NUMERICAL ANALYSIS OF THE PHASE CHANGE BEHAVIOR OF HIGH POWER LATENT HEAT STORAGES WITH 3D WIRE STRUCTURES

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Overview

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  - Latent Heat Storage
  - 3D Wire Structure
- Definition and Modelling the Unit Cell
  - Simplifications
  - Phase Change
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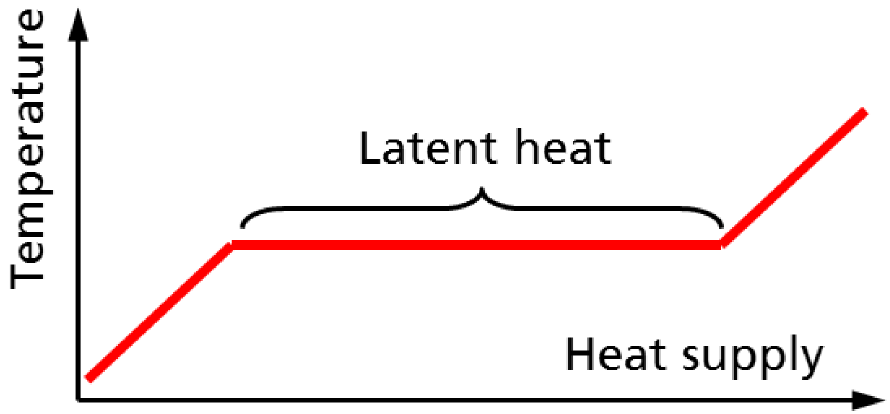
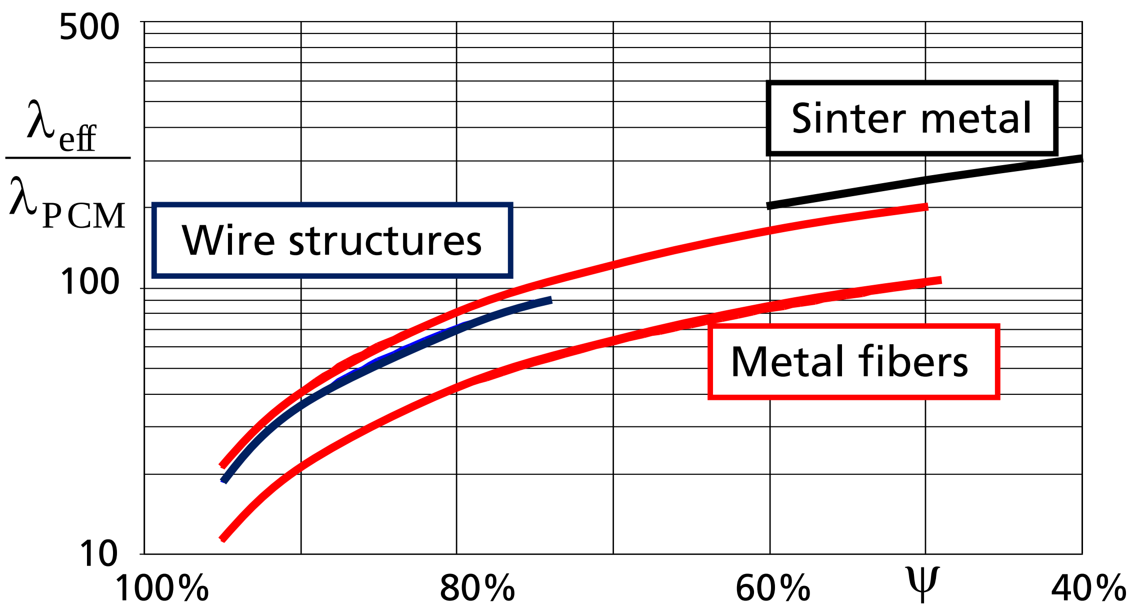
- Simplified Geometry
  - Modelling
  - Thermal Behavior Validation
- Conclusions

Latent Heat Storage with Tailored Power and Capacity

- Latent heat storage
  → Using phase change solid – liquid to store thermal energy



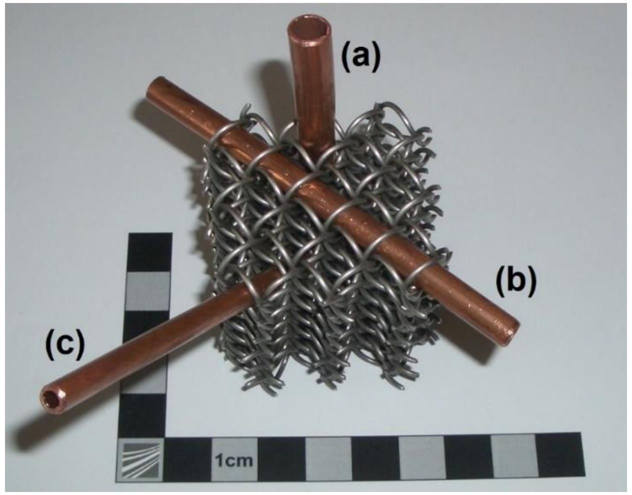
- Open porous metal structure as heat conductive structure to increase storage power

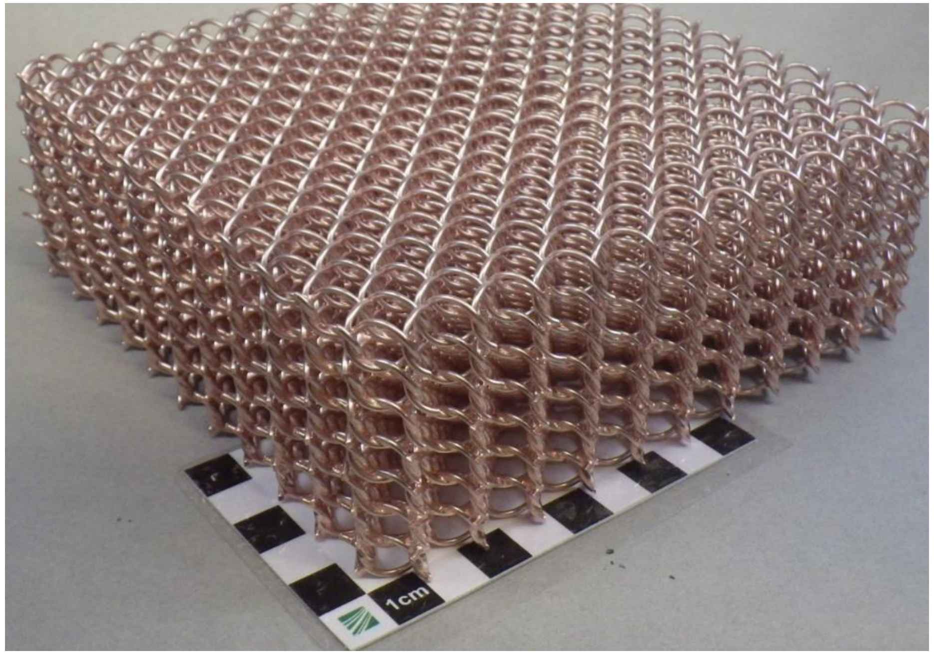


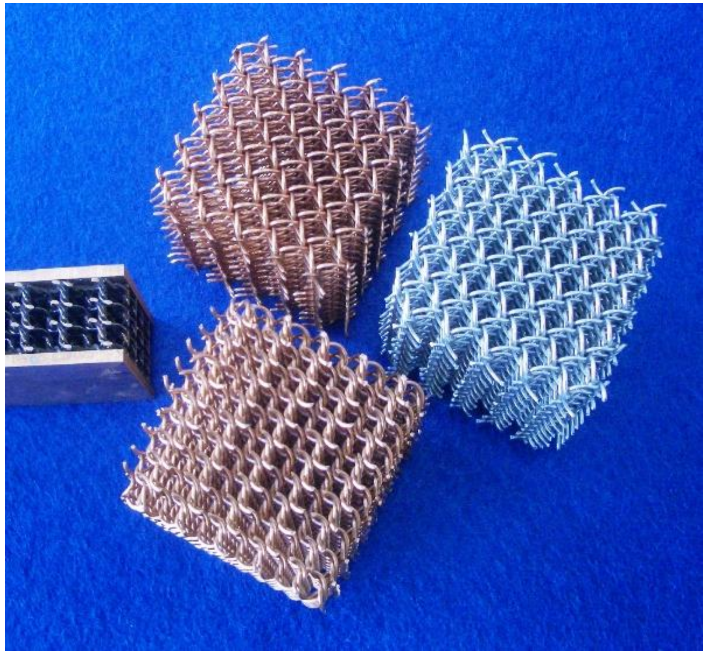
3D Wire Structure

- Based on regular helices twisted together parallel and perpendicular in one plane and stacked into 3D structure

- Heat carrier pipes fit in multiple directions in the modelled pores (option (a) is preferred)

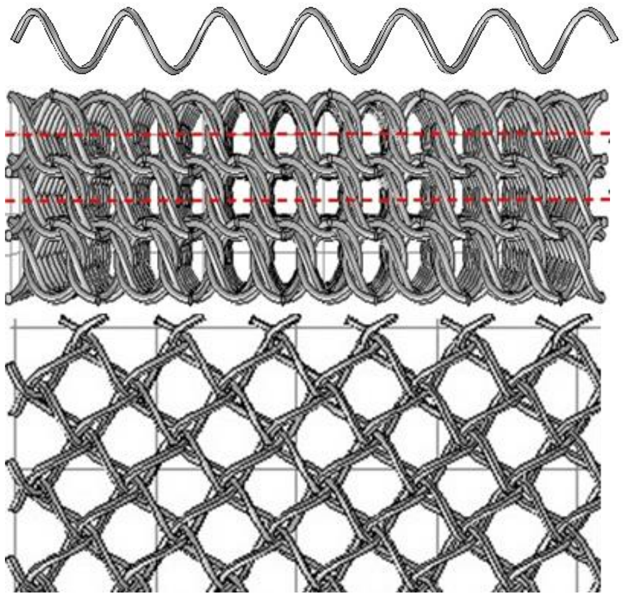


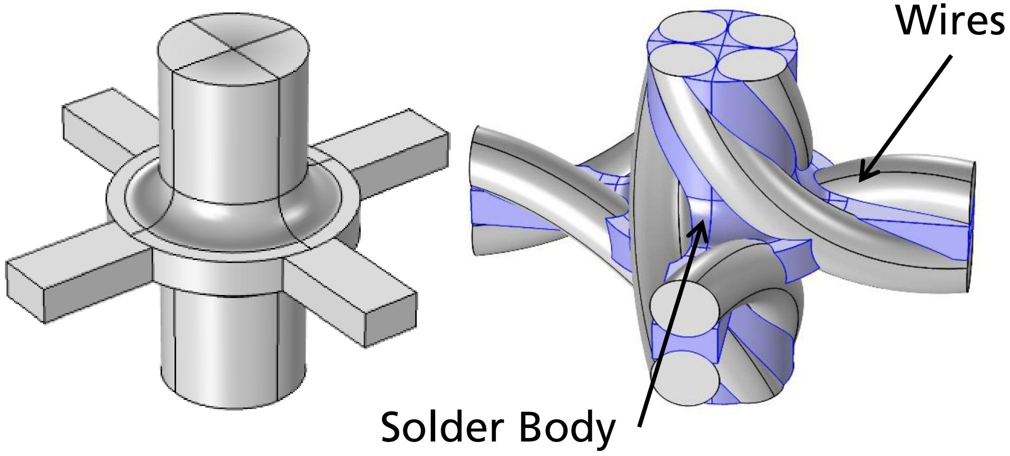


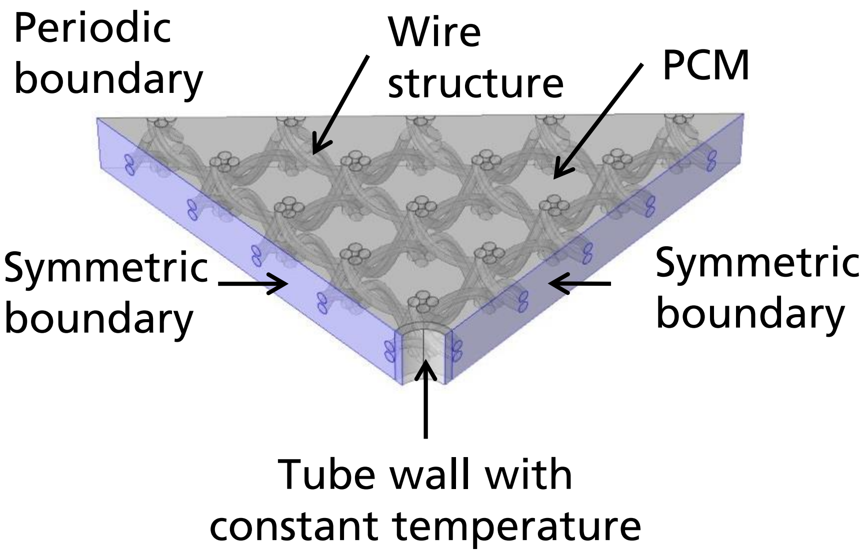


Geometric Model and Simplifications

- Full geometric modelling within COMSOL
- Complexity reduction by using symmetry, periodicity
- Constant temperature as thermal source
- Brazed Structure modelled by Boolean combination with solder body







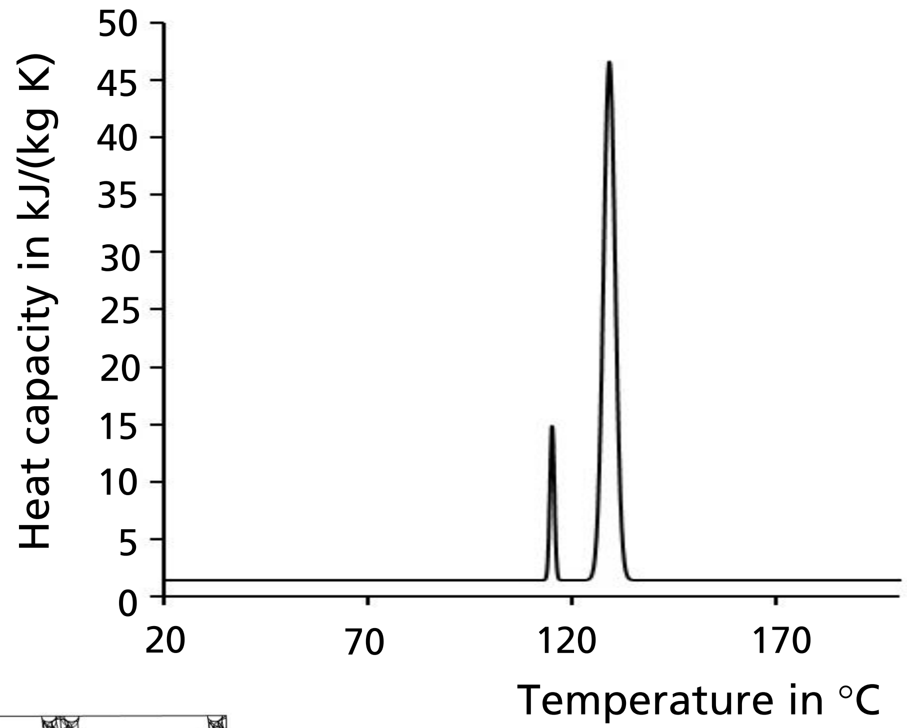
Modelling the Phase Change and Melting Time Analysis

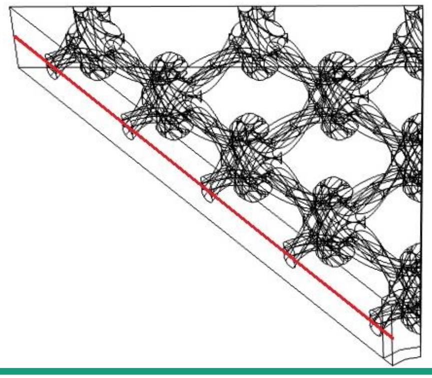
- Simulation of eutectic mixture of $LiNO_3$ – KNO_3 with 33 wt.-% $LiNO_3$

- Complex melting behavior with two phase changes
  → solid-solid change at 115 °C ± 1.5 K with 18 kJ/kg
  → solid-liquid change at 133 °C ± 4.0 K with 160 kJ/kg

- Heat of fusion represented by peaks within the temperature dependent heat capacity

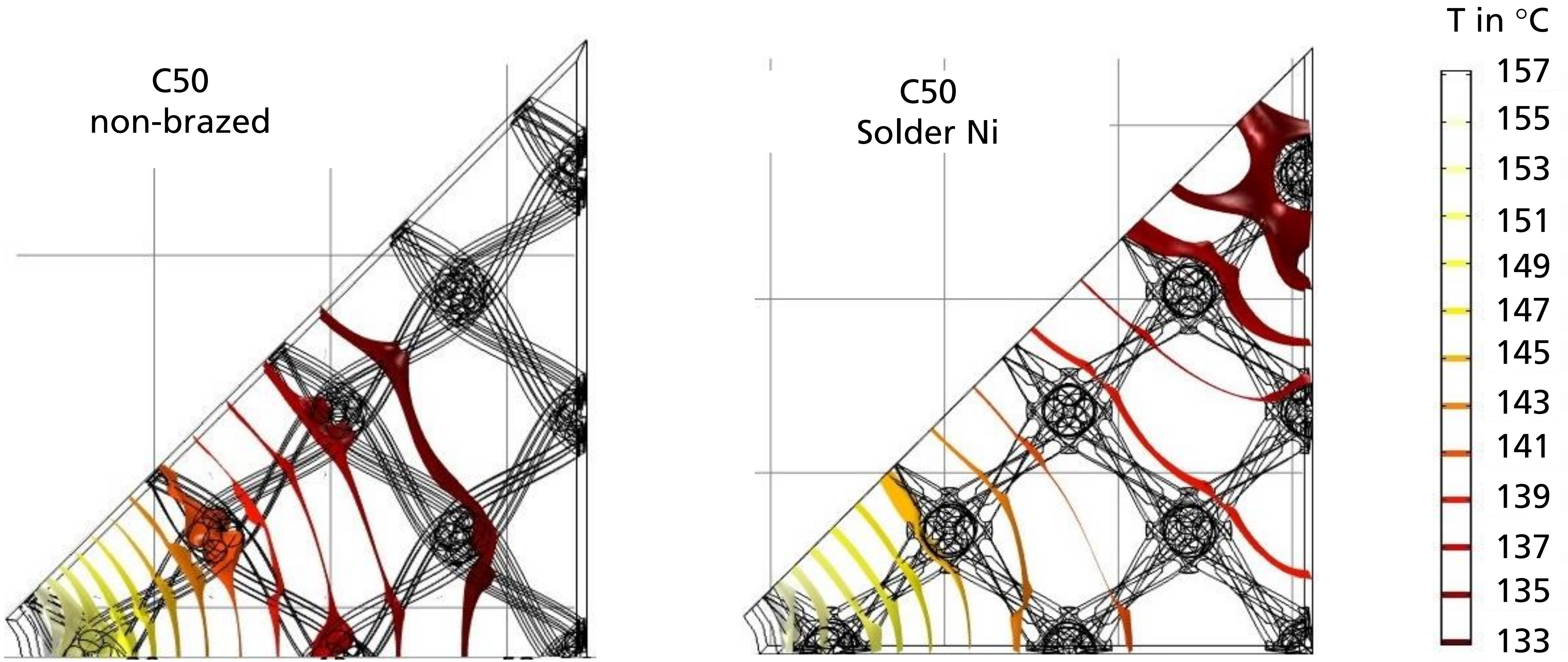
- Melting Time is defined when the whole PCM within the unit cell has changed to liquid phase
  → monitoring the heat capacity at a cutline (red) for every calculated time step





Results: Influence of brazing

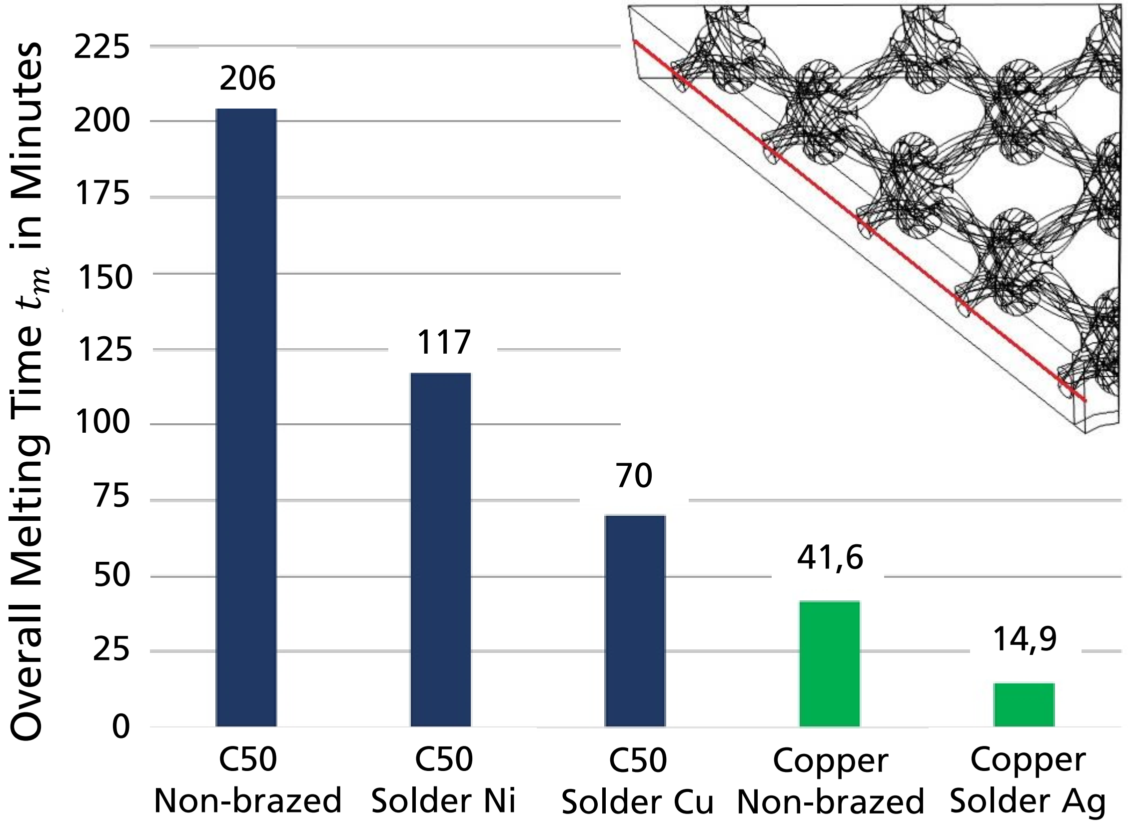
- Brazed structure shows a clearly more advanced melting front
  → considerably higher storage power possible



Temperature distribution within the unit cell at a time of 100 minutes

Results: Influence of Material Combinations

- Wire materials with high heat conductivity result in significantly shorter melting time
- Brazing the structure also reduces melting time
- Copper brazed C50 wire structure represents a highly cost effective option with good storage power

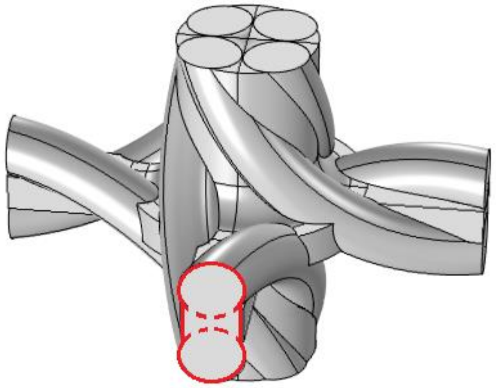


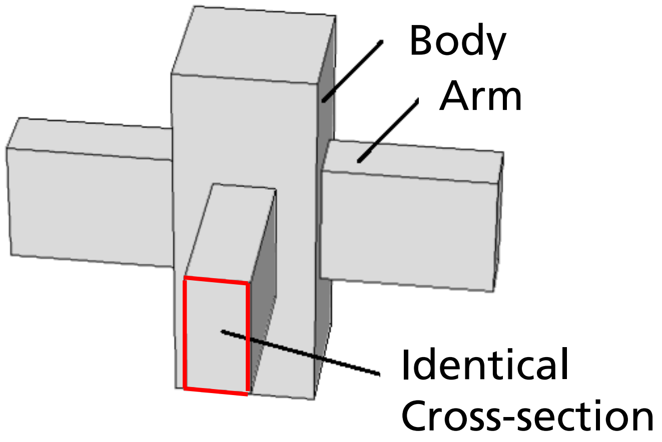
Modelling the Simplified Geometry

- Different length scales within the full model lead to high mesh resolution and simulation times
  → upscaling to whole heat storage system is difficult

- Solution: simplification of the wire crossroads to reduce scale differences

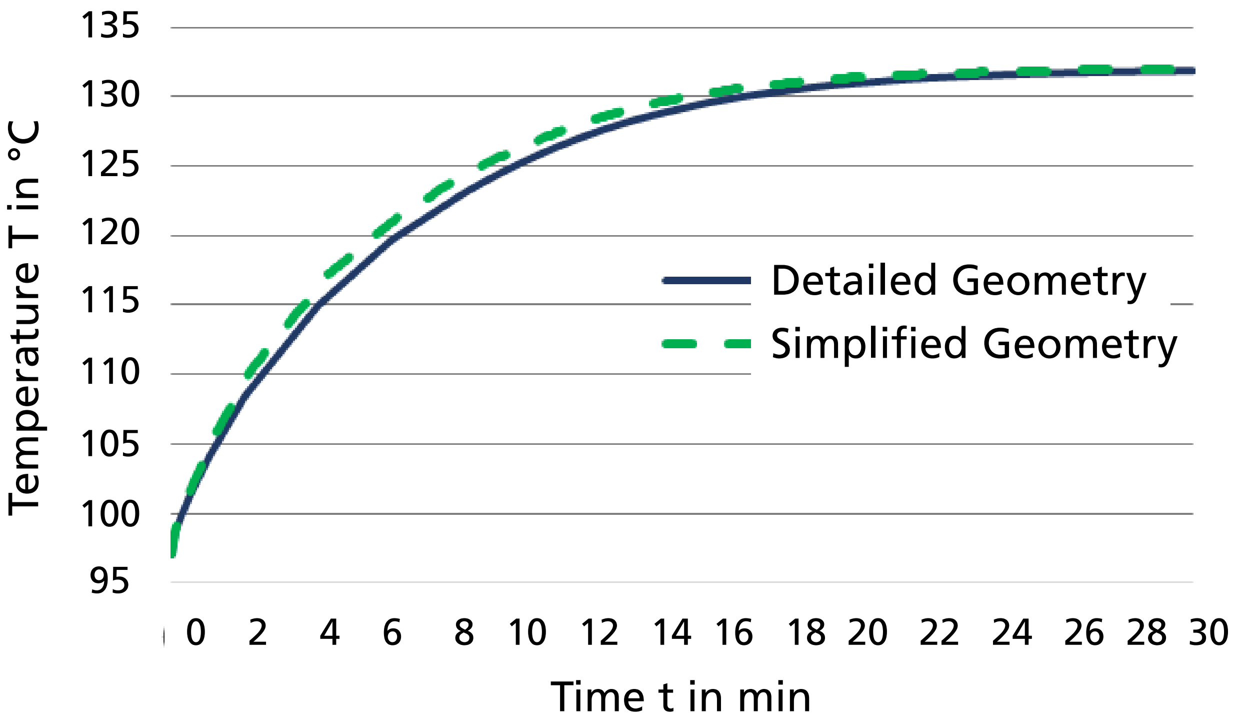
- Conditions:
  - Identical volume, heat transfer surface and heat conductive area connecting two crossroads
  - Identical thermal behavior by maintaining thermal properties





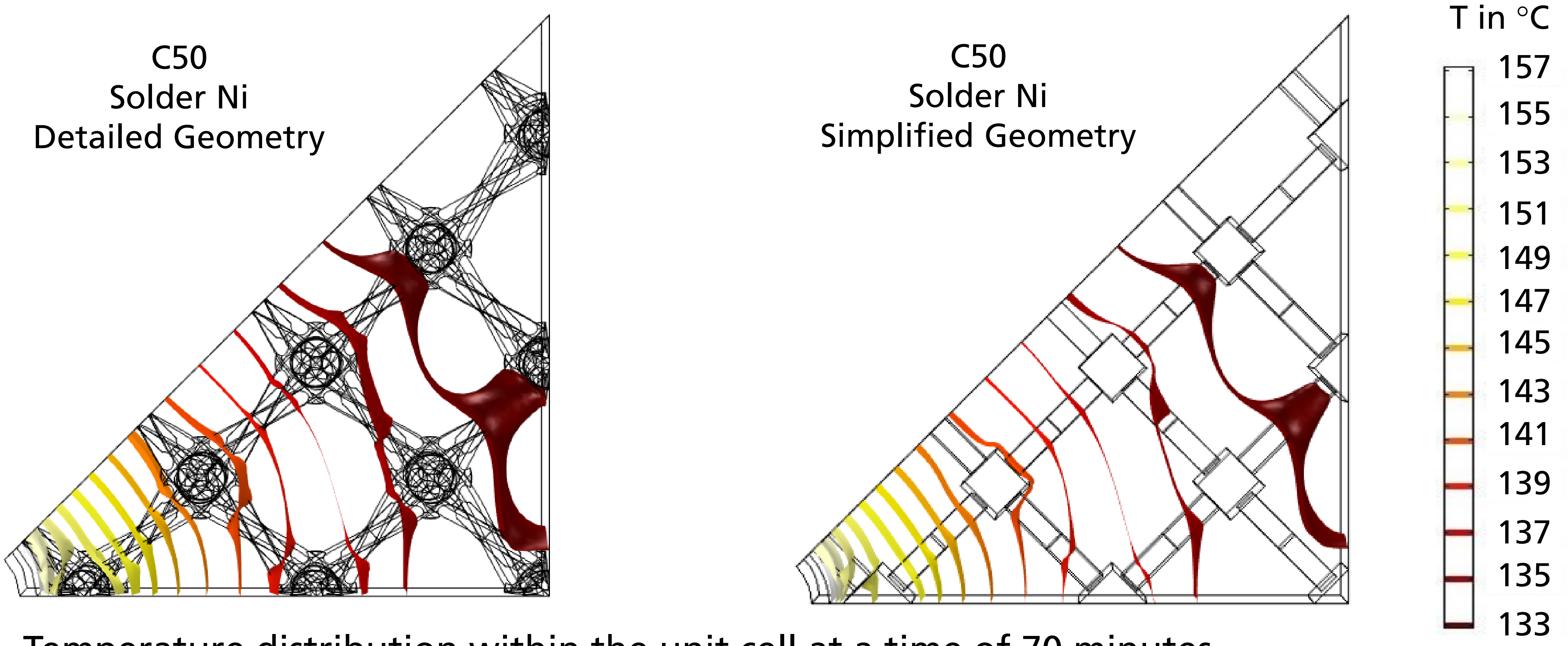
Simplified Model: Thermal Behavior Validation

- Thermal properties of arm and body modelled separately
- Use of mass weighted mixture resulted in ≈10 % variation in melting time
- Compensation by an empirical coefficient
  - Determined by comparative simulations
  - Coefficient Range 0.90 … 1.05
  - Coefficient depends on wire/solder material combination
- Use of simplified geometry reduces simulation time by 25 %



Simplified Model: Thermal Behavior Validation

- Compensation coefficient for material combination C50/Ni: 0.91
  → Both models show identical thermal behavior
  → upscaling to whole storage with simplified model possible



Temperature distribution within the unit cell at a time of 70 minutes

Conclusions

- Open porous metal structures, such as 3D wire structures, increase the power of latent heat storages.
- The presented simulation model allows the investigation of transient phase change behavior within a unit cell.
- Two main impact factors on storage power were identified: wire material and brazing the structure.
- A brazed C50 structure is a very cost effective option compared to using copper as wire material.
- The developed simplified geometry allows the design of tailored latent heat storages for any given application.

Acknowledgement

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