Sandia National Laboratories

SAND2011-1292C

Surface Characterization of Mesoscale Springs

L.M. Serna, B.H. Jared, B.L. Boyce, and G.A. Knorovsky

Acknowledgements: M.A. Martinez, M.P. Saavedra, J.A. Ohlhausen, R.P. Grant

Sandia National Laboratories
PO BOX 5800-0888
Albuquerque, NM 87185

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

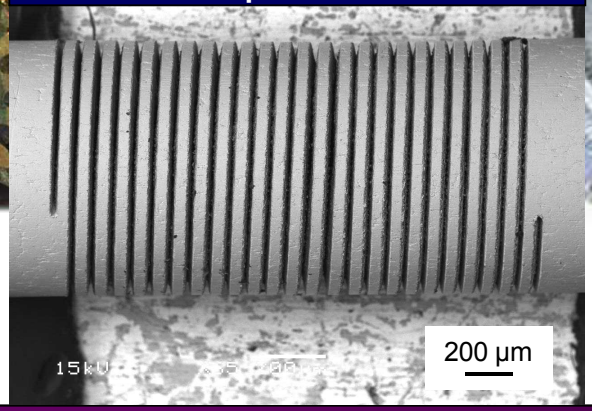
Mesoscale machining bridges the gap between miniature and micro-scale manufacturing processes

Metal machining → Silicon machining

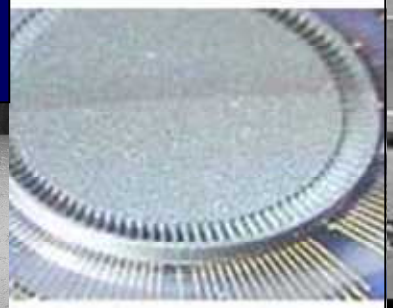
Miniature-scale

Meso-scale

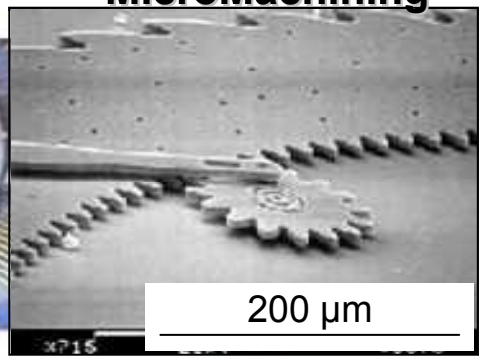
Pulsed laser machining and μWEDM*



Bulk Silicon



Surface MicroMachining



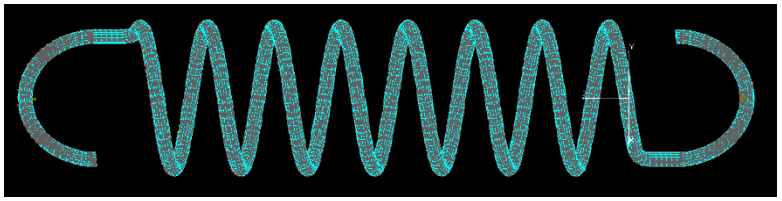
Dimensional tolerances decrease

± 10s μm ± X μm ± 0.X μm

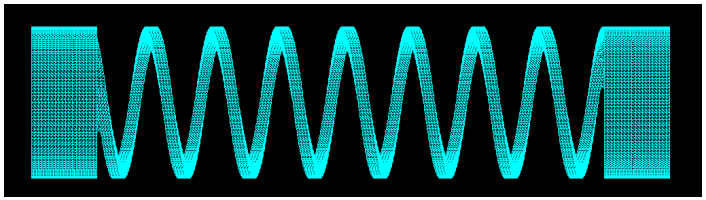
* Micro-wire Electrodischarge Machining

Mesoscale vs. conventional springs

- **Conventional (coil wound)**
  - 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

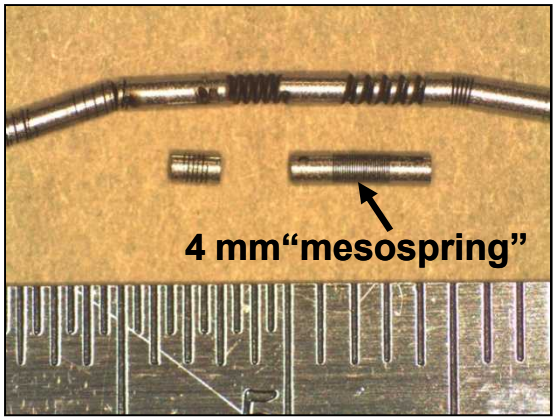


- **Mesospring**
  - Precision machining (fs* & ns+ pulsed lasers and μWEDM) can be used to produce springs with lower uncertainties
  - Key design parameters: size, stiffness, fatigue life & cost
  - Electropolishing can provide surface remediation

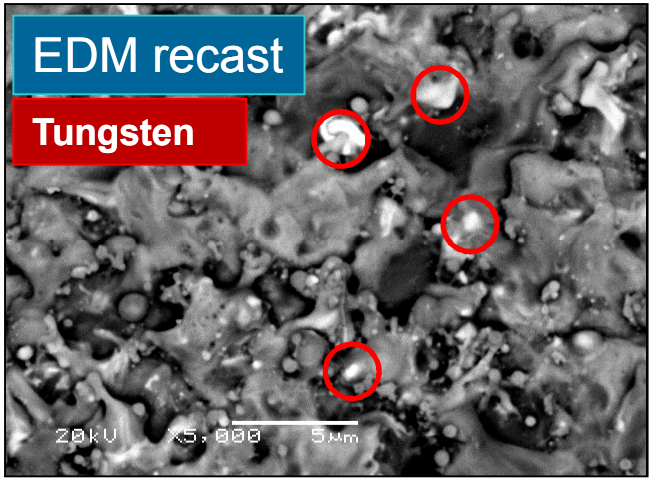


μWEDM uses spark erosion to create small, intricate parts and achieve tight tolerances

- **Advantages:**
  - Independent of material hardness
  - Little / no distortion of thin parts
  - Minimal heat affected zone



- **Disadvantage:** ***“recast”***
  - Thin layer (~2 microns) of re-solidified part material and traces of wire material
  - Adversely affects fatigue resistance and wear particle generation



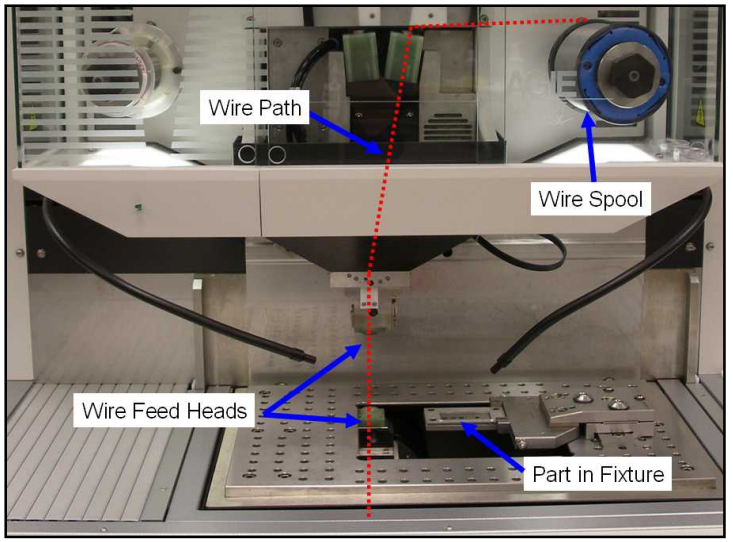
Surface finish affects small mechanism performance, reliability and lifetime.

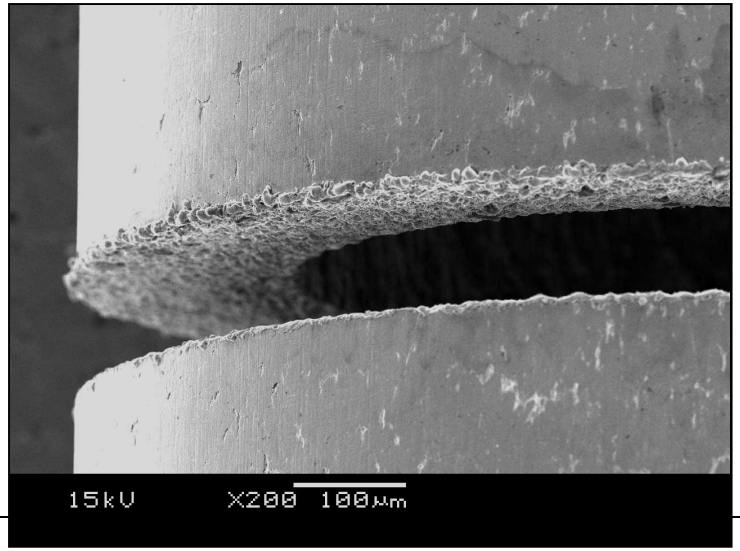
μWEDM Experimental Details

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

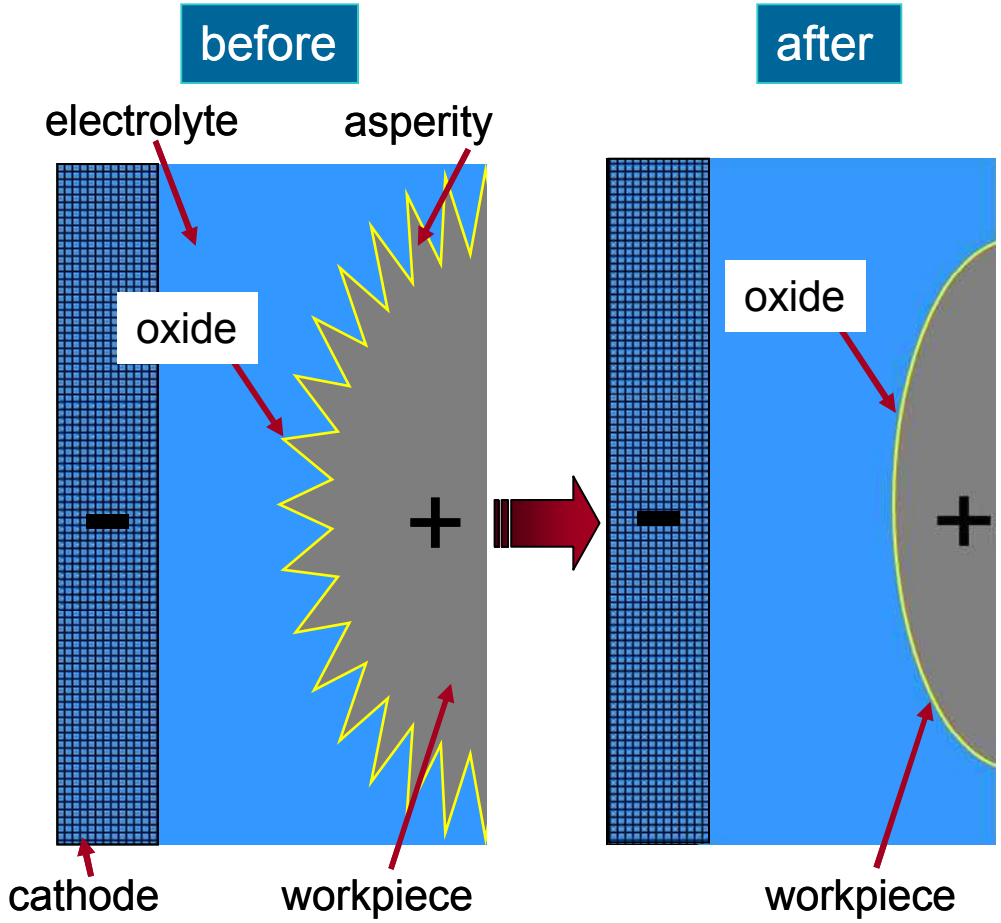
- **Agie Vertex 1F EDM machine**
  -"technologies" i.e., proprietary process parameters
  - AC pulse generating circuit
  - 20 μm tungsten wire
  - Dielectric – deionized water

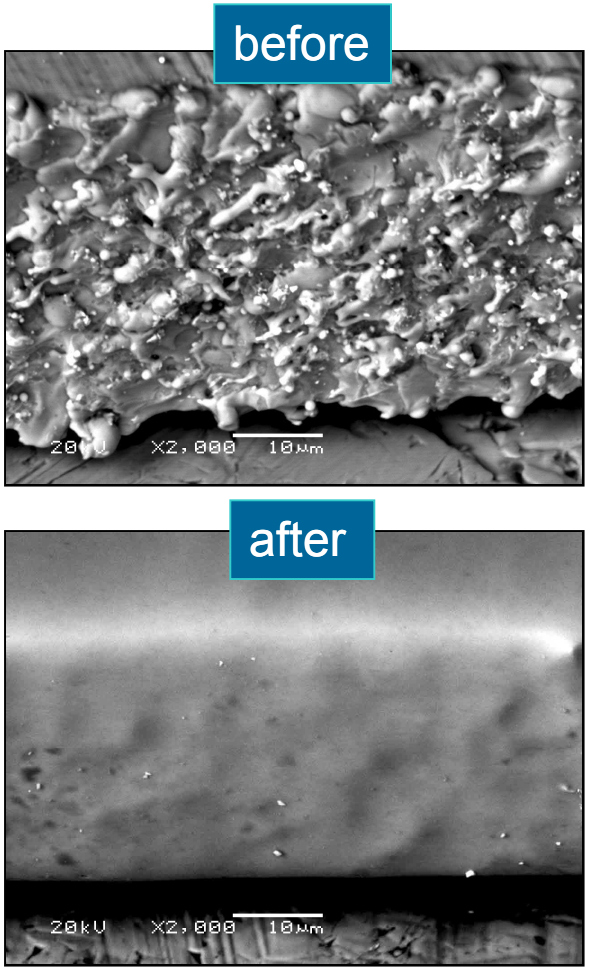
- **Wire gap distances (μm)**
  Main pass = 13-15
  Trim pass =10-12





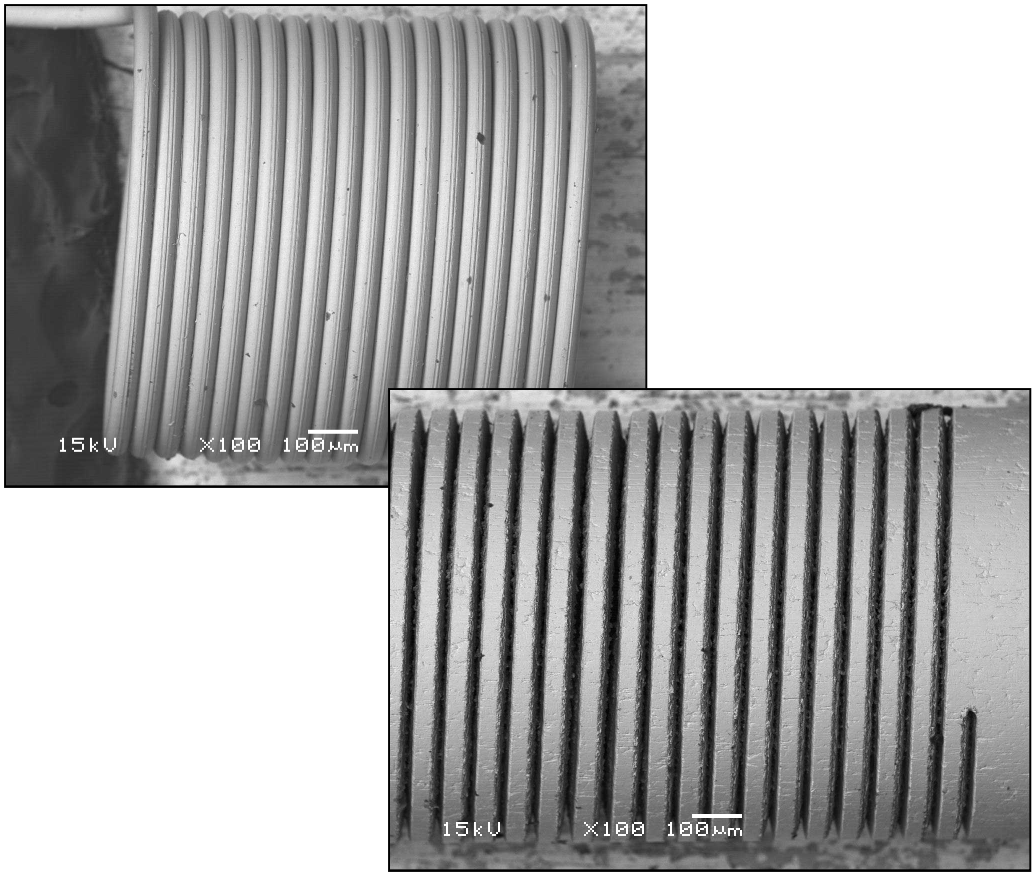
Electropolishing can improve surface finish by removing asperities





Sandia National Laboratories

Geometry of mesospring vs. coil wound spring

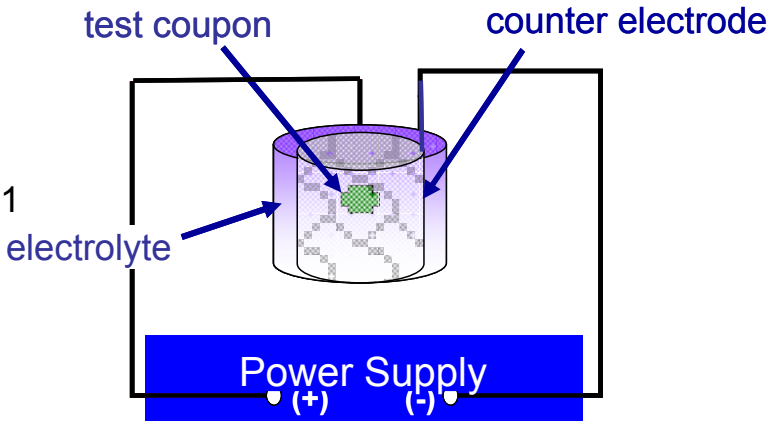


Coil wound spring	
diameter, in	0.046
wire dia, in	0.004
total length, in	0.162
# of coils	9.5
Mesospring equivalent	
tube dimensions, in	0.050 OD x 0.008 W
coil / strut thickness, in	0.0022
total length, in	0.157
# of coils	15

Mesosprings: what is effect of gap size on electropolishing throwing power?

Electropolishing Experimental Details

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

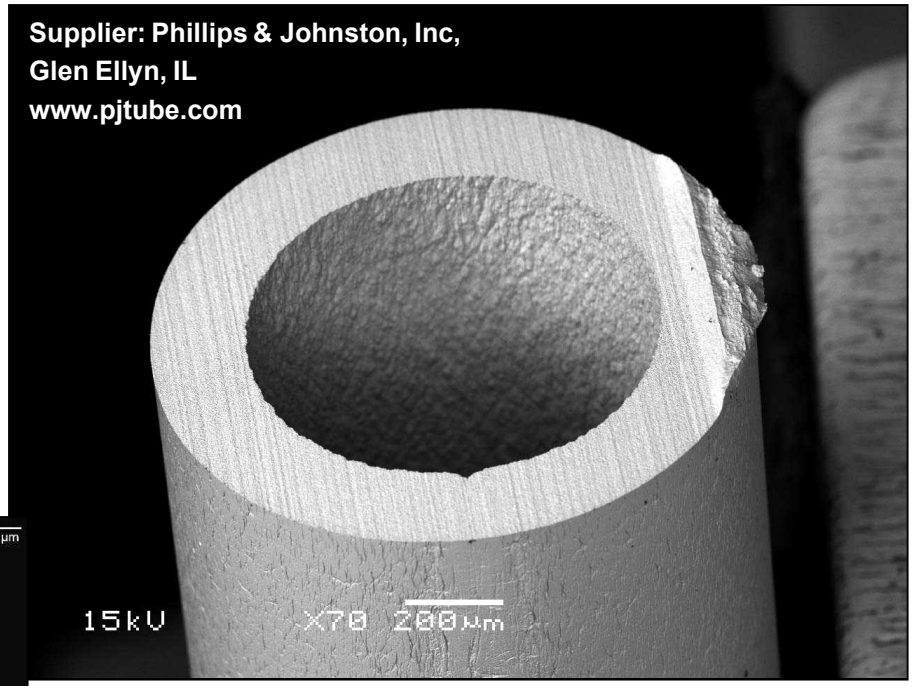


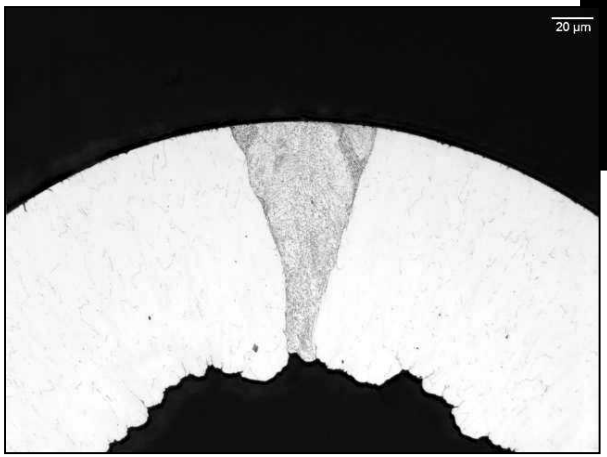
300 rpm	300 mA	400 mA	500 mA
1 minute	X	X	X
2 minutes	X	X	X
3 minutes	X		

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

Commercially available hypodermic needle tubing was used for this study

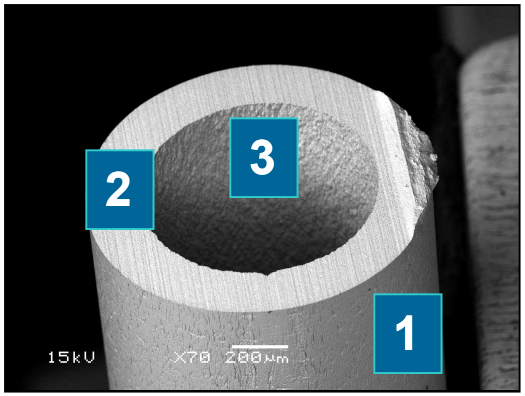
- 304 stainless steel
- OD = 0.050” ± 0.005”
- ID = 0.033” ± 0.0015”
- Wall = 0.008” (~200 µm)
- Gas arc resistance welded (GARW)

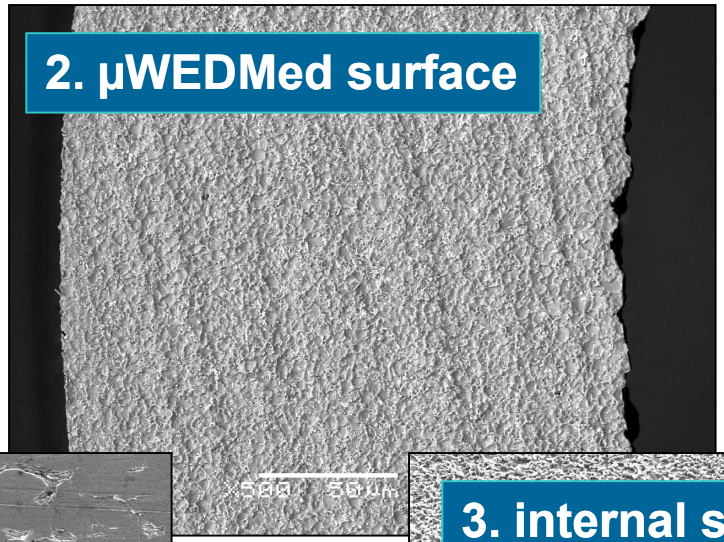


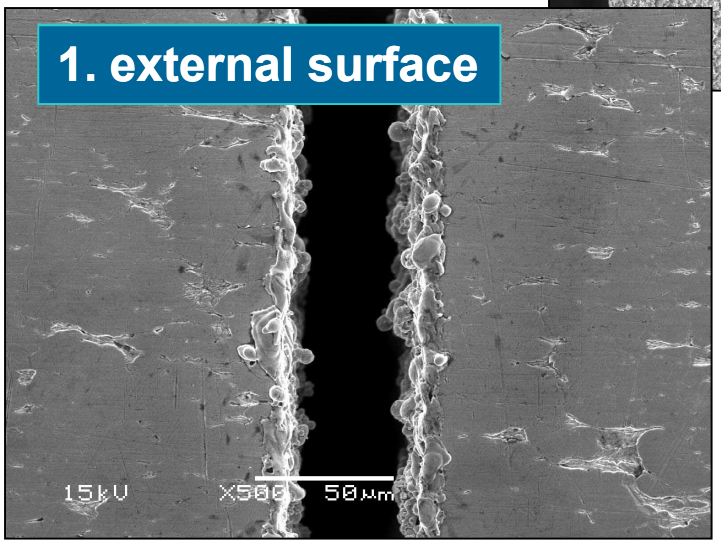


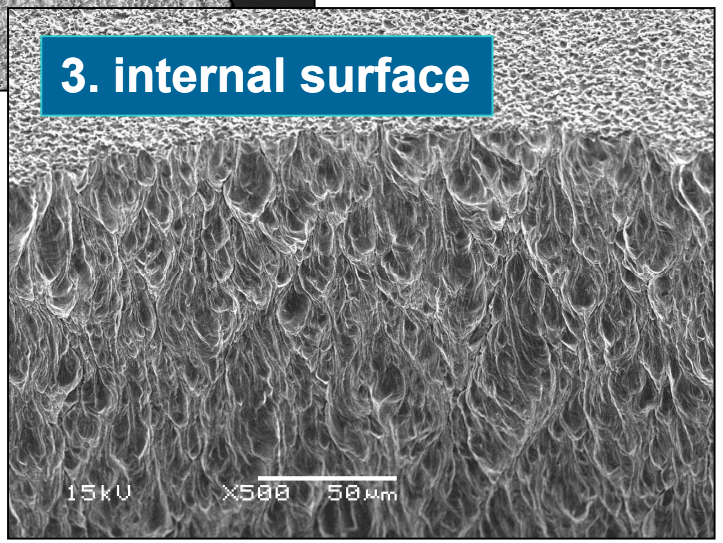
Sandia National Laboratories

Three distinct surface morphologies were observed on machined hypodermic needle



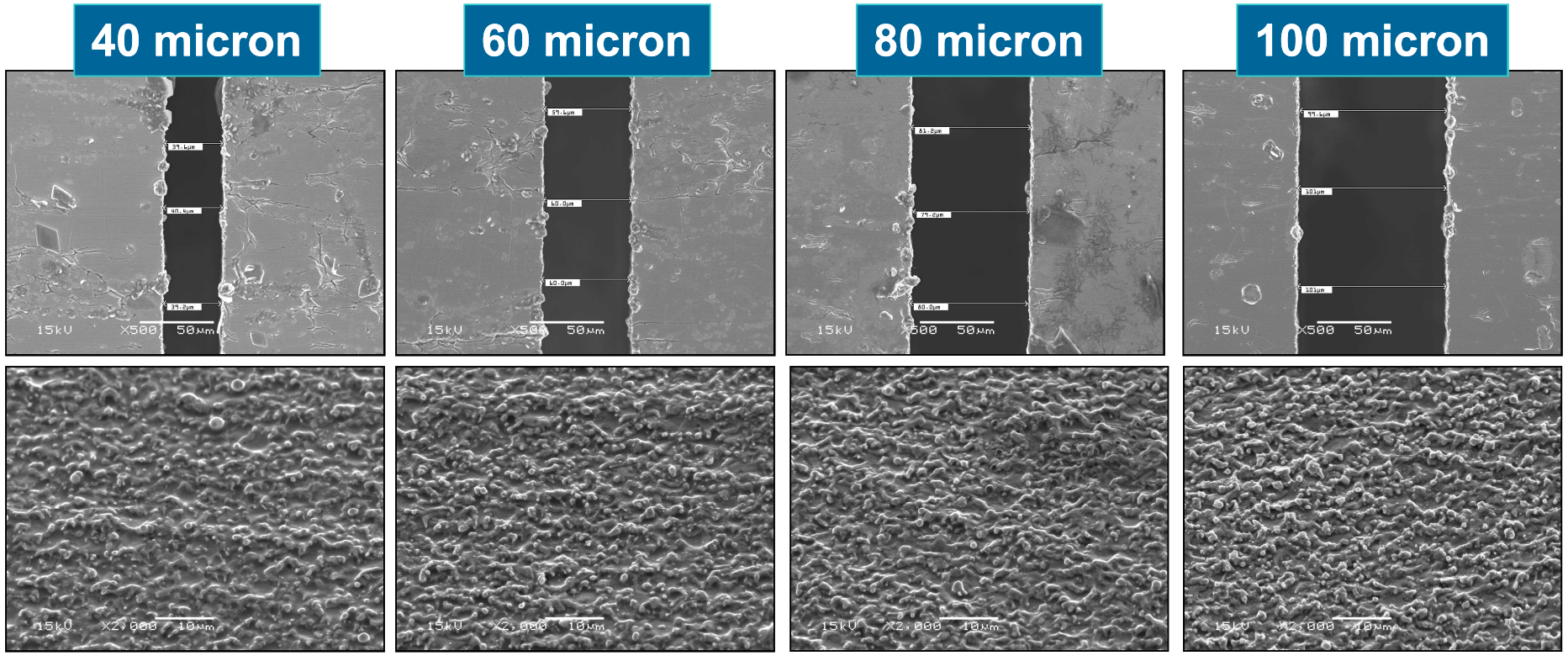






Sandia National Laboratories

Gap size was varied by EDM to determine electropolishing throwing power



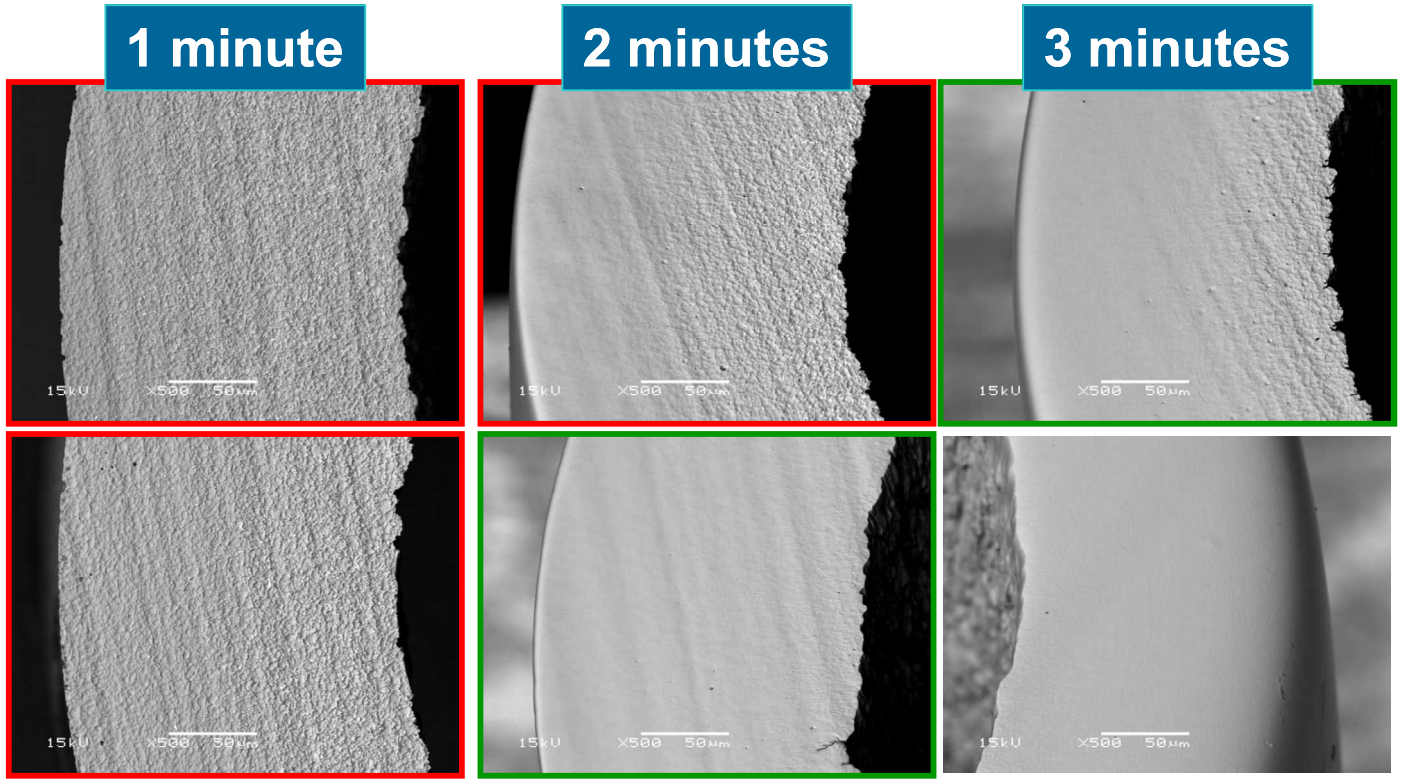
Gap size does not affect as machined surface finish (Ra ~ 300 nm).

Sandia National Laboratories

Minimal recast removal occurs at low current and short immersion time

all samples polished at 300 mA

Backscatter Electron images

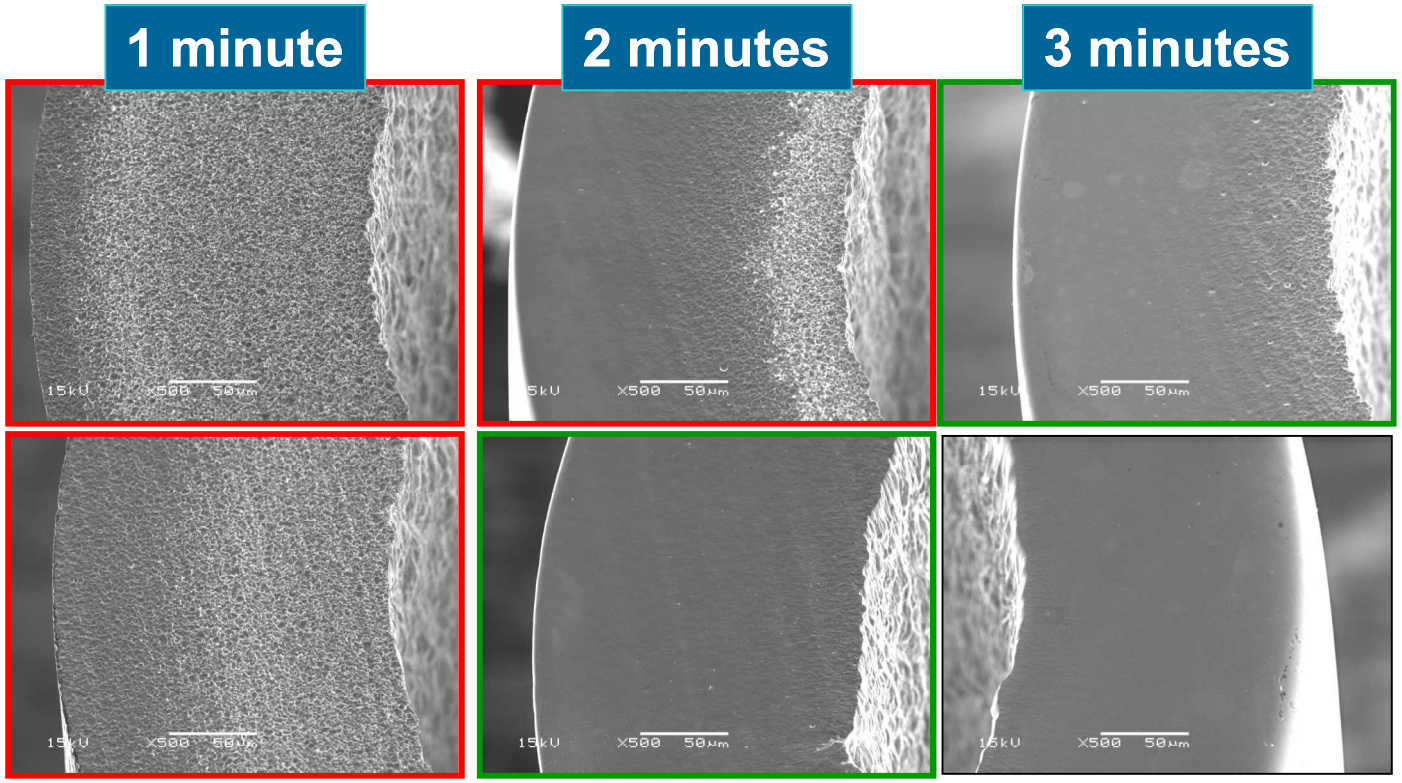


Optimum electropolishing parameters will vary depending on gap size.

Minimal recast removal occurs at low current and short immersion time

all samples polished at 300 mA

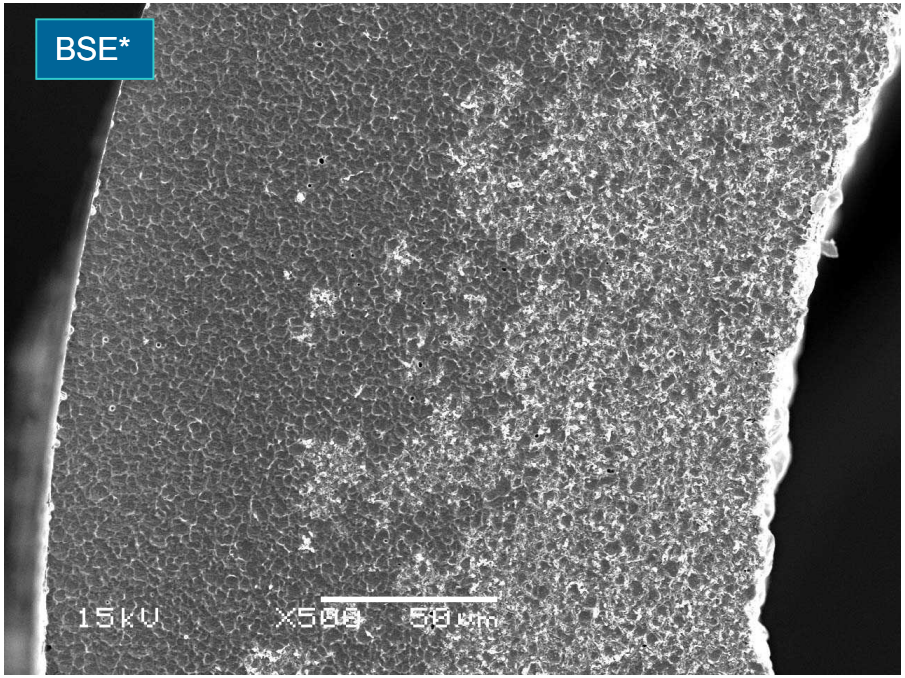
Secondary Electron images

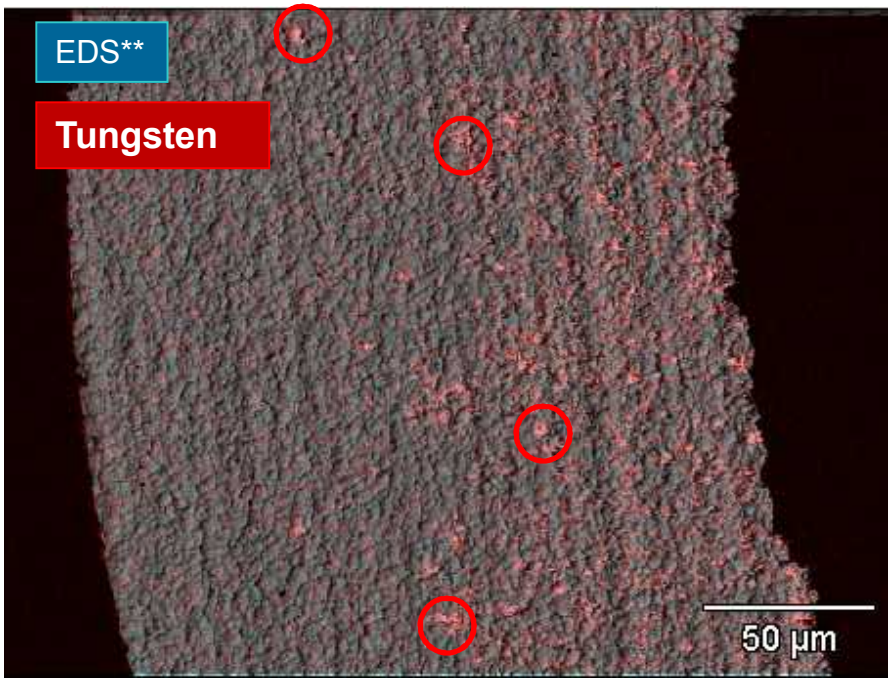


Optimum electropolishing parameters will vary depending on gap size.

Electropolishing removes tungsten particles from surface

Note: similar areas are shown





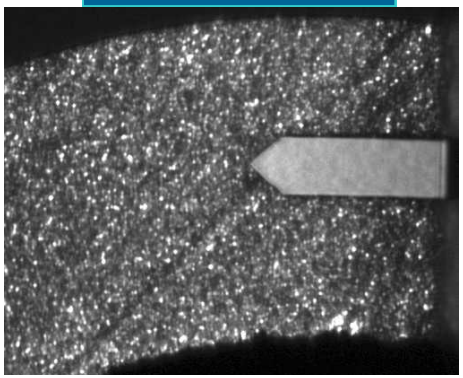
150 mA, 1 minute

* Backscatter Electron (image)

** Electron Dispersive Spectroscopy

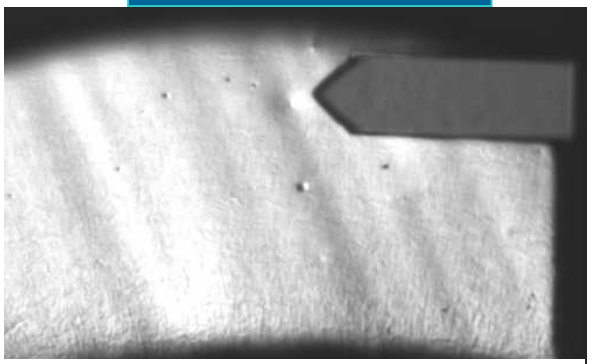
Surface roughness measurements were obtained by AFM*

as machined

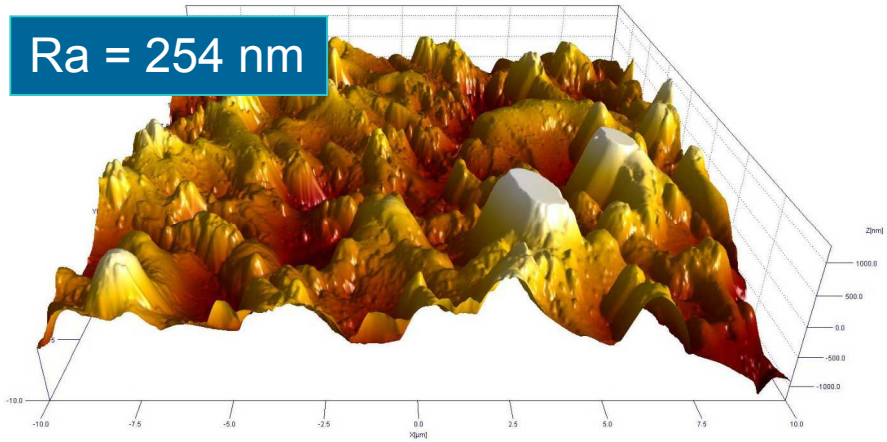


Veeco Dimension Icon AFM / TESPA tip
20 x 20 μm scan (512 x 512 pixels)
0.4 Hz Peakforce Tapping Mode

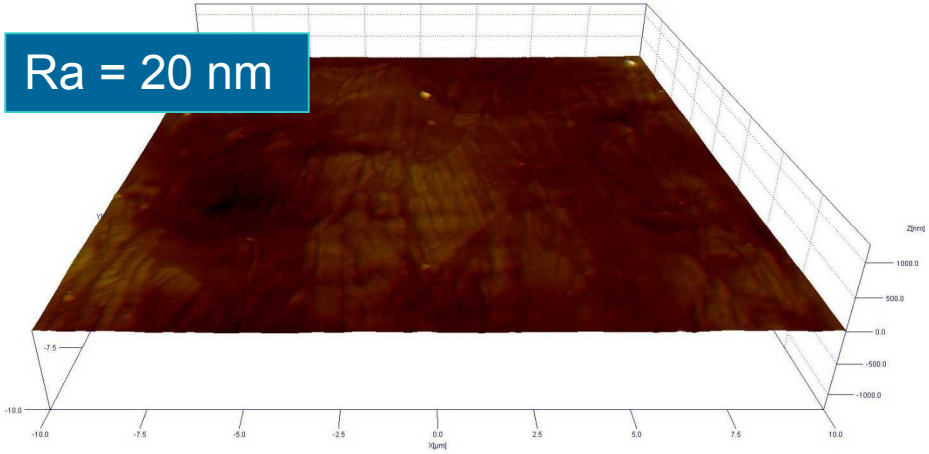
electropolished



Ra = 254 nm



Ra = 20 nm



Electropolishing can produce a smooth surface with minimal roughness.

* Atomic Force Microscopy

Sandia National Laboratories

Summary and Conclusions

- Electropolishing is effective at removing recast between simulated coil gaps.
- Optimum electropolishing parameters will vary depending on gap size.
- Parameter limits were identified:
  - 40 mm gap: 300 mA / 3 minutes combination is minimum requirement
  - 100 mm gap: 300 mA / 2 minutes combination completely removes recast layer (maximum)
- Surface roughness is reduced by approximately 90%
- Electropolishing of internal surface will be explored.

Sandia National Laboratories

Questions?