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Effect of Electropolishing on the Surface Topography of Micro-Wire Electrodischarge Machined Simulated Coil Gaps

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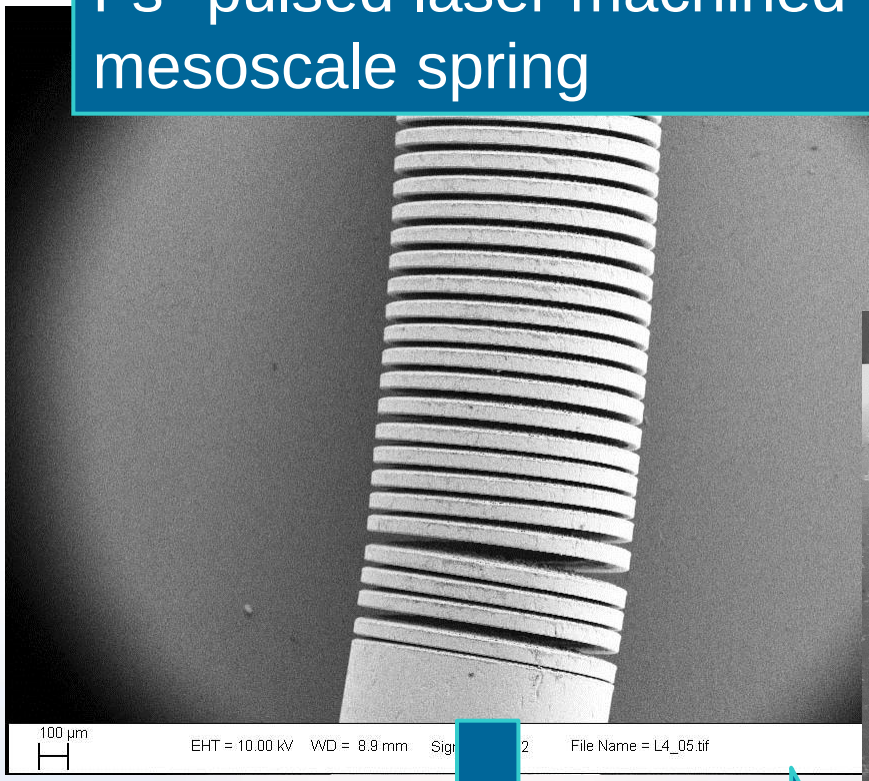
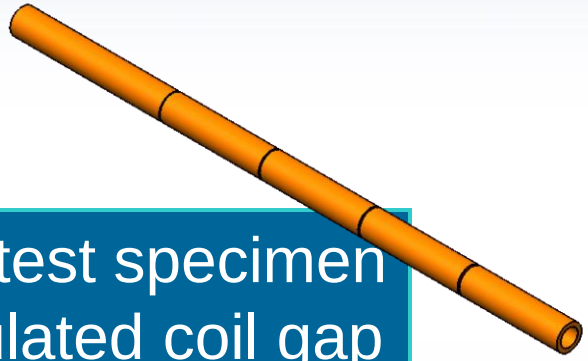
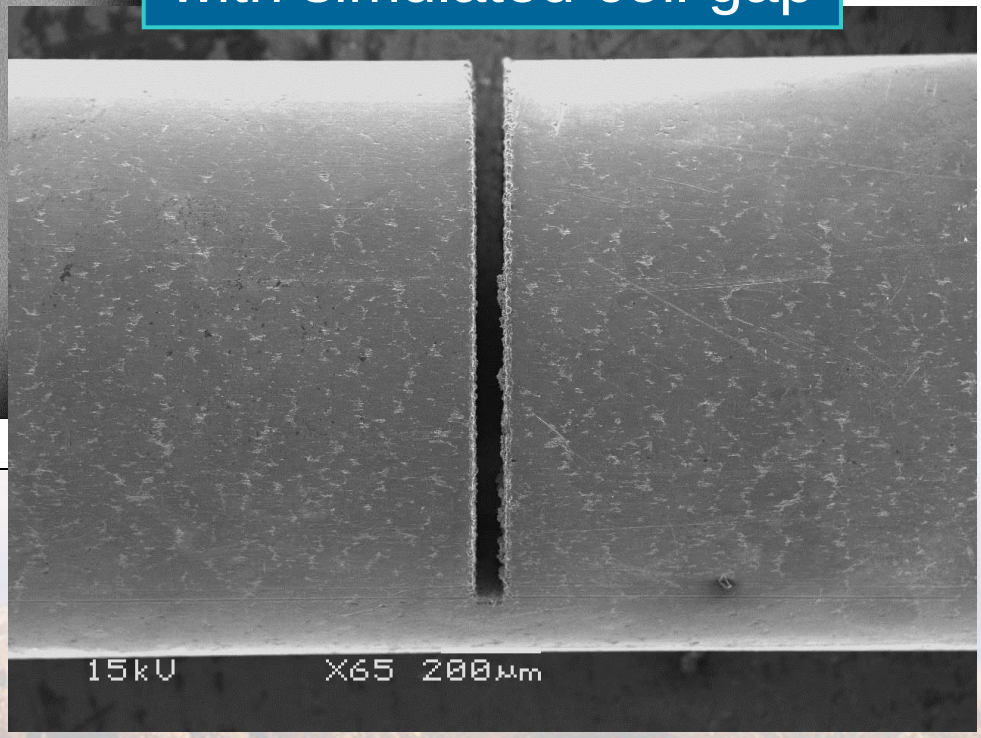
What is a simulated coil gap?

Fs* pulsed laser machined mesoscale spring





µWEDM test specimen with simulated coil gap



*Femtosecond

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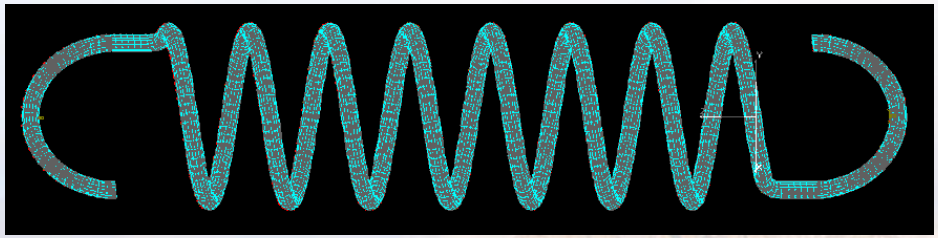
Mesoscale springs offer a higher precision and lower uncertainty option

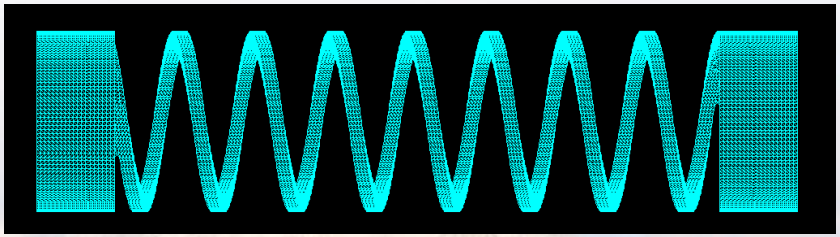
Coil wound spring

- Manufacturing uncertainties (e.g. bend radius and tang orientation) result in large design tolerance margins
- Increases in mechanism size, mass, force and power consumption
- Limits materials selection

Direct machined mesoscale spring

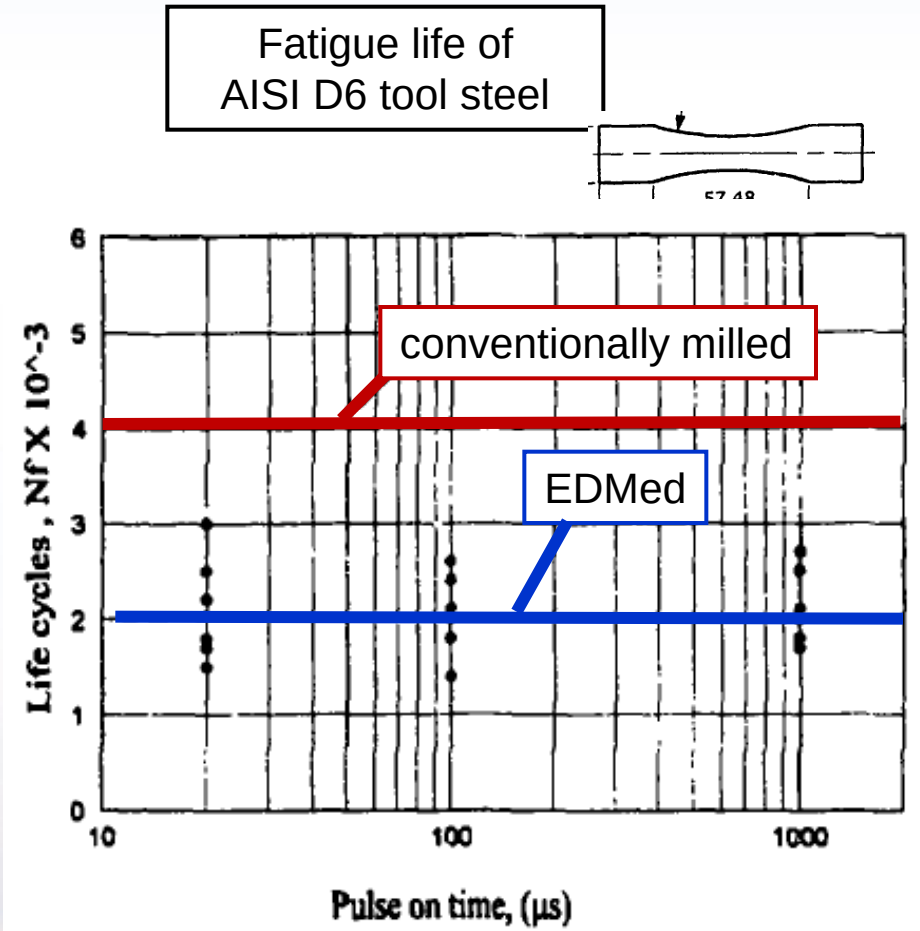
- Precision machining (fs pulsed lasers and μWEDM) can be used to produce springs with lower uncertainties
- Key design parameters: size, stiffness, fatigue life & cost
- Electropolishing can provide surface remediation





Fatigue resistance is reduced by surface defects (e.g. microcracks)

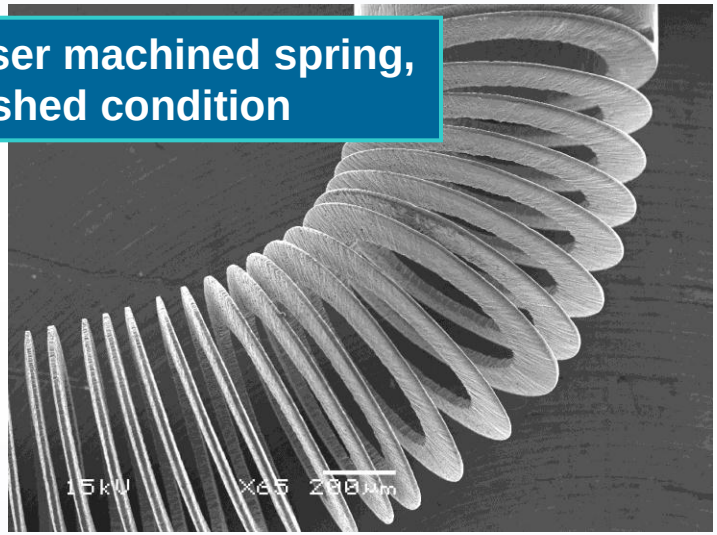
- EDM & laser machining leave a "recast" layer.
  - Residual tensile stresses from the rapid re-solidification process.
  - Highly susceptible to micro-cracking.
- Fatigue life: EDMed < conventional machined parts.
- Removal of recast layer is required to improve fatigue life.



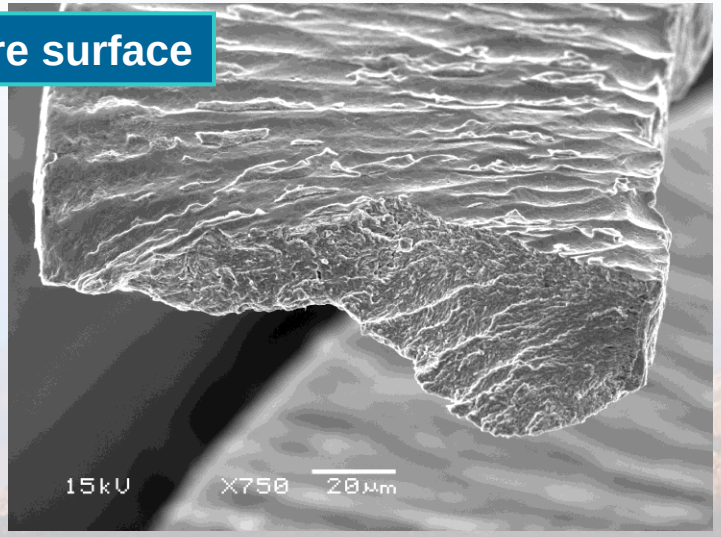
Zeid, J.Mat.Proc.Tech, 1997

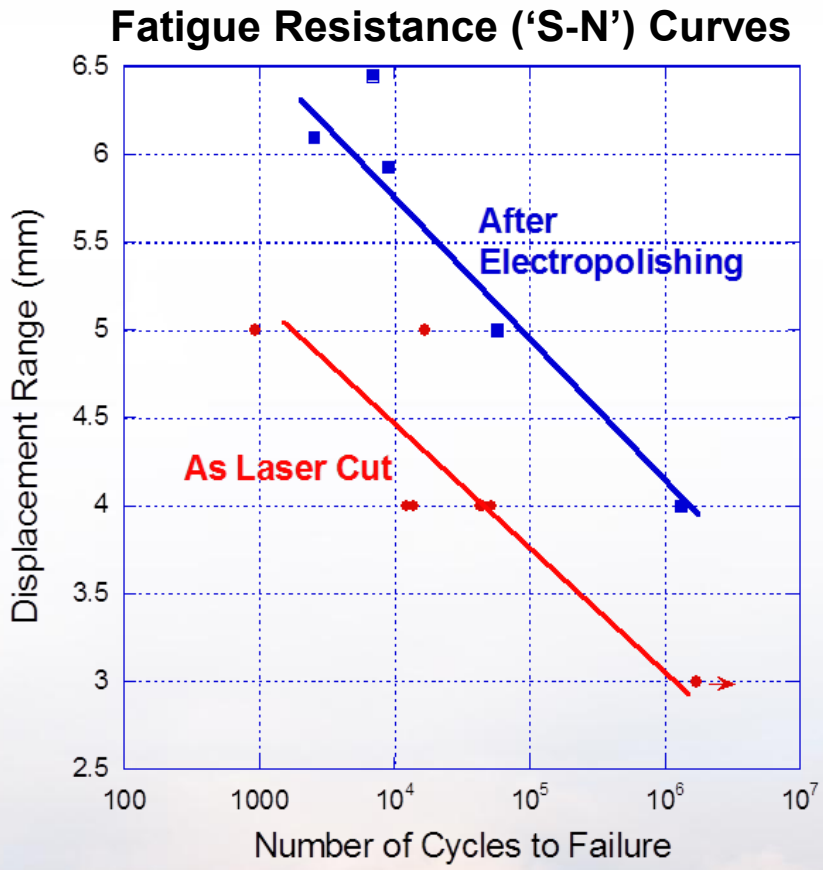
Fatigue resistance is markedly improved by electropolishing.

Fs laser machined spring, epolished condition



fracture surface





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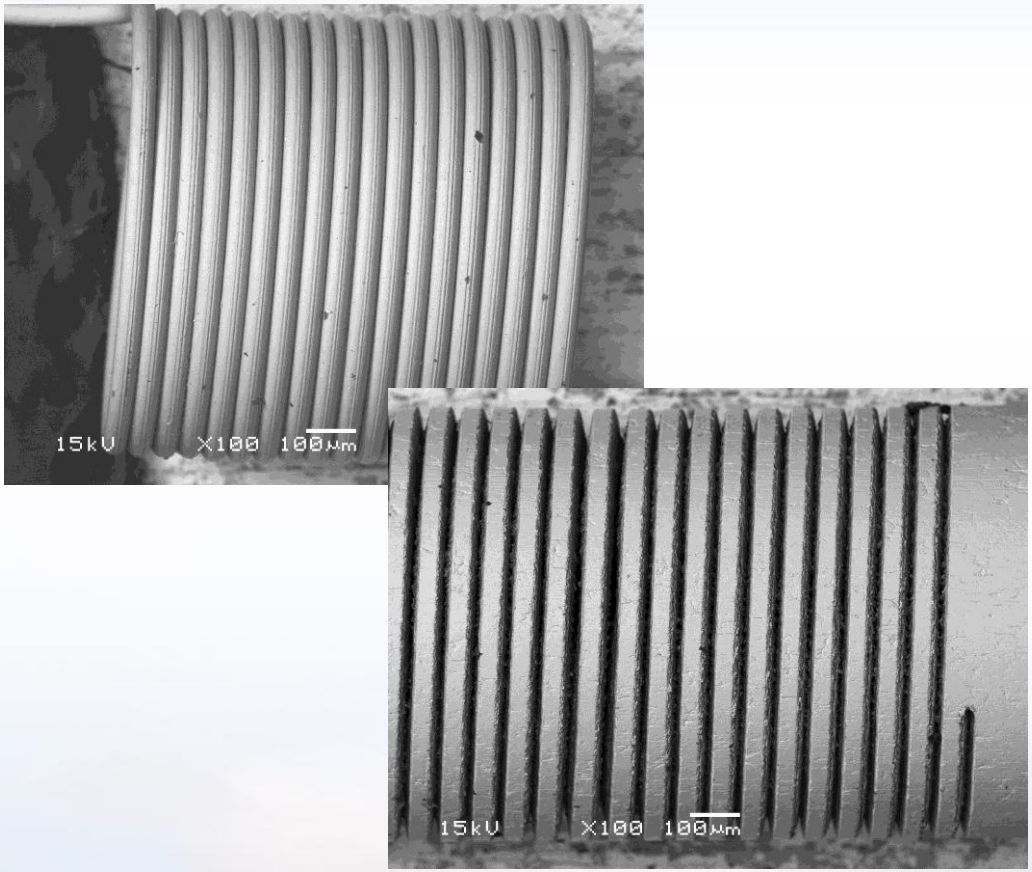
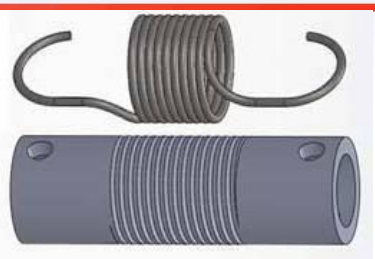
Geometry of coil wound vs. mesoscale springs





Coil wound spring	
diameter, in	0.046
wire dia, in	0.004
total length, in	0.162
# of coils	9.5
Mesoscale equivalent	
tube dimensions, in	0.050 OD x 0.008 W
coil / strut thickness, in	variable
total length, in	0.157
# of coils	15

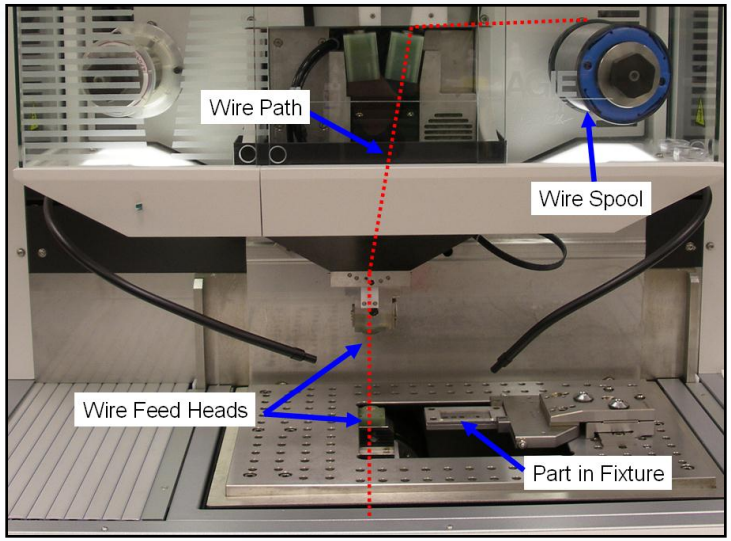
Meso-springs: what is effect of gap size on electropolishing throwing power?

µWEDM Experimental Details

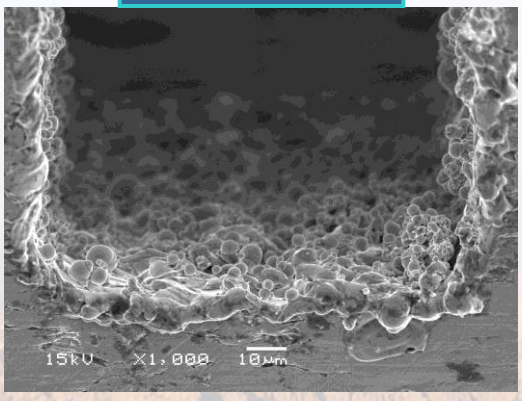
304L stainless steel
- 18Cr-8Ni-balance Fe
- ¾ to full hard

Agie Vertex 1F EDM machine
- "technologies" i.e., proprietary process parameters
- AC pulse generating circuit
- 20 µm tungsten wire
- Dielectric – deionized water

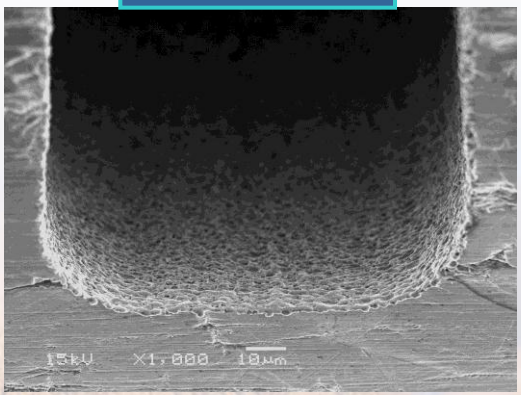
Wire offset (µm)
- Main pass = 13-15
- Trim pass =10-12



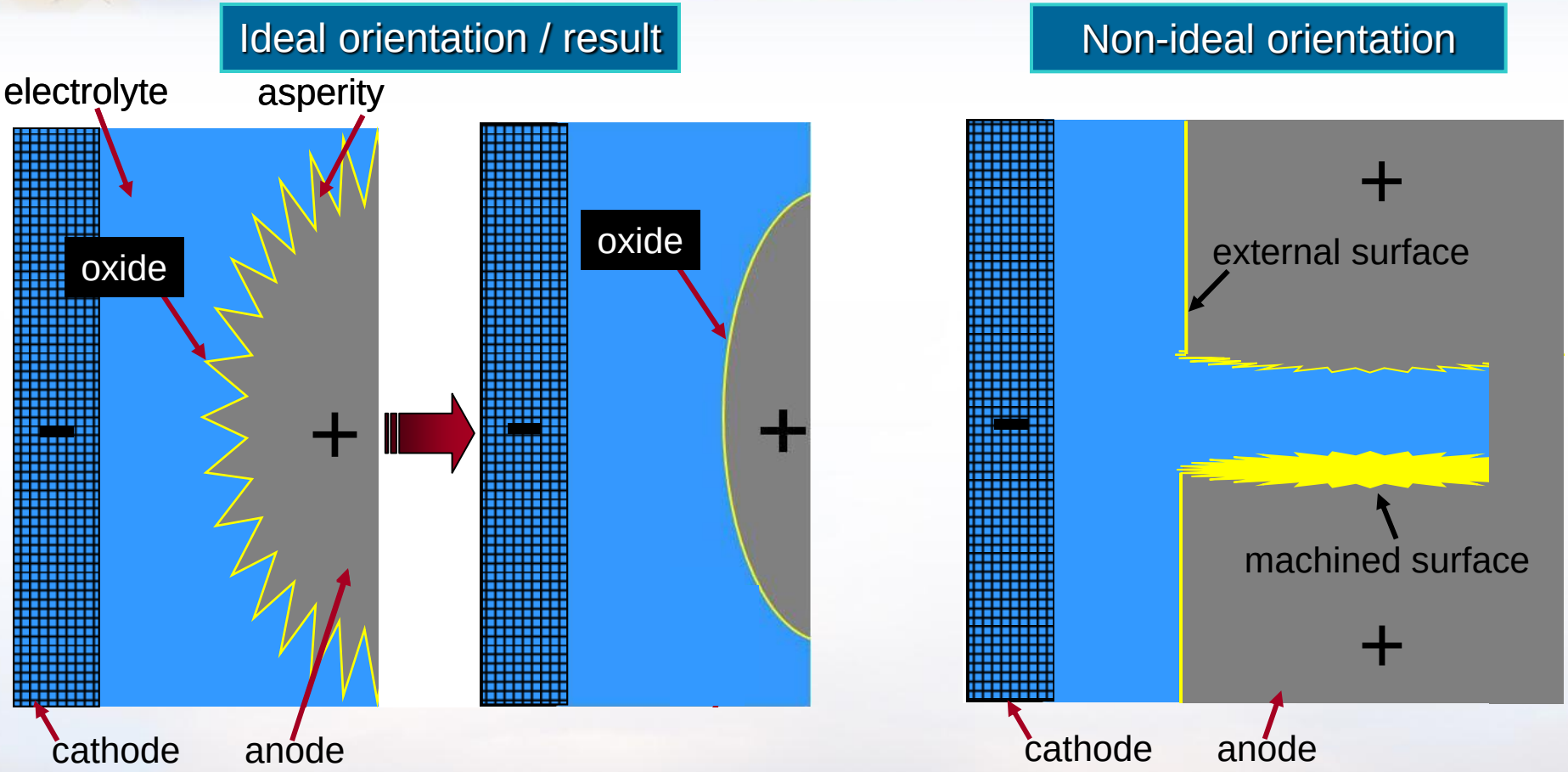
Main pass



Trim pass



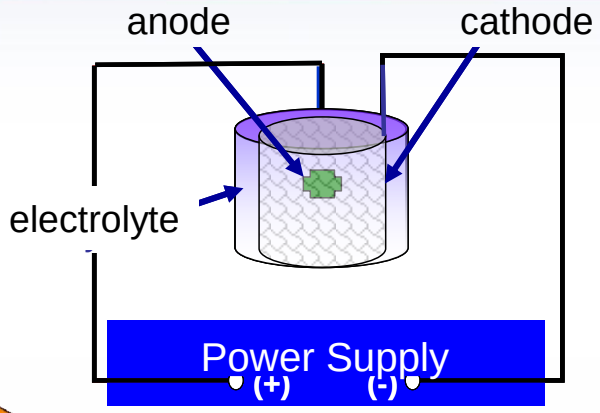
Electropolishing can improve surface finish by removing asperities

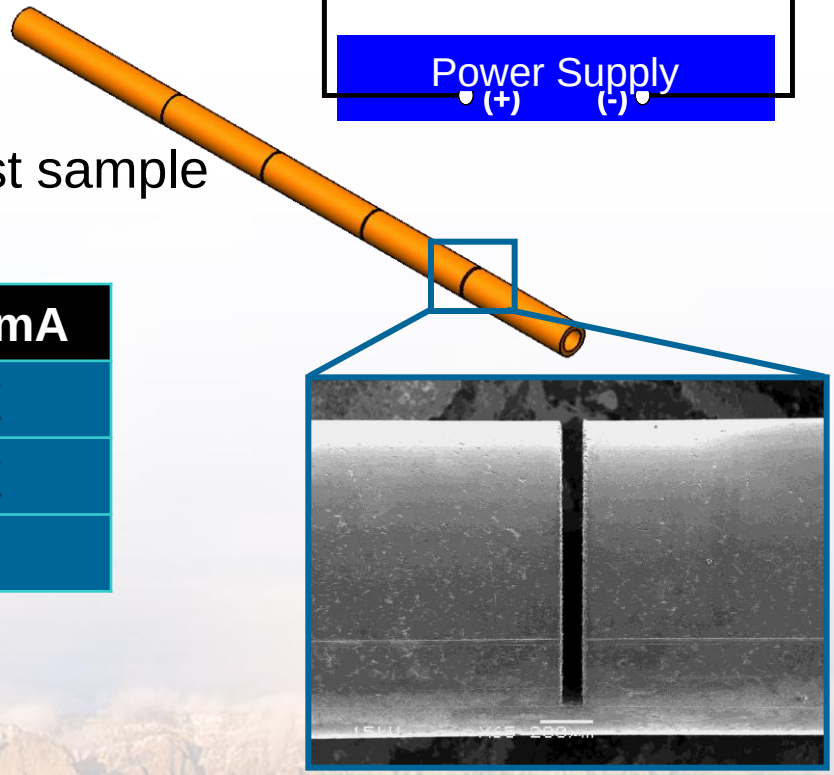


Anode to cathode orientation has a large effect on throwing power.

Electropolishing Experimental Details

- Power Supply: BK Precision Model 9121A
- Cathode: platinized Nb mesh
- Solution: 80vol% H_3PO_4 + 20vol% n-butanol[1]
- Temperature: 70°C ± 5°C
- Gap size: 40, 60, 80, 100 µm
- Stir rate: 300, 400, 500 rpm

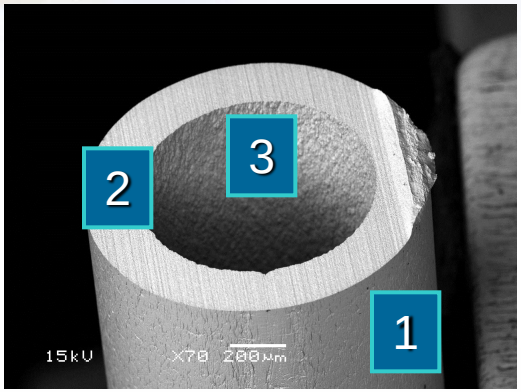


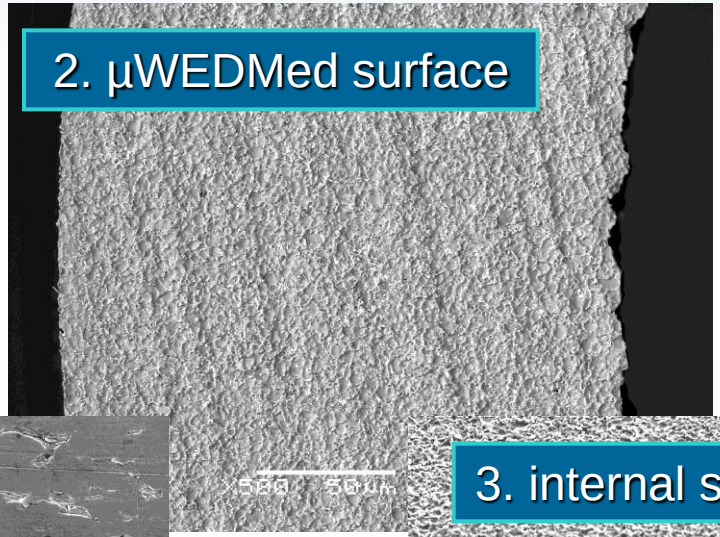


300 rpm	300 mA	400 mA	500 mA
1 minute	X	X	X
2 minutes	X	X	X
3 minutes	X		

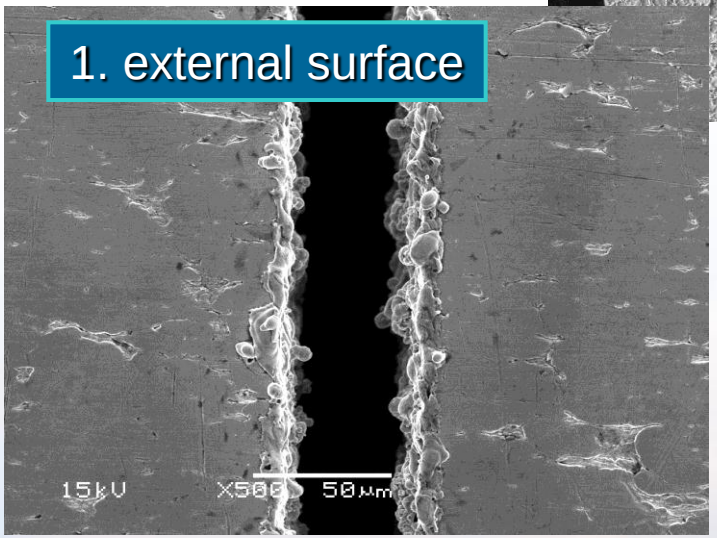
[1] P. Dettner, Electrolytic and Chemical Polishing of Metals, Ordentlich Publishers, 1987.

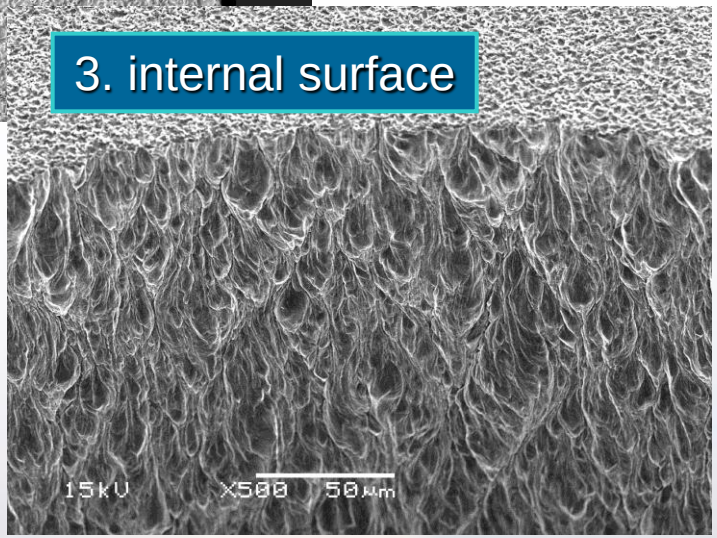
Commercially available hypodermic needle tubing was used for this study





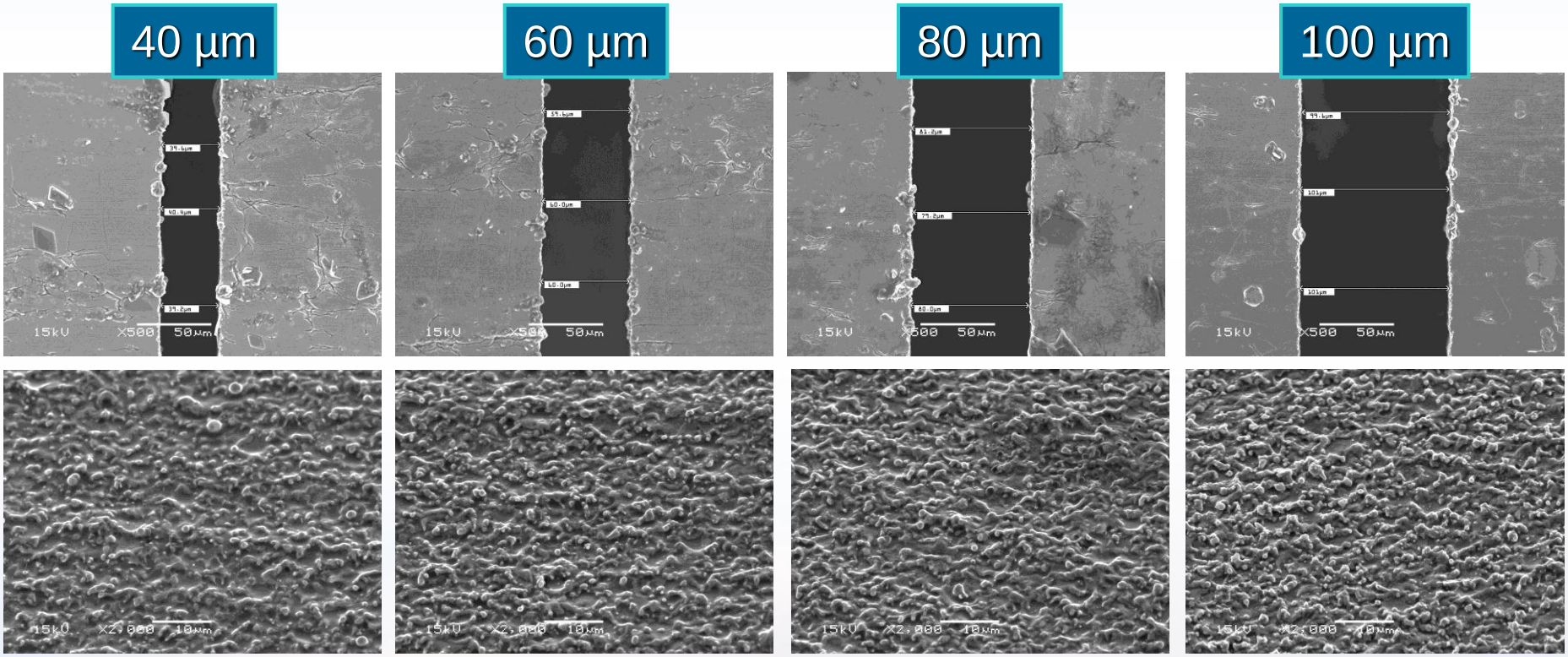
OD = 1270 µm
Wall = 203 µm





There are three distinct surface morphologies on machined tubing.

Gap spacing was varied by µWEDM to investigate electropolishing throwing power



Gap spacing does not affect as machined surface finish (R_a ~ 300 nm).

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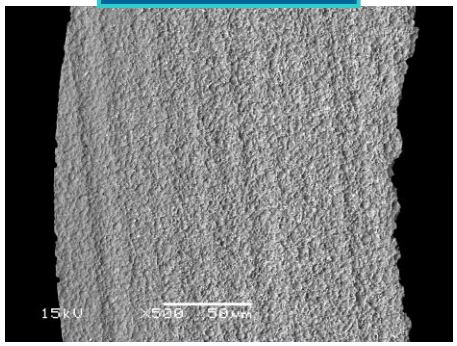
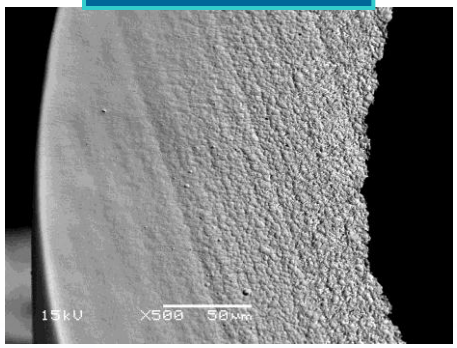
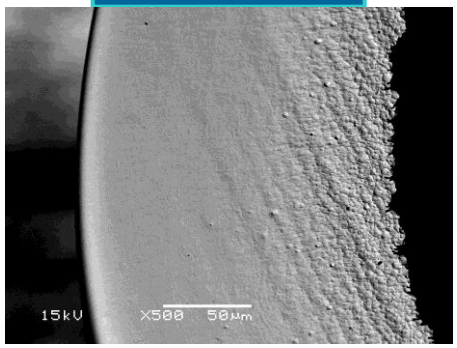
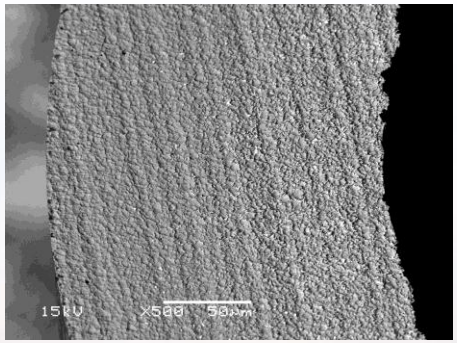
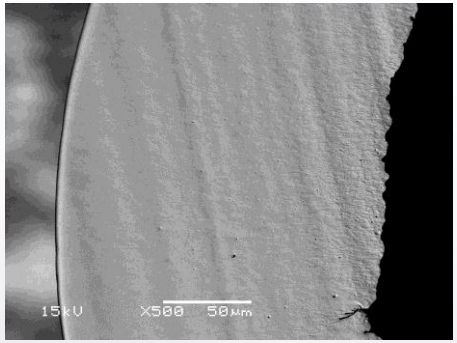
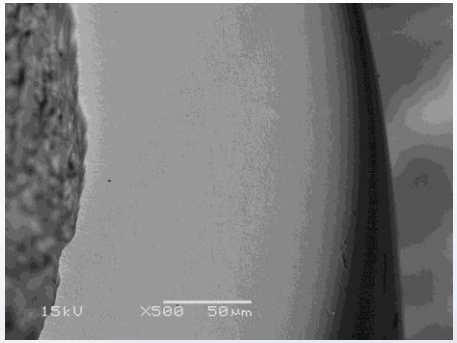
Throwing power decreases from outer edge to inner edge of tubing

all samples: 300 rpm and 300 mA

Backscatter electron images

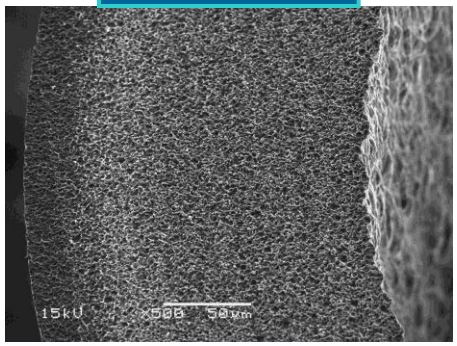
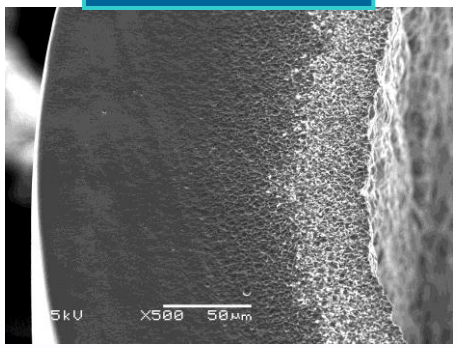
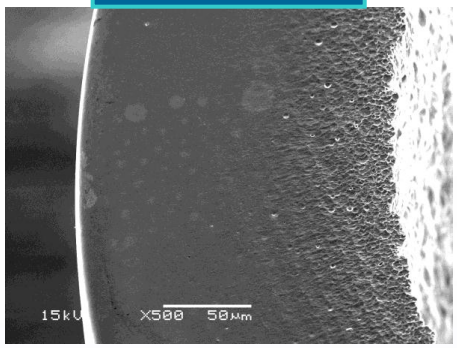
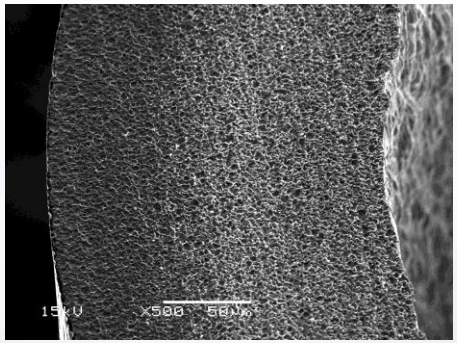
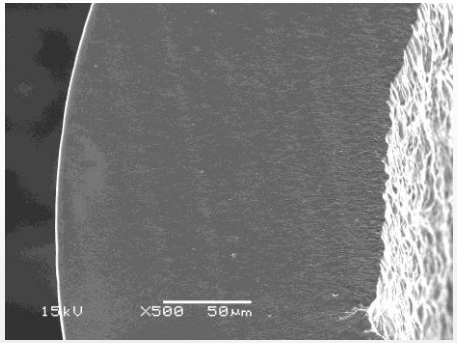
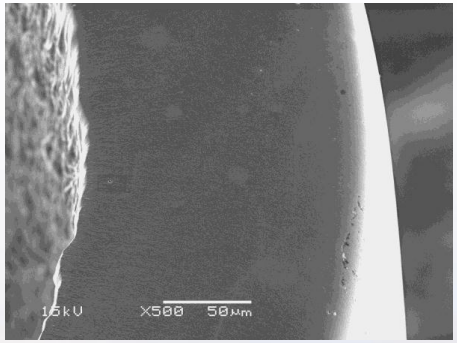
	1 minute	2 minutes	3 minutes
40 µm gap surface			
100 µm gap surface			

Optimum electropolishing parameters depend on gap size.

Throwing power decreases from outer edge to inner edge of tubing

all samples: 300 rpm and 300 mA

Secondary electron images

	1 minute	2 minutes	3 minutes
40 µm gap surface			
100 µm gap surface			

Optimum electropolishing parameters depend on gap size.

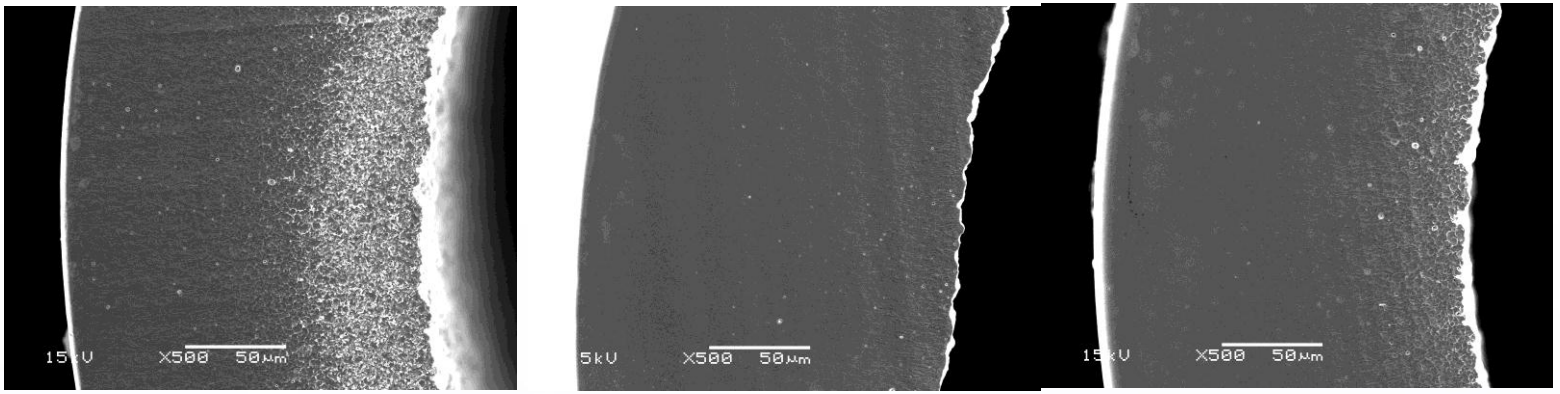
EDS* mapping shows electropolishing also removes tungsten particles from surface

40 µm, 2 minutes

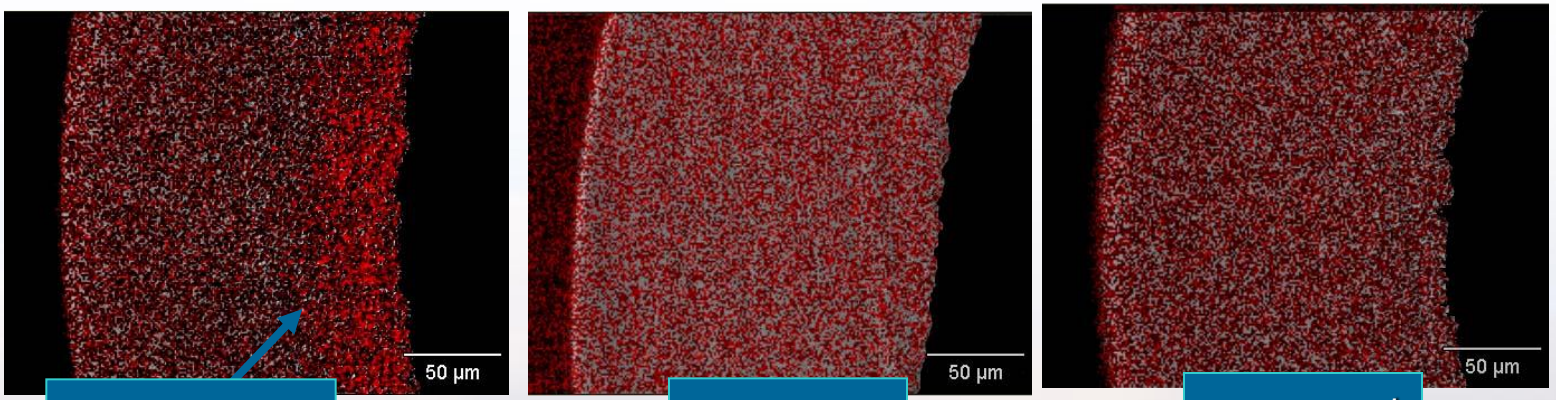
40 µm, 3 minutes

100 µm, 2 minutes

SEI



EDS W mapping



recast zone

no recast

no recast

* Energy Dispersive Spectroscopy

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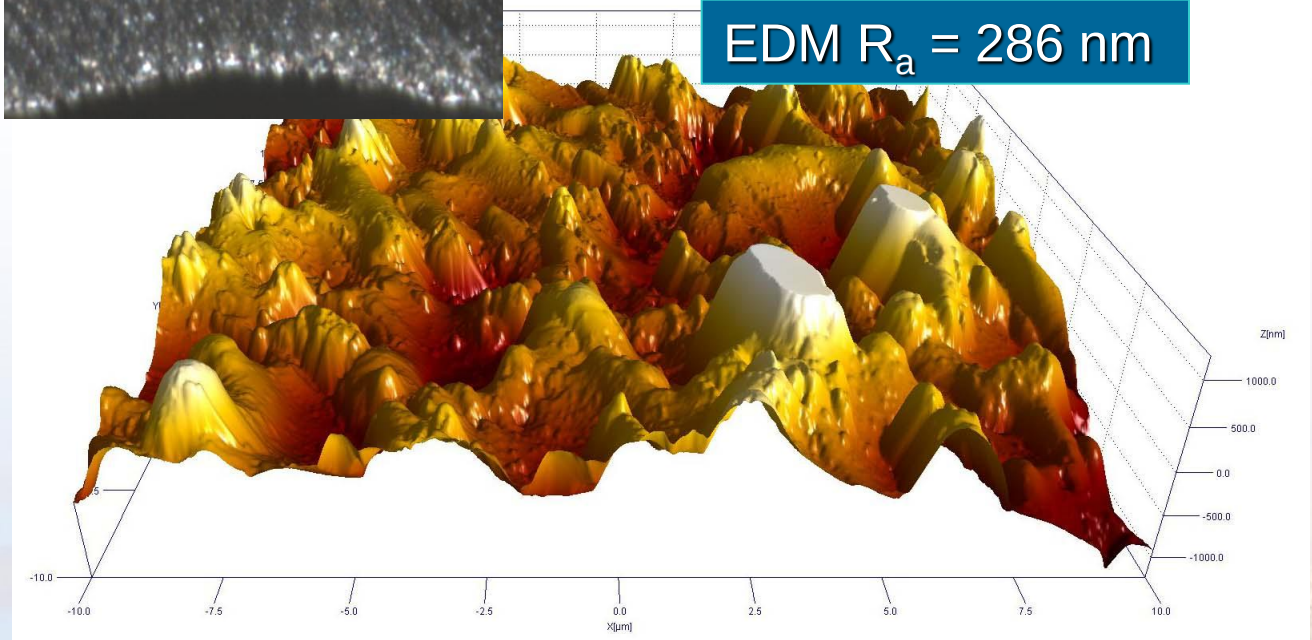
Surface roughness was measured by AFM at outer and inner edges for electropolished tubes

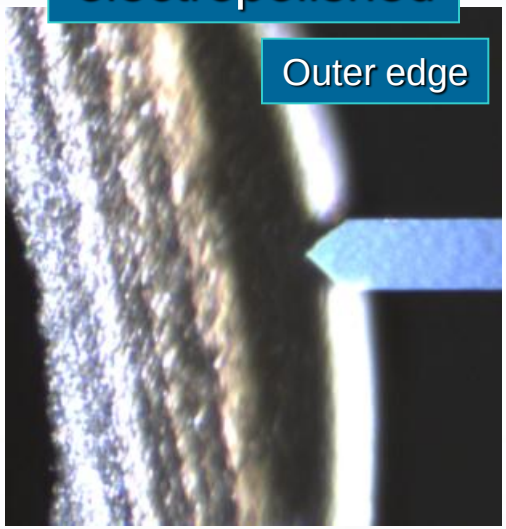
µWEDM

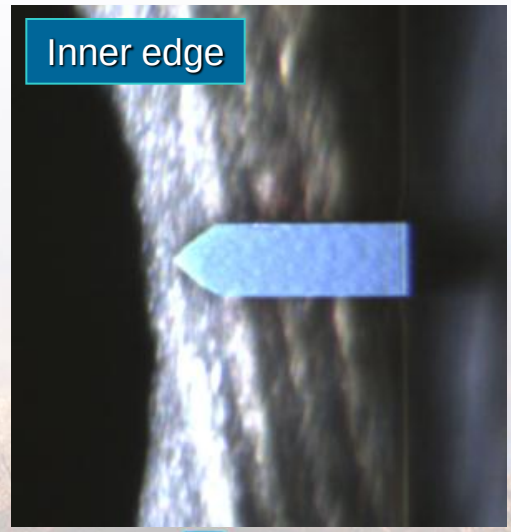
Veeco Dimension Icon AFM / TESPA tip
0.4 Hz Peakforce Tapping Mode
20 x 20 µm scan (512 x 512 pixels)

EDM R_a = 286 nm



electropolished





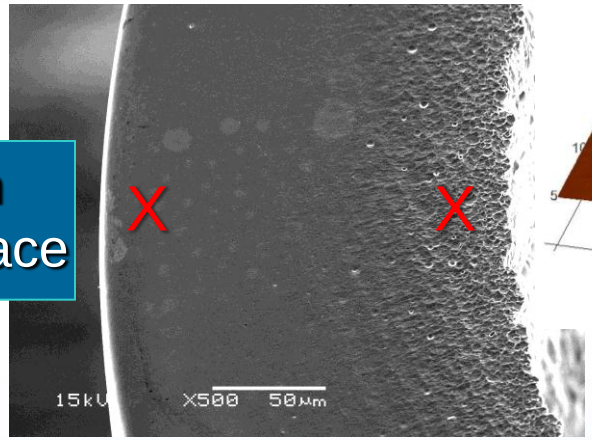
Effect of gap width on throwing power is evident at 3 minutes electropolishing time

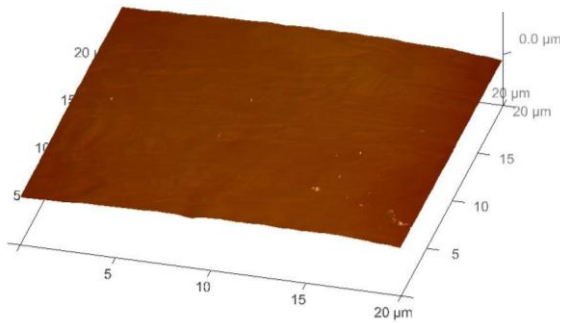
Epolish: 3 minutes, 300 rpm, 300 mA

Outer edge

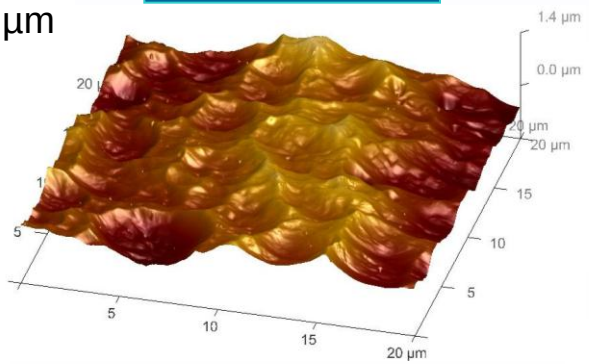
Inner edge

40 µm gap surface



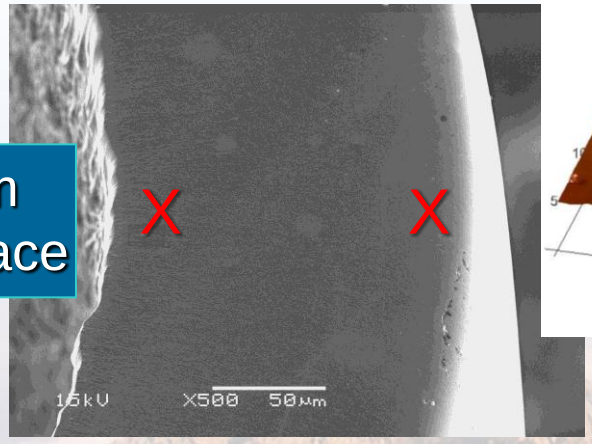


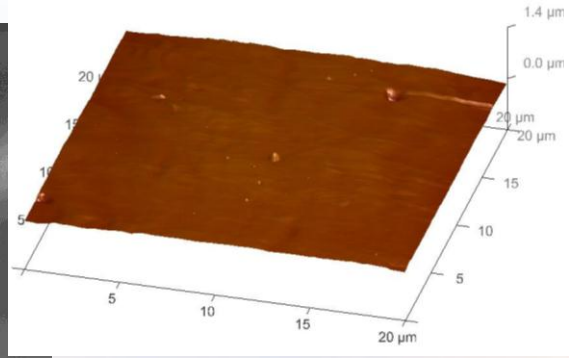
R_a = 34 nm



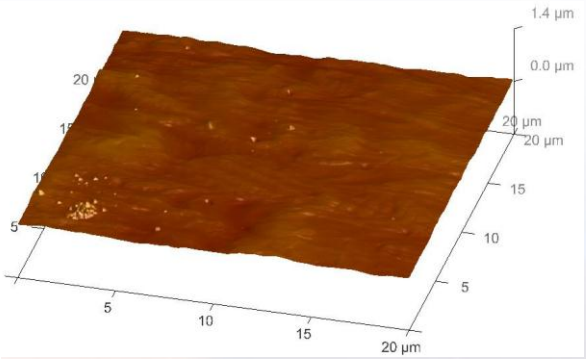
R_a = 219 nm

100 µm gap surface





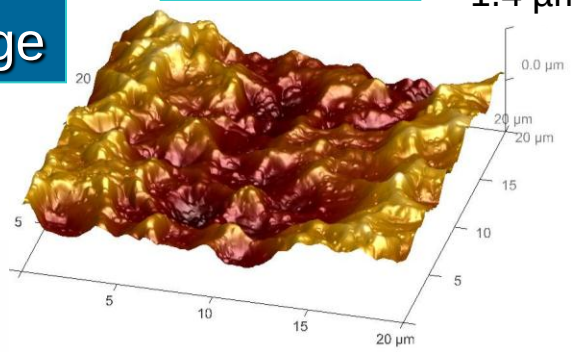
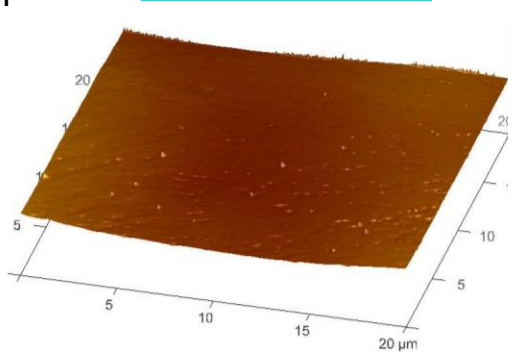
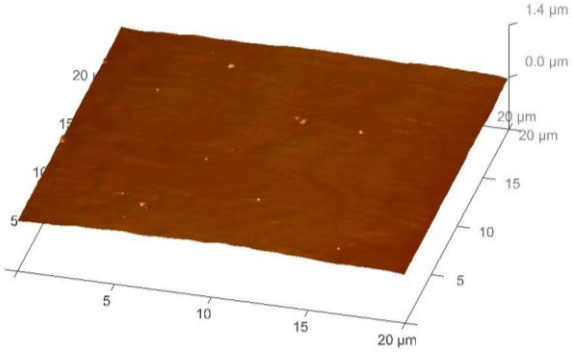
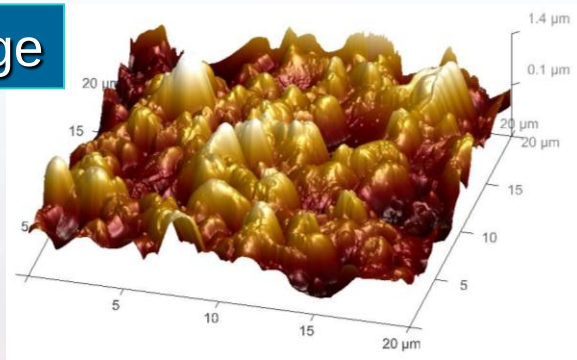
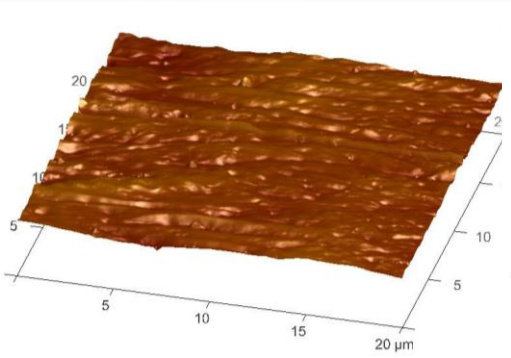
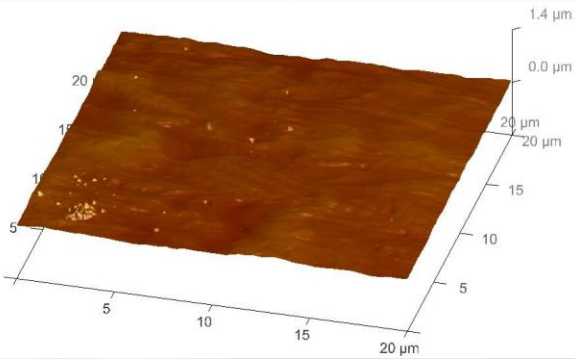
R_a = 30 nm



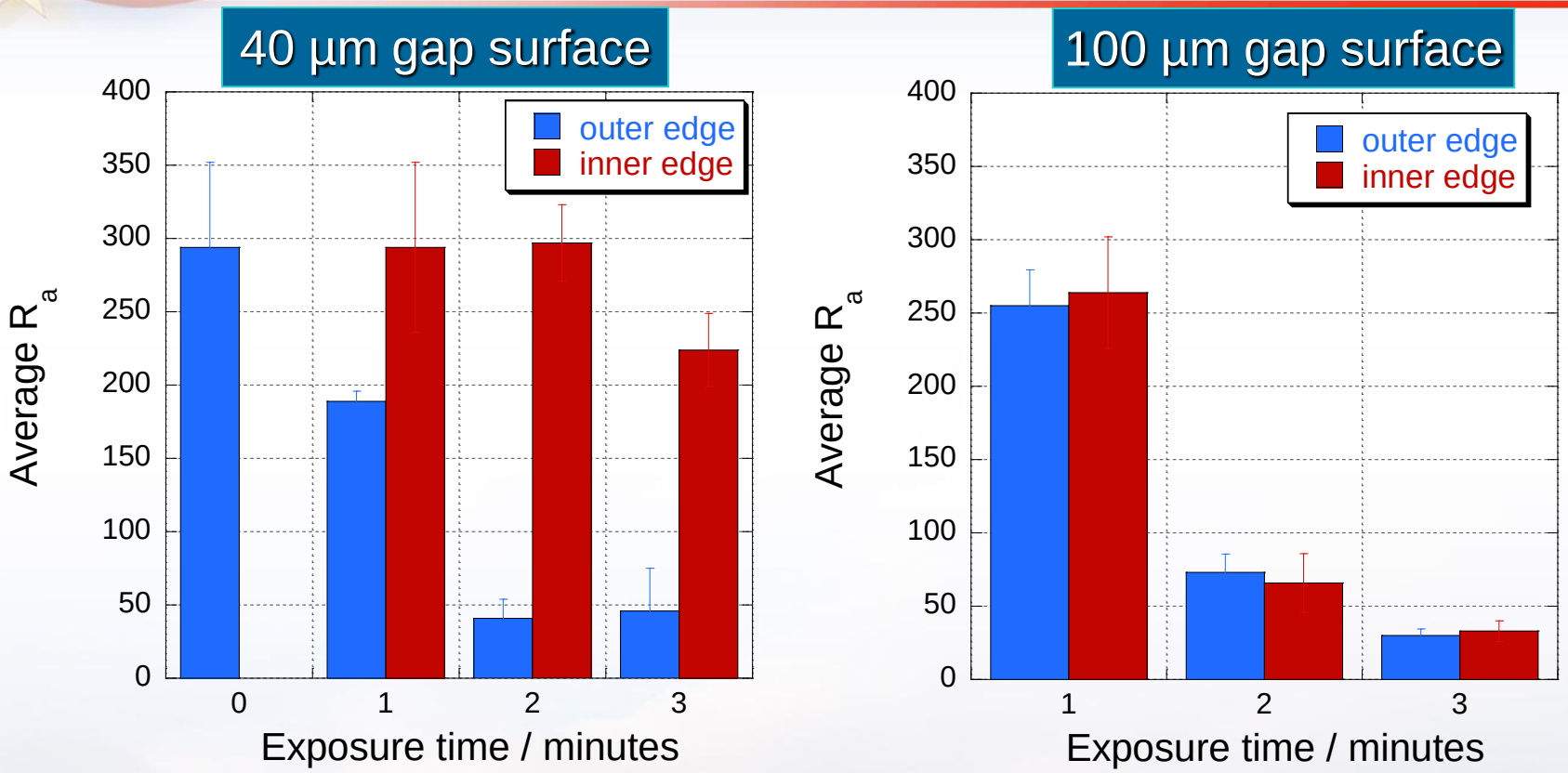
R_a = 33 nm

For a 100 µm gap, increased electropolishing time decreases surface roughness

300 rpm, 300 mA

	1 minute	2 minutes	3 minutes
Outer edge			
	R_a = 263 nm	R_a = 66 nm	R_a = 30 nm
Inner edge			
	R_a = 308 nm	R_a = 87 nm	R_a = 33 nm

Surface roughness comparisons



- At smaller gaps, increased polishing time will not produce a uniform surface finish.
- For large gaps, uniform surface roughness is maintained & reduced by increased polishing time.

Summary and Conclusions

- Electropolishing improves fatigue resistance of fs laser machined mesoscale springs.
- Electropolishing is effective at removing recast between simulated coil gaps.
- Optimum electropolishing parameters will vary depending on gap size.
  - 40 µm gap: 300 mA/cm^2 / 3 minutes (minimum)
  - 100 µm gap: 300 mA/cm^2 / 2 minutes (maximum)
- Surface roughness reduced by ~90% for 100 µm gap polished for 3 minutes
- In future work, fs pulsed laser surfaces & alternative spring materials (e.g. Nitinol, Elgiloy) will be examined.

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- Tony Ohlhausen – AFM
- Ana Trujillo – AFM
- Dick Grant - SEM

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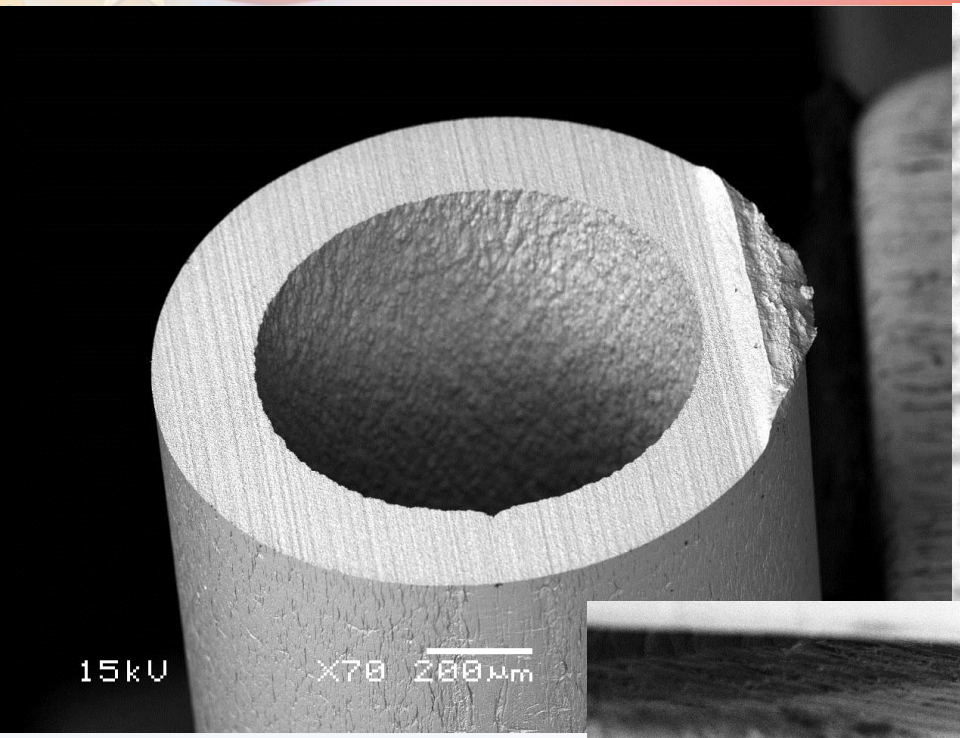
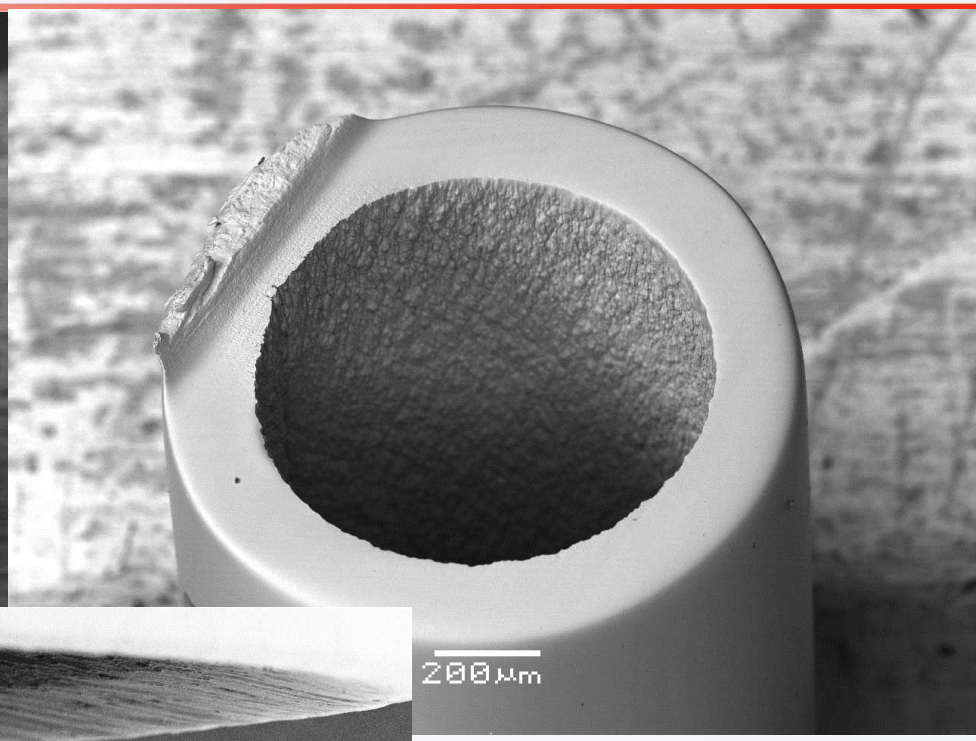
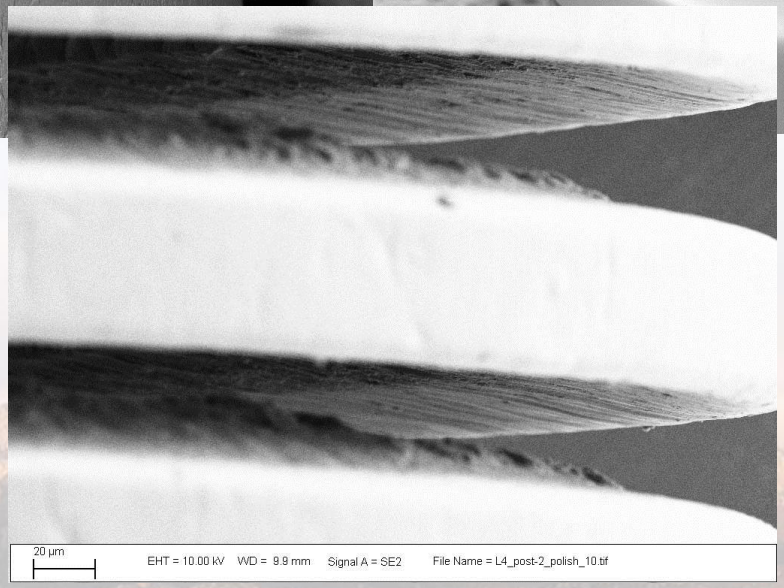
Questions?


15kV X70 200µm


200µm


20 µm
EHT = 10.00 kV WD = 9.9 mm Signal A = SE2 File Name = L4_post-2_polish_10.tif