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Enhanced oxidation resistance of Ti-rich Mo-Si-B alloys by pack-cementation process

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Enhanced oxidation resistance of Ti-rich Mo-Si-B alloys by pack-cementation process

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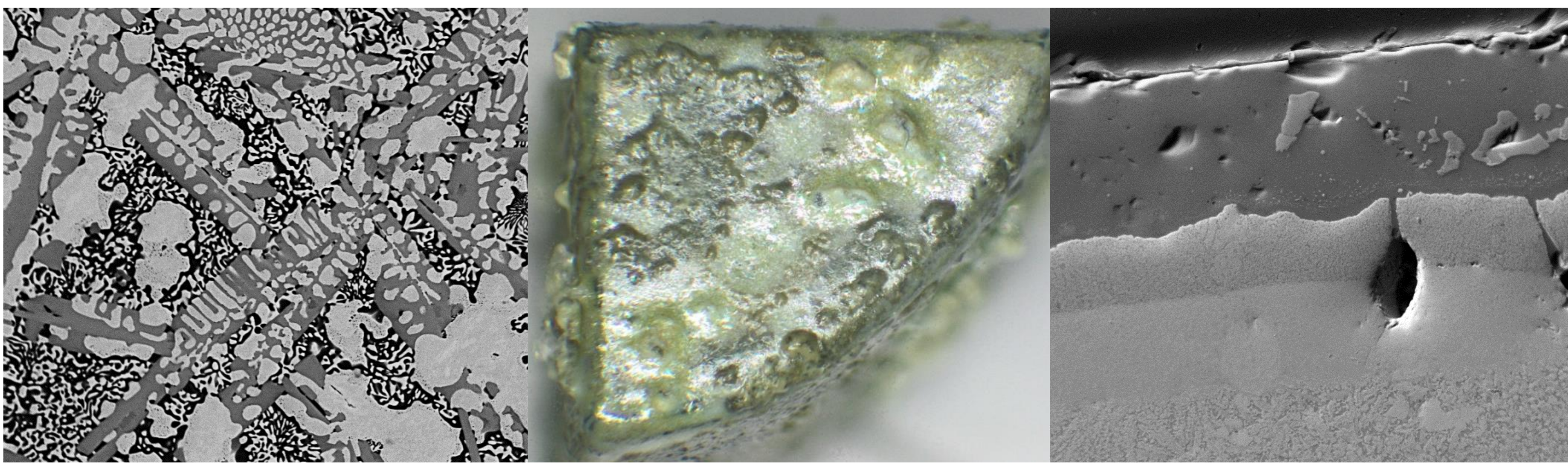


Motivation

- Mo-Si-B alloys
  - Possess oxidation resistance and good creep resistance at 1200 °C
  - Suffer from relatively high density (9.6 g/cm^3)
- Potential alternatives are Ti-rich Mo-Si-B alloys
  - Reduced density (7.8 g/cm^3)
  - Higher creep resistance
  - Lower oxidation resistance (formation of mixed $SiO_2 \cdot TiO_2$ duplex oxide scale)
- Improve oxidation behavior of Ti-rich Mo-Si-B alloys

↓

- Pack-cementation previously successfully applied to Mo-Si-B based alloys to enhance oxidation resistance

↓

- Transfer the process to Mo-Si-B-Ti

Material and experimental procedure

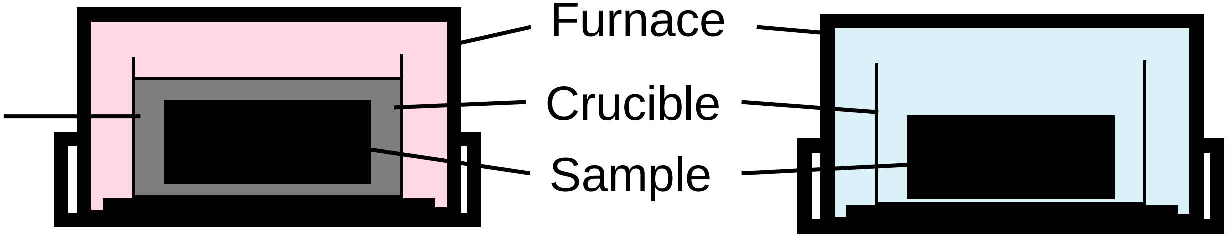
- Substrate to be coated: Mo-12.5Si-8.5B-27.5Ti (in at.%)
  - Prepared by arc-melting in Ar-atmosphere
  - Heat-treated at 1600 °C for 100 h

- Pack-cementation process / two-step process

1) Pack-coating at 1000 °C for 40 h in Ar-atmosphere

2) Conditioning at 1400 °C for 10 h in air

Powder mixture:
35 wt.% Si + B
2.5 wt.% NaF
62.5 wt.% Al_2O_3



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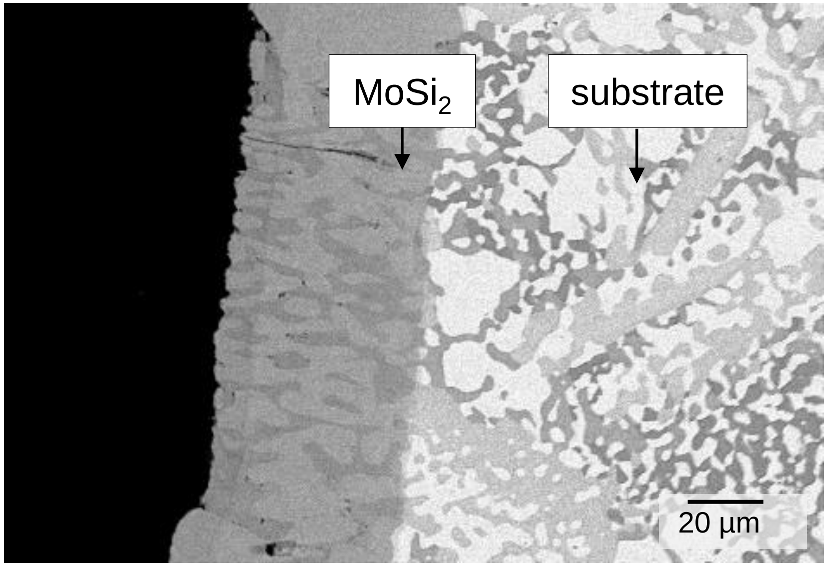
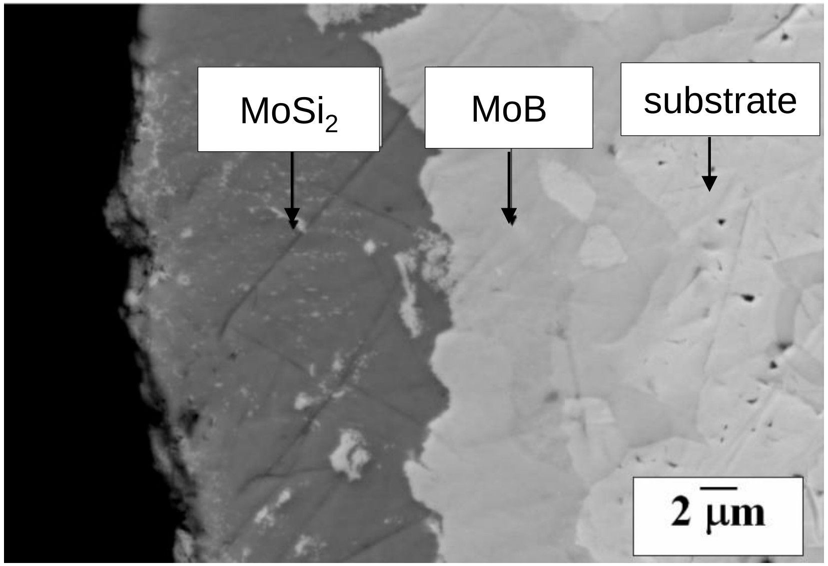
- Investigation
  - Cyclic oxidation experiments: between T (800, 1100, 1200 °C) and 25 °C
    → Oxidation kinetics up to 1000 h
  - Microstructure examination
    → Characterize layer development

Microstructure: layer after step 1

Si+B pack-cementation on Mo-12.5Si-8.5B-27.5Ti



Si+B pack-cementation on Ti-free Mo-alloy



R. Sakidja et al., Scripta Mater. 53, 723 (2005)

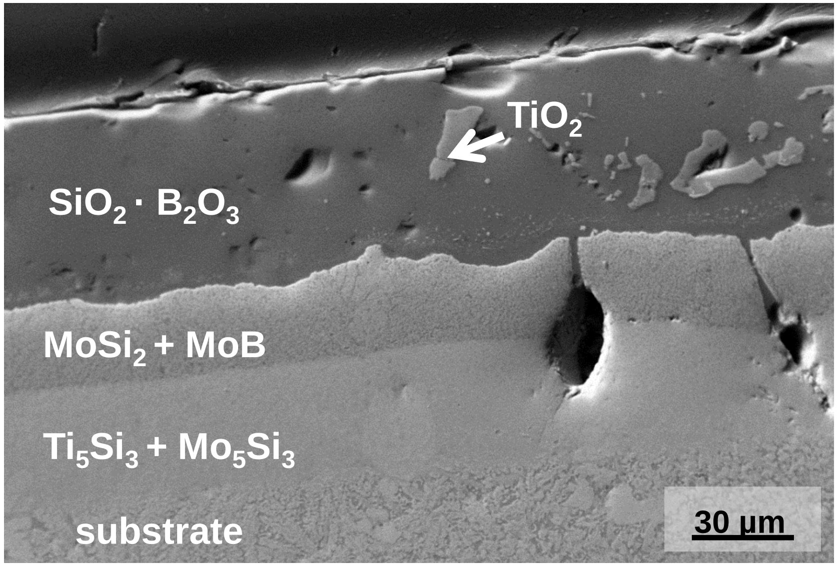
- Layer consists of $MoSi_2$ with a Ti content of 13 at.%
- No equilibrium between $MoSi_2$ layer and substrate

- Outer layer composed of $MoSi_2$ while inner layer is MoB
- MoB layer after cementation favors formation of Mo_5SiB_2 – acts as a diffusion barrier

Microstructure

Layer after conditioning (step 2)

Mo-12.5Si-8.5B-27.5Ti



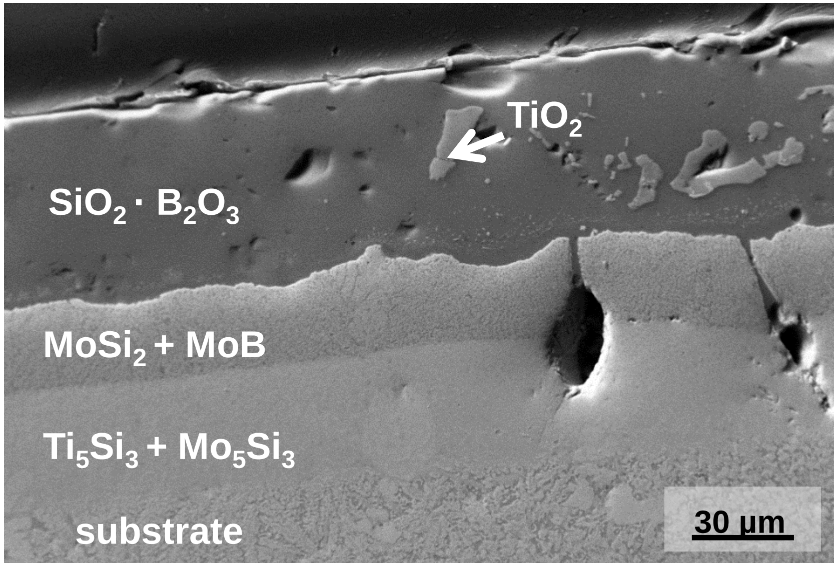
- Three separate layers

→ Oxide scale and two diffusion layers

Microstructure

Layer after conditioning (step 2)

Mo-12.5Si-8.5B-27.5Ti

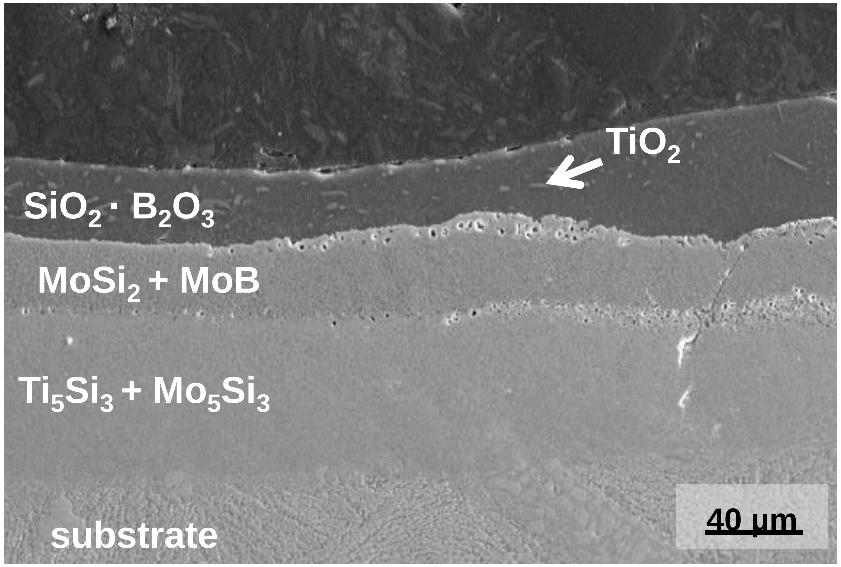


- Three separate layers

→ Oxide scale and two diffusion layers

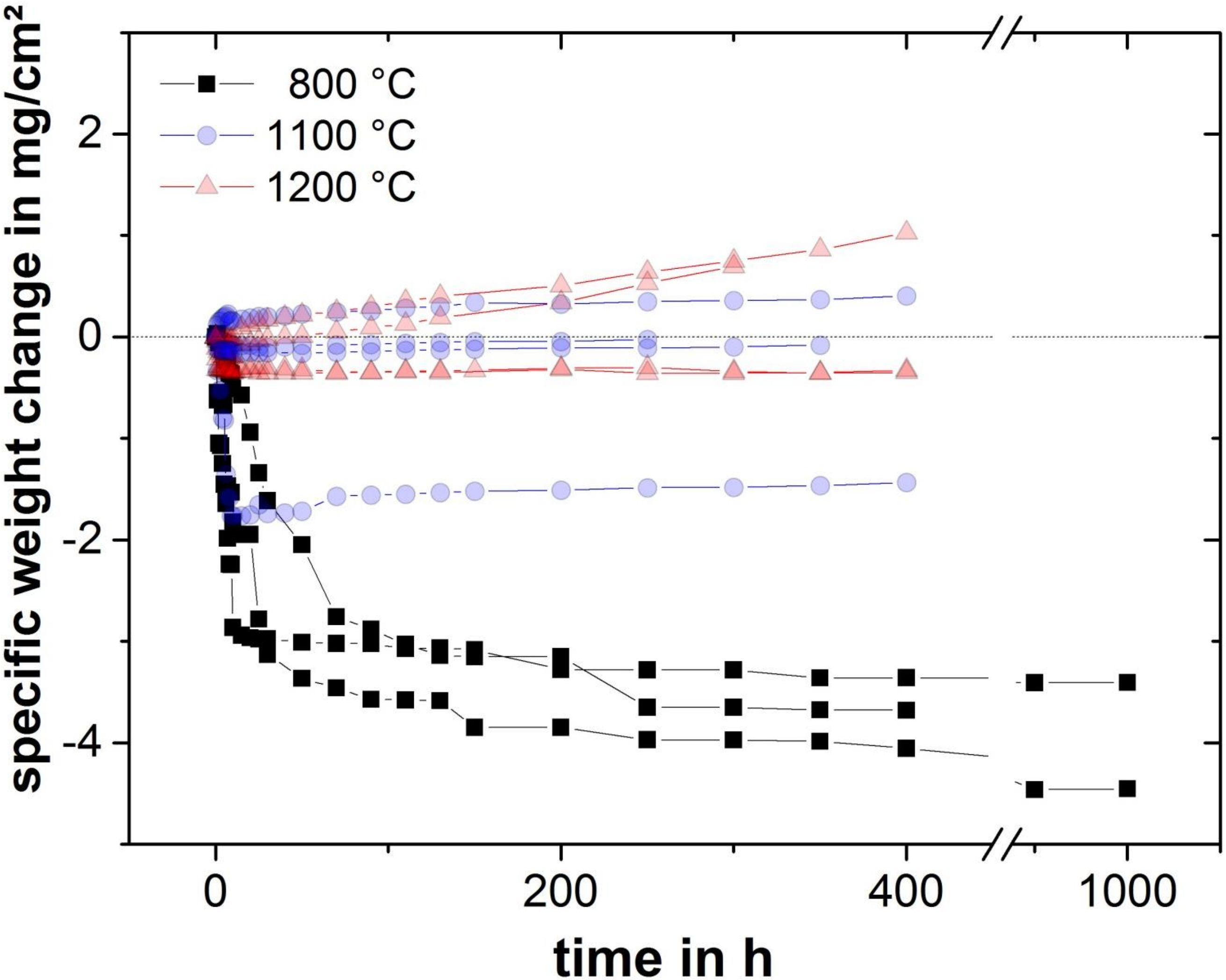
Layer after cyclic oxidation test

1100 °C for 500 h



- $MoSi_2$ layer still present
- No spalling
- Coating intact after thermal cycling

Oxidation behavior: Effect of temperature



- Weight change

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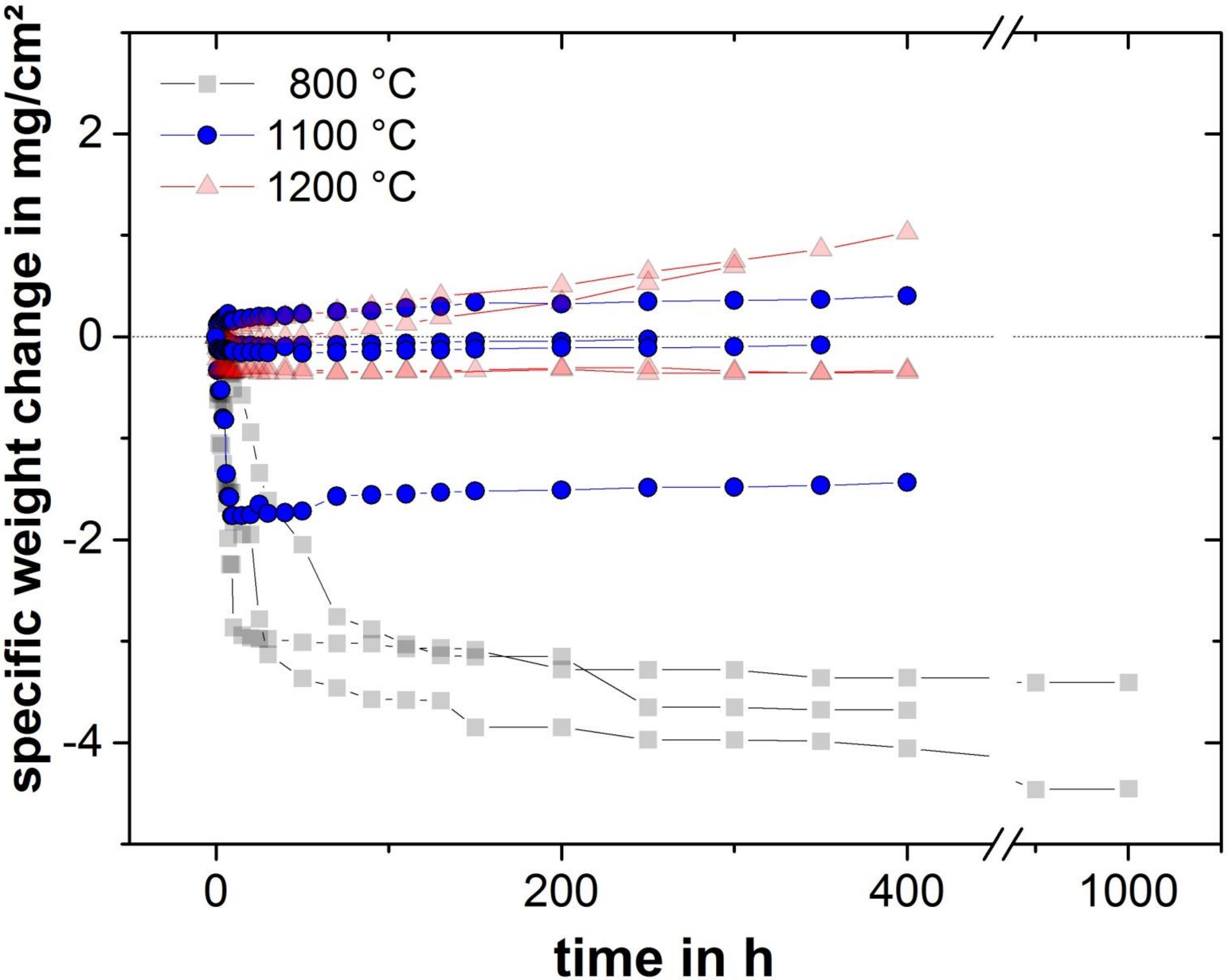
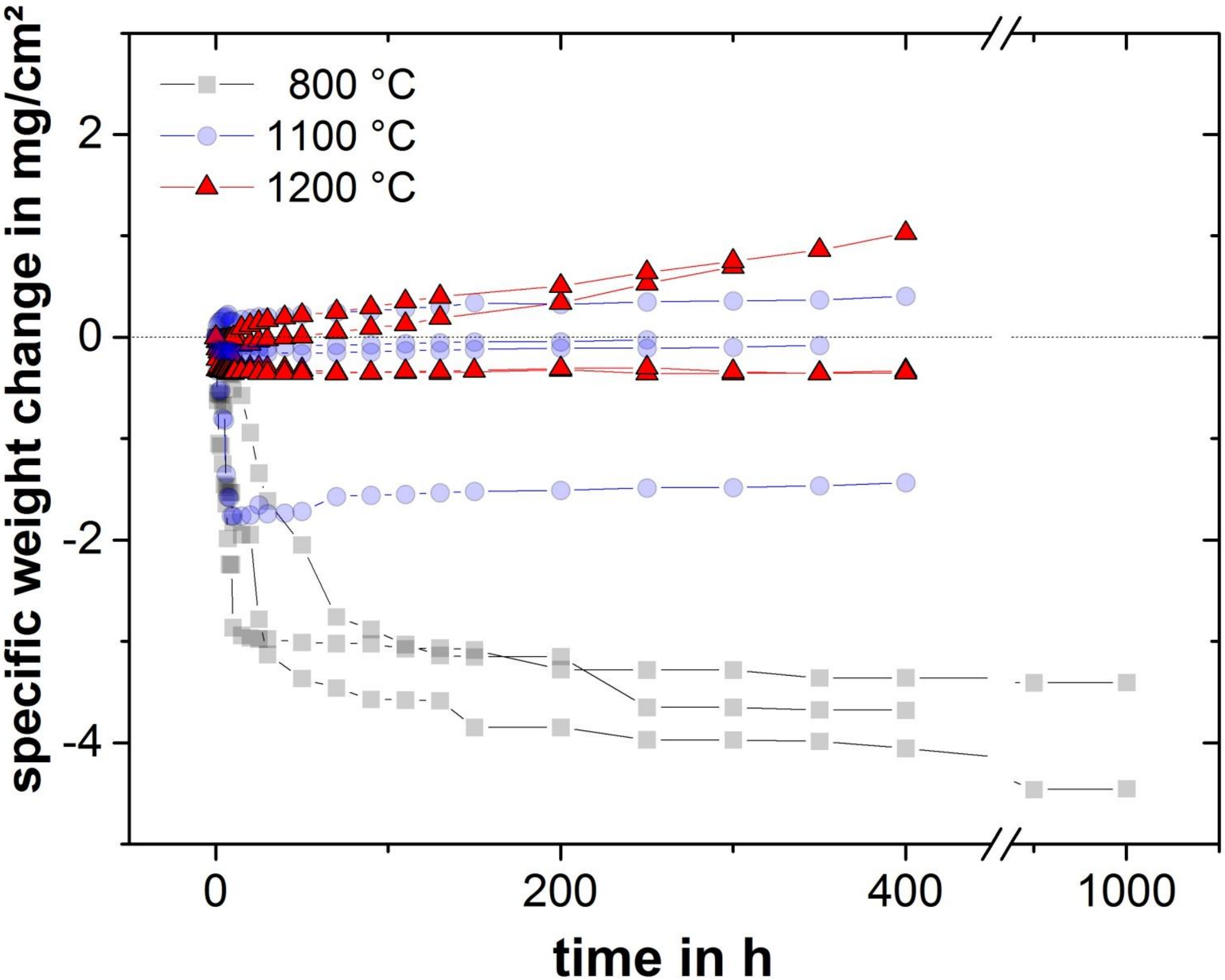
Oxidation behavior: Effect of temperature



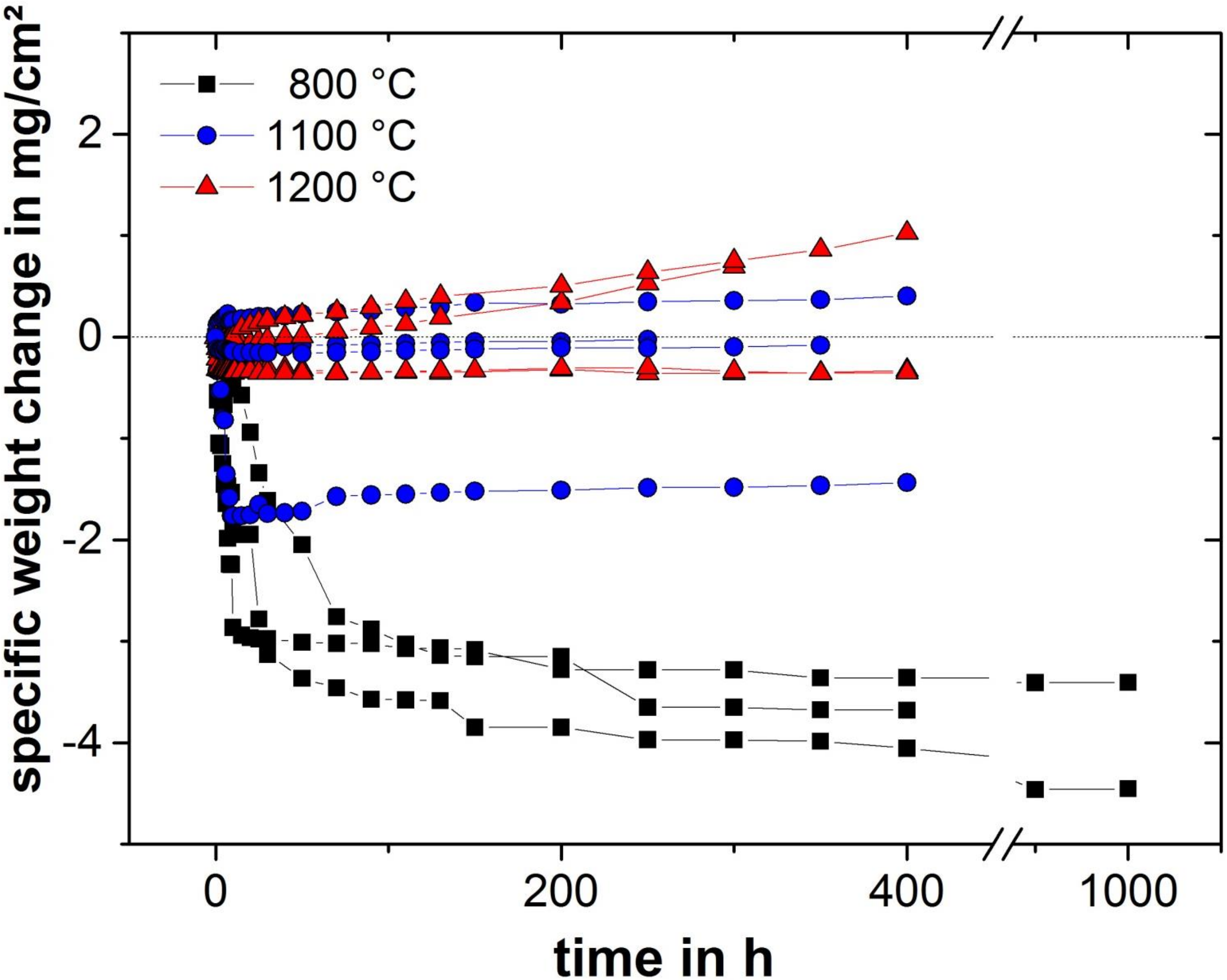
- Weight change
- Self-healing

Oxidation behavior: Effect of temperature



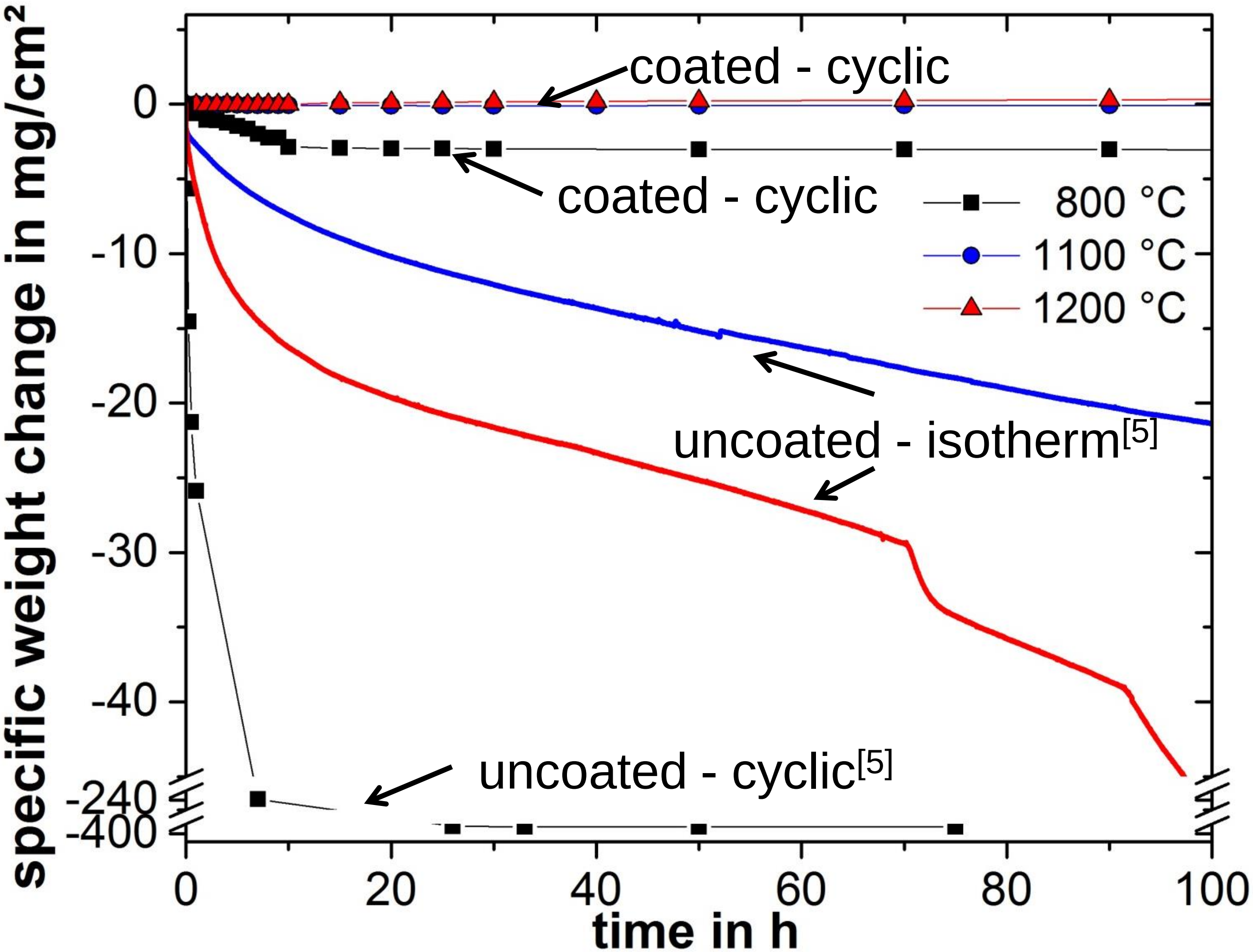
- Weight change
- Self-healing
- Temperature effect

Oxidation behavior: Summary



- $T_{oxidation}$ ↑
  - less initial weight loss
  - earlier transition to mass gain

Oxidation behavior: benefit of coating



Significant improvement of oxidation resistance

[5] M. A. Azim et al., *Oxid. Met.* 80, 231 (2013)

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Summary

- Same Pack-cementation process used for ternary Mo-Si-B can be also applied to Ti containing alloy, but it has a benefit of density
- Increasing temperatures
  - initial mass loss decrease
  - earlier turnover to mass gain
- Formation of a three layer coating during conditioning
  - consisting of borosilicate, $MoSi_2$ and Ti_5Si_3
- Layers are intact after thermal cycling and no spalling

Thank you for listening

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