National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

DCA24MM031

MATERIALS LABORATORY

Factual Report 24-080

November 27, 2024

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A. ACCIDENT INFORMATION

Location: Baltimore, Maryland
Date: March 26, 2024
Vehicle: M/V Dali
Investigator: Barton Barnum (MS-10)

B. COMPONENTS EXAMINED

Terminal Block 381 and two associated wires from vessel, and unused exemplar terminal blocks.

C. EXAMINATION PARTICIPANTS

Specialist — Adrienne Lamm
National Transportation Safety Board
Washington, D.C.

D. DETAILS OF THE EXAMINATION

On March 26, 2024, about 0129 eastern daylight time, the 947-foot-long Singapore flagged cargo vessel (containership) *Dali* was transiting out of Baltimore Harbor in Baltimore, Maryland, when it experienced a loss of electrical power and propulsion and struck the southern pier supporting the central truss spans of the Francis Scott Key Bridge (Key Bridge). A portion of the bridge subsequently collapsed into the river, and portions of the deck and the truss spans collapsed onto the vessel's forward deck. A seven-person road maintenance crew employed by Brawner Builders—which was contracted by the Maryland Transportation Authority (MDTA)—and one inspector employed by Eborn Enterprises, Inc., a subconsultant to the MDTA, were on the bridge when the vessel struck it. The inspector escaped unharmed, and one of the construction crewmembers survived with serious injuries. The bodies of the six fatally injured construction crewmembers were recovered. One of the 23 persons aboard the *Dali* was injured.

During on-scene examination of the electrical system from the *Dali*, Terminal Block 381 was identified as having a loose wire at connection point 1. As part of the on-board troubleshooting and testing the loose wire was re-inserted into and removed from the terminal block more than once. After testing, Terminal Block 381 and the ferrule ends of the wires assembled to it were disassembled from the electrical cabinet and submitted to the NTSB Materials Laboratory in Washington, D.C. for examination.

1.0 Terminology and Functionality

Terminal blocks are components used in electrical systems that secure multiple wires together so they can transfer electricity between them. As shown in Figure 1, terminal blocks are assemblies consisting of polymer forms that act as insulators to metal conductor bars into which wires are connected. Individual terminal blocks can snap together into larger units that are then housed inside an electrical cabinet. Figure 2 shows multiple terminal blocks snapped together into one unit.

Figure 3 shows that wires are also assemblies with multiple parts. A wire has strands inserted into a ferrule, with the ferrule then crimped to secure the strand cluster within it. Labeling bands are often installed over the ferrule casing to facilitate easy identification of wires when terminal blocks are assembled in large arrays within an electrical cabinet.

The terminal blocks utilized in the electrical system on board the *Dali* had three connection points into which wires could be installed, as shown in Figure 4. Operating ports next to the connection points allow tools to actuate the spring clamps that secure the wires.

A connection point with components labeled is shown in Figures 5 and 6. Each connection point consists of a spring clamp assembled to a cage. The cage is connected to the conductor bar at the bottom and has two walls, a cage front that holds the wire ferrule within the cage and a cage side against which the spring clamp presses the ferrule. The spring clamp has an opening on the top face through which the ferrule is inserted. A cage tab extending upwards from the cage side guides the ferrule into place when it is being installed through the spring clamp opening. The movement of the spring clamp when a tool is installed within the associated operating port is illustrated in Figures 7 and 8. When the spring clamp is open the ferrule can be inserted into the cage through the opening in the spring clamp face. Removal of the tool releases the spring clamp, which then secures the ferrule against the cage side. Figure 9 shows a ferrule inserted into the cage and secured against the cage side by a closed spring clamp.

2.0 Terminal Block 381

A photo of Terminal Block 381 with wires connected as installed within the electrical cabinet onboard the *Dali* is shown in the top of Figure 10. The configuration of the electrical system on the *Dali* had wires assembled to connection points 1 and 3 of Terminal Block 381, labeled in the figure. The bottom photos in Figure 10 show the appearance of the terminal block after removal from the electrical cabinet. Figure 11 shows the two sides of Terminal Block 381 as received in the NTSB Materials Laboratory. One side had markings identifying the terminal block as a model WAGO 280, IEC 60947-7-1, with a size of 2.5 millimeters-squared and 800-volt capacity.

Views looking downwards into connection points 1 and 3 at the top of the cage tab and spring clamp face are shown in Figure 12. Scrape marks were visible on the cage tabs, indicated by the red arrows. More scrape marks were present on the cage tab from connection point 1 than the cage tab on connection point 3. Metal spatter consistent with arcing was observed on the spring clamp face in connection point 1, indicated by the white arrow. With the spring clamp actuated, the opening of the connection points measured approximately 0.081 inches long by 0.099 inches wide.

The terminal block was examined using x-ray to nondestructively view inside the cages with the conductor bar still assembled within the polymer form. Planar views inside the cages of connection points 1 and 3 are shown in Figure 13, while an angled view showing an isometric view of the cage from connection point 1 is shown in Figure 14. No wire debris or other obstructions were observed within either cage.

The conductor bar was disassembled from the polymer form and both pieces were examined. Views of both sides of the components after disassembly are shown in Figure 15. Figure 16 shows digital microscope images of connection points 1 and 3 on the polymer form. A distinct gouge was visible in the gate channel of connection point 1, indicated by the yellow dotted line. The gouge was consistent with contact from the spring clamp gate during actuation of the spring clamp. Scratches and ridges from scratching were observed in the operating ports of both connection points, as indicated by the red dashed lines. The scratches were consistent with tool insertion into the operating ports during spring clamp actuation.

Figures 17 and 18 show digital microscope images of the cages from connection points 1 and 3, respectively, on the disassembled conductor bar. The red arrows point to scrape marks on the cage tabs and cage sides. The cage side of connection point 1 had multiple sets of scrape marks at different heights, while the cage side of connection point 3 only had scrape marks at one height. Material transfer consistent with electrical conduction (white arrows) was also observed on the cage sides. Close-up images of the arcing damage on the spring clamp face from connection point 1 are shown in Figure 19. The arcing damage consisted of distinct circular marks surrounded by light-colored halos, with adjacent blue and purple discoloration, consistent with metal spatter.

3.0 Wires from Terminal Block 381

The submitted portion of the wire assembled within connection point 1 is shown in Figure 20, and hereafter is referred to as wire 1. The portion of wire 1 was submitted with the labeling band still installed. The following part markings were observed on wire 1: AWM 1015 VW-1 105°C 600V 17AWG.[1] Digital microscope

[1] The "AW" portion of the part markings is not shown in Figure 20, but was observed underneath the labeling band when examined using stereomicroscopy.

images of opposing sides of the wire 1 ferrule are shown in Figure 21. Higher magnification images of the two sides are shown in Figures 22 and 23. Figure 22 shows one side had multiple distinct linear gouges (yellow arrows), consistent with contact with the edge of the spring clamp gate. A depression with scrape marks (red arrows) was observed on the end of the ferrule in-line with one of the gouges. Material transfer consistent with electrical conduction was visible on the side of the ferrule opposite the gouges, indicated by the white arrows in Figure 23. The same side of the ferrule also had material smeared along the edge, as indicated by the orange arrows.

The submitted portion of the wire assembled within connection point 3 is shown in Figure 24, and hereafter is referred to as wire 3. The following part markings were observed on wire 3: LL69935 CSA TEW 105°C 600V FT1 -F- RoHS LF PoHS LF SHIN HWA. Digital microscope images of opposing sides of the wire 3 ferrule are shown in Figure 25. Higher magnification images of the two sides are shown in Figures 26-28. Figure 26 shows one distinct linear gouge (yellow arrow), consistent with contact with the edge of the spring clamp gate. Figure 27 shows two circular gouges (black arrows) observed on the same side as the linear gouge but closer to the ferrule casing. The cause of the circular gouges was unknown. Material transfer consistent with electrical conduction was visible on the side of the ferrule opposite the gouges, indicated by the white arrows in Figure 28.

Figure 29 shows a side-by-side view of the ferrules from wires 1 and 3. The wire 1 ferrule had four crimp marks circumferentially while wire 3 had six crimp marks around the circumference. The different crimp patterns created different ferrule profiles, as seen in the comparison of the wire ends shown in Figure 30. The four-sided crimping of the wire1 ferrule resulted in a roughly square-shaped profile that measured roughly 0.077 inches by 0.091 inches, while the six-sided crimping of wire 3 resulted in a circular profile with an approximate 0.084-inch diameter. The depression with scrape marks (red arrow) on the end of the wire 1 ferrule resulted in the flattening of one corner. The strands adjacent to the flattened ferrule corner had also been flattened. Figure 31 shows an angled view of the flattened corner of the wire 1 ferrule. The flattening resulted from the depression (red arrows) which angled inwards towards the center of the wire. The yellow arrows in Figure 31 indicate the linear gouges discussed previously, with one linear gouge directly in-line with the depression that caused the flattened ferrule corner.

There was additional damage to the end of the wire 1 ferrule along the side opposite the flattened corner. Material appeared to have been dragged from the side of the ferrule and smeared over the edge, covering one of the strands (orange arrows, Figures 30 and 31). Erosion consistent with arcing (white arrows) was observed on one strand adjacent to the damaged ferrule edge, as well as on the ferrule edge adjacent to the strand covered by smeared material.

The smeared material was removed from the edge of the ferrule and the end of wire 1 was re-examined. White arrows in Figure 32 point to multiple locations with erosion consistent with arcing on the ferrule edge, as well as on one strand adjacent to that edge.

4.0 Exemplar Terminal Blocks

Several new, unused terminal blocks of the same model from the same manufacturer as those used on the *Dali* (i.e. WAGO model 280) were obtained to serve as exemplars. Actuation of the spring clamps on the exemplar terminal blocks resulted in similar damage to the polymer forms observed on Terminal Block 381. During actuation of the spring clamp, distinct gouges were made in the gate channel of connection points due to contact from the spring clamp gates. Scratches and ridges from scratching were observed in the operating ports after tools had been used to actuate the spring clamps. Both types of damage could be produced after just one actuation of the spring clamp, and thus seemed to be characteristic of routine use of the terminal blocks.

The conductor bar was disassembled from one exemplar terminal block to expose the connection points in the polymer form. The wires from Terminal Block 381 were then inserted into their respective connection points at different positions in the exemplar terminal block form. The top of Figure 33 shows wire 1 positioned with the depression on the end of the ferrule in-line with the spring clamp gate edge, with the white dotted line indicating the path along which the spring clamp gate would move. The bottom of Figure 33 shows wire 3 positioned with the sole linear gouge in the ferrule in-line with the spring clamp gate edge, with the white dotted line again indicating the path along which the spring clamp gate would move. Both wires were then inserted to the maximum depth possible in their current condition into the cage areas of the connection points, as shown in Figure 34. The ferrule on wire 3 could touch the bottom of the cage area, while the depth to which the ferrule on wire 1 could be inserted was shallower due to the still assembled labeling band restricting movement into the connection point. The depth of the wire 1 ferrule into the corresponding connection point being restricted by the labeling band as compared to the wire 3 ferrule is illustrated by the macro photo shown in Figure 35.

Submitted by:

Adrienne V. Lamm
Materials Engineer

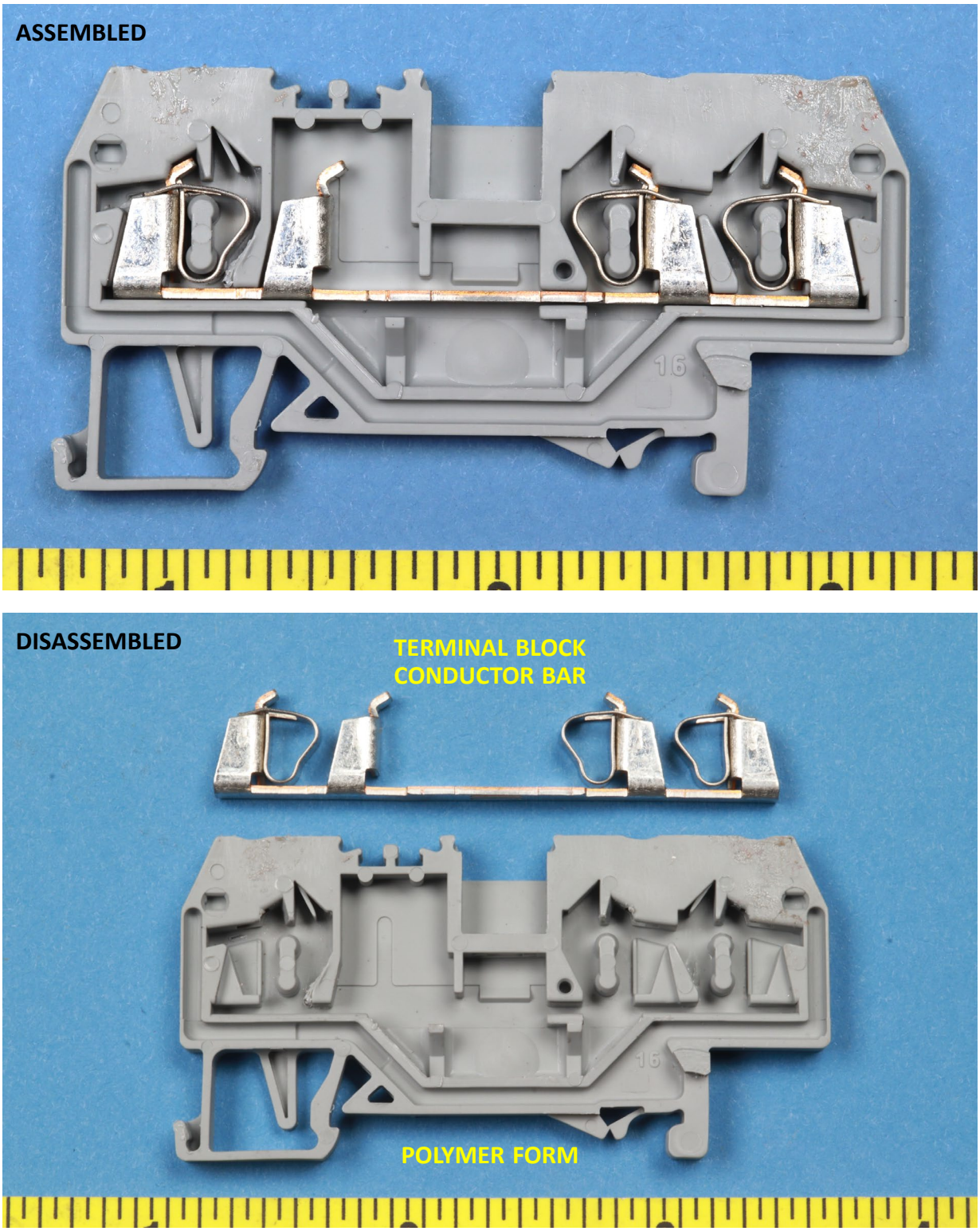

Figure 1. Macro photos showing a terminal block assembled and disassembled.

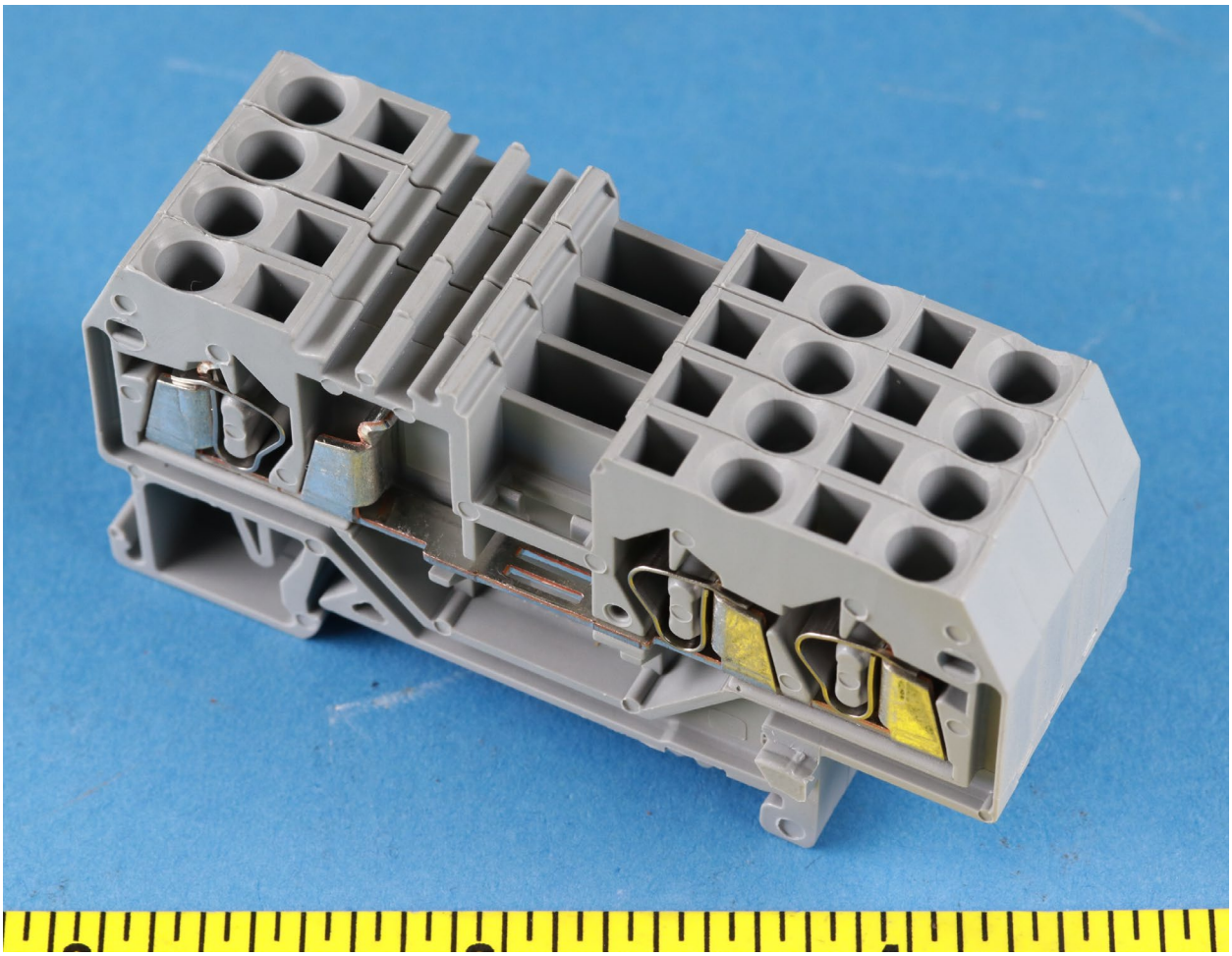

Figure 2. Macro photo showing multiple terminal blocks snapped together into one unit.

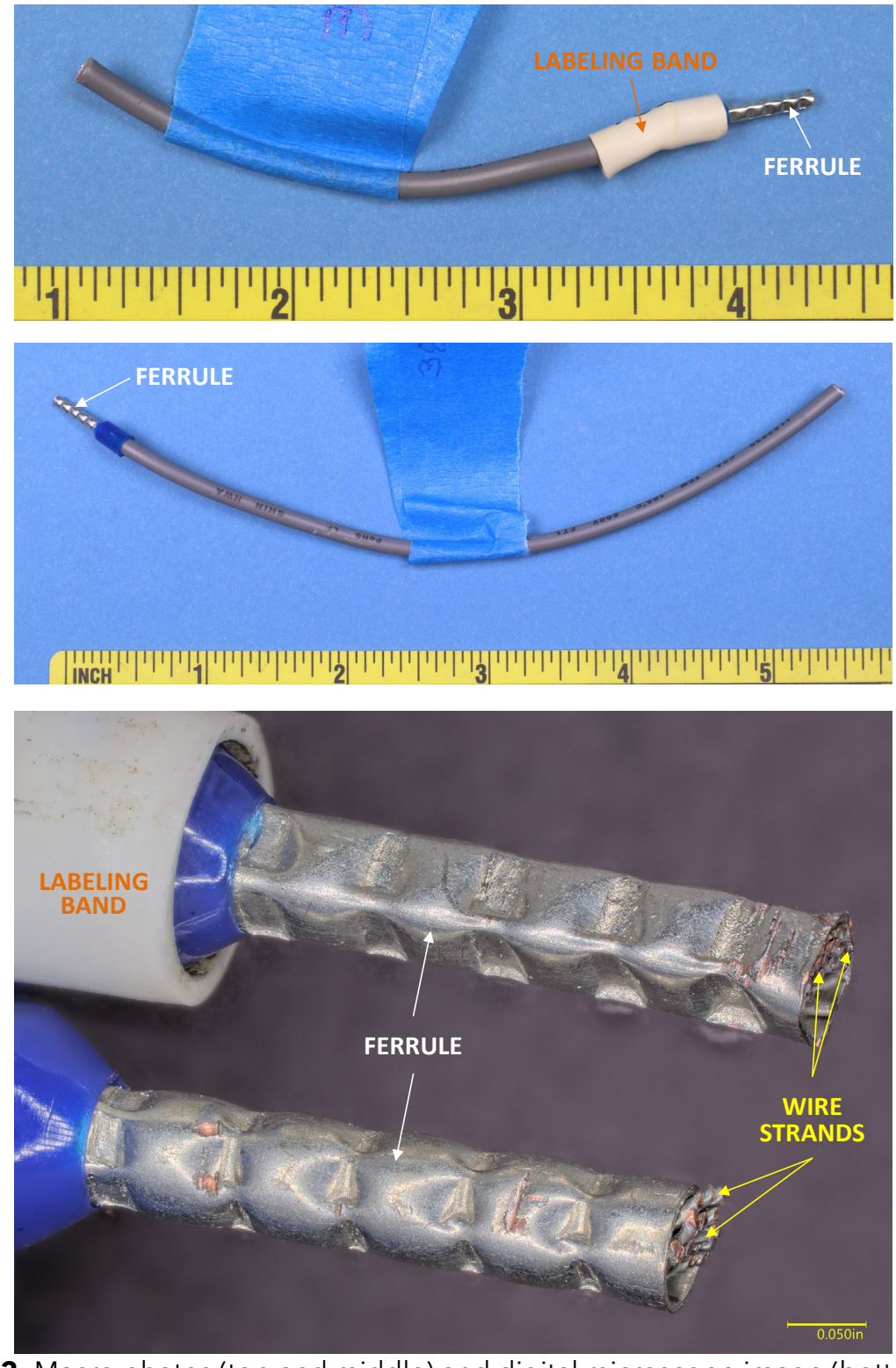

Figure 3. Macro photos (top and middle) and digital microscope image (bottom) of wires with components labeled.

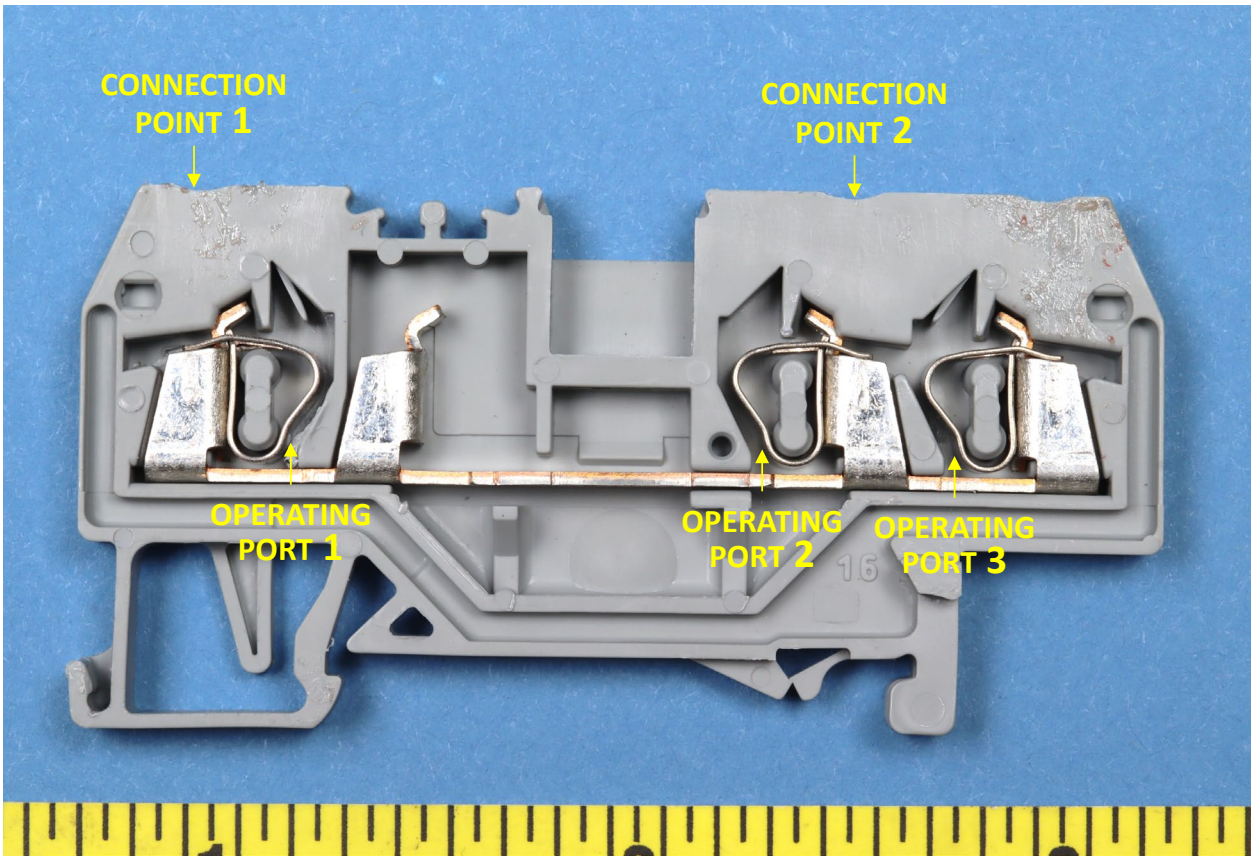

Figure 4. Macro photo of a terminal block with polymer form components labeled.

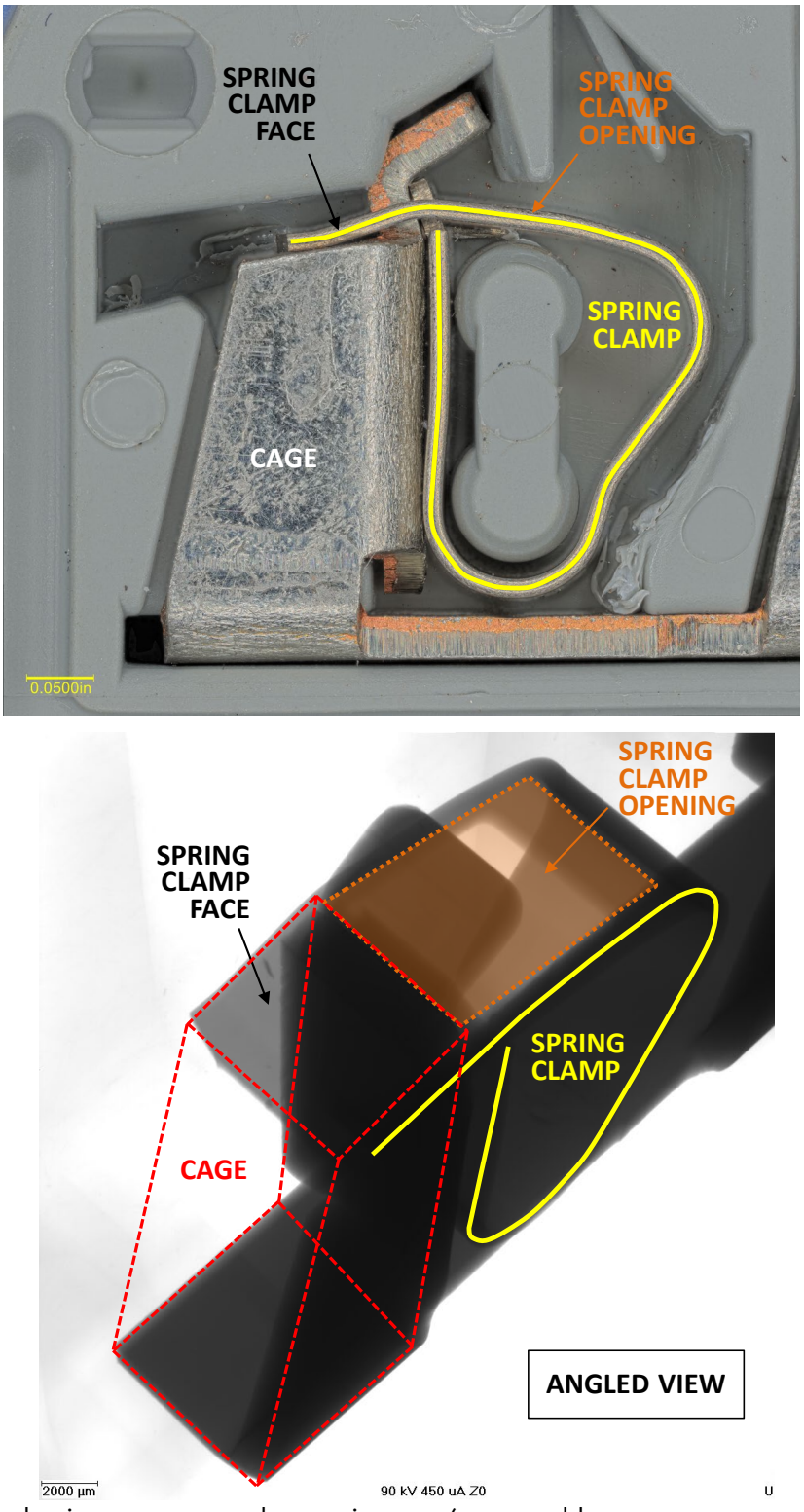

Figure 5. Digital microscope and x-ray image (top and bottom, respectively) of a terminal block with conductor bar spring clamp components labeled.

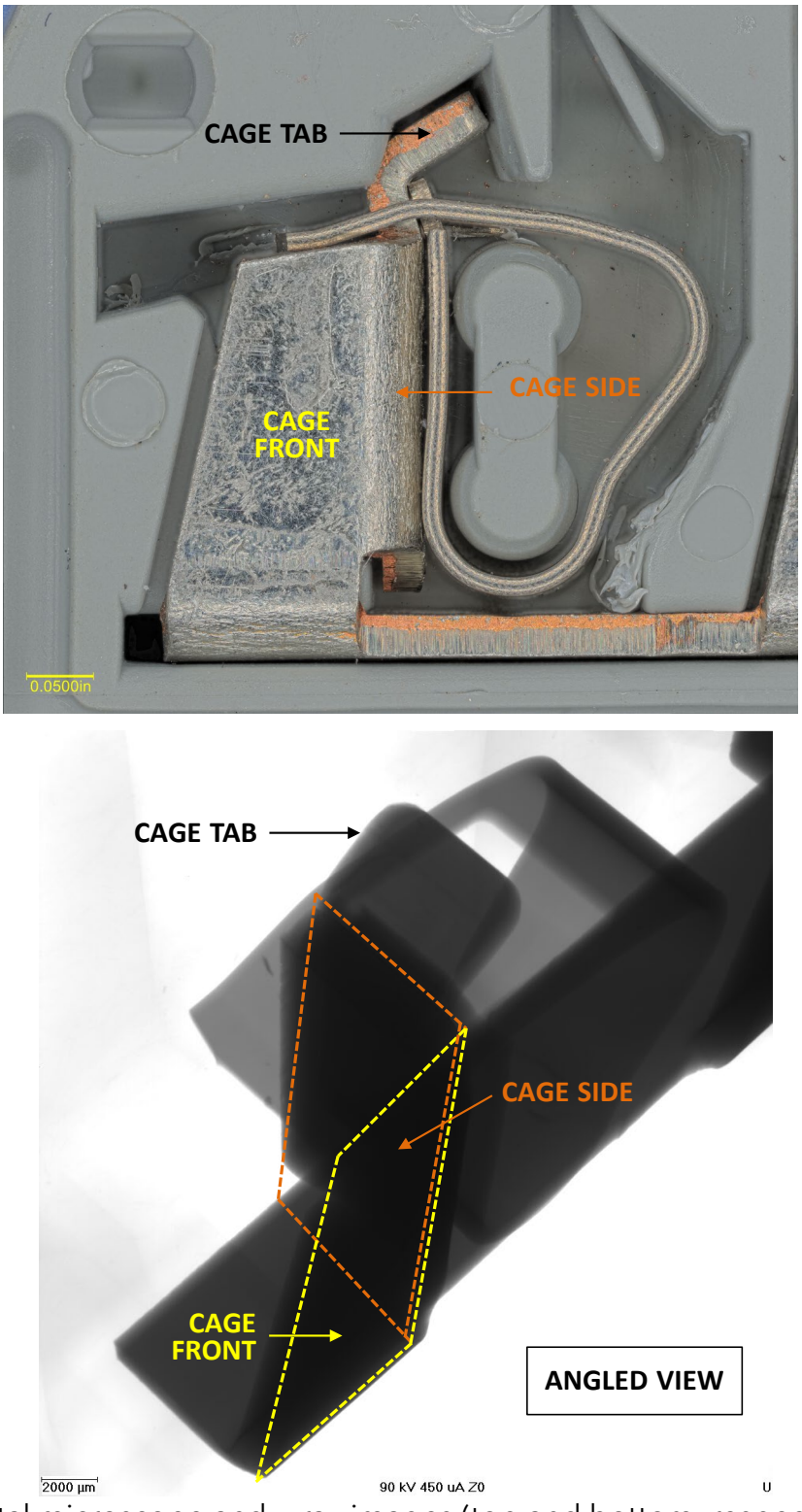

Figure 6. Digital microscope and x-ray images (top and bottom, respectively) of a terminal block with conductor bar cage components labeled.

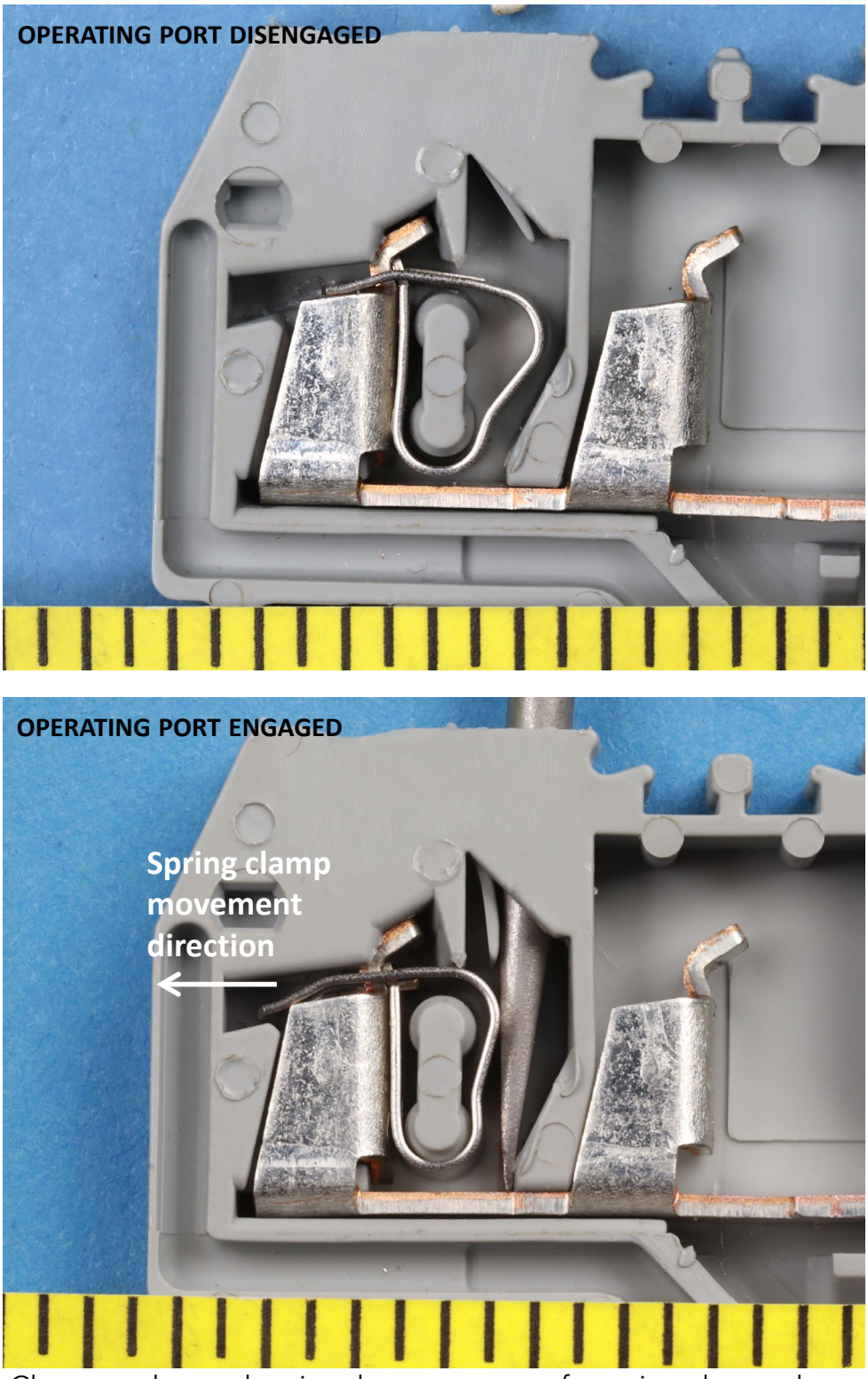

Figure 7. Close-up photos showing the movement of a spring clamp when a tool is installed in the operating port of connection point 1 on an exemplar terminal block.

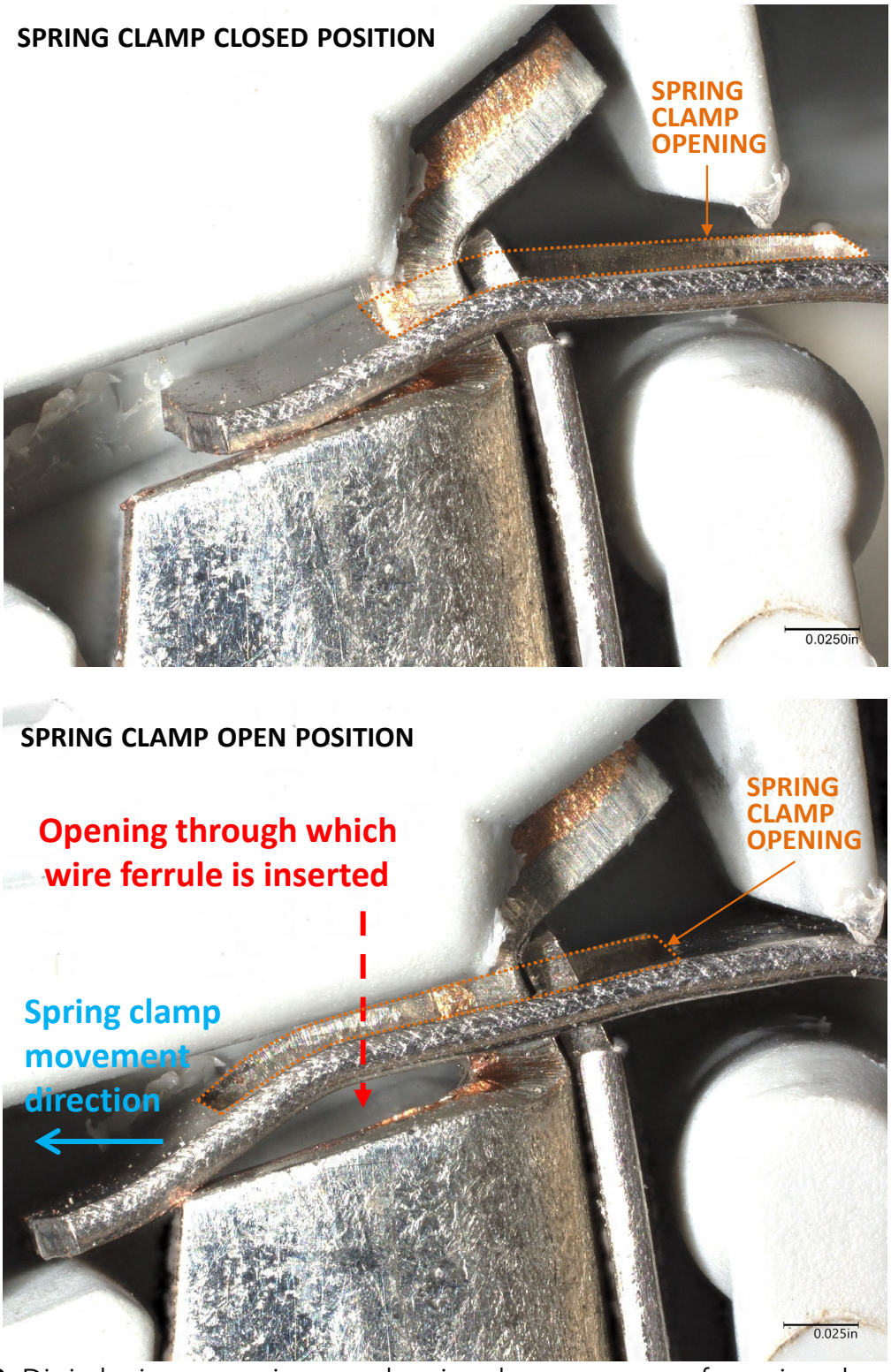

Figure 8. Digital microscope images showing the movement of a spring clamp when a tool is installed in the operating port of connection point 1 on an exemplar terminal block.

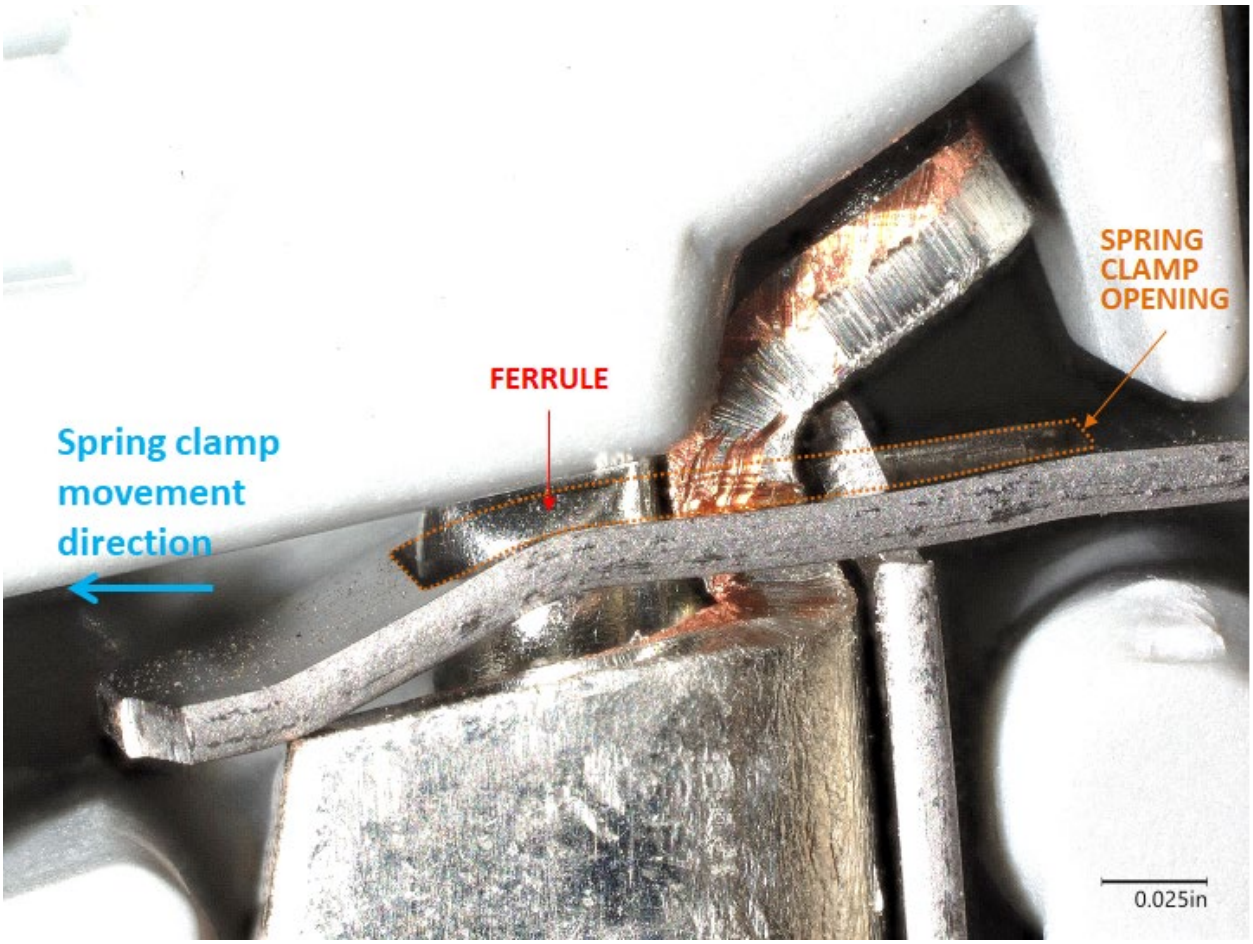

Figure 9. Digital microscope image showing a wire ferrule installed within a cage and secured by a spring clamp in connection point 1 on an exemplar terminal block.

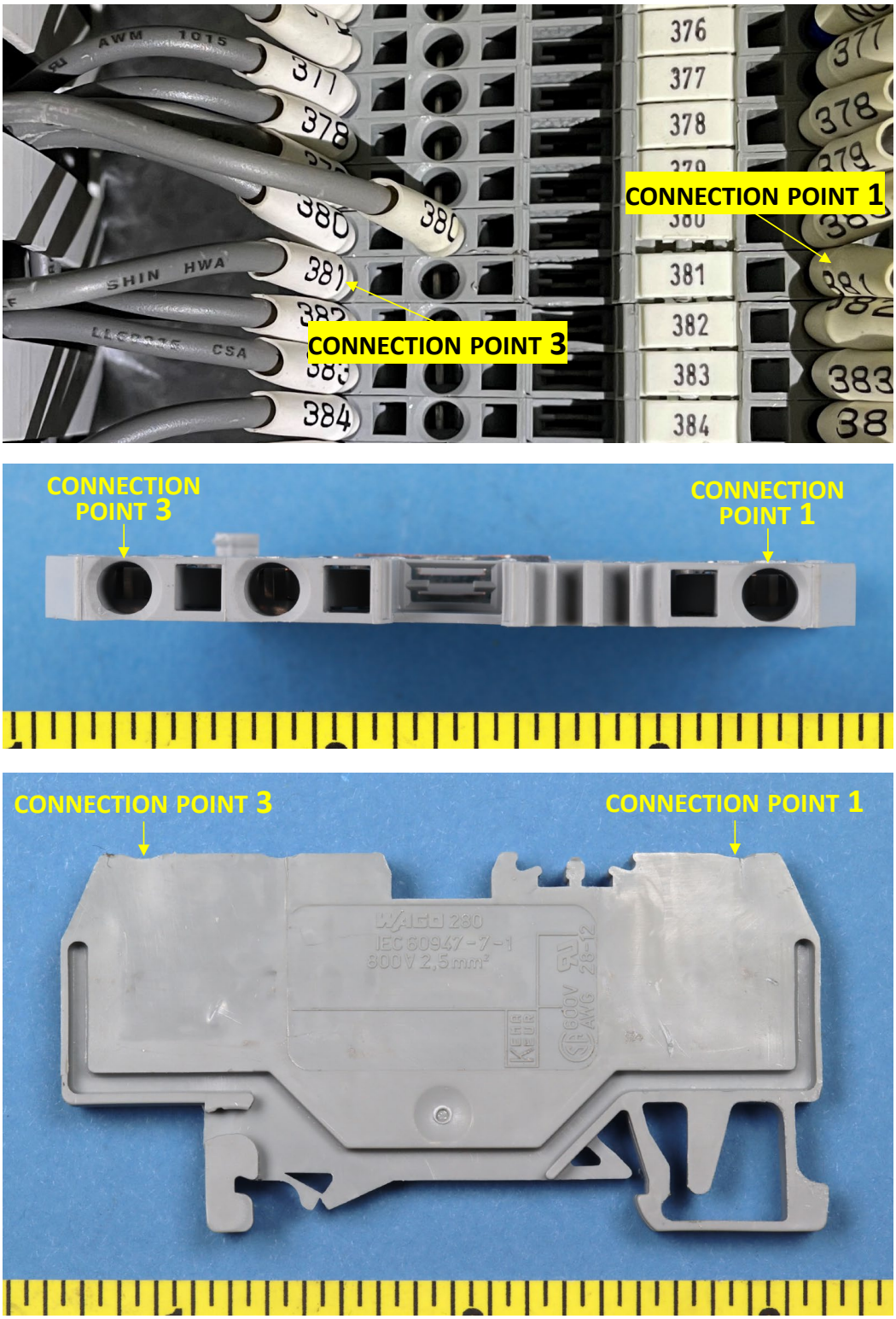

Figure 10. (Top) Close-up photo of Terminal Block 381 with wires connected as installed within the electrical cabinet onboard the *Dali*. (Middle and Bottom) Close-up photos showing the top and side of Terminal Block 381 after removal from the electrical cabinet.

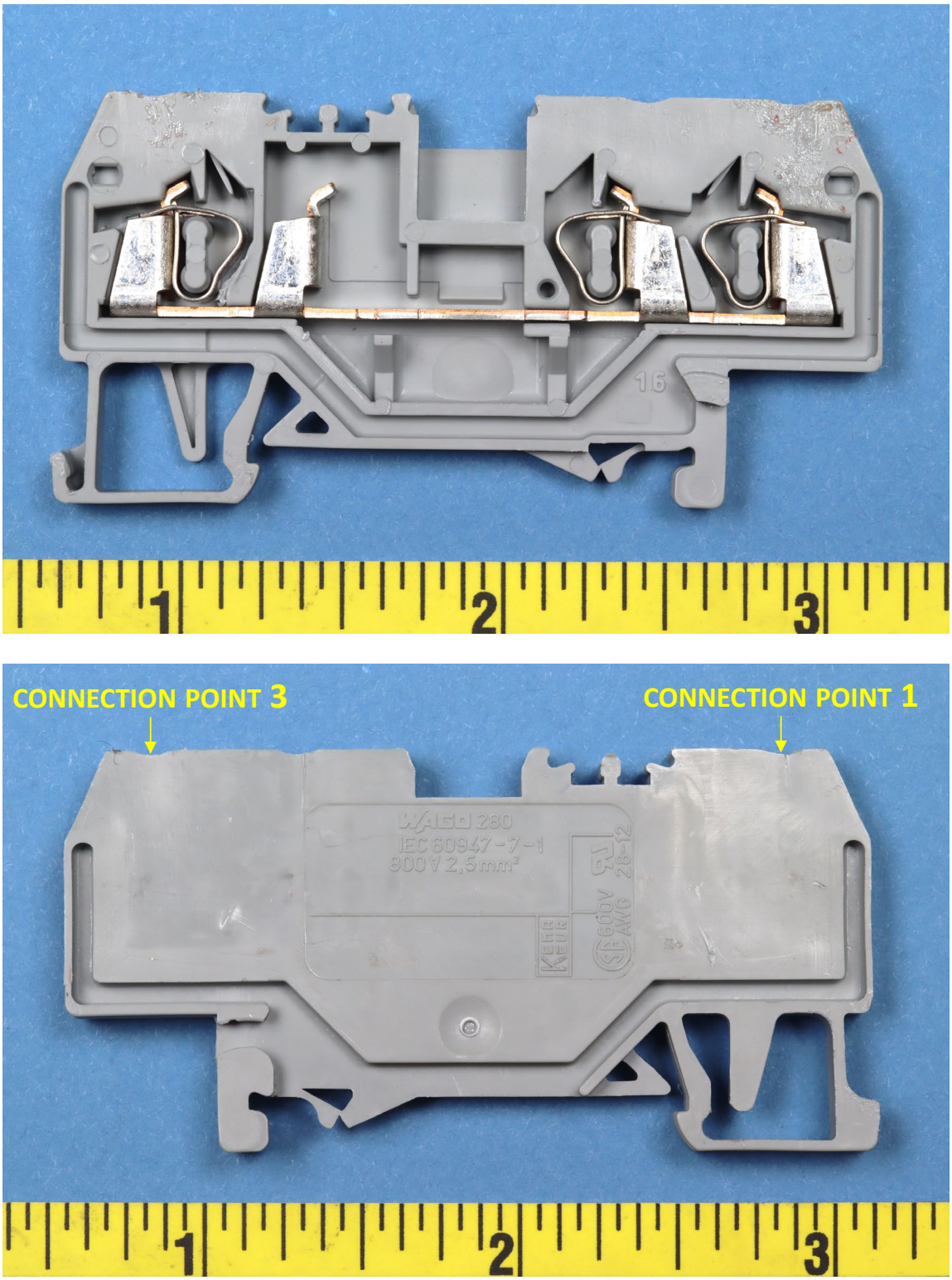

Figure 11. Close-up photos showing the two sides of Terminal Block 381 after removal from the electrical cabinet.

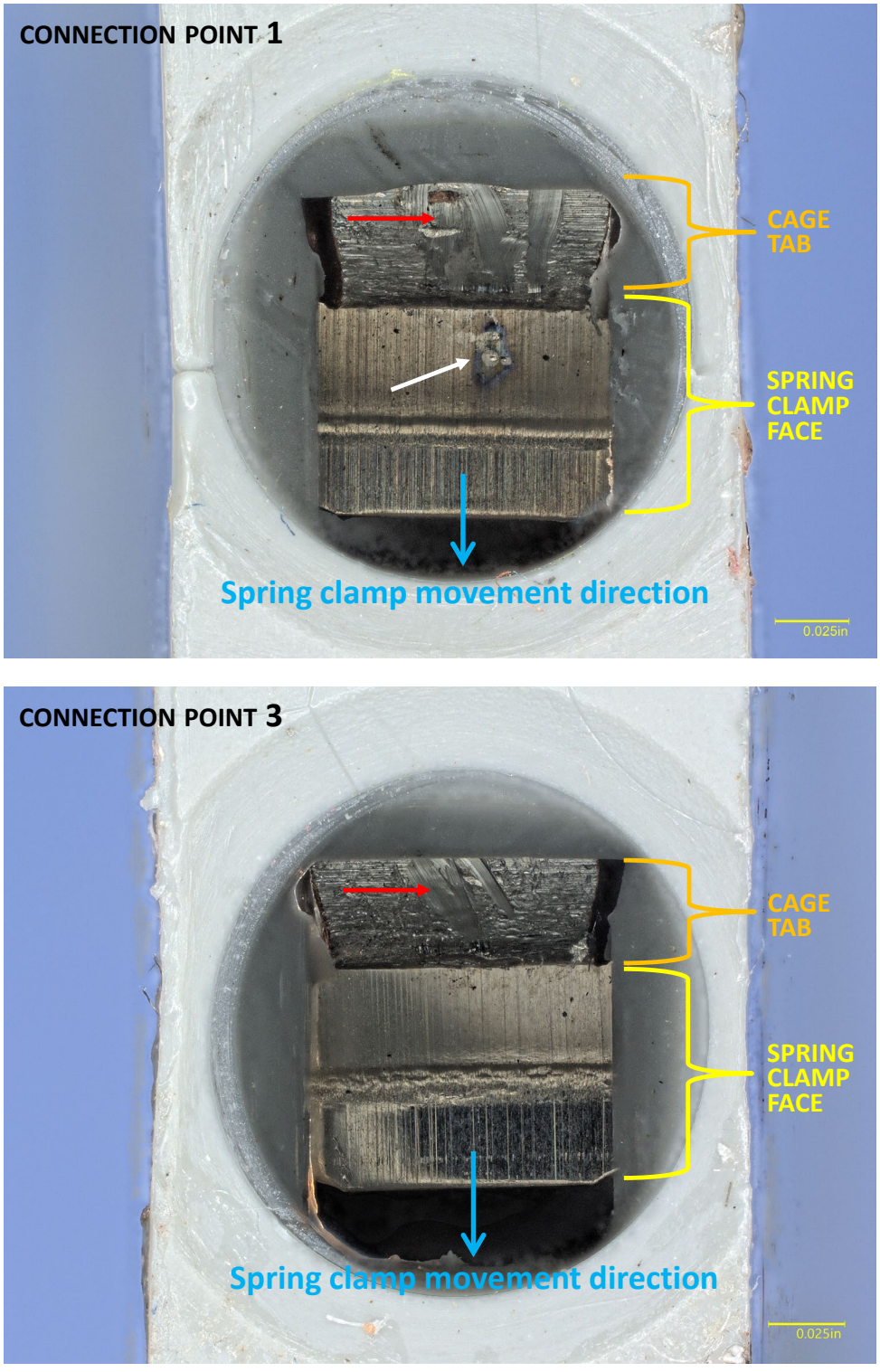

Figure 12. Digital microscope images looking downwards on Terminal Block 381 into connection points 1 and 3 at the top of the cage tab and spring clamp face. Red and white arrows point to scrape marks and arcing damage, respectively.

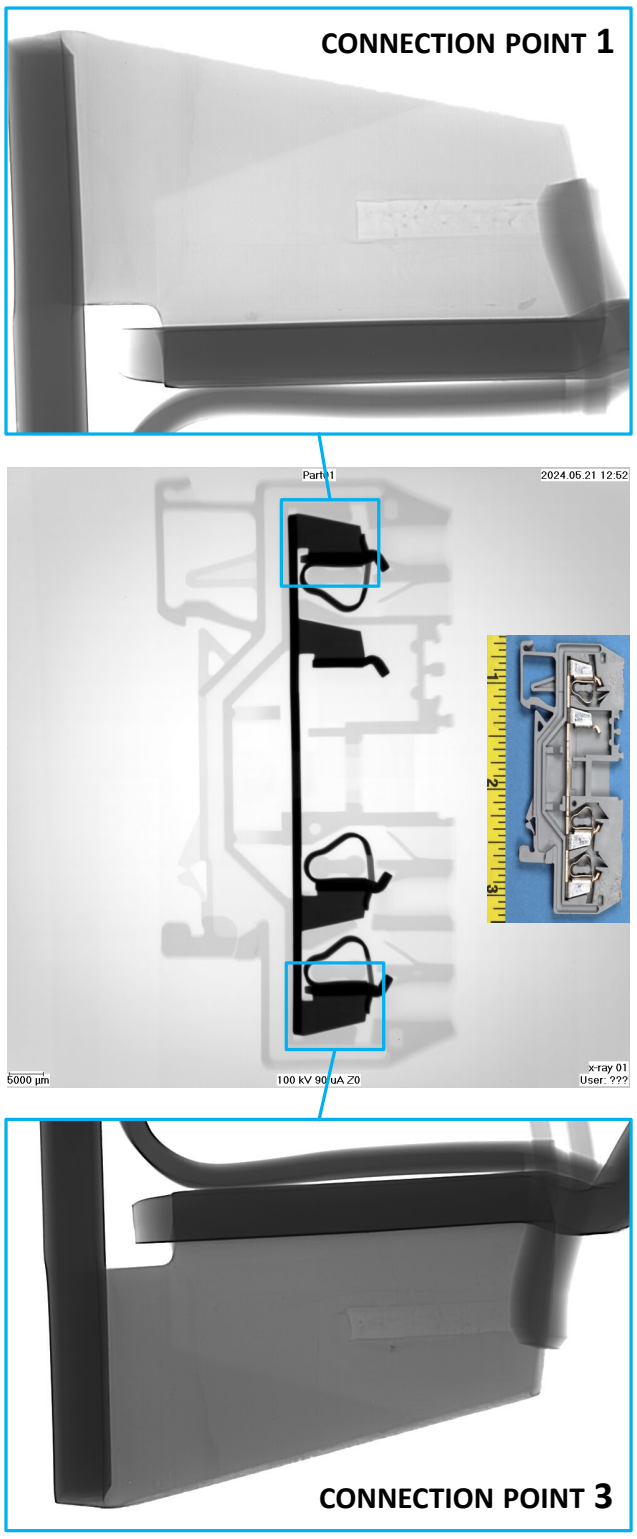

Figure 13. X-ray images of planar views inside the cages of connection points 1 and 3 on Terminal Block 381.

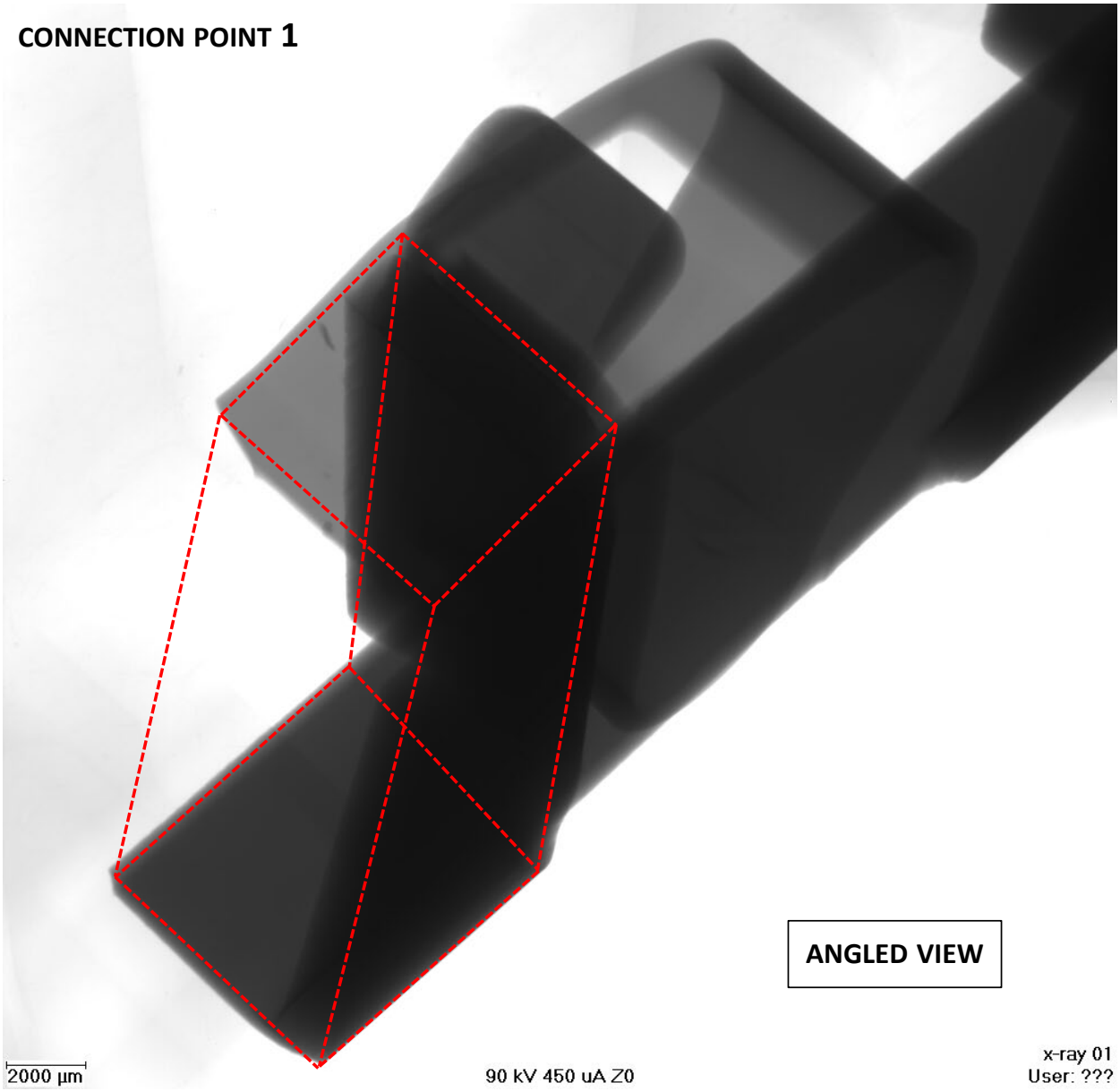

Figure 14. X-ray image of an angled view inside the connection point 1 cage on Terminal Block 381.

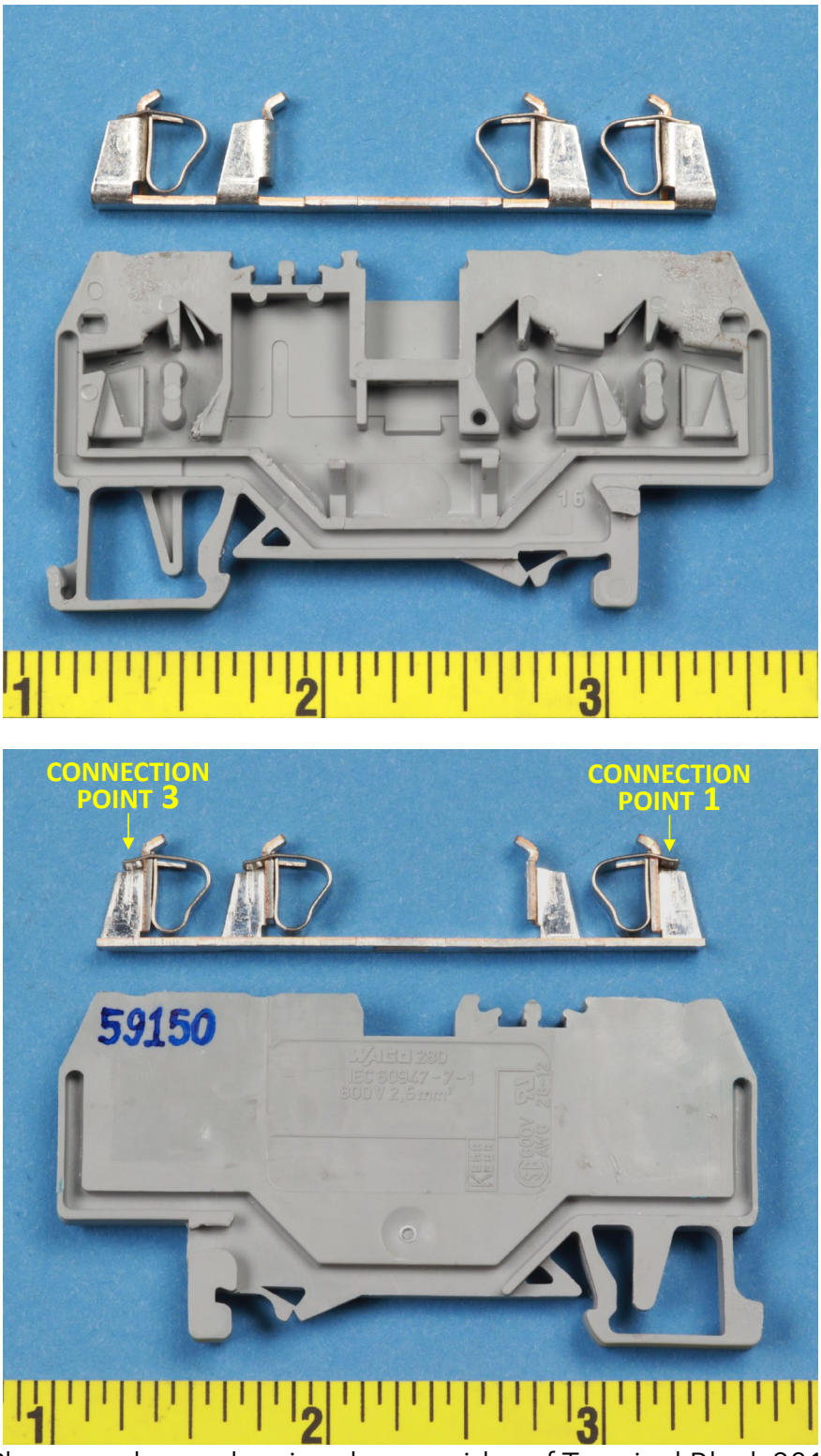

Figure 15. Close-up photos showing the two sides of Terminal Block 381 after disassembly.

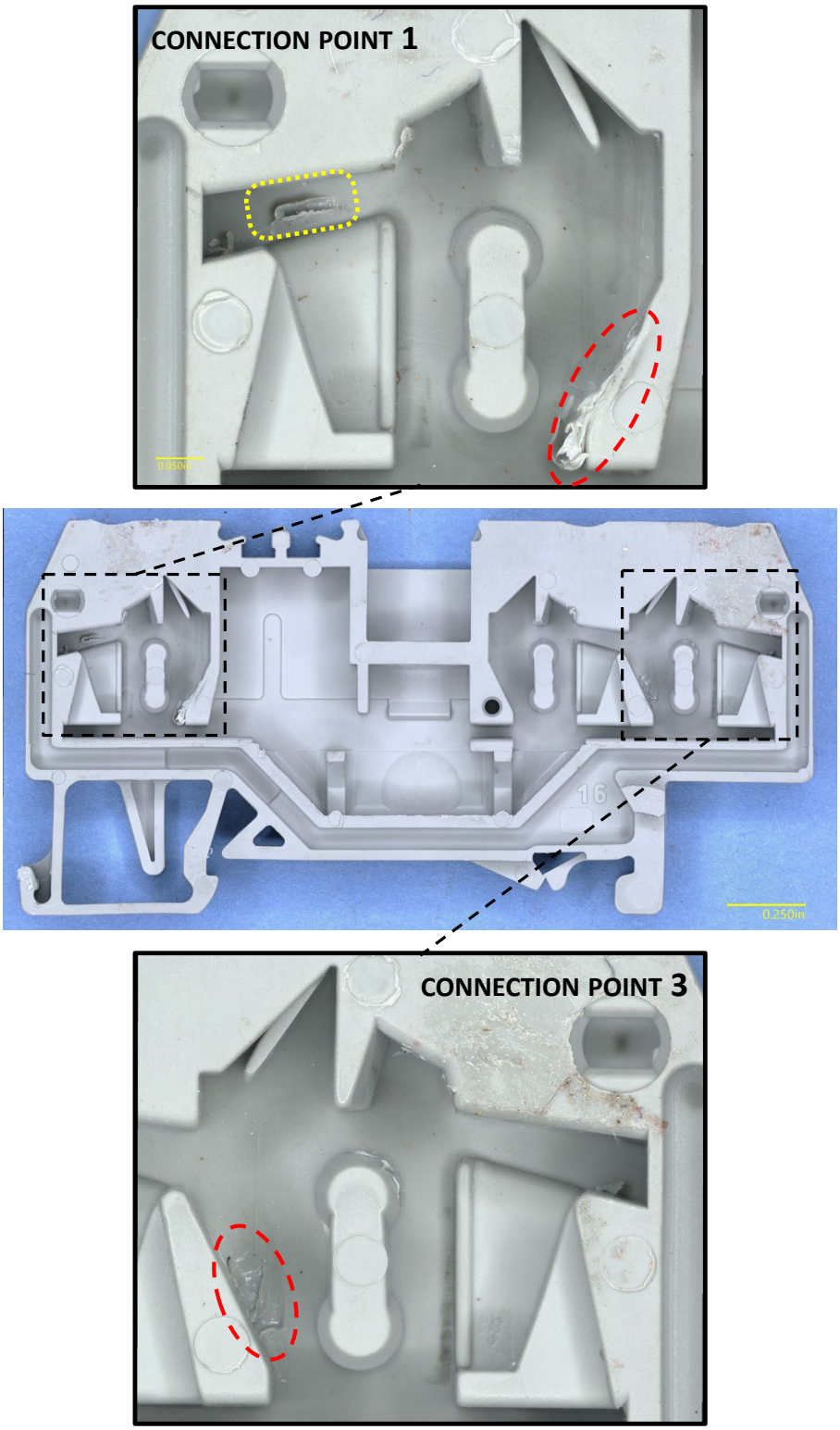

Figure 16. Digital microscope images of connection points 1 and 3 on the polymer form of Terminal Block 381. The red dashed lines encircle scratches and ridges in the operating ports of both connection points. The yellow dotted line encircles a distinct gouge in the gate channel of connection point 1.

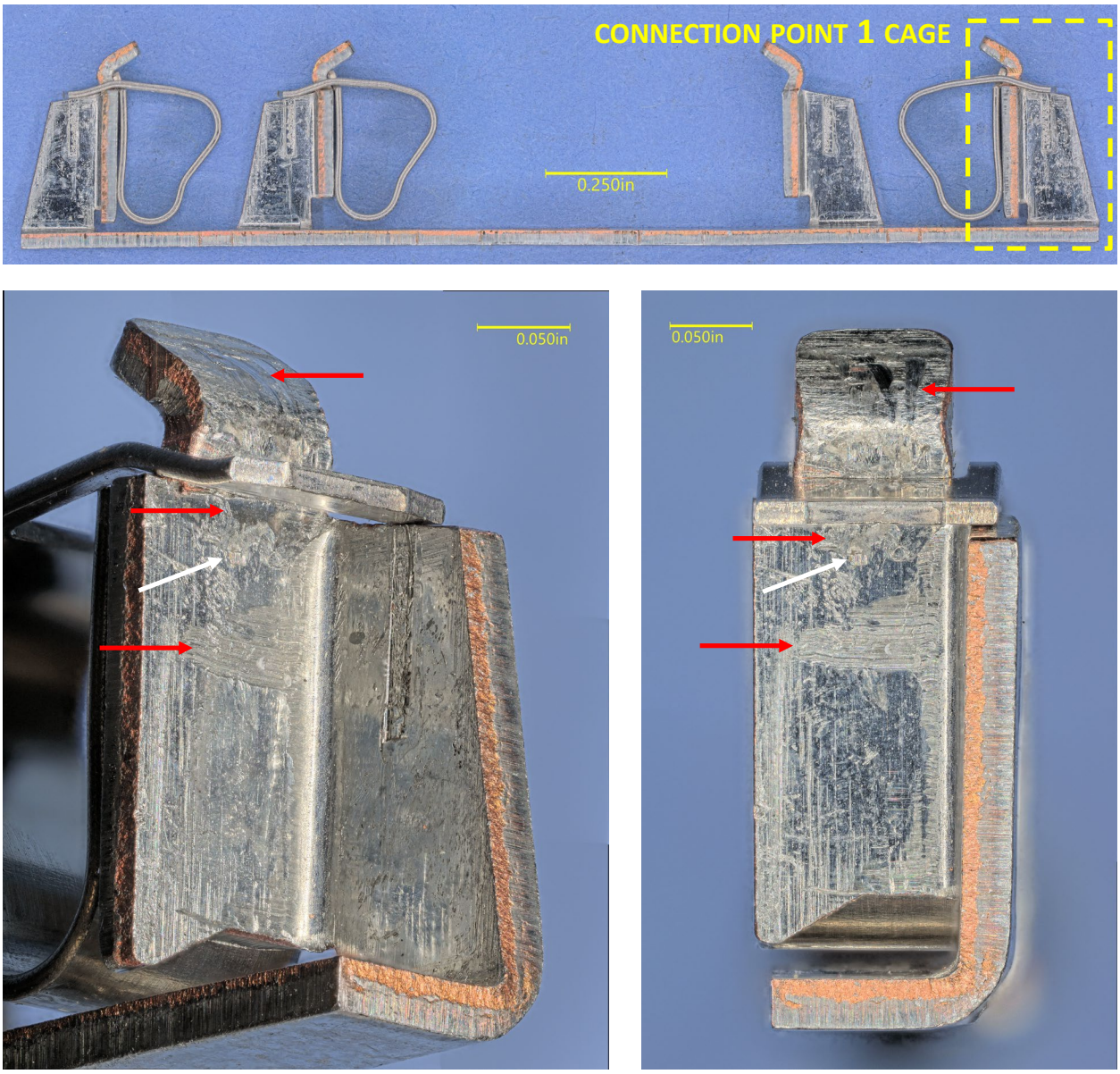

Figure 17. Digital microscope images of the cage from connection point 1 in Terminal Block 381. The red and white arrows point to scrape marks and material transfer from electrical conduction, respectively.

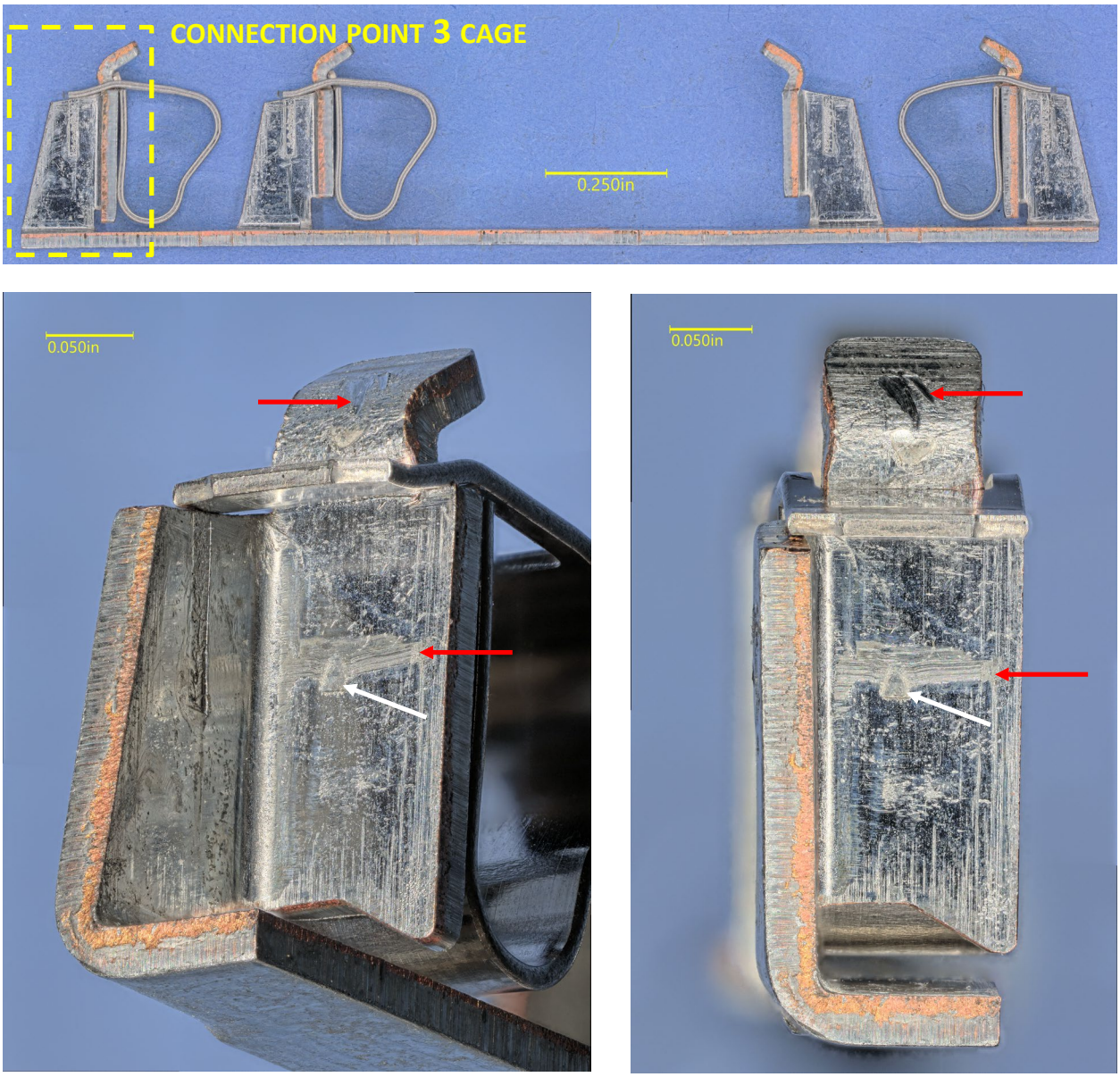

Figure 18. Digital microscope images of the cage from connection point 3 in Terminal Block 381. The red and white arrows point to scrape marks and material transfer from electrical conduction, respectively.

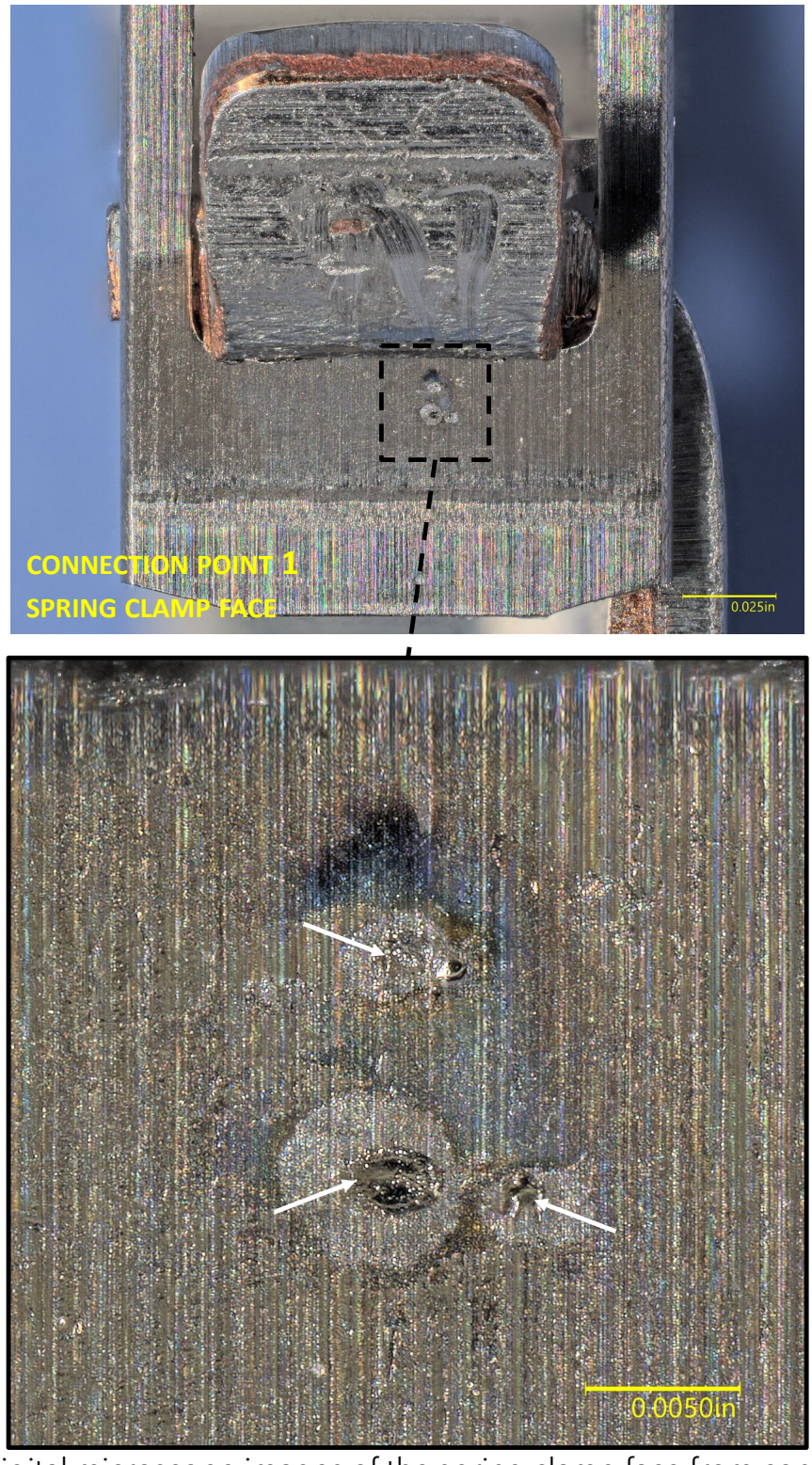

Figure 19. Digital microscope images of the spring clamp face from connection point 1 in Terminal Block 381. The white arrows point to metal spatter consistent with arcing.

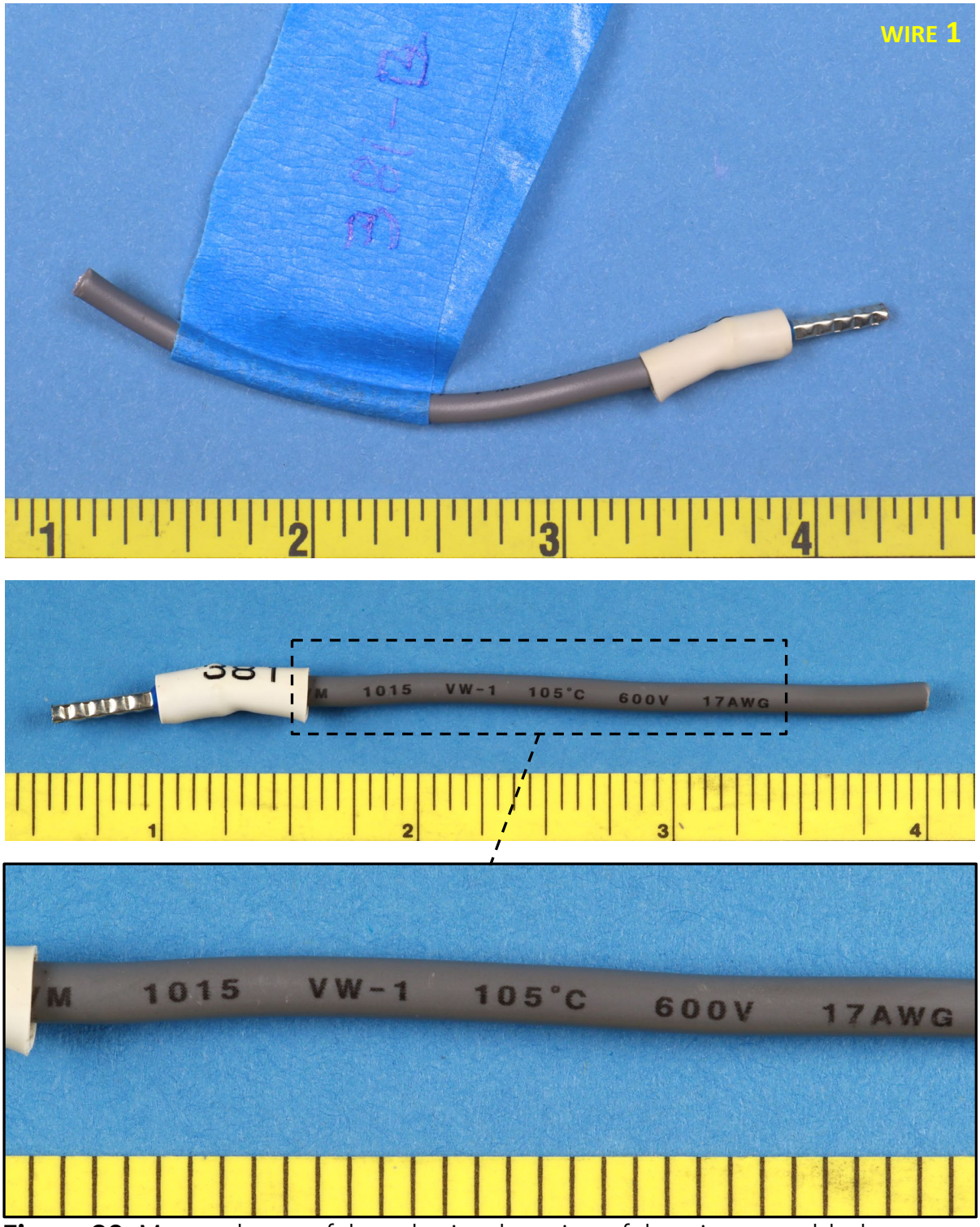

Figure 20. Macro photos of the submitted portion of the wire assembled to connection point 1 in Terminal Block 381 in the as-submitted condition and after identifying tape was removed (first and second images, respectively). A close-up photo of the identifying marks on the wire is shown in the third image.

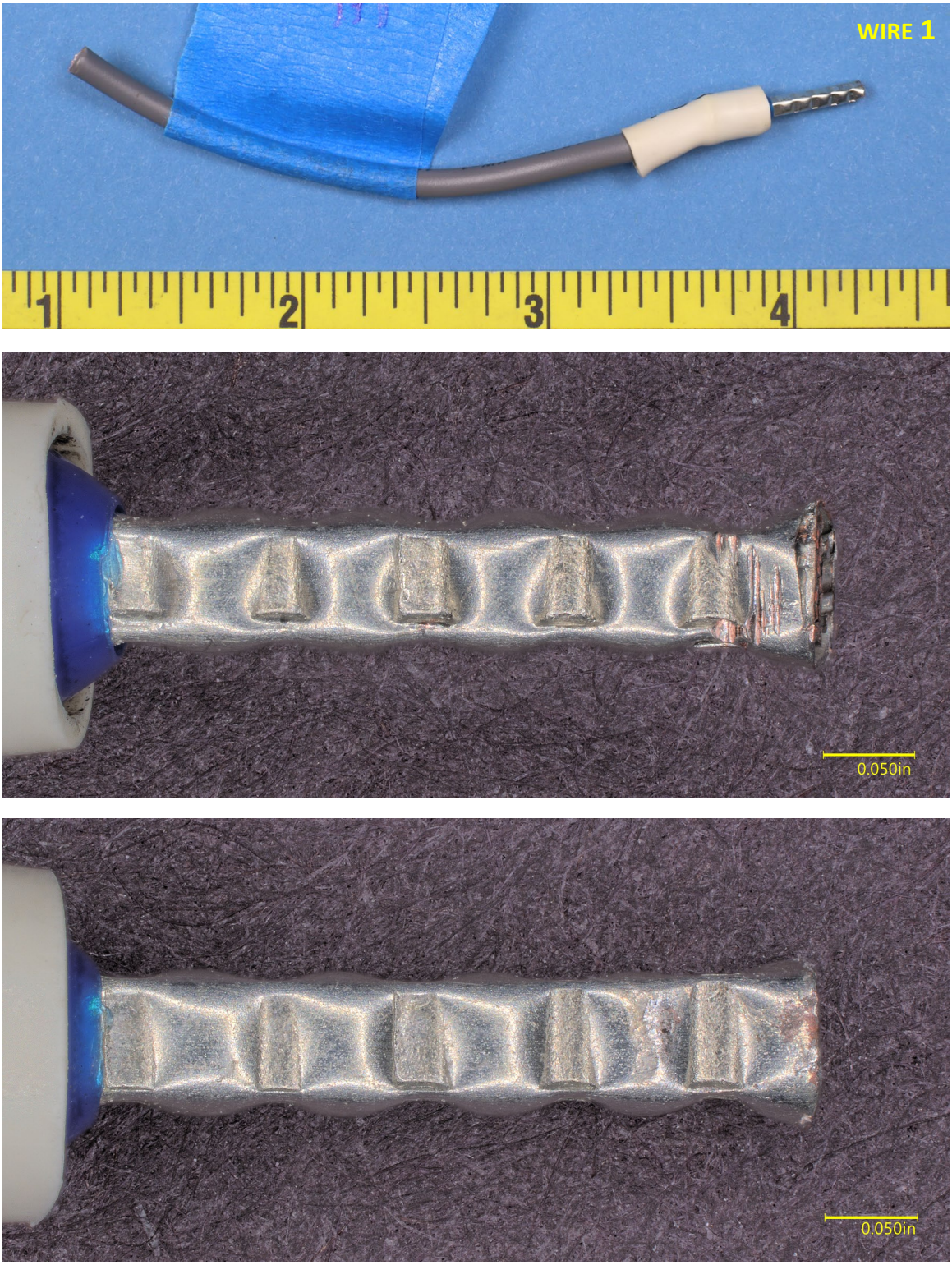

Figure 21. (Top) Macro photo of the submitted portion of the wire assembled to connection point 1 in Terminal Block 381. (Middle and Bottom) Digital microscope images of opposing sides of the wire 1 ferrule.

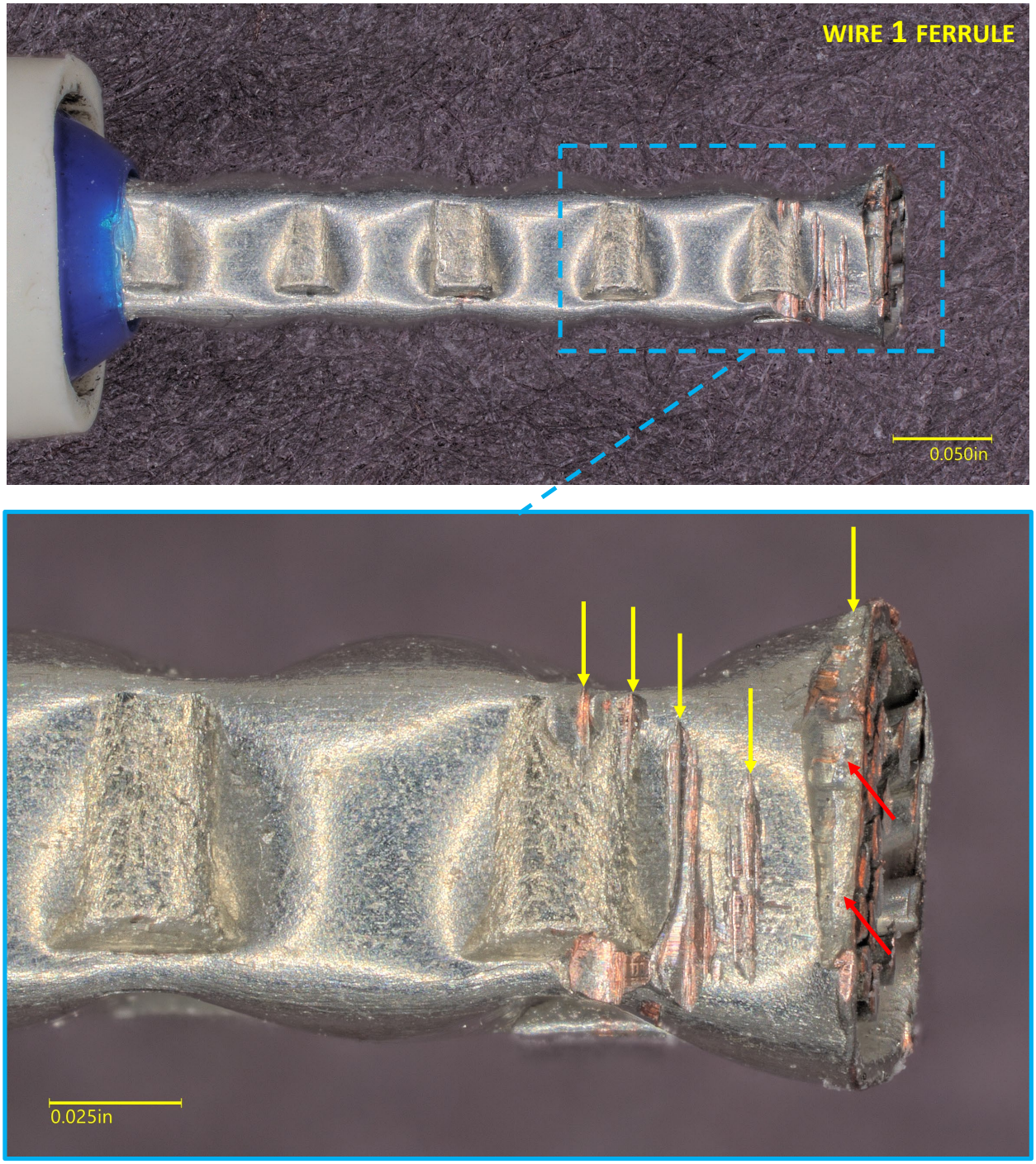

Figure 22. Digital microscope images of one side of the wire 1 ferrule from Terminal Block 381 with multiple distinct linear gouges (yellow arrows). A depression on the end of the ferrule in-line with one of the gouges is indicated by the red arrows.

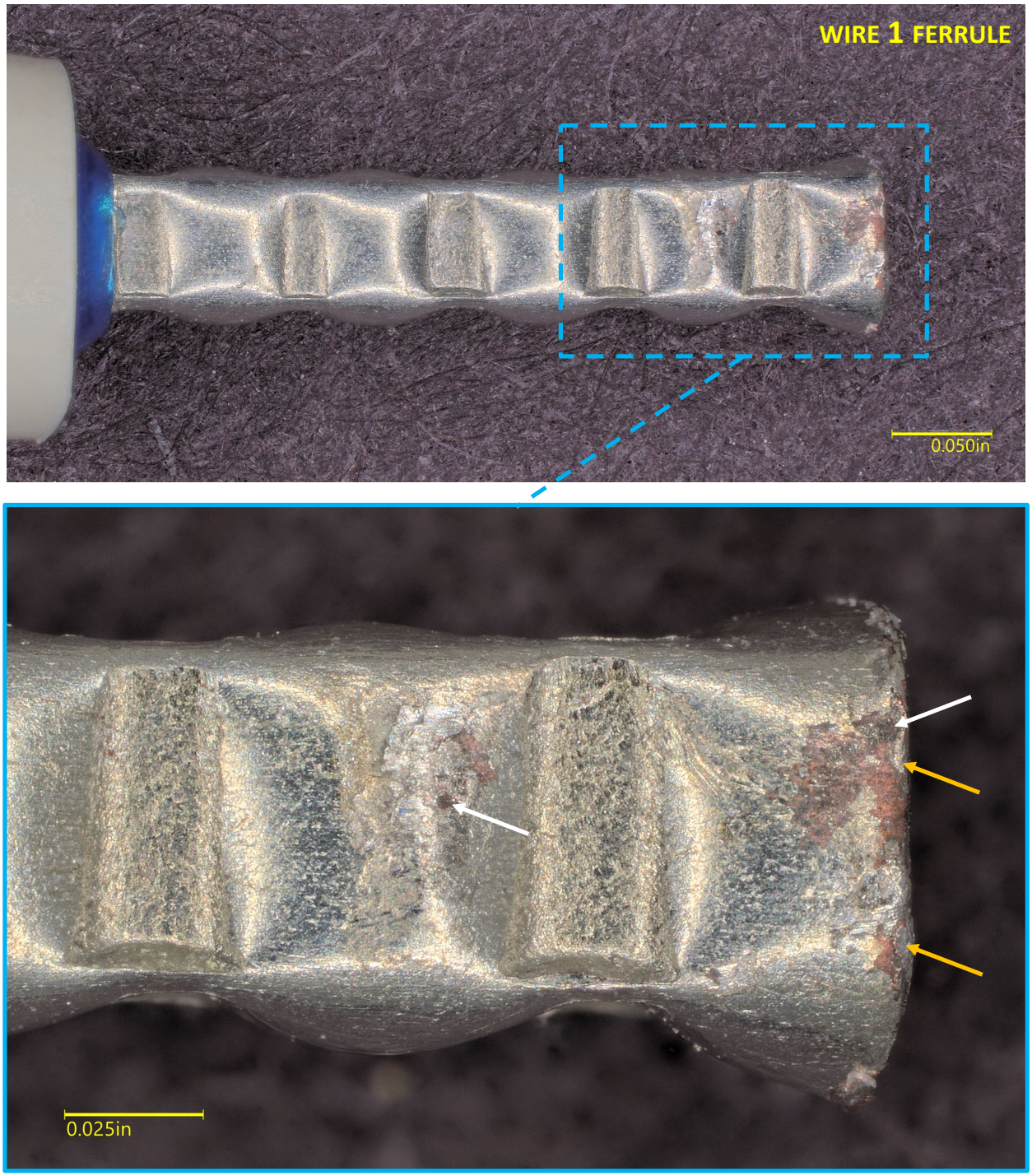

Figure 23. Digital microscope images of the side opposite the one from Figure 21 of the wire 1 ferrule from Terminal Block 381. The white and orange arrows point to material transfer from electrical conduction and smeared material, respectively.

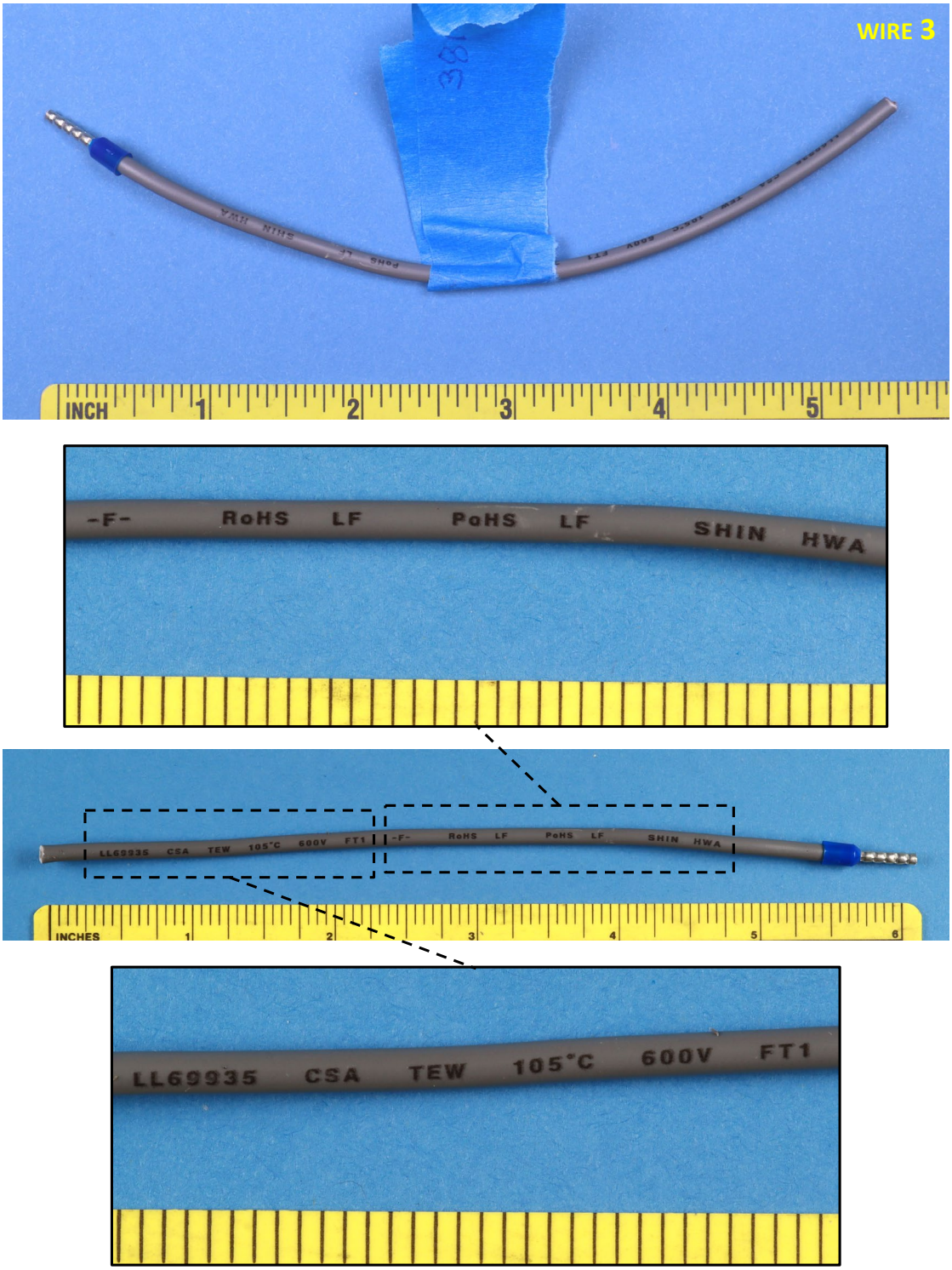

Figure 24. Macro photos of the submitted portion of the wire assembled to connection point 3 in Terminal Block 381 in the as-submitted condition and after identifying tape was removed (first and third images, respectively). Close-up photos of the identifying marks on the wire are shown in the second and fourth images.

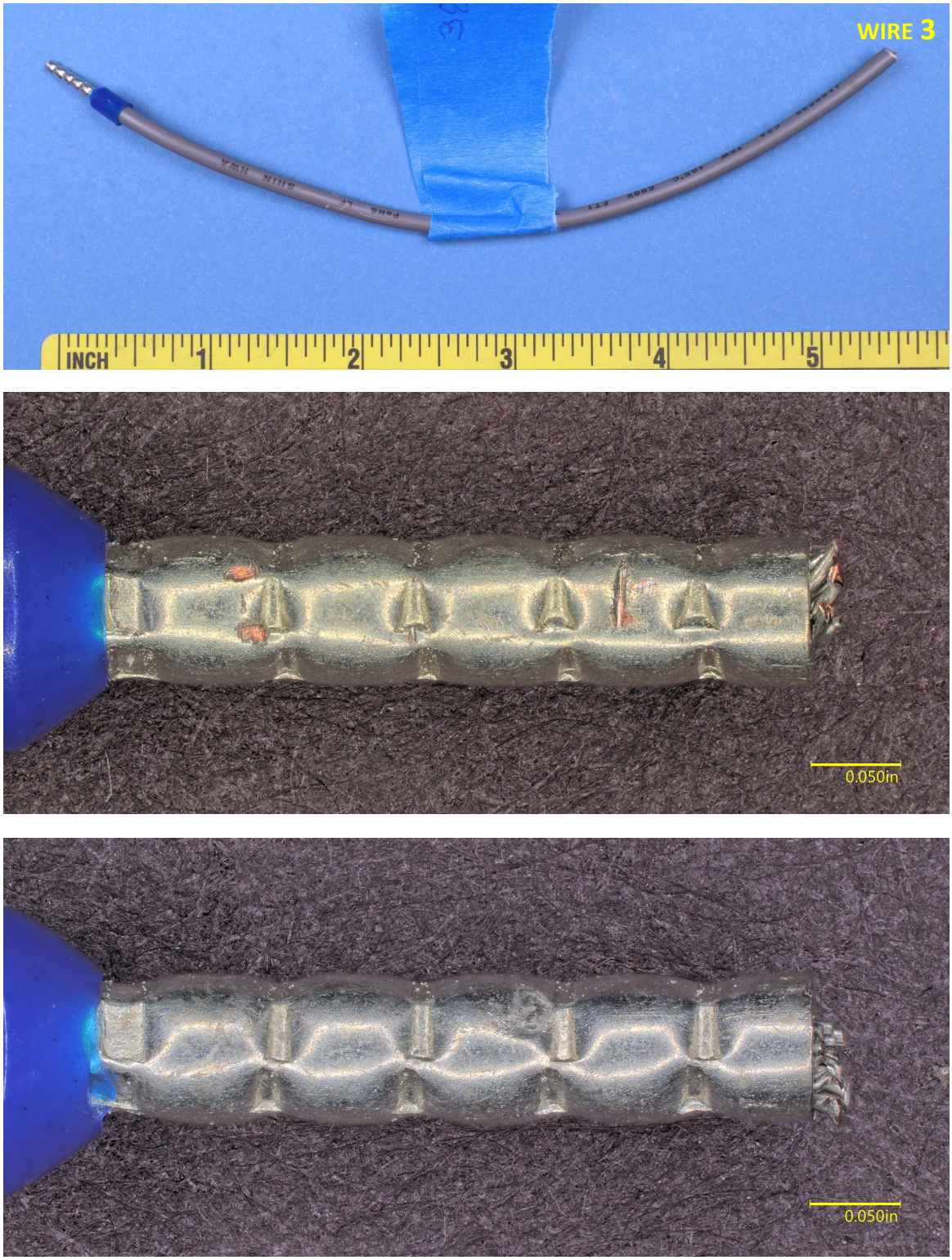

Figure 25. (Top) Macro photo of the submitted portion of the wire assembled to connection point 3 in Terminal Block 381. (Middle and Bottom) Digital microscope images of opposing sides of the wire 3 ferrule.

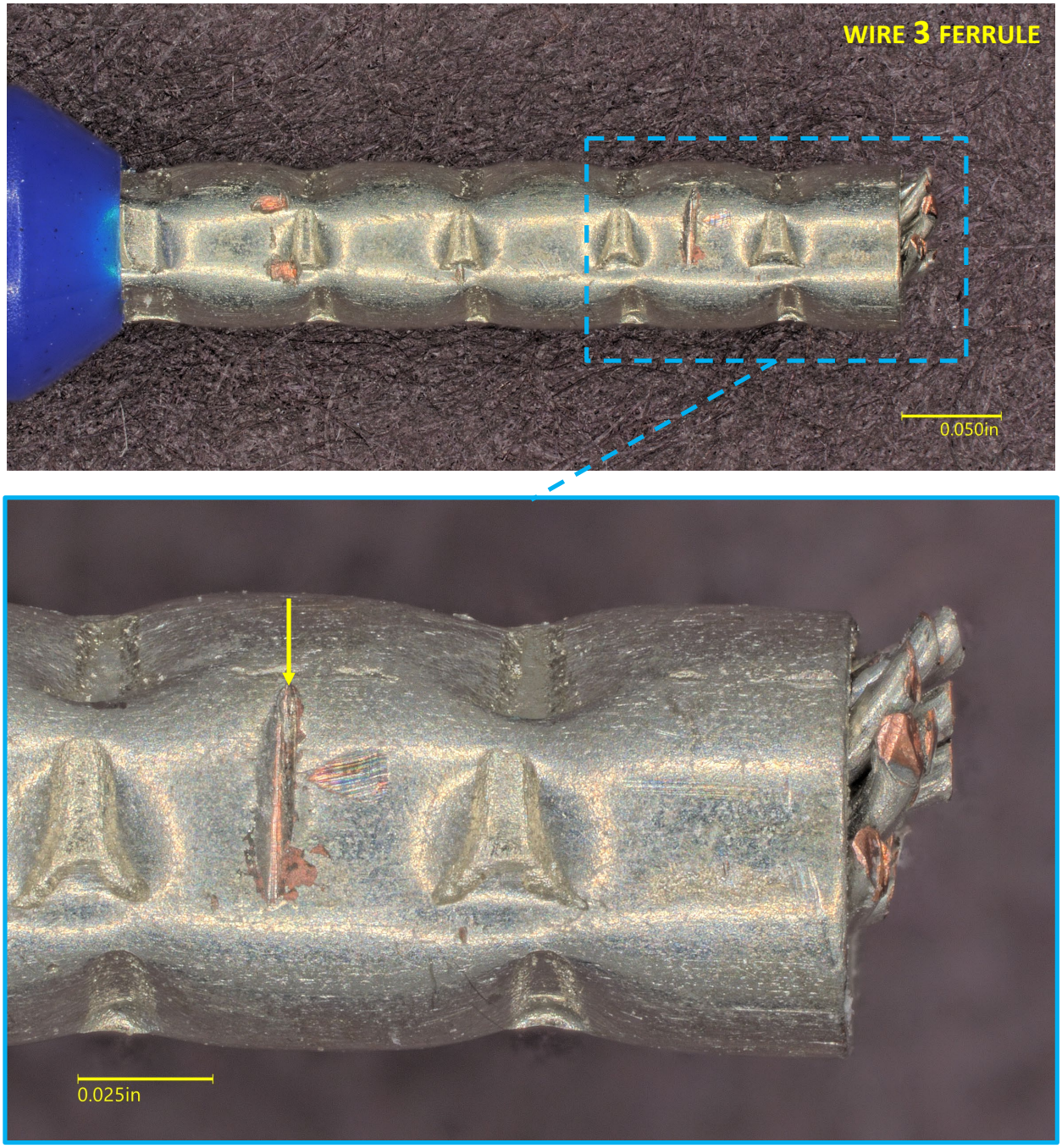

Figure 26. Digital microscope images of one side of the wire 3 ferrule from Terminal Block 381 with one distinct linear gouge (yellow arrow).

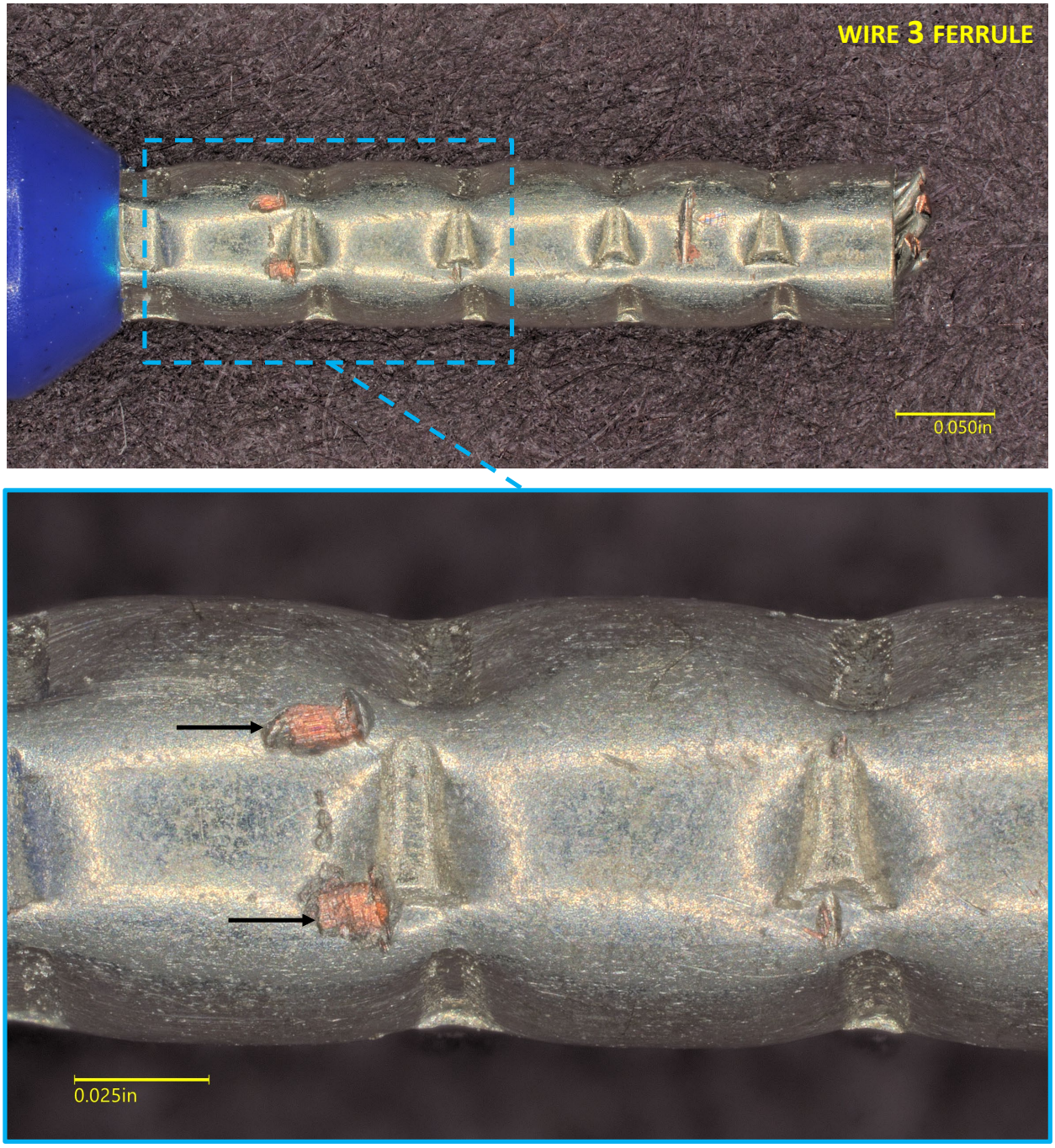

Figure 27. Digital microscope images of the same side shown in Figure 24 of the wire 3 ferrule from Terminal Block 381. The black arrows point to two circular gouges.

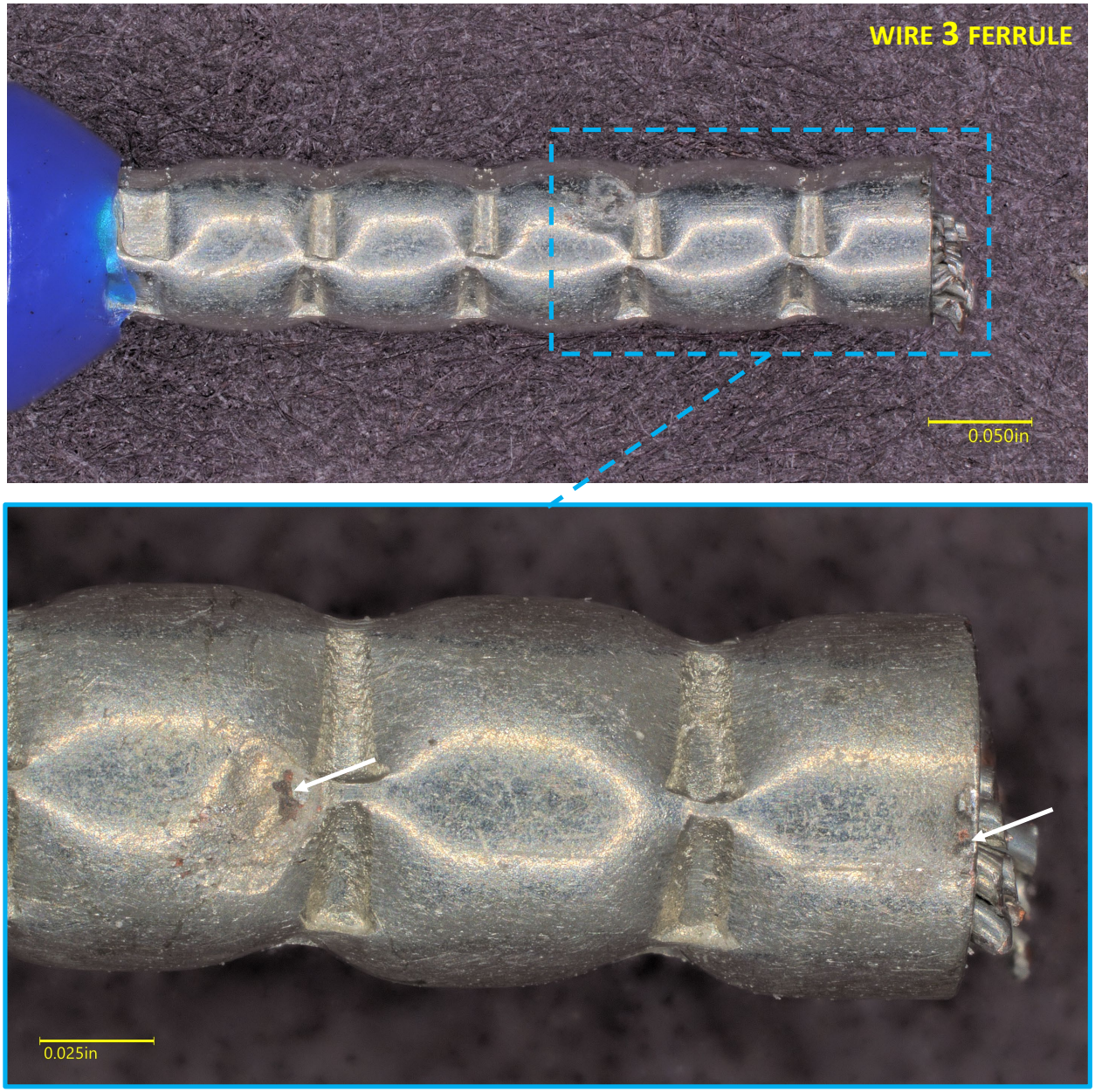

Figure 28. Digital microscope images of the side opposite the one from Figures 24 and 25 of the wire 3 ferrule from Terminal Block 381. The white arrows point to material transfer from electrical conduction.

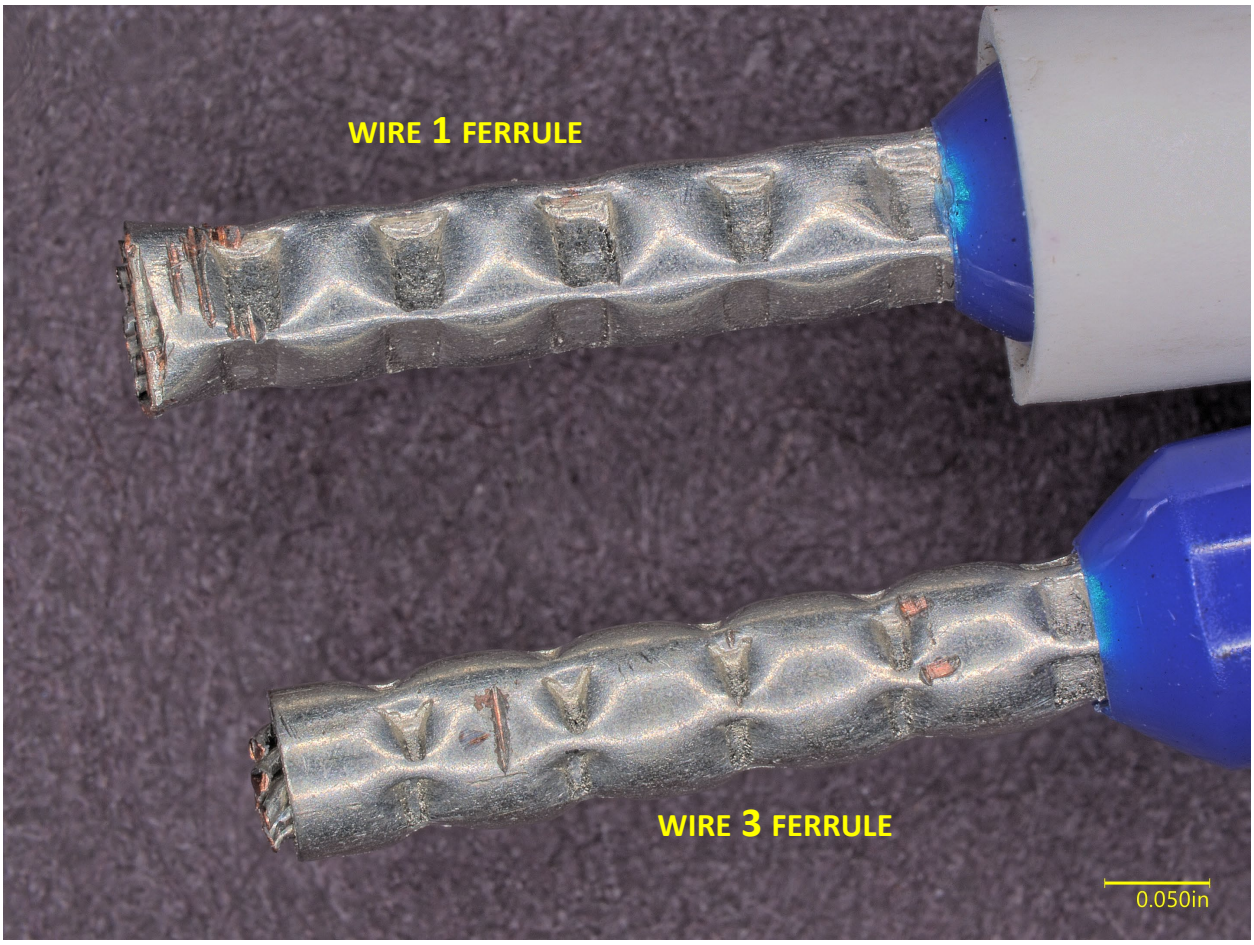

Figure 29. Digital microscope image comparing side views of the ferrules from wires 1 and 3 from Terminal Block 381.

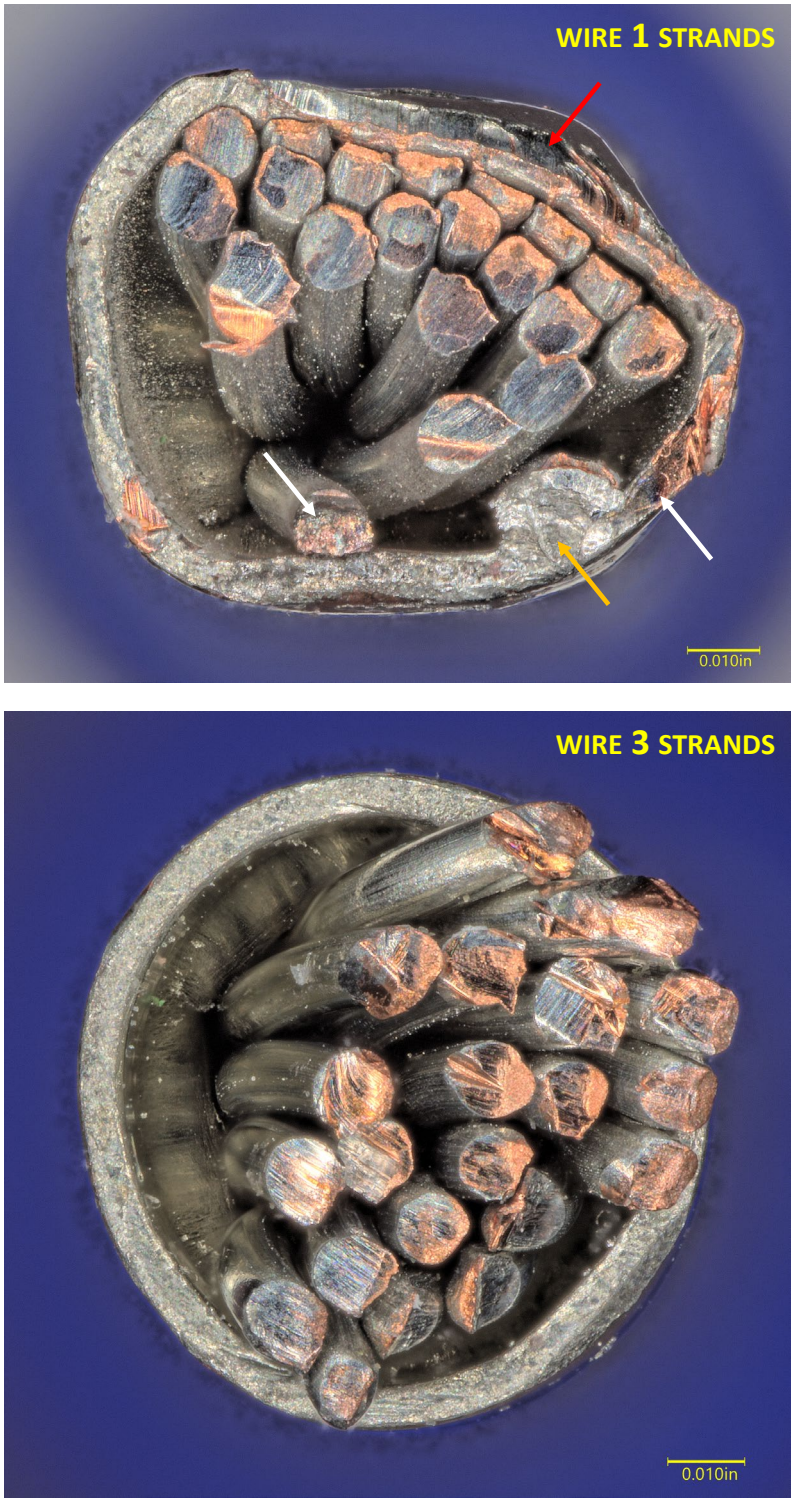

Figure 30. Digital microscope images of end views comparing the ferrules from wires 1 and 3 from Terminal Block 381. The red arrow points to the depression in one corner of the wire 1 ferrule. On the opposite side of the wire 1 ferrule there was erosion consistent with arcing and smeared material (white and orange arrows, respectively).

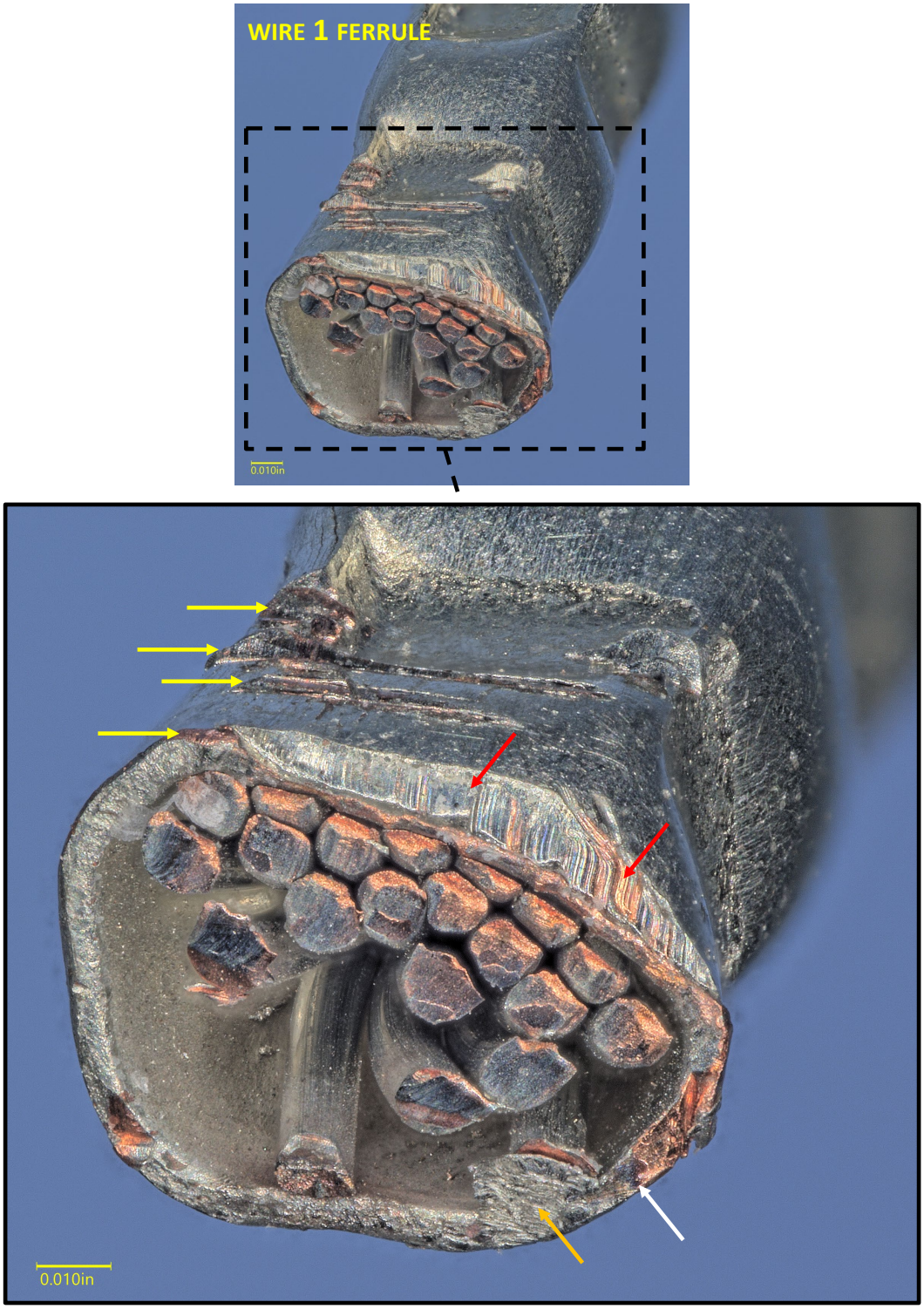

Figure 31. Digital microscope image of an angled view of the ferrule on wire 1 from Terminal Block 381. The yellow and red arrows point to linear gouges and a depression, respectively, on one side of the ferrule, while the white and orange arrows point to erosion consistent with arcing and smeared material, respectively, on the opposite side.

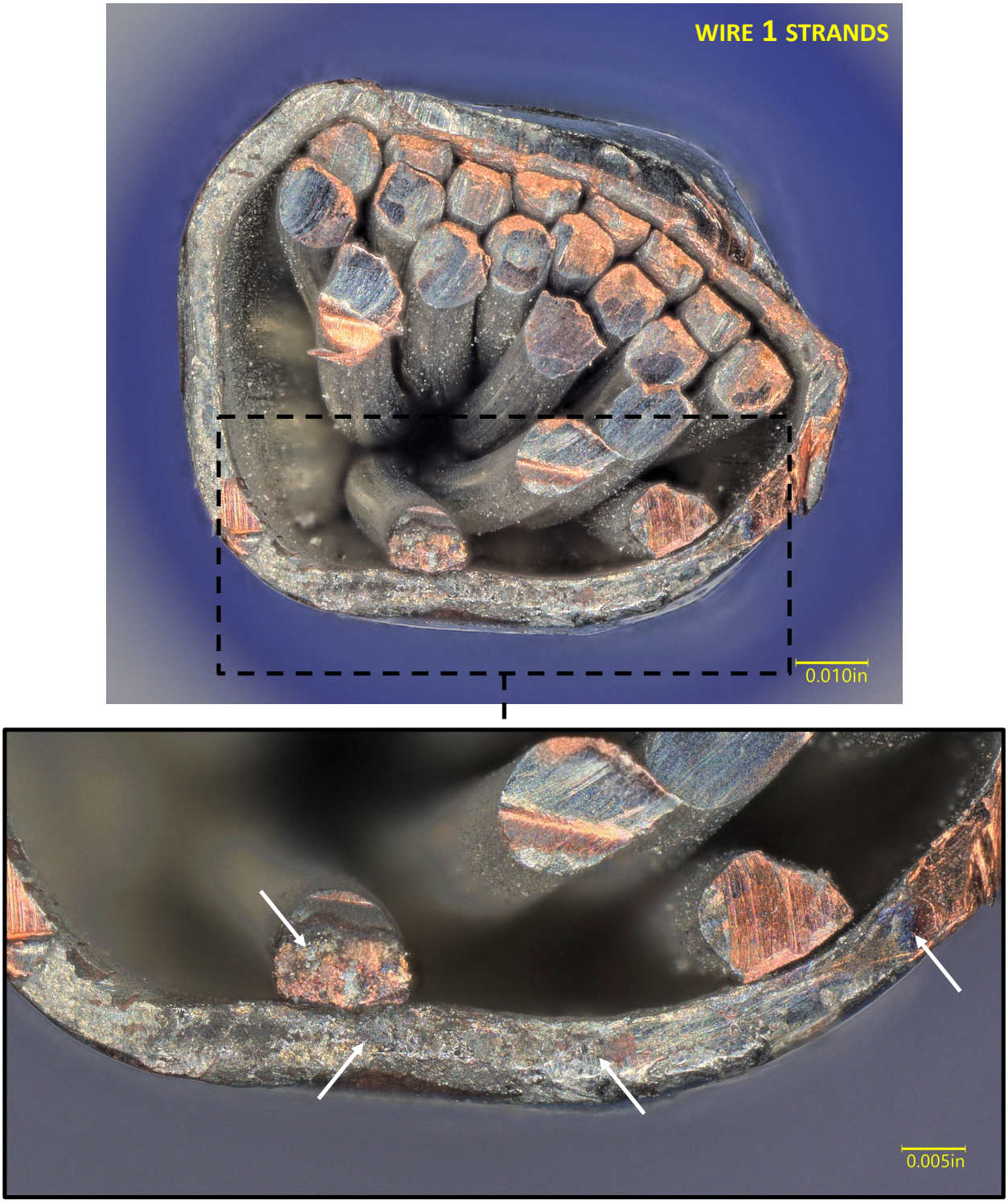

Figure 32. Digital microscope images of the end on the wire 1 ferrule from Terminal Block 381 after smeared material was removed from one side. The white arrows point to erosion consistent with arcing on the ferrule edge and one adjacent strand face.

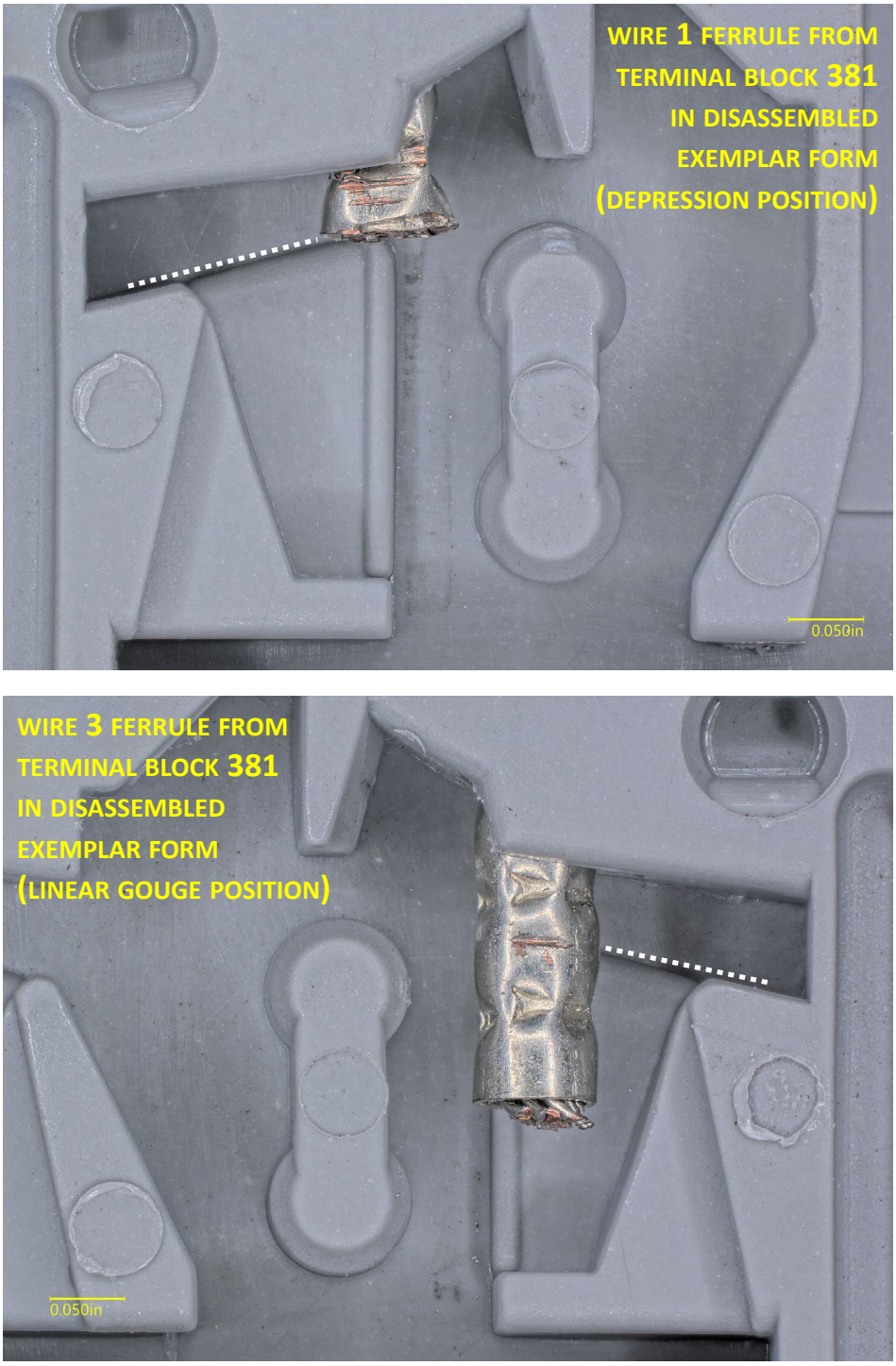

Figure 33. Digital microscope images of the ferrules from wires 1 and 3 from Terminal Block 381 inserted inside the corresponding connection points in a disassembled polymer form from an exemplar terminal block. The white dotted lines indicate the path along which the spring clamp gate would move. (Top) Wire 1 was positioned with the depression on the end of the ferrule in-line with the spring clamp gate edge. (Bottom) Wire 3 was positioned with the sole linear gouge in the ferrule in-line with the spring clamp gate edge.

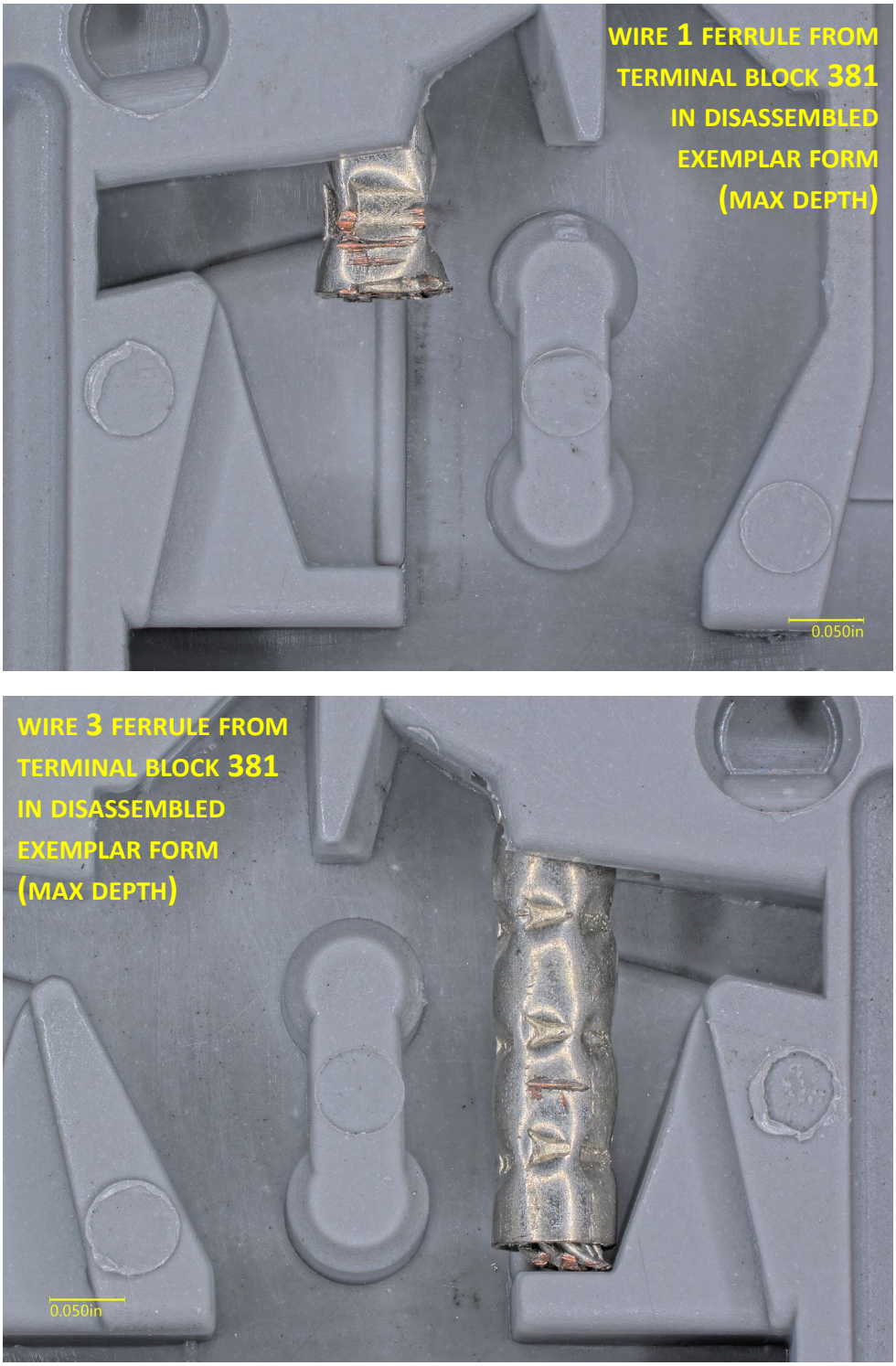

Figure 34. Digital microscope images of the ferrules from wires 1 and 3 from Terminal Block 381 inserted inside the corresponding connection points in a disassembled polymer form from an exemplar terminal block. Both wires were inserted to the maximum depth possible into the cage areas of the connection points.

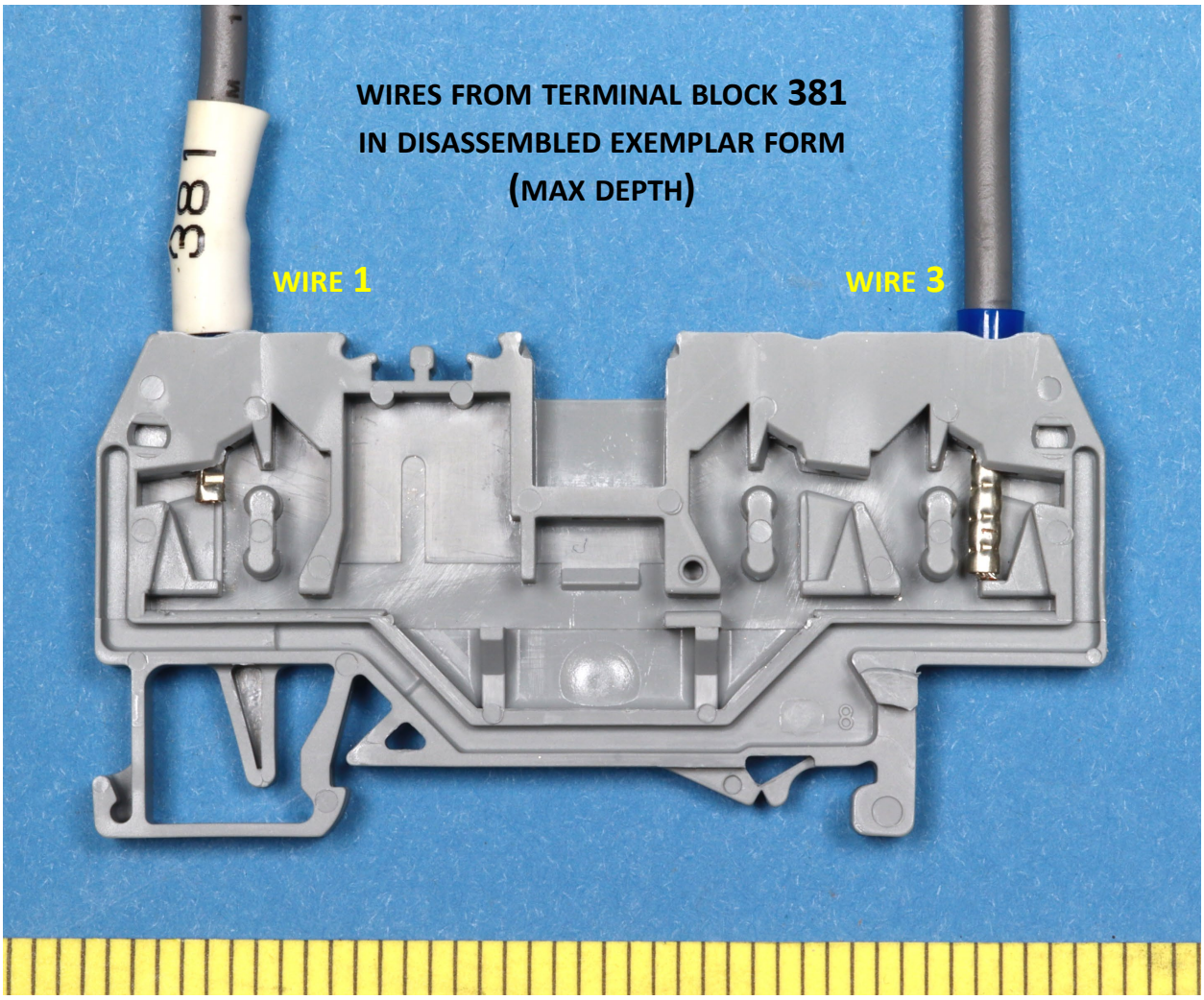

Figure 35. Macro photo showing wires 1 and 3 from Terminal Block 381 inserted inside the corresponding connection points in a disassembled polymer form disassembled from an exemplar terminal block. Both wires were inserted to the maximum depth possible into the cage areas of the connection points.