UNIVERSITÄT BAYREUTH

Metallische Werkstoffe

Mechanical characterization of modified Compositionally Complex Alloy (CCA) $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$ (in at.%) at elevated temperatures

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- Mechanical characterization
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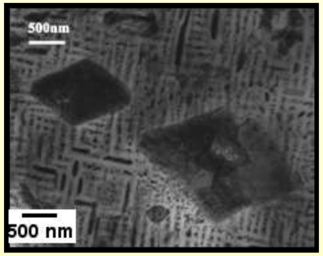
Development of $Al_{10}Co_{25}Cr_{8}Fe_{15}Ni_{36}Ti_{6}$

Starting point:

Equiatomic & multicomponent alloy system AlCoCrCuFeNi

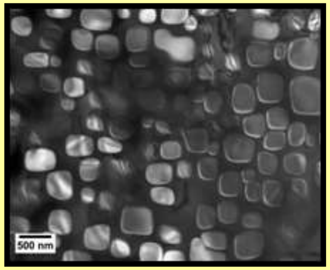
- more than 6 (bcc) phases
- brittle



High Entropy Alloy (HEA) ✗

Optimization steps:

- Elimination of segregation-element Cu
- Increase of face-centered cubic Ni
- Addition of Ti
- **$Al_{10}Co_{25}Cr_{8}Fe_{17}Ni_{36}Ti_{6}$**
  - no base element
  - good mechanical properties



Compositionally Complex Alloy (CCA) ✓

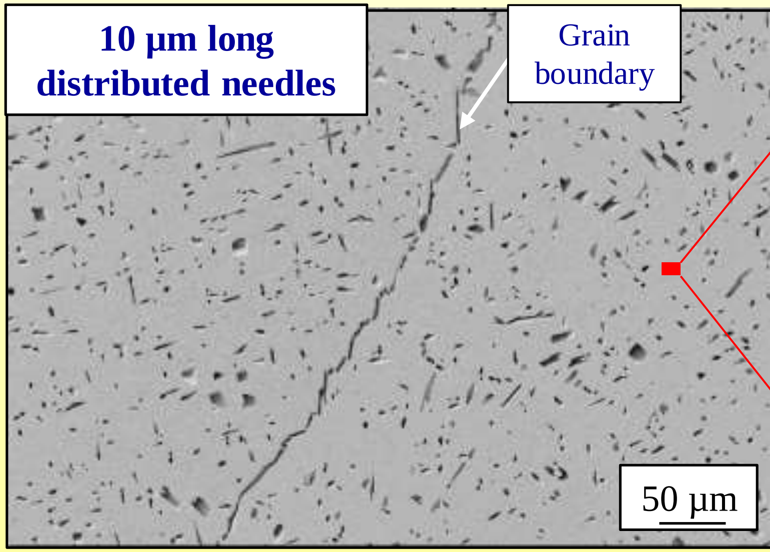
Characterization of $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$

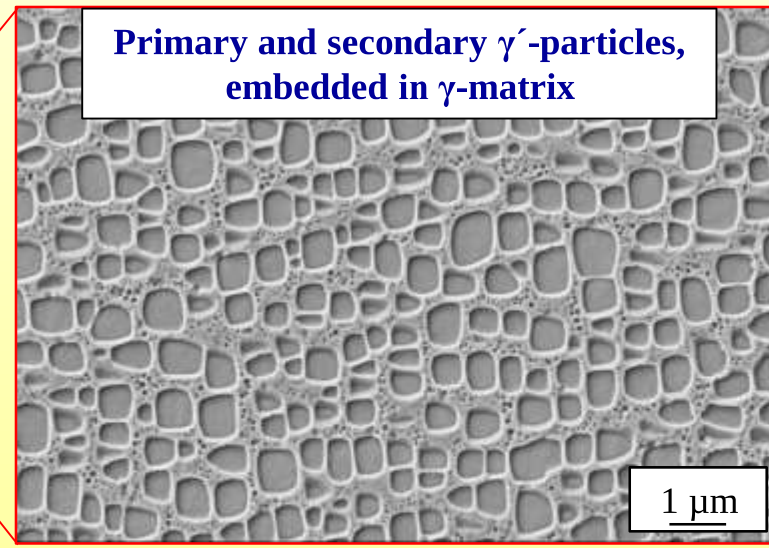
Dendritic solidification

Heat treatment:

- 1220°C / 20 h "Homogenization"
- 900°C / 50 h "Annealing"

→ 3-phase microstructure





<u>Needles:</u>
Al-rich phase (4% volume fraction)

Particle length (γ´): ~ 450 nm
Volume fraction (γ´): ~ 40%
Secondary γ´ in the range of some nanometers

Characterization of $Al_{10}Co_{25}Cr_{8}Fe_{15}Ni_{36}Ti_{6}$

Chemical analysis (SEM/TEM*-EDS)

in at.%	Original composition	Needles	γ/γ´-structure*	
			γ-matrix	γ´-precipitates
Al	10	**28**	7	**11**
Ni	36	33	30	**45**
Ti	6	7	3	**8**
Fe	15	10	**21**	9
Co	25	19	**30**	23
Cr	8	3	**9**	4

High Al-content in needle-phase, due to a decrease of Ni and especially Fe, Co and Cr

Co-, Cr-, Fe-rich matrix

Al-, Ti-, Ni-rich precipitates

* *Dr. Anna Manzoni - Helmholtz-Zentrum Berlin*

Aims and goals

- Optimization of γ/γ´-morphology (volume fraction & particle size)
  - ➢ Improvement of heat treatment

- Addition of trace elements (max. 1 at.%)
  - Molybdenum
  - Hafnium
  - Zirconium
  - Boron
  - Yttrium
  - Tungsten
  - Carbon

Solid solution strengthening

Ductility

Carbide formation (hardness)

Oxidation resistance

Strengthening of grain boundaries

Hall-Petch hardening

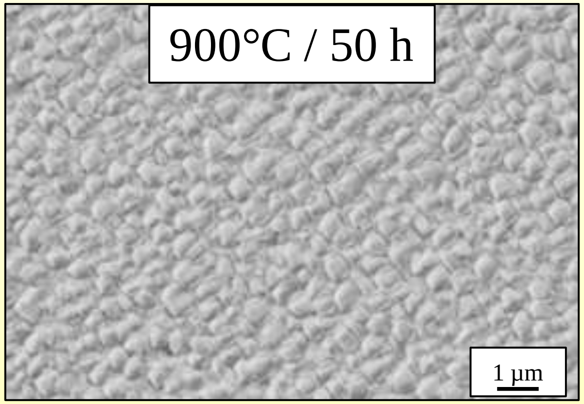
Microstructural investigations

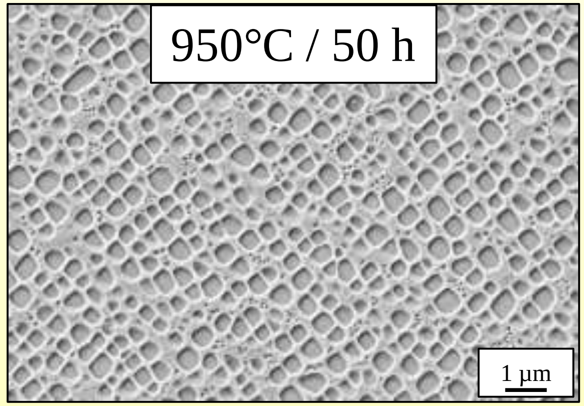
HZB Helmholtz Zentrum Berlin

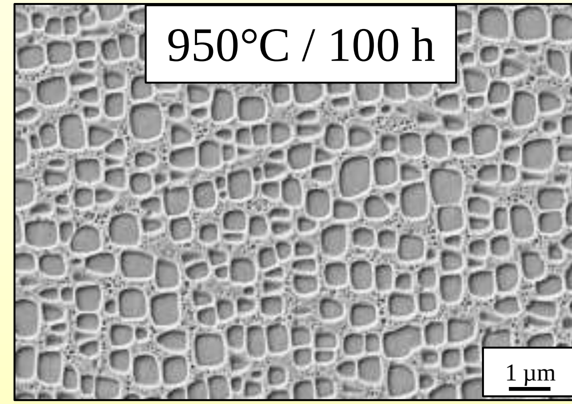
Mechanical characterization

Metallische Werkstoffe

Base alloy: Optimization of heat treatment

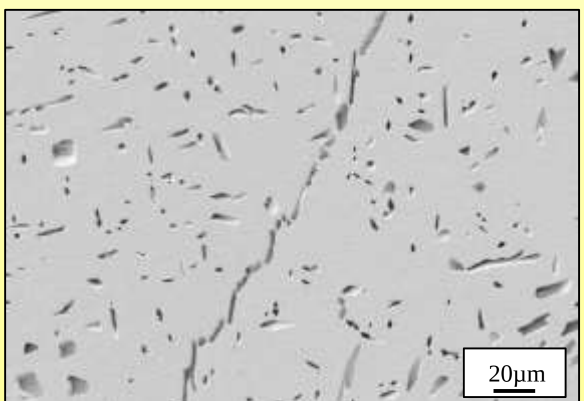


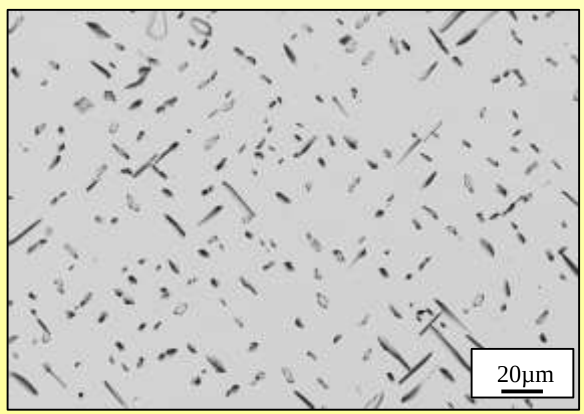


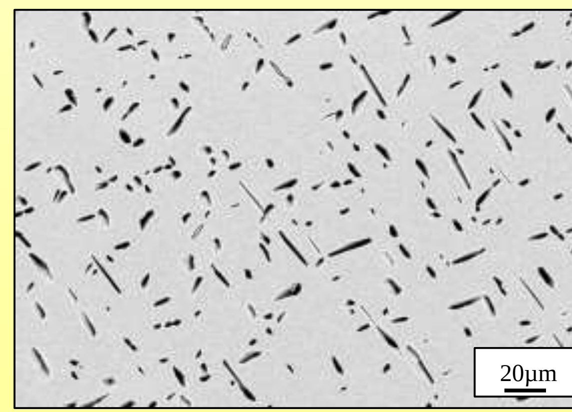


→ Cubic shape of γ´-particles

→ Size and volume-fraction of γ´-particles



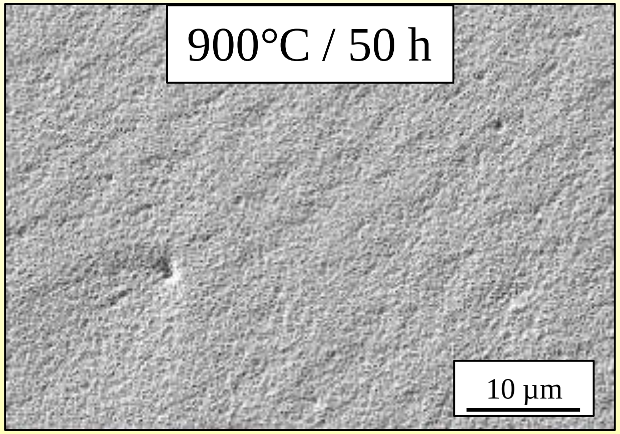


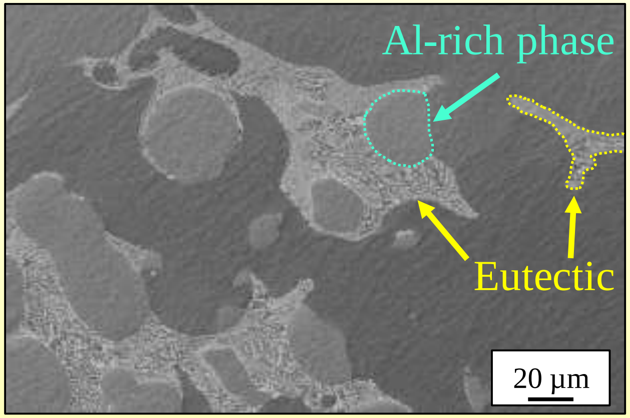


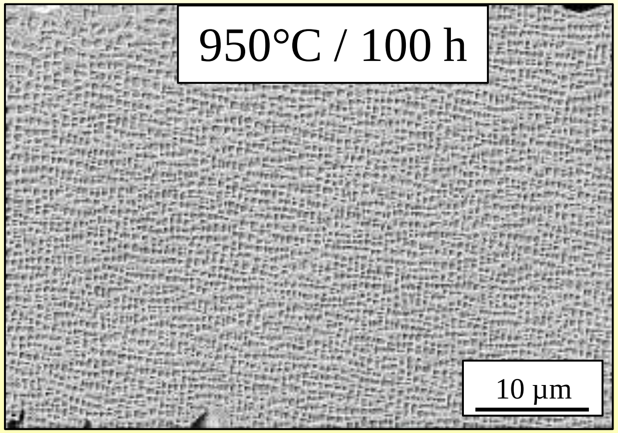
Same kind of distribution of Al-rich needle phase

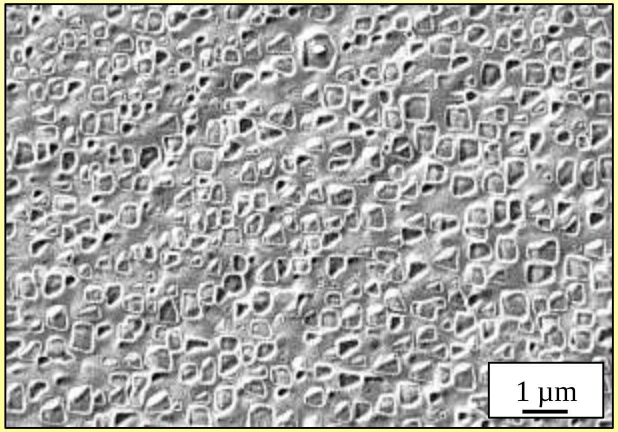
Addition of Hafnium

$Al_{9,5}Co_{25}Cr_{8}Fe_{15}Ni_{36}Ti_{6}\mathbf{Hf_{0,5}}$ (in at.%)



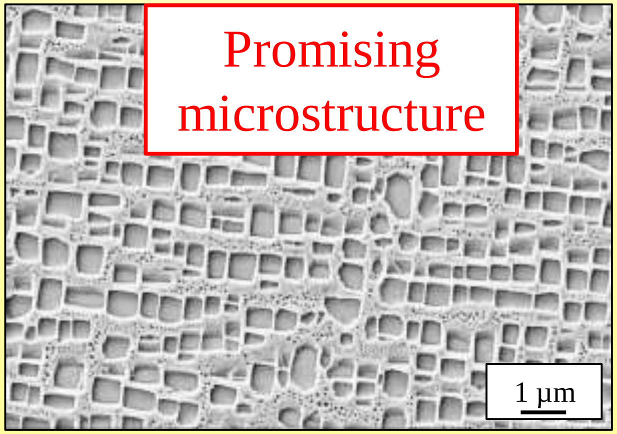






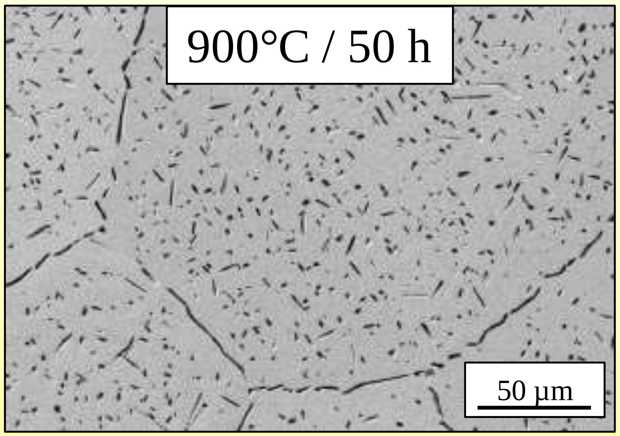
- Eutectic formation at grain boundaries;
  T(hom) ≠ 1220°C
  - ➢ T(hom) = 1140°C
- Spheric shape of Al-rich needle phase

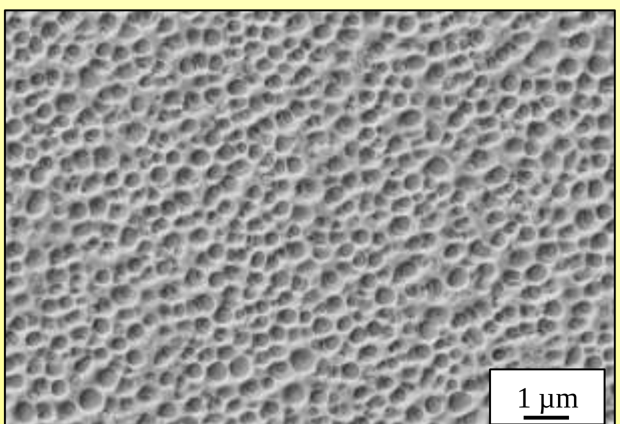
➢ Optimization of heat treatment



Addition of Molybdenum

$Al_9Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6\mathbf{Mo_1}$ (in at.%)



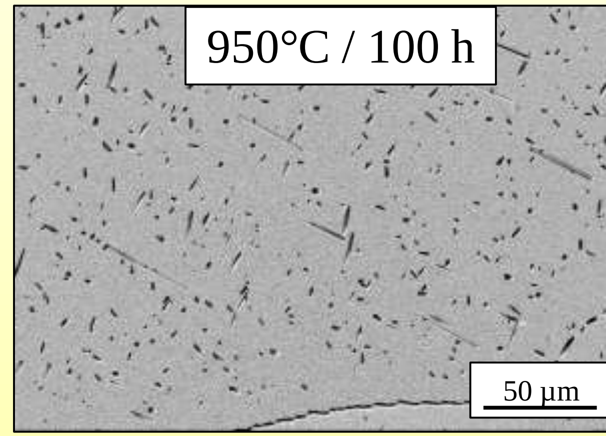


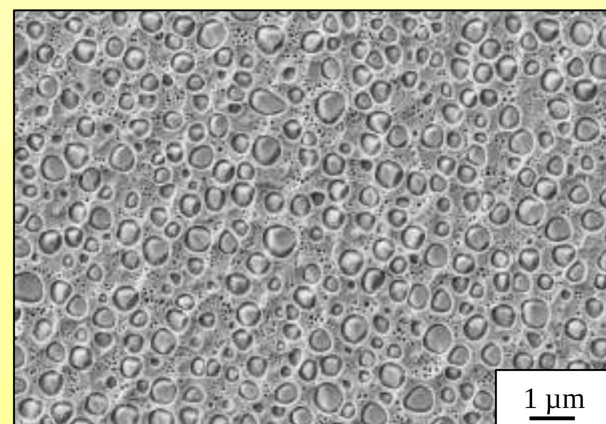
Nickel-based superalloys:

- Molybdenum enters matrix and precipitates
- Solid solution strengthening of matrix

- Reduction of misfit between γ and γ´
- Spheric shape of γ´-particles

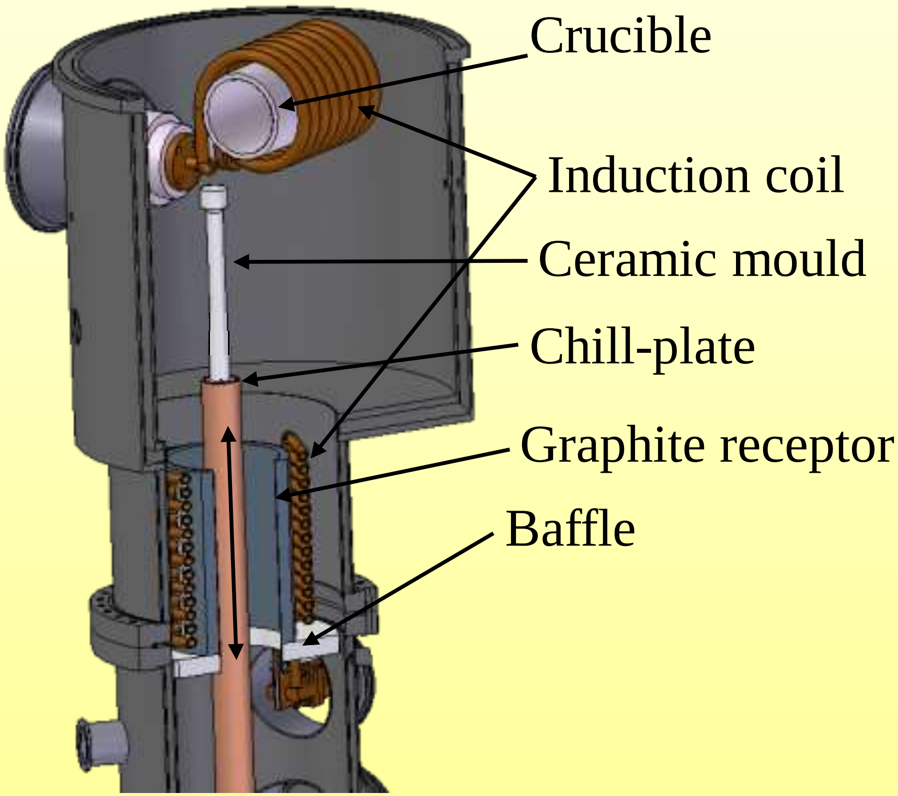
- Optimization of heat treatment





Alloy manufacturing: Directionally solidification

Induction casting



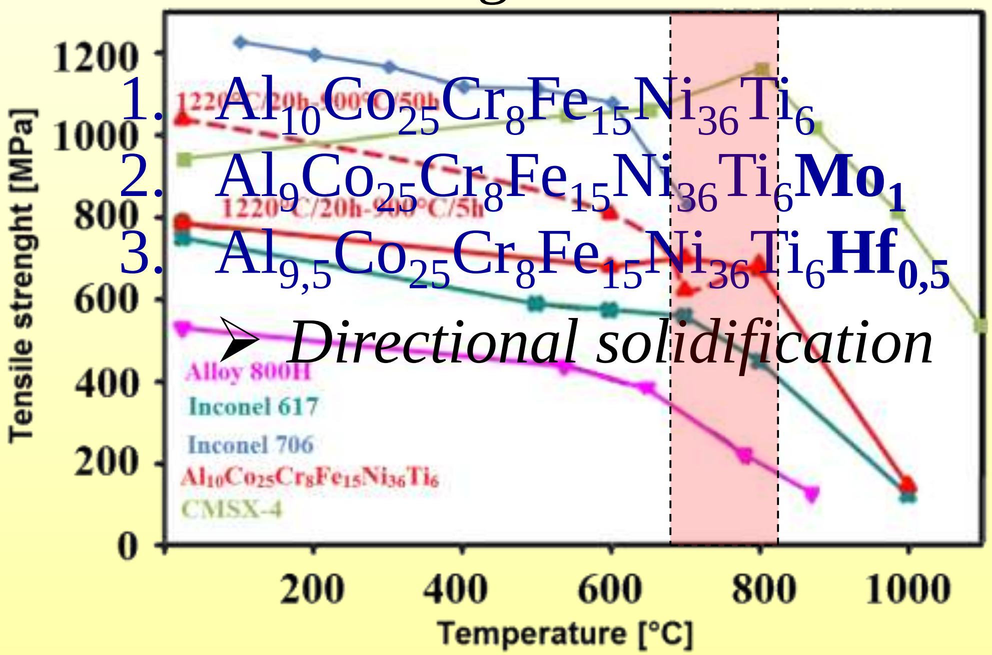
"Bridgman process"

Vacuum extraction	$5 \cdot 10^{-4}$ mbar
Casting atmosphere	Argon
Mould temperature	1400 °C
Initial weight	300 g
"Pull-down speed"	3 mm/min

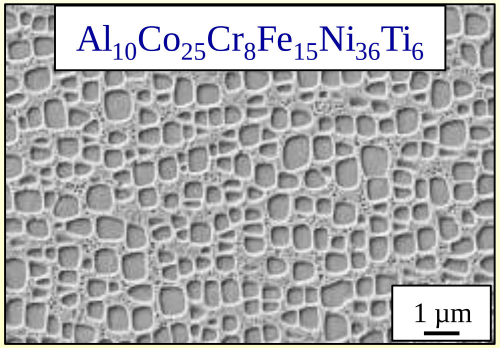
Mechanical characterization

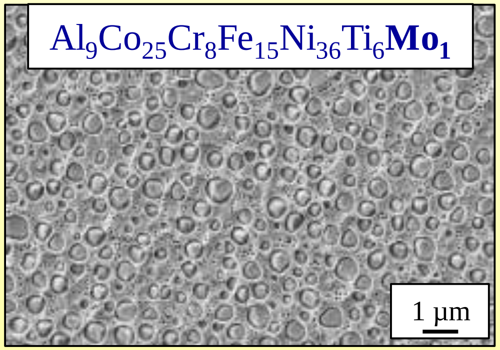
- Current investigated and tested alloys:

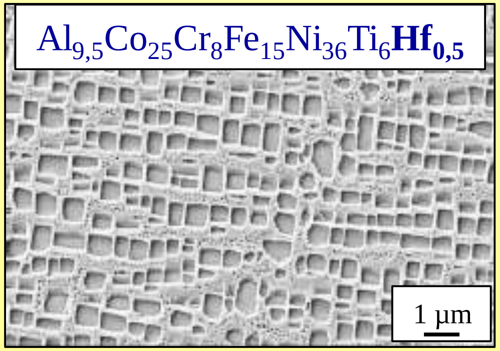
Daoud H.M. – High-Temperature Tensile Strength of $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$ Compositionally Complex Alloy (High-Entropy Alloy) – JOM 2015



1. $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$
2. $Al_9Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$**$Mo_1$**
3. $Al_{9,5}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$**$Hf_{0,5}$**
   - *Directional solidification*







- Substance of examinations:
  - High temperature tensile tests (RT, 600°C, 700°C, 800°C, 900°C, 1000°C)
  - Creep experiments

Conclusion & Outlook

- $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$ as a promising material for applications at elevated temperatures (700 – 800°C)
- Microstructural changes due to the addition of molybdenum and hafnium
- Successful heat treatment optimization steps respective microstructural improvement
- DS-alloy manufacturing by induction casting & Bridgman process

- <u>Outlook:</u>
  - Creep and high-temperature tensile testing
  - Polycrystalin samples
  - Influence of sample-orientation (0°, 45°, 90°)
  - Investigation of $Al_{10}Co_{25}Cr_8Fe_{15}Ni_{36}Ti_6$ + Zr, B, C, W, Y

Thank you for your attention!