7-19-2016

Microstructural stability of Co-Re-Cr-Ta-C alloy strengthened by TaC precipitates

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Recommended Citation

Debashis Mukherji, Ralph Gilles, Lukas Karge, Pavel Strunz, Přemysl Beran, and Joachim Rösler, "Microstructural stability of Co-Re-Cr-Ta-C alloy strengthened by TaC precipitates" in "Beyond Nickel-Based Superalloys II", Chair: Dr Howard J. Stone, University of Cambridge, United Kingdom Co-Chairs: Prof Bernard P. Bewlay, General Electric Global Research, USA Prof Lesley A. Cornish, University of the Witwatersrand, South Africa Eds, ECI Symposium Series, (2016). http://dc.engconfintl.org/superalloys_ii/25

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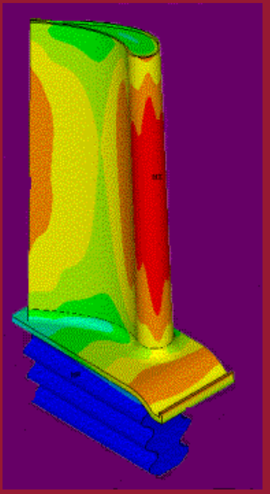


Microstructural stability of Co-Re-Cr-Ta-C alloys strengthened by TaC precipitates

Debashis Mukherji , **Niklas Wagener** and **Joachim Rösler** (*TU Braunschweig, Braunschweig, DE)*

Ralph Gilles and **Lukas Karge** *(TU Munich, Garching, DE)* | **Pavel Stunz** and **Přemysl Beran** (*NPI, Rez near Prague, CZ*)

Beyond Ni-based Superalloy II | Clare College Cambridge UK | 17-21 July.2016

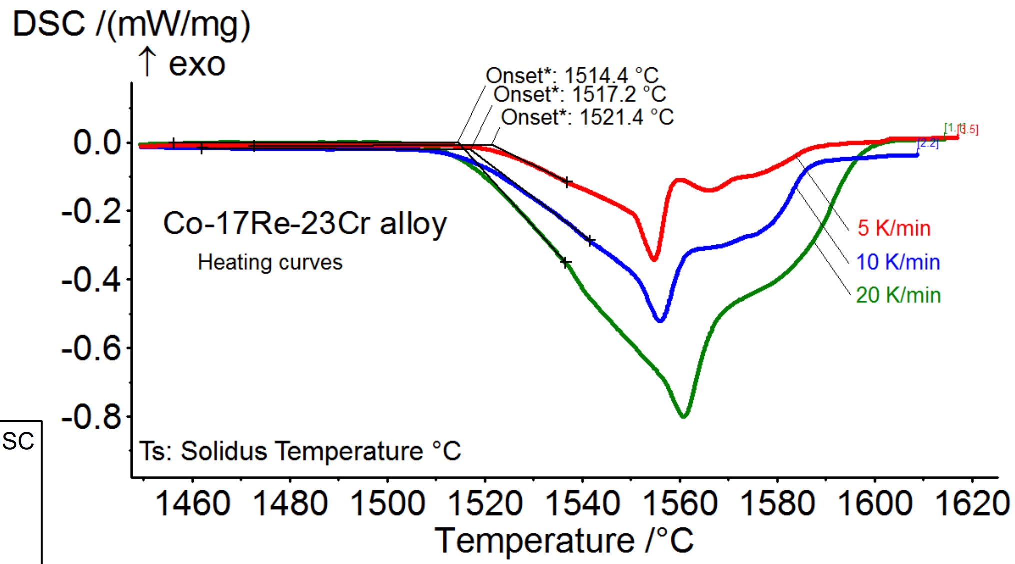
Co-Re-based alloys: for high temperature gas turbine applications

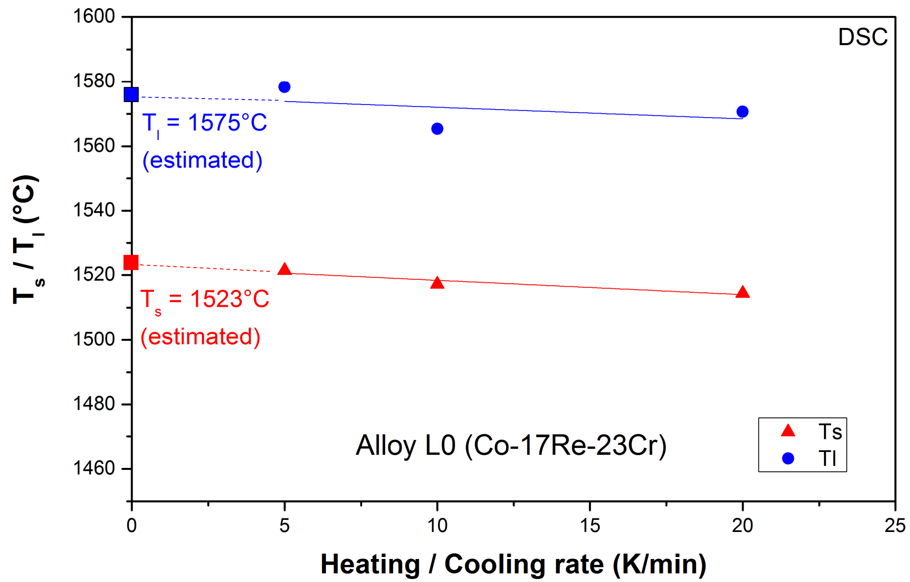
- **Present Status of Co-Re alloy development**
  - alloy development concept
- **Microstructural stability**
  - Co-matrix transformation: $\varepsilon \leftrightarrows \gamma$
  - TaC precipitates
- **Creep properties**
- **Outlook**

Melting range: Metallic Alloys *“Beyond Ni-Base Superalloys”*

Co-Re-Cr alloy melting range

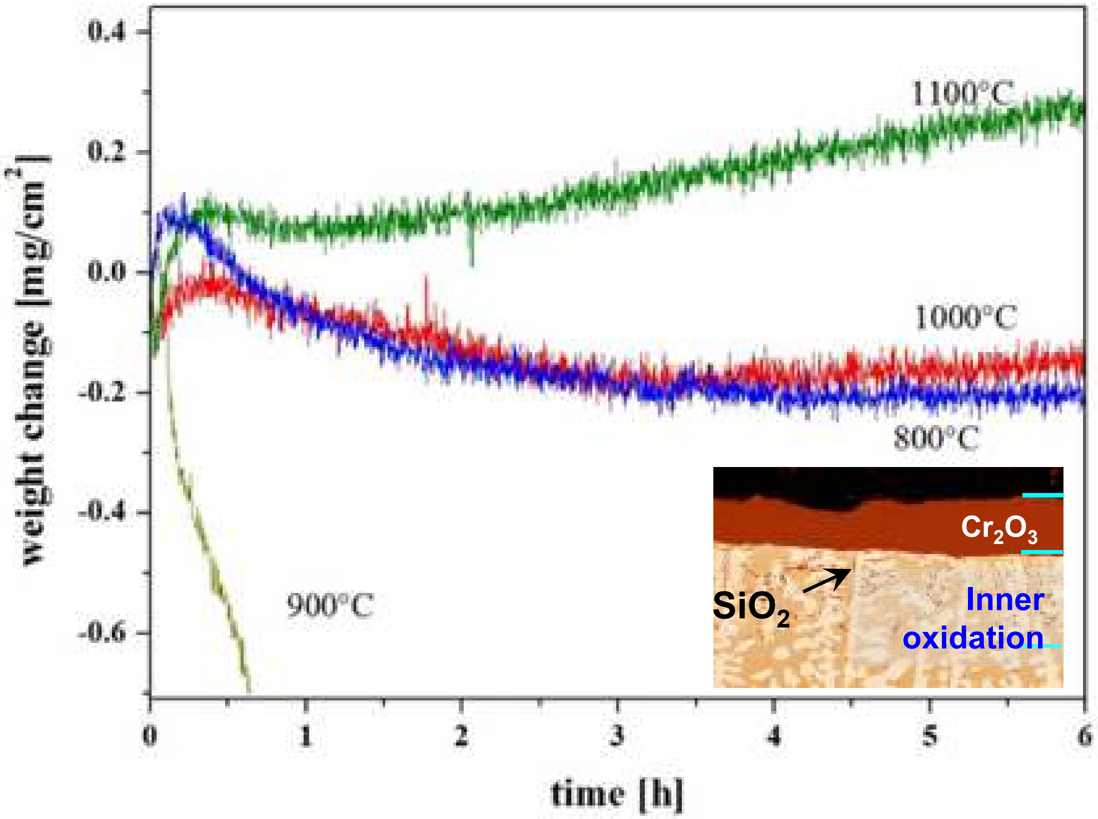
~ 1523° to 1575°C

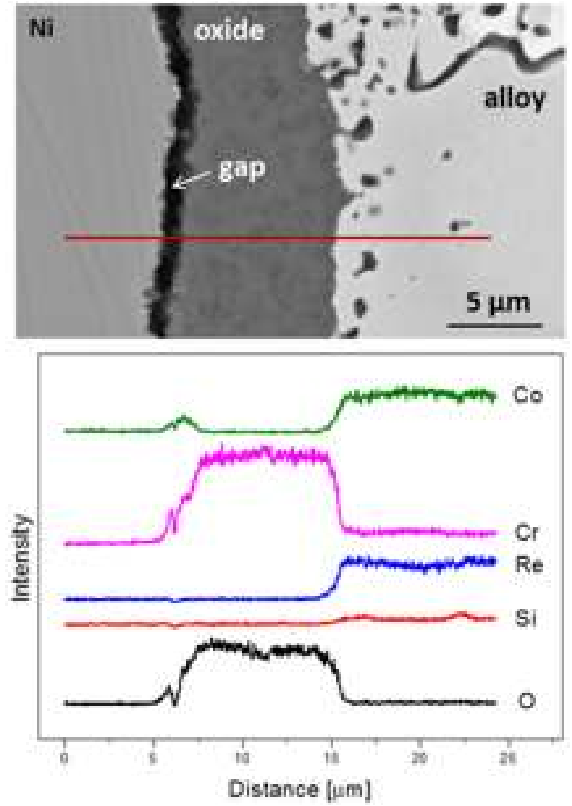




Considerably higher Melting Range than Ni-superalloys

Oxidation resistance: Co-Re-Cr-Si system

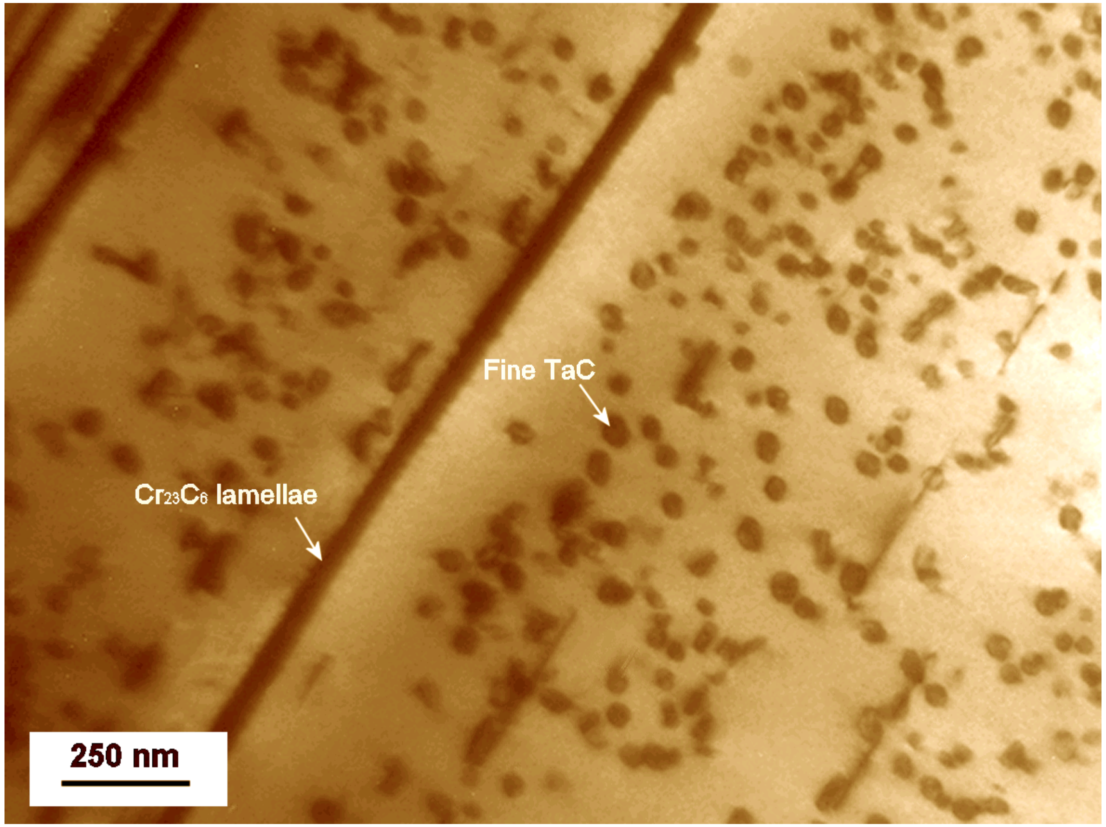




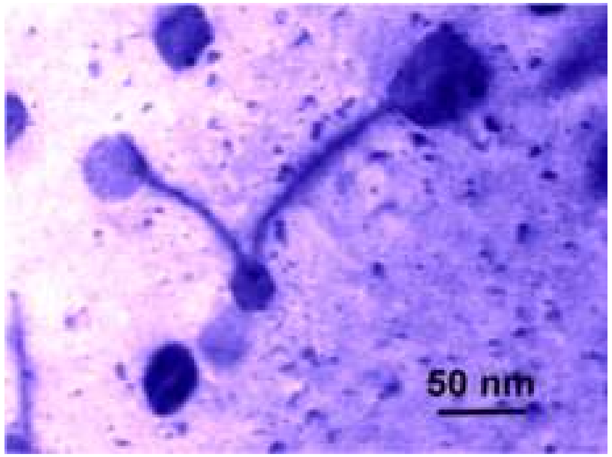
Good oxidation resistance up to 1100°C

K. Hennes, Dr L. Wang, Dr B. Gorr, Prof H.-J. Christ (Uni Siegen)

Alloy strengthening: by carbides



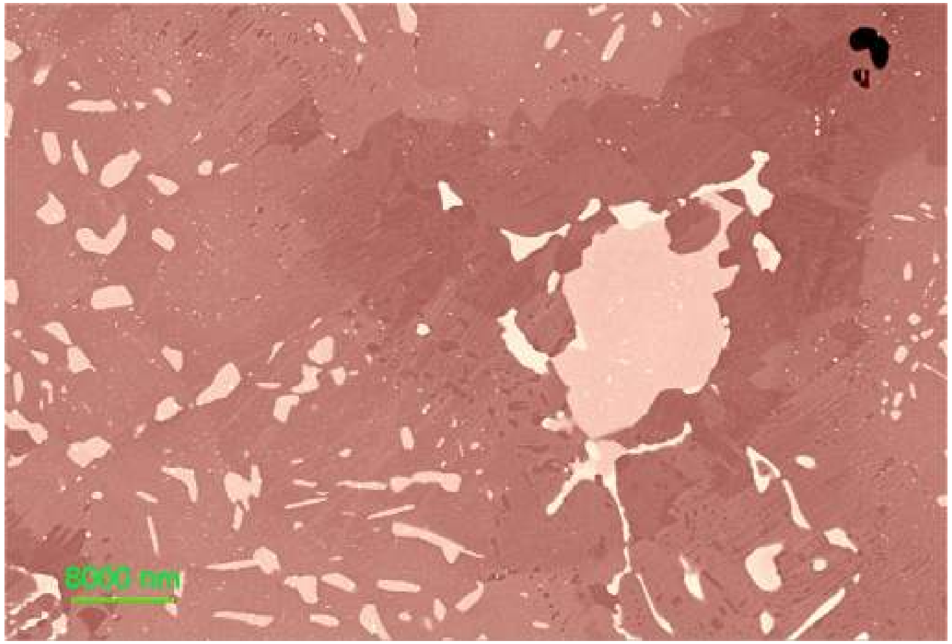
Fine dispersion of carbides in alloys with Cr, Ta and C addition



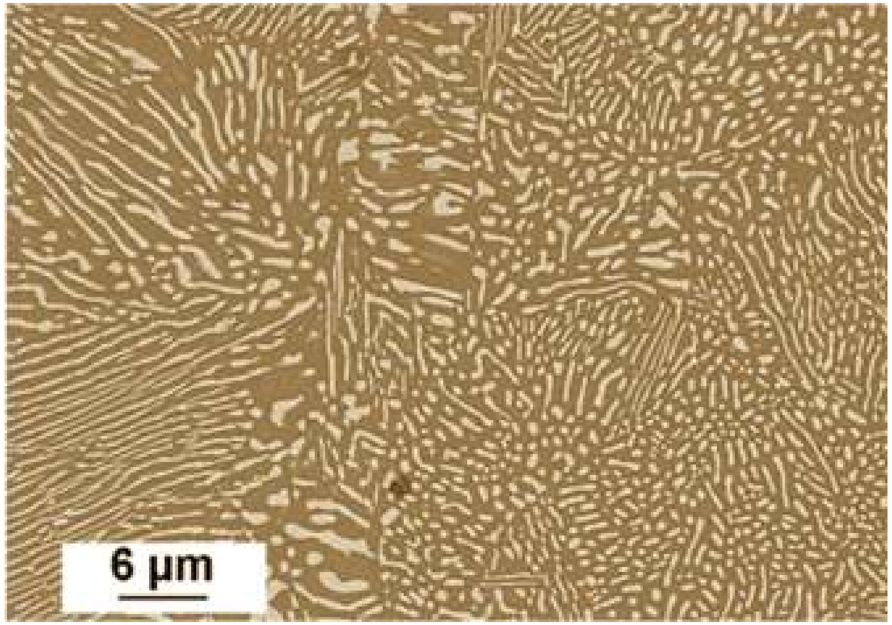
Dislocations interacting with TaC precipitates

Carbides provide effective strengthening in Co-Re-Cr-Ta-C alloys

Design considerations : tcp phase

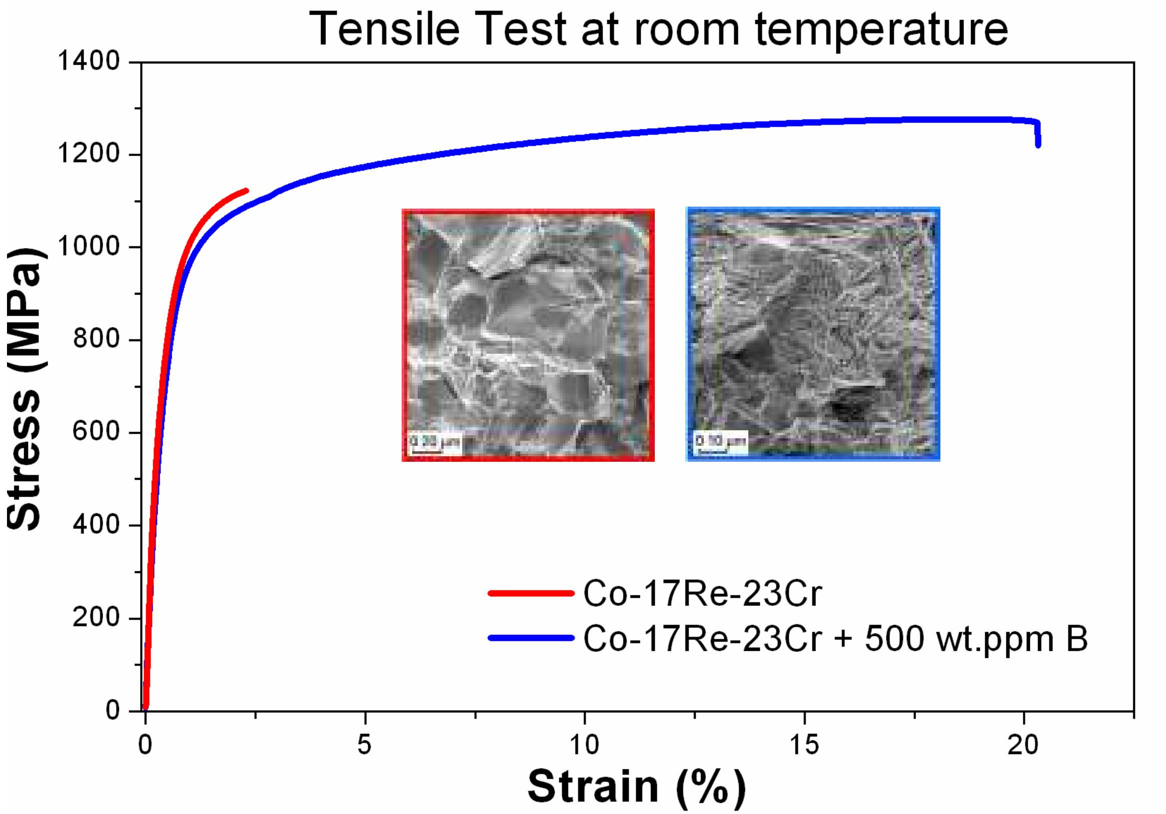


> 20% Cr addition stabilizes σ phase (Cr_2Re_3)



- fine dispersion of σ phase in alloys can be achieved
- can provide effective strengthening with high ductility

Design considerations : grain boundaries in polycrystalline alloys



Boron addition mitigates environment embrittlement and improves ductility

Polycrystalline Co-Re-Cr alloy is stronger than SX Ni-superalloys

Alloy	Density (ρ) g / cc	UTS (σ) MPa	Specific Strength (σ / ρ)	Ductility (ε) %
Co-17Re-23Cr + 500B	11.5	1276	110.9	20.3
CMSX4	8.7	894	102.7	22

Co-Re-based alloys: for high temperature gas turbine applications

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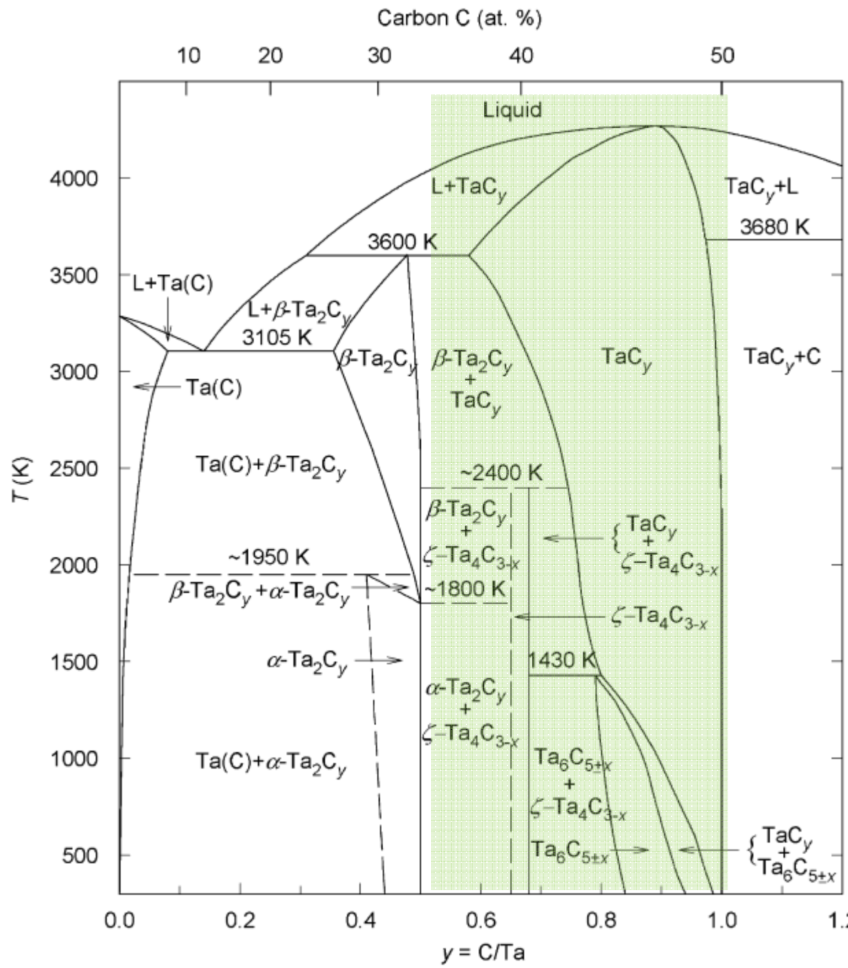
  - alloy development concept
- **Microstructural stability**
  - Co-matrix transformation: $\varepsilon \leftrightarrows \gamma$
  - TaC precipitates
- **Creep properties**
- **Outlook**

Microstructural stability:

- In order to study TaC precipitates Co-Re-Ta-C alloys investigated [C/Ta – 0.5y to 1.0y]
- This ensured no σ phase and Cr-carbides in the alloy
- Study – TaC morphology and stability and Co matrix transformation
- Binary TaC is stable to very high temperatures but in Co-Re system its stability not investigated
- Binary TaC is not a stoichiometric compound and exists in wide composition range
- Other Ta-carbides can be also stable in this composition range



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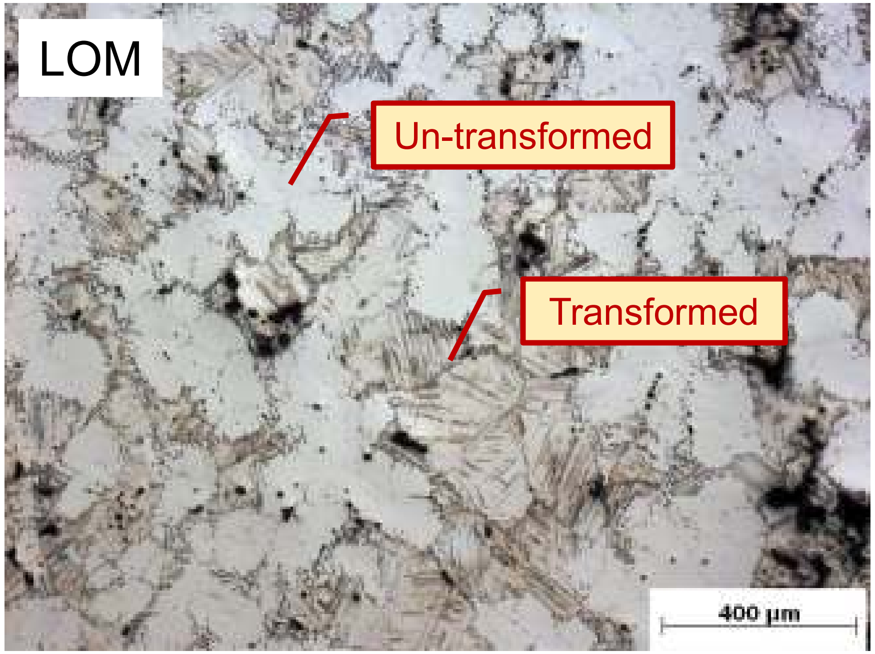
Co matrix transformation: ε (hcp) ⇆ γ (fcc)



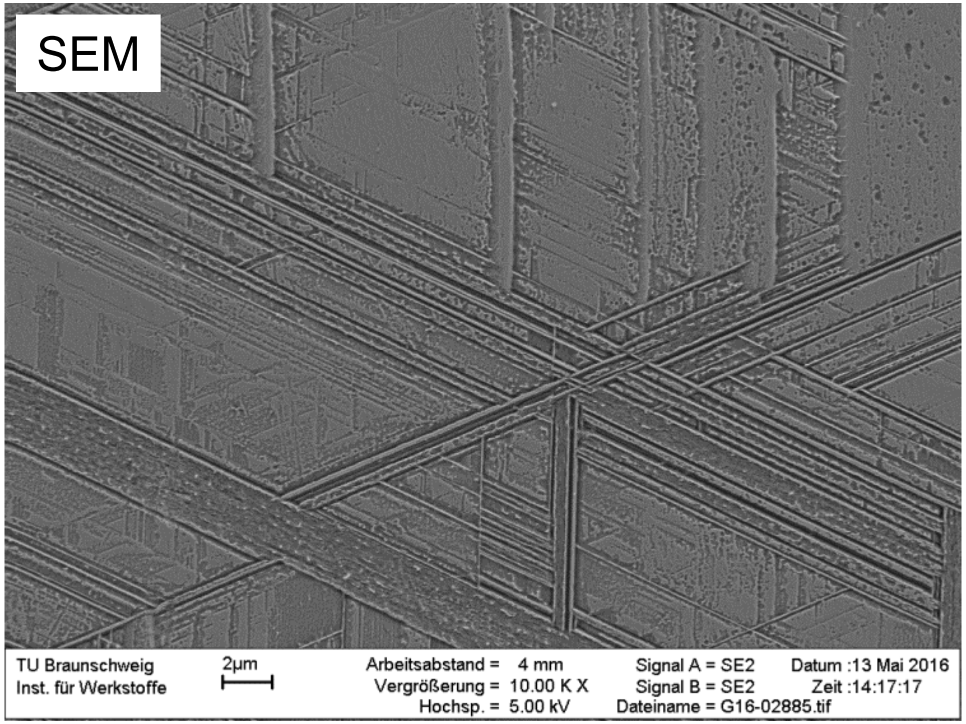
Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C

Lower C/Ta ratio in the alloy
higher Transformed region

Transformation:

On heating – Co (hcp) → SF + MT → Co (fcc)

On cooling – Co (fcc) → SF + MT → Co (hcp)

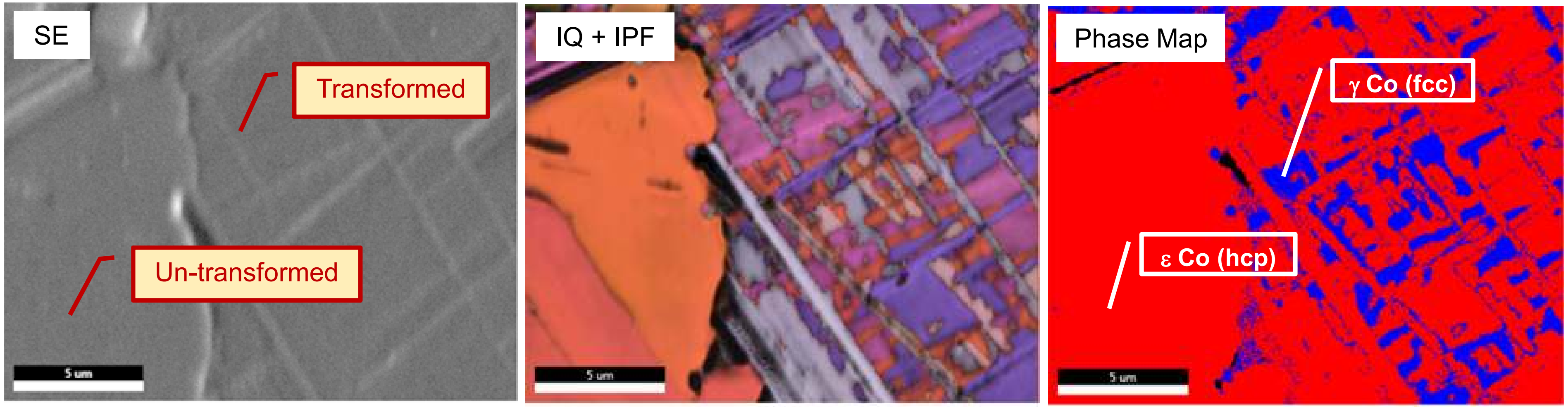


Co-17Re-1.2Ta-0.6C (0.5y) alloy ST + 1100°C

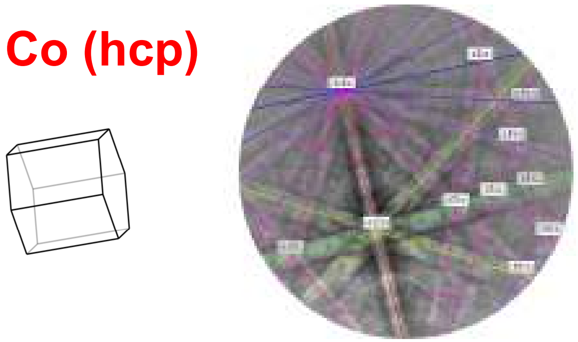
Co matrix transformation: ε (hcp) ⇆ γ (fcc)

EBSD

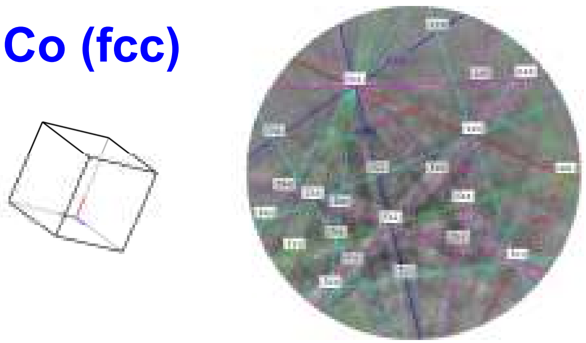
Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C



ε Co (hcp)



γ Co (fcc)

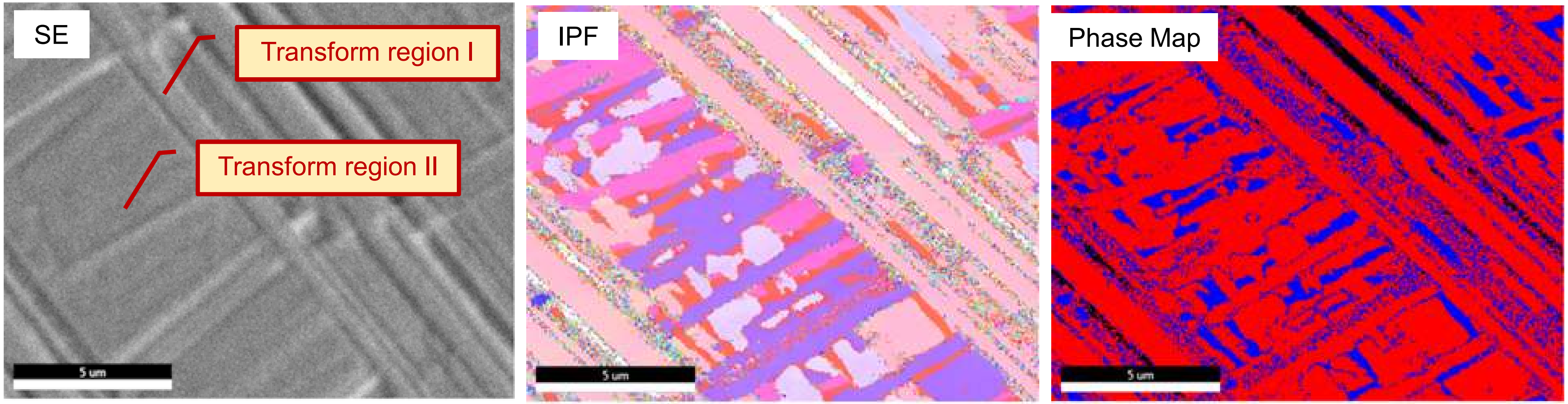


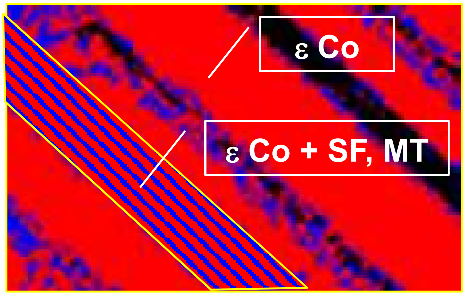
Transformed region is a mixture of ε + γ phases

Co matrix transformation: ε (hcp) ⇆ γ (fcc)

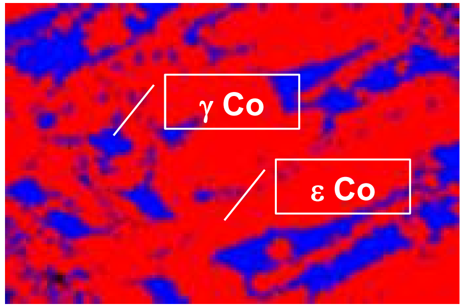
EBSD

Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C





Transformation Region I
(ε Co + SF and MT)

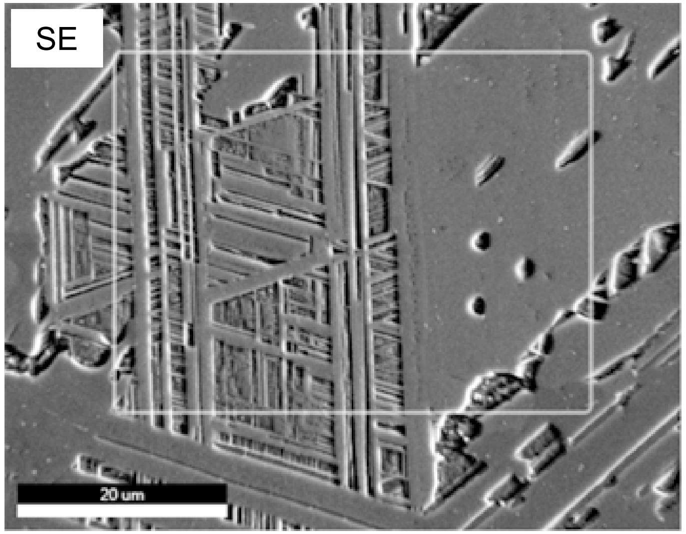


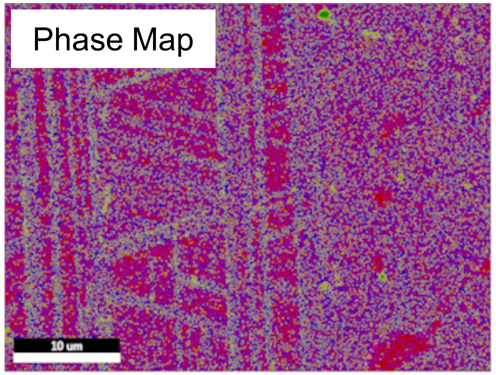
Transformation Region II
(ε Co + γ Co)

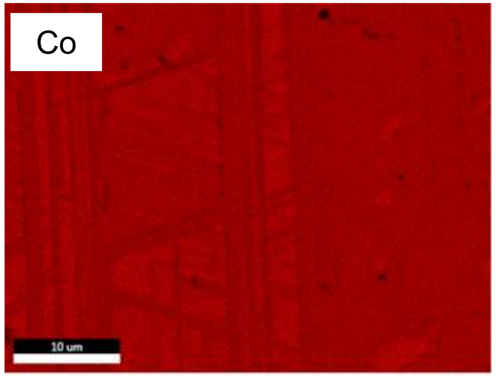
Transformation occurs through SF and MT formation

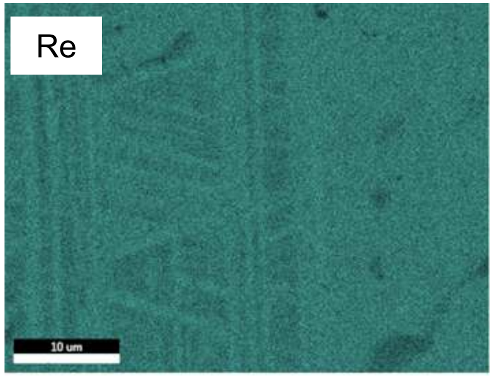
Co matrix transformation: ε (hcp) ⇆ γ (fcc)

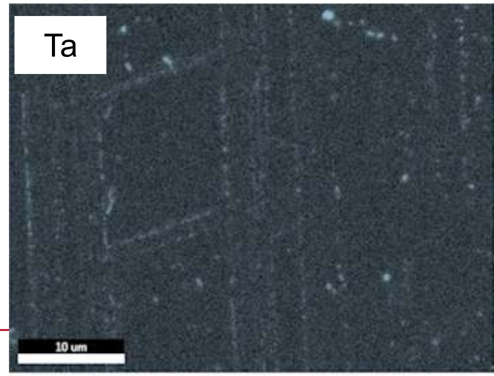
EDS











Co-17Re-1.2Ta-0.8C (0.7y) alloy ST + 1000°C

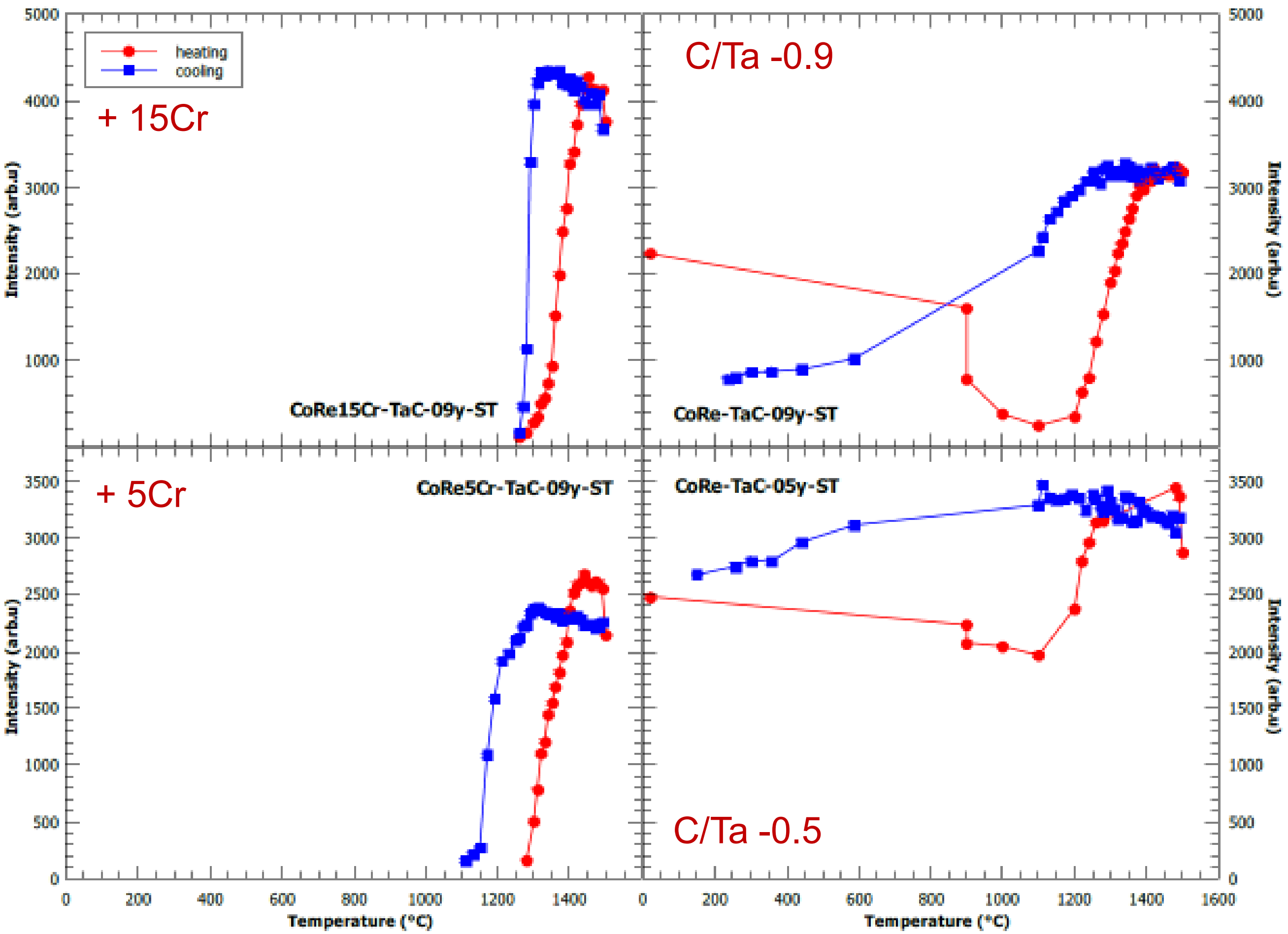
Transformed regions are rich in **Co** and
Un-transformed regions rich in **Re**

Co matrix transformation: ε (hcp) ⇆ γ (fcc)

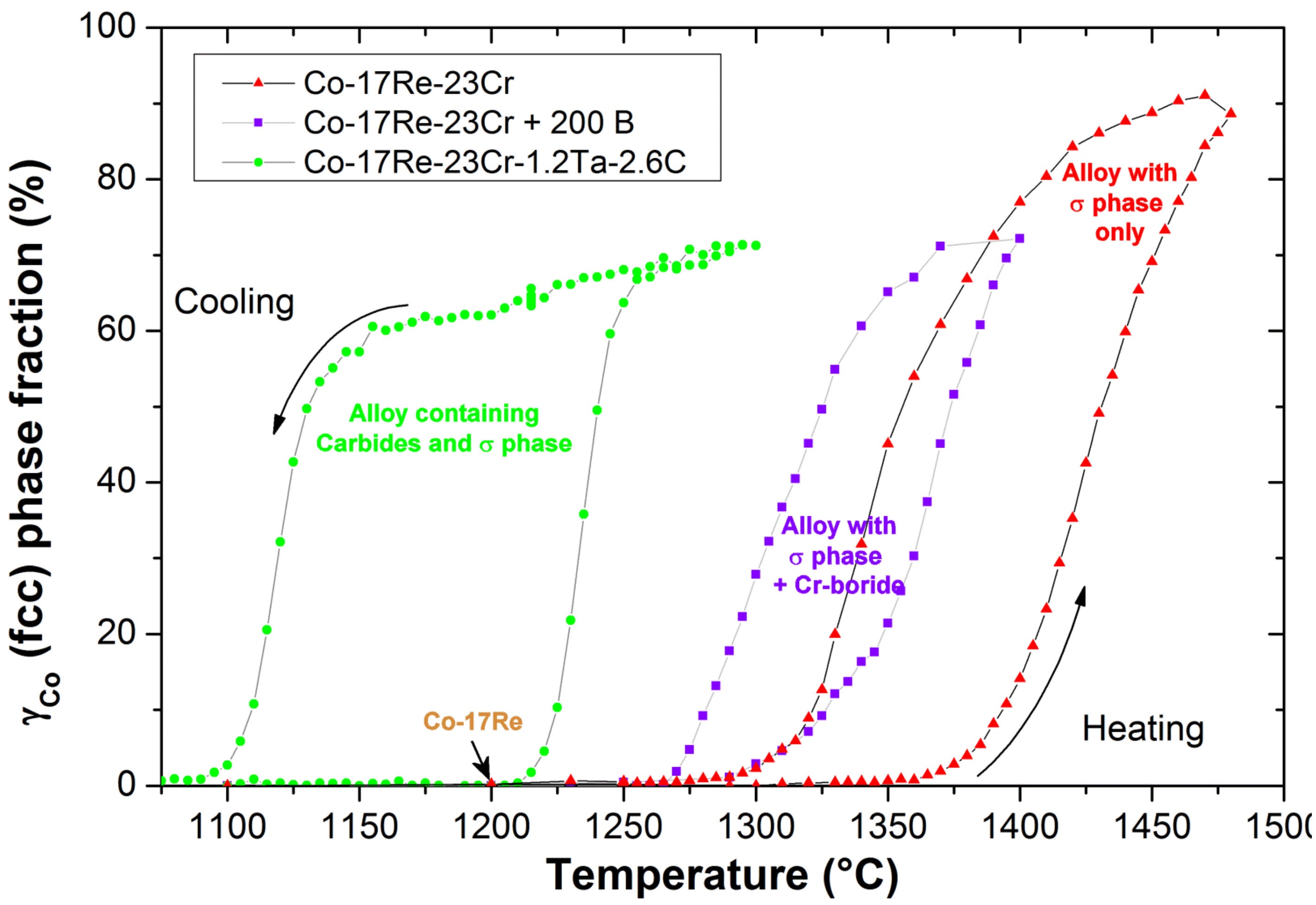
In-situ neutron diffraction

- γ Co (200) peak evolution during heating and cooling
- Left side alloys with Cr and right side alloys without Cr
- γ Co retained to RT in alloys without Cr
- Metastable γ Co transform to stable ε Co on heating (see hold at 900°C)
- Allotropic ε ⇆ γ Co transformation occurs above 1100°C.

γ Co (200) peak



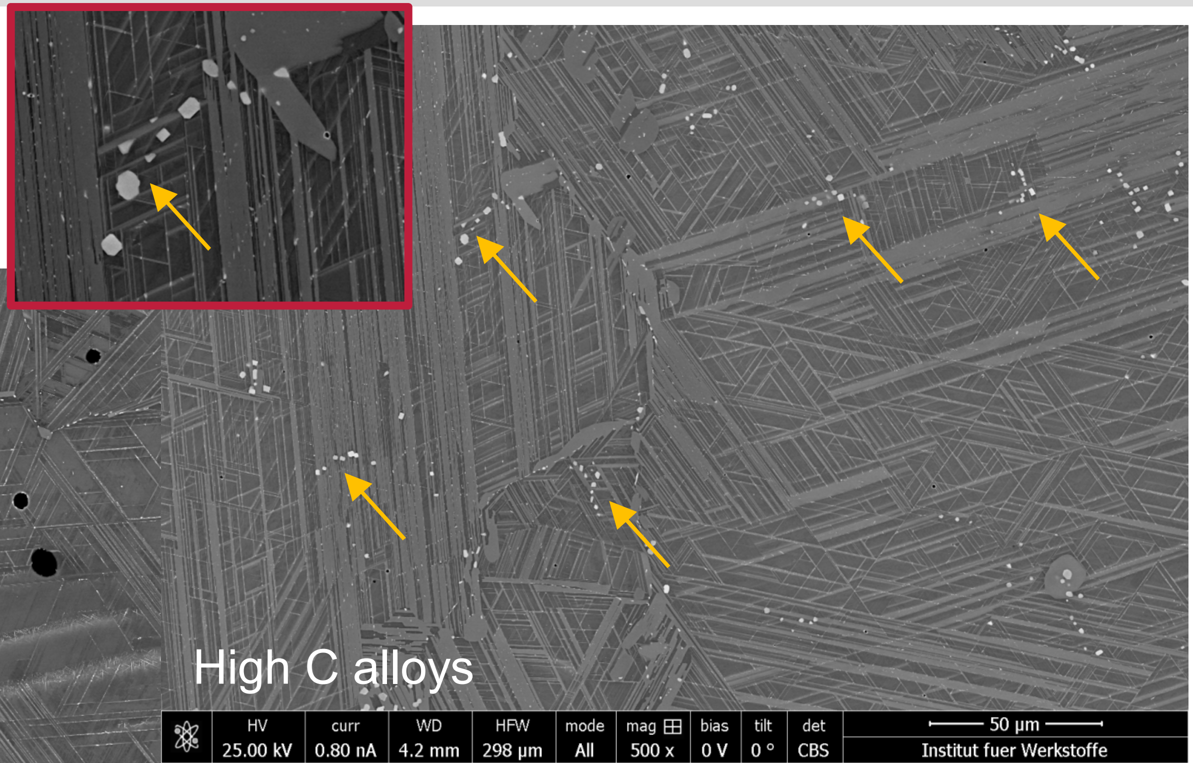
Co matrix transformation: ε (hcp) ⇆ γ (fcc)



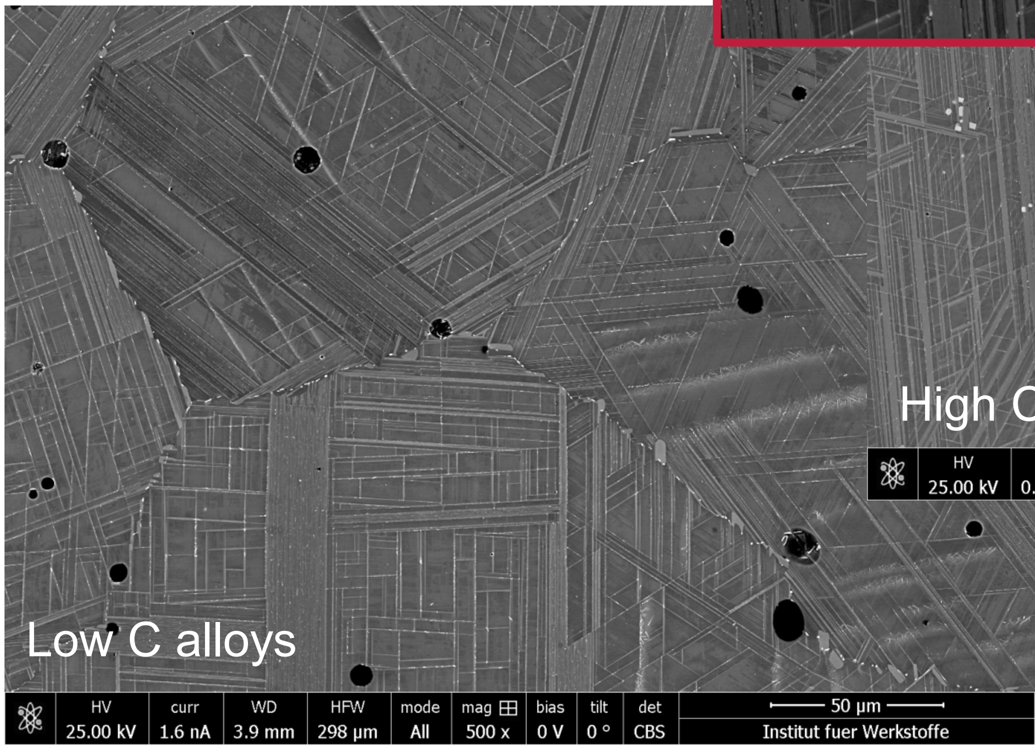
- Co has allotropic transformation from ε (hcp) to γ (fcc) phase
- In pure Co it is at 417°C
- The transformation is composition dependent
- In Co-Re alloys the transformation temperature is high > 1000°C

TaC precipitates: morphology and stability

Low C alloys:
100% Transformed Matrix



Co-17Re-1.2Ta-1.2C (1.0y) alloy ST + 1100°C

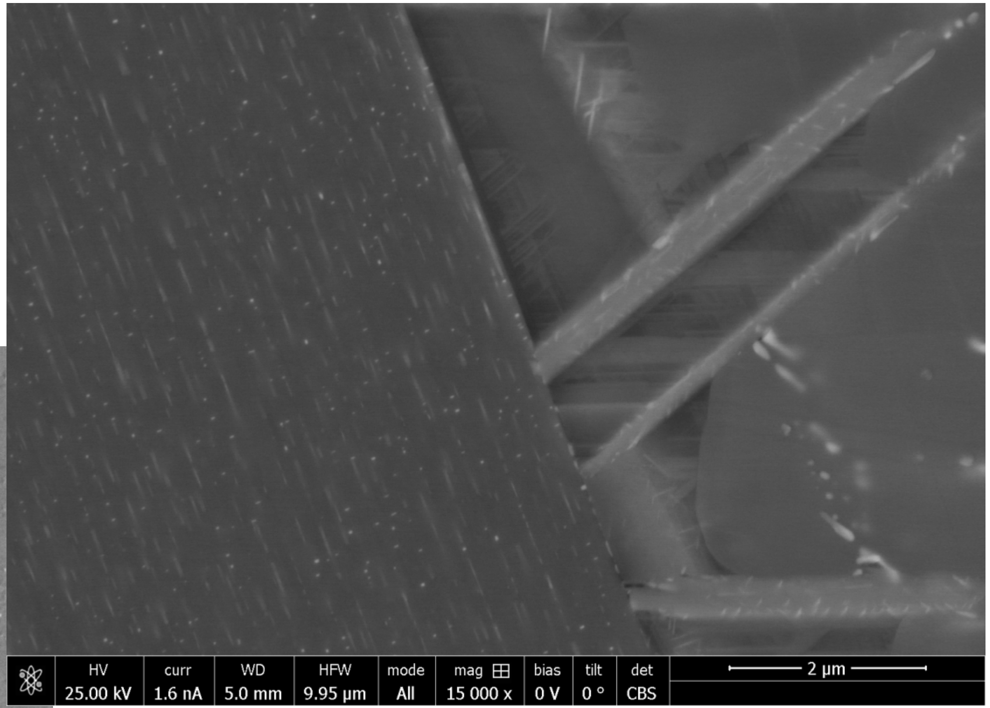


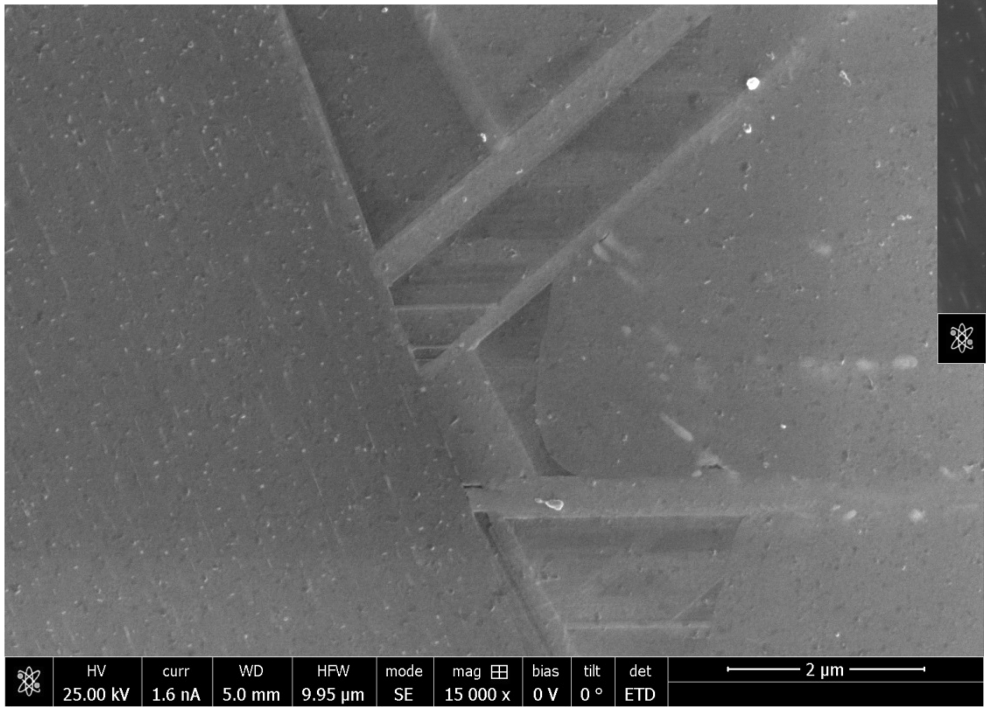
High C alloys:
Large Cuboidal TaC

Co-17Re-1.2Ta-0.6C (0.5y) alloy ST + 1100°C

TaC precipitates: morphology and stability

A wide variety of TaC precipitate morphology is possible





A very fine disperssion of TaC (less than 10 nm spherical particles)

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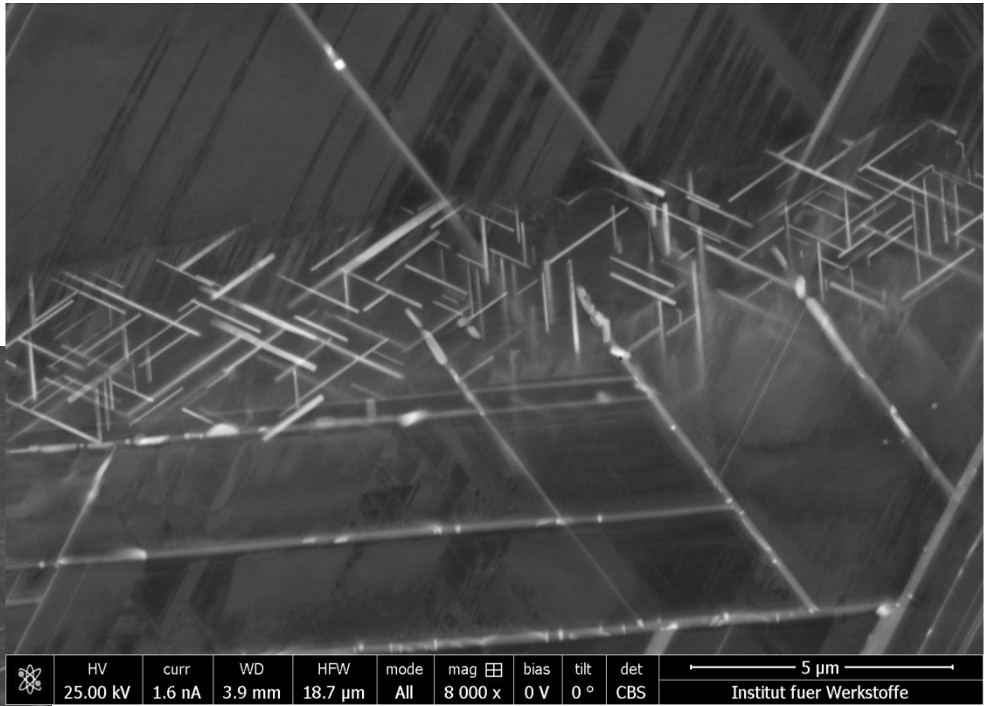
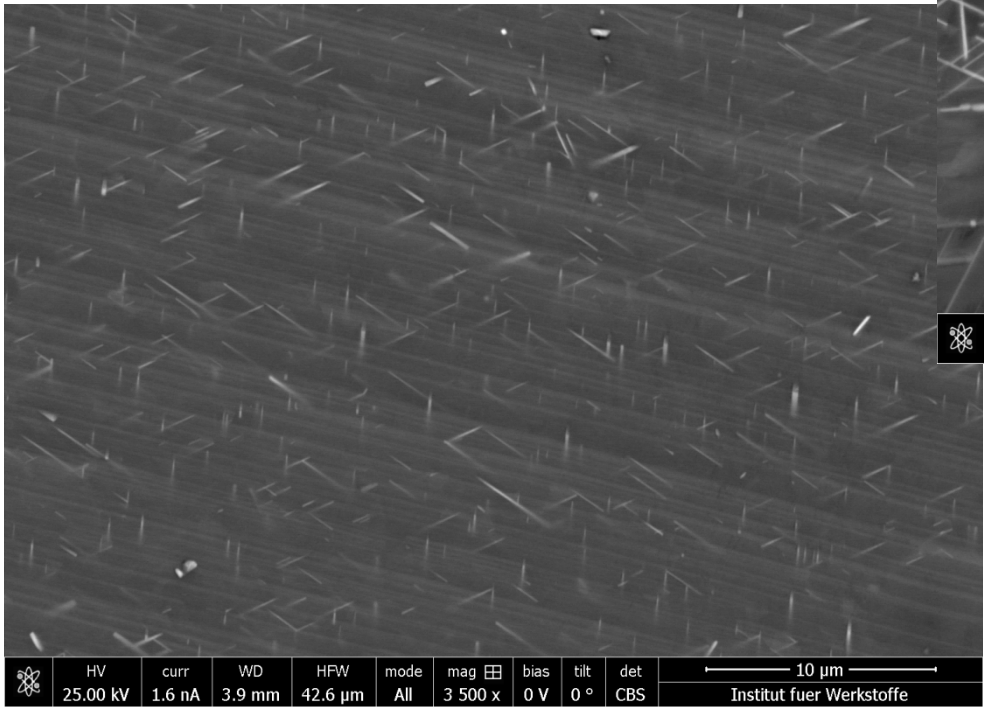
TaC precipitates: morphology and stability



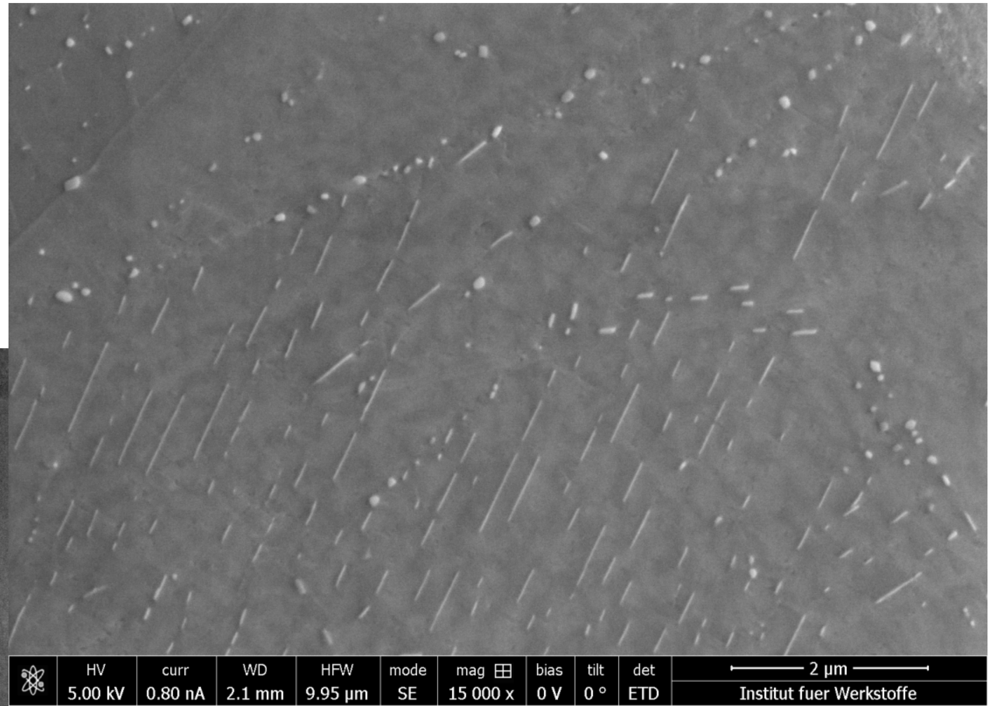
A wide variety of TaC precipitate morphology is possible

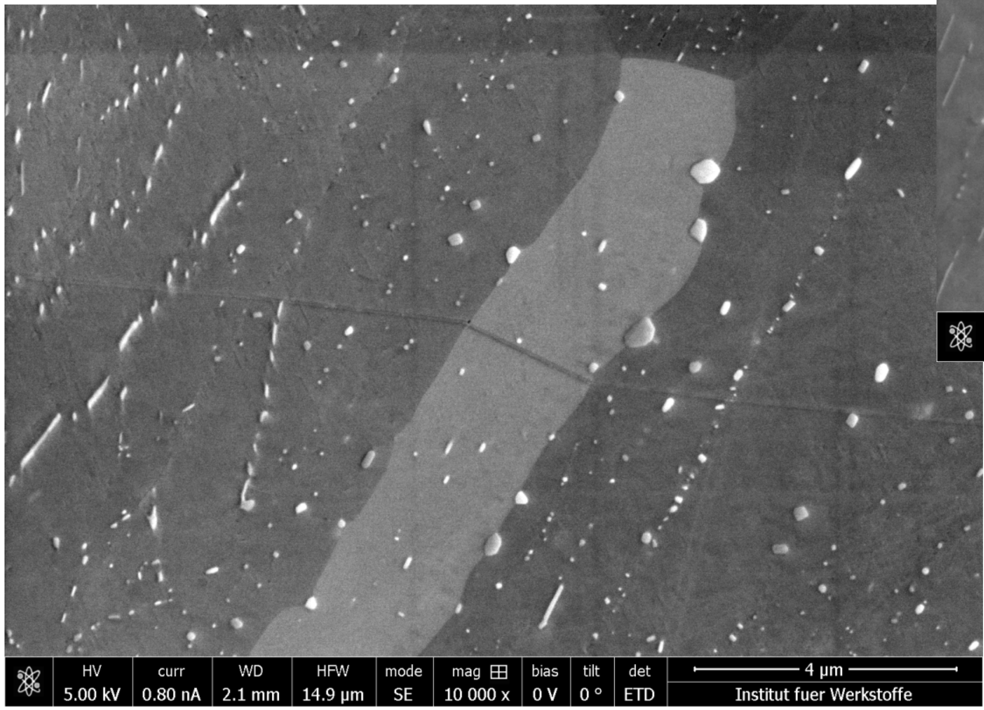


Short and long needle-like TaC precipitates

TaC precipitates: morphology and stability

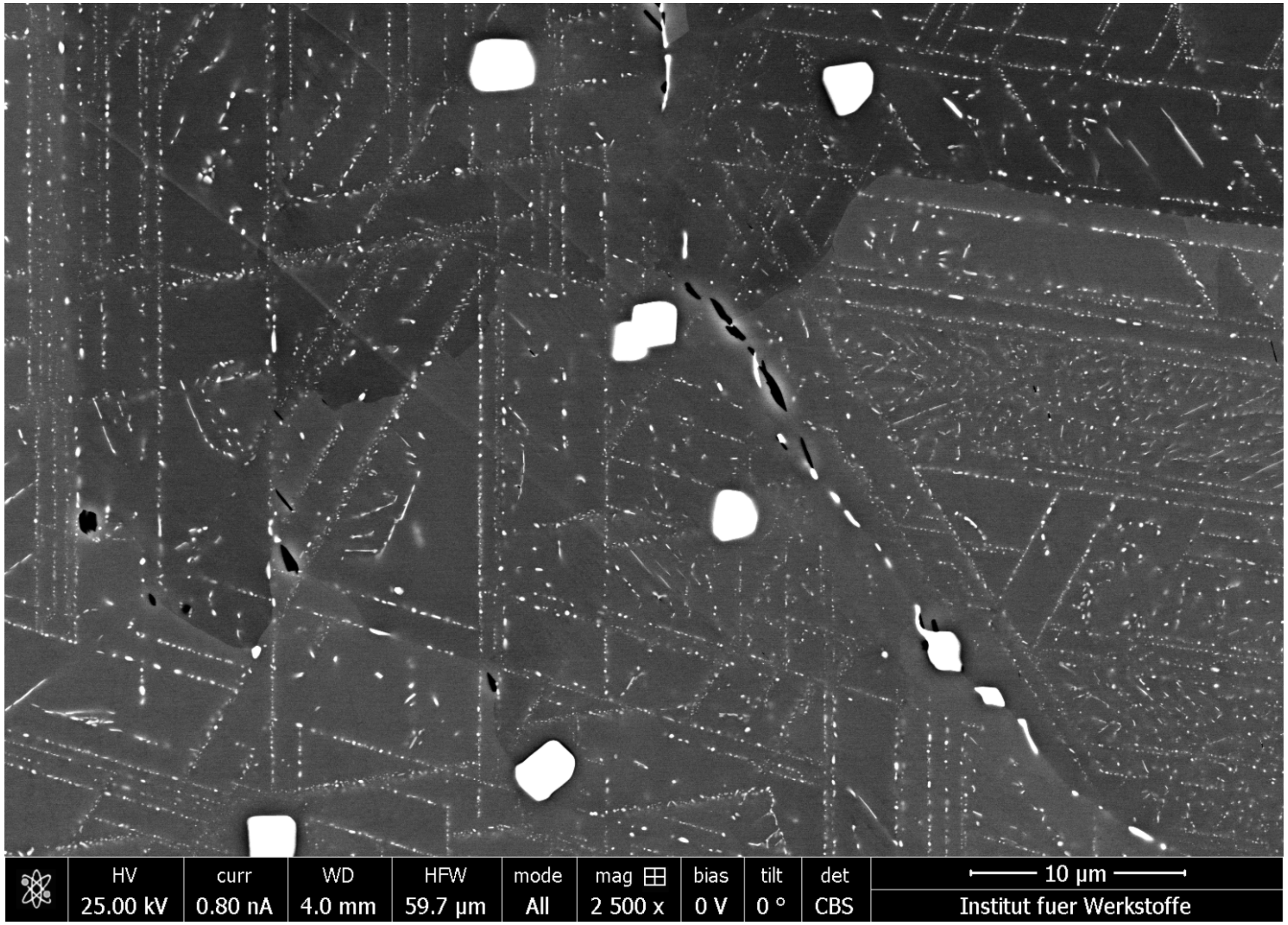
A wide variety of TaC precipitate morphology is possible





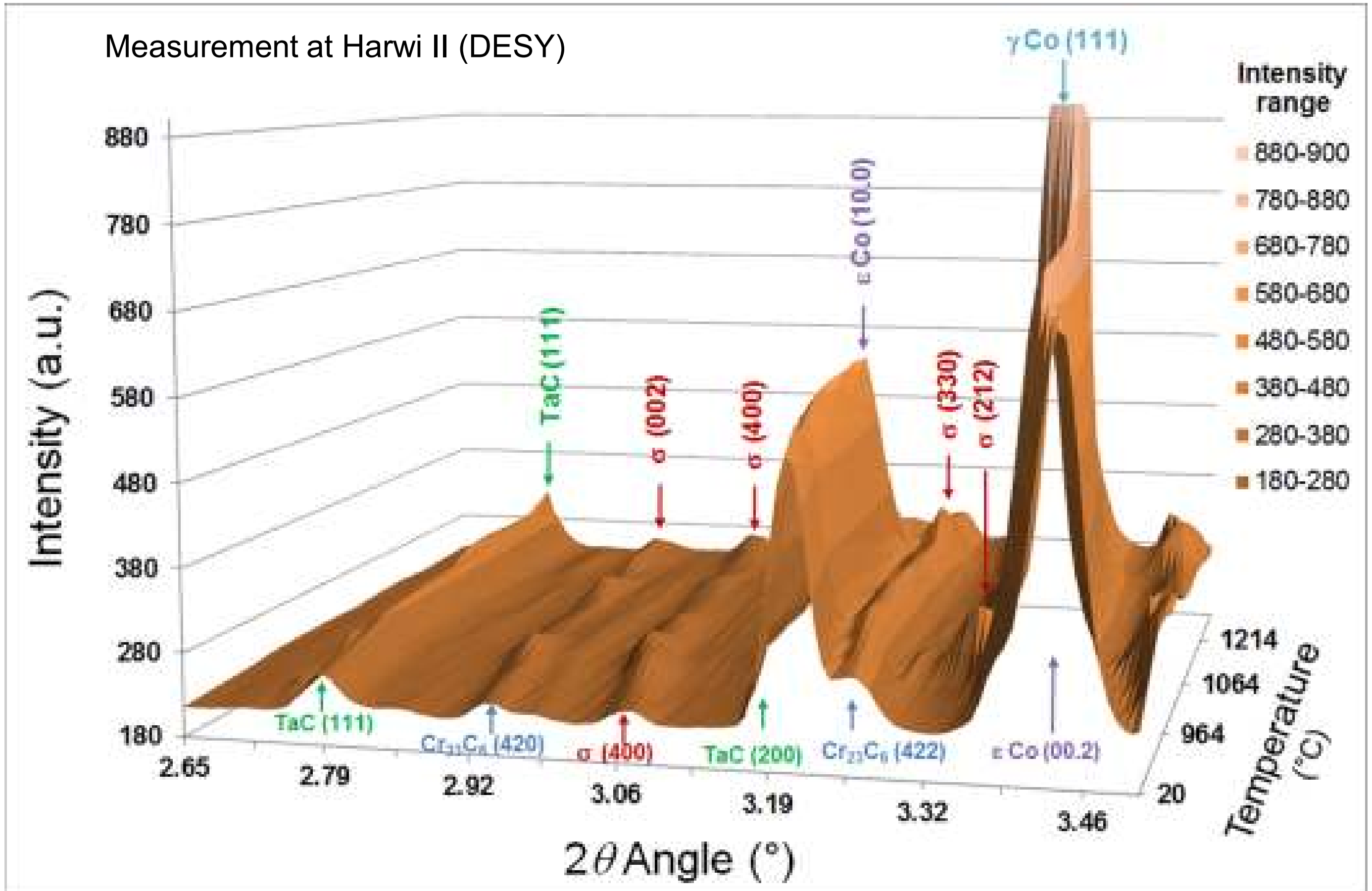
Relatively coarse and also lamellar TaC precipitates

TaC precipitates: morphology and stability



Co matrix transformation affects TaC precipitates

Some Recent Results: synchrotron measurements



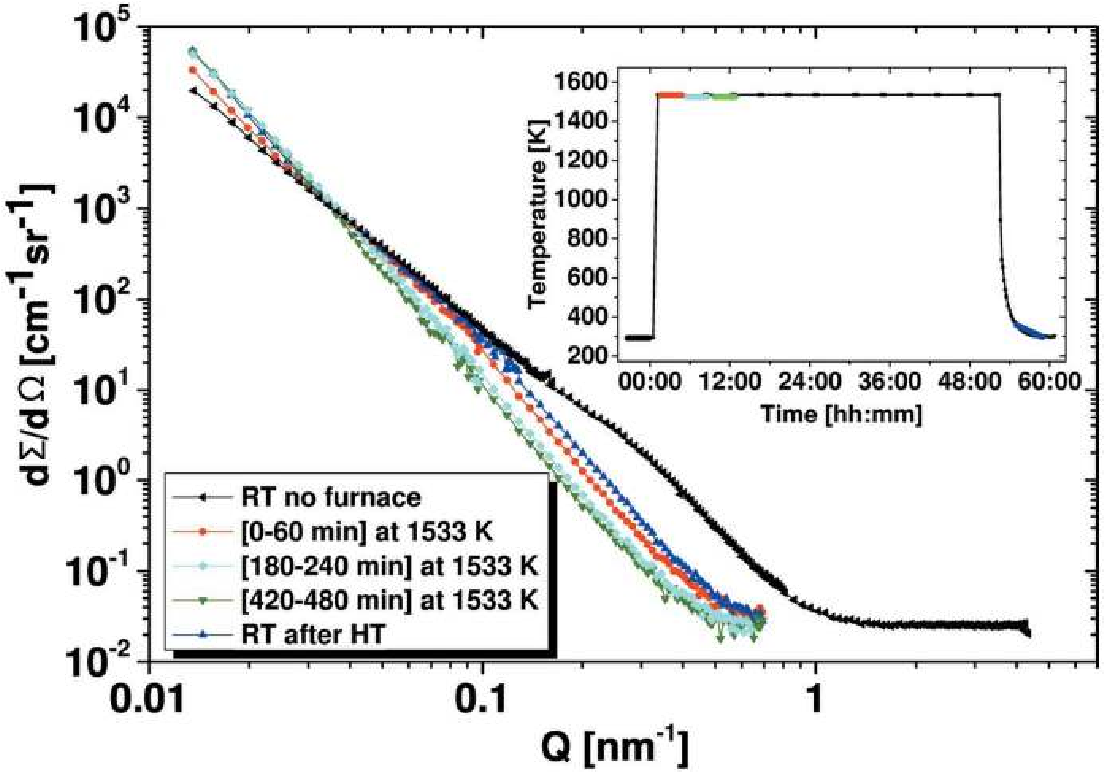
Long term microstructural stability during application in gas turbine is very important

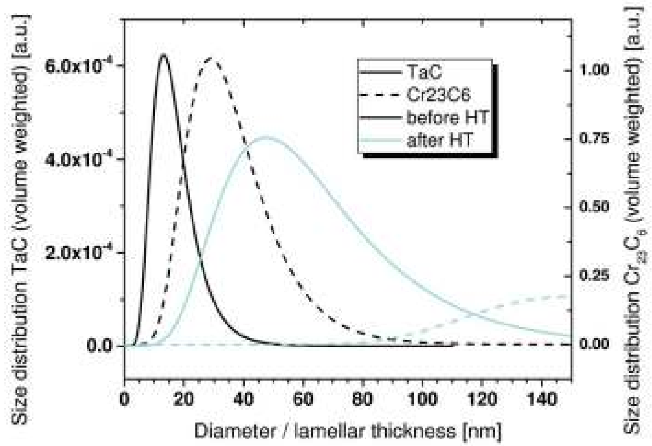
In-situ diffraction show TaC precipitates are stable upto 1200°C

R. Gilles, D. Mukherji et al, J App Cryst. (2016) 49 in print

Co-17Re-23Cr-1.2Ta-2.6C

Some Recent Results: neutron measurements





In-situ SANS show TaC precipitates remain fine (< 100 nm)

R. Gilles, D. Mukherji et al, J App Cryst. (2016) 49 in print

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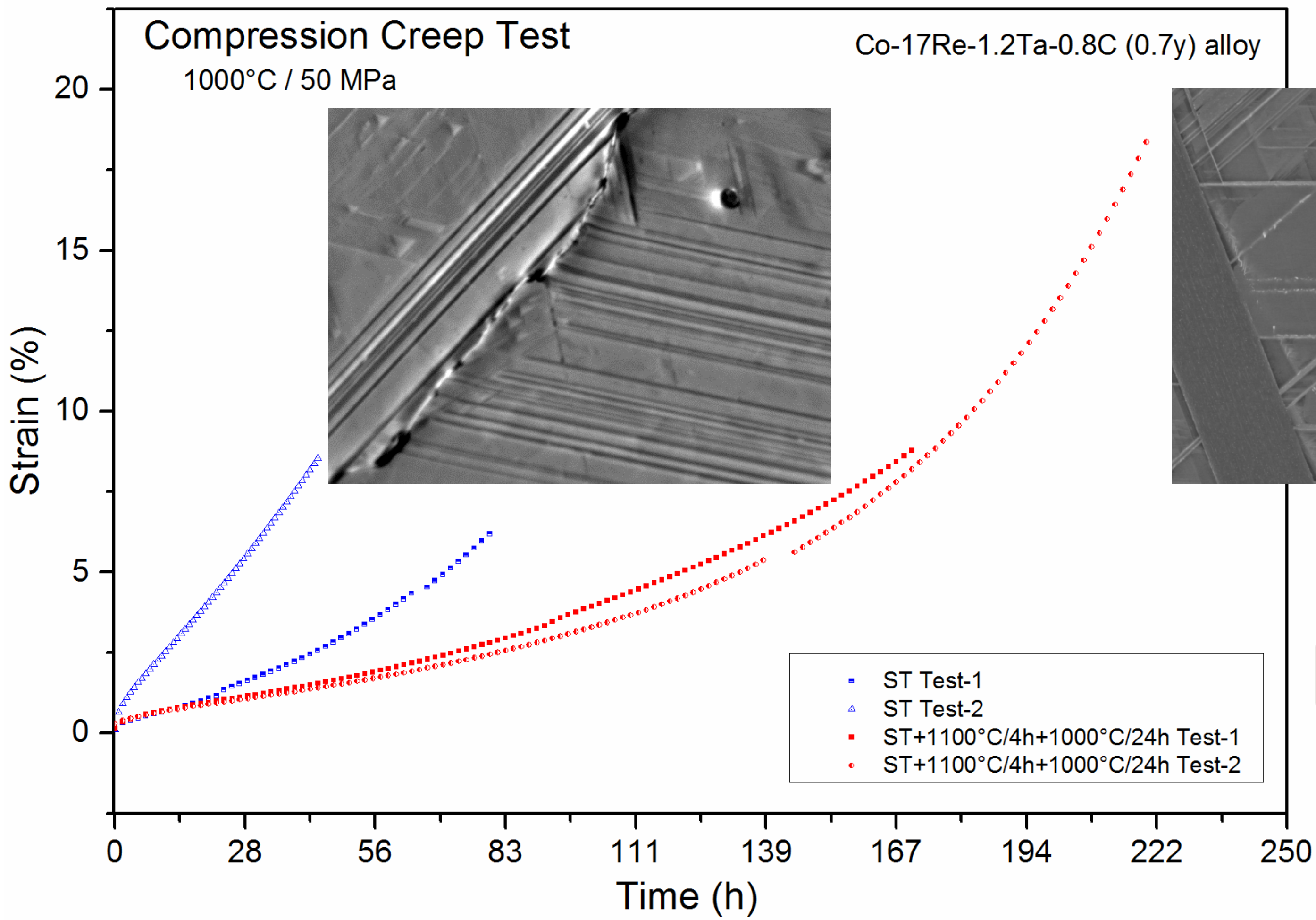
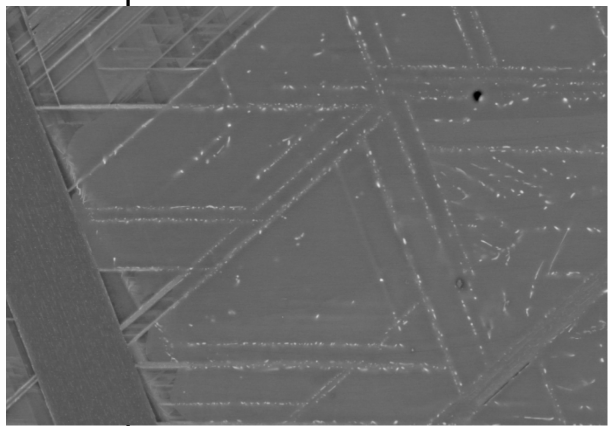
Creep Results: compression creep

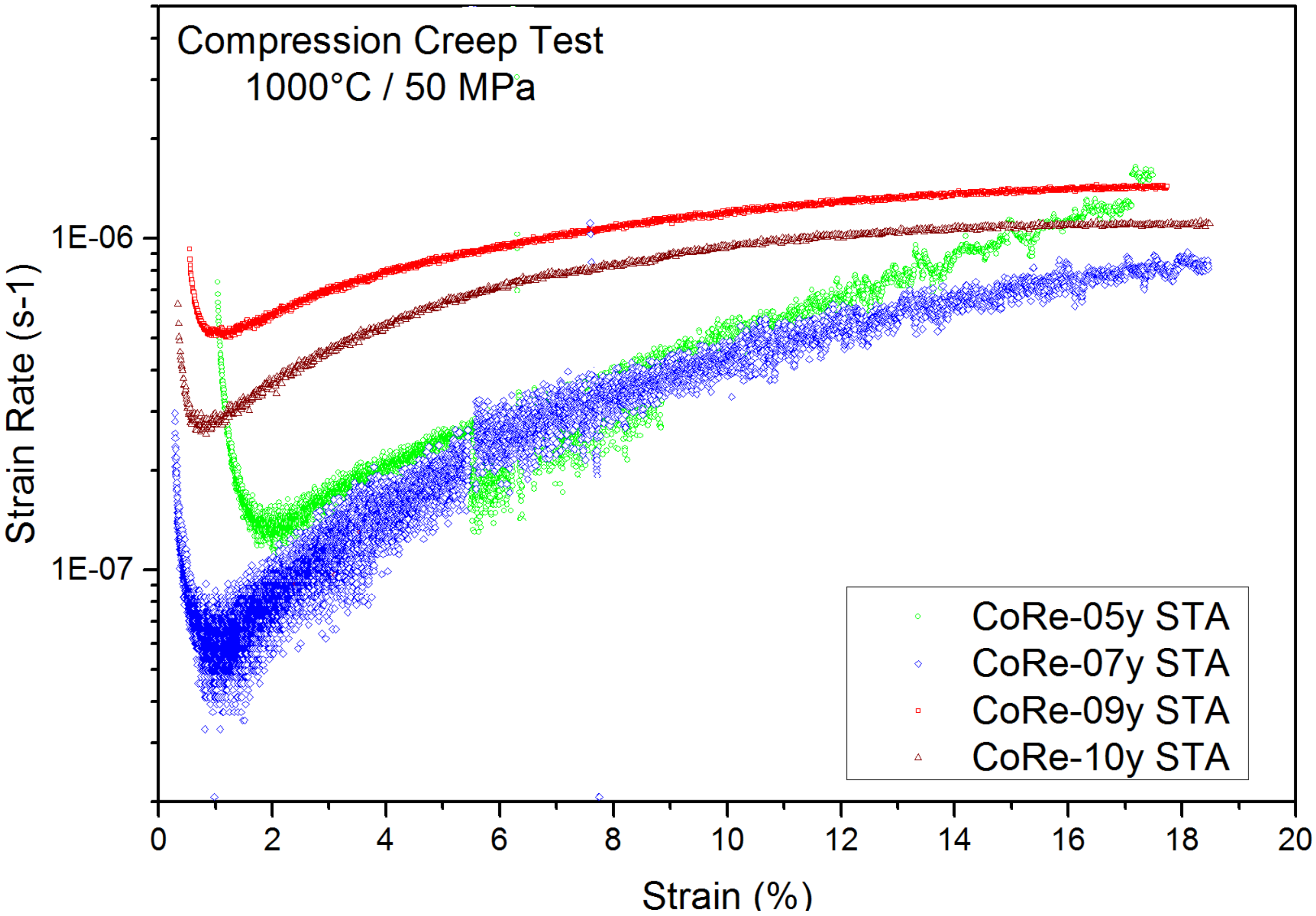
ST: - only few precipitates
STA: - fine precipitates





TaC precipitates provide creep strengthening

Creep Results: compression creep



- High C alloys had higher amounts of TaC phase
- Low C alloys had finer TaC precipitates

TaC precipitates morphology and size can be tailored through heat treatment

Summary & Outlook

- ❖ Co-Re alloys show great potential for development and in-situ measurements with synchrotron and neutron provide tools for understanding the alloy system
- ❖ TaC precipitates are effective in providing high temperature strengthening
- ❖ Co matrix transformation can be exploited in tailoring microstructure and precipitate dispersion, however, the transformation temperature should be pushed to temperature higher than the envisaged application

Outlook:

1. Directional solidification and single crystal growth studies are essential for blade application: *initial studies indicate there are significant challenges posed by the Co-matrix allotropic transformation.*
2. Oxidation resistance of Co-Re alloys must be improved to higher temperature: *investigation jointly with Universität Siegen is in progress.*

Acknowledgements

I would like to thank the following persons for their support and contribution to Co-Re alloy development -

Prof. Rösler (TU Braunschweig)

Dr Strunz, Dr Beran (NPI,Czech Republic),

Dr Gilles, Mr Karge, Dr Hofmann, Dr Hölzel (FRM II, Garching)

Dr Wanderka, Dr Schumacher (HZB, Berlin)

Dr Eckerlebe, Dr Stark, Dr Staron, Prof Pyczak (HZG Geesthacht)

Prof Heilmaier (Uni Magdeburg, KIT – Karlsruhe)

Dr Depka, Dr Somsen, Prof Eggeler (Rühr Universität Bochum)

Dr Hüttner, Dr Brunner, Dr Völkl, Prof Glatzel (Uni Bayreuth)

Dr Gorr, Ms Hennes, Dr Wang, Prof Christ (Uni Siegen)

Prof Krüger, (Uni Magdeburg)

also thanks to DFG for financial support

and MLZ, HZG, HZB, NPI, BNC, PSI for beam time