

NATIONAL TRANSPORTATION SAFETY BOARD

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



February 12, 2018

MATERIALS LABORATORY FACTUAL REPORT

Report No. 16-023

A. ACCIDENT INFORMATION

Place : Hanalei, HI
Date : January 17, 2016
Vehicle : Airbus Helicopter EC130T2, N11VQ
NTSB No. : WPR16FA055
Investigator : Van McKenny, AS-WPR

B. COMPONENTS EXAMINED

Pieces of fractured fuel line from a Turbomeca Arriel 2D engine.

C. DETAILS OF THE EXAMINATION

The as-received fuel line pieces are shown in Figure 1 with manufacturer markings on the tubing and flange indicated. As identified in Figures 1 and 2, the tube fractured at the flared end. A closer view of the fracture surface on the tube portion is shown in Figure 3. Using a digital microscope, fractographic features such as ratchet marks and crack arrest marks were observed. Such marks are consistent with reverse bending fatigue fracture initiation on the outside surface of the tube in the regions identified in Figure 4. Oblique angle views of the crack initiation regions are shown in Figures 4b and 4c.

Figure 5 shows the locations of two diffuse-origin fatigue cracks that initiated on the outside surface of the tube about 180 degrees from each other. These cracks propagated through the thickness of the tube wall and circumferentially around the tube. Regions of final overstress fracture are identified in Figure 5.

The fracture surface on the separated flare portion (see Figure 1) was examined using a Zeiss Auriga field emission scanning electron microscope (SEM). The sample was cleaned in acetone with ultrasonics prior to SEM analysis. An overall view of the fracture surface is shown in Figure 6 with the fatigue crack initiation regions indicated. Figure 7 is a duplication of Figure 6 with reference lines for the fatigue crack termini and regions of overstress fracture. Higher magnification oblique SEM images of the fatigue crack initiation regions are shown in Figures 8-11.

Six regions on the fracture surface, arbitrarily labelled A through F, were surveyed with the SEM as shown in Figure 12. Very fine striation features were observed in these six regions as documented in Figures 13 through 18. The variation in

the striation spacing is consistent with fatigue crack propagation under spectrum loading conditions.

Longitudinal and transverse cross sections of the tube were taken adjacent to the fractured region for microstructural analysis. Samples were prepared in accordance with ASTM E3 and were microetched for microstructural evaluation in accordance with ASTM E407 etchant 221 (Ralph's etch). Optical micrographs are shown in Figures 19 through 21. The general microstructure is comprised of austenite grains exhibiting fine twinning. In Figure 20a, the exterior surface exhibits a shallow cold worked layer. The inside surface exhibits occasional fine laps or seams. Infrequent oriented colonies of oxide and nitride particles were observed as noted in Figure 21. In accordance with ASTM E384 the average microhardness of the tube was determined to be 539 HV500.

Near the fractured end of the fuel line, the surface roughness in the longitudinal direction on the outside of the tube was measured with a Nanovea ST400 non-contact profilometer using a CL1 chromatic lens. The surface metrology results are documented in Figure 22 and include an example trace of the surface profile.

The internal and external surfaces of the flare were examined by SEM as shown in Figures 23 through 25. Longitudinal cracks propagating partially through the wall thickness of the flare were observed as identified in the figures. The presence and morphology of the cracks are consistent with their formation due to the tangential stretching (i.e. hoop stretching) of the tubing during the flaring process.

Michael Budinski
Chief, Materials Laboratory Division

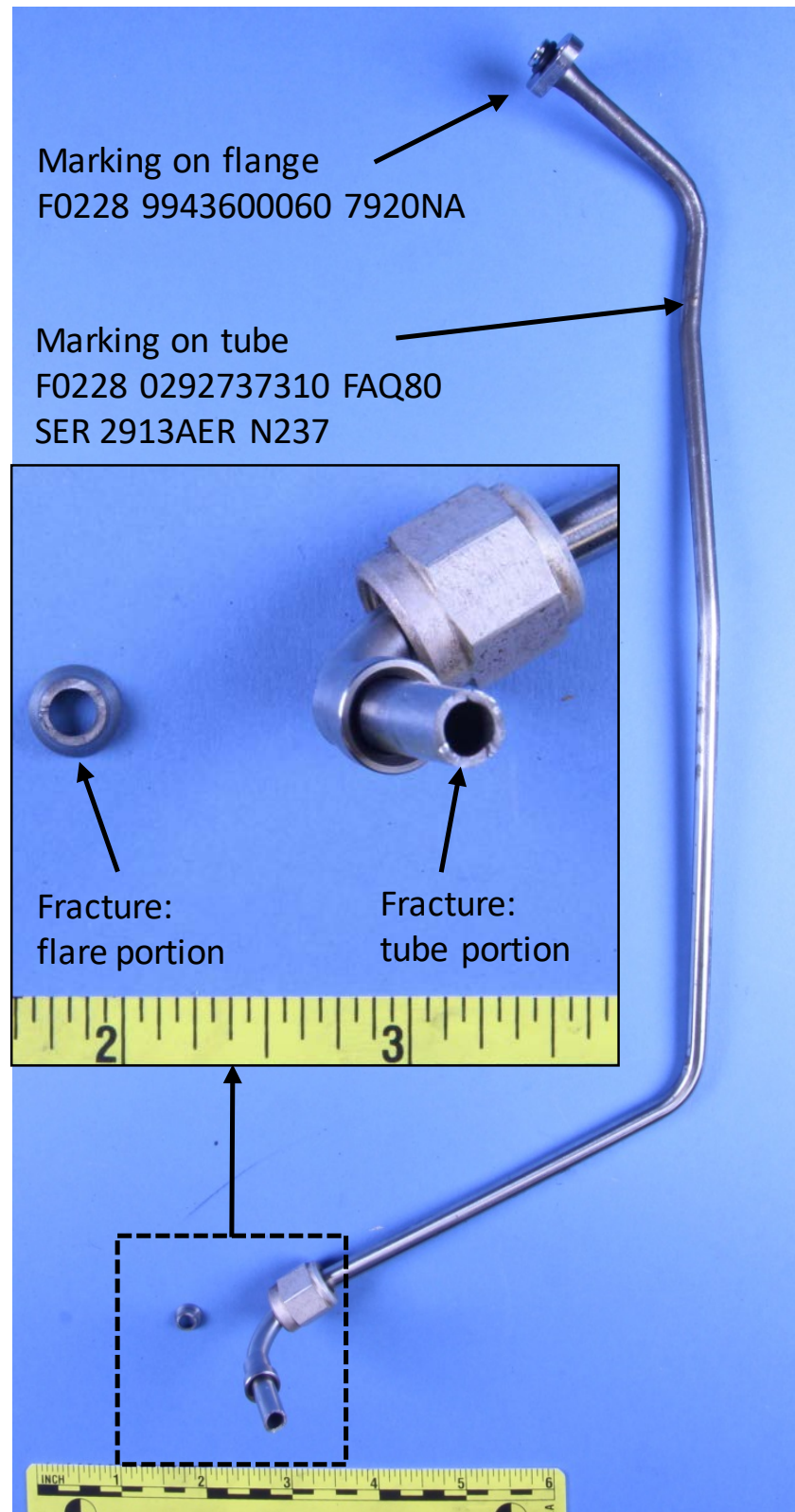


Figure 1 Images of the as-received fuel line pieces.

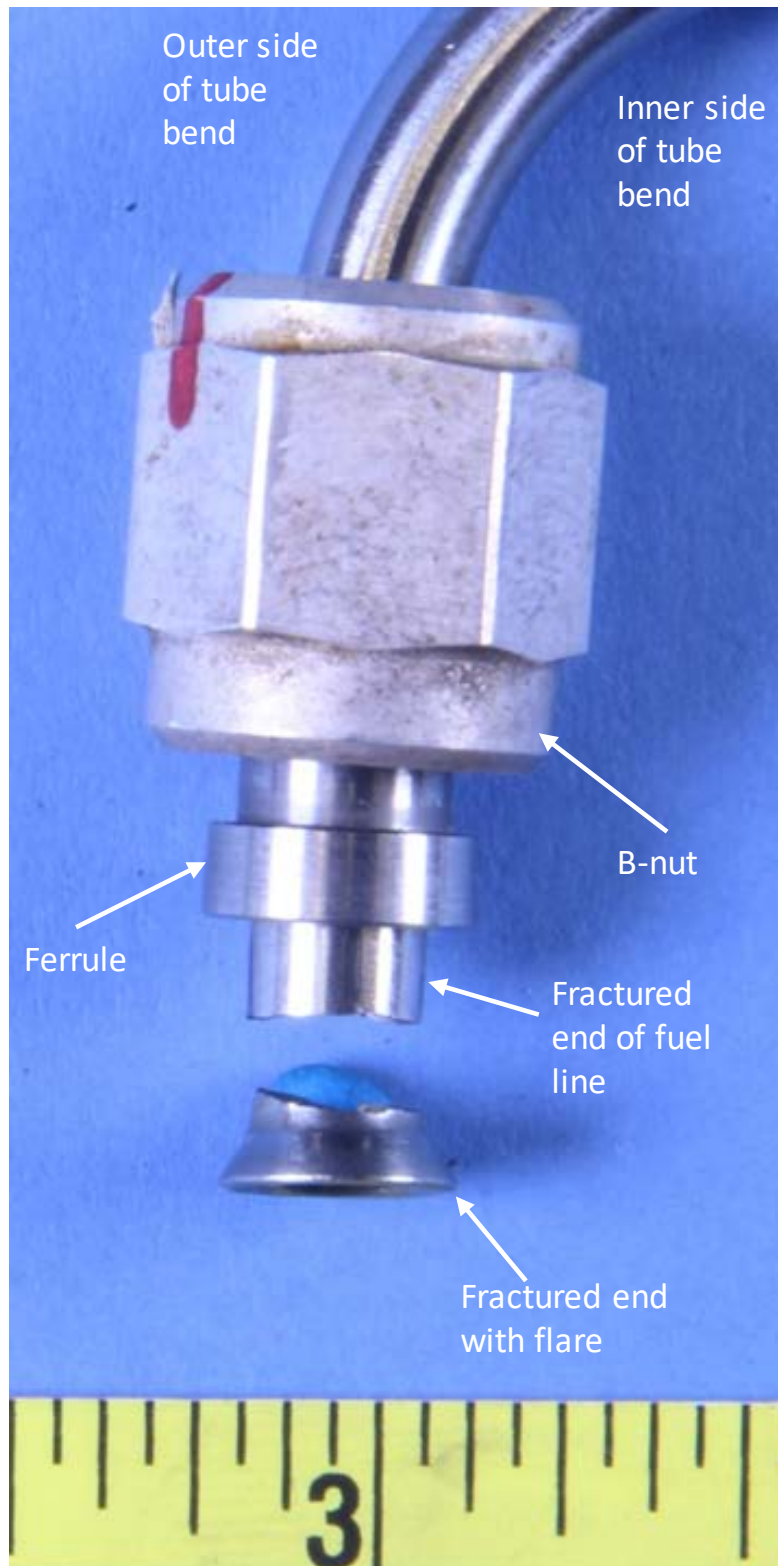


Figure 2 Image showing a close view of the b-nut ferrule assembly at the fractured flare end of the fuel line.



Figure 3 Close view of the fractured end of the fuel line tube with the fracture initiation regions identified.

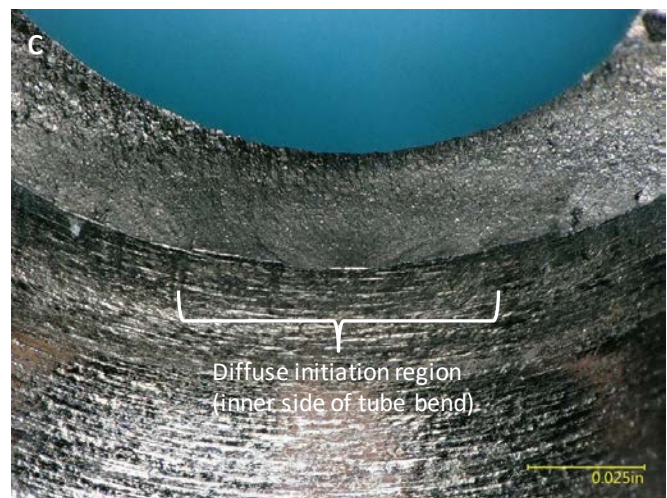
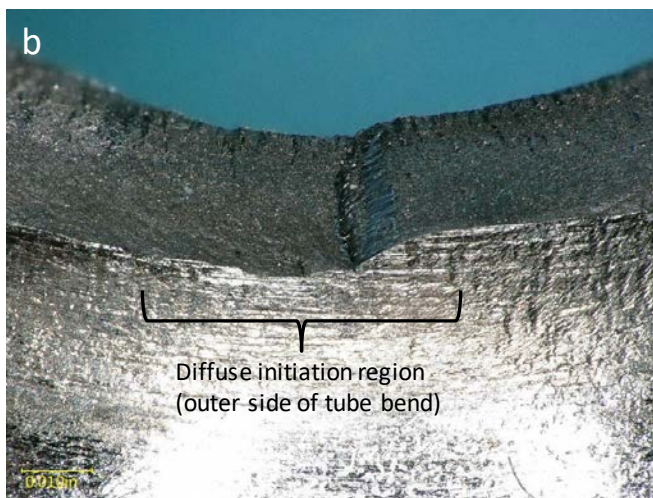
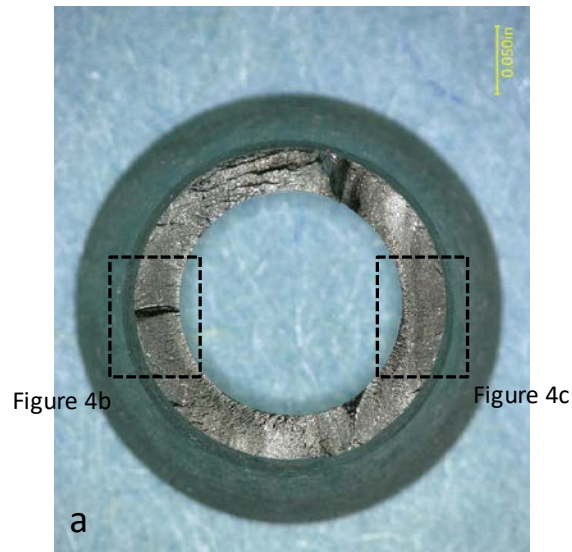


Figure 4 Digital microscope images of the fractured flare portion of the fuel line. View a is an overall view of the fracture surface. View b is a closer image of the initiation region at the outer side of the tube bend. View c is a closer image of the initiation region at the inner side of the tube bend.

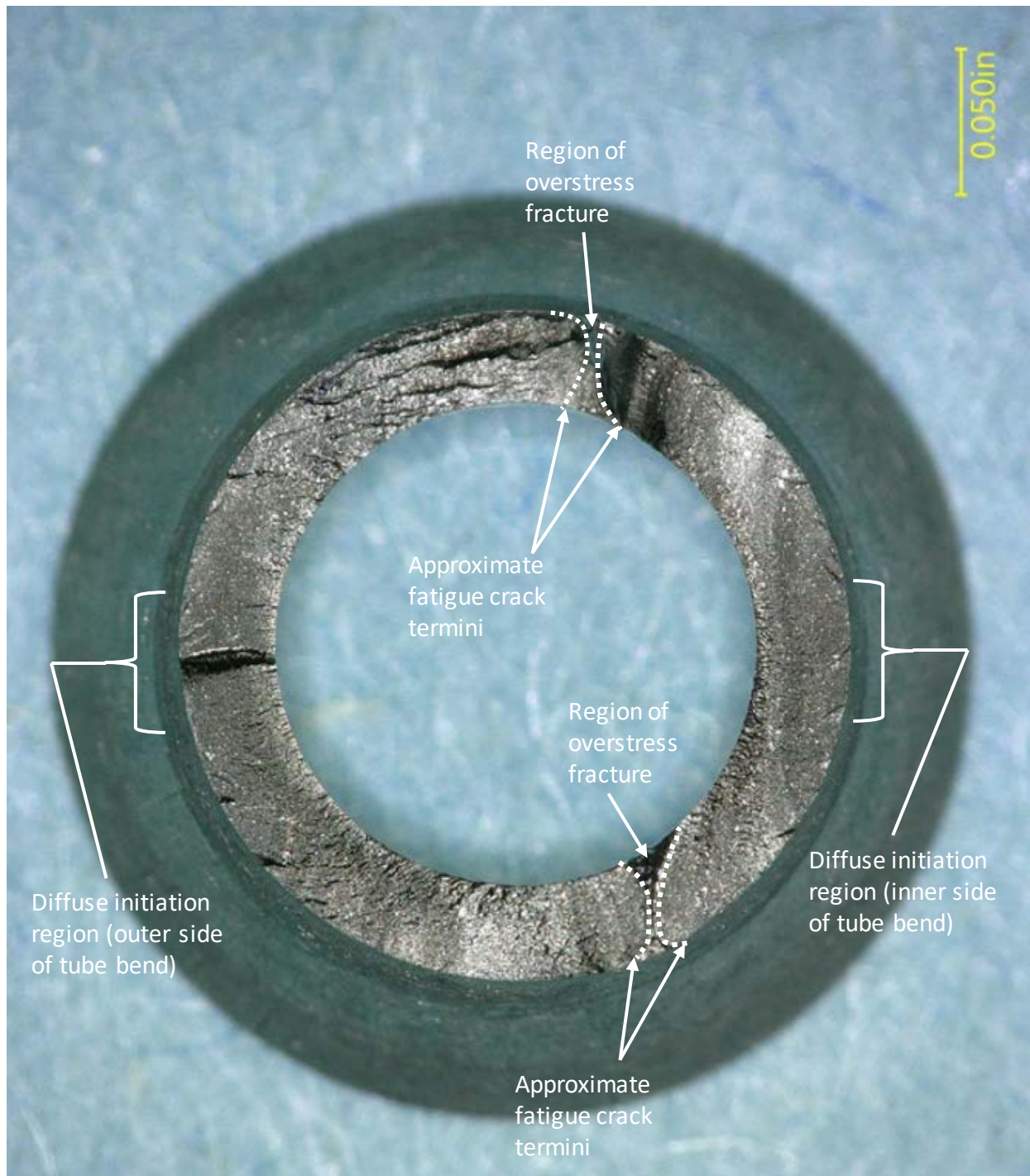


Figure 5 Digital microscope image of the fractured flare portion of the fuel line with annotations to identify the fatigue crack initiation regions and the regions of final overstress fracture.

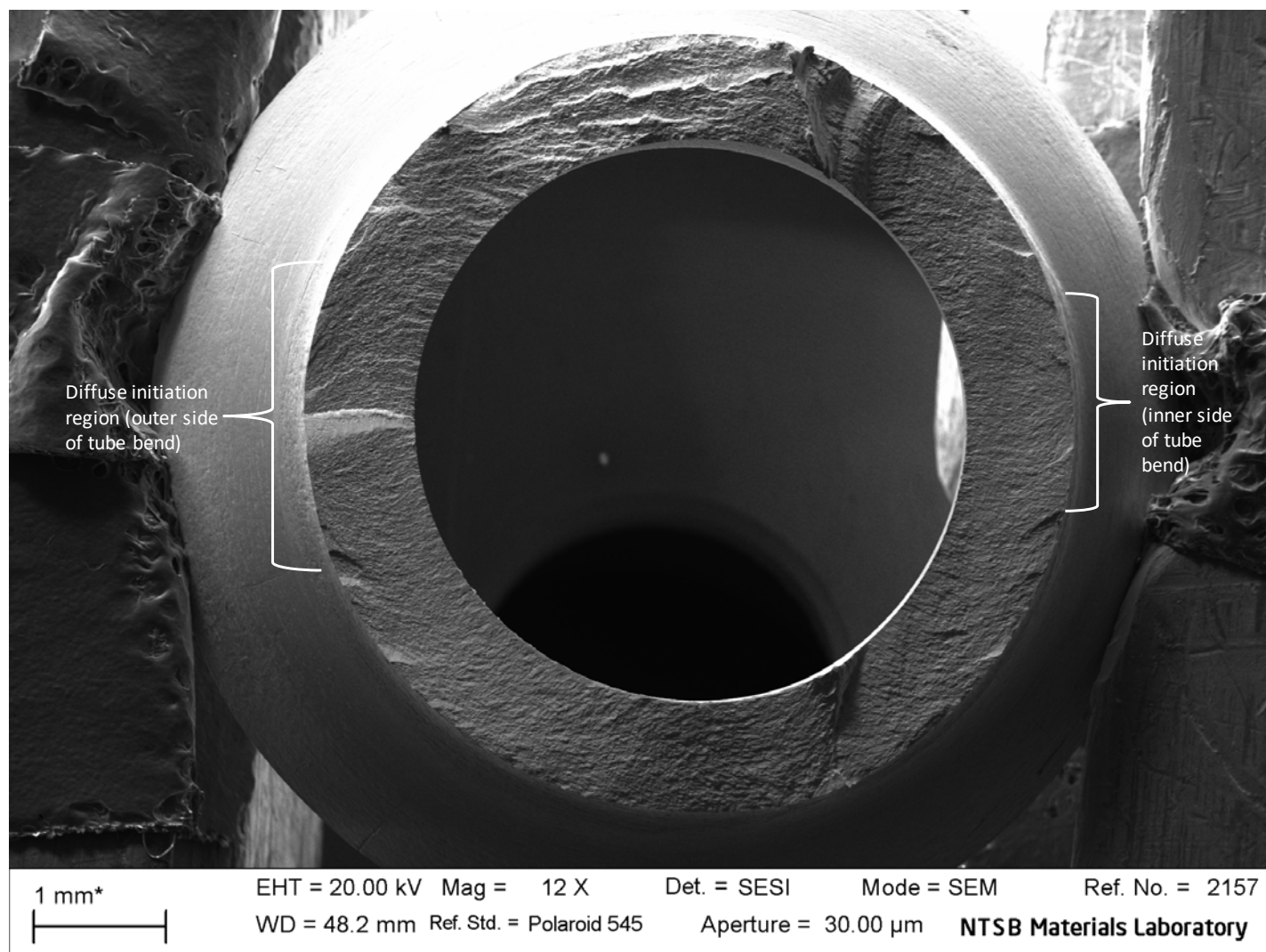


Figure 6 Scanning electron micrograph of the fractured flare portion of the fuel line with annotations to identify the fatigue crack initiation regions.

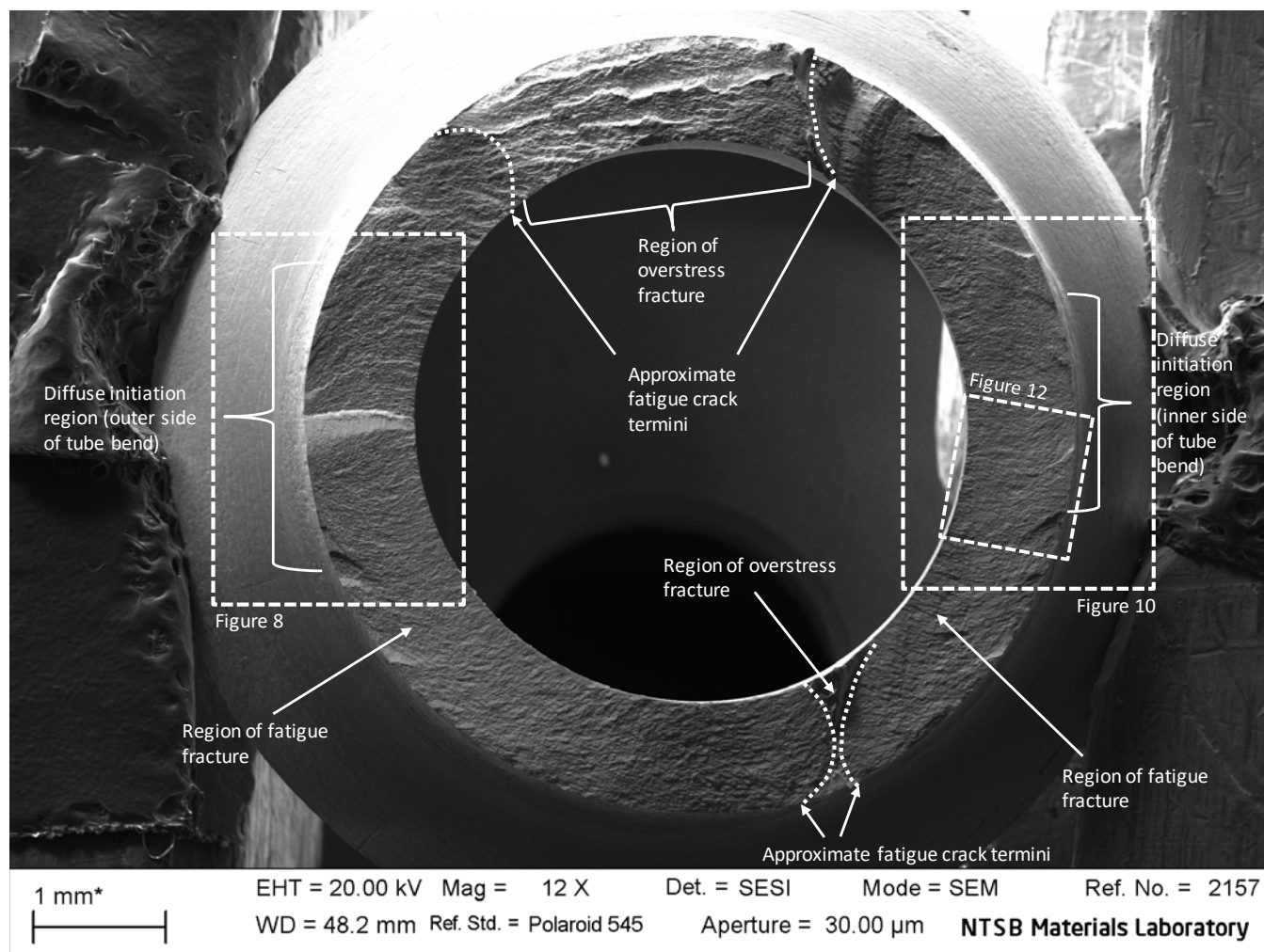


Figure 7 Scanning electron micrograph of the fractured flare portion of the fuel line with annotations to identify the fatigue crack initiation regions and the regions of final overstress fracture.

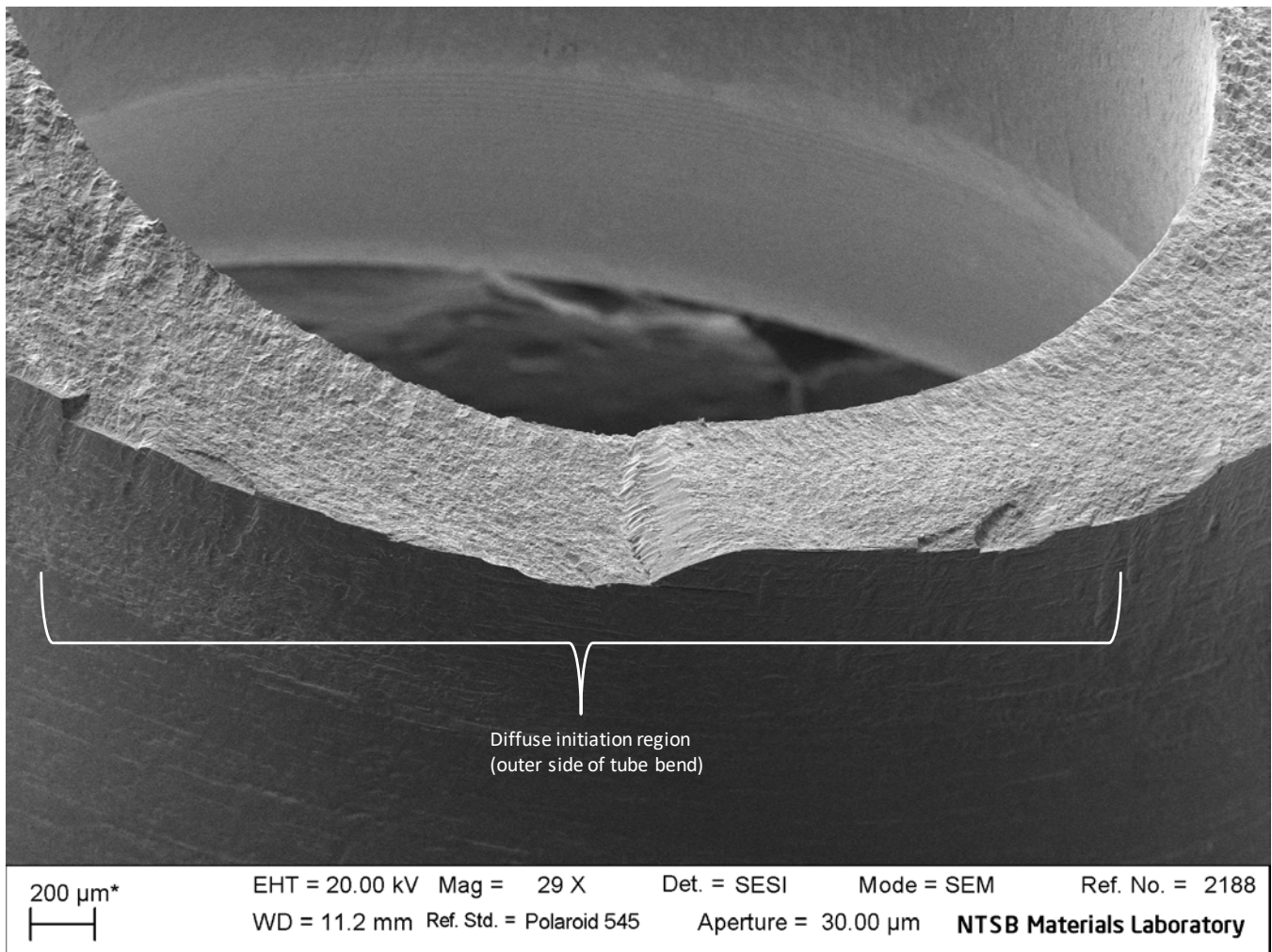


Figure 8 Close oblique scanning electron micrograph of the initiation region at the outer side of the tube bend.

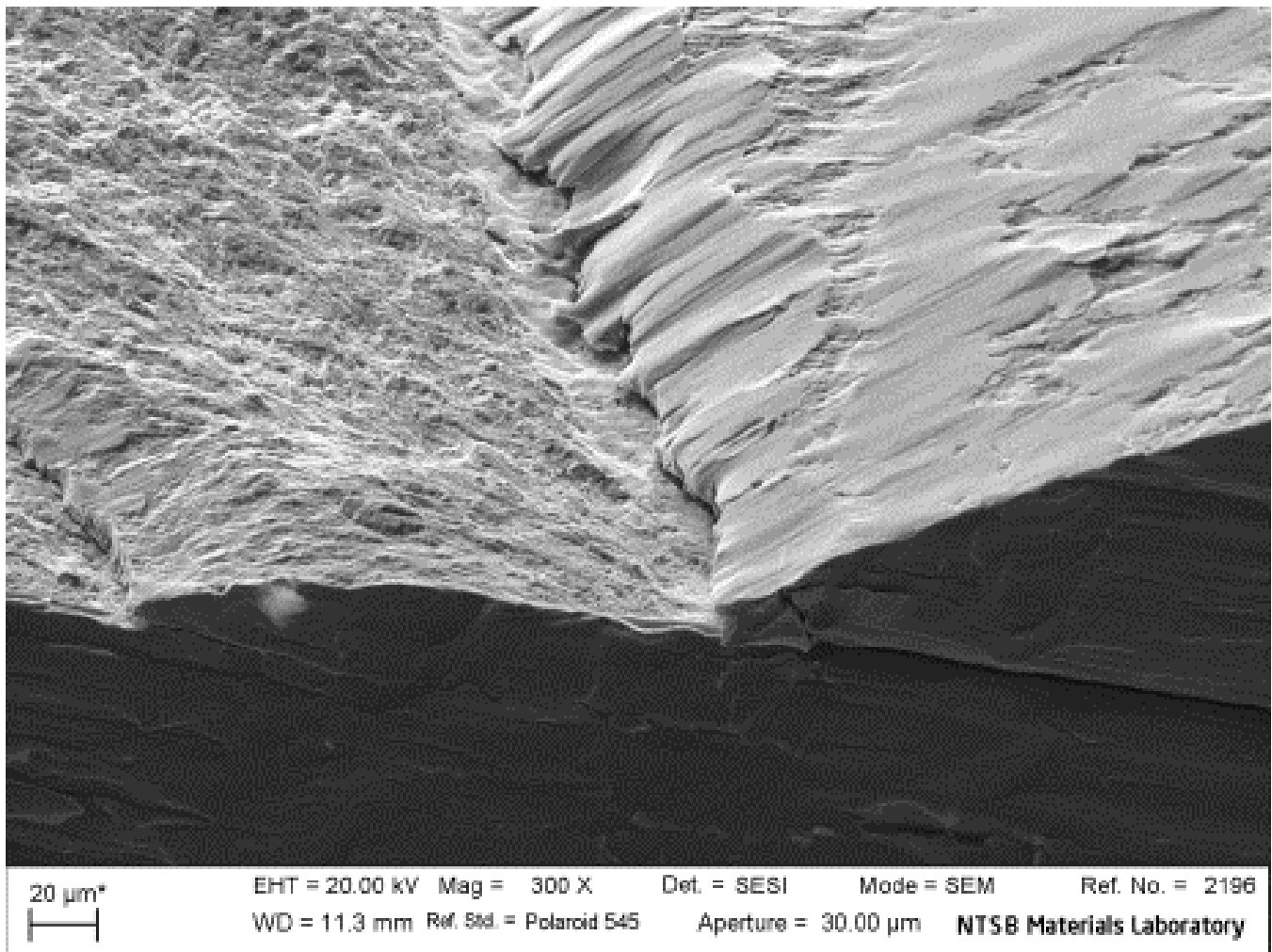


Figure 9 Closer oblique scanning electron micrograph of the initiation region at the outer side of the tube bend shown in Figure 8.

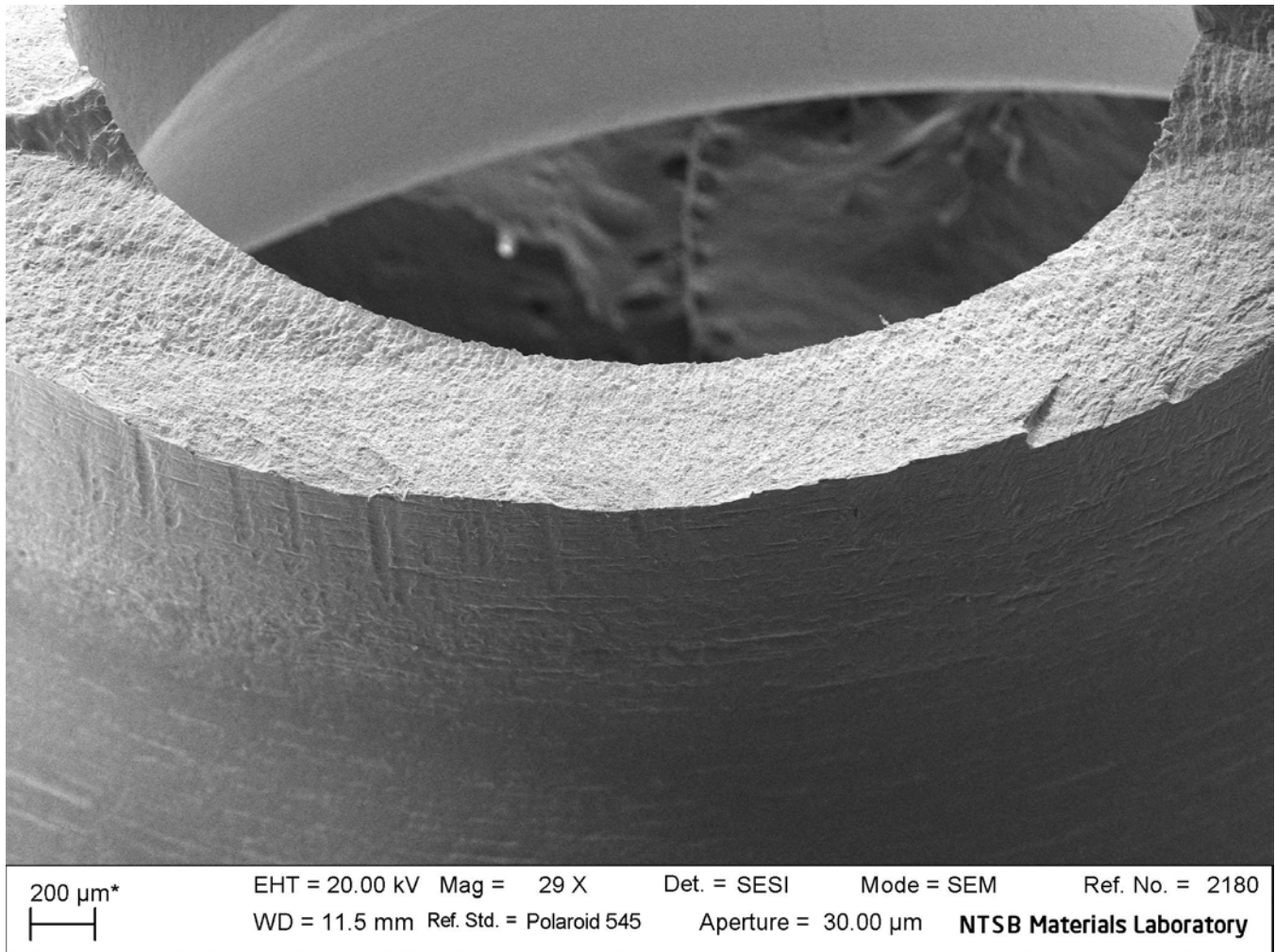


Figure 10 Close oblique scanning electron micrograph of the initiation region at the inner side of the tube bend.

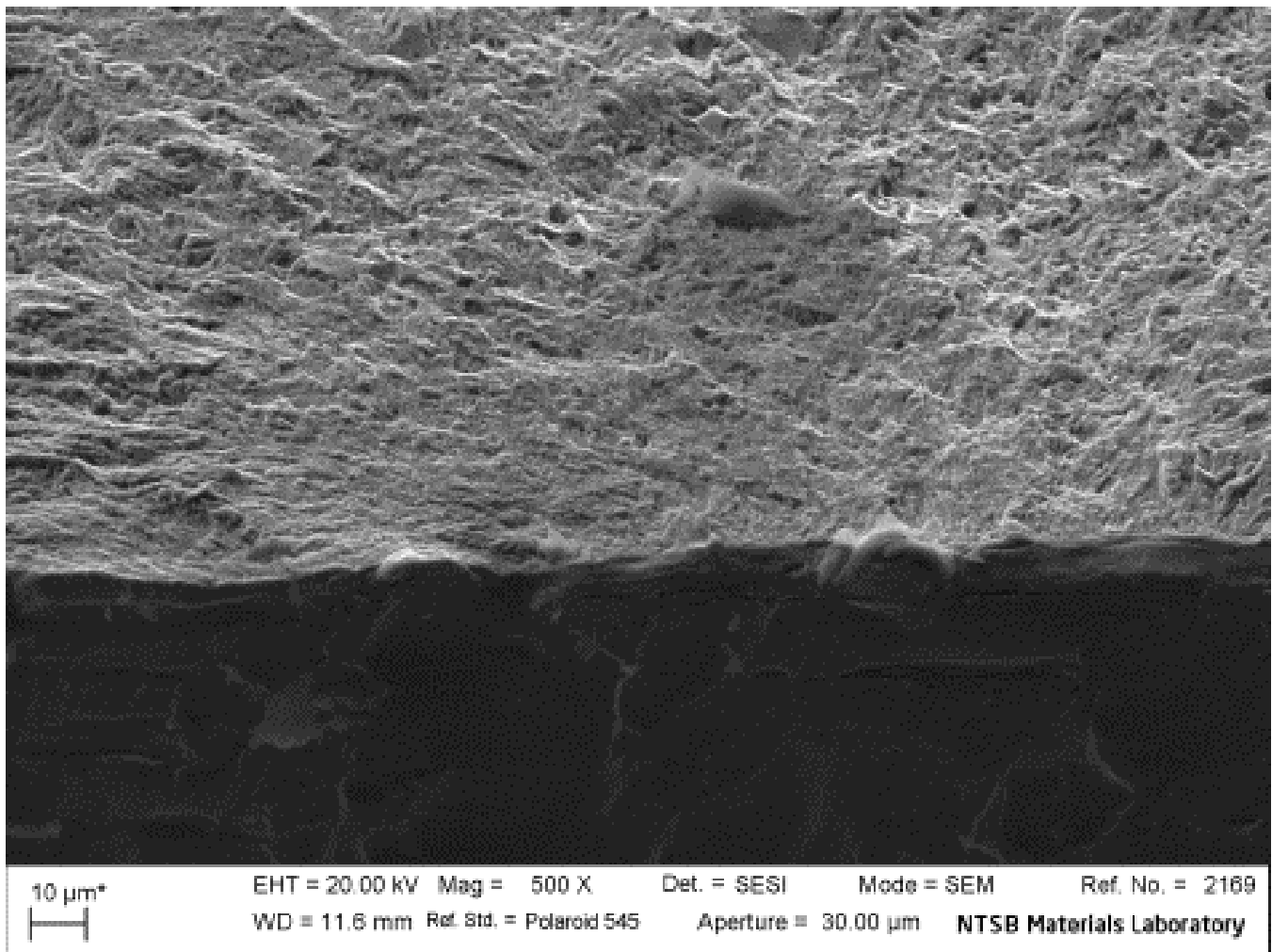


Figure 11 Closer oblique scanning electron micrograph of the initiation region at the inner side of the tube bend shown in Figure 10.

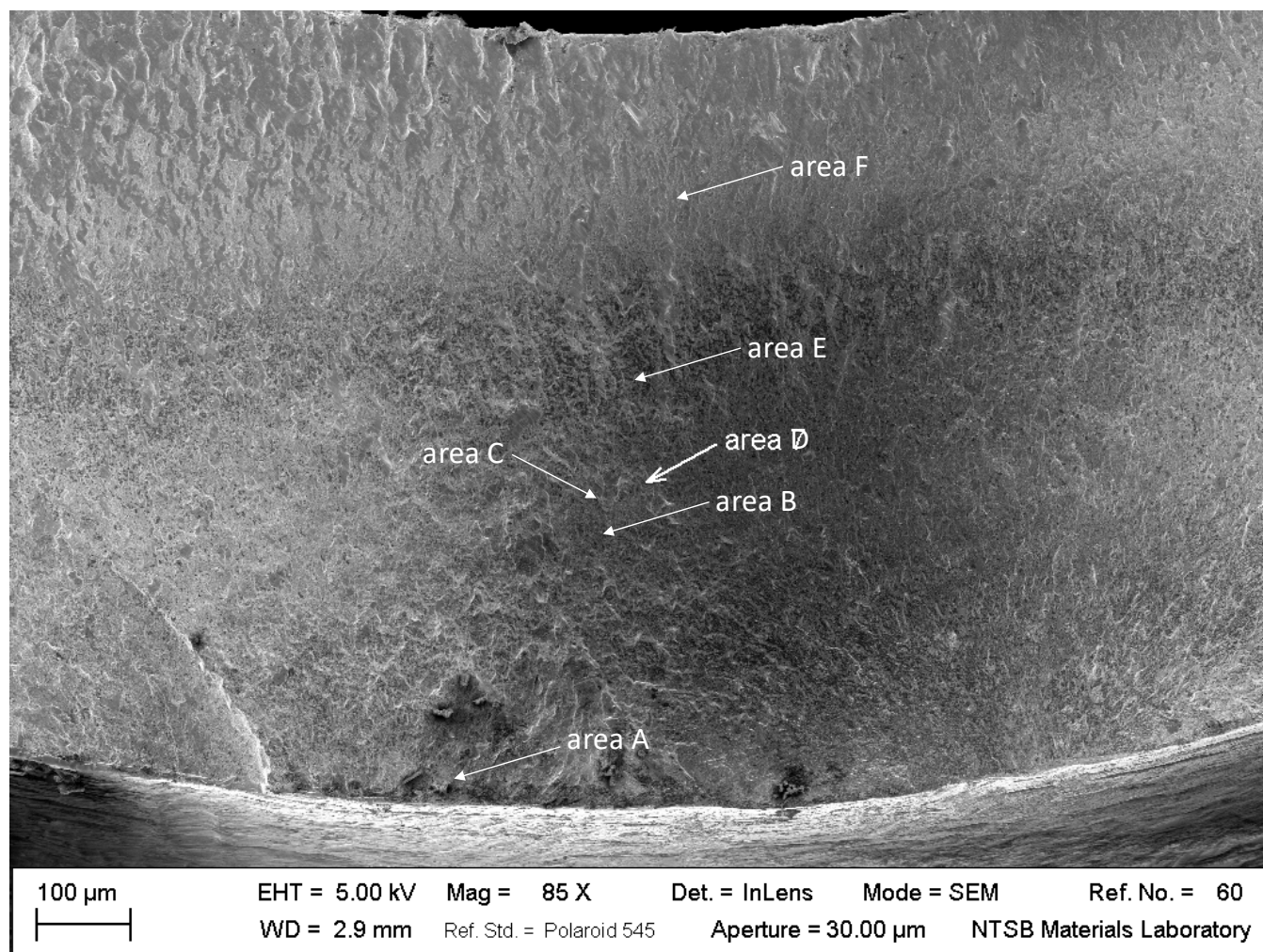


Figure 12 Overall top down view scanning electron micrograph of the fracture surface on the flare portion near the center of the fatigue crack initiation region on the inner side of the tube bend. Higher magnification imaging was performed in the areas marked A through E shown in subsequent Figures 13 through 18.

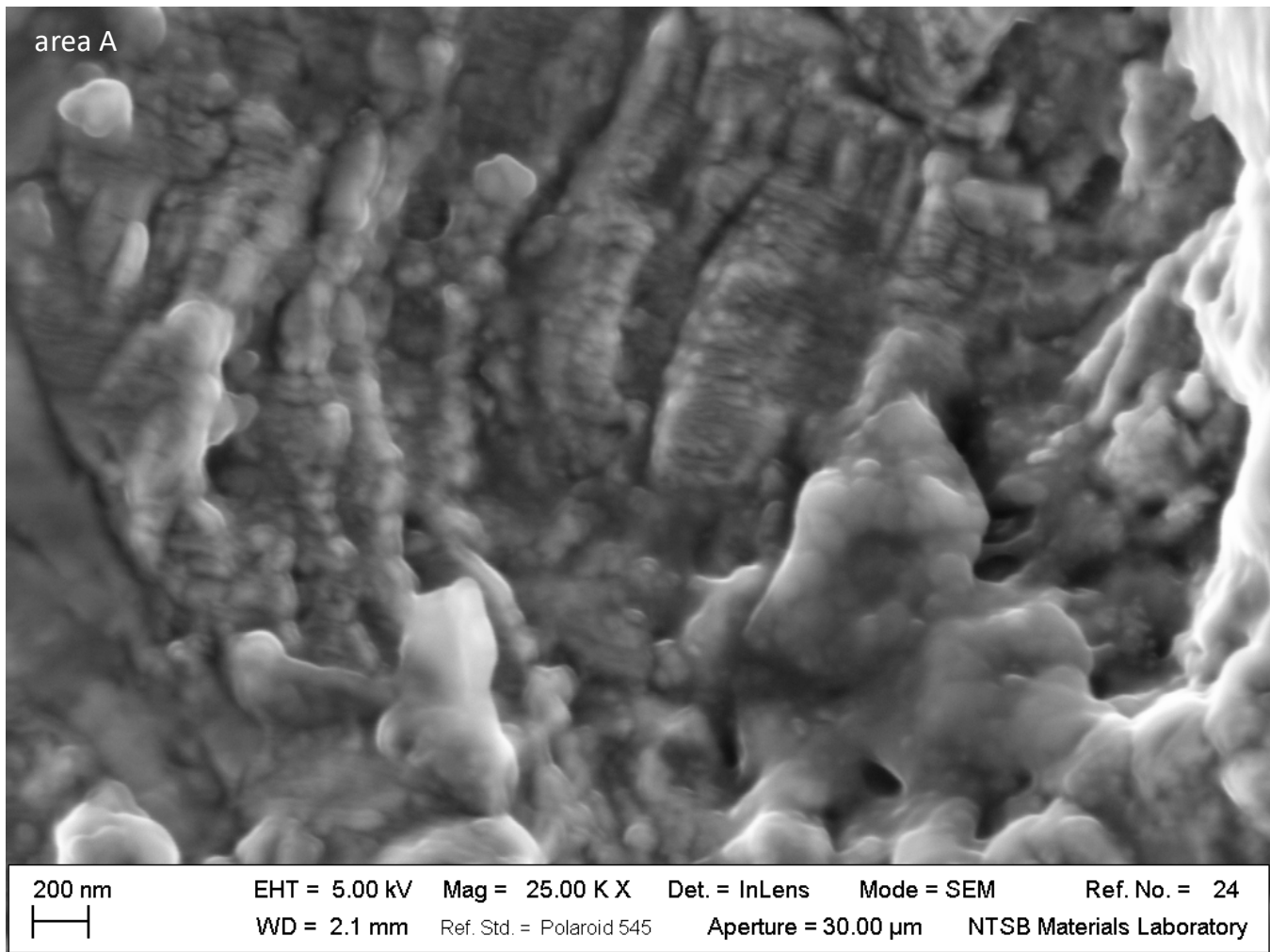


Figure 13 Scanning electron fractograph of fatigue striations in area A (See Figure 12).

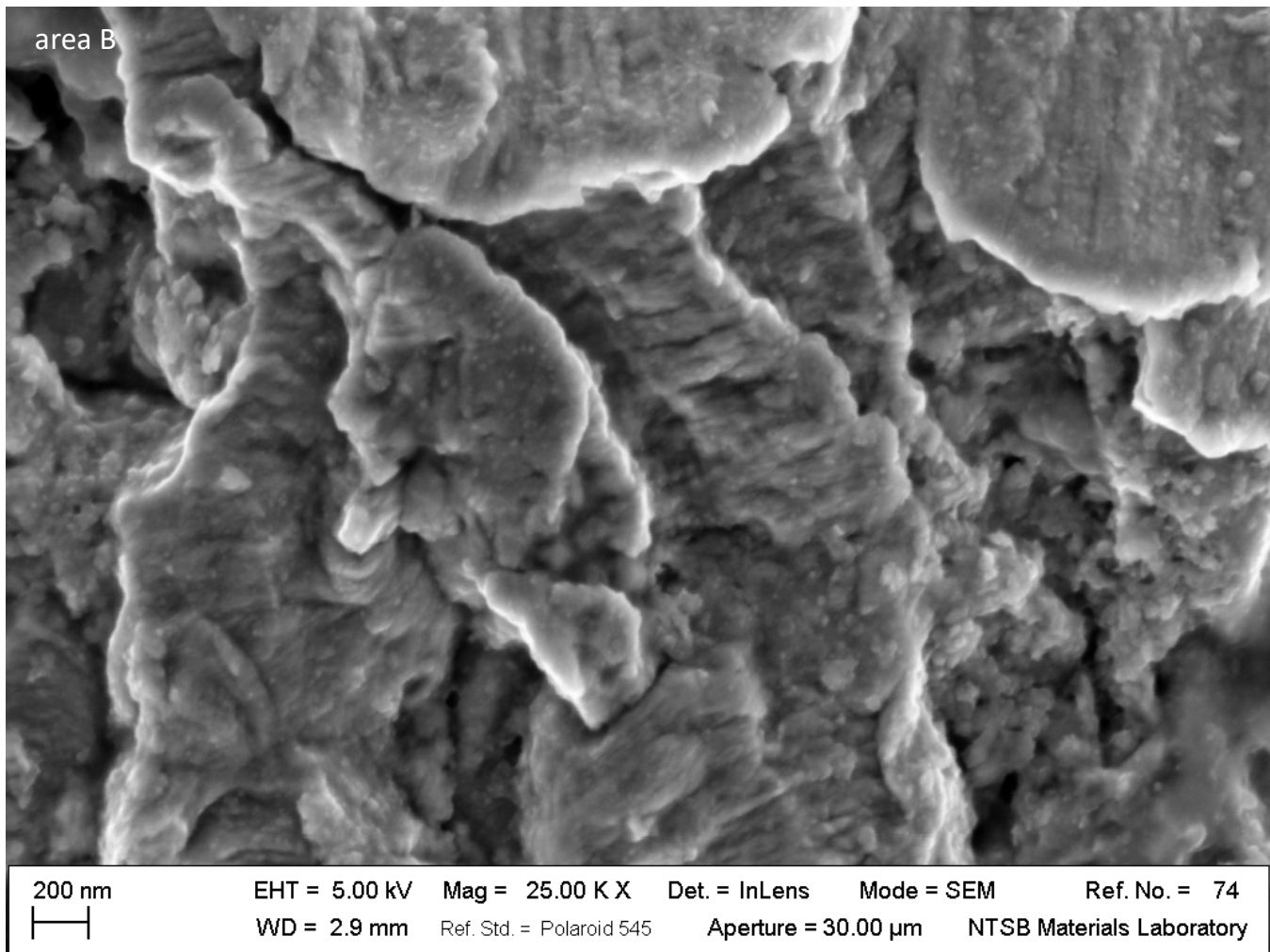


Figure 14 Scanning electron fractograph of fatigue striations in area B (See Figure 12).

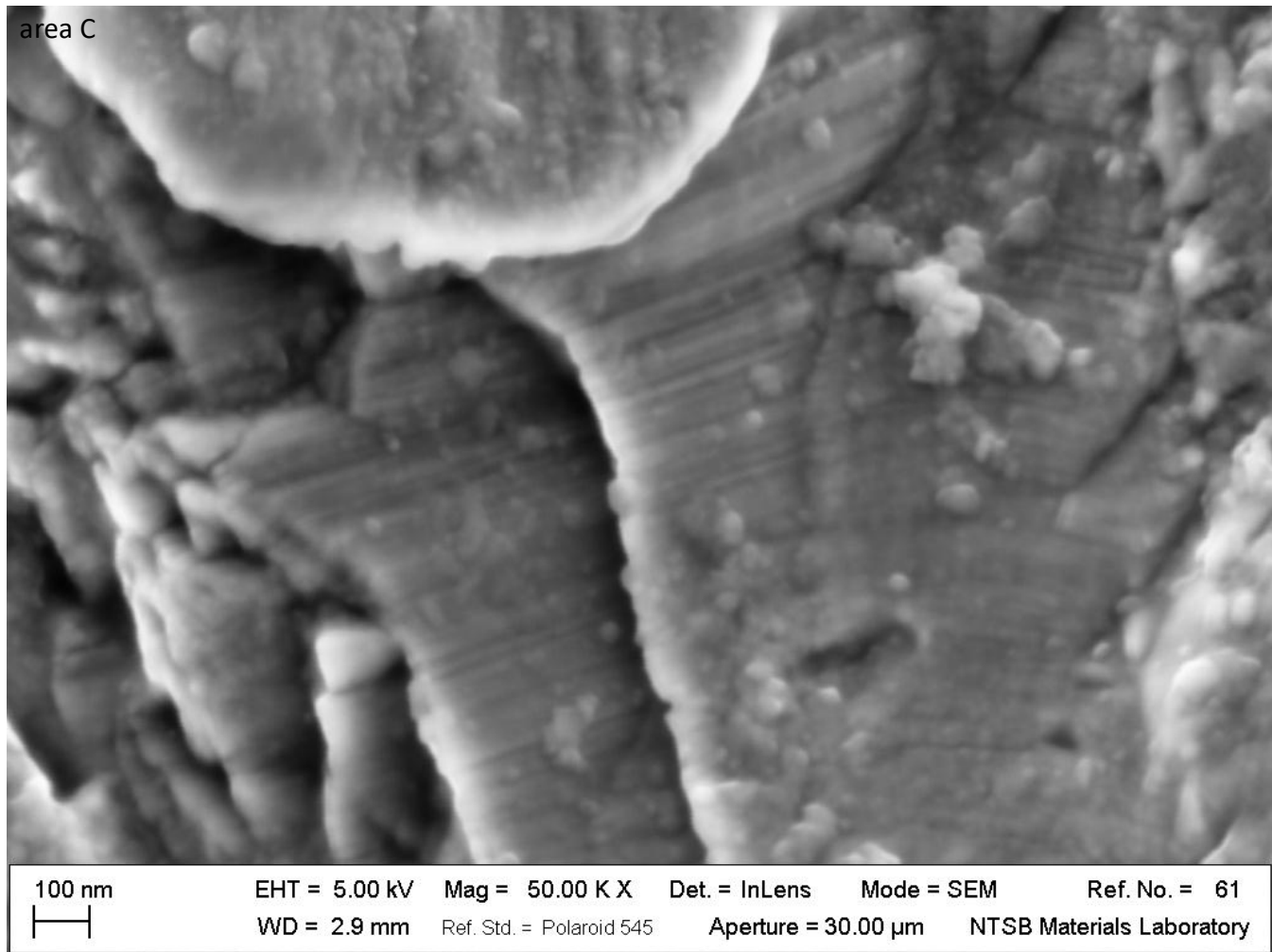


Figure 15 Scanning electron fractograph of fatigue striations in area C (See Figure 12).

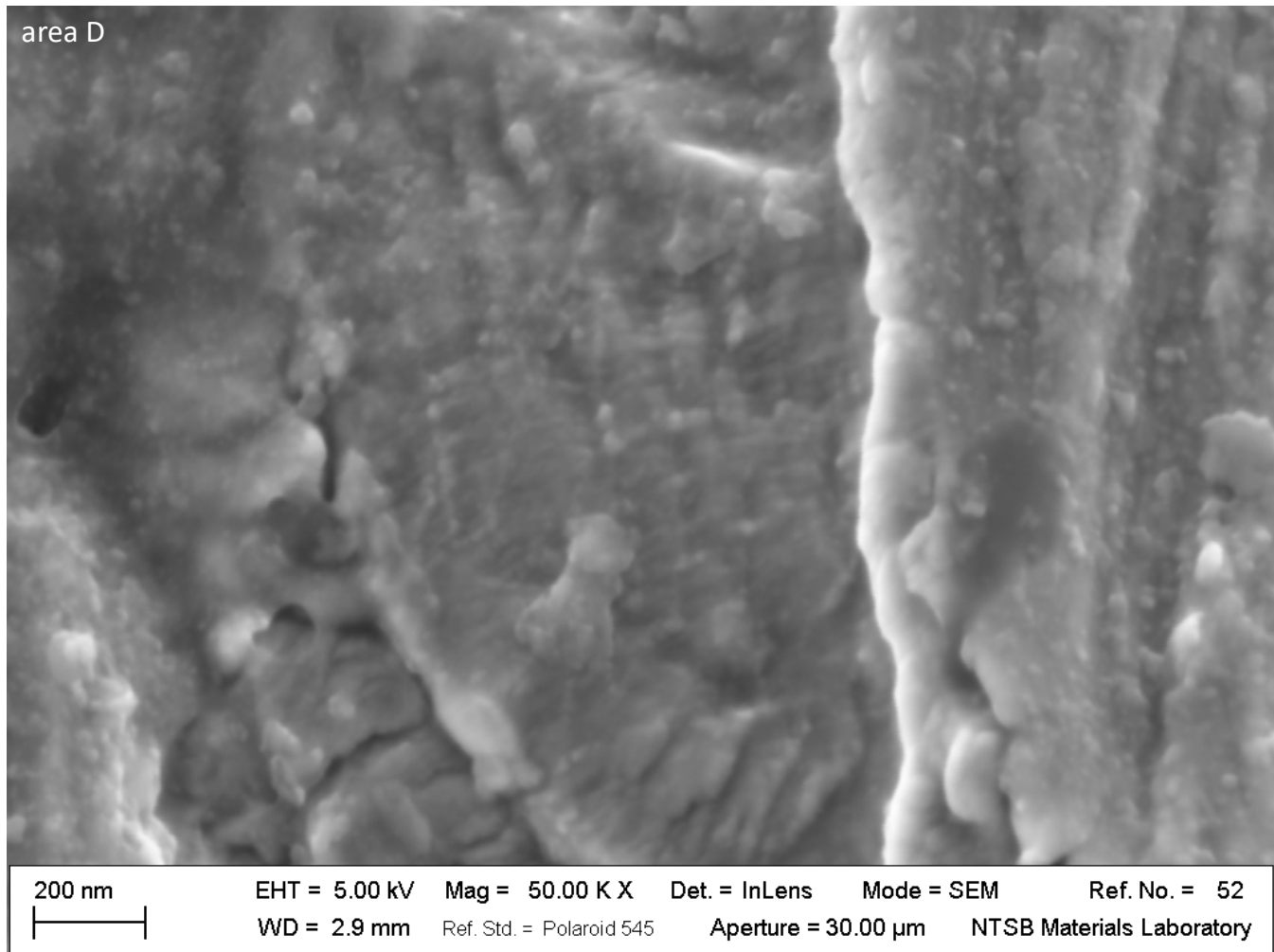


Figure 16 Scanning electron fractograph of fatigue striations in area D (See Figure 12).

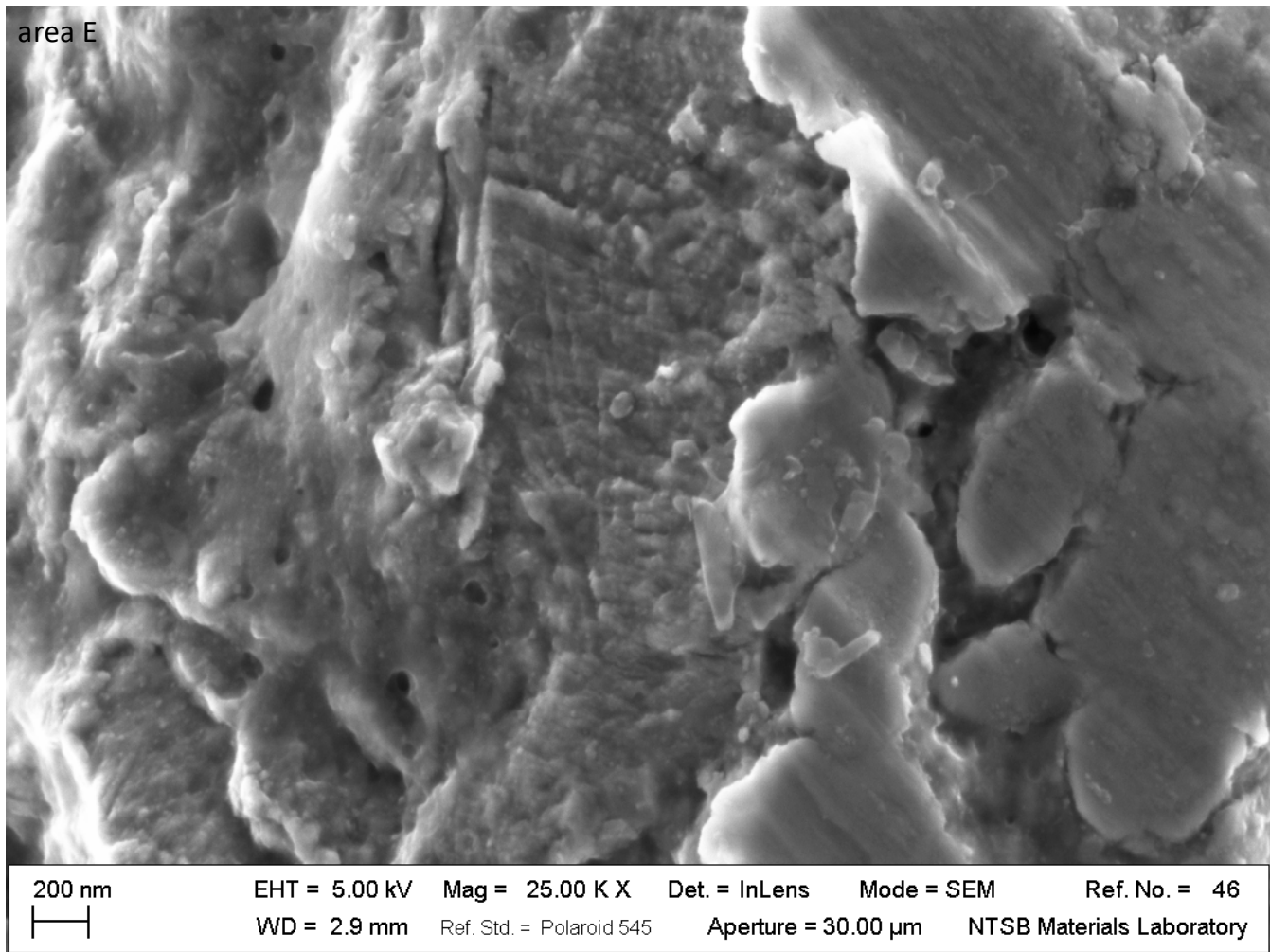


Figure 17 Scanning electron fractograph of fatigue striations in area E (See Figure 12).

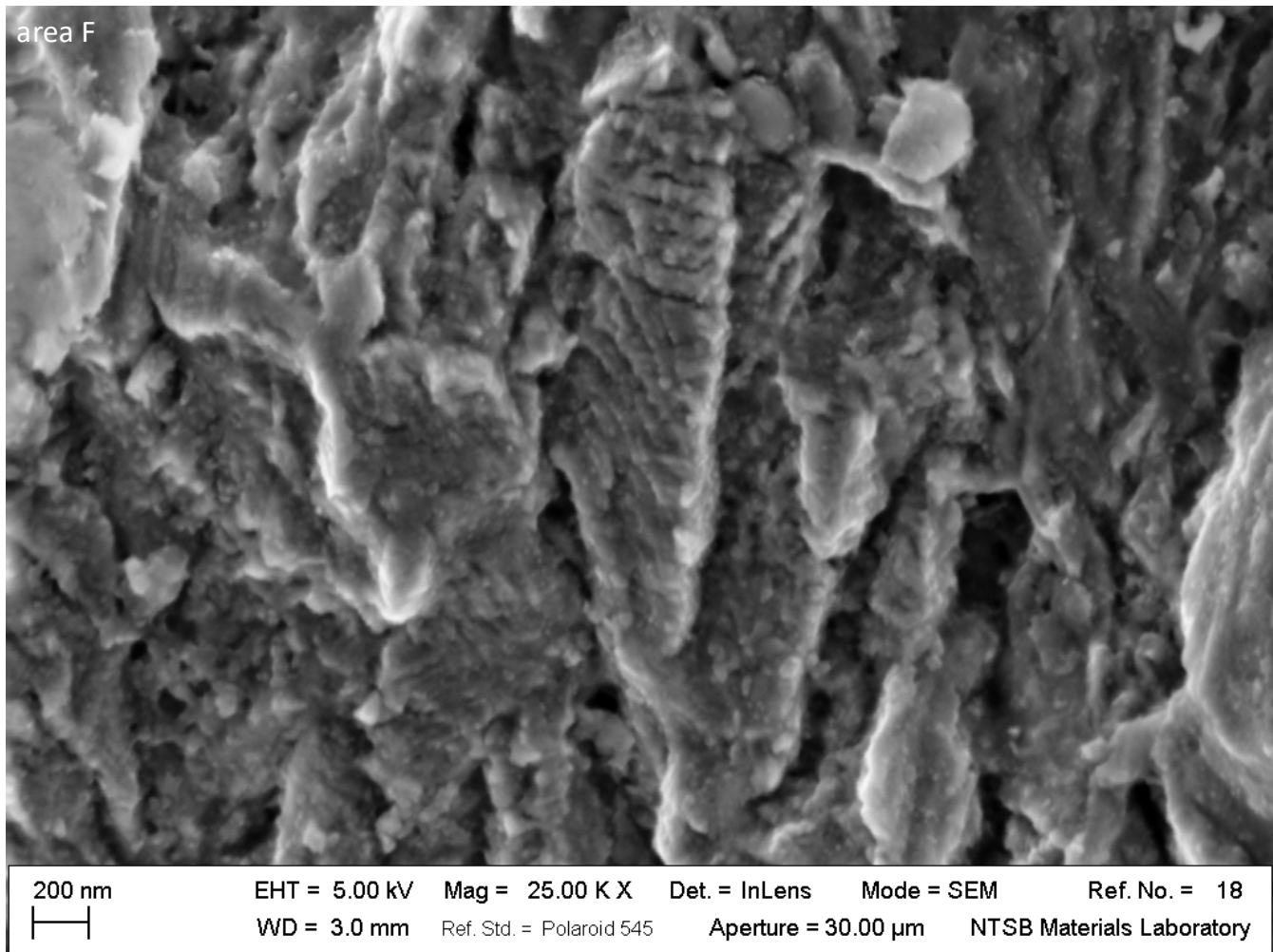


Figure 18 Scanning electron fractograph of fatigue striations in area F (See Figure 12).

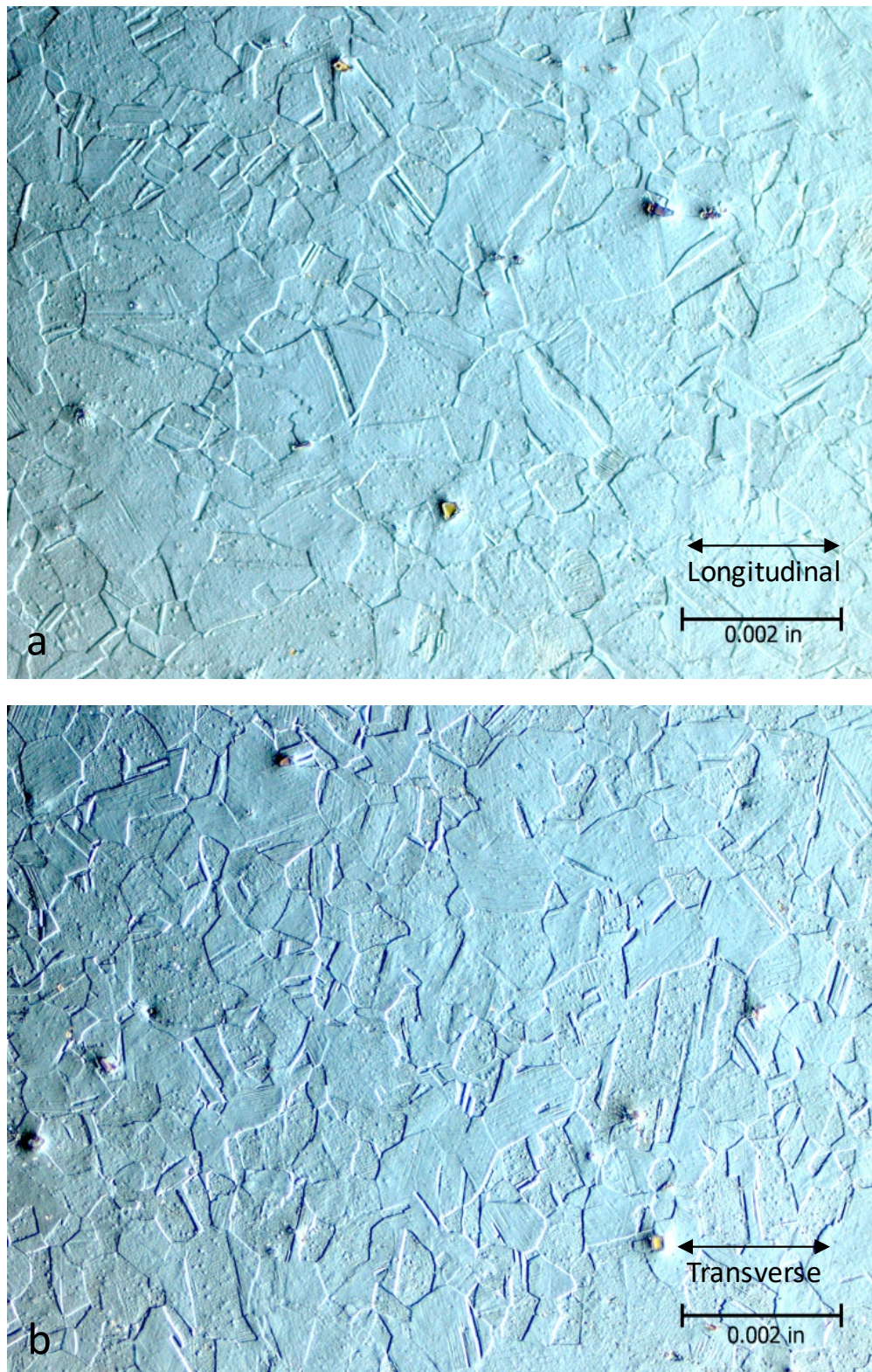


Figure 19 Optical micrograph of the microstructure of the tube in the longitudinal (view a), and the transverse (view b) direction (500X, Ralph's etch, differential interference contrast).

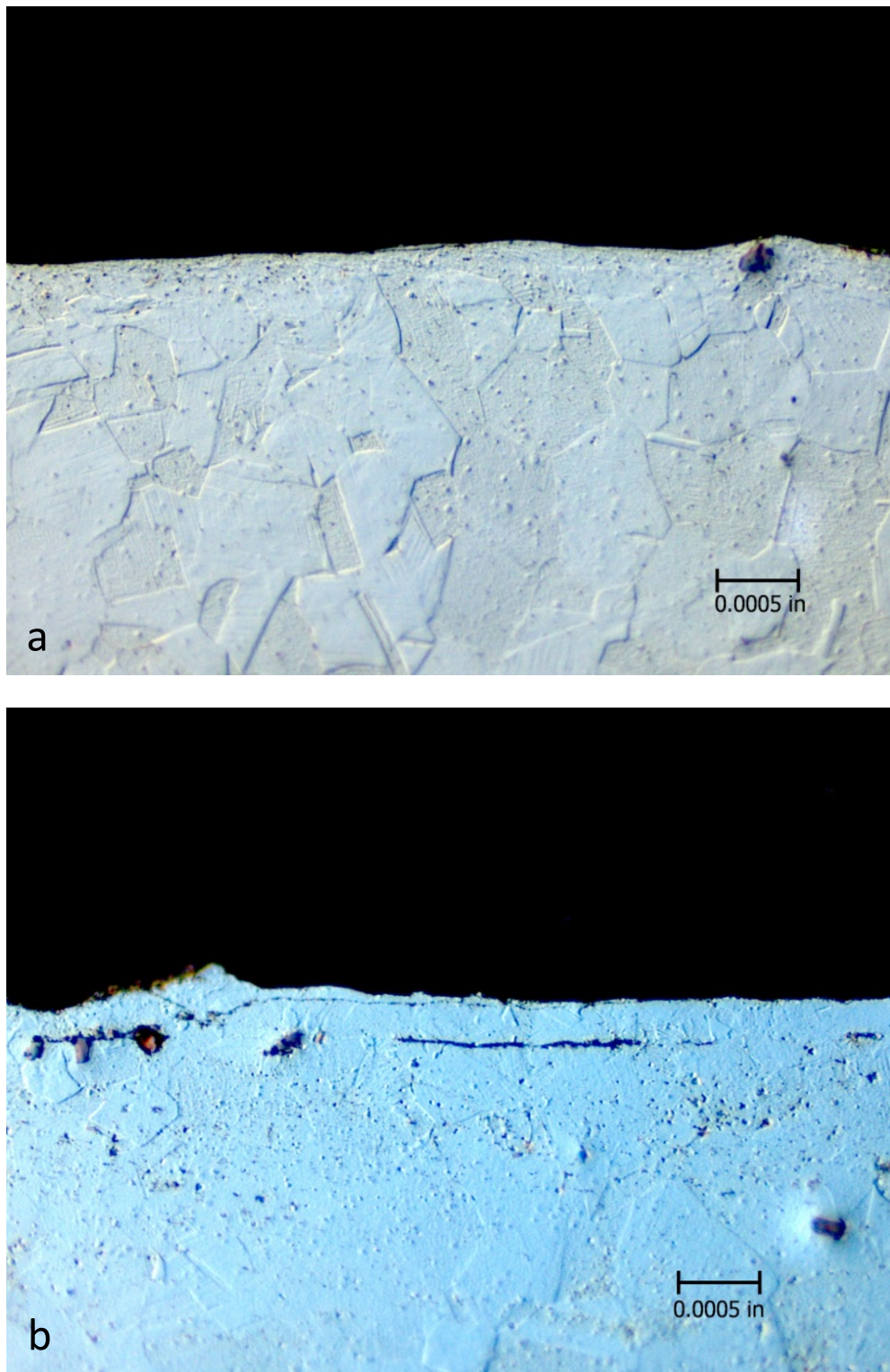


Figure 20 Optical micrographs of cross section of the tube surface microstructure. View a shows the structure below the outside diameter surface. View b shows the structure below the inside diameter surface (1000X original magnification , Ralph's etch, differential interference contrast).

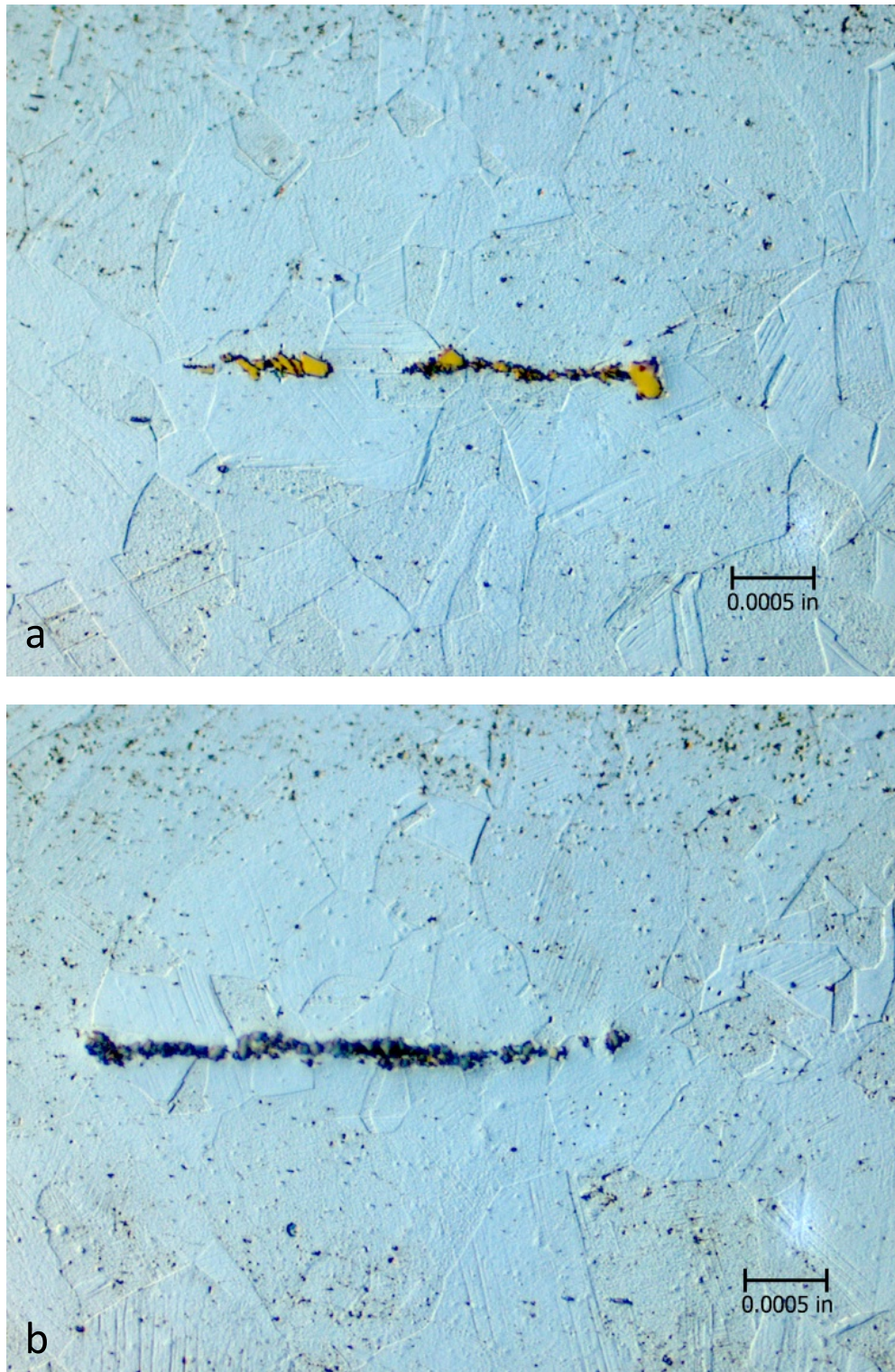
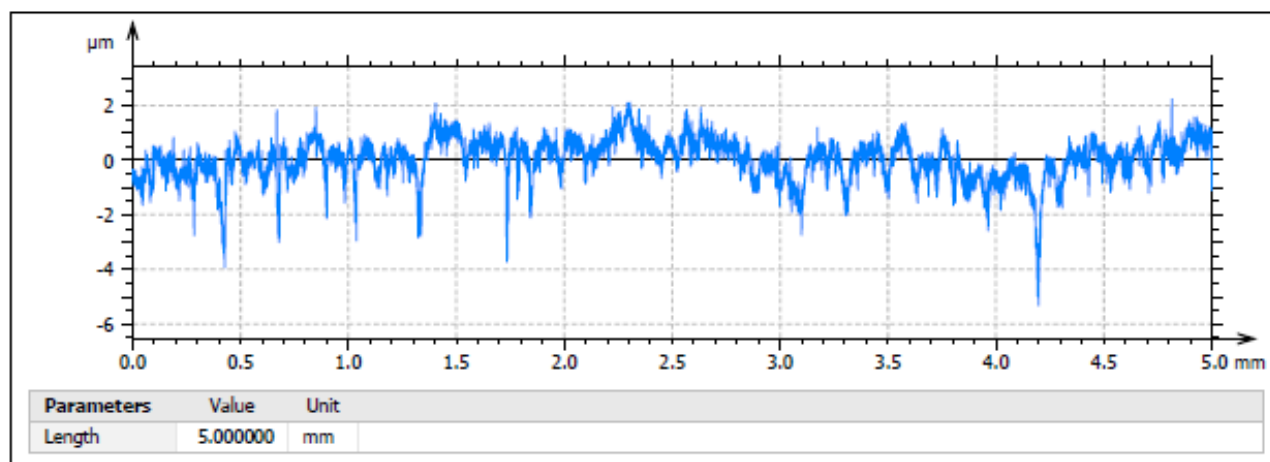


Figure 21 Optical micrographs of a transverse cross section of the tube showing infrequent, but typical colonies of nitride (view a) and oxide (view b) particles (1000X original magnification, Ralph's etch, differential interference contrast).

**ISO 4287****Amplitude parameters - Roughness profile**

Rp	1.605640 μm	Gaussian filter, 0.8 mm	Maximum Peak Height of the roughness profile.
Rv	3.130009 μm	Gaussian filter, 0.8 mm	Maximum Valley Depth of the roughness profile.
Rz	4.735649 μm	Gaussian filter, 0.8 mm	Maximum Height of roughness profile.
Rc	3.373083 μm	Gaussian filter, 0.8 mm	Mean height of the roughness profile elements.
Rt	6.509926 μm	Gaussian filter, 0.8 mm	Total Height of roughness profile.
Ra	0.457220 μm	Gaussian filter, 0.8 mm	Arithmetic Mean Deviation of the roughness profile.
Rq	0.625638 μm	Gaussian filter, 0.8 mm	Root-Mean-Square (RMS) Deviation of the roughness profile.
Rsk	-1.171462	Gaussian filter, 0.8 mm	Skewness of the roughness profile.
Rku	6.501920	Gaussian filter, 0.8 mm	Kurtosis of the roughness profile.

Material Ratio parameters - Roughness profile

Rmr	1.913700 %	c = 1 μm under the highest peak, Gaussian filter, 0.8 mm	Relative Material Ratio of the roughness profile.
Rdc	0.879070 μm	p = 20%, q = 80%, Gaussian filter, 0.8 mm	Roughness profile Section Height difference

Figure 22 Results of surface profile measurements on the outside surface of the tube (measurements taken in the longitudinal direction).

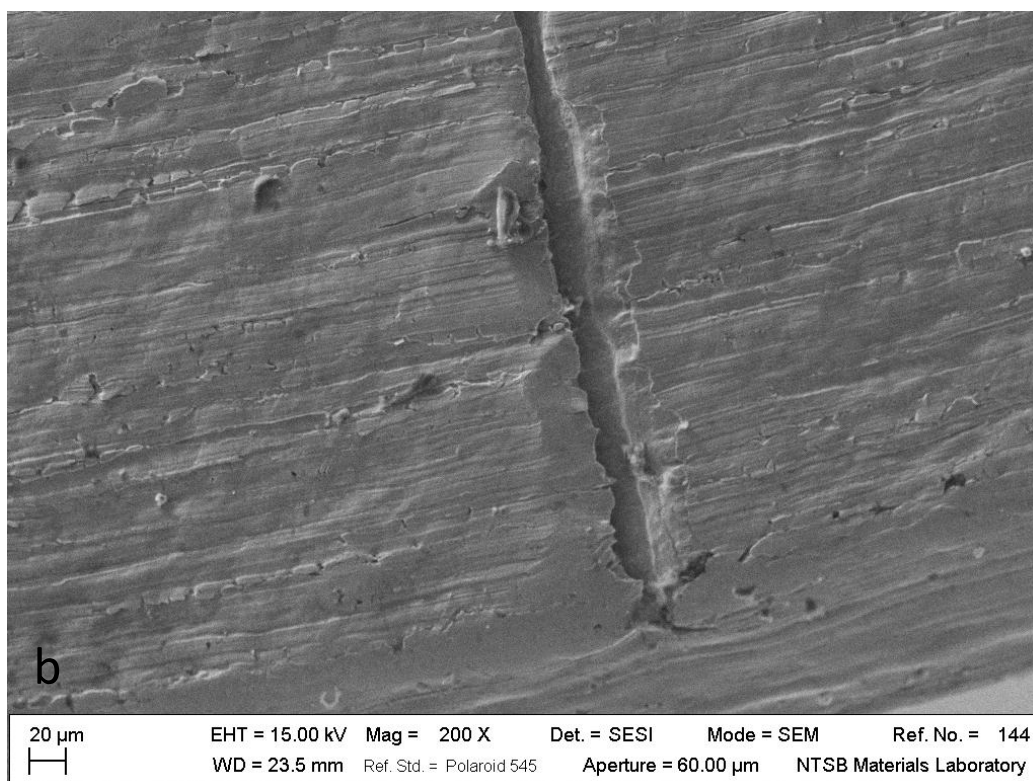
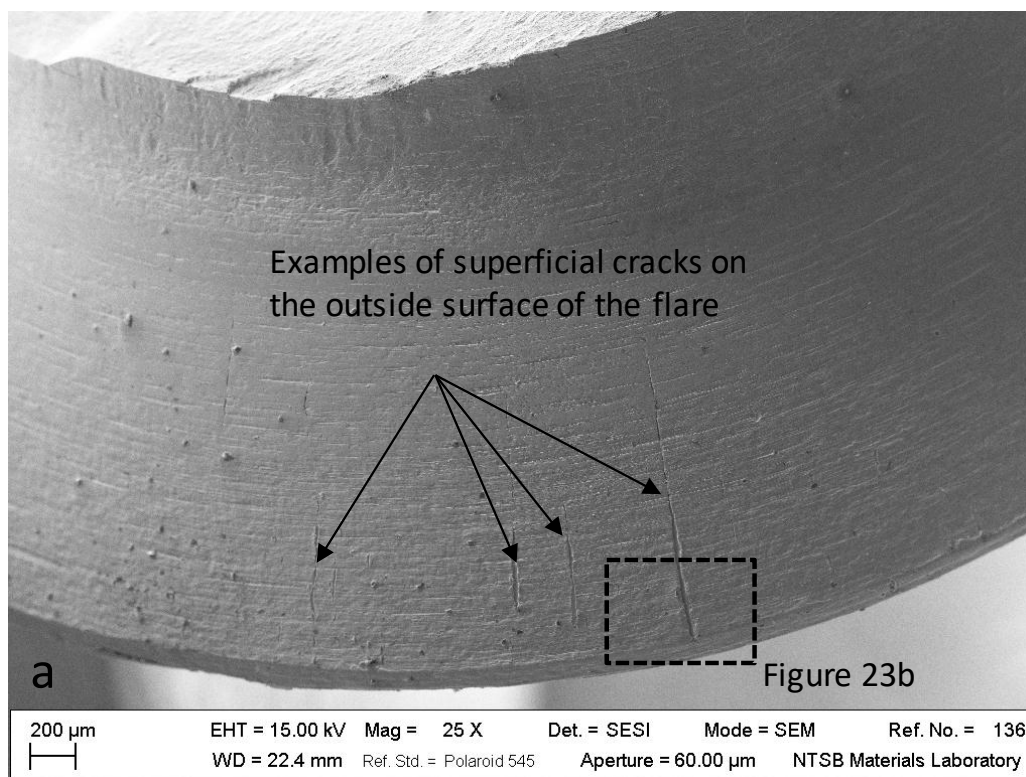


Figure 23 Scanning electron micrographs of the outside surfaces of the flared portion of the tube. View b shows a closer image of an example crack.

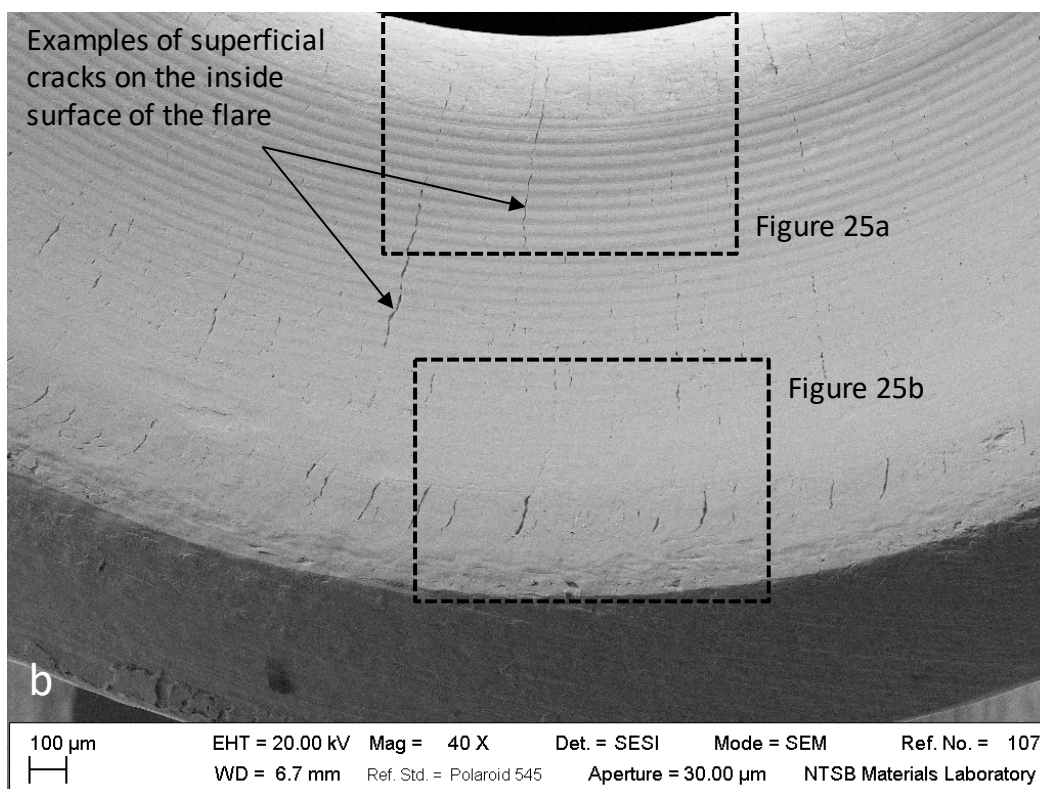
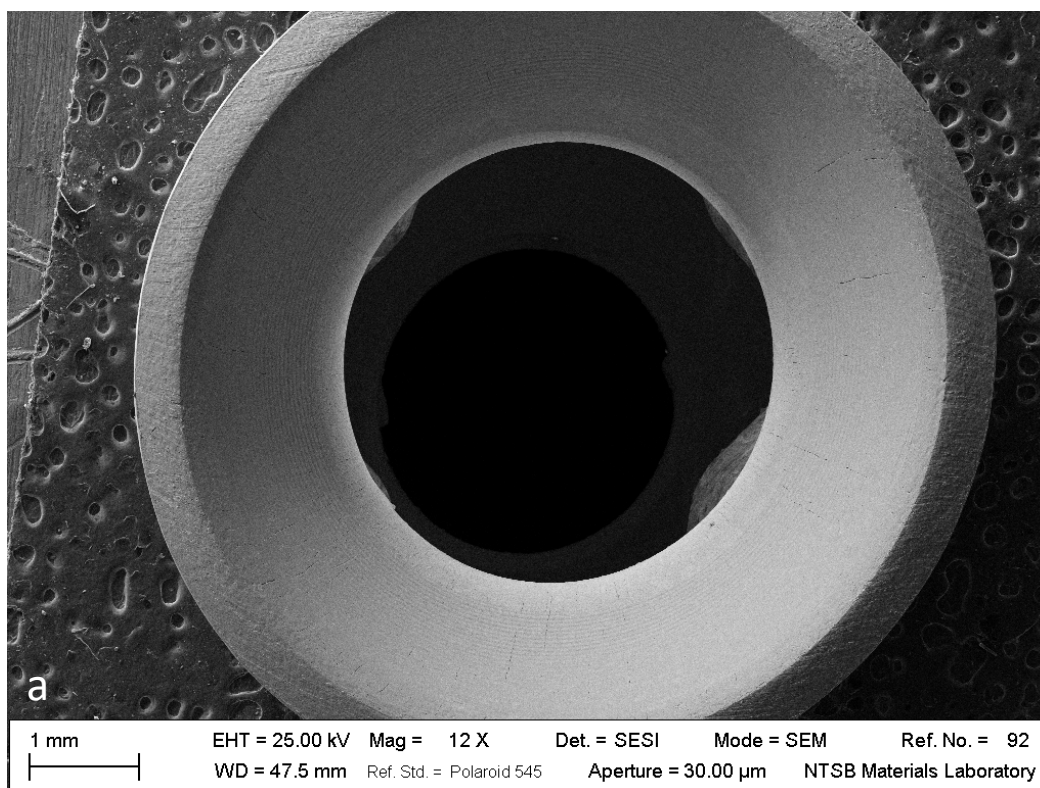


Figure 24 Scanning electron micrographs of the inside surfaces of the flared portion of the tube.

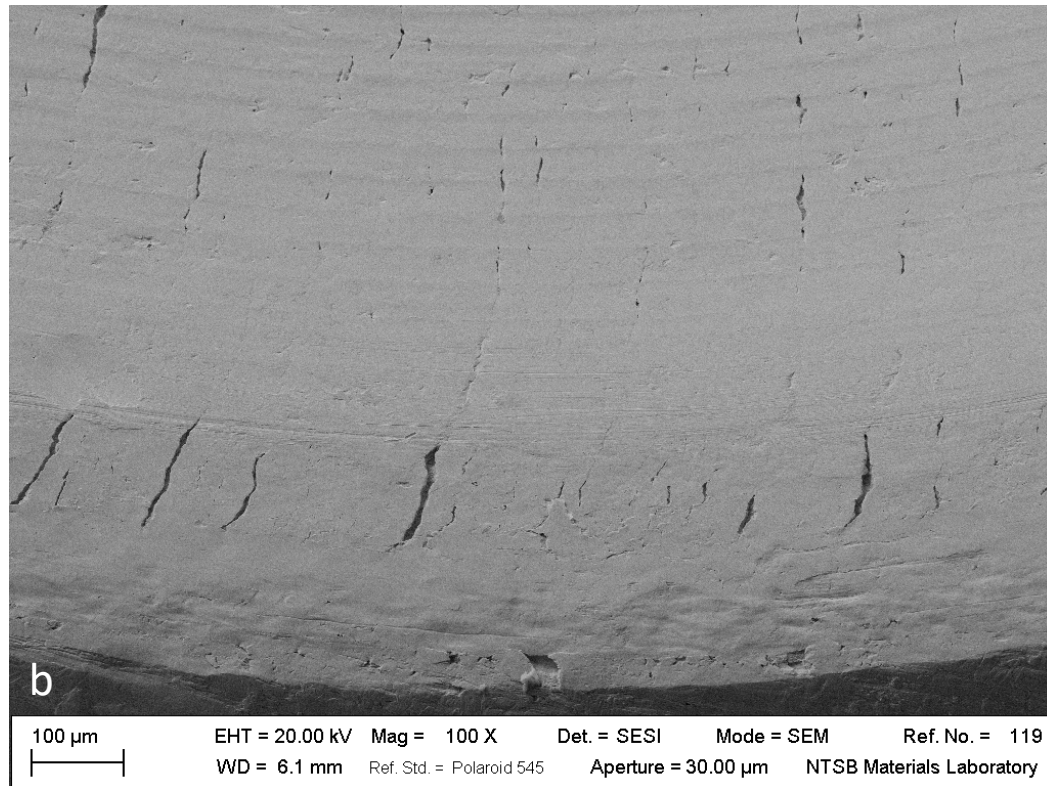
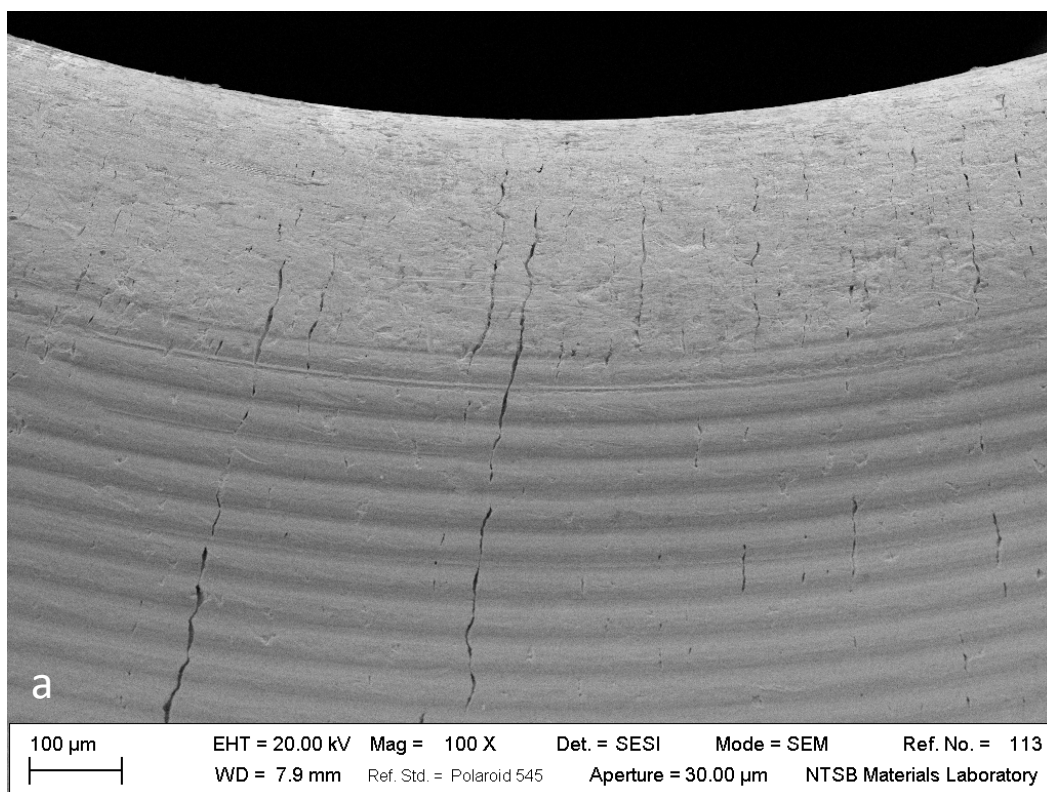


Figure 25 Closer scanning electron micrographs of the inside surfaces of the flared portion of the tube showing examples of cracks.