MEEN 489-500 Nanoscale Issues in Manufacturing

Severe Plastic Deformation (SPD)

Lecture 1
Example of material element distortion and near surface non-uniform strain in annealed OFHC copper.

Uniform deformation except end regions

$\Theta = 26^\circ$

Homework #1: Why is the angle shown in the image $26^\circ$ instead of $45^\circ$?
**ECAE Die Angle Effects**

Low Pressure requirement
no change in cross section

<table>
<thead>
<tr>
<th>Full Die Angle</th>
<th>Punch Pressure Flow Stress</th>
<th>Strain Intensity</th>
<th>Equivalent Reduction Ratio</th>
<th>Area Reduction</th>
<th>Conventional Extrusion ECAE Pressure Ratio</th>
<th>Load Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2(\gamma))</td>
<td>((p/\sigma_0))</td>
<td>((\varepsilon_i))</td>
<td>((A_0/A_f))&lt;sub&gt;e&lt;/sub&gt;</td>
<td>(AR)&lt;sub&gt;e&lt;/sub&gt;</td>
<td>((p_{CE}/p_{ECAE}))</td>
<td>((p_{CE}/p_{ECAE}))</td>
</tr>
<tr>
<td>150</td>
<td>0.27</td>
<td>0.31</td>
<td>1.37</td>
<td>30</td>
<td>1.80</td>
<td>2.50</td>
</tr>
<tr>
<td>120</td>
<td>0.58</td>
<td>0.68</td>
<td>1.95</td>
<td>49</td>
<td>2.20</td>
<td>4.30</td>
</tr>
<tr>
<td>90</td>
<td>1.16</td>
<td>1.17</td>
<td>3.20</td>
<td>69</td>
<td>2.50</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Reduction Ratio (RR) = \(\frac{A_0}{A_f} = \exp(N\varepsilon_i)\)

Area Reduction (AR) = \((1 - RR^{-1}) \times 100\%\)

**Homework #1:** Show that \(\gamma = 2\cot\phi\)?
The effect of the number of passes (N) and routes (A and C) of room temperature deformation of Armco Iron on (a) hardness (HV), ultimate tensile stress (UTS) and limit of elasticity (ES at permanent strain 0.005%); (b) area reduction (AR) and elongation (EL).
Increase in both strength and ductility with increasing number of passes. Strain softening is evident initially, but with increasing number of passes strain hardening occurs.
ECAE Processed Cu Samples
Both Strength and Ductility Increases

![Graph showing UTS (MPa) and strain at fracture (%) for Bulk Cu with different # of passes.]
Is continuous ECAE possible?

- Conshearing:
  - Compression force is used to put the sheet into the ECAE die.
  - Folding is prevented by the guideshoe
  - Difficult to obtain UFG
  - Difficult to make channel angle 90°
  - Difficult to work alloys?
Is continuous ECAE possible?

Continuous Confined Strip Shearing Process (C2S2):
- Lower roll surface is roughened to feed the material into the ECAE die.
- Surface quality is a problem.
- Channel angle is about 100° - 140°
- Difficult to work alloys? Scale up?
Other SPD Techniques

Cyclic Extrusion Compression
- Extrusion to decrease the diameter, compression to increase the diameter
- Batch process with limited sizes
- Hydrostatic compressive stress field needed to avoid fracture
- Scale Up?

\[ \Delta \varepsilon = 4 \ln \left( \frac{d_0}{d_m} \right) \]
Other SPD Techniques

Continuous Cyclic Bending
- Repetition of bending and bending-back.
- Strain in the single bending pass is 0.1056.
- Difficult to achieve UFG.
- Difficult to work alloys?
Other SPD Techniques

- Repetitive Corrugation and Straightening (RCS)
- Constraint Groove Pressing (CGP)
Other SPD Techniques

Accumulative Roll-Bonding (ARB)
- Surface quality is very important
- Degreasing and wire brushing is needed.
- For good bonding, elevated temperatures might be necessary.
- There is a minimum rolling reduction in one-pass for roll bonding
- Edge cracking is a major problem
Other SPD Techniques

- High Pressure Torsion
  - The amount of shear strain differs depending on the radial position.
  - Solid state-amorphization, nanocrystallization
  - Scale-up? Impossible
Potential benefits of nanocrystalline materials

** Biomedical: **
- Nanostructured bulk protheses, implants or implantable sensors/delivery systems with high strength, light-weight and adjustable young’s modulus

** Electronics and Communication: **
- Superior soft magnetic properties enable the nanostructured parts to be used for meso-/micro- signal transformers and other communication networks; giant magnetostrictive actuators with high frequency response, etc.

** Aerospace, Automotive, Chemical and Military Application: **
- The light-weight, high-strength, thermally stable, low power consuming properties: For example, an aluminium based nanostructure alloy will have as high as 800MPa in tensile strength, which is nearly 200% higher than that of microstructured aluminium alloys and comparable to the steel’s strength, but the weight is only 1/3 of that of steel parts.