

NATIONAL TRANSPORTATION SAFETY BOARD

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



August 3, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 22-008

A. ACCIDENT INFORMATION

Place : Saratoga, Wyoming
Date : February 8, 2021
Vehicle : Abbett Gerry Lancair Evolution, N7569A
NTSB No. : WPR21LA108
Investigator : Maja Smith, AS-WPR and Stephen Stein, AS-WPR

B. COMPONENTS EXAMINED

Windshield pieces.

C. DETAILS OF THE EXAMINATION

An overall view of the submitted windshield pieces is shown in figure 1. The submitted pieces were comprised mostly of the edges of the windshield where it was bonded to the frame. The windshield had fractured while in cruise flight at flight level 270, and the missing middle portion was not recovered. The pieces were received numbered as shown in figure 1 in a clockwise sequence (unless specified otherwise, clock and side references are as viewed looking forward) starting at the upper side of the windshield.

The windshield was manufactured from 3/8-inch-thick cast polymethyl methacrylate (PMMA), commonly referred to as acrylic. According to build instructions for the Lancair Evolution,¹ the outer edges of the windshield are to be cut and smoothed to fit within a joggle around the windshield opening in the composite fuselage frame, and the opening is marked with tape on the windshield for reference during the bond surface preparation. Next, the interior and exterior bond surfaces are to be sanded first by hand with 80-grit abrasive paper along the edge of the reference tape followed by sanding across the entire bond area (about 2 inches wide around the perimeter) using a dual-action (DA) sander with 40-grit paper. The outer edges of the windshield are beveled to a rounded shape also using the DA sander with 40-grit paper. After sanding, the bond areas are cleaned using alcohol (type not specified). The exterior bond surface is bonded to the frame using Hysol 9360 epoxy,² and the interior bond surface is bonded with a wet layup of carbon fabric and Rhino 1307-LV epoxy resin and hardener.³

¹ Document Number 011-0017, Rev. 0, *Windshield and Window Installation Procedures, LV*, Lancair International Inc. (2013).

² Henkel Corp., Bay Point, California.

³ Rhino Linings Corp., San Diego, California.

The outer edge of the windshield had a frosted appearance consistent with the roughening process used during the windshield installation before bonding to the windshield frame. The bond surface on the windshield frame showed minimal visual evidence of adhesive material. Blue epoxy consistent with Hysol was observed on the exterior surface mostly around the edges of bond area next to the window opening and at the outer edge. On the interior face of the windshield, isolated areas consistent with epoxy resin were observed around the bond faces. Fiber impressions were observed in some of the remaining resin, and chunks of laminate with fiber reinforcement and filler material remained attached to the outer edges on many of the pieces.

The windshield thickness was measured on piece 7 in a clear portion of the windshield using a ball-flat micrometer. The thickness measured 0.3752 inch.

Unlabeled arrows in figure 1 indicate the general directions of fracture propagation as observed on the fractured pieces. Based on fracture features and crack branching patterns, a primary origin area was observed on piece 8 at the lower right side of the windshield, and red arrows indicate the primary fracture emanating from the origin. To the right of the origin, the primary fracture extended across piece 8 and terminated in the bond area in piece 7. To the left of the origin, the primary fracture turned upward. On the upper pieces, the fracture between pieces 3 and 4 had a mirror-like flat fracture across the thickness, consistent with fast fracture under primarily tensile loads, a feature consistent with the upper end of the primary fracture through the windshield extending from the origin in piece 8. The remaining fractures generally had fracture planes that varied across the thickness with curving hackles turning toward the interior or exterior surface, features consistent with fracture under a combination of tension and bending loads consistent with fractures that occurred after the primary fracture.

Unlabeled black arrows in figure 1 indicate fractures that emanated from the primary fracture based on crack branching patterns and secondary origin locations. Yellow arrows indicate fractures that extended from secondary origins not directly associated with a crack and had secondary intersections with the black-arrowed fractures.

Optical images of the fracture surface at the origin area are shown in figure 2. The origin was located at the exterior surface of the windshield, and a smooth thumbnail shaped region was observed as shown in the lower image in figure 2. A curving boundary consistent with a crack arrest line was observed at the location indicated with arrows in figure 2. The crack emanated from a broad origin area that was positioned toward the right side of the thumbnail. The fracture intersected a secondary crack located to the left of the origin but within the thumbnail region.

The origin was located within the bond surface on piece 8 as shown in figure 3. The red arrow on the surface was marked to help identify the origin location during the examination. The origin was located approximately 1/8 inch below the upper edge of the bond line. A bracket in the upper image in figure 3 indicates a portion of the bond area that appeared relatively lighter in some lighting conditions relative to the rest of the bond area. The area also appeared to be associated with transverse scratches that were

predominantly oriented parallel to the bond edge, consistent with the build instructions that instructed hand-sanding along the taped edge. The origin was located near the lower end of that lighter region, but the fracture plane was angled relative to the transverse scratches.

In a closer view of the exterior surface adjacent to the origin, isolated linear scratches were observed that were angled at an orientation nearly parallel to the fracture plane as indicated in the lower image in figure 3. Additionally, elliptical scratches were observed across most of the bond surface consistent with use of a DA sander. To the right of the origin, a group of elliptical scratches indicated with unlabeled arrows in the upper image in figure 3 appeared relatively deeper compared to others. To the right of the indicated group of elliptical scratches, the exterior surface had a whitened appearance with corresponding damage to the edge of the fracture consistent with rubbing contact.

Next, the fracture surface at the origin area was examined using a scanning electron microscope (SEM), and a montage of SEM images are shown stitched together in figure 4 to show an overall view of the origin area including the arrest line indicated with unlabeled arrows. The middle left portion of the origin area is shown in figure 5 where radial features emanated from the broad origin that extended beyond the field of view shown. A closer view of the secondary crack to the left of the origin area is shown in figure 6. Unlabeled arrows in figure 6 indicate the local direction of fracture propagation for the primary crack that emanated from the origin area indicated in figure 4. Fracture features up to the crack arrest line were relatively smooth showing evidence of microductility with small tear ridges, dimple features, and isolated parabolic marks as indicated in figure 7.⁴ Beyond the arrest line, the density of parabolic marks increased as shown in figure 8. Further from the origin, intersecting parabolic marks consistent with fast fracture in the acrylic material were observed as shown in figure 9.

In addition to the secondary crack at the origin, the primary fracture intersected secondary cracks further from the origin area as shown in figure 10. The SEM images in figure 10 were taken where the fracture surface intersected the upper end of the bonded area, and paint is observed on the surface adjacent to the fracture. The boundary of the secondary cracks is indicated with a dashed line in the lower image and is associated with a distinct change in the fracture plane.

The exterior surface adjacent to the origin area is shown in figure 11, and an area of the exterior surface to the left of the origin area is shown in figure 12. The surface was mostly covered with parallel scratches oriented parallel to the bond edge. However, additional scratches oriented approximately parallel to the fracture plane were also observed as indicated with connected black arrows in figures 11 and 12. An apparent crack-like feature was observed at the base of some scratches including the horizontal scratch oriented parallel to the bond edge indicated with red arrows in figure 12.

⁴ A parabolic mark is a curved feature with tails pointing in the direction of propagation that forms due to fracture reinitiation ahead of the crack front as the fracture progresses.

An optical image of the exterior edge of the primary fracture where the fracture intersected the upper edge of the bonded area is shown in figure 13. Layers of black sealant, white paint and/or primer, and translucent epoxy were observed as labeled in figure 13. The thickness of the epoxy appeared to be variable at this area, and paint and/or primer appeared to be adhered directly to the acrylic adjacent to the bond area. Another view of the layers on the acrylic at the upper end of the bond area are shown in figure 14 as viewed looking outward through the clear portion of the acrylic on piece 11. Material of varying colors were observed on the exterior surface of the acrylic as shown labeled in figure 14 including blue, yellow, white, and black materials. Samples of the blue, yellow, and white materials were analyzed using Varian IR600 Fourier-transform infrared (FTIR) spectrometer with a diamond attenuated total reflectance (ATR) accessory in accordance with ASTM E1252-98 (American Society for Testing Materials E1252-98: Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis. Results showed a spectrum for the blue material consistent with Hysol epoxy. The spectrum for the yellow material had a spectrum that was similar to the Hysol epoxy but had a couple peaks that varied in height and width, often an indication of degradation. The surface of the white area in contact with the acrylic had a spectrum consistent with an epoxy paint.

Oblique views of the exterior surface in the bond area on pieces 8 and 11 are shown in figures 15 and 16. Faint curving lines showing a slight change in color from darker to lighter were observed at locations indicated by unlabeled arrows. On piece 8, the origin was located between two curving lines as shown in figure 15. Arrows in figure 16 show several curving boundaries on piece 11. The number and locations of the curving lines appeared to coincide with locations where the sealant and paint were scraped and disturbed at the upper edge of the bond area.

As indicated with unlabeled arrows in the upper image in figure 3, a grouping of elliptical grinding marks in the bond area to the right of the origin area appeared relatively deeper than the adjacent areas. SEM images of two of the relatively deep elliptical grinding marks are shown in figure 17. A crack-like feature was observed at the bottom of some of the scratches such as the scratch in the lower image in figure 17, where unlabeled arrows indicate the location of the crack-like feature.

A 3D representation of the relatively deep elliptical grinding marks was obtained with a Keyence VHX-7000 microscope set at 80x magnification. A tilt correction was applied to the entire field of view, and a color-coded depth profile was obtained. Next a depth profile chart was obtained for a linear trace across the surface. The resulting image and profile measurements for an area with relatively deep elliptical grinding marks is shown in figure 18. The two deepest scratches in the field of view had measured peak-to-valley height differences of 0.0018 inch and 0.0019 inch (45 micrometers and 48 micrometers).

The area of scratches was viewed at an oblique angle by looking through the fracture surface to show the back face of the scratched surface. Additionally, side lighting was applied to accent features emanating into the acrylic from the surface. Under these

viewing conditions, small cracks were visible emanating from several of the relatively deeper elliptical cracks. One of these cracks is indicated in figure 19.

Relatively deep elliptical grinding marks were also observed on the interior bond surface of piece 5, and multiple cracks were detected in the area. Unlabeled arrows in figure 20 indicate multiple small cracks emanating from the interior bond surface in piece 5 that were illuminated using lighting and viewing conditions comparable to those used on piece 8.

A sample of the acrylic was cut from the clear windshield portion of piece 7 to create exemplar scratch patterns for examination. The sample was clamped to a rubber-coated surface, and the exterior surface of the sample was scratched using a Fein vibrating sander with a 40-grit abrasive paper. The resulting surface was examined for cracks, and no cracks were observed. The sanded surface was also cleaned with ethanol, and no cracks appeared following the cleaning.

The exemplar scratched surface was examined using the Keyence VHX-7000 microscope, and the scratch profiles were analyzed using the same methods used for the data presented in figure 18 but with a 50x lens to cover a broader field of view. The resulting scratch profile for the exemplar scratched surface is shown in figure 21. The deepest scratches in the field of view had depths of 0.00053 inch and 0.00073 inch (13.35 micrometers and 18.53 micrometers).

Around the circumference of the windshield, many areas of the edge had a flat angled chamfer with linear grinding marks on the flat portion. A view of the edge profile on piece 8 is shown in figure 22 where a flat chamfer was present on the interior side of the piece. Figure 23 shows relatively deep linear grinding marks at the edge of piece 8 on the flat chamfered edge. According to build instructions, the edge of the windshield should be ground with a DA grinder to a rounded (bullnose) edge profile.

Matthew R. Fox, Ph.D.
Senior Materials Engineer

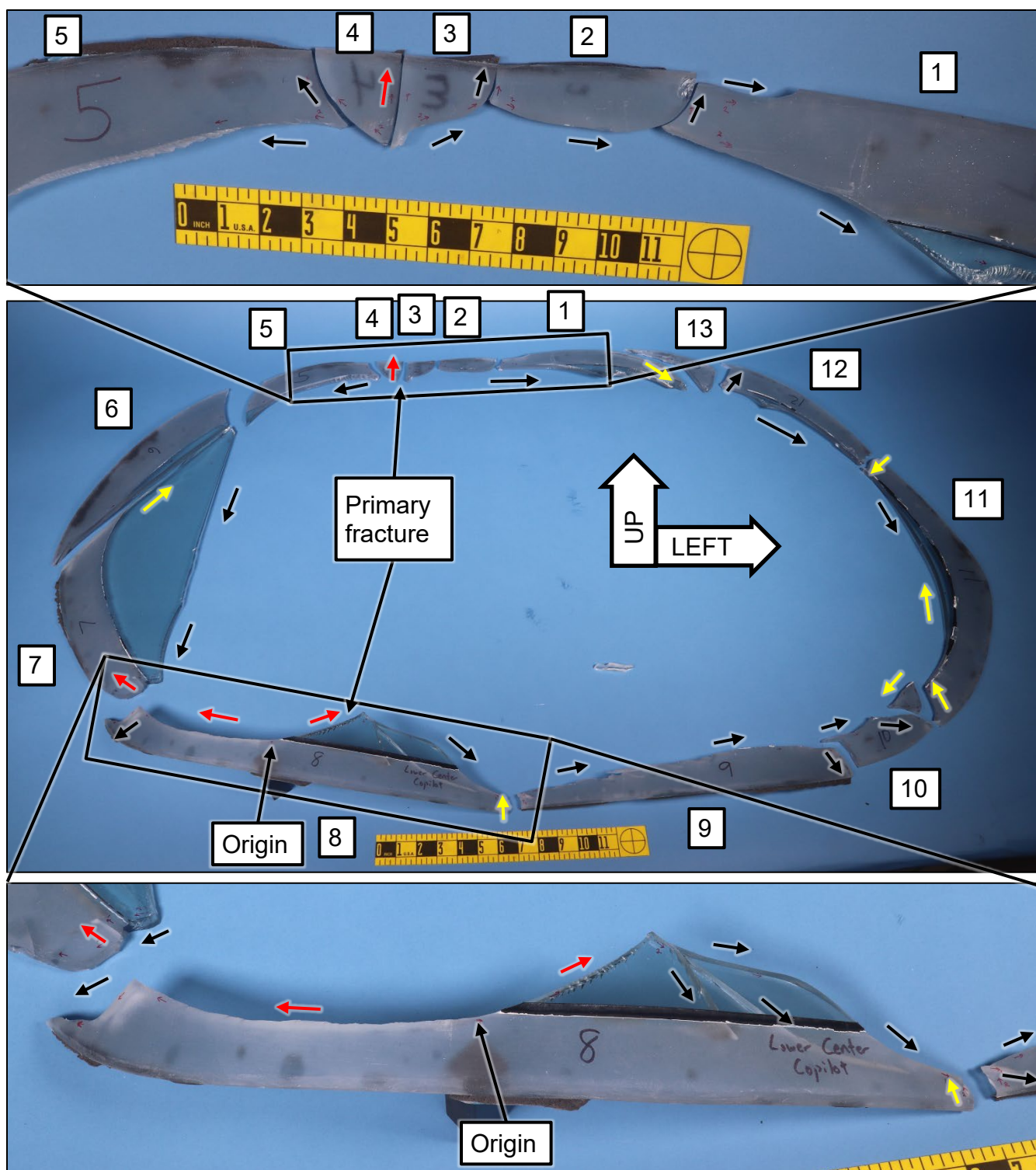


Figure 1. Overall view of the submitted windshield pieces (middle image) with closer views of the primary fracture locations (upper and lower images). Unlabeled red arrows indicate the primary fracture, black arrows indicate the direction of fracture propagation emanating from the primary fracture, and yellow arrows indicate secondary fractures.

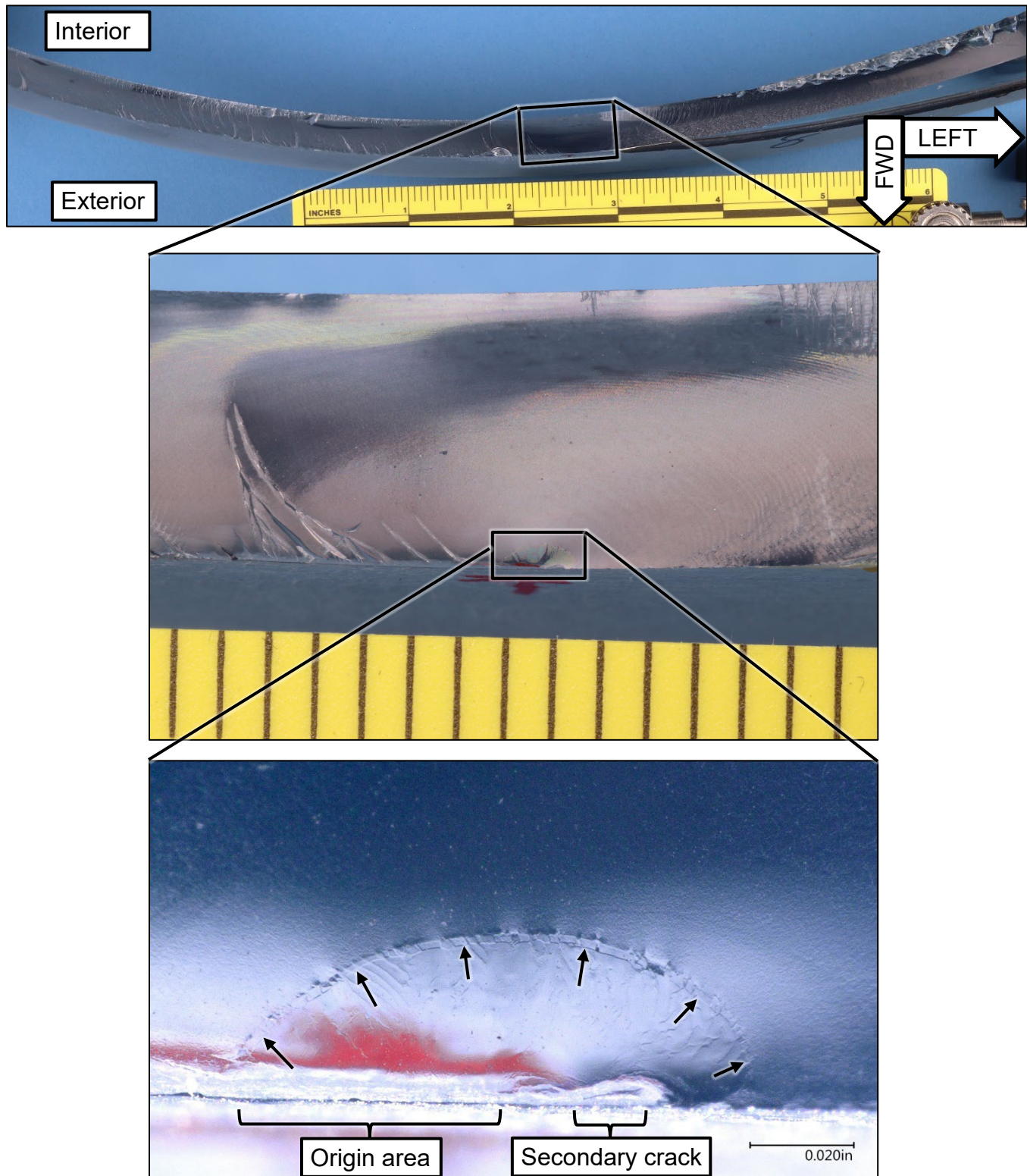


Figure 2. Views of the origin area at progressively higher magnifications. Unlabeled arrows indicate a crack arrest line.

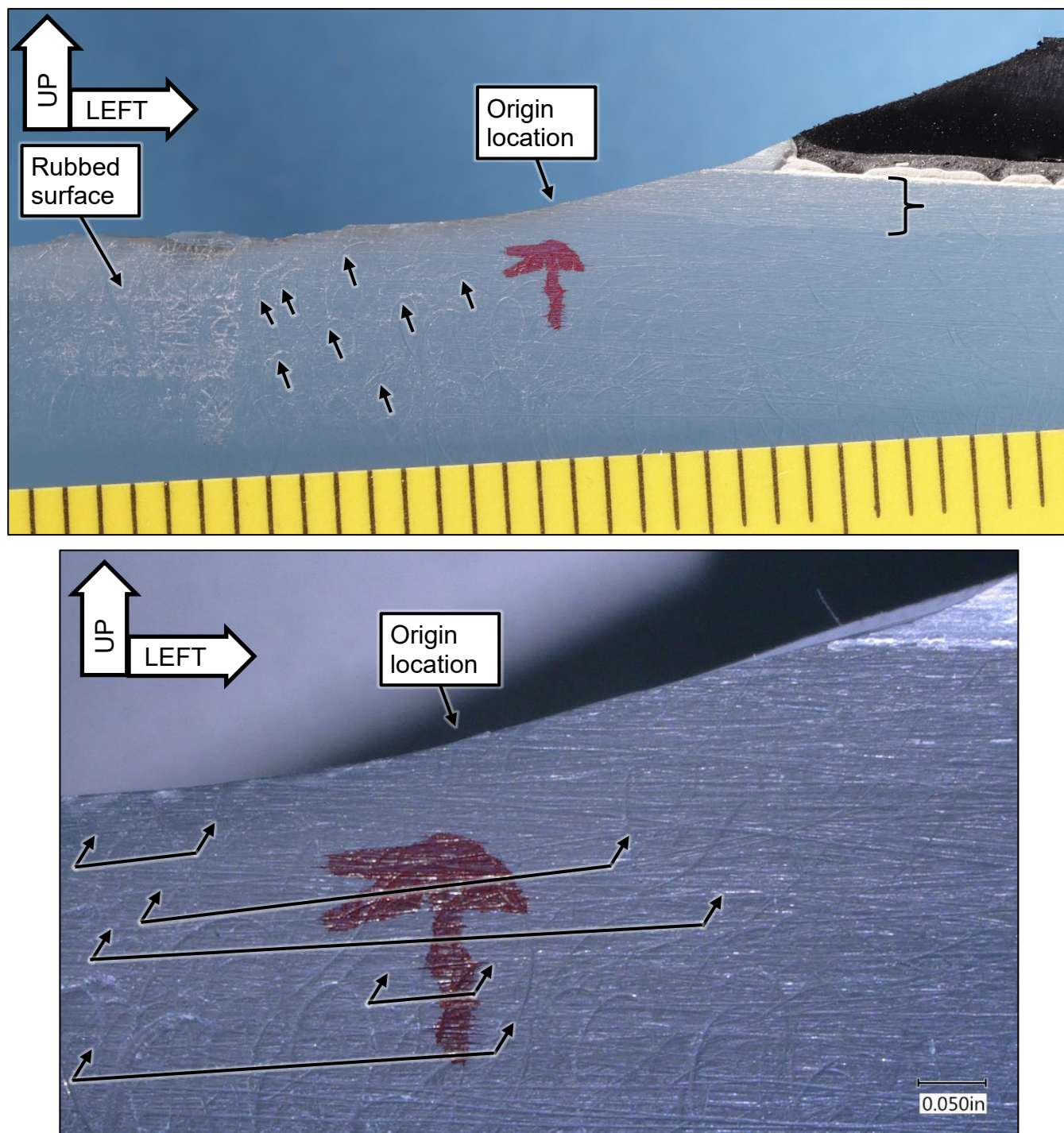


Figure 3. Exterior surface adjacent to the origin. Unlabeled arrows point to relatively deep elliptical scratches in the upper image and connected arrows point to linear scratches approximately parallel to the fracture plane in the lower image. A bracket in the upper image indicates an area of the surface that had a slightly lighter optical appearance.

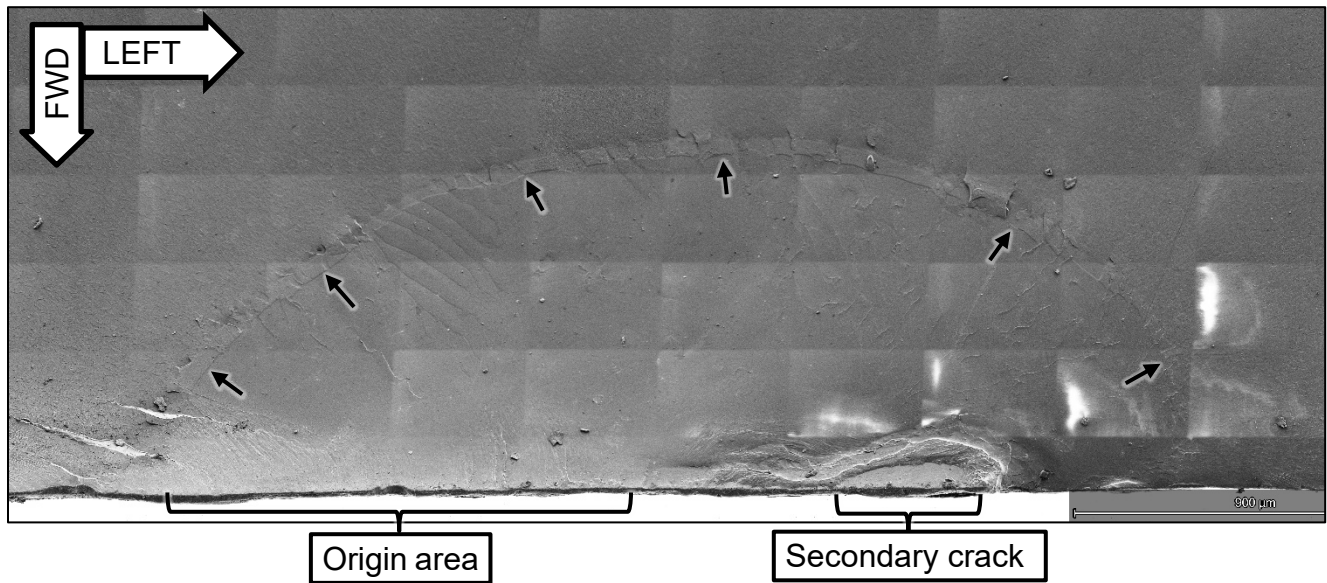


Figure 4. Stitched SEM images of the origin area. Unlabeled arrows indicate the crack arrest line.

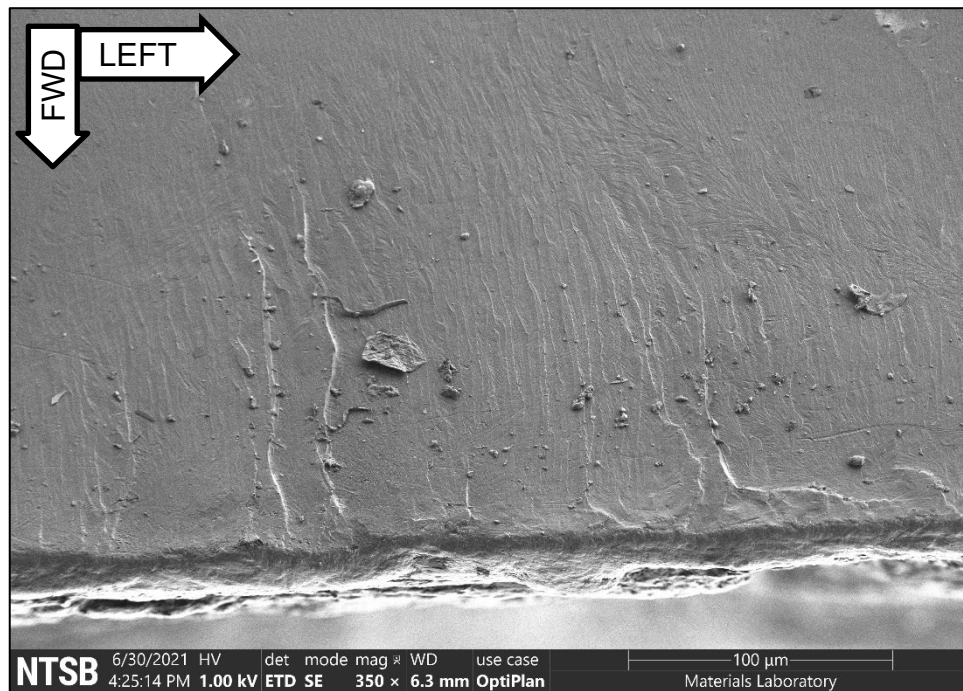


Figure 5. SEM image of the middle left (right side of the bracket as viewed in figure 4) portion of the origin area.

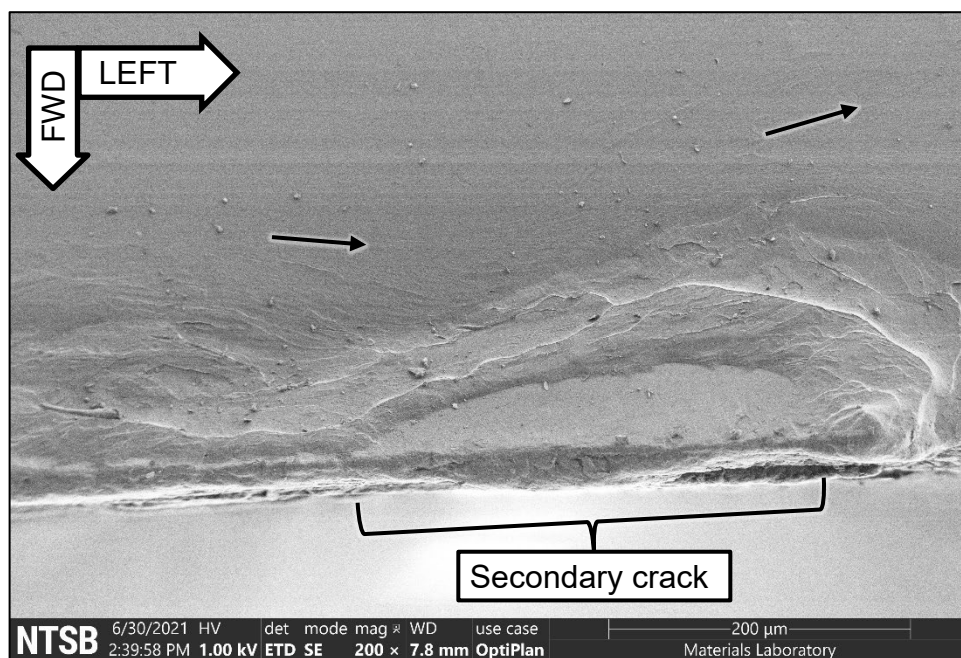


Figure 6. SEM image of the secondary crack to the left (airplane orientation) of the origin area. Arrows indicate propagation from the primary origin area.

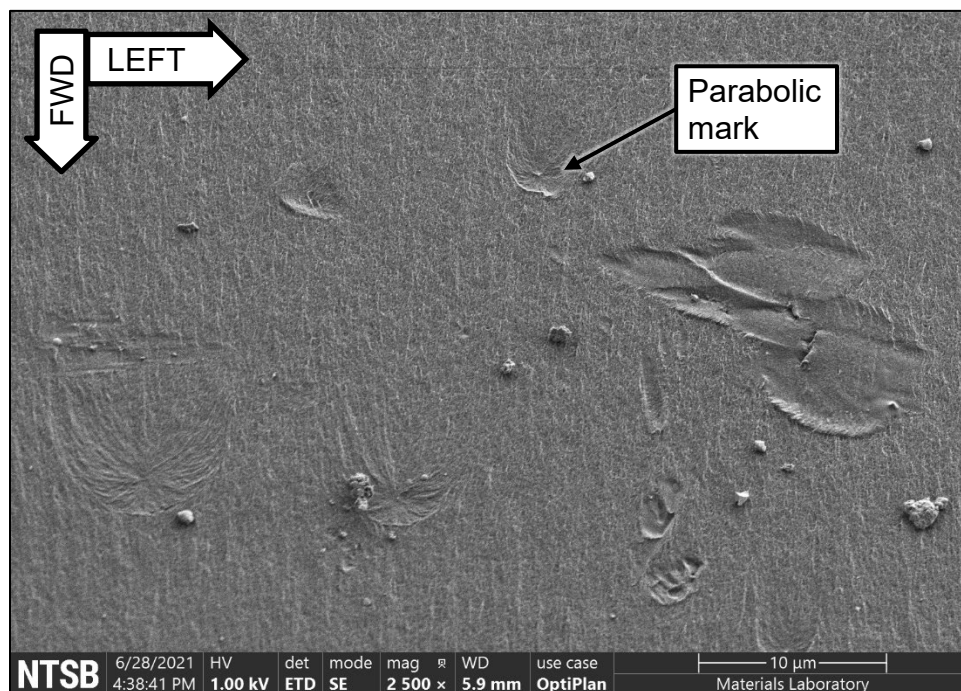


Figure 7. SEM image of typical fracture features near the origin inside the arrest line boundary showing isolated parabolic marks.

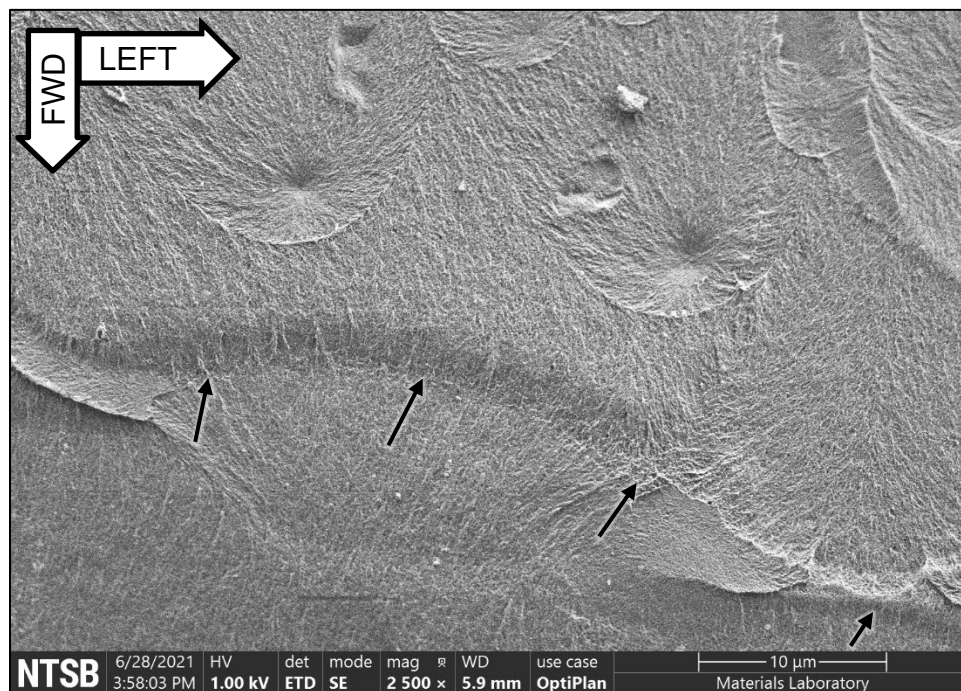


Figure 8. SEM image of fracture features at the arrest line boundary (boundary indicated with unlabeled arrows).

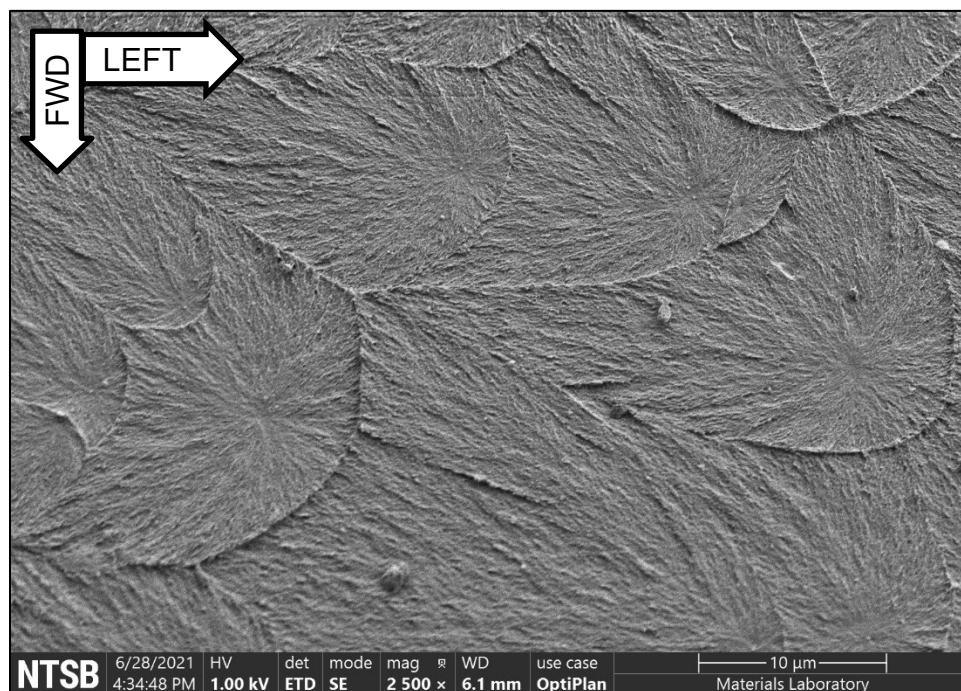


Figure 9. SEM image of fast fracture features beyond the arrest line showing intersecting parabolic marks.

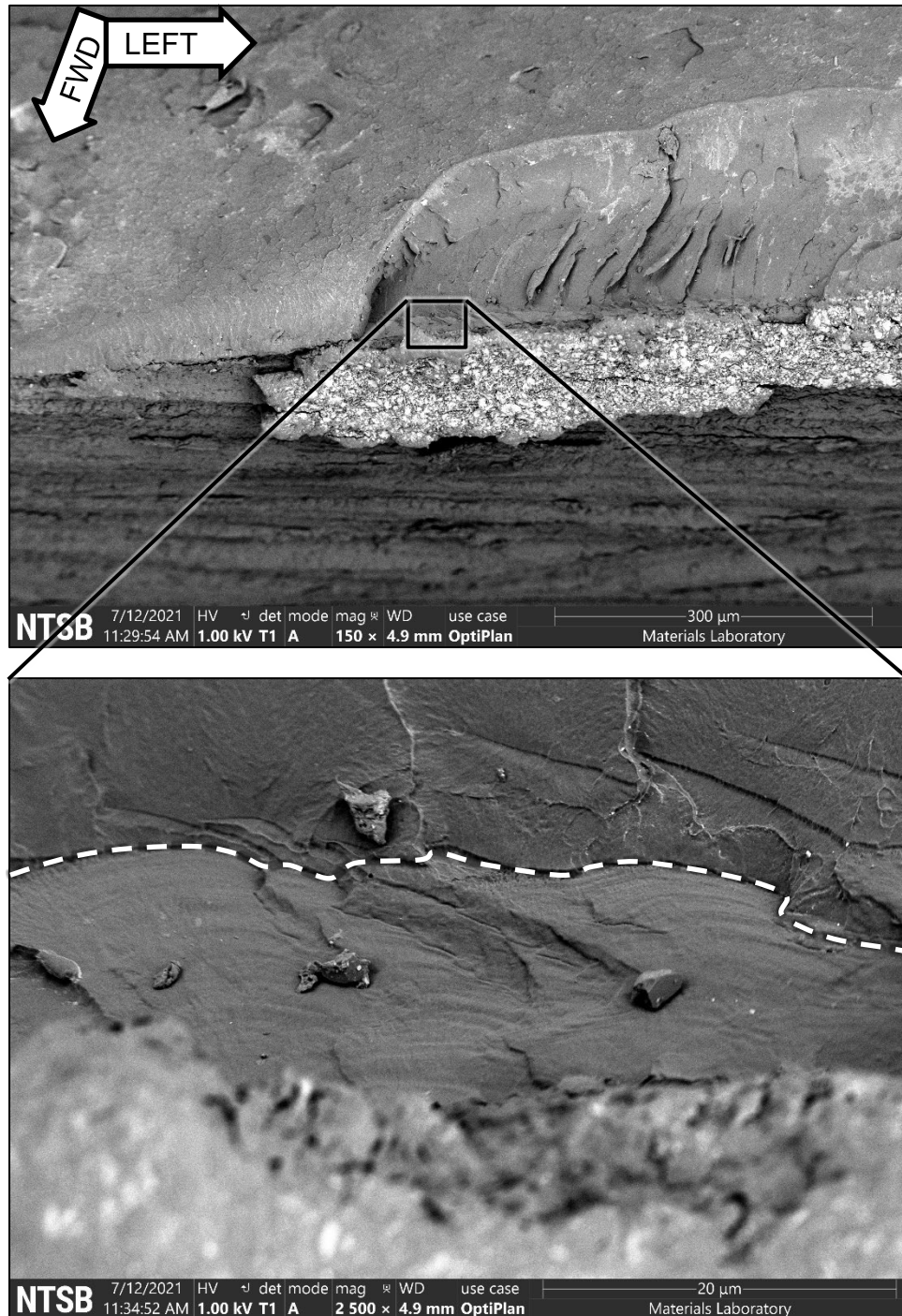


Figure 10. Region of secondary cracks intersecting the primary fracture surface to the left (as viewed looking forward) of the origin area. A dashed line in the lower image indicates the secondary crack boundary.

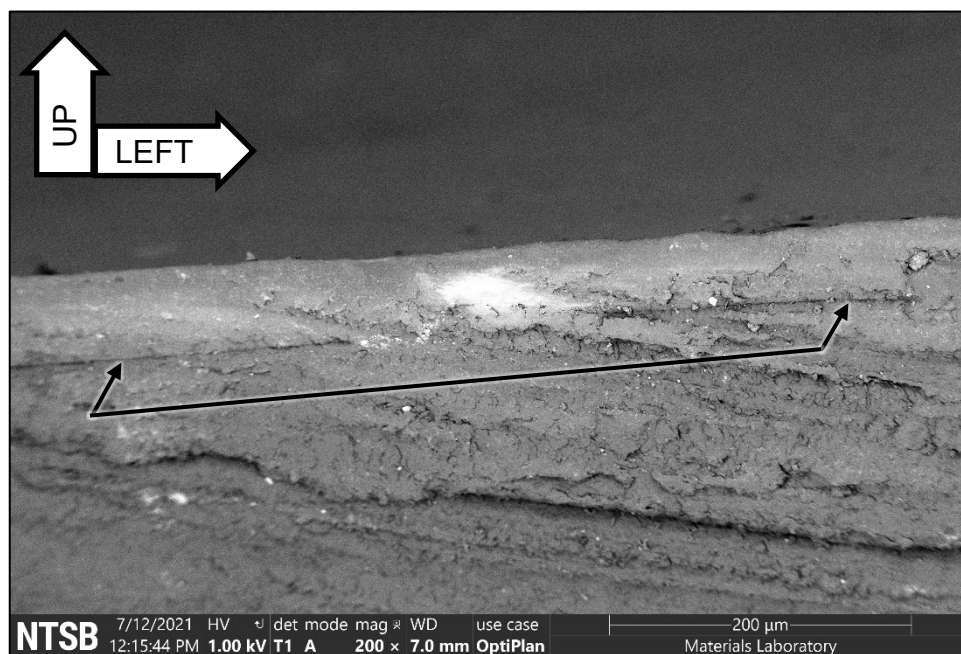


Figure 11. SEM image of the exterior surface adjacent to the origin area. Connected arrows indicate a linear scratch nearly parallel to the fracture plane.

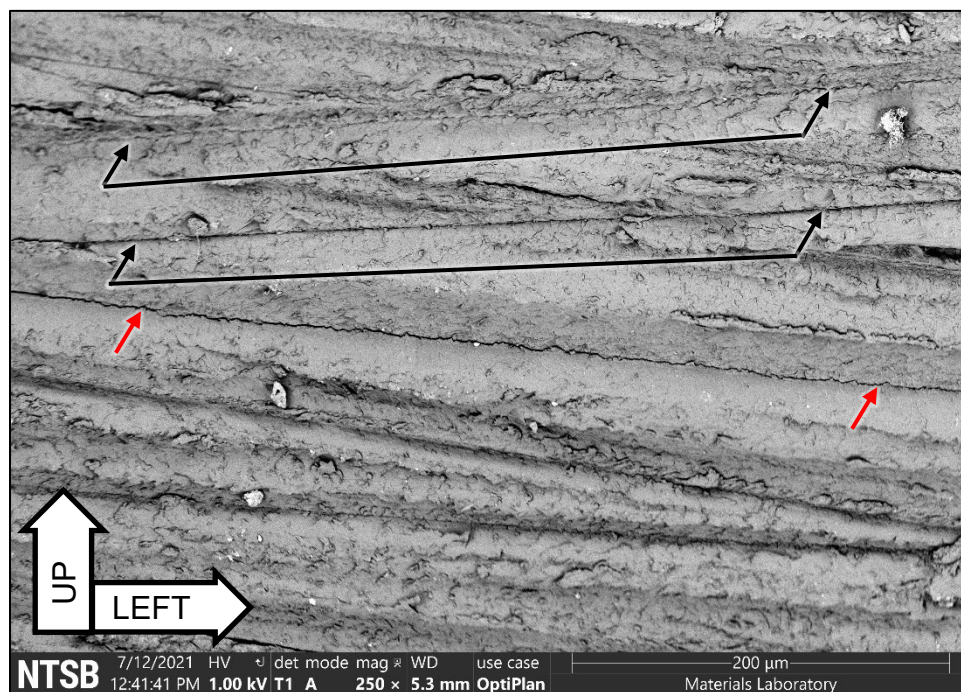


Figure 12. Exterior surface to the left of the origin area within the lighter region indicated with a bracket in figure 3. Connected black arrows point to scratches nearly parallel to the fracture plane, and red arrows point to a crack-like feature at the base of a horizontal scratch.

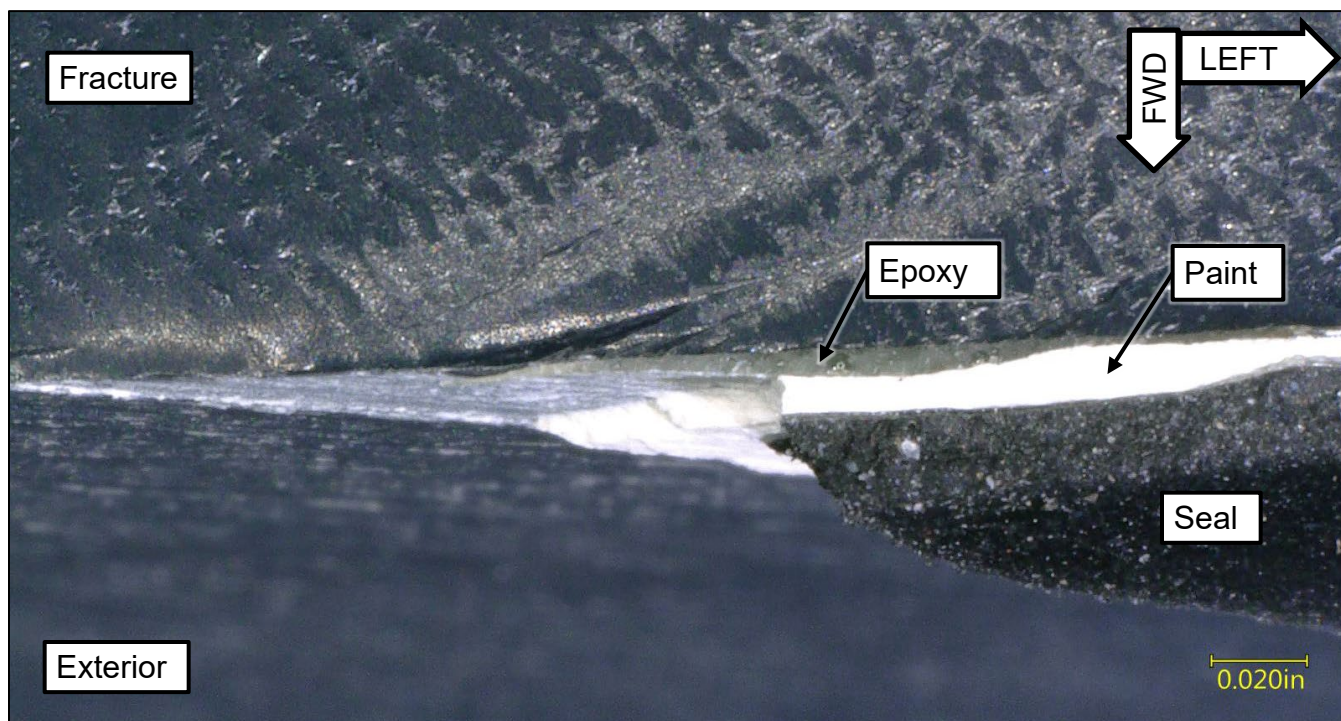


Figure 13. Optical image of the exterior edge of the fracture surface to the left of the origin area showing layers of epoxy, paint, and an elastomer seal.

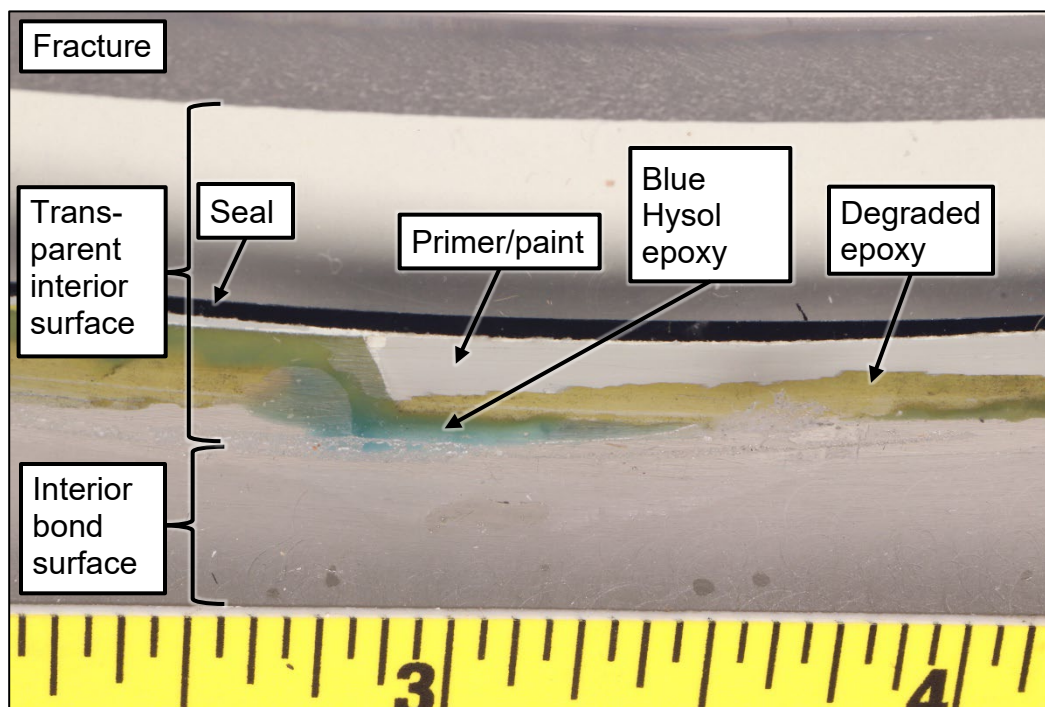


Figure 14. Upper end of the bond region on piece 11 as viewed looking through the windshield from the interior side showing areas where an elastomer seal, primer/paint, blue Hysol epoxy, and degraded epoxy contacted the exterior surface of the windshield.

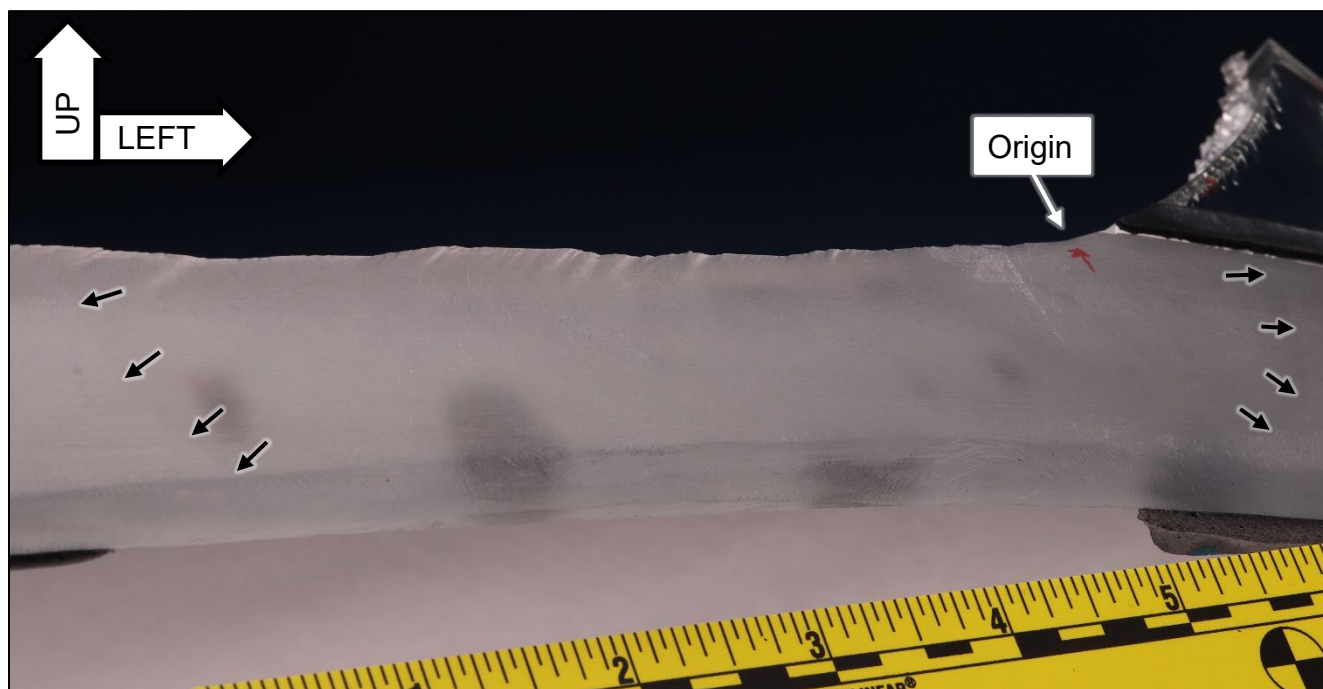


Figure 15. Oblique view of the bond surface on piece 8. Unlabeled arrows indicated an optically visible curving boundary associated with a slight color change from darker to lighter in the direction of the arrows.

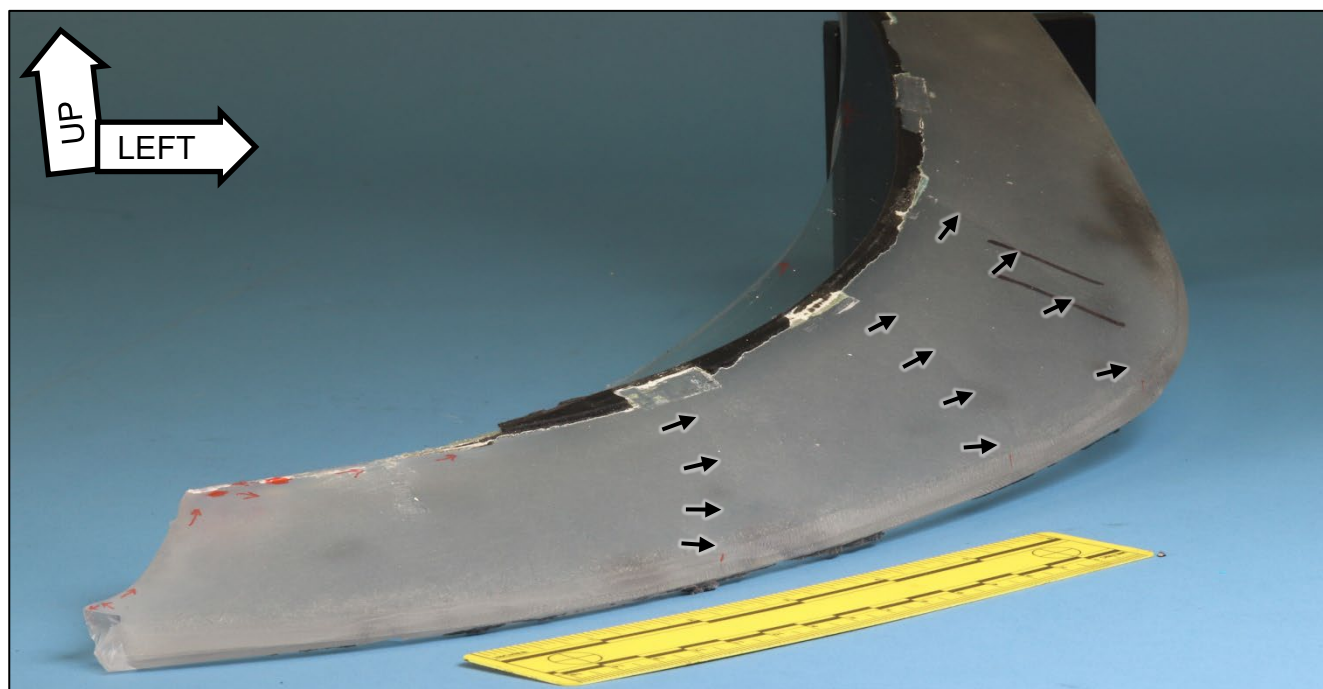


Figure 16. Oblique view of the bond surface on piece 11. Unlabeled arrows indicated an optically visible curving boundary associated with a slight color change from darker to lighter in the direction of the arrows.

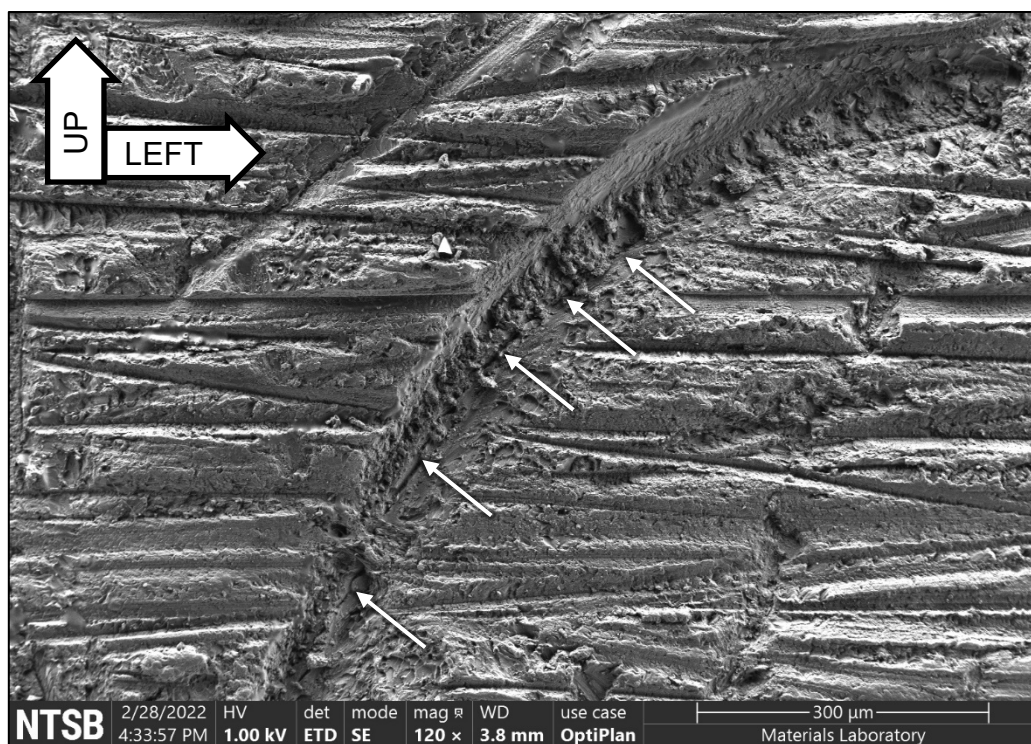
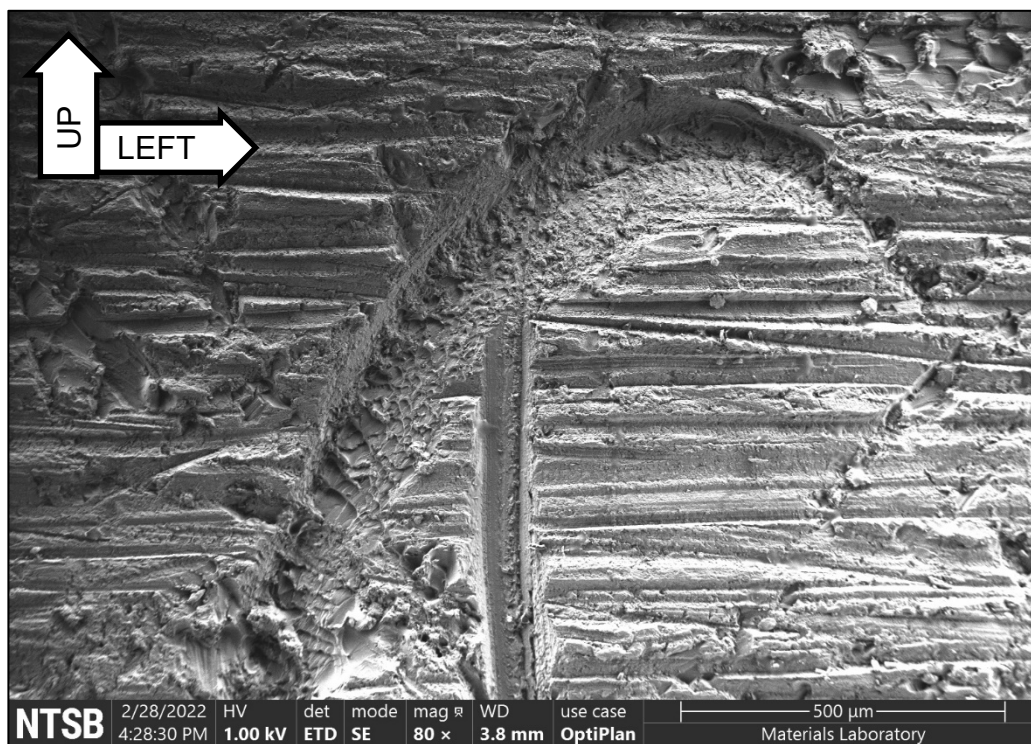


Figure 17. SEM images of relatively deep elliptical scratches in the bond area to the right of the origin area. Unlabeled arrows in the lower image indicate a crack-like feature at the bottom of the relatively deep scratch.

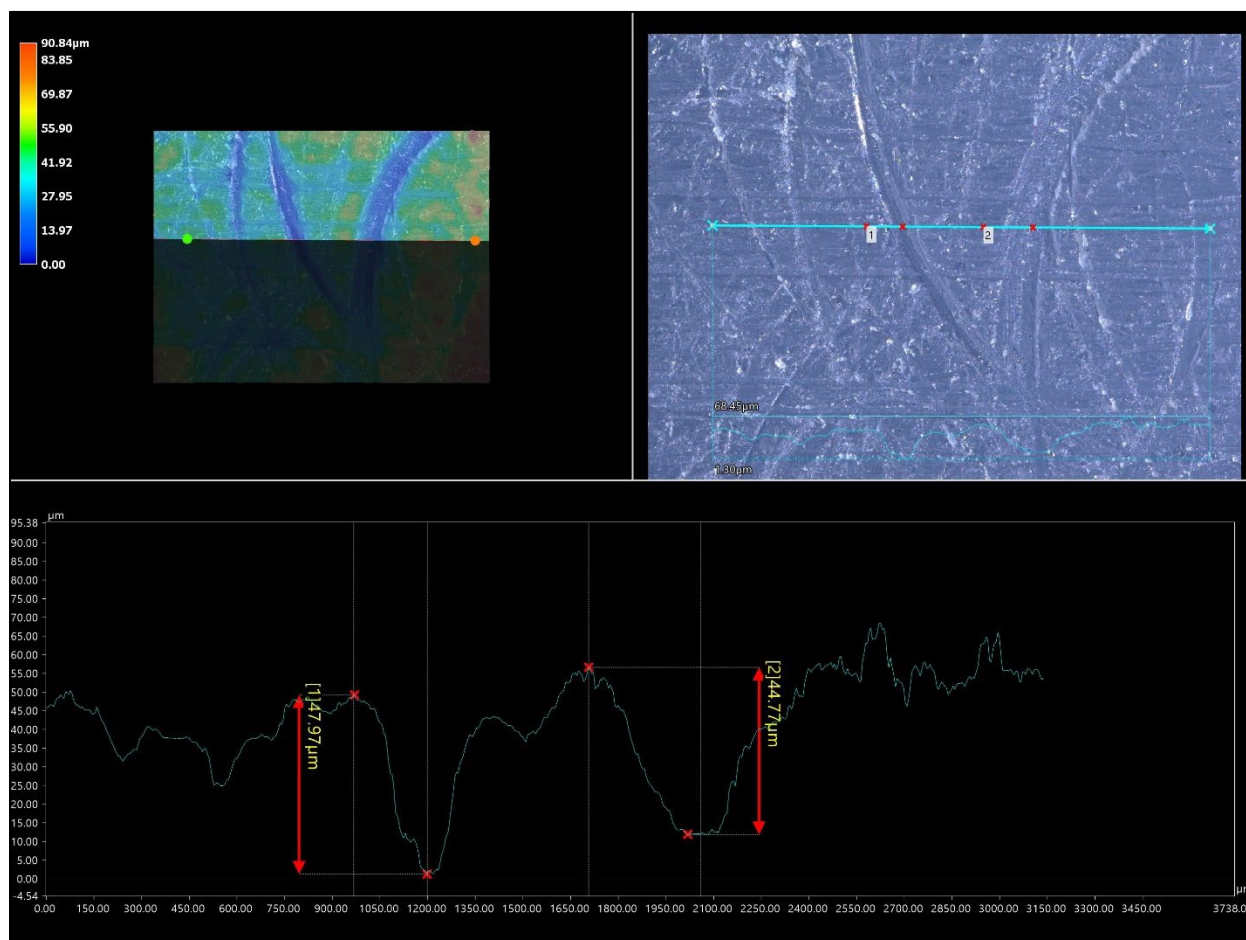


Figure 18. Color-coded 3D height map (upper left) of the bond surface area (upper right image) with relatively deep elliptical scratches near the origin and a chart showing relative height differences along the trace shown by the blue line in the upper right image.



Figure 19. Crack emanating from an elliptical scratch on the exterior surface in the bond area near the origin.

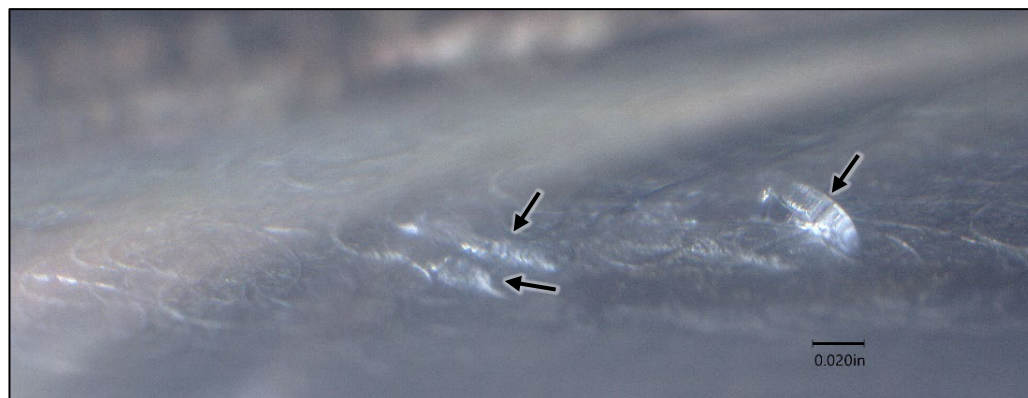


Figure 20. Cracks emanating from elliptical scratches on the interior surface in the bond area of piece 5.

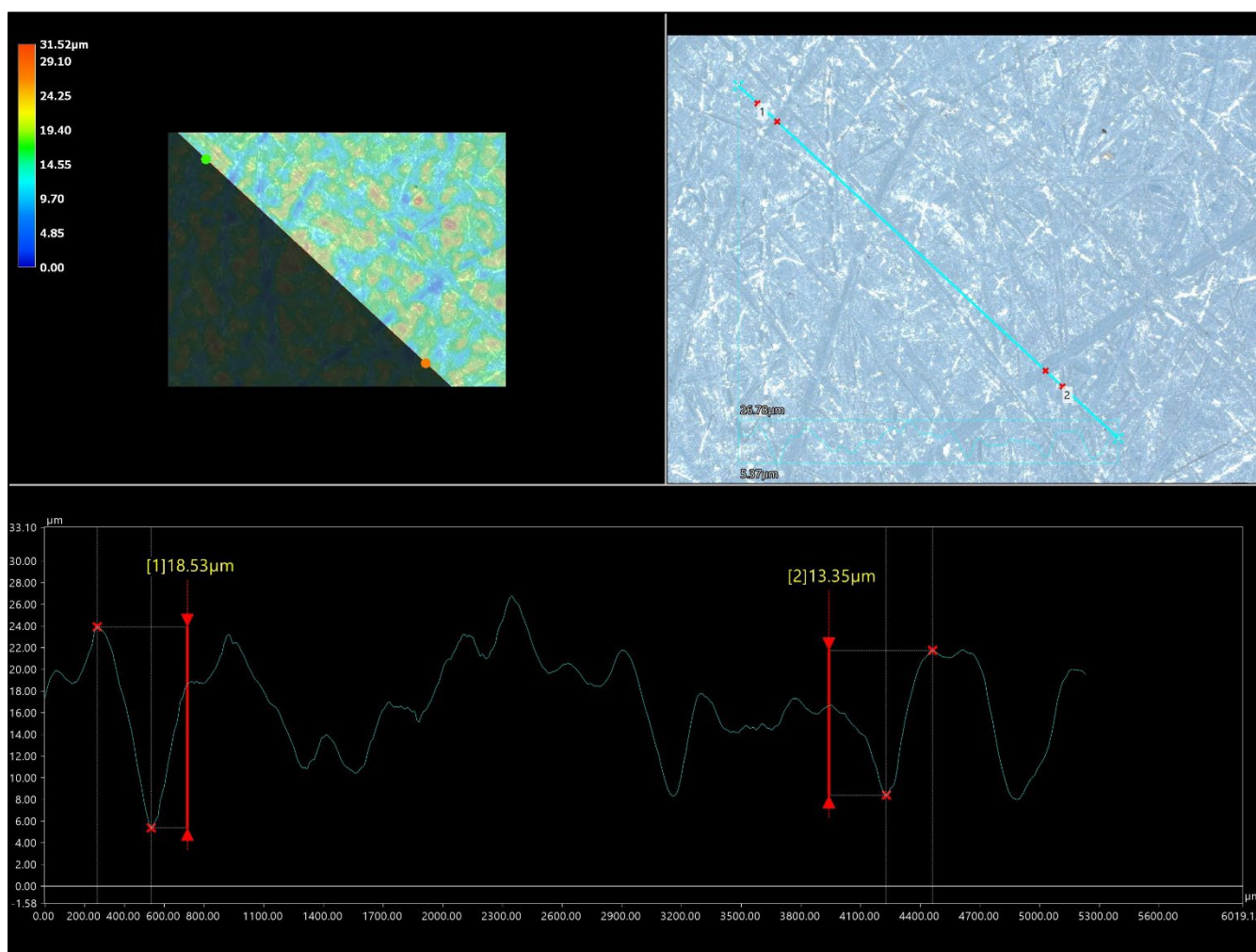


Figure 21. Color-coded 3D height map (upper left) and optical image (upper right) of a surface scratched with a vibrating sander with 40-grit paper in area with scratches that appeared relatively deep. Relative height differences along the trace shown by the blue line in the upper right image are plotted in the chart below the images.

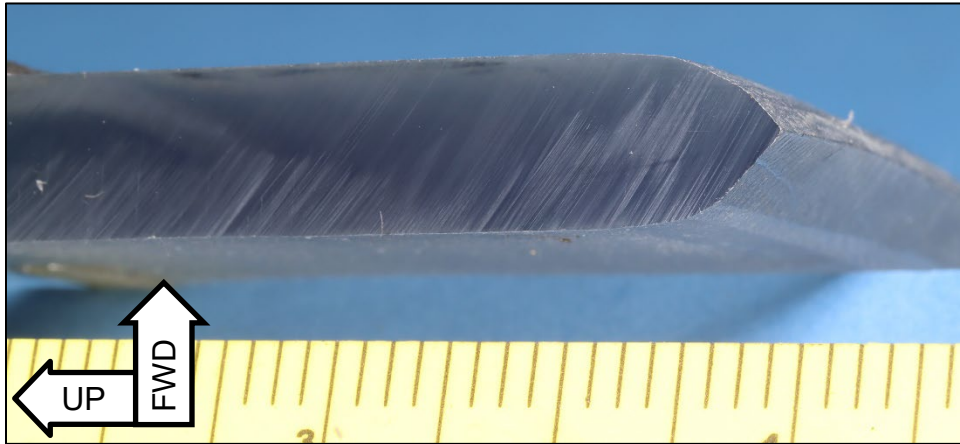


Figure 22. Section through piece 8 showing the edge profile.



Figure 23. Linear grinding marks at the lower edge of piece 8 on the interior side of the windshield.