Analysis of the interaction between liquid tin and austenitic steels, nickel-based alloys as well as protective surface layers at high temperature

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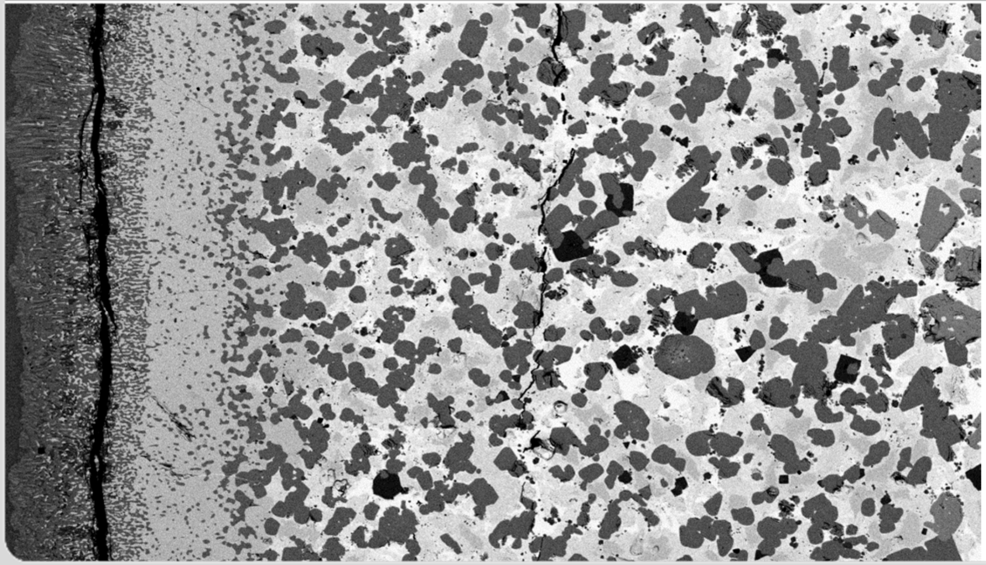
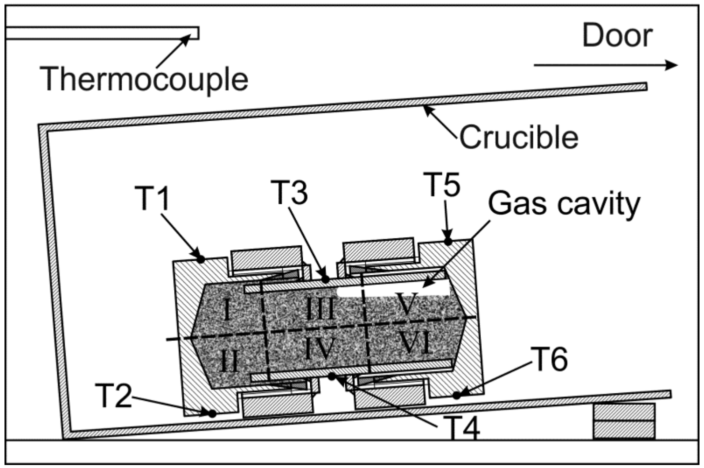
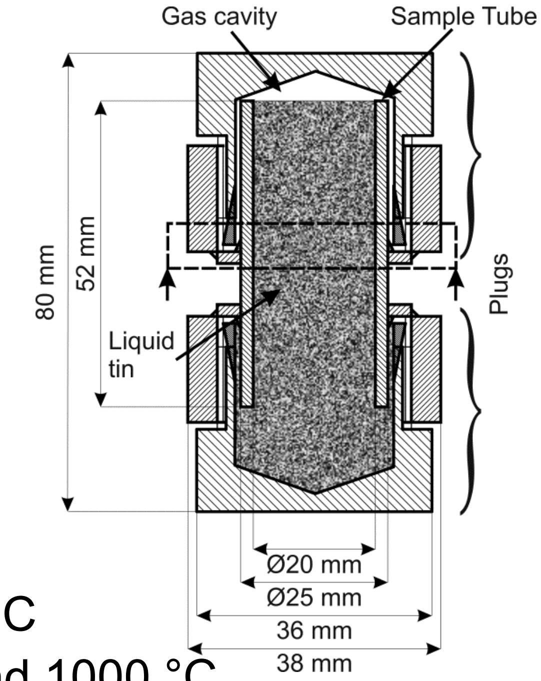


Liquid tin

- Application as a heat transfer medium
  - Large liquid temperature range 232 – 2620 °C
  - High heat flux
  - Not volatile or toxic
- Corrosion of metallic materials
  - Solution of alloying elements
  - Formation of intermetallic phases with Sn (stannides)
- Compatible materials
  - Rhenium, tungsten, quartz-glass, ceramics, graphite
- Alternative
  - Protective surface layers on steels or Ni-based alloys

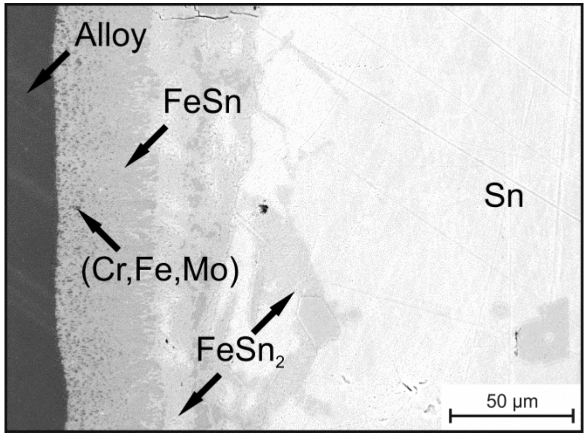
Experimental



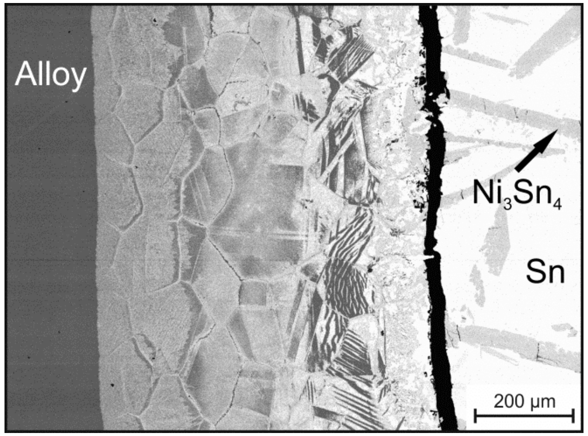


- Tin filled tubular samples
  - Austenitic steels (1.4301, 1.4571) at 500 and 700 °C
  - Ni-based alloys (2,4642, 2.4650, 2.4663) at 700 and 1000 °C
- Procedure
  - Testing at 500, 700 and 1000 °C for 25, 50 und 100 h
  - Formation of surface layers by gas-phase processes and PVD
- Post-test analysis
  - Measurement of material loss
  - OM, REM, EDX and XRD

Corrosion by liquid tin



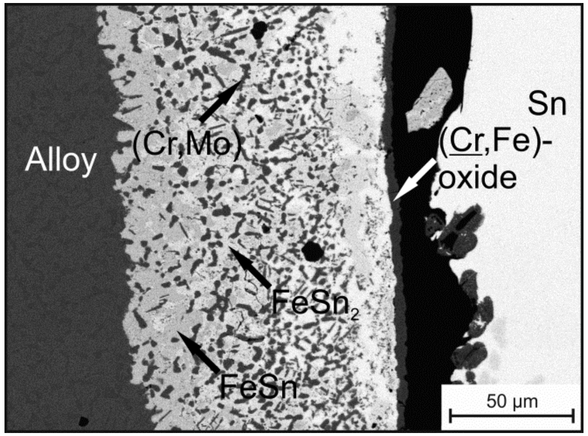
1.4571 at 700 °C for 25 h



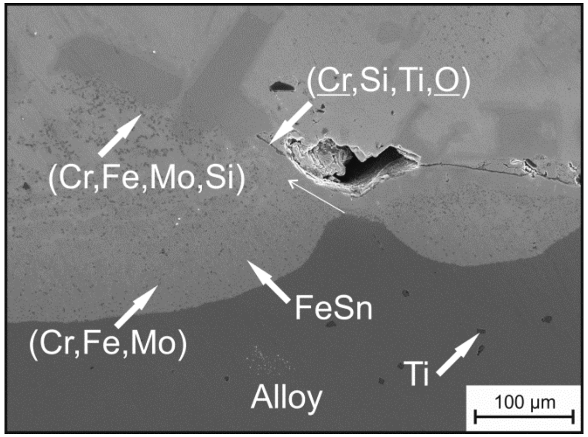
2.4663 at 700 °C for 25 h

- Steels and Ni-based alloys
  - Solution of alloying elements, especially Ni
  - Penetration by Sn
  - Cr, Fe and Mo form α-, σ- or similar phases
  - Steels formation of stannide layers
  - Stannides allow solutes to re-precipitate in case of local saturation of the melt
- Material losses
  - Steels at 500 °C: 40 µm after 100 h
  - Steels at 700 °C: 150 µm after 100 h
  - Ni-based alloys at 700 °C: 1100 µm after 50 h
  - Ni-based alloys at 1000 °C: 2500 µm after 25 h

Surface layers



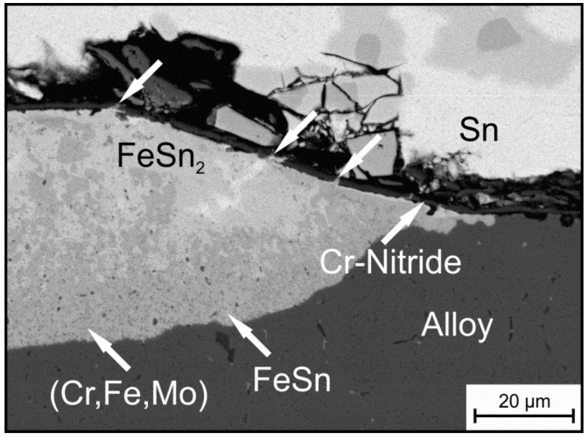
1.4571 at 700 °C for 100 h



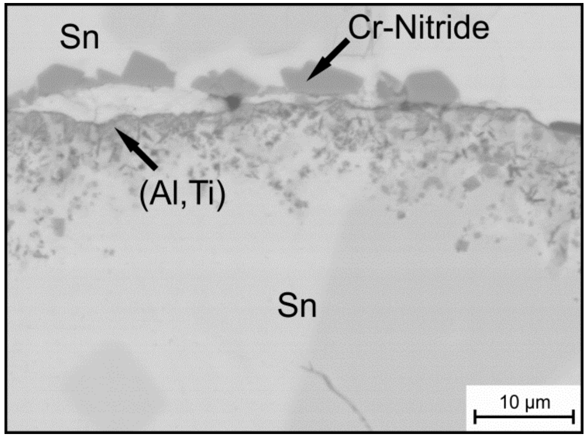
1.4571 at 700 °C for 100 h

- Low pressure carburisation
  - At 1000 °C in propane
  - Internal carbides instead of layer
  - No significant reduction of corrosion at 700 °C
- High temperature gas oxidation
  - At 800 °C in flowing Ar
  - Continuous oxide layers
  - Oxide layers partially dissolved
  - Local protection of alloy at 700 °C

Surface layers



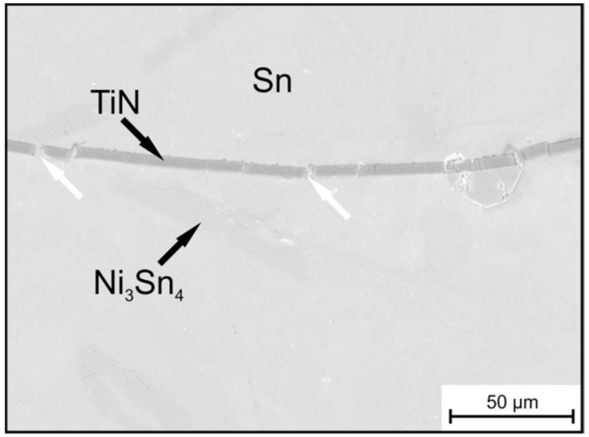
1.4571 at 700 °C for 100 h



2.4642 at 700 °C for 100 h

- High temperature gas nitration
  - At 800 °C in flowing N_2
  - Continuous Cr-nitride layers
  - 1.4571 sample mainly protected (700 °C,100 h)
  - Local penetration by Sn through defects
  - Cr-nitride layers on 2.4642 were transformed into (Al, Ti)-nitrides

Surface layers



2.4663 at 700 °C for 50 h

- Physical vapor deposition
  - 5 µm thick layers of TiC and TiN on 2.4663
  - Layer defects formed, likely due to different thermal expansion than substrate
  - Penetration by Sn through defects
  - No transformation of TiC and TiN observed

Conclusions

- Corrosion
  - Dense protective surface layers necessary to prevent solution of alloying elements, especially leaching of Ni
  - Short grace periods, especially at 1000 °C
  - Precise corrosion monitoring necessary
- Oxides
  - Thick layers necessary for longer durability
  - Stabilisation by oxygen content in melt
- Nitrides
  - Improvement of process to ensure layer continuity
  - Alloys with higher alloying content of Al or Ti than Cr
- PVD
  - Multi-layer, or gradually structured layers to compensate thermal expansion difference

Thank you for your attention!

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