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

November 6, 2008

MATERIALS LABORATORY FACTUAL REPORT — Report No. 08-101

## A. ACCIDENT

| | | |
|---|---|---|
| Place | : | Greensburg, Indiana |
| Date | : | August 31, 2008 |
| Vehicle | : | Bell 206L1 |
| NTSB No. | : | CHI08FA269 |
| Investigator | : | Tim Sorensen (ASI-NCRA) |

## B. COMPONENTS EXAMINED

Main rotor blade that fractured into three pieces.

## C. DETAILS OF THE EXAMINATION

Figure 1 shows a photograph of the fractured pieces from the main rotor blade and a sketch showing the approximate location of the fractures. The blade was fractured into three pieces, with a span-wise fracture at approximately 96 inches (8 feet) from the blade tip (corresponding approximately to blade station 126.5[1]) and a fracture without a preferred orientation 32 inches to 38 inches inboard of the span-wise fracture.

Figure 2 shows a closer view of the top surface of the blade in the area of the two fractures and photographs of the mating faces of the span-wise fracture. A span-wise saw cut had been made in the field approximately 5 inches outboard from the span-wise fracture face to facilitate shipping and handling. An identification tag that was bonded to the inboard end of the blade indicated the blade was Bell Helicopter Textron part number 206-015-001-115, and serial number A-5165. According to a representative from the operator of the helicopter, the blade was installed on the helicopter March 21, 2005 and accumulated a total of 2,807.9 hours time-in-service. The blade has a retirement life of 3,600 hours.

The blade was examined in the NTSB Materials Laboratory on September 10 through 11, 2008. Participating in this examination were Aaron Slager from Bell Helicopter, Gary Roach from the Federal Aviation Administration's Rotorcraft Directorate, and James Loftin representing the operator of the accident helicopter (Air Evac Lifeteam).

[1] The stations of the blade are determined relative to the centerline of the helicopter mast, designated a station 0. The blade attachment hole is located approximately at station 18.5, or 18.5 inches outboard of the mast.

## Design

Figure 3 shows a photograph of the cross section of the main rotor blade, when looking at the span-wise saw cut face. At this cross section, the blade contains a spar at the leading edge; an enclosure piece at the trailing edge of the leading edge of the spar, skin overlying a honeycomb core structure trailing the spar; and a trailing edge strip. Approximately a 0.9 inch wide portion of the leading edges of the upper and lower skin pieces are bonded to the upper and lower surfaces of the spar at steps on the trailing side of the spar. The upper and lower skin pieces at the trailing edge for the most part are attached to the edge strip. Lead weight is attached to the inner wall of the spar at the leading edge portion. The pieces on the blade are specified to be mostly bonded to each other with adhesive film, which is cured at elevated temperature. According to a representative from Bell Helicopter, the thickness of an uncured adhesive film is about 0.009 inch. The length of a main rotor blade between the mast and tip is about 222.1 inches. On this model blade, the lead weight extends approximately between blade stations 108 and 215.

## Binocular Microscope Examination

Bench binocular microscope examination of the spar revealed the faces of the diagonal oriented fracture between 32 inches to 38 inches inboard of the span-wise fracture contained matte features on a slant plane consistent with overstress separation with no evidence of fatigue cracking. The inboard face of the span-wise fracture contained fine elliptical-like clam-shell marks typical of fatigue cracking that emanated from the inner surface of the spar at the upper portion of the leading edge radius, in the area indicated by arrow “O” in figures 1, 2, and 4 through 8. The area next to the fatigue origin “O” contained two ratchet marks in figure 5 indicating that the fatigue crack emanated from multiple origins at the inner surface of the spar. The fatigue crack propagated up and through the upper wall portion of the spar and in both directions around the spar. Unmarked arrows in figures 4 through 8 indicate general orientation of fatigue crack propagation.

At the leading edge, the lead weight was spaced from the inside surface of the spar by 0.08 inch, and the space between the weight and the spar was only partially filled with adhesive. The fatigue origin area coincided with a large void in the adhesive. The inner surface of the spar in the area that coincided with the void was clean and did not contain adhesive. The inner surface of the spar in the area that coincided with the adhesive void exhibited fine lengthwise extrusion marks that intersected the fracture, including the fatigue origin area. The fatigue origin area contained no evidence of corrosion or mechanical damage, as shown in figure 6. The vertical length (distance in the up and down direction) of the adhesive void in the area of the fracture face measured approximately 0.4 inch. The depth (distance in the leading edge – trailing edge direction) of the adhesive void measured approximately 0.1 inch. To determine the length of the adhesive void that intersected the span-wise fracture, a 0.02-inch diameter lead-tin solder wire was inserted into the open ends of the void. The length of the wire that could be inserted into the adhesive void via the inboard face of the chord-wise fracture measured approximately 8.4 inches, and the length of the wire that could be inserted into the adhesive void via the outboard face of the fracture measured approximately 0.8 inch, indicating a total void length of 9.2 inches.

Closer examination of the spar revealed the face of the span-wise fracture contained four distinct fatigue crack regions, labeled fatigue crack regions 1 through 4 in figure 4. Fatigue crack region 1 in figure 4 exhibited a luster and extremely fine crack arrest marks. Fatigue crack region 2 contained moderate luster and moderately fine crack arrest marks. Fatigue crack region 3 contained a matte appearance and coarse crack arrest marks. Fatigue crack region 4 exhibited very dull matte and very coarse crack arrest marks. The four fatigue regions were on a flat plane that was perpendicular to the length of the blade.

Fatigue region 1 intersected the interior and exterior surfaces of the spar, measuring approximately 0.164 inch on the exterior surface, as shown in figure 4. The origin of the fatigue crack was located approximately 0.83 inches toward the trailing edge from the leading edge of the spar. The exterior surface of the spar at the upper and lower faces in the areas that extended between the leading edge and approximately 1.5 inches toward the trailing edge was original bare metal. The remaining exterior portion of the blade was coated with paint. Fatigue region 1 in figure 4 intersected the bare metal portion of the exterior surface. The combined length of fatigue crack regions 1 and 2 measured 2.3 inches on the exterior surface. When combined, the four fatigue regions extended across the upper portion of the spar between the leading edge and an area located approximately 3 inches toward the trailing edge. Fatigue crack region 4 extended below the leading edge of the spar, but the fatigue crack portion below the leading edge of the spar at the bottom edge was not exposed to the exterior surface. The fracture at the bottom edge of the spar in the area that extended between the leading edge and 1.2 inch toward the trailing edge contained a shear lip, as indicated in figure 4. The four fatigue crack regions extended through approximately 50% of the spar cross section. The face of the fracture in the areas located outside of the four fatigue crack regions exhibited a rough matte appearance and was on a slant plane consistent with overstress separation. The fracture face at the upper wall portion of the spar in the area located outside of the fatigue region contained two separate crack arrest positions, indicated by two solid lines in figure 4.

**Adhesive**

As indicated earlier, the lead weight was specified to be bonded to the inner wall of the spar with adhesive film. A representative of Bell Helicopter indicated that the color of the adhesive film has been supplied only in red. Although the adhesive between the lead weight and the spar was red, its thickness at the leading edge radius was not consistent with a film application.

Examination of the inboard face of the span-wise fracture revealed that the adhesive material contained the crack arrest marks typical of fatigue cracking, with initiation at the interface with the spar, and propagation mainly in the downward direction and mostly through the thickness of the adhesive material, in the general direction indicated by unmarked arrows in figure 5. Fatigue crack propagation in the adhesive material extended to the trailing edge of the lead weight on the upper surface of the weight, and downward to the leading edge, positions indicated by dashed lines in figure 4. The fracture in the adhesive outside of the

fatigue region was on a slant plane consistent with overstress separation and showed no indication of crack arrest marks.

**Lead Weight**

The lead weight contained upper and lower wall portions and a curved portion at the leading edge between the upper and lower wall portions (see figure 4). Examination of the inboard face of the fracture revealed the upper wall portion of the lead weight showed coarse crack arrest marks typical of fatigue cracking that extended down and through the wall thickness of the lead weight, then to both sides. Fatigue crack propagation was in the general direction indicated by unmarked arrows in figure 4. On the upper side, the fatigue crack terminated near the trailing edge weight, and on the lower side, the fatigue crack terminated approximately in an area that coincided with the leading edge of the spar, in the areas indicated by dashed lines in figure 4. The fracture face outside of the fatigue region (lower wall portion) was on a slant plane consistent with overstress separation and showed no indication of crack arrest marks.

The lower wall portion of the lead weight in the areas that extended between the leading edge and the trailing edge was found debonded from the adhesive film on the inboard side of the fracture. The inner surfaces of the spar and weight were coated with a layer of green primer. The layer of green primer at the lower wall portion of the weight exhibited span-wise cracks in areas adjacent to the fracture face, whereas, the layer of green primer at the upper wall portion and curved leading edge portion between the upper and lower wall portion in areas adjacent to the fracture face did not contain span-wise cracks. The bottom face of the lead weight showed no evidence of fretting or rubbing damage. All portions of the lead weight on the outboard side of the fracture were bonded to the spar.

**Scanning Electron Microscope Examination**

To facilitate scanning electron microscope (SEM) examination of the inboard face of the span-wise fracture, a span-wise saw cut was made through the spar and lead weight approximately 1 inch inboard from the fracture. At this point, the spar remained attached to closure and skin portions. A wedge was driven between the cut surfaces at the leading edge of the spar, and this wedging action caused the 1-inch inboard portion of the spar to separate from the larger inboard blade portion. Figure 4 shows a photograph of the 1-inch inboard portion of the spar that was removed from the larger inboard portion of the blade. This section is referred as the inboard 1-inch section, and is marked with hatched lines in figure 2.

The fracture face from the inboard 1-inch section was cleaned with several applications of replica tape.[2] A replica was then made of the fatigue origin area, and the replica was provided to a representative from Bell Helicopter. SEM examination of the fracture face from the inboard 1-inch section confirmed that the fatigue crack emanated from the inner surface of the spar at the apex portion of a groove that was associated with length-wise extrusion marks,

[2] Replica tape is an acetate-base tape that is applied to and removed from the fracture to replicate the topographical features of a fracture face and to remove debris from the fracture.

see figure 7. The origin of the fatigue crack contained a pore-like feature as shown in figures 7 and 8. The diameter of this pore-like feature measured approximately 4 micrometers (0.0002 inch). As indicated earlier, the inner surface of the spar and the fracture face in the area of the fatigue origin showed no evidence of corrosion damage. Figure 8 shows the fracture features directly adjacent to the origin area. No striations were resolved in this area, either because they were too fine or because of deterioration of the surface as a result of rubbing or other damage. Figures 9 through 13 show the fatigue striation pattern in region 1 in figure 4 with increasing distance from the origin. Figure 13 shows the fatigue striation pattern in region 2 in figure 4. Fatigue crack region 3 in figure 4 contained few striations and for the most part contained ductile dimples. Fatigue crack region 4 in figure 4 contained ductile dimples with very coarse crack arrest marks, consistent with very rapid crack propagation prior to separation. The areas outside of the fatigue regions contained ductile dimple features on a slant plane consistent with overstress separation.

**Removal of Lead Weight to Expose Adhesive Void at the Inboard Side of Chord-Wise Fracture**

The inboard 1-inch section of the spar was immersed for several minutes in a stainless steel tank that contained liquid nitrogen. The inboard 1-inch section was removed from the solution and the trailing edge of the lower wall was secured to the grips of a bench vise with the upper wall portion extending above the bench vise. A wedge was forced into the adhesive bond line between the lead weight and the lower wall portion of the spar at the trailing end area, and this action created a grip area for pliers at the trailing edge of the lead weight. The grip area at the trailing end of the lead weight was grasped by pliers and the lead weight was pulled out of the spar, thus, exposing the void in the adhesive film layer. Visual examination of the inner surface of the spar revealed adhesive film remained attached to the spar with the exception that the adhesive film contained a void in the curved area between the upper and lower wall portion. As indicated earlier, the void is consistent with an air bubble in the adhesive. The void extended through the entire length of the inboard 1-inch section, as previously demonstrated when a wire was inserted into the void. The width of the void was about the same along the entire length of the section.

A Dremel portable grinding tool was used to grind off the edges of the adhesive void to maximize the visibility of the inner surface of the spar in the area that did not contain adhesive. Figure 15 shows a photograph of the inner surface of the inboard 1-inch section. The exposed inner surface portions contained at least eight secondary span-wise cracks, which are indicated by arrowheads in figure 15. .

**Removal of Lead Weight to Expose Adhesive Void at the Outboard Side of Chord-Wise Fracture**

A section of the spar was also excised from the outboard face of the fracture and is referred as the outboard 1-inch section, indicated by hatchet lines in figure 2. The size of the outboard 1-inch section was similar to the size of the inboard 1-inch section. The lead weight was peeled from the outboard 1-inch section using the technique mentioned earlier in the report. Examination of the outboard 1-inch section revealed the adhesive void extended

through the entire length of the 1-inch section. A Dremel portable grinding tool was used to grind off the edges of the adhesive void to maximize the visibility of the inner surface of the spar in the area that did not contain adhesive. Figure 16 shows a photograph of the inner surface of the outboard 1-inch section. At least six secondary span-wise cracks were found on the inner surface (see figure 16). The outboard face of the span-wise fracture contained another fatigue crack that originated from the inner surface of the spar in the area indicated by arrow “O2 in figure 16.

**Metallurgical Sections**

A transverse (span-wise) metallurgical section approximately 0.35 inch outboard of the span-wise fracture in the orientation indicated by section line “A-A” in figure 16 was prepared for metallographic examination. The as-polished section revealed no evidence of delamination between the adhesive and the spar, porosity in the adhesive material, or metallurgical anomalies in the spar material. The same section after it was etched with Keller’s reagent revealed the outer edges of the spar contained much larger grains compared to the core of the spar. A close-up photograph of the etched section is shown in figure 17.

A longitudinal (lengthwise) section was made through the outboard face of the span-wise fracture at an area that intersected the approximate origin of the fatigue crack in the orientation indicated by section line “B-B” in figure 16. Examination of the as-polished surface revealed multiple irregular pore-like features in the spar. A large amount of irregular pore-like features was found adjacent to the inner surface of the spar in an area located approximately between 0.1 inch and 0.15 outboard from the fatigue crack origin “O” in figure 18. The amount of irregular pore-like features was less at the fatigue origin area. Higher magnification view of the section revealed that the pore-like features did not contain inclusion material, as shown in figure 19. Section “B-B” intersected cracks labeled cracks “E” and “F” in figure 16. Crack “E” extended approximately 0.045 inch below the inner surface of the spar, and crack “F” extended approximately 0.062 inch below the inner surface of the spar.

**Additional Cuts to Expose the Lead Weight**

The inboard end of the lead weight was located approximately 16 inches inboard of the span-wise fracture. In order to expose the lead weight portion on the inboard side of the span-wise fracture, a longitudinal saw cut was made approximately 3.3 inches toward the trailing edge from of the leading edge, and an area that extended between the span-wise fracture and an area located approximately 17.5 inches inboard of the span-wise fracture. At the inboard face of the span-wise fracture, the lower wall portion of the lead weight was deformed and extended above the spar inner surface. Adhesive film remained bonded to the spar inner surface in the area that corresponded to the location of the deformed lower wall portion of the lead weight. An air gap existed between the deformed lower wall portion and spar inner surface. The air gap between the lower wall of the lead weight and the spar inner surface extended 4.6 inches inboard from the span-wise fracture.

**Elemental Analysis, Hardness Testing, and Electrical Conductivity**

The spar, skin, honeycomb core, closure piece and edge strip are to be made from 2014 aluminum alloy that was to be heat treated to the –T6 condition. X-ray energy dispersive spectroscopy analysis of the cut surface of the spar produced a spectrum that contained a major peak of aluminum and minor peaks of silicon, copper, manganese, and magnesium, consistent with the specified 2014 aluminum alloy. According to a representative from Bell Helicopter, the specified minimum hardness was to be Rockwell “B” 78. Rockwell hardness testing of the cut surface at the leading edge portion of the excised 1-inch spar portion produced an average hardness of HRB 81, which was greater than the specified minimum hardness (HRB 78). The same representative indicated that the specified electrical conductivity for this material in the T6 condition should be in the range between 36% and 39.5% IACS. The conductivity of the cut surface at the leading portion of spar measured 38.5% IACS, which was within the specified range.

Frank P. Zakar
Senior Metallurgist

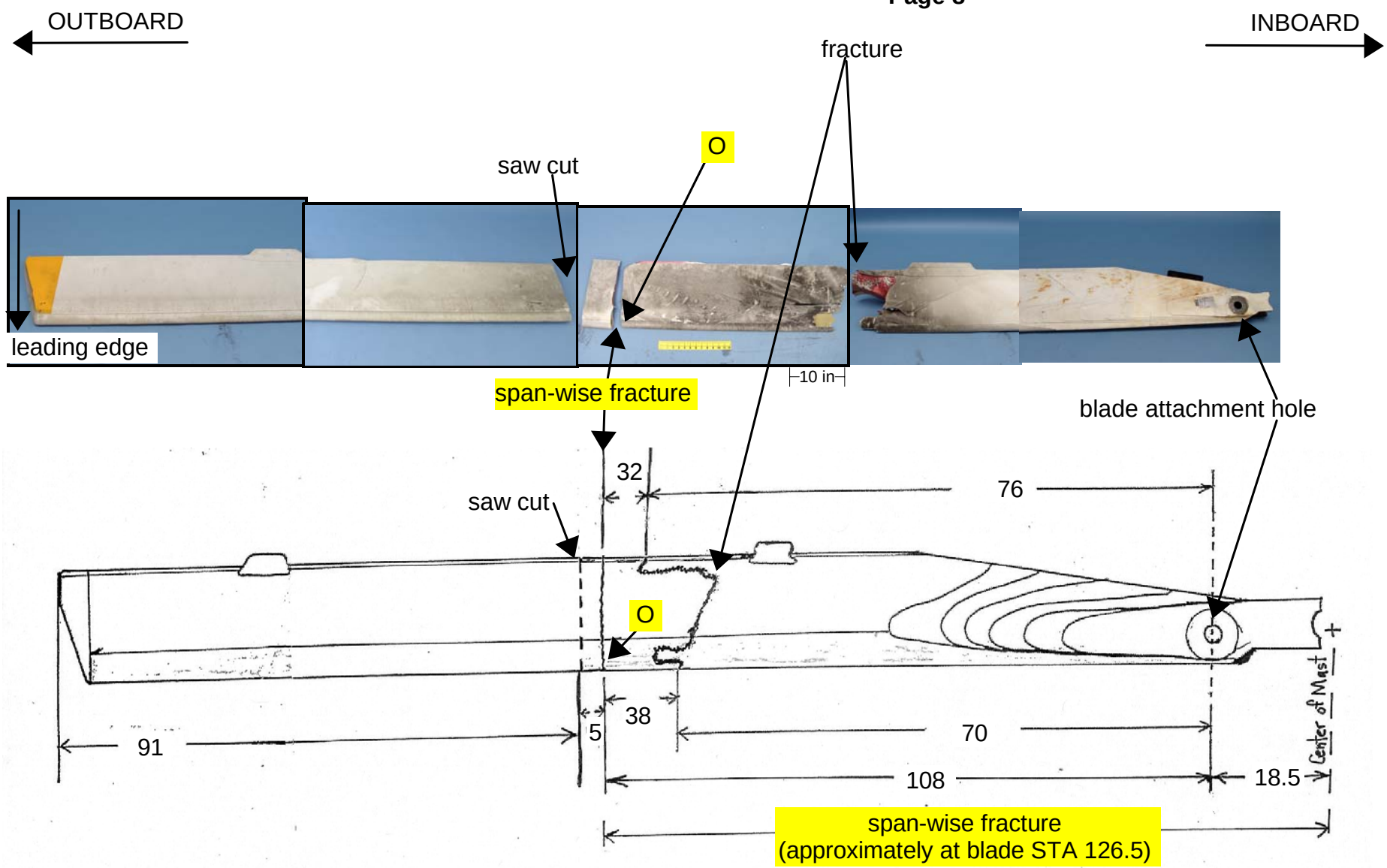


Figure 1. Composite photograph showing the top face of the main rotor blade that fractured into three pieces (top of page) and sketch not to scale of the fractured blade (bottom of page). A fatigue crack emanated from the inner face of the spar in the area indicated by arrow "O". Dimensions shown are in inches and were measured relative to the attachment hole for the blade. The fatigue crack was located approximately at blade station 126.6. Blade station numbers are measured relative to the center of the mast.

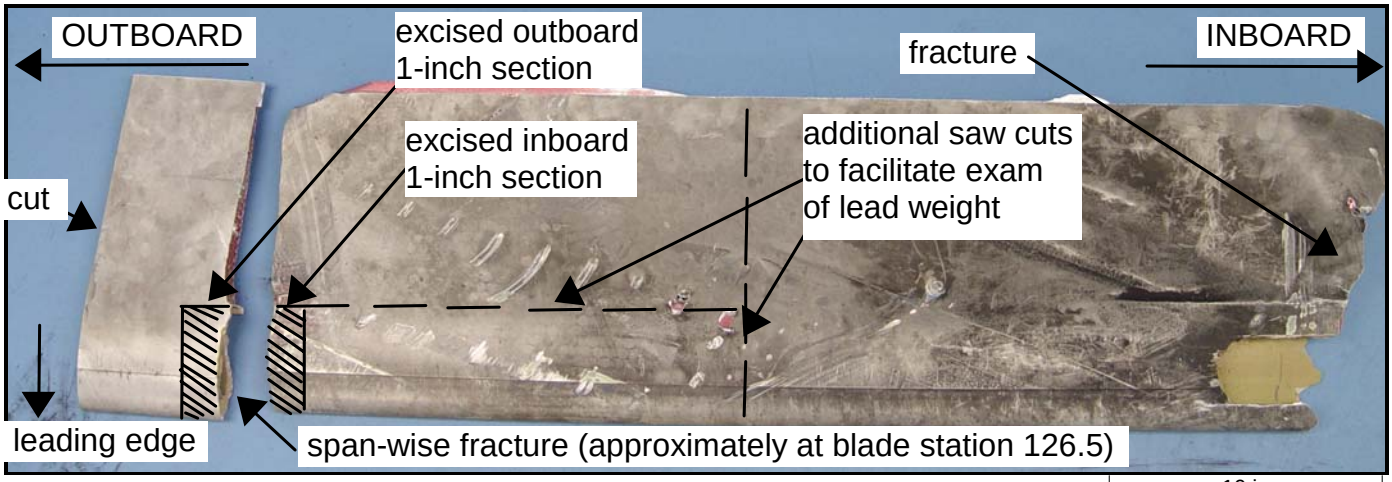


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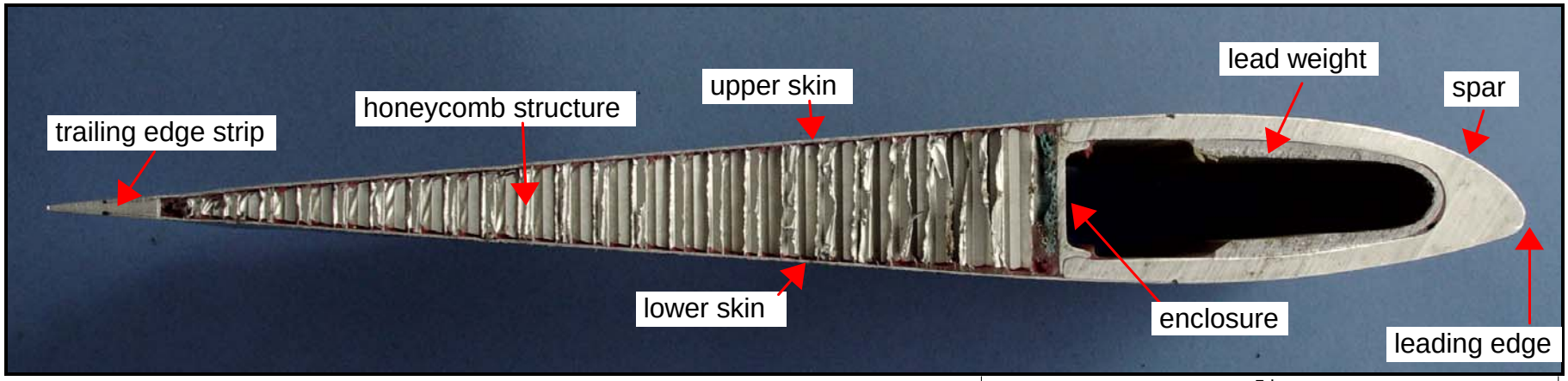
Figure 2. Close-up view of the top face of the main rotor blade in the general area of the span-wise fracture (top of page), inboard face of the span-wise fracture (center of page), and outboard face of the span-wise fracture (bottom of page). A fatigue crack was found in the span-wise fracture and emanated from the inner face of the spar in the area indicated by arrow "O". One-inch thick sections were removed from the span-wise fracture to facilitate examination of fatigue origin area.

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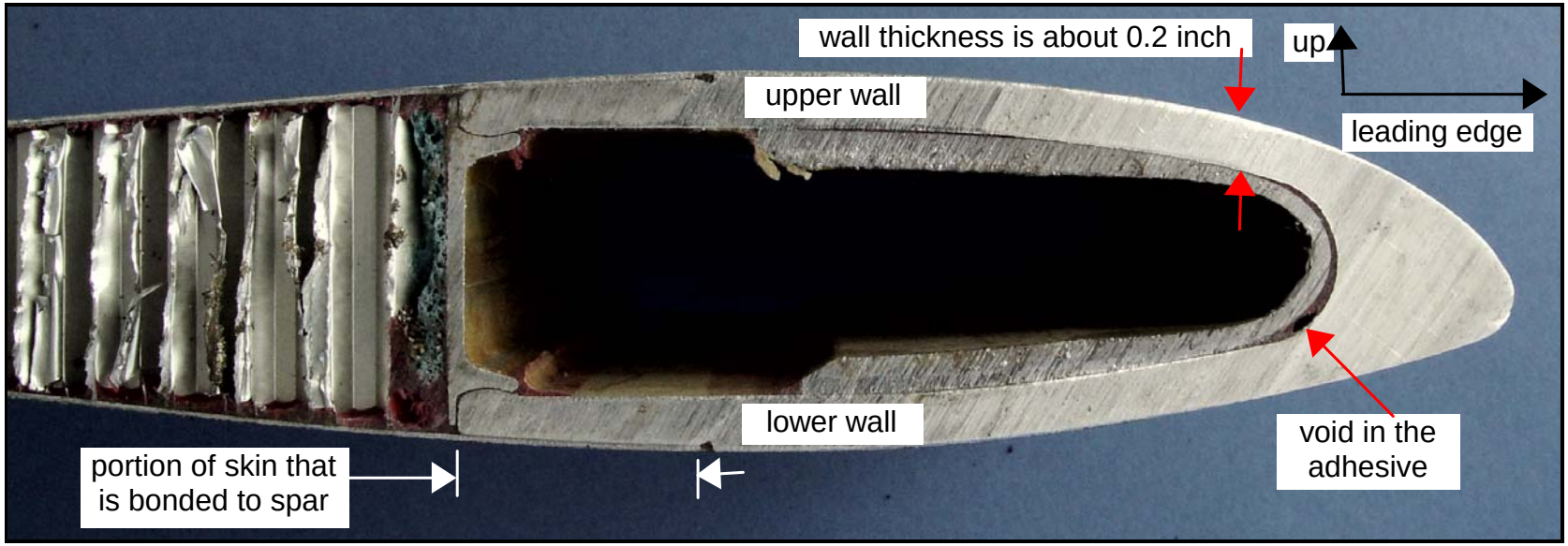


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Figure 3. Cross section of the main rotor blade showing the different parts of the blade (top photograph) and a close-up view of the spar portion (bottom photograph). Photographs were taken from the saw cut portion in figure 1. Color of the adhesive between the spar and lead weight is red.

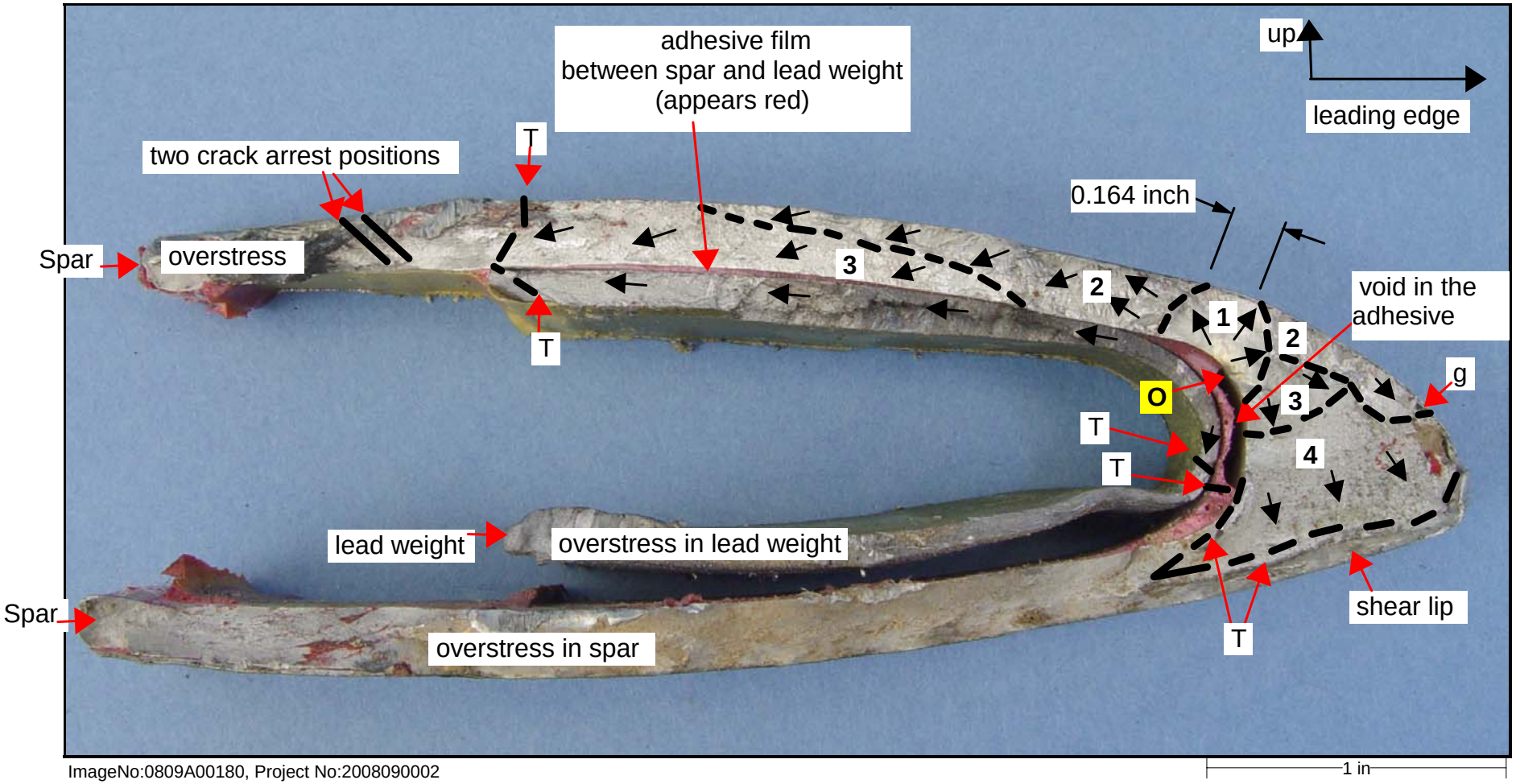
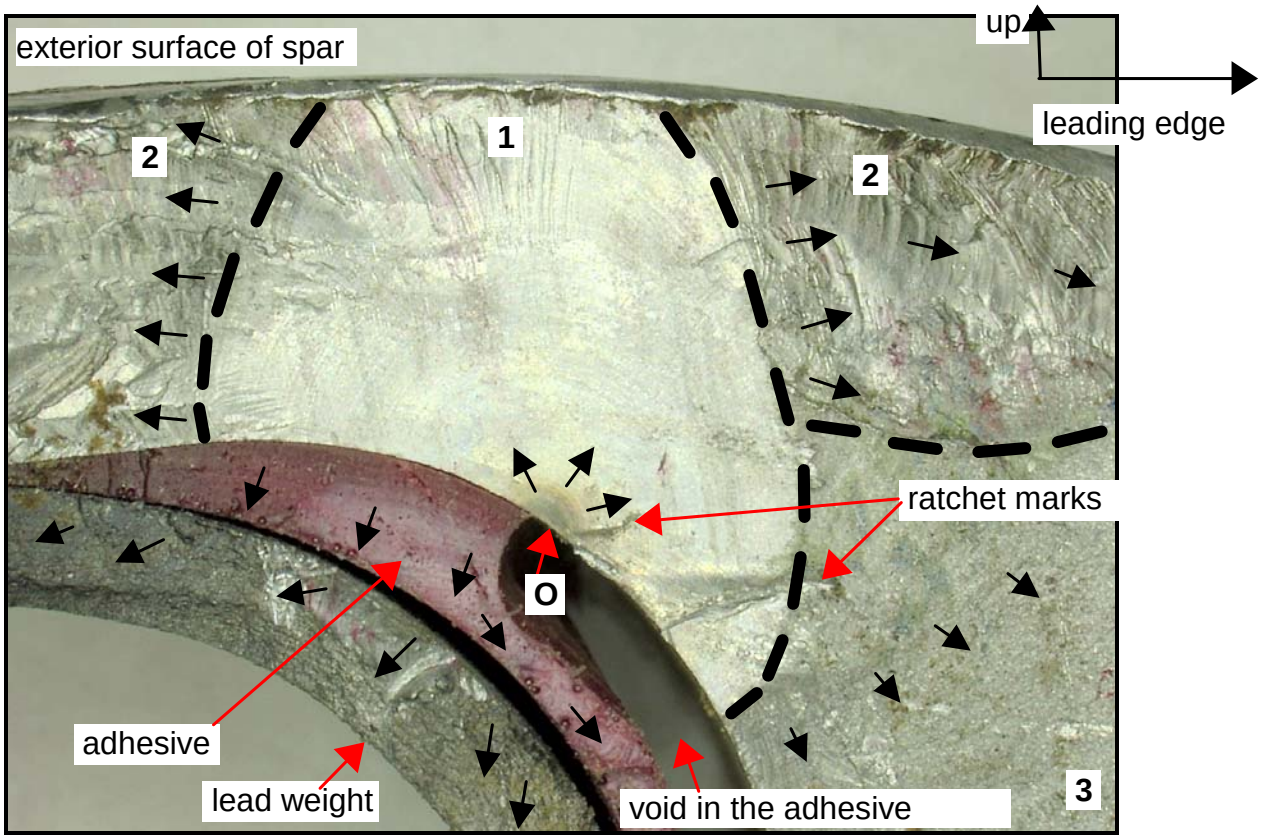



Figure 4. View of the inboard face of the span-wise fracture after the fracture was excised from the larger inboard piece of the main rotor blade. The closure was removed to facilate examination of the inner face of the spar. A fatigue crack emanated from the inner surface of the spar in the area indicated by arrow "O". Arrow "T" indicates the terminus of the fatigue crack in the different parts of the spar, lead weight and adhesive film.

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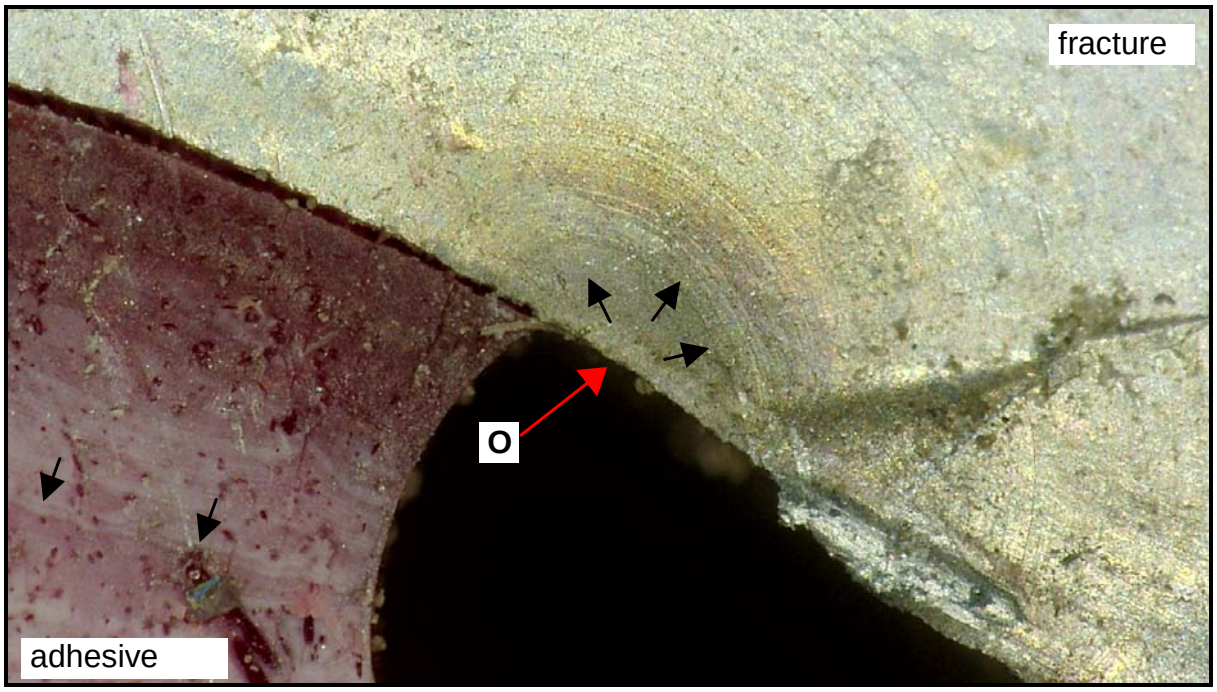


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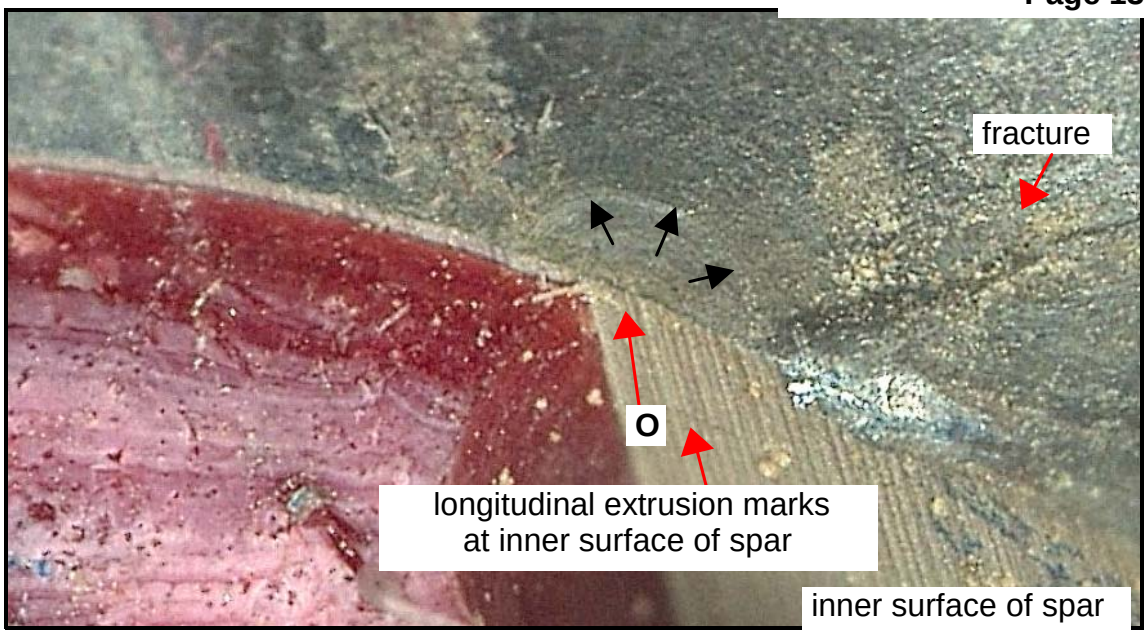
Figure 5. Photographs of the inboard face of the span-wise fracture in the area of the fatigue origin area, indicated by arrow "O". Fatigue regions 1 through 3 on the upper photograph correspond to the regions shown in figure 3.

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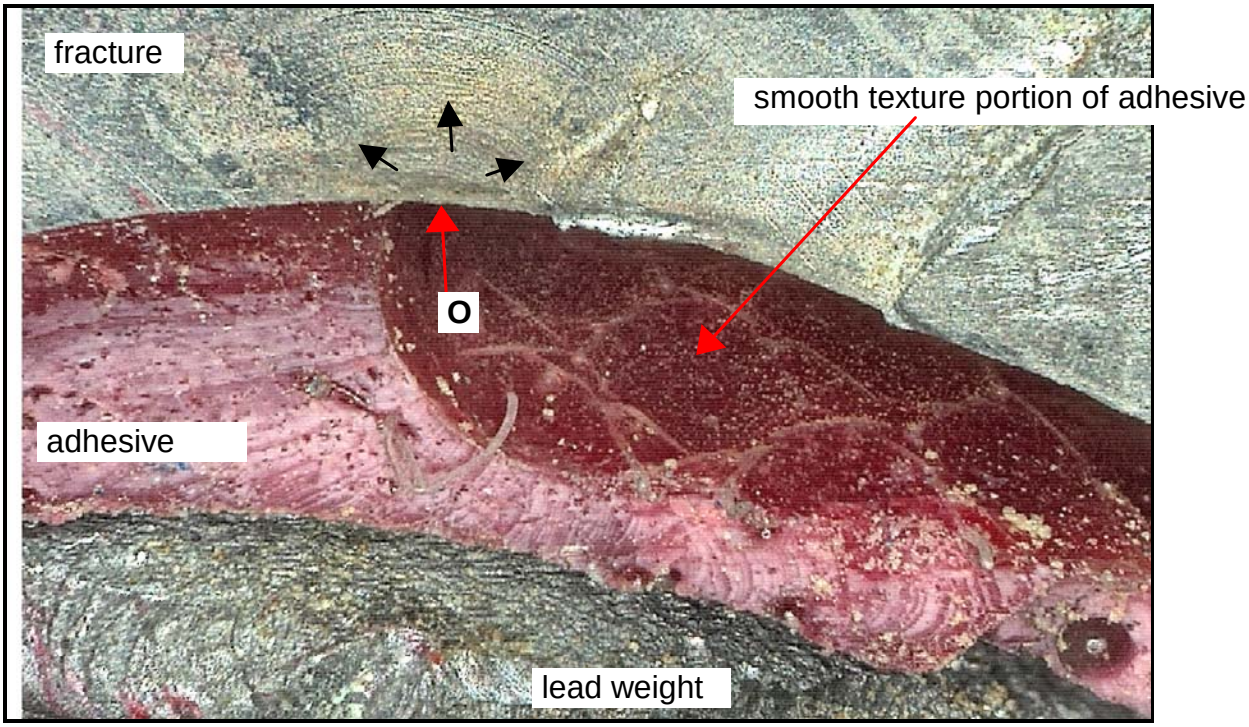


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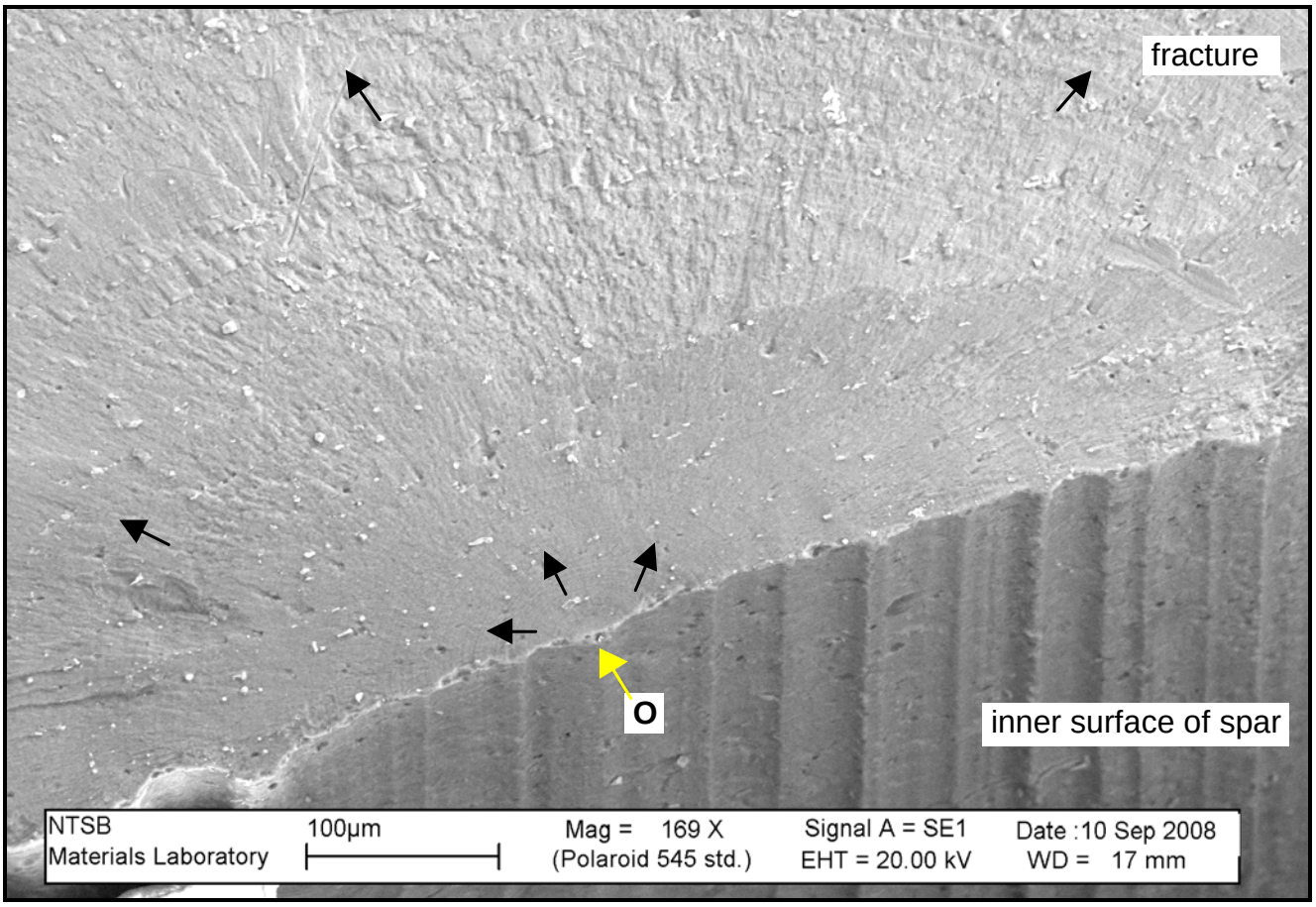
Figure 6. Photographs of the inboard face of the span-wise fracture in the area of the fatigue origin area, indicated by arrow "O". The photograph at the top of the page shows the inner surface of the spar and longitudinal extrusion marks that intersected the fatigue origin area. The photograph at the bottom of the page shows the corresponding surface of the adhesive.

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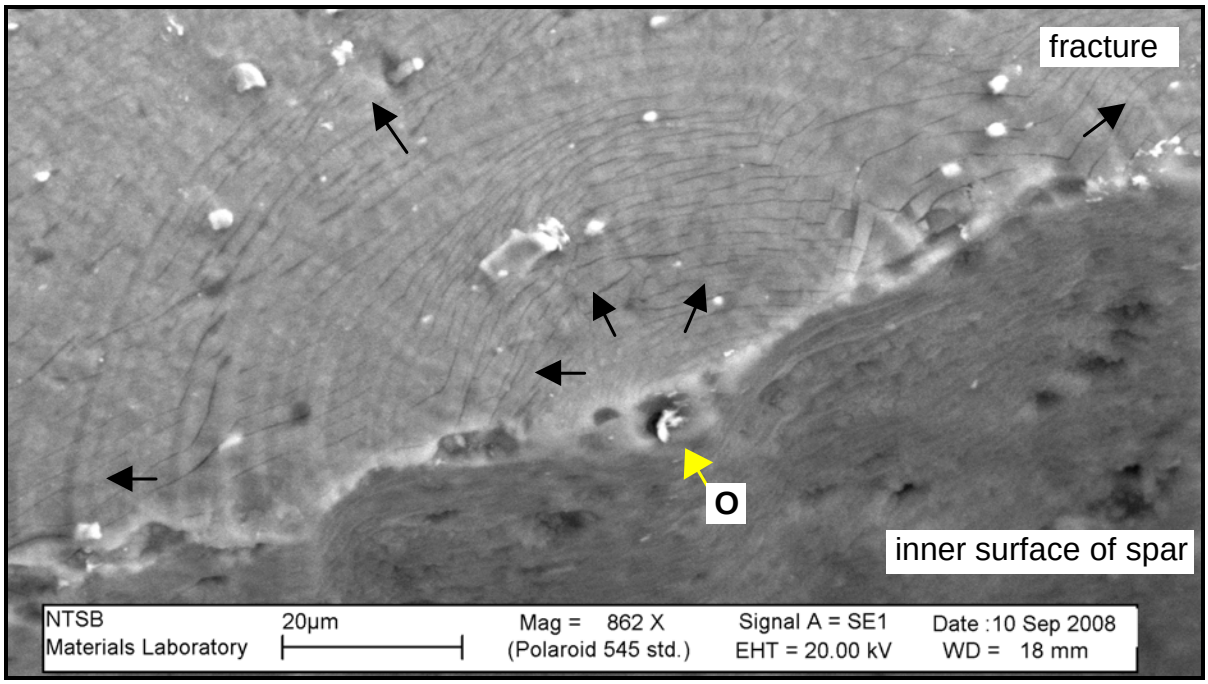


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Figure 7. Scanning electron microscope (SEM) photographs showing a portion of the inboard face of the span-wise fracture and the inner surface of the spar. A fatigue crack emanated from the inner surface of the spar in an area that contained longitudinal extrusion marks. The origin of the fatigue crack is indicated by arrow "O". The fatigue crack emanated from a pore on the inner surface of the spar.

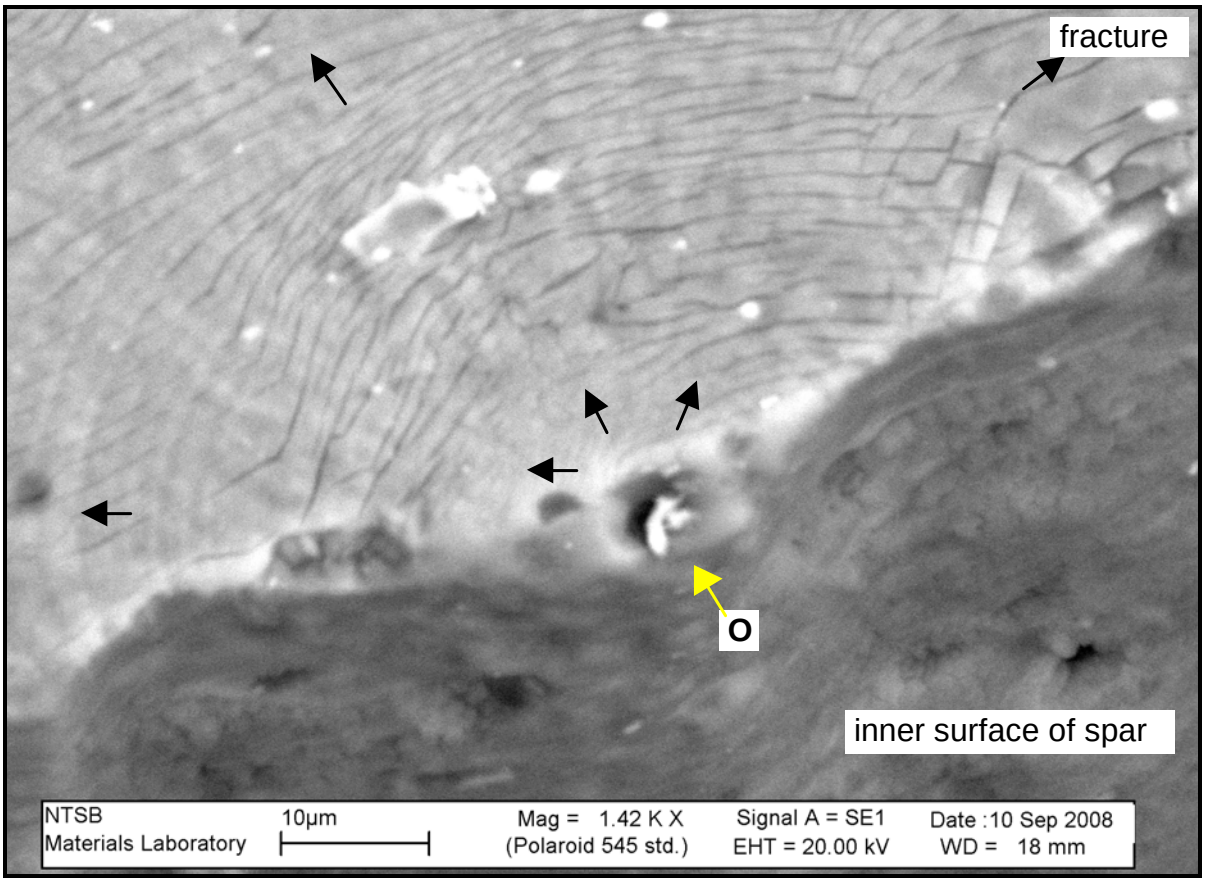


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Figure 8. Higher magnification SEM photograph of the fatigue origin that was shown in figure 7. The fatigue crack emanated from a pore at the inner face of the spar, in the area indicated by arrow "O".

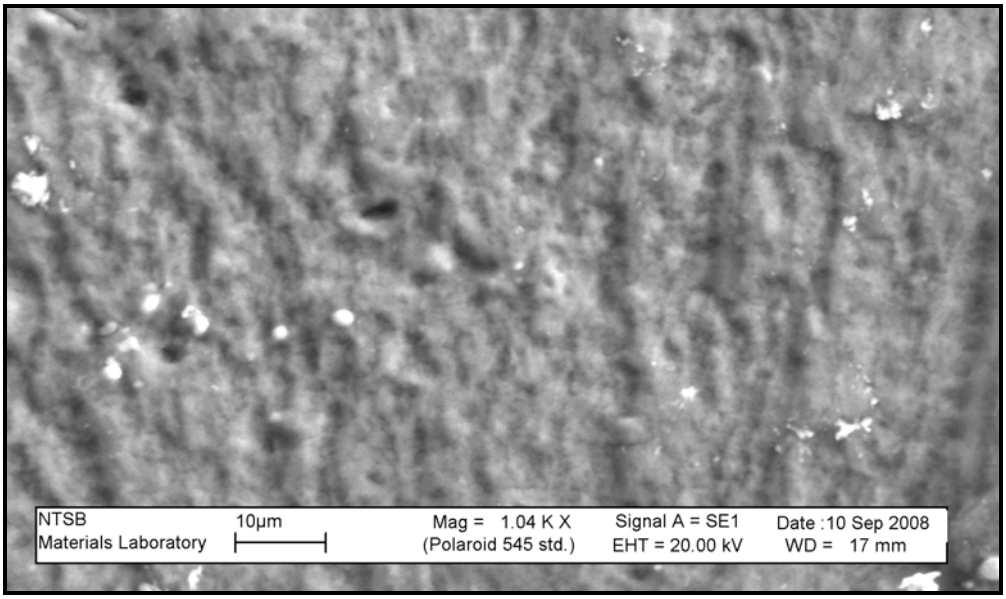


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Figure 9. SEM photograph of the face of the fracture located adjacent to the fatigue origin area, indicated by arrow "O" in figure 8.

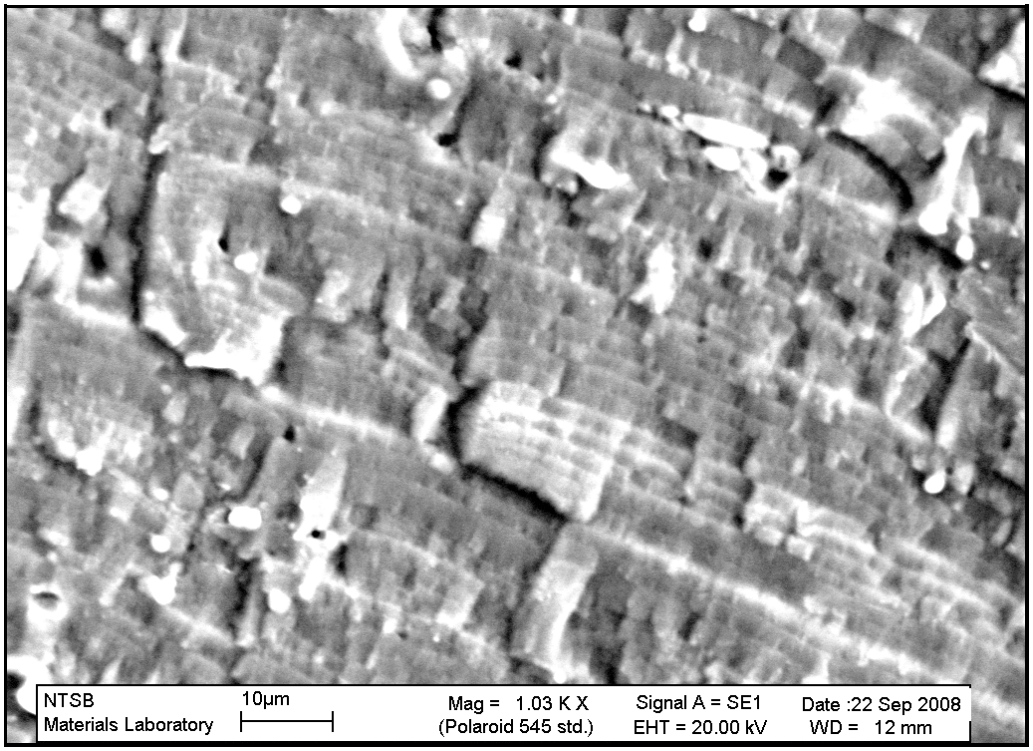


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Figure 10. SEM photograph of the fracture in an area located approximately 0.004 inch vertically above the origin of the fatigue crack.

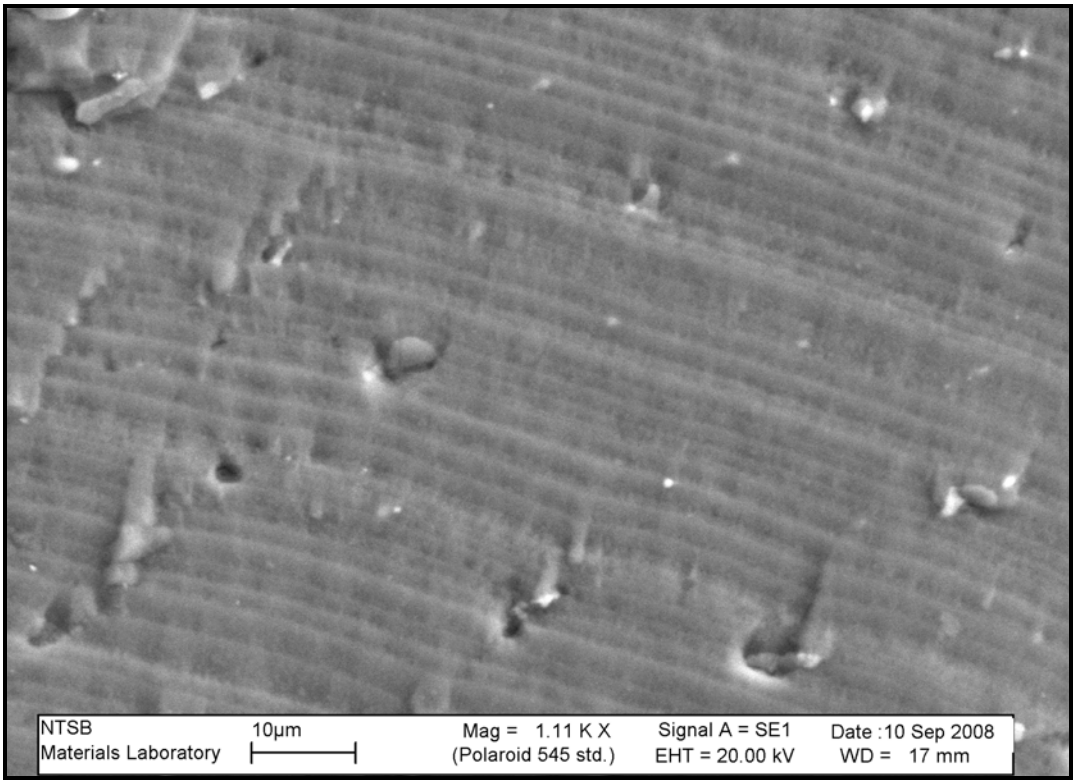


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Figure 11. SEM photograph of the fracture in an area located approximately 0.02 inch vertically above the origin of the fatigue crack.

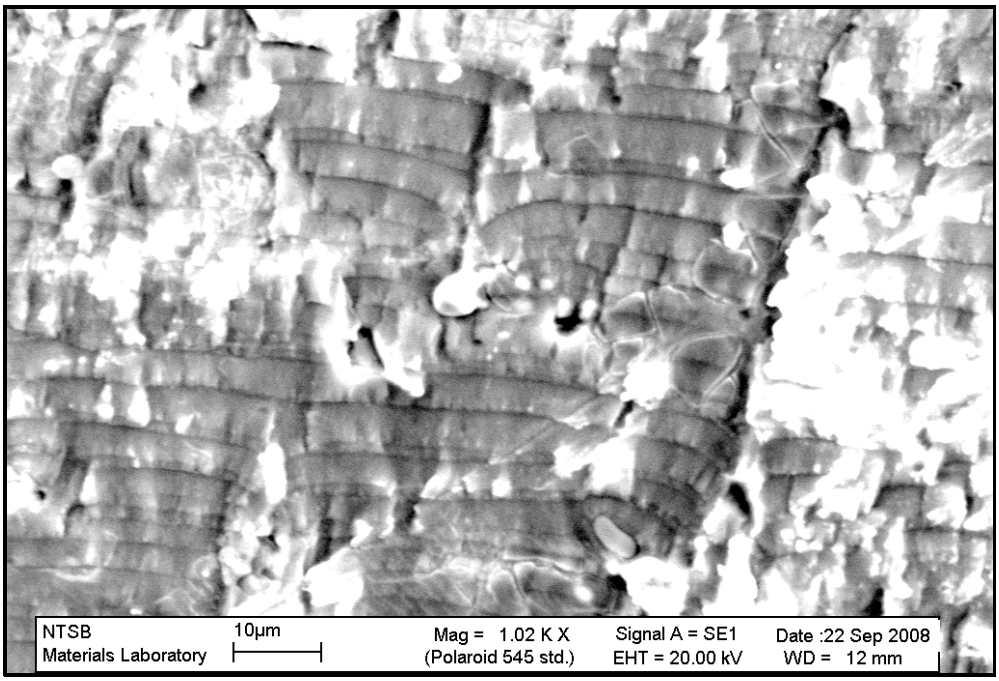


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Figure 12. SEM photograph of the fracture in an area located approximately 0.1 inch vertically above the origin of the fatigue crack.

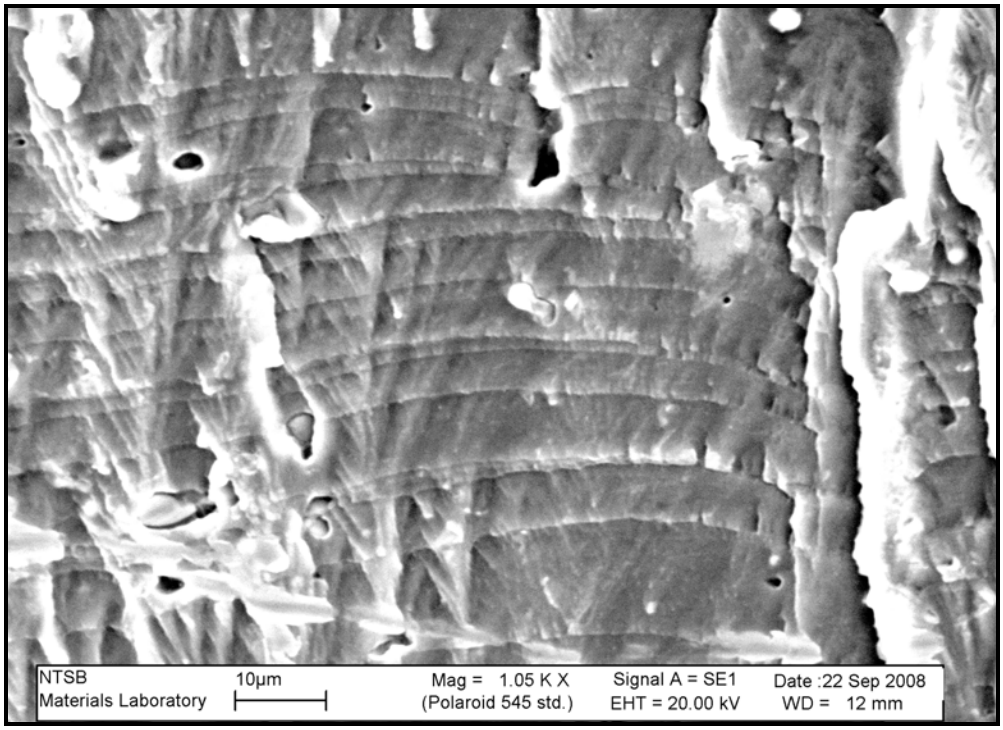


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Figure 13. SEM photograph of the fracture in an area located vertically above the origin of the fatigue crack and next to the external surface.

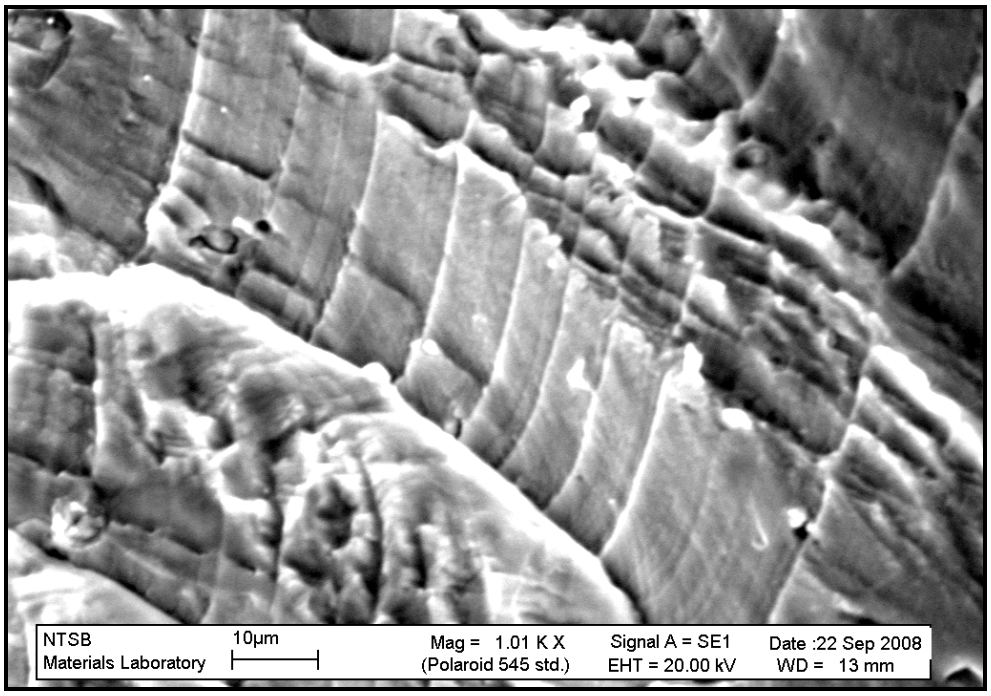


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Figure 14. SEM photograph of the fracture in an area located by arrow "g" in figure 4.

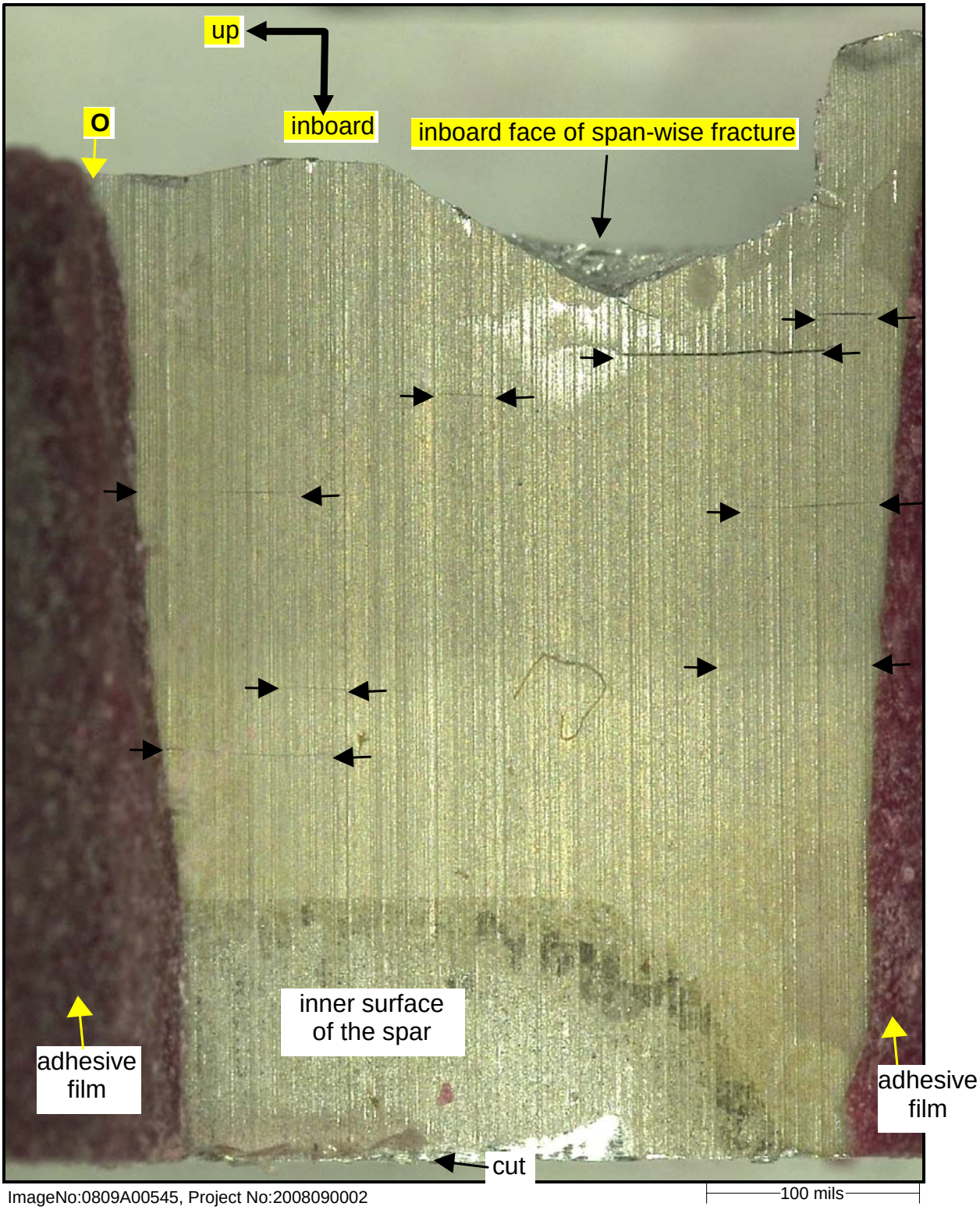



Figure 15. Composite photograph of the inner surface of the spar at the curved portion between the upper and lower wall of the spar in the area that coincided with a void in the adhesive. The edges of the void in the adhesive was ground to maximize exposure of multiple cracks that were found adjacent to the span-wise fracture. The cracks are located between unmarked arrows and they were oriented parallel to the fracture. Fatigue origin is indicated by arrow "O".

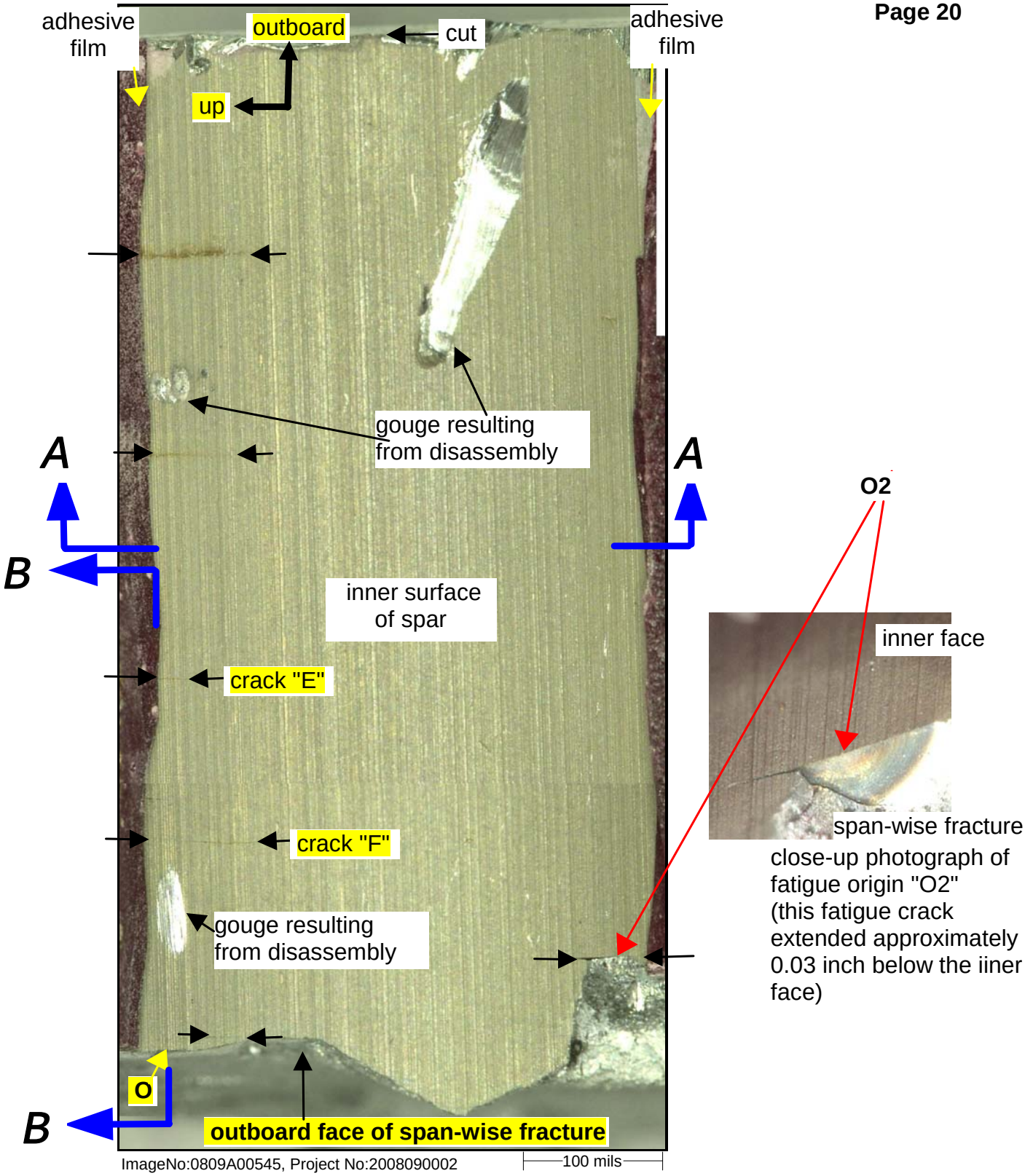
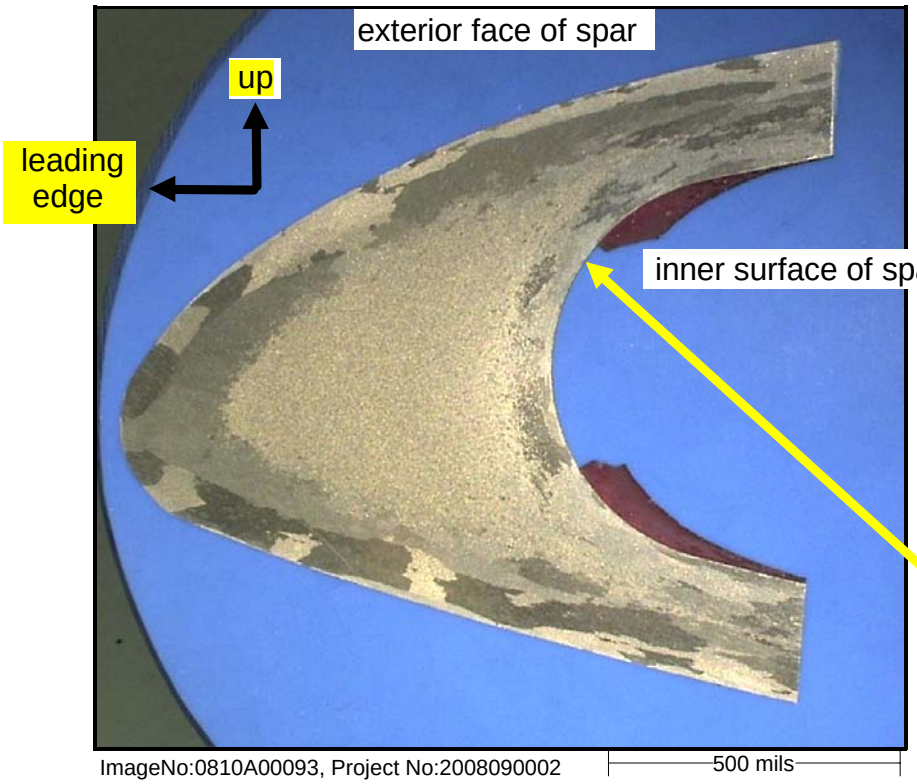



Figure 16. Composite photograph of the inner surface of the spar at the curved portion between the upper and lower wall of the spar in the area that coincided with a void in the adhesive. The adhesive film was ground to maximize exposure of the inner surface. Multiple cracks that were found on the inner surface. The cracks were located between unmarked arrows and they were oriented parallel to the fracture. Fatigue origin is indicated by arrow "O". Another fatigue crack region was found in the area indicated by arrow "O2". Photograph of sections "A-A" and "B-B" are shown in the next few pages.



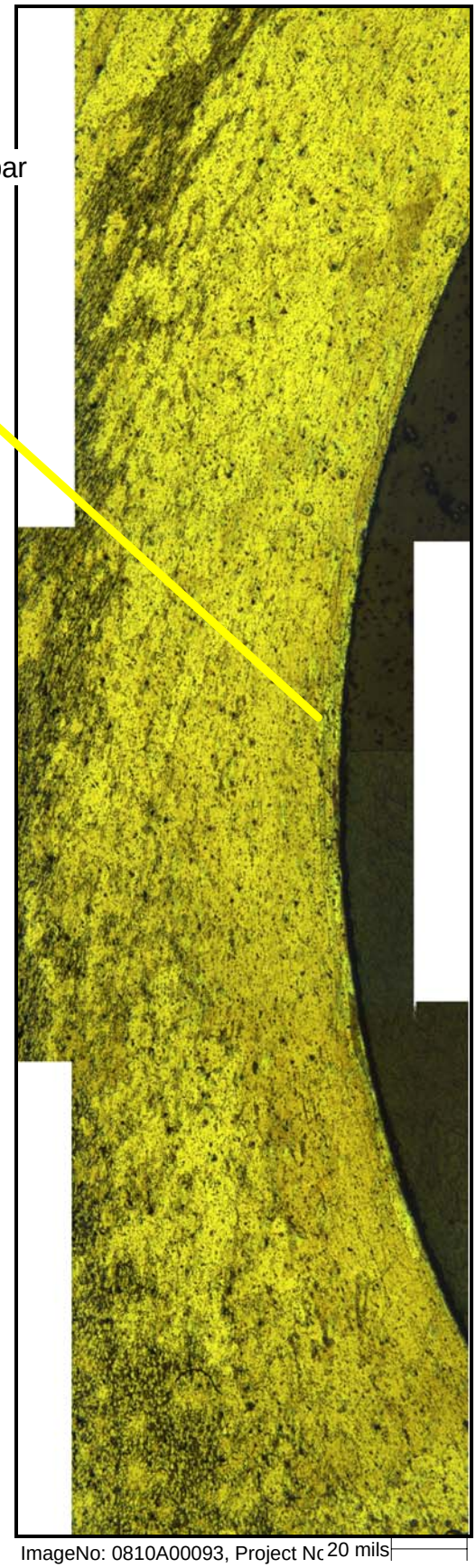
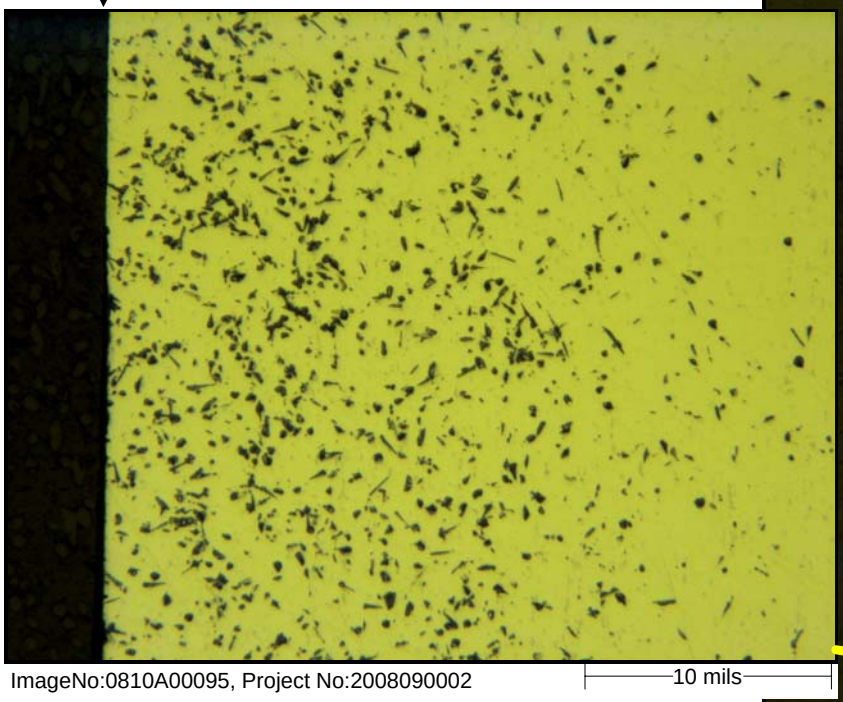




Figure 17. Photograph of section "A-A" (upper photograph) and higher magnification of an area at the inner surface (photograph on the right). Etched with Keller's reagent.



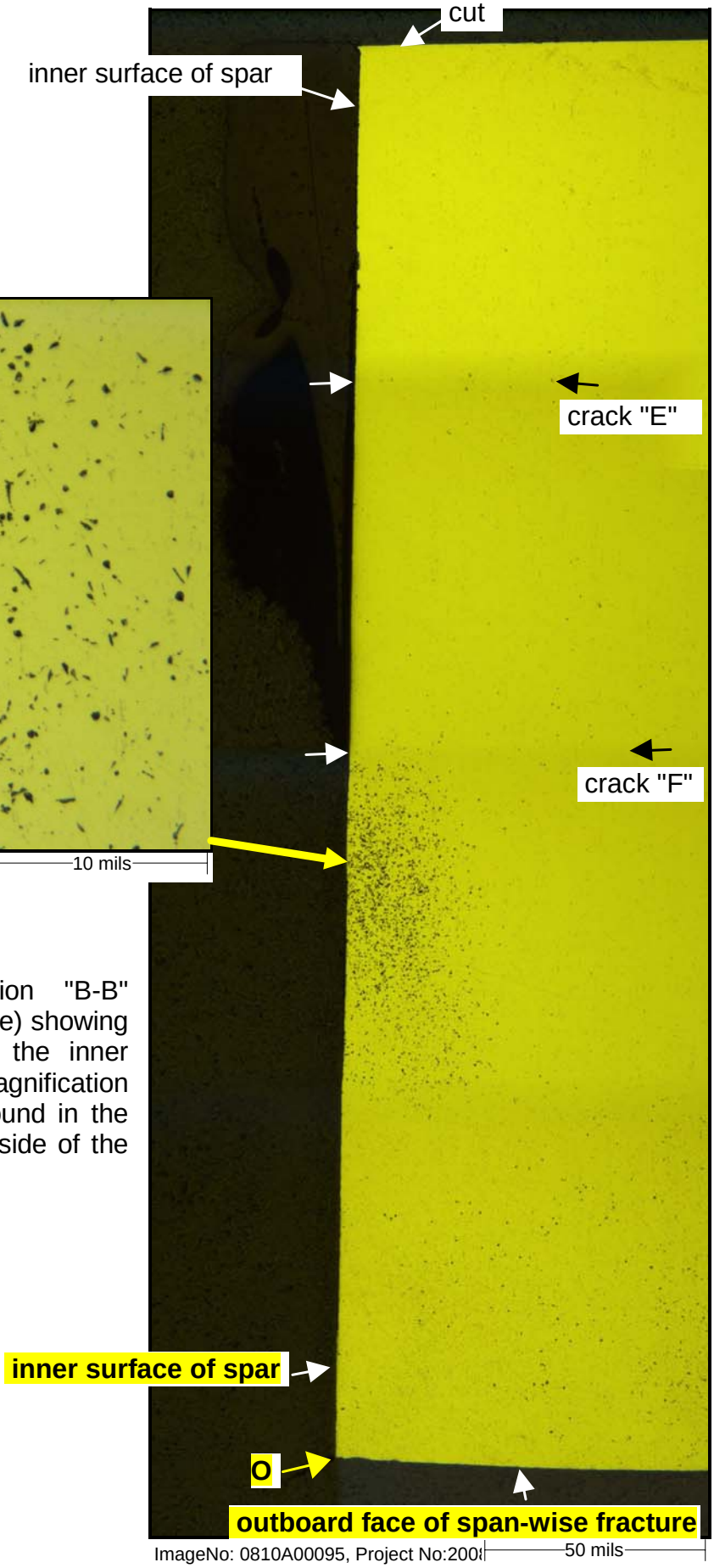




Figure 18. Photograph of section "B-B" (photograph on the right side of the page) showing cracks "E" and "F" that intersected the inner surface of the blade, and higher magnification view of pore-like features that were found in the microstructure (photograph on the left side of the page).

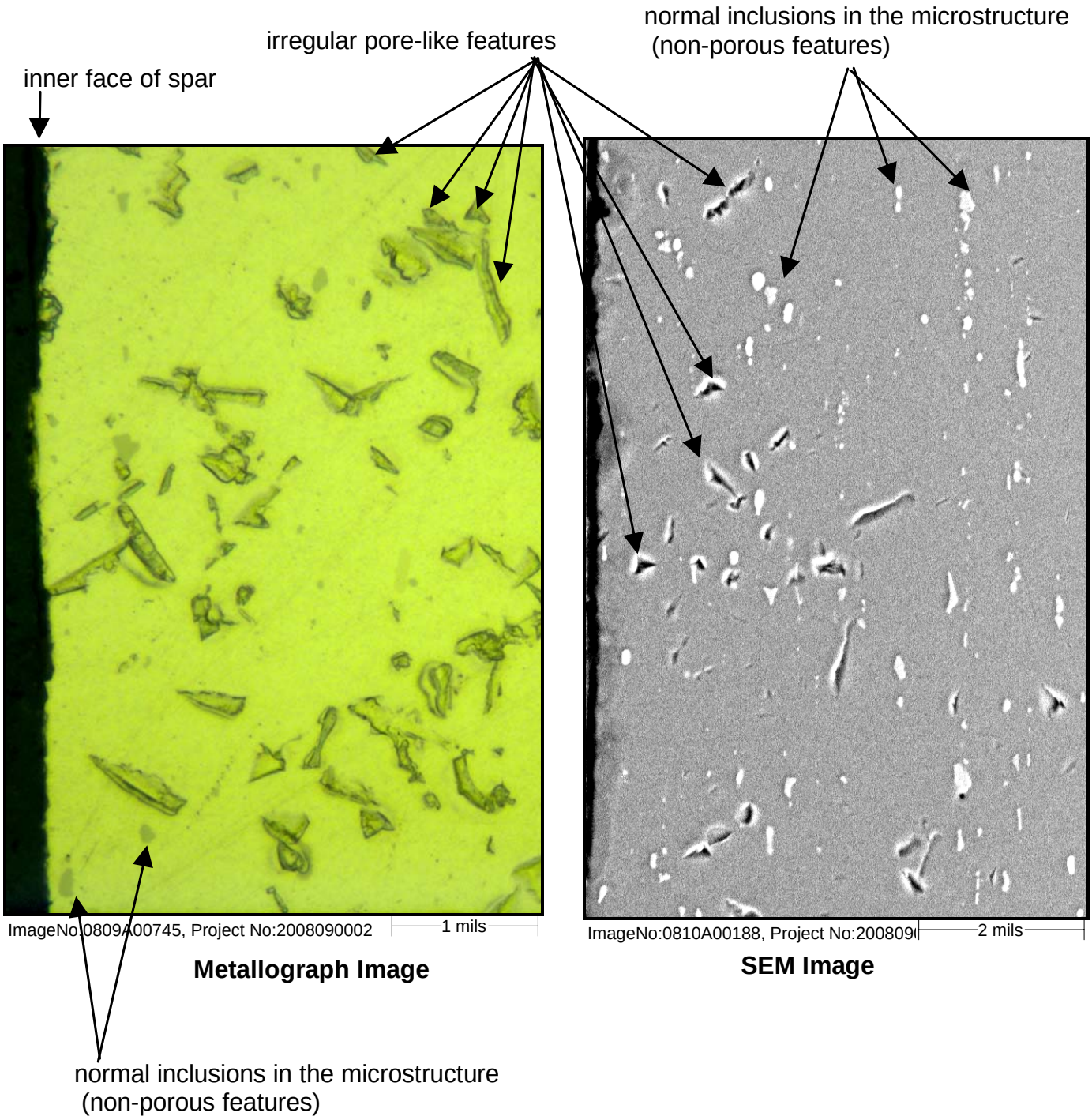



Figure 19. Photographs of a portion of metallurgical section "B-B" showing typical irregular pore-like features when viewed with a metallograph (left side of page) and viewed with scanning electron microscope (right side of page). Photographs of the section are in the as-polished condition.