Nanocrystalline Metals

Dept. of Mechanical Engineering, MIT
nanocrystalline metals

Nanocrystalline (nc) Ni
100 nm

Ultra-fine-crystalline (ufc) Ni
1000 nm

Microcrystalline (mc) Ni

Grain size

**strengthening effects of grain size**

- **mc**
  - Hall-Petch relationship \( (\sigma \sim d^{-1/2}) \)

- **ufc**
  - \( \sigma \uparrow \) as \( d \downarrow \), but not like H-P

- **nc**
  - \( \sigma \) plateau or **decreasing**!

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![Diagram showing the strengthening effects of grain size.](link)

strengthening effects of grain size

\[ \sigma_y = \sigma_0 + kd_g^{-1/2} \]

\[ \sigma \uparrow \text{ as } d \downarrow, \text{ but not like H-P} \]

\[ \sigma \text{ plateau or decreasing} \]


dislocation motion in nc materials

Grain Boundaries (GB) can act as dislocation sources

3 step process:
- Nucleation
- Propagation
- Reabsorbed at GB

nc (partial) dislocation emission


with very fine nc grains (d < 10 nm)

塑料性主要发生在晶界（暗原子表示移动）

0.4% strain

before

after

Courtesy of Jakob Schiøtz. Used with permission.
nc tensile testing data

increased strain rate sensitivity

very low ductility (<10%)


**nc yield criteria**

(a) tension/compression asymmetry

<table>
<thead>
<tr>
<th>σ</th>
<th>(GPa)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
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Mohr - Coulomb

Drucker–Prager

atomistic simulations for d = 4 nm


mechanically-induced grain growth

Driven by mechanical force
- GB migration
- GB rotation

“Nanovated” material

“Integran’s patented Nanovating process, creates materials with 1000 times smaller grain sizes.”

“Integran’s Grain Boundary Engineering (GBE®) process enhances reliability and durability by altering the internal structure of materials on the nanometre-scale.”

Images removed due to copyright restrictions. Please see “Nanovate Technology.” Integran, 2008.

| conventional grains | average “nanovated” grain size ~ 20 nm |

http://www.integran.com/tech/nanovate.htm
video – nc testing

- Atomistic simulation of nc Al:

- Bending test of nc Ni-W coating on steel:
Have a good day!