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Microstructure and creep resistance of Ti-rich Mo + Mo5Si3 + Mo5SiB2 alloys

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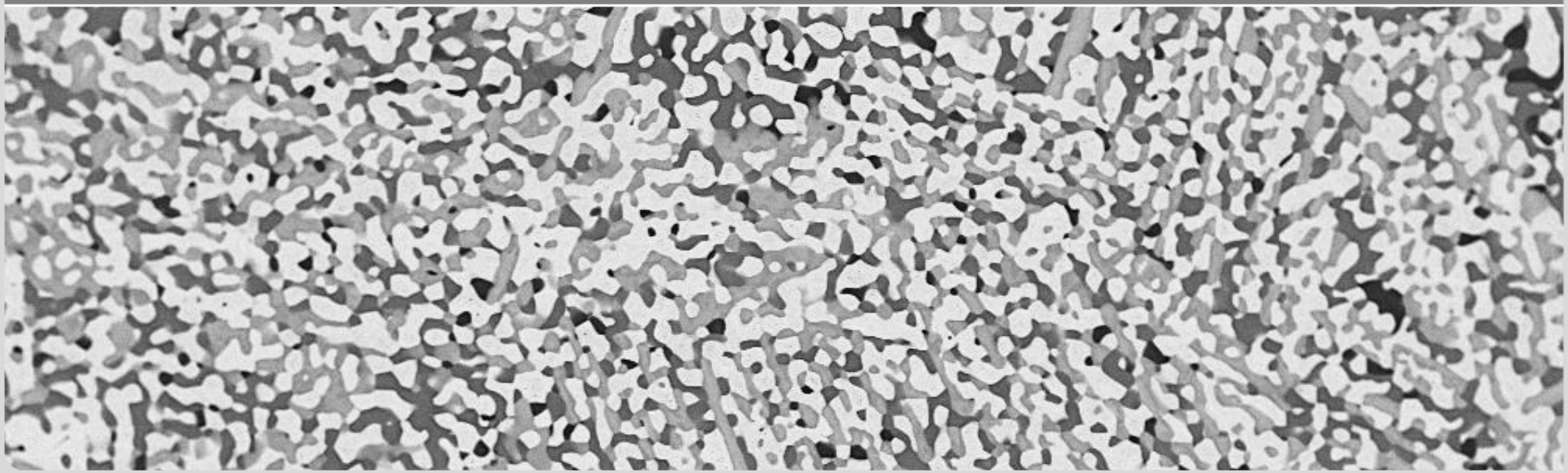


Background: Mo-Si-B Phase Diagram

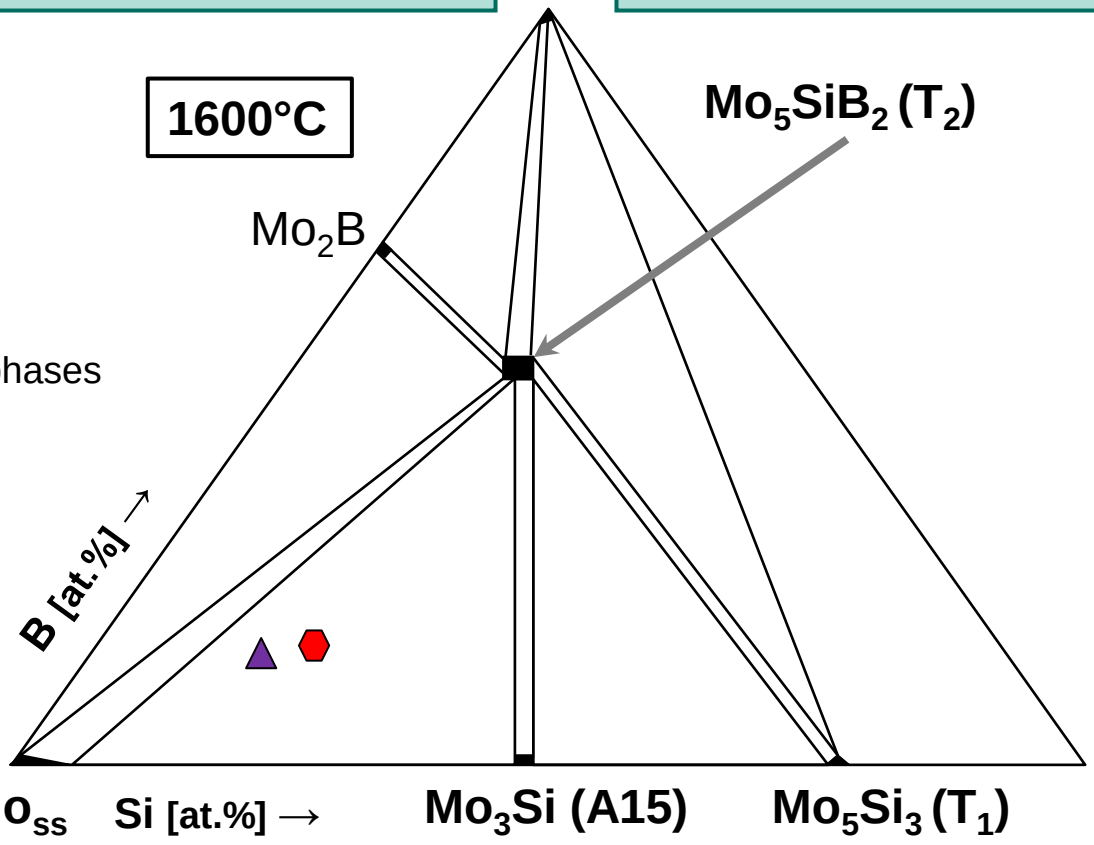
Mo_{ss} + A15 + T_2
good creep/oxidation resistance
acceptable ductility

A15 + T_1 + T_2
very good creep/oxidation resistance
low ductility

Typical alloys:

- Mo-12.5Si-8.5B
- Mo-9Si-8B

50-60% intermetallic phases
$T_m \geq 2000°C$



Schematic according to Nowotny et al., *Monatshefte für Chemie* (1957)
Nunes et al., *Structural Intermetallics* (1997)

Background: Mo-Si-B Phase Diagram

Mo_{ss} + A15 + T_2
good creep/oxidation resistance
acceptable ductility

Optimal Mo_{ss} + T_1 + T_2
very good creep/oxidation resistance
acceptable Ductility

Typical alloys:

- Mo-12.5Si-8.5B
- Mo-9Si-8B

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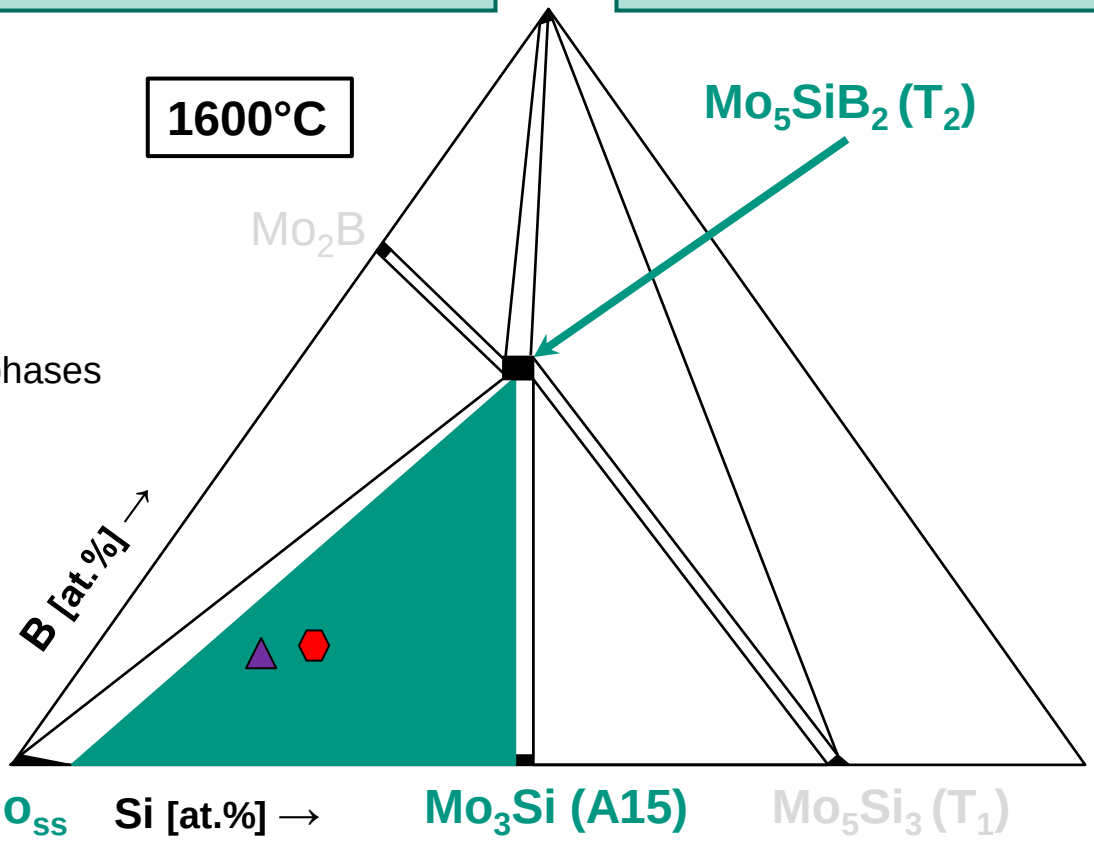
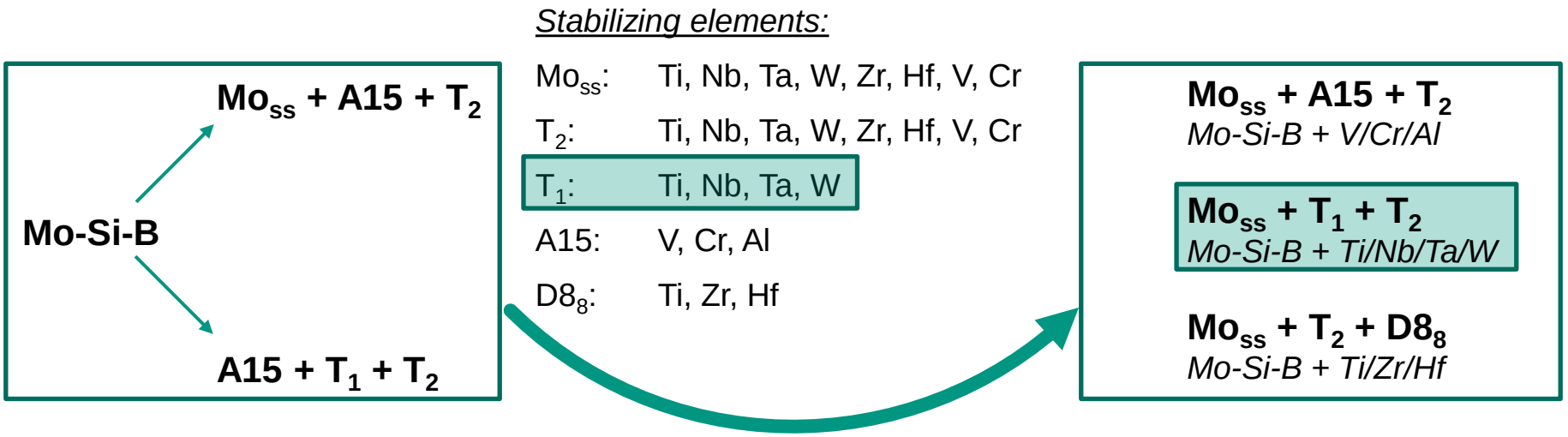


Schematic according to Nowotny et al., *Monatshefte für Chemie* (1957)
Nunes et al., *Structural Intermetallics* (1997)

Alloying Concept in Mo-Si-B Alloys

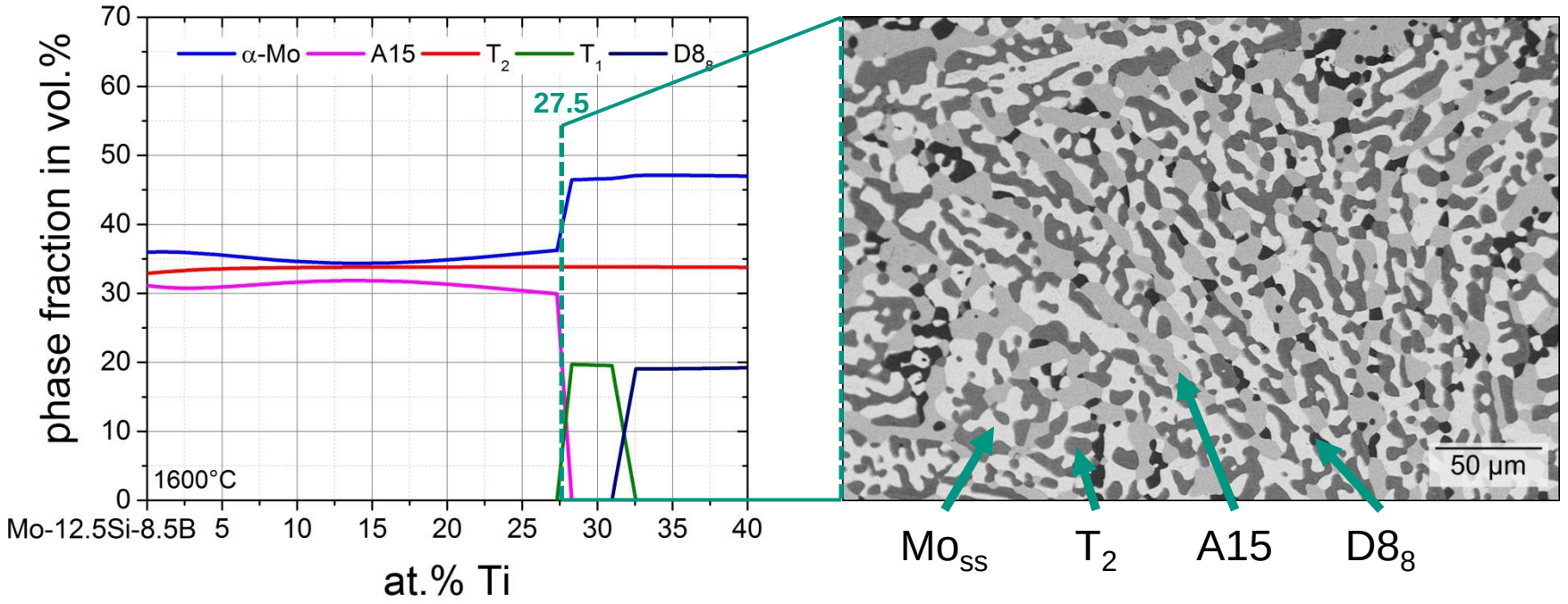


Schematic according to Sakidja et al., *Acta Mater.* **56** (2008) Yang et al., *Acta Mater.* **58** (2010)

- Some elements can stabilize additional phase equilibria
- Mo$_{ss}$ + T$_1$ + T$_2$ by alloying with **Ti**, Nb, Ta, W

Thermodynamic calculation of Mo-Si-B-xTi alloys

Mo-12.5Si-8.5B-27.5Ti 1600 °C 150 h



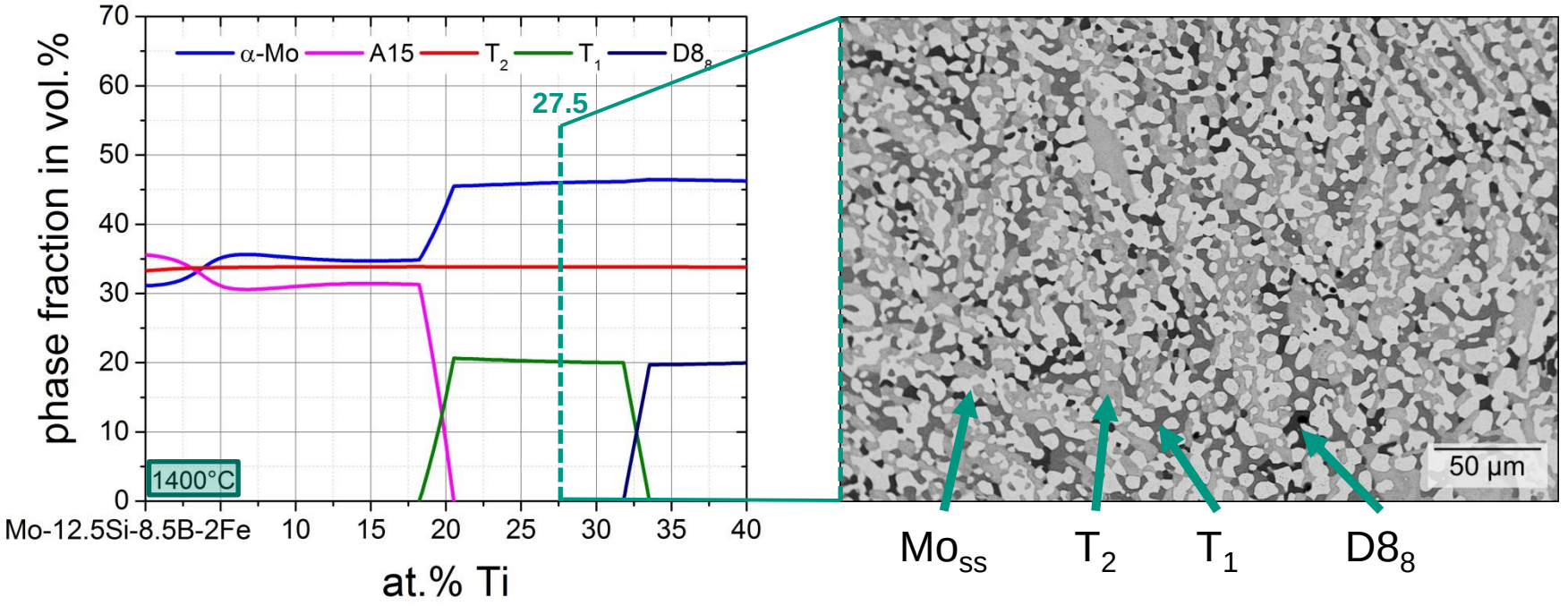
- Formation of T_1 instead of A15 phase and increase of Mo_{ss} phase fraction at 27 at.% Ti
- Yang et al. [1] found Mo_{ss} + T_1 + T_2 + A15 phase equilibria at 1600°C
- Could not be reproduced in this work

→ How can T_1 be stabilized?

[1] Yang et al., *Acta Mater.* **58** (2010)

Effect of Fe on stability of Mo_{ss} + T_1 + T_2 phase equilibria

Mo-12.5Si-8.5B-27.5Ti-2Fe 1400 °C 100 h

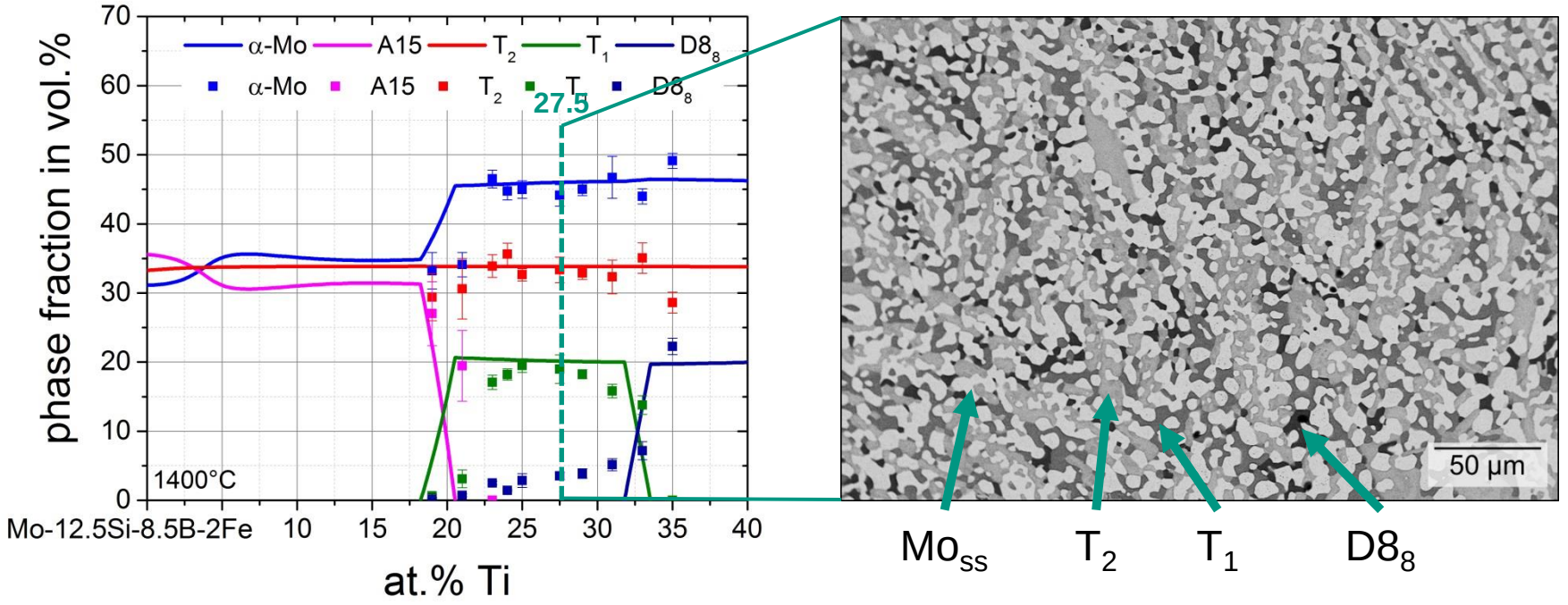


- Ti-concentration for Mo_{ss} + T_1 + T_2 phase equilibrium is expanded by 2 at.% Fe
- Heat treatment at lower Temperature increase possible Ti-concentration
- $D8_8$ as a residual phase below 3 vol.%

→ Validation for Mo-12.5Si-8.5B-xTi-2Fe at 1400°C

Experimental results for Mo-12.5Si-8.5B-xTi-2Fe

Mo-12.5Si-8.5B-27.5Ti-2Fe 1400 °C 100 h

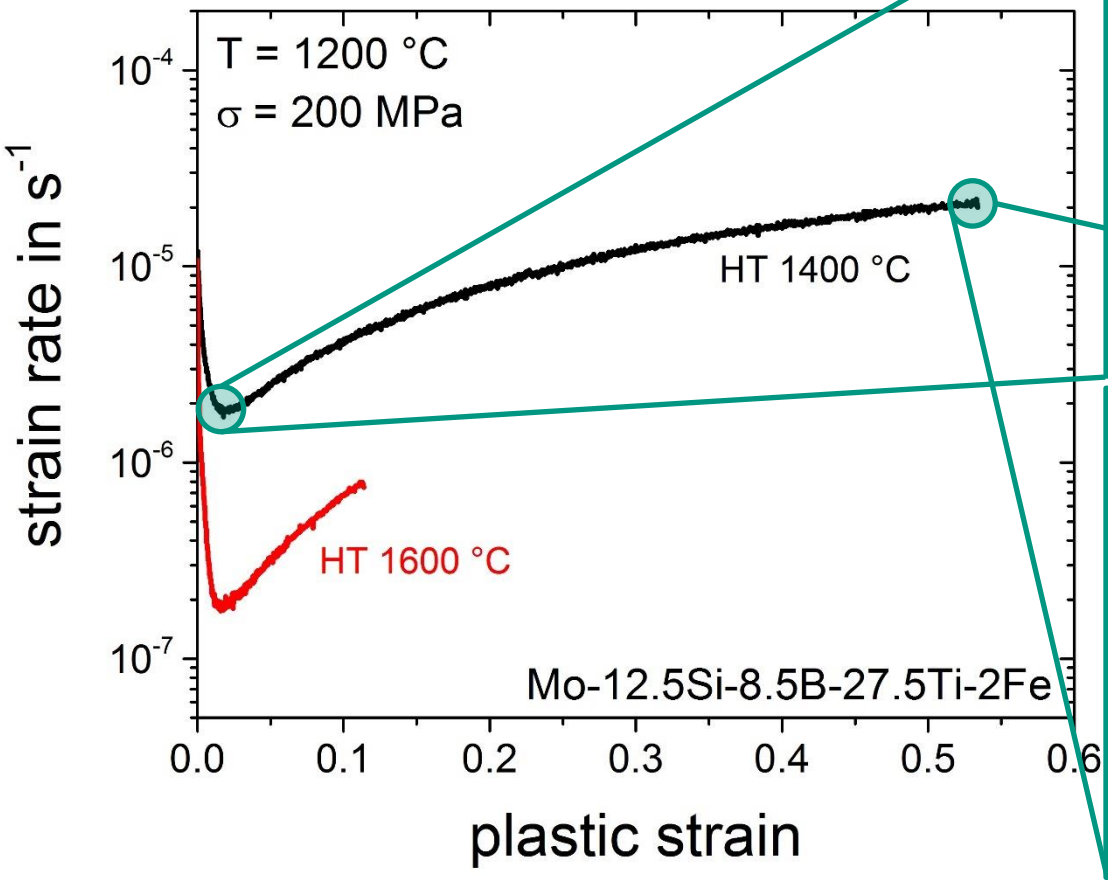


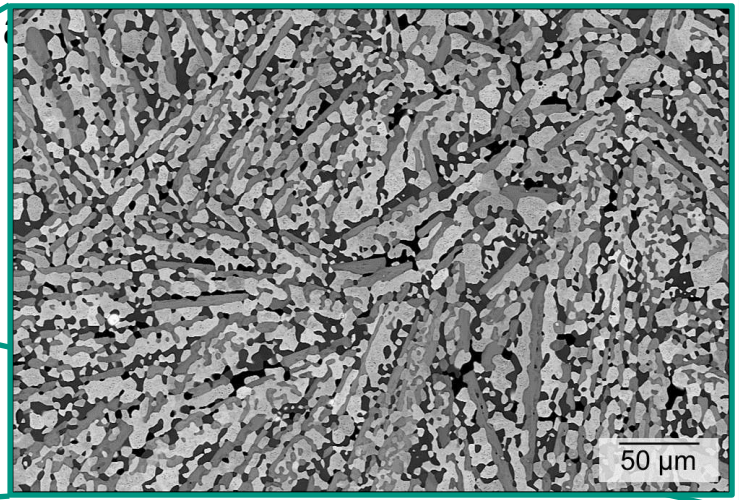
- Results and simulation are in good agreement, slight shift to higher Ti
- T_1 stable for wide range of Ti after heat treatment at 1400°C

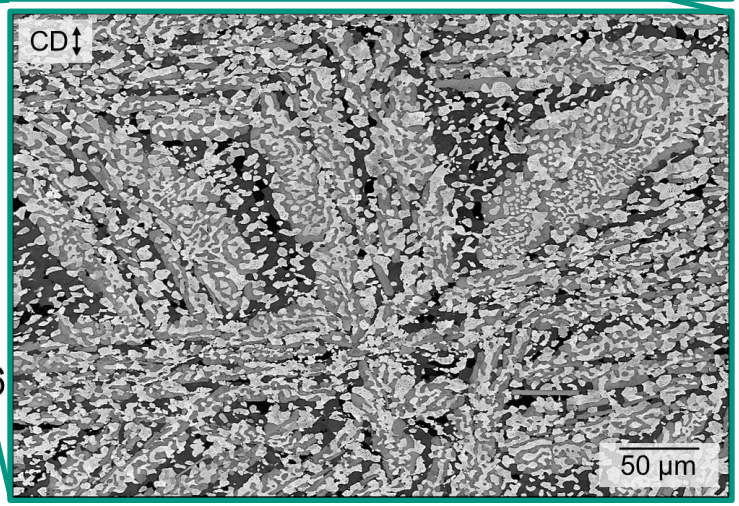
→ How is the creep behavior of Mo_{ss} + T_1 + T_2 alloys?

Creep behavior of $Mo_{ss} + T_1 + T_2$ alloys

- Compression creep behavior was examined in vacuum
- Formation of slight <111> texture during deform

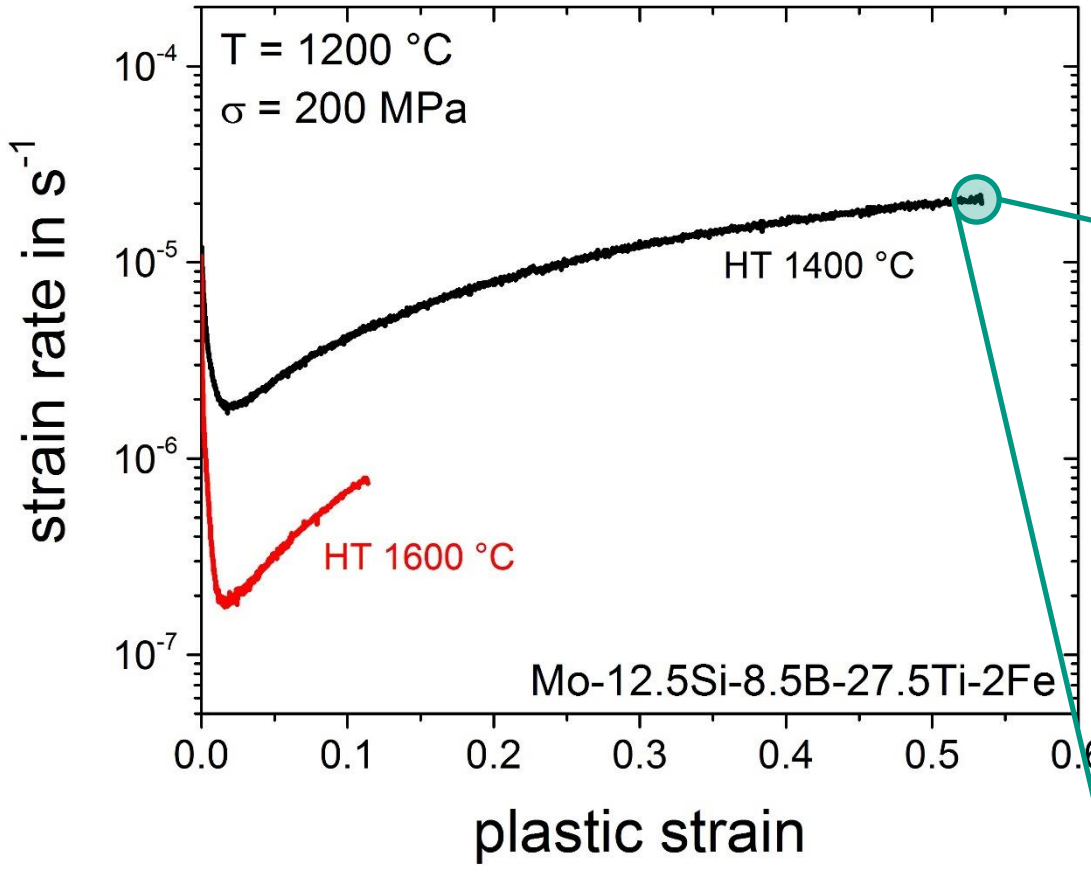


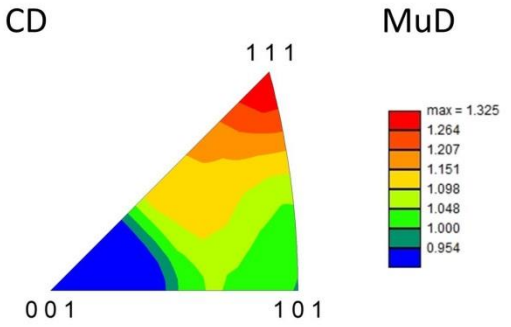


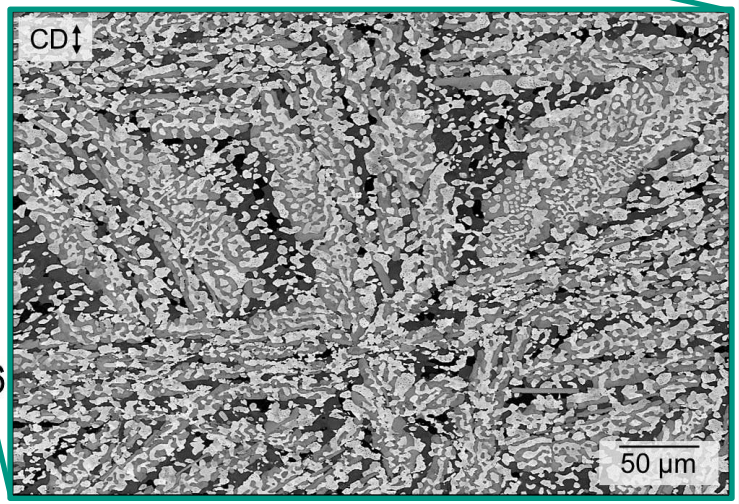


Creep behavior of Mo_{ss} + T_1 + T_2 alloys

- Compression creep behavior was examined in vacuum
- Formation of slight <111> texture during deformation of Mo_{ss}

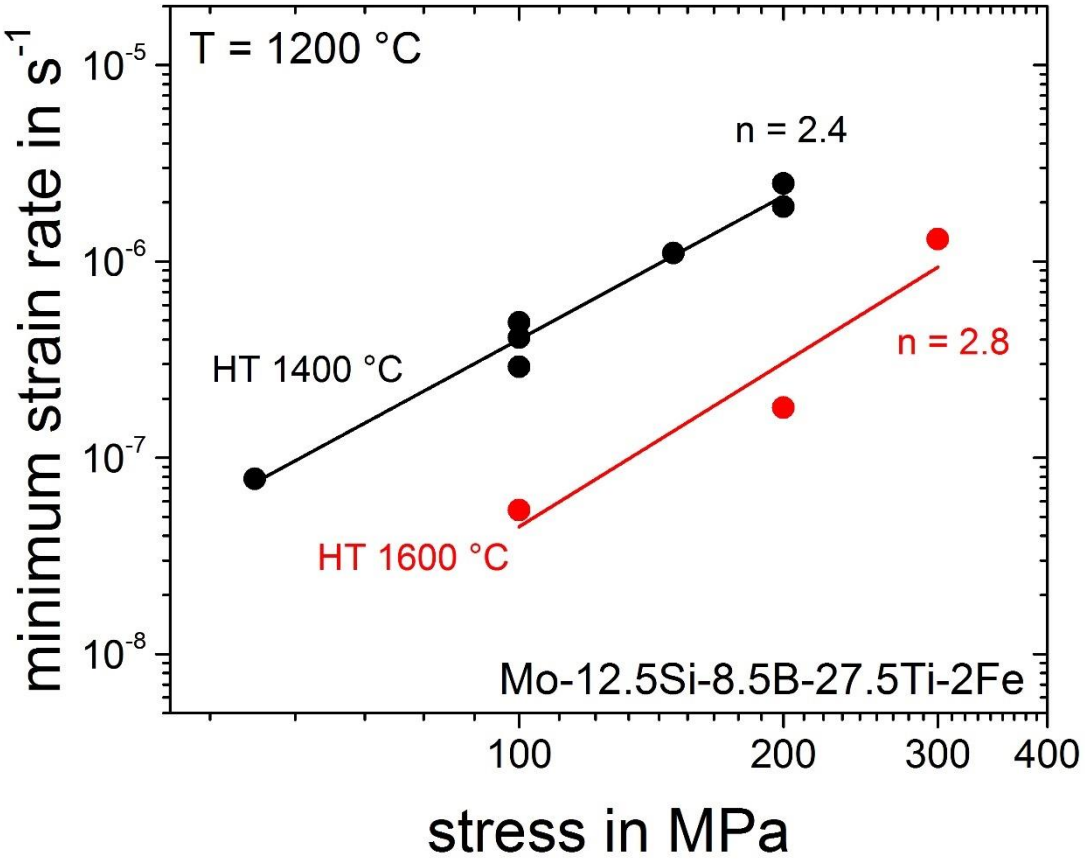






Creep behavior of Mo_{ss} + T_1 + T_2 alloys

Norton Plot

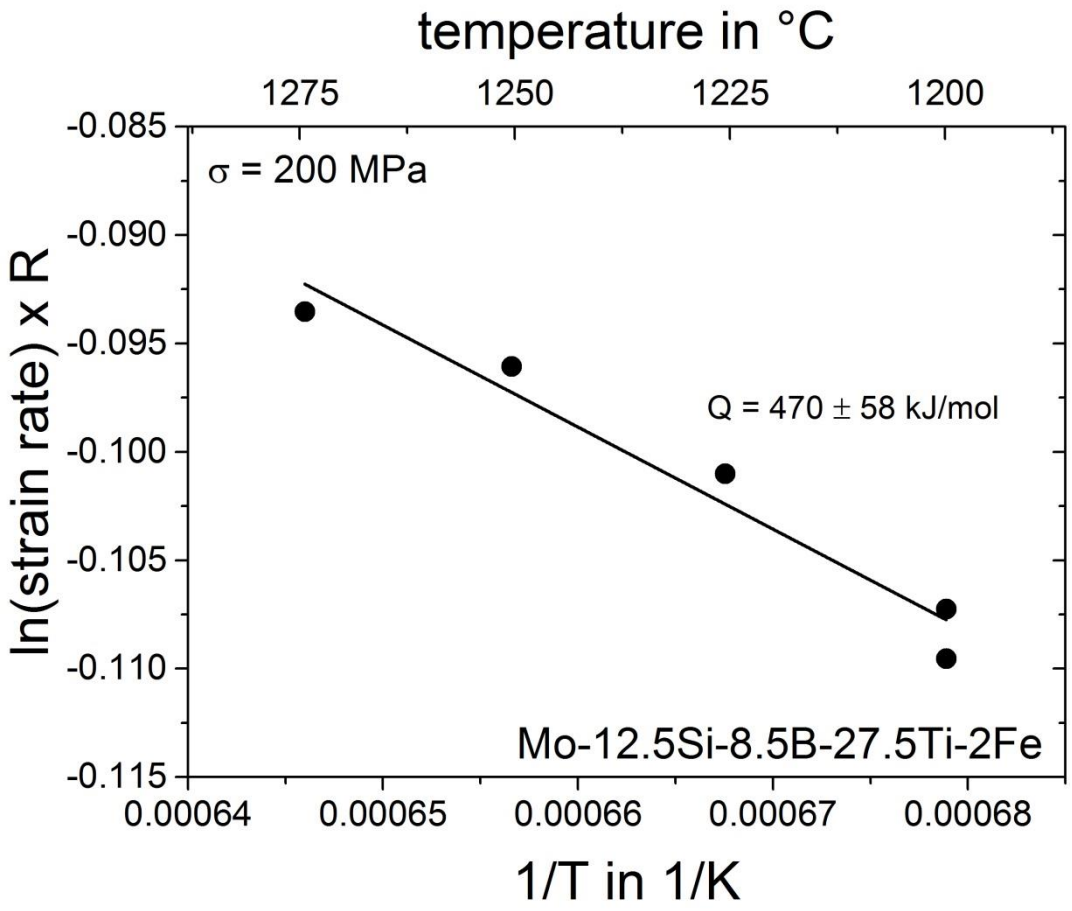


- Value of n is close to 3

→ suggests dislocation climbed controlled creep in Mo_{ss} as dominate mechanism

Creep behavior of Mo_{ss} + T_1 + T_2 alloys

Arrhenius Plot



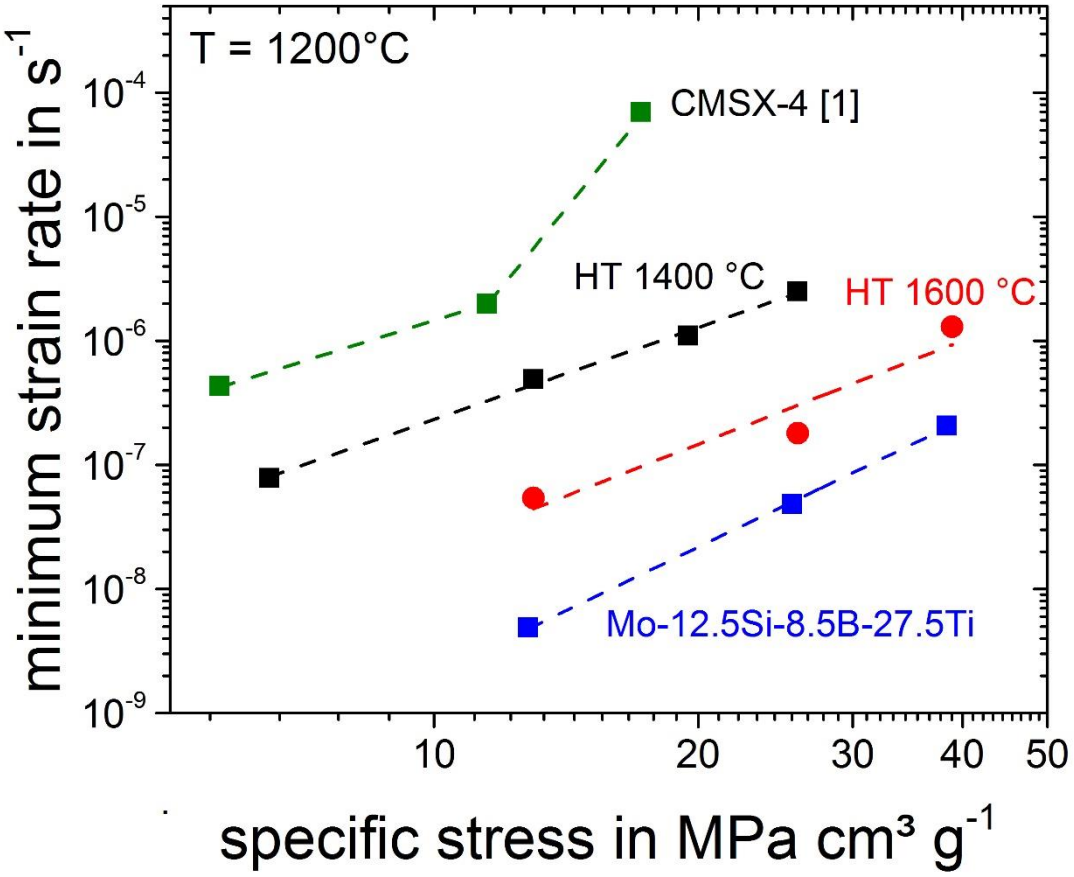
- Activation energy only slightly larger than for pure Mo self diffusion (405 kJ/mol)

→ suggests dislocation climbed controlled creep in Mo_{ss} as dominate mechanism

→ higher value probably by interdiffusion of Ti in Mo

Creep behavior of Mo_{ss} + T_1 + T_2 alloys

Literature comparison



- Mo_{ss} + T_1 + T_2 alloys have better creep resistance than CMSX-4 at 1200 °C
- Mo-12.5Si-8.5B-27.5Ti have lowest minimum strain rates

[1] Heilmaier et al., *JOM* **61** (2009)

Summary and Conclusion

- Mo_{ss} + T_1 + T_2 phase equilibria is stable in Ti-rich Mo-Si-B alloys while Fe is present
- T_1 is stabilized for wide range of Ti
- Necessary Ti-concentration depends also on HT temperature
- Simulation and Experiment are in good agreement

- Creep is controlled by dislocation climb in Mo_{ss} at 1200 °C
  - Refinement of microstructure during creep deformation
  - Slight <111> texture in compression direction
  - Stress exponent n is close to 3
  - Activation energy of 470 kJ/mol slightly higher than Mo self diffusion (405 kJ/mol) → Interdiffusion coefficient?
- Creep resistance higher than for CMSX-4

Karlsruhe Institute of Technology

Thank you for your Attention!

Acknowledgement

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DFG Deutsche Forschungsgemeinschaft