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FABRICATION OF MESO-SCALE NANOCRYSTALLINE METAL COMPONENTS BY WIRE EDM

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Abstract

Research has shown that severe plastic deformation during machining operations can produce nanocrystalline metals and alloys with superior mechanical properties. These nanocrystalline materials are hard and therefore are difficult to fabricate into engineering parts especially for meso-scale components. In this study, meso-scale components such as gears and flexures were directly fabricated from an extrusion-cut nanocrystalline inconel 718 alloy by μ-electro-discharge machining (μ-EDM) process. The objective is to demonstrate that the combination of these techniques is a viable manufacturing process to produce nanocrystalline meso-scale components for engineering applications. Special attention is placed on the mechanical properties of extrusion-cut nanocrystalline inconel alloy and microstructure changes associated with extrusion-cutting and EDM processes.

Extrusion-Cutting and Nanocrystalline Inconel 718 Alloy

Extrusion-cutting is a geometrically constrained cutting process where the machined chip is extruded through a controlled gap between shoe and cutting tool; therefore, materials of different shear strains and a fine surface finish can be fabricated. Furthermore, a variety of nanocrystalline metals and alloys can be produced by this technique with low-cost for engineering applications.

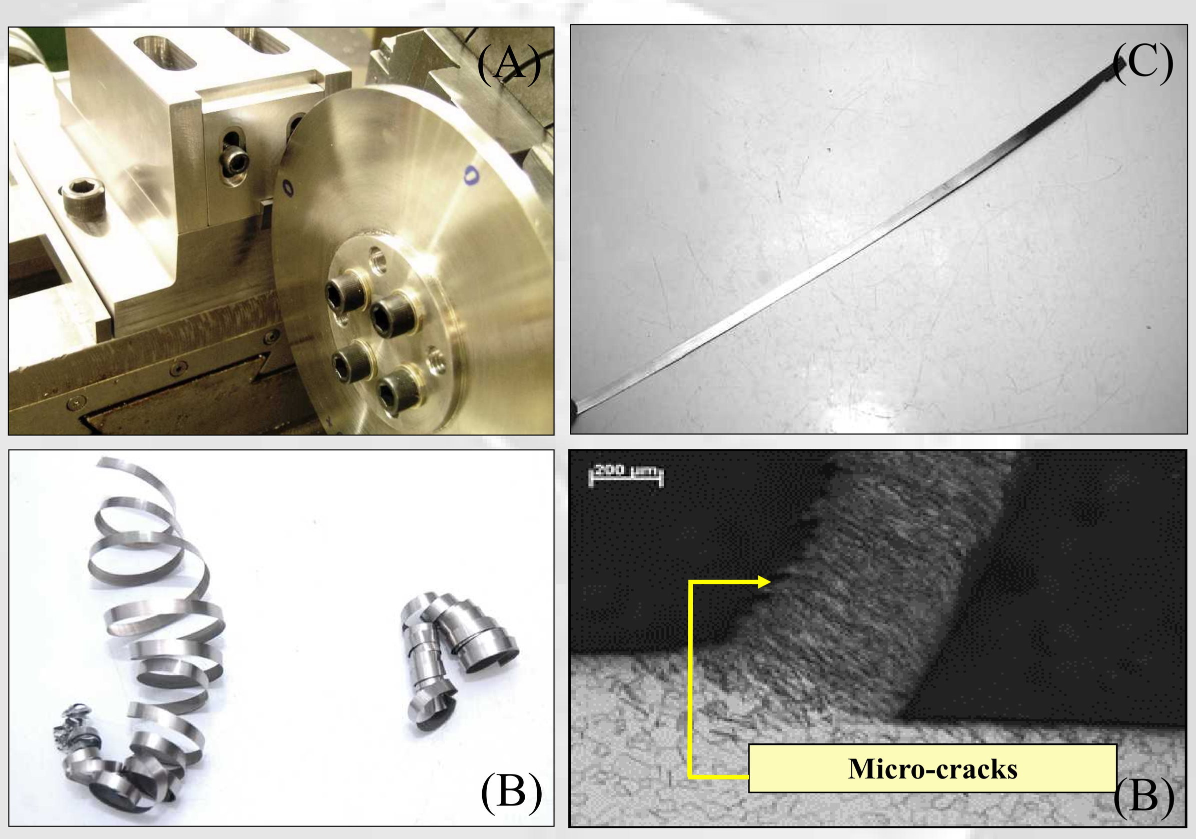


Figure 1. Photographs of (A) extrusion-cutting, (B) free machine chip, and (C) extruded foil.

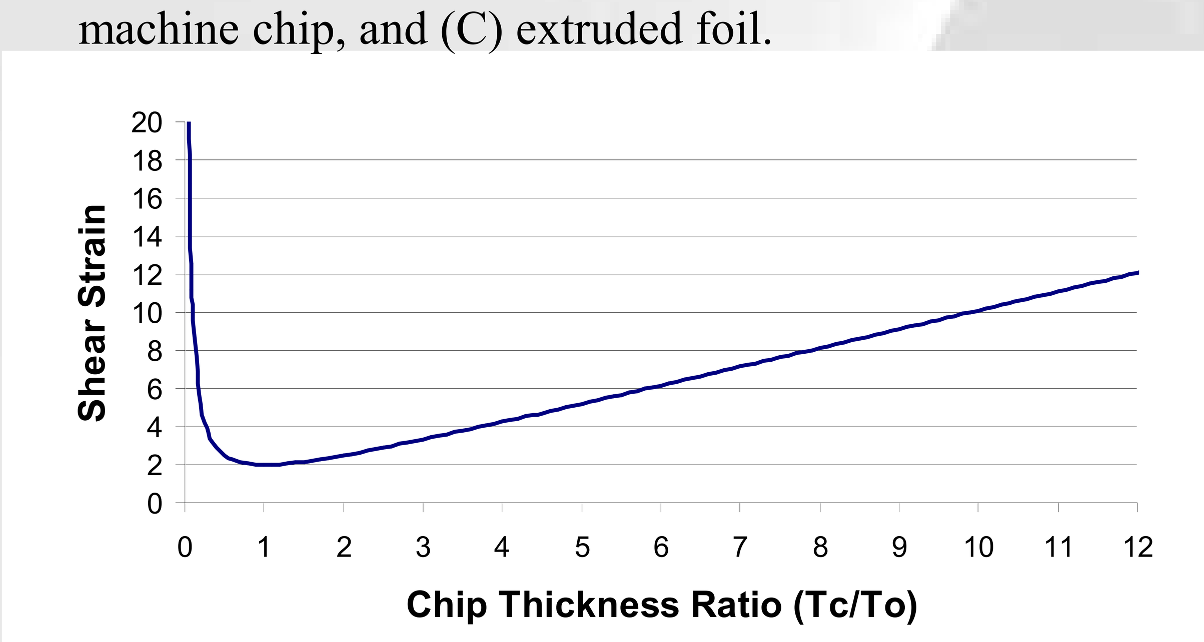


Figure 2. By changing the ratio of foil thickness (Tc) and depth of cut (To), various shear strains can be achieved by extrusion-cutting technique.

Microstructure

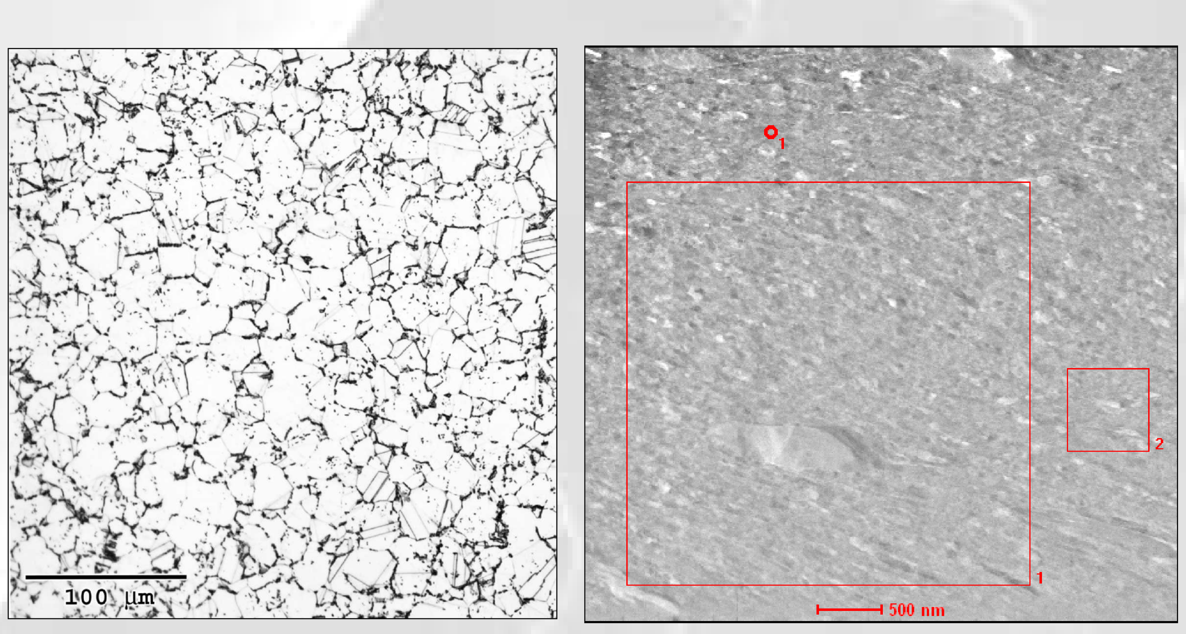


Figure 3. Microstructure change (A) before and (B) after extrusion-cutting of a solution treated Inconel 718 (TEM).

- After extrusion-cutting, a nanocrystalline (< 100 nm) inconel alloy is produced with sub-micron size precipitates.

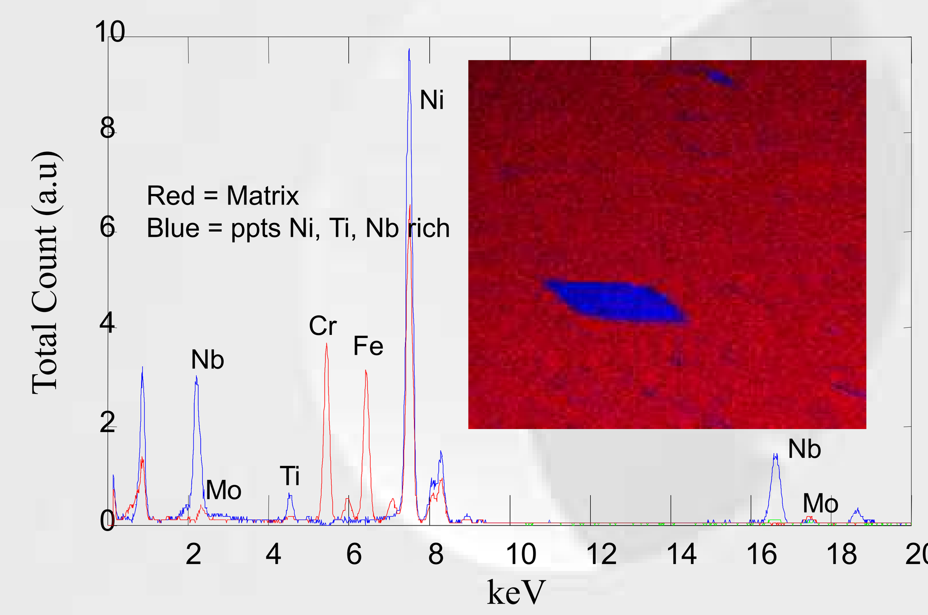


Figure 4. After extrusion-cutting, nickel-niobium rich precipitates formed from solution treated inconel alloy.

Nanoindentation Measurements

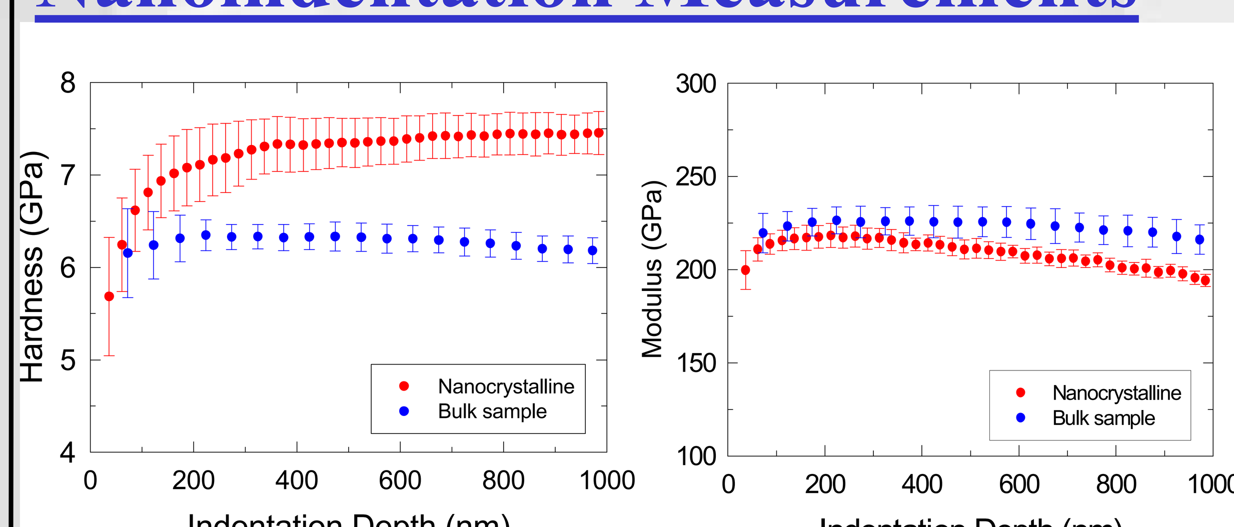
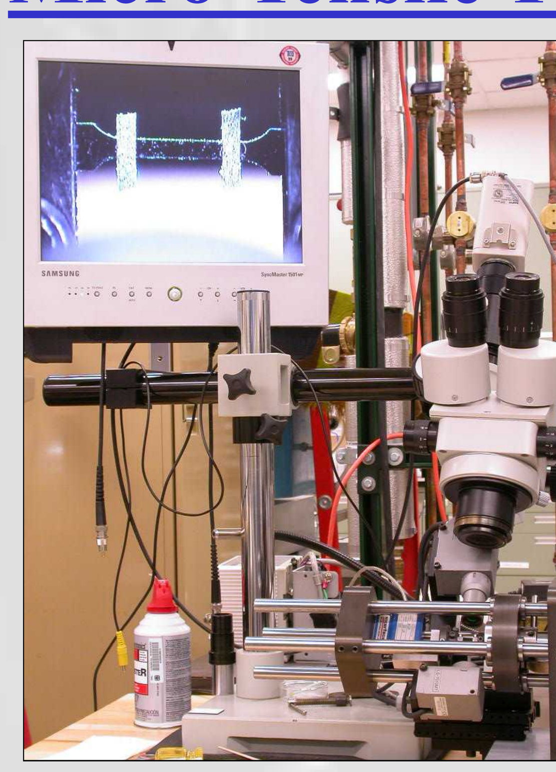
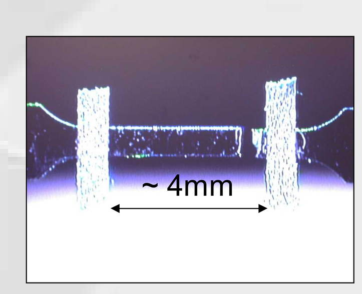


Figure 5. Nanocrystalline inconel possesses a greater hardness than bulk specimen (aged inconel).

Micro-Tensile Tests





- Non-contact laser displacement measuring system.
- Resolution is approximately 5 μm providing a strain measurement resolution of 0.001.

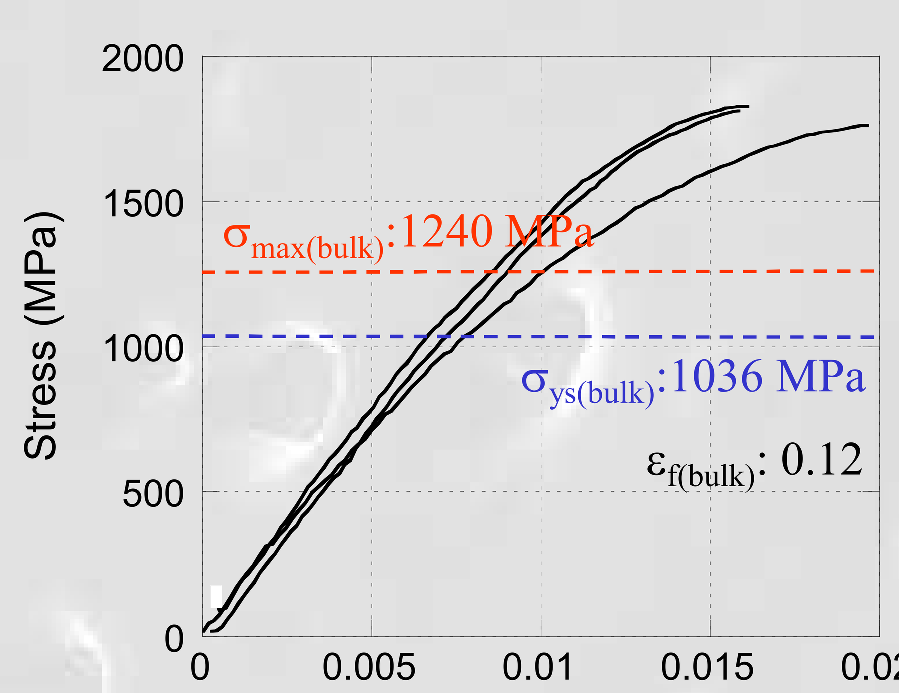


Figure 6. Tensile stress-strain results of nanocrystalline inconel 718.

Summary of Tensile Test Results

Test No.	E (GPa)	σ_{ys} (MPa)	σ_{max} (MPa)	ε_f
1	158	1205	1760	0.020
2	162	1630	1830	0.016
3	150	1700	1810	0.016

Microstructure of Fracture Surface

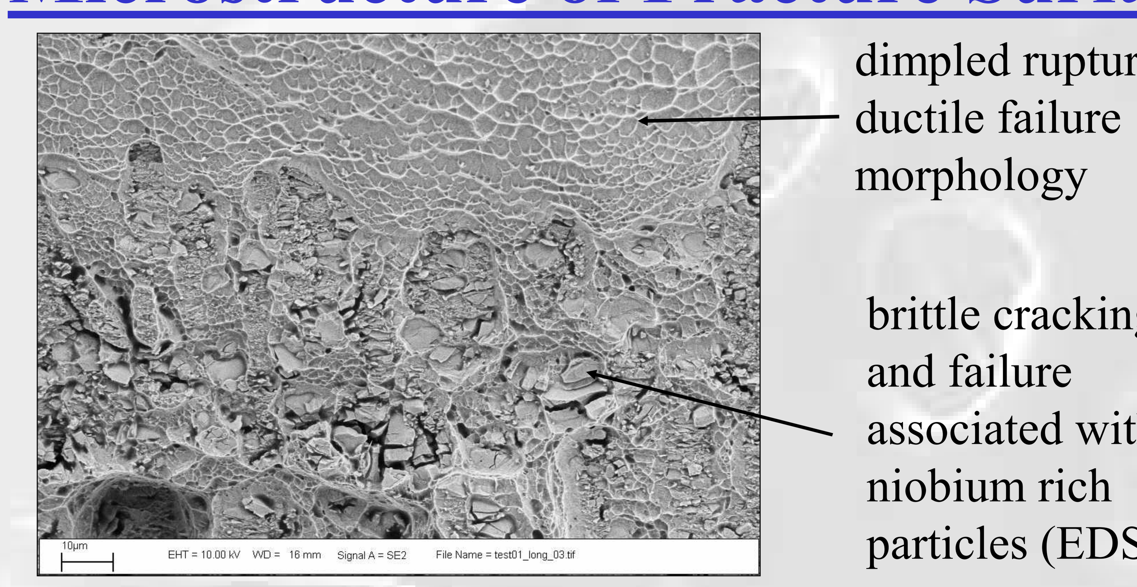


Figure 7. Microstructure of fracture surface of extrusion-cut inconel 718 alloy after tensile test.

- Fracture surfaces of nanocrystalline inconel 718 samples exhibited regions with both ductile and brittle failure morphologies

μ-Wire EDM of Inconel 718 Alloy

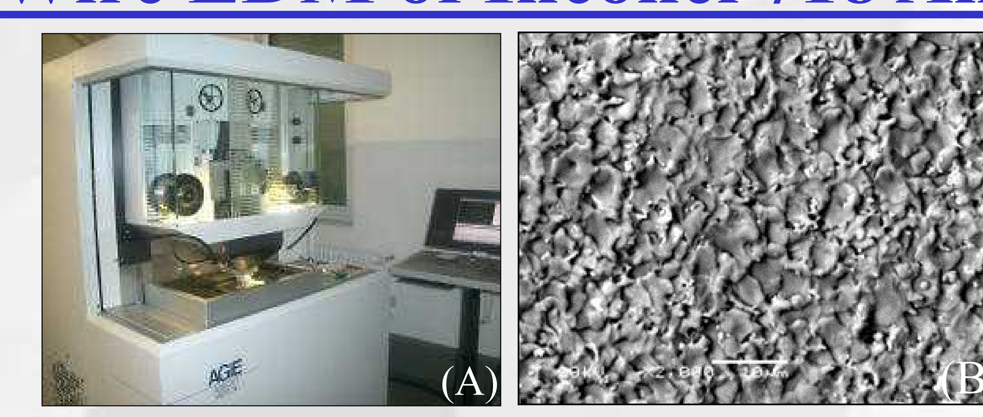


Figure 7. (A) Photograph of wire EDM machine (B) SEM microphotograph of a recast layer on cutting surface.

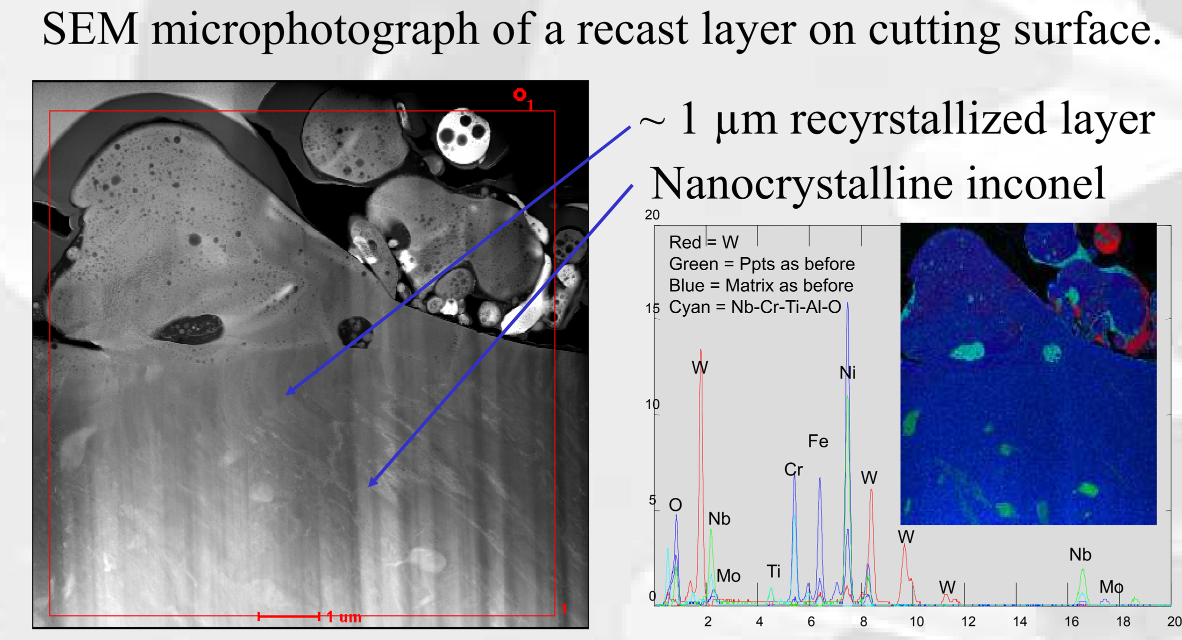


Figure 8. (A) TEM microphotograph of the recast layer (B) tungsten and additional metal-oxide formed on the recast layer.

Prototype Component

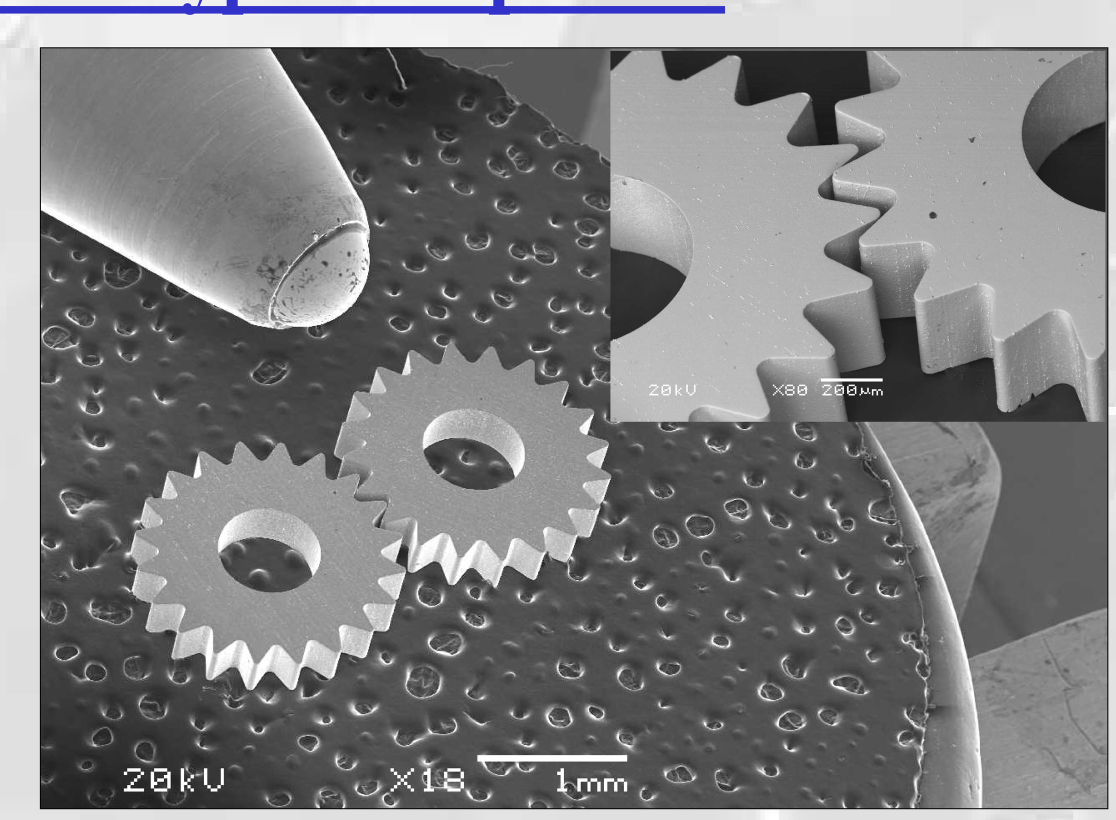


Figure 9. SEM images of Meso-scale, nanocrystalline superalloy gears after electropolishing (up left is a ball point pen tip).

Conclusions

- Nanocrystalline inconel superalloy with superior properties was successfully fabricated by an extrusion-cutting process.
- EDM is a viable process to fabricate meso-scale, nanocrystalline engineering components.