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Key factors for room-temperature ductility of monolithic tungsten sheets

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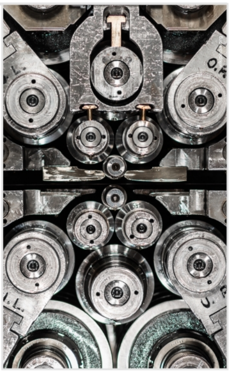
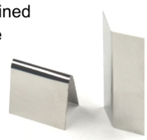
Motivation

In order to transform tungsten (W) from a brittle into a safe and powerful armor material, production methods are in demand, which reduce the brittle-to-ductile (BDT) temperature effectively and also can scaled-up easily to an industrial level.

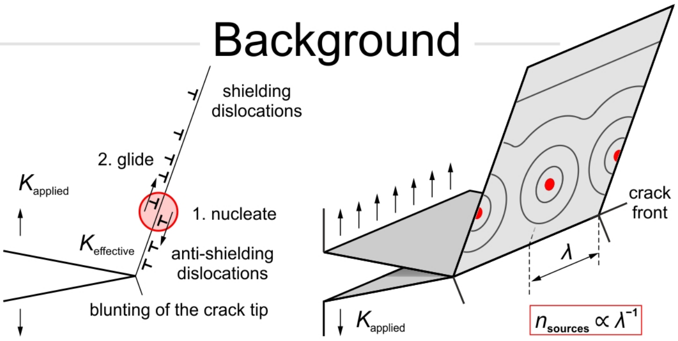
With BDT temperatures well below room-temperature recent studies of cold-rolled W, e.g. conducted by *Németh et al.* (2015) and *Bonnekoh et al.* (2018), have proven that severe deformation by warm- and cold-rolling is a very promising approach having the potential to meet both challenges.

However, the effect of an ultrafine-grained microstructure (as a result of severe deformation) on the BDT temperature is not fully understood so far.



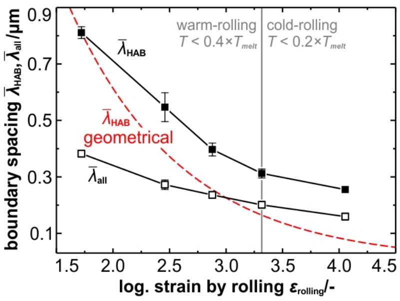


Background

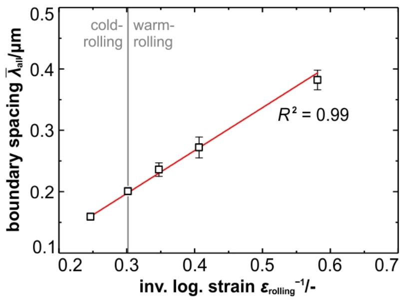


According to *Roberts* (1993), the BDT temperature correlates with the emission of dislocations close to the crack tip. If some microstructural defects act as dislocation sources, the BDT temperature will decrease with reduced spacing of promoting defects (λ) along the crack front.

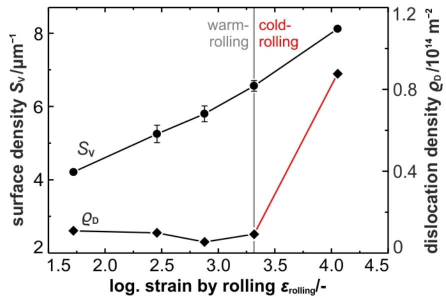
Results



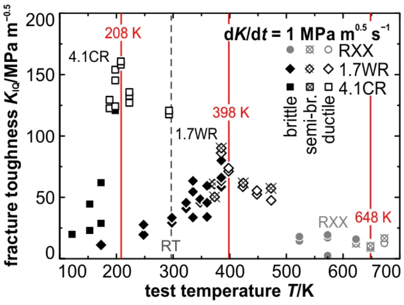
Reduction of $\bar{\lambda}_{HAB}$ (including boundaries with disorientation angles $\theta > 15°$) and $\bar{\lambda}_{all}$ ($\theta > 2°$) slows down with increasing $\varepsilon_{rolling}$, independent of the pre-heating temperature (T) the sheets were exposed to bevor the single steps of rolling.



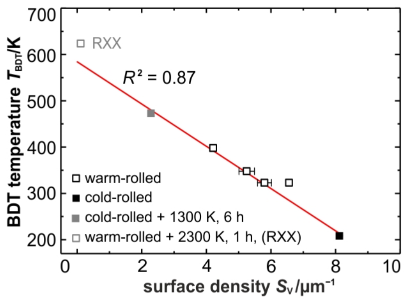
Although the refinement of $\bar{\lambda}_{HAB}$ is less distinct than expected due to geometrical considerations, $\bar{\lambda}_{all}$ follows the relation published by *Nes* (1998). This raises the question asking for the origin of the slowed-down decrease of $\bar{\lambda}_{HAB}$ in rolled W.



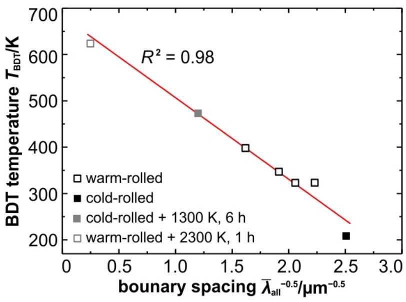
The trend towards higher S_V with increasing $\varepsilon_{rolling}$ seems to be predominantly controlled by $\varepsilon_{rolling}$ rather than by the selected pre-heating temperature. In contrast to that, ϱ_D shows a significant increase after changing from warm- to cold-rolling.



The most deformed W sheet (4.1CR) exhibits with 208 K a BDT temperature well below room temperature. This is 400 K lower than determined for the undeformed condition (RXX) and 250 K below the less deformed W sheet (1.7WR).



With the exception of the undeformed condition (RXX), the BDT temperature can quite well be expressed as a linear function of the surface density, if all boundaries with a disorientation angles above 2° are included.



The most promising link between BDT temperature and a microstructural property was found considering the evolution of the mean boundary spacing in the normal direction, if all boundaries with disorientation angles above 2° are included.

Conclusions

(1) Severe deformation by cold-rolling is a (cost)efficient way to produce room-temperature ductile W sheets in large quantities.

(2) Boundary spacing along ND and the surface density are mainly controlled by the strain conducted by rolling. However for the studied deformation states the evolution of the dislocation density strongly depends on the pre-heating temperature selected for the single steps of rolling and less on the applied thickness reduction.

(3) A comparison of BDT temperatures and mean boundary spacings revealed a strong correlation between both properties.

(4) The direction-dependent size of the boundary spacing might furthermore explain the impact of the crack system on the measured BDT temperatures in materials with highly anisotropic grain shapes – as well-known for sheets produced by severe rolling.

Where can I find more details?
C. Bonnekoh, A. Hoffmann, and J. Reiser; In: Int. J. Refract. Met. Hard Mater. 2018;(71):181–189.
C. Bonnekoh, U. Jäntsch, J. Hoffmann et al.; In: Int. J. Refract. Met. Hard Mater. 2019;(78):146–163.

Methods

Materials with the log. strains 1.7, 2.5, 2.9 and 3.3 were shaped by warm-rolling (WR). A section of 3.3WR was subsequently cold-rolled (CR) by log. 0.8 to a cumulated log. strain of 4.1.

Taking into account ASTM E399-12, fracture toughness tests (L-T crack) were conducted to assess the impact of severe rolling on the BDT temperature of the above-mentioned W sheets.

To study the deformation-induced evolution of the microstructure, EBSD scans and XRD measurements were carried out.

PLANSEE EUROfusion
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