Karlsruhe Institute of Technology

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

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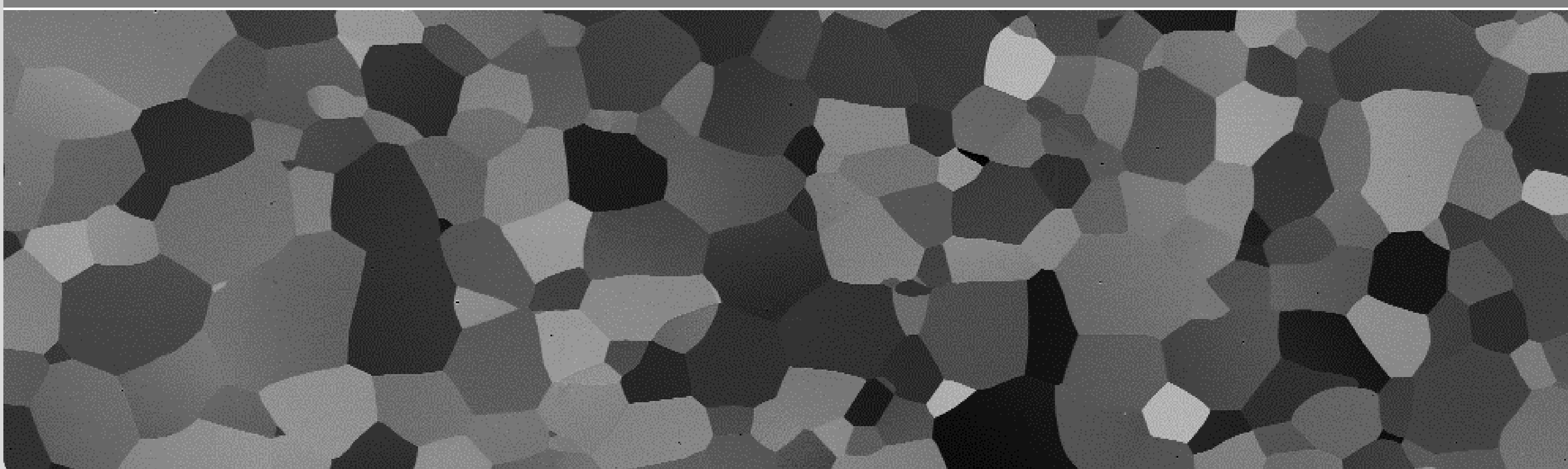
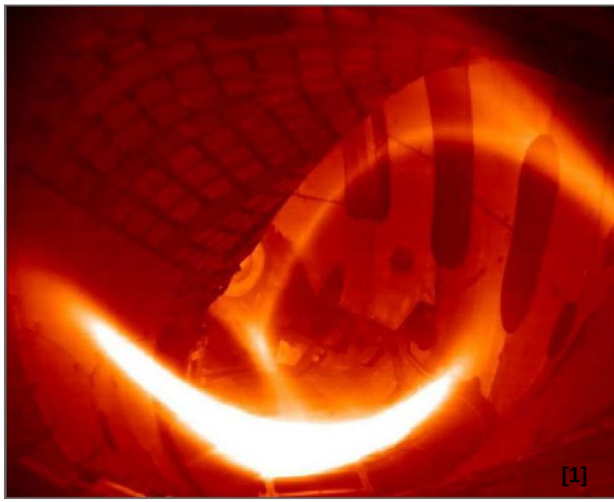


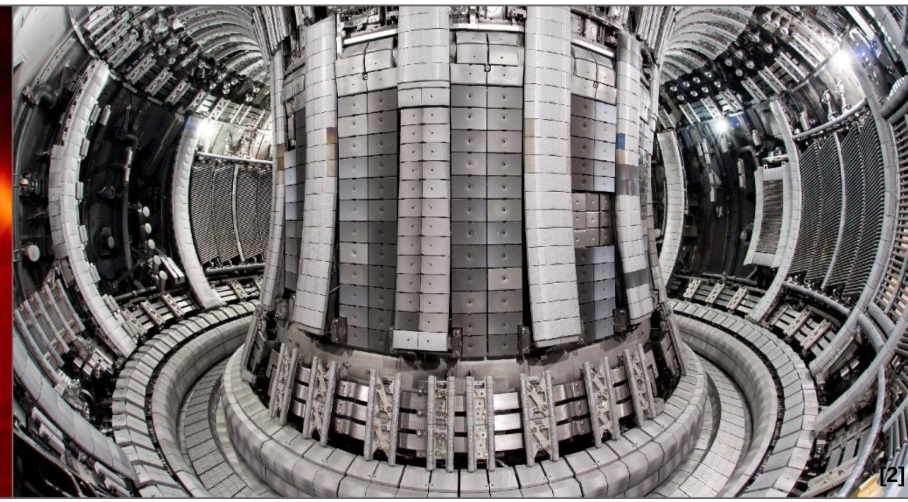
Outline

- 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

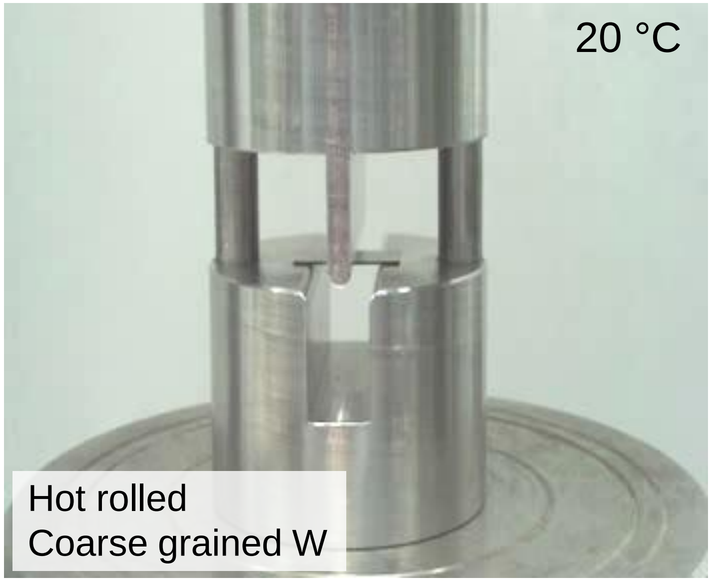


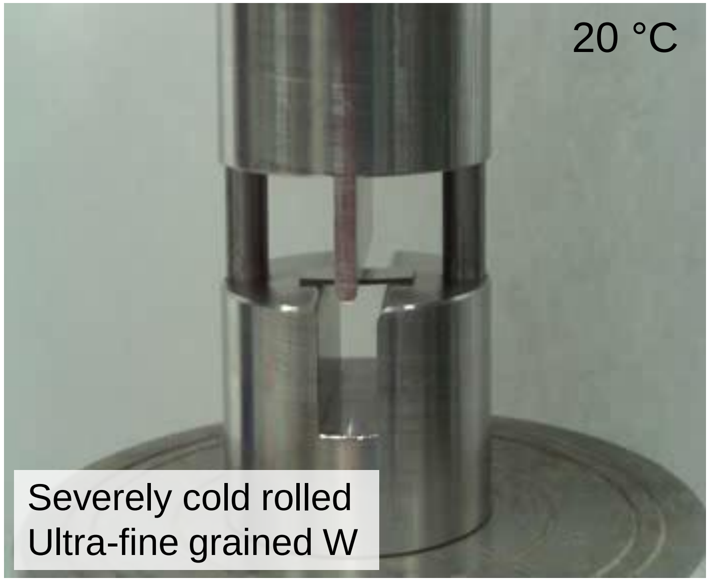


- Poor oxidation resistance
- Brittle fracture at ambient temperature
  - Not in use as structural material, only applied as functional material nowadays

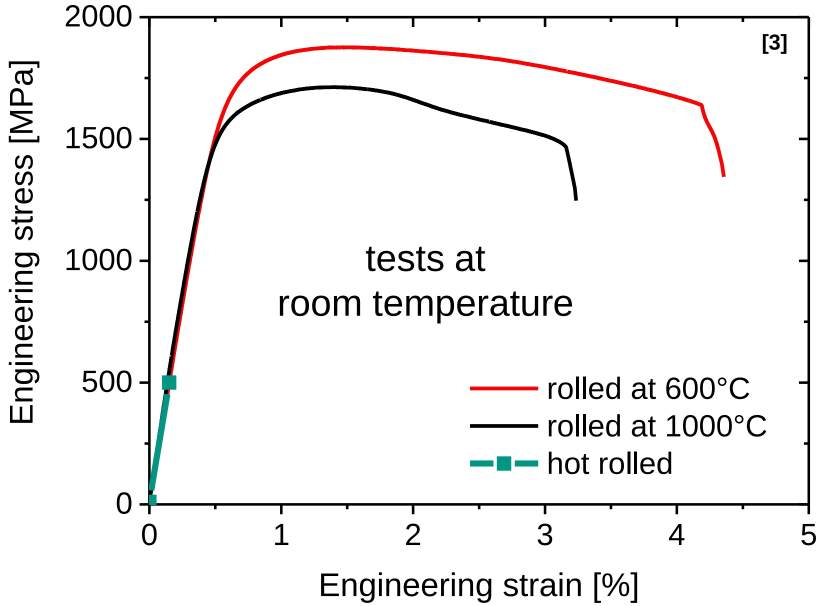
[1] Wendelstein X7 Newsletter
[2] www.euro-fusion.org

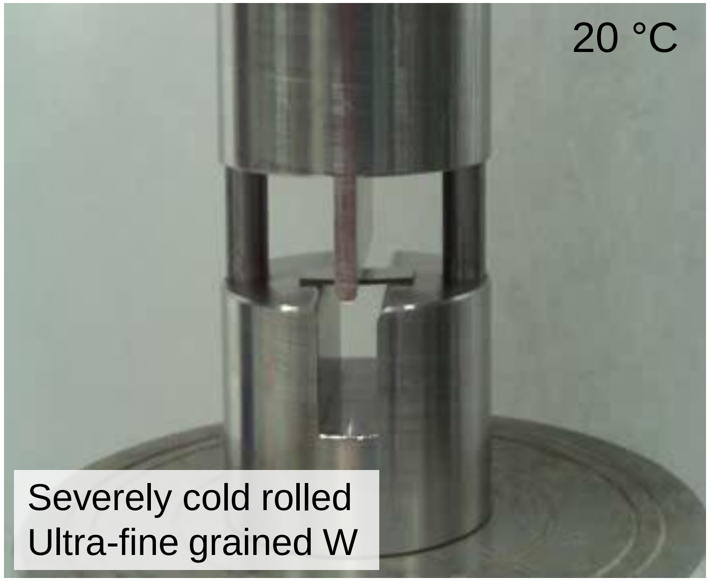
Improvements through severe cold rolling





Improvements through severe cold rolling

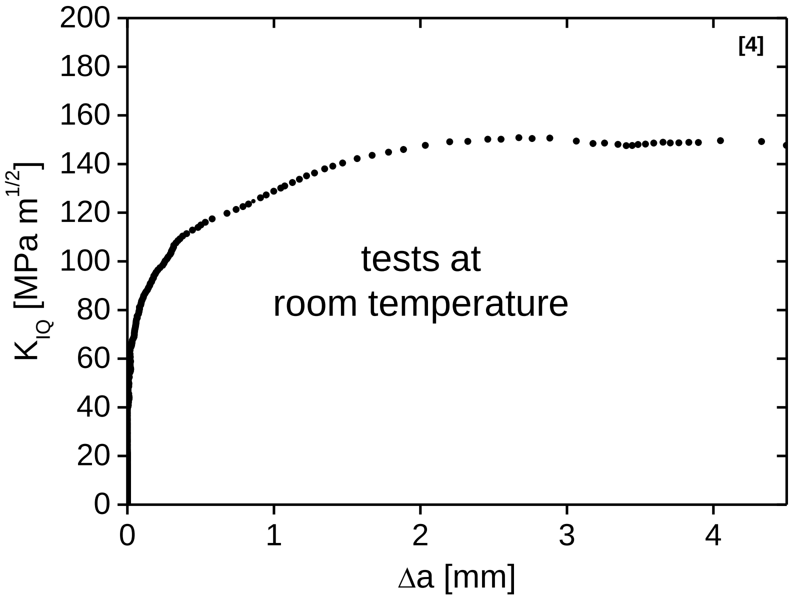


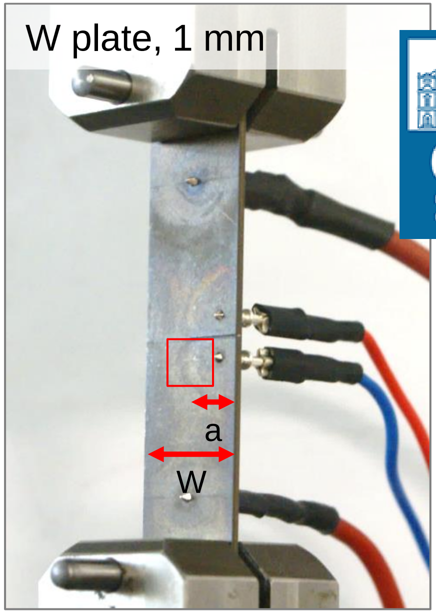


- Tensile test: Ductility and yield strength improved

[3] Reiser, J. et al.: Ductilisation of tungsten (W): On the increase of strength and room-temperature tensile ductility through cold-rolling

Improvements through severe cold rolling

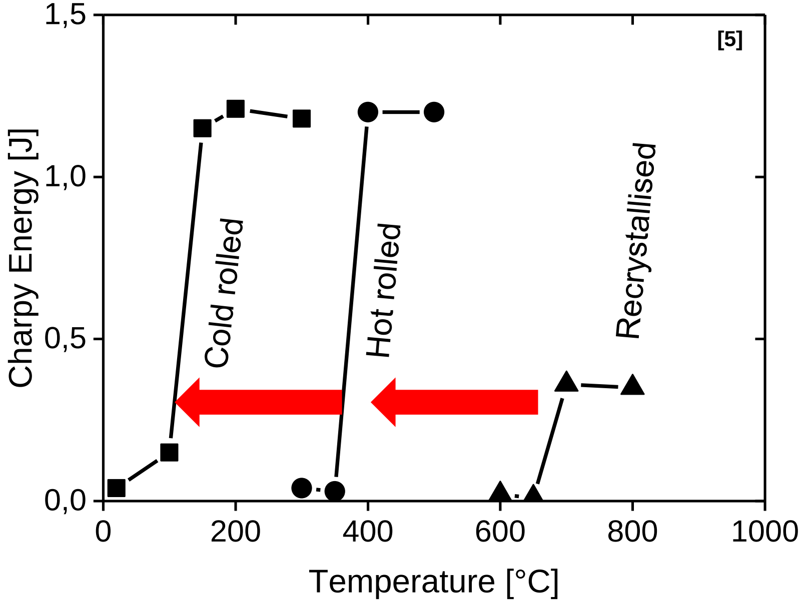




- Tensile test: Ductility and yield strength improved
- Fracture behavior: Stable crack growth at room temperature achieved

[4] Reiser, J. et al.: Ductilisation of tungsten (W) through cold-rolling: R-curve behaviour

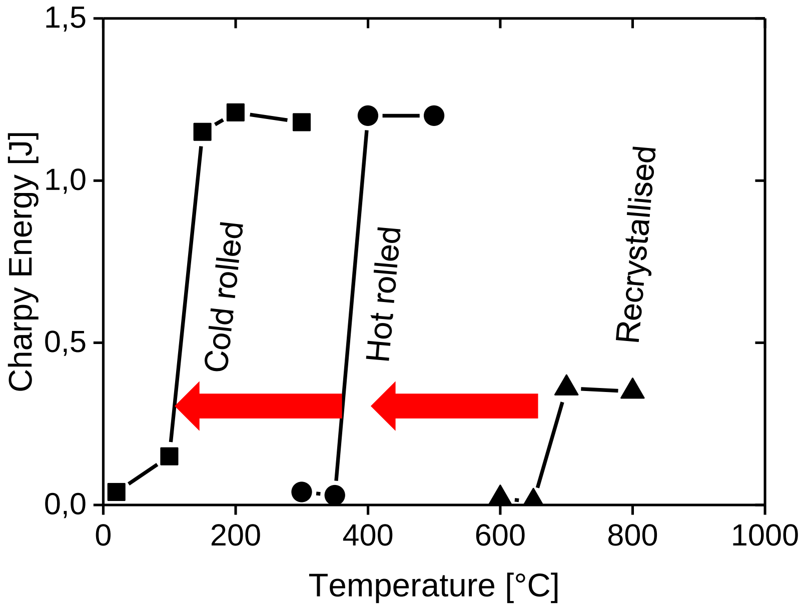
Improvements through severe cold rolling

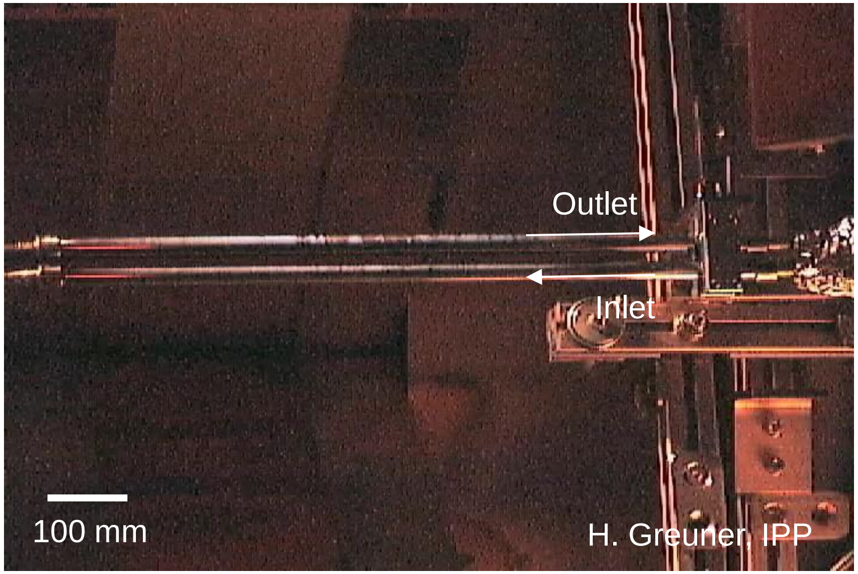


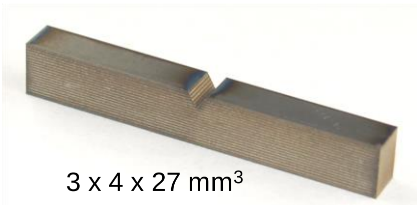
- Tensile test: Ductility and yield strength improved
- Fracture behavior: Stable crack growth achieved
- Charpy tests: BDTT shifted to lower temperatures

[5] Reiser, J. et al.: Ductilisation of tungsten (W): On the shift of the brittle-to-ductile transition (BDT) to lower temperatures through cold rolling

Improvements through severe cold rolling

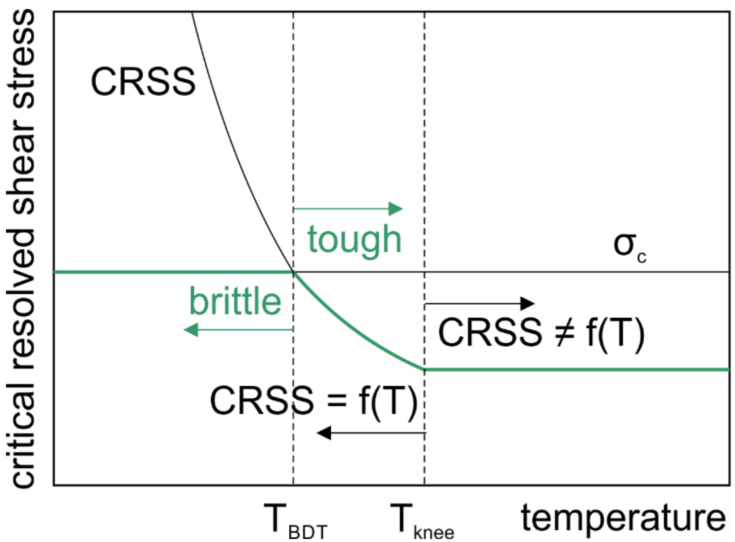


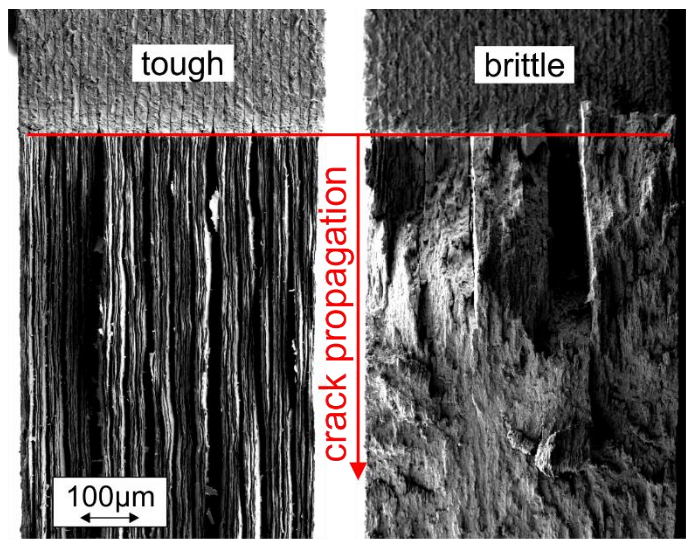




Theory of BDT

- 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, loading rate
  - Cleavage stress independent on temperature
- If CRSS reaches cleavage stress, transition in fracture behaviour





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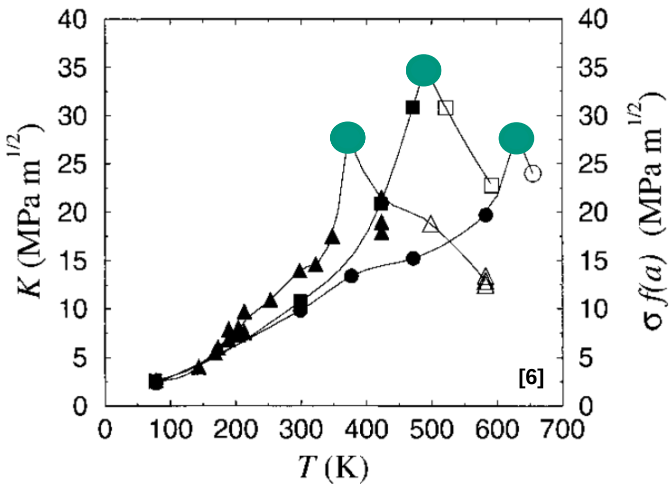
- If CRSS reaches cleavage stress, transition in fracture behavior
- Activation energy for BDT can be calculated

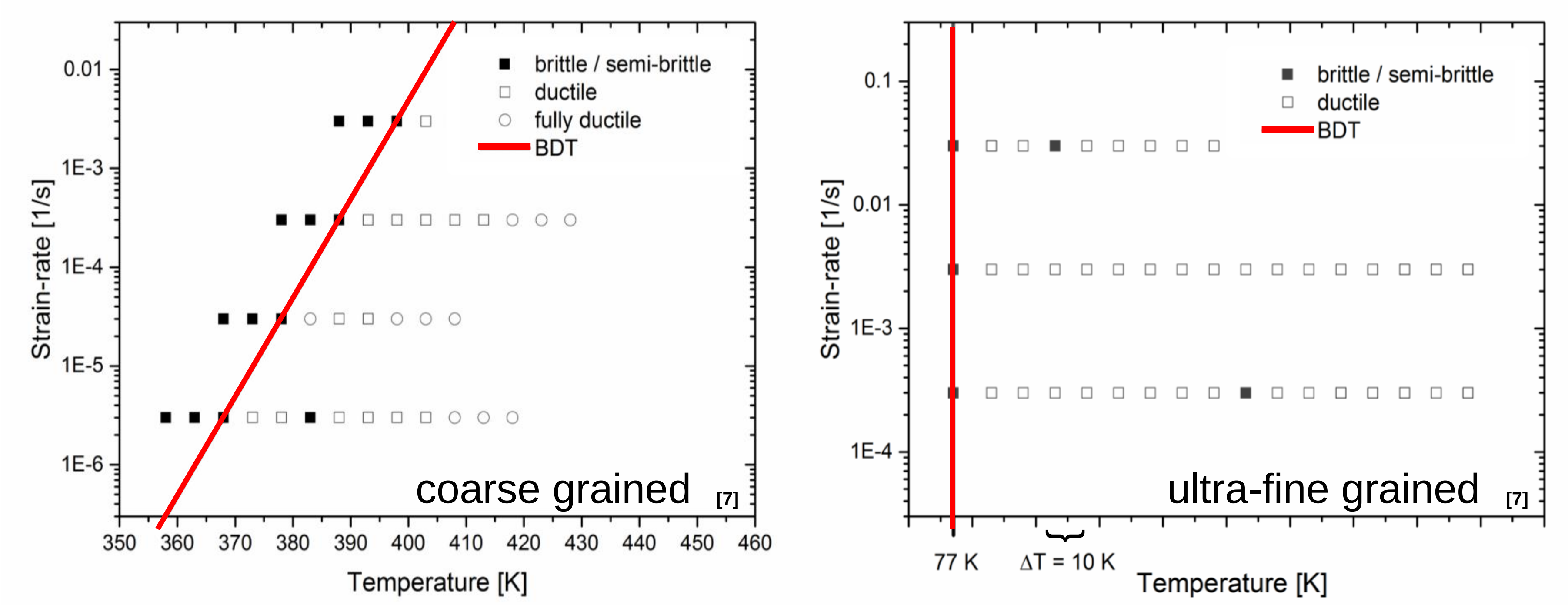


$$\dot{K} = A \exp\left(-\frac{Q_{BDT}}{\mathrm{k_B}\, T_{BDT}}\right)$$

[6] Hartmaier, A. et al.: On the Activation Energy for the Brittle/Ductile Transition

Motivation

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



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

[7] Németh, A. et al.: The nature of the brittle-to-ductile transition of ultra fine grained tungsten (W) foil

Material

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

Sheet thickness s /mm	1.0	0.5	0.3	0.2	0.1
Degree of cold work φ_{CR} /-	1.8	2.5	3.0	3.4	4.1

- 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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Summary

- 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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