

NATIONAL TRANSPORTATION SAFETY BOARD

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



February 28, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-103

A. ACCIDENT INFORMATION

Place : Port Orange, Florida
Date : 08/21/2021
Vehicle : Enstrom Helicopter Corporation Model 280C
NTSB No. : ERA21LA339
Investigator : Daniel Boggs

B. COMPONENTS EXAMINED

1. Portion of tail rotor drive flange
2. Portion of a tail rotor drive shaft

C. DETAILS OF THE EXAMINATION

The as-received portion of a tail rotor drive shaft and a tail rotor drive flange are shown in Figure 1. To facilitate microscopy, x-ray CT imaging, and photodocumentation, the drive shaft piece was cut at the line indicated in the figure. A sketch showing an exploded view of the drive coupling and drive shaft assembly, referenced from the Enstrom F-28F/280F Series Maintenance Manual, is shown in Figure 2 with key components annotated.

Projection views of each side of the drive coupling piece are shown in Figure 3. As revealed in the images in Figure 3a and 3c, a portion of an aluminum plug (part number 28-13619) and a portion of the steel drive shaft tube are present within the bore of the drive coupling. In Figure 3b, the polymer locking feature in the locknut has fused and extruded from the locknut. The image in Figure 3d reveals coloration on the outside of the steel drive coupling, consistent with heat exposure. A pronounced concave bend is observed in the flange portion of the drive coupling as revealed in Figure 3d.

A closer internal view of the top of the drive coupling piece is shown in Figure 4. This image reveals a portion of the aluminum plug (part number 28-13619), with rotational surface deformation just top side of the tapered bolt. Some features consistent with fusion and re-solidification of the aluminum plug are also present.

X-ray computed tomography (CT) radiographs of the drive coupling piece are shown in Figures 5 and 6. The fractured portion of the drive shaft tube is observed within the bore of the drive coupling. No necking or large-scale plastic deformation is associated with the fracture surfaces of the drive shaft tube. The fracture surface is rather planar through the thickness of the drive shaft tube wall. Figure 6 details distortion in the bolt

holes in the drive shaft tube wall consistent with gross mechanical shear deformation (e.g. mode II loading). A pronounced concave bend is observed in the flange portion of the drive coupling.

Figure 7 and 8 show close views of the internal bore at the top side of the drive coupling. In Figure 7, a portion of aluminum plug exhibiting features consistent with fusion and resolidification is observed. The fracture surface of the drive shaft tube is obscured by remnants of the aluminum plug. To reveal the fracture surface of the drive shaft tube, the drive coupling was placed in concentrated sodium hydroxide to partially dissolve the aluminum plug remnants, while the steel drive coupling and bolt remain intact. In Figure 8, a close view of the drive coupling bore from the top side is shown with the aluminum plug remnants partially dissolved to reveal the tapered bolt and the drive shaft fracture surface. As shown in the image, the bolt holes in the drive shaft tube are mechanically distorted consistent with the presence of an axially applied torsional shear-stress in the drive shaft tube in the clockwise direction. Macroscopically, the fracture surface in the drive shaft tube is consistent with overstress due to torsionally-applied shear stress (e.g. mode II loading).

Figure 9 shows a close view of the internal bore at the bottom or flange side of the drive coupling. This image reveals a portion of the aluminum plug, the chamfered end of the drive shaft tube, and extruded and thermally degraded organic material. Based on its location, the extruded and thermally degraded organic material is consistent with an adhesive (Loctite A) which is applied to the aluminum plug before it is inserted into a reamed counterbore in the end of the drive shaft tube.

The side view of the drive shaft in Figure 10b shows a region of thermal damage approximately 1.5 inches long. Detailed in Figures 11-13, the drive shaft outside diameter (OD) at the end adjacent to the fractured end has been mechanically reduced by about 0.02 inch due to wear which occurred due to relative rotational sliding between the OD surface of the drive shaft and the ID surface of the drive coupling. The OD surface of the drive shaft also exhibited areas with transferred aluminum (Figure 12).

Figure 14a shows the inner bore of the drive shaft at the end facing away from the drive coupling. The image shows the end of the aluminum plug remnant and aluminum that has been fused, extruded, and resolidified. An x-ray CT cross section of the drive shaft is shown in Figure 14b. The cross-sectional radiograph reveals voids and extrusion features consistent with fusion and resolidification of the OD surface of the aluminum plug.

The as received fracture surface of the drive shaft tube is shown in Figure 15. A portion of the aluminum plug fills to inner void space of the tube. The fracture surface of the steel drive shaft tube was also coated with aluminum from the plug. To expose the fracture surface of the drive shaft, the assembly was immersed in concentrated sodium hydroxide to partially dissolve the aluminum while leaving the drive shaft steel intact. The exposed drive shaft tube fracture surface is shown in Figure 16. Much of the fracture

surface was damaged by mechanical contact—obliterating most fracture surface macro and micro-features. Portions of both bolt holes are present on this fracture surface (see annotations in the figure for locations) and their elongated shape are consistent with shear deformation from axial torsional loads (e.g. mode II loading). The figure also shows a location on the fracture surface where the fracture micro-features were minimally damaged. A scanning electron microscope was used to image the fracture micro-features in this region. The images are shown in Figures 16 and 17. In all instances elongated microvoids were observed consistent with mode II microvoid coalescence (overstress fracture in shear).

Figure 19 shows a side view of both fractured ends of the drive shaft pieces. The pieces are arranged to approximate their general positions at the time of final fracture. The distortion to the bolt hole due to the torsional shear overload is evident.

A sample of the trail rotor drive shaft was removed for compositional analysis and hardness testing. The hardness is 25 HRC, tested in accordance with ASTM E18. The composition was determined using an Olympus Vanta C x-ray fluorescence (XRF) alloy analyzer. The alloy analyzer identified the drive shaft material as type 4130 alloy steel. The hardness and composition of the drive shaft are consistent with normalized type 4130 steel.

Michael Budinski
Chief, Materials Laboratory Division

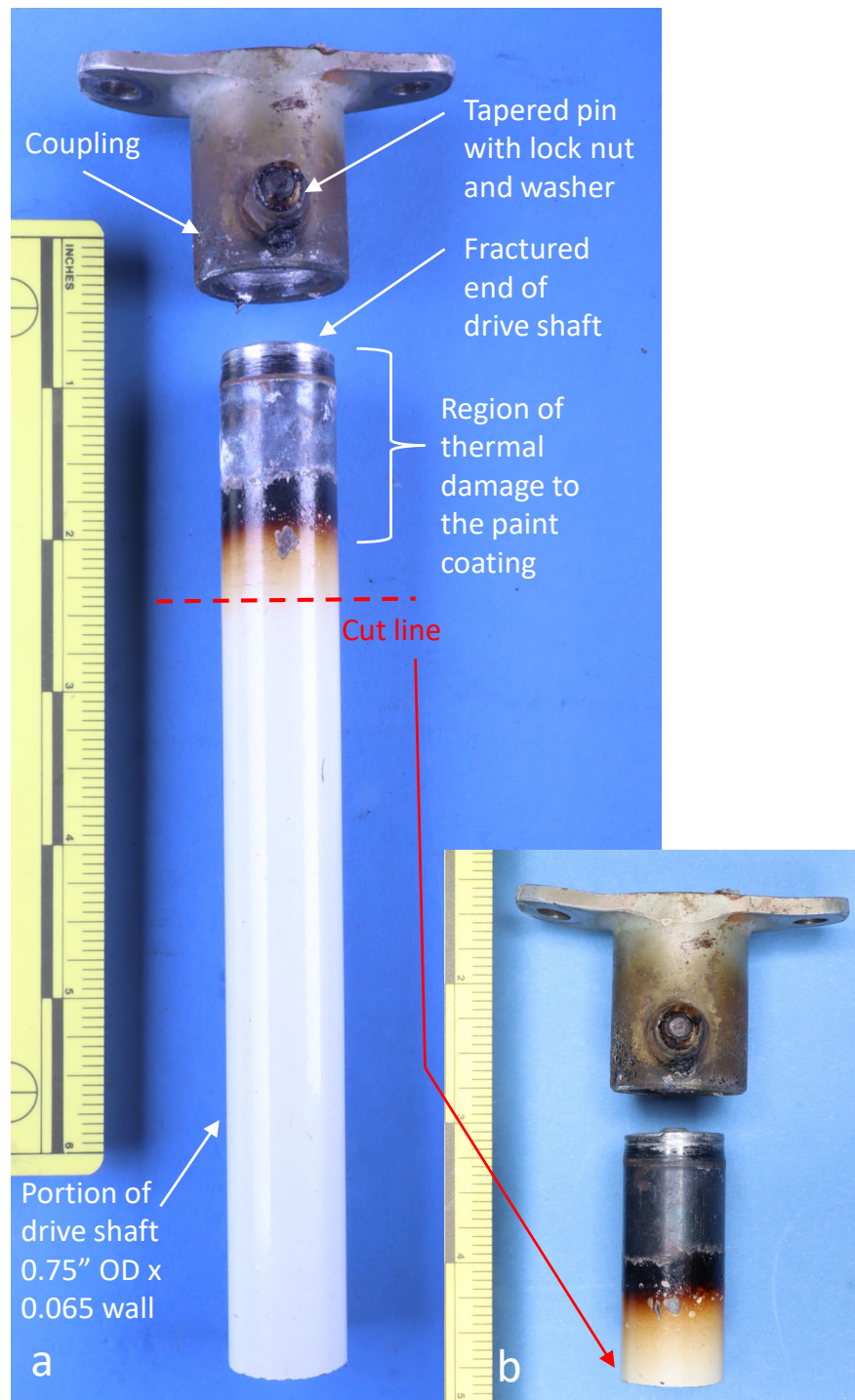


Figure 1 The as-received portion of a tail rotor drive shaft and a tail rotor drive coupling. The drive shaft tube was cut along the red dashed line to facilitate imaging.

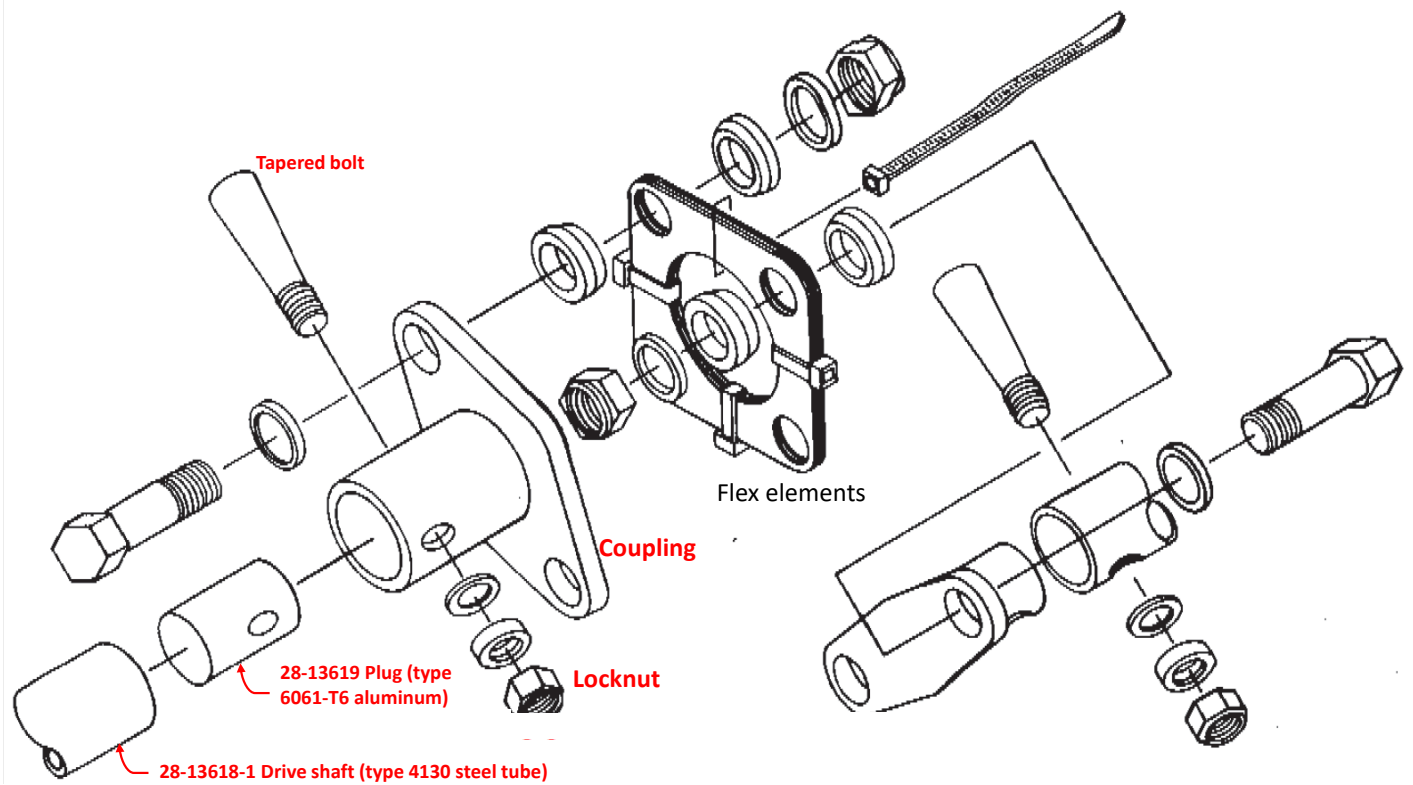


Figure 2 A sketch showing an exploded view of the drive coupling and drive shaft assembly, referenced from the Enstrom F-28F/280F Series Maintenance Manual. The submitted components are indicated by red annotation.

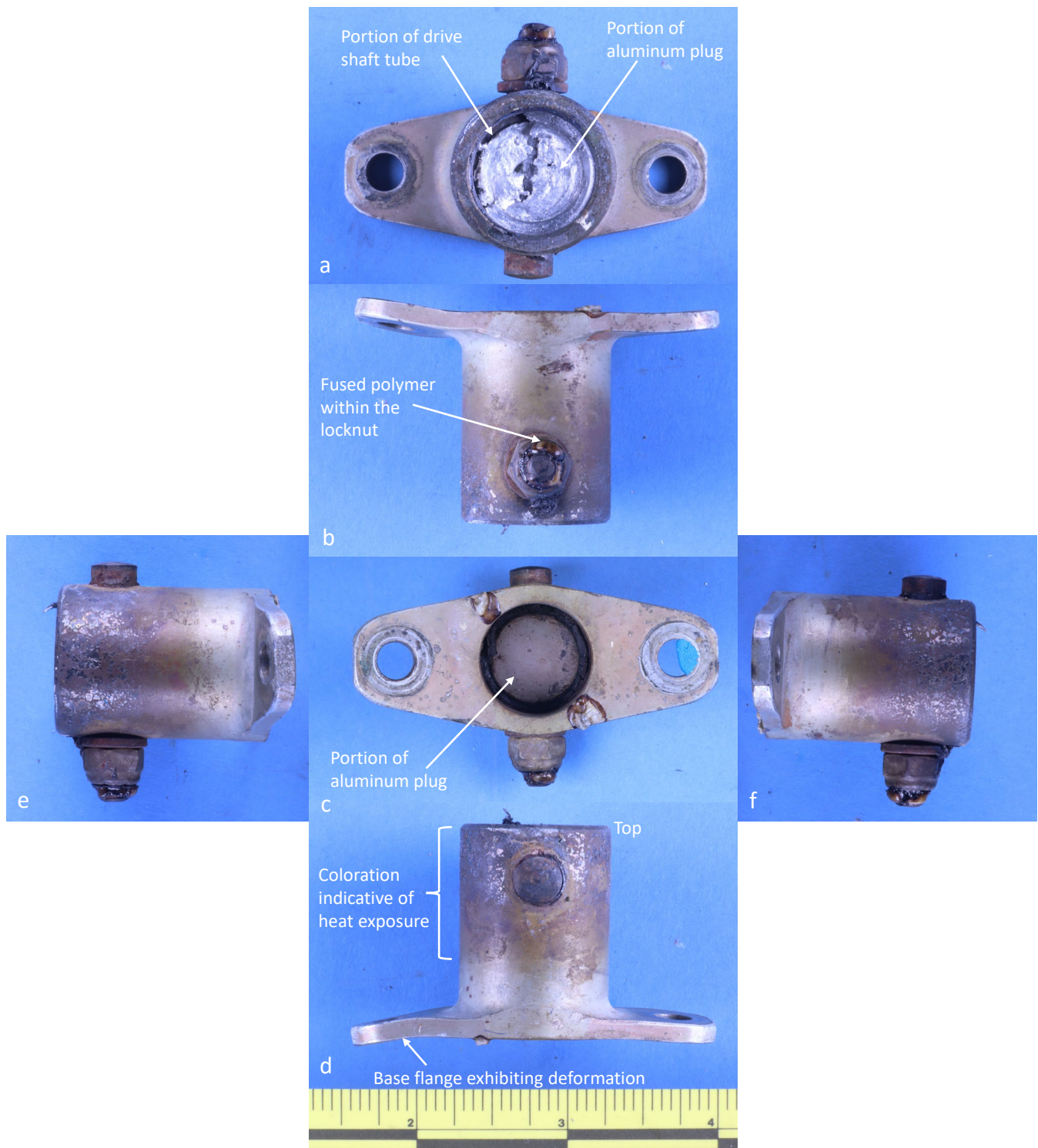


Figure 3 Projection views of each side of the as-received drive coupling piece.

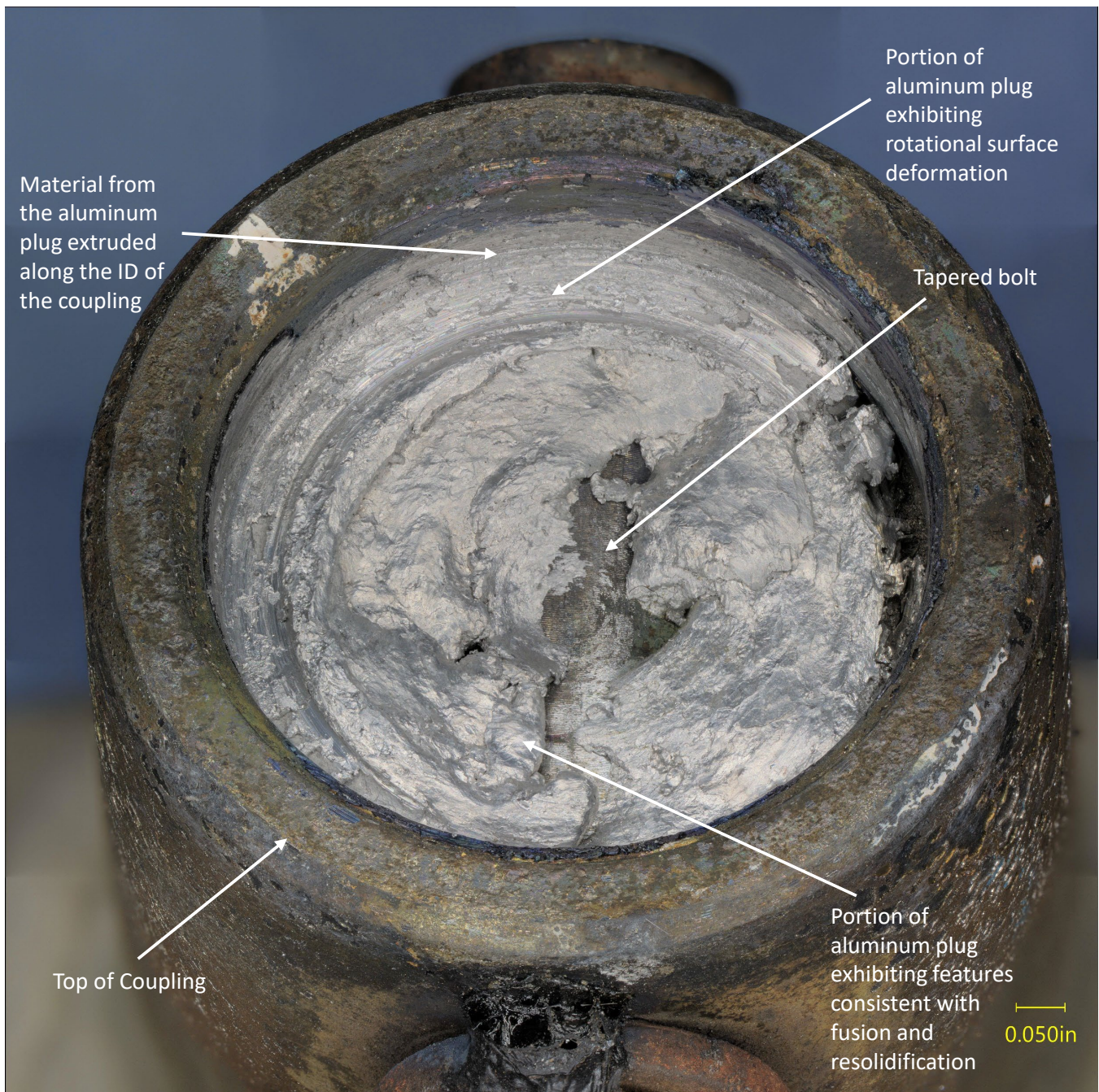


Figure 4 Oblique view of the inner bore of the top of the drive coupling piece. Annotations detail the condition of the damaged aluminum plug.

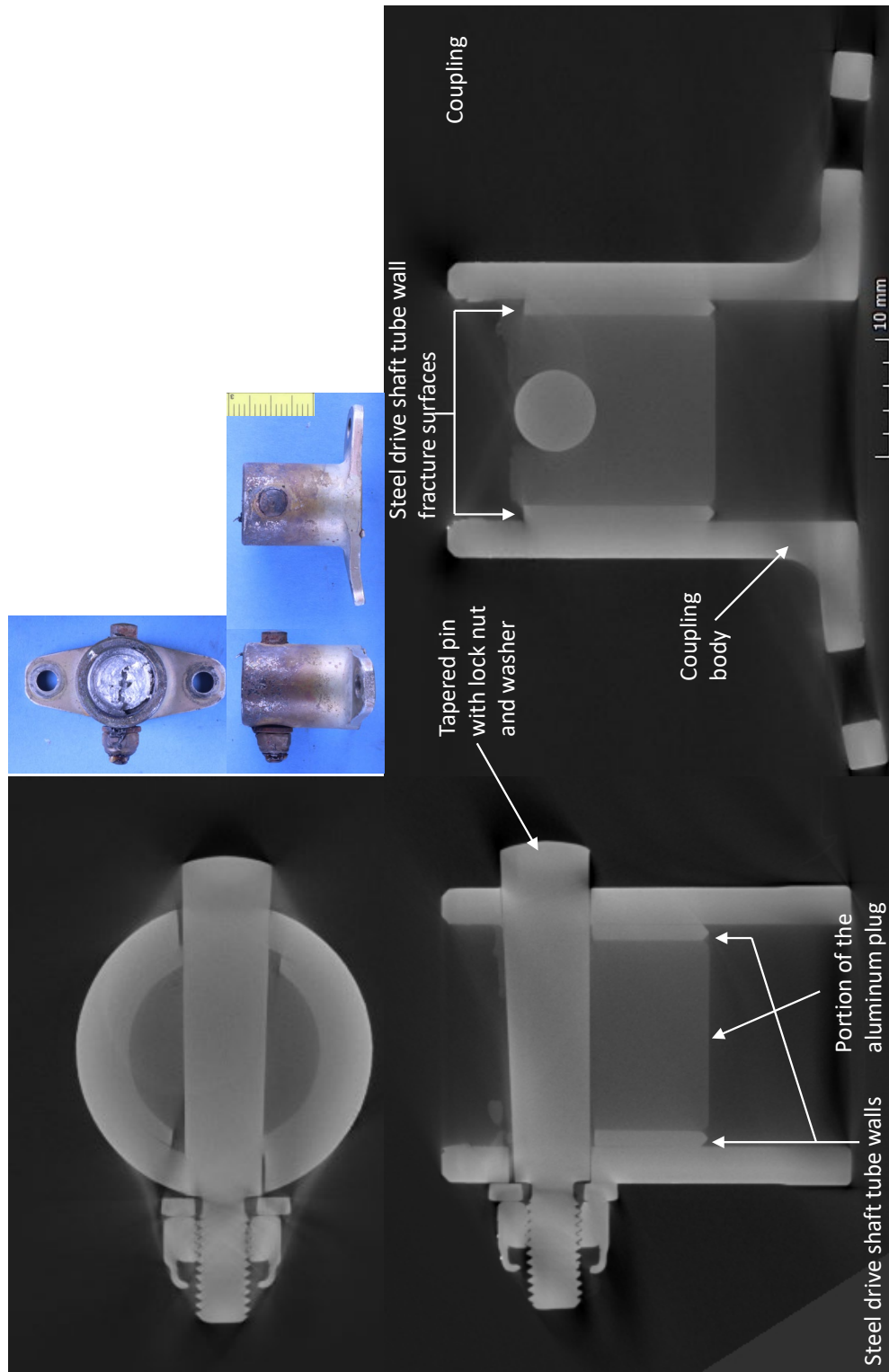


Figure 5 X-ray CT radiographic images of the drive coupling piece showing a portion of the fractured drive shaft tube and the location of the fracture relative to the tapered bolt.

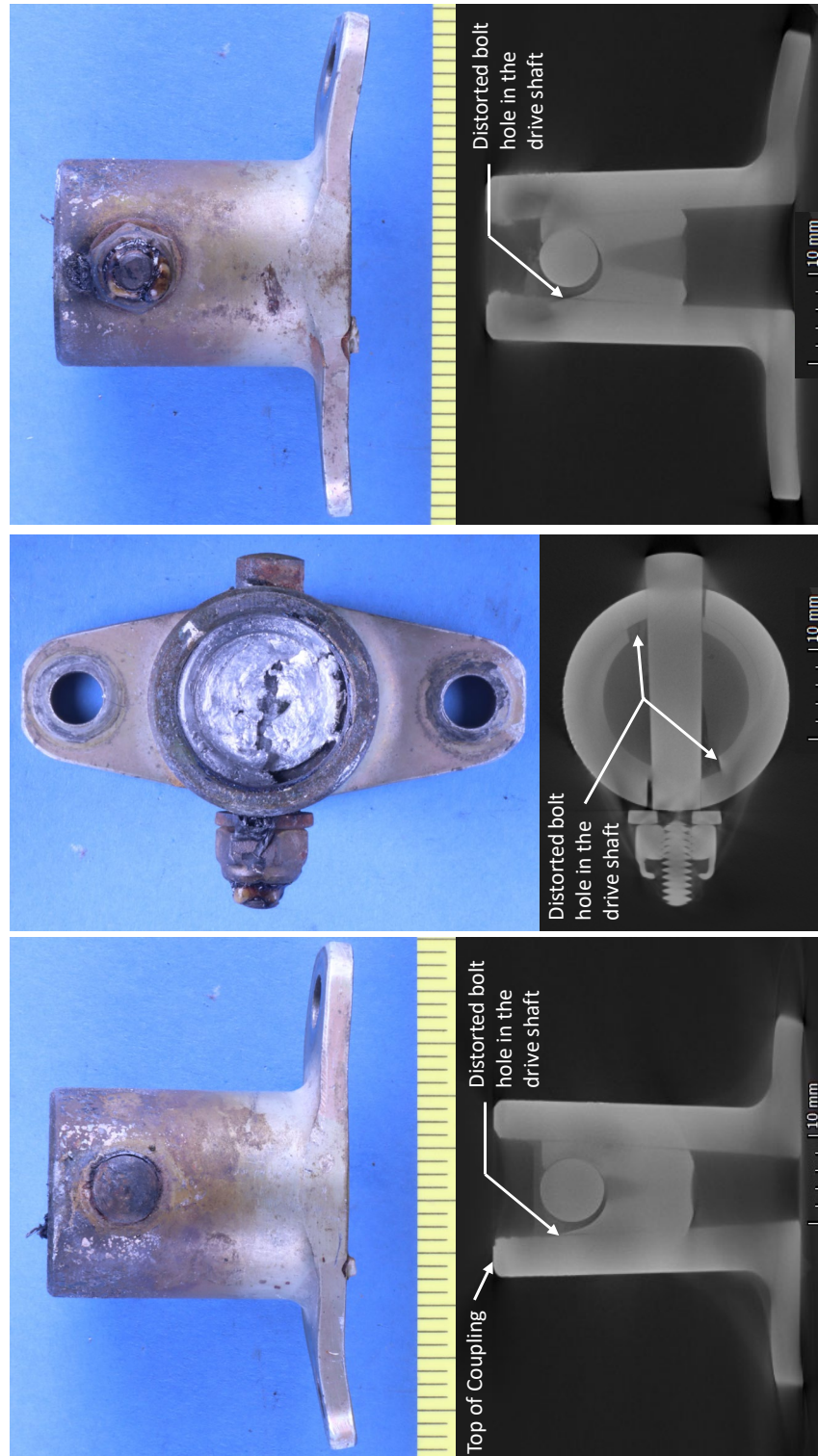


Figure 6 X-ray CT radiographic images of the drive coupling piece showing a portion of the fractured drive shaft tube and distortion of the cross-drilled bolt hole in the drive shaft.

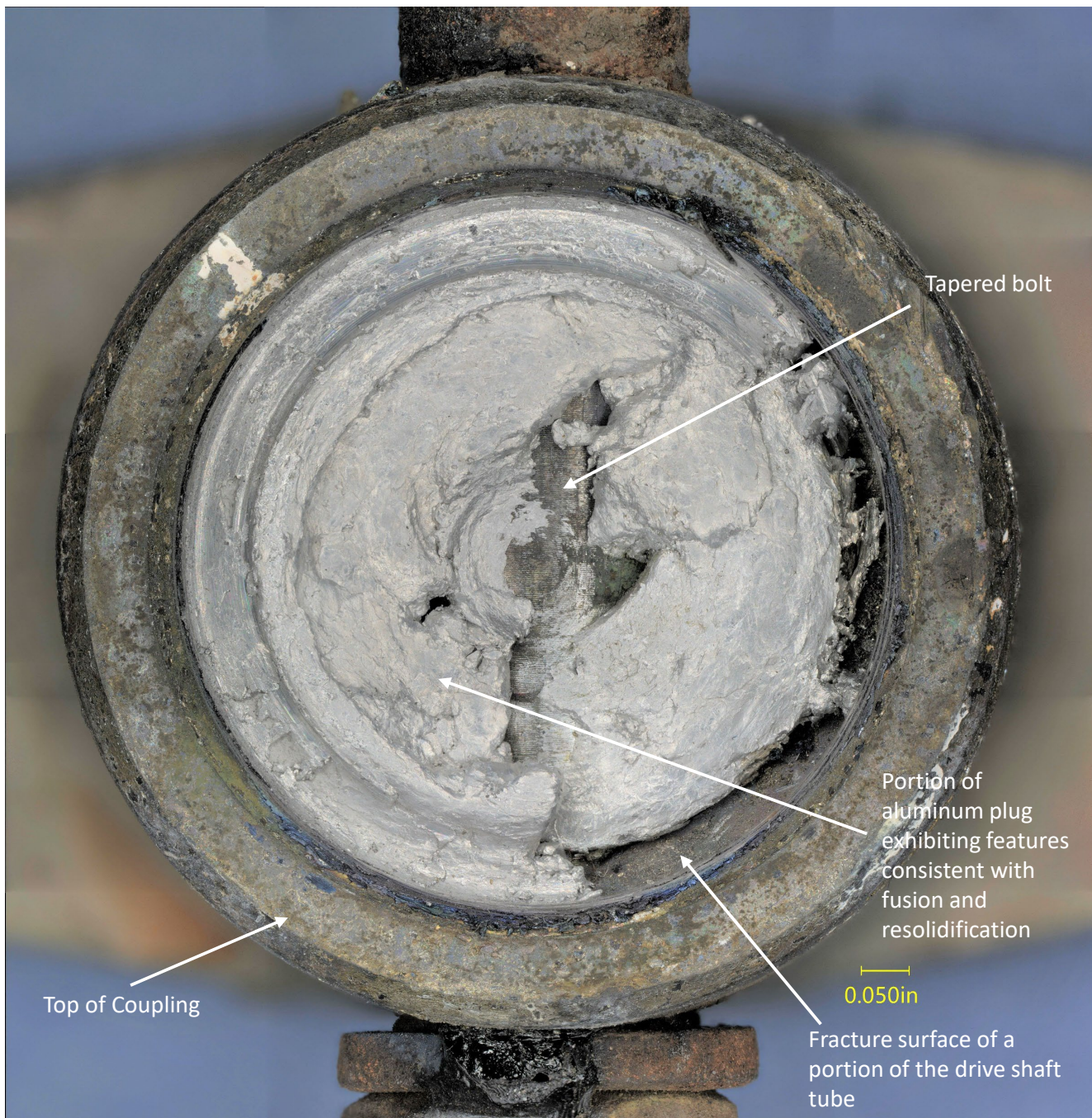


Figure 7 Close view of the internal bore at the top side of the drive coupling. A portion of aluminum plug exhibiting features consistent with fusion and resolidification is observed. The fracture surface of the drive shaft tube is obscured by remnants of the aluminum plug.

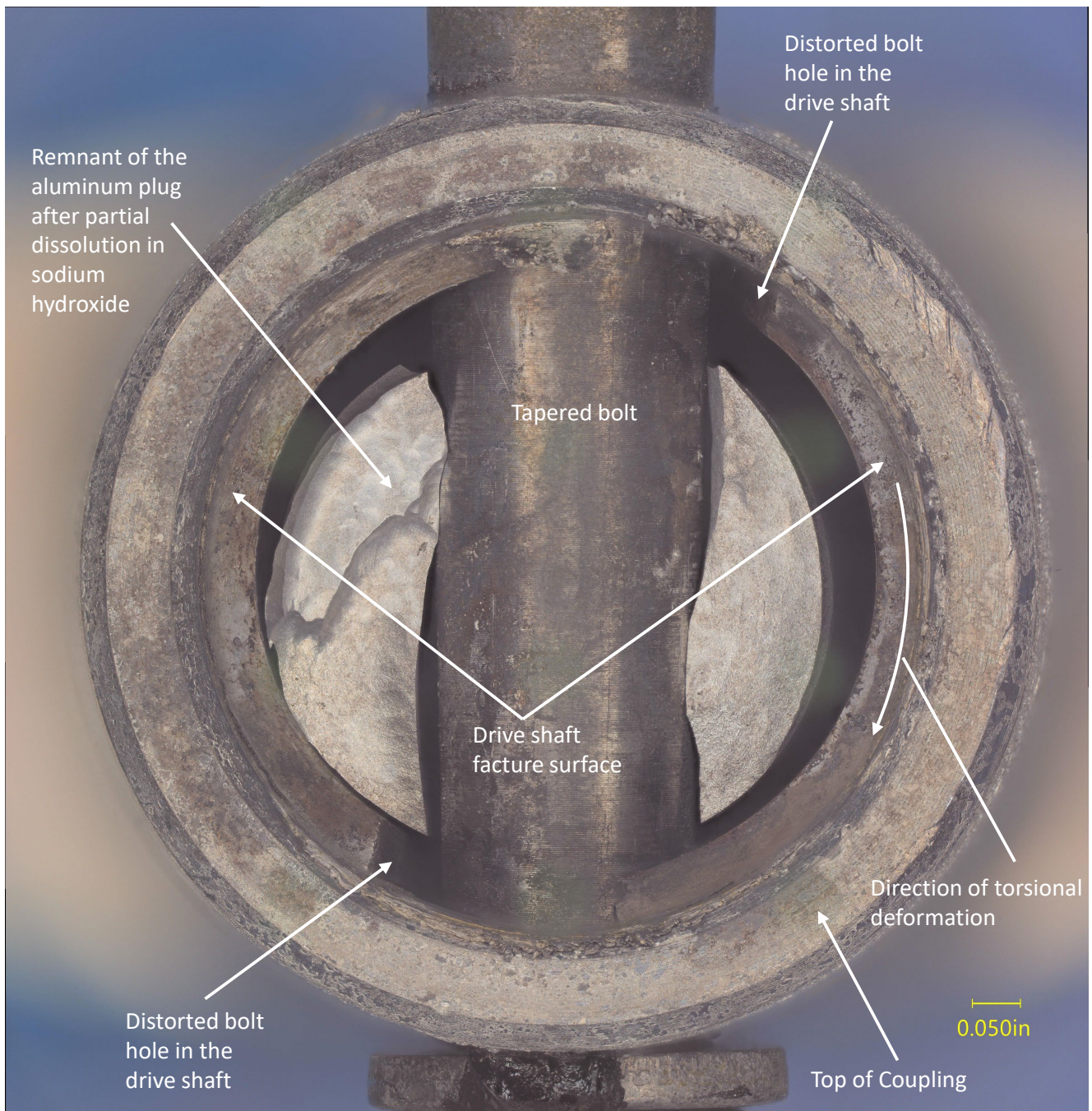


Figure 8 Close view of the drive coupling bore from the top side, shown with the aluminum plug remnants partially dissolved to reveal the tapered bolt and the drive shaft fracture surface. The bolt holes in the drive shaft tube are mechanically distorted consistent with the presence of an axially applied torsional shear-stress in the drive shaft tube in the clockwise direction.

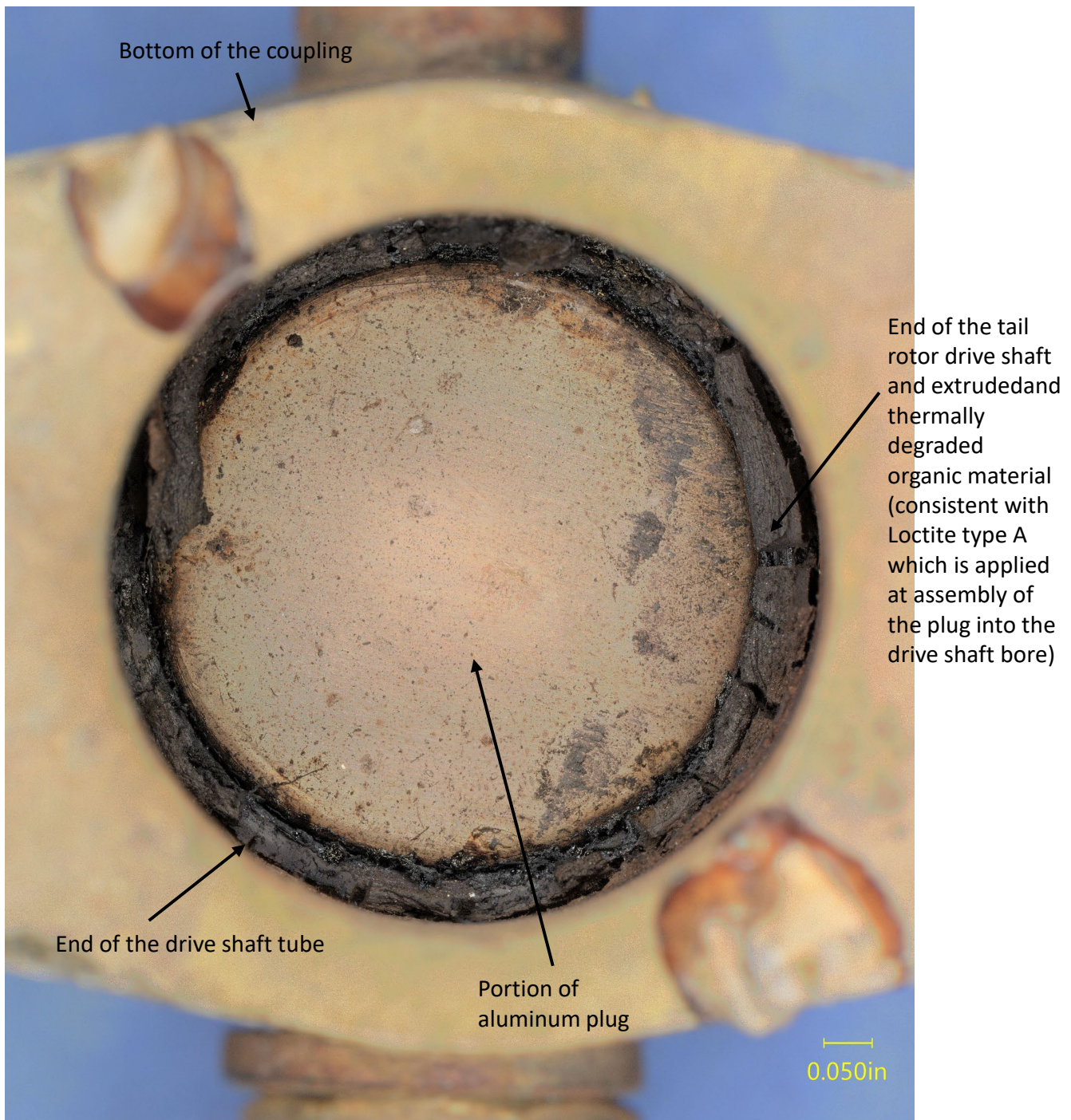


Figure 9 A close view of the internal bore at the bottom or flange side of the drive coupling. This image reveals a portion of the aluminum plug, the chamfered end of the drive shaft tube, and extruded and thermally degraded organic material.

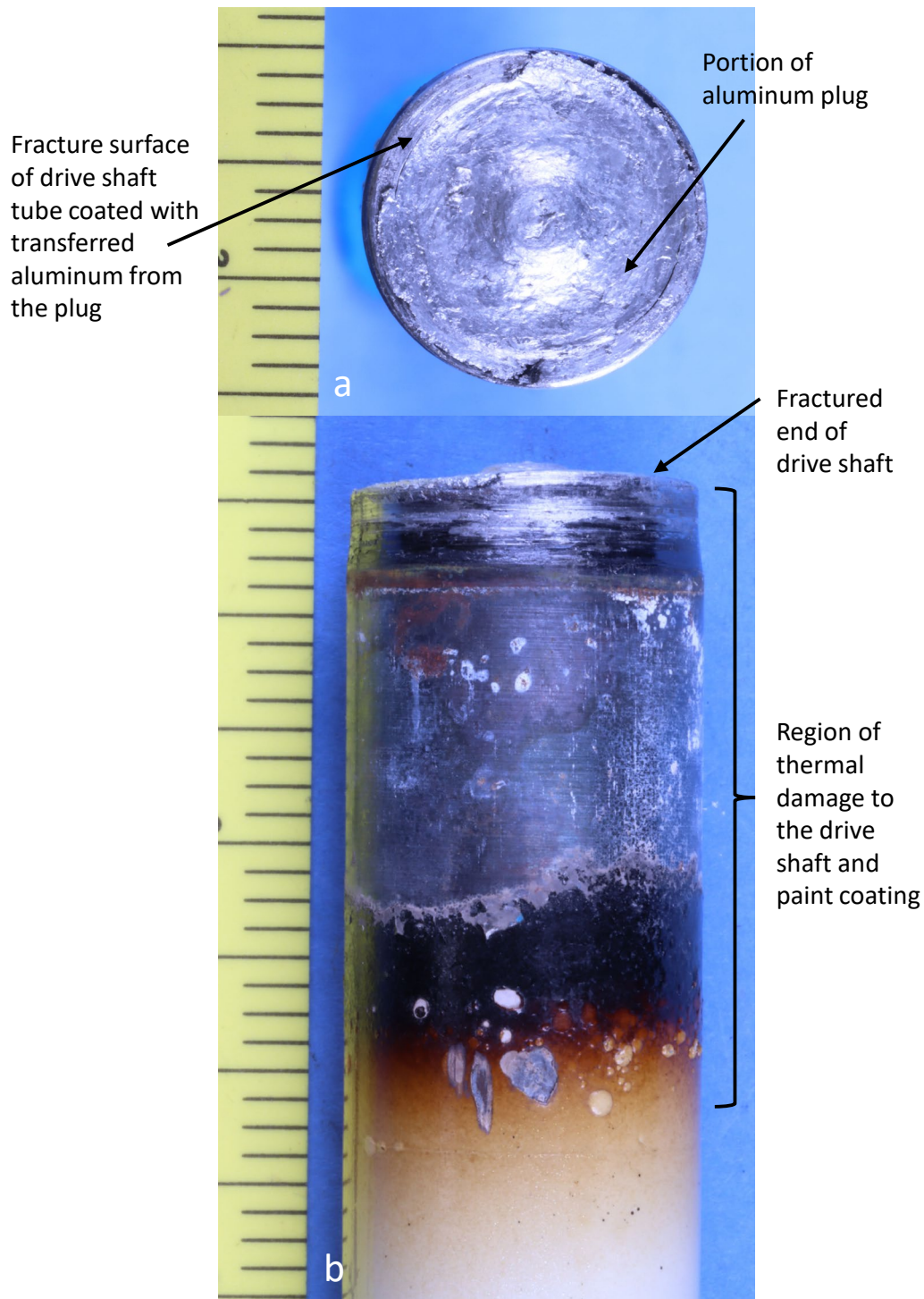


Figure 10 Images of the fractured end of the as-received drive shaft tube. A region of thermal damage is noted as well as the presence of a portion of the aluminum plug.



Figure 11 Oblique view of the fractured end of the as-received drive shaft tube showing rotational contact damage on the outside diameter of the drive shaft where it mates with the coupling.



Figure 12 Closer side view of the fractured end of the as-received drive shaft tube showing rotational contact damage on the outside diameter of the drive shaft where it mates with the coupling.

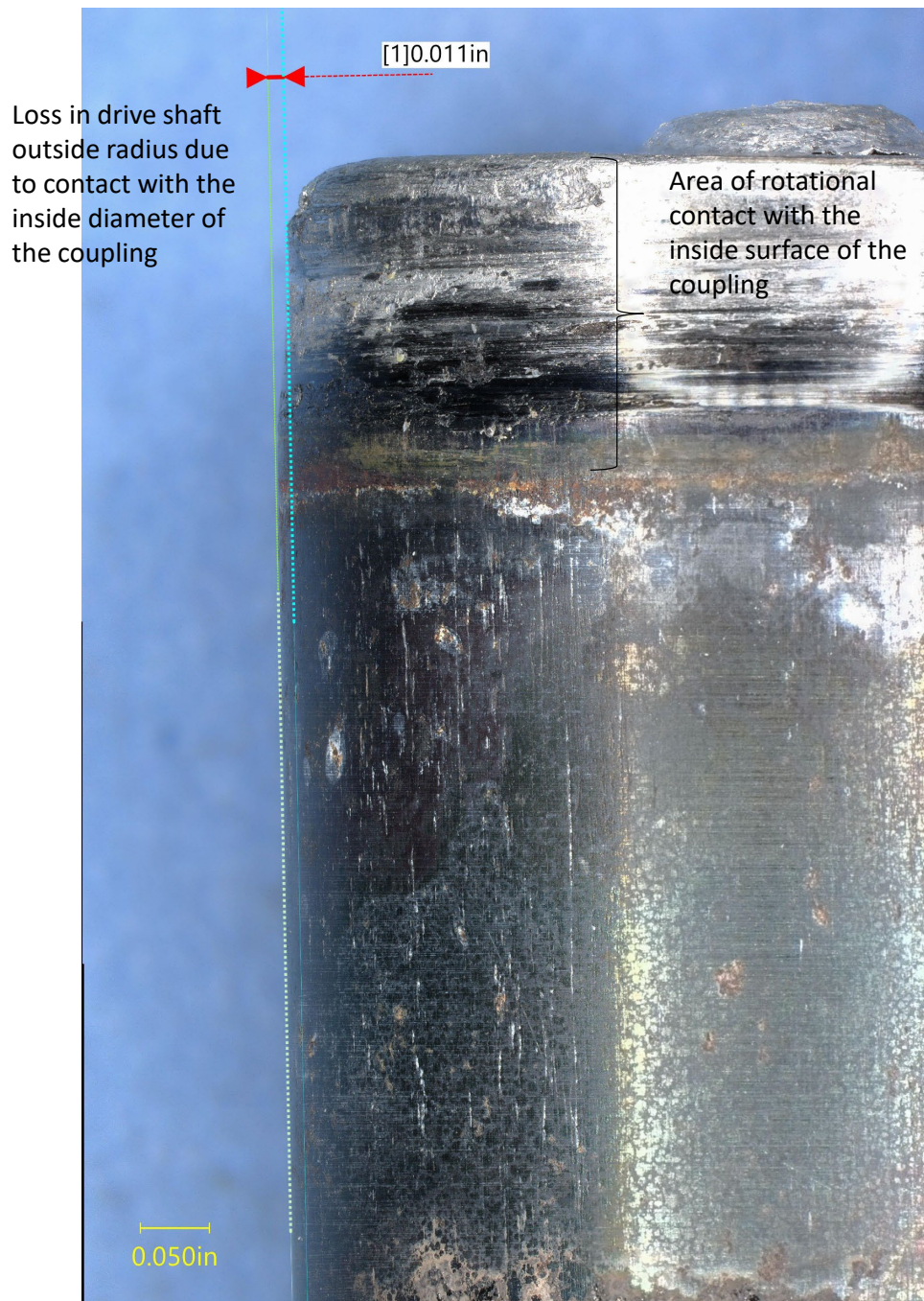


Figure 13 Image of the fractured end of the as-received drive shaft tube showing the reduction in outside diameter due to rotational contact of the outside diameter of the drive shaft where it mates with the coupling.

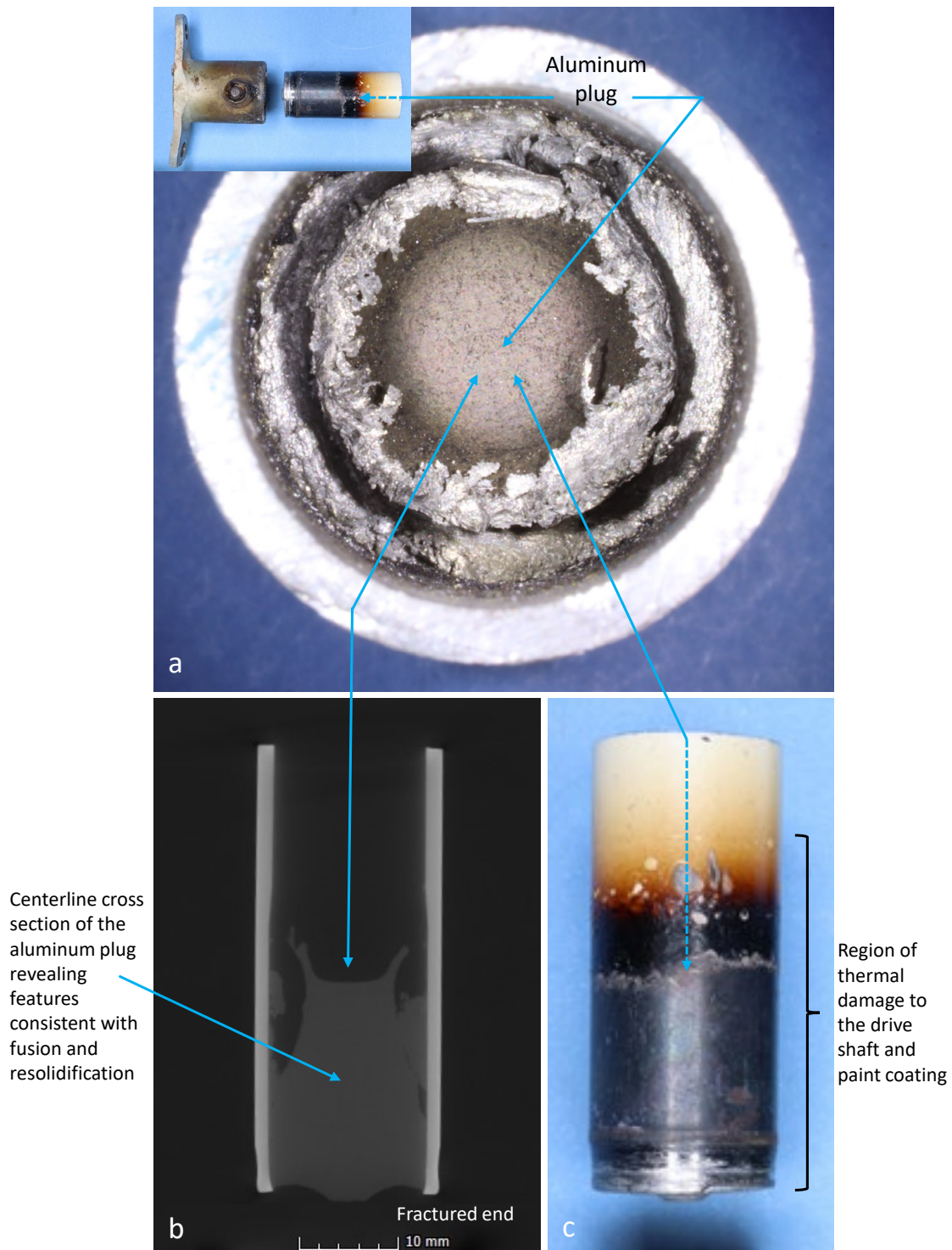


Figure 14 The as-received fractured end of the drive shaft tube. View a shows the bore of the tube with melted, resolidified, and extruded aluminum from the plug. View b shows a longitudinal cross-sectional x-ray CT radiograph of the damaged plug piece inside the bore.

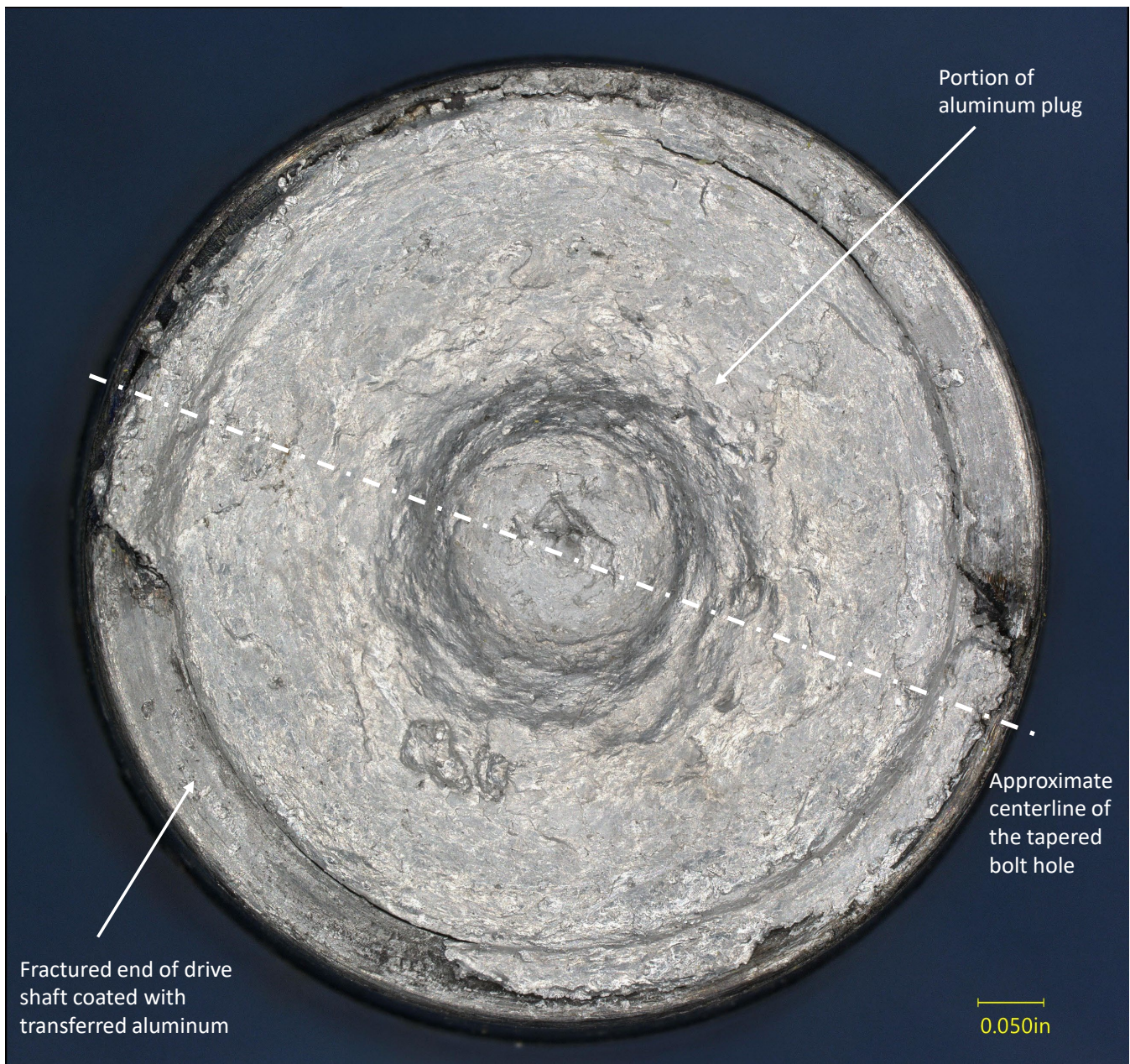


Figure 15 Image of the fractured end of the as-received drive shaft tube showing the presence of aluminum from the damage plug.

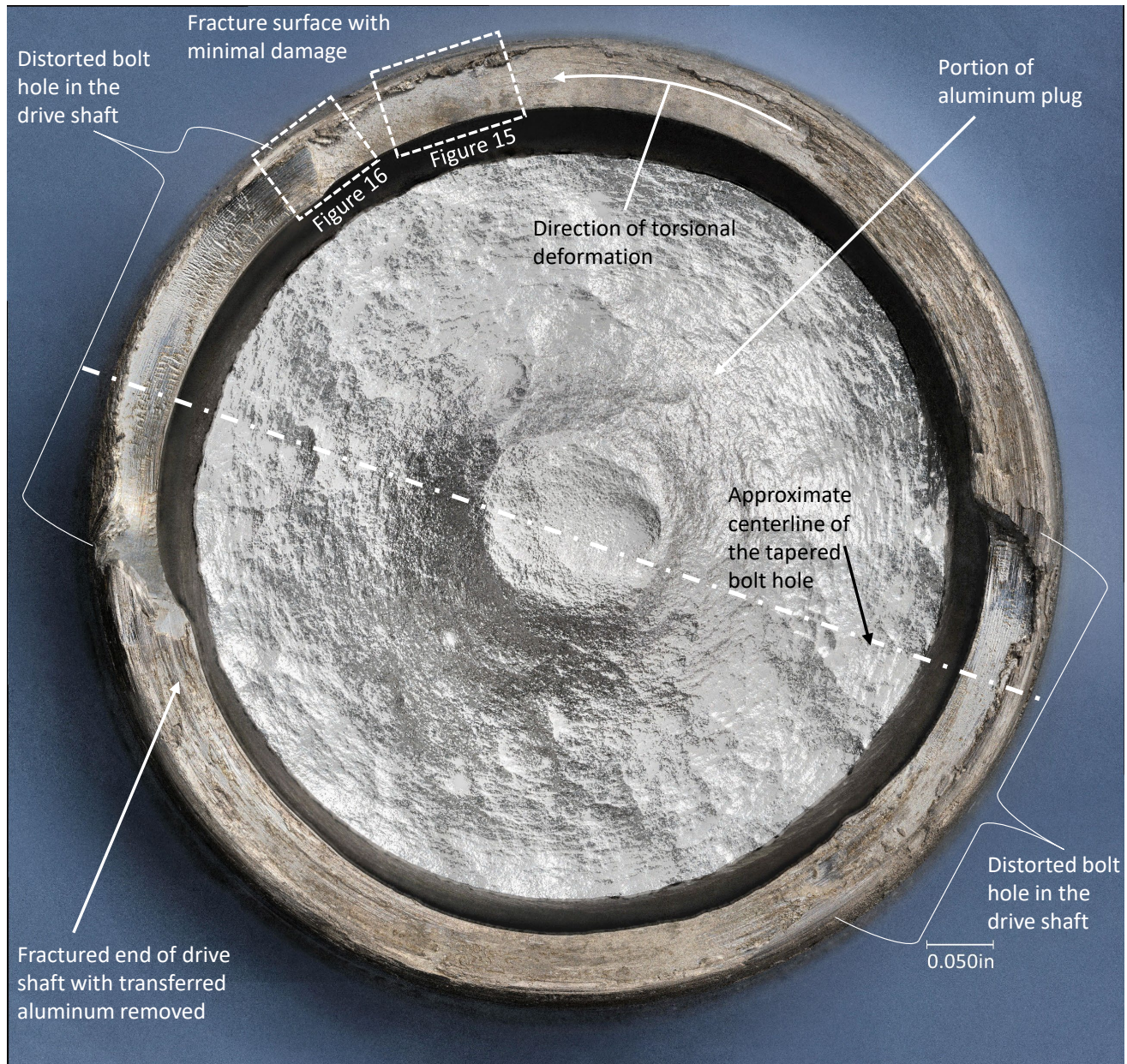


Figure 16 The drive shaft fracture surface after immersing in concentrated sodium hydroxide to partially dissolve the aluminum while leaving the drive shaft steel intact. Much of the fracture surface was damaged by mechanical contact—obscuring most fracture surface macro and micro-features. Portions of both bolt holes are present on this fracture surface (see annotations in the figure for locations) and their elongated shape are consistent with shear deformation from axial torsional loads.

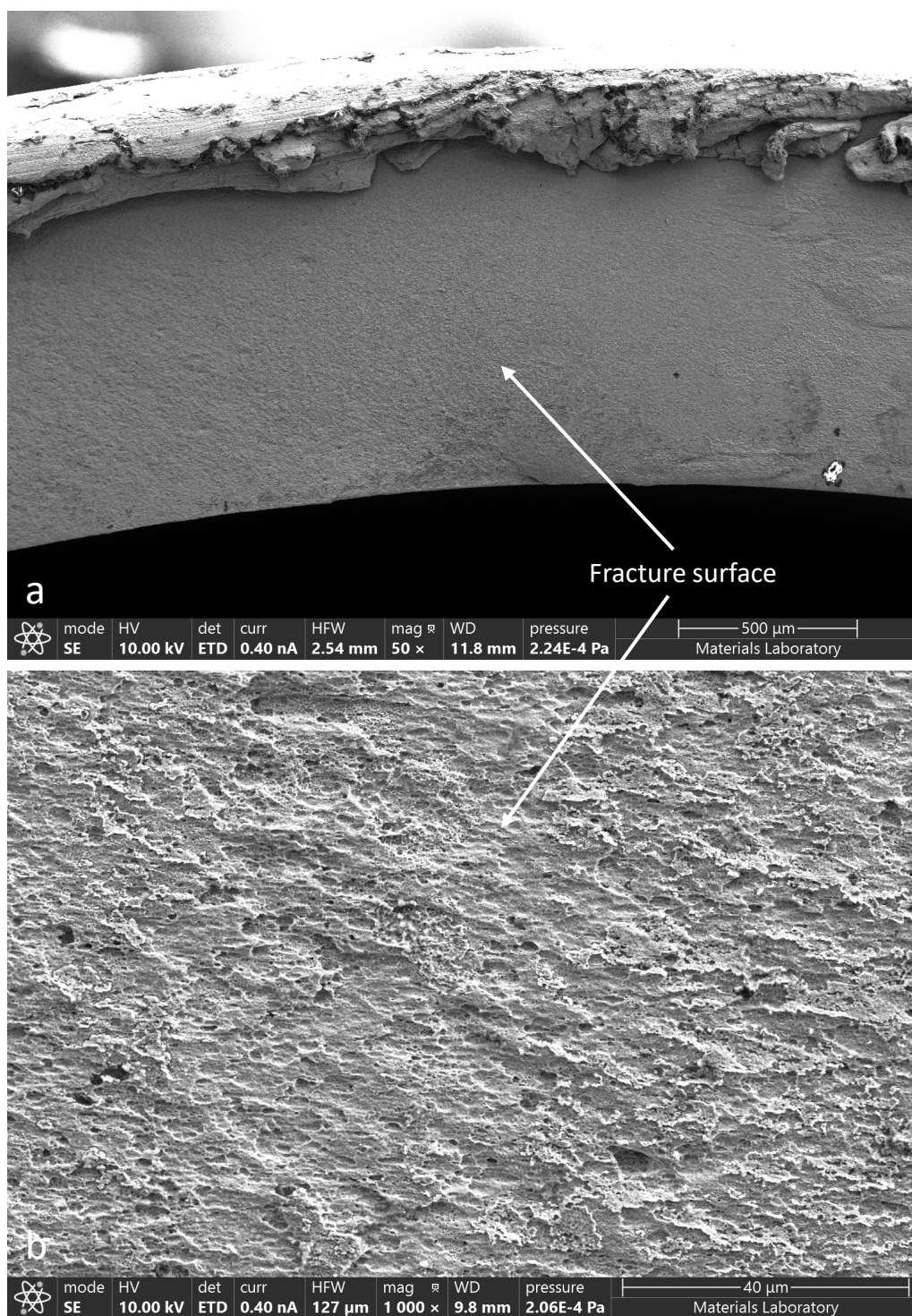


Figure 17 Scanning electron fractographs of the fracture surface region identified in Figure 16. View b shows microvoid coalescence with elongated microvoids consistent the mode II shear overstress fracture.

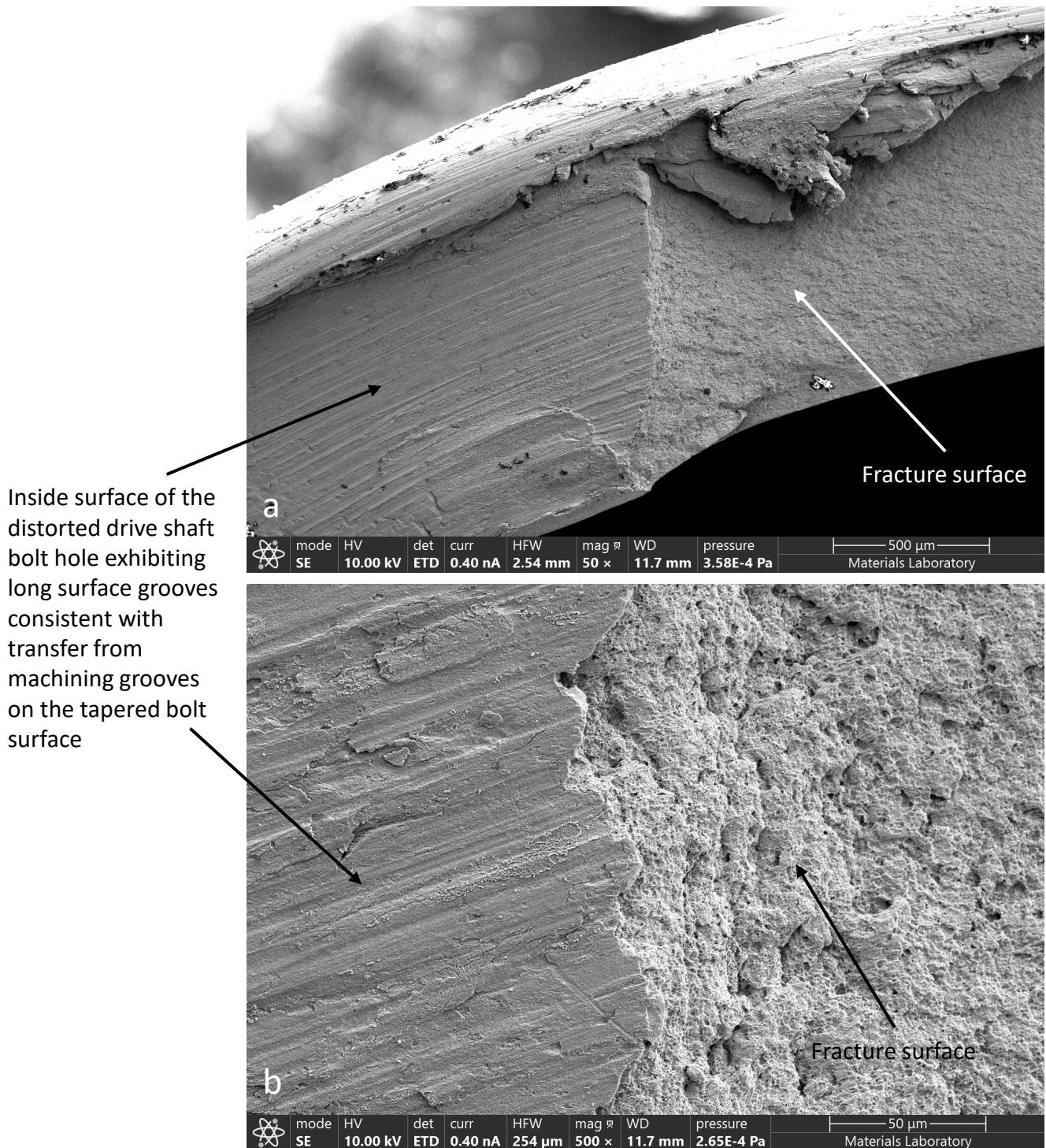


Figure 18 Scanning electron fractographs of the fracture surface region identified in Figure 16. View b shows microvoid coalescence with elongated microvoids consistent the mode II shear overstress fracture.

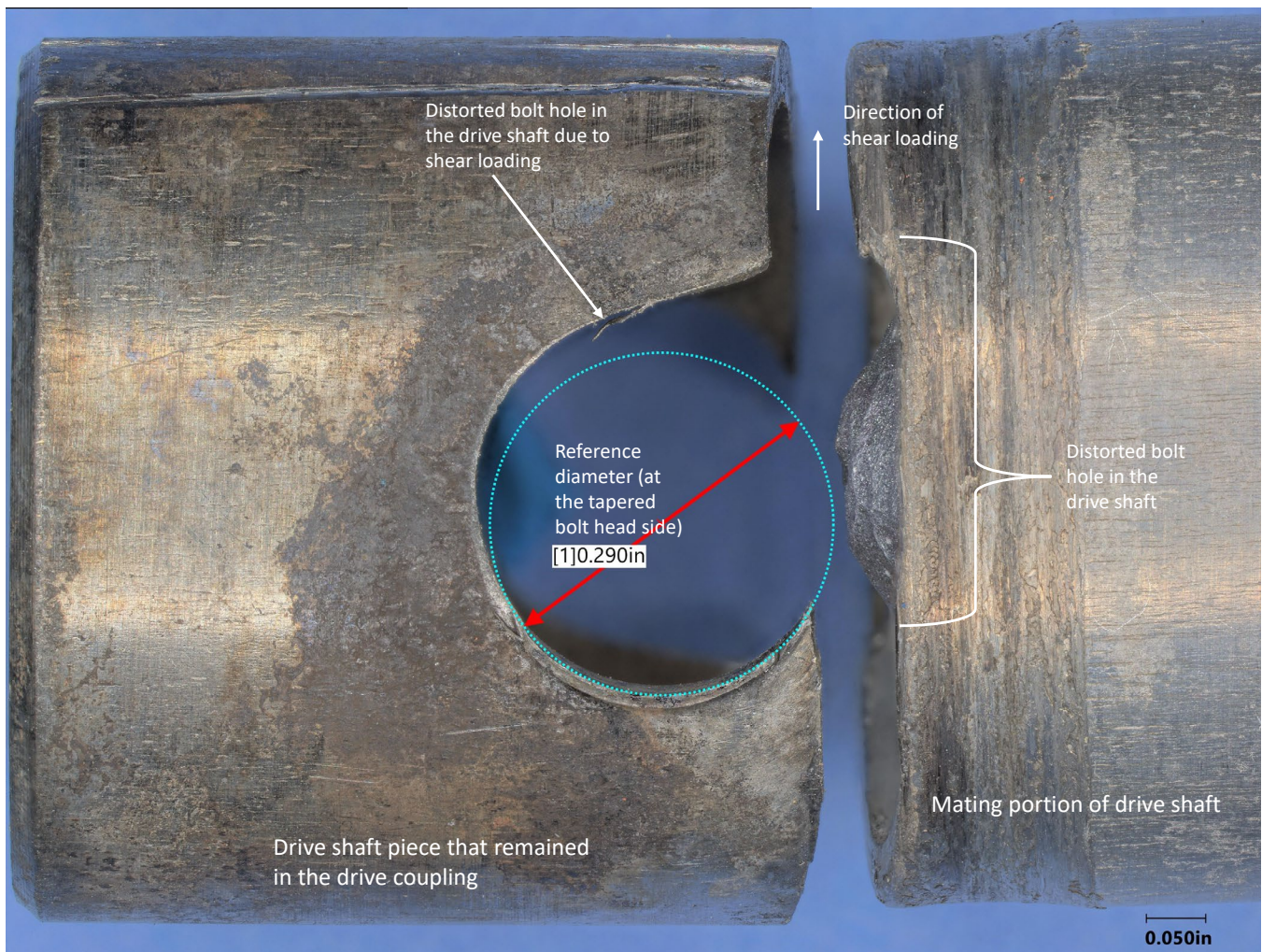


Figure 19 A side view of both fractured ends of the drive shaft piece. The pieces are arranged to approximate their general positions at the time of final fracture.