# Surface Characterization of Micro-EDMed and Electropolished Metal Micro-parts

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# Presentation Outline

- ## Motivation
- ## Process Descriptions
  - Micro-Electrical Discharge Machining
  - Electropolishing
- ## Results: SEM and Optical Interferometry
  - 302 stainless steel
  - Inconel 718
  - Ti-6Al-4V
- ## Summary

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# MicroElectroMechanical Systems (MEMS) encompass a wide range of size scales and a variety of fabrication techniques
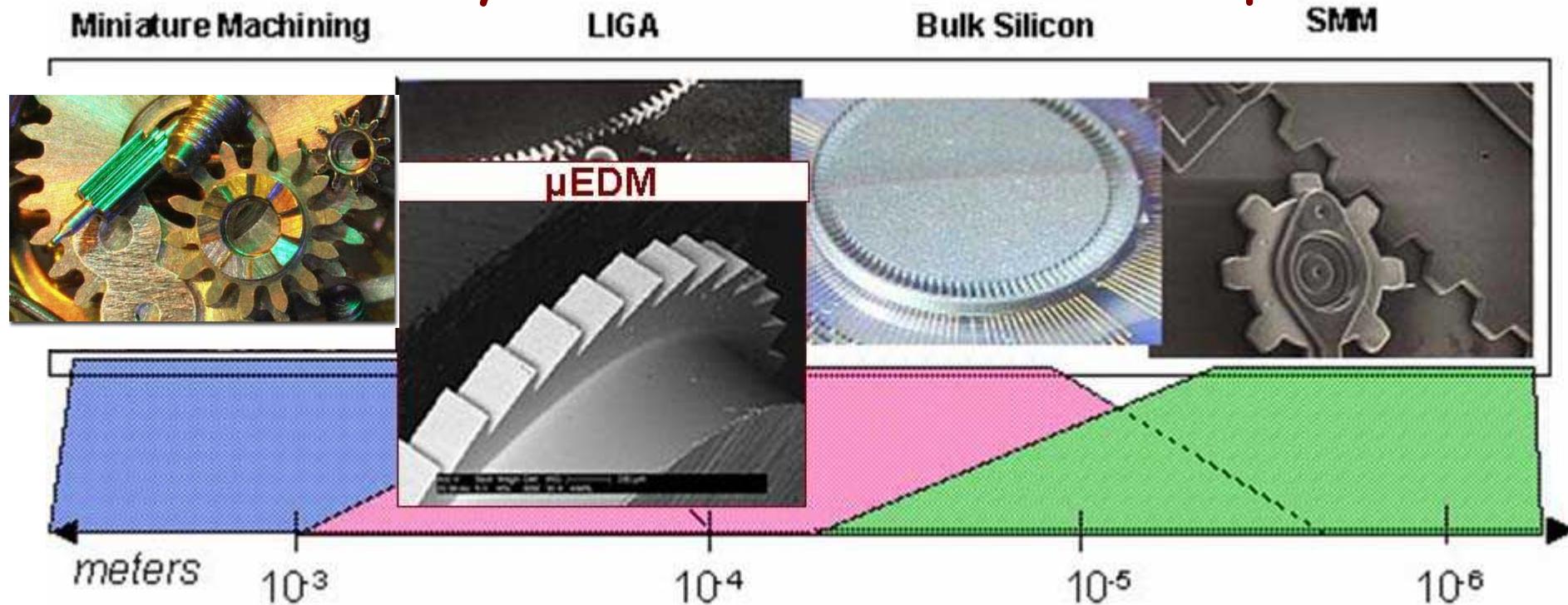


μEDM is enabling the creation of parts for advanced development mechanisms.

# μEDM uses spark erosion to create intricate parts and achieve tight tolerances

- Variables:
  - wire diameter
  - gap distance
  - voltage
  - spark rate

- Key advantage: applies very little force to part preventing distortion

- μEDM always produces a thin "recast" layer on the machined surface

wire supply reel

wire diameter, 20 μm

V

workpiece

spark gap, 10 μm

workpiece

wire take-up reel

Agie Vertex EDM

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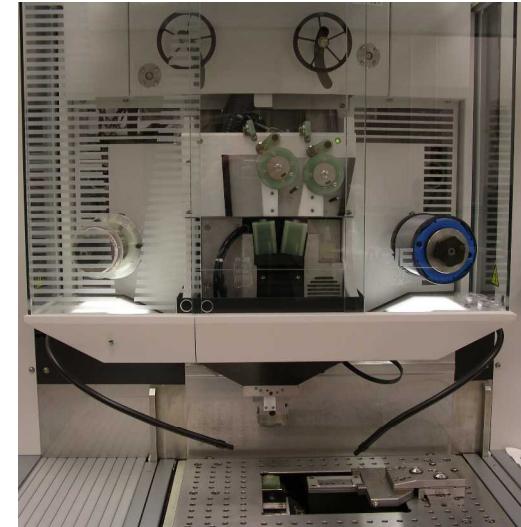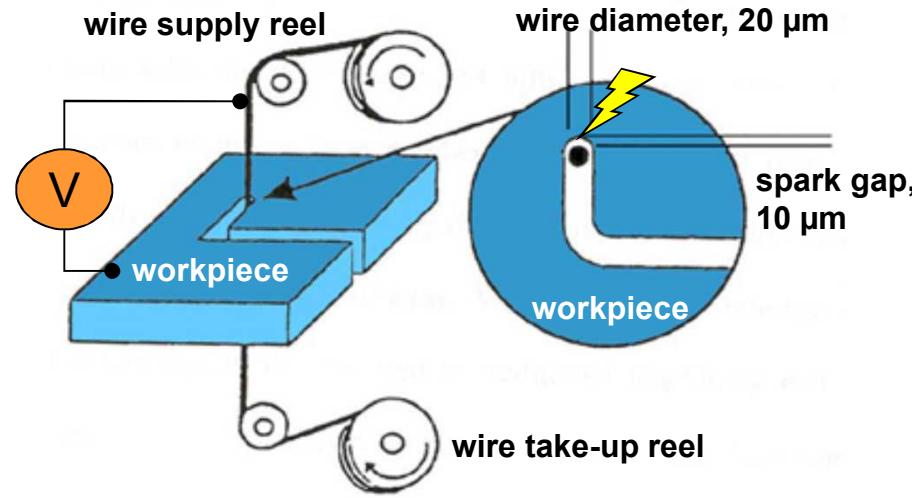
# Why remove the recast layer?

Surface finish is a critical factor which affects:



➤ Friction behavior

➤ Coverage and adhesion
  of coatings (e.g. DLN)

➤ Wear particle generation

➤ Layer is in tension resulting in small cracks which increase fatigue susceptibility.
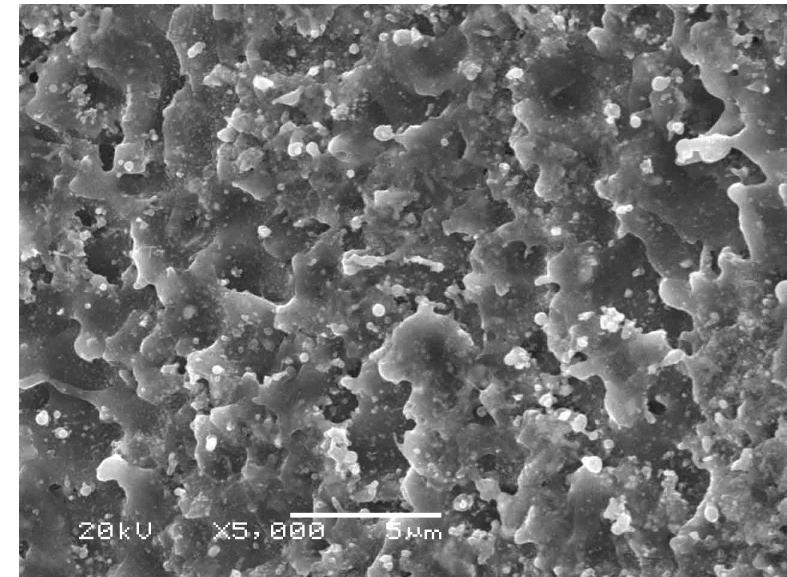
The recast layer is a thin layer (2 microns) of primarily re-solidified part material.

# EDS of recast layer on Inconel 718 machined with tungsten wire



Tungsten

INC718

Tungsten + INC718

Tungsten

INC718

Tungsten

Tungsten+ INC718

Tungsten

20kV  X5,000  5μm

**Typical Tungsten Spectrum**

Full scale counts: 3611    Area_3_3_02BC_pt3

W

**Typical INC718 Spectrum**

Full scale counts: 2071    Area_3_3_02BC_pt8

Ni
Cr
Fe
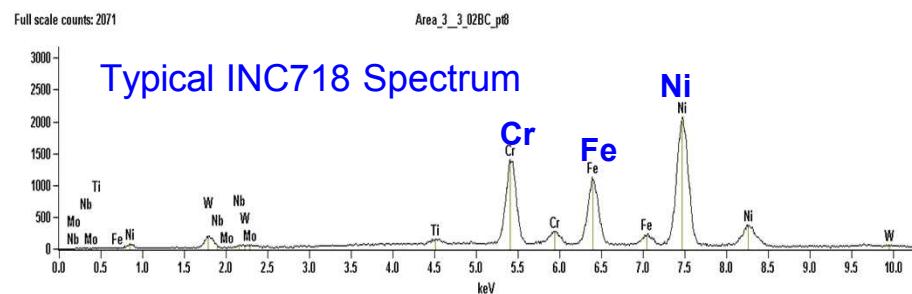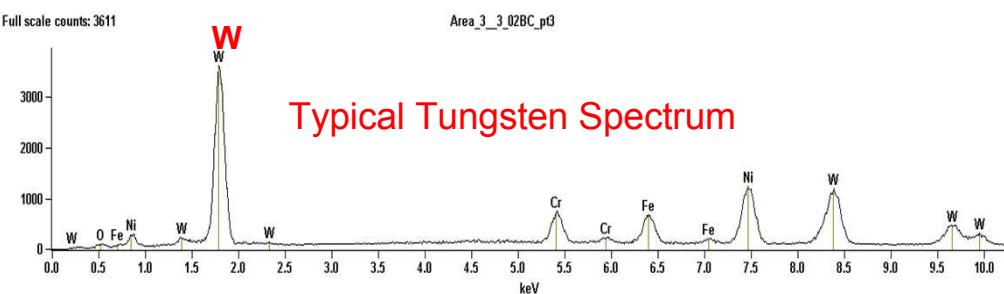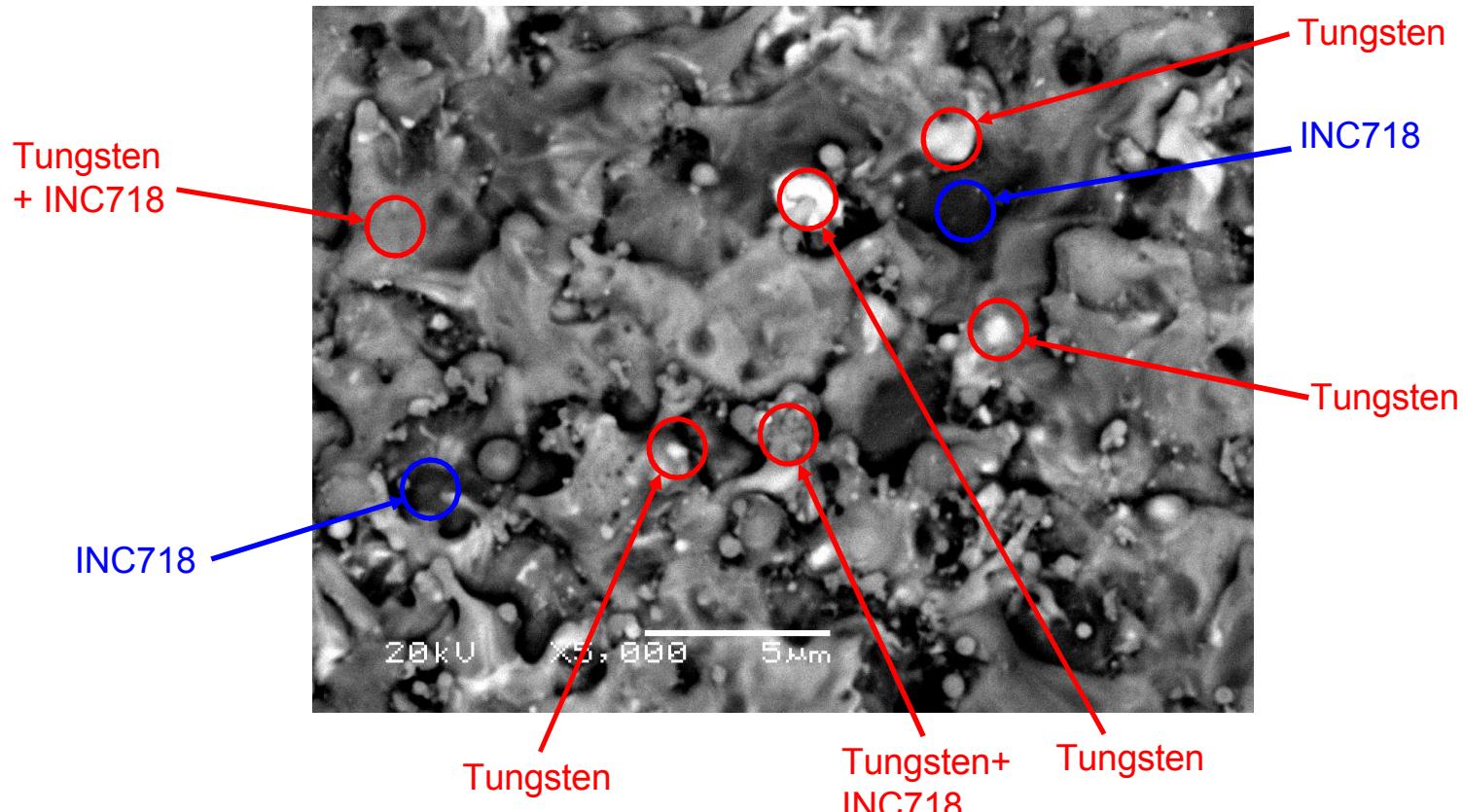
# Electropolishing Set-up

**Variables:**
- Solution
- Temperature
- Current
- Immersion Time

sample

counter electrode (platinized Nb mesh)

**Multimeter (+)       (-)**

**HP Power Supply (+)        (-)**

W wire contact spring

sample

302SS
80/20 $H_3PO_4$/n-butanol
70°C

polishing

etching          pitting

I / Amps

E / Volts

0.3

0.2

0.1

0

2      2.25      2.5      2.75      3
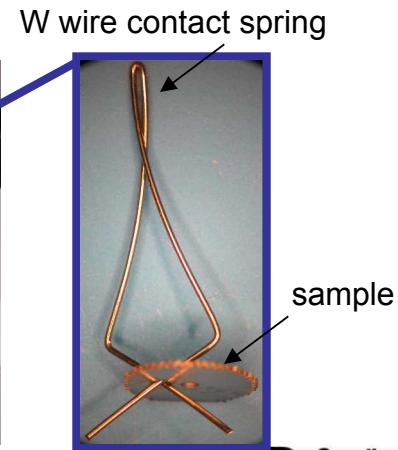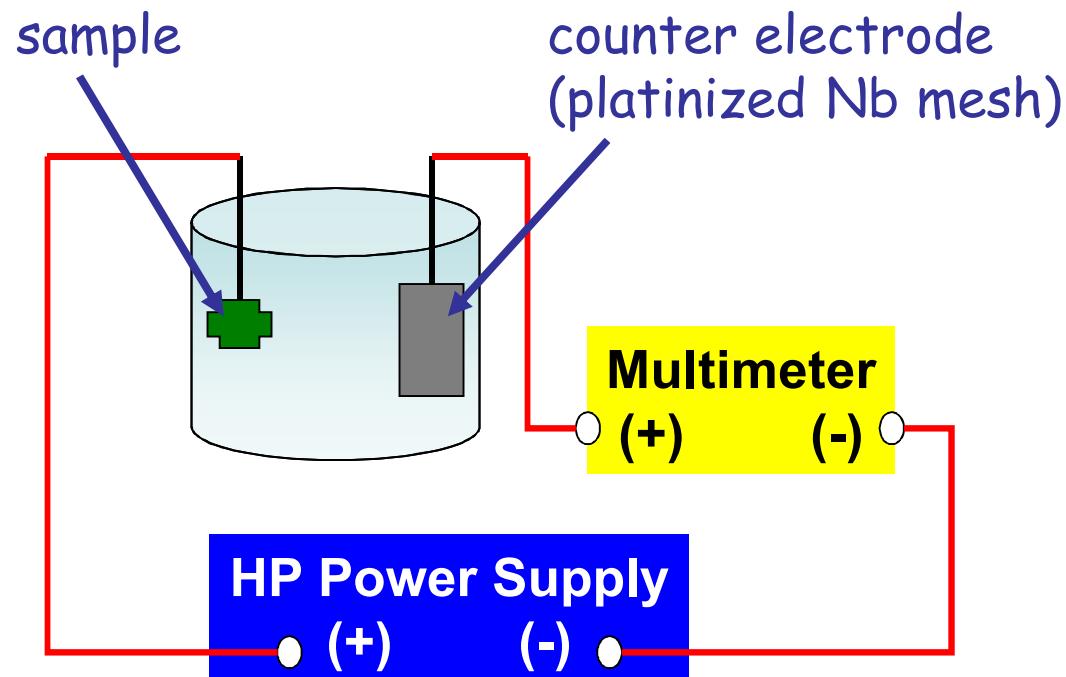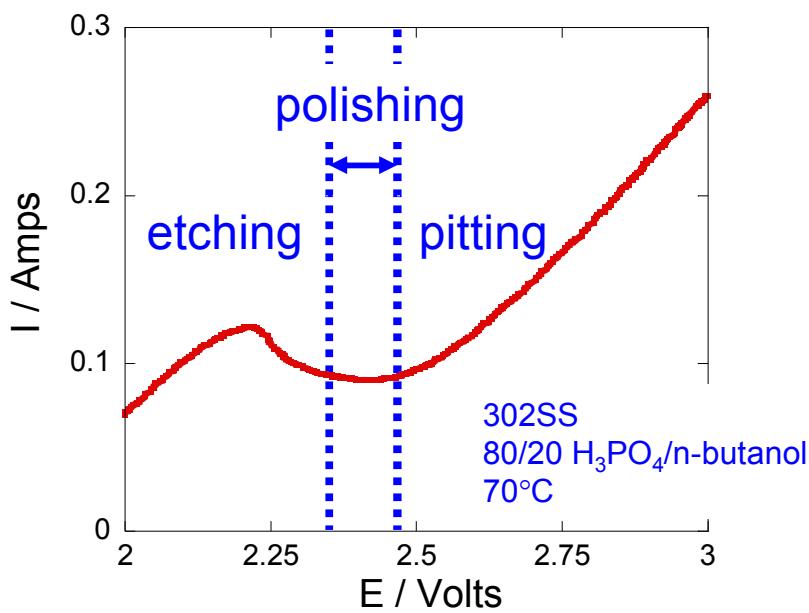
# The challenge is to remove the recast layer and maintain tight part tolerances
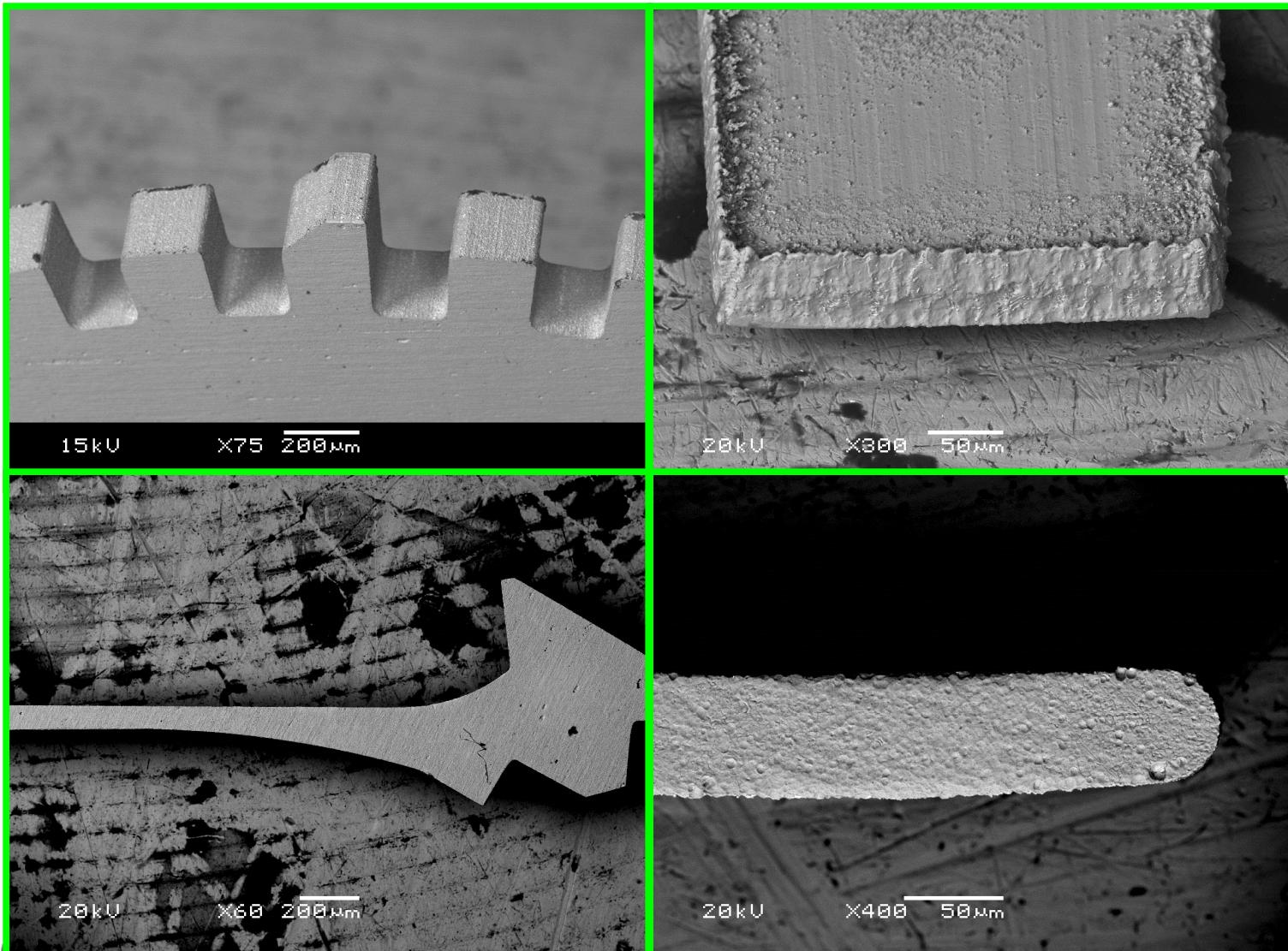
# Electropolishing results:
## the good, the bad and the ugly
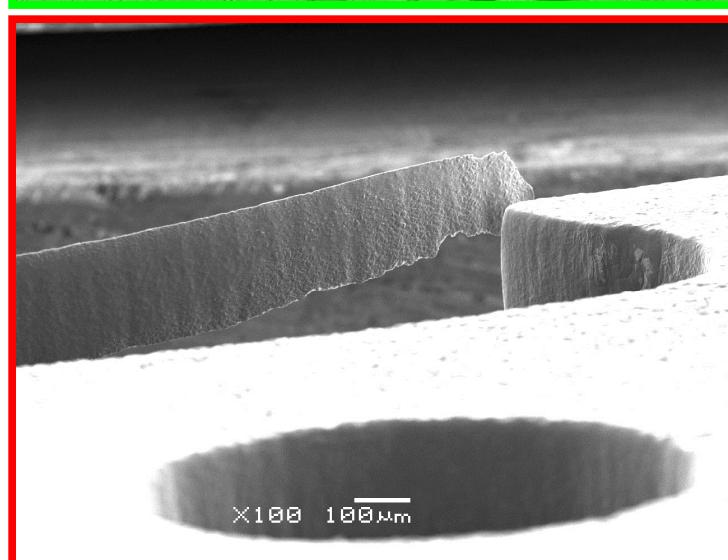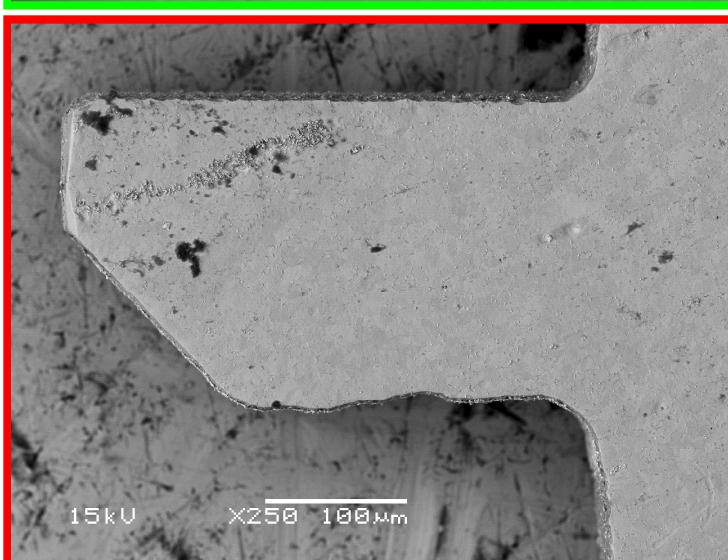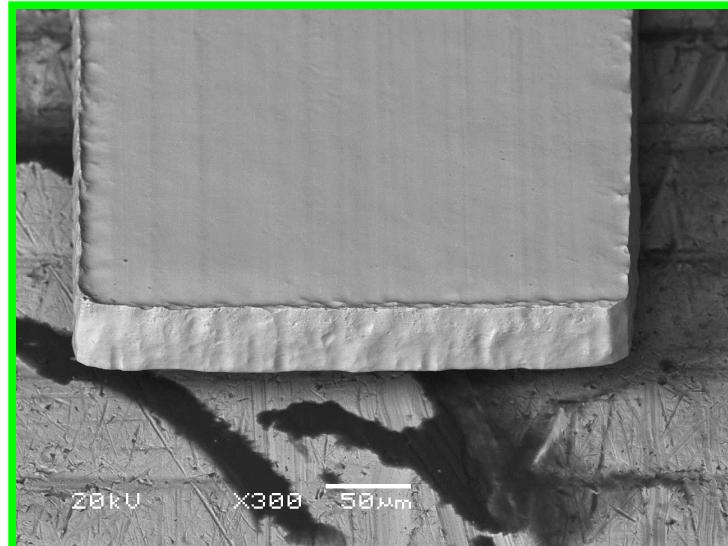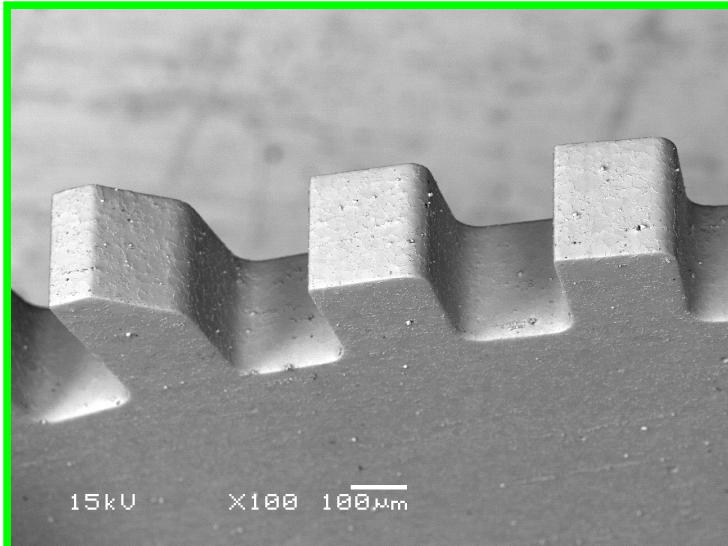
# A test part was designed with features that mimic actual design
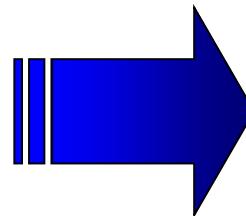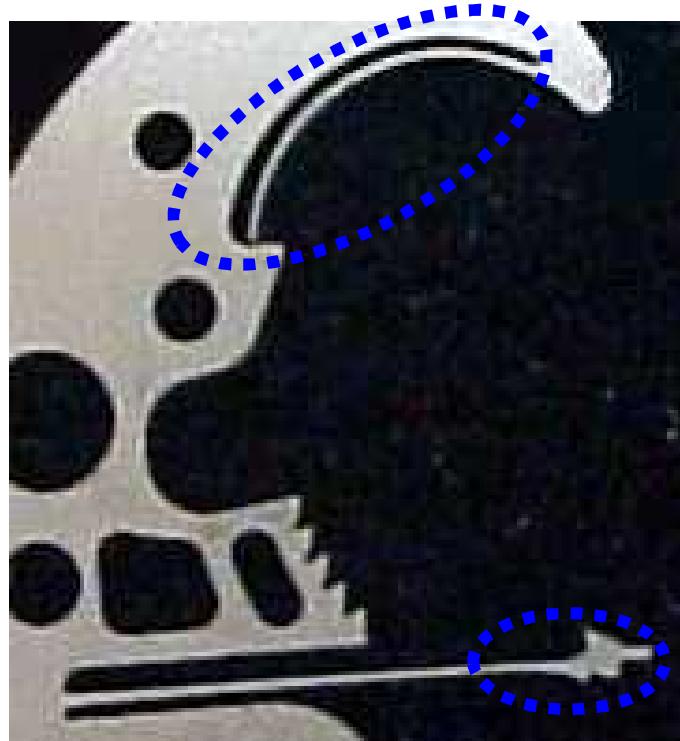


Test part allows for development of processing parameters with time and cost savings.

# Material Compositions

| Material | Composition (in weight %) |
|---|---|
| 302 SS | 17-19% Cr + 8% Ni + <2% Mn, balance Fe |
| Inconel 718 | 17-21% Cr + 50-55% Ni + 4.75-5.5% Nb + 2.8-3.3% Mo + 0.65-1.15% Ti, balance Fe |
| Ti-6-4 | 6% Al + 4% V, balance Ti |
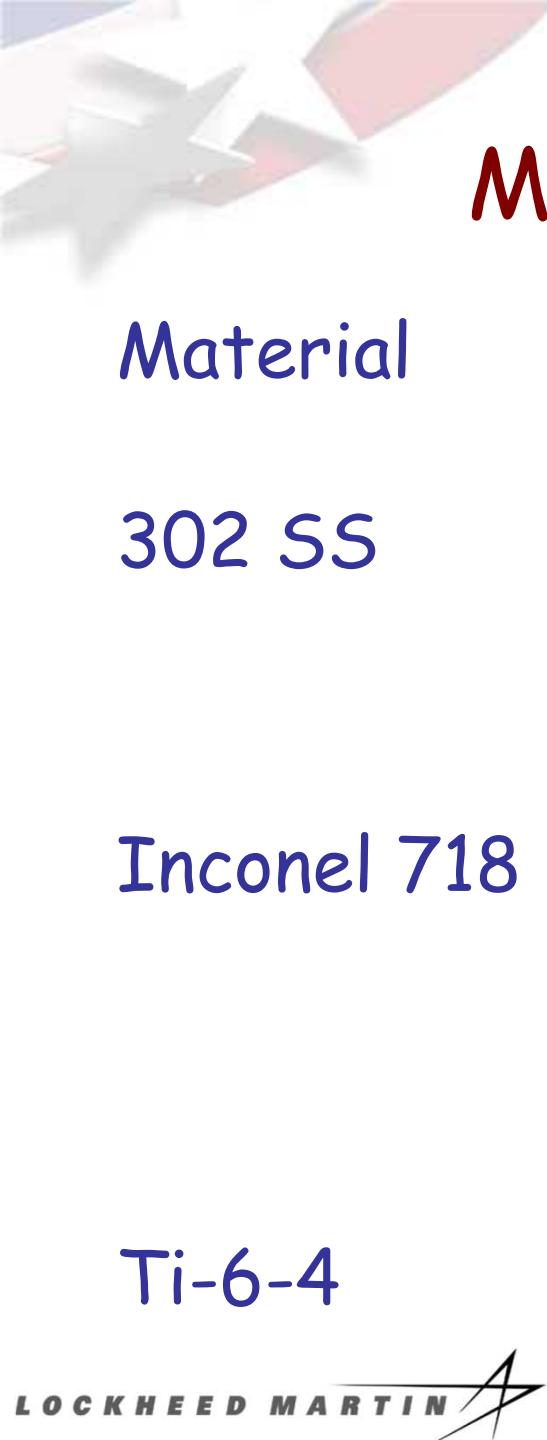
# Electropolishing Solutions
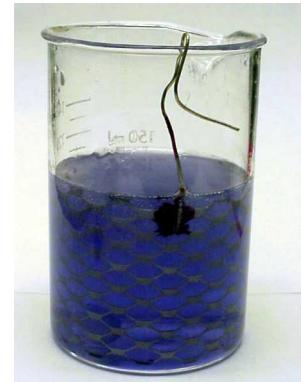
| Material | Solution (in volume %) |
|---|---|
| 302 SS | 80% $H_3PO_4$ + 20% 1-butanol (70°C) [1] |
| Inconel® 718 | 70% $H_2SO_4$ + 20% glycerol + 10% water [2] (ambient T) |
| Ti-6-4 | 60% $H_2SO_4$ + 30% HF + 10% glycerol [1] (ambient T) |

[1] P. Dettner, **Electrolytic and Chemical Polishing of Metals,** Ordentlich Publishers, 1987.
[2] G.L. Wynick and C.J. Boehlert, Materials Characterization, 55 (2005) 190-202.

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# Electropolishing successfully removed the recast layer for 302 stainless steel.
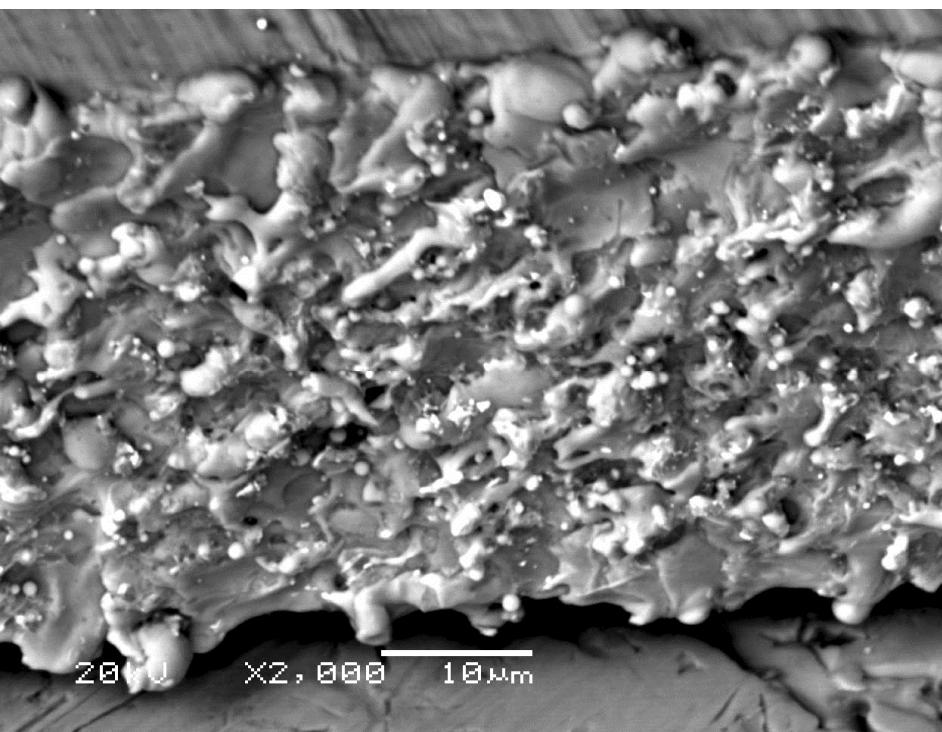
**EDM recast**                 **electropolished**
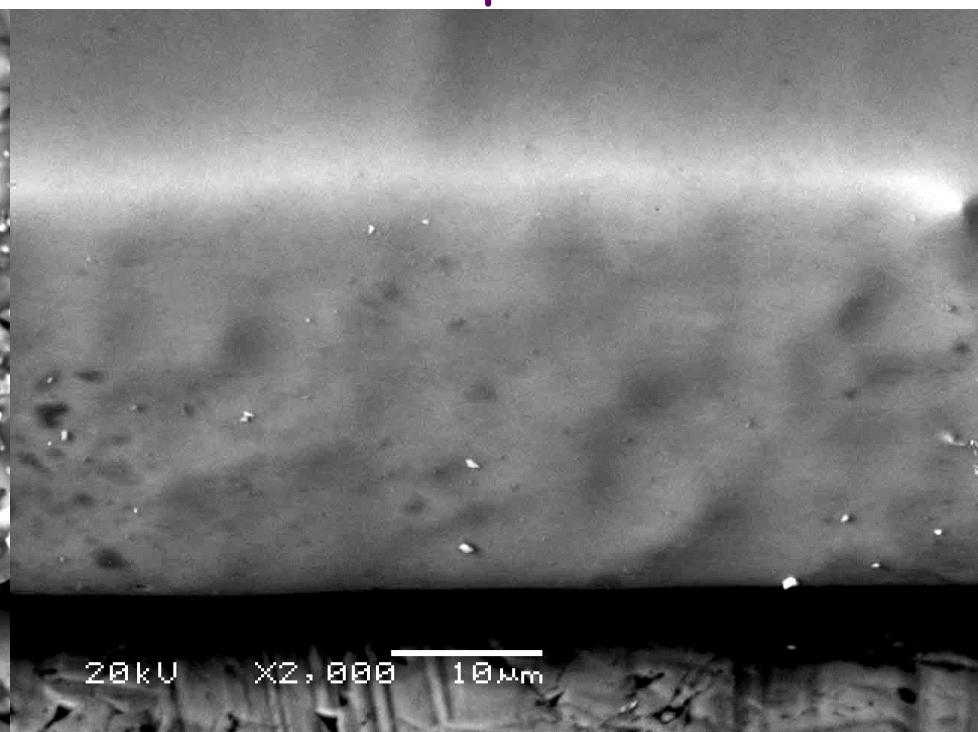


## Electropolished surface is essentially featureless.

# 302 SS:
# Surface roughness was reduced by 41%.

EDM recast
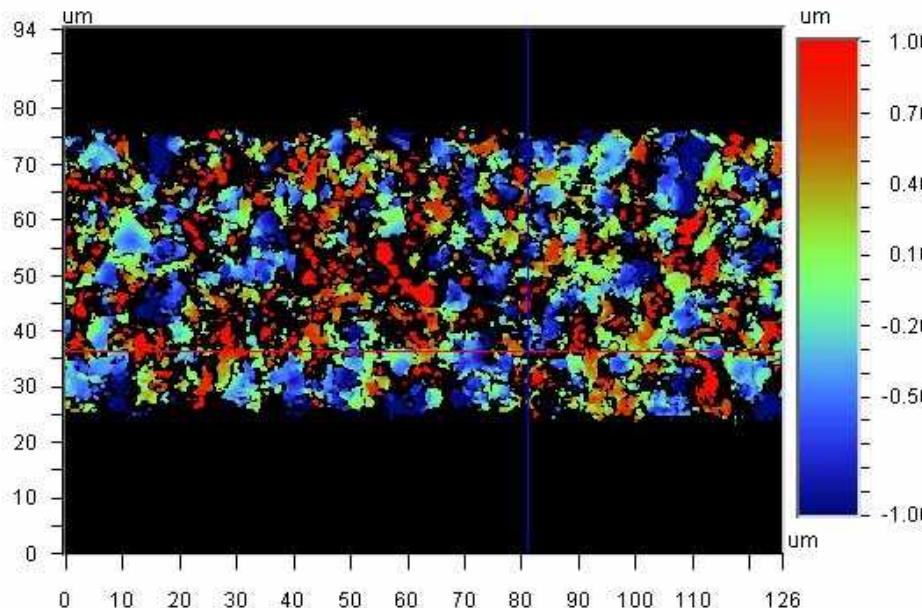
electropolished



Average roughness, Ra = 554 nm
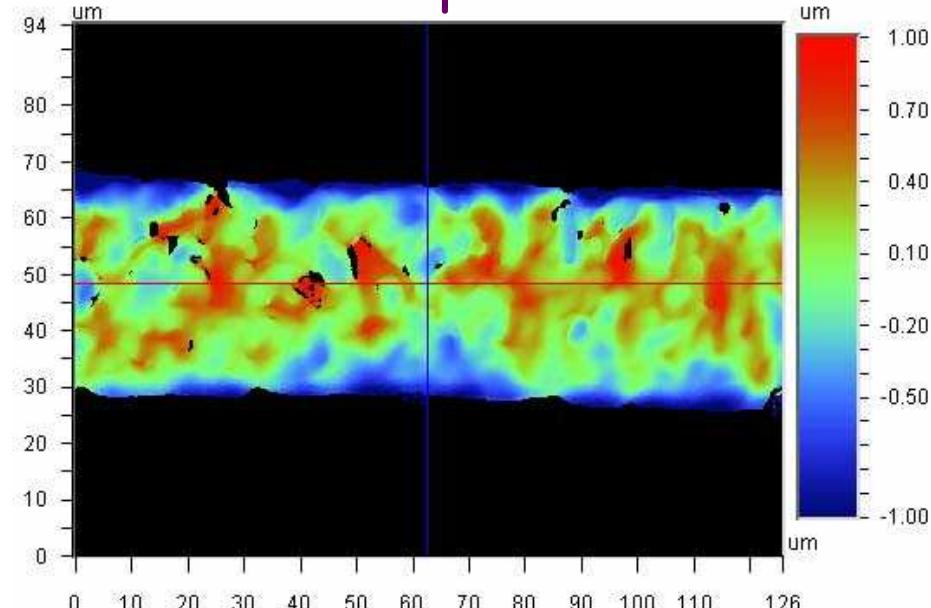
Average roughness, Ra = 324 nm

# Electropolishing reveals the underlying microstructure of Inconel 718
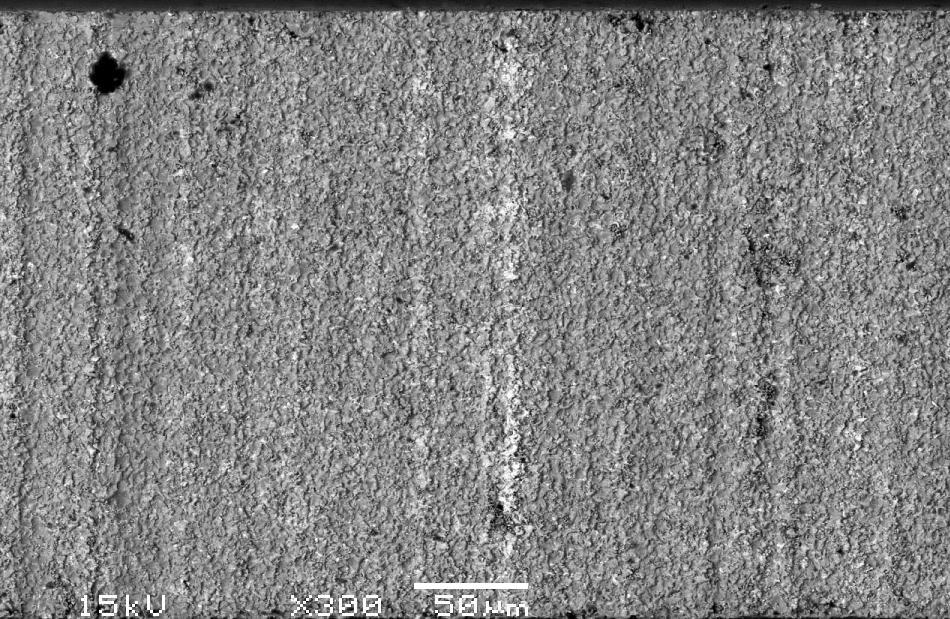
EDM recast                    electropolished
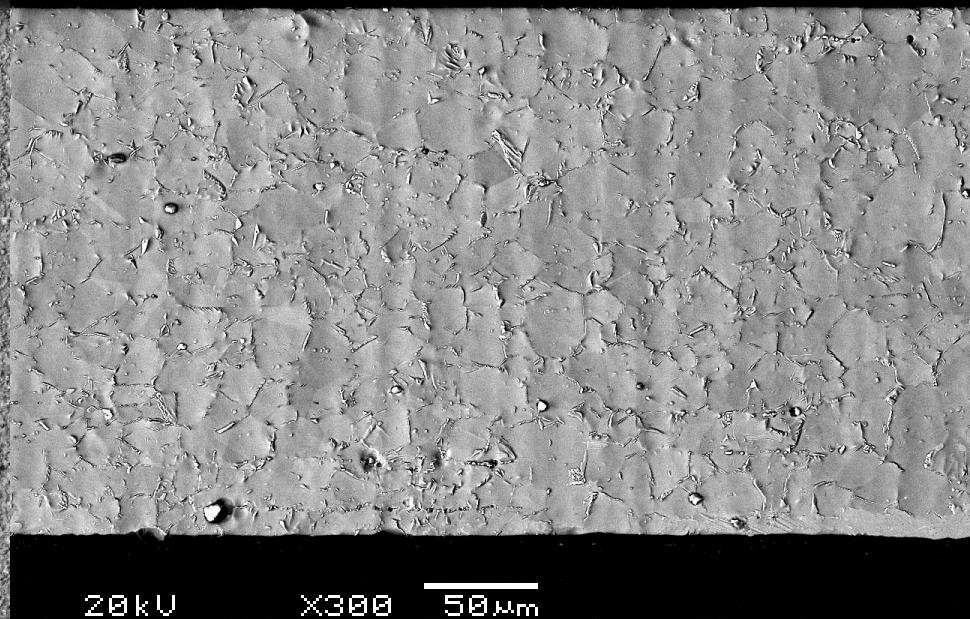


Precipitates are evident on polished surface.

# At least two types of precipitates are present on polished surface of Inc718



BEI

BEI

NbC / NbN

Laves phase or δ phase

20kV    X300    50μm

20kV    X2,000    10μm
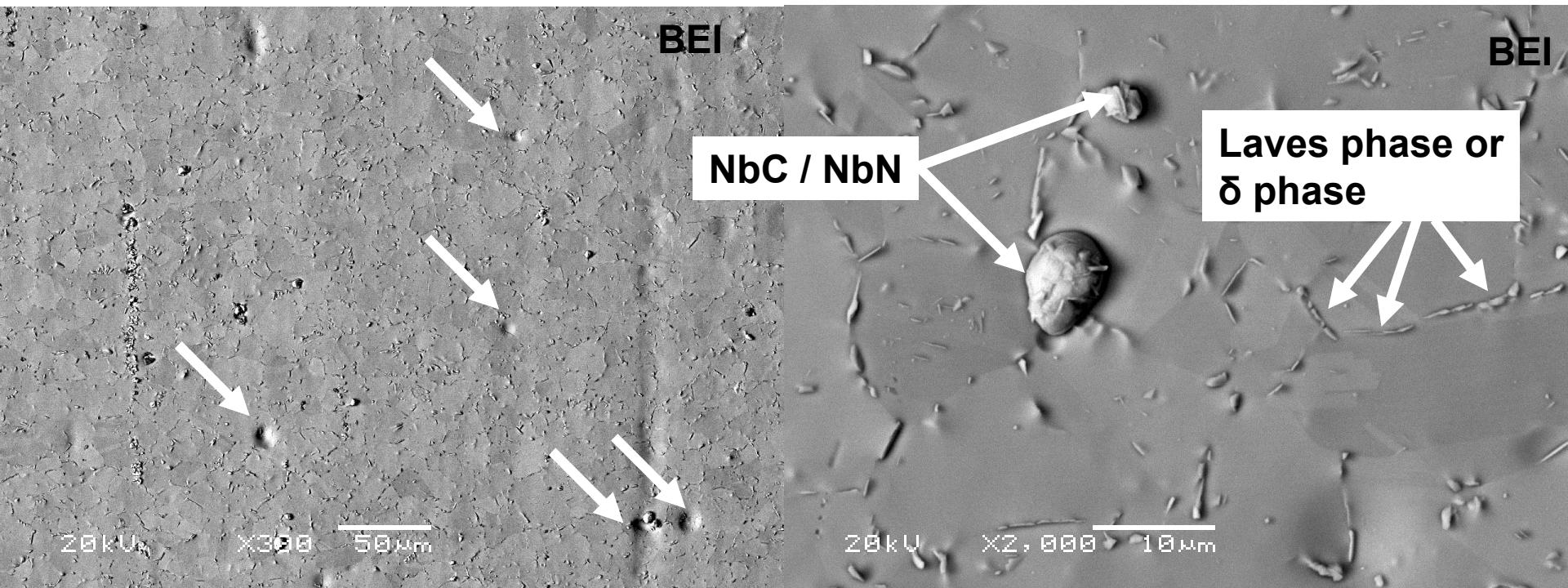
Large NbC particles fall out leaving "craters" in the matrix.

# Inconel 718:
# Surface roughness was reduced by 77%.

EDM recast
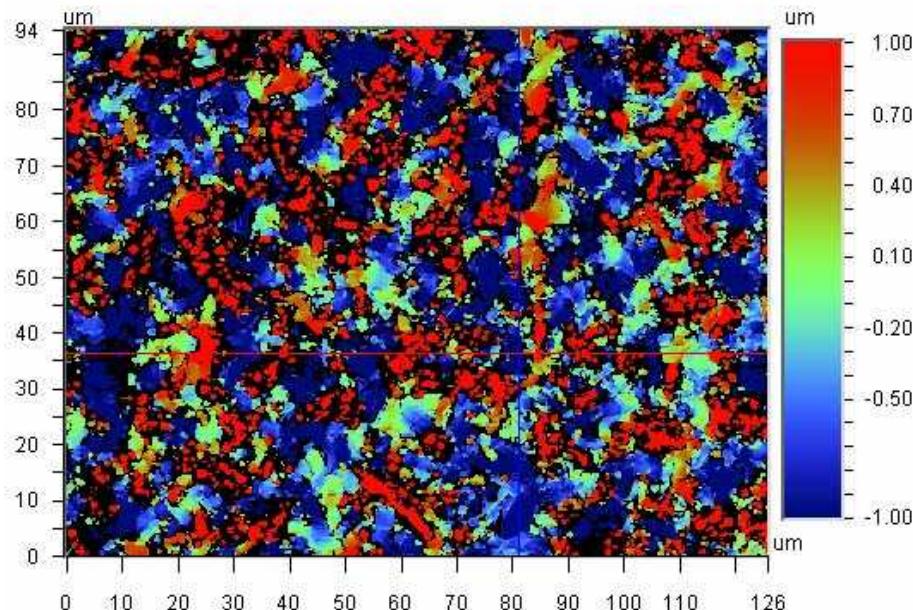
electropolished



Average roughness, Ra = 906 nm

Average roughness, Ra = 208 nm

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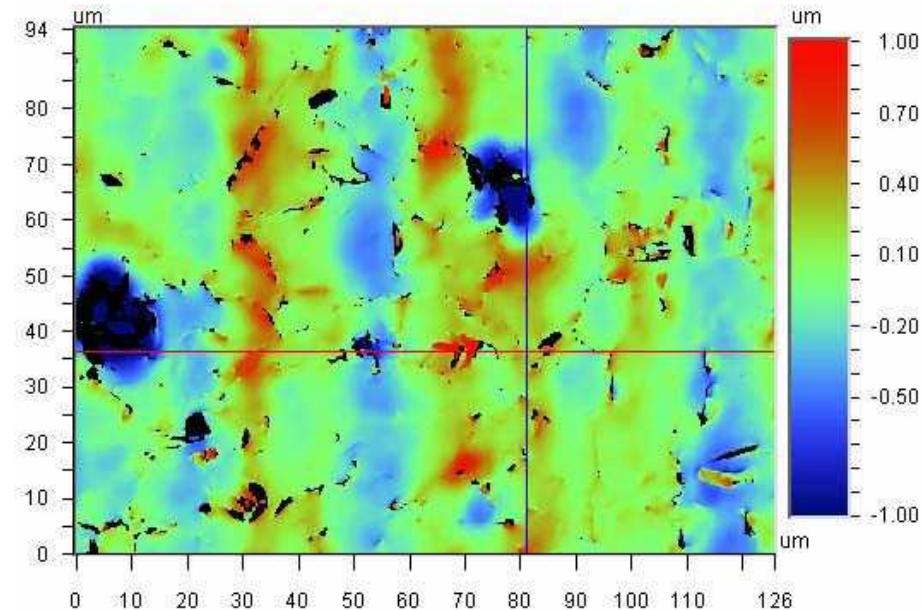
# Ti-6Al-4V surfaces are relatively smooth

## EDM recast

## electropolished
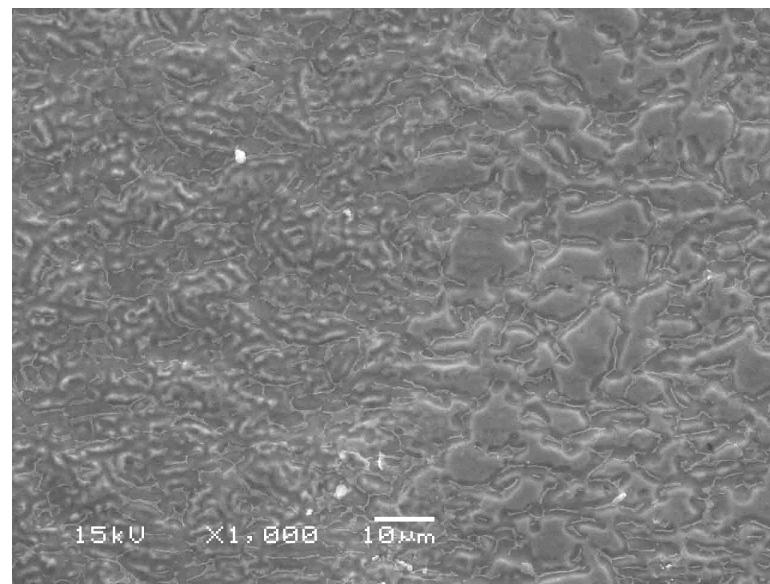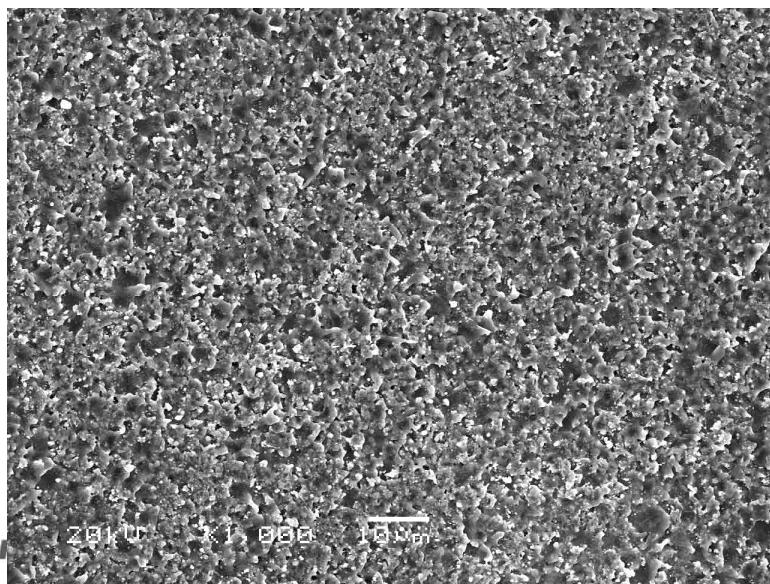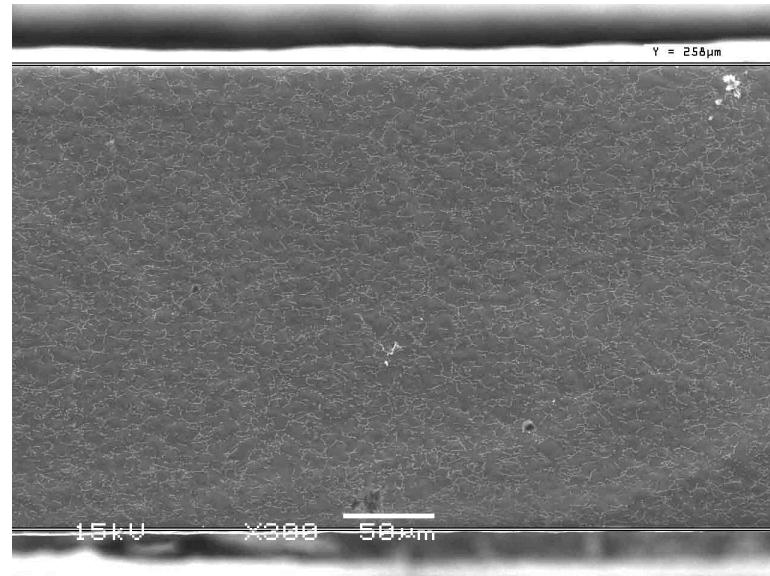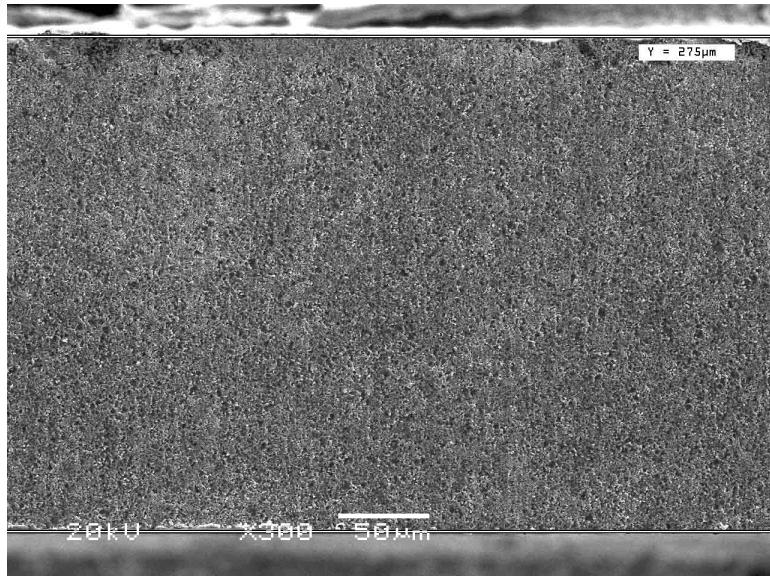
# Ti-6Al-4V:
# Surface roughness was reduced by 13%.



EDM recast
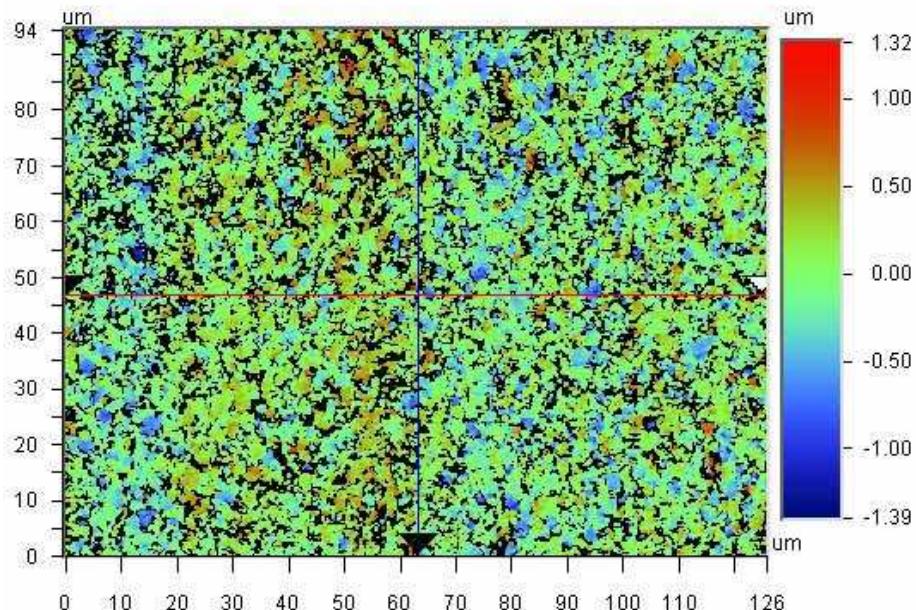
electropolished

Average roughness,
Ra = 237 nm
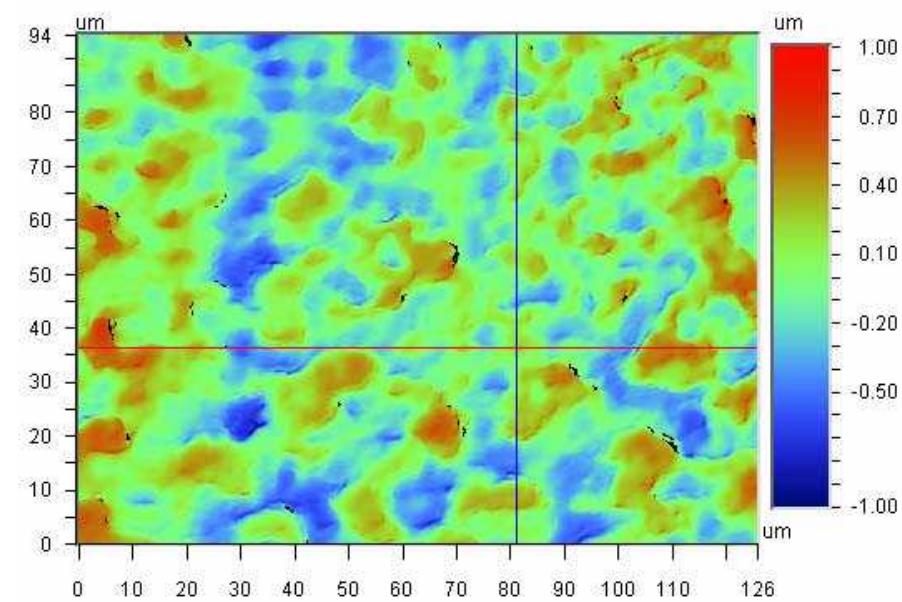
Average roughness,
Ra = 206 nm

# UV laser cutting of Ti-6Al-4V produces a rough surface finish compared to micro-EDM
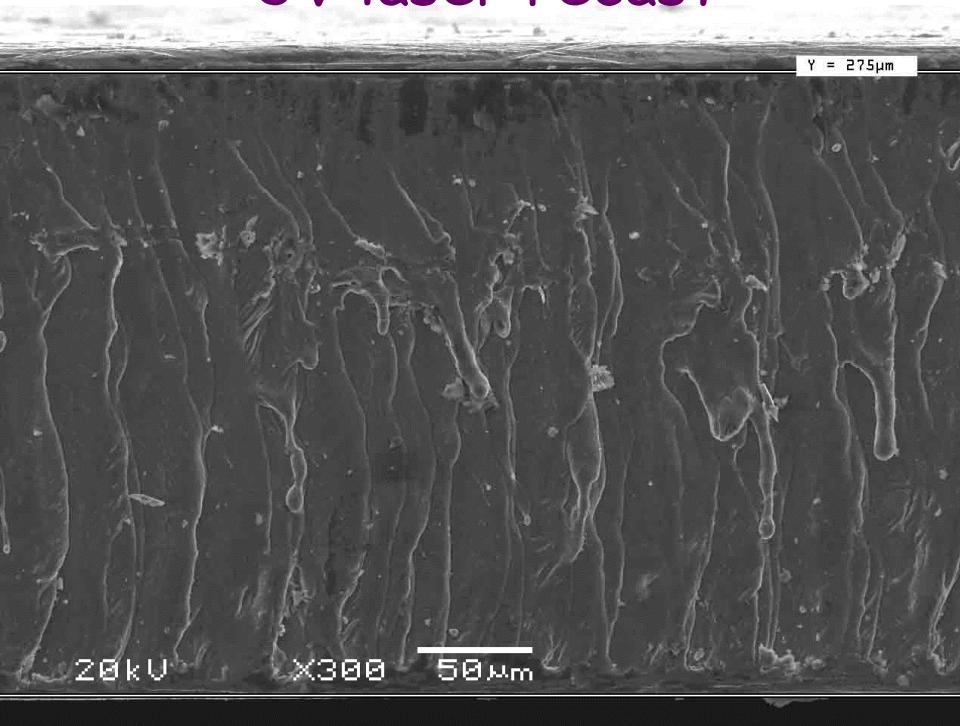
UV laser recast                   electropolished
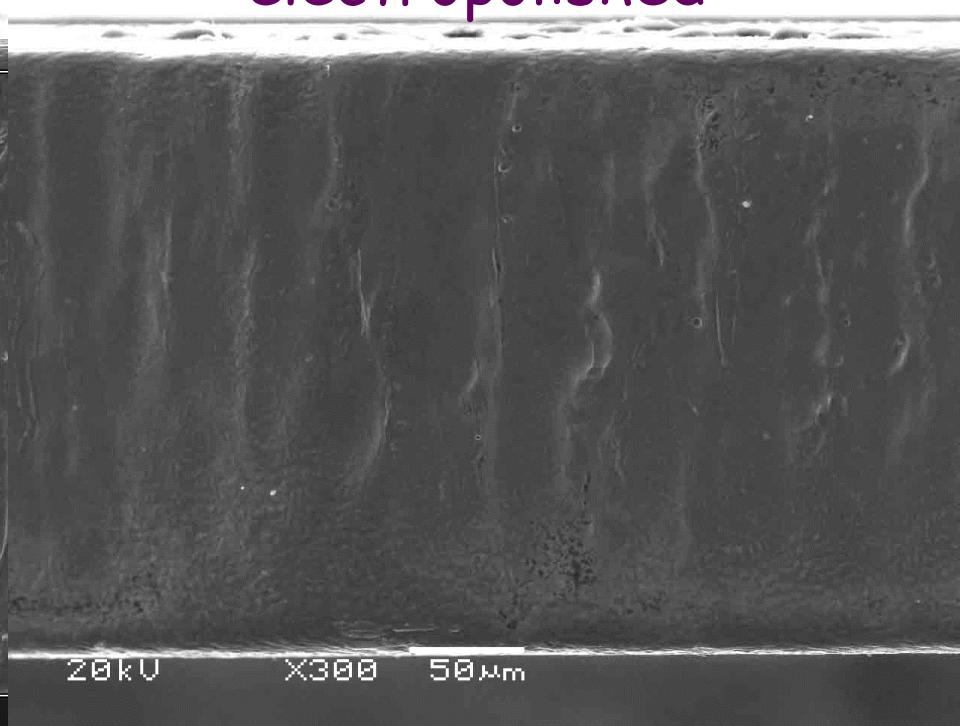


*Underlying morphology is maintained after "light" electropolishing.*

# UV laser cut Ti-6Al-4V:
# Surface roughness was reduced by 54%.

UV laser recast
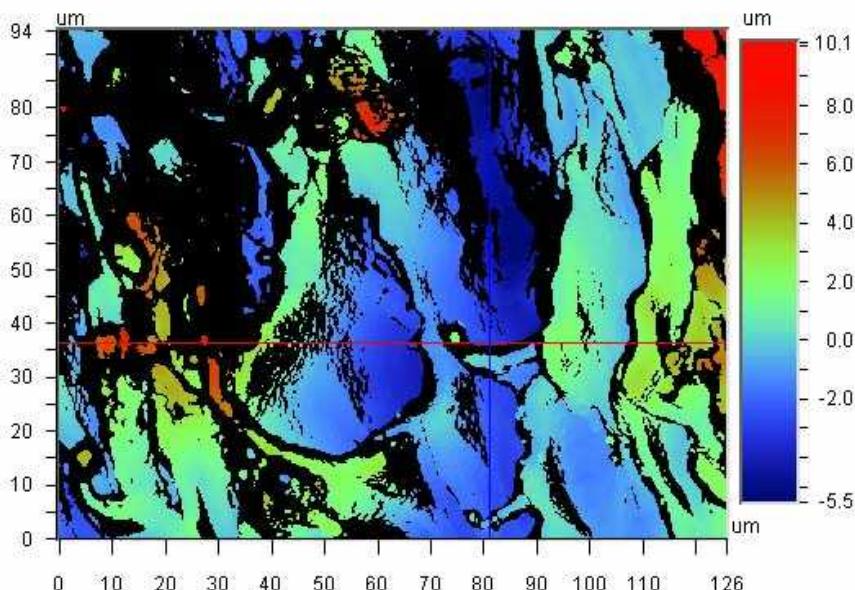
electropolished



Average roughness,
Ra = 1700 nm
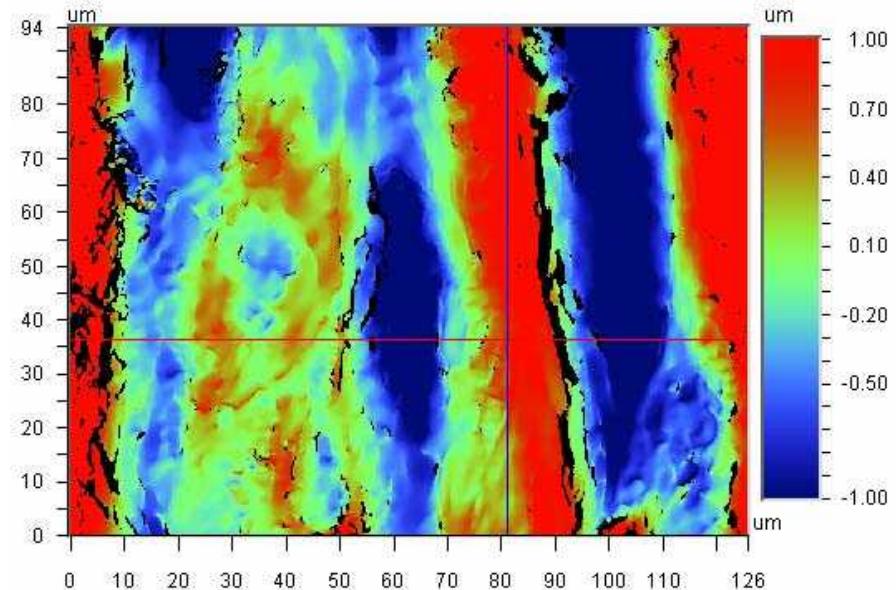
Average roughness,
Ra = 647 nm

# Friction measurements on Inc718 indicate less variability in $\mu_k$ for polished surface



**EDM recast**
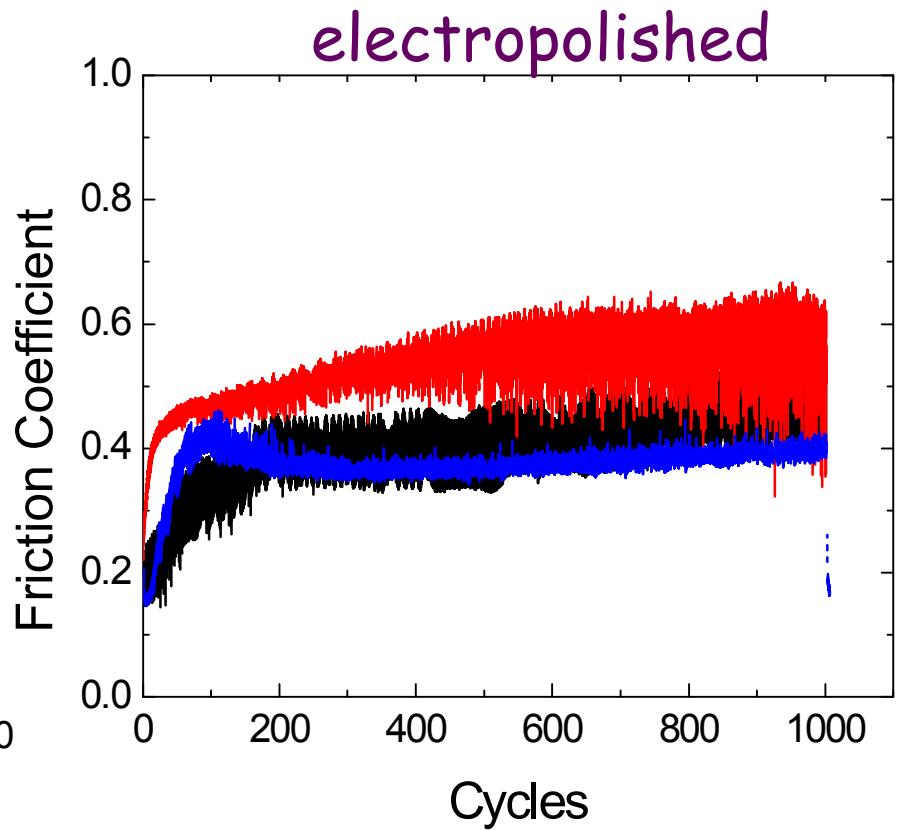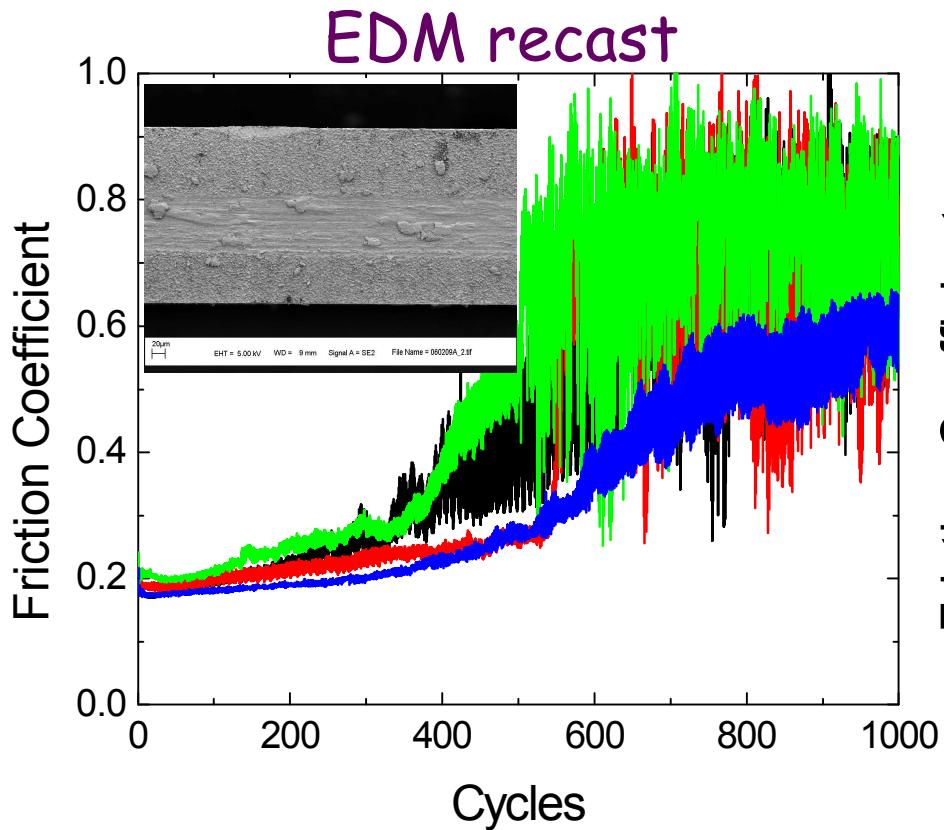
**electropolished**

Courtesy of S. Prasad, 1824

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# Summary

- Micro-EDM was used to create high precision metal parts with fine features to tight tolerances.

- Electropolishing was used successfully to remove the recast layer; future work is required to optimize process and determine process windows.

- UV laser cutting provides cost savings, but surface finish that is difficult to remediate.

- Electropolished surface has more stable friction behavior compared to surface with recast layer.

# Acknowledgements

Somuri Prasad, 1824
Mike Saavedra, 2455
Liz Huffman, 1824
Dick Grant, 1822

# Example of a metal micro-part



as machined

electropolished

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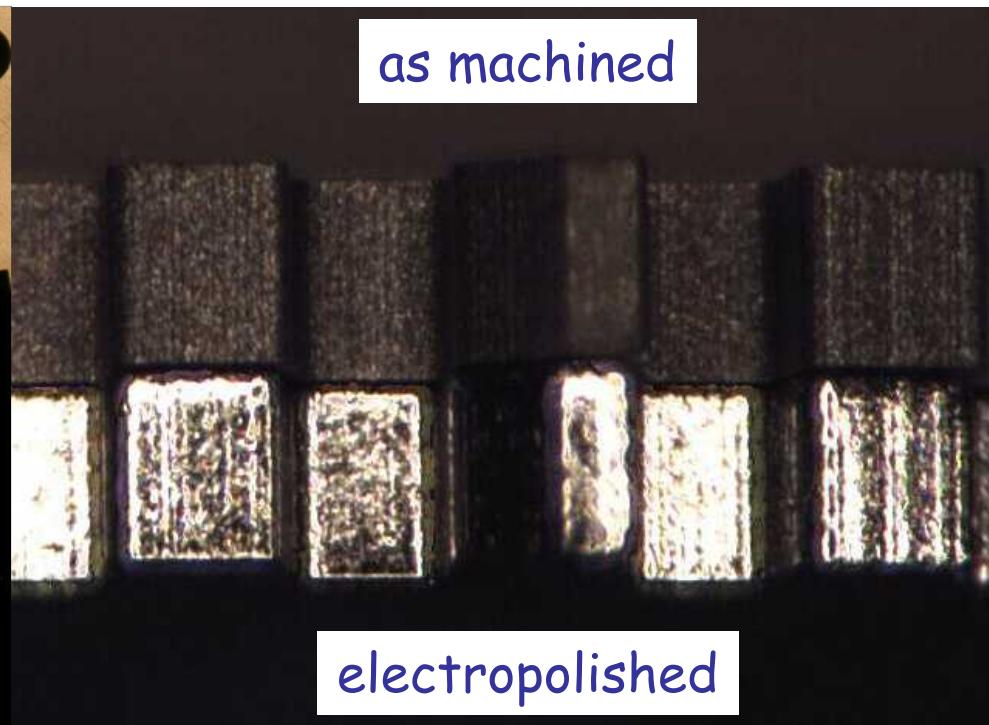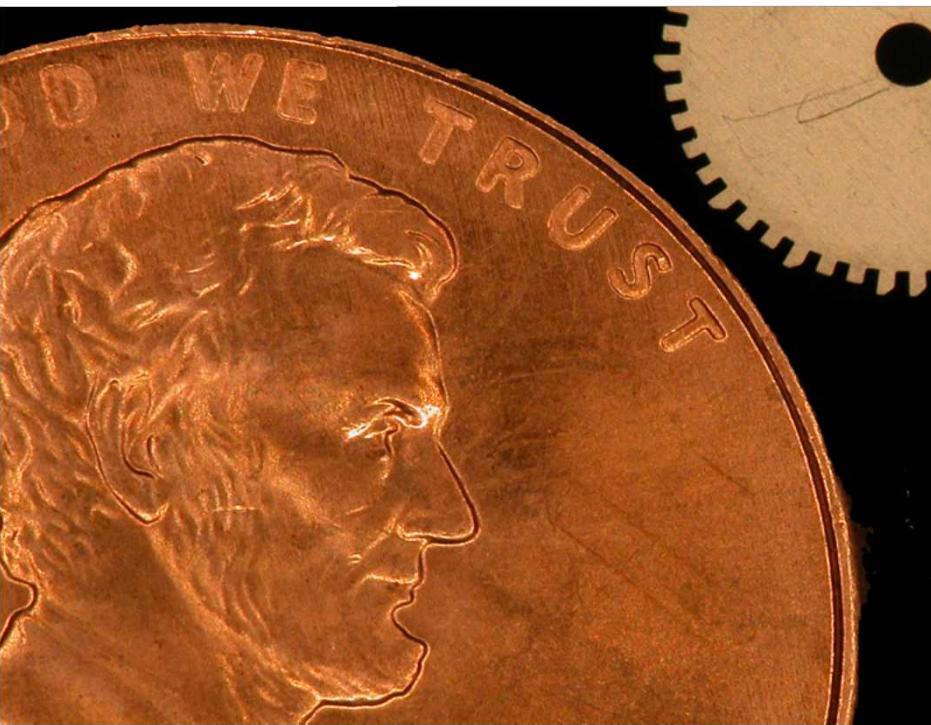
# Extra Slides

# Precipitates are identified by EDS as Nb-rich particles

Possibilities:
- NbC / NbN
- Laves phase
- $Ni_3Nb$



large particle, point 1

grain interior, point 2