Strengthening mechanisms of single crystalline CrCoNi and CrMnFeCoNi at creep temperatures above 700°C

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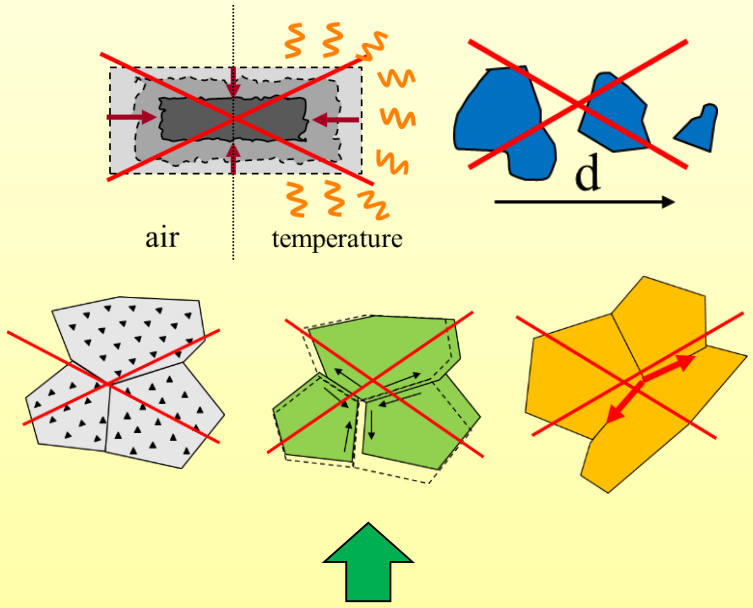
Motivation

Investigation of temperature dependent solid solution strengthening in single phase multicomponent alloys with medium and high entropy using creep testing

Possible negative effects:

- Oxidation effects during experiments in air and different temperatures
- Grain size effects
- Sliding processes at the grain boundaries
- Diffusion processes at the grain boundaries
- Effects occurring due to precipitation



Realization / Solution :

→ Creep testing under high vacuum **($2 \cdot 10^{-4}$ Pa)**

→ Using single-phase multi-component alloys: **medium and high entropy alloy (MEA + HEA)**

→ Use of single crystalline materials: **investigated alloys and reference**

Material selection

	1 Ia	2 IIa	3 IIIb	4 IVb	5 Vb	6 VIb	7 VIIb	8	9 VIIIb	10	11 Ib	12 IIb	13 IIIa	14 IVa	15 Va	16 VIa	17 VIIa	18 VIIIa
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	Ac	Rf	Ha	Sg	Ns	Hs	Mt									

Periodic tabel of elements:
http://www.chemgapedia.de

similar atomic radius

MEA

$Cr_{33,3}Co_{33,3}Ni_{33,3}$ (in at.%)

fcc solid solution

$S_{conf} = 1{,}1 \cdot R$ in J/(mol ·K)

HEA

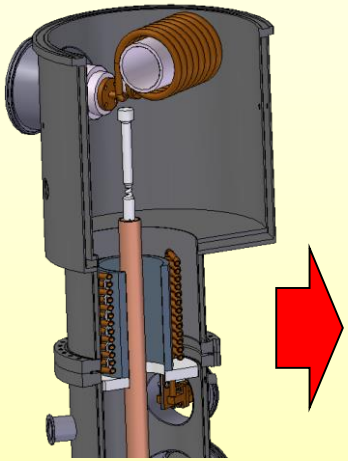
$Cr_{20}Mn_{20}Fe_{20}Co_{20}Ni_{20}$ (in at.%)

Cantor Alloy

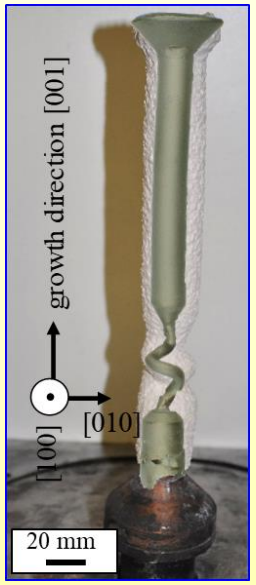
fcc solid solution

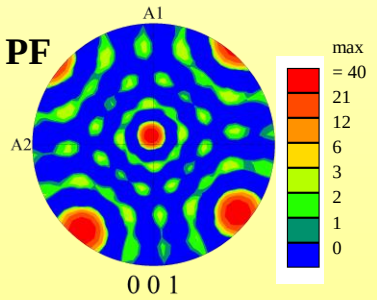
$S_{conf} = 1{,}6 \cdot R$ in J/(mol ·K)

Reference material:
fcc **pure Nickel**
$S_{conf} = 0 \cdot R$ in J/(mol ·K)



SX casting by Bridgman process

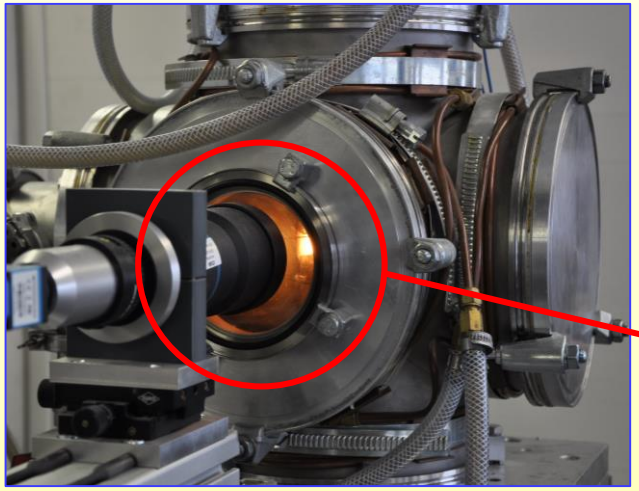


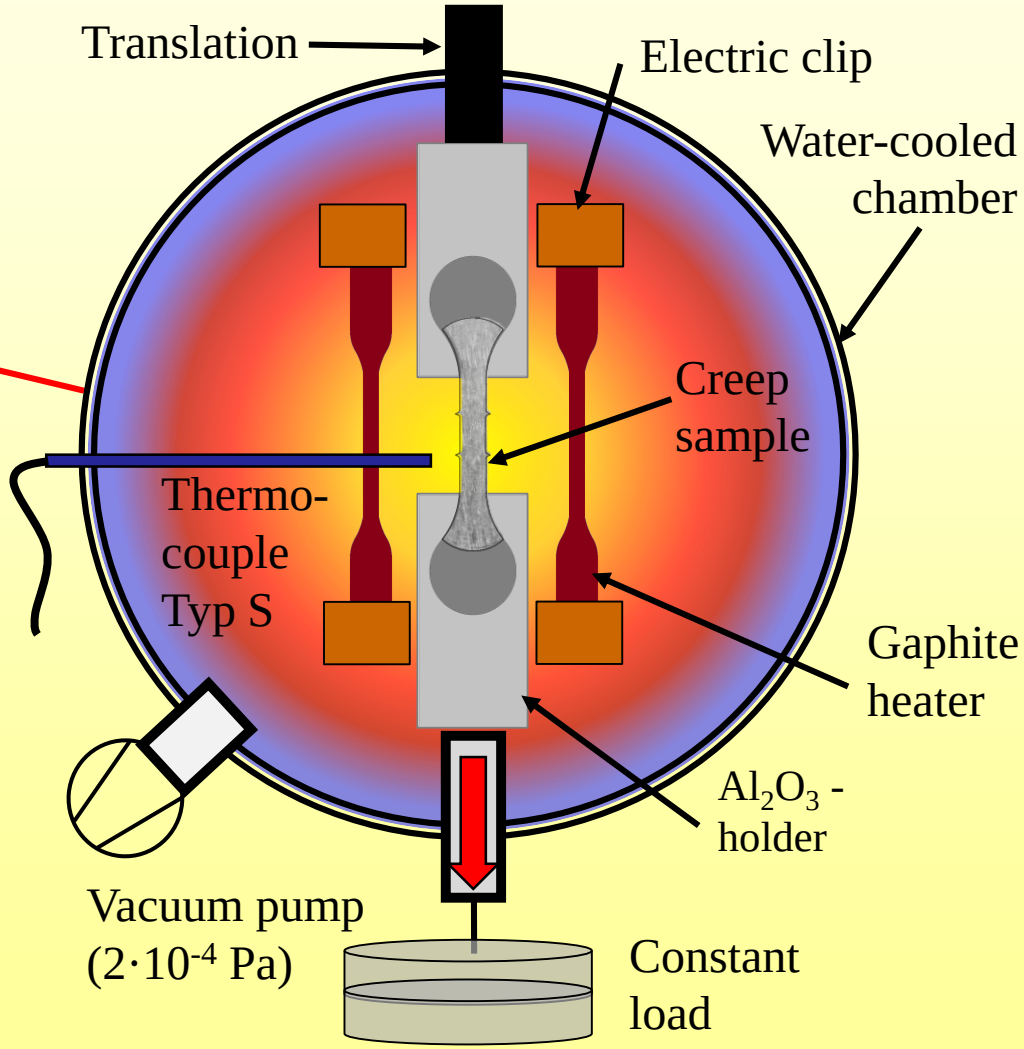


EBSD
Quality check

Wire EDM
Sample preparation

Mechanical testing
Creep testing under vacuum

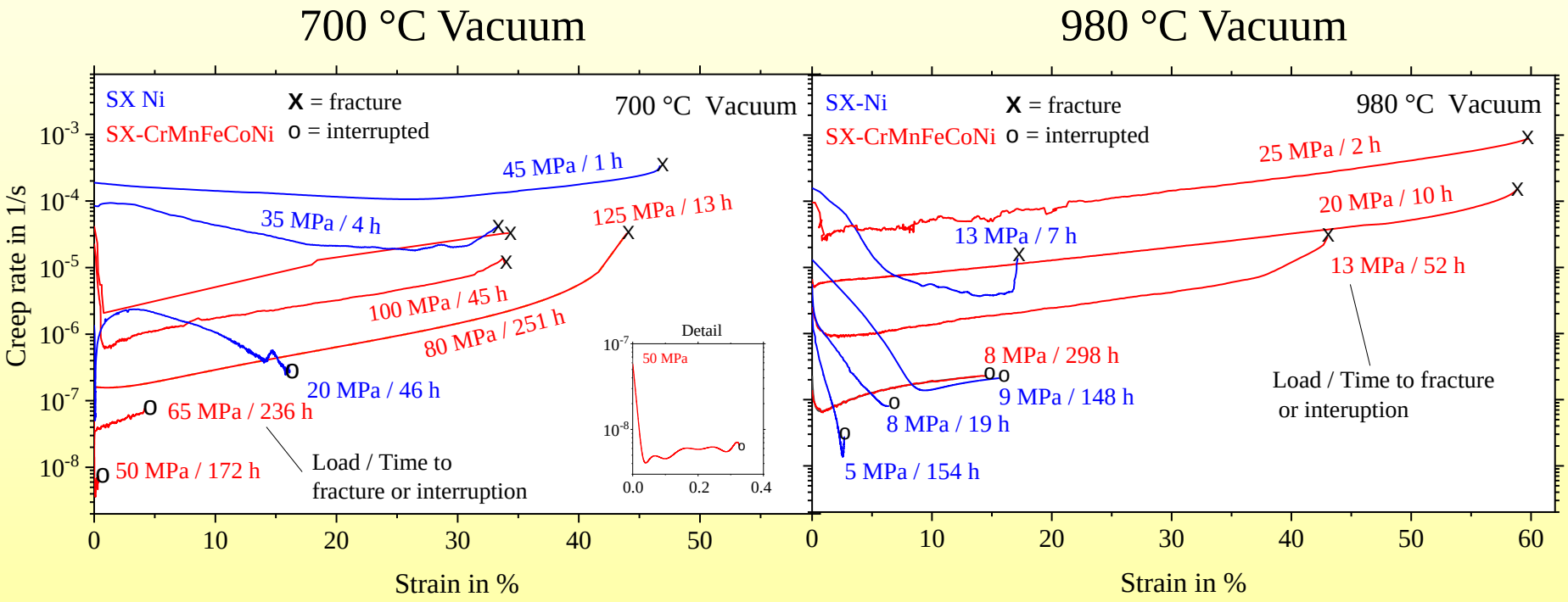




Testing conditions

Atmosphere: vacuum $2 \cdot 10^{-4}$ Pa
Temperatures: 700 / 980 / 1050 1100 and 1200 °C
Constant Load: 2 to 125 MPa
Geometry: 27x2.9x1 mm^3

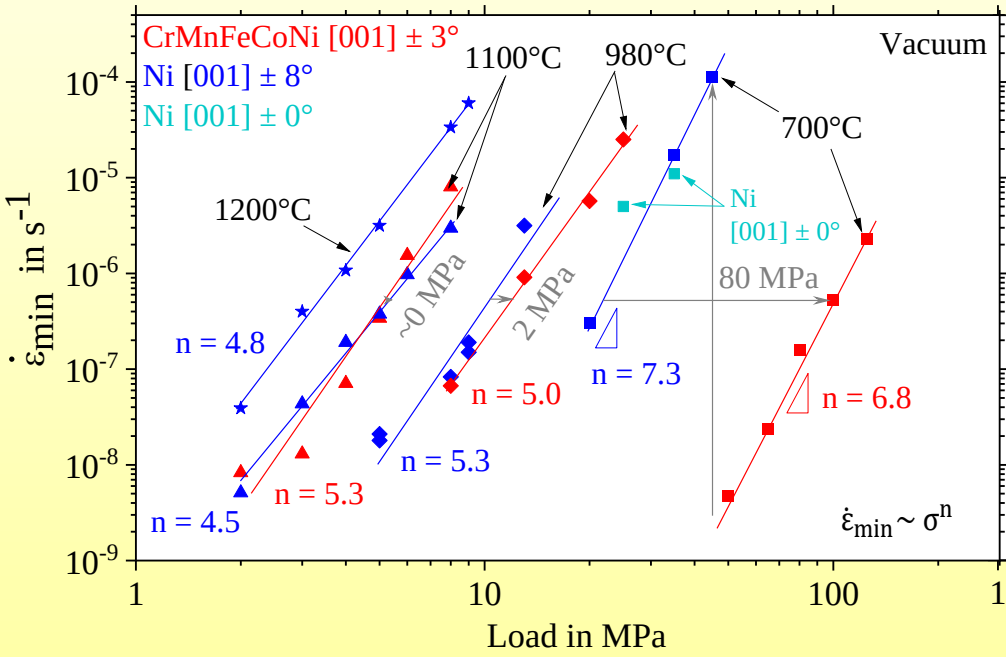
Comparison 700 and 980 °C SX-CrMnFeCoNi and SX-Ni



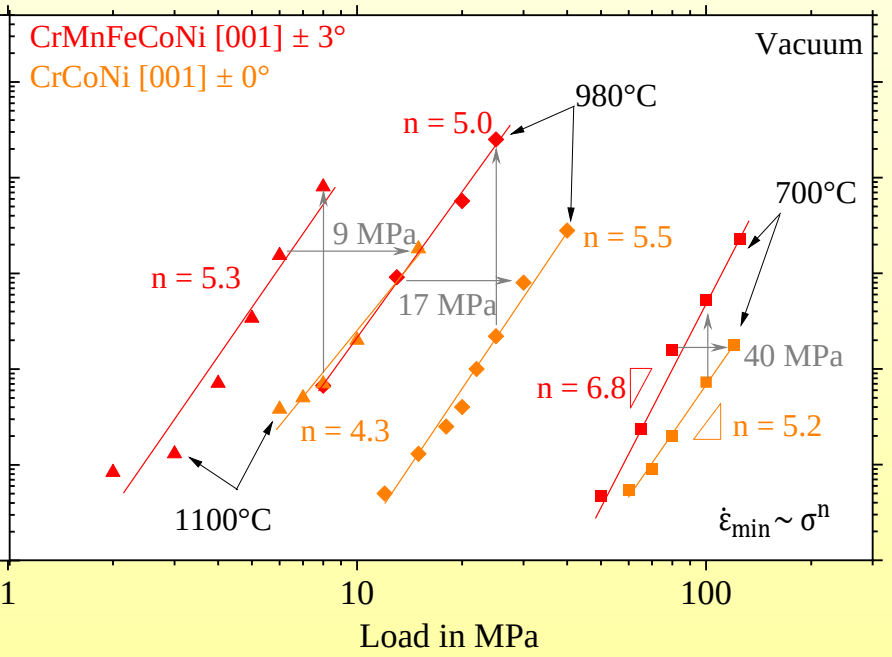
- Test carried out form 700 to 1200°C and interrupted in some cases for TEM-investigations

Norton Plot 700 – 1200°C

Ni and CrMnFeCoNi



CrCoNi and CrMnFeCoNi



- Decreasing stress difference from 80 MPa to 0 MPa from 700 to 1100 °C

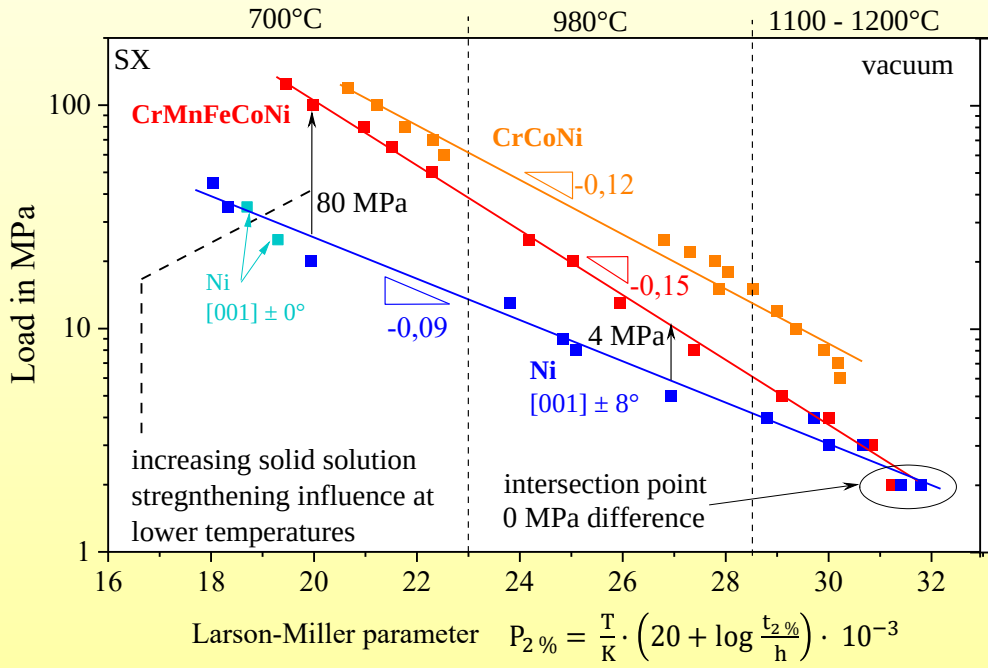
Solid solution strengthening at lower temperatures of 700 °C

- Decreasing stress difference from 40 MPa to 9 MPa from 700 to 1100 °C

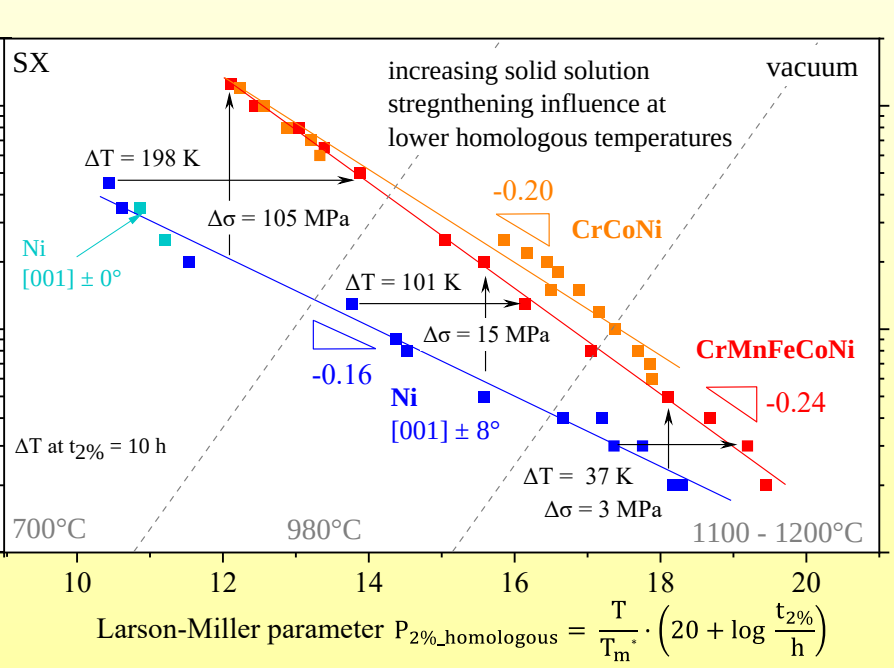
Further strengthening mechanisms could be active in the CrCoNi alloy

Larson-Miller Plot 700 – 1200°C

Absolut temperature



Homologous temperature



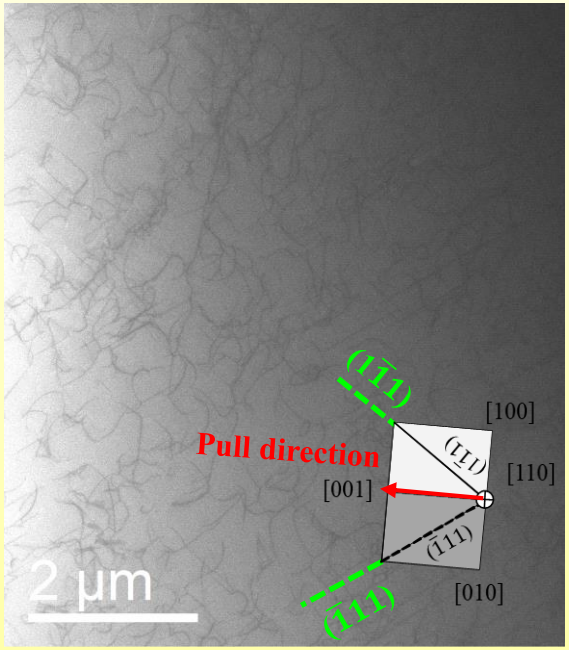
Ni: $T_m^* = T_m^{Ni} = 1728$ K **CrMnFeCoNi:** $T_m^* = T_m^{CrMnFeCoNi} = 1607$ K **CrCoNi:** $T_m^* = T_m^{CrCoNi} = 1690$ K

- Flatter slope of -0.09 for pure nickel in comparison to CrCoNi and CrMnFeCoNi with -0.12 and –0.15
- Comparable behavior of CrCoNi and CrMnFeCoNi in relation to homologous temperature

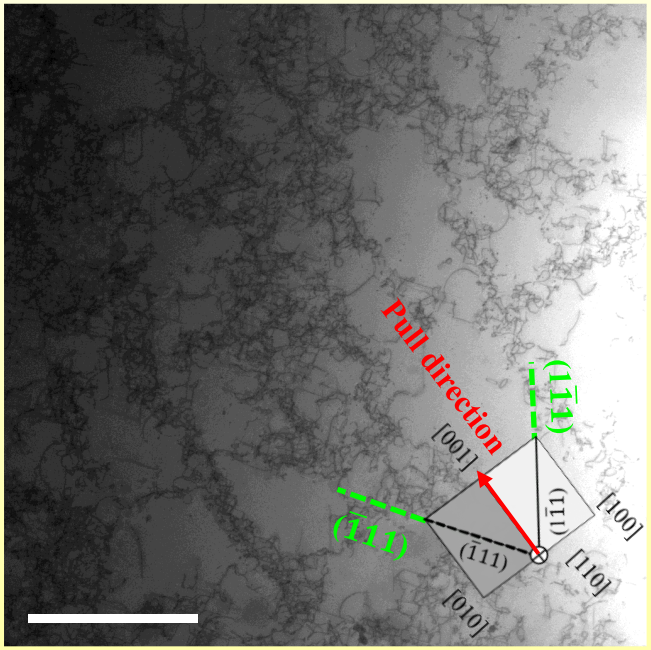
Solid solution strengthening recognisable

Interrupted creep tests at 700°C Ni, CrCoNi and CrMnFeCoNi TEM-analysis

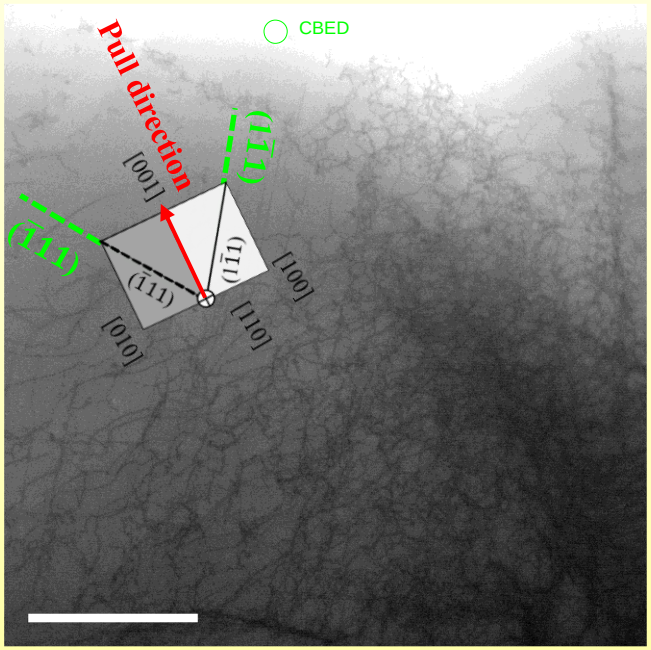
pure Ni



CrCoNi



CrMnFeCoNi



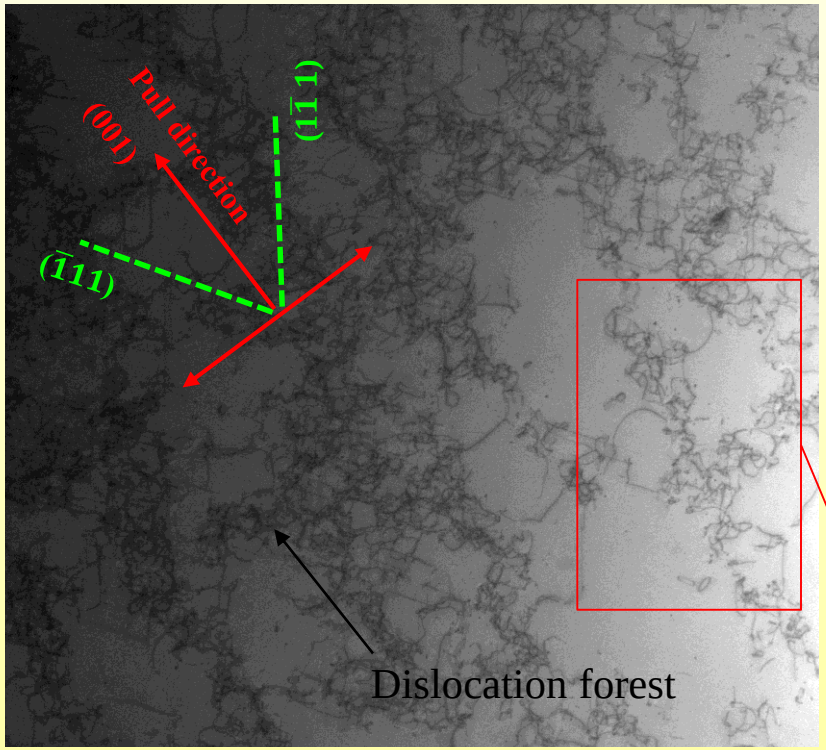
- homogenous dislocation distribution
- low content of stacking faults

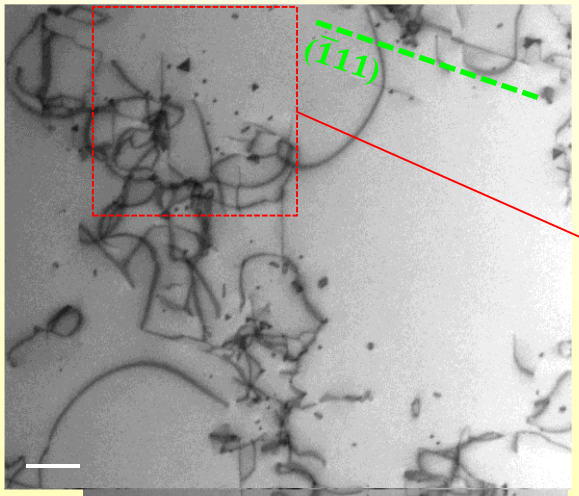
- inhomogeneous distribution: areas with higher dislocation content and areas with no or low dislocation content
- Dislocation networks (with high dislocation density) → dislocation forest structure

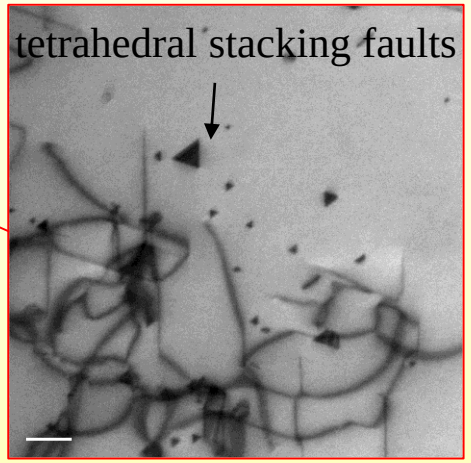
CrCoNi-SX 700 °C

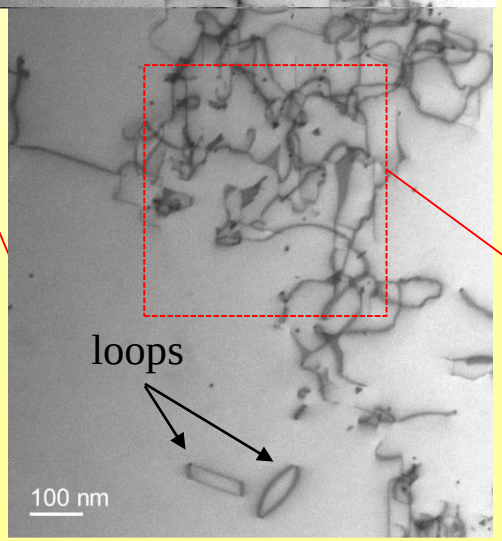
120 MPa (interrupted)

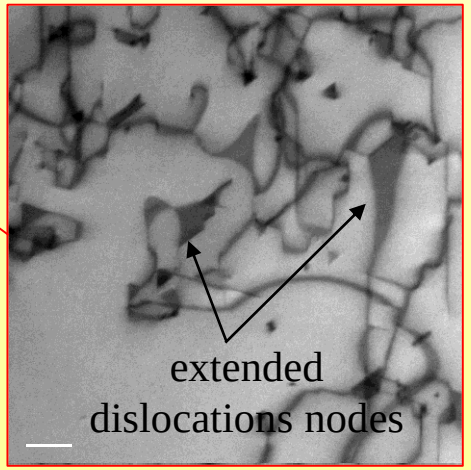
TEM-analysis











Higher content of loops, tetrahedral stacking faults and, extended dislocation nodes in the dislocation forests in comparison to CrMnFeCoNi and pure Ni

Summary

- The single phase alloys CrCoNi and CrMnFeCoNi were successfully cast as single crystals.
- Creep tests carried out on single-phase SX-CrCoNi, CrMnFeCoNi and pure Ni from 700 to 1200 °C excluding oxidation, grain boundaries and multiphase effects.

- **The influence of solid solution strengthening of CrCoNi and CrMnFeCoNi increases by decreasing temperature (1200 to 700°C).**

- **Dislocation forests occur in CrCoNi and CrMnFeCoNi in comparison to pure Ni.**

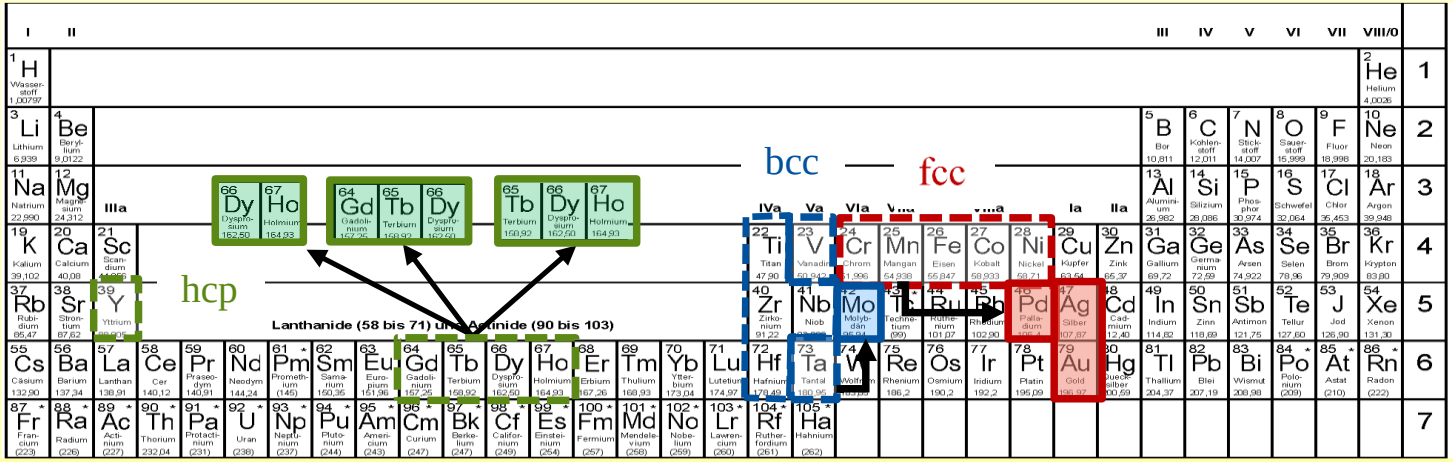
- **Possible influence of stacking faults and extended dislocation nodes recognizable on the creep resistance for CrCoNi above 700°C.**

Planned work in the 2nd funding period

Material Development and Mechanical Properties of Single-Phase High Entropy Alloys

Laura Rosenkranz

Base alloys in the project

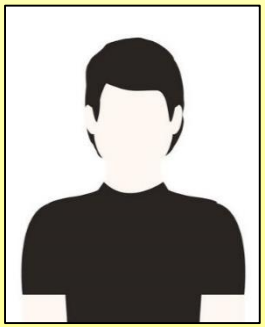


hcp-phase:
YGdTbDyHo

bcc-phase:
TiZrNbHfX
↓
V*, Ta* and Mo

fcc-phase:
SX-CrXFeCoNi
↓
Mn*, Pd, Ag or Au

*investigated in the 1st period



N.N.

Topics in the 2nd phase

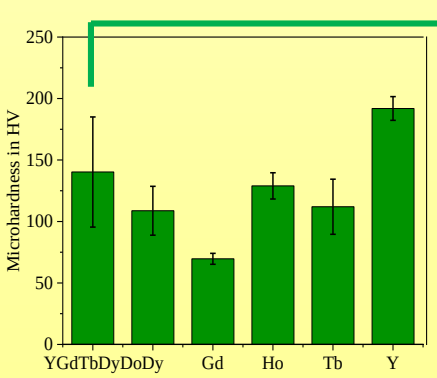
1. Intrinsic deformation process of fcc, bcc and hcp structured HEA

Mechanical testing: Tensile, creep and compression tests from RT to 1400 °C

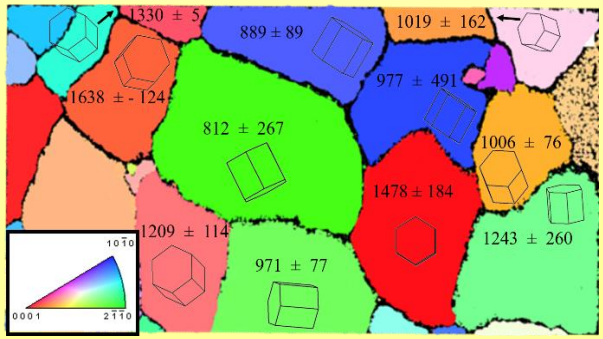
2. Stacking fault energy (using non-equiatomic fcc)

$Cr_{20}Mn_{24}Fe_{30}Co_{20}Ni_6$ and $Cr_{20}Fe_{24}Mn_{30}Co_{20}Ni_6$

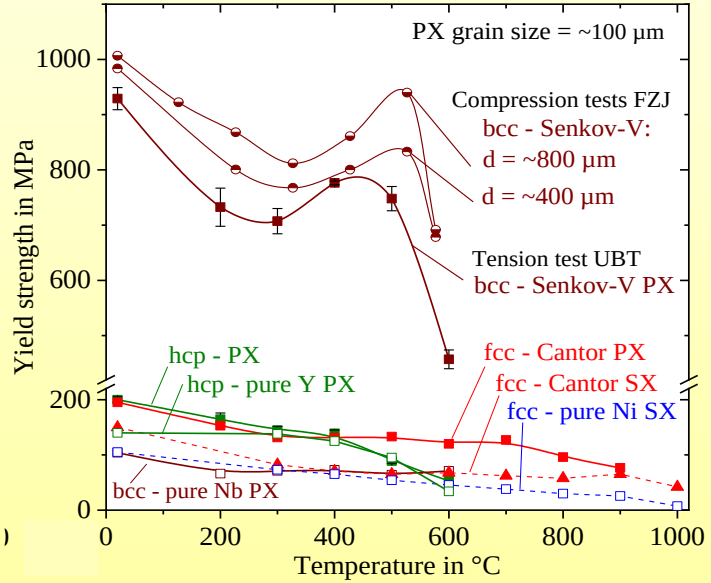
3. Gibbs paradox (using hcp HEA)



YGdTbDyHo



4. Yield-stress anomaly of TiZrNbHfV and further bcc HEA



Lienig, T.. Thomas, C., Feuerbacher, M.; Yield-stress anomaly in equiatomic ZrNbTiVHf high-entropy alloys. ARXiv (2019)

Thank you for your attention!

Please also read the following publication:

C. Gadelmeier, S. Haas, T. Lienig, A. Manzoni, M. Feuerbacher, U. Glatzel; **Temperature Dependent Solid Solution Strengthening in the High Entropy Alloy CrMnFeCoNi in Single Crystalline State. Metals 2020, 10, 1412**