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γ/γ' Co-base superalloys – new high temperature materials beyond Ni-base Superalloys?

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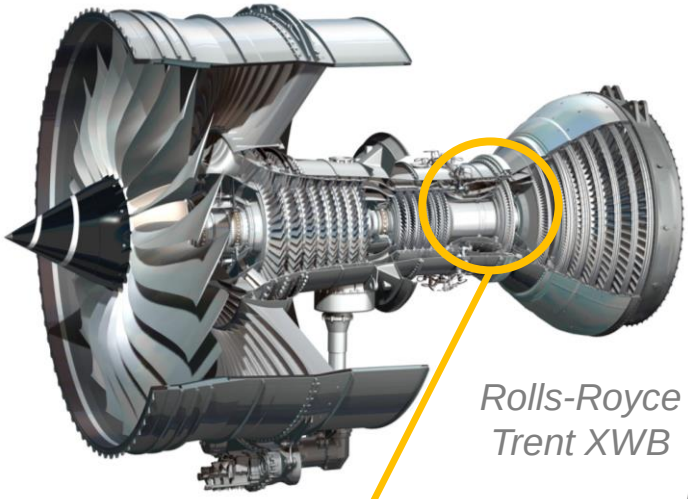
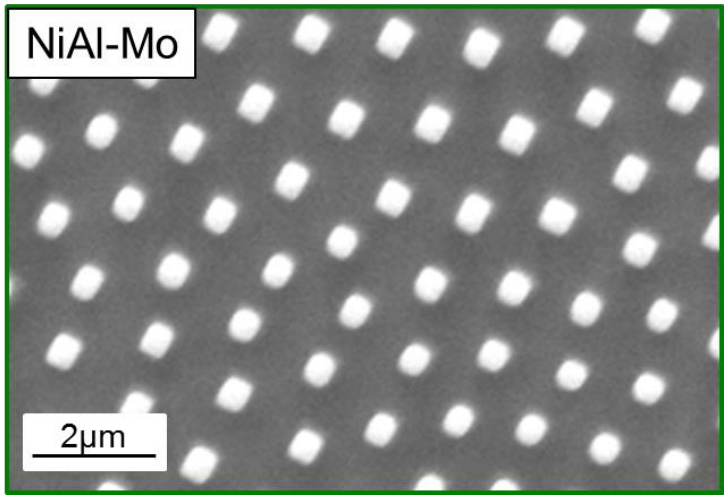
SFB/Transregio 103
SUPERALLOY SINGLE CRYSTALS

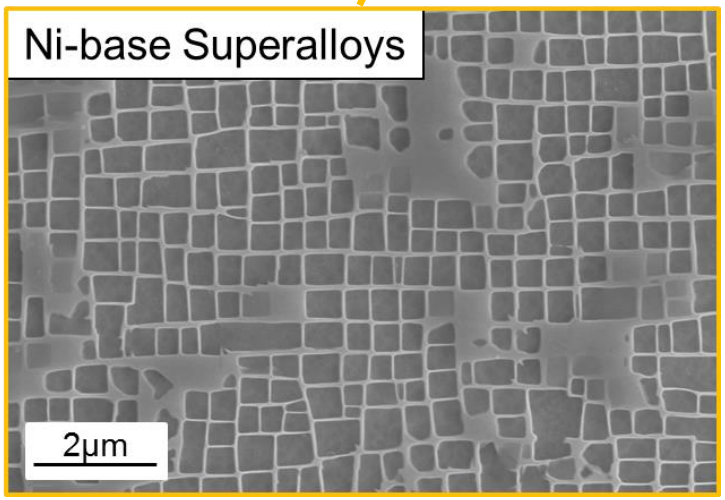
Intermetallic-based materials for structural applications

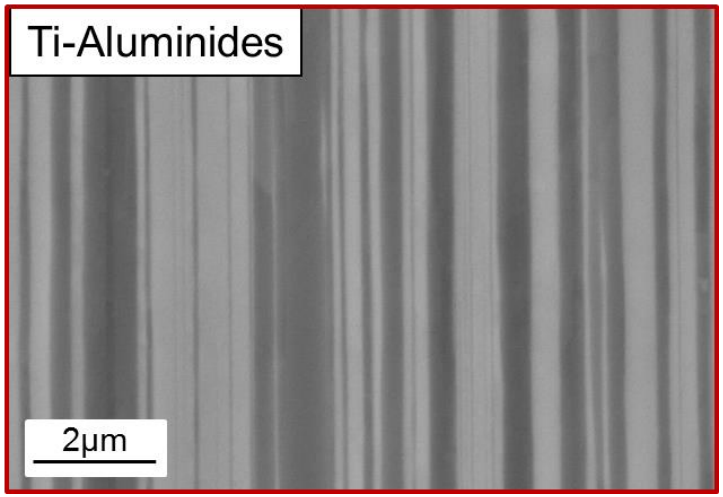


Rolls-Royce Trent XWB



Haenschke et al., J. Physics: Conf. Series, 240 (2010), 012063





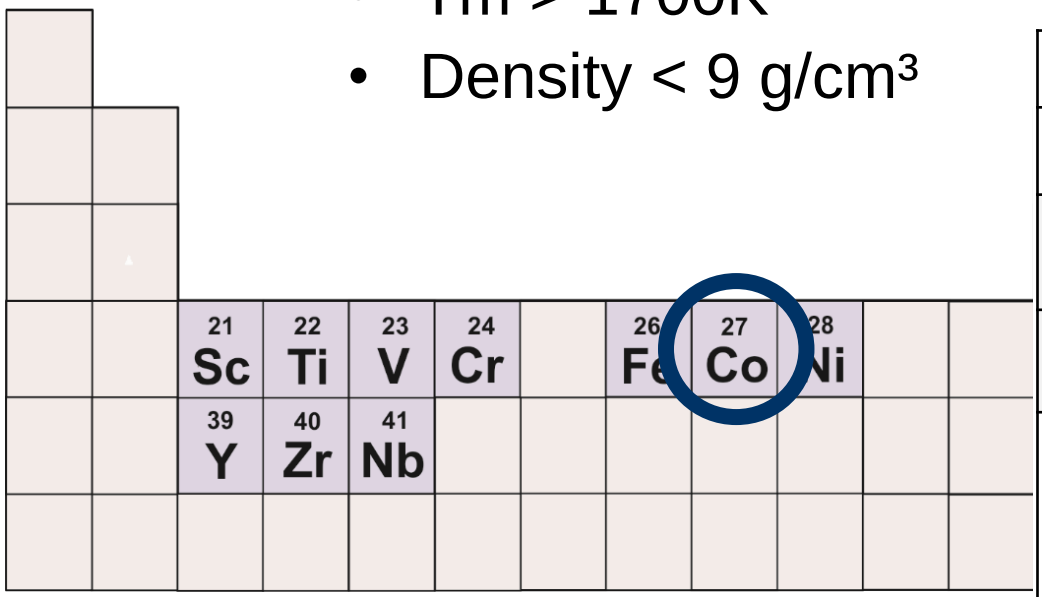
f_{IP} up to 75%

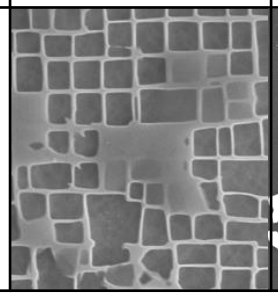
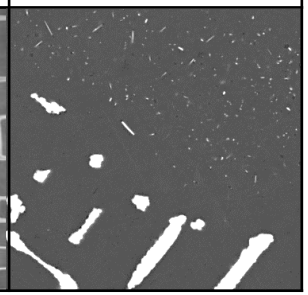
f_{IP} = 100%

Periodic table of elements

Metalls with

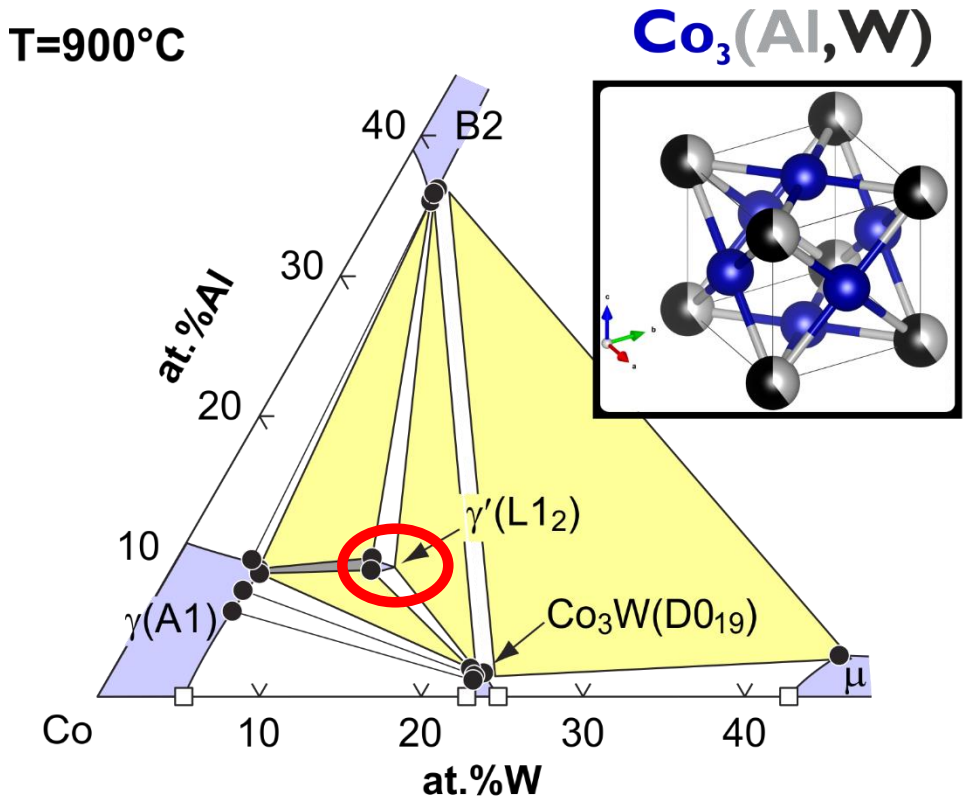
- Tm > 1700K
- Density < 9 g/cm³



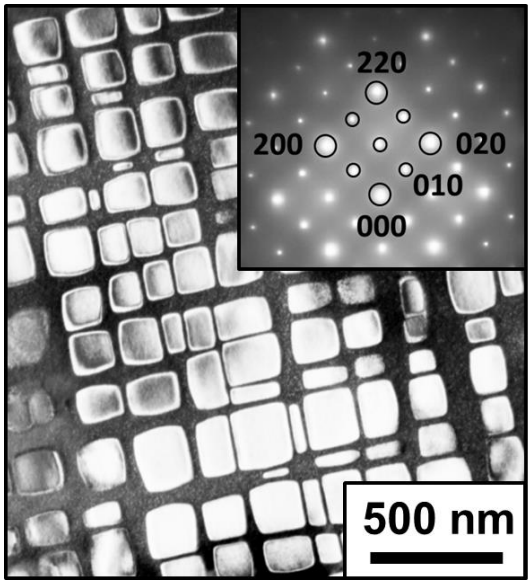
	Nickel	Cobalt
T_m / °C	**1455**	**1495**
Crystal structure	fcc	fcc / hcp (417°C)
Density g/cm³	8.9	8.9
hardening phase	Ni_3Al	✗
Micro-structure		

- Ni-base superalloys: $\gamma'(Ni_3Al)$ precipitates coherently embedded in fcc γ Ni_{ss}
- Co-base superalloys: carbides in fcc Co_{ss}

$L1_2$-$Co_3(Al,W)$ hardened Co-base-superalloys



*J. Sato et al., Science **312**, 90 (2006)*



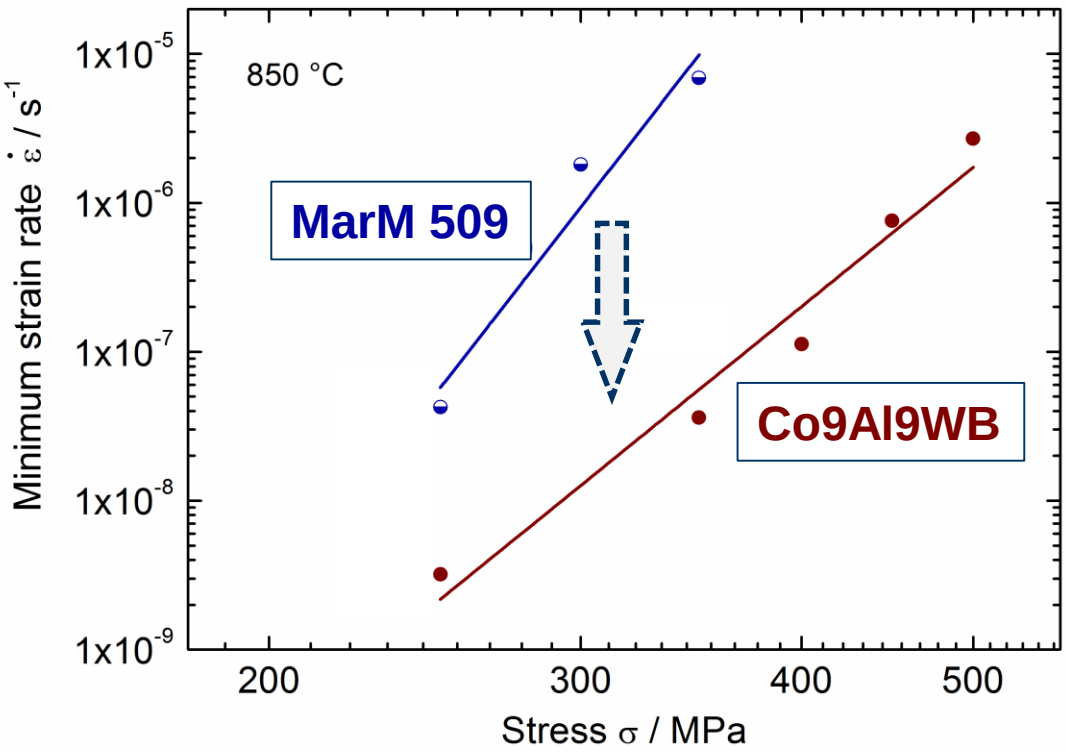
Co-9Al-9W (at.%) 900°C/200h

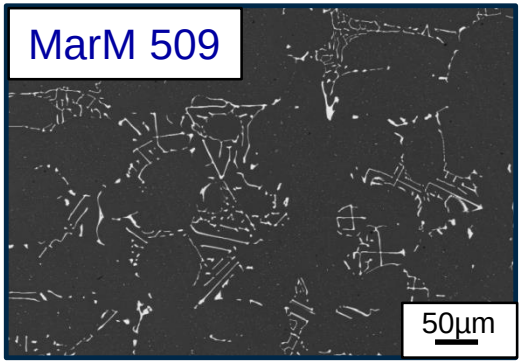
- γ' $Co_3(Al,W)$: (meta)stable $L1_2$ phase in ternary Co-Al-W-system
- Coherent γ' precipitates in γ fcc solid solution

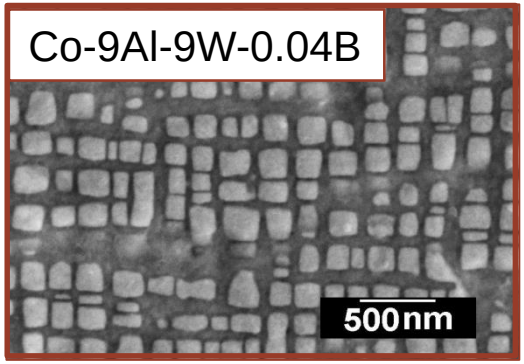
→ New class of high temperature materials

Creep properties of γ/γ′ alloy Co-9Al-9W

MarM 509: Co-28Cr-10Ni-2W-1Ta-3C-0.3Zr (at.%)

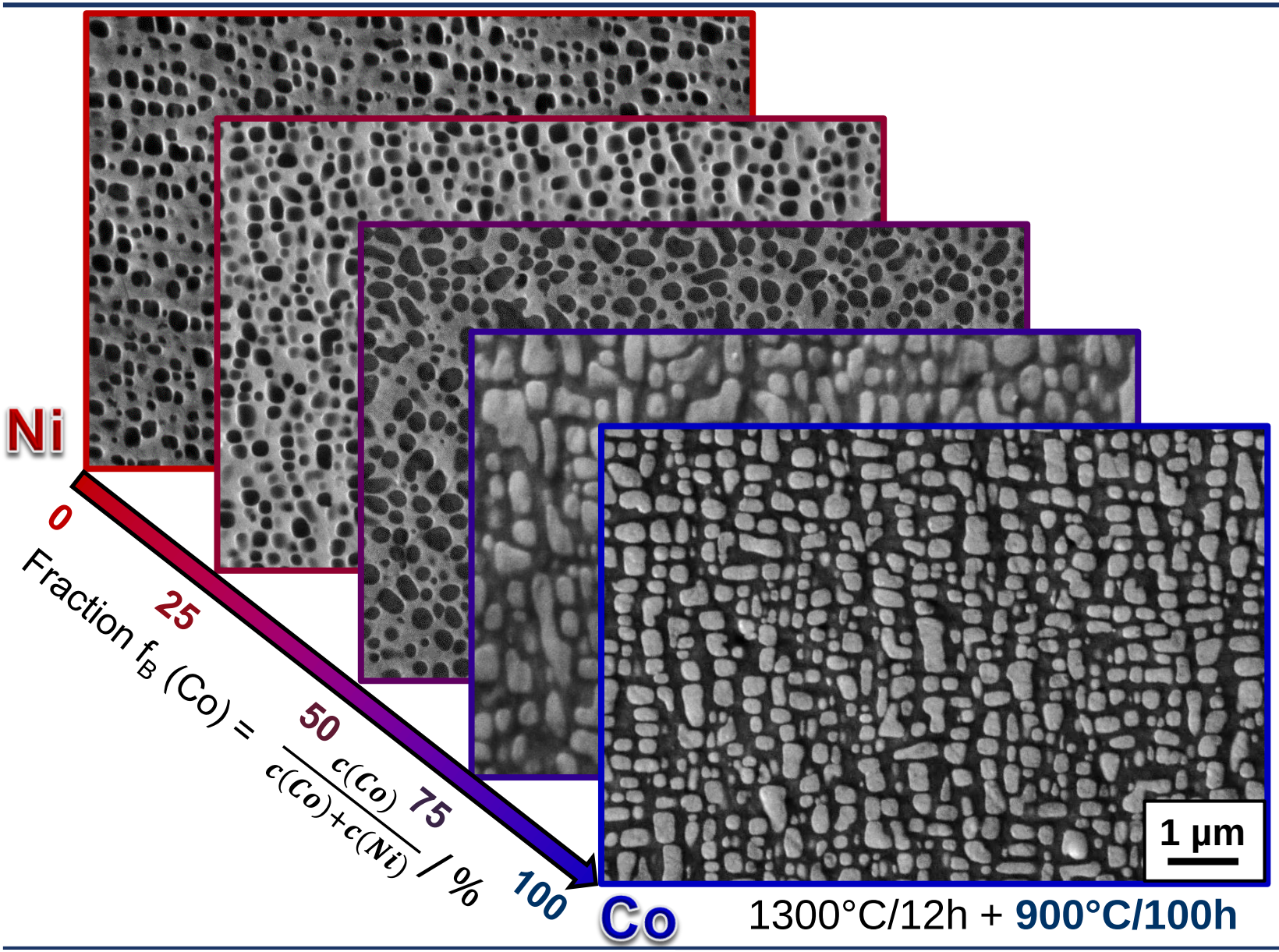






- $Co_3(Al,W)$ hardened have a much higher creep strength than conventional carbide hardened Co-base superalloys

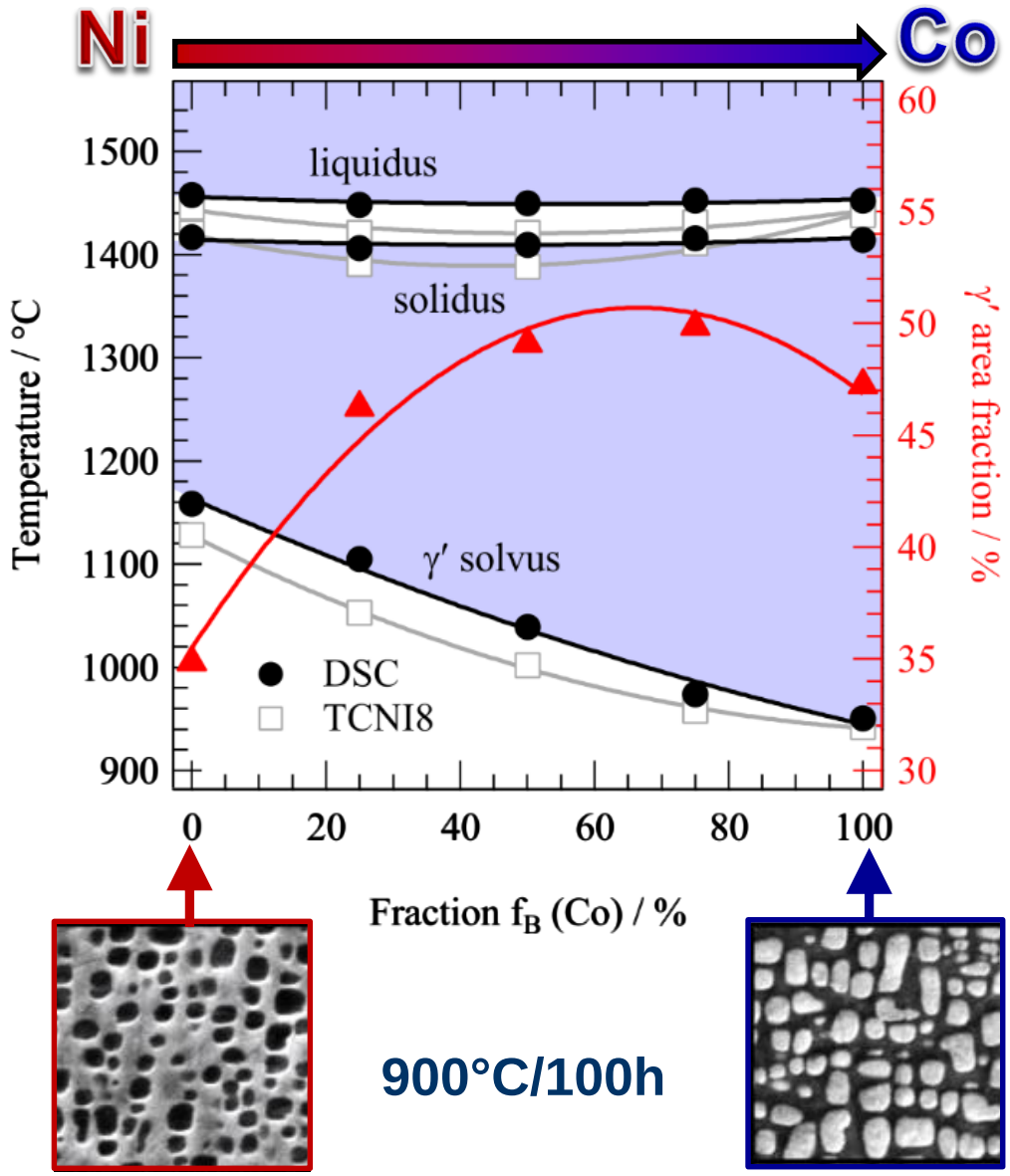
Microstructure of Ni-Co-9Al-8W-8Cr alloy series



1300°C/12h + **900°C/100h**

Zenk, Neumeier et al., Scripta. Mater. 112 (2016)
Zenk, Neumeier et al., accepted at Superalloys 2016

Pseudo-binary phase diagram of Ni-Co-9Al-8W-8Cr



900°C/100h

- TCNI8 describes trends correctly (metastable calculation)

With increasing Co content…

- no significant changes of liquidus and solidus temperature
- decrease of γ′ solvus temperature
- increase of γ′ fraction

Zenk, Neumeier et al., Scripta. Mater. 112 (2016)
Zenk, Neumeier et al., accepted at Superalloys 2016

Composition of developed alloys

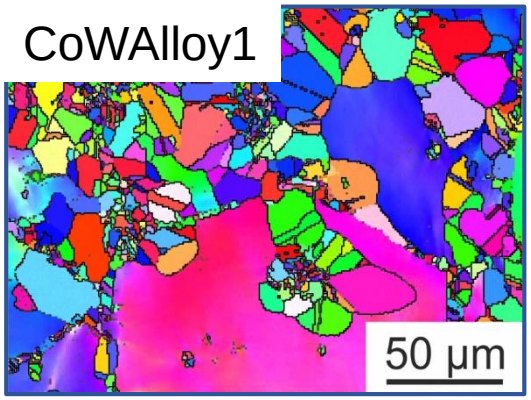
at.%	Co	Ni	Cr	Al	W	Ti	Ta	Si	Zr	Hf	B	C
CoWAlloy1	42.3	32.0	12.0	6.0	3.0	2.5	1.5	0.4	0.01	0.1	0.08	0.08
CoWAlloy2	40.8	32.0	12.0	9.0	5.0	0.3	0.2	0.4	0.01	0.1	0.08	0.08

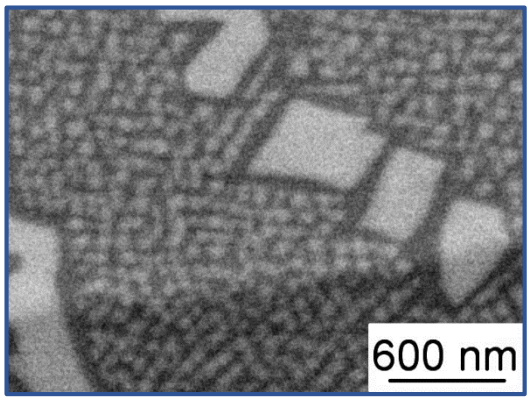
- Ni: phase stabilisation
- Al, Ti, Ta, W, Hf: γ' former
- Cr, Si: oxidation resistance
- B, C, Zr: grain boundary strengthening

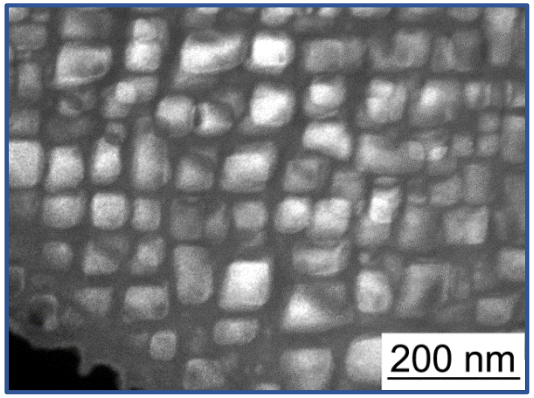
Patent application WO 2016/016437 A2

Microstructure

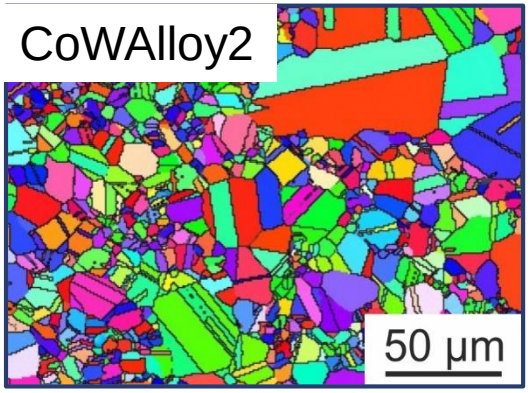
CoWAlloy1

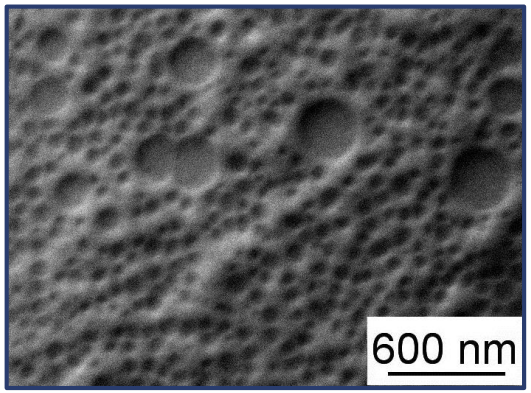


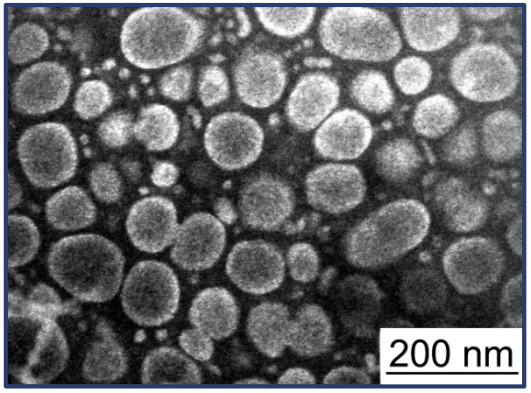




CoWAlloy2

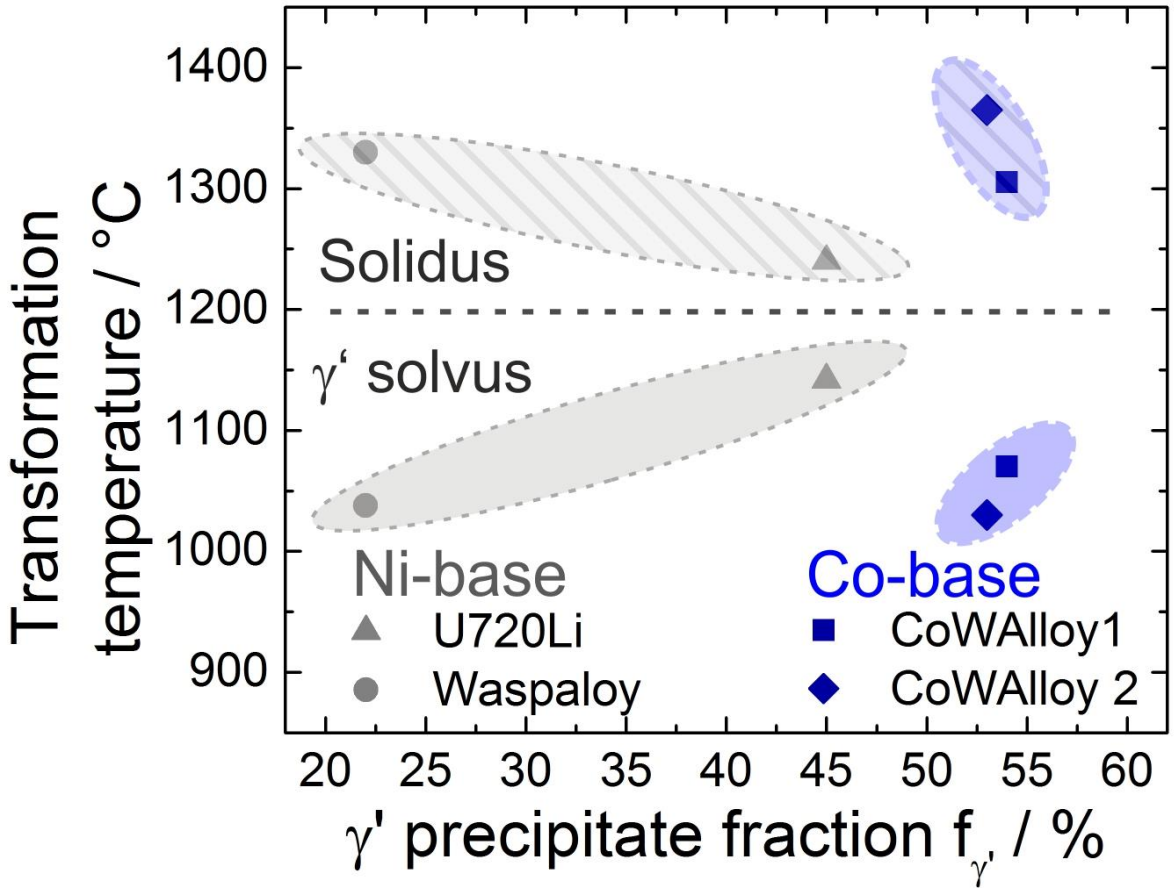






	median grain size	median $\gamma'_{sec.}$ diameter	$\gamma'_{sec.}$ area fraction
CoWAlloy1	4.3 µm	57 nm	~50 %
CoWAlloy2	7.2 µm	64 nm	~50 %

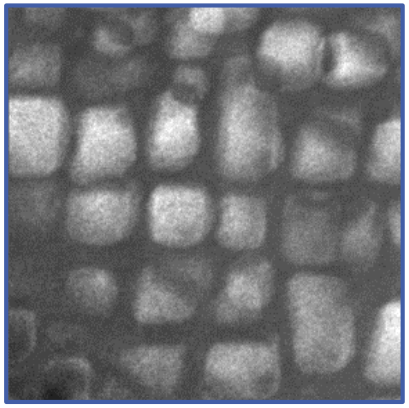
Thermo-physical properties

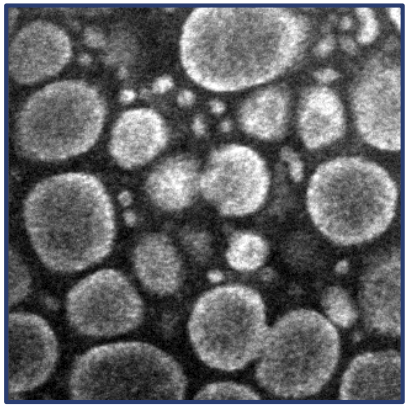


- **CoWAlloys:** Large processing window and higher γ' precipitate fraction
  → **Intermetallic-based wrought alloys**

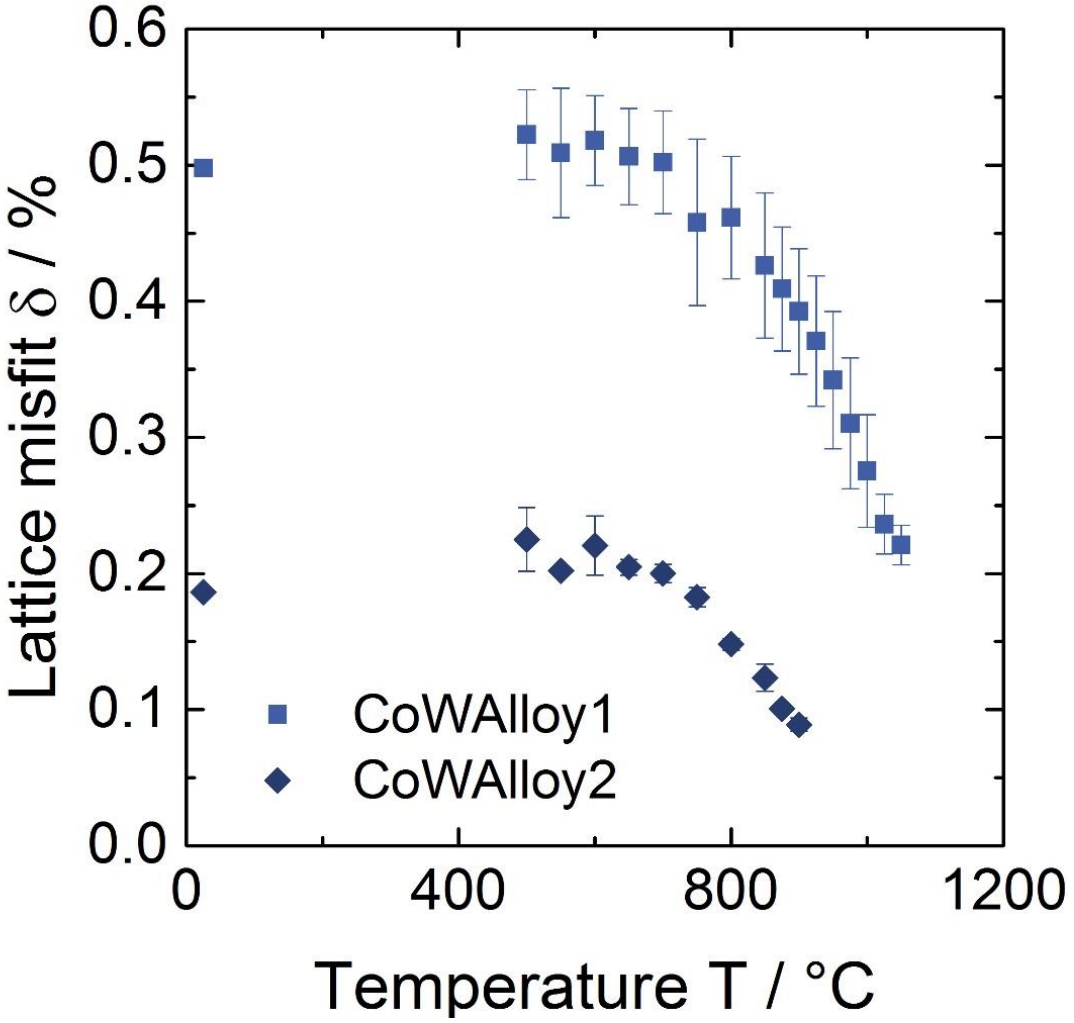
γ/γ' Misfit

Synchrotron diffraction at HEMS beamline, DESY, Hamburg

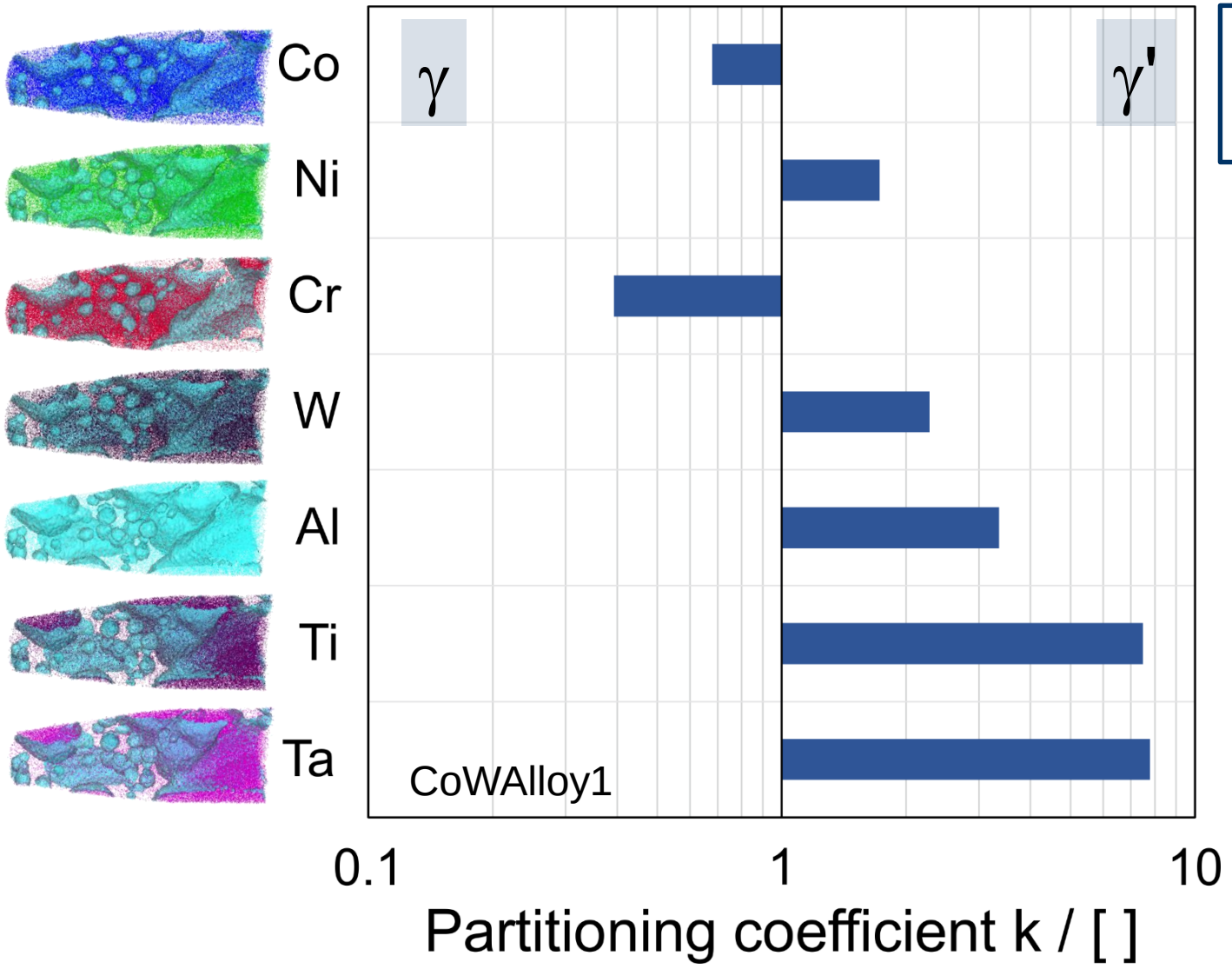




$$\delta = \frac{2(a_{\gamma'} - a_{\gamma})}{(a_{\gamma'} + a_{\gamma})}$$



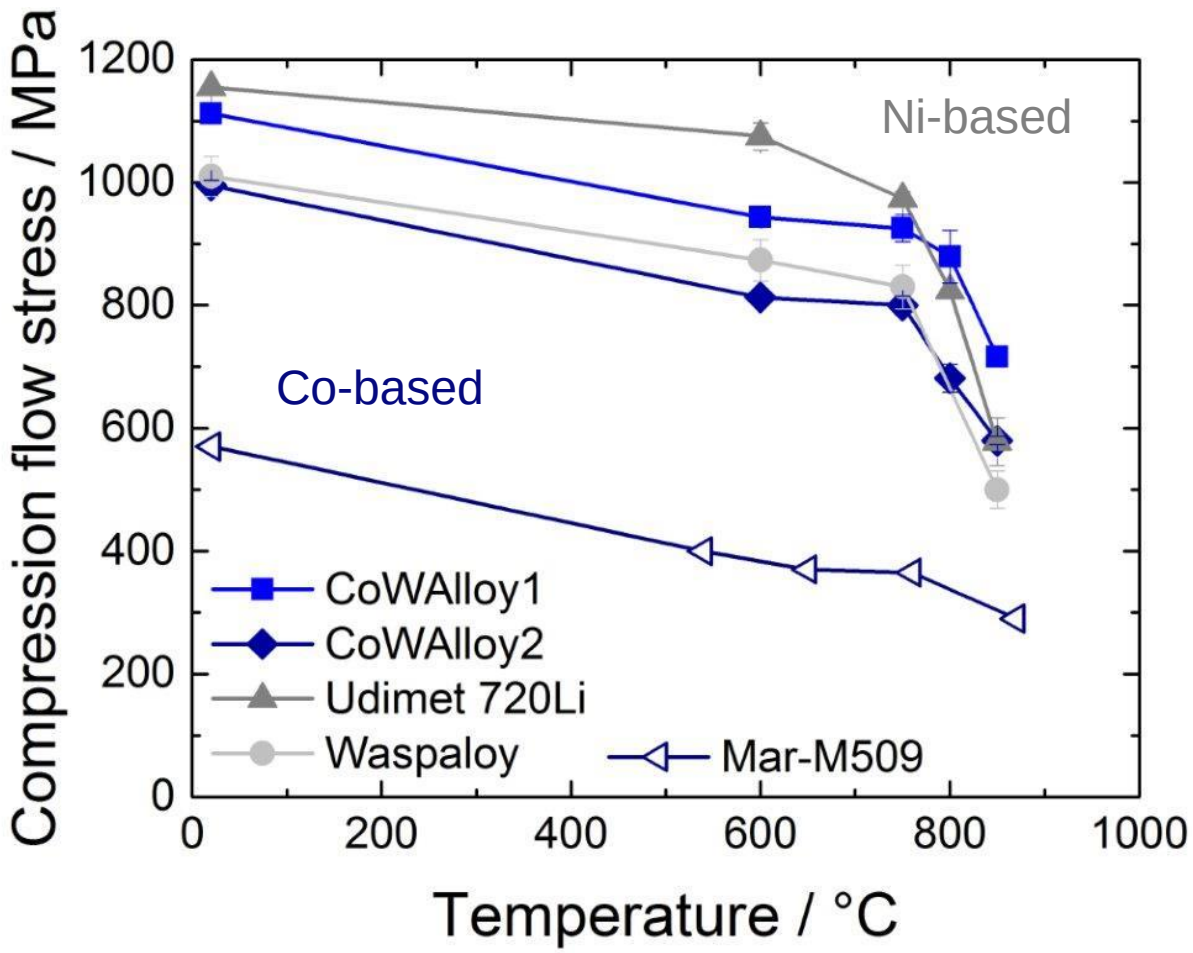
Elemental partitioning from APT

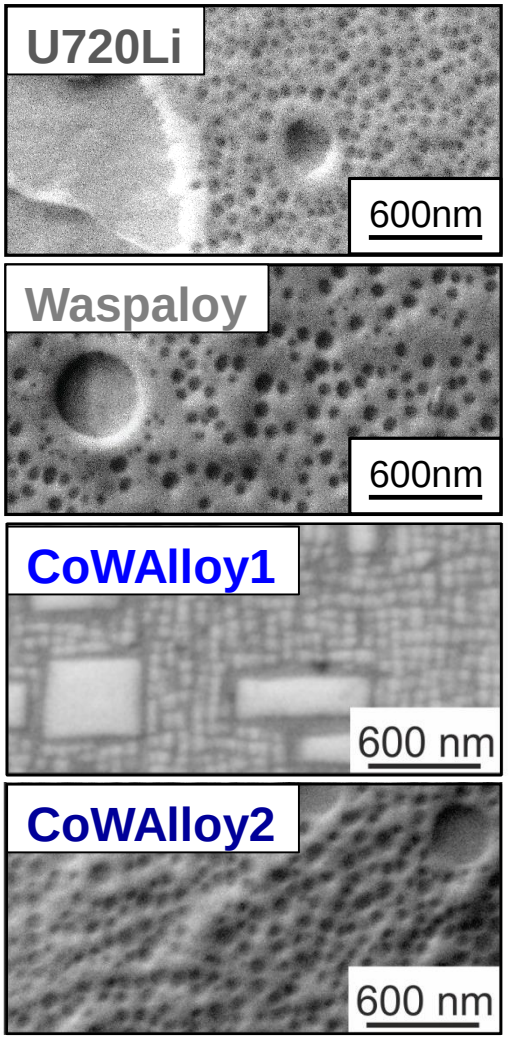


$$k = \frac{c_{\gamma'}}{c_{\gamma}}$$

CoWAlloy1

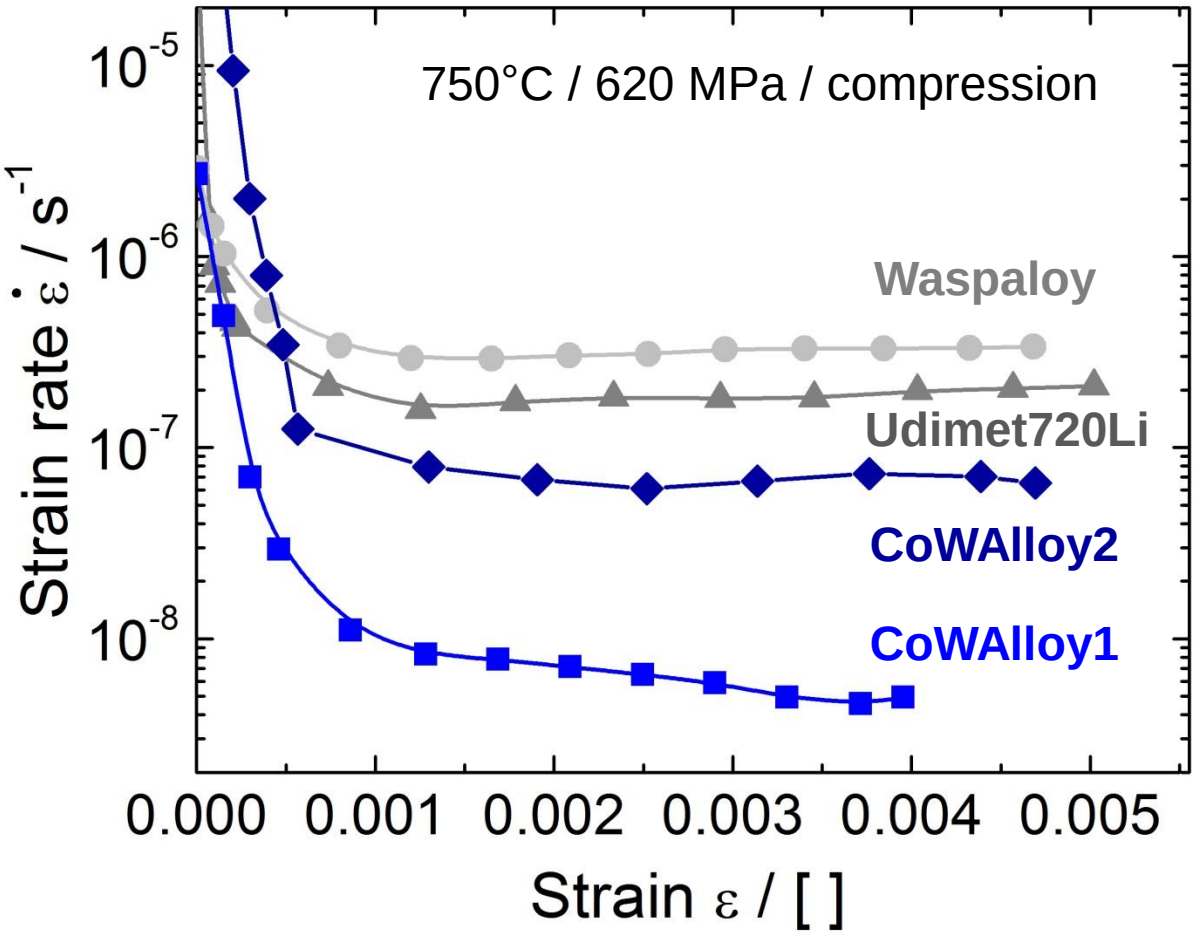
Yield strength





- Similar yield strength compared to commercial Ni-base superalloys
- Higher yield strength at T ≥ 800°C

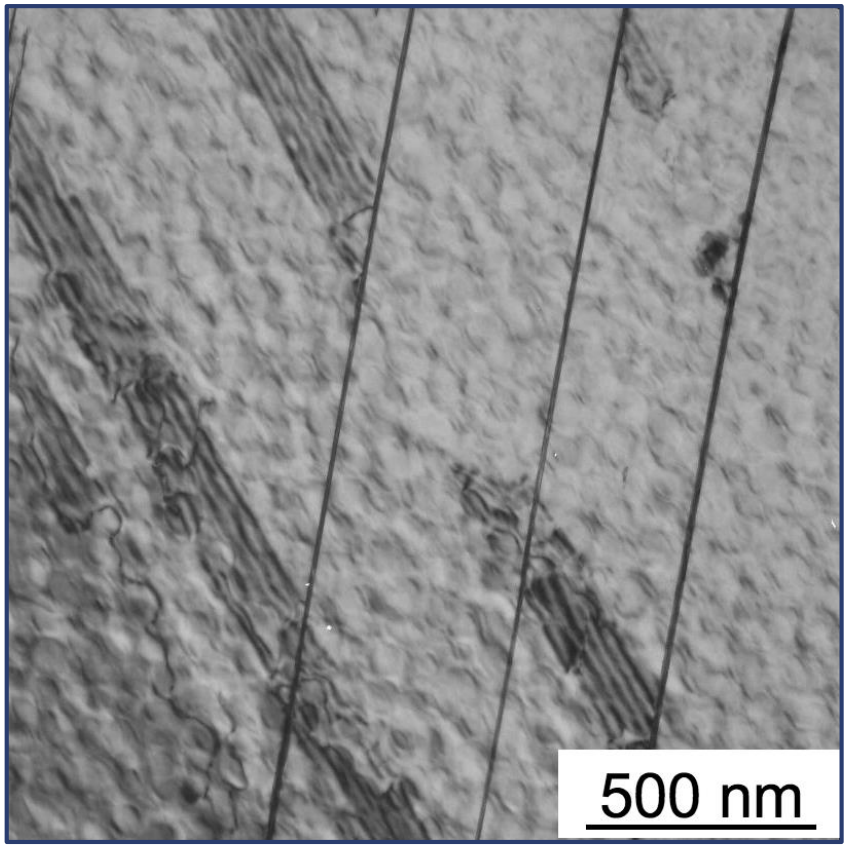
Creep strength

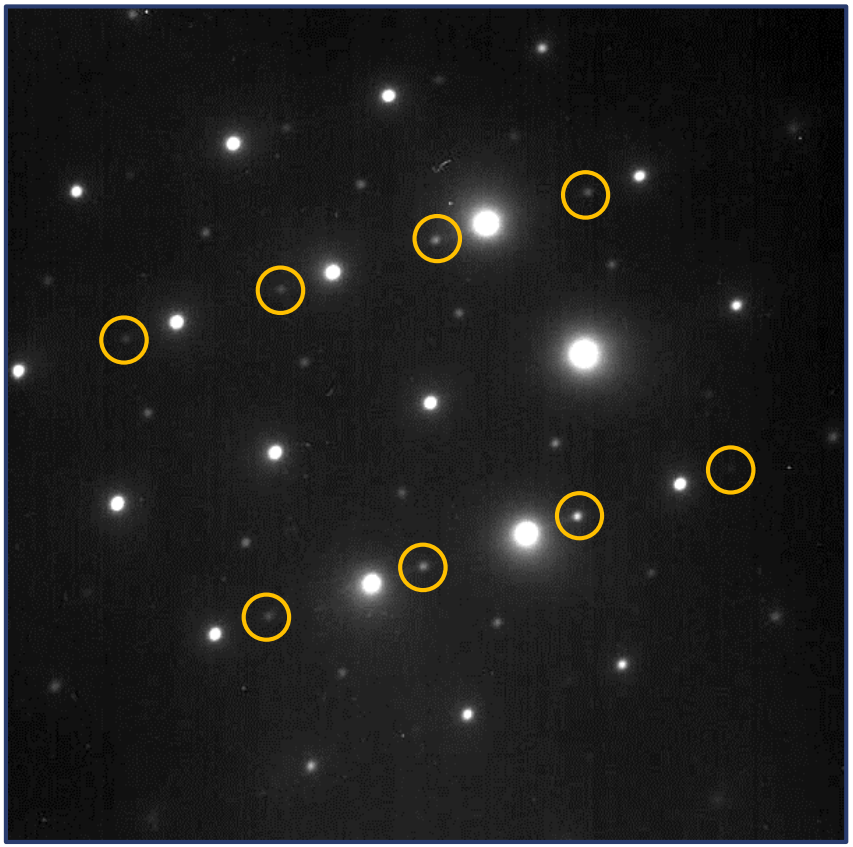


- Enhanced creep strength compared to Ni-base superalloys

Creep mechanisms

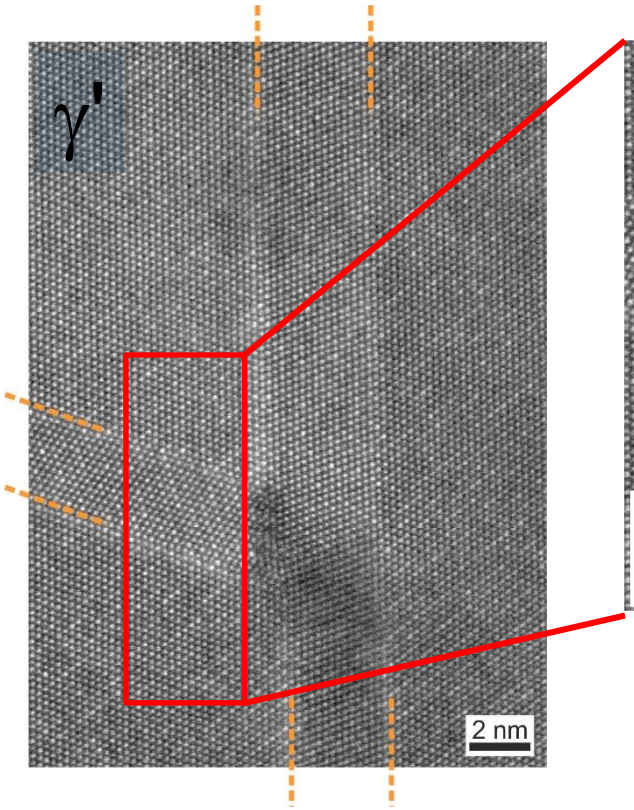
CoWAlloy2: tensile creep, 750°C/530MPa, 1% strain

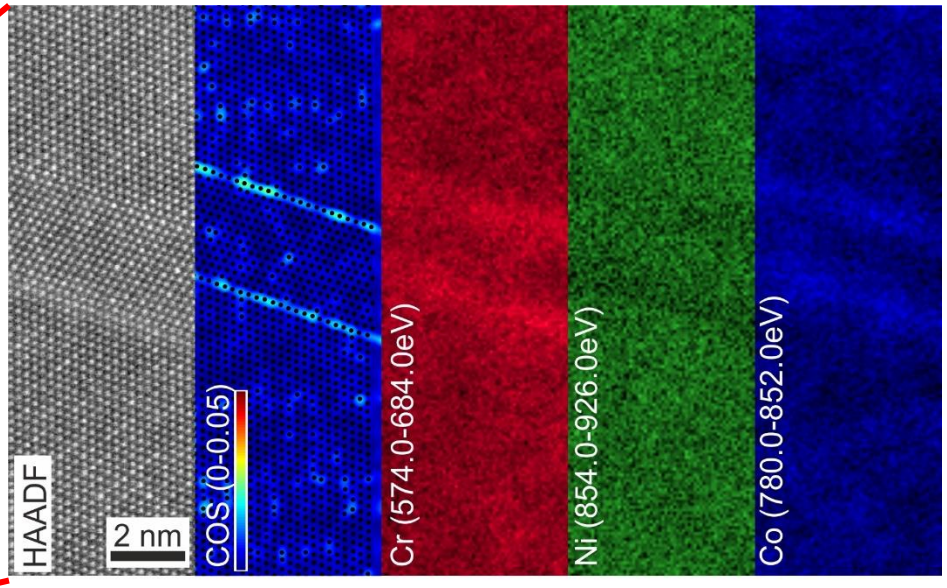


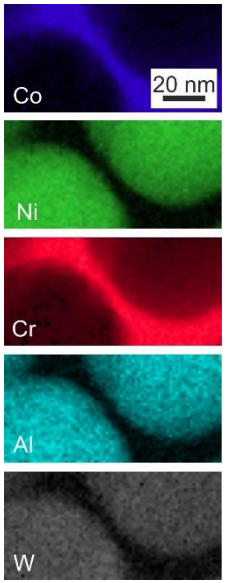


Deformation via microtwinning

Creep mechanisms







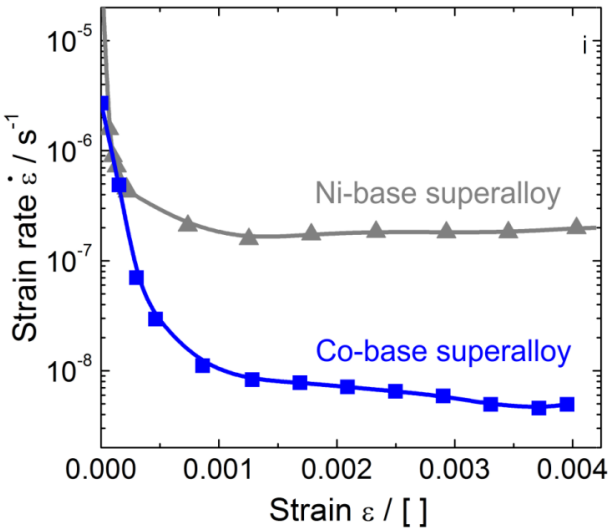
- Segregation of Co+Cr to the twin boundary
- Local composition shifted to γ-composition
- Lower SF-Energy and less ordering

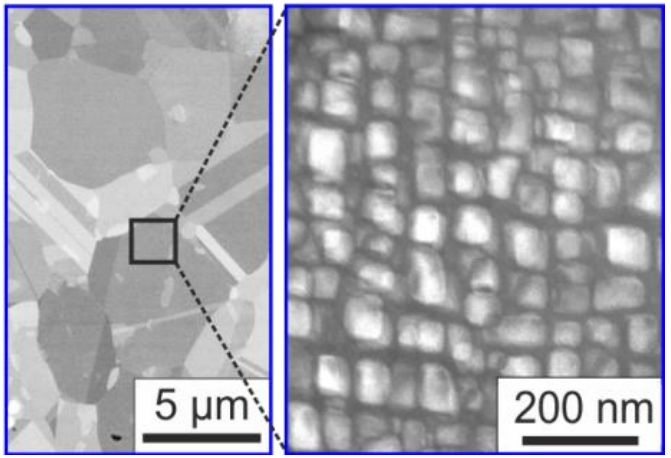
→ Slip becomes possible for a/6 [112] partial dislocations

Diffusion as time controlling step

Summary & Conclusion

- New polycrystalline **γ/γ′ Co-base superalloys** have been developed





→ Large processing window & high γ' precipitate fraction

→ Enhanced creep strength and comparable yield strength

➡ **Intermetallic-based wrought alloys**

Co-base superalloys are new high temperature materials beyond *polycrystalline wrought* Ni-base superalloys