Practical IP1
Background Information

Dr Paul J Warren
October 2014
Strength of Materials

- **Strength** is the ability of a materials to withstand an applied stress without failure.
- **Yield Strength** is the lowest stress to cause permanent deformation (e.g. 0.2% strain).

\[ \sigma = \frac{F}{A} \]

\[ \varepsilon = \frac{\Delta L}{L} \]
Why are some materials stronger than others?

• Strength depends upon microstructure

• Plastic deformation occurs by the motion of dislocations through the material

• Strength is due to the cumulative effect of
  – Solid Solution Strengthening
  – Particle/Precipitate Strengthening
  – Grain boundary strengthening
  – Work Hardening
Dislocations - a Bubble Raft model

A dislocation is the line defect created by an extra plane of atoms in the crystal structure.

Where is the dislocation?
Defects in a Bubble Raft model
Grain Boundary in Bubble Raft
Dislocation motion

- Video of dislocations moving in an electron microscope on YouTube
Grain Strengthening

- Grain boundaries hinder the motion of dislocations
- Dislocations pile-up at grain boundaries and the stress fields around each dislocation accumulate effectively reducing the external stress necessary to propagate the deformation
- Large grains can contain larger pile-ups of dislocation causing higher local stress concentrations at the grain boundaries so the external stress necessary for yield is lower
- Smaller grains means more grains and lower local stresses due to smaller pile-ups so the external stress needed for yield is higher
Hall Petch Equation

- Yield Stress is inversely proportional to the square-root of grain size

\[ \sigma_y = B + \frac{A}{\sqrt{d}} \]

- i.e. smaller grain size makes stronger material
Hall Petch – an Experiment

• Make a series of alloys with different grain sizes (try to keep everything else the same!)
• Measure the average grain size of each alloy, $d$
• Measure the yield strength of each alloy $\sigma_y$
• Compare data against the Hall Petch equation

• Ideally follow recognised standards when making measurements
How to measure yield stress

• Measure extension under increasing load.
• E.g. Hounsfield Tensometers

\[ \sigma_y = \frac{\Delta F}{A} \]

\[ \varepsilon = \frac{\Delta L}{L} \]

Figure 3. Tensile test necking simulation
How to measure grain size

• Metallographic observation of microstructure

• Mean Lineal Intercept Length $L_L$ is related to the number of intercepts per length $N_L$ for a total length $L_T$ with $P$ intercepts at magnification $M$.

• The mean lineal intercept length is proportional to the grain size

\[
\overline{L}_L = \frac{1}{N_L} = \frac{L_T}{PM}
\]
Model Data

- Spreadsheet containing the model data for grain-size and yield stress

<table>
<thead>
<tr>
<th>d (mm)</th>
<th>1/sqrt(d)</th>
<th>Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>
Results Analysis

- Plot $\sigma$ vs $d$
- Plot $\sigma$ vs $\sqrt{d}$
- Use TREND and LINEST to find best fit line
- Plot best fit line
- Insert graph into brief report or “write-up”
What about Errors?

• Only one tensile test specimen so only one measurement. Error is measurement due to precision of measurement.

• Grain size measurement is the average of many measurements and it is possible to calculate the standard deviation as a measure of the error

\[
\sigma = \sqrt{\frac{\sum (d_i - \bar{d})^2}{N}}
\]

grain size is \(d \pm 2\sigma\) (95% confidence)
Results with errorbars

Petch Plot with error bars

Yield Stress (MPa) vs. Grain size (mm)