Entropy effects on mechanical properties of high entropy alloy CrMnFeCoNi at high and low temperatures

Christian Gadelmeier[1], Sebastian Haas[1]
Mike Moosbacher[1], Fabian Krieg[1], Uwe Glatzel[1]

[1] Metals and Alloys, University Bayreuth, Germany

In cooperation with Forschungszentrum Jülich GmbH

Overview

“Entropy Effects on Mechanical Properties of Single-Phase High Entropy Alloys”

Metallische Werkstoffe

Jülich Forschungszentrum

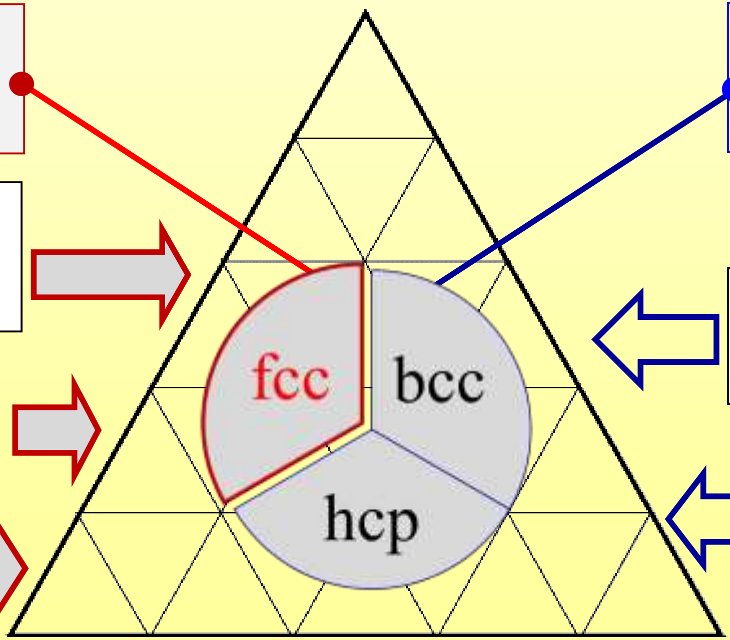
Fabrication **Cantor alloy** as single-crystal

Fabrication **bcc + hcp** as single-crystal

Specific heat capacity → Entropy determination

- Tensile & creep testing
- Elastic properties

SEM investigations



Compression testing

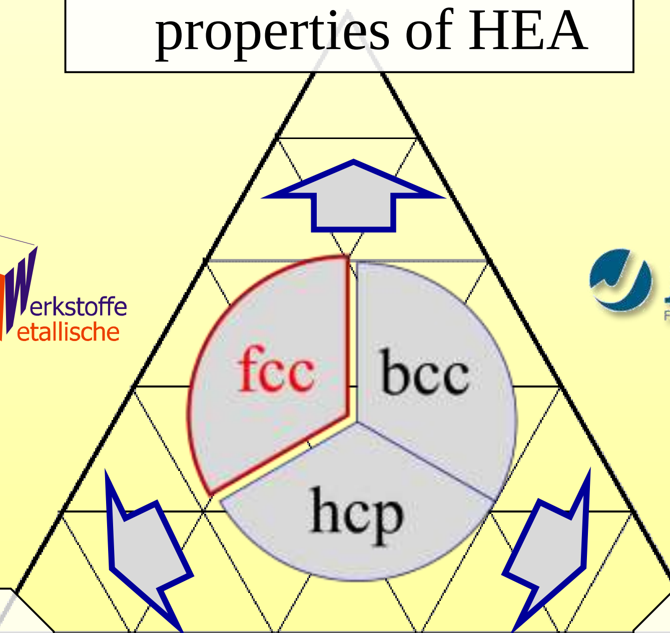
SEM & TEM investigations

Goals of the Project

Central scientific questions to be answered for:

1. Mechanical properties of HEA

Depending on:
- Temperature (low → high)
- Slip system
- Composition



2. Localization dislocation

3. Experimental determination of entropy

Alloy manufacturing

Arc-melting furnace
- Vacuum: 10^{-5} mbar
- Argon atmosphere
- Tungsten-kathode
- Cu-chillplate

Initial weight ~50 g
Cr, Mn, Fe, Co, Ni

Pre-alloyed buttons polycrystalline (CC)

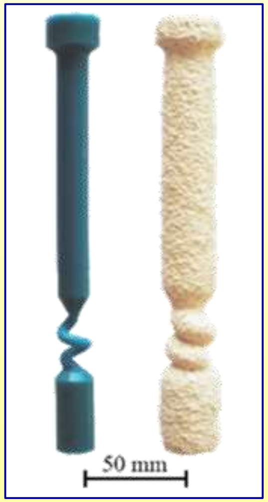
Quality check of element content: µ-XRF ✔

Induction casting of single-crystal (SX) Cantor

Single-crystal fabrication

Arc melting → Master Alloys

Single crystal casting



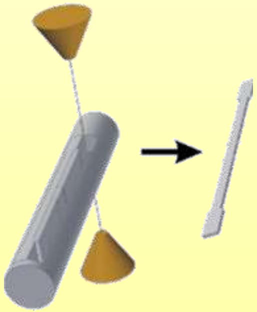
Wax model → Ceramic mould

Induction furnace
- Vacuum 10^{-4} mbar
- Argon atmosphere
- Pull down speed 0.5-10 mm/min

Single crystal

Heat treatment of the samples (vacuum)

Determination of c_p via differential scanning calorimetry

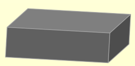


wire-EDM

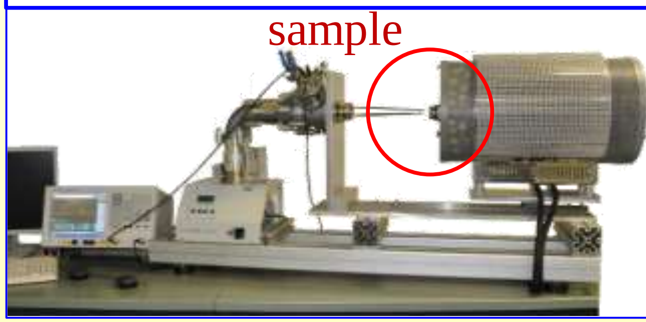
Mechanical testing

Mechanical testing
from -269 °C to ~1300 °C

Ultrasound resonant spectroscopy

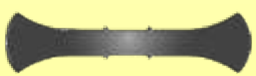


4x5x6 mm^3



- Tensor of elastic constants
- Temperature range:

Tensile and creep testing (on air, vacuum or protecitve gas)



27x7x1 mm^3

- <u>Tensile test</u>

TU Dresden ← → Metals and Alloys, Bayreuth

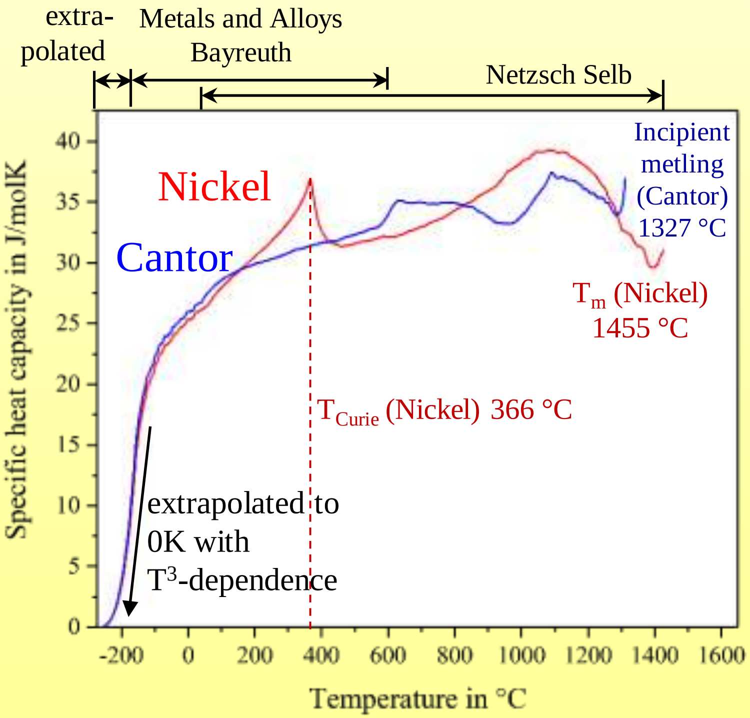
- <u>Creep testing</u>

→ Metals and Alloys, Bayreuth

Measuring of specific heat capacity and determination of entropy

Two Netzsch DSC instruments used:

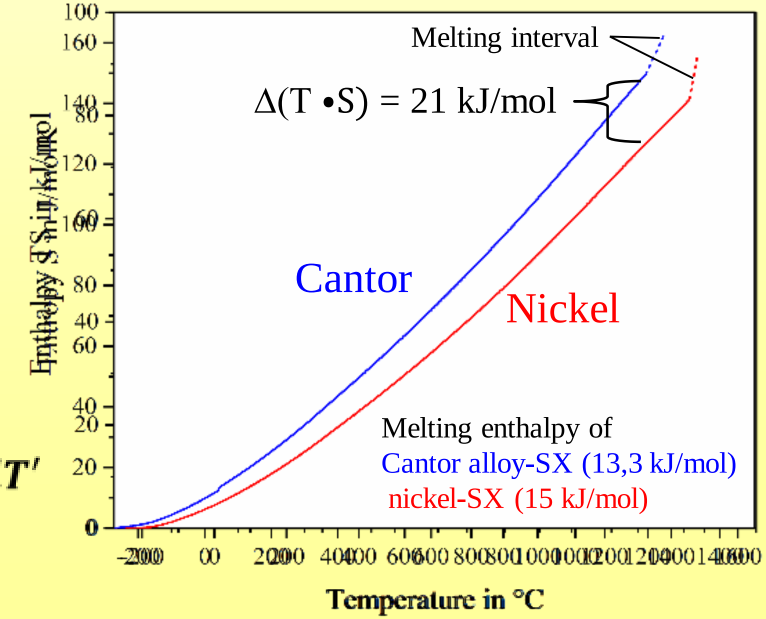
- - 170 °C → +600 °C (Metals and Alloys Bayreuth – DSC 204)
- room temperature → melting point (Netzsch Selb – DSC 404)
- Cooling / heating rate 20 K/ min
- Liquid nitrogen as cooling agent



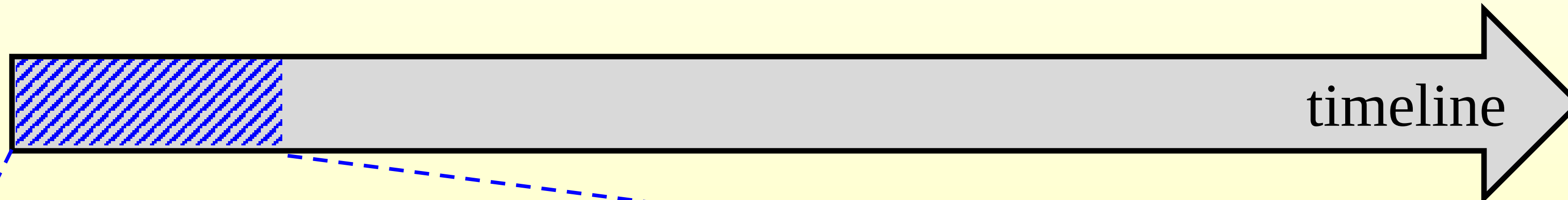
C_p(Cantor)

$$S_{th} = \int_{0K}^{T} c_p(T') \cdot \frac{1}{T'} dT'$$

Enthalpy $T \cdot S = T \cdot (S_{conf} + S_{th})$



Preliminary Investigations



1. Single-crystal casting under **vacuum** → Mn concentration is nonconstant SX

optimizing

2. Variation of Mn content under **argon** → low loss of Mn content PX

transfer

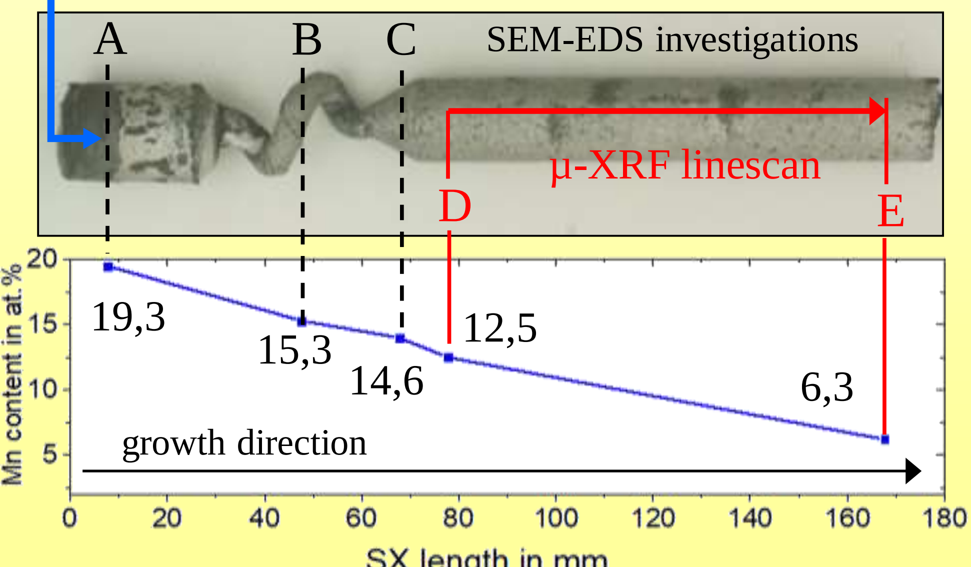
3. Poly-crystal casting under **argon** → constant Mn concentration PX

1. Single-Crystal under vacuum

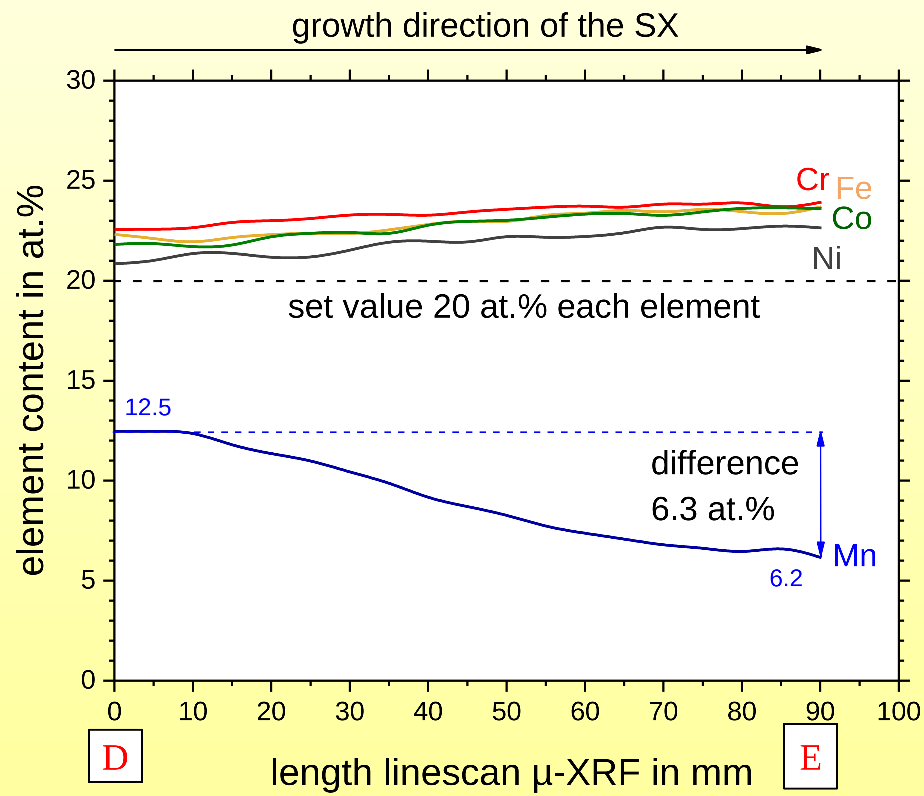
Single-crystal

Manufactured:	Bridgman furnace
Atmosphere:	vacuum
Cast temp.:	1400 °C
Initial weight:	300 g
Pull-down speed:	3 mm/min

- nominal: 20 at.% each element



Position D → E: µ-XRF linescan



→ Optimizing: variation of Mn, argon

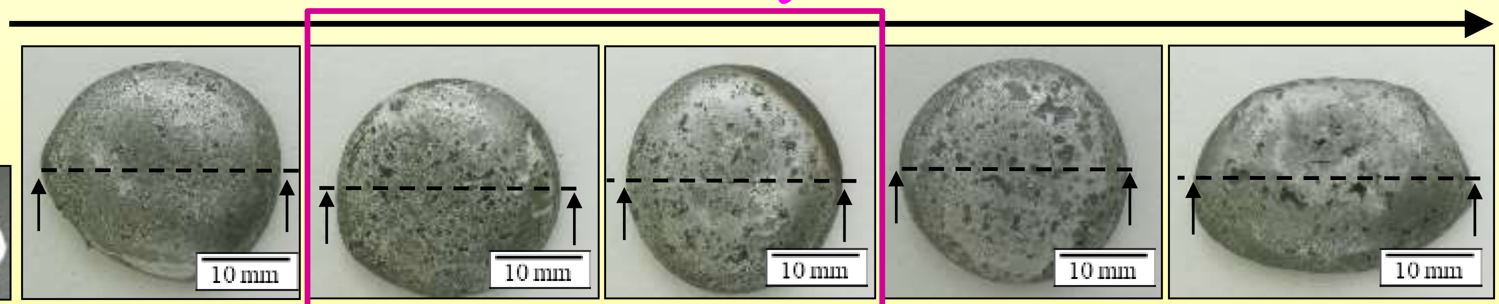
2. Variation of Mn content

Poly-crystal

Manufactured:	arc melting
Atmosphere:	argon
Initial weight:	50 g

✔ increase of Mn - 20 to 30 at.%

SEM-EDS cross section



target value at.%	20.0	21.0	22.0	25.0	30.0
actual value at.%	19.5± 0.5	20.0 ± 0.2	21.0 ± 0.2	24.0 ± 0.3	28.3 ± 0.3
difference at.%	**0.5**	**1.0**	**1.0**	**1.0**	**1.7**

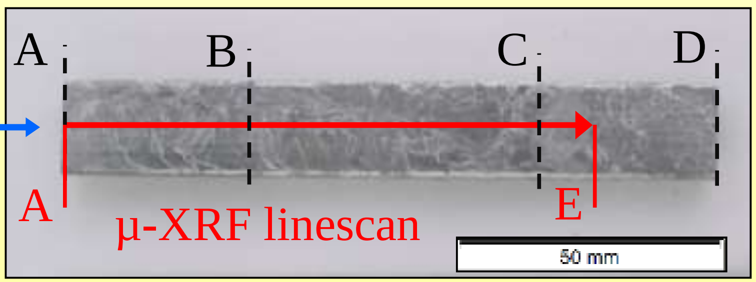
→ Transfer: Poly-crystal production using induction casting / argon atmosphere

3. Poly-Crystal under argon

Poly-crystal

Manufactured:	induction casting
Atmosphere:	argon
Casting mould:	Copper
Initial weight:	250 g

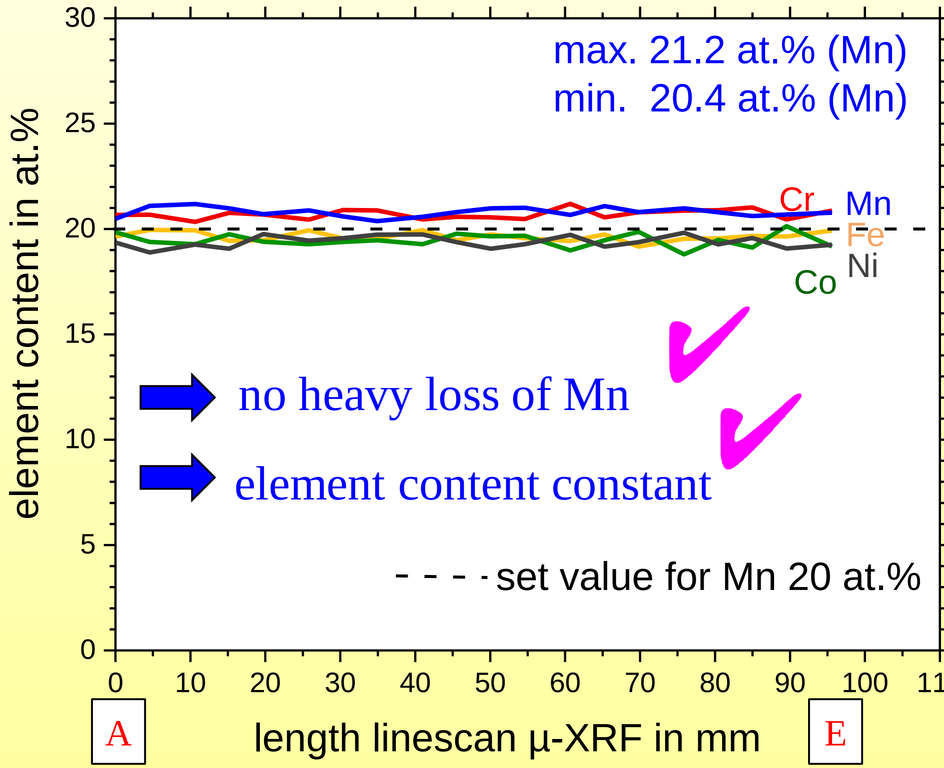
20+2 at.% Mn → for balance



SEM-EDS microsection

Mn at.%	A	B	C	D
average	21.1	20.8	20.7	20.8
deviation	0.3	0.1	0.1	0.2

µ-XRF linescan - Position A → E



→ next step: SX production

Conclusion & Outlook

- First c_p measurements of SX Cantor-alloy realized → Entropy S_{th} determined ✔
- Using argon as atmosphere for fabrication→ stable melting process ✔
- Best element distribution at an initial weight of Mn of 21-22 at.% ✔
- Master alloy fabrication of Cantor alloy has already been started ✔

(element content constant)

Outlook

- Current studys: first tensile tests of SX Cantor alloy at low temperature (→ TU Dresden)
- **Fabrication of SX Cantor alloy for HT-characterization will start next**

  → Mechanical properties : - variation of the composition

  - SX in comparison to PX

Thank you for your attention!