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Mo-9Si-8B alloys with additons of Zr – microstructure and creep properties

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Werkstoffe Metallische

Mo-9Si-8B alloys with additions of Zr - microstructure and creep properties

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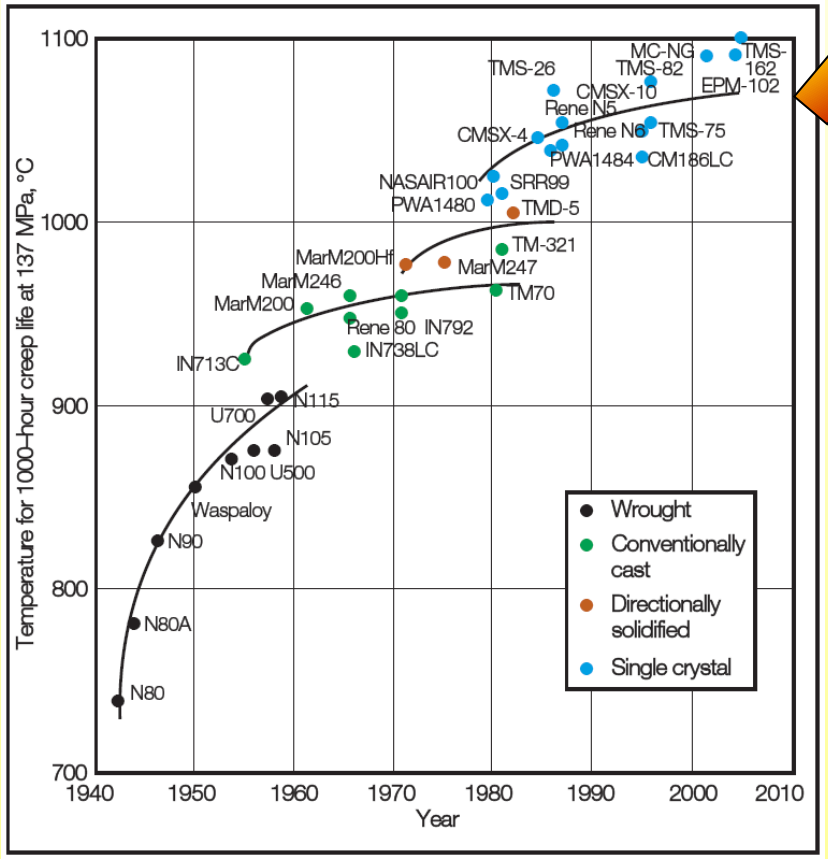
[2]Werkstoffkunde, KIT, Karlsruhe, Germany

Beyond Ni-Base Superalloys

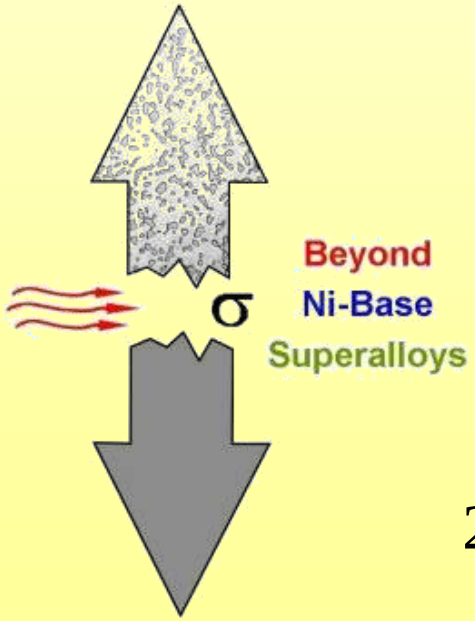
------ 1200°C in 2020



The Superalloys, R.C. Reed, Cambridge University Press

Requirements at 1200°C:

- good oxidation resistance
- good creep properties
- ductility at low temperatures



2007 - 2014

Beyond Ni-Base Superalloys

$T_m^{Ni} = 1455°C$

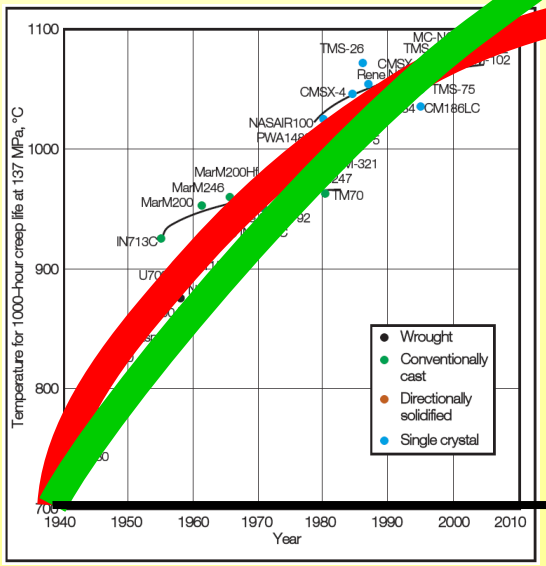
1400°C

$T_{eut.}^{\gamma/\gamma'} = 1385°C$

1300°C

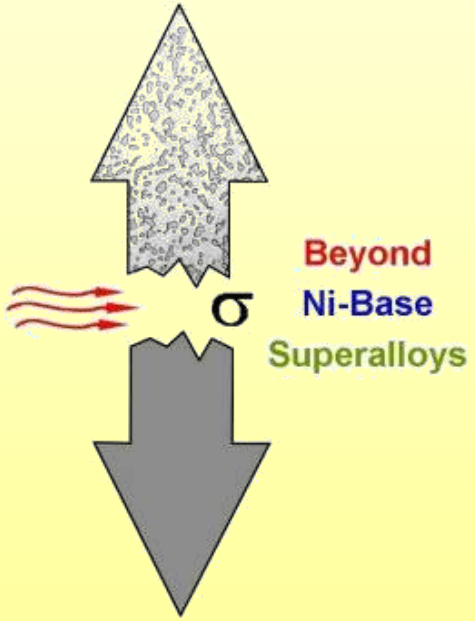
?

1200°C

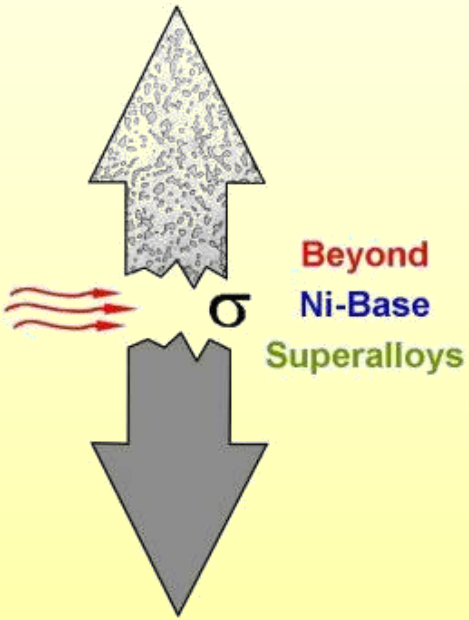


my retirement age

2030 2050 2070 2090



Beyond Ni-Base Superalloys Research Group 727



- **6 institutes** (Karlsruhe, Siegen, Braunschweig, Darmstadt, Bochum, Bayreuth)
- 2 alloy systems: **Mo-Si-B**, Co-Re-Cr

powder metallurgy (SPS)

(Karlsruhe, Heilmaier)

simulation

(Darmstadt, Albe)

oxidation

(Siegen, Christ)

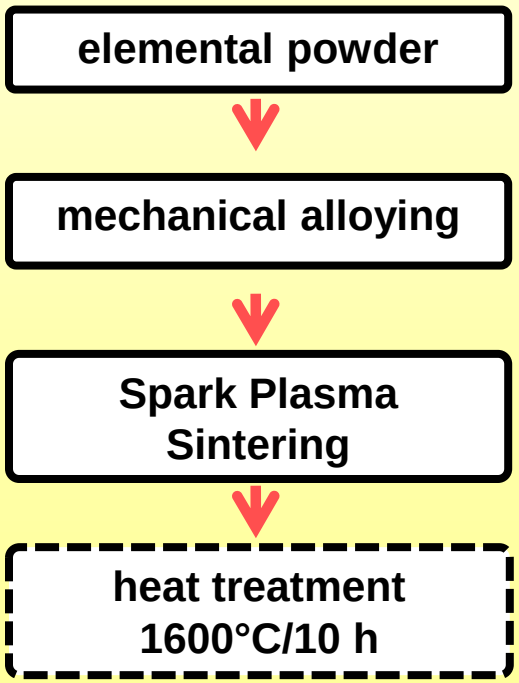
microstructure and creep properties

(Bayreuth, Glatzel)

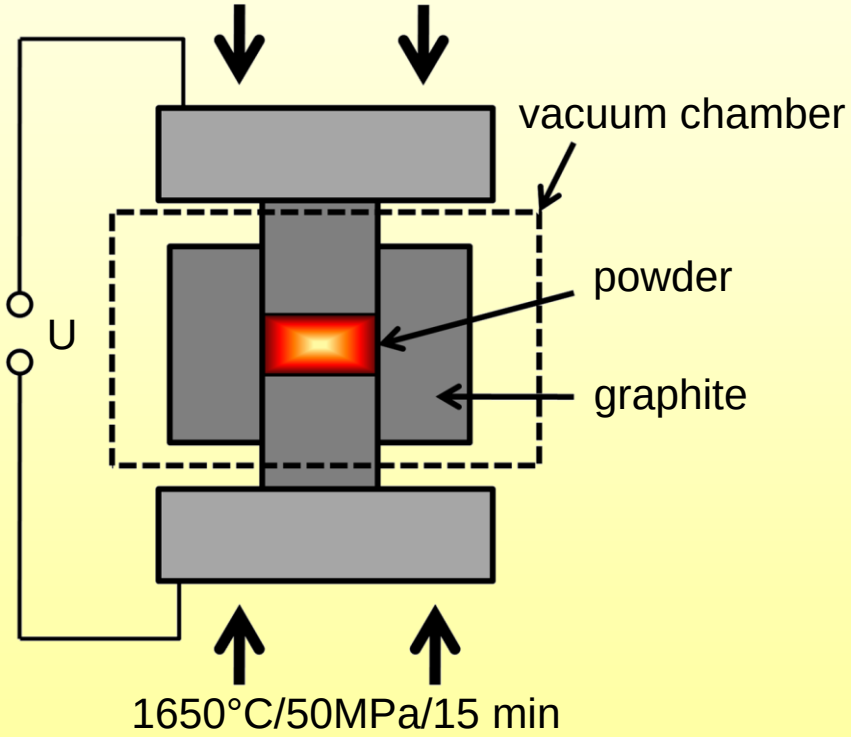
new DFG project since 1.5 years:
arc-melting, Ge and Al additions
see talk by Peter Kellner, Tue 11:10

Mo-Si-B Alloys
SPS Sample Production (KIT)

compositions (at. %):	
Mo-9Si-8B (**0Zr**)	Mo-9Si-8B-**2Zr**
Mo-9Si-8B-**1Zr**	Mo-9Si-8B-**4Zr**



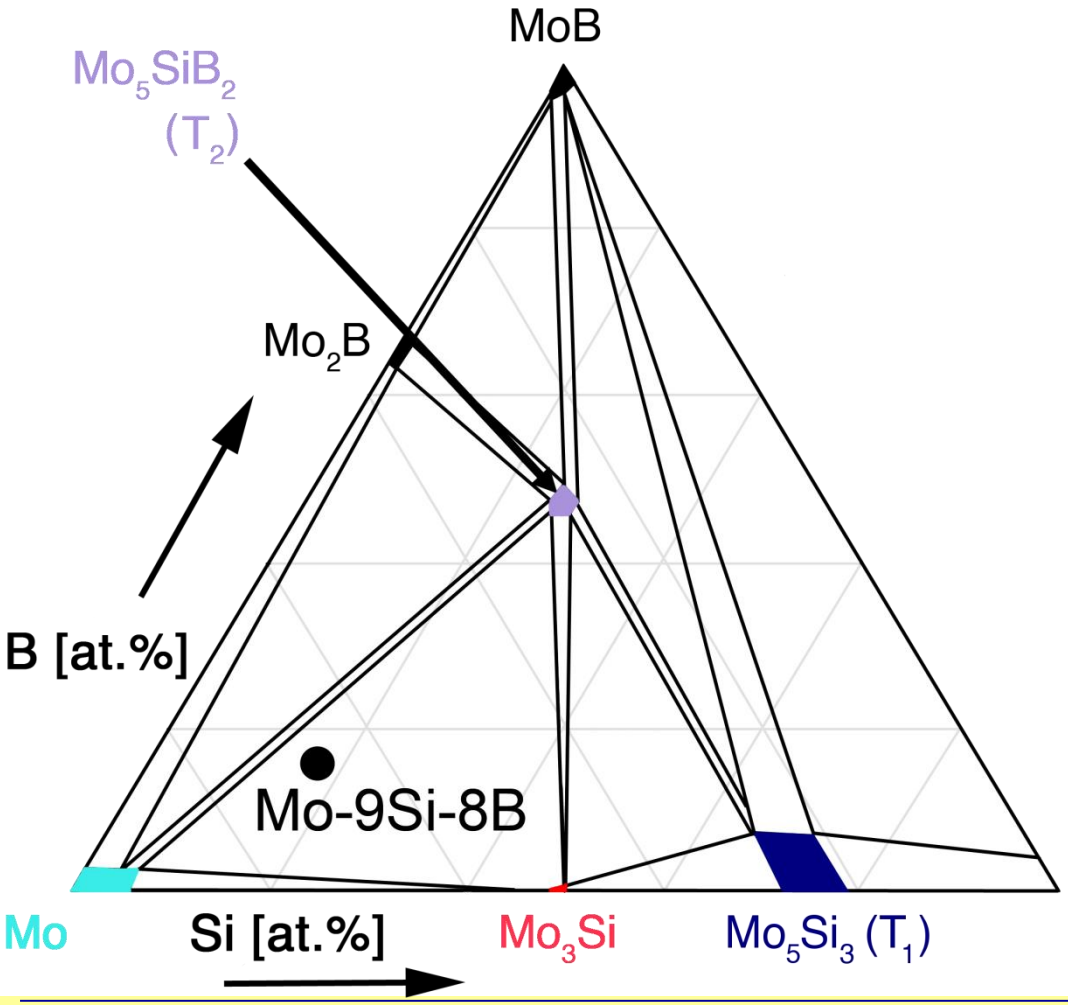
Spark Plasma Sintering (SPS):

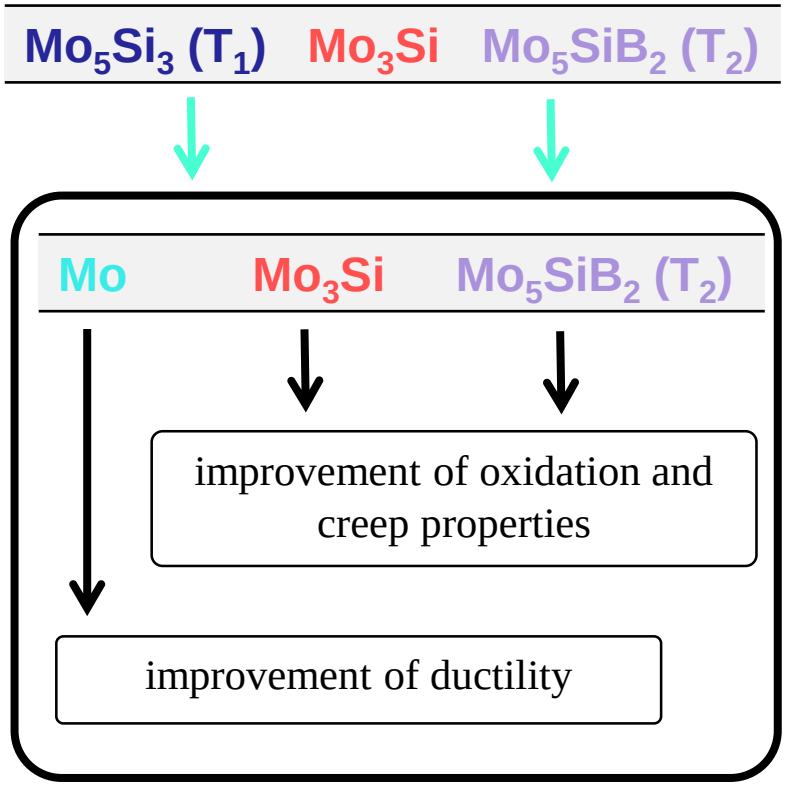


sample shape:

Mo-Si-B Alloys

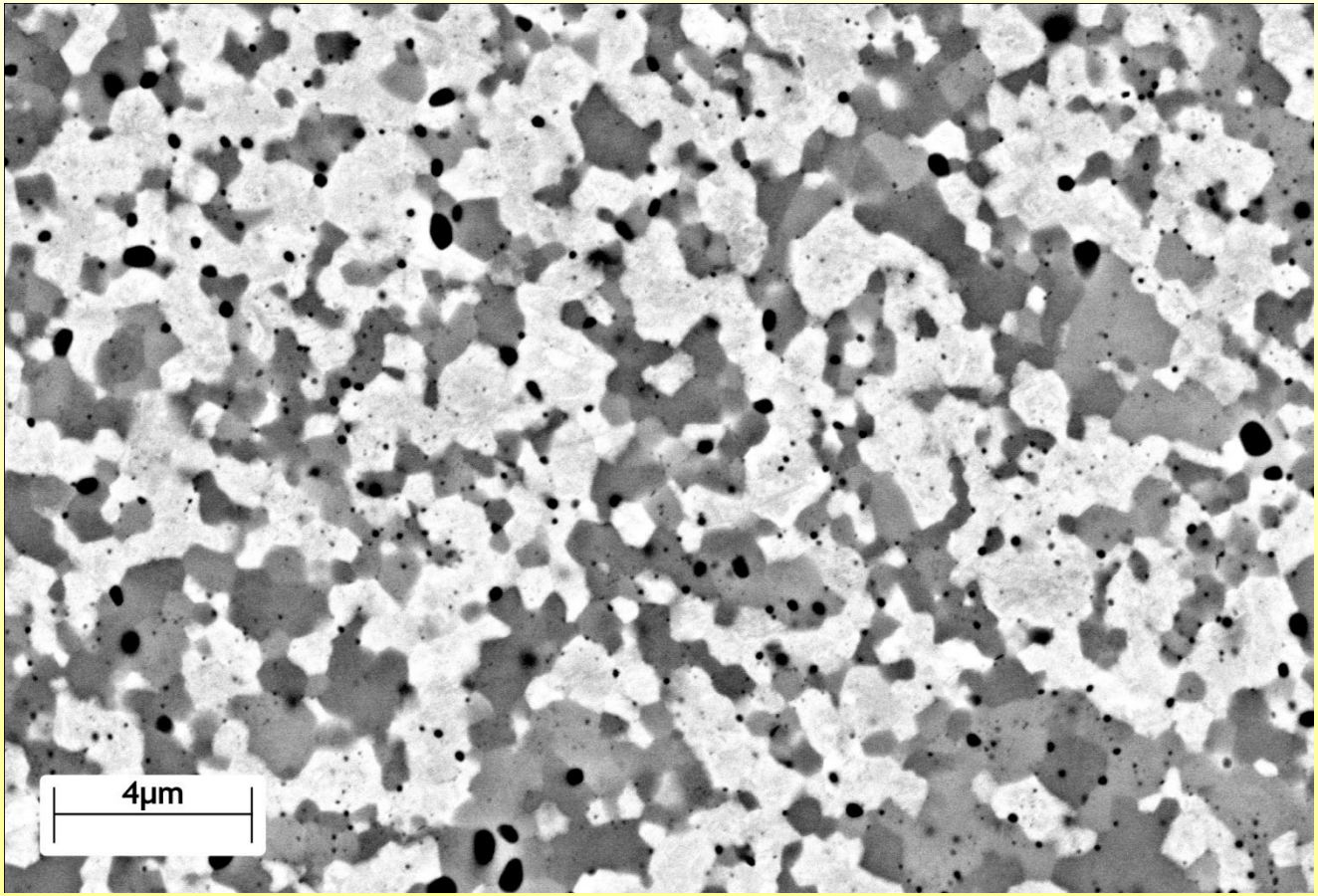
calculated phase diagram at 1600°C:





Microstructure

Mo - 9Si - 8B - 1Zr (at.%)

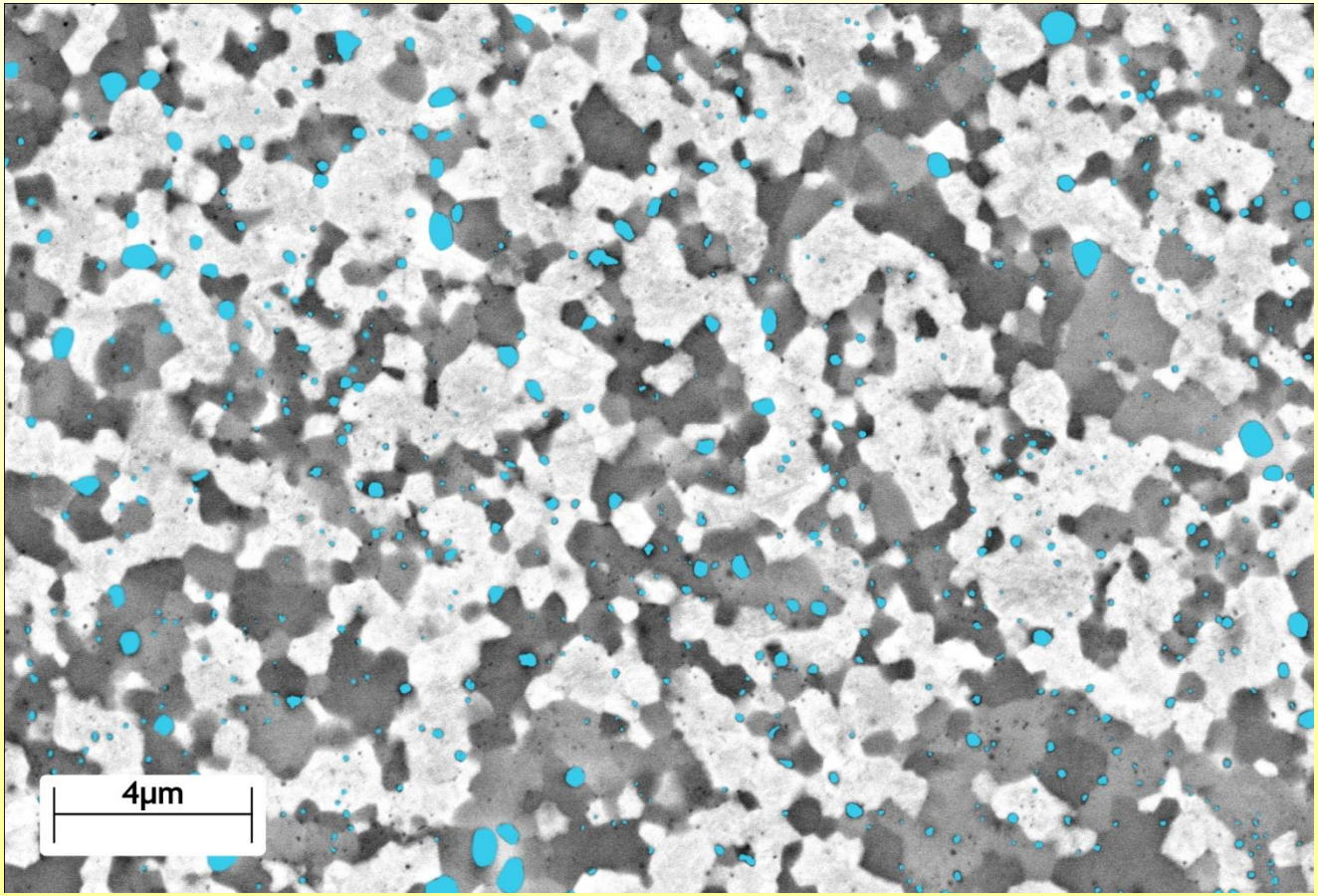


density:

MoSiBZr: 9.34 g/cm³
MoSiBTi: 9.32 g/cm³

Microstructure

Mo - 9Si - 8B - 1Zr (at.%)

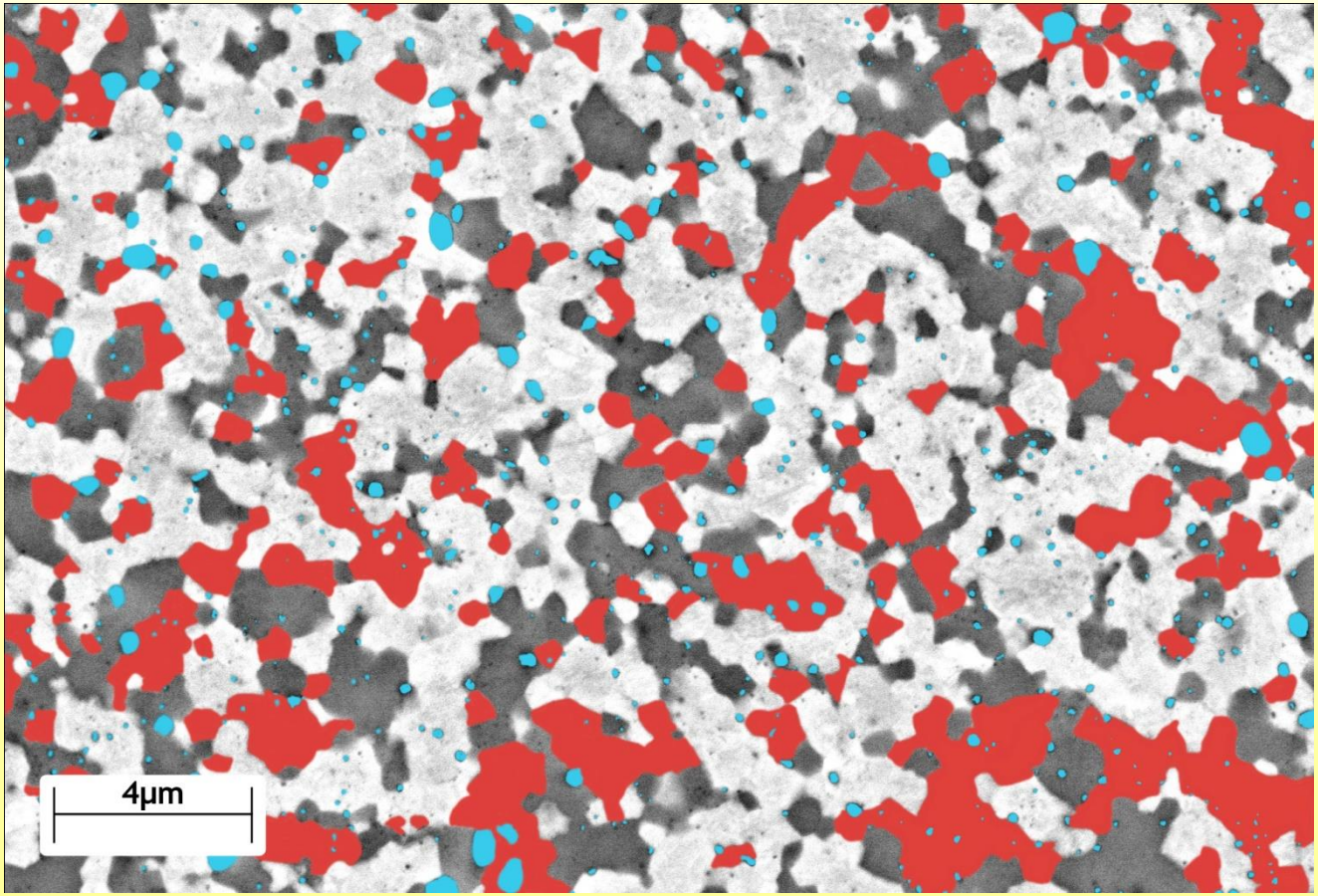


4 phases:

- Zr/Si-oxide

Microstructure

Mo - 9Si - 8B - 1Zr (at.%)

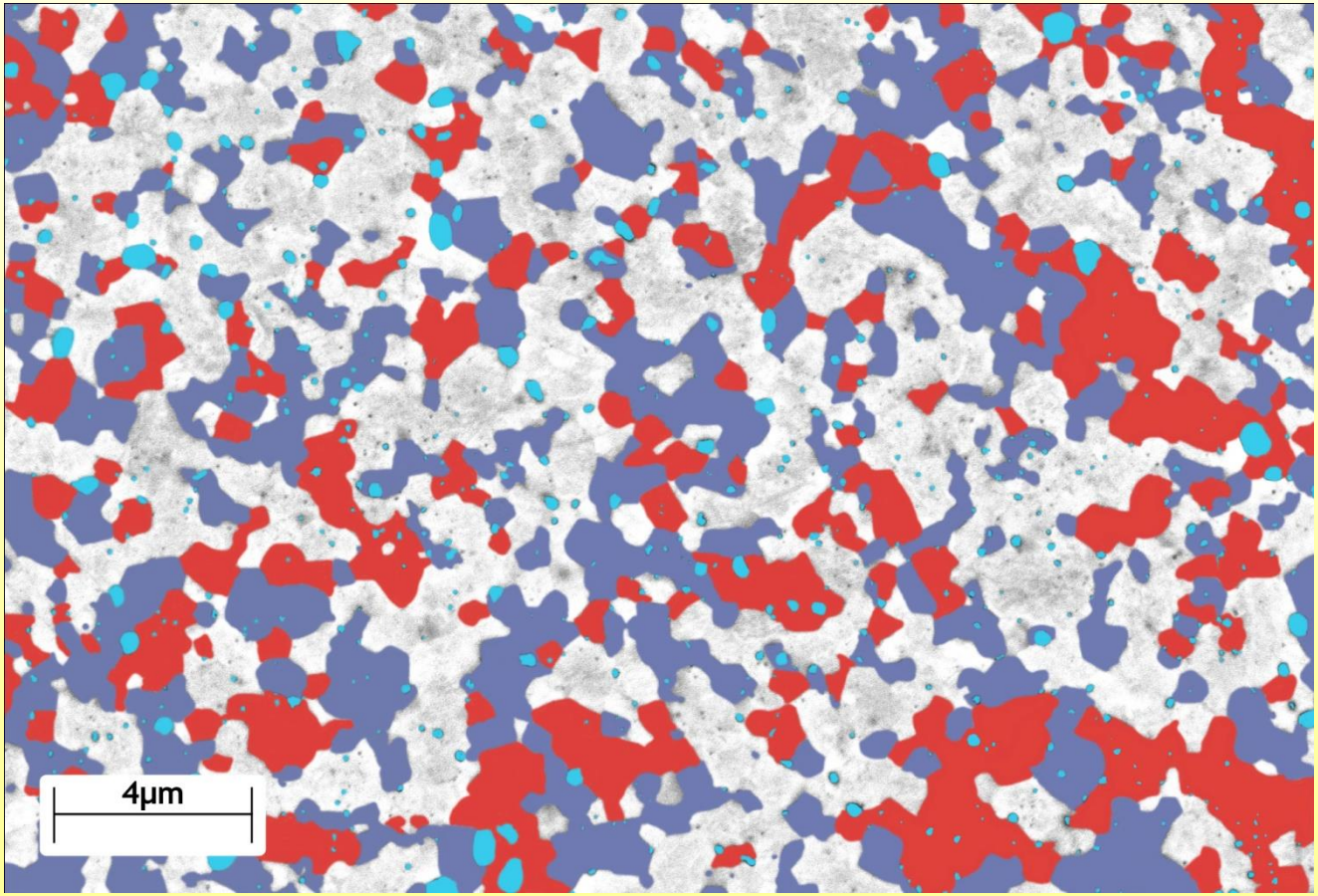


4 phases:

- Zr/Si-oxide
- Mo_3Si

Microstructure

Mo - 9Si - 8B - 1Zr (at.%)

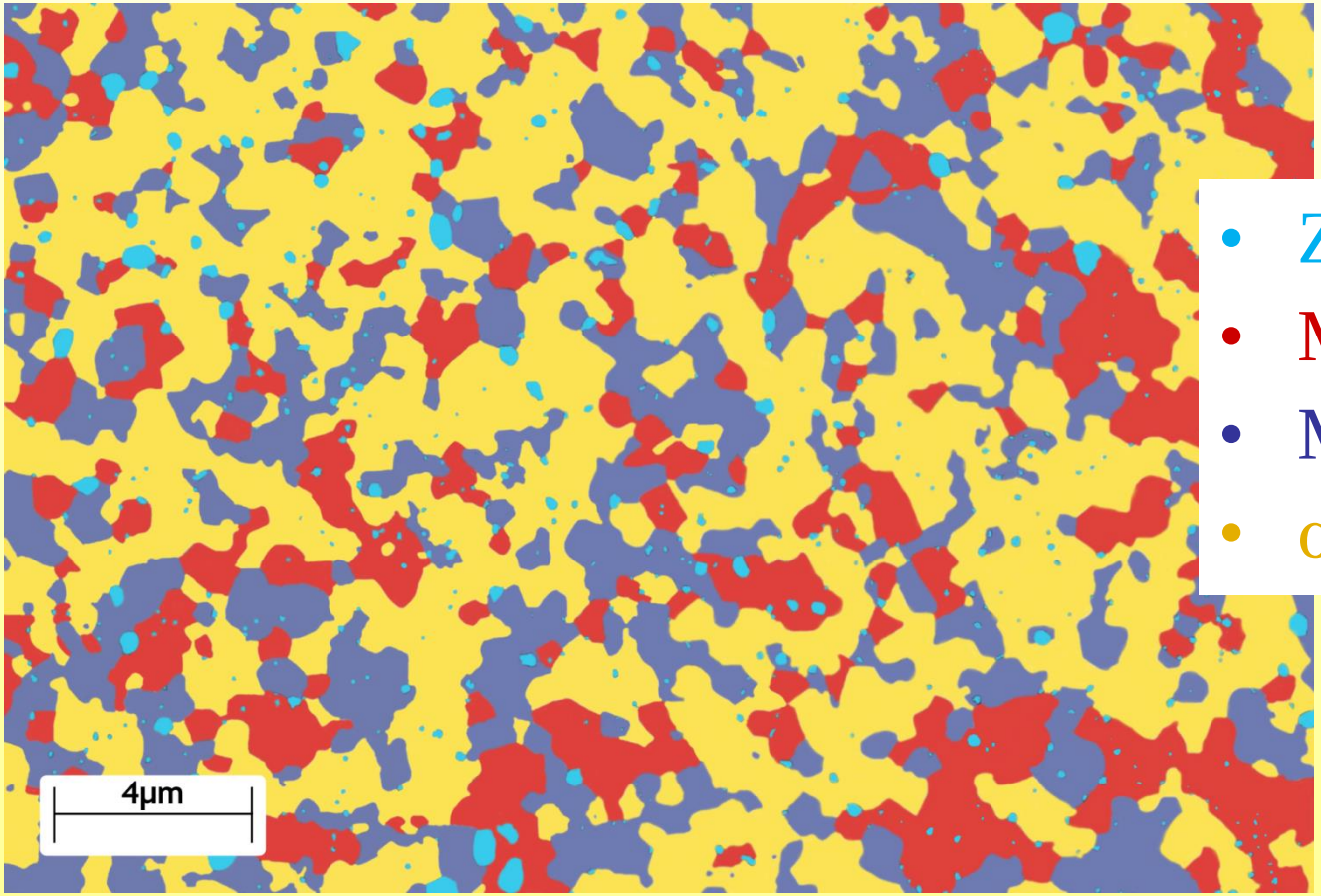


4 phases:

- Zr/Si-oxide
- Mo_3Si
- Mo_5SiB_2

Microstructure

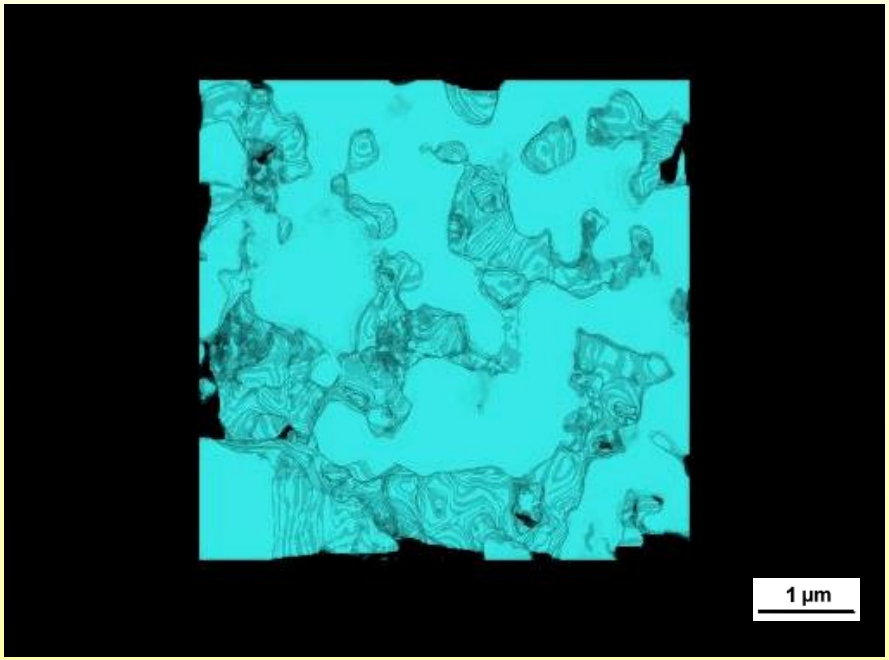
Mo - 9Si - 8B - 1Zr (at.%)

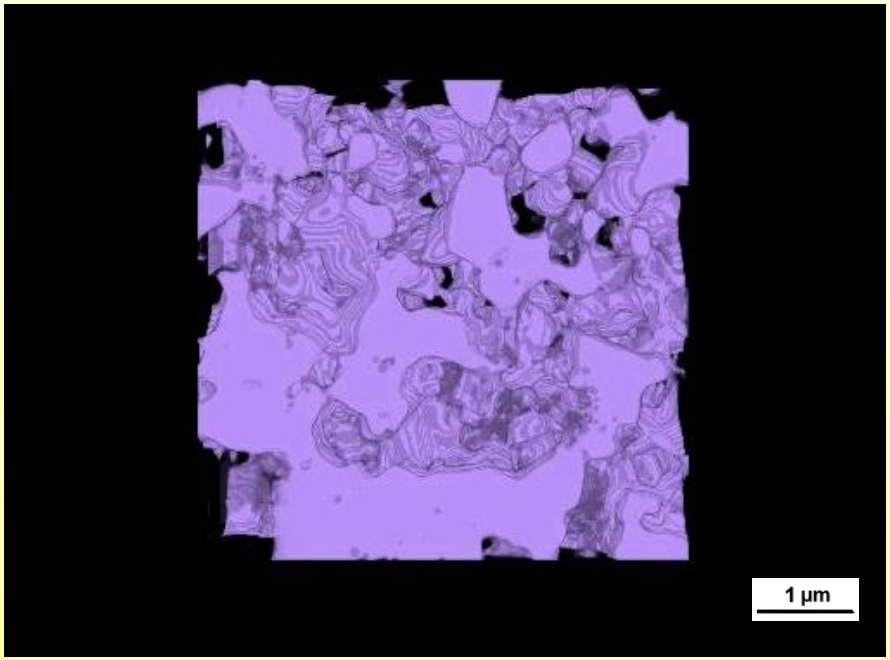


4 phases:

- Zr/Si-oxide (3%)
- Mo_3Si (22%)
- Mo_5SiB_2 (25%)
- α - Mo (50%)

FIB Tomography
MoSiB-2Zr





Mo solid solution (61%)

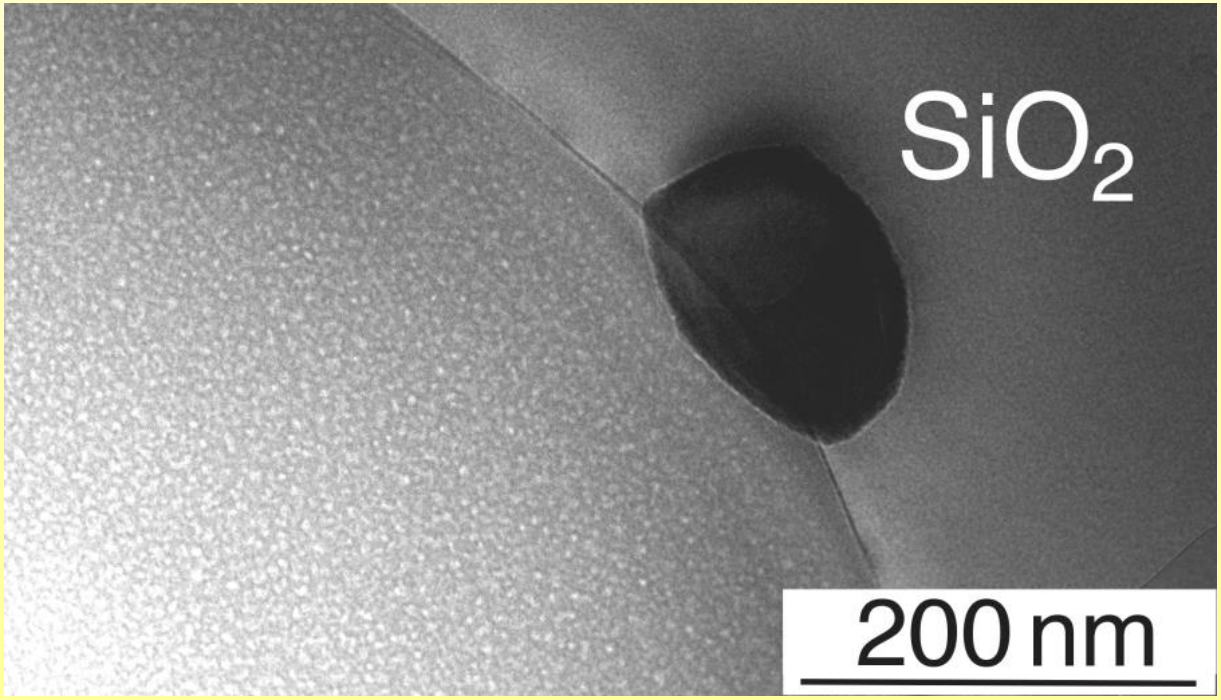
Mo_3Si, Mo_5SiB_2 (T2) (39%)

- Mo matrix and intermetallic phases show both a continuous morphology
- can not be observed in 2D

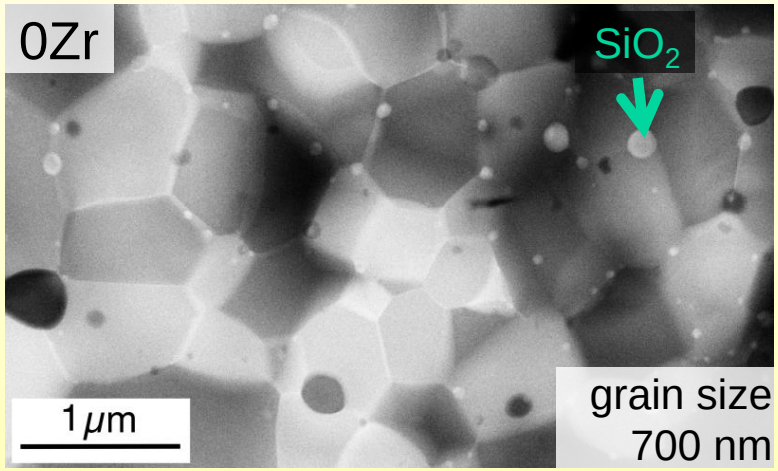
SiO_2 Influence on Creep?

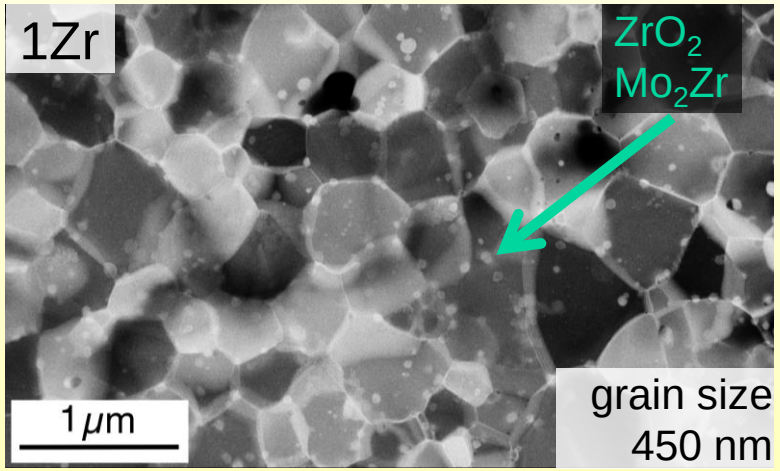
SiO_2 on grain boundaries enhance grain boundary sliding

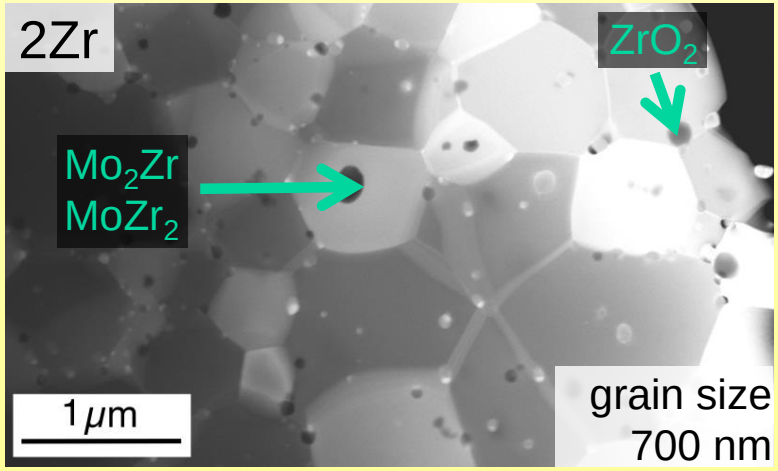
→ Zr should prevent SiO_2 formation

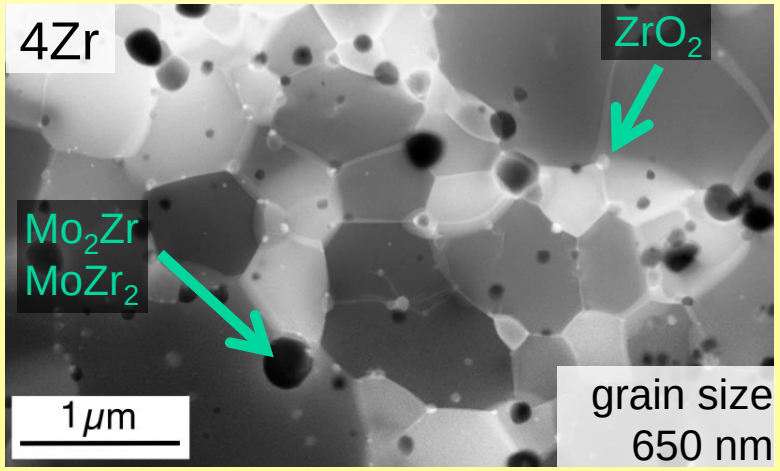


Zr Content from 1 - 4 at.%

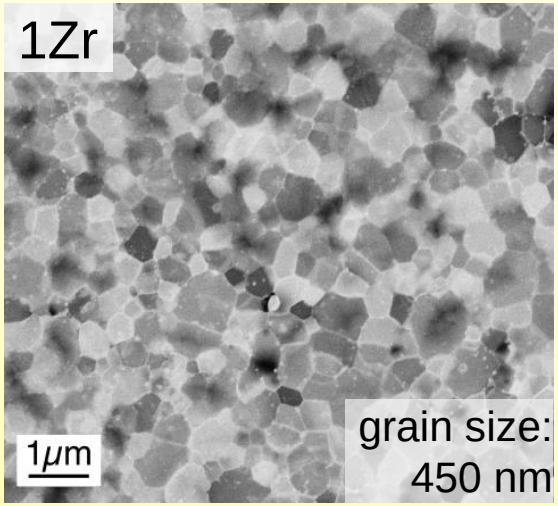


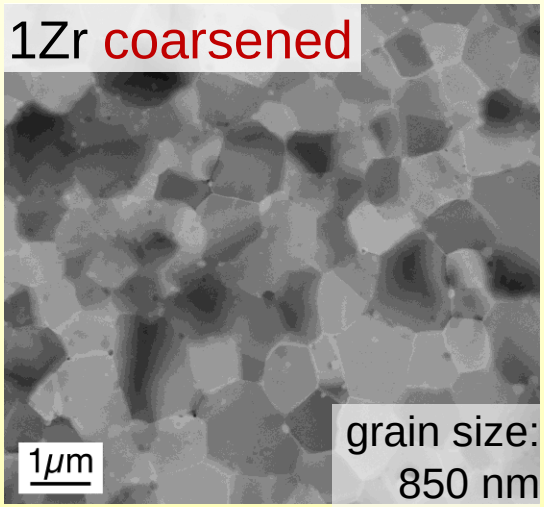


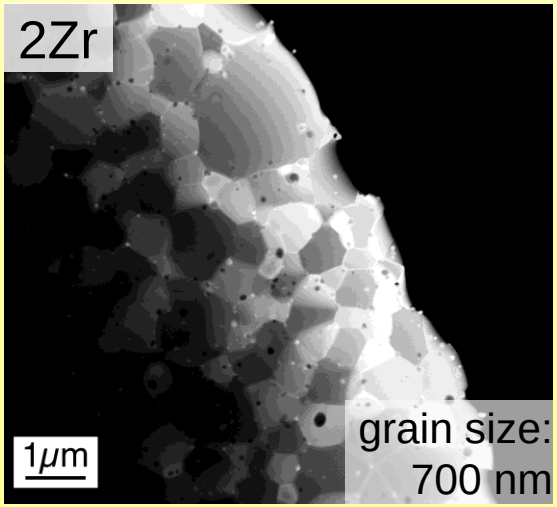


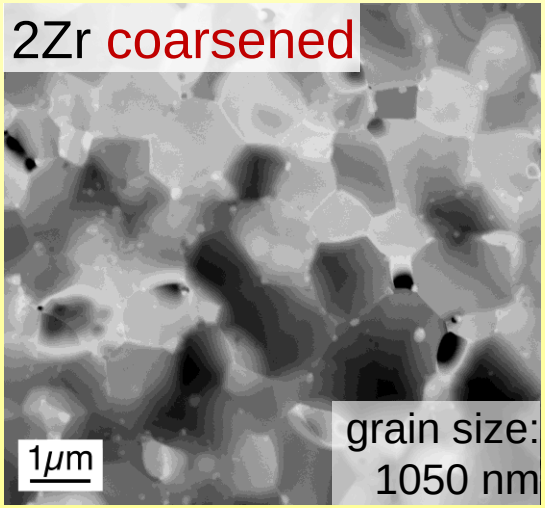


microstructure after heat treatment (1600°C/10h)





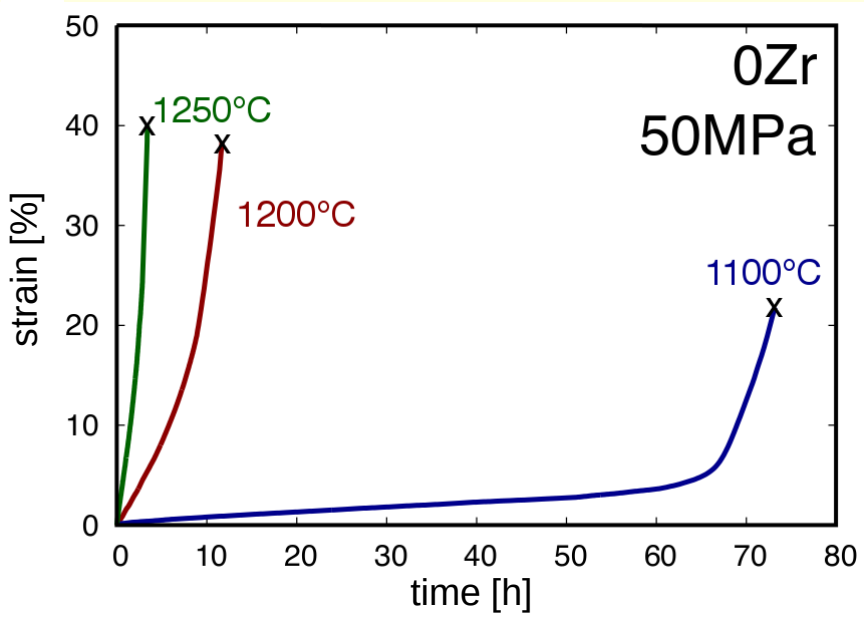


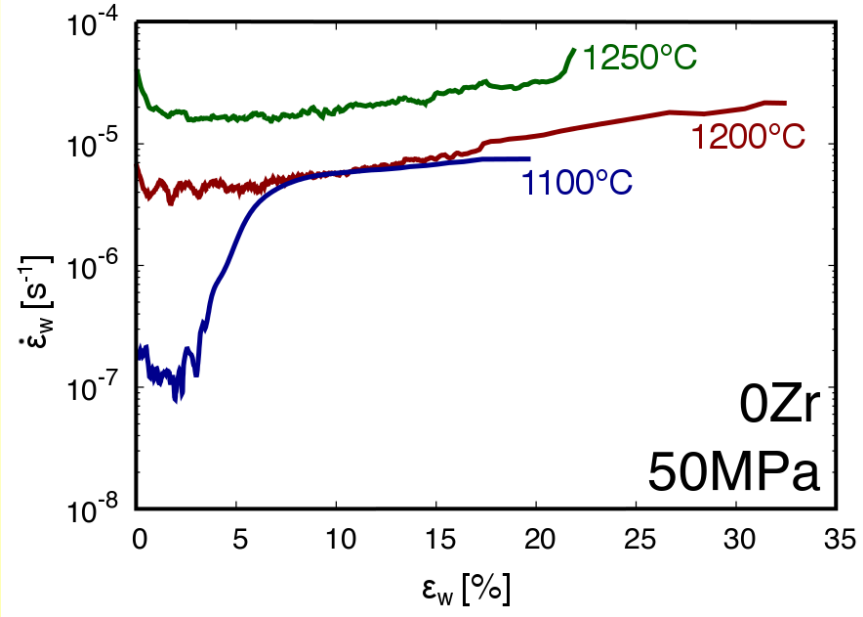


- 1Zr and 2Zr were heat treated under hydrogen atmosphere in **Karlsruhe (KIT)**
- 10 hours at 1600°C
- coarsening is observed
- particles found in the alloys remain stable during heat treatment

but:
grain size < 1 µm

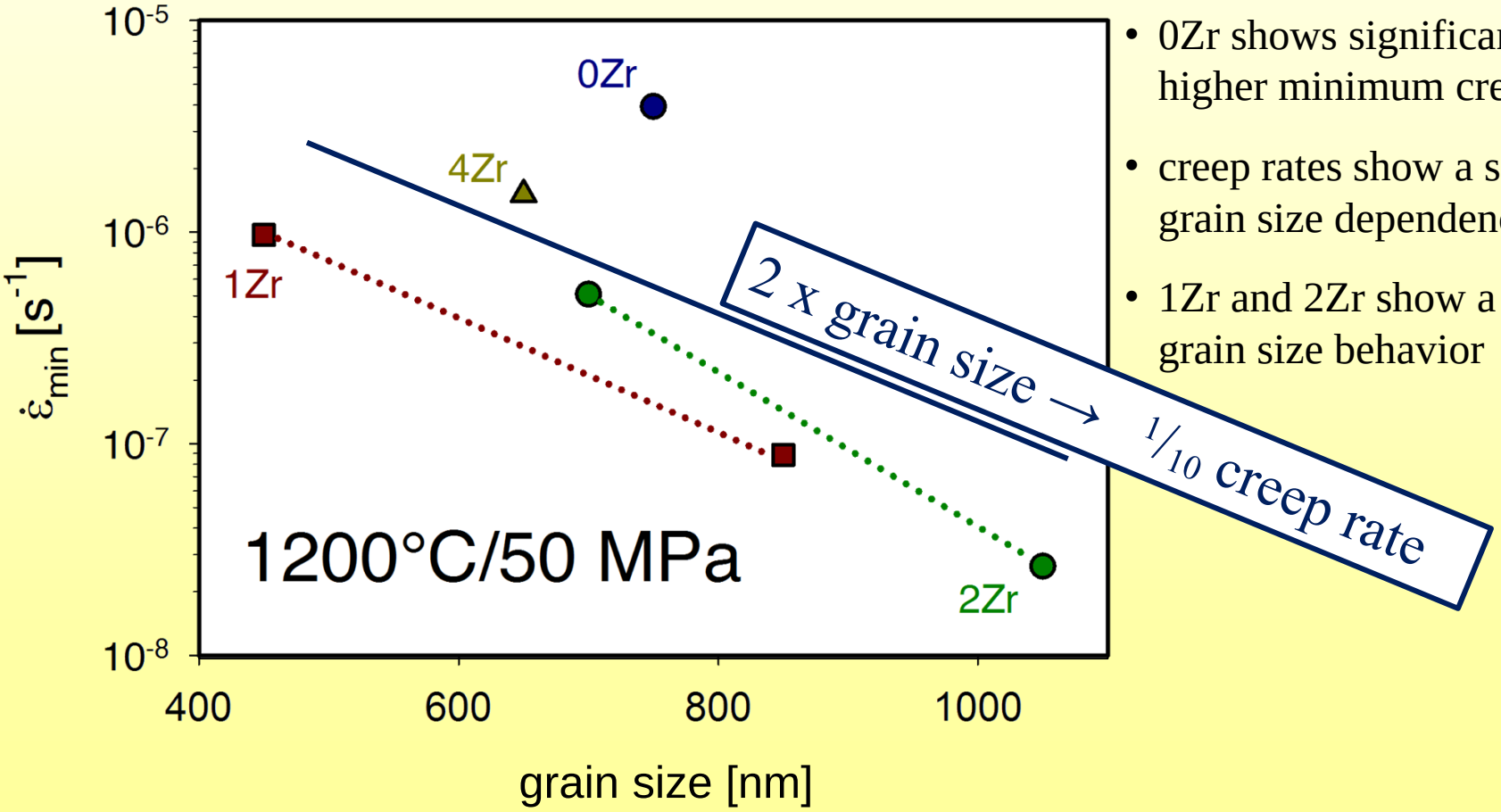
Examples of Creep Data





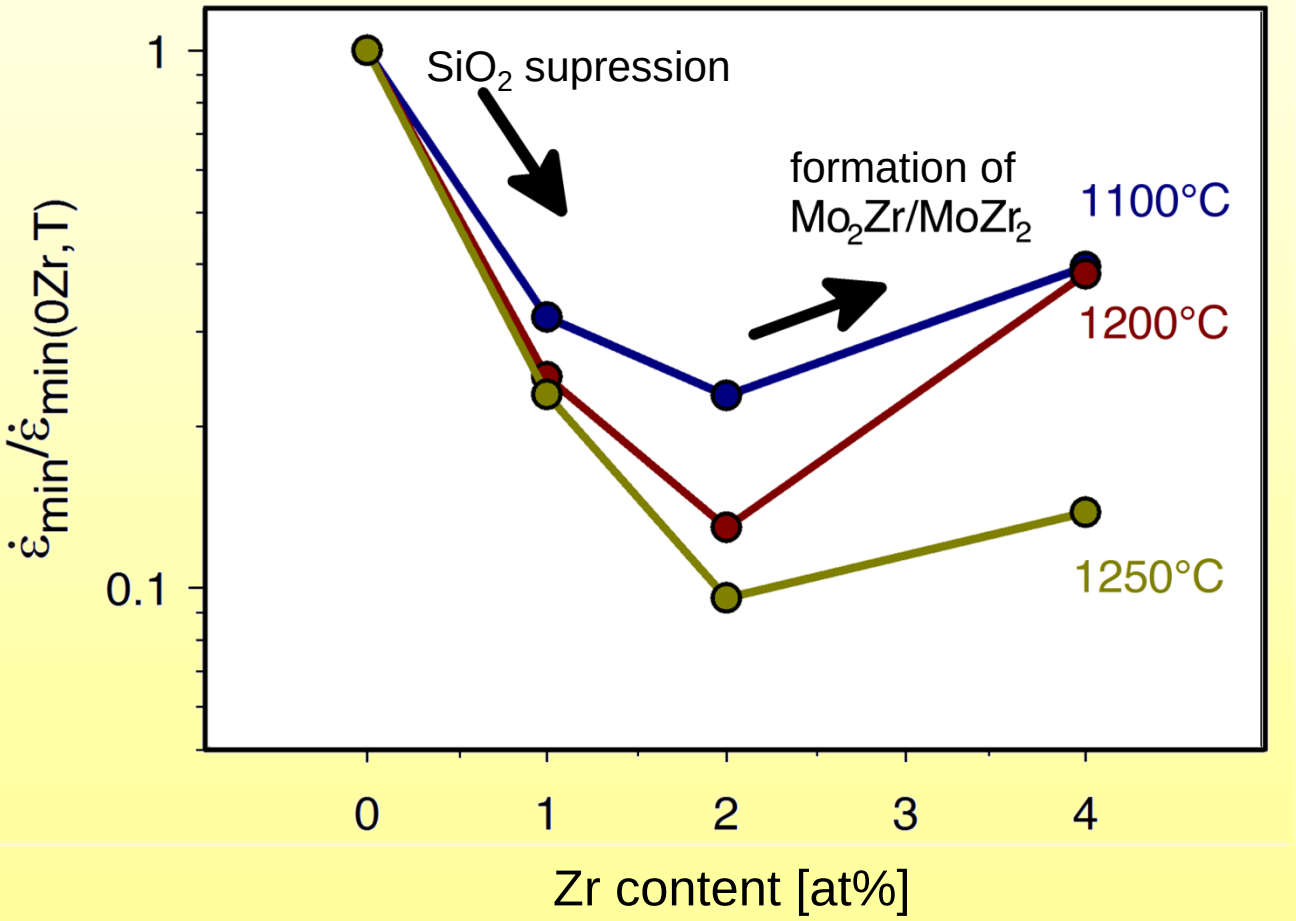
creep experiments were carried out at temperatures of 1100°C – 1250°C and stresses of 50 MPa – 125 MPa

Influence of Grain Size



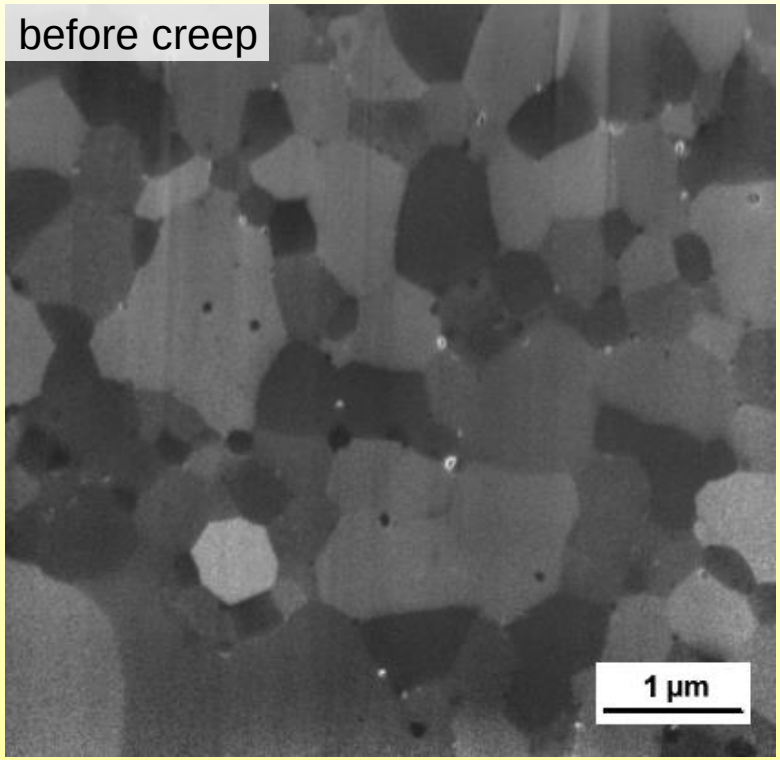
- 0Zr shows significantly higher minimum creep rates
- creep rates show a significant grain size dependence
- 1Zr and 2Zr show a similar grain size behavior

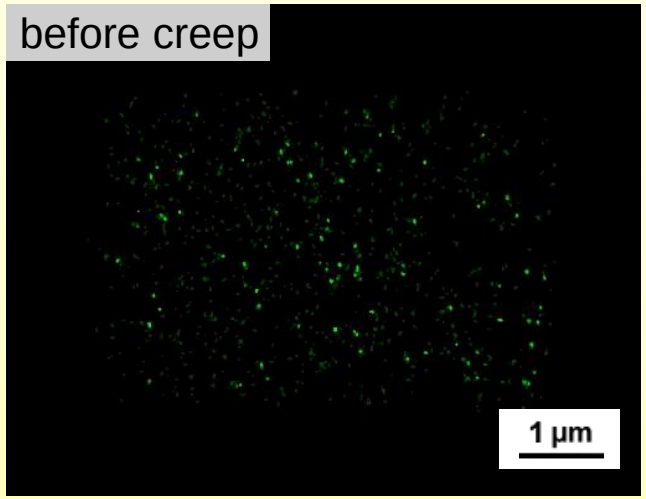
Influence of SiO_2

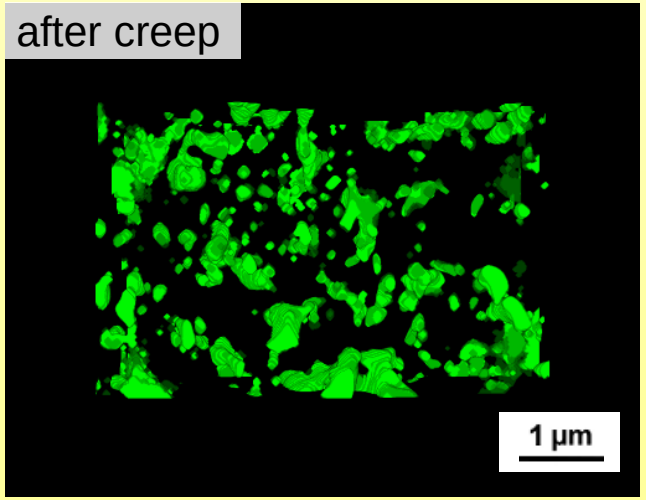


- suppression of SiO_2 lowers the min. creep rates significantly
- effect increases with higher temperatures
- change in grain aspect ratio → deformation mainly in Mo-solid solution and Mo_3Si

Development of Creep Pores 2Zr



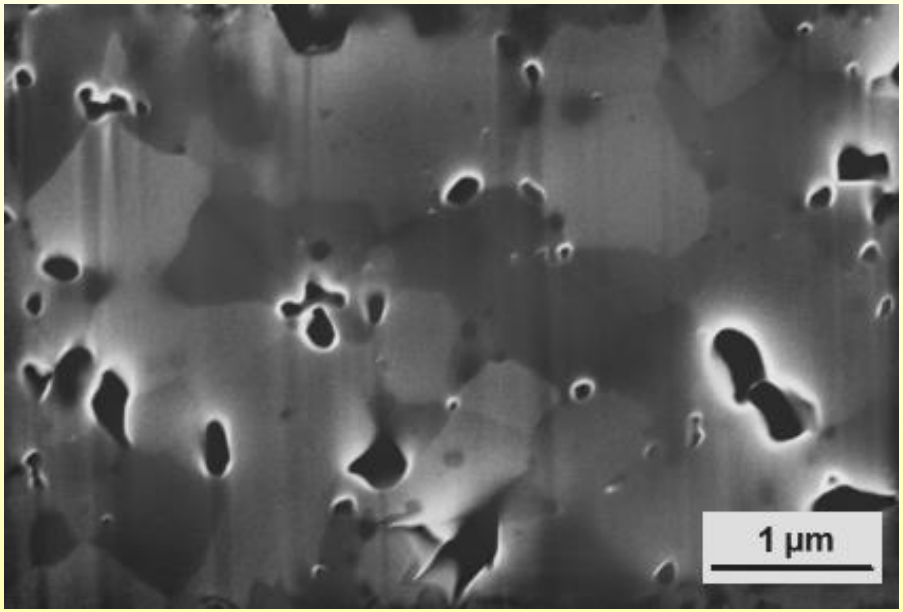


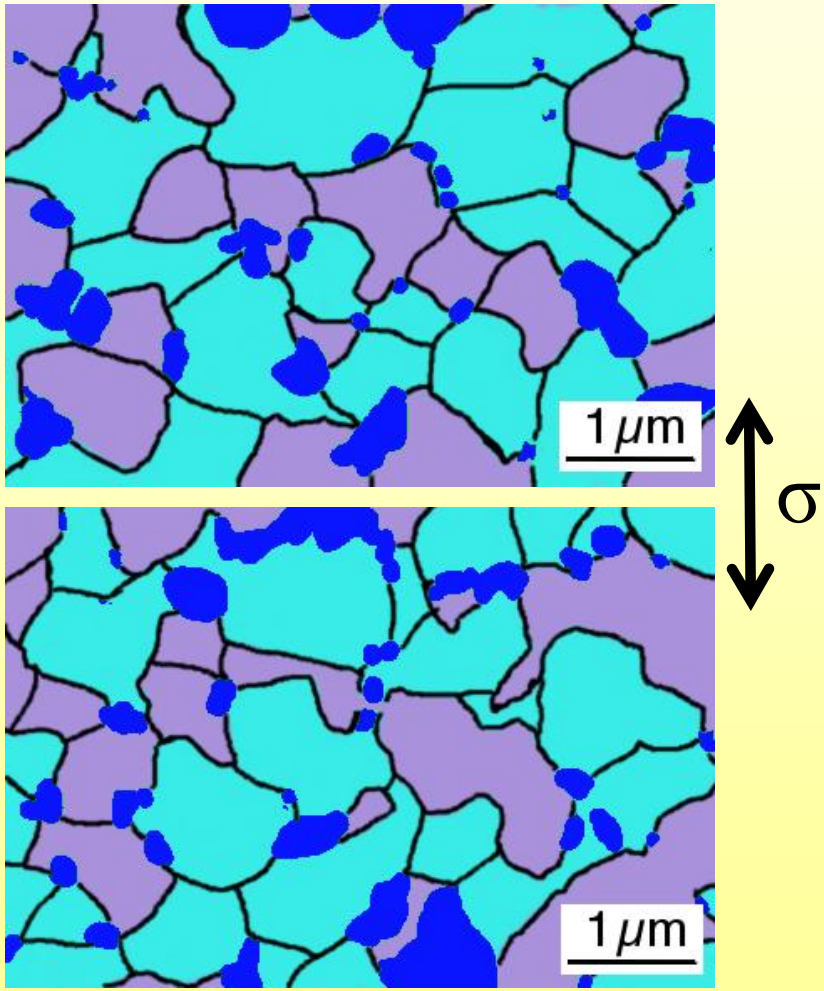


σ

Pores do already form during the powder metallurgical production process

After Creep
2Zr

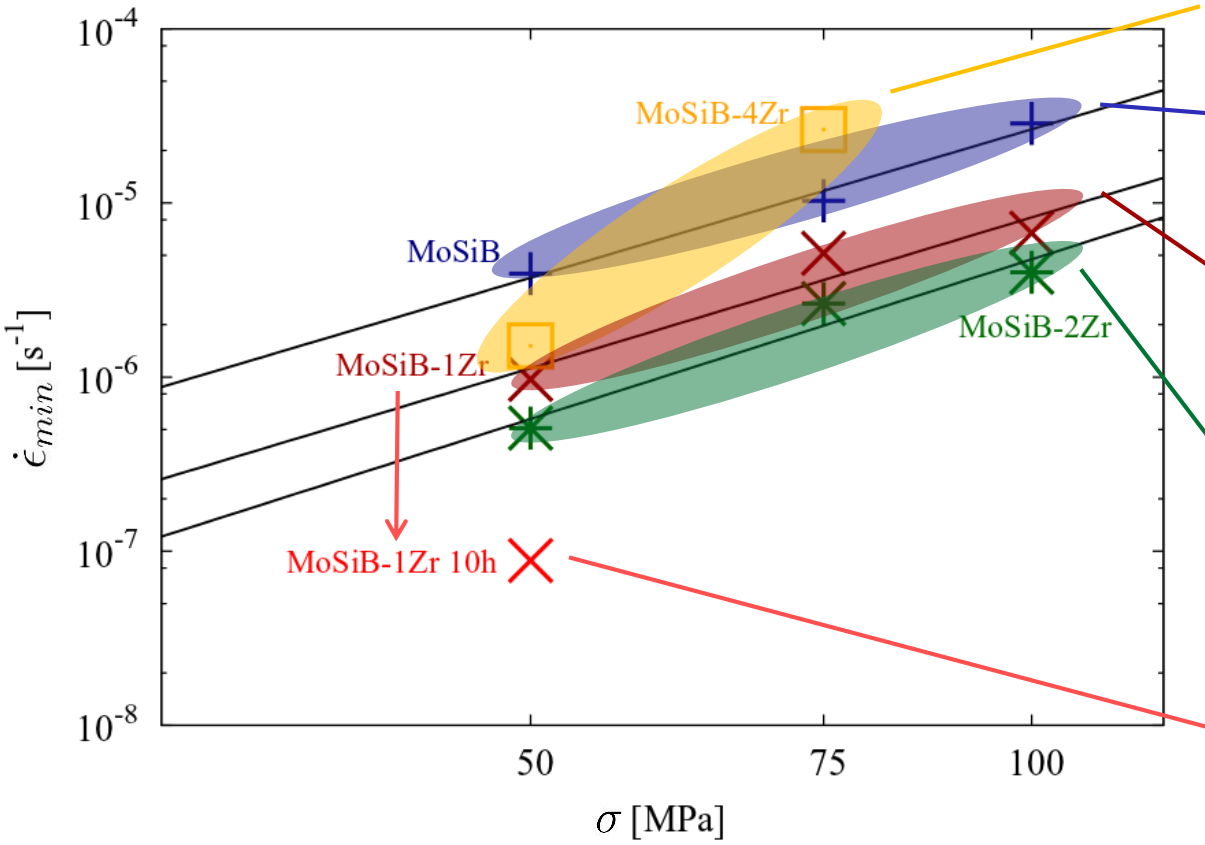




- creep **pores** develop at phase boundaries between **Mo** and the **intermetallic phases**
- grains which can be identified as **Mo** show a higher deformability than the **intermetallic phases**

Why does 1-2 at.% Zr increase creep strength?

Creep Behavior at 1200°C



700 nm large areas $Mo_2Zr/MoZr_2$

700 nm Si-oxide changes ratio of phases

450 nm grain size
particles in solid solution

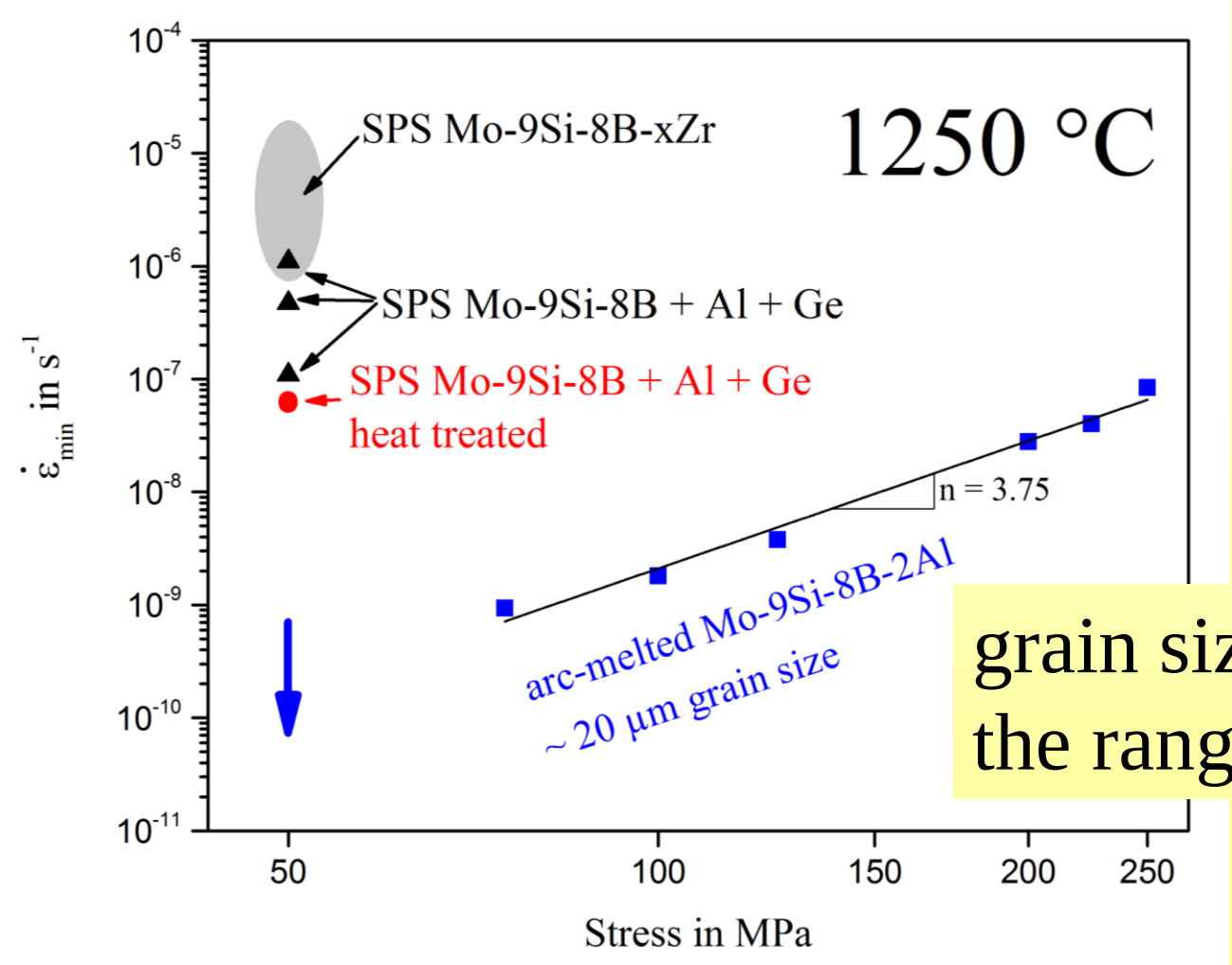
700 nm grain size
small particles in solid solution
lead to lower strains to failure

900 nm grain size
like 1Zr

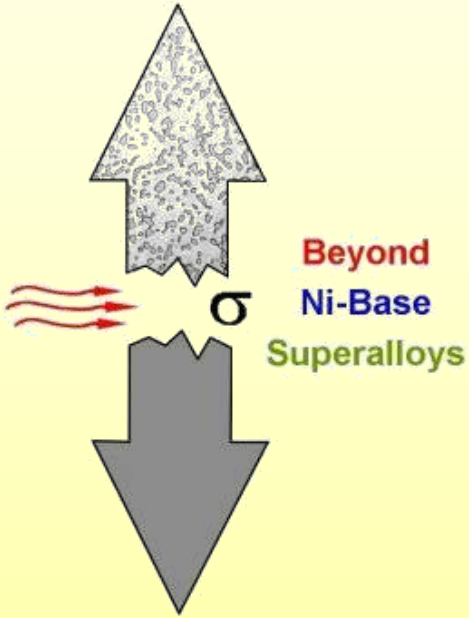
Summary

- Mo solid solution and the two intermetallic phases are continuous
  - continuous Mo → good for ductility at HT
  - continuous T2 and Mo_3Si phase → good for oxidation
- Creep strength increase by 1-2 at.% Zr (no SiO_2 at grain boundaries, small particles in grain)
- grain size increase (450 ⇗ 900 nm) → creep strength increase
- strain to failure scatter decreases because of ~ 20 nm particles in Mo solid solution ($MoZr_2$ and/or Mo_2Zr)

Outlook (Kellner, Tue 11:10)
Arc-Melted Samples



grain size now in the range of 20 µm



Thank you for your attention!