Ductilisation of tungsten through cold rolling: Change of brittle to ductile transition temperature in highly deformed tungsten

Carsten Bonnekoh, Jens Reiser, Simon Bonk, Jan Hoffmann
Outline

- Improvements through severe cold rolling
- Theory of BDT
- Motivation
- Microstructure
  - Inverse pole figure maps
  - ODF maps
  - Grain boundary character
- Mechanical testing
  - Influence of specimen thickness
  - Influence of microstructure
- Summary
Improvements through severe cold rolling

- BCC metal with melting temperature of 3422 °C
- High heat conductivity, high temperature strength and low thermal expansion coefficient
  - Tungsten (W) - perfect material for high temperature vacuum applications
- Poor oxidation resistance
- Brittle fracture at ambient temperature
  - Not in use as structural material, only applied as functional material nowadays

[1] Wendelstein X7 Newsletter
Improvements through severe cold rolling

Hot rolled
Coarse grained W

20 °C

Severely cold rolled
Ultra-fine grained W

20 °C
Improvements through severe cold rolling

- Tensile test: Ductility and yield strength improved

Improvements through severe cold rolling

- Tensile test: Ductility and yield strength improved
- Fracture behavior: Stable crack growth at room temperature achieved

Improvements through severe cold rolling

- Tensile test: Ductility and yield strength improved
- Fracture behavior: Stable crack growth achieved
- Charpy tests: BDTT shifted to lower temperatures

Improvements through severe cold rolling

Charpy Energy [J] vs. Temperature [°C]

- Cold rolled
- Hot rolled
- Recrystallised

3 x 4 x 27 mm³

Inlet
Outlet

H. Greuner, IPP

100 mm

1 m
BCC metals exhibit two kinds of fracture
- Low energy fracture – brittle
- High energy fracture – tough

Competition between critical resolved shear stress and cleavage stress
- Mobility of ⟨111⟩ screw dislocation depends on temperature, loading rate
- Cleavage stress independent on temperature

If CRSS reaches cleavage stress, transition in fracture behaviour
Theory of BDT

- BCC metals exhibit two kinds of fracture
  - Low energy fracture – brittle
  - High energy fracture – tough
- Competition between critical resolved shear stress and cleavage stress
  - Mobility of ⟨111⟩ screw dislocation depends on temperature, load rate
  - Cleavage stress independent on temperature
- If CRSS reaches cleavage stress, transition in fracture behavior
- Activation energy for BDT can be calculated

\[ \dot{K} = A \exp\left(-\frac{Q_{BDT}}{k_B T_{BDT}}\right) \]

Motivation

- Observation: UFG microstructure affects strain rate sensitivity of BDT
- Hypothesis: Change of controlling mechanism

![Graphs showing strain rate vs. temperature for coarse and ultra-fine grained materials.]

- Question: Identification of controlling mechanism of BDT in ultra-fine grained W
- Methods: Indirect by K-tests; direct via electron microscopy

Material

- Five W sheets produced exclusively at PLANSEE SE, Reutte, Austria
- Processing through hot and cold rolling out of one single sintered compact

<table>
<thead>
<tr>
<th>Sheet thickness s /mm</th>
<th>1.0</th>
<th>0.5</th>
<th>0.3</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of cold work $\varphi_{CR}$/-</td>
<td>1.8</td>
<td>2.5</td>
<td>3.0</td>
<td>3.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

- Extremely high degree of deformation through cold-rolling
- Five degrees of deformation causing
  - Five sheet thicknesses
  - Five microstructures

- No further heat treatment after rolling applied
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Microstructure
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- ODF maps
- Grain boundary character

Mechanical testing
- Influence of specimen thickness
- Influence of microstructure

Summary
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- Tungsten: Designated material for plasma facing components in fusion devices but inherently brittle up to 400 °C

- Motivation: Dramatic improvement of its mechanical properties through cold rolling

- Goal: Identification of mechanism causing BDTT in ultra-fine grained tungsten

- Experimental: Five cold rolled sheets, five microstructures made of same sintered compact

- Result 1: Grain refinement down to 300 nm
- Result 2: Alpha and gamma fiber, pronounced rotated cube orientation
- Result 3: BDTT less dependent of specimen thickness
- Result 4: BDTT shift of 500 K downwards to -100 °C for the 0.1 mm UFG W
Thank you for your attention

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