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Experimental investigation and thermodynamic assessment of Cr-Mo-Si ternary system

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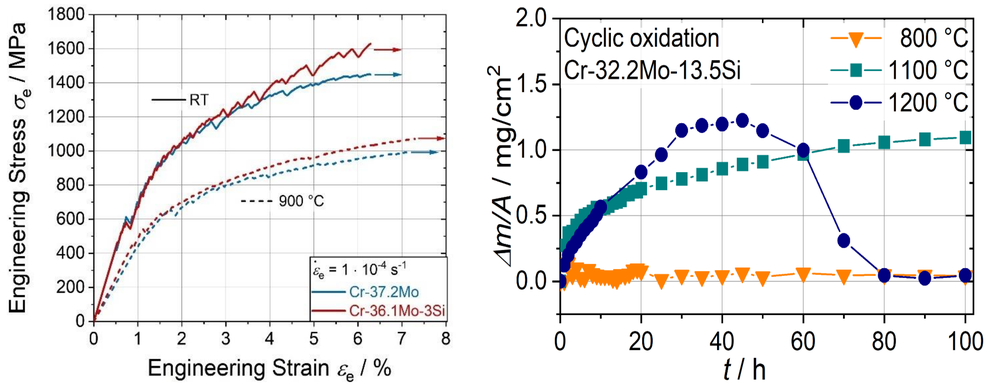
Introduction and Motivation

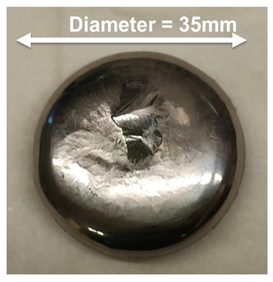
- Alloys containing high concentrations of refractory metals demonstrate promising properties for high temperature applications [1].
- Unique property profile of newly developed alloy Cr-32.2Mo-13.5Si: plasticity at RT and oxidation resistance [2].
- Commercial thermodynamic database of the Cr-Mo-Si ternary system does not provide reliable results - thermodynamic assessment of this ternary system is required.

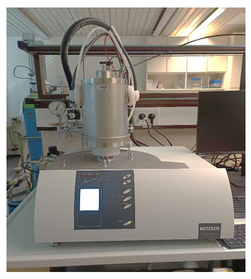


Compression tests (let) and cyclic oxidation behavior (right) of Cr-32.2Mo-13.5Si alloys

Experimental Section

- Modelling approach → **CALPHAD** (CALculation of PHAse Diagrams)
- Alloys are manufactured by arc melting in argon atmosphere.
- Phase constitution is identified by powder XRD and SEM/BSE.
- Chemical composition of the phases is measured by Electron probe microanalysis (EPMA).
- Phase transition, solidus and liquidus temperatures are investigated by high-temperature differential thermal analysis (DTA) (ongoing studies).





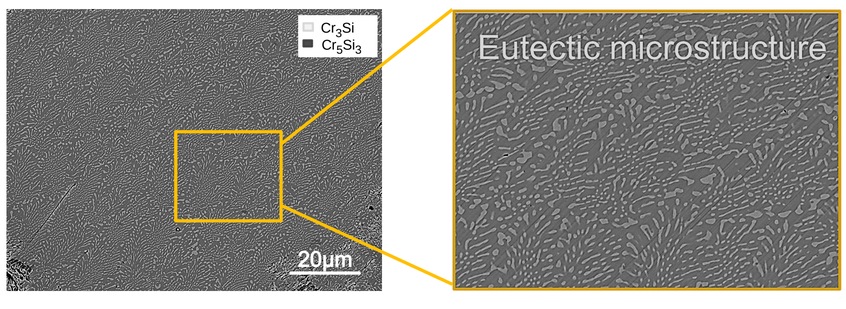
Binary Subsystems

Mo-Si and Cr-Mo systems:

- Mo-Si and Cr-Mo binary systems are well-assessed, and their thermodynamic description is adopted from [3] and [4], respectively.

Cr-Si system:

- Available experimental and theoretical data on Cr-Si system do not allow to precisely determine the solidification behavior of the alloy 65Cr-35Si (at.%) and the phase transition (allotropic transformation) from α-Cr_5Si_3 to β-Cr_5Si_3 above 1500°C.
- Our results on 65Cr-35Si confirms the eutectic solidification of Cr_3Si and Cr_5Si_3 phases.



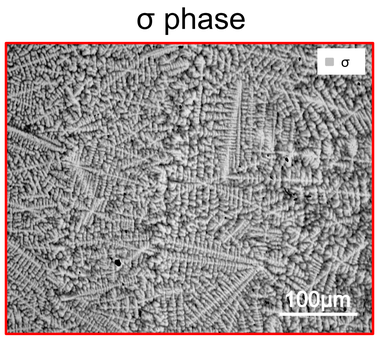
Experimental Results of Cr-Mo-Si Alloys

As-cast alloys (composition in at.%)

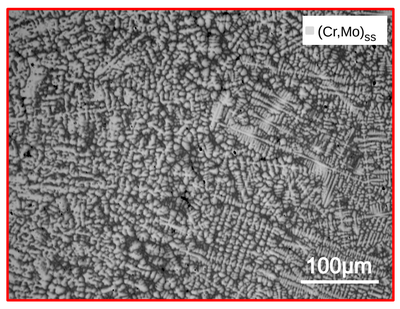
- To determine the solidification behavior, a series of Cr-Mo-Si alloys was produced and the results are reported below.

Single-phase microstructure ***Three-phase microstructure***

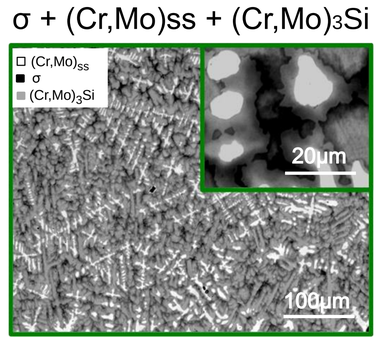
54.3Cr-32.2Mo-13.5Si
σ phase



57.7Cr-37.3Mo-5Si
(Cr,Mo)ss

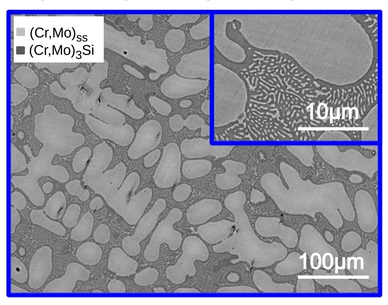


30Cr-52.6Mo-17.4Si
σ + (Cr,Mo)ss + $(Cr,Mo)_3Si$

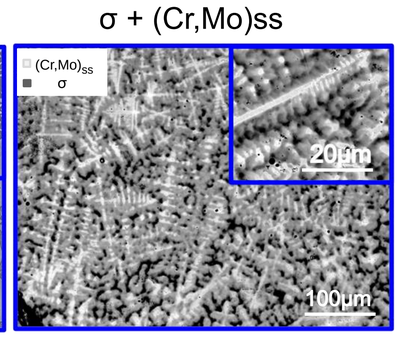


Two-phase microstructure

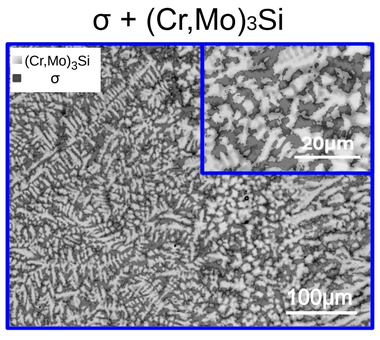
70Cr-18.5Mo-11.5Si
(Cr,Mo)ss + $(Cr,Mo)_3Si$

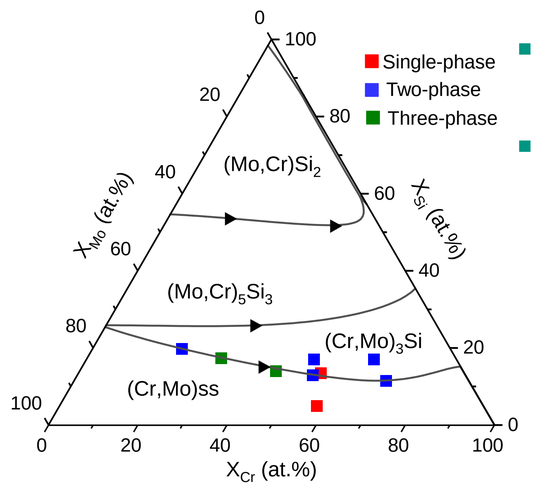


52.8Cr-34.2Mo-13Si
σ + (Cr,Mo)ss



51Cr-32Mo-17Si
σ + $(Cr,Mo)_3Si$





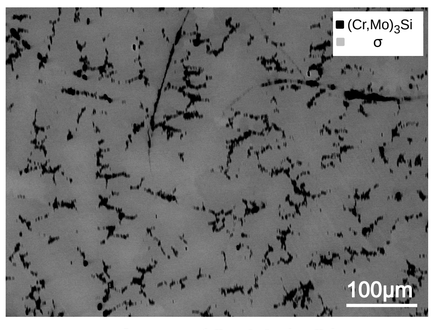
- As-cast alloys exhibit dendritic microstructure.
- Cr-rich (Alloy 70Cr-18.5Mo-11.5Si) and Si-poor (Alloy 57.7Cr-37.3Mo-5Si) regions does not contain σ phase.

Calculated liquidus projection using commercial Cr-Mo-Si database

Thermally-treated alloys

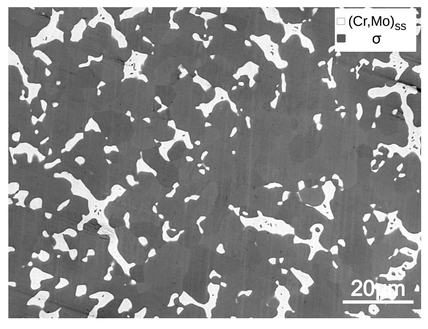
- To investigate phase equilibria (1500°C, 70h, Ar).

54.3Cr-32.2Mo-13.5Si



σ → σ + $(Cr,Mo)_3Si$

30Cr-52.6Mo-17.4Si



σ + $(Cr,Mo)_3Si$ + (Cr,Mo)ss → σ + (Cr,Mo)ss

Conclusions and Outlook

- Eutectic solidification path of the alloy 65Cr-35Si is established.
- One-, two- and three-phase microstructure in Cr-Mo-Si alloys (as-cast state) are investigated.
- First experimental evidence of σ phase formation at high Si content in Cr-Mo-Si alloys.
- Thermodynamic reassessment of Cr-Si system and further development of the database for Cr-Mo-Si system are pending.

[1] J.H. Perepezko, Science 326, 1068 (2009)
[2] F. Hinrichs et al., Corrosion Science 207, (2022), 110566
[3] A. Czerny et al., AEM (2024), 2302085
[4] K. Frisk et.al., Calphad 12, 247-254 (1988)