

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA23LA245

MATERIALS LABORATORY

Factual Report 23-093

October 29, 2024

(This page intentionally left blank)

A. ACCIDENT INFORMATION

Location: Hollywood, Florida
Date: May 25, 2023
Time: 12:09 eastern daylight time
16:09 coordinated universal time
Vehicle: Piper PA-25-260, N454AB
Investigator: Todd Gunther, AS-ERA

B. COMPONENTS EXAMINED

Remnants of rudder arm assemblies

C. EXAMINATION PARTICIPANTS

Specialist Erik Mueller, Ph.D., P.E.
Office of Research and Engineering - Materials Laboratory Division
NTSB, Washington, DC

D. DETAILS OF THE EXAMINATION

On May 25, 2023, at about 1209 eastern daylight time, a Piper PA-25-260 operated by Aerial Banners North Inc. was substantially damaged when it was involved in an accident near Hollywood, FL. The commercial pilot was seriously injured. According to the flight director, following a missed attempt to pick up a banner for tow, the airplane spun toward the ground and crashed from an approximate altitude of 100 feet above ground level. According to FAA and maintenance records, the aircraft was manufactured in 1974 and was powered by a Lycoming O-540-G1A5 engine. The airplane's most recent annual inspection was completed on March 6, 2023, at 9573.1 total hours of operation.

A postaccident examination of the pitch control and roll control systems revealed that continuity could be established from the control stick in the cockpit through the breaks in the system to the elevator and ailerons, respectively. Examination of the yaw control system revealed that continuity could be established from the rudder pedals in the cockpit to the left rudder control horn but could not be established to the right rudder control horn. The rudder control horn was later found to have fractured. These parts were sent to the NTSB Materials Laboratory for further examination.

Figure 1 shows the rudder arm assembly, with the two extensions, as received. The right side of the rudder horn had fractured approximately 1.25 inches from the vertical arm assembly body. While the right extension was still affixed to the broken right rudder horn remnants, the left extension had been disassembled from the still intact left rudder horn. The cast link had also fractured in two locations. The rest of the

rudder arm assembly had been sectioned in two places, facing downward and toward the reader in Figure 1.

Figure 2 shows the mating sides of the fractured rudder horn, positioned in their locations at the time of fracture. Figures 3 and 4 show the mating fracture surfaces of the outer horn remnant and inboard horn flange, respectively. The lower filament towards the arm assembly exhibited an upward out-of-plane deflection (lower right in Figure 2 and upper right in Figure 4). The mating side showed a primarily straight orientation, but with a slight downward bending deformation (left in Figure 3). All fracture surfaces exhibited enough surface oxidation (rust) to conceal the underlying metal surfaces, including the fracture surfaces. Much of the yellow paint in these areas had also begun to spall.

The outboard rudder horn fragment was sectioned, and the fracture surface is shown in Figure 5 after cutting. To examine the underlying fracture features, the sectioned horn piece was cleaned in an ultrasonic bath using an aqueous solution of a commercial chelating agent (Evapo-Rust).¹ Figure 6 shows the fracture surface after the removal of the surface rust.

Along with closer views of the fracture morphology shown in Figures 7 through 9, Figure 6 shows the fracture surfaces of the outer horn fragment exhibited a rough, tortuous surface texture with a dull, fibrous luster. The smaller filament on the left side of Figure 6 exhibited thinning and necking near the fracture surface. In addition, as shown in Figure 7, the upward deformation and smearing of the necked area near the hole bore to the right. Examination of this surface using a field emission scanning electron microscope (SEM) revealed dimpled rupture, as typified in Figures 8 and 9. These features were consistent with overstress fracture of ductile material in tension and localized bending.

The larger filament on the right side of the rudder horn fragment is shown in Figure 10. This figure demonstrates the fracture surface at a 45° slant angle relative to the part. There was a localized downward deformation of the highly textured grain flow near the hole bore. Examination of this part of the surface using an SEM revealed the localized flow deformation (Figure 11, inverted relative to Figure 10). The fracture surface exhibited dimpled rupture, consistent with overstress fracture (Figure 12). Examination of the rightmost (L-shaped) side of the horn fracture showed localized necking near the fracture surface (Figure 13). These features were consistent with tensile and bending overstress fracture of the horn.

The rudder horn was examined using energy-dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The composition was consistent with carbon steel. The

¹ Evapo-Rust - a commercially-available chelating rust stripper currently manufactured CRC Industries, headquartered in Horsham Township, PA.

hardness was examined per ASTM E18.² The hardness averaged 43 HRA, consistent with a tensile strength of 59 ksi (407 MPa) per ASTM E140.³

The fractured link casting was also examined, as shown in Figures 14 and 15. These fractures had occurred adjacent to the rudder arm assembly body. The broken surfaces were sectioned from the rudder arm assembly and cleaned in an ultrasonic bath of acetone to remove much of the post-fracture surface contamination on the component.

As illustrated in Figure 16, much of the fracture surfaces were flat and 90° in orientation relative to the fractured arms, though parallel to the rudder arm cylinder. Figure 17 shows the dull luster and rough texture of the fracture surface. The surfaces were examined using SEM, and the composition was examined using EDS. The composition of the link was consistent with 319 aluminum-silicon casting alloy.

As shown in Figures 18 and 19, the surface exhibited roughness and faceted regions, consistent with the constituents of the casting. The lighter areas shown in the backscattered view of Figure 19 were consistent with silicon-rich phases present in the microstructure.⁴ Figure 20 shows a closer view of one of the silicon-rich phases on the fracture surface, revealing a star-shaped radial pattern, typical of fracture of these phases. The surrounding aluminum-rich matrix exhibited fine dimpled rupture, as typified in Figure 21. These features were consistent with overstress fracture of the link.

Submitted by:

Erik M. Mueller
Materials Research Engineer

² ASTM E18 - *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

³ ASTM E140 - *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*. ASTM International, West Conshohocken, PA

⁴ Backscattered electrons - SEM micrographs produced using backscattered electrons display contrast that is associated with the atomic numbers of the elements in the micrograph. Materials containing elements with higher atomic numbers visually appear lighter relative to other materials containing elements with lower atomic numbers.

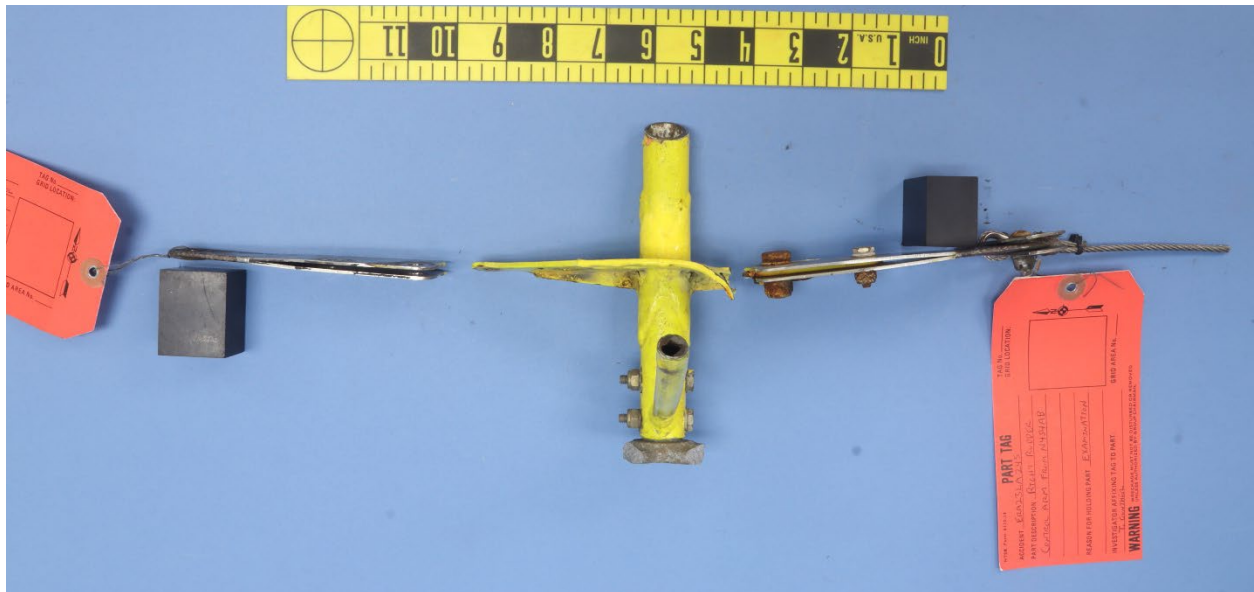


Figure 1. View rudder arm assembly, with the two extensions on either side. The right rudder horn had fractured attached to the extension.

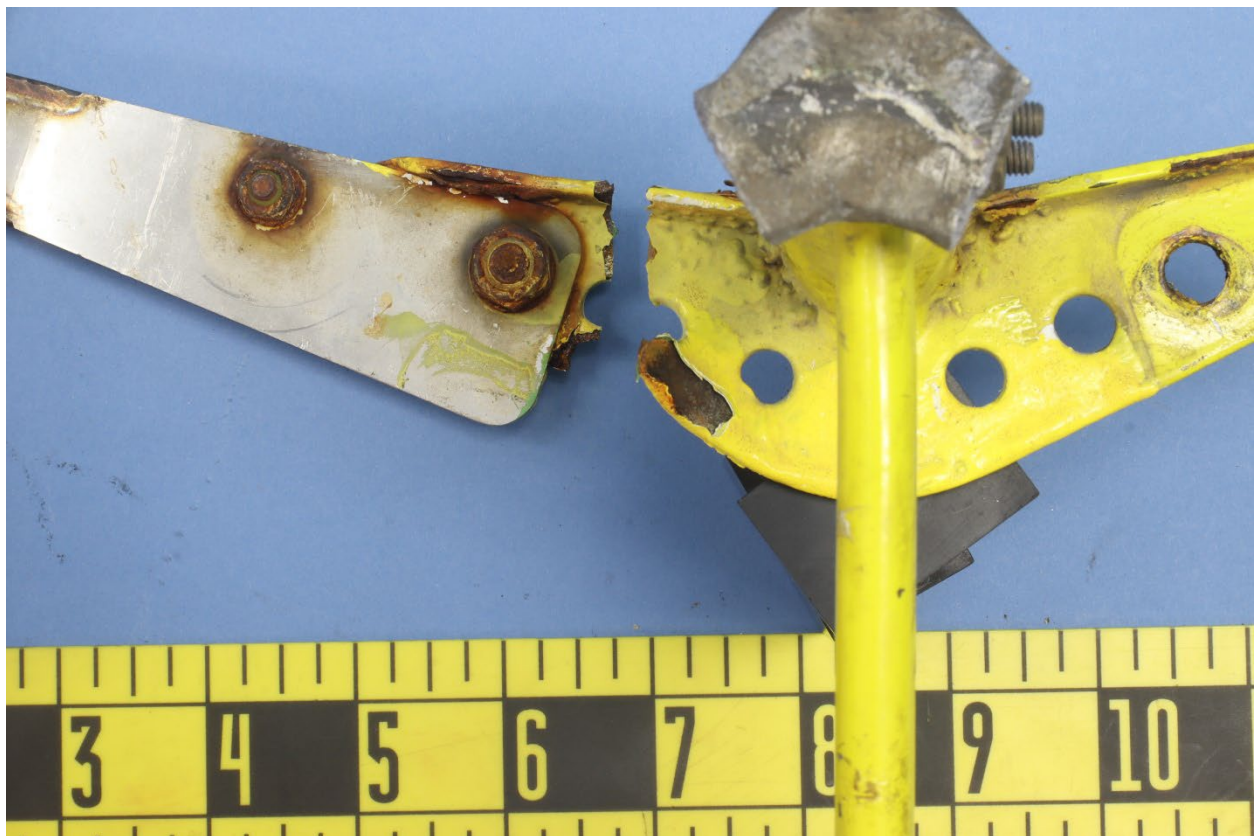


Figure 2. Fractures of the link casting (upper right) and the right rudder horn (center) from Figure 1, showing the mating fracture surfaces.



Figure 3. View of the outboard horn fracture still attached to the respective extension.

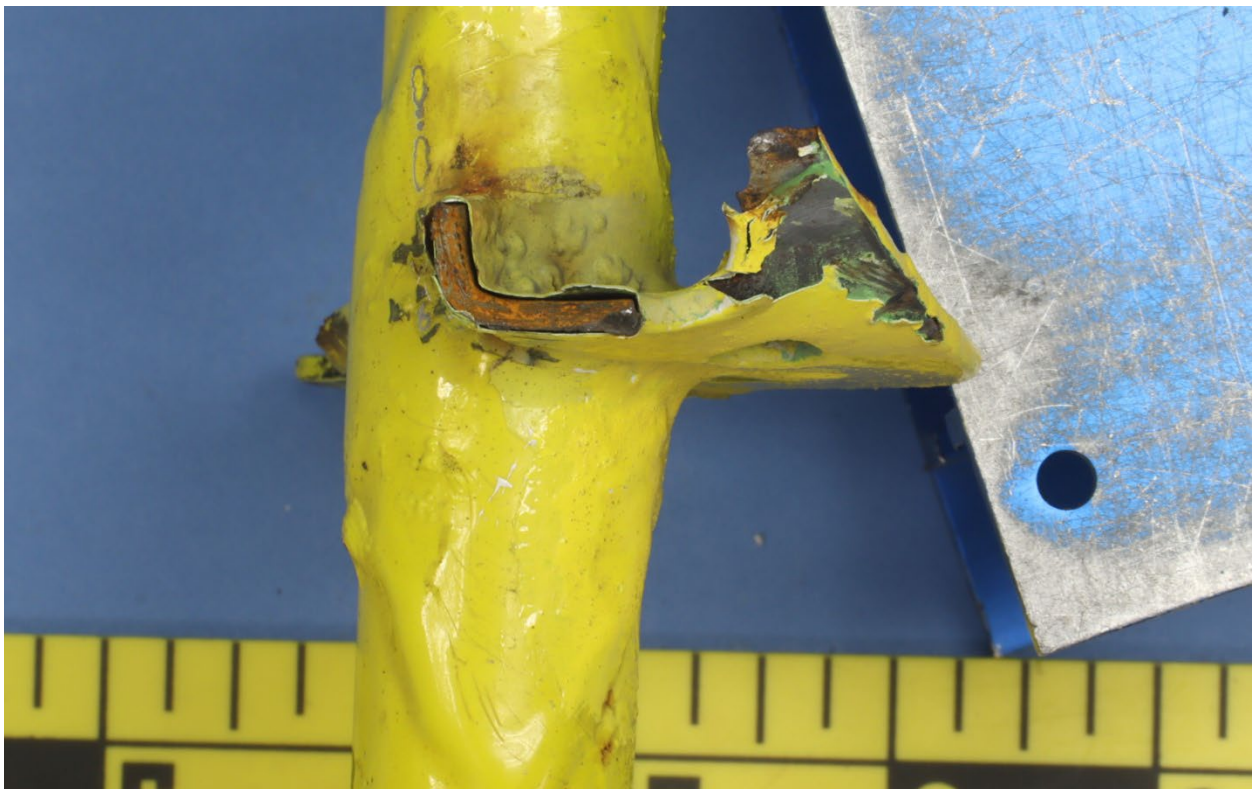


Figure 4. View of the inboard fracture surface of the rudder horn that mates to the one shown in Figure 3.

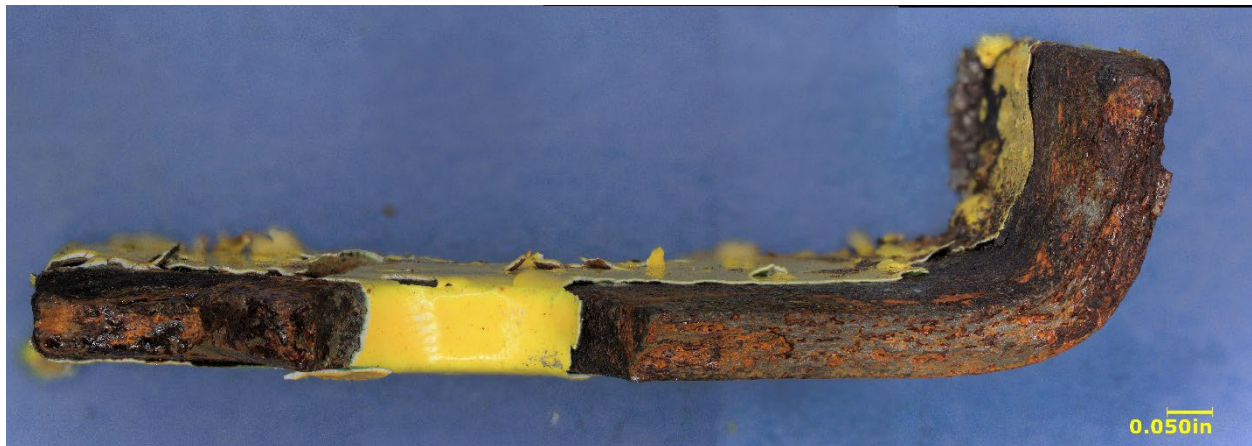


Figure 5. Section of the outboard rudder horn fracture surface, with surface corrosion.

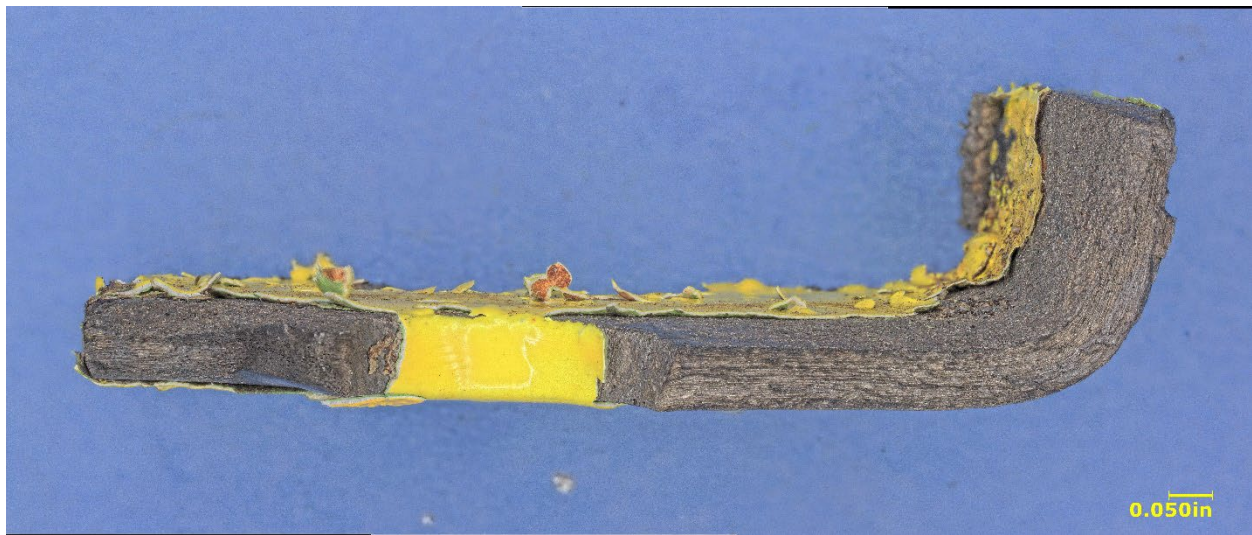


Figure 6. View of the rudder horn fracture surface section shown in Figure 5, after cleaning with acetone and chelating rust removal.



Figure 7. Closer view of the fractured segment of the horn to the left in Figure 6.

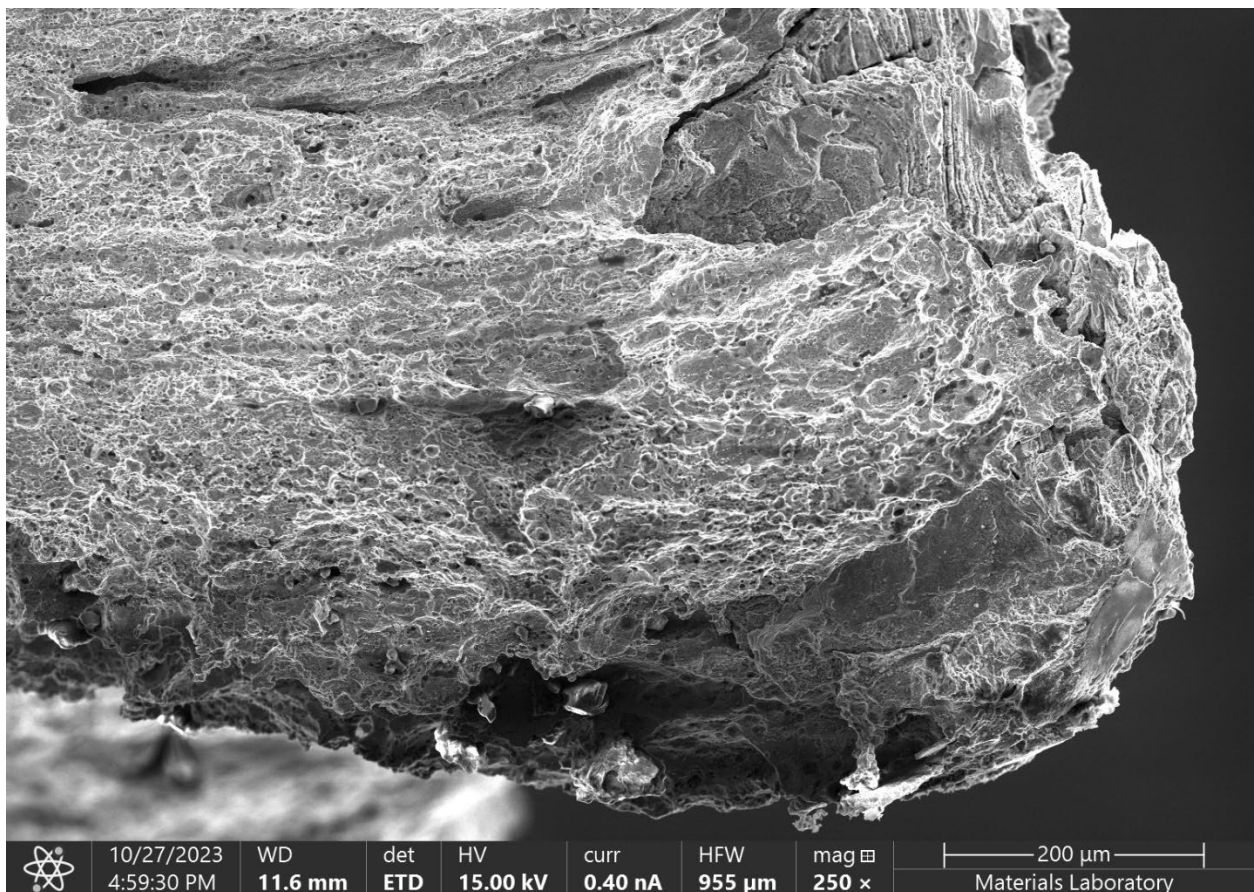


Figure 8. Secondary electron (SE) micrograph of the bore corner of the fracture surface in Figure 7, showing plastic deformation.

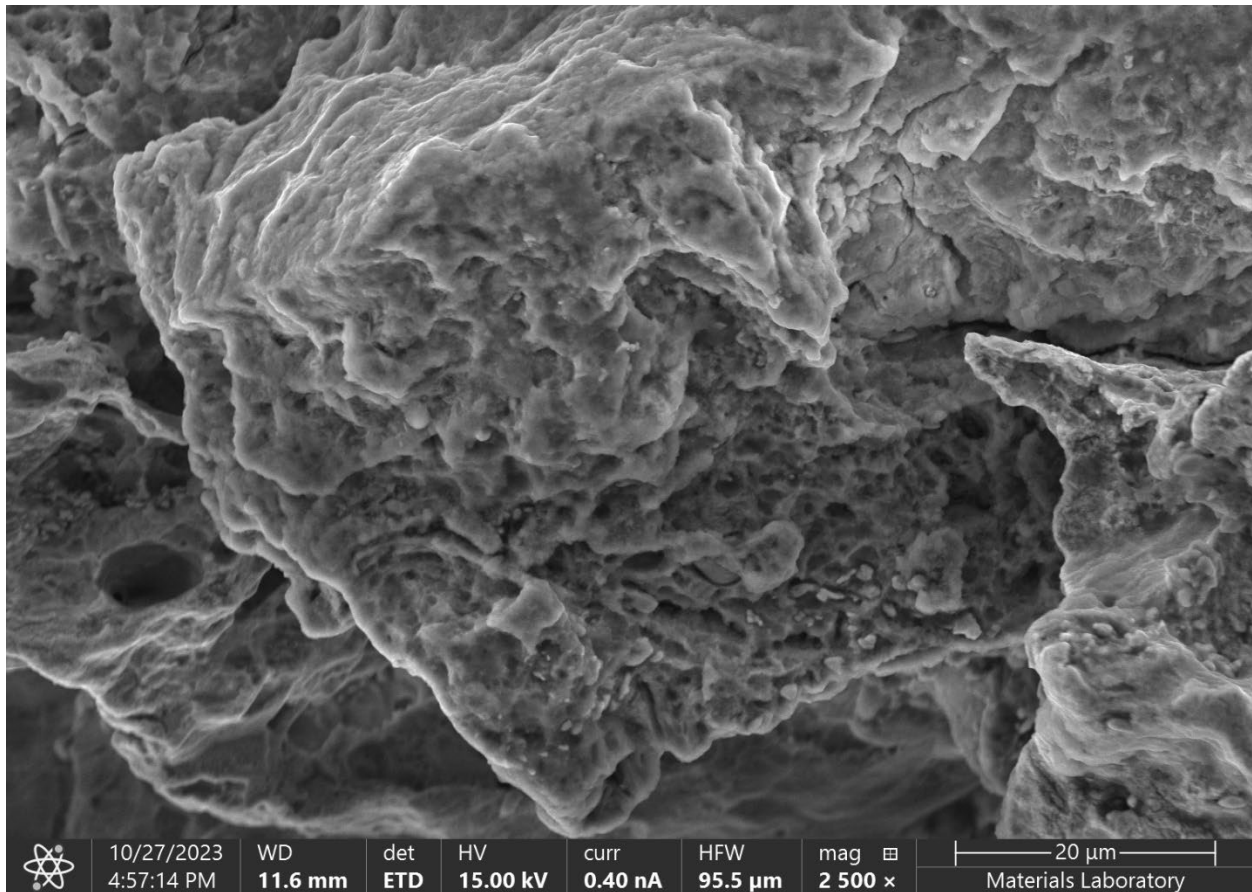


Figure 9. SE micrograph of dimpled rupture and corroded material in Figure 8.



Figure 10. Fracture surface edge with the bore of the horn section in Figure 6.

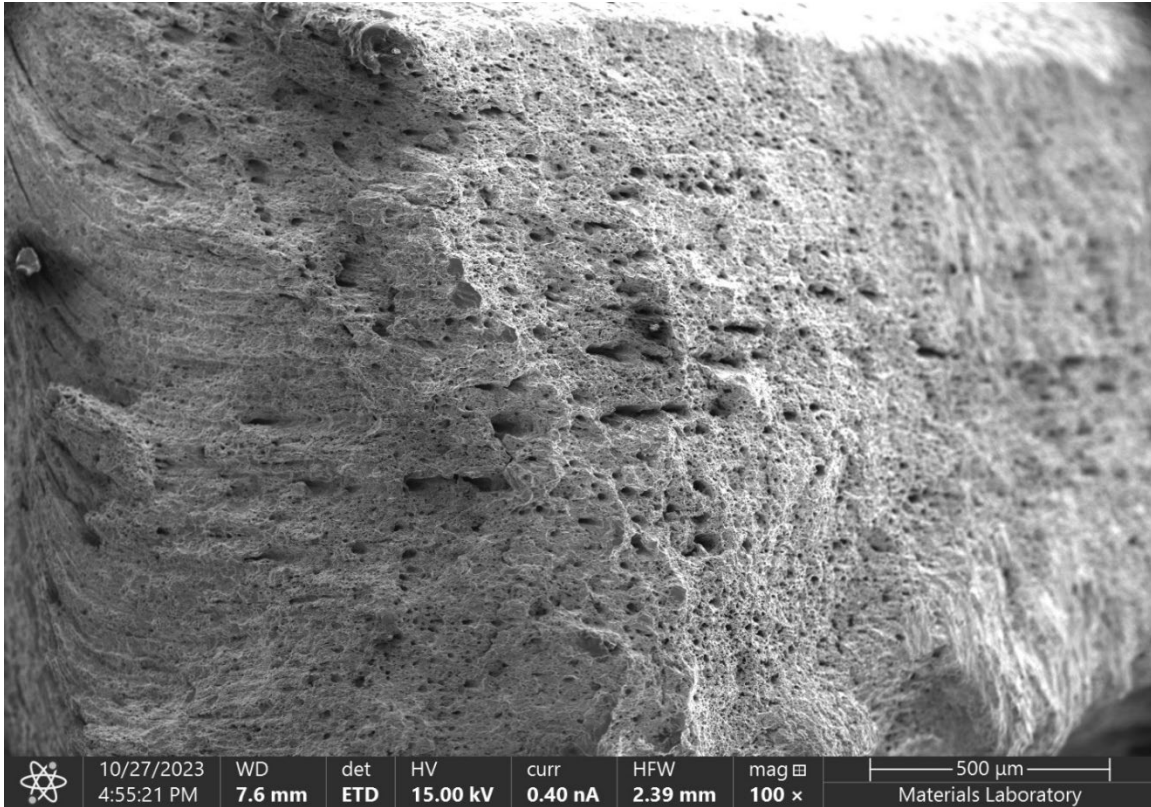


Figure 11. SE micrograph of a closer view of the corner in Figure 10.

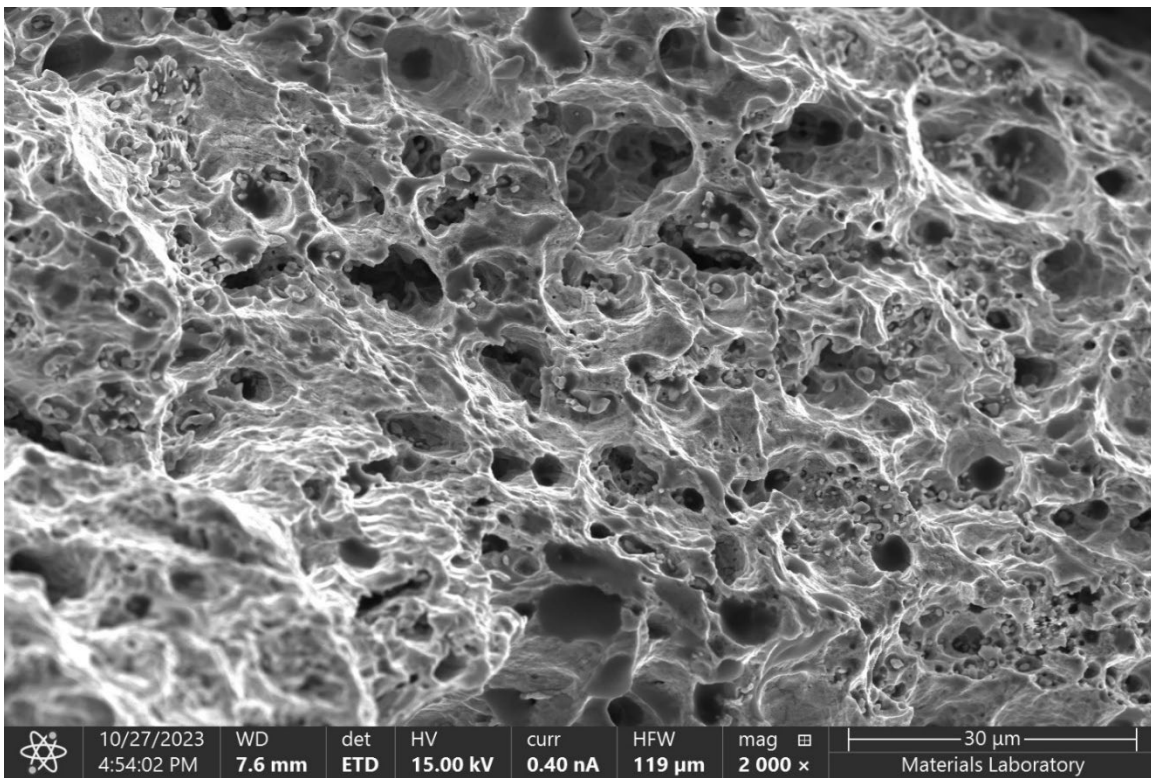


Figure 12. SE micrograph of dimpled rupture in the area in Figure 11.



Figure 13. Opposite edge of the right fractured segment in Figure 6, showing thinning.



Figure 14. View of one of the fracture surfaces of the link casting.



Figure 15. The opposite fracture surface from that shown in Figure 14.

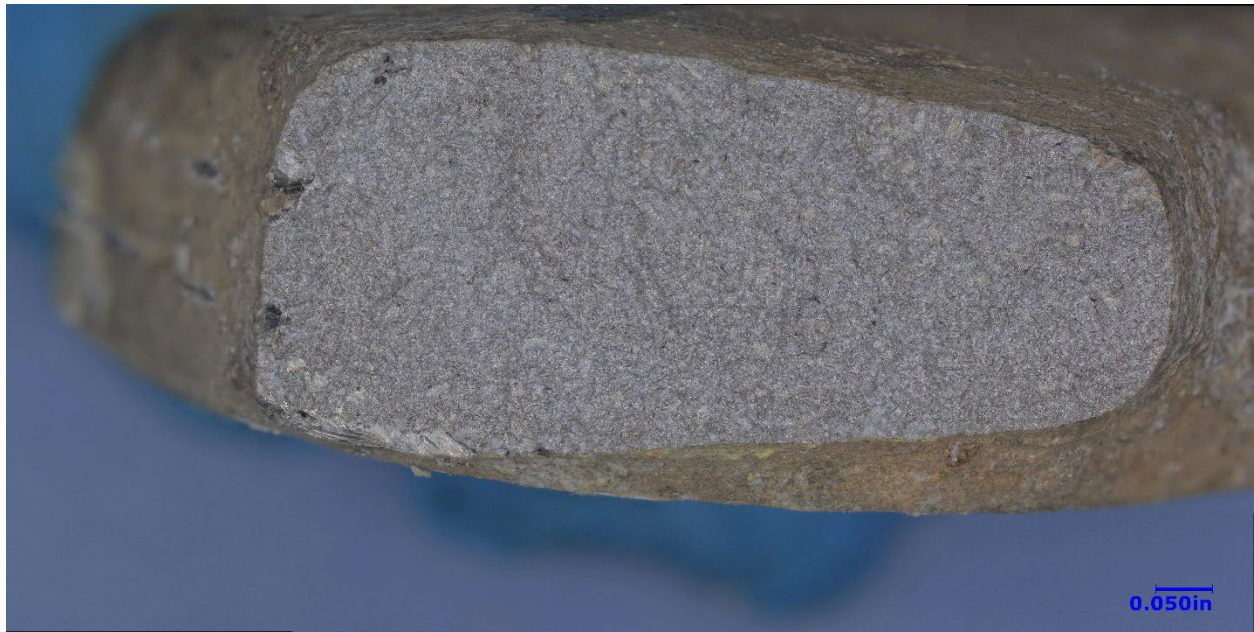


Figure 16. Closer view of the fracture surface in Figure 15.



Figure 17. Typical area of the fracture surface in Figure 16.

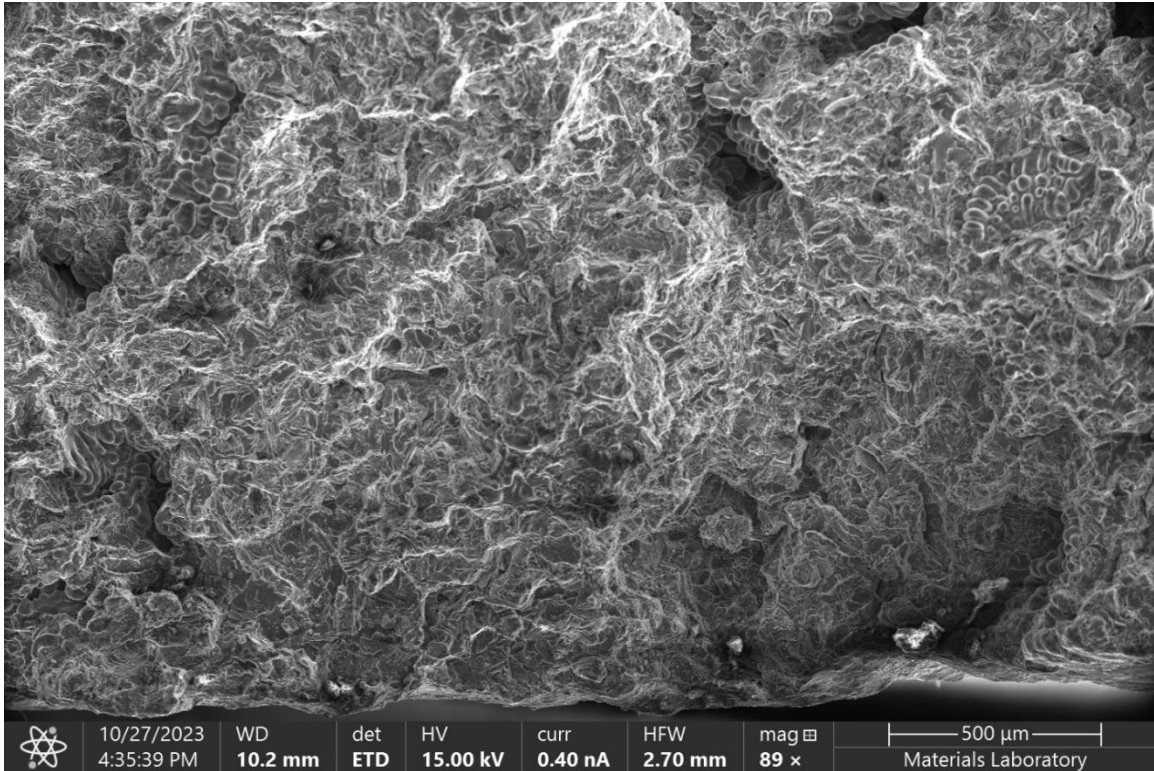


Figure 18. SE micrograph of the lower right edge of the casting fracture surface.

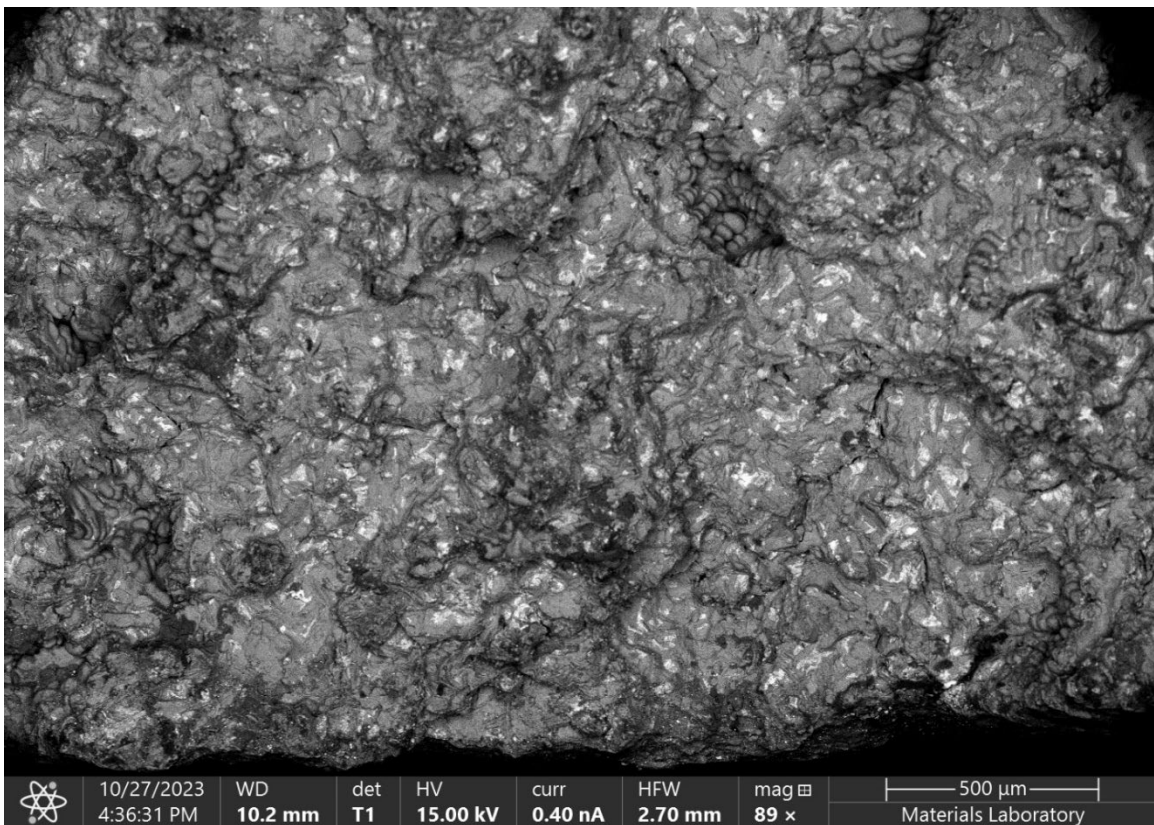


Figure 19. BE micrograph of Figure 18, showing the Si-rich regions (white).

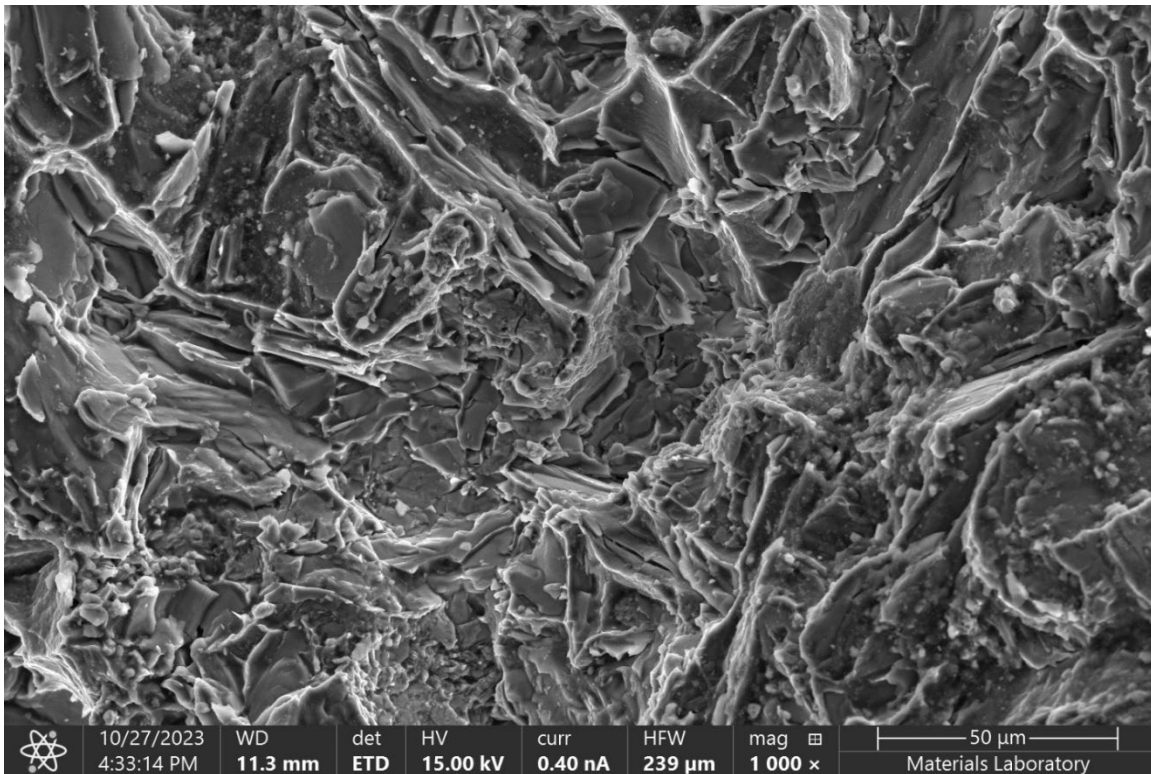


Figure 20. SE micrograph of a Si-rich region, showing dimpled rupture.

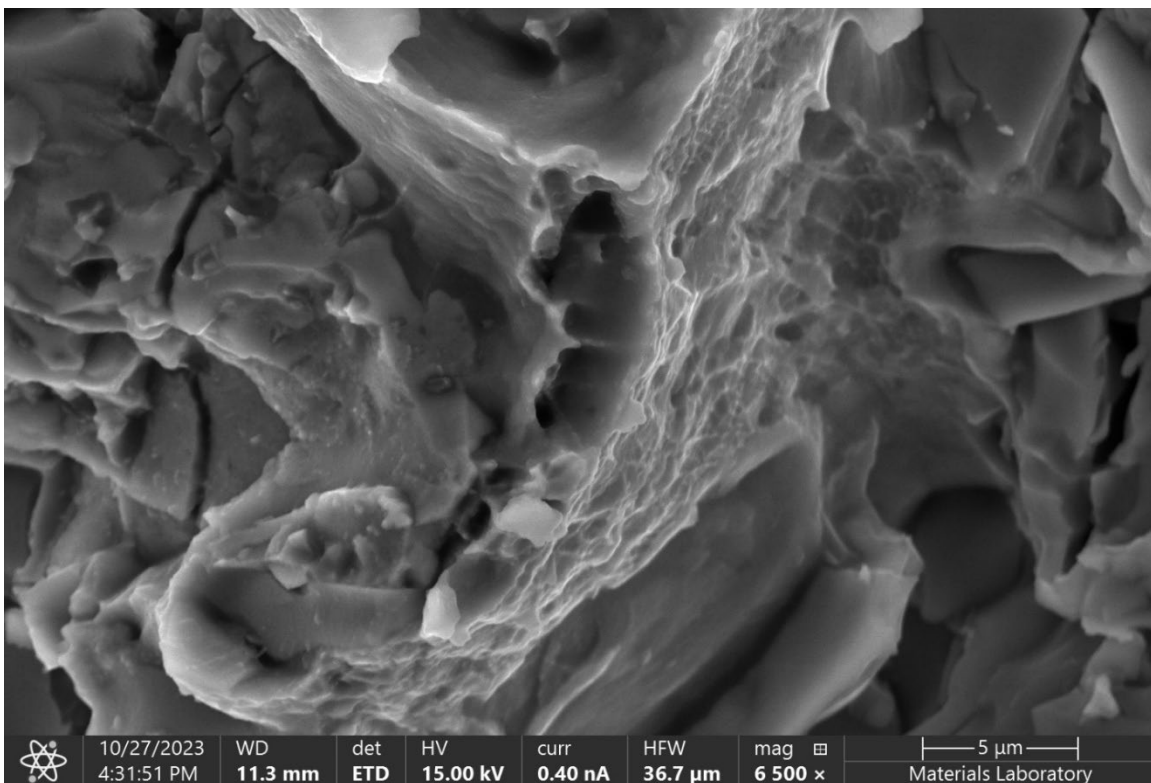


Figure 21. SE micrograph of dimpled rupture from Figure 20.