Achieving room-temperature ductility for monolithic tungsten (W)

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19.05.2016, Ruhr-Universität Bochum

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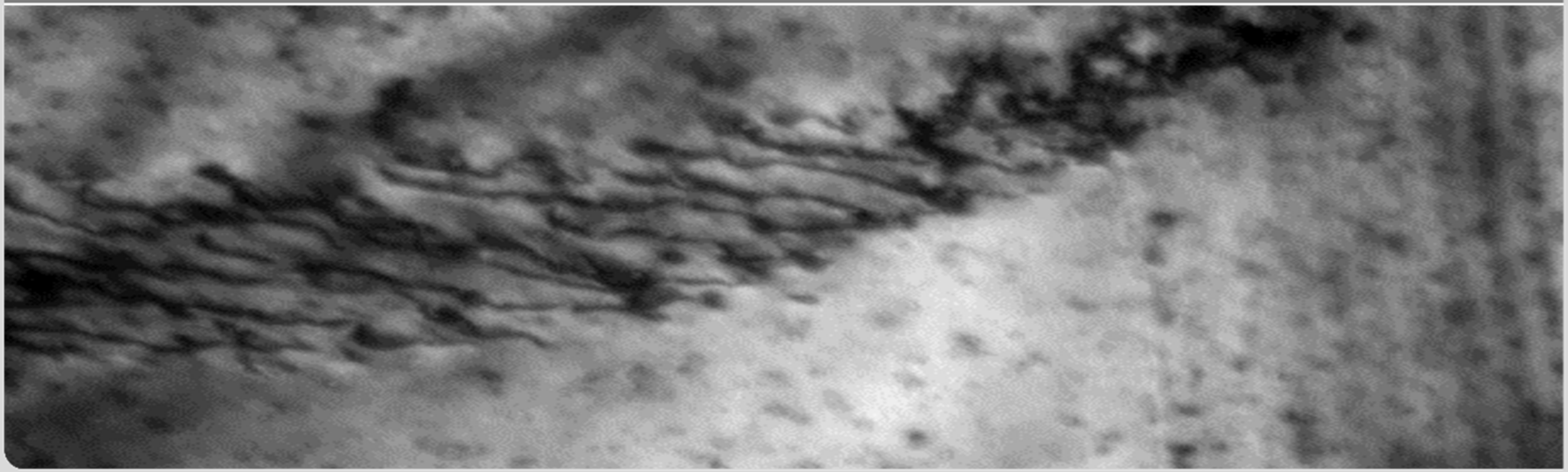

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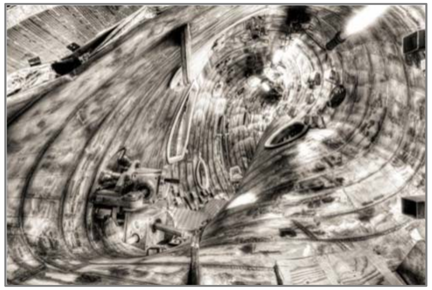
What is the problem?

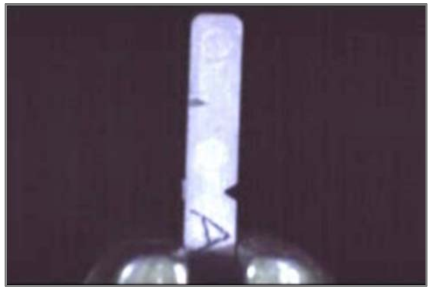
- Innovative high-temperature energy conversion systems ask for advanced structural materials
- Tungsten (W)
  - Advantage: T_m = 3422°C (3695 K)
  - bcc
  - Disadvantage: brittleness, BDT

→ How to make tungsten ductile?



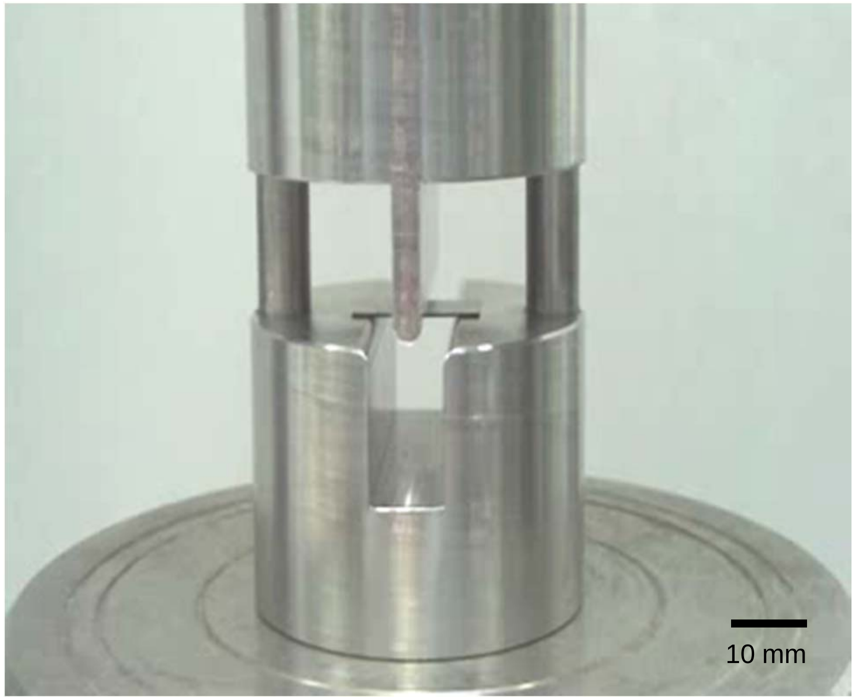
Wendelstein 7-X, Greifswald, Germany (C. Lünig)

Abengoa Solar

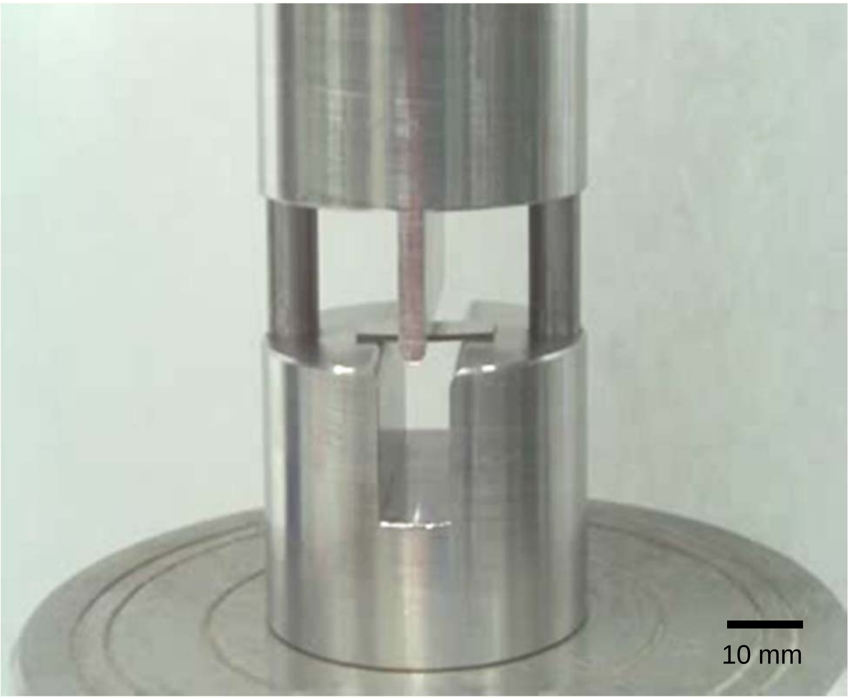


Approach: Severe cold-rolling

Hot-rolled, coarse-grained W
Test temperature: RT



Severely cold-rolled, ultrafine-grained W
Test temperature: RT



→ What happens during cold-rolling that makes W ductile?

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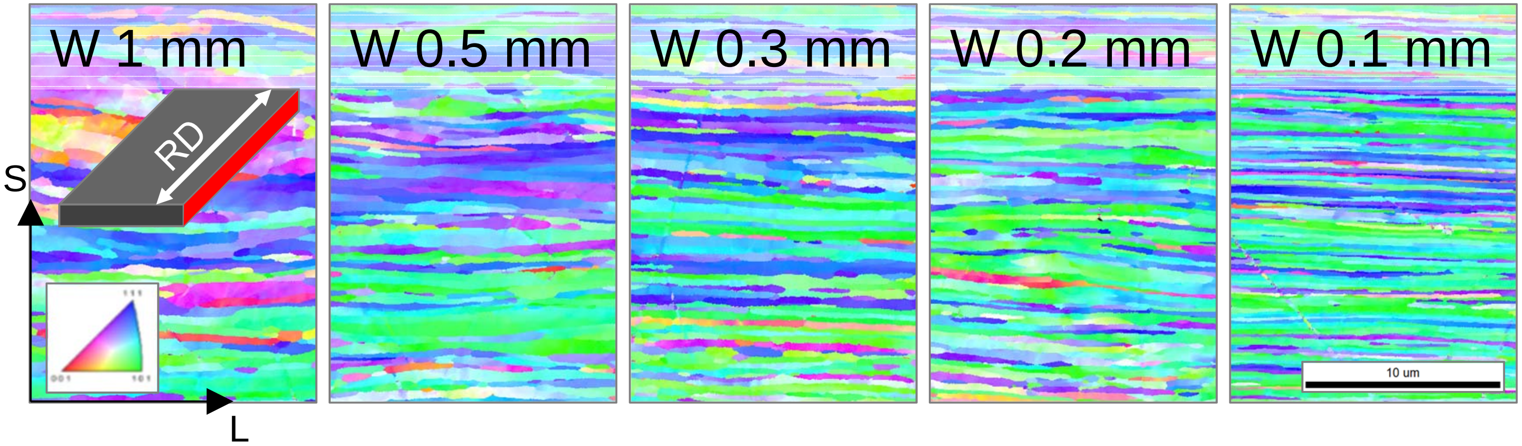
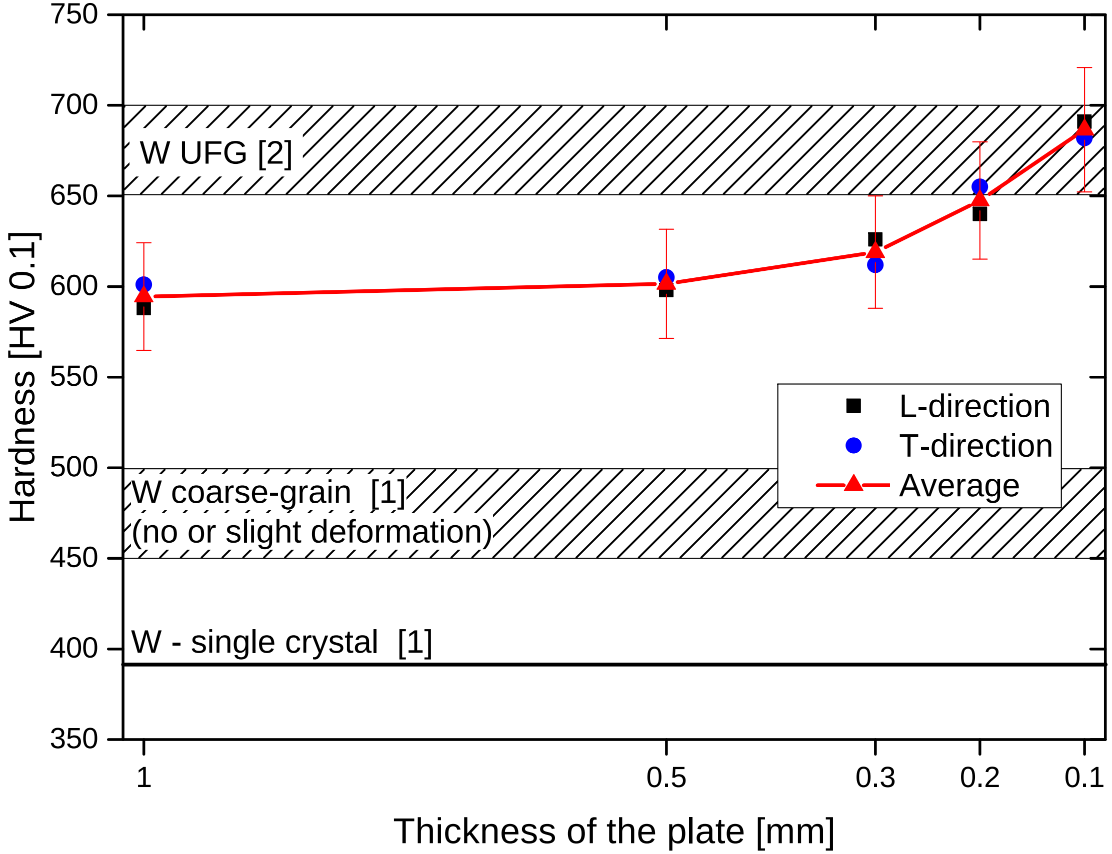
Materials: Plates, rolled-out from one ingot



- Purity: 99.97 wt % W
- Rolling parameter
  - Def. cold-rolling: $T_{rolling} < T_{rxx}$ (1250°C)
  - Degree of deformation: $\varphi = -\ln(h_1/h_0)$

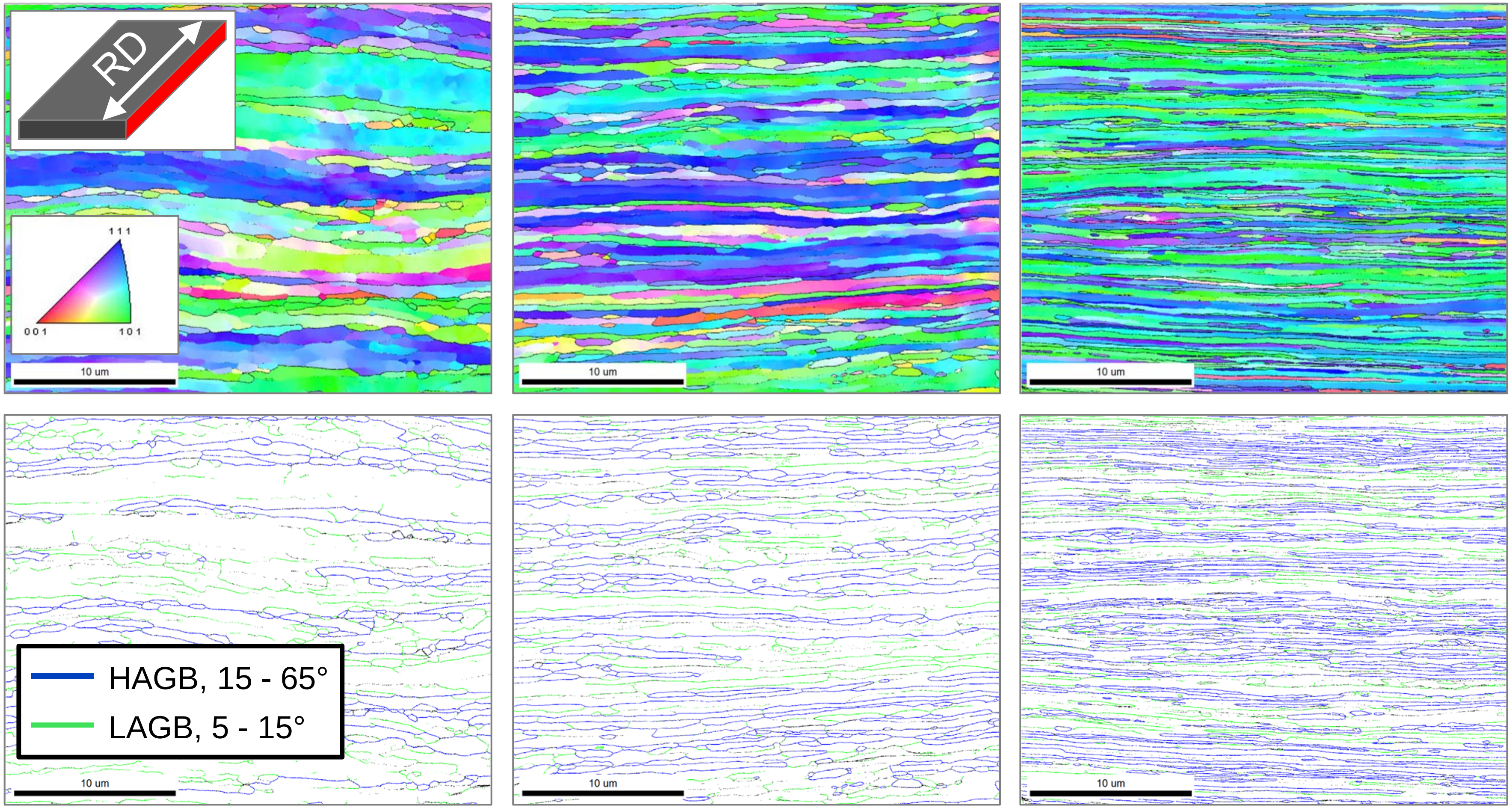
Microstructure: Hardness, HV0.1



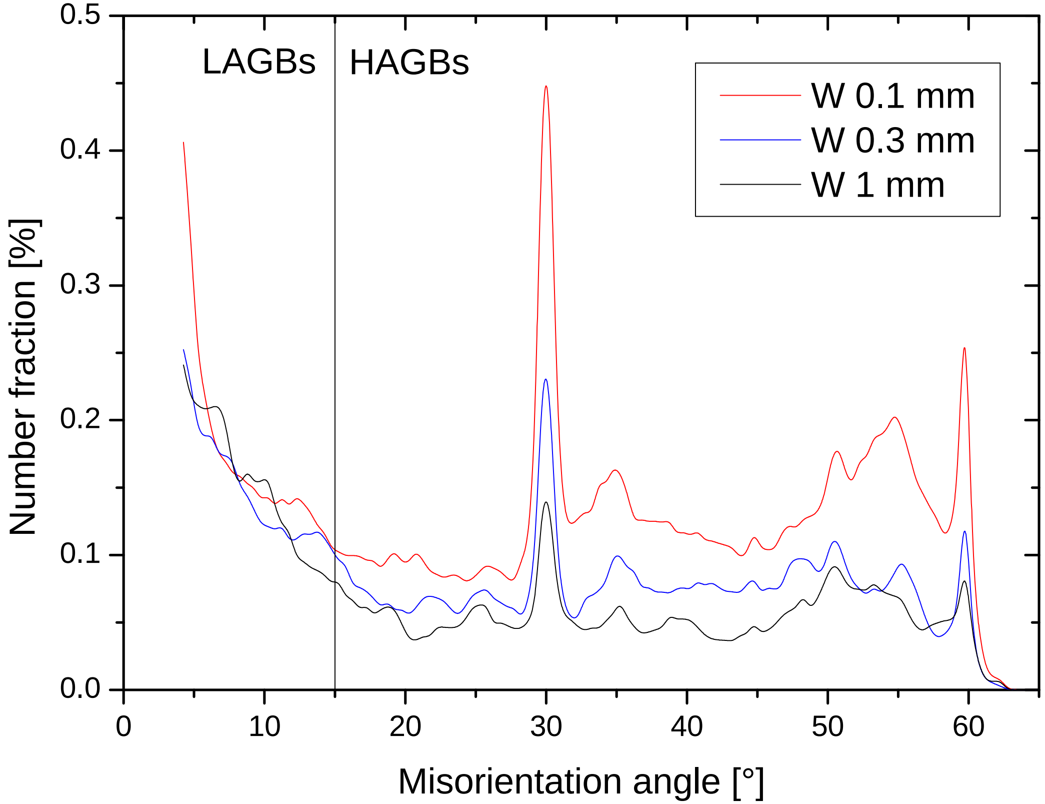
[1] E. Lassner, W.D. Schubert, Springer, Berlin, 1999.
[2] Q. Wei, L.J. Kecskes, Mater. Sci. Eng. A. 491 (2008) 62–69.

Microstructure: HAGBs and LAGBs

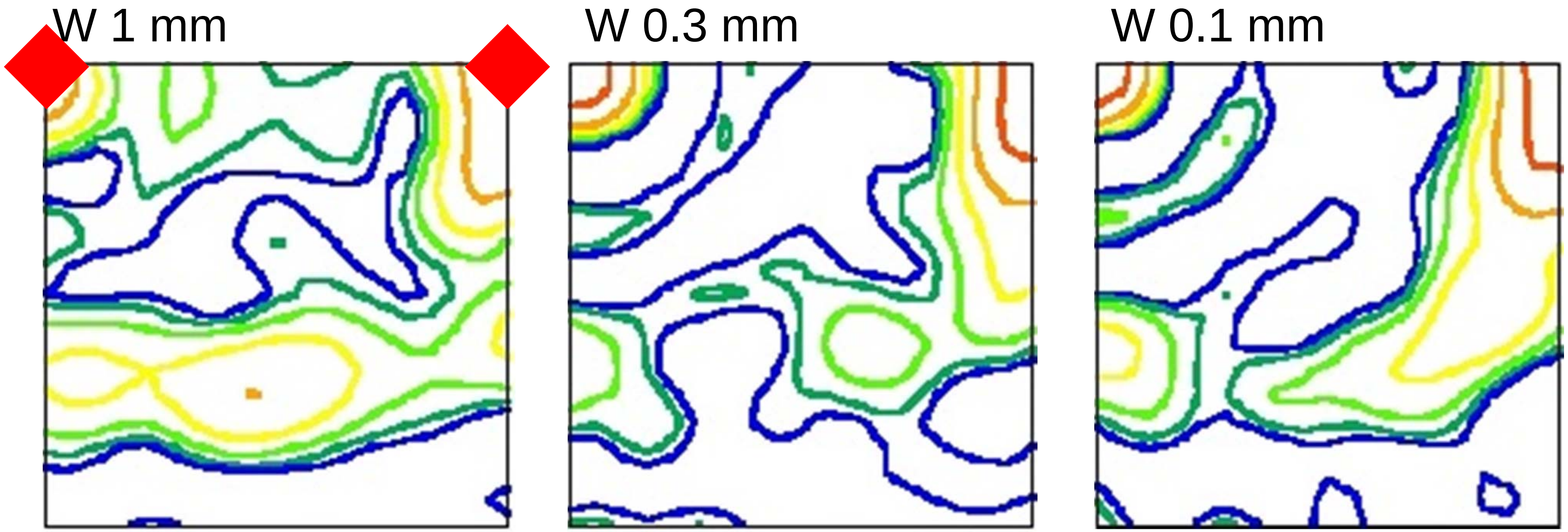
W 1 mm W 0.3 mm W 0.1 mm

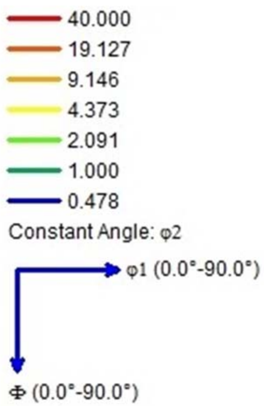


Microstructure: Misorientation angel

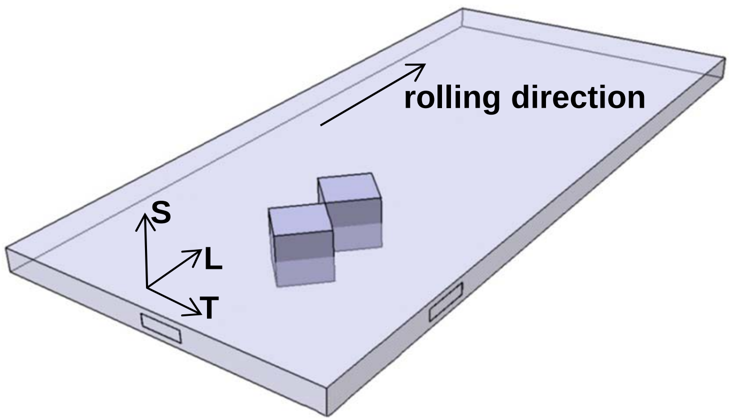


Microstructure: Crystallographic texture

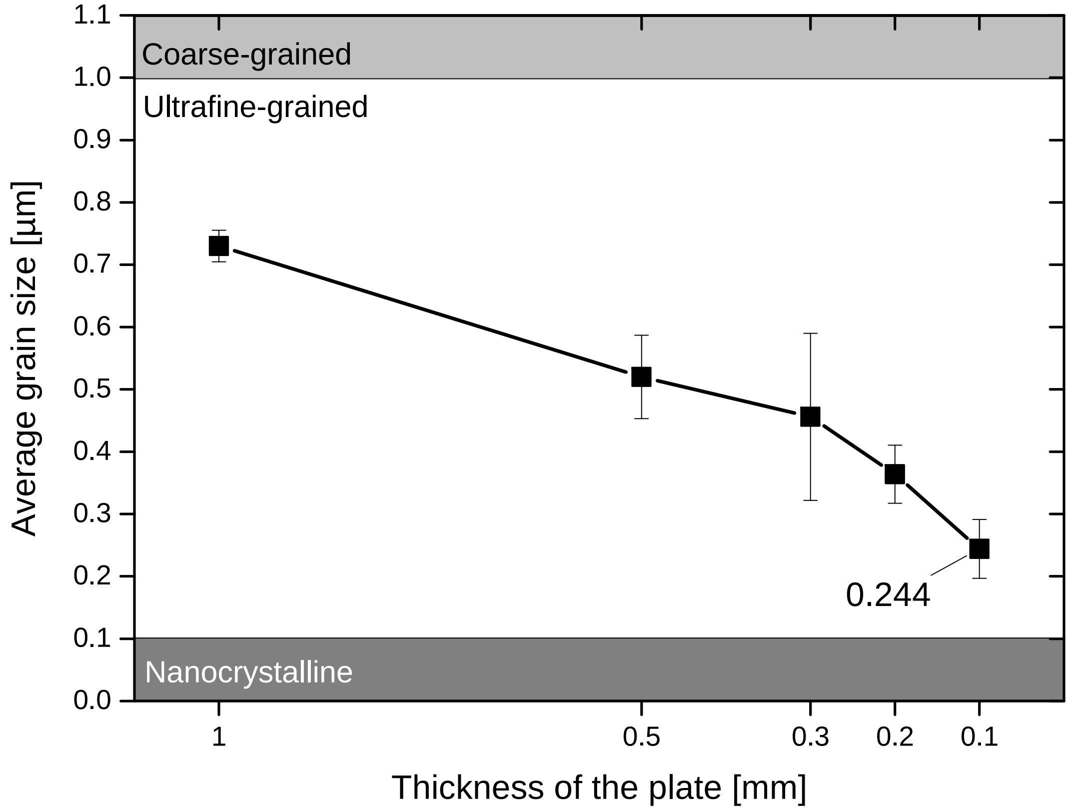




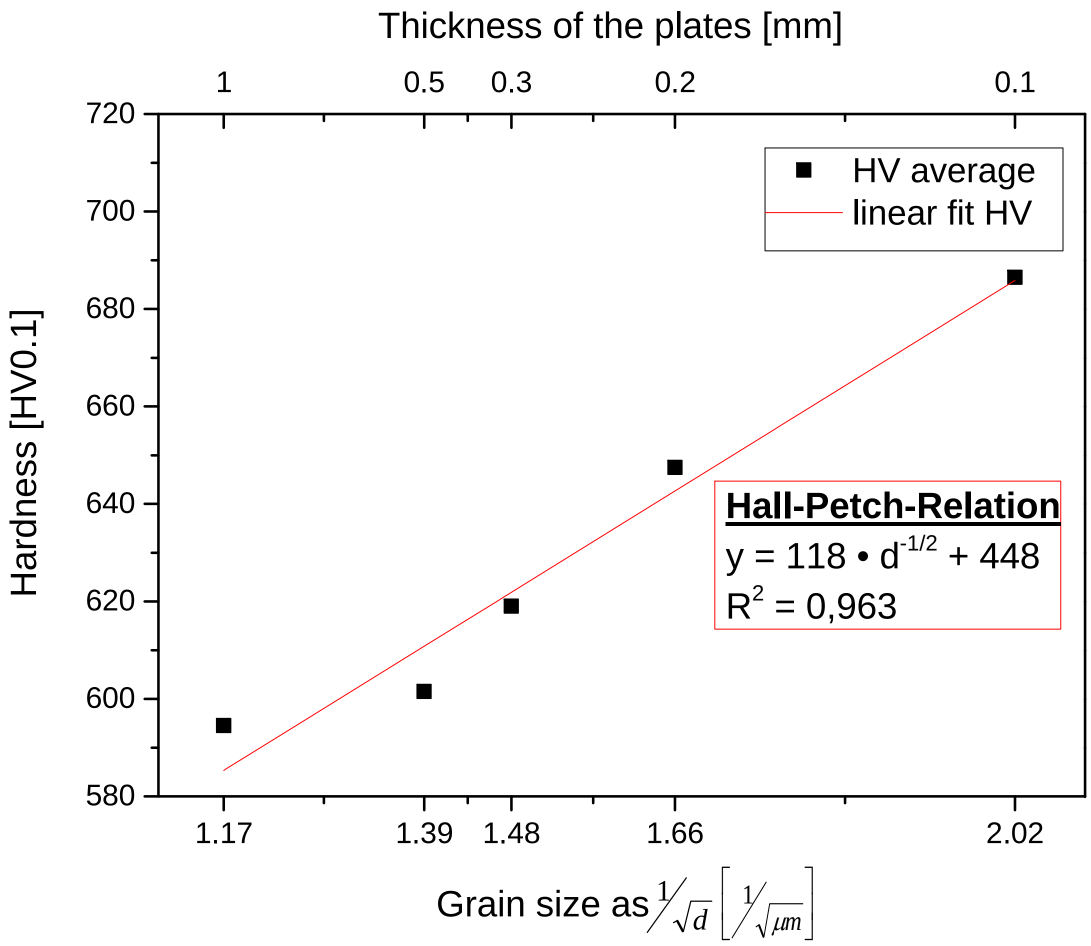
φ_2 = 45°, ODF



Microstructure: Grain size (in the S-direction)

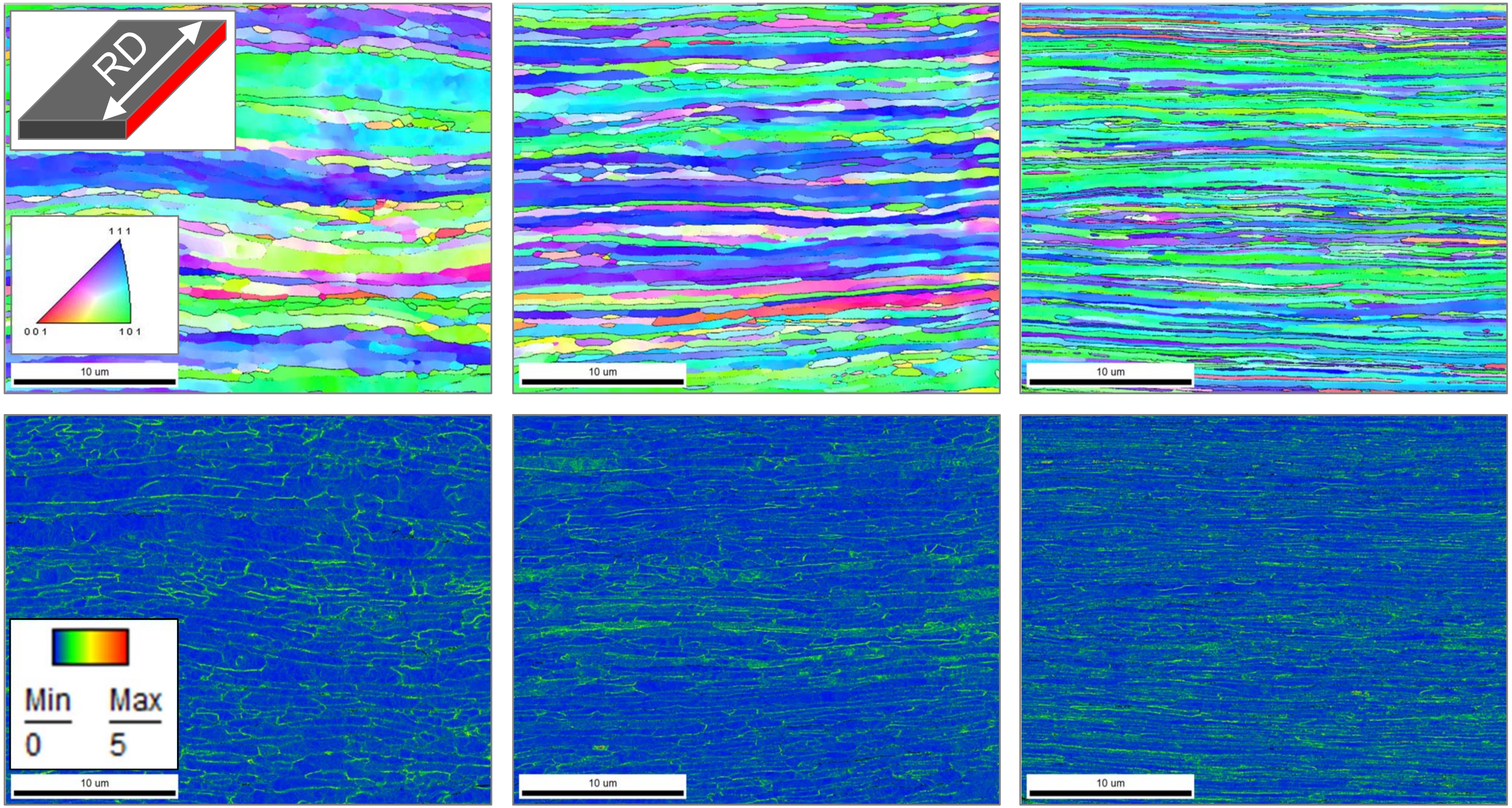


Hall-Petch relation (gran size ~ hardness)



Microstructure: KAM

W 1 mm | W 0.3 mm | W 0.1 mm



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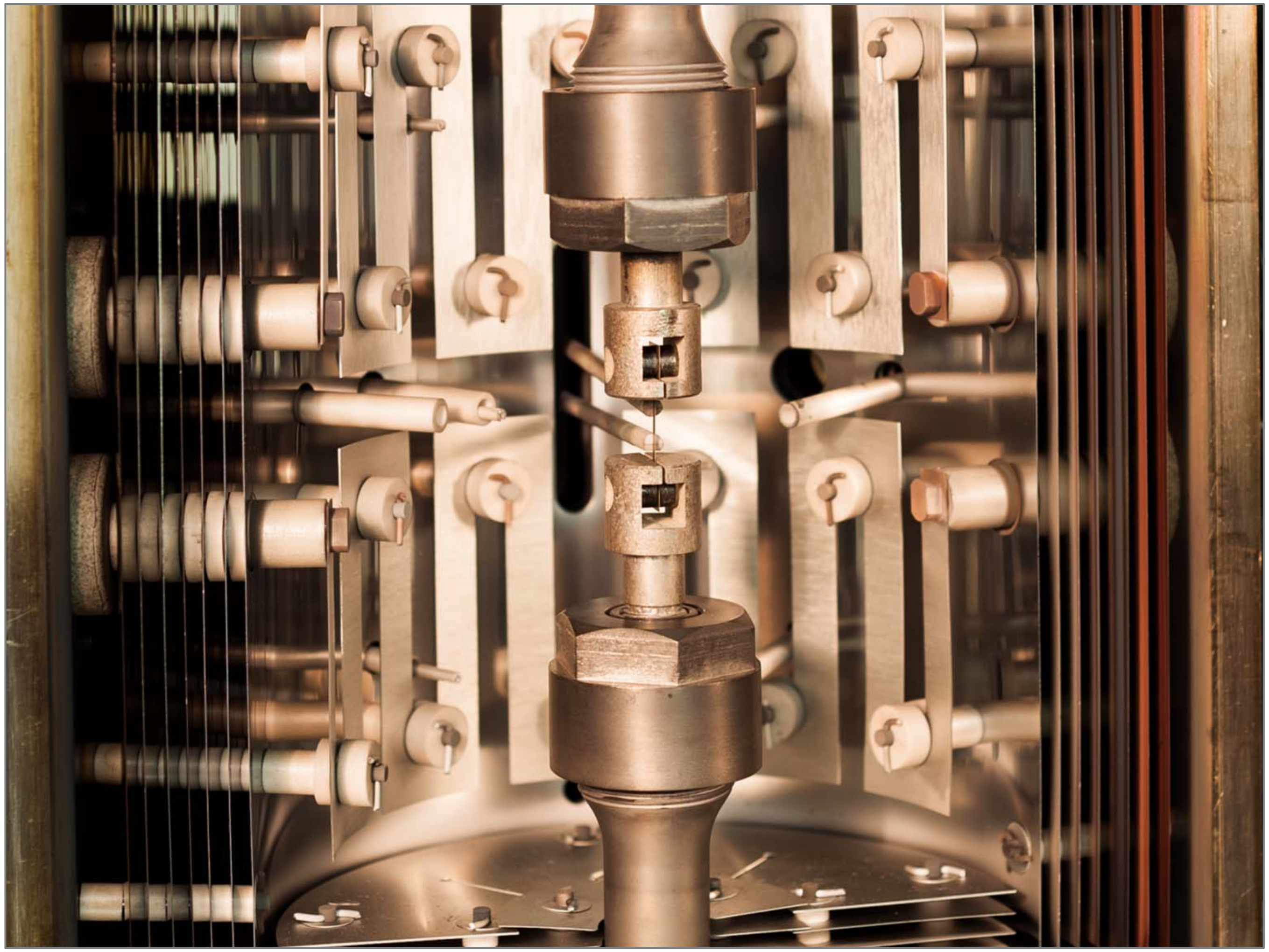
Methods: Strain-rate jump tests



10 mm

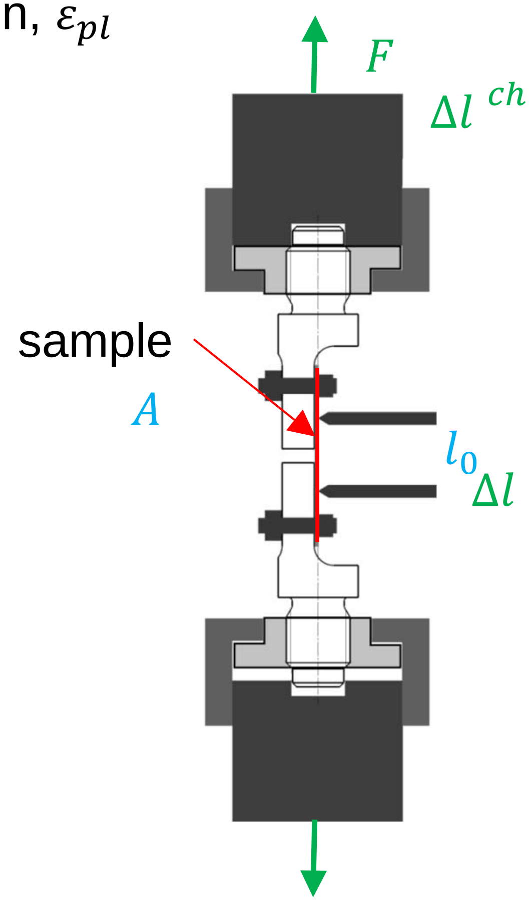
Methods: Strain-rate jump tests

- Aim: to change the strain-rate, $\dot{\varepsilon}$, at a certain plastic strain, ε_{pl}
- Measure: Load, F
  - Displacement cross head, $\Delta l^{\,ch}$
  - Displacement extensometer, Δl
- Input: Gauge length, l_0
  - Area of cross section, A

$$\varepsilon_{ges} = \varepsilon_{pl} + \varepsilon_{el}$$

$$\frac{\Delta l}{l_0} = \varepsilon_{pl} + E\sigma$$

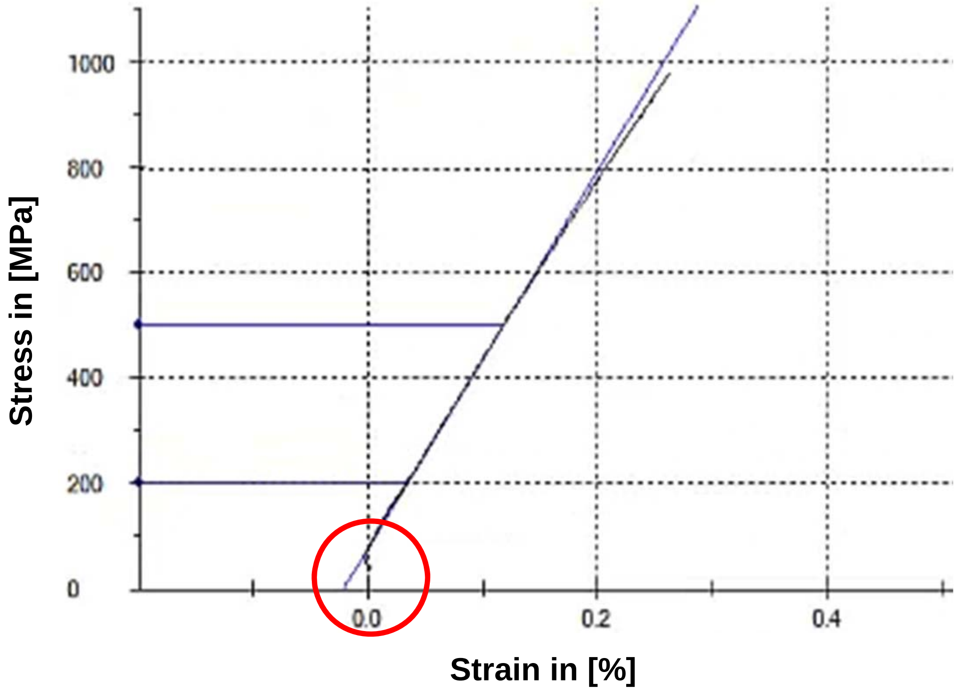
$$\frac{\Delta l}{l_0} = \varepsilon_{pl} + E\frac{F}{A}$$

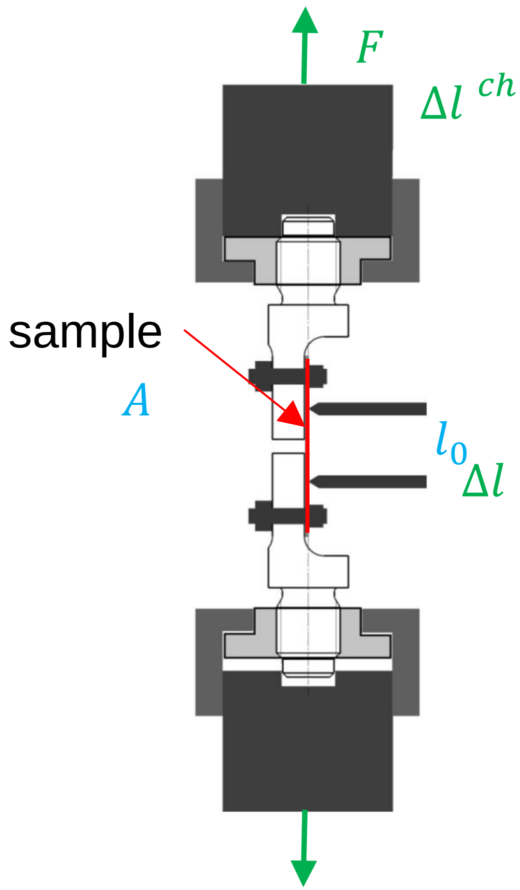


→ Code a channel for plastic strain, ε_{pl}

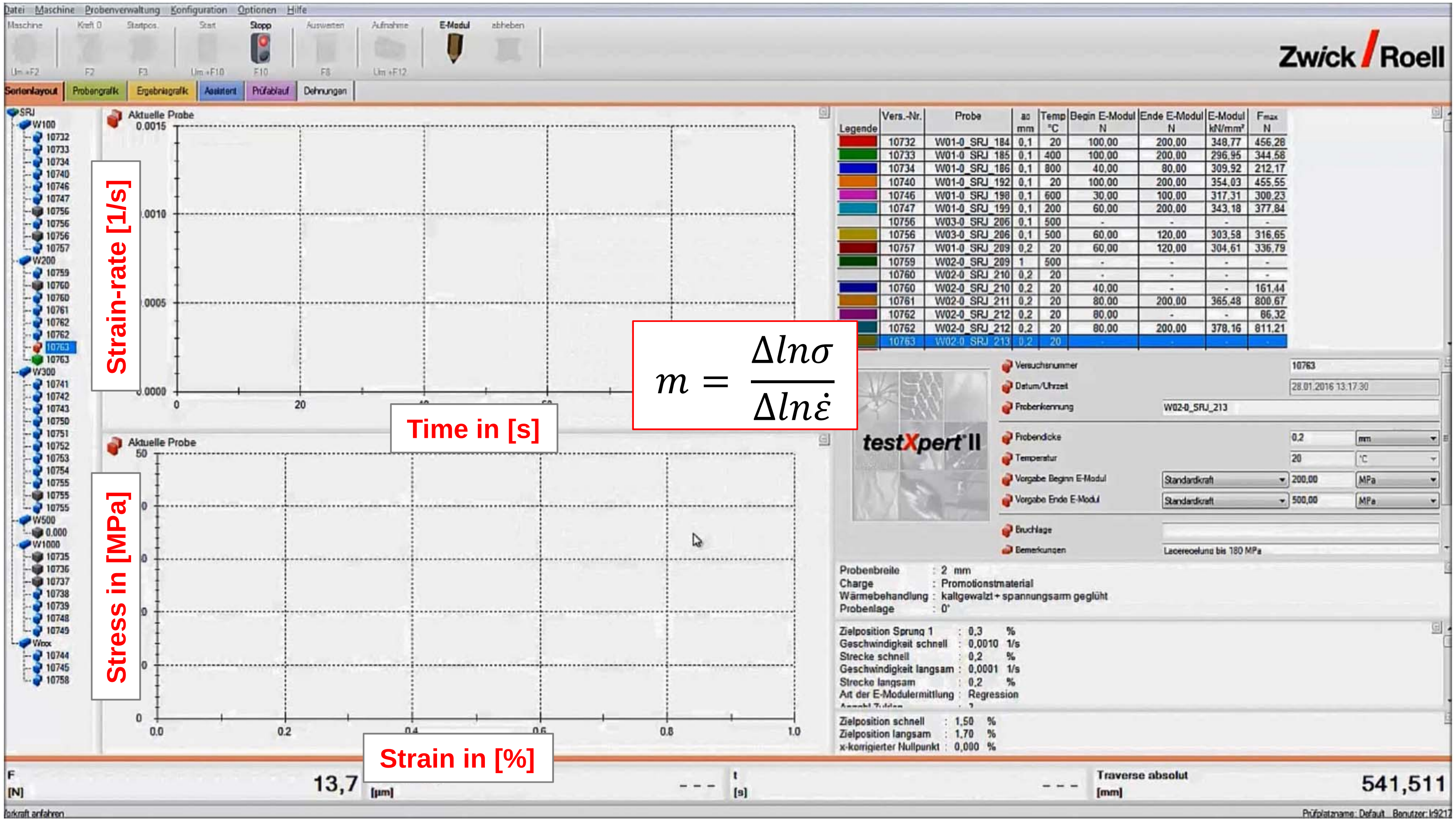
Methods: Strain-rate jump tests

- Temperature, preload
- Dynamic strain rate adaption, $\dot{\varepsilon}$
- In situ Young's modulus, zero point correction → ε_{pl}
- Change from cross-head to extensometer controlled
- Weight of the clamp is considered





Methods: Strain-rate jump tests



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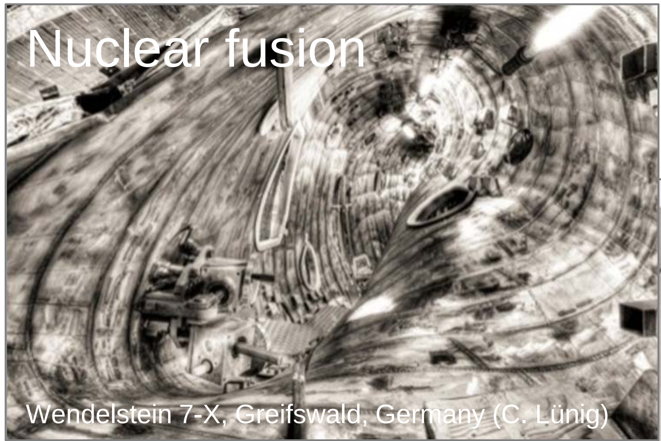
Summary



We do not know why
W foils are ductile at RT,
but…

Thank you for your attention

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