

NATIONAL TRANSPORTATION SAFETY BOARD

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



May 8, 2019

MATERIALS LABORATORY FACTUAL REPORT

Report No. 19-016

1. ACCIDENT INFORMATION

Place : Billings, Montana
Date : September 12, 2018
Vehicle : Rotorway RW-1, N166LC
NTSB No. : WPR18FA260
Investigator : Thomas Little, AS-WPR

2. COMPONENTS EXAMINED

Pieces of right-seat position anti-torque pedal tubes
Right side position anti-torque pedal

3. DETAILS OF THE EXAMINATION

On September 12, 2018, about 1240 mountain daylight time, a experimental amateur-built RW-1 helicopter was substantially damaged after colliding with a hangar while maneuvering at Billings Logan International Airport in Billings, MT. The pilot was fatally injured. The helicopter impacted the top section of a hangar with its main rotor blades while hover-taxiing, after which it came to rest with its tailboom laying on the ground. The remainder of the helicopter came to rest on its left side, oriented upward on about a 30° angle against the front of the hangar on a southwesterly heading. The helicopter was recovered to a secured hangar for further examination.

Two pieces of the anti-torque pedal tubes from the right pilot seat position were retained and sent to the NTSB Materials Lab, shown as received in Figure 1. Both anti-torque tube assemblies consisted of a parallel tube with flanges on both ends, joined to a perpendicular tube at the midpoint. The flanged ends of the parallel tube from the fractured assembly were closed, whereas the ends of the intact assembly were open to the interior. Holes had been drilled in the perpendicular tubes oriented parallel to the parallel tube direction.

The left tube assembly in Figure 1 had fractured at the joint. The right tube assembly was intact, and still had a bolt and nut through one of the holes. Figure 2 and Figure 3 show the intact and fractured anti-torque tube assemblies, respectively, annotated to show various dimensions. As demonstrated from the measurements, the two anti-torque tube

assemblies were inconsistent in their measurements, as well as the material used for their respective joining processes.

Also different were the number of and quality of the holes drilled in the perpendicular tubes. The perpendicular tube of the intact assembly contained three holes, whereas the corresponding tube of the fractured assembly included two holes. These two holes exhibited elongation and loss of material in the direction of the tube, consistent with wear.

The chemical compositions of all the components were inspected using energy dispersive x-ray spectroscopy (EDS) and x-ray fluorescence (XRF). The compositions of the fractured tubes were consistent with commercial aluminum alloys. The filler metal was consistent with a zinc-copper alloy, typical of some commercial alloys used for soldering galvanized steels. The material hardness of the tube was inspected per ASTM E18, and the electrical conductivity was inspected per ASTM E1004.^{1,2} The hardness averaged 39 HRBW. The conductivity averaged 41.2 %IACS. These data were consistent with those typically reported for as-fabricated aluminum products of this composition.³

The compositions of the intact assembly tubes were consistent with alloy steel. The weld filler was also consistent with alloy steel. The hardness of the tubes was inspected per ASTM E18. The hardness averaged 20 HRC (42 HR30N).

Figure 4 shows the mating fracture surfaces of the left anti-torque tube assembly. As shown in Figure 5, the mating fracture surface from the parallel tube side included remnant filler material on only 0.5 inches on one side and 0.05 inches on the other. The remainder of the fracture surface exhibited features such as mill marks and scratches consistent with as-fabricated exterior tube surface. These exterior features were consistent with those on the tube surface away from the joint location. The fractured joint areas on the parallel tube surface absent any fractured filler metal remnants were consistent with interfacial disbonding, rather than fracture.

Figure 6 highlights the 0.5 inch fractured remnant on the parallel tube surface. The material appeared as a peeled-lip shape, with a small gap against the tube surface. The fracture surface faced up and away from the tube. The surface was rough and tortuous, with a generally clean appearance and dull luster. The lip material beneath to the fracture surface exhibited localized thinning in the form of necking.

This remnant fracture surface was examined using a scanning electron microscope (SEM). As typified in Figure 7, the fracture surface on the parallel tube side exhibited dimple rupture, consistent with tensile overstress fracture. No other features consistent

¹ ASTM E18 – *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*. ASTM International, West Conshohocken, PA.

² ASTM E1004 – *Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*. ASTM International, West Conshohocken, PA

³ "Properties of Aluminum Castings." *Metals Handbook Desk Edition*, 2nd ed., J.R. Davis, ed., ASM International: Materials Park, OH (1998) pp. 489-498

with other fracture modes were observed on this portion of the fracture surface on the parallel tube.

Figure 8 shows the mating fracture surface on the perpendicular tube. This fracture surface consisted of an interior perpendicular tube, surrounded by filler material. Figure 9 and Figure 10 highlight opposite sides of the joint fracture surface. Some portions of this material exhibited parallel transverse marks, consistent with matching surface fabrication marks on the parallel tube. Much of the rest of the joint surface exhibited longitudinal marks, inconsistent with those present on the exterior of the parallel tube surface.

Figure 11 shows another area of the fracture surface on the perpendicular tube, viewed using a SEM. The flat areas shown in Figure 11 were consistent with areas that had been in contact with the mating side of the parallel tube surface. As shown in Figure 12, these areas exhibited a lumpy surface texture, consistent with the underlying dendritic microstructure (indicative of an as-solidified material). Figure 13 shows lamellar surface features, consistent with the eutectic solidification.

In addition, the flat cross-section surface of the perpendicular tube facing the parallel tube was visible in the lower portion of the Figure 11. This surface was recessed from the flat portions of the filler metal, and were fully exposed, consistent with a lack of contact against the mating tube. This surface had not been covered by the filler metal.

As shown in Figure 9, Figure 10, and Figure 11, much of the filler metal facing the parallel tube was smooth and reflective. Gaps and areas of consistent with lack of seal and penetration were present between the filler metal and the perpendicular tube (see Figure 14). The areas that had been in contact with the mating tube surface were generally flat in orientation. The areas consistent with having not been in contact with another metal surface were rounded. The smooth, rounded areas in Figure 11 were positioned away from the flat areas that had been in contact with the mating tube surface. These exhibited local rumpling consistent a surface oxide wrinkling as the filler alloy cooled and shrank. These portions were consistent with areas that solidified in air without contacting another metal surface.

The round areas exhibited wrinkling on their surfaces, as shown in Figure 13 through Figure 15. The wrinkling on the surface was consistent with a thin oxide skin that formed at the beginning of solidification process while the molten filler metal was in contact with air. This skin then buckled as the filler metal cooled and shrank. The surface wrinkled oxide skin was present on much of the filler metal surface, as shown in Figure 16 and Figure 17. Some areas exhibited thicker oxide layers, shown in Figure 18.

Figure 19 and Figure 20 show the joint between the two tubes of the intact anti-torque tube assembly. The joint was consistent with a welding process, as described below. The weld encompassed the mating surfaces of both tubes, with few external issues. These included pores visible to the exterior surface (as shown in Figure 21) and a small crack approximately 0.05 inches in length (see Figure 22).

The parallel tubes of both assemblies were sectioned longitudinally through the respective joints. The exterior and interior of both tube joints are illustrated in Figure 23. The intact assembly is shown on the right in both figures. The interior surface of the intact joint exhibited penetration consistent with a welding operation performed about the melting temperature of the alloy. The interior of this tube also exhibited the darker complexion typical of steel tubes. The interior of the parallel tube of the fractured anti-torque tube assembly exhibited no indications consistent with penetration by a second filler material.

The cross-sections were vacuum-mounted in epoxy and polished. As shown in a closer view montage of the fractured assembly parallel tube surface, no indications of penetration or fusion with the perpendicular tube were present (Figure 24). The surface of the tube facing the fracture in this cross-section exhibited two divot marks, consistent with where the perpendicular tube was seated (Figure 25). The interior of this tube exhibited porosity as demonstrated by the dark spots on Figure 25. There were some subsurface second phases near the location of the divots of this tube (Figure 26). These second phases were not found elsewhere on the tube.

Figure 27 shows a section of the intact weld joint, as polished. While there were areas with gaps between the tubes and weld filler, the joint was intact with some fusion and penetration. A typical area of the microstructure of the parallel tube and the perpendicular tube are illustrated in Figure 28 and Figure 29 respectively. Both tubes exhibited microstructures consistent with a worked material, exhibiting longitudinal-oriented mixture of ferrite and pearlite. The microstructure of the weld filler exhibited a martensite, consistent with more rapid cooling of the material in this region (Figure 30). There were no noted issues with the microstructures of the intact tube assembly.

The observations of this examination of the fractured anti-torque tube assembly were consistent with a fillet joint that exhibited a lack of complete fusion. These areas either had not bonded to the parallel tube surface or had disbonded. The areas that had bonded to the parallel tube fractured in overstress during the accident flight.

Erik M Mueller
Materials Research Engineer



Figure 1 – The anti-torque tubes, as received. The tube on the left had fractured at the joint, whereas the assembly on the right was intact.

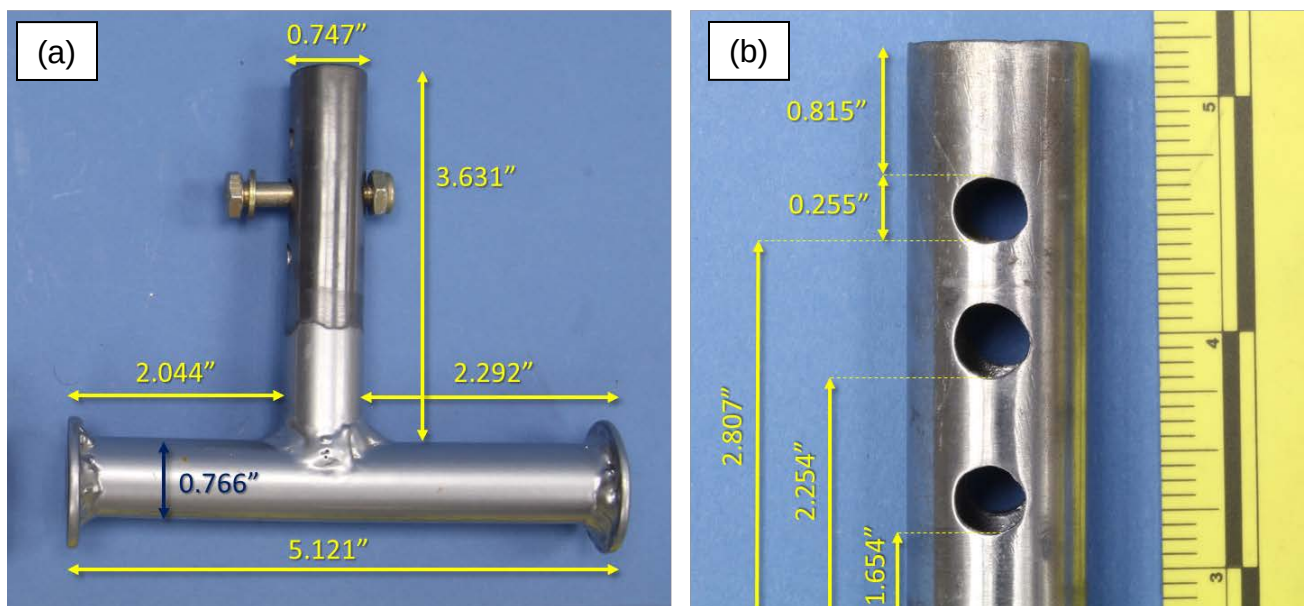


Figure 2 – Annotated various measurements on the intact anti-torque tube assembly showing (a) the entire assembly and (b) the perpendicular tube section with drilled holes. The vertical measurements on the right figure extend to the parallel tube upper surface in the left figure.

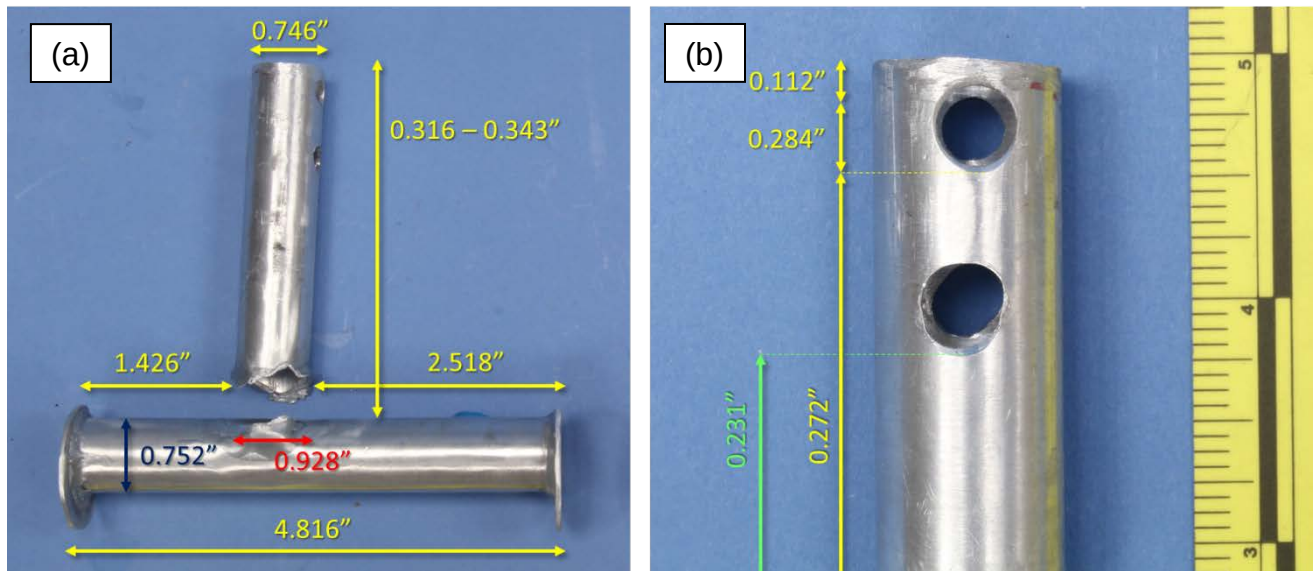


Figure 3 – Annotated various measurements on the fractured anti-torque tube of (a) the entire assembly and (b) the perpendicular tube section with drilled holes. The vertical measurements on the right figure extend to the parallel tube upper surface in the left figure.

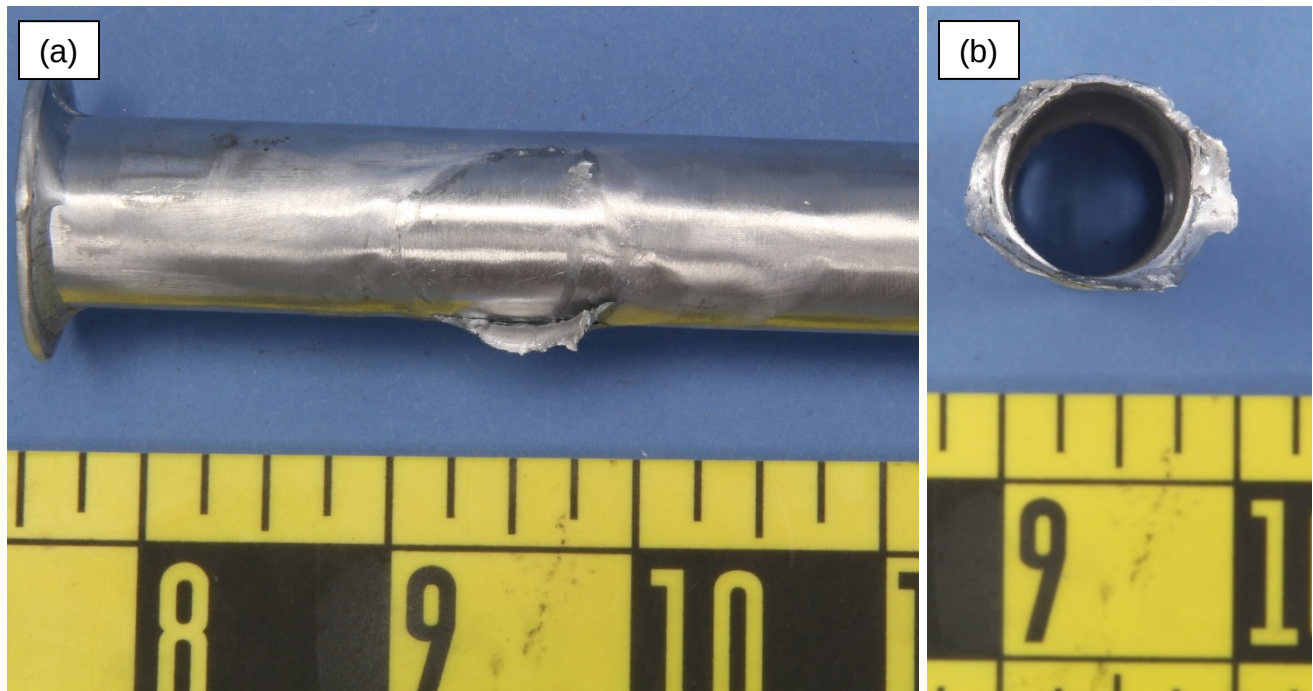


Figure 4 – The mating sides of the broken tube fracture surfaces from the (a) parallel tube side and (b) the perpendicular tube side.



Figure 5 – Closer view of the parallel tube side fracture surface.



Figure 6 – Closer view of the largest remnant of the fractured joint on the parallel tube.

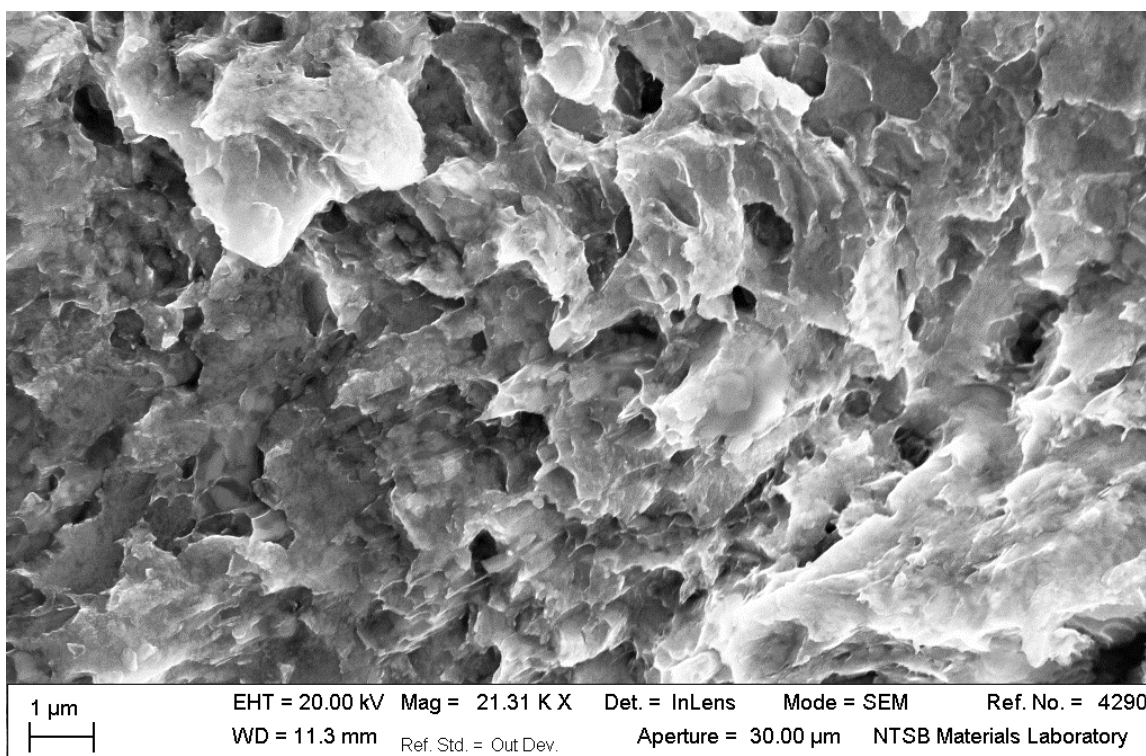


Figure 7 – Secondary electron (SE) micrograph of the fracture remnant in Figure 6. The features were consistent with dimple rupture.

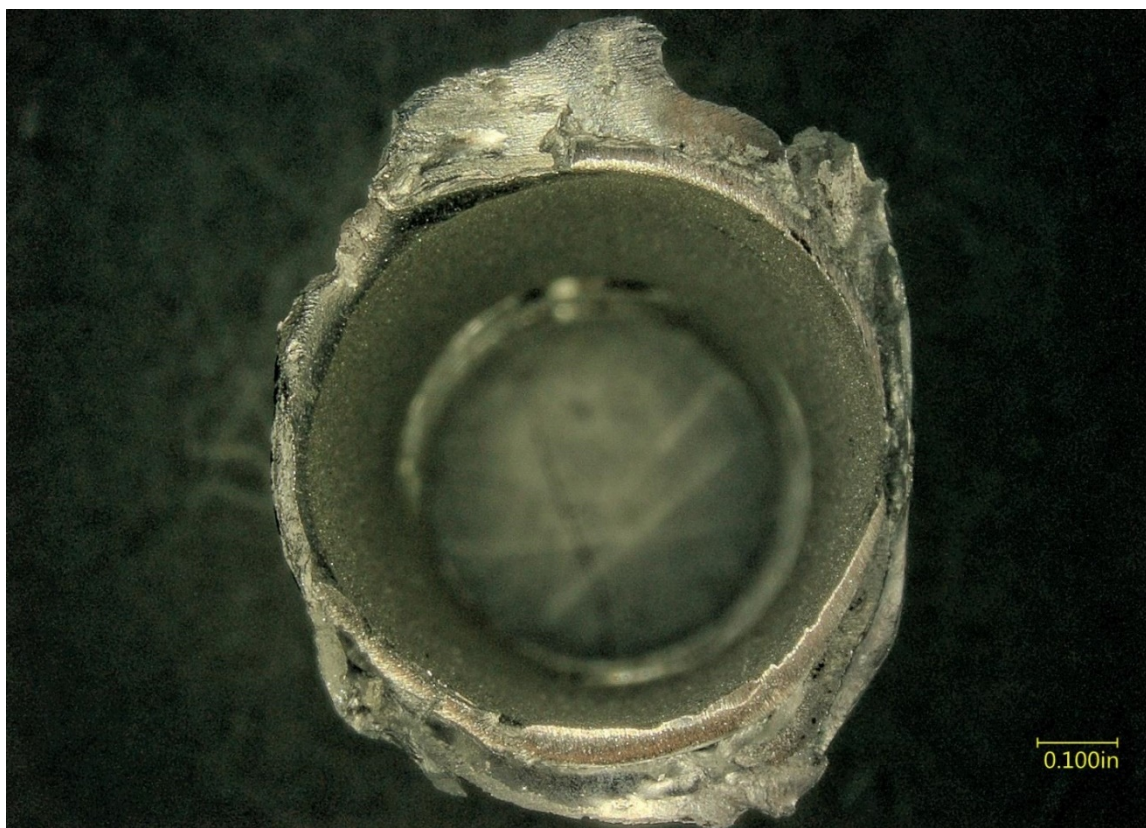


Figure 8 – Closer view of the perpendicular tube side fracture surface.



Figure 9 – View of the largest filler metal remnant on the perpendicular tube fracture surface.

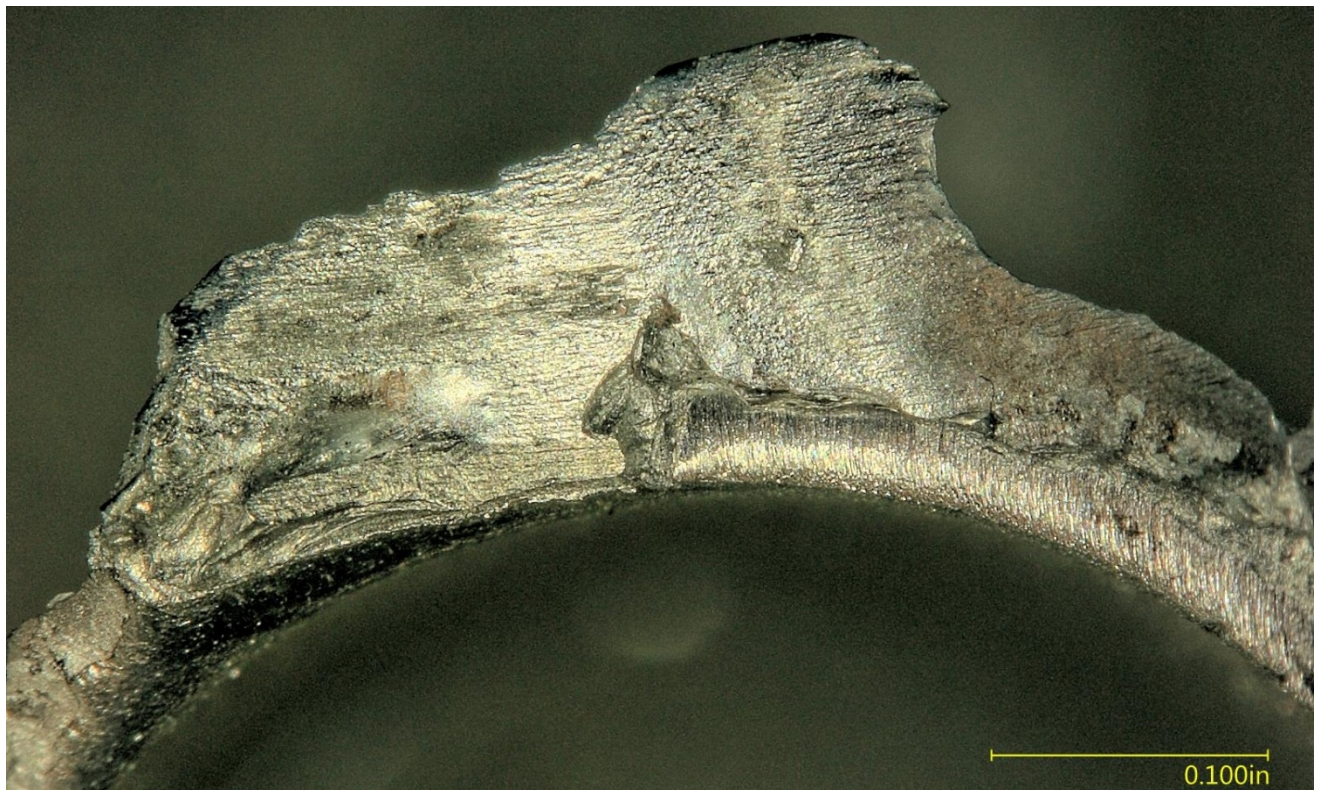


Figure 10 – View of the fracture surface opposite of the portion shown in Figure 9.

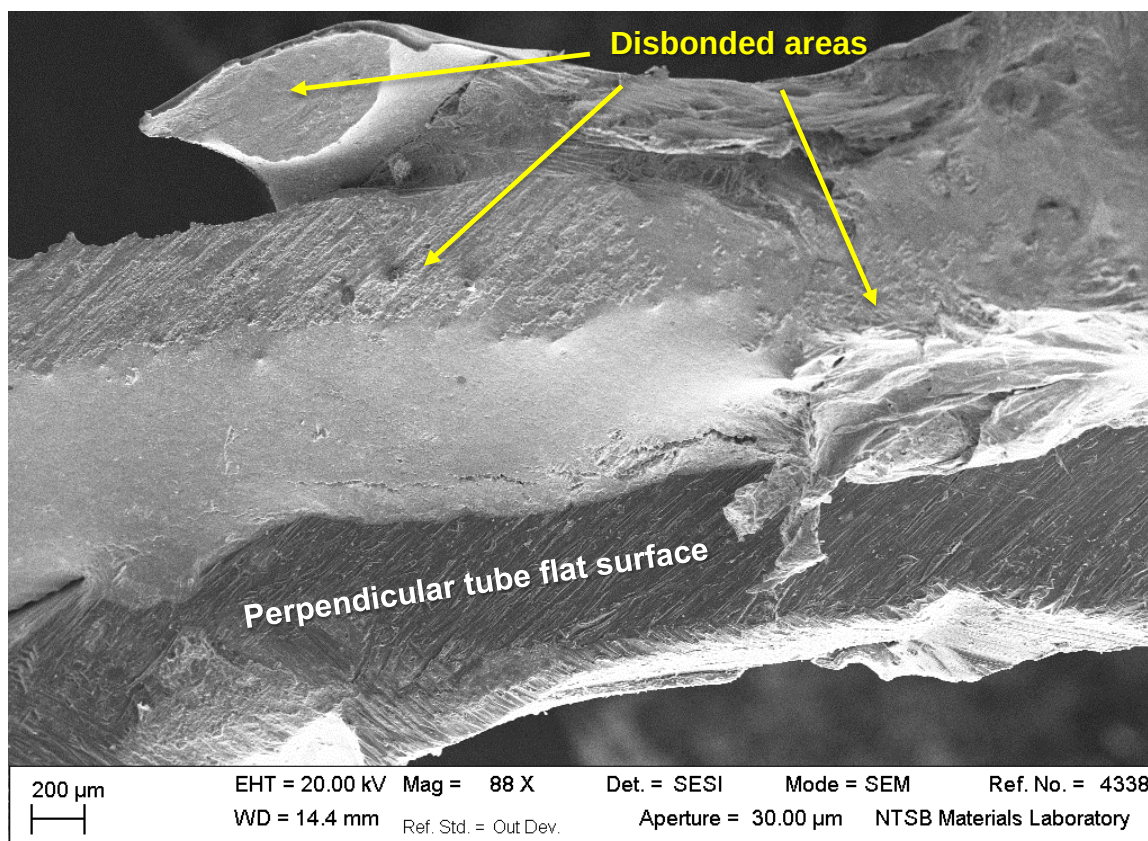


Figure 11 – SE micrograph of the joint fracture surface, showing the disbonded areas and the unbonded regions.

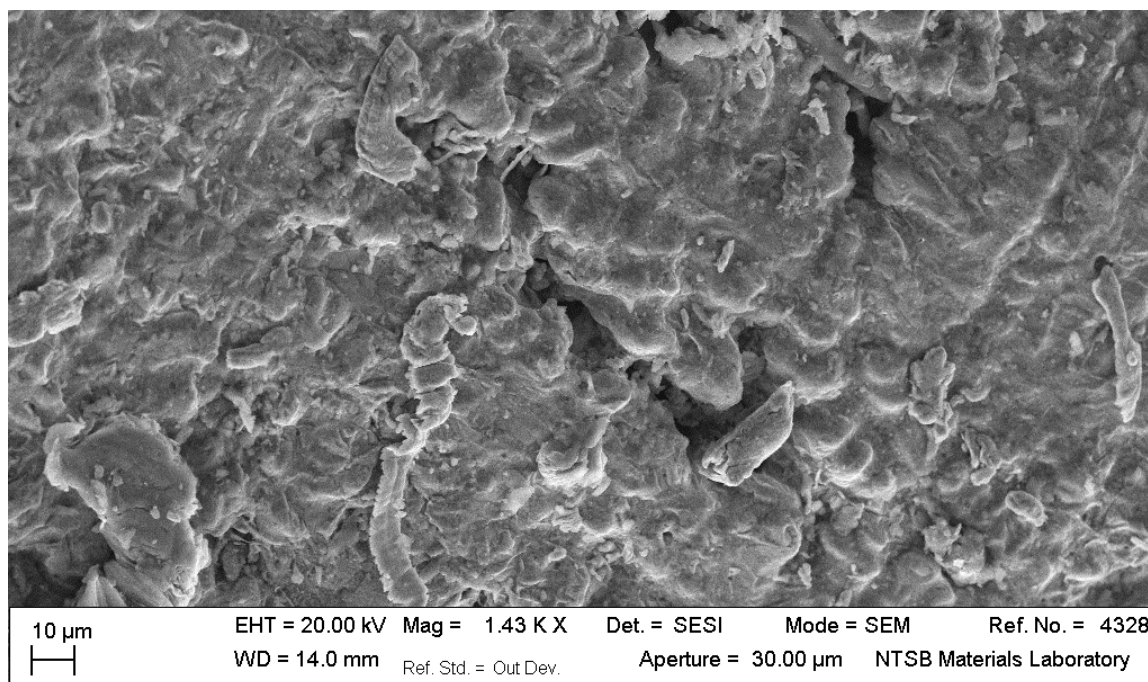


Figure 12 – SE micrograph showing the dendritic structure of a solidified filler metal, with surface wrinkling and oxidation.

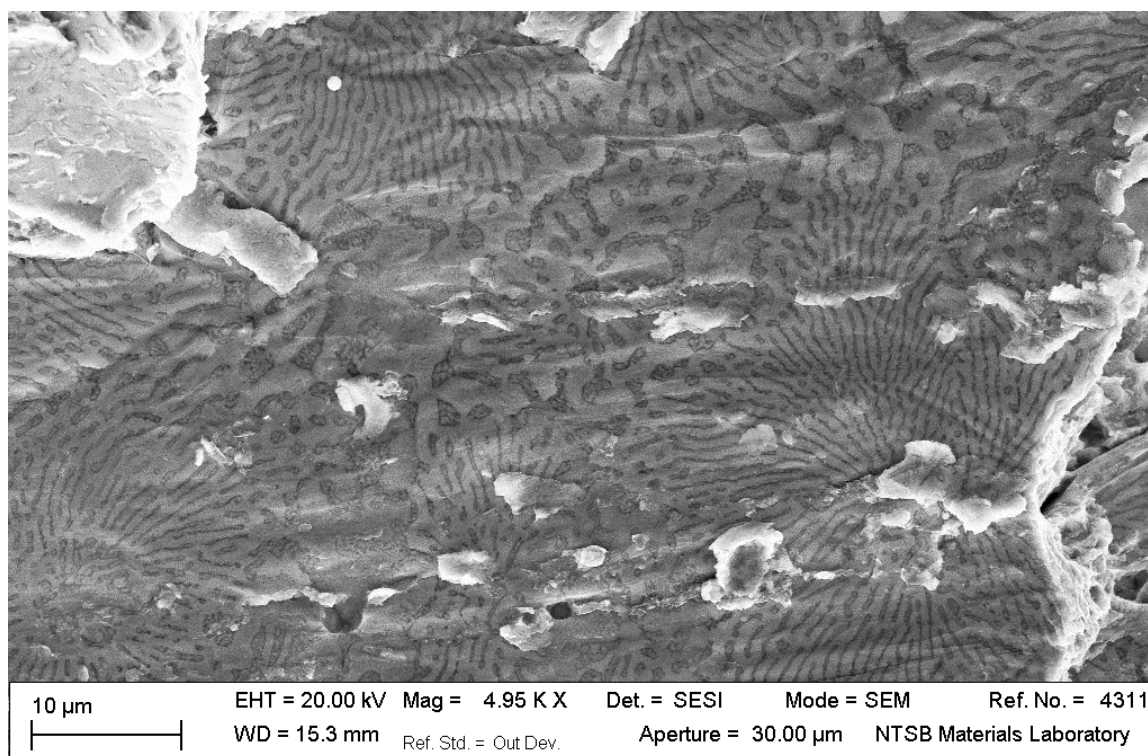


Figure 13 – SE micrograph of a closer view of the rounded fracture regions, showing eutectic lamellar features on the surface.

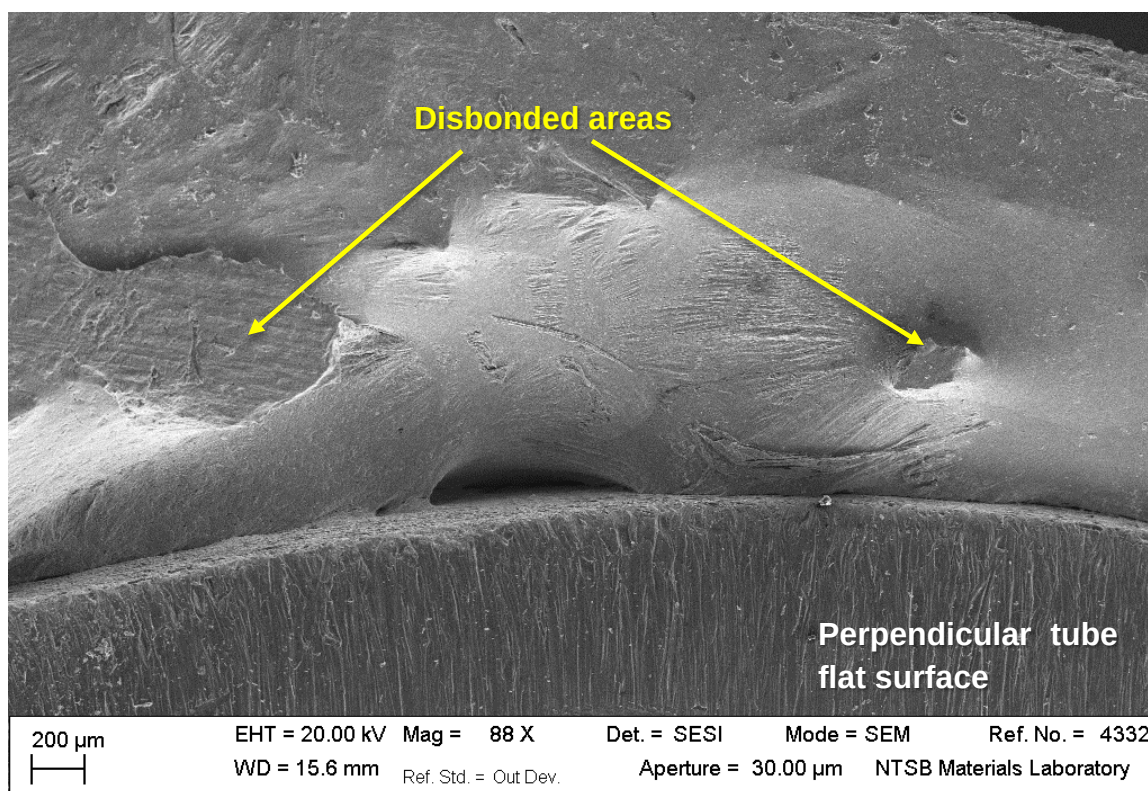


Figure 14 – SE micrograph of the fracture surface from Figure 9.

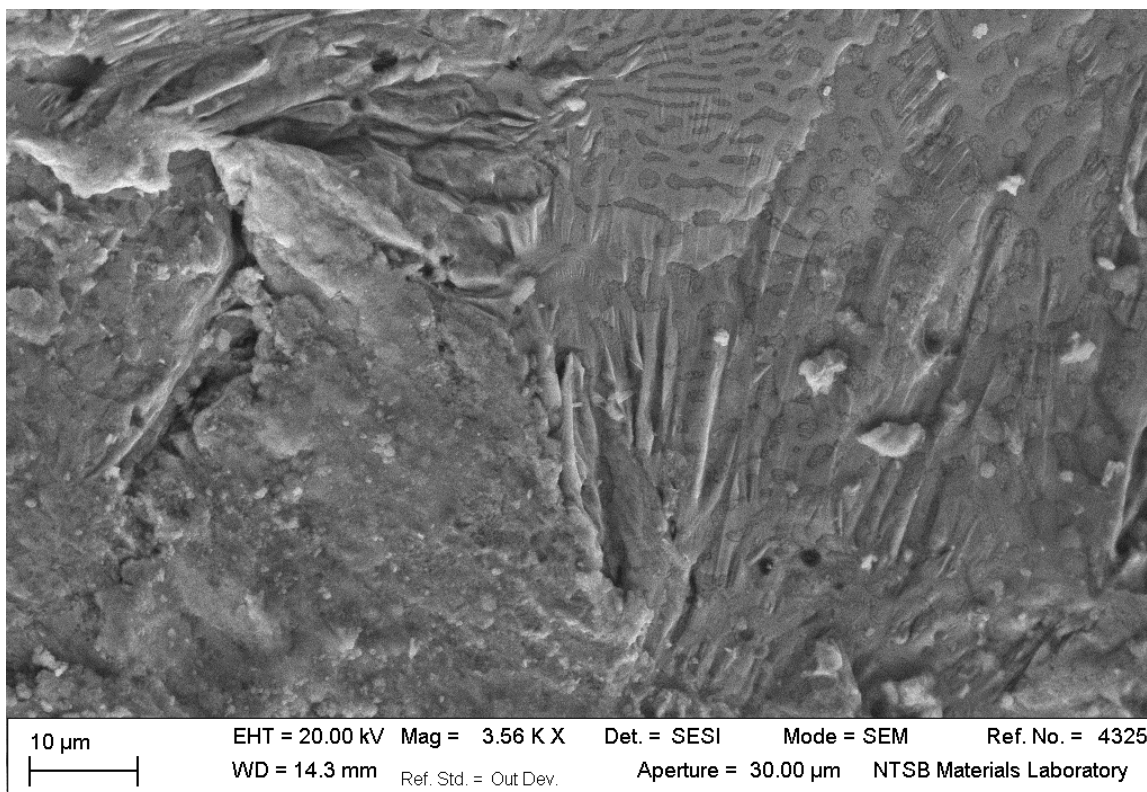


Figure 15 – SE micrograph showing a closer view of Figure 13, highlighting surface wrinkles consistent with solidification shrinkage.

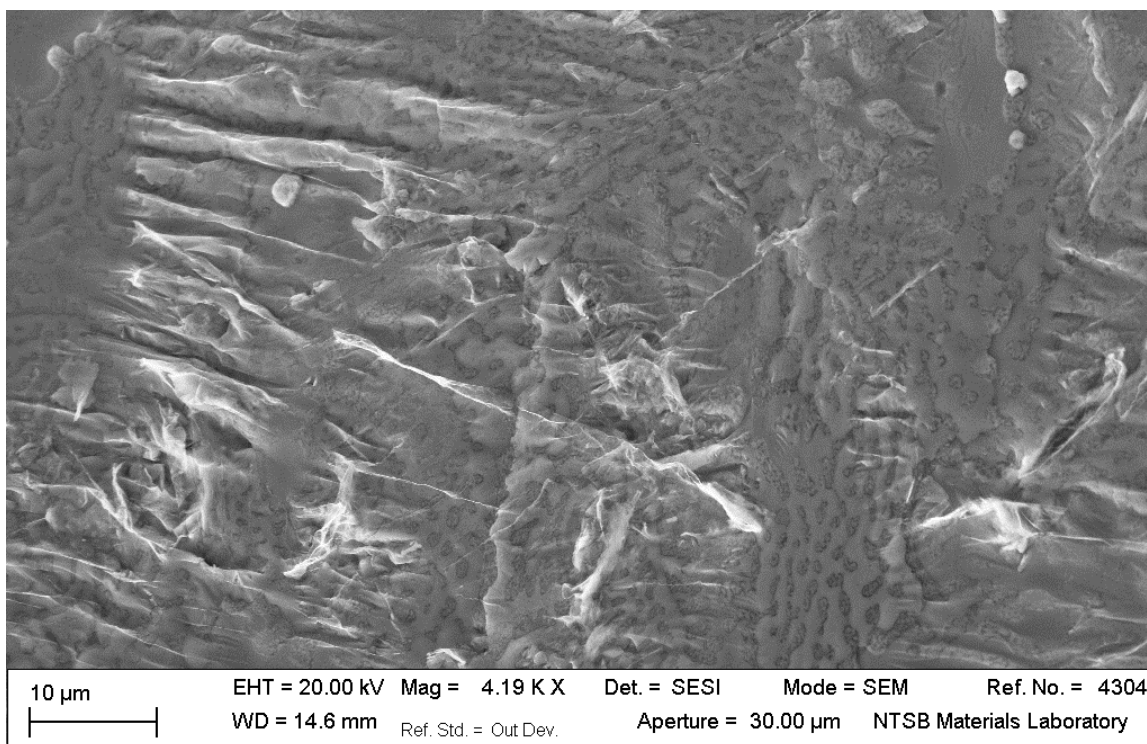


Figure 16 – SE micrograph showing a closer view of Figure 13, highlighting surface wrinkles consistent with solidification shrinkage.

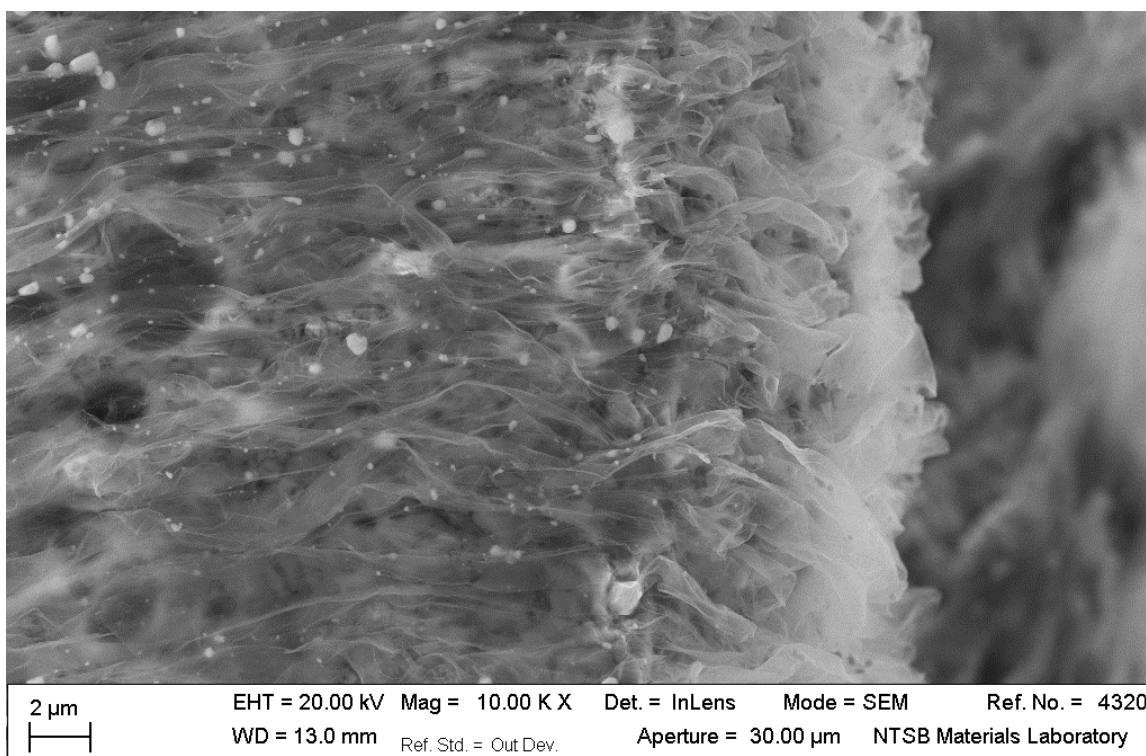


Figure 17 – SE micrograph of another area on the fracture surface, showing a wrinkled oxidation layer.

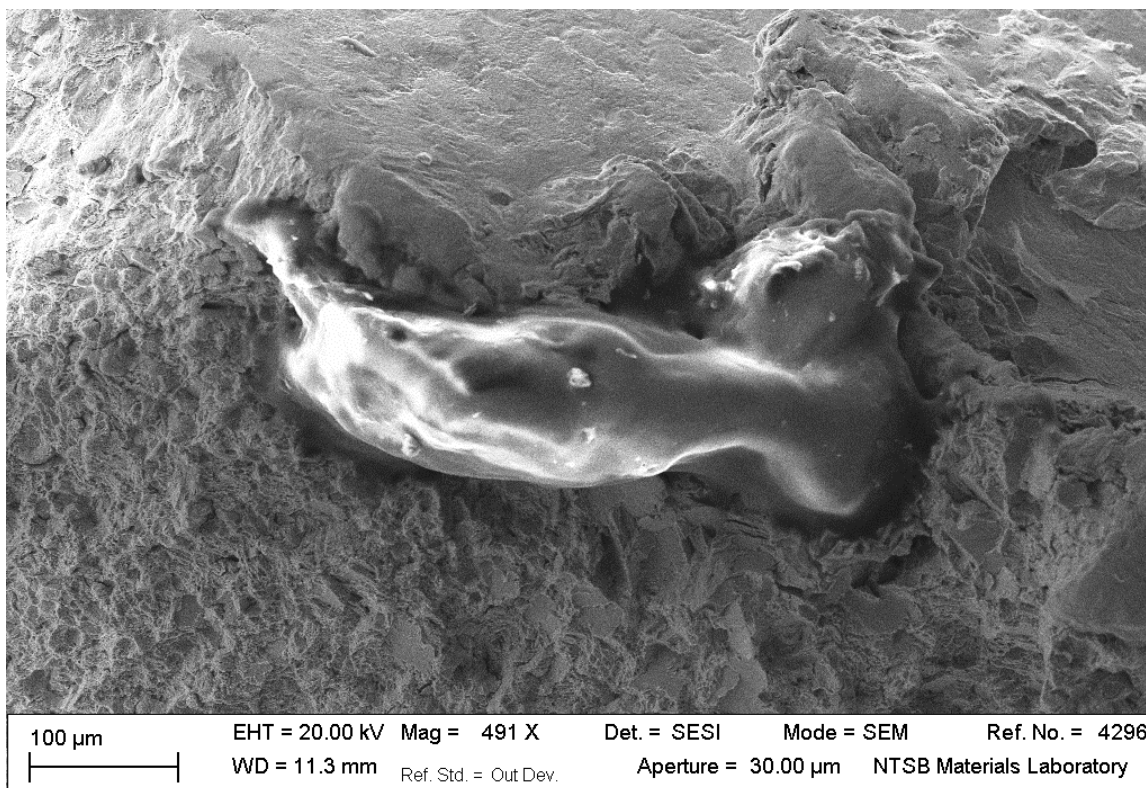


Figure 18 – SE micrograph showing an embedded contamination particle on the filler metal material.

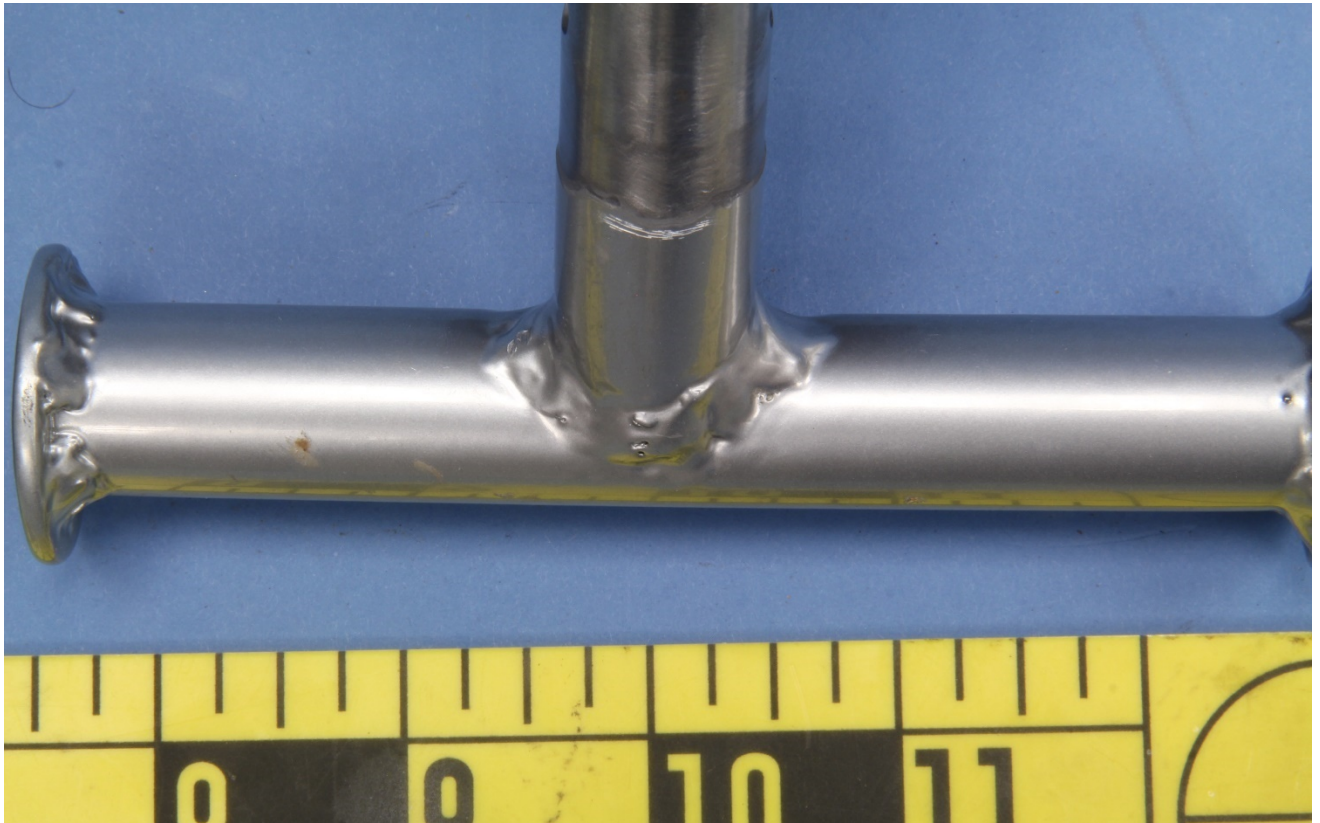


Figure 19 – The intact torque tube, highlighting the joint of the two tubes.

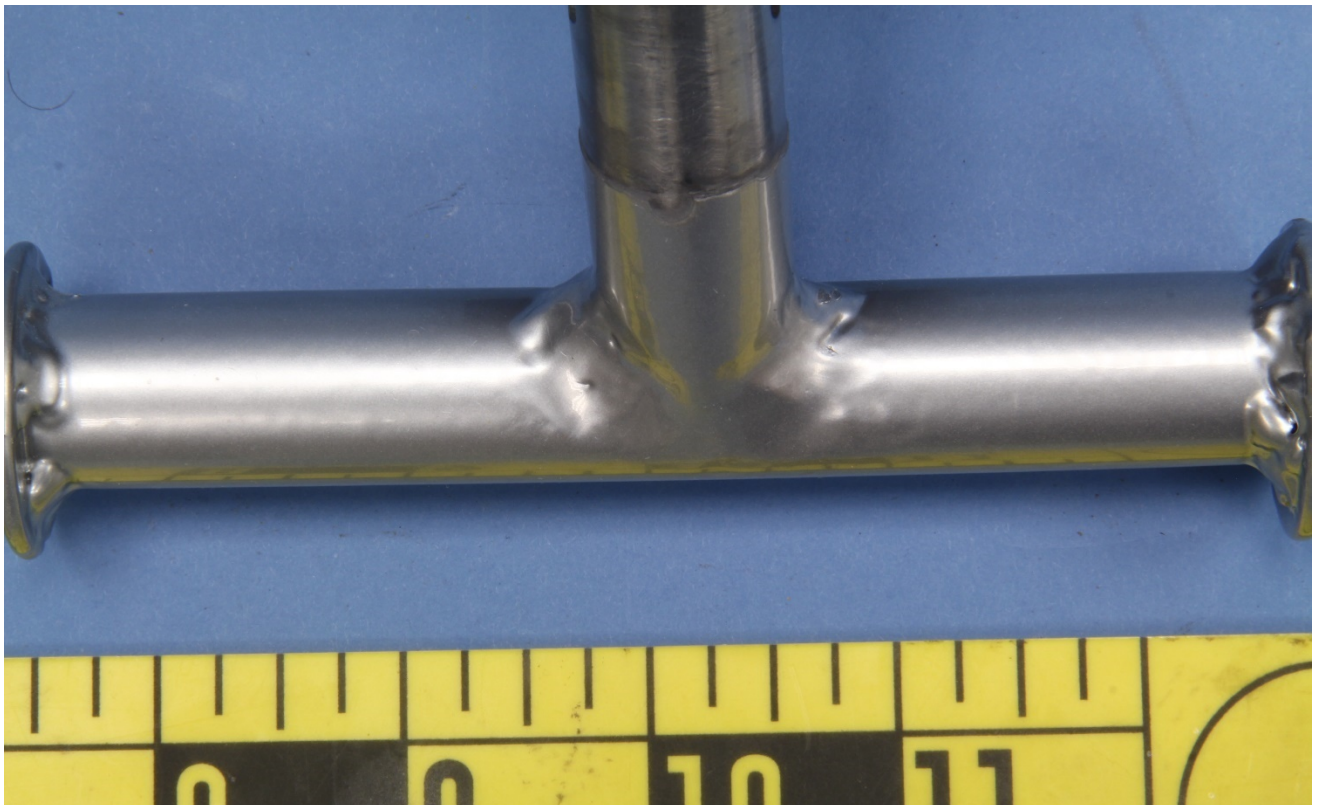


Figure 20 – View of the tube joint from the side opposite Figure 19.



Figure 21 – Closer view of the intact anti-torque tube showing surface porosity.



Figure 22 – Closer view of a surface crack on the intact tube joint.

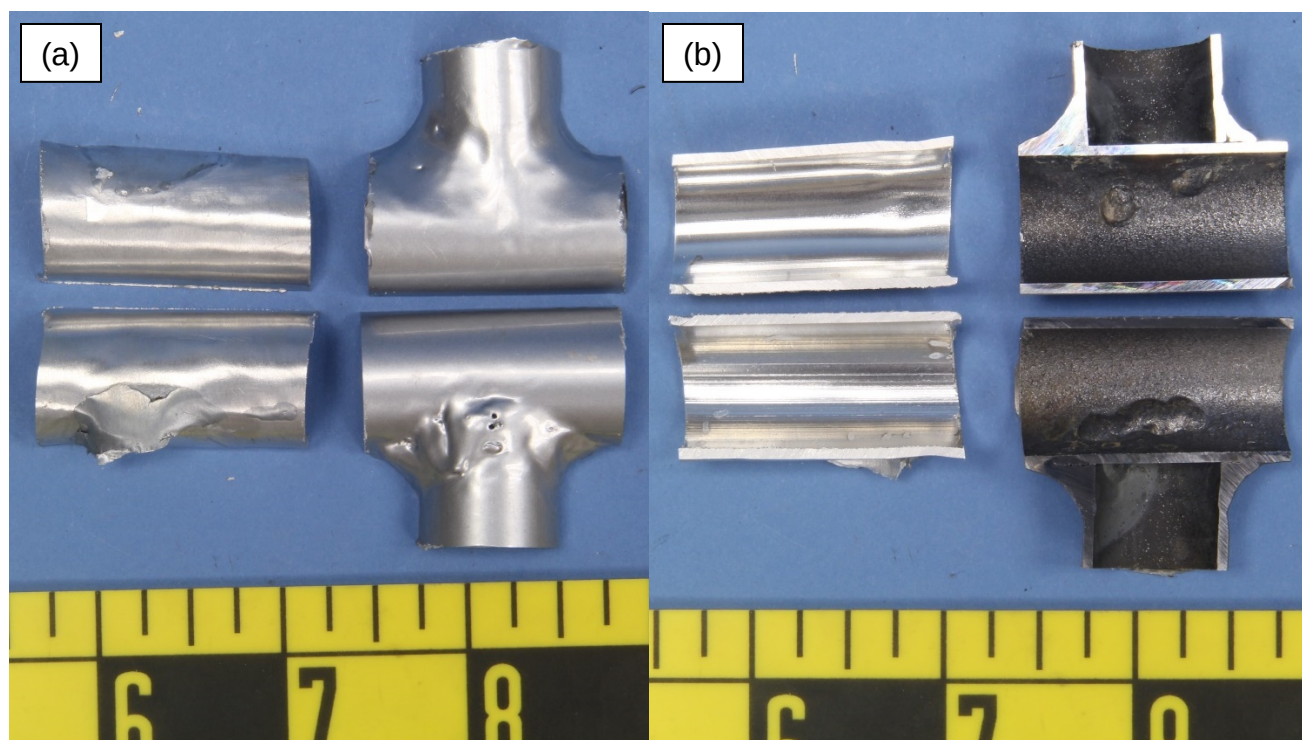


Figure 23 – Cross sections of the anti-torque tubes from the (a) exterior surfaces and (b) the interior surfaces. The aluminum, fractured tube is positioned on the left and the intact tube was on the right.



Figure 24 – Bright-field optical micrograph montage of the cross section of the parallel aluminum tube through the fractured joint. Those divots where the filler metal had disbonded from the joint are annotated (~25X, as polished).

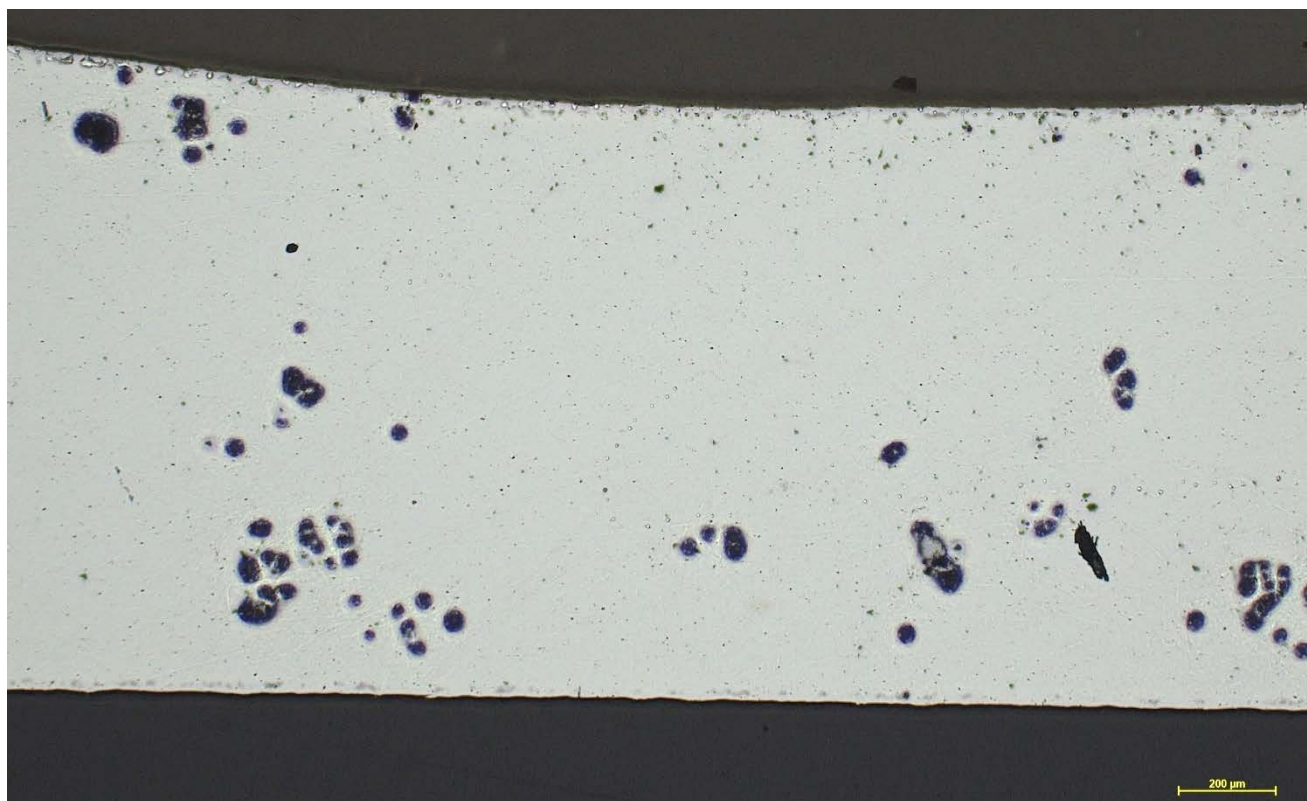


Figure 25 – BF optical micrograph at one of the aluminum tube fracture sites, showing a lack of material at the divot and internal porosity (~50X, as polished).

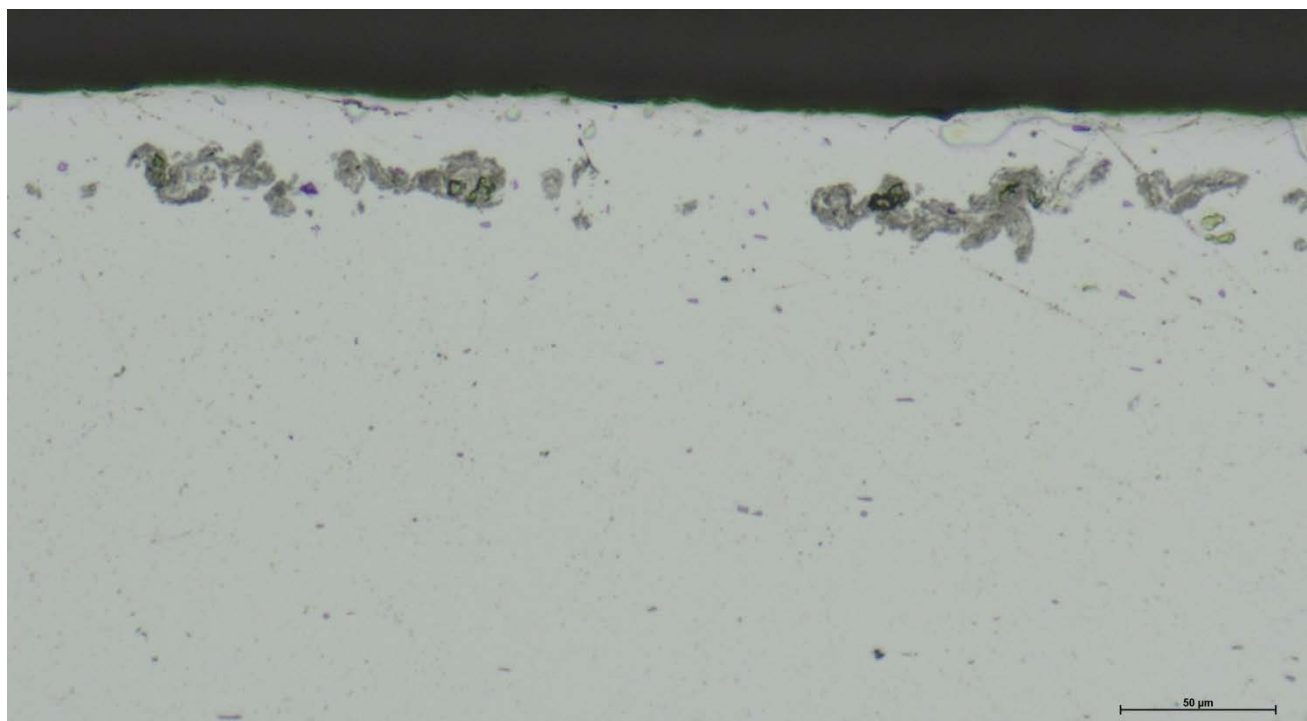


Figure 26 – BF optical micrograph of the aluminum tube divot (~200X, as polished).

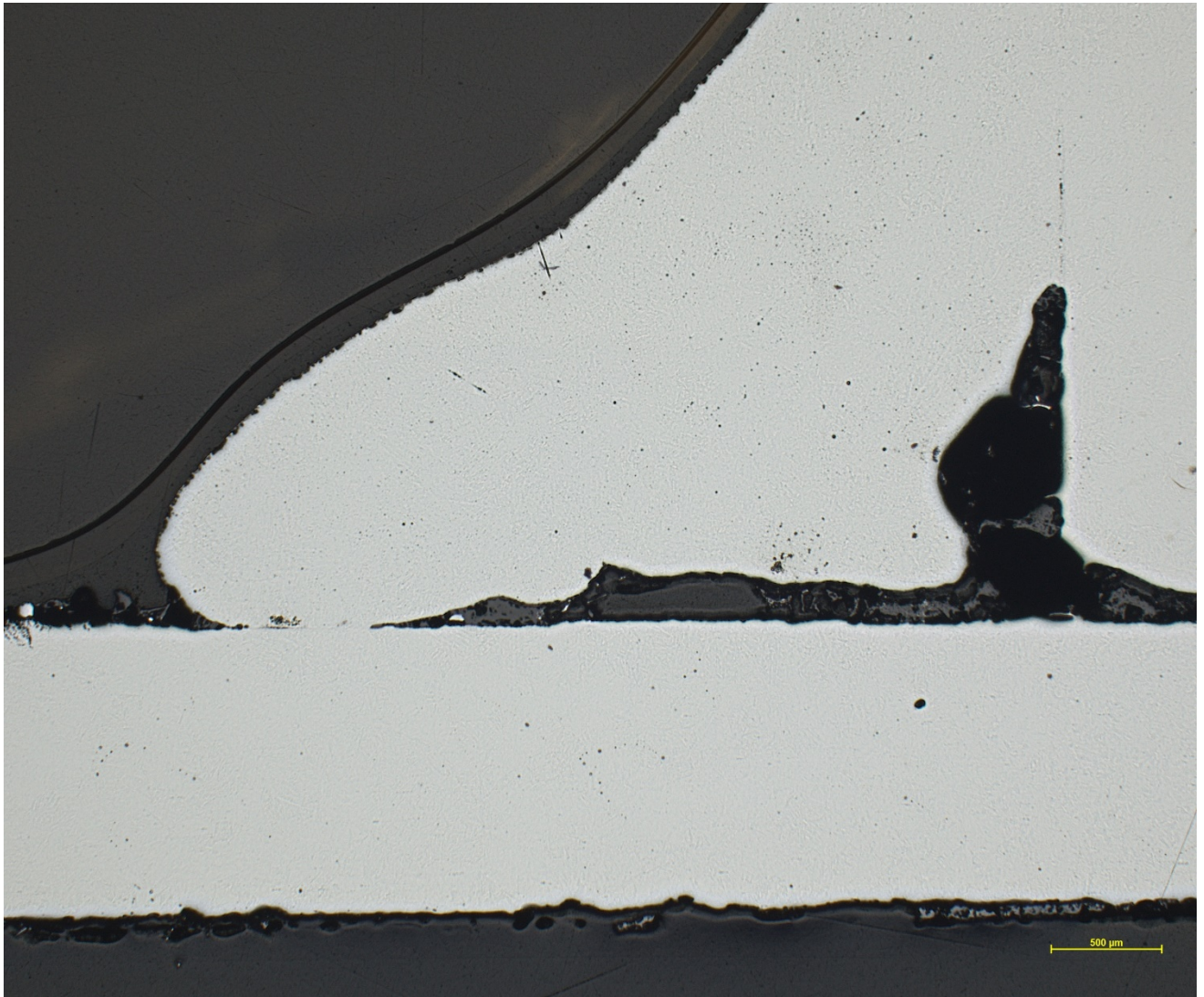


Figure 27 – BF micrograph of a cross section of the steel tube weld from the intact anti-torque tube assembly (~25X, as polished).

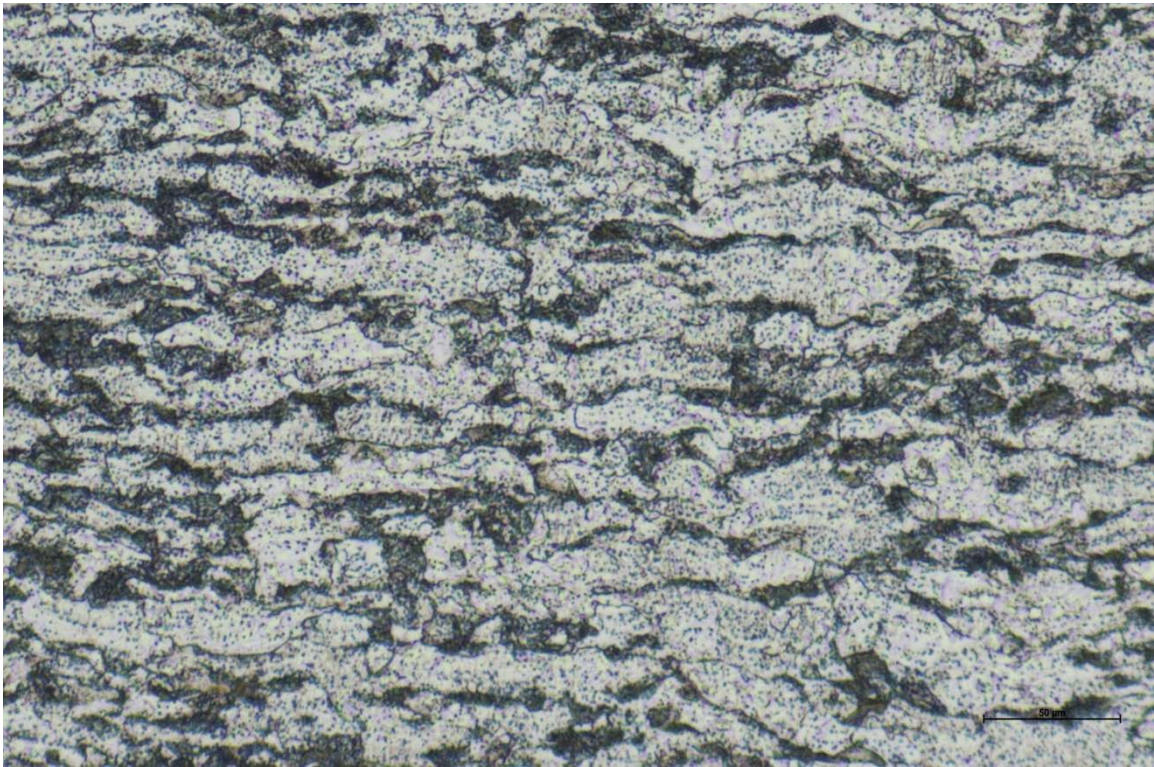


Figure 28 – BF micrograph of the parallel tube microstructure from the intact anti-torque tube assembly (~500X, etched 2% Nital).

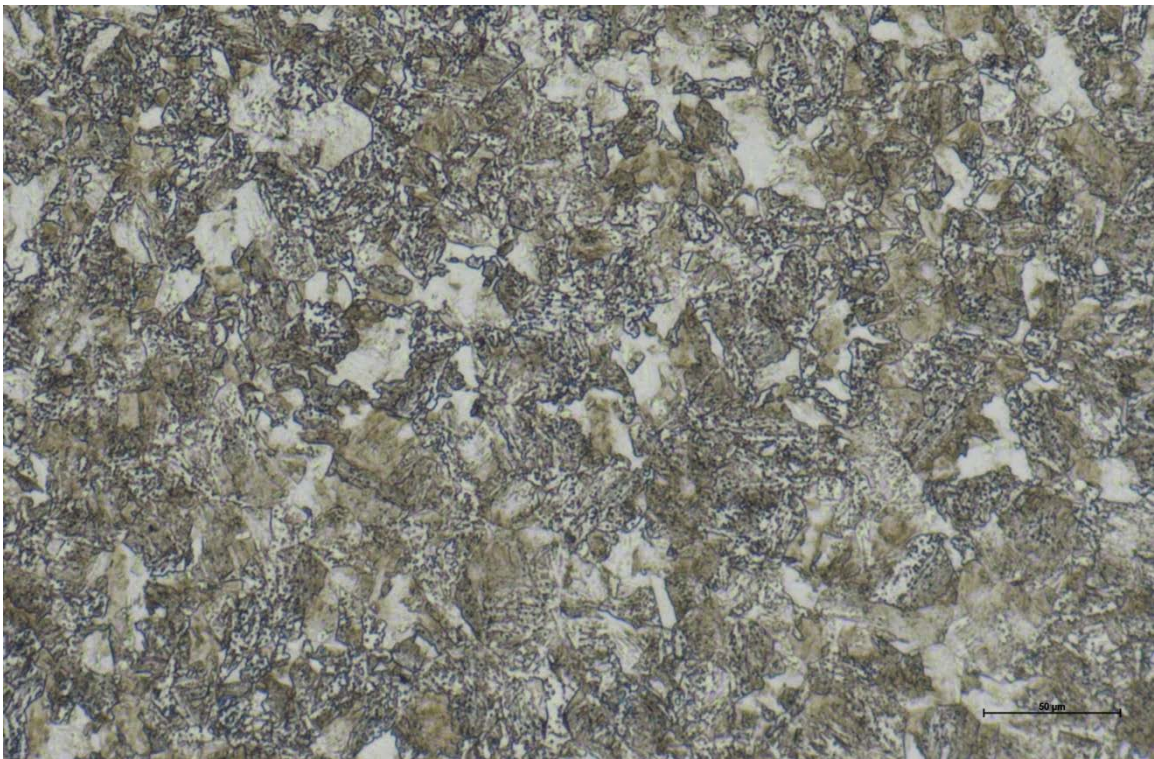


Figure 29 – BF micrograph of the perpendicular tube microstructure from the intact anti-torque tube assembly (~500X, etched 2% Nital).

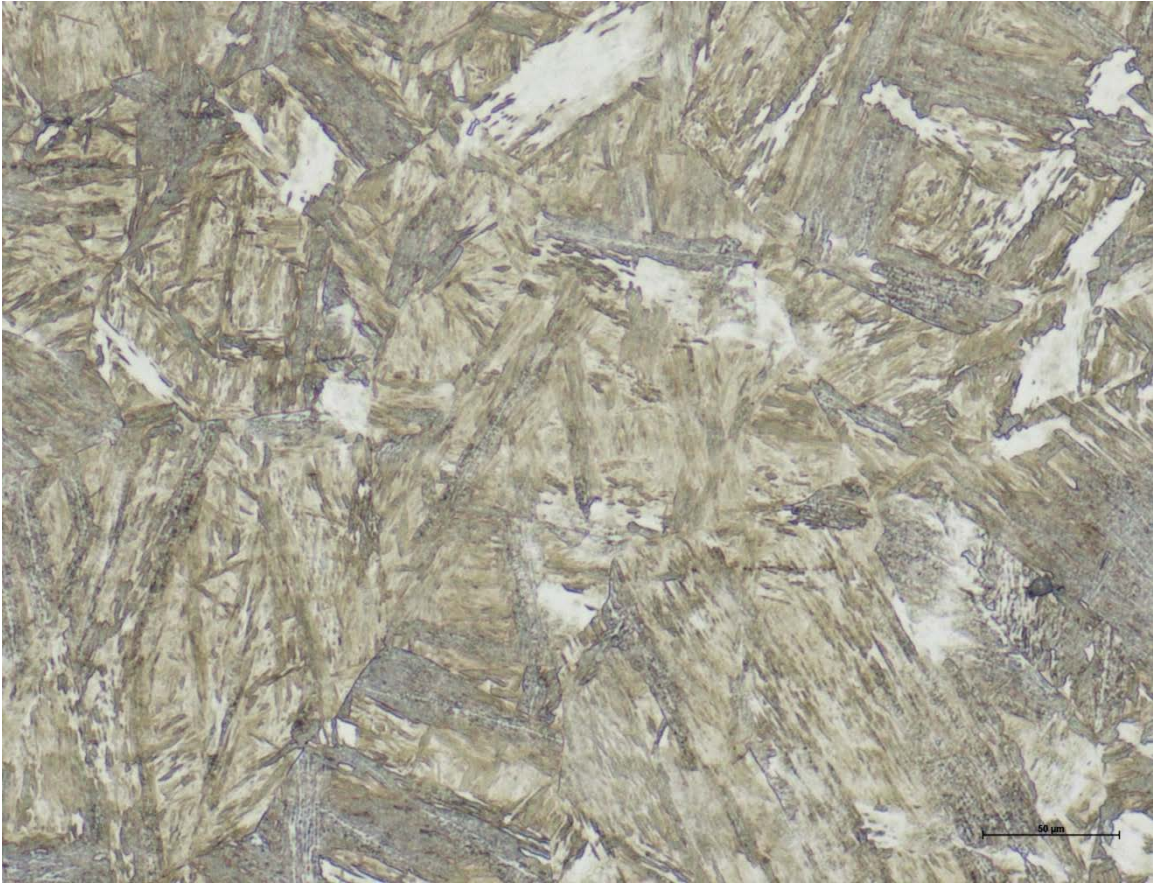


Figure 30 – BF micrograph of the weld filler metal microstructure from the intact anti-torque tube assembly (~500X, etched 2% Nital).