

NATIONAL TRANSPORTATION SAFETY BOARD

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



October 17, 2017

MATERIALS LABORATORY FACTUAL REPORT

Report No. 17-061

A. ACCIDENT INFORMATION

Place : Venice, Louisiana
Date : May 2, 2017
Vehicle : Bell 407, N457PH
Operator : PHI International
NTSB No. : CEN17LA174
Investigator : Arnold Scott, AS-CEN

B. COMPONENTS EXAMINED

Tail Rotor Hub and Blade Assembly with Gearbox Assembly and Gearbox Support Assembly with aft portion of the Tail Boom.

C. DETAILS OF THE EXAMINATION

The tail rotor hub and blade, gearbox and gearbox support assemblies were received as three separated units. They reportedly remained attached to the aircraft but were disassembled from the aircraft at the scene. As received, the tip block and weights were missing from one blade, two gearbox mounting studs were fractured on the gearbox and the tail boom structure was extensively cracked. No other damage was apparent on the blades or hub and the gearbox appeared to remain functional with free rotation.

The tail rotor assembly had a part number (p/n) of 407-012-101-115 and serial number (s/n) 53390. Both blades were p/n 406-016-100-119. The blade with the separated tip block was s/n BH051533 and the mating intact blade was s/n A-4436. The tail rotor assembly had been installed about 65 hours prior, following tip block replacement repairs to both tail rotor blades. The tail rotor gearbox was marked p/n 406-040-400-121FM, s/n A-1003. It was further marked "ABLE Overhaul 1-27-2016". The tail rotor gearbox support fitting in the tail boom was p/n 407-030-016-105, s/n 33488.

The blade assembly was located on the left side of the tail boom with the flat sides of the blades to the outboard (left) and the curved (cambered) side on the inboard side nearest the boom. Rotation was clockwise looking from the left side of the aircraft.

1. Tail Rotor Blades

The tail rotor blade assembly was disassembled to separate both blades from the hub and to remove the pitch link attachments. Both blades were mainly of fiberglass

reinforced composite construction with metallic leading edges and abrasion strips on the outboard ends. Fiberglass epoxy tip blocks¹ were bonded with 3M AF-163-2K² structural adhesive film between the skins at the outboard tips and brass inertia and balancing weights were screwed into the tip blocks. The blade skins were fiberglass reinforced epoxy with spar straps integrated into each skin.

a. Blade s/n BH051533

The tip block had separated from blade s/n BH051533, shown in figure 2, along with the weights and was not recovered. The blade had a total service life of 2658.65 hours and had a tip block replacement repair³ approximately 65 hours prior to the separation.

The tip block was reportedly bonded into the blade with 3M manufactured AF 163-2K structural adhesive film. AF 163-2K film is red in color. Remnants of the red adhesive are visible in the lower views of figure 2. Adhesive remnant indicated that the tip block had been inserted about 0.6 inch and 0.4 inch into the blade at the leading and trailing edge respectively. This would equate to about 2.60 in² bond surface on the flat side and 2.65 in² on the camber side.

Close examinations found that where it was adhered, the bond line separated at the adhesive interface with the tip block, leaving the majority of the adhesive attached to the skin as shown in figure 2. One large area of skin inter-ply separation was present toward the trailing edge on the camber skin as denoted by the bracket in figure 2.

The adhesive remaining on both skins appeared as a waffle pattern of high (thick) and low (thin) areas with the high areas following the pattern of the open weave carrier cloth as shown in the two views of figure 3. Magnified examinations found that the adhesive surfaces of the high areas displayed a textured matte surface indicative of bonding and subsequent interfacial separation, outlined in yellow in the lower view of figure 3. A small percentage of the area had a textured glossy surface indicating areas of the adhesive that had contacted the surface of the tip block but did not bond to it. One unbonded area is outlined in red in the lower view of figure 3. Many of the high areas also displayed fine parallel lines in the surfaces. The orientation of the lines varied over the separation surface as indicated by the double yellow arrows in figure 3. The lines were consistent with the fiber pattern in the surface of the tip block and are also visible and indicated in figure 6. The lower areas had predominately smooth and glossy surfaces consistent with voids and lack of contact between the adhesive and the tip block. Some of the inboard void areas had a powder like coating that was not removed by blowing with low pressure air.

¹ EM 7302 Sumitomo Bakelite North America, Inc.

²3M™ Scotch-Weld™ AF-163-2K is a thermosetting modified epoxy structural adhesive in film form with a knitted open weave supporting carrier cloth. The weave spacing is about 1 mm. The red color denotes a 9.5 mil thickness.

³ Repair by Rotor Blades, Inc LA repair station R8DR713Y completed January 19, 2017.

The flat side skin in the area of the tip block was cut from the blade in four sections, as denoted in the montage of figure 4. The forward section was used for visual and Fourier transform infrared spectroscopy (FTIR) testing and examinations, the adjacent section was used for scanning electron microscope (SEM) examinations, a small strip (not shown) was a metallographic section and the trailing edge section was visually examined then forwarded to Bell Helicopter (Bell) for additional testing.

Removal of the flat side skin allowed direct viewing of the separation surfaces of both skins. The waffle pattern was apparent throughout both skin separations as visible in figures 4 and 5. In these figures, the upper portions of each image shows the as-received adhesive surfaces⁴ of the skins. In the lower portions of each image, the void areas have been highlighted by black outlines.

Magnified visual examinations found the percentage of bonding and the local apparent thickness of the adhesive varied from leading to trailing edge.

Estimates of the area percentage of voids were made on each skin side by software based pixel counting⁵ in arbitrarily defined areas of images. The defined count areas are defined by yellow boxes in figures 4 and 5. The skin separation area was not included. Void area percentages ranged from a low of about 40% to a high of 79% with the aggregate void percentage of 50.5% (49.5% bond) for the camber side and 53.8% (46.2% bond) on the flat side. No clear pattern was apparent except for high void content at both leading edge areas under the abrasion strip.

The thickness of the adhesive layer was estimated by measuring the height of the high points relative to adjacent lower voids using proprietary software⁶. The apparent adhesive heights ranged from 0.002 inch to 0.027 inch and are presented on the views in figures 4 and 5 as thousandths of inches. One location measured 0.060 inch in height but it was found to be mostly filler material. The adhesive thickness averaged 0.0072 inch on the flat side and 0.0101 in the camber side (not including the 0.060 inch measurement). These values do not include the thickness of the adhesive in the voids.

The outboard edge of the separation on the flat side of the blade displayed a darker band of surface deposits adjacent to the tip, as shown in figure 6. The band extended inboard about 0.1 inch at its maximum. The dark band was visible for about 3 inches chordwise aft from a location forward of the strap. FTIR analysis established it to be a carbonaceous material. Close examinations found that a large number of voids intersected the tip of the blade. Several of them were filled with a light tan material as identified in the middle view of figure 6.

⁴ Surface of the SEM section has been coated with a thin layer of carbon to allow SEM viewing without charging.

⁵ Void areas were manually defined in Materials Solutions of Stream Enterprise 2.2© from Olympus Soft Imaging Solutions GmbH.

⁶ Keyence VHX-5000 profile mode at 100X to 200X.

Metallography

A metallographic specimen was prepared by mounting a spanwise section of the flat side skin in room temperature curing epoxy and polishing to reveal the skin and adhesive structure in cross section. The section revealed complex layers of adhesives, skin, erosion shield and various surface coating as shown in figure 7. The waffle pattern of thick (bonded) and thin (voids) adhesive was apparent on the specimen and enlarged views of features are also shown in figure 7. A continuous layer of adhesive had adhered to the skin material with the void area adhesive measuring between 0.001 inch and 0.002 inch thick. The thicker bonded adhesive areas corresponding to the scrim cloth locations mostly measured between 0.006 inch and 0.009 inch with the most inboard area measuring 0.013 inch thick.

SEM

An approximate one-inch wide section of the flat side skin was prepared for scanning electron microscope (SEM) examination. The skin was abrasively cut from near the trailing side of the skin strap and contained a portion of the strap. The cutting debris was blown from the specimen with low pressure air and the adhesive side was vacuum coated with gold and palladium to make the surface electrically conductive and viewable in the SEM.

Figure 8 displays low magnification SEM views of two typical areas of adhesive showing both the bonded and void areas. The bond areas displayed texturing of the surfaces while the void areas had smooth surfaces. The threads of the scrim cloth are partially visible in some of the void spaces as denoted.

At higher magnification, figure 9, the texturing indicative of bond separation was visible on large parts of the surface. Remnant fibers and fiber tracks from the tip block were also present as shown in figure 10. The texturing and fiber markings were most visible toward the inboard half of the tip block bond line. The bond surfaces in the outboard portion of the bond line particularly near the blade tip displayed worn appearances with fine features rubbed away, as shown in figure 11. The worn areas also contained more debris on the surfaces as shown in figure 12.

Large amounts of particulate debris were also noted in many of the voids, particularly toward the inboard portions of the bond line, as presented in figure 13. At higher magnifications, figure 14, the debris was visible as granules and fragments of fibers.

As measured by energy dispersive x-ray analysis at 20 kV (EDS), the major elements in the particulate debris were carbon (C), oxygen (O), aluminum (Al) silicon (Si) and calcium (Ca), upper left spectra of figure 15. Carbon (C), oxygen (O) and aluminum (Al) were the major elements in the adhesive with a minor peak for silicon (Si), upper right spectra of figure 15. Identifiable individual debris fibers had spectra showing major peaks for carbon (C), oxygen (O), aluminum (Al) silicon (Si) and calcium (Ca) with a minor

magnesium (Mg) peak. With the exception of the carbon peak, this composition was consistent with E-glass⁷ fiberglass. Overlaying the spectra and EDS spectral mapping of the elements, found the composition of the particulate debris to be consistent with a mixture of adhesive and E-glass fibers and possibly other organic materials.

Spectra were also acquired from samples of the skin reinforcing fibers and the block reinforcing fibers. Both were silicon glass fibers with the skin fibers containing oxygen (O), aluminum (Al) silicon (Si) and magnesium (Mg) consistent with a typical composition for S-glass⁸. The block fibers contained oxygen (O), aluminum (Al) silicon (Si) and calcium (Ca) consistent with E-glass. The presence of calcium in the debris fibers indicates E-glass consistent with the glass fiber reinforcement of the tip block. An overlay of the fiber spectra is shown in the lower view of figure 15.

FTIR

Fourier transform infrared spectroscopy⁹ (FTIR) was performed both directly on the adhesive separation of the flat side skin and on hexane extracts from the flat and camber skin adhesive surfaces. In addition, FTIR spectra were acquired from a known cured sample of the adhesive supplied and cured by Bell Helicopter.

FTIR spectra from seventeen distinct regions were acquired directly from the adhesive surfaces of the flat side of the blade. The base spectra on the accident blade were consistent with the supplied known specimen. No contaminants were detected except for carbon deposits near the outboard edge of the separation.

Additional spectra were acquired from evaporated hexane extractions from the central portion of the flat side skin and from the leading edge, central and trailing edge regions of the camber side adhesive surfaces. No contaminants were identified by FTIR spectroscopy in the residue from the extractions.

b. Blade s/n A-4436

Blade s/n A-4436, figure 16, appeared intact with no obvious damage and no cracking was noted in the coatings on the tip of the blade. The blade had a tip block replacement and wire mesh repair¹⁰ at a service time of 6,808.26 hours about 65 hours

⁷ E-glass – Alkali free, highly electrically resistive glass made with alumina-calcium borosilicates. E-glass is known in the industry as a general-purpose fiber for its strength and electrical resistance. It is a commonly used fiber in the fiber reinforced polymer composite industry. Typical compositions contain oxides of silicon, calcium, aluminum, magnesium and boron.

⁸ S-glass – High strength glass made with magnesium aluminosilicates. Used where high strength, high stiffness, extreme temperature resistance, and corrosive resistance is needed. Typical compositions contain oxides of silicon, aluminum and magnesium.

⁹ FTIR microspectrometer with a germanium attenuated total reflectance (ATR), in accordance with ASTM E1252: *Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis* and ASTM E334-*Standard Practice for General Techniques of Infrared Microanalysis*.

¹⁰ Repair by Rotor Blades, Inc LA repair station R8DR713Y completed February 22, 2017.

prior to the incident. Tap testing¹¹ the area of the tip block at the outboard end of the blade uncovered a void indication as shown in figure 16. The void was located on the flat side of the blade just aft of the leading edge abrasion strip. It was estimated to be about ½ inch in diameter.

An approximate one inch by 1.75 inch strip of the blade skin over the tip block was cut near the middle of the camber skin of the blade. The strip was lifted at the inboard end to induce a separation in the skin to tip block adhesive joint. The separated skin strip is displayed in figure 17. Magnified examination found that the majority of the separation occurred within the skin plies and only a small portion occurred at the adhesive skin interface. No indications of a waffle pattern were visible.

Following the skin separation test, blade s/n A-4436 was forwarded to Bell Helicopter for additional tests and examinations including calibrated peel testing of the tip block bond line, non-destructive tests.

2. Tail Rotor Gearbox and Support Assemblies

The as-received tail rotor gearbox and support assemblies are displayed in figure 18. The gearbox was disassembled and removed from the support structure on-scene and the tailboom was subsequently cut to remove the support assembly.

c. Gearbox Support Assembly

The gearbox support assembly consisted of an aluminum support casting on the upper side (p/n 407-030-016-105, s/n 33488) and a sheet metal skin and inspection cover on the lower side. The entire support casting was fractured and all but 2.7 inches of the skin and the four inch wide cover were cracked. The fracture in the casting and crack in the skin both appeared consistent with overstress separations. Additionally, a piece of the support casting was broken out at the left forward stud area.

The gearbox mounting pads surrounding the stud holes displayed surface fretting patterns on both the gearbox and nut sides. All four stud bores had thread marks consistent with all around contact with the stud threads. Locating pin holes were positioned adjacent to the two right-hand stud holes. The pins were not received and were reportedly not recovered during disassembly of the tail rotor. The support casting was fractured through the forward right-hand stud and pin hole.

d. Tail Rotor Gearbox

On the gearbox, the two right-hand gearbox mounting studs were intact with nuts and washers present. The forward and aft studs extended 0.78 inches above the surface of the gearbox. The two left-hand studs were fractured below the surfaces of the gearbox. The locating pins adjacent to the right-hand studs were not received and reportedly not

¹¹ Nondestructive test method where discontinuities are revealed by a change in the response sound when the object is tapped with a metallic object.

recovered. The mounting surfaces displayed directional fretting patterns mirroring those seen on the support casting, as shown in figure 19. The gearbox assembly otherwise appeared intact and relatively undamaged.

Macroscopically both fractured left-hand studs displayed reversed bending fatigue fractures. The directional orientation of the fatigue progression matched the respective directions of the adjacent fretting. Fretting and fatigue directions are indicated by double headed red arrows in figure 19. The directions of fatigue and fretting are consistent with a common axis of rotation for the gearbox relative to support located near the right edge of the gearbox housing midway between the right stud locations, as denoted by the red and yellow cross in the central view of figure 19.

Gearbox Studs

The fractured stud shanks were recovered with nuts threaded on and torque paint in-place as shown in the upper left image of figure 20. The stud segments were between 0.92 and 0.93 inch in length. Based on the stud segment lengths and the locations of the fractures, the left-hand studs originally extended approximately the same distances above the gearbox surfaces as the right-hand studs, 0.78 inch. The Illustrated Parts Breakdown (IPB) indicated that AN126XXX studs¹² were to be installed. AN126324 studs were reported installed at last overhaul.

As can be seen in figure 20, the nuts were at different positions relative to the ends of the fractured studs. The red torque paint indicates that the nuts had not moved since installation. The forward nut was threaded on to the stud 0.190 inch or about 0.055 inch further than the aft nut. No washers were received with the stud and nut segments but the washers received with the right-hand studs measured about 0.060 inch in thickness. The thread roots below the nuts were partially embedded with material consistent with the aluminum of the gearbox support casting.

The studs were fractured in the coarse threaded portions of the studs. Cracks and thread stretching were noted in the root radii adjacent to the fractures. Magnified optical examinations of the fracture faces revealed features and topographies consistent with multiple origin reversed bending fatigue initiating in the respective root radii on opposed sides of each studs. Fatigue origins were between the 4th and 5th threads from the center on one side and between the 3rd and 4th threads on the opposite side. Progression was inward with increasing coarseness until final overstress fracture. Fatigue progression penetrated about 90% of the forward and 80% of the aft stud before final overstress fracture. The fatigue initiation areas are indicated by red brackets in figure 20 and the fatigue termini are indicated by the dashed yellow lines. Closer optical examinations found significant fracture face mechanic damage consistent with crack face closure.

¹² Air Force-Navy Aeronautical Standard Stud, Straight 0.3125-18 x 0.3125-24. XXX between 275 and 586 determined by thread lengths and over under size.

High magnification optical and SEM viewing also uncovered small slant fracture planes at all four origin areas. The slant planes measured between 0.003 and 0.005 inch in width. A typical fracture origin area is shown in figure 21 with the slant region denoted. Scanning electron microscope (SEM) viewing of the studs uncovered ductile dimples on the slant region in undamaged locations as shown in figure 22.

The studs were forwarded to Bell Helicopter Textron for striation counting.

Joe Epperson, FASM
Senior Metallurgist

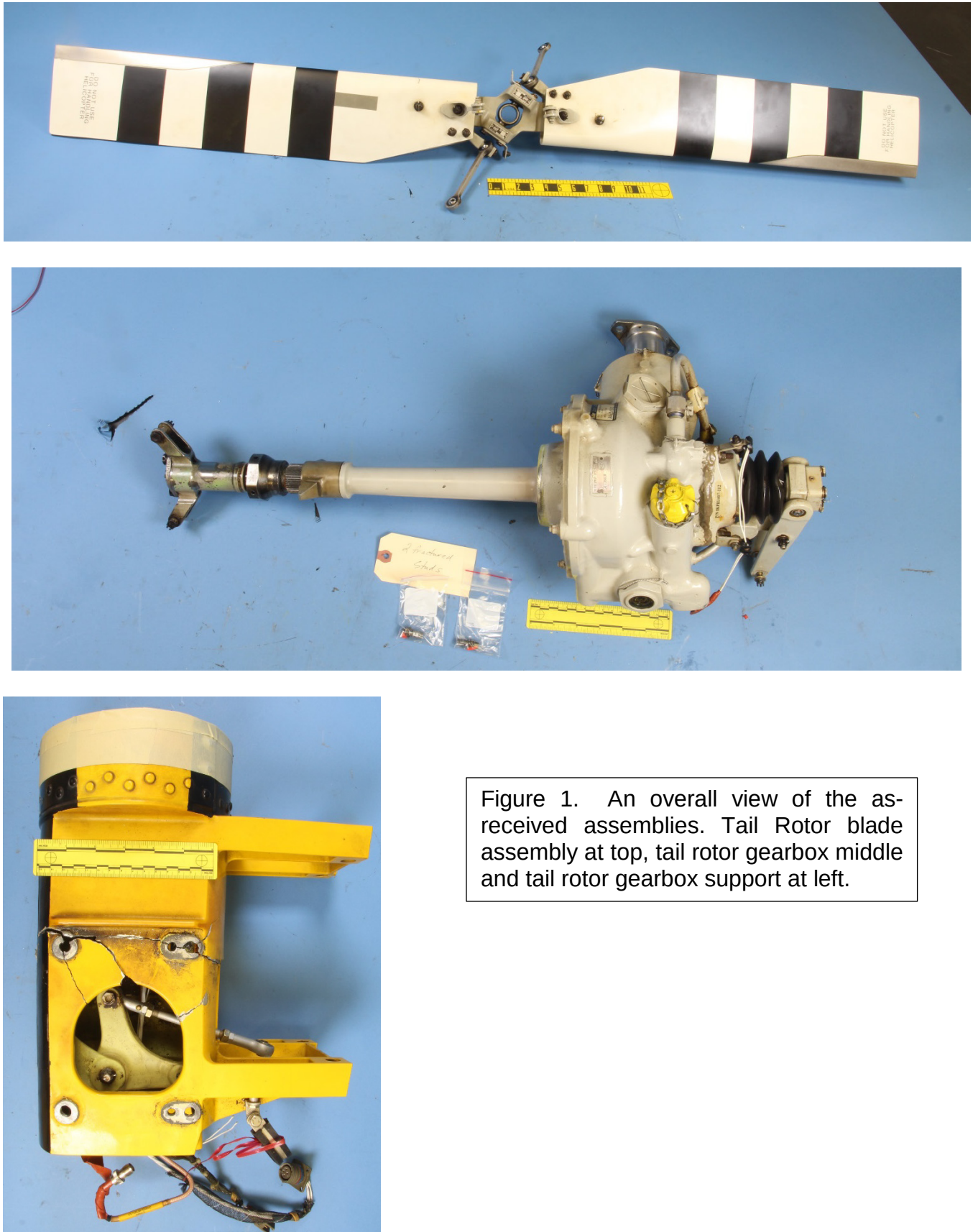


Figure 1. An overall view of the as-received assemblies. Tail Rotor blade assembly at top, tail rotor gearbox middle and tail rotor gearbox support at left.

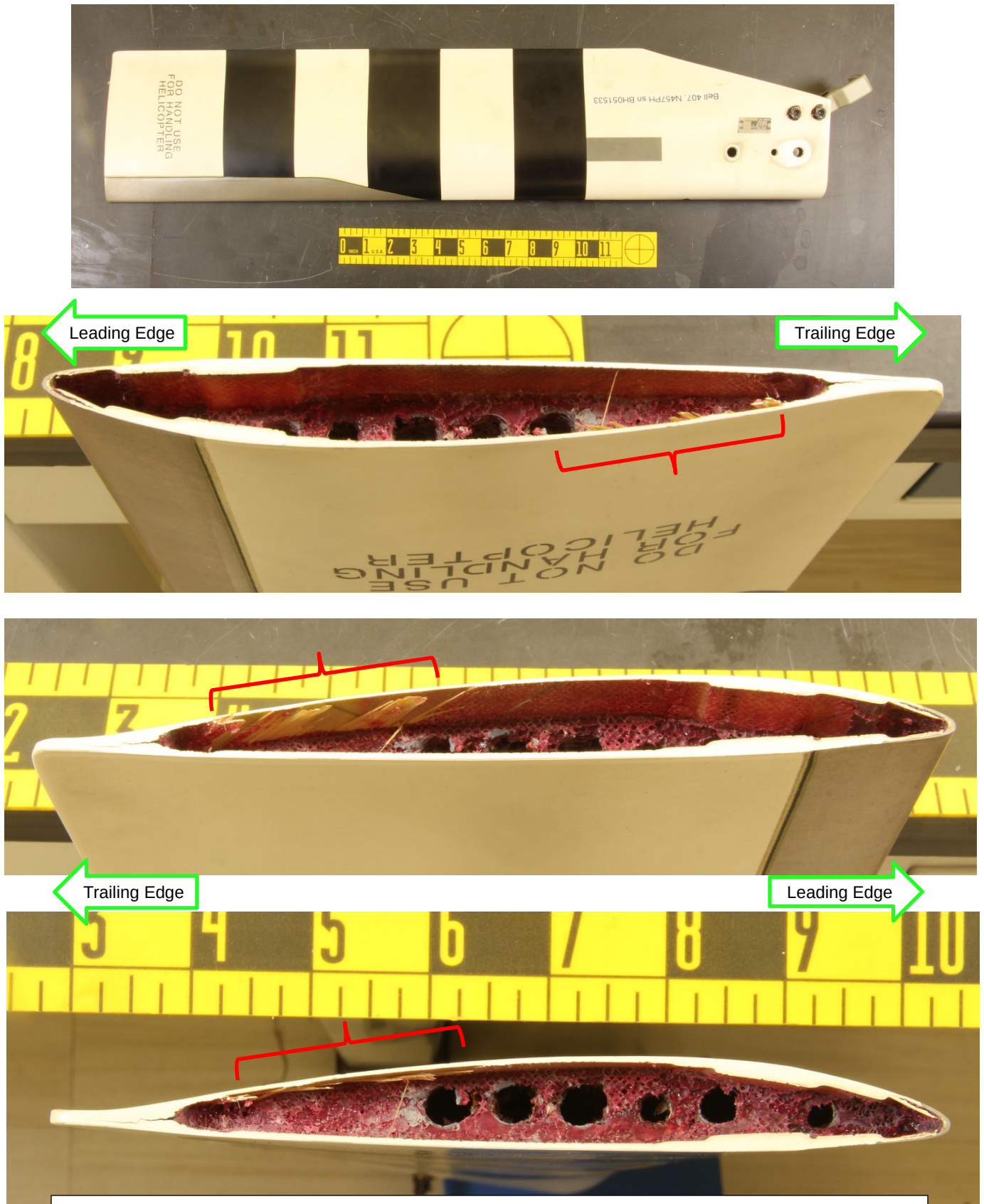


Figure 2. Upper view shows the camber side of blade s/n BH051533. Two middle views are oblique views of the inner surfaces of the flat and camber skins. Lower view looks directly inboard at the void from the separated tip block. Red adhesive visible. Red bracket indicates where the separation was in the skin material.

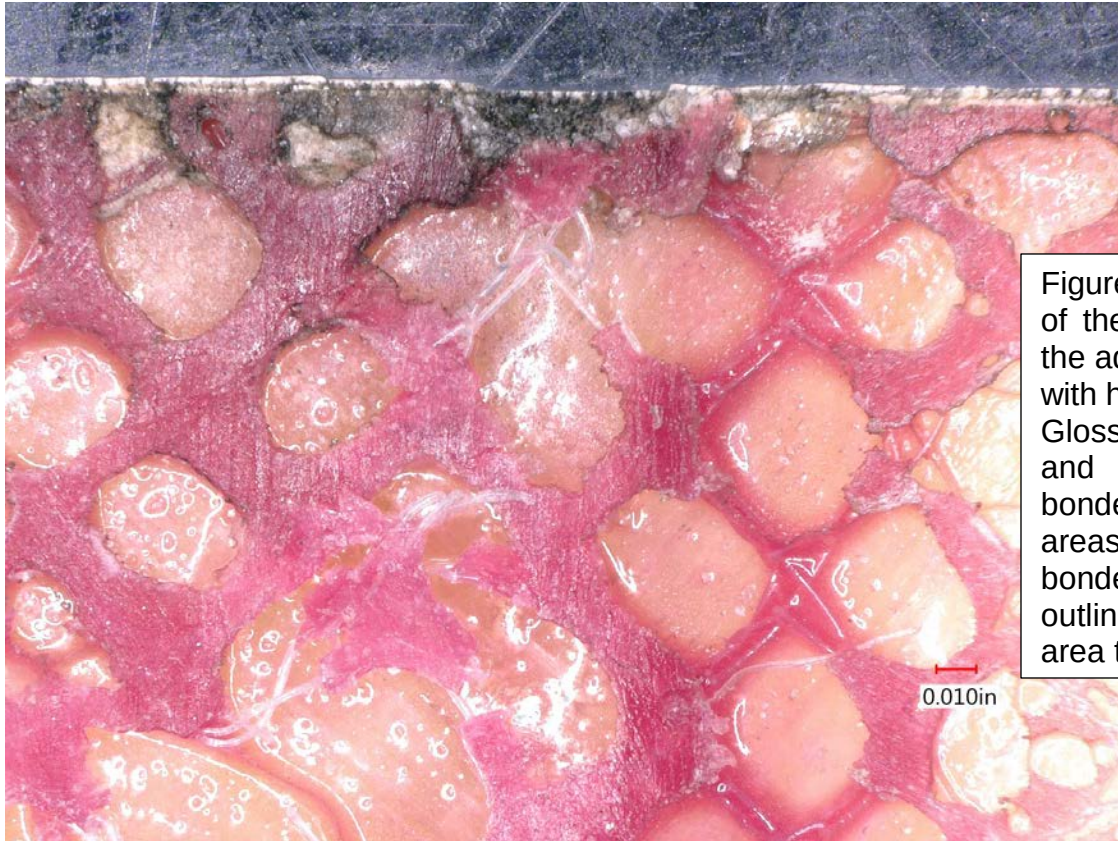
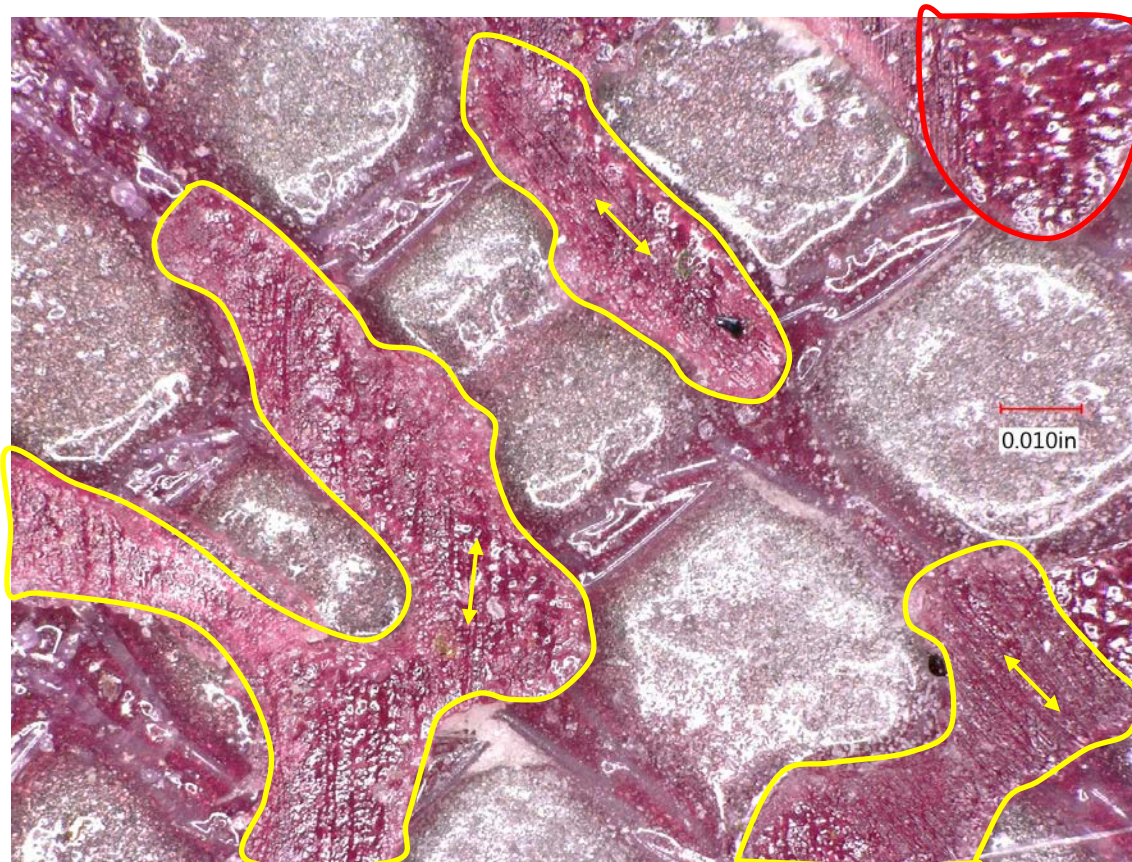


Figure 3. Typical views of the waffle pattern of the adhesive separation with high and low areas. Glossy areas are voids and matte area were bonded. Yellow outlined areas below were bonded high areas. Red outlined area was a high area that did not bond.



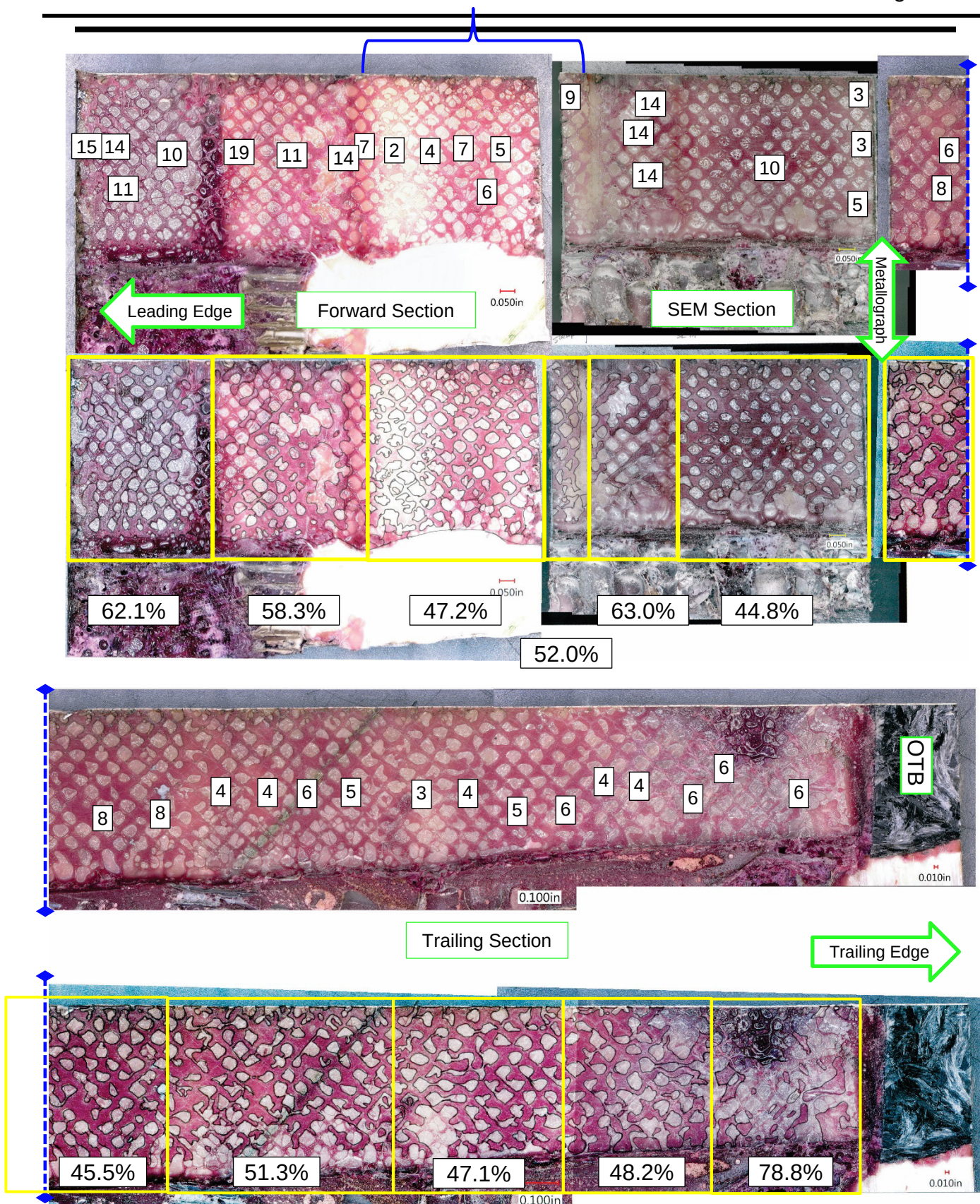


Figure 4. A montage of the flat side skin. Upper two images are of the same area from leading edge to about mid chord with the upper image annotated with adhesive thicknesses in thousandth of inches. Lower image has the void areas outlined and percentage void per measurement area (yellow box) denoted. Lower two images show the surface from mid chord to trailing edge with the same annotations. The blue bracket denotes the approximate location of the blade strap. The remains of the original tip block is denoted "OTB".

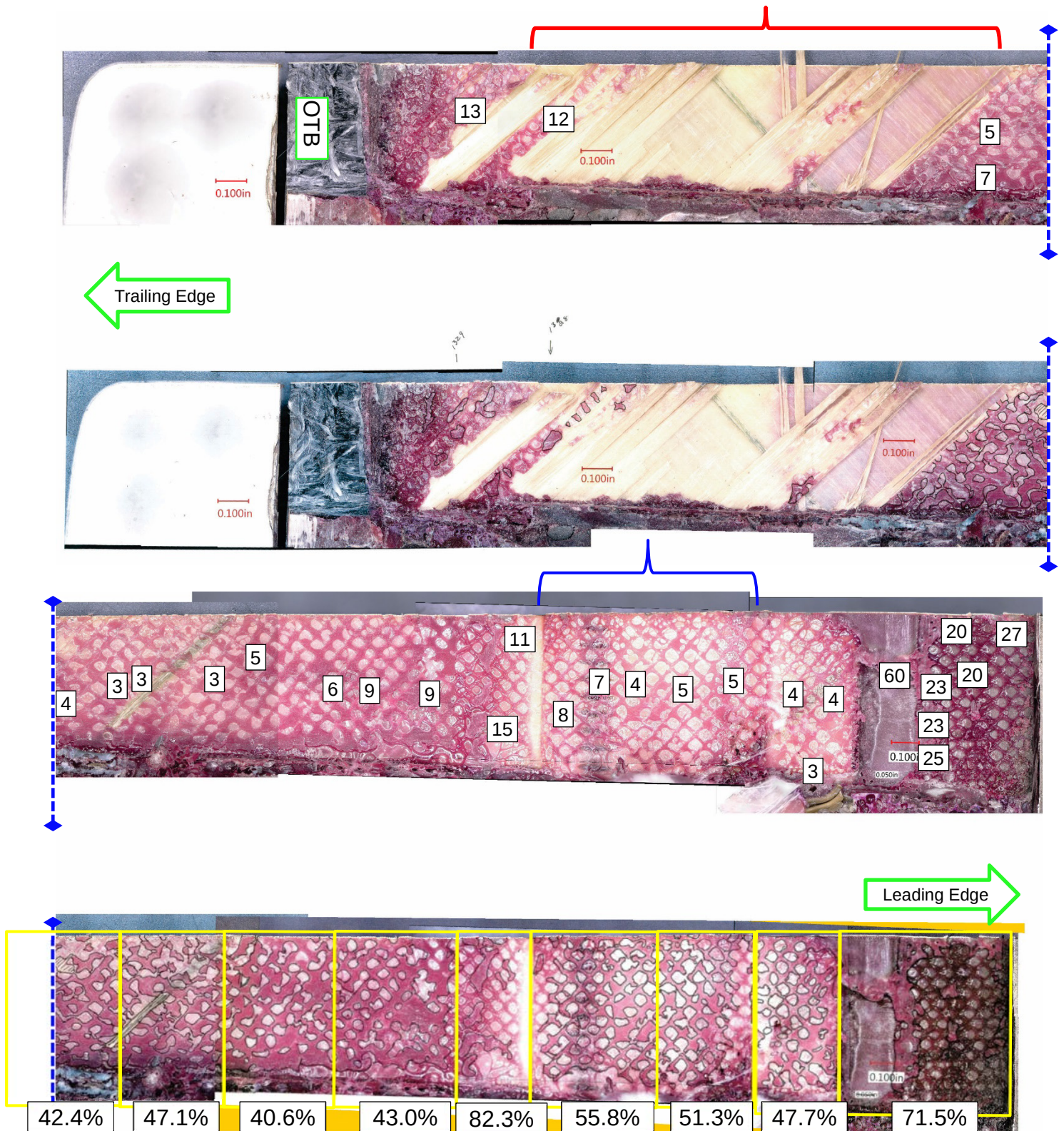


Figure 5. A montage of the camber side skin. Upper two images are of the same area from trailing edge to about mid chord with the upper image annotated with adhesive thicknesses in thousandths of inches. Lower image has the void areas outlined and percentage void per measurement area (yellow box) denoted. Lower two images show the surface from mid chord to leading edge with the same annotations. The blue bracket denotes the approximate location of the blade strap. The remains of the original tip block are denoted "OTB".

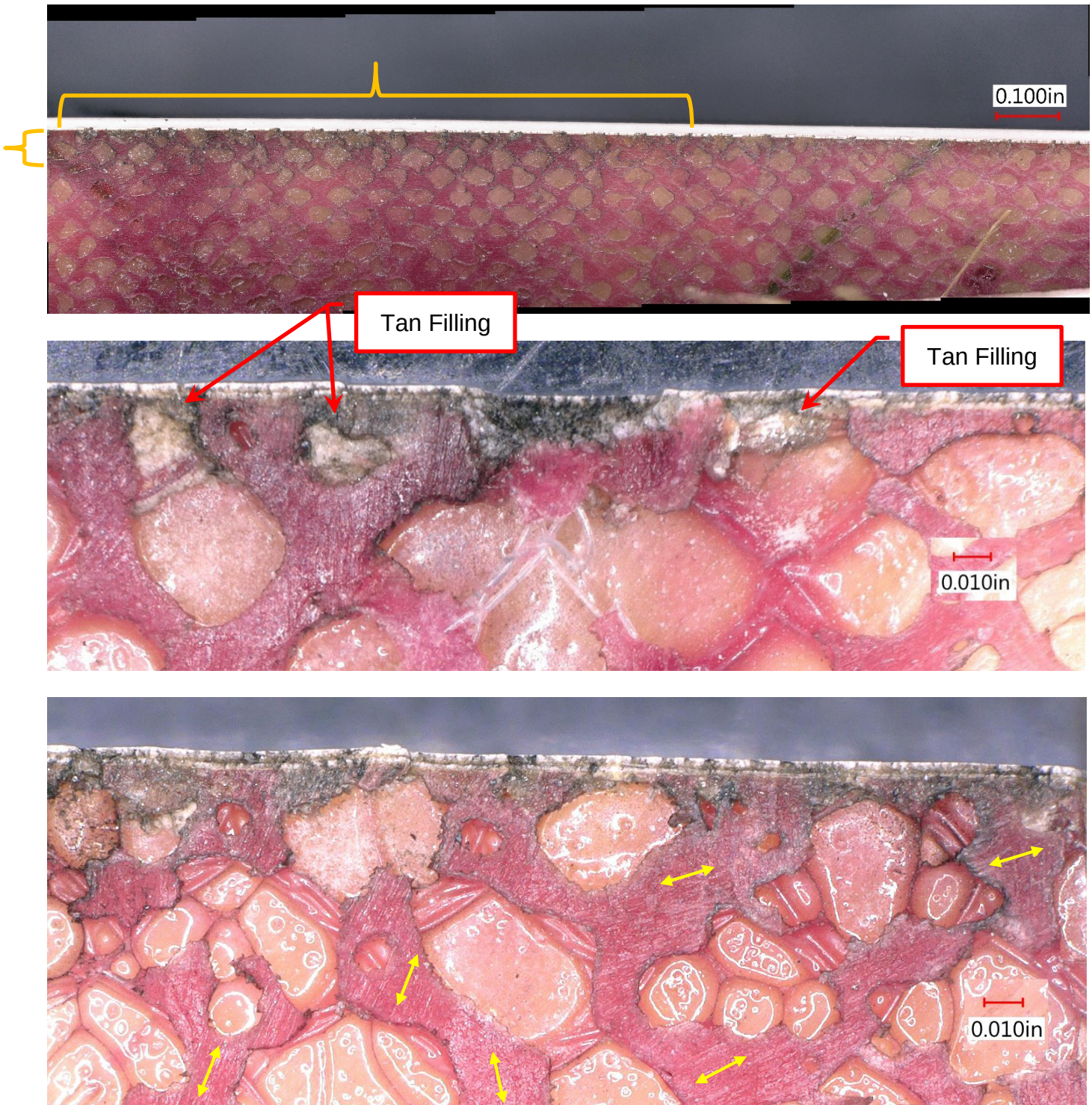


Figure 6. Three views of the flat side adhesive separation showing the dark band and tan filling at the blade tip. Lower view has double arrows showing the fiber impression directions in the adhesive.

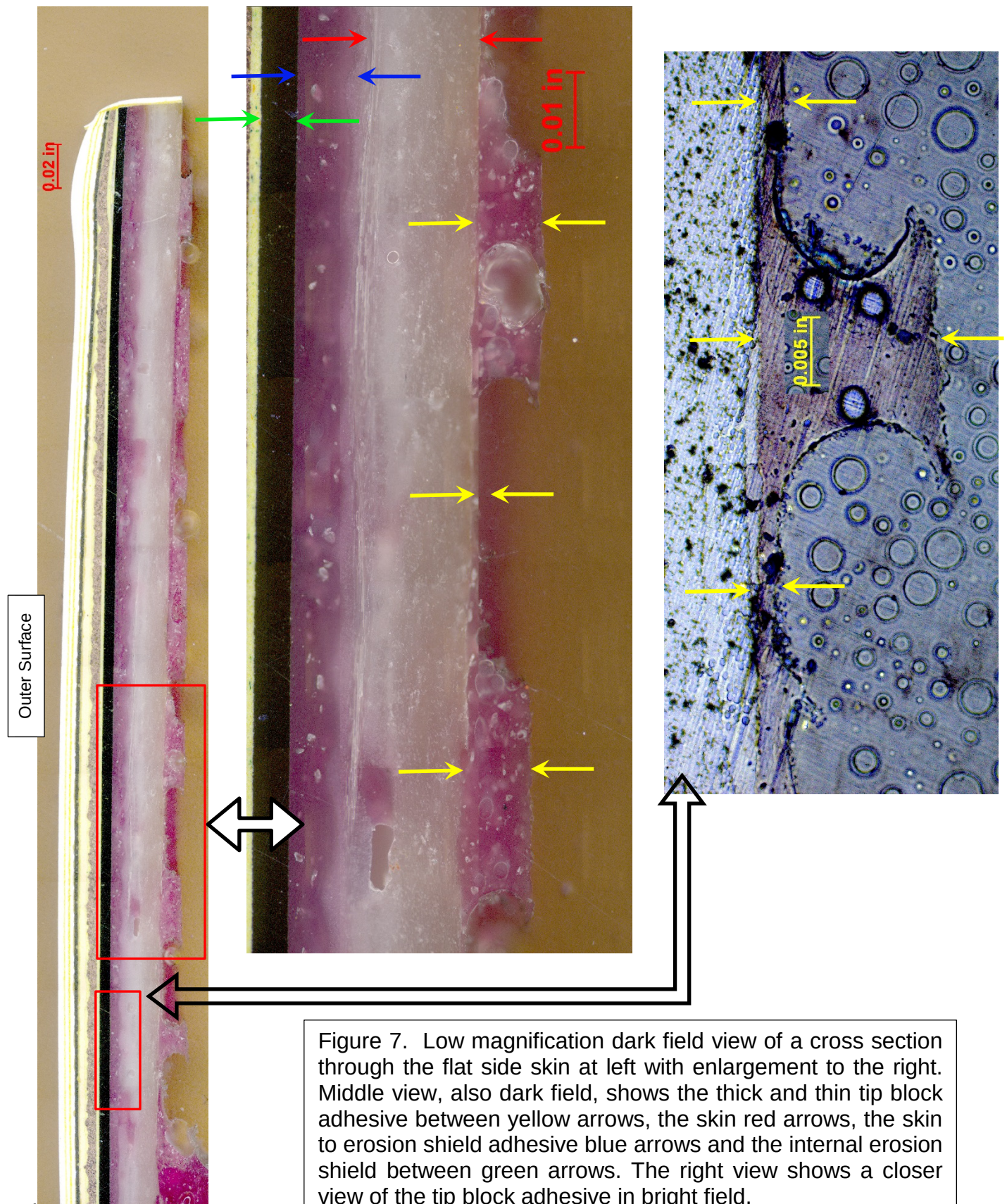


Figure 7. Low magnification dark field view of a cross section through the flat side skin at left with enlargement to the right. Middle view, also dark field, shows the thick and thin tip block adhesive between yellow arrows, the skin red arrows, the skin to erosion shield adhesive blue arrows and the internal erosion shield between green arrows. The right view shows a closer view of the tip block adhesive in bright field.

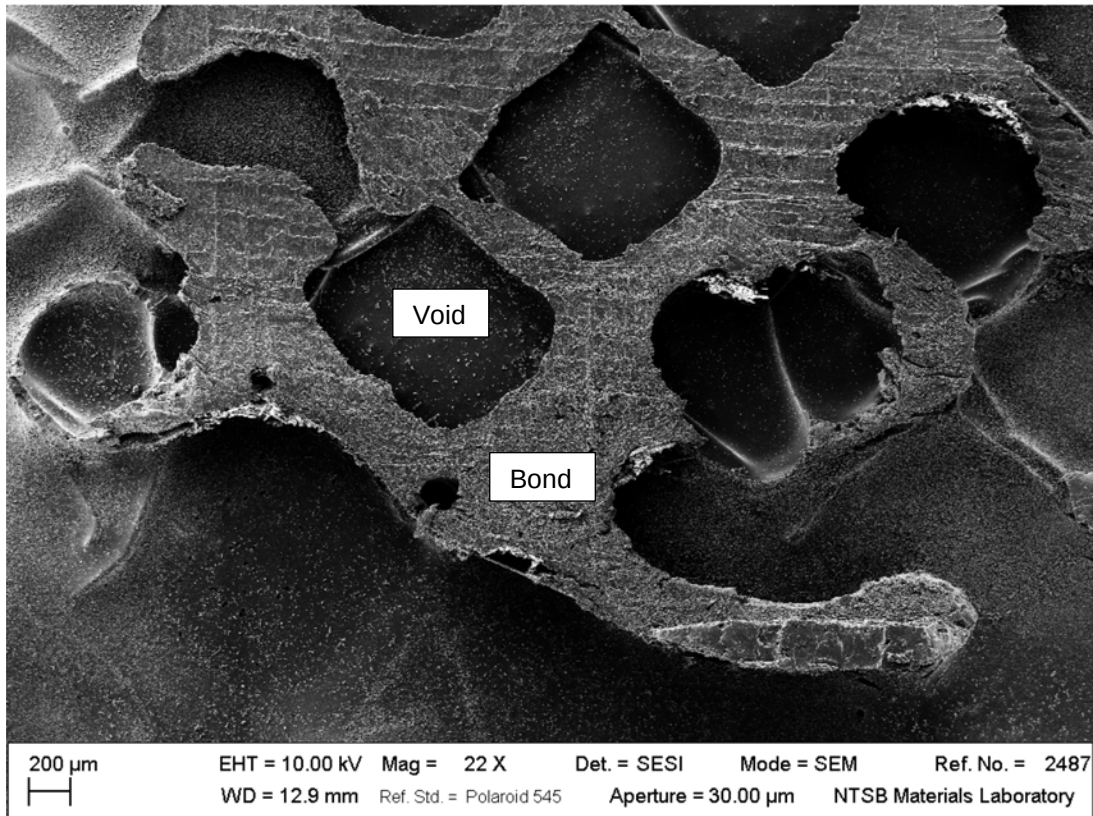
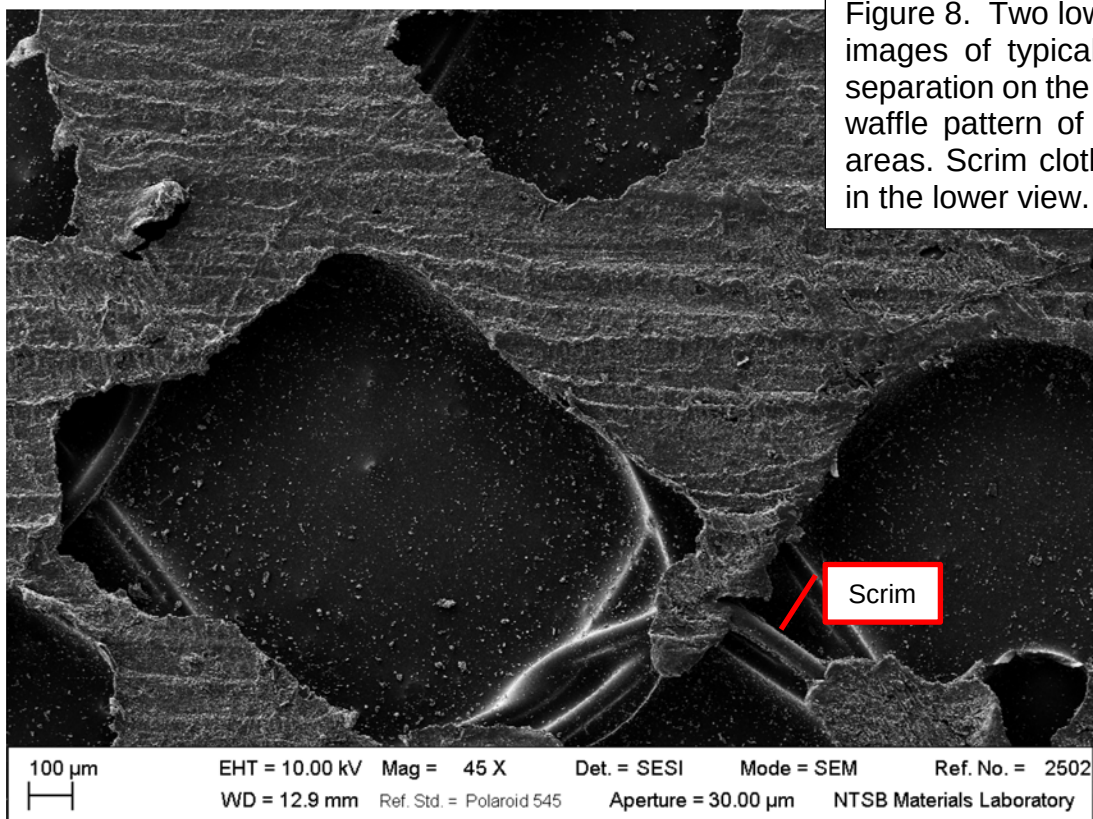


Figure 8. Two low magnification SEM images of typical areas of adhesive separation on the flat skin showing the waffle pattern of bonded and voided areas. Scrim cloth fibers are denoted in the lower view.



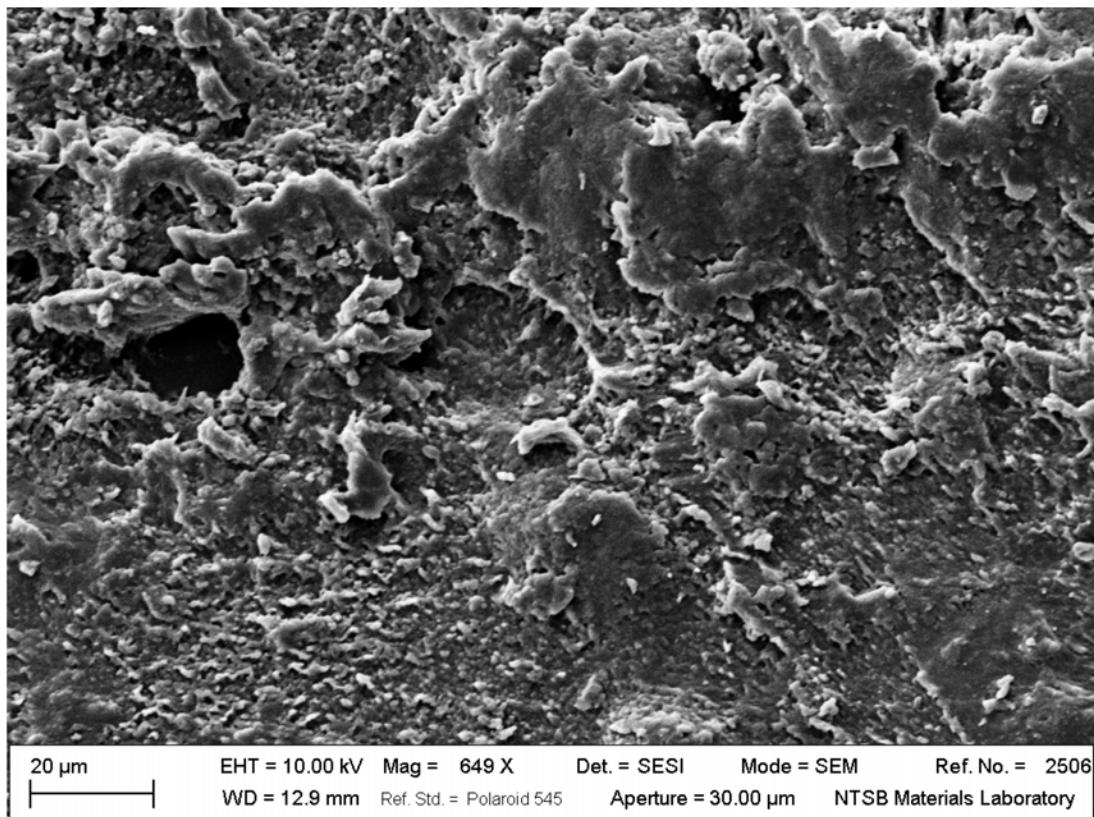
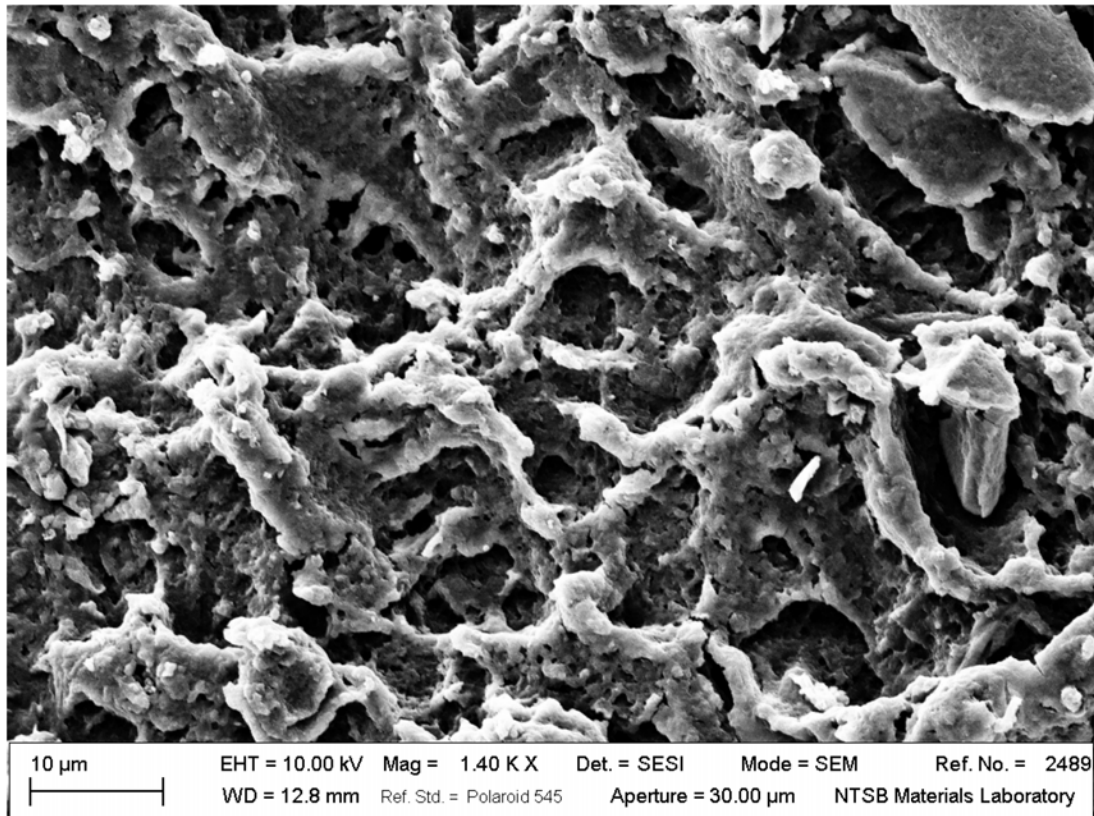


Figure 9. Two SEM images showing texturing indicative of bond separation.

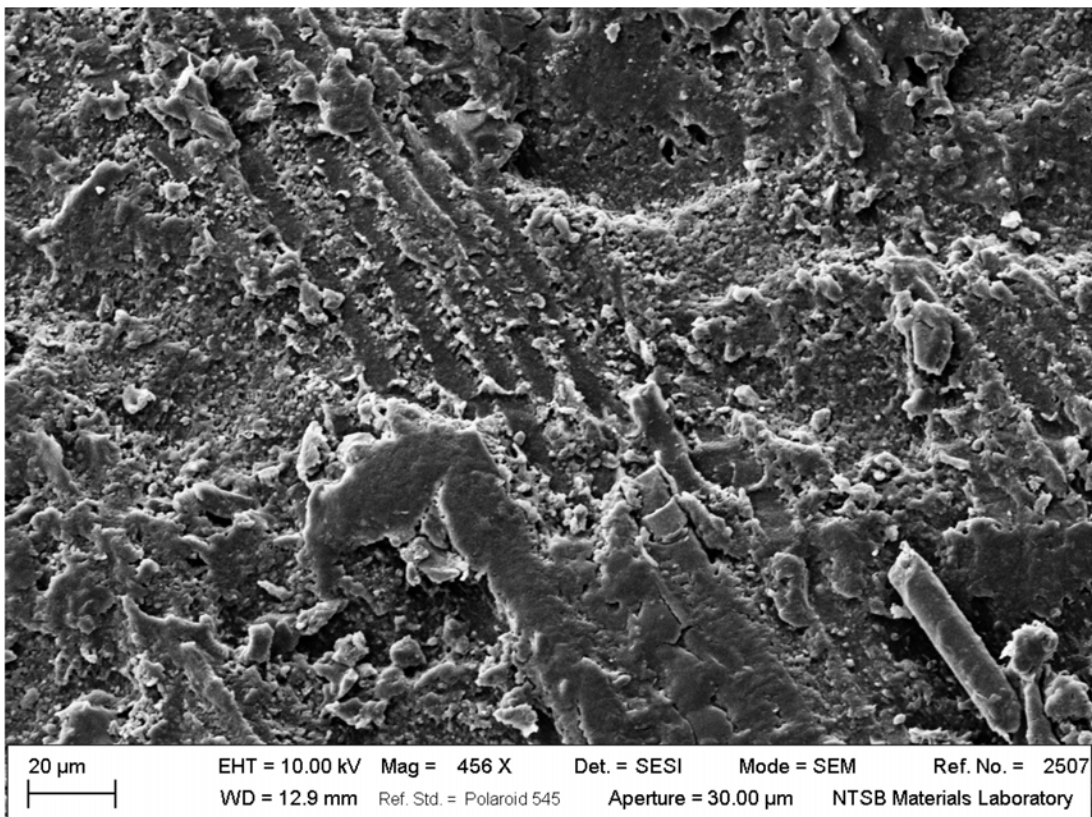
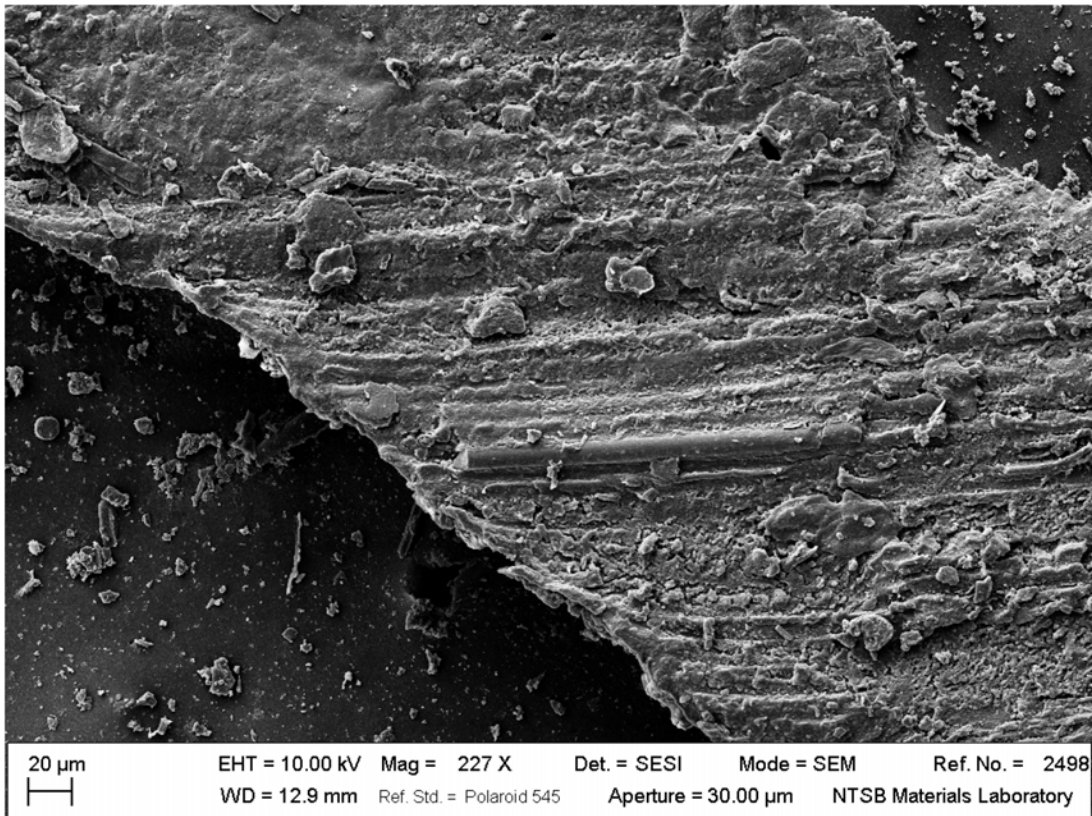


Figure 10. SEM images showing remnant tip block fibers (top) and fiber tracks (bottom) in the separation surface.

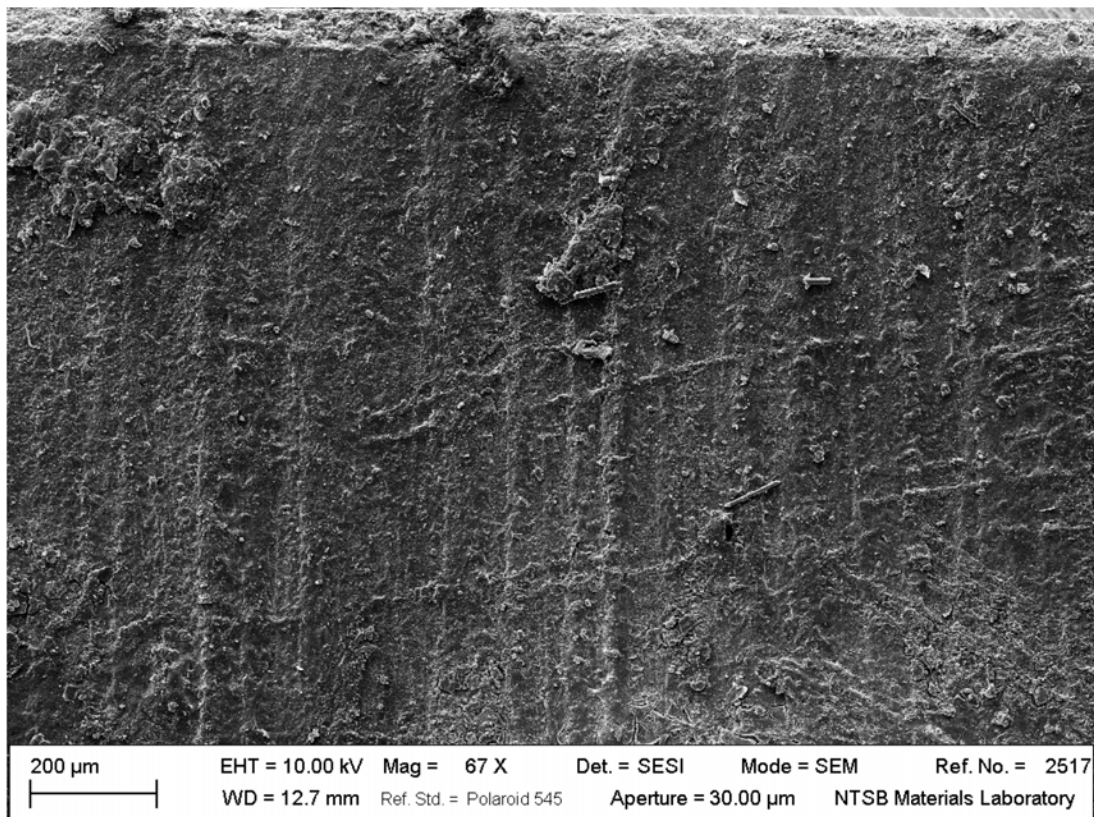
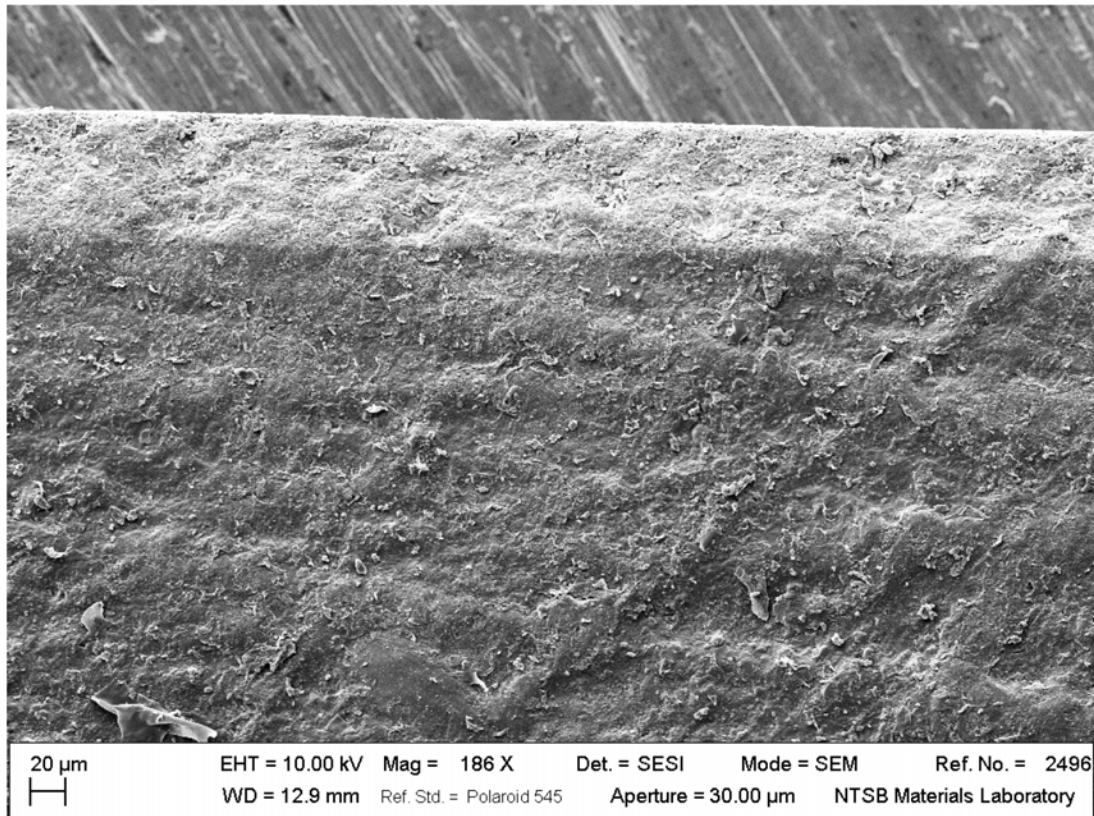


Figure 11. SEM images of worn separation features near the tip edge of the blade on the flat side.

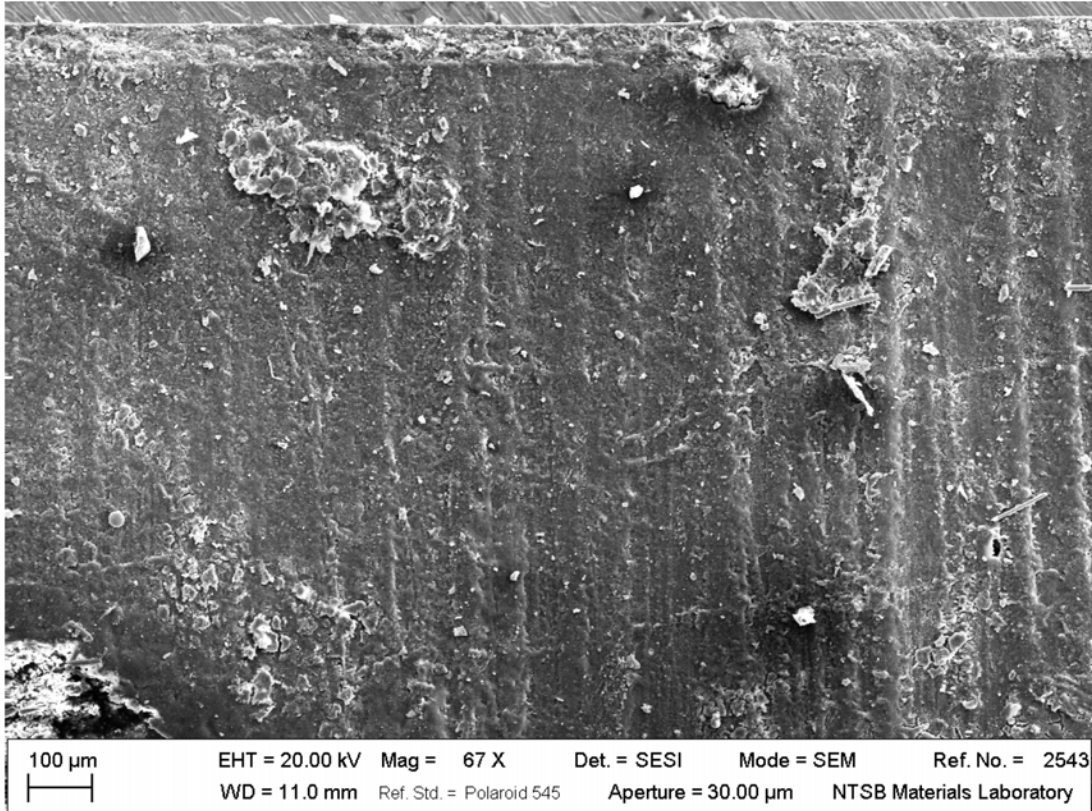
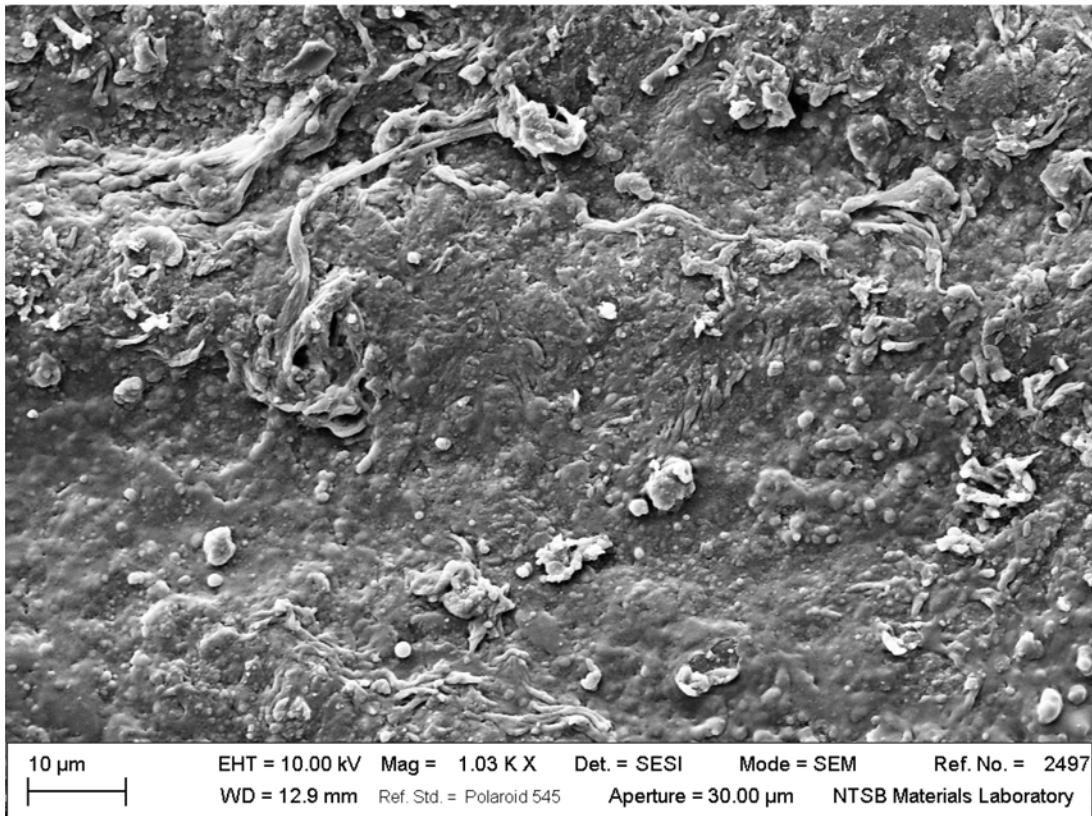


Figure 12. More SEM images of worn separation features with attached debris including scrim and glass fiber fragments.

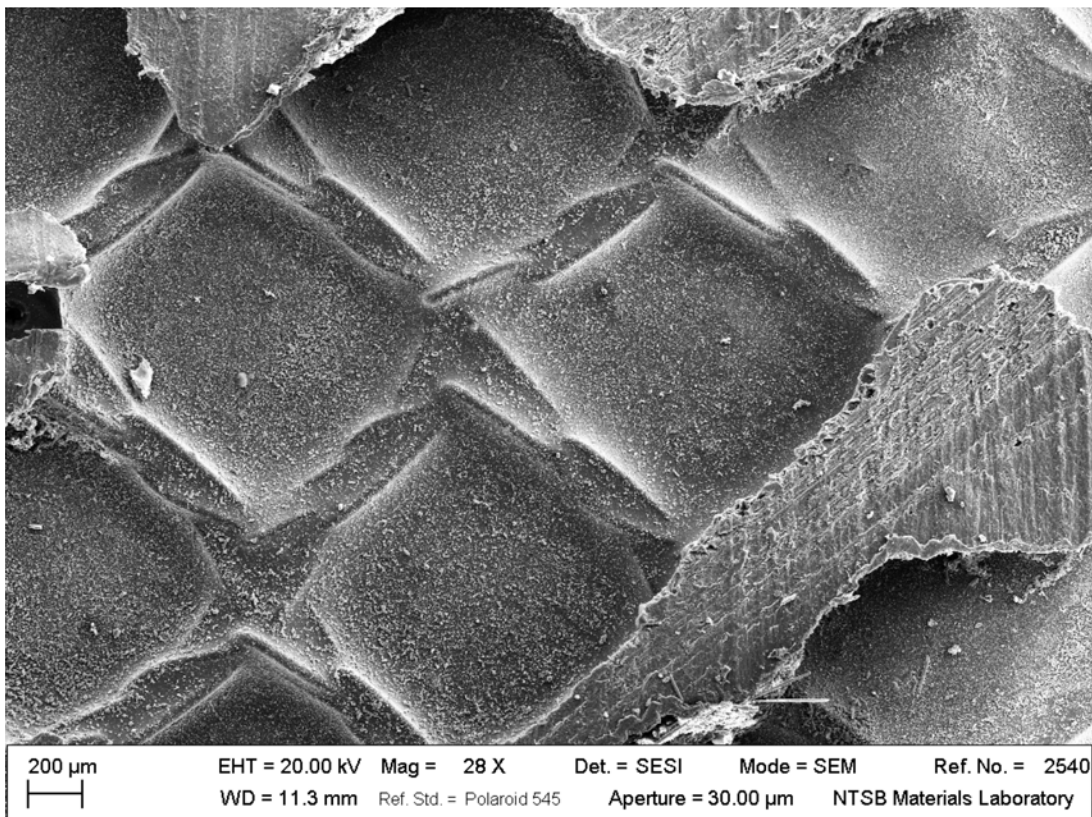
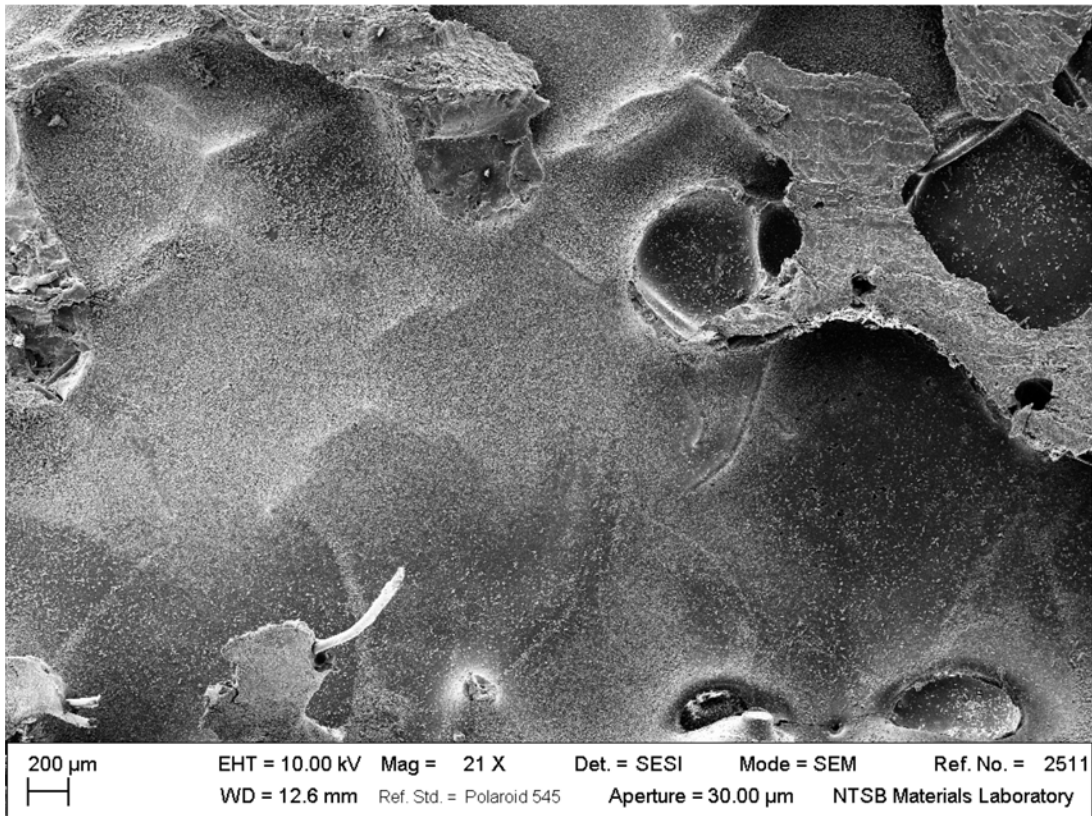


Figure 13. SEM images of fine particulate debris (light colored granular appearing) on the void surfaces.

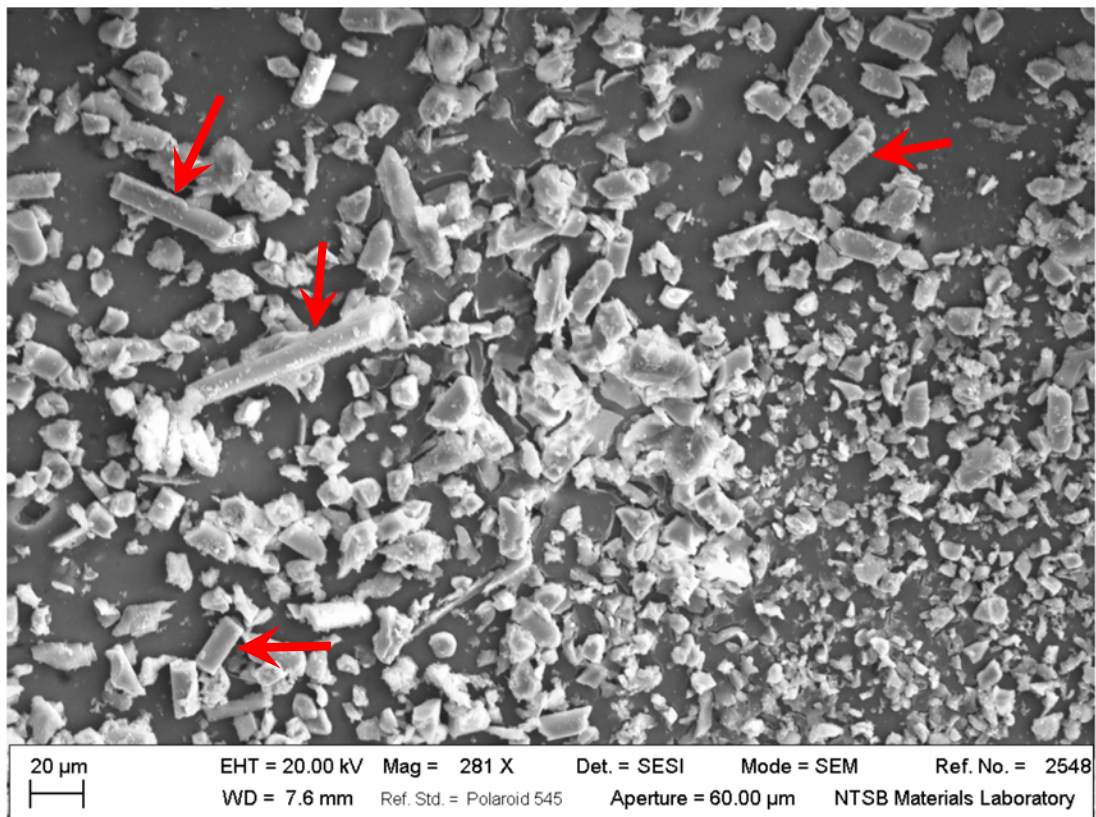
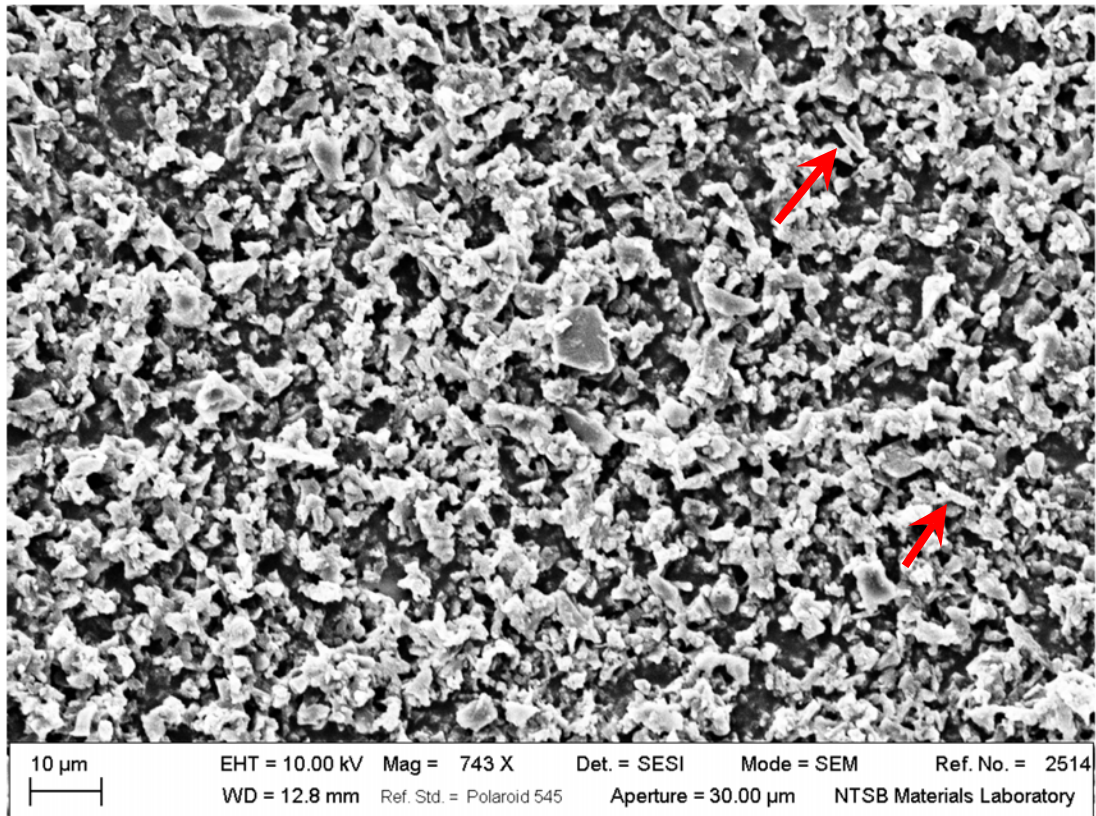


Figure 14. Higher magnification SEM micrographs of the particulate debris from figure 13. Fragmented fibers at red arrows.

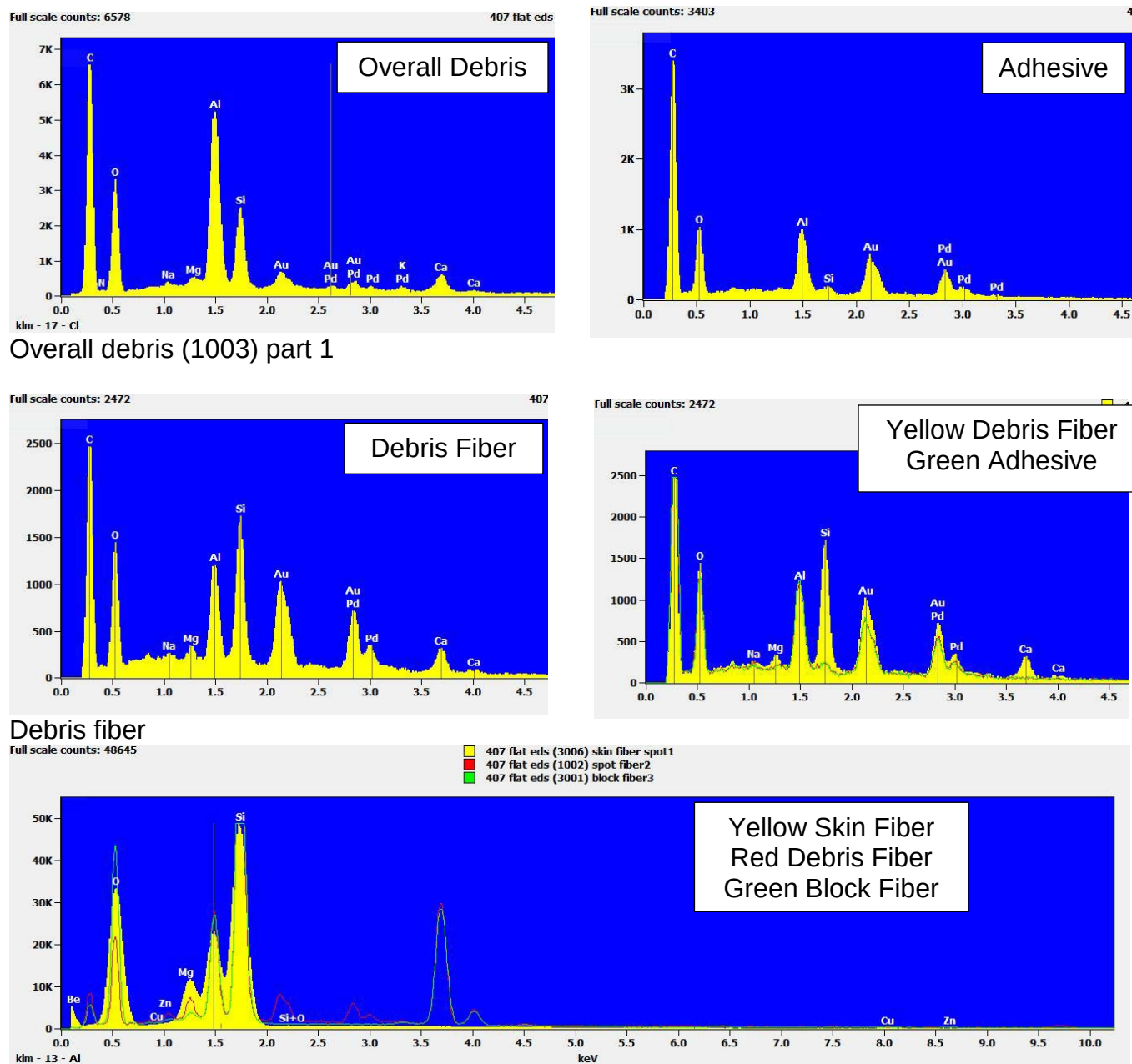


Figure 15. EDS spectra of various regions and components of the blade and debris. All spectra collected at 20kV. Gold (Au) and palladium (Pd) peaks are from the coating. Upper left is an overall spectrum of the debris. Upper right is from the adhesive. The middle left is a spot spectrum from a fiber fragment in the debris. The middle right compares the debris fiber spectrum to the adhesive. The lower compares spectra from debris fibers to that of skin fibers and tip block fibers and establishes that the debris fibers were consistent with the tip block fibers.

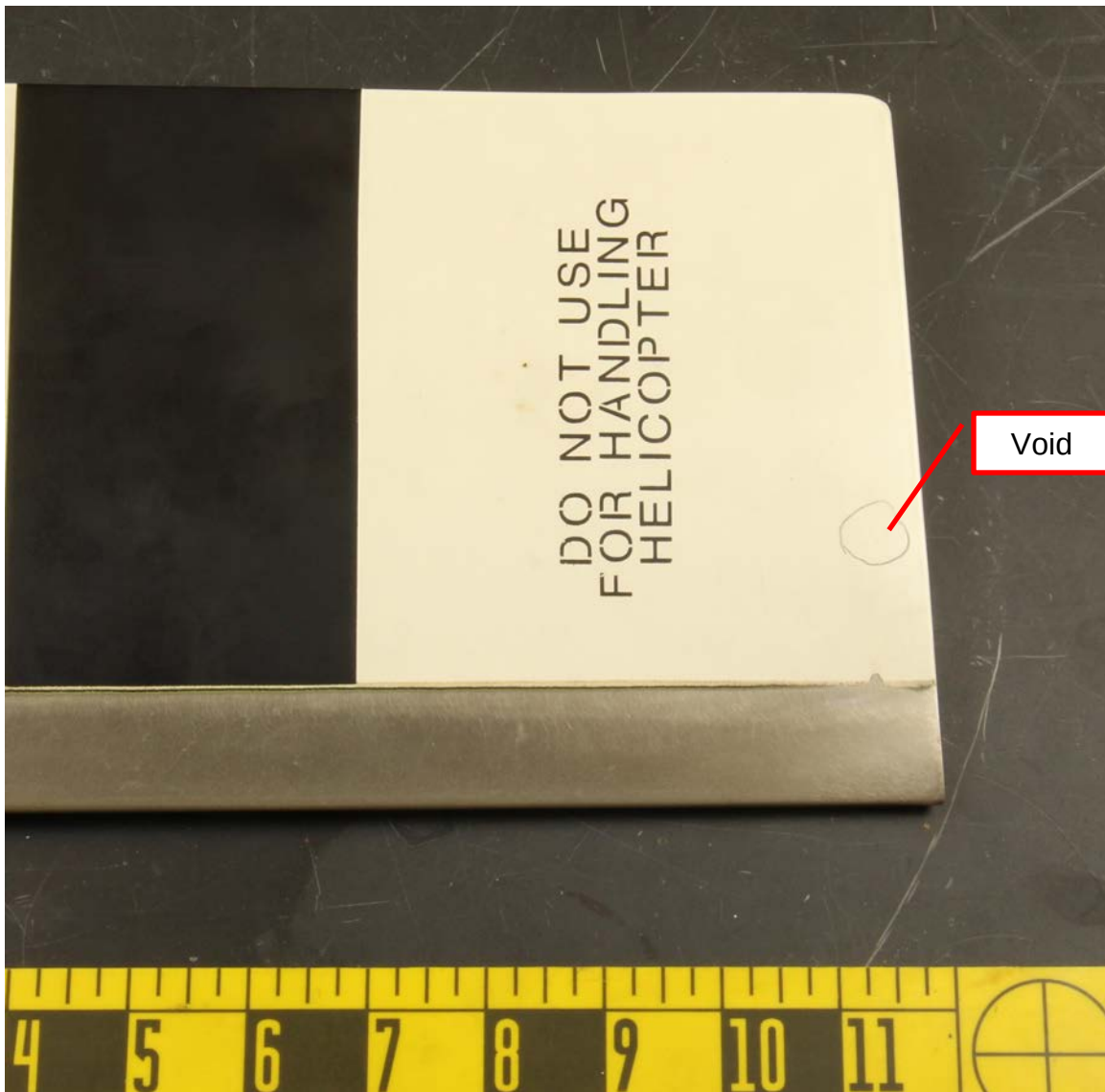


Figure 16. Upper view shows the camber side of intact blade s/n A-4436. Lower view shows the circled location of a void indication in the tip block area on the flat side of the blade.

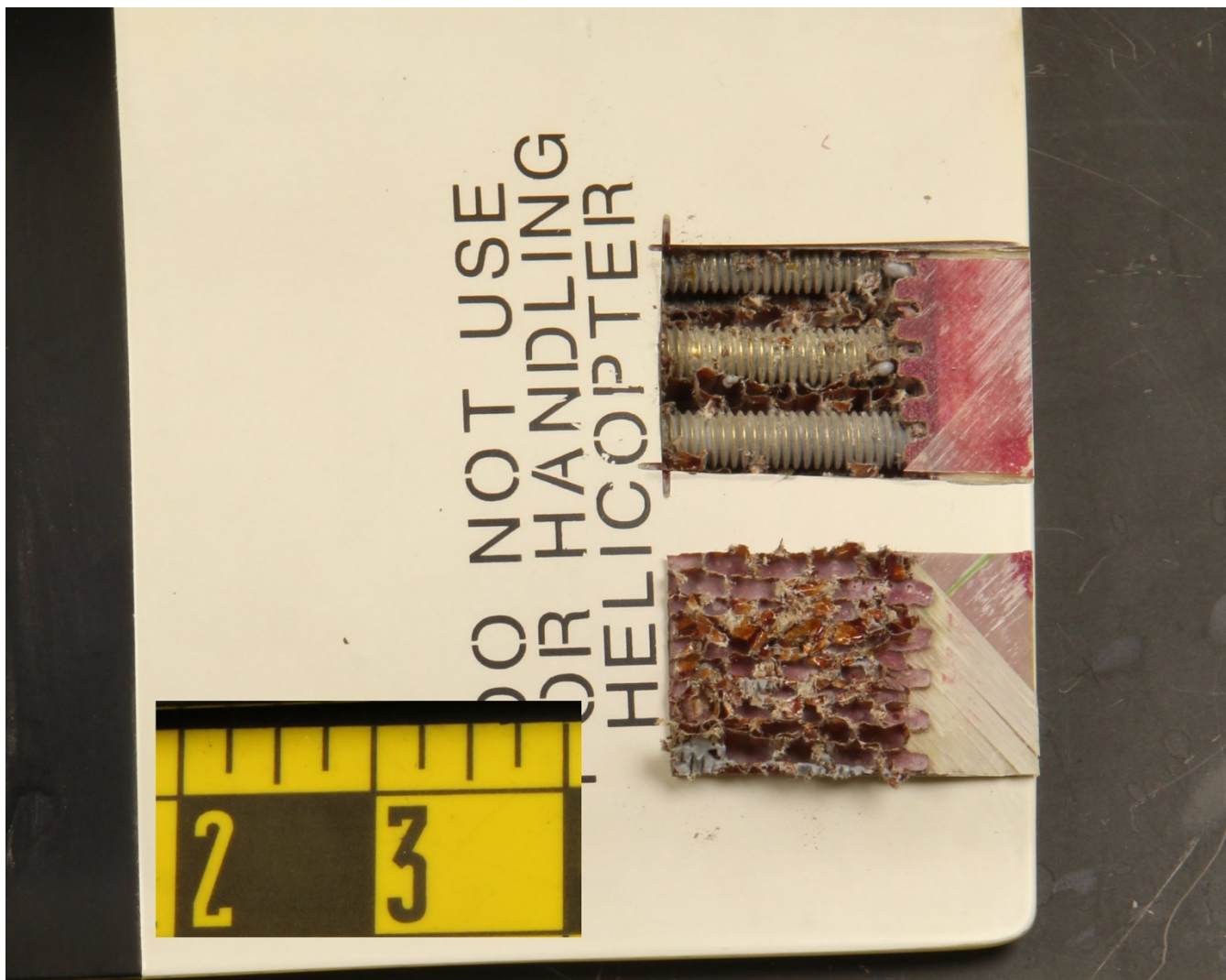
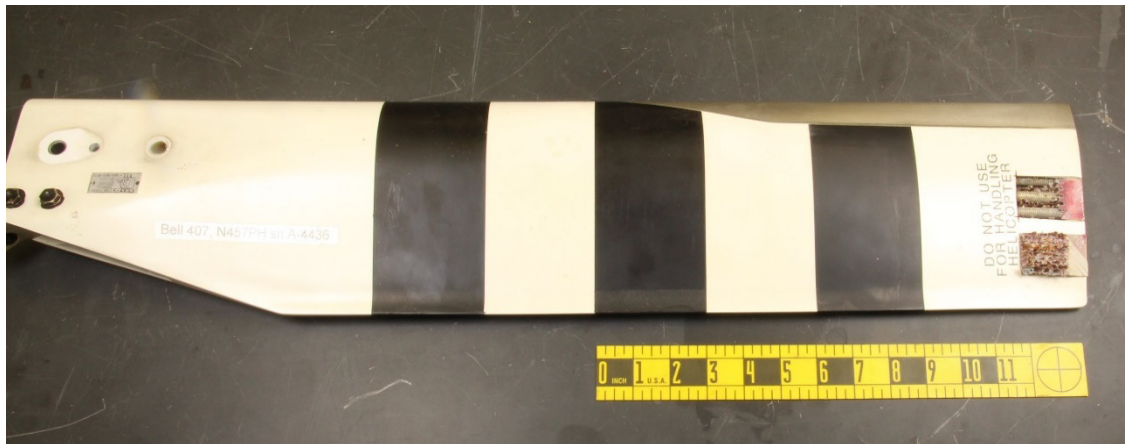


Figure 17. Two views showing blade s/n A-4436 after a test strip was peeled from the camber side of the blade at the tip block. Separation was mostly in the skin material.

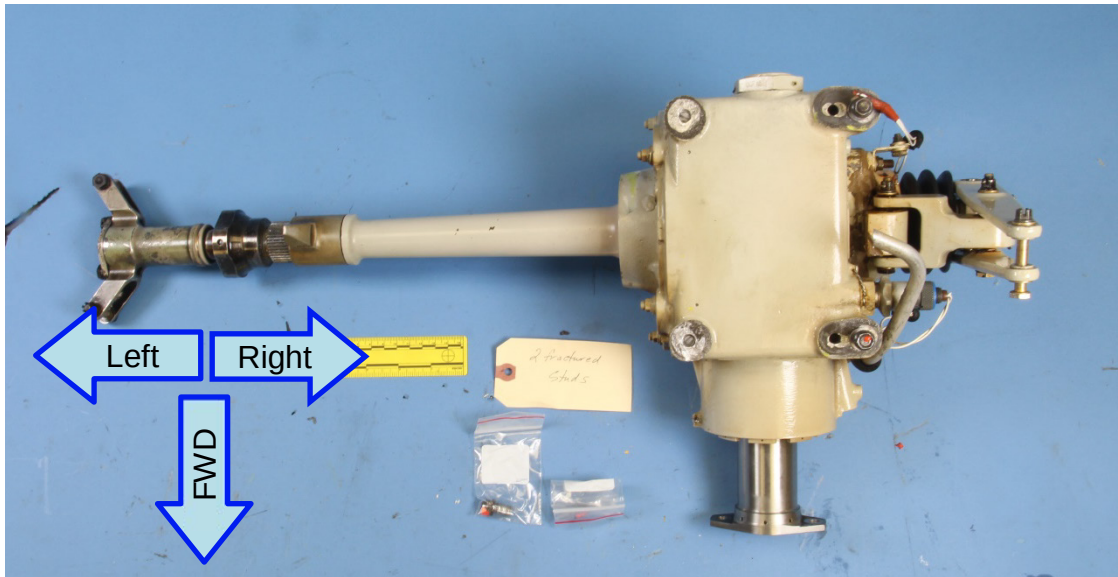
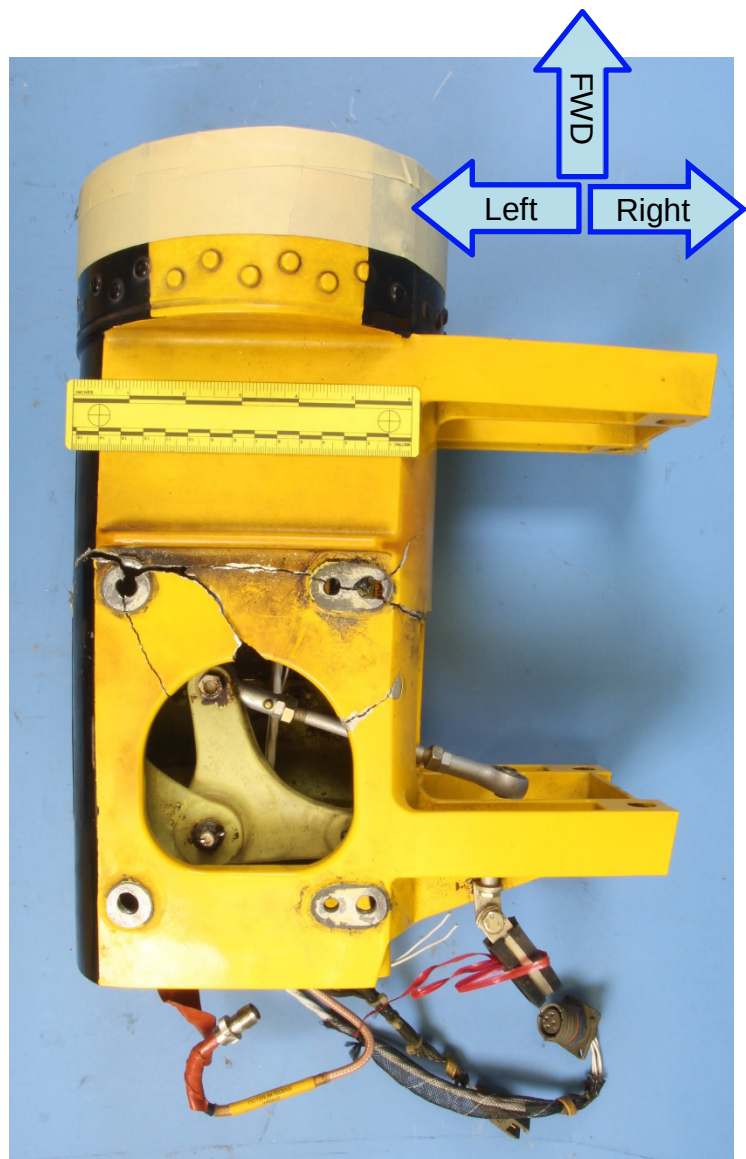
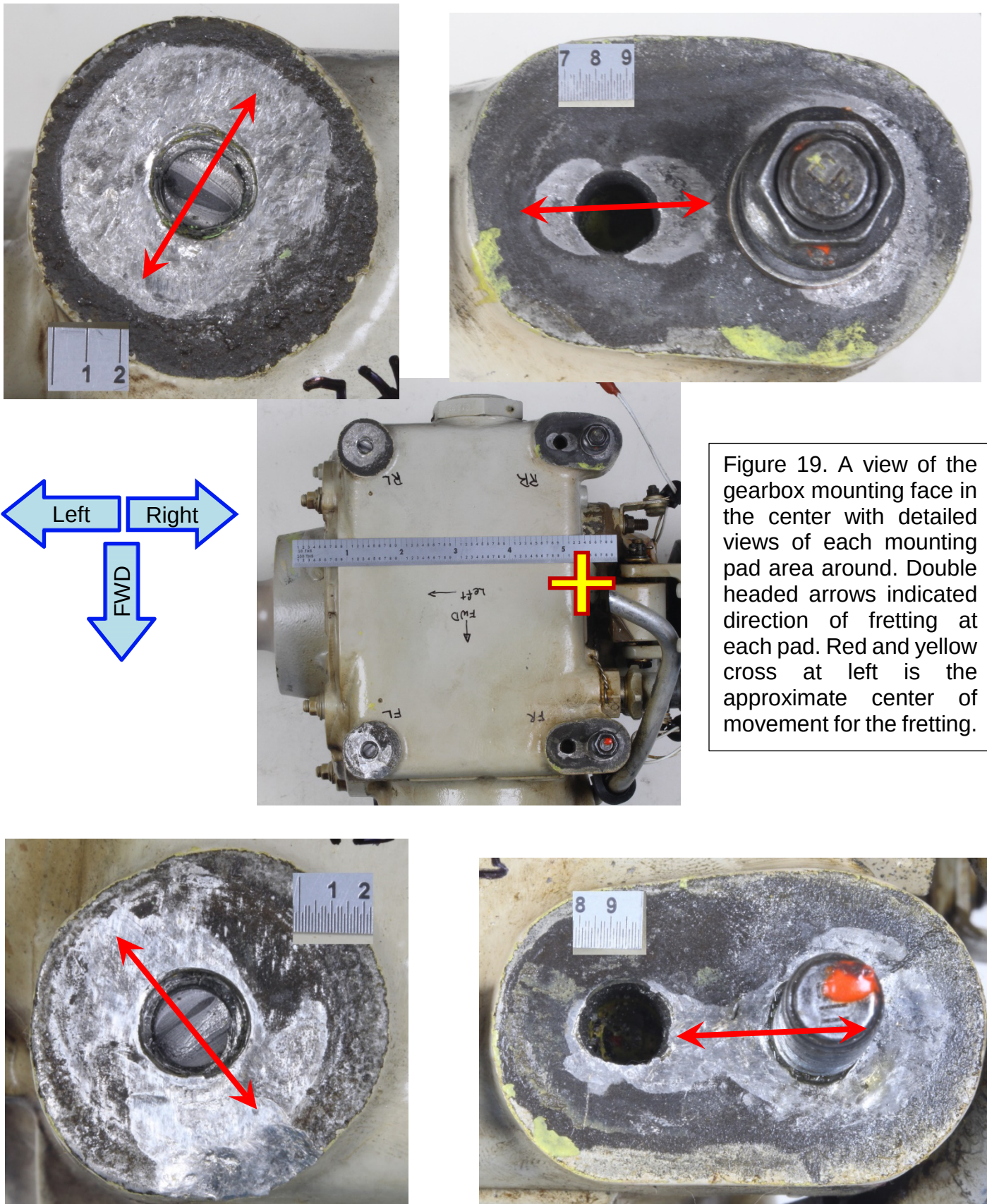


Figure 18

Figure 18. overall views of the as-received tail rotor gearbox assembly with fractured studs (top) and the cracked gearbox support assembly (right).





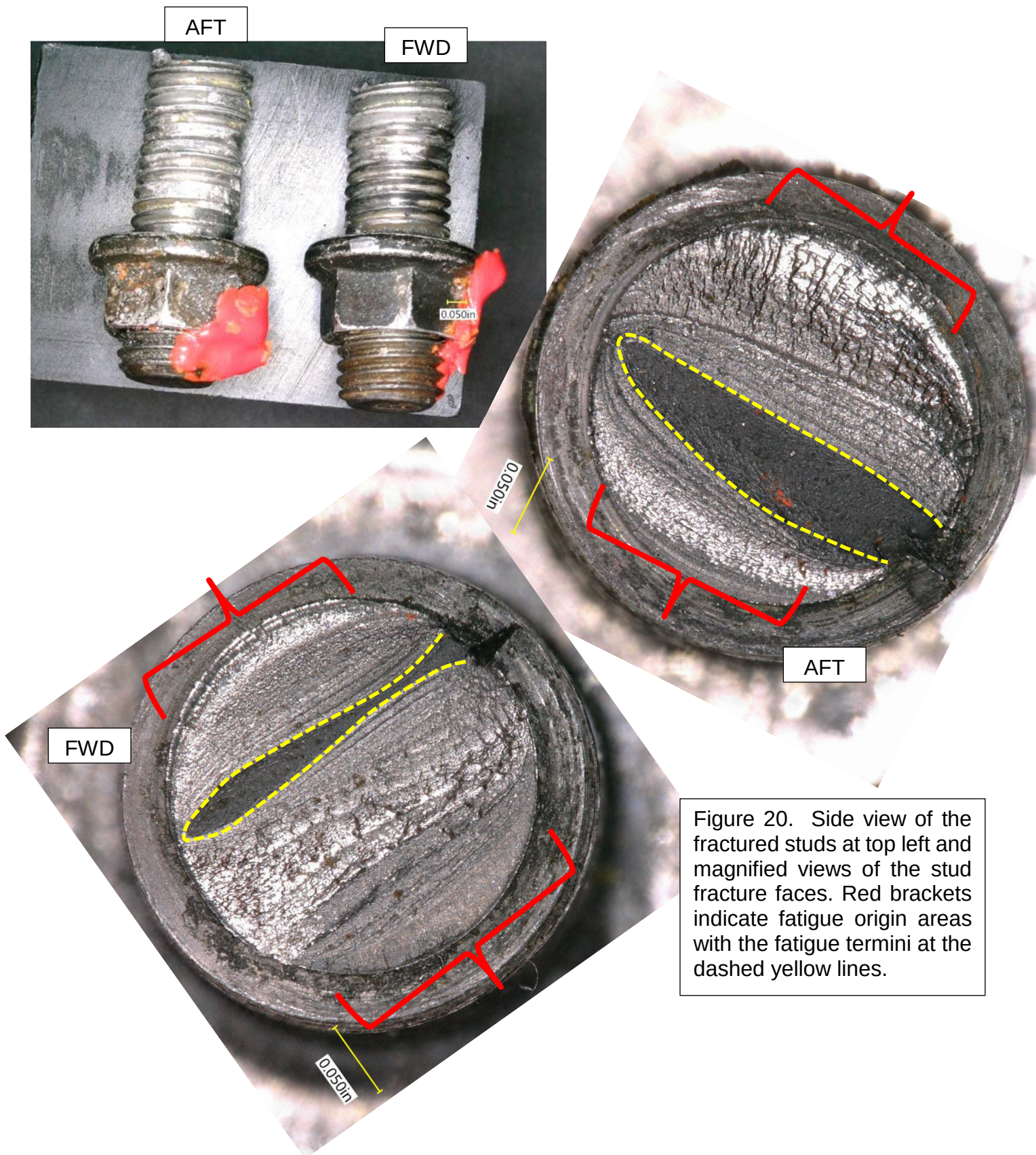


Figure 20. Side view of the fractured studs at top left and magnified views of the stud fracture faces. Red brackets indicate fatigue origin areas with the fatigue termini at the dashed yellow lines.

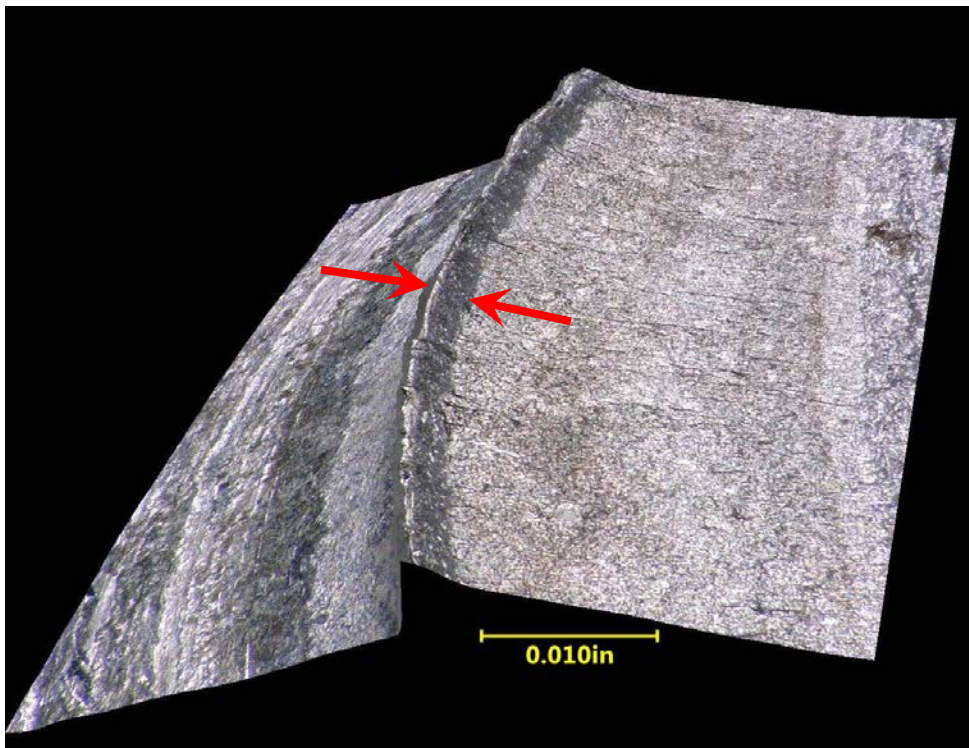
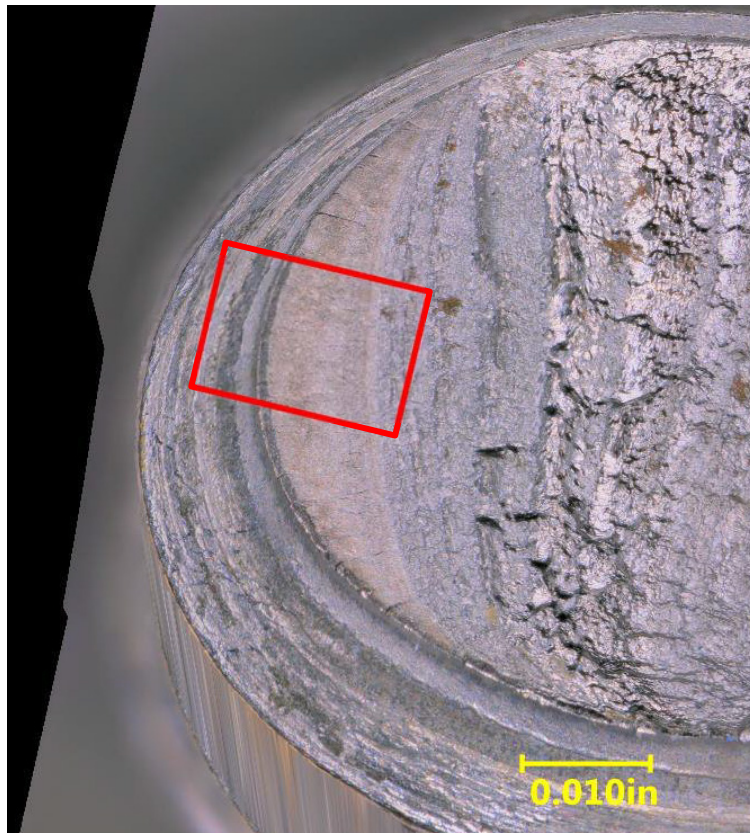


Figure 21. Three-dimensional optical constructions of one fatigue side of the forward stud typical of other fatigue regions. Red box area of upper view showing the small slant plane (between red arrows) at higher magnification below.

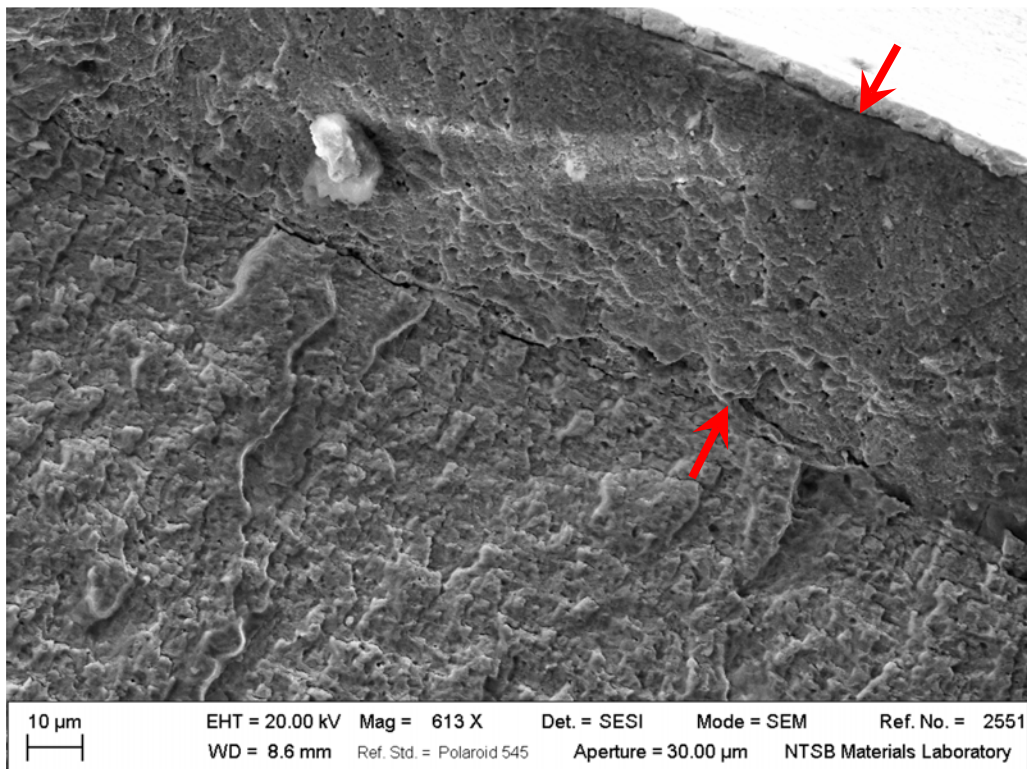
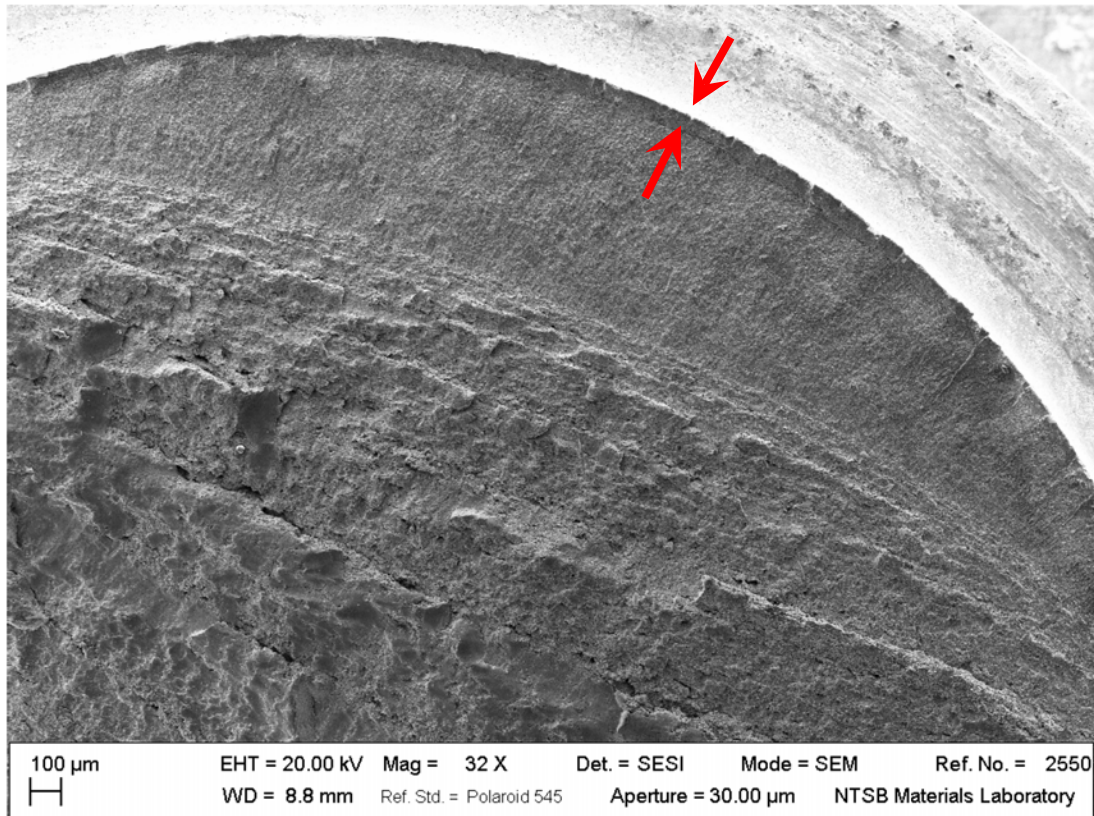


Figure 22. SEM images showing the slant plane (between red arrows) at the fatigue origin of the forward stud. Ductile dimples are visible on the plane in the lower view along with fatigue features emanating from the plane.