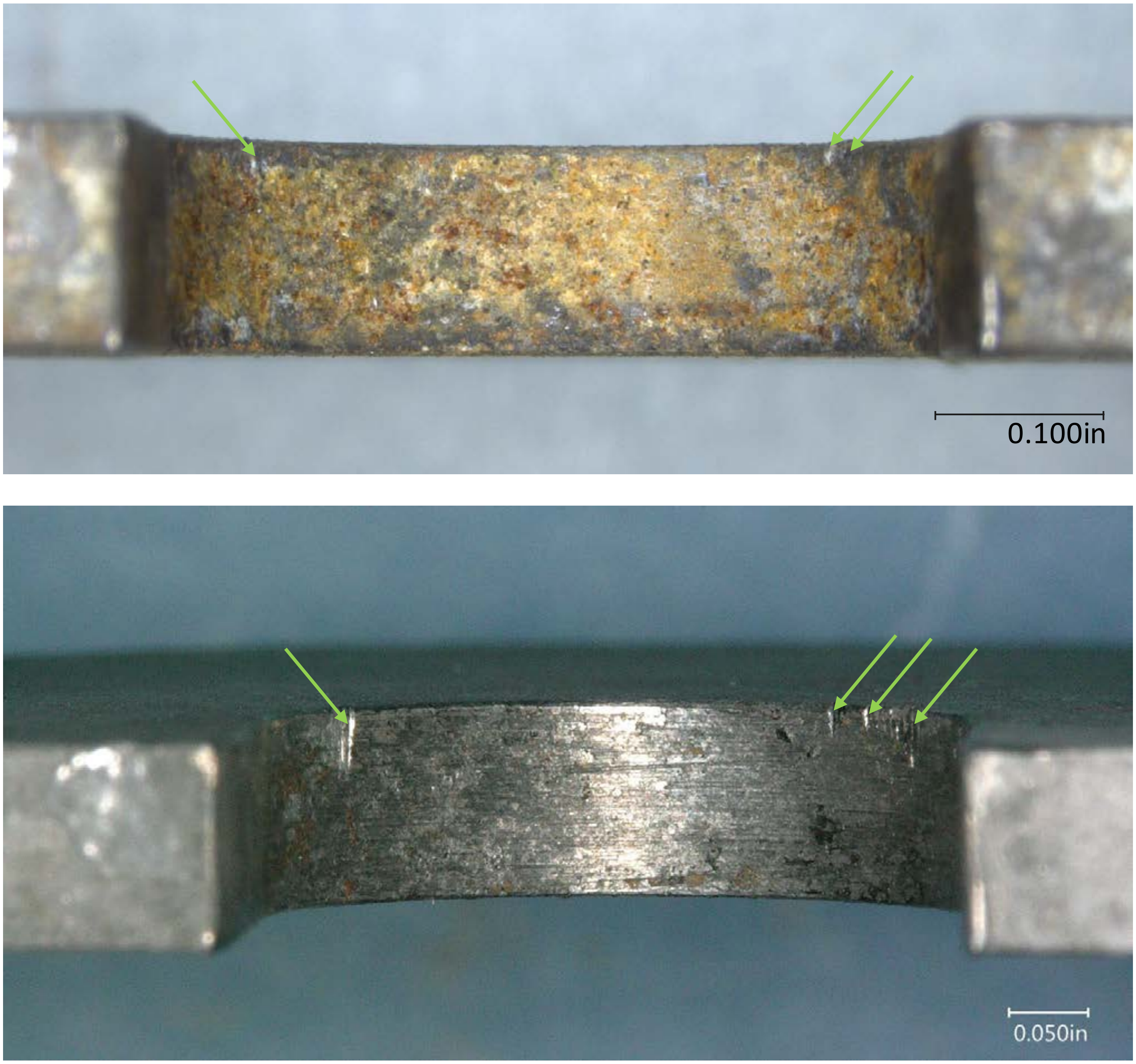


Figure 27: Digital microscope photos of the elevator hook slot bottom before and after cleaning (top and bottom images, respectively). The green arrows point to linear marks observed on the slot surface.

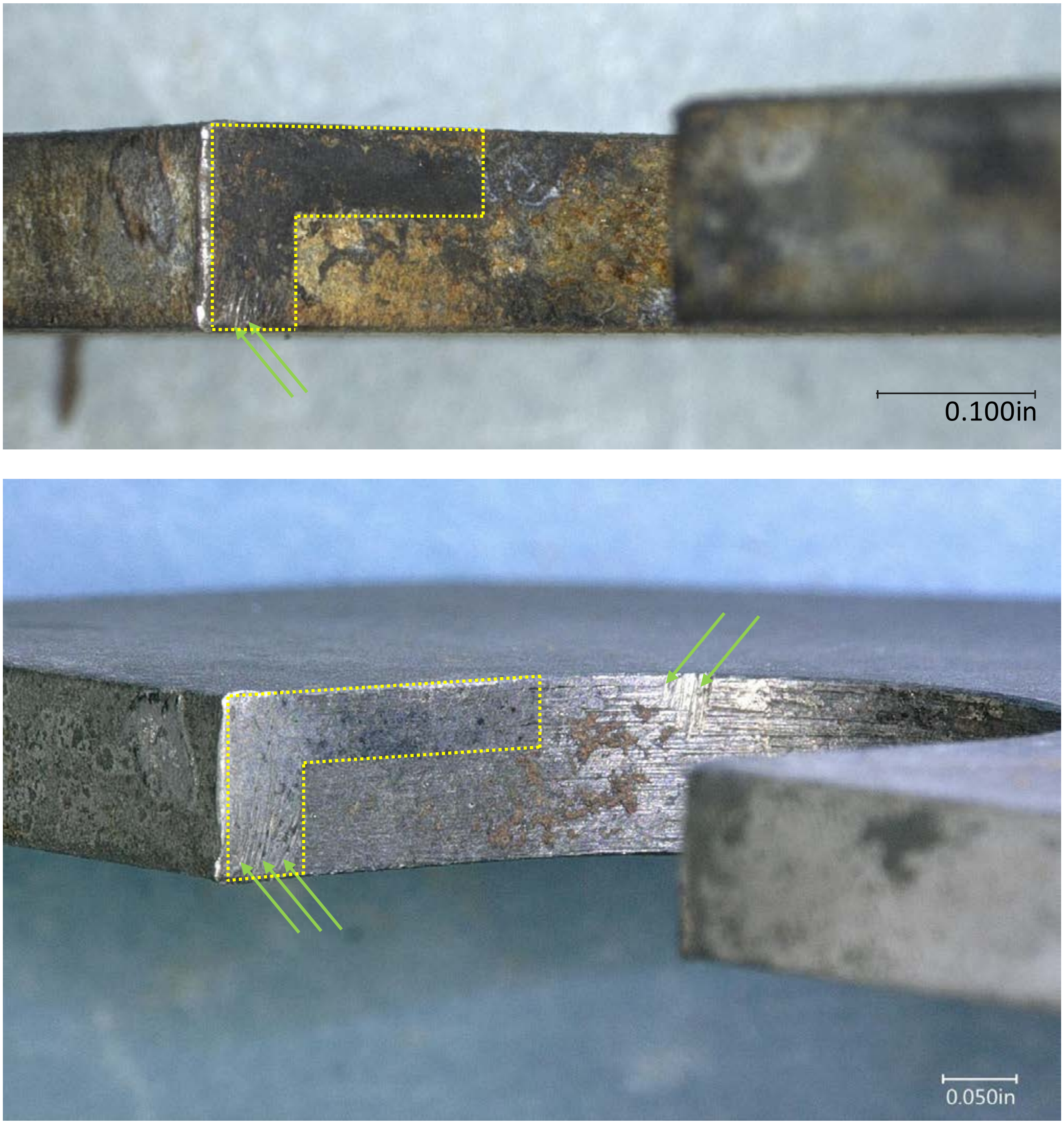


Figure 28: Digital microscope photos of one end of the elevator hook slot before and after cleaning (top and bottom images, respectively). The yellow dotted lines outline an L-shaped pattern visible on the surface of the slot end. The green arrows point to linear marks observed on the slot surface.

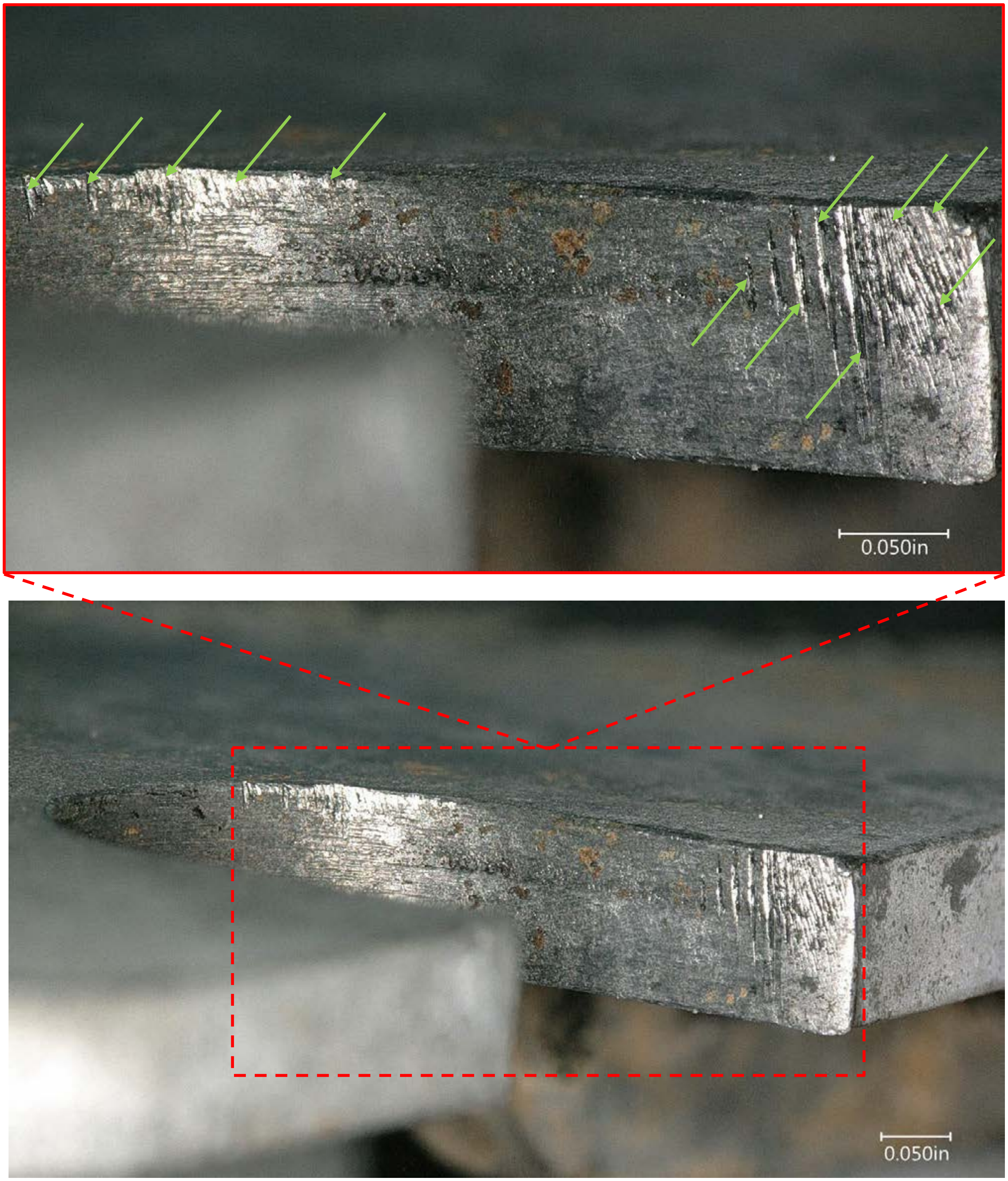


Figure 29: Digital microscope photos of the end of the elevator hook slot opposite the end shown in Figure 28. The green arrows point to linear marks observed on the slot surface.

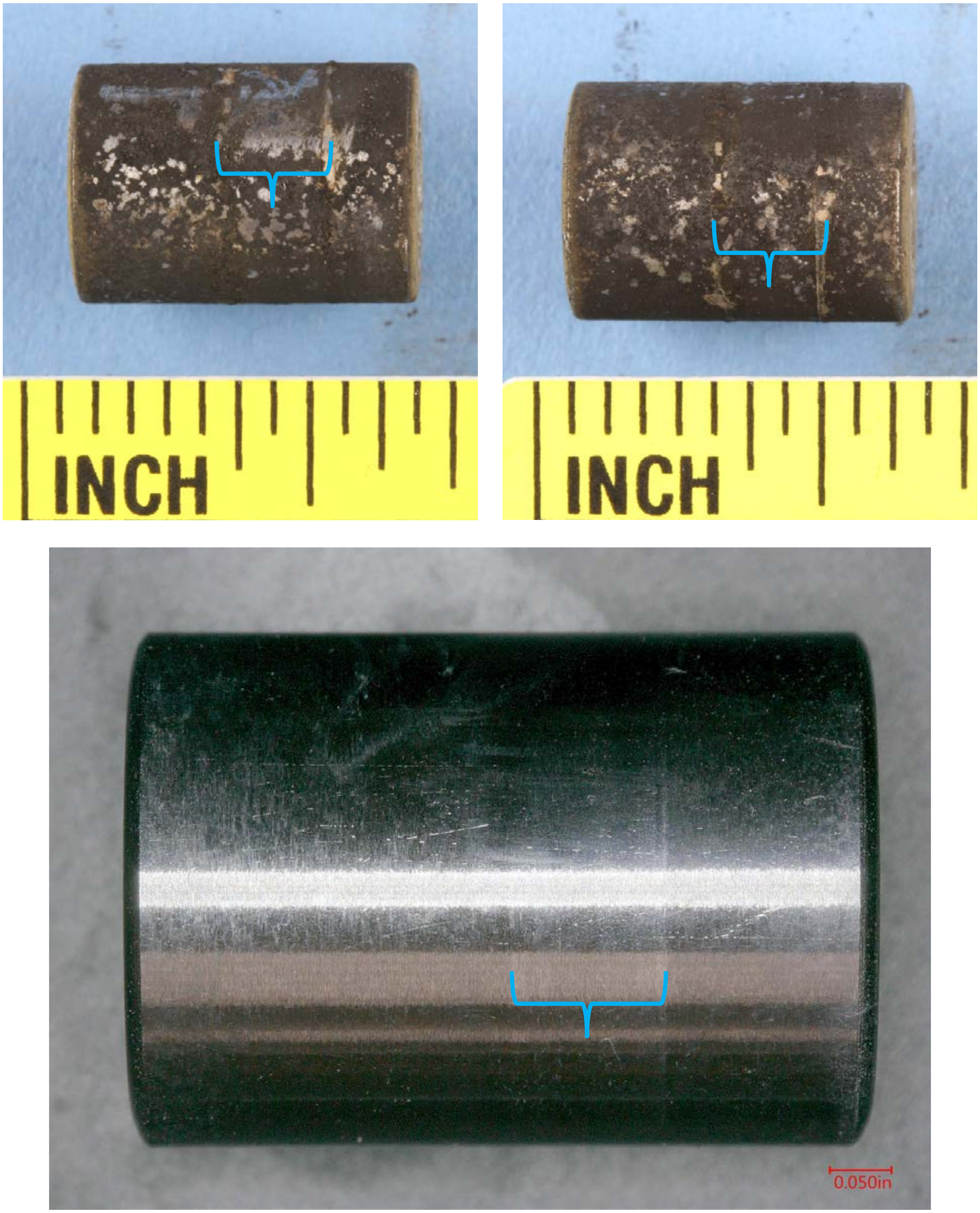


Figure 30: Digital microscope photos showing the circumferential markings (blue brackets, top images) through the dark-colored deposits on the OD of the elevator roller. After cleaning, a circumferential band of wear (blue bracket, bottom image) was observed in the location of the markings.

Figure 31: Overall photos of the sunglasses as-submitted**.**

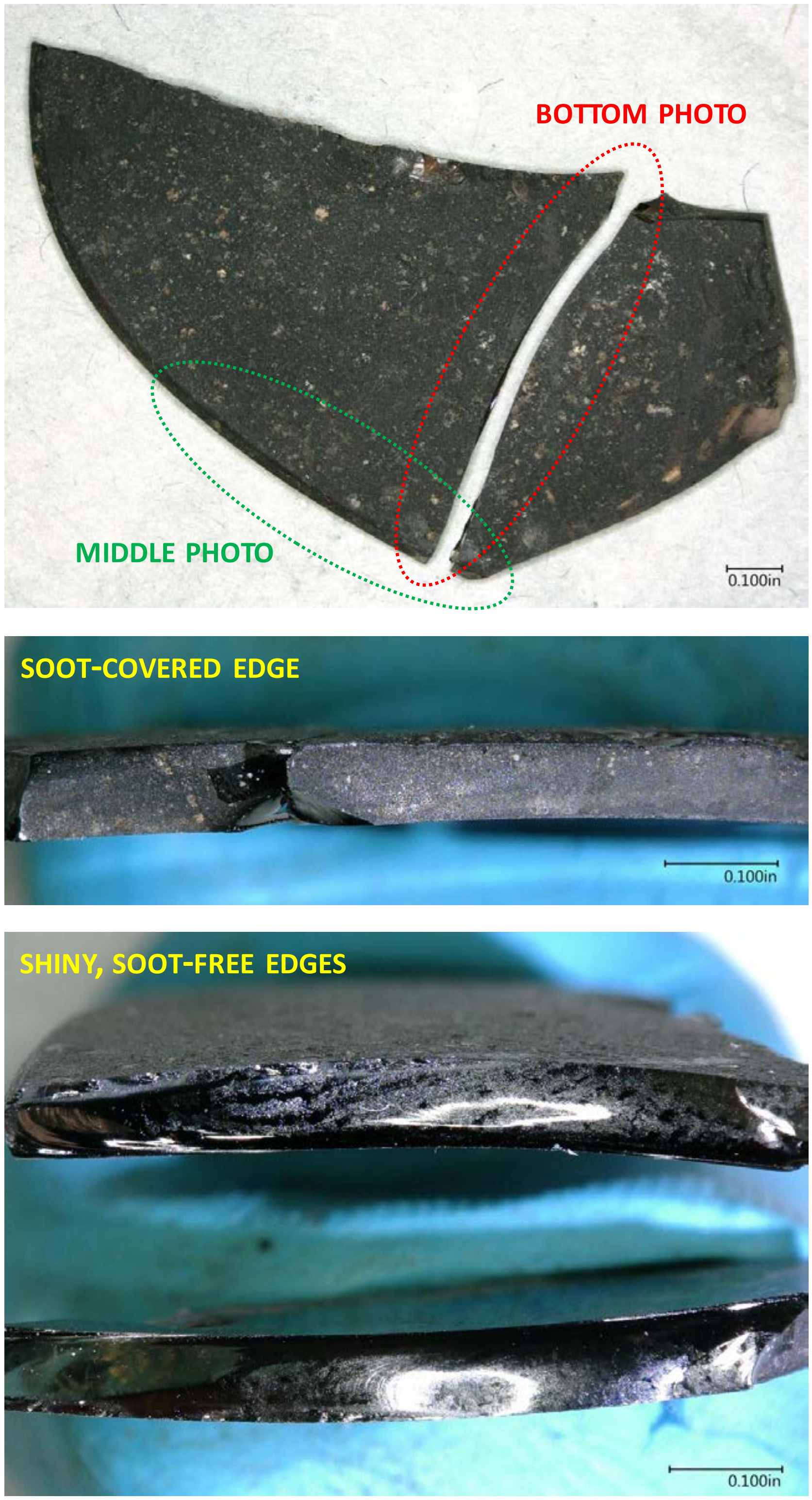


Figure 32: Digital microscope photos of the sunglasses lens piece that was broken during recovery.

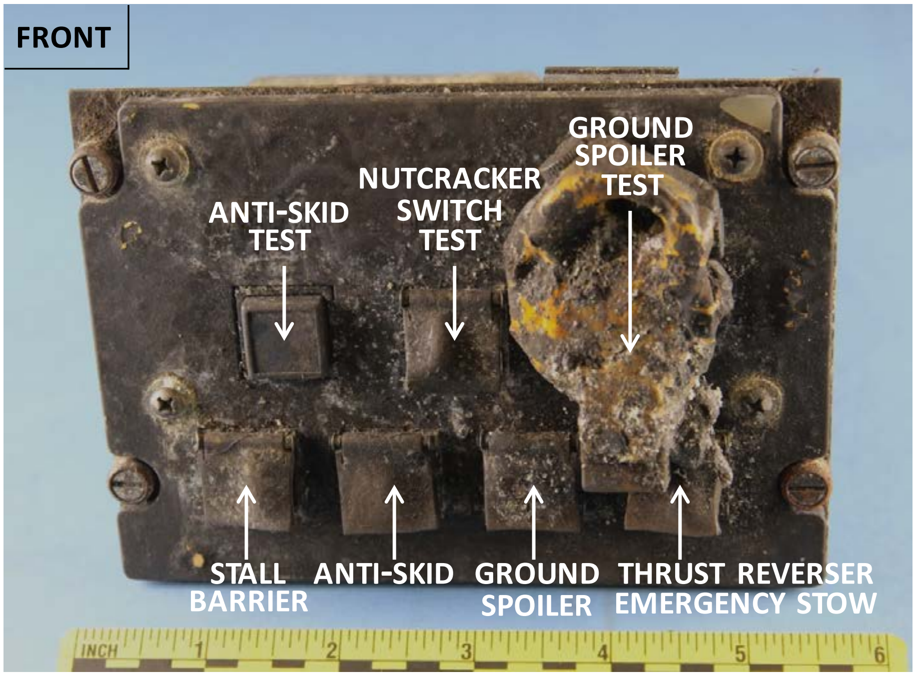


Figure 33: Overall photos of the pedestal switch panel.

Thrust Reverser Emergency Stow Switch from Incident Aircraft

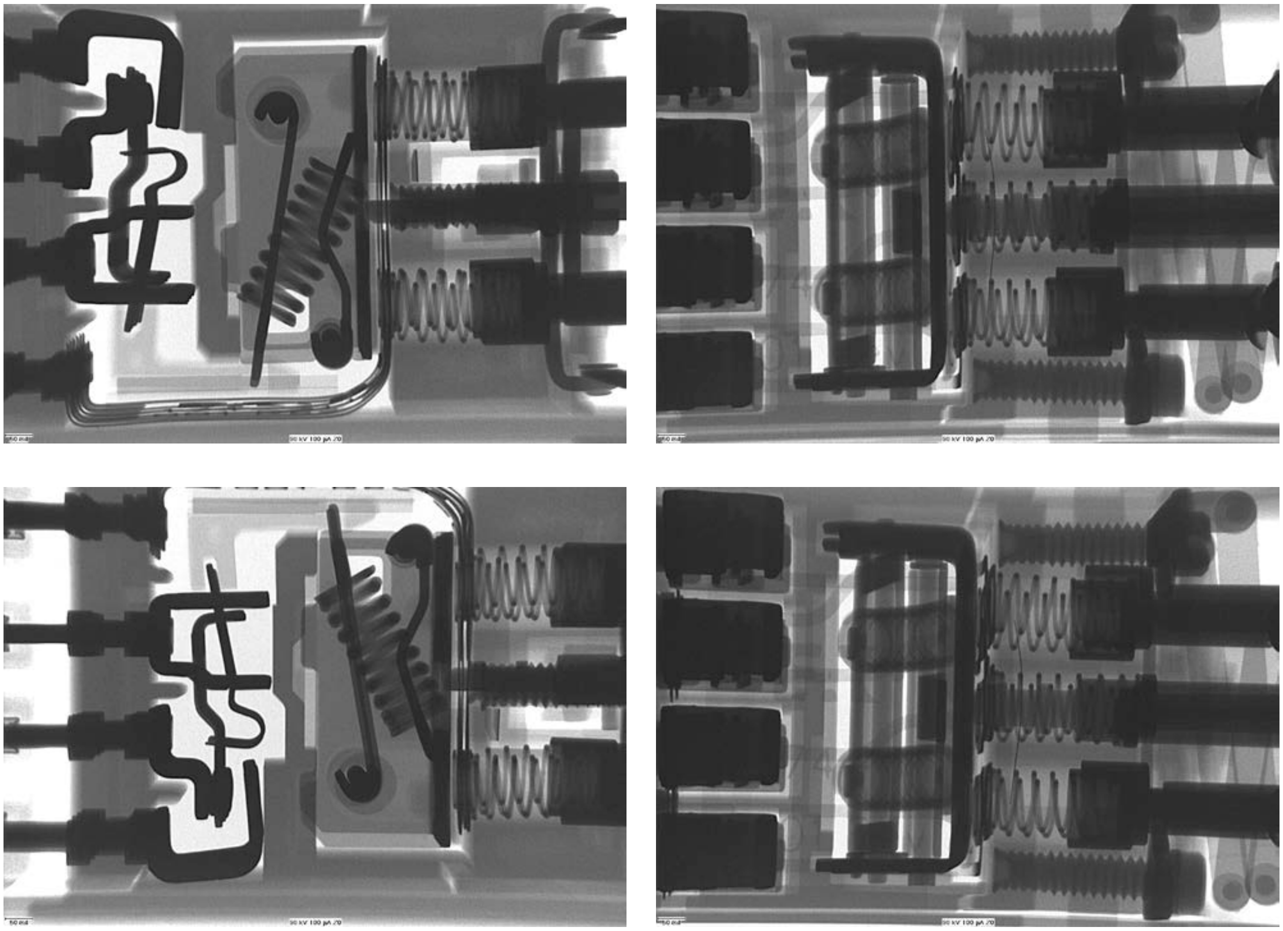


Figure 34: Radiographs of the 4 sides of the thrust reverser emergency stow switch from the incident aircraft.

<u>Ground Spoiler Switch from Incident Aircraft</u>

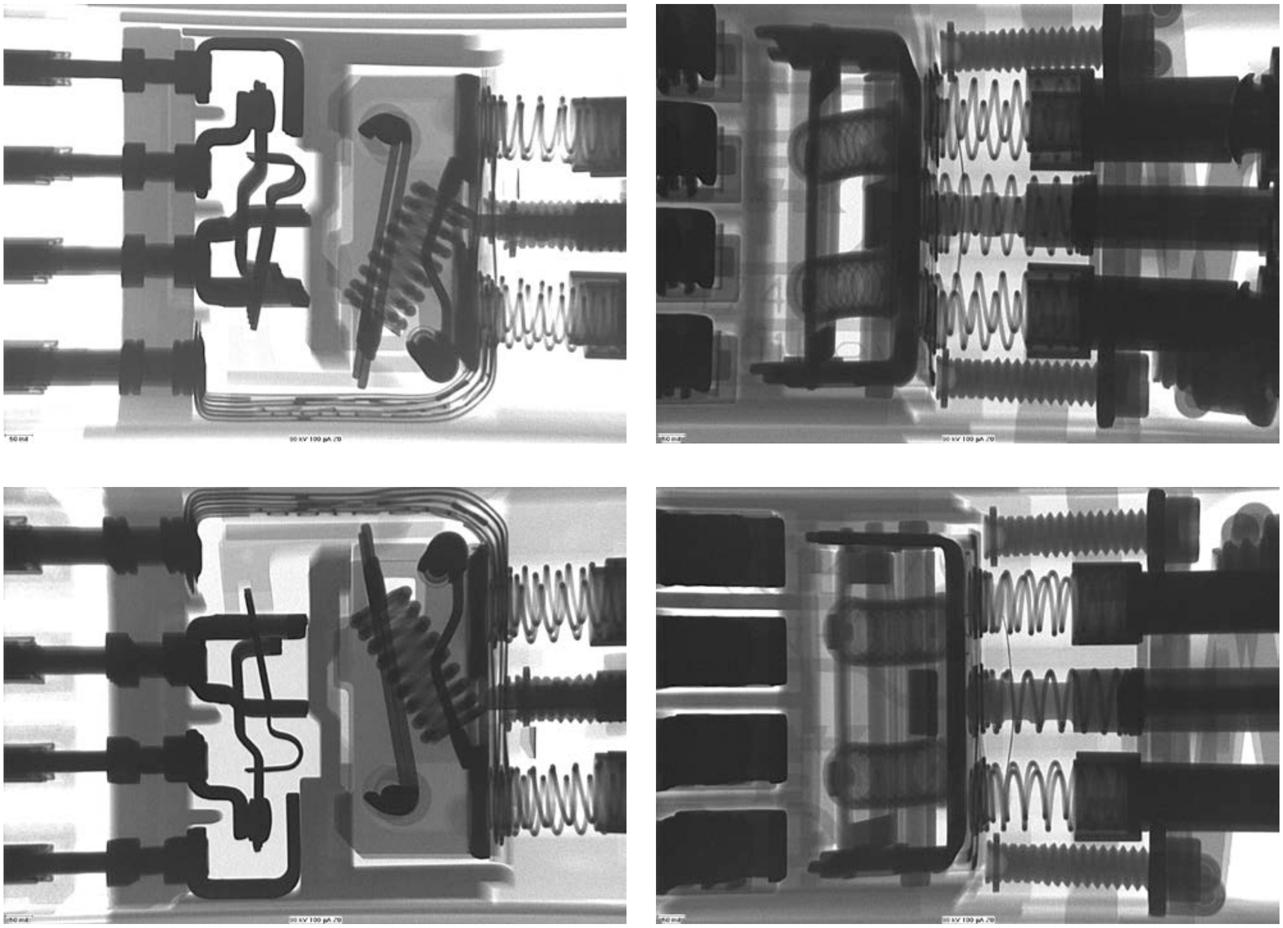


Figure 35: Radiographs of the 4 sides of the ground spoiler switch from the incident aircraft**.**

Anti-Skid Switch from Incident Aircraft

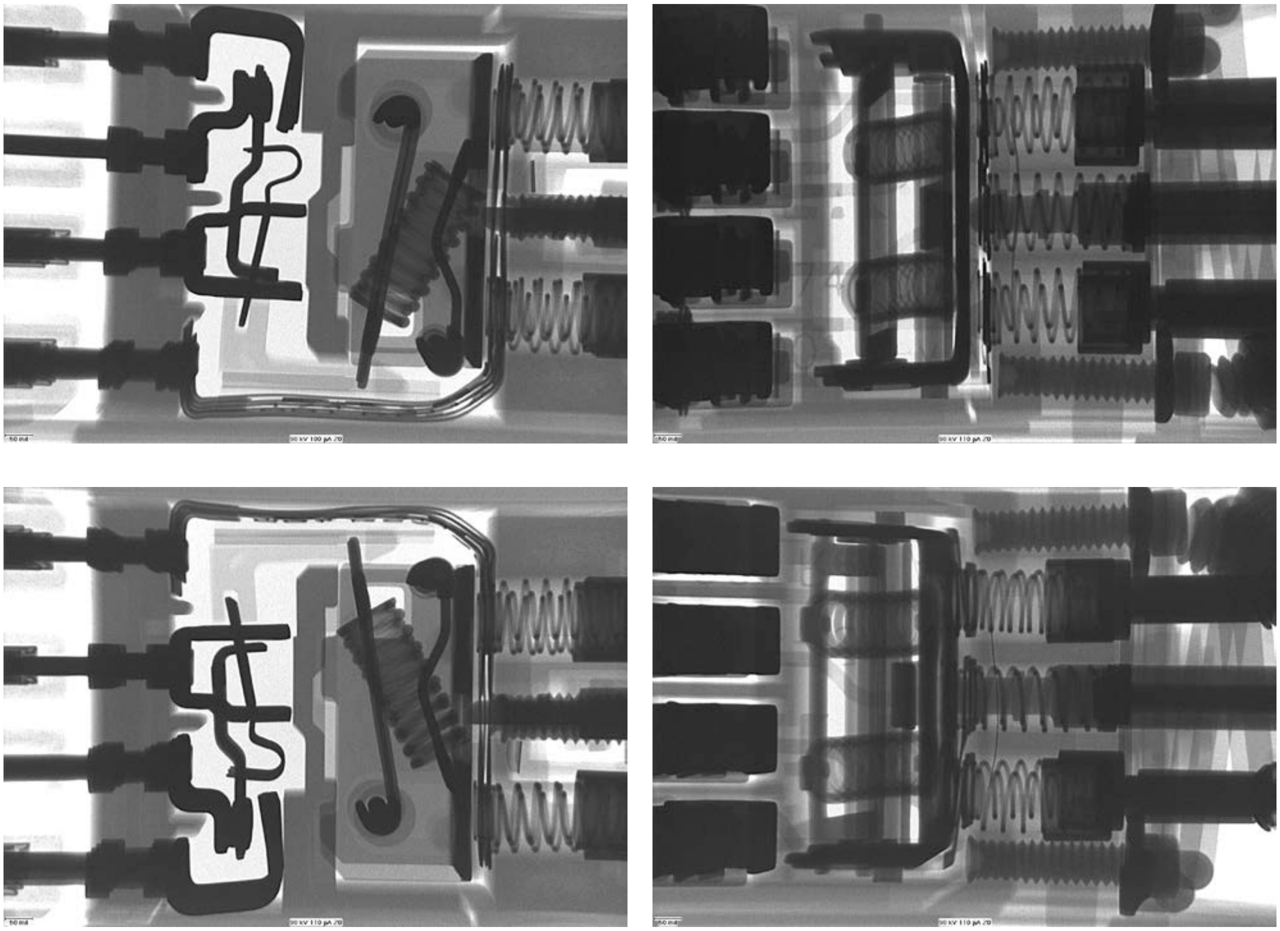


Figure 36: Radiographs of the 4 sides of the anti-skid switch from the incident aircraft**.**

Stall Barrier Switch from Incident Aircraft

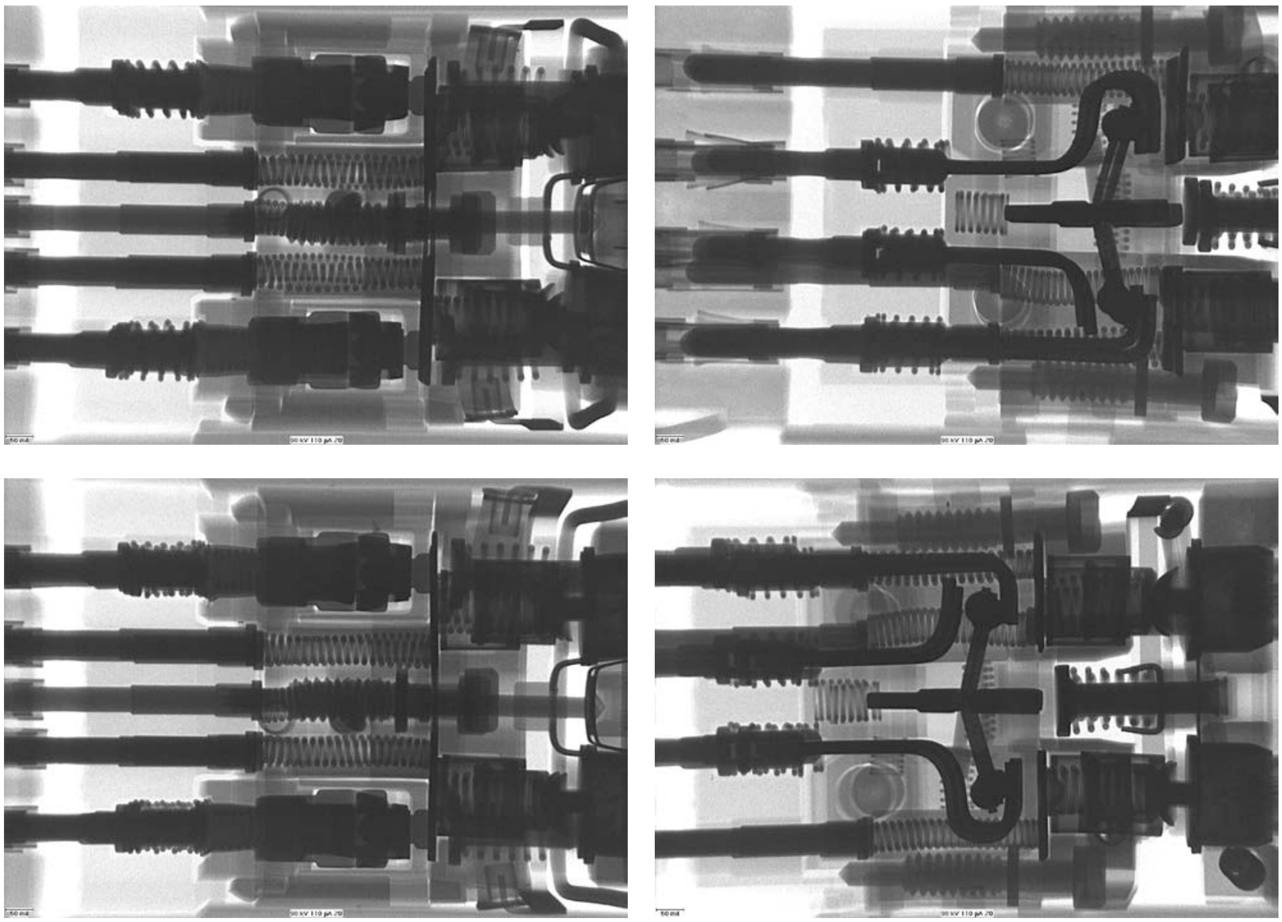


Figure 37: Radiographs of the 4 sides of the stall barrier switch from the incident aircraft.

Exemplar Switch, Wiring Scheme #1 – Depressed

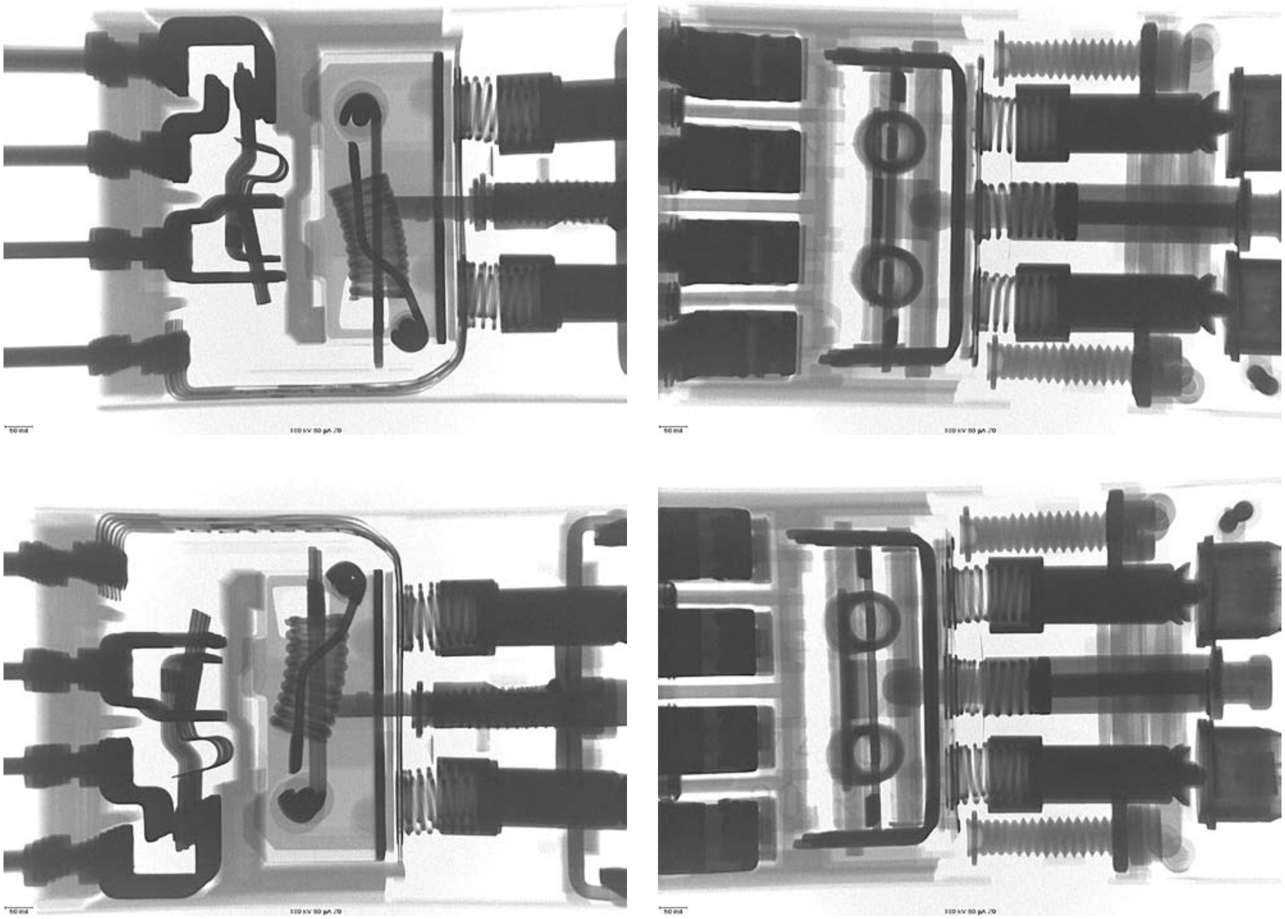


Figure 38: Radiographs of the 4 sides of the exemplar switch with the first wiring scheme in the depressed position.

Exemplar Switch, Wiring Scheme #1 – Extended

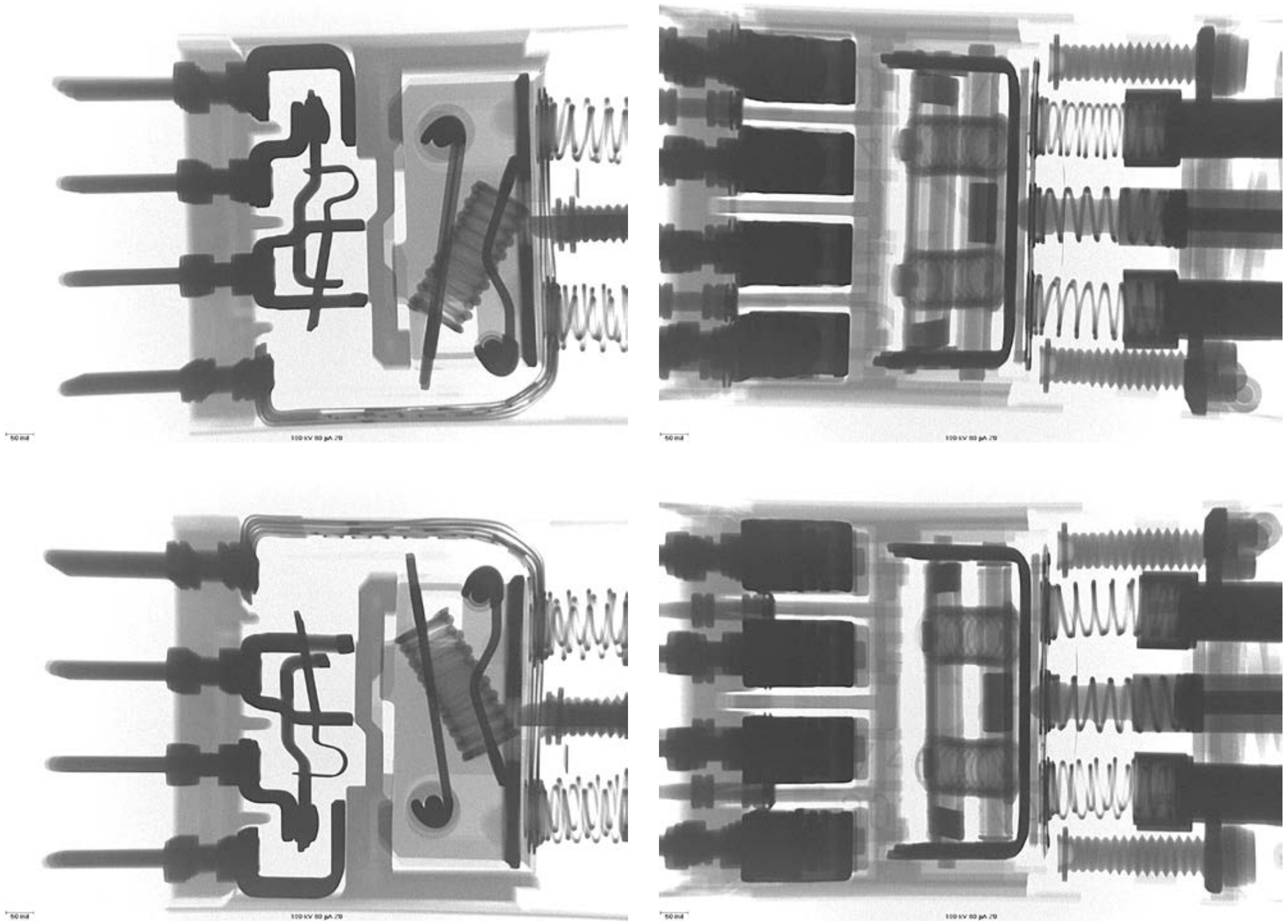


Figure 39: Radiographs of the 4 sides of the exemplar switch with the first wiring scheme in the extended position.

Exemplar Switch, Wiring Scheme #2 – Depressed

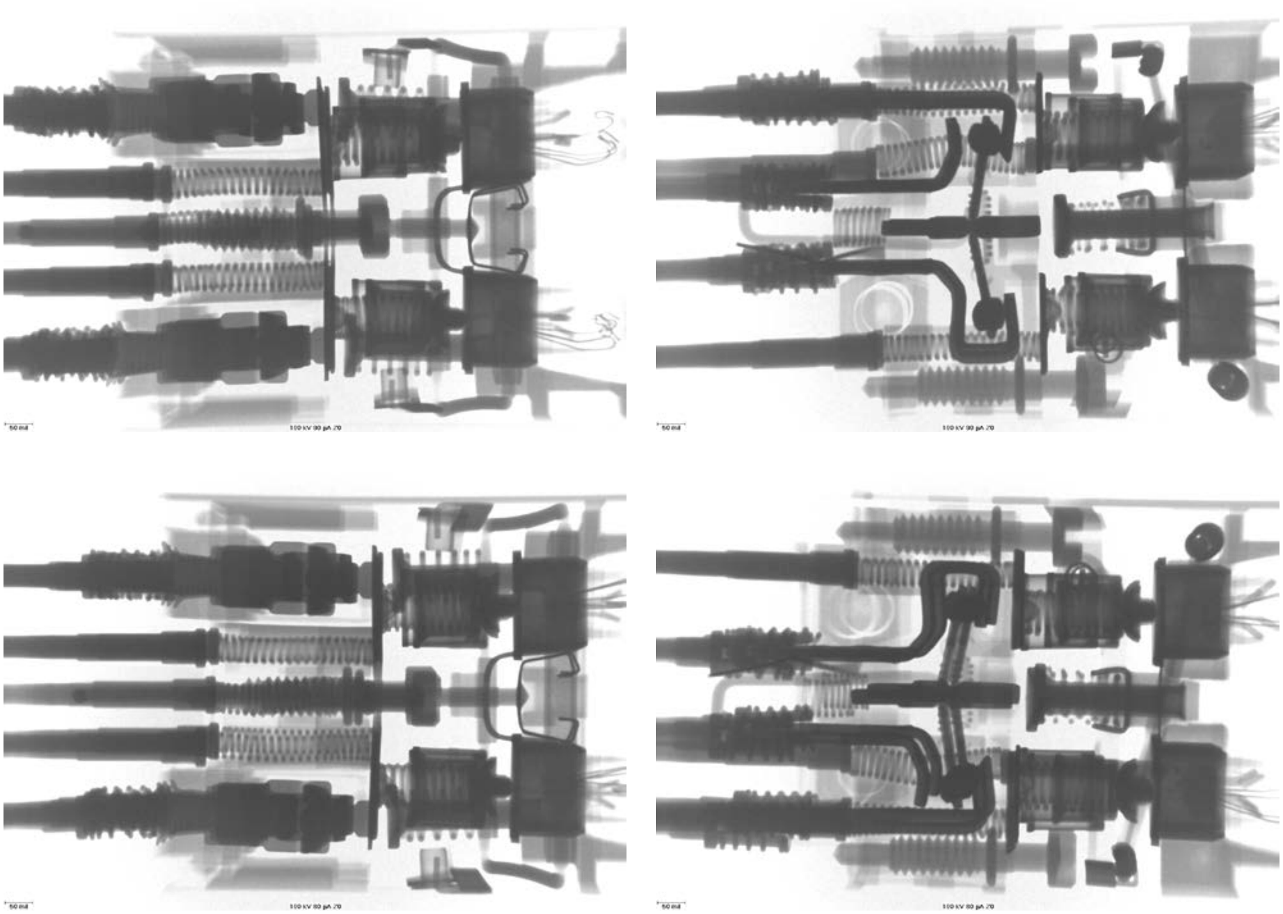


Figure 40: Radiographs of the 4 sides of the exemplar switch with the second wiring scheme in the depressed position.

Exemplar Switch, Wiring Scheme #2 – Extended

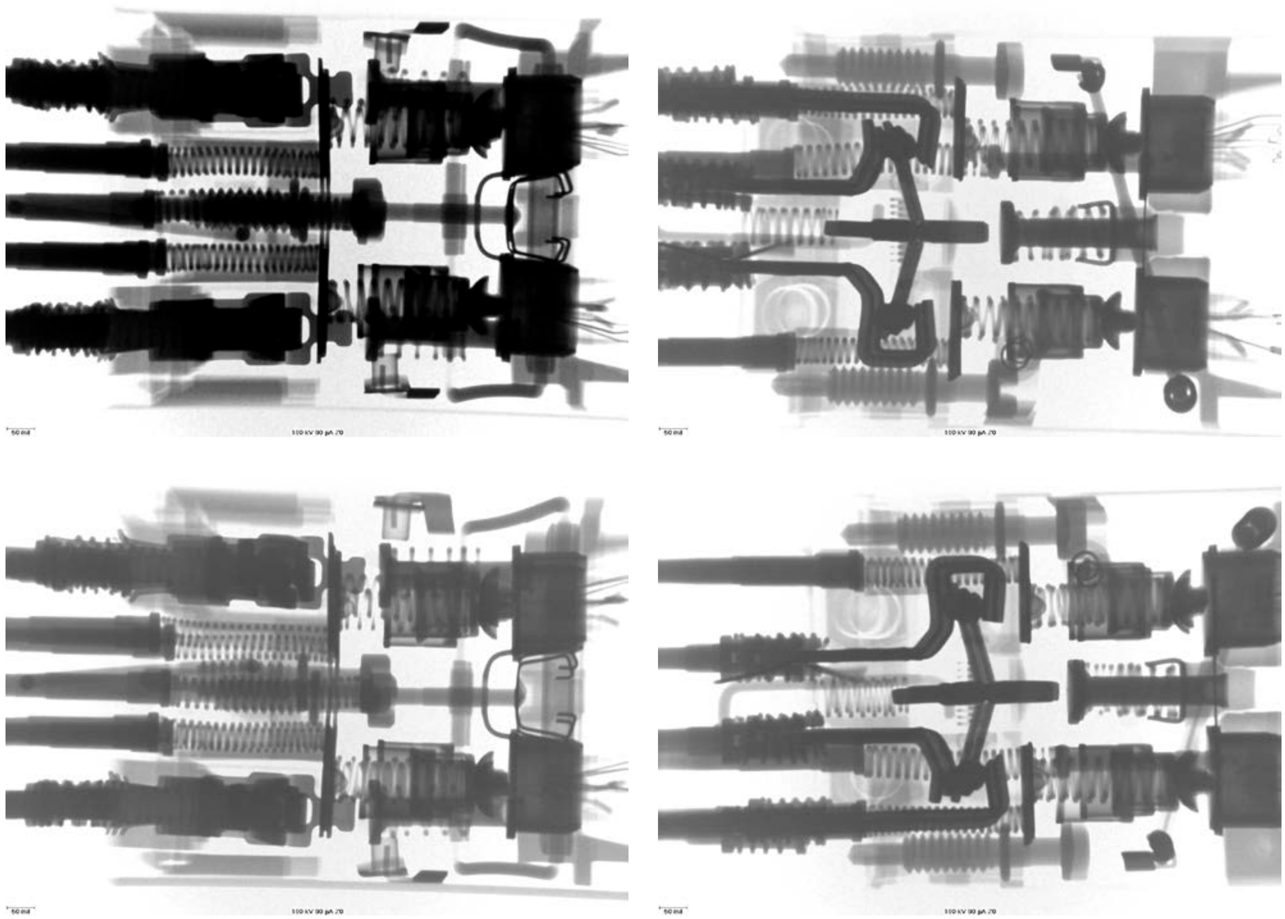
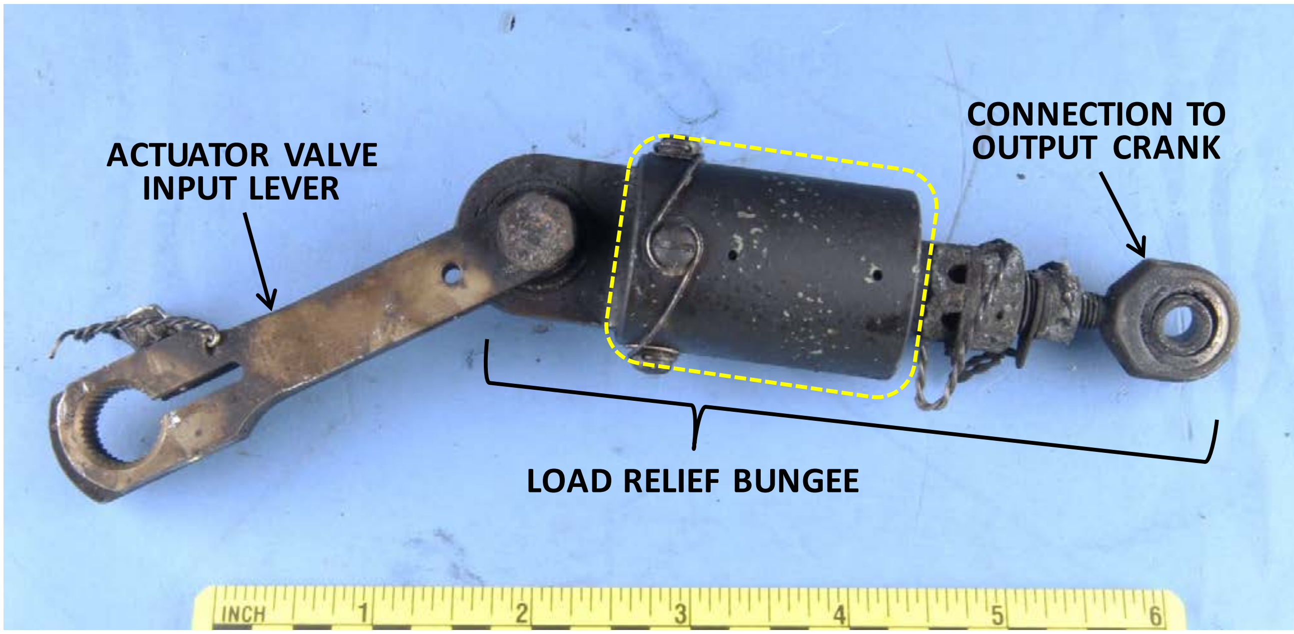


Figure 41: Radiographs of the 4 sides of the exemplar switch with the second wiring scheme in the extended position.



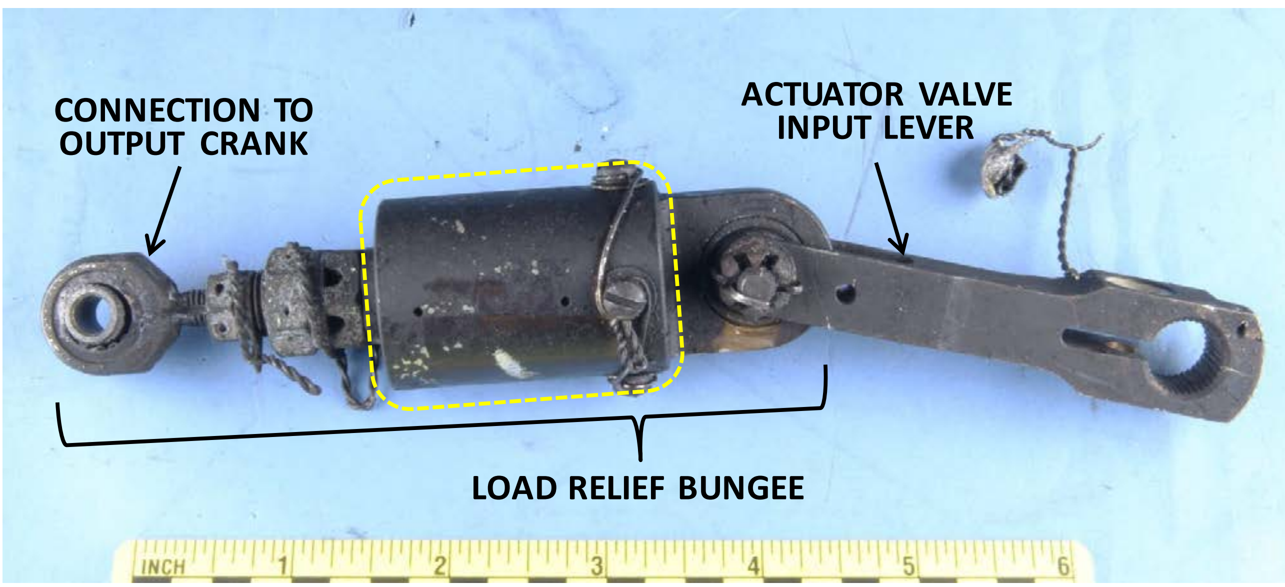


Figure 42: Overall photos of the elevator input bungee. The chamber of the load relief bungee that contained the spring is encircled by the yellow dashed line.

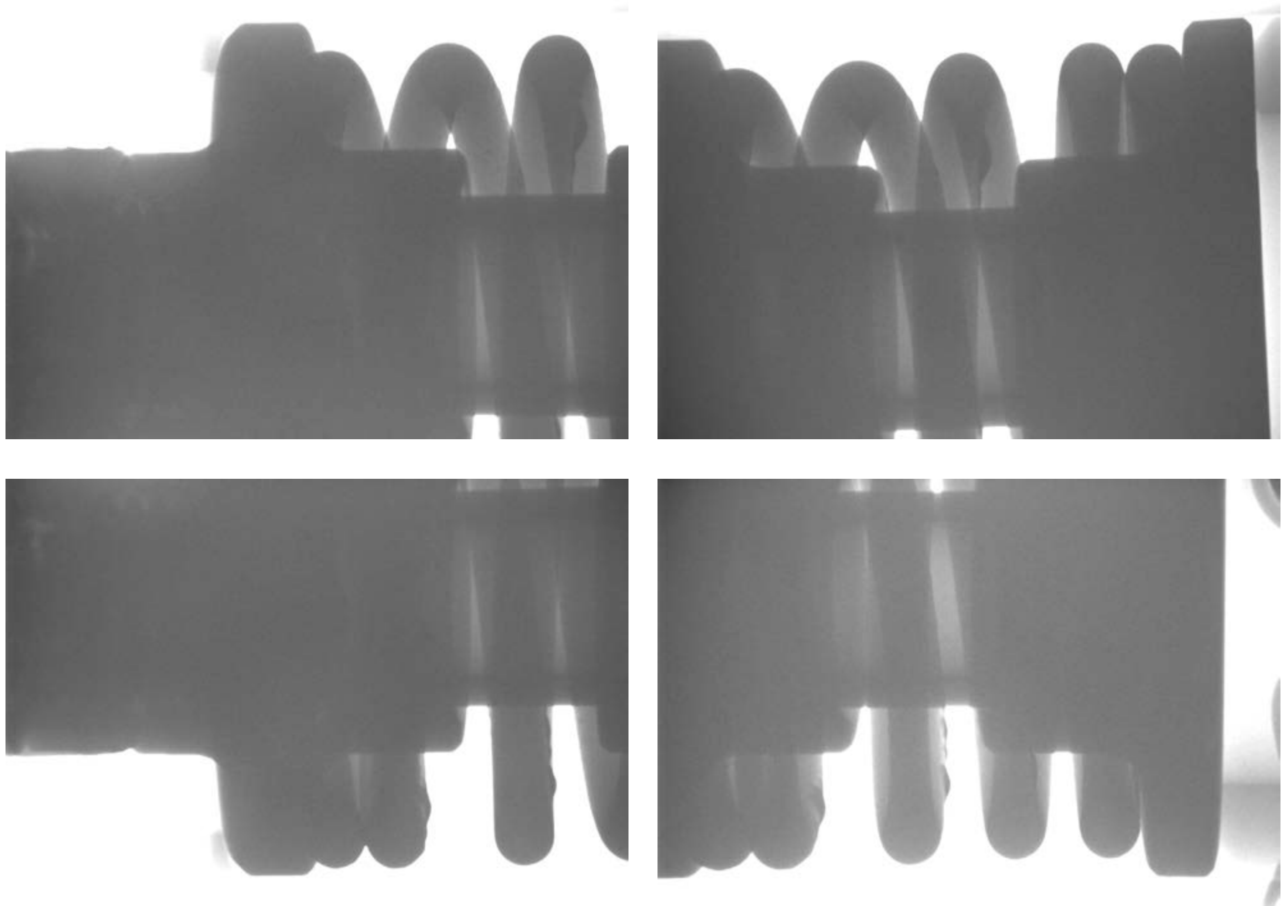


Figure 43: Radiographs of one side of the spring inside the chamber of the load relief bungee on the elevator input bungee.

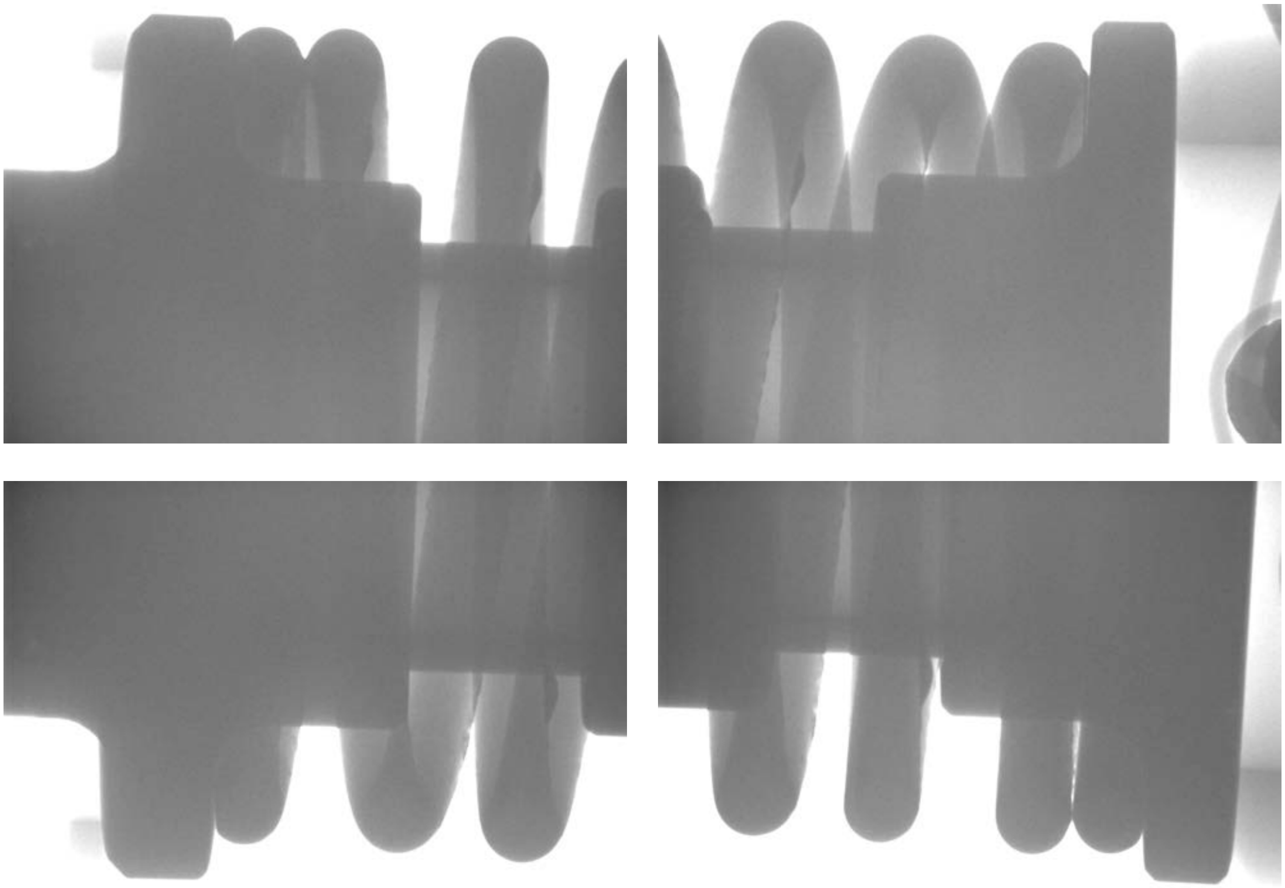


Figure 44: Radiographs of the side of the spring opposite the side shown in Figure 43 inside the chamber of the load relief bungee on the elevator input bungee.