RUHR UNIVERSITÄT BOCHUM RUB

Effect of grain size, temperature and texture on mechanical properties of the CrCoNi medium-entropy alloy

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CCA HEA

LWW Lehrstuhl Werkstoffwissenschaft materials science and engineering

1. Theoretical basics of grain size strengthening

Hall-Petch[1]

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

σ_y =	yield stress
σ_0 =	friction stress
k_y =	material constant
d =	grain diameter

Concept: Interaction dislocation/grain boundaries.

- Sources emit dislocations.
- GB act as barriers to dislocation movement.
- Stress concentration at the tip of the pile-up must exceed a critical value to transmit slip.

([1]G.E. Dieter et al., MM, 1986 / E.O. Hall, PPS, 1951 / N.J. Petch, JISI, 1953)
([2]http://simap.grenoble-inp.fr/gpm2/bicrystal-220086.kjsp?RH=SIMAP_GPM2)

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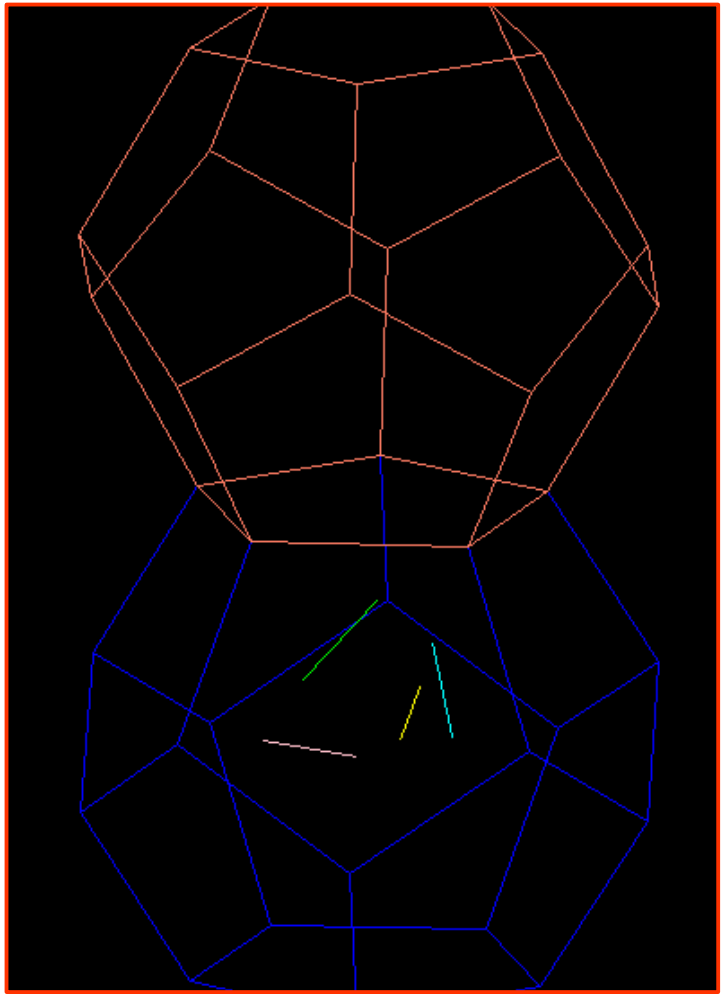

Movie: Bicrystal[2]

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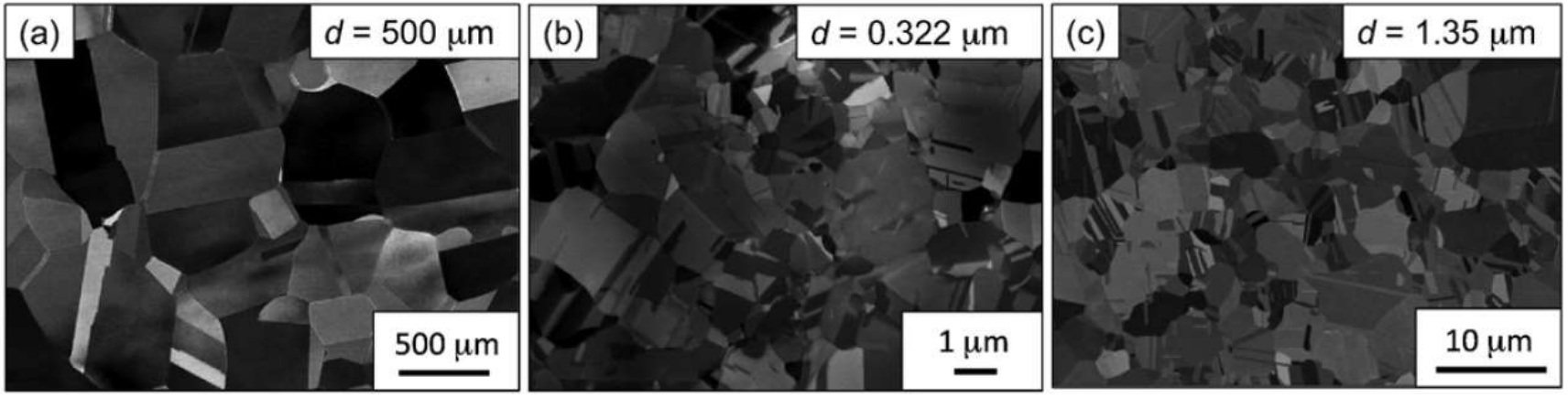
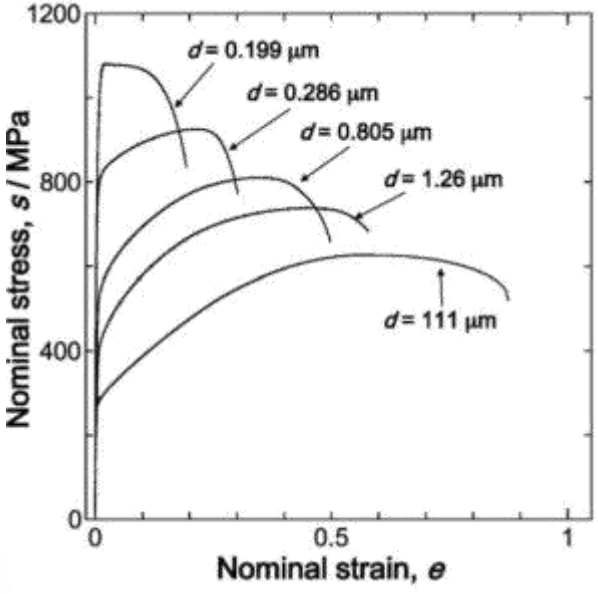
1. Theoretical basics of grain size strengthening

Hall-Petch relationship of **CrCoNi** first investigated by Yoshida et al., but:

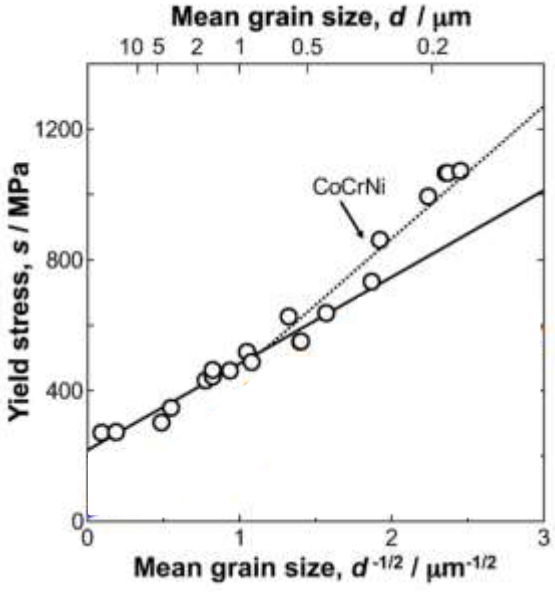
- *no texture analysis* (S. Yoshida et al., Scripta134, 2017)



- *tests only at room temperature*



- *no error bars in plots*



Sample preparation

1. Casting

Raw materials (Cr, Co, Ni)

↓

Vacuum induction melting

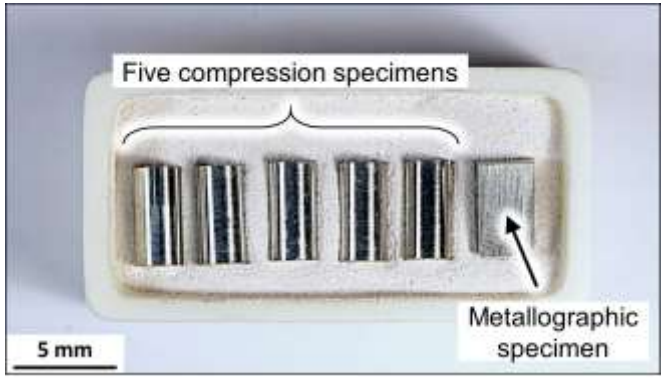
↓

Homogenization 1200°C (48h)

Air cooled

2. Swaging

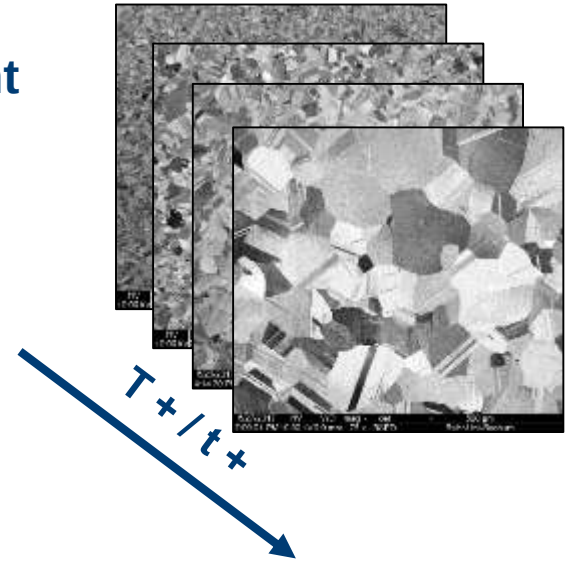
3. Compression specimen



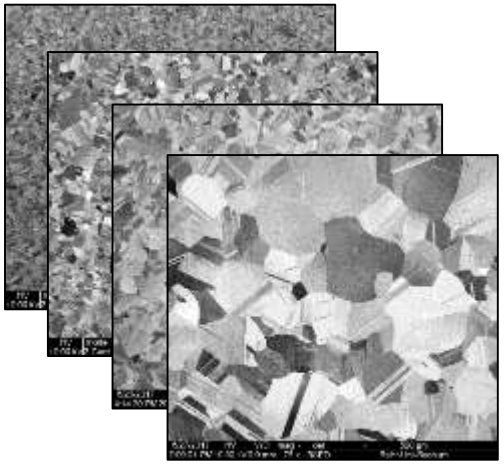
4. Heat treatment

800°C - 1200°C
10min - 3 weeks

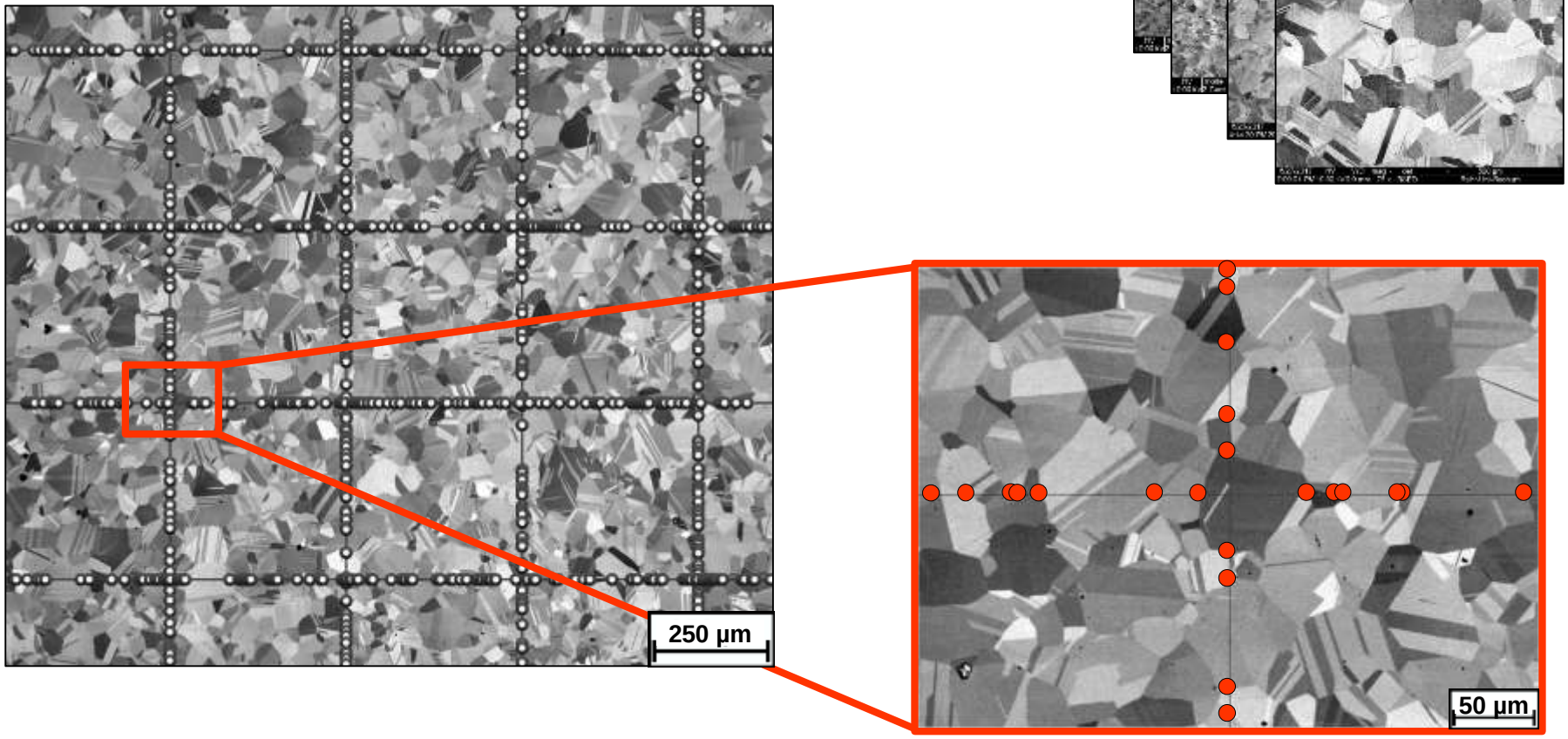
16 different grain sizes



3. Grain size determination methods
Line intercept - without twins

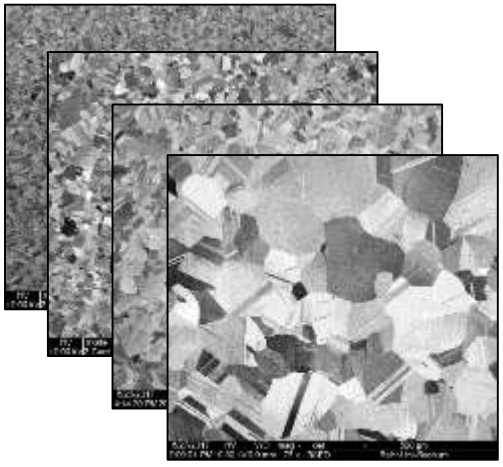


CrCoNi 1000°C 60min



- Method is based on the standard **ASTM - E 112**.
- Grid of 4x4 lines, which must contain minimum of 50 x 50 grains.

3. Grain size determination methods
Line intercept - including twins



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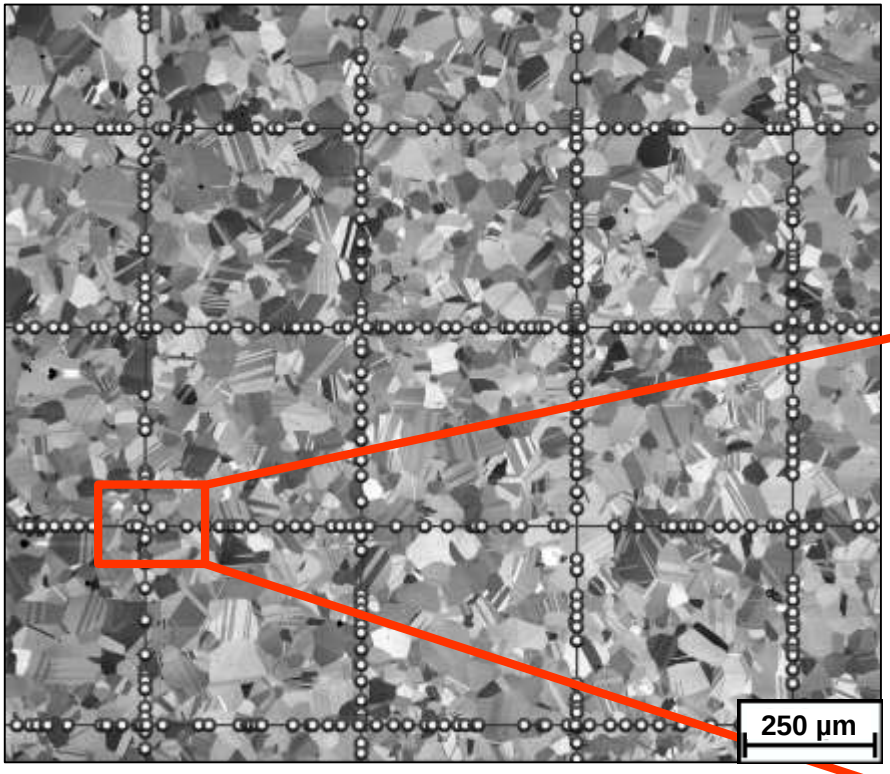
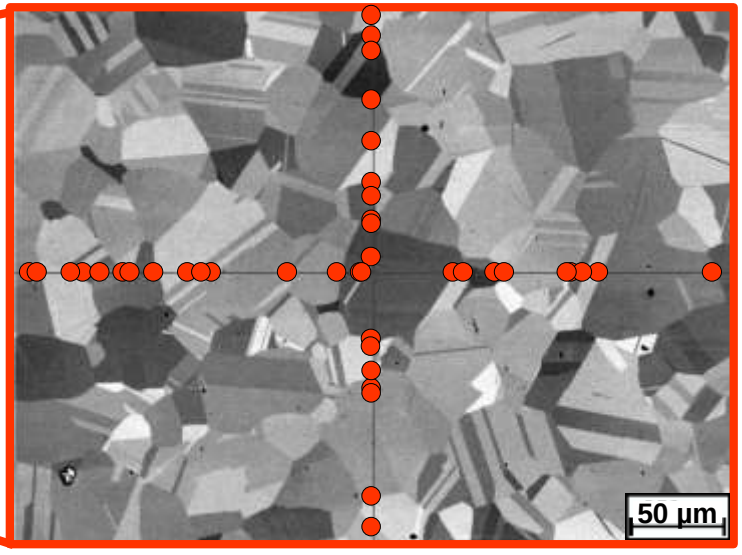
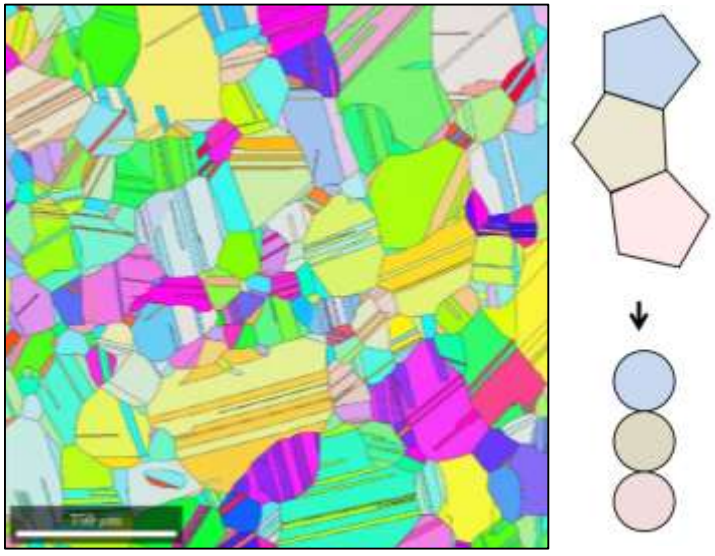


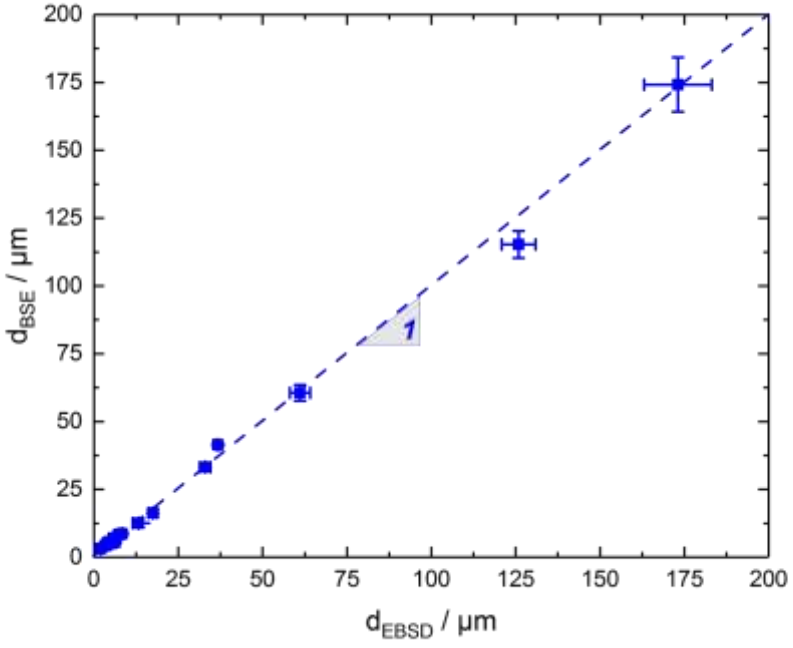


3. Grain size determination methods
EBSD data (TSL OIM) - Grain size

CrCoNi 1000°C 60min



BSE (line intercept) vs. EBSD (TSL OIM)

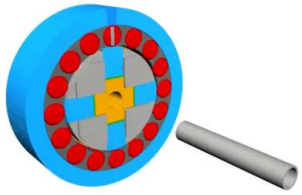


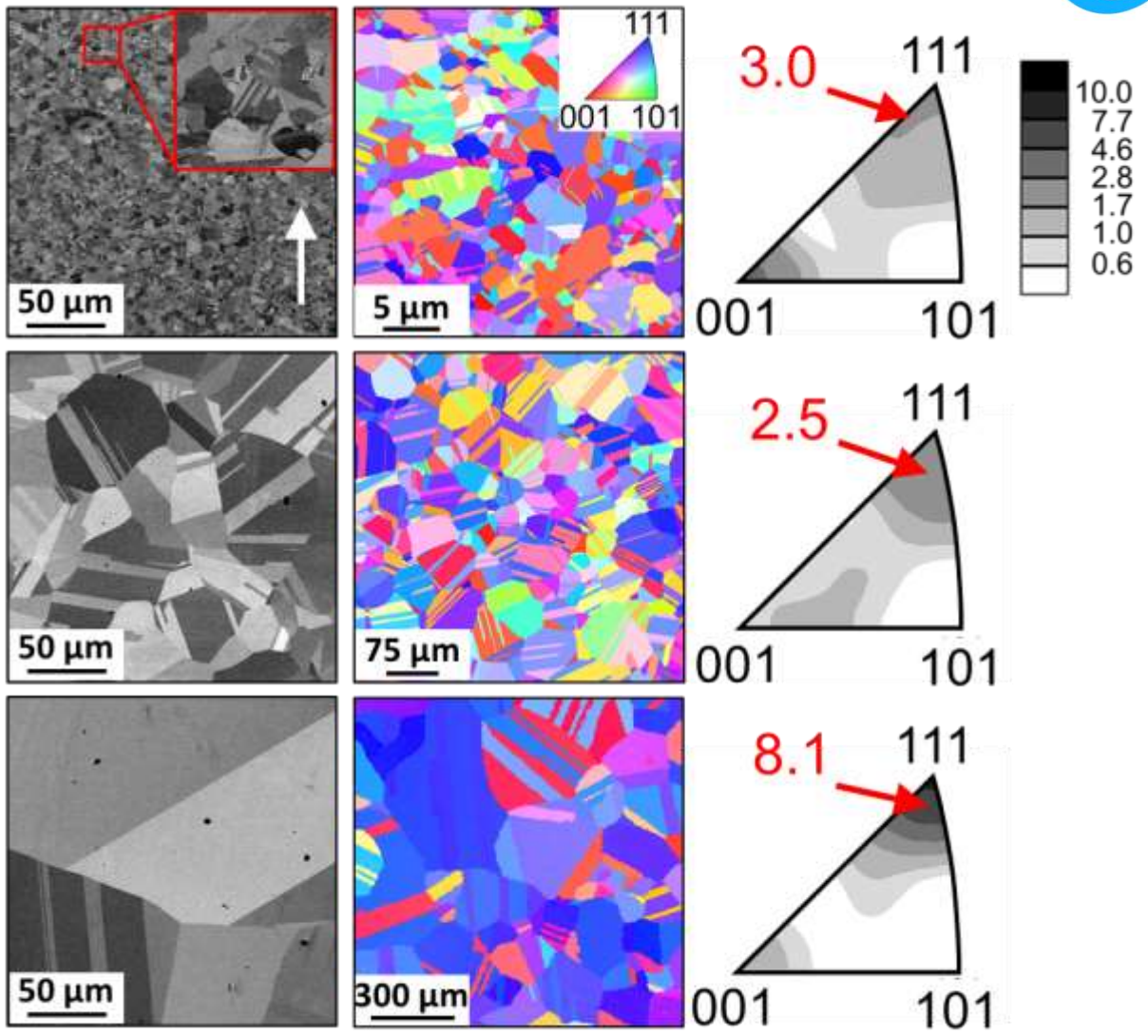
- Use of TSL OIM for determining grain and crystallite size.

- Values for grain size are in perfect agreement ($\frac{dd_{BSE}}{dd_{EBSD}} \sim 1$).

- The two values are equivalent, when grainsizes are equiaxed.

3. Grain size determination methods
EBSD data (TSL OIM) - Texture analysis





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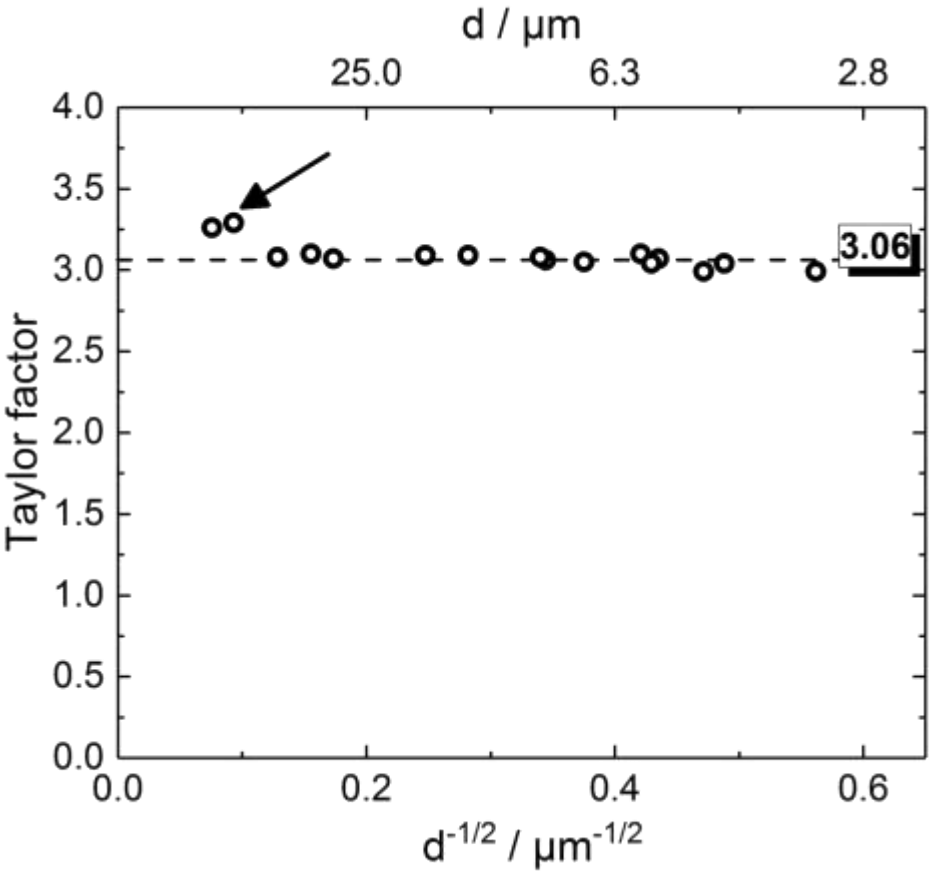
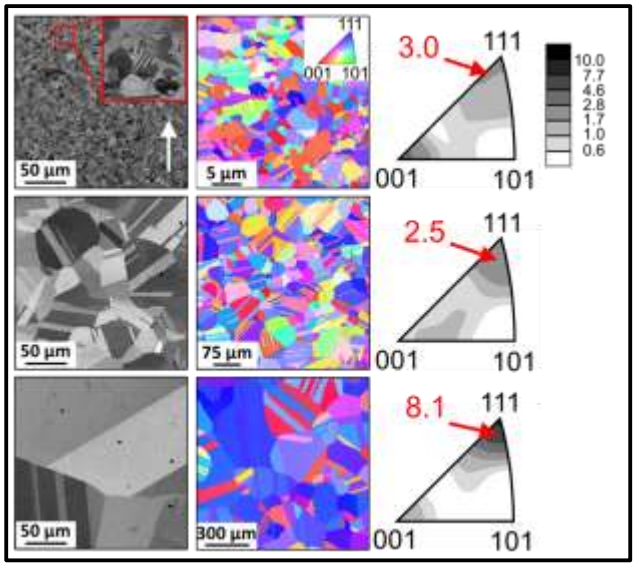




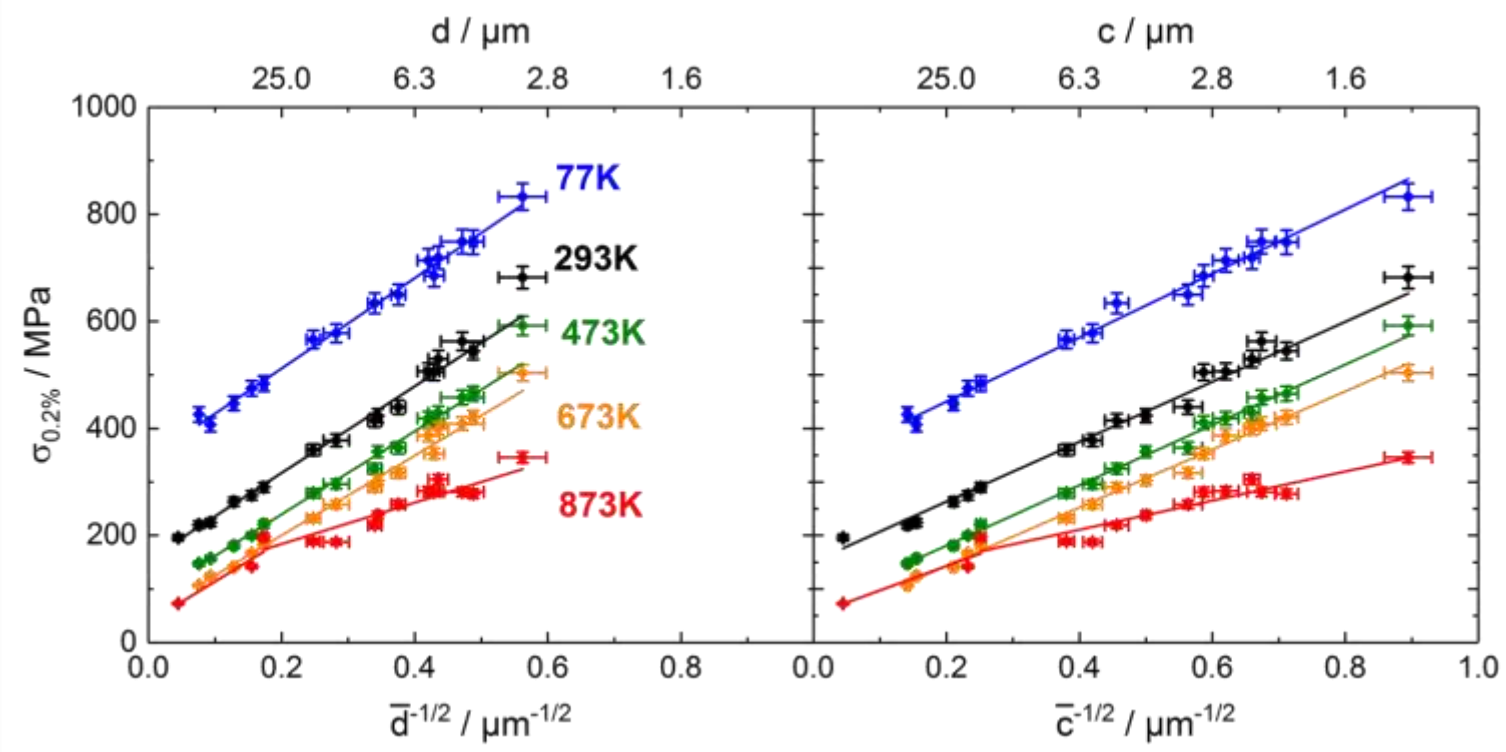
- Taylor factor between 2.99 and 3.29 → Mechanical properties not affected by texture.

- Small texture only observable in sample annealed at 1200°C for 3 weeks.
  - Taylor factor corrected values of σ_y.

4. Grain size strengthening in the CrCoNi medium-entropy alloy
Grain vs. crystallite size (Hall-Petch)

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

Excluding twins **Including twins**

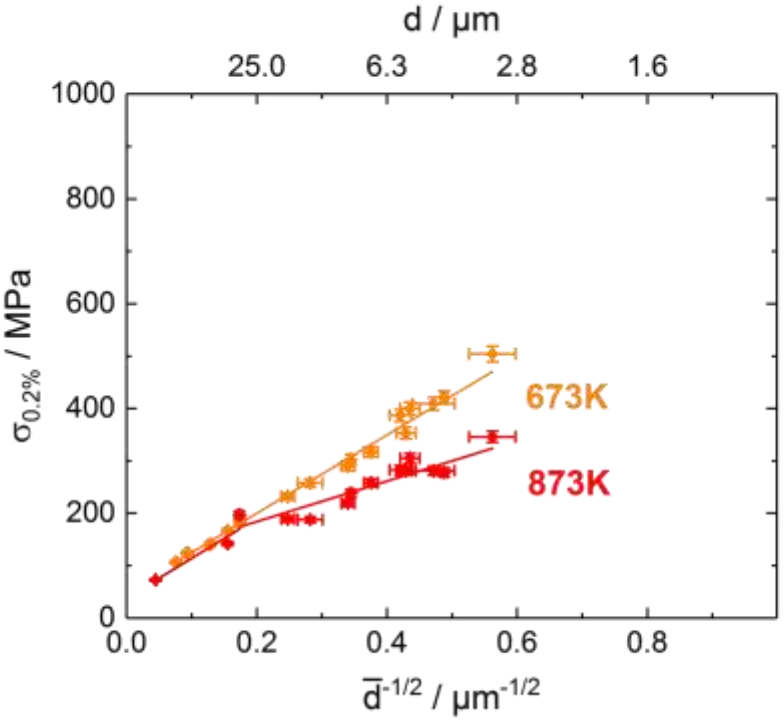


- Slope (k_y) much higher for grain than crystallite size.
- <u>BUT:</u> Both values in good agreement with Hall-Petch model.
- Fitting done with method after ***Fasano & Vio***, taking into account errorbars in x- and y-direction.

(G. Fasano & R. Vio, Modern astron. Meth. 7, 1988)

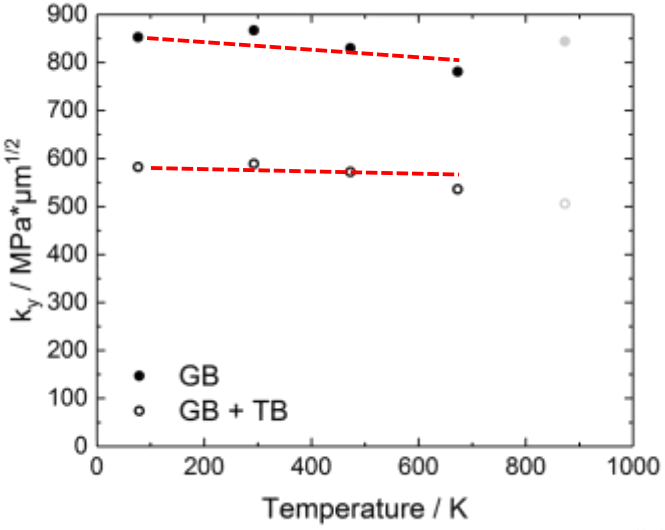
4. Grain size strengthening in the CrCoNi medium-entropy alloy

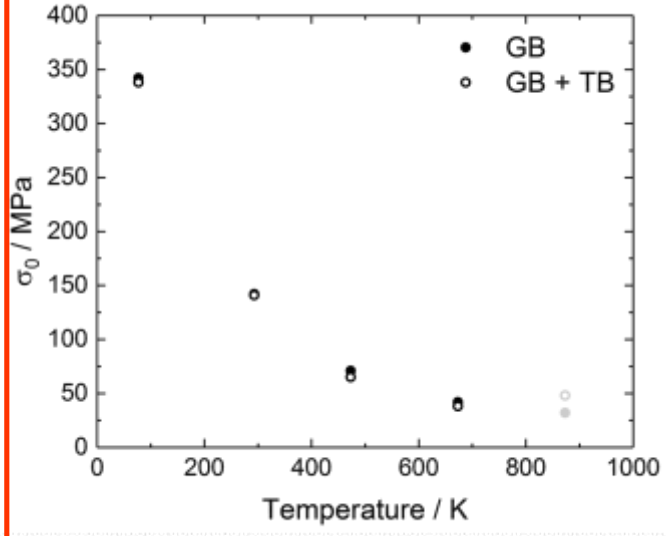
Discussion



- From 77K to 674K the slope remains the same, which shows an athermal behavior.
- Change at 873K observed: Change of mechanism expected, because: $T \geq \frac{T_S}{2}$.
  - ***Grain boundary sliding***
  - ***Grain boundary diffusion***

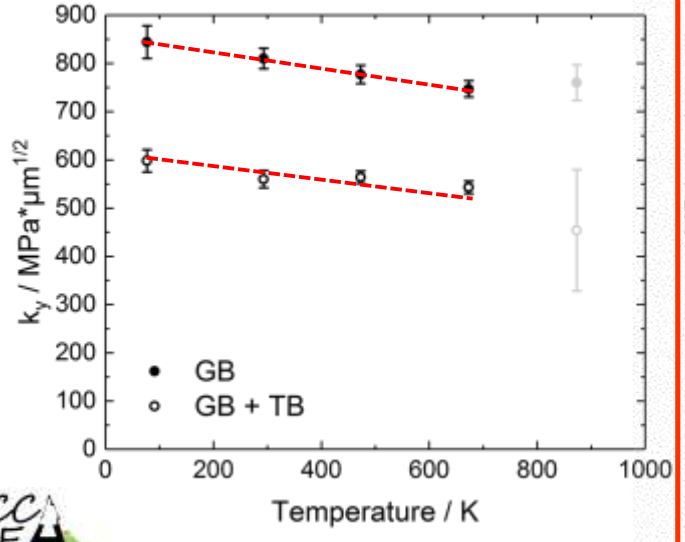
4. Grain size strengthening in the CrCoNi medium-entropy alloy
σ_0 and k_y as a function of temperature

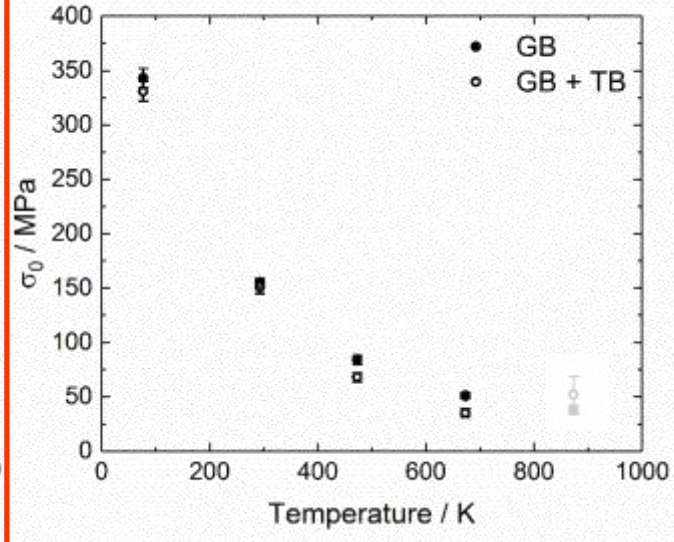




Fit without error bars.

Similar to strength of a single crystal
→ Modeling of solid solution strengthening



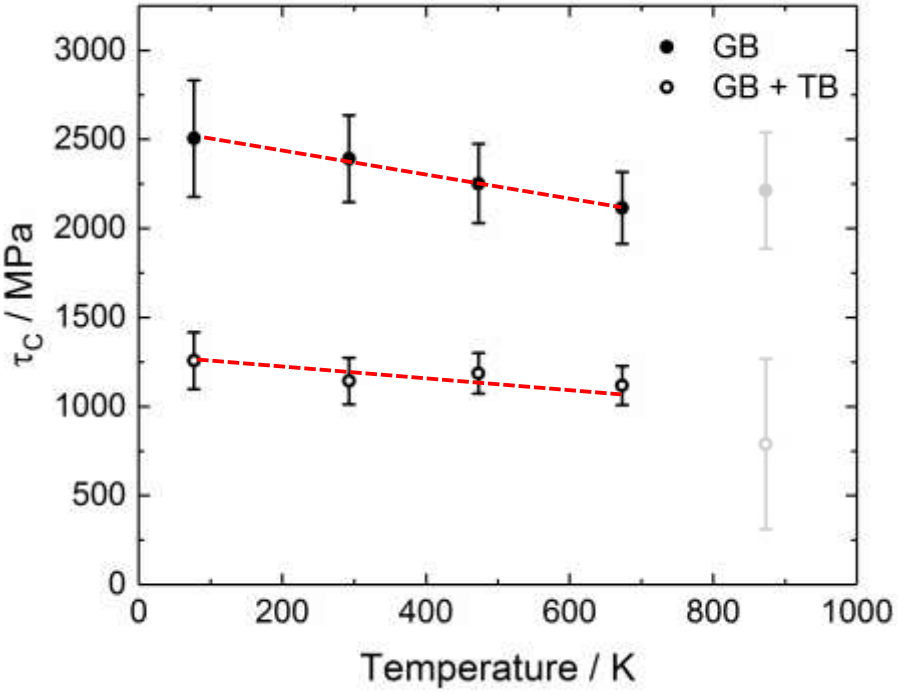


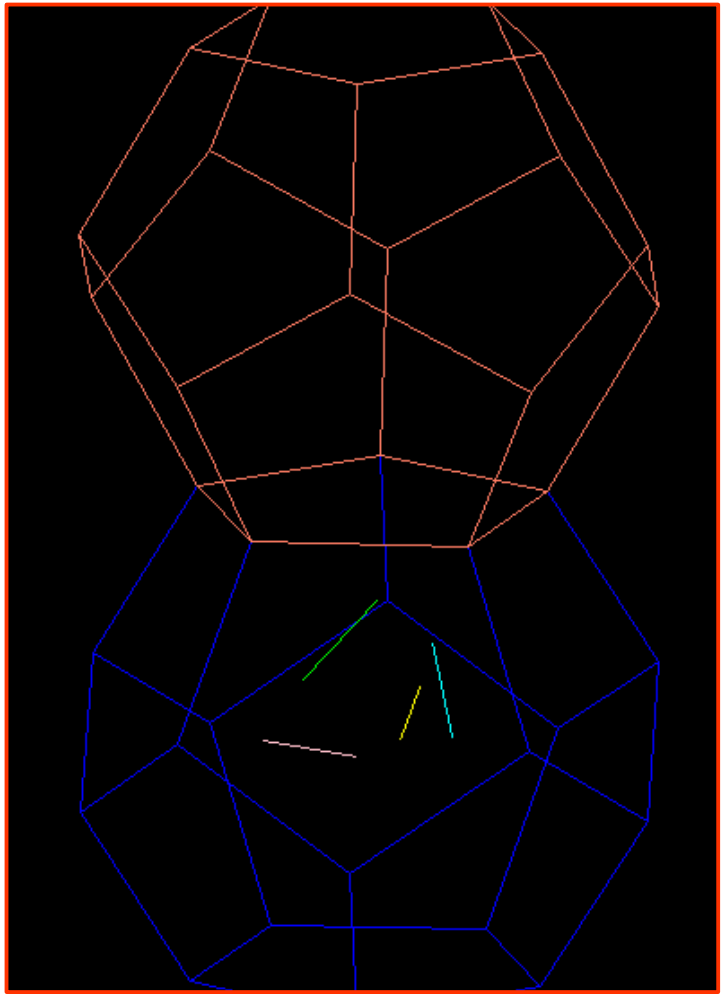
Fit accounting for error bars.

4. Grain size strengthening in the CrCoNi medium-entropy alloy

τ_c as a function of temperature

$$\tau = \tau_i + \left(\frac{\tau_c 4Gb}{\pi D}\right)^{\frac{1}{2}} = \tau_i + k' D^{-\frac{1}{2}}$$





Movie: Bicrystal

(G.E. Dieter et al., MM, 1986)
(http://simap.grenoble-inp.fr/gpm2/bicrystal-220086.kjsp?RH=SIMAP_GPM2)

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Thank you for your attention !

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