

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN24LA358

MATERIALS LABORATORY

Factual Report 25-073

October 20, 2025

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A. ACCIDENT INFORMATION

Location: Canton, Michigan
Date: September 11, 2024
Vehicle: Hughes 369D, N8969F
Investigator: Michael Hodges (AS-CEN)

B. COMPONENTS EXAMINED

3 helicopter main rotor blades

C. EXAMINATION PARTICIPANTS

Group Chair	Adrienne Lamm, Materials Engineer National Transportation Safety Board Washington, D.C.
Specialist	Van McKenny, Aerospace Engineer (Helicopters) National Transportation Safety Board Washington, D.C.
Group Member	Heidi Kemner, Sr. Air Accident Investigator Federal Aviation Administration Washington, D.C.
Group Member	Eduardo Orozco, Structures COS focal for MD369 Federal Aviation Administration Los Angeles, California
Group Member	Bill Salus, Sr. Director Engineering MD Helicopters Mesa, Arizona
Group Member	Lawrence Johnson, Chief Air Safety Investigator MD Helicopters Mesa, Arizona

D. DETAILS OF THE EXAMINATION

While in flight the pilot operating the subject aircraft experienced trouble with the main rotor and subsequently landed without incident. Post flight inspection revealed a crack in one of the main rotor blades. All three rotor blades were disassembled and shipped to the NTSB Materials Lab in Washington D.C. for examination. A group exam including party members was convened and occurred October 15-17, 2024.

1.0 Group Exam Work

Part markings on the main rotor blades identified them as part number 369D21100523 and serial numbers 009999-K358, 009999-K364, and 009999-K374. The crack reported by the pilot was observed in the -K364 blade. The weight and center of balance were measured for each main rotor blade; all blades weighed 24 pounds and had a center of balance located 72 inches from the tip.

The blades were visually examined and photo documented, as shown in Figures 1-5. The crack in blade -K364 extended from the leading-edge spar on the lower surface (Figure 6) to the middle of the blade along the doubler leading-edge on the upper surface (Figure 7). There was an area of chipped paint adjacent to the crack at the outboard tip of the root fitting on the lower side of the blade (Figure 8). Cracking was observed in the paint on blades -K358 (Figure 9) and -K374 (Figure 10) on the lower side at the outboard tip of the root fitting. The paint cracking on blades -K358 and -K374 spanned 2.54 inches chordwise (2.89-inch arc length) and 1.26 inches chordwise (1.31-inch arc length), respectively.

The tip weight, adhesive, and screw weight were disassembled from the -K364 blade for examination, with no discrepancies observed. A band saw was used to cut a chord-wise cross-section in each of the three blades to facilitate closer examination of the cracking. The cuts removed the grip ends of the blades at the transition from white paint to black paint on the inboard end.

1.1 Blade -K364

A second chord-wise cross section just inboard of the fitting root was prepared through the -K364 blade using an abrasive wet saw and the internal cavities were examined. The crack extended through the thickness of the blade skin along most of its length (red arrows, Figures 11 and 12). Cracks were also visible through the internal stiffener close to the trailing edge of the blade (red arrows, Figure 13).

The crack in blade -K364 was mechanically exposed, and the fracture surfaces were examined using a 5x-to-50x stereomicroscope and a 20x-to-200x digital microscope. Photos of the outboard fracture surface are shown in Figures 14 and 15. Feathery features consistent with fatigue were observed on the lower side fracture surfaces of the doubler, skin, and spar. Numerous ratchet marks¹ (red arrows, Figure 14) were visible at the doubler-skin and skin-spar interfaces. Dark colored deposits were observed on the spar fracture surface at the tip and on the adjacent skin fracture surface (Figure 15).

¹ Ratchet marks are slight vertical steps on a fracture surface that link slightly offset planes of fatigue cracking. Ratchet marks generally are aligned in the direction of cracking.

The outboard fracture surface of blade -K364 was examined using a Thermo Scientific Apreo 2 field emission scanning electron microscope (SEM). The fracture surface on the spar had flat features and striations consistent with fatigue (Figures 16 and 17). The fatigue emanated from near the aft end of the spar, at a location measured roughly 2.73 inches from the leading edge. Damage and embedded debris from the mating fracture surfaces rubbing obscured the initiation area on the spar end (Figure 16). Flat features and striations consistent with fatigue were also observed on the doubler and skin (Figures 18-20). Numerous ratchet marks were visible at the outboard sides of both layers, consistent with multiple initiation fatigue starting from the outboard side. Striation direction indicated the fatigue emanated from a location approximately 2.31 inches from the leading edge. Deposits from contacting fracture surfaces were observed on the fracture surfaces in several locations.

1.2 Blade -K374

A second chord-wise cross section just inboard of the fitting root was prepared through the -K374 blade using an abrasive wet saw. The paint was removed from the lower surface around the fitting using Henkel Bonderite® S-ST5351 AERO paint stripper (Henkel Corporation, Düsseldorf, Germany). The lower fitting was removed from the lower doubler using a combination of heating and mechanical leverage. The exposed lower doubler surface was examined using a 20x-to-200x digital microscope. Cracks were observed in the doubler at the edge of the root fitting underneath the sealant. Multiple cracks were visible between gaps in the sealant.

2.0 Post Group Exam Work

2.1 Blade -K374

Bonderite® paint stripper was applied to the exposed lower doubler surface on blade -K374 to remove the remaining sealant. Twenty-five (25) individual cracks were observed on the lower doubler surface (Figure 21). The crack pattern was roughly parallel to the profile of the fitting edge, with the total length across which the cracks were dispersed measuring 1.31 inches. The individual cracks were slightly angled to the profile of the fitting edge, as shown in Figures 22-24. The longest crack measured approximately 0.18 inches.

The lower doubler surface was removed from the lower skin surface using a combination of heating and mechanical leverage. Bonderite® paint stripper was applied to the underside of the lower doubler and to the exposed lower skin surface. Both surfaces were then examined for cracks; no cracks were observed on either surface. Consequently, none of the cracks observed in the lower doubler had propagated through the doubler thickness.

The doubler was bent along the overall crack pattern until the two halves of the underside surface contacted, which mechanically exposed most of the individual cracks. The exposed cracks were then examined in the SEM. The exposed fracture surfaces of the cracks had feathery features consistent fatigue extending shallowly from the surface inwards (Figures 25-28). The depth of fatigue extended from several microns to a maximum of approximately 30 microns (0.0011 inch) from the doubler surface. The remainder of the exposed fracture surfaces had rough features consistent with overstress in aluminum (consistent with the laboratory procedure used to expose the crack surfaces). The depth of fatigue on a crack fracture surface is highlighted by the yellow area in Figure 28.

2.2 Blade -K358

A second chord-wise cross section just inboard of the fitting root was prepared through the -K358 blade using an abrasive wet saw. The paint was removed from the lower surface around the fitting using Bonderite® paint stripper. The exposed lower doubler surface was examined using a 20x-to-200x digital microscope. Localized damage was visible on the doubler surface (Figure 29). The damage appeared to be multiple small, shallow indents and was located under where the fitting had been, centered near the profile edge. The damage was examined in the SEM and an image of it is shown in Figure 30. The damage was confirmed as randomly scattered indents, most of which were filled with debris that was likely leftover adhesive from bonding the fitting and doubler. No cracks were observed on the doubler surface.

The lower doubler surface was removed from the lower skin surface using a combination of heating and mechanical leverage. Bonderite® paint stripper was applied to the underside of the lower doubler and to the exposed lower skin surface. Both surfaces were then examined for cracks; no cracks were observed on either surface.

2.3 Material Properties

Per the manufacturer, the doublers and skins were both specified as 2024 aluminum alloy in the T3 heat treated condition. Samples from the lower doublers and skins of all three blades were prepared and tested for chemical composition, alloy heat treatment condition, and hardness. Samples from the doublers are identified with a 'D' and samples from the skins are identified with an 'S'.

The chemical composition of the samples was inspected using arc spark optical emission spectroscopy (OES) per ASTM E1251². The results are compared to the AA2024³ standard in Table 1.

² ASTM E1251 - *Standard Test Method for Analysis of Aluminum and Aluminum Alloys by Spark Atomic Emission Spectroscopy*. ASTM International, West Conshohocken, PA.

³ AA2024 - *Aluminum Standards and Data*. The Aluminum Association, Arlington, VA.

Table 1: Chemical analysis (wt%) of AA2024 and blade doubler and skin samples

Sample	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
2024 minimum		-	-	3.8	0.30	1.2	-	-	-
2024 maximum	Rem	0.50	0.50	4.9	0.9	1.8	0.25	0.10	0.15
-K358D	93.1	0.07	0.19	4.4	0.67	1.5	0.07	<0.01	0.04
-K358S	93.0	0.07	0.20	4.3	0.67	1.5	0.13	<0.01	0.03
-K364D	92.9	0.06	0.20	4.5	0.67	1.4	0.11	<0.01	0.03
-K364S	93.1	0.07	0.19	4.3	0.65	1.4	0.12	<0.1	0.03
-K374D	93.0	0.07	0.17	4.4	0.67	1.5	0.12	0.01	0.03
-K374S	93.1	0.07	0.18	4.3	0.68	1.5	0.08	<0.01	0.03

The electrical conductivity of each sample was examined per ASTM E1004⁴ and the results are listed in Table 2, along with results that have a correction factor for sample thickness applied. Per AMS 2658⁵, a 2024 aluminum alloy has electrical conductivity of 27.5-32.5%IACS (International Annealed Copper Standard) for the T3 heat-treated condition and 27.5-34.0%IACS for the T4 heat-treated condition.

Table 2: Electrical conductivity measurements of blade doubler and skin samples

Sample	Measured Thickness (in)	As-Measured (%IACS)	2024 Clad Aluminum^ (%IACS)
-K358D	0.0249	34.4	35.9
-K358S	0.0242	35.5	37.5
-K364D	0.0249	34.5	36.0
-K364S	0.0241	35.4	37.4
-K374D	0.0246	35.9	37.9
-K374S	0.0248	36.2	38.2

^ Correction factor applied

The hardness of the samples was tested per ASTM E18⁶. The average hardness of each sample is listed in Table 3, with measurements taken in HRB15TW and converted to HRBW⁷. Per AMS 2658, a clad 2024 aluminum alloy has a maximum hardness of 63HRB for both the T3 and T4 heat treat condition.

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

⁵ AMS 2658 - *Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts*. SAE International, Warrendale, PA.

⁶ ASTM E18 - *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

⁷ HRBW - Hardness, Rockwell B scale. An indentation method of determining the hardness of softer metals using a 1/16-inch diameter tungsten ball indenter and 100 kg major load.

Table 3: Hardness measurements of blade doubler and skin samples

Sample	HRB15TW	HRBW
-K358D	81.7	64
-K358S	83.0	70
-K364D	80.3	60
-K364S	80.6	62
-K374D	81.7	64
-K374S	82.7	62

The composition of all doublers and skins was consistent with clad 2024-series aluminum alloy. The electrical conductivity and hardness results are most consistent with the doublers and skins manufactured to either a T3 or T4 heat-treated condition.

Submitted by:

Adrienne V. Lamm
Materials Engineer



Figure 1. Macro and close-up photos of the bottom surfaces of all the blades.



Figure 2. Macro and close-up photos of the top surfaces of all the blades.



Figure 3. Close-up photos of the bottom and top surfaces of the -K364 blade with a crack through most of the blade.

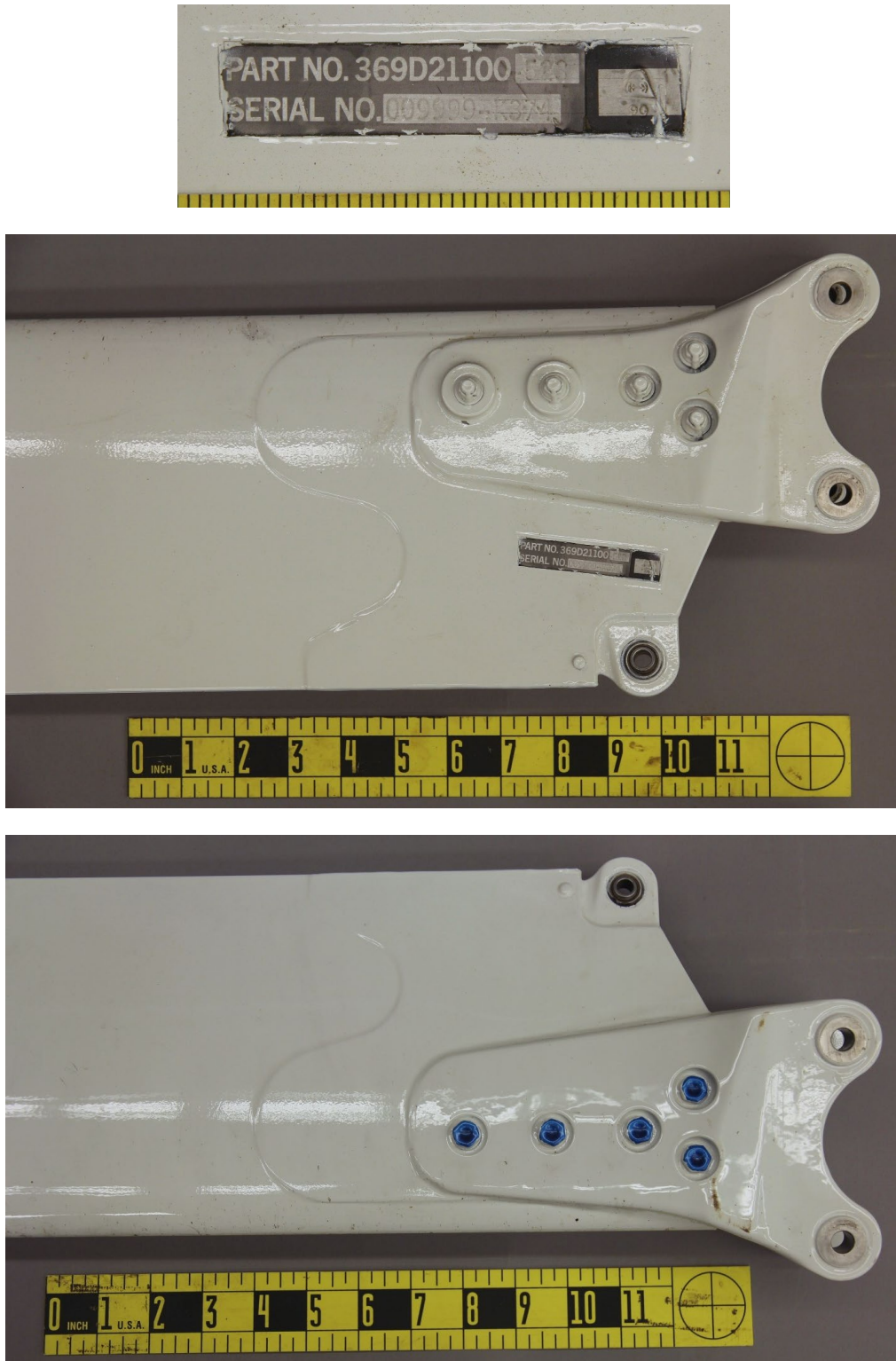


Figure 4. Close-up photos of the bottom and top surfaces of the -K374 blade.



Figure 5. Close-up photos of the bottom and top surfaces of the -K358 blade.

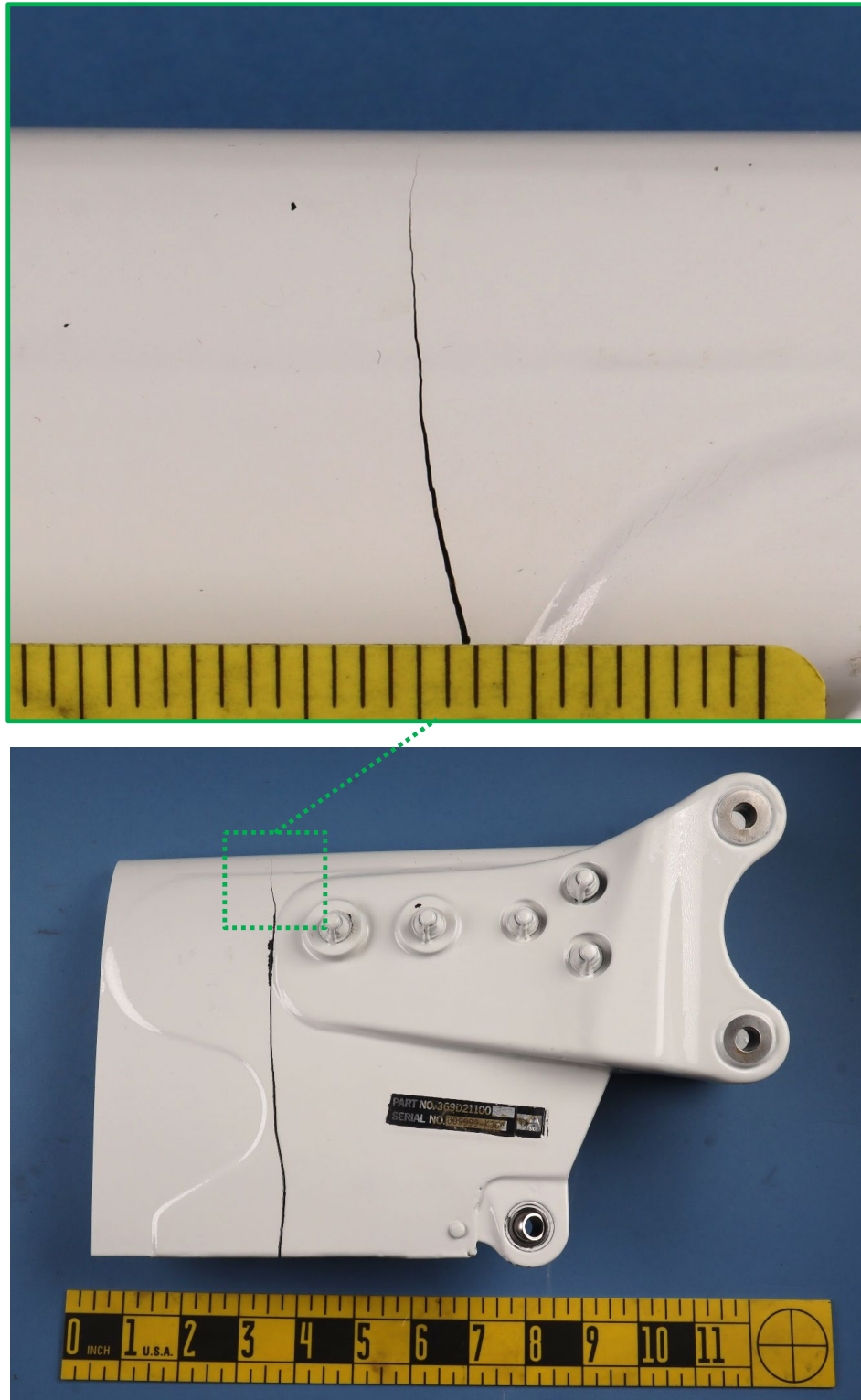


Figure 6. Macro and close-up photos of the bottom surface of the -K364 blade after sectioning.

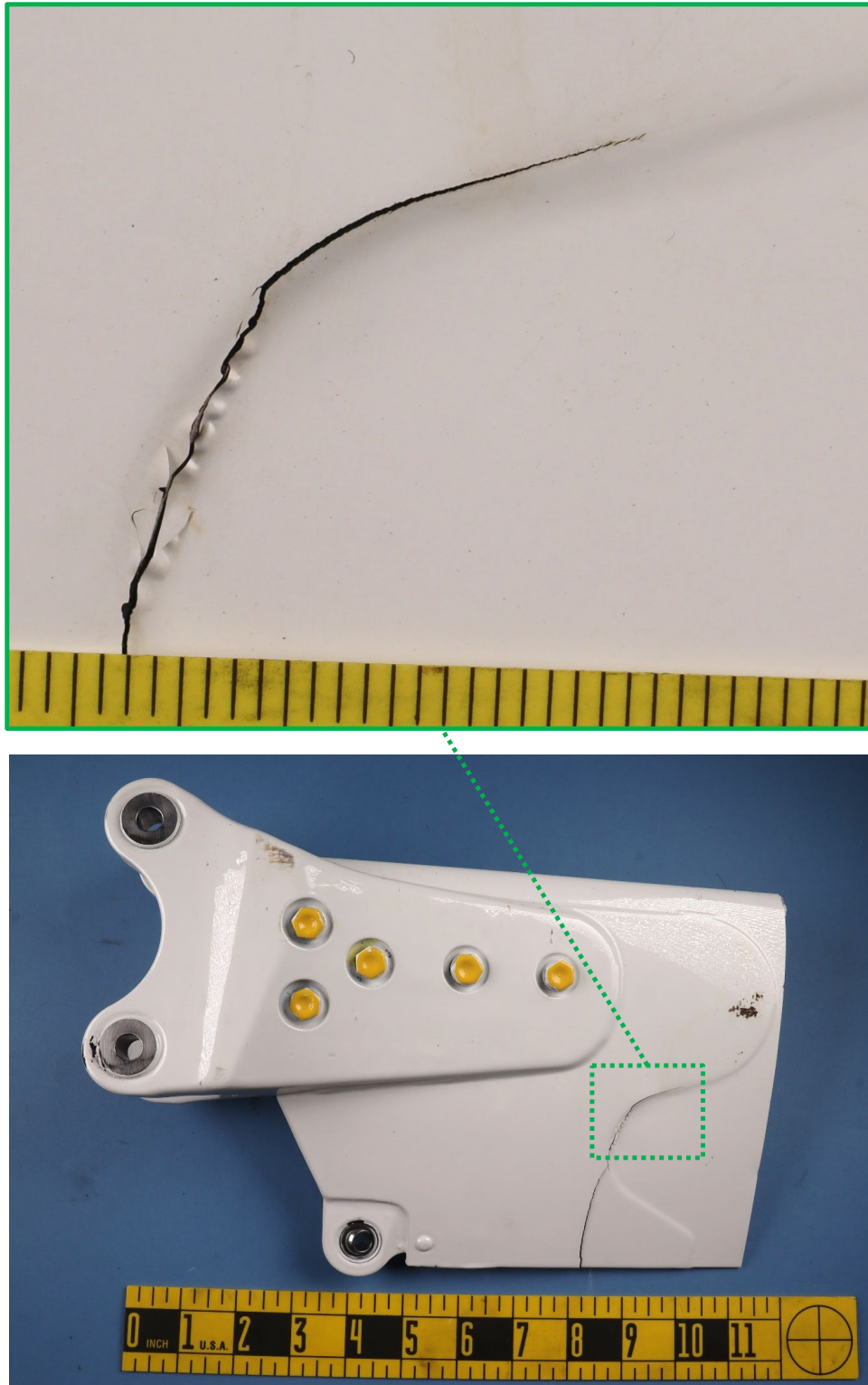


Figure 7. Macro and close-up photos of the top surface of the -K364 blade after sectioning.

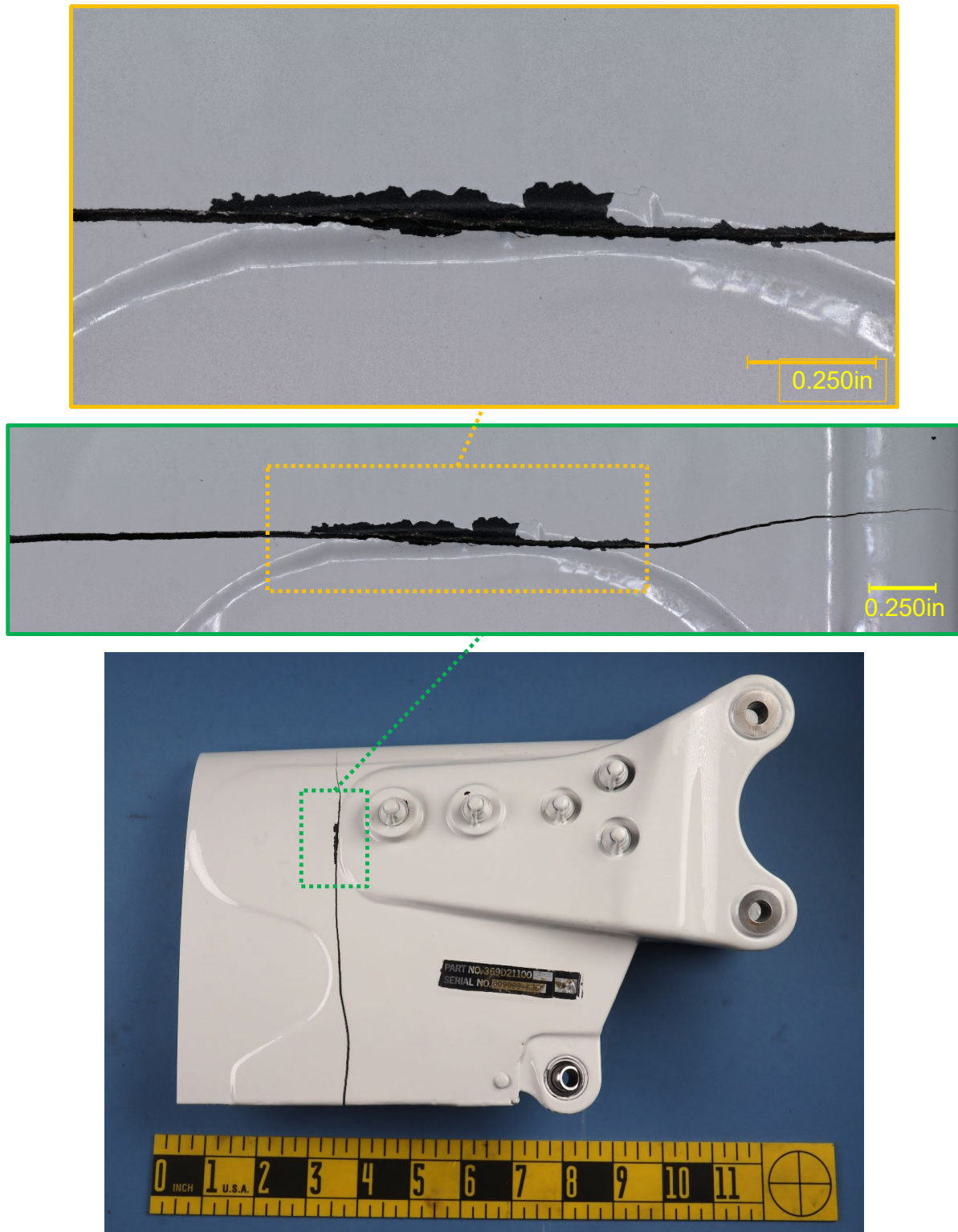


Figure 8. Macro and close-up photos of the chipped doubler paint at the root of the fitting on the bottom surface of the -K364 blade.

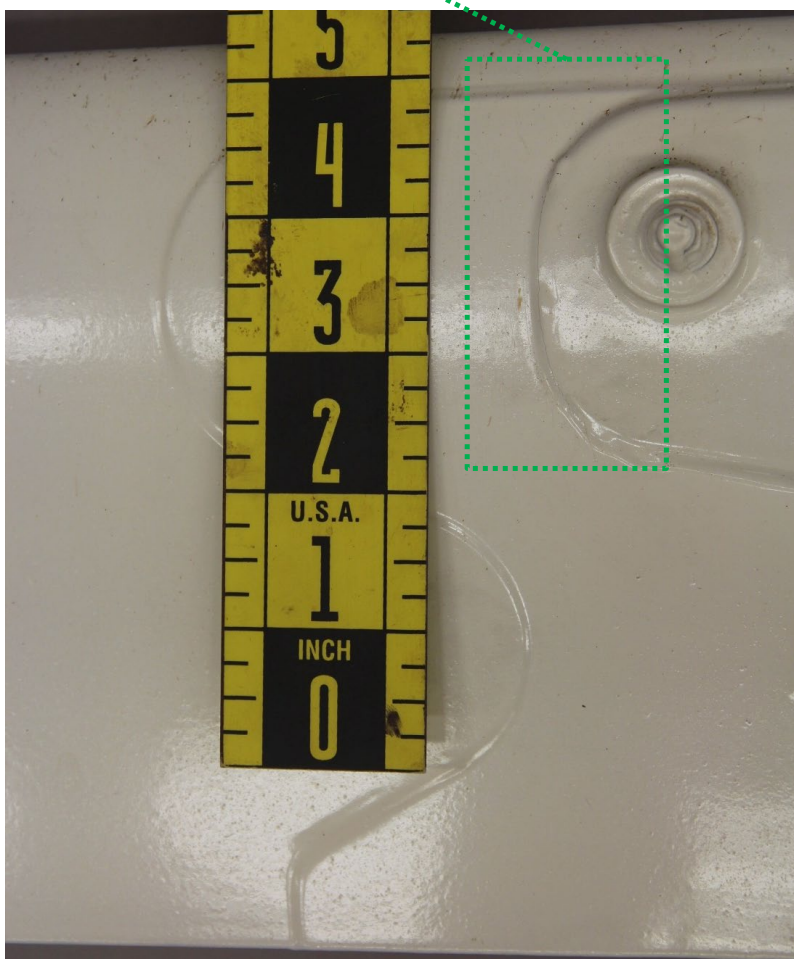


Figure 9. Macro photos of the bottom surface of the -K358 blade with a crack (red arrows) in the doubler paint at the root of the fitting.

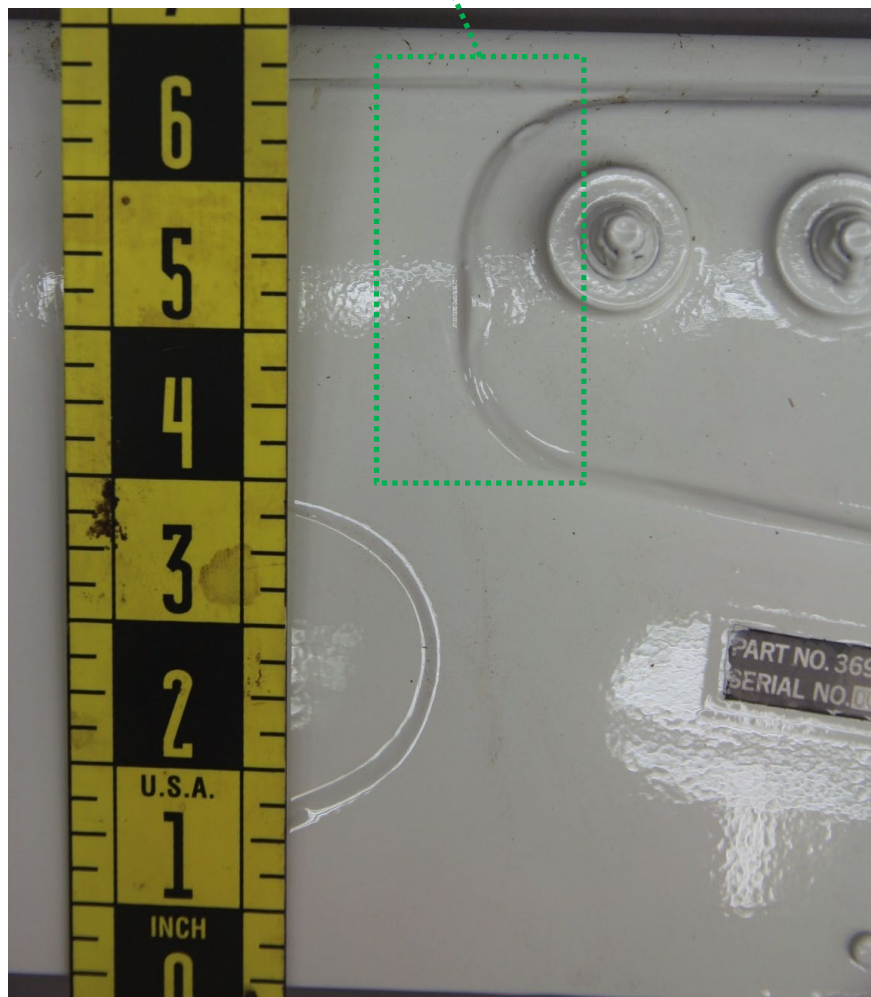
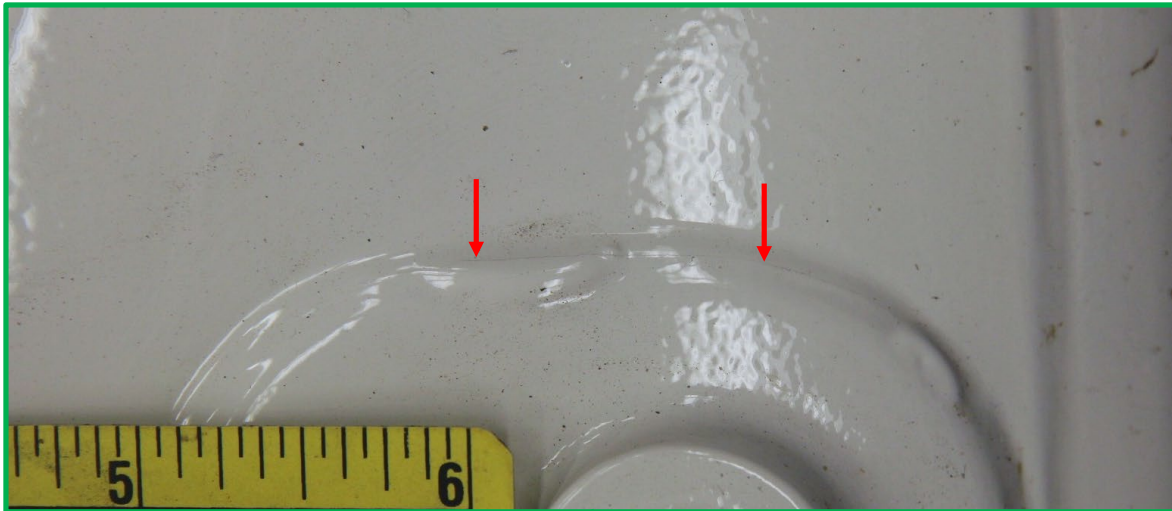


Figure 10. Macro photos of the bottom surface of the -K374 blade with a crack (red arrows) in the doubler paint at the root of the fitting.

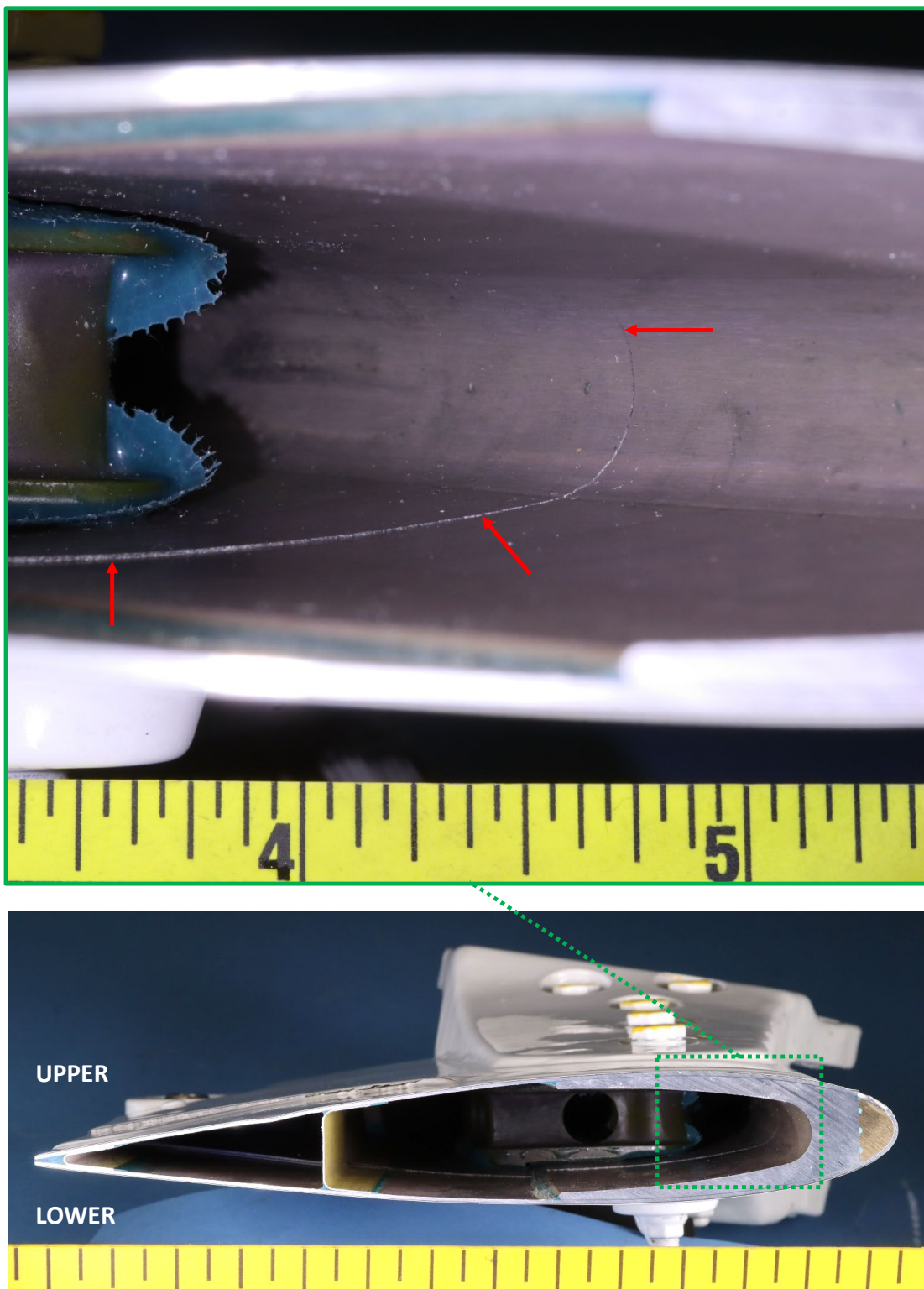


Figure 11. Macro photos of the internal cavity of the -K364 blade after mechanical exposure in the laboratory. The red arrows point to the crack visible on the inner surface.

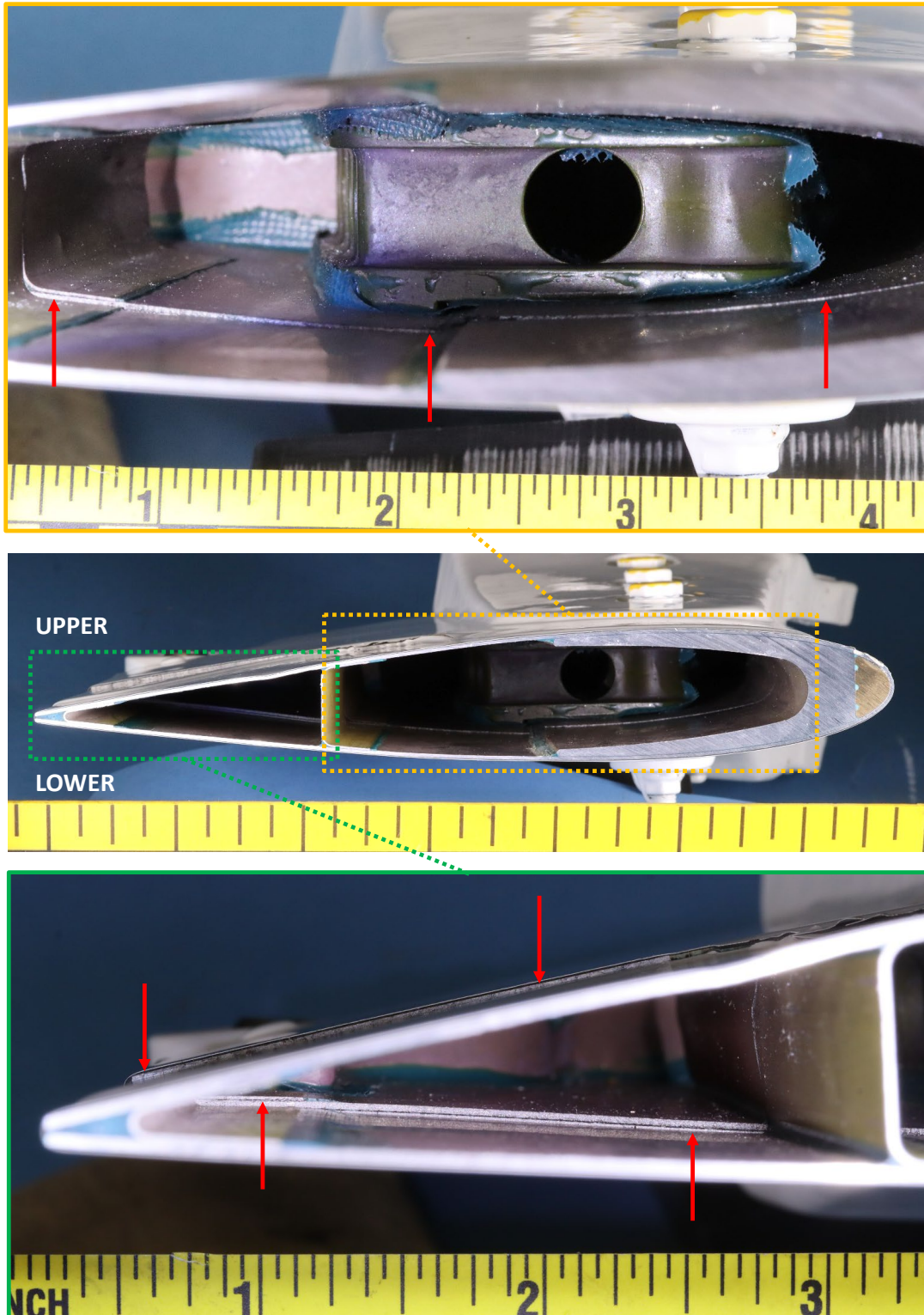


Figure 12. Macro photos of the internal cavity of the -K364 blade after mechanical exposure in the laboratory. The red arrows point to the crack visible on the inner surface.

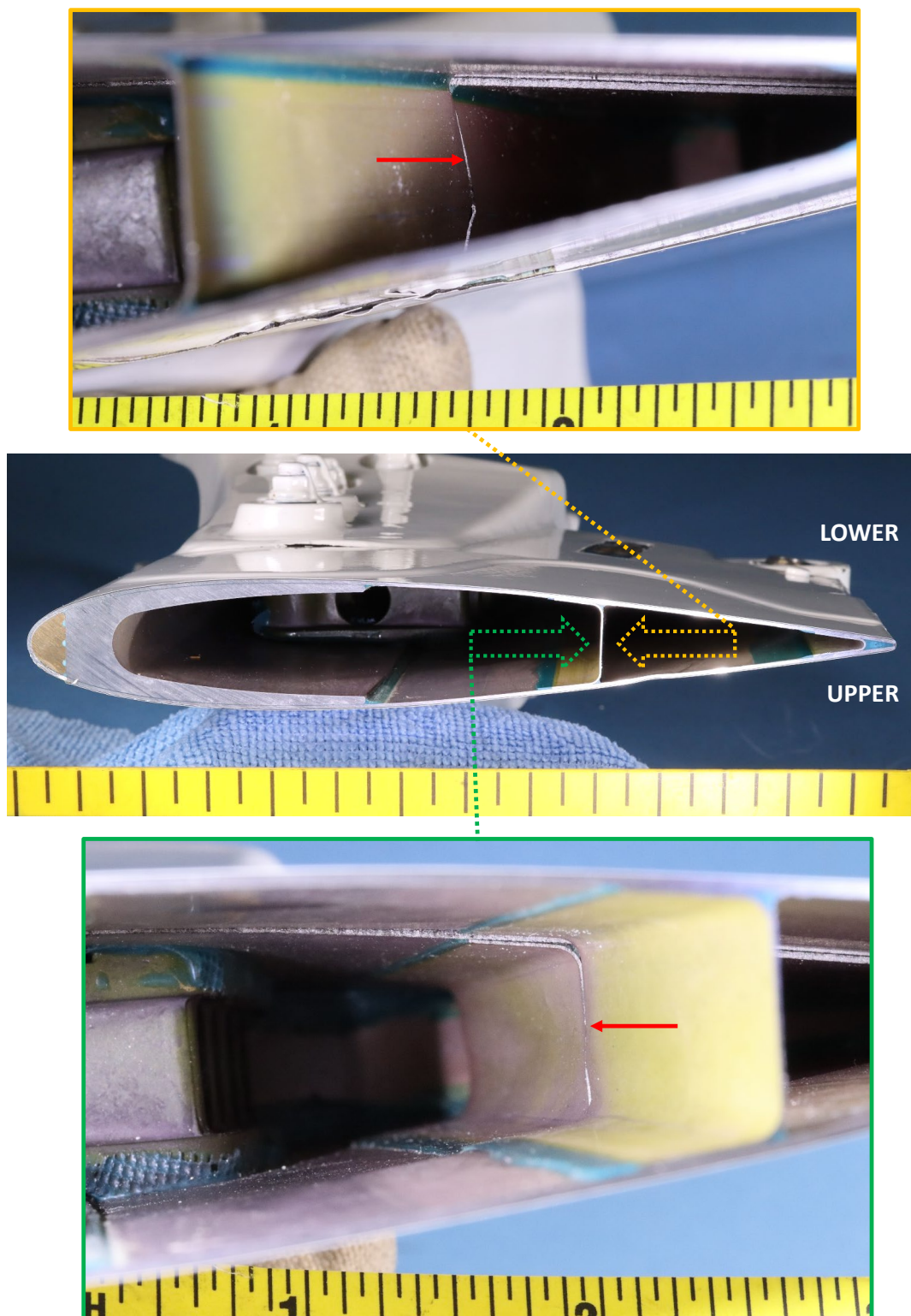


Figure 13. Macro photos of the internal cavity of the -K364 blade after mechanical exposure in the laboratory. The red arrows point to the crack visible on the inner stiffener.



Figure 14. Macro photos of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. Numerous ratchet marks (red arrows) were observed on the fracture surfaces.

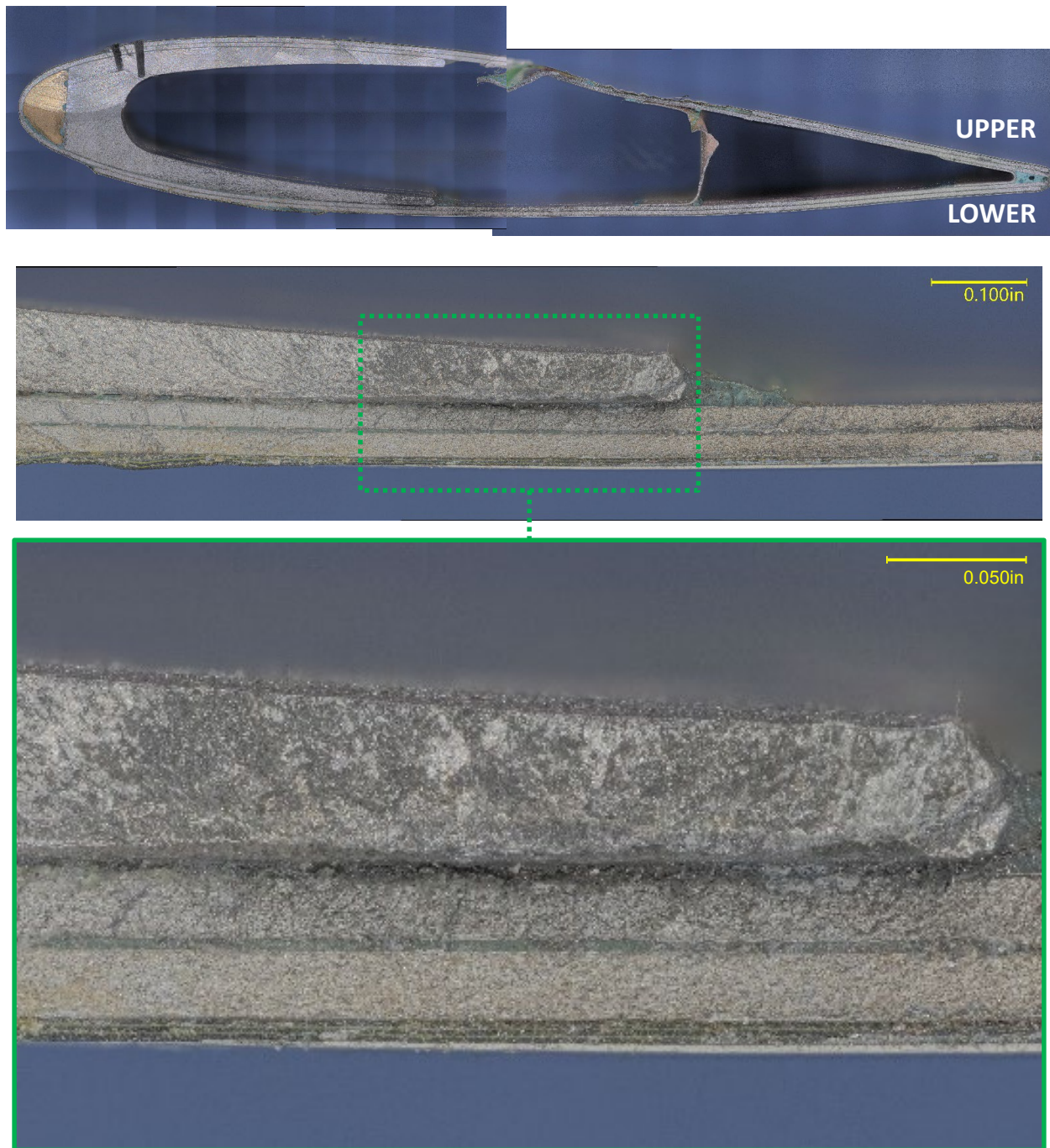


Figure 15. Digital microscope images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory.

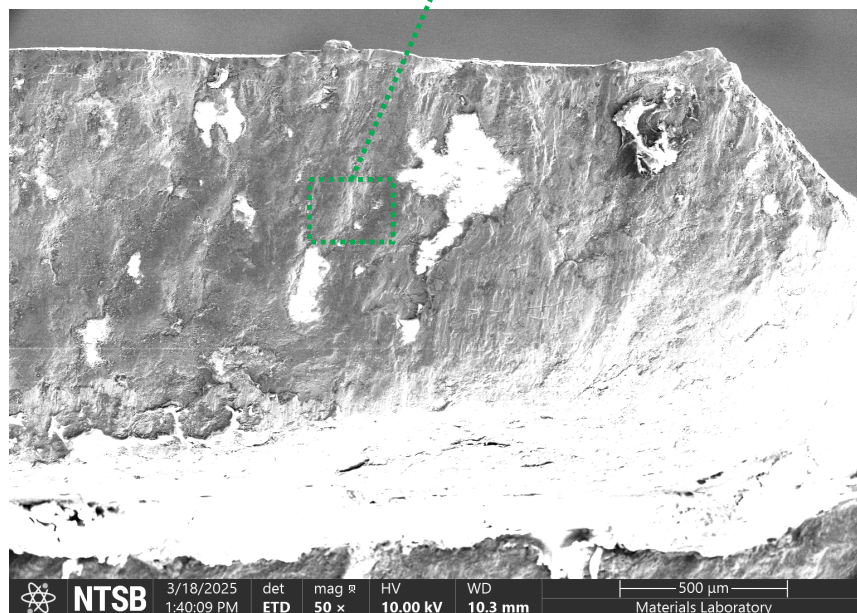
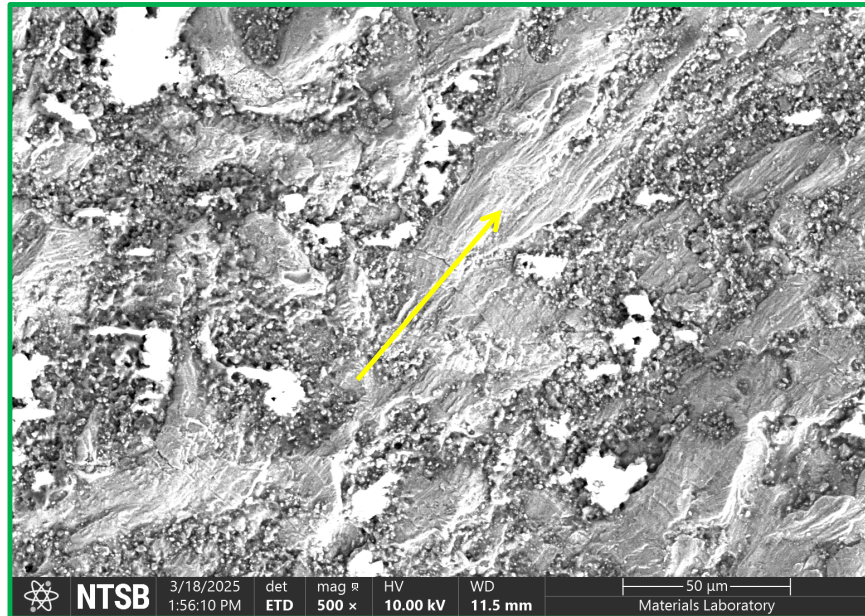
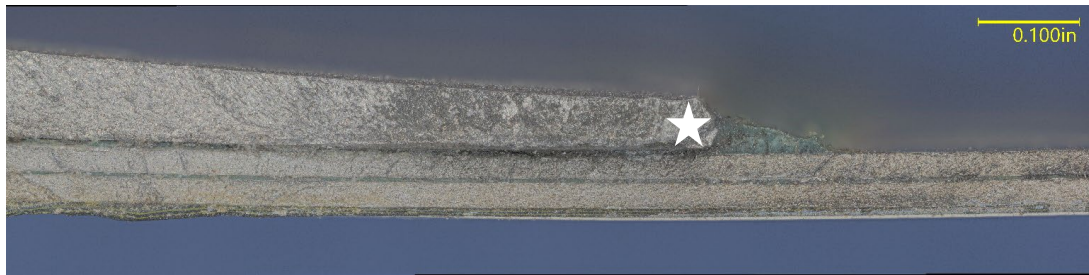


Figure 16. Digital microscope (top) and SEM (middle and bottom) images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. The white star in the digital microscope image indicates the location of the SEM images. The yellow arrow indicates the direction of crack propagation.

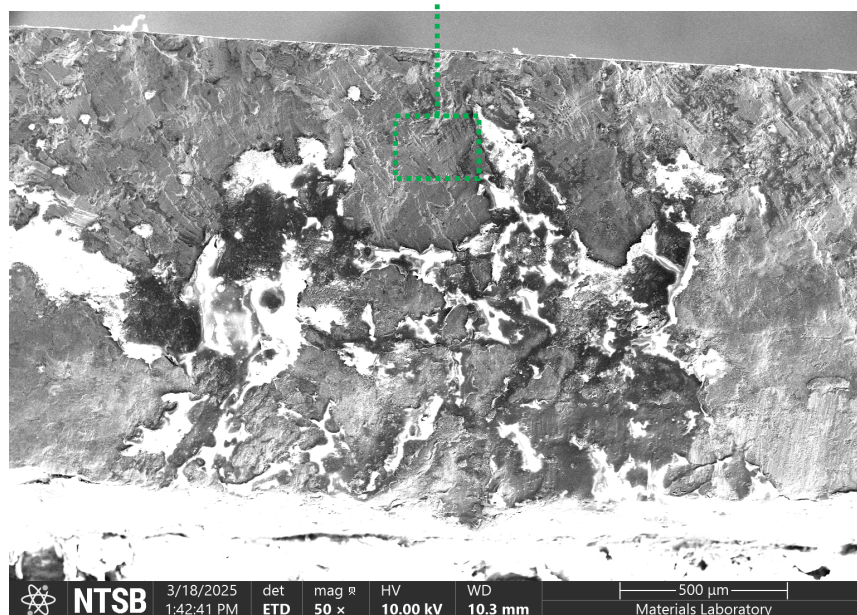
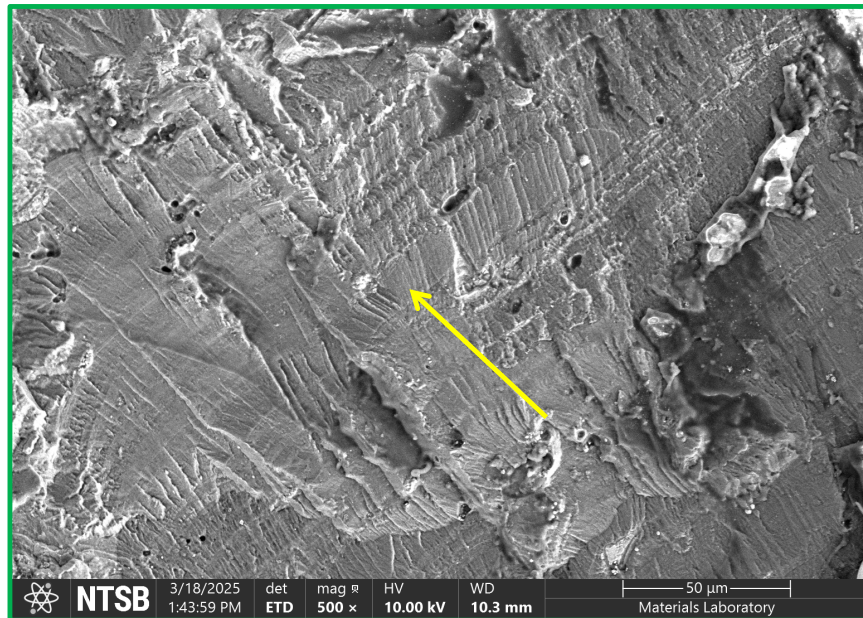
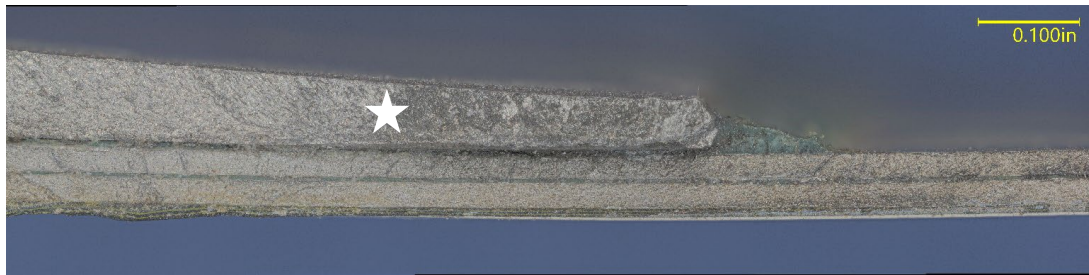


Figure 17. Digital microscope (top) and SEM (middle and bottom) images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. The white star in the digital microscope image indicates the location of the SEM images. The yellow arrow indicates the direction of crack propagation.

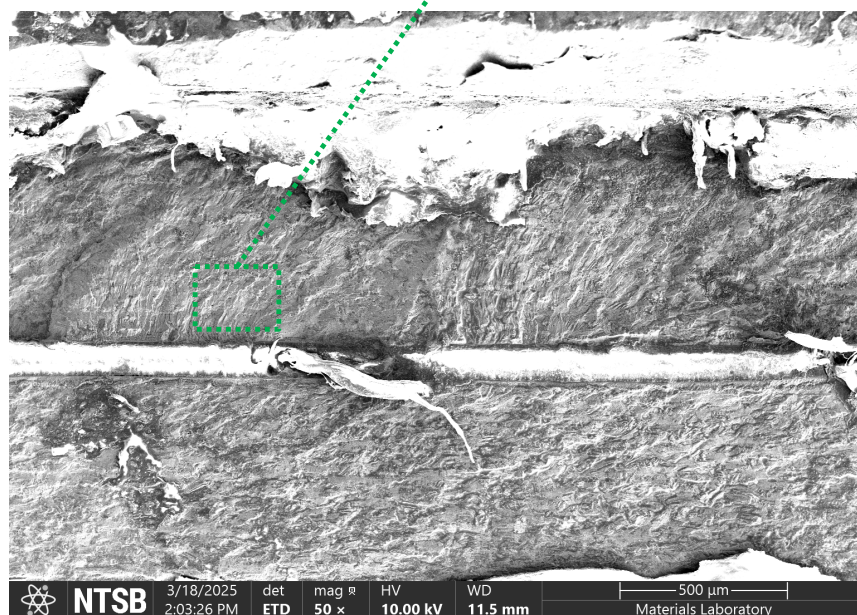
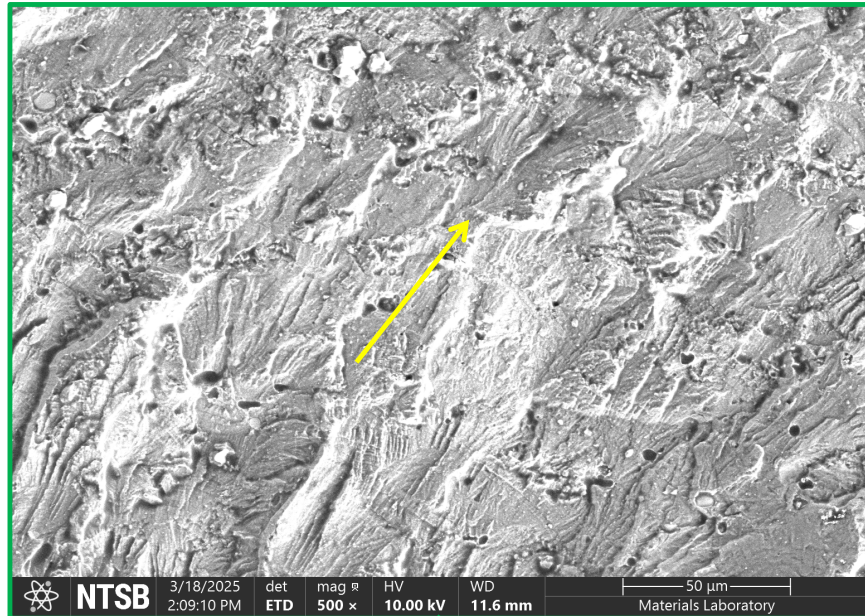
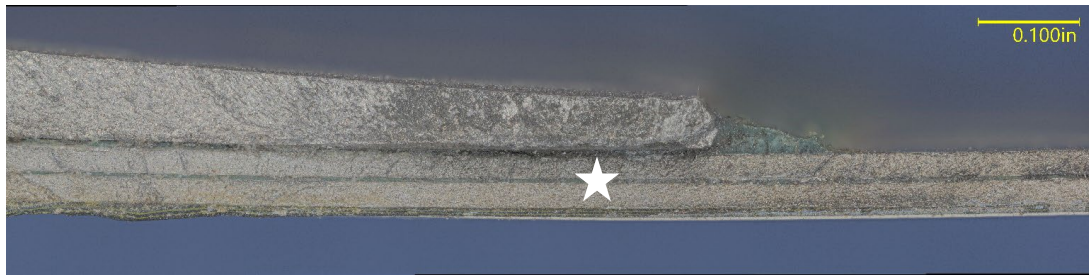


Figure 18. Digital microscope (top) and SEM (middle and bottom) images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. The white star in the digital microscope image indicates the location of the SEM images. The yellow arrow indicates the direction of crack propagation.

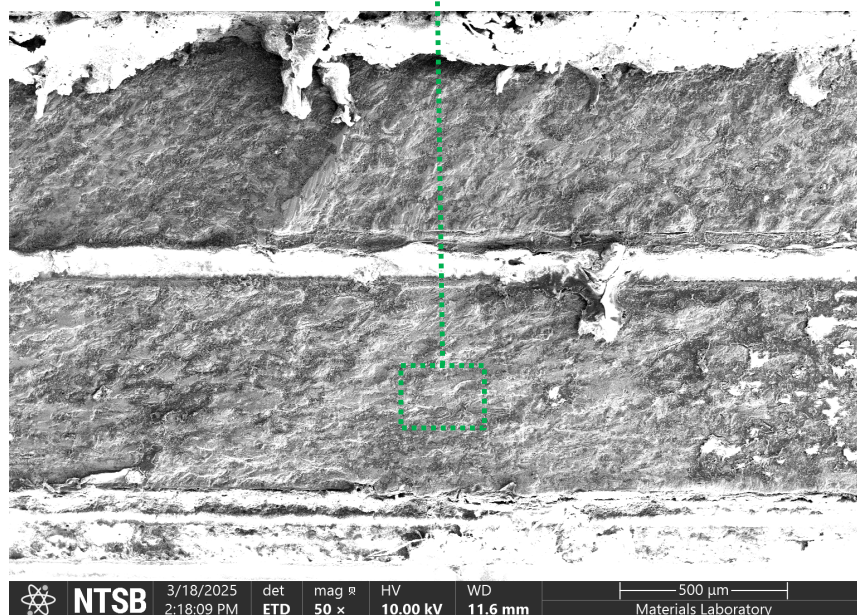
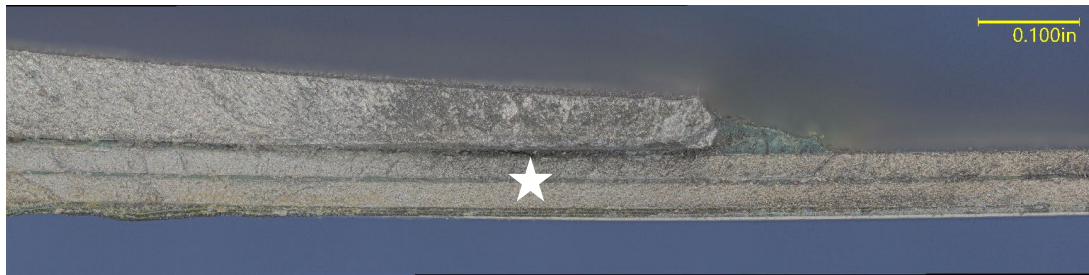


Figure 19. Digital microscope (top) and SEM (middle and bottom) images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. The white star in the digital microscope image indicates the location of the SEM images. The yellow arrow indicates the direction of crack propagation.

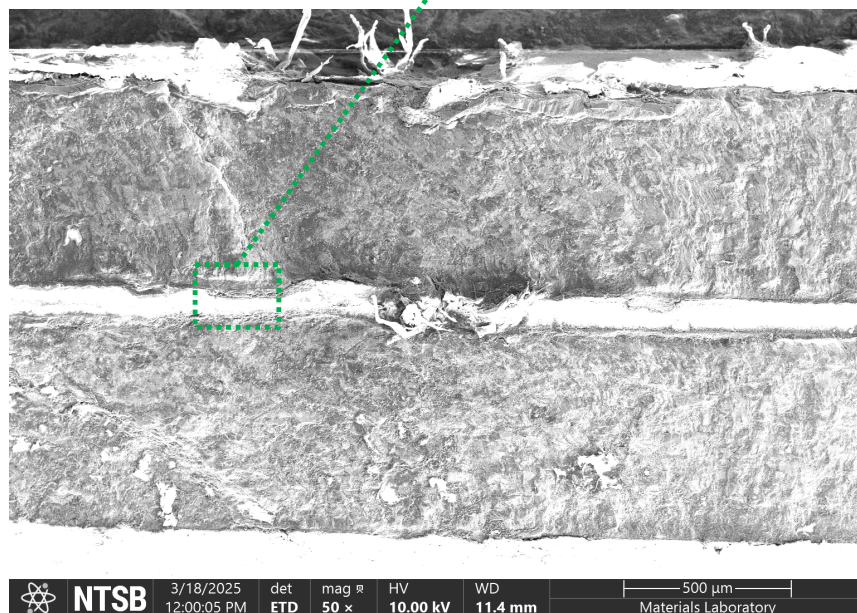
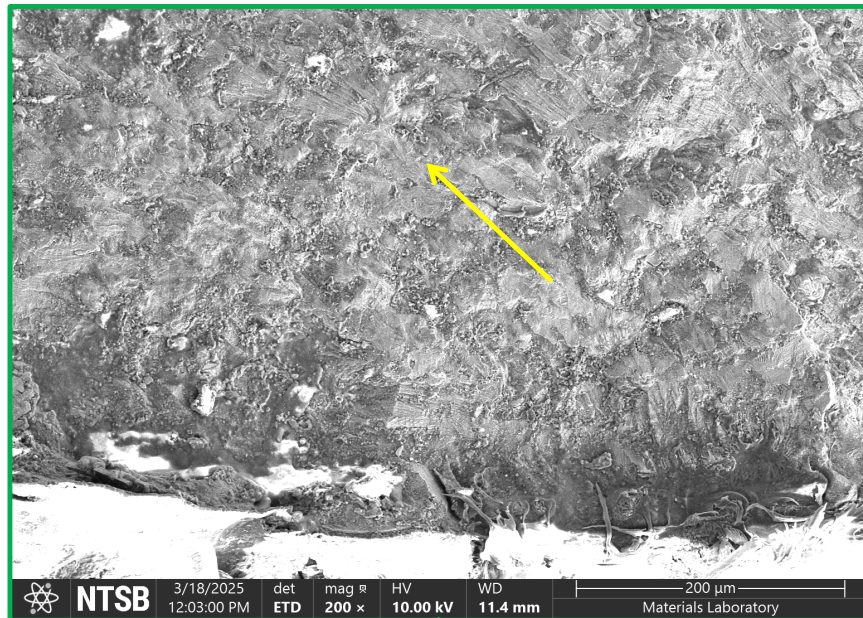
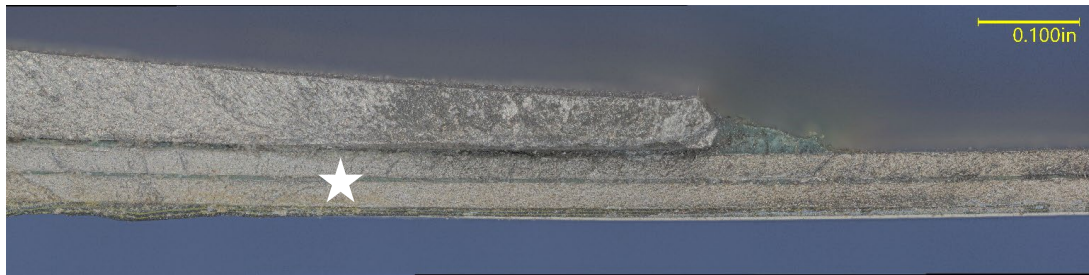


Figure 20. Digital microscope (top) and SEM (middle and bottom) images of the fracture surface of the crack in the -K364 blade after mechanical exposure in the laboratory. The white star in the digital microscope image indicates the location of the SEM images. The yellow arrow indicates the direction of crack propagation.

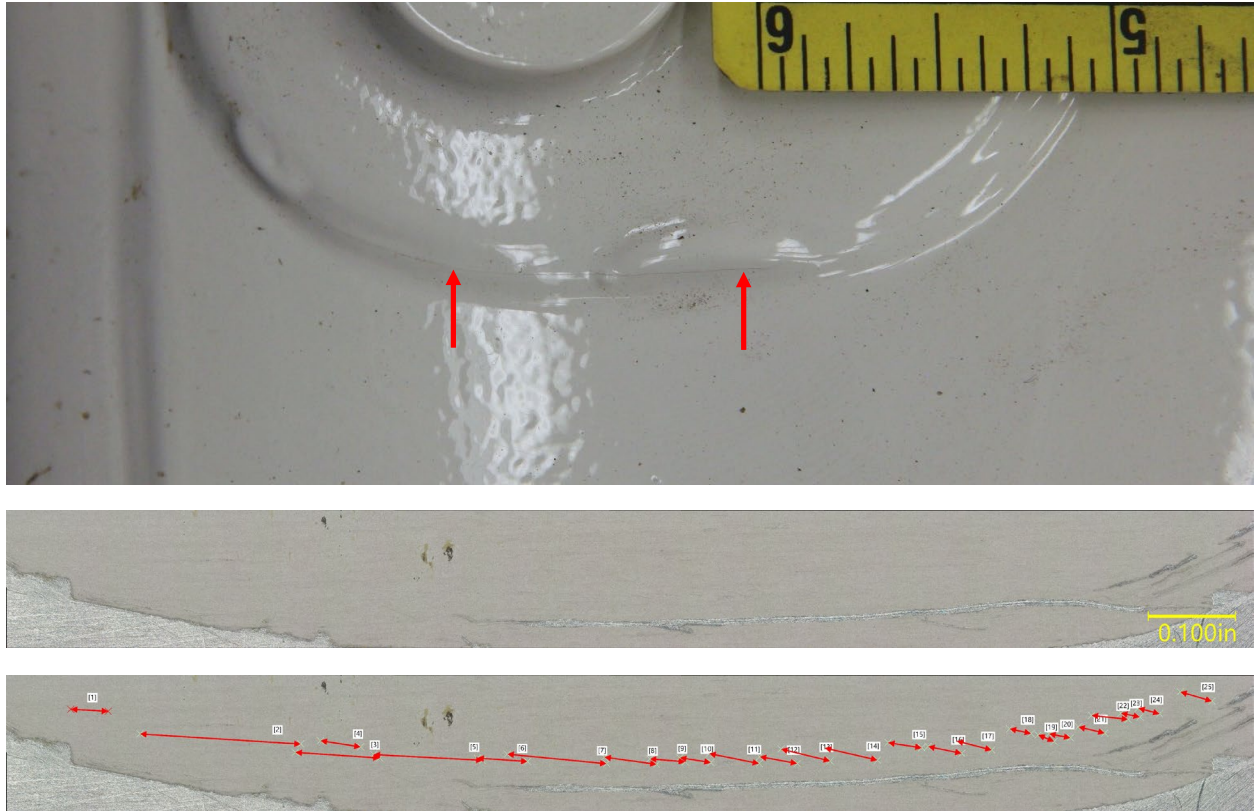


Figure 21. (Top) Macro photo of the bottom surface of the -K374 blade with a crack (red arrows) in the doubler paint at the root of the fitting. (Bottom) Digital microscope image of the doubler surface after paint and fitting removal. The red arrows indicate individual cracks observed in the doubler under the fitting.



Figure 22. Digital microscope images of the -K374 blade doubler surface after paint and fitting removal. The red arrows indicate a crack observed in the doubler under the fitting.

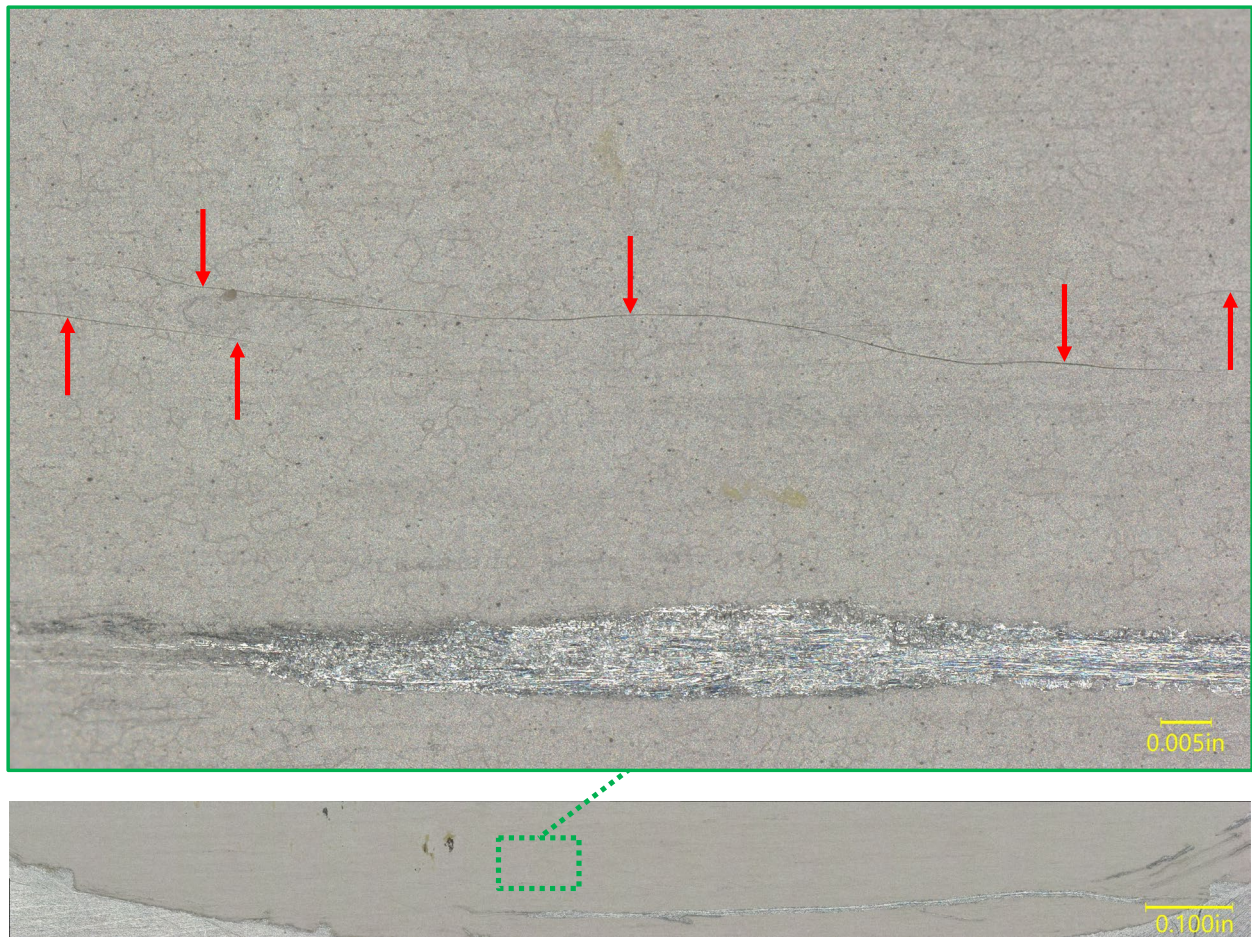


Figure 23. Digital microscope images of the -K374 blade doubler surface after paint and fitting removal. The red arrows indicate cracks observed in the doubler under the fitting.



Figure 24. Digital microscope images of the -K374 blade doubler surface after paint and fitting removal. The red arrows indicate cracks observed in the doubler under the fitting.

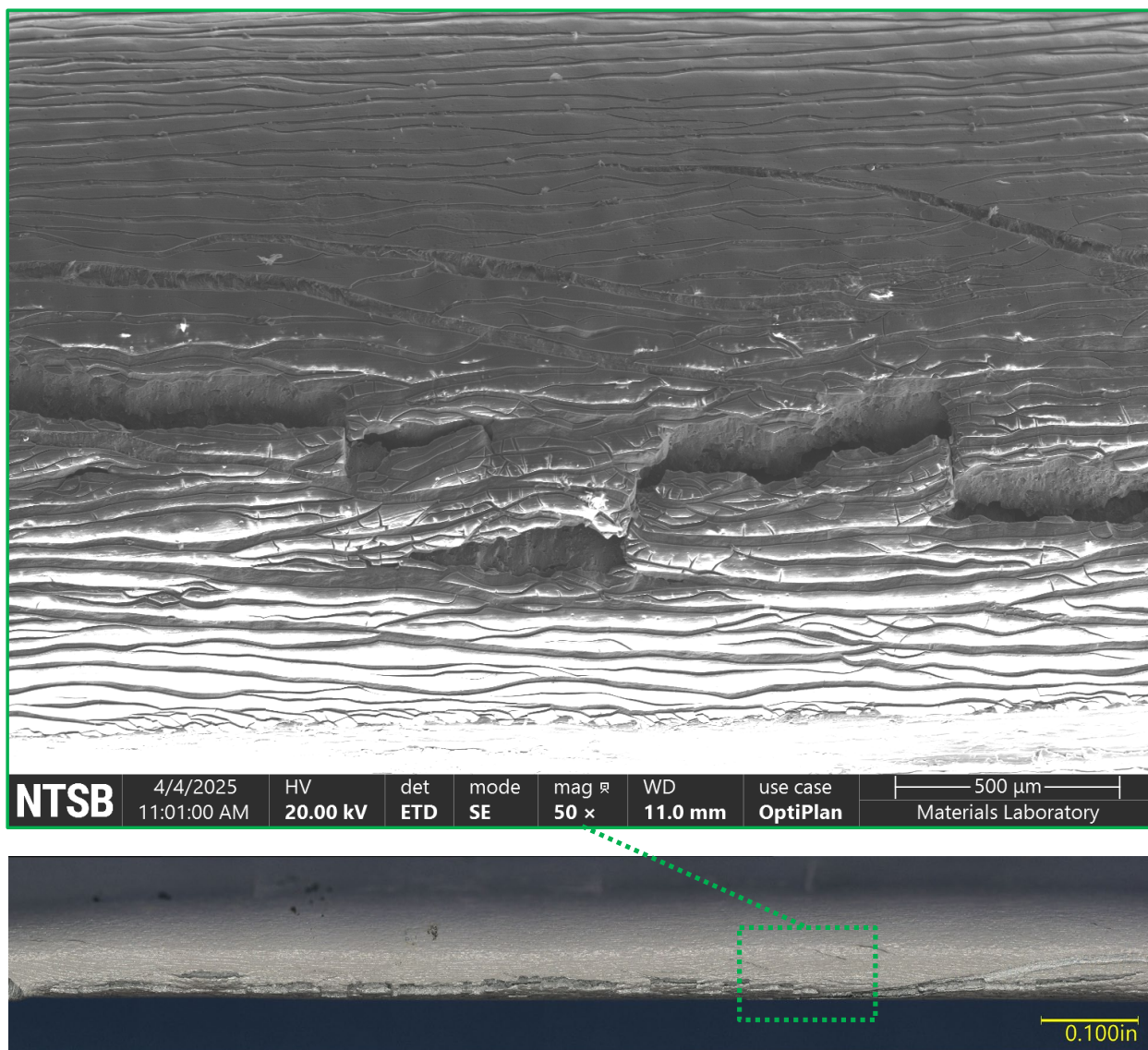


Figure 25. (Top) SEM and (bottom) digital microscope images of the -K374 blade doubler surface after mechanical exposure of the cracks in the doubler.

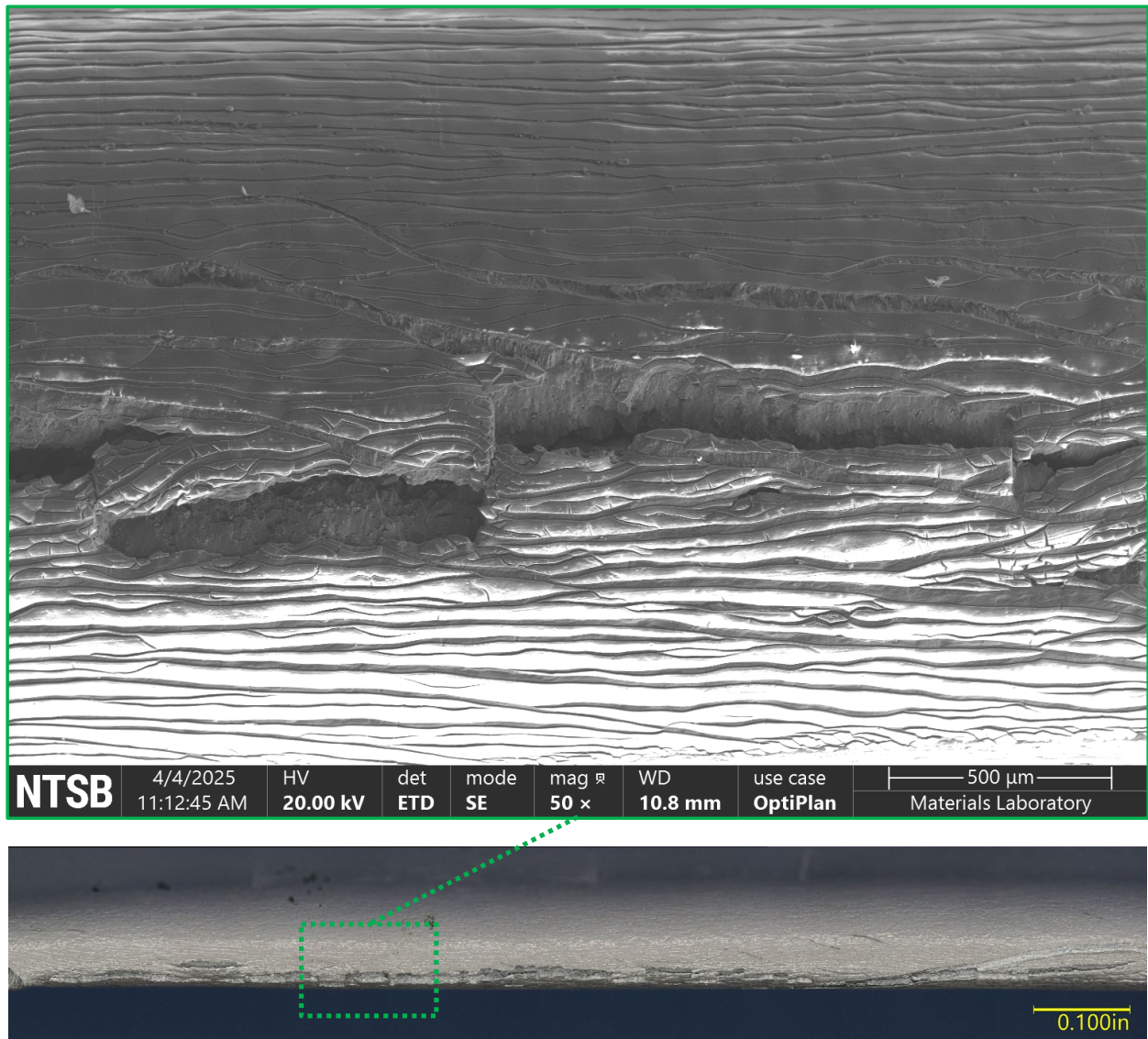


Figure 26. (Top) SEM and (bottom) digital microscope images of the -K374 blade doubler surface after mechanical exposure of the cracks in the doubler.

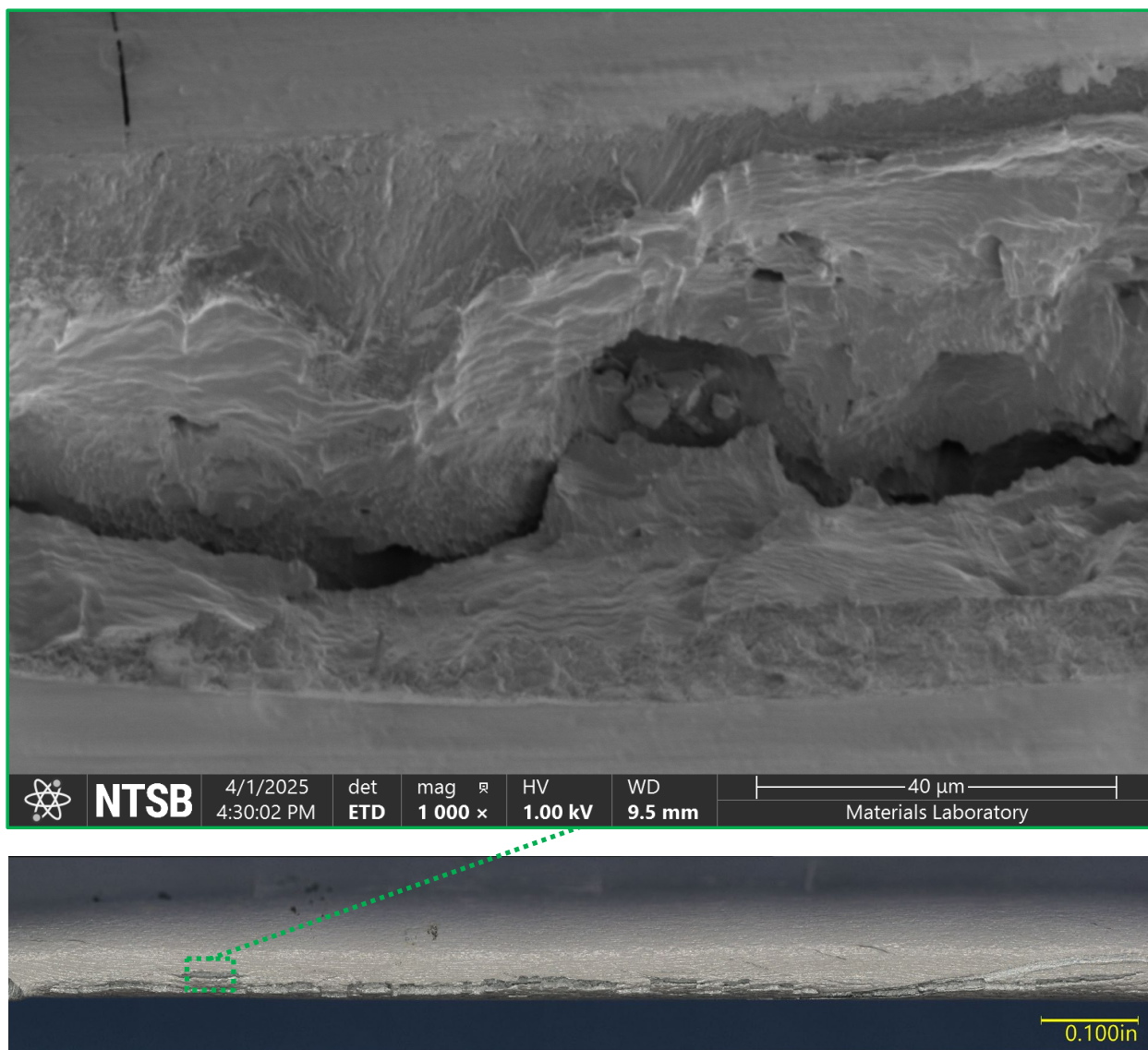


Figure 27. (Top) SEM and (bottom) digital microscope images of the -K374 blade doubler surface after mechanical exposure of the cracks in the doubler.

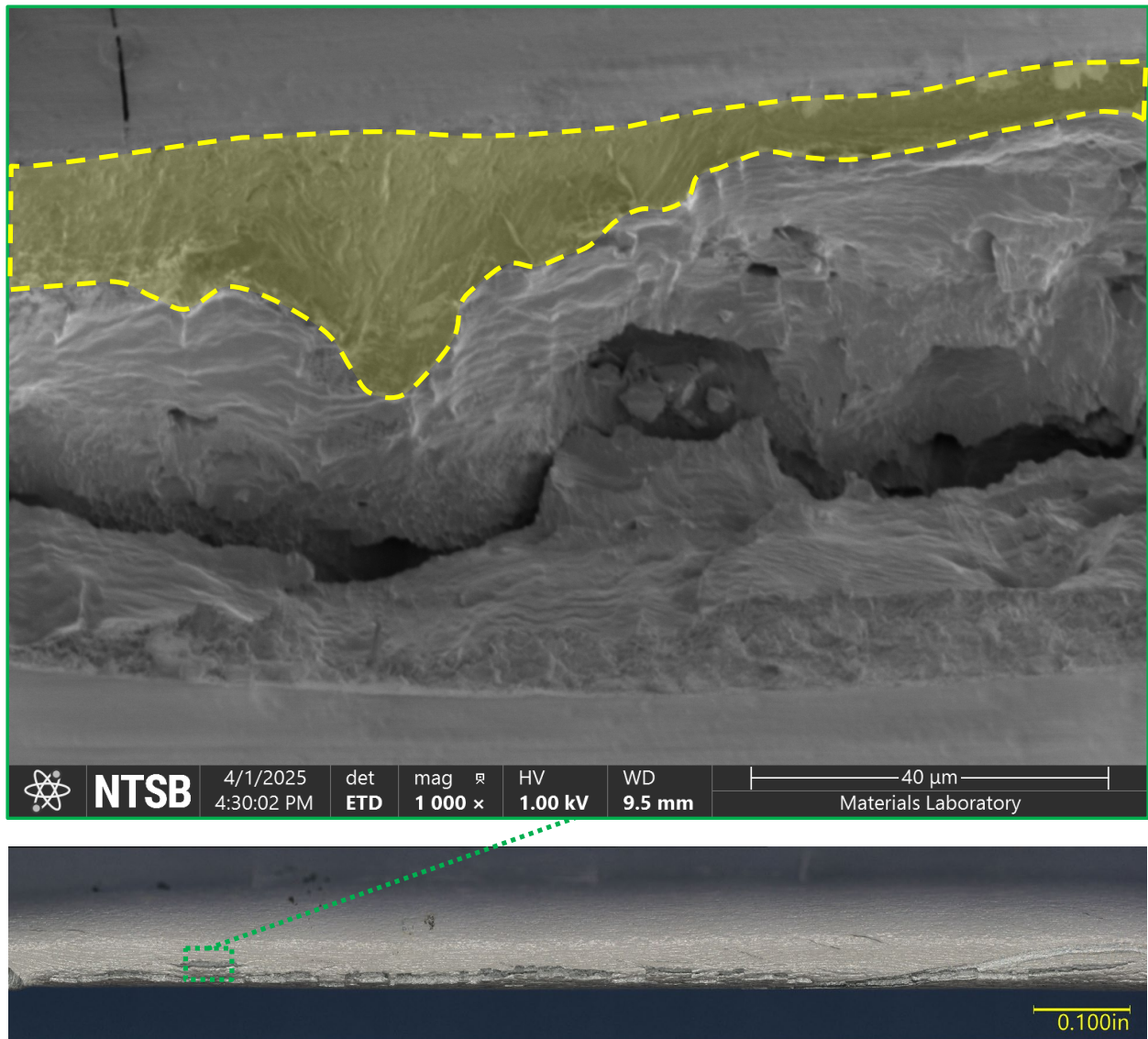


Figure 28. (Top) SEM and (bottom) digital microscope images of the -K374 blade doubler surface after mechanical exposure of the cracks in the doubler. The figure is the same as Figure 27 but includes a highlight of the fatigue portion of the top fracture surface (yellow area).

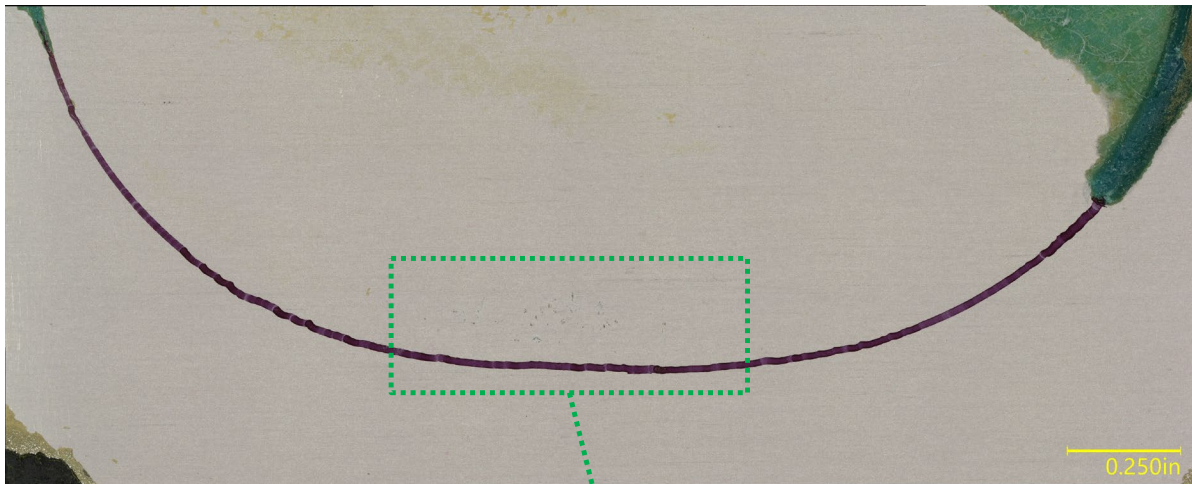
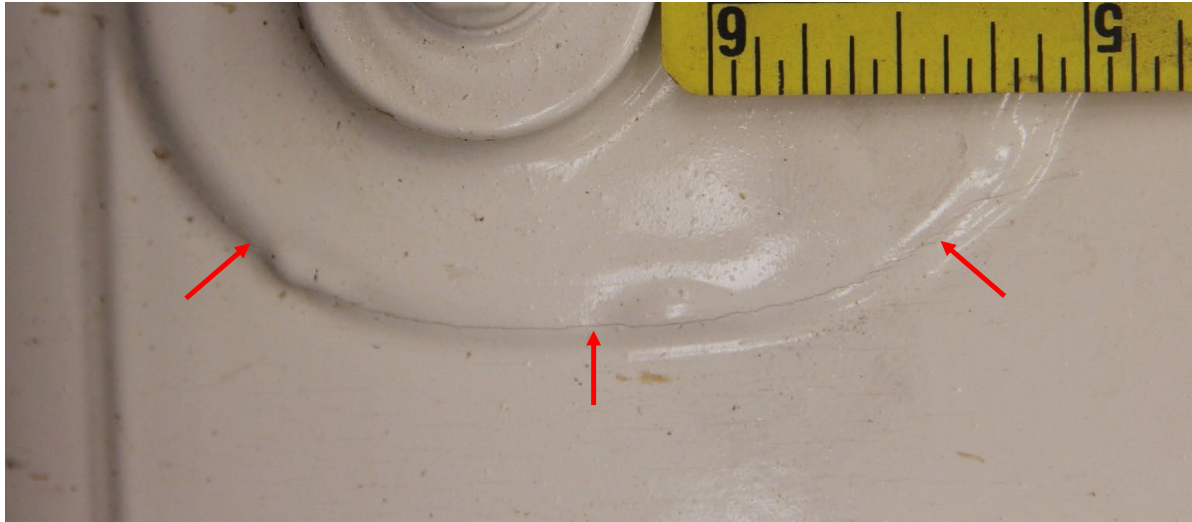


Figure 29. (Top) Macro photo of the bottom surface of the -K358 blade with a crack (red arrows) in the doubler paint at the root of the fitting. (Bottom) Digital microscope image of the doubler surface after paint and fitting removal. The black line indicates the profile edge of where the fitting mated.

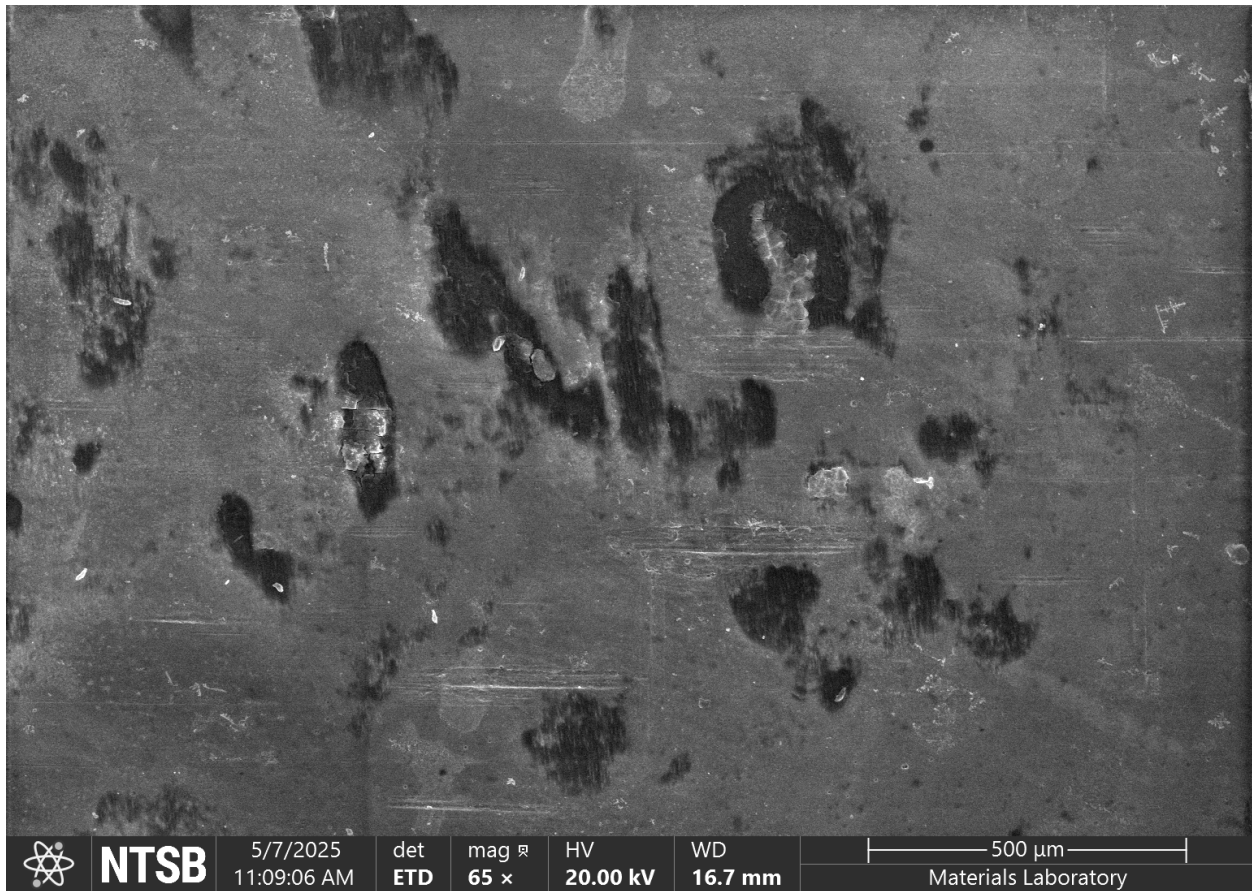


Figure 30. SEM image of some of the randomly scattered indents filled with debris on the doubler surface under where the fitting mated on blade -K358.