Numerical Analysis of the Phase Change Behavior of High Power Latent Heat Storages with 3D Wire Structures

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Introduction: Latent heat storage devices use the phase change of a phase change material (PCM) to store energy at a nearly constant temperature with a high volumetric storage density. The main drawback of the most common PCM is their low heat conductivity and, therefore, the storage power is limited. Open porous metals, such as 3D wire structures, are able to improve the effective heat conductivity of the system. This allows the design of systems with tailored storage capacity and power.

Geometrical Model and Simplifications: The 3D wire structure strucwire® is shown in Figure 1. Market available pipes fit in the meshes and were placed every 5th mesh. Using the symmetric and periodic properties of the structure, the resulting simulation model can be seen in Figure 2.

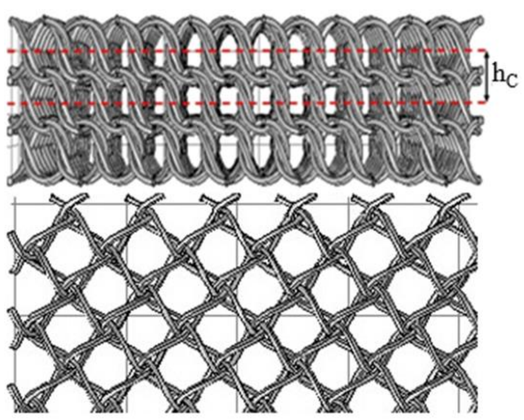

Figure 1. Geometrical Model of the 3D wire structure (top: front view, bottom: top view).

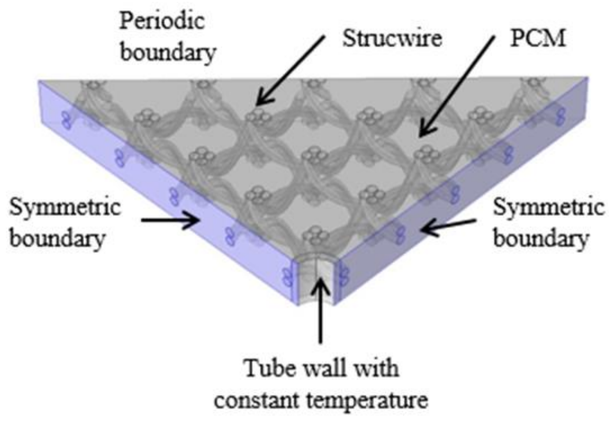

Figure 2. Resulting simulation model with boundary conditions.

Brazing the 3D wire structures increases their effective heat conductivity and structural integrity. The solder was modeled geometrically by a solder body (Figure 3, left) which was integrated into the wire crossroads by Boolean operations (Figure 3, mid). The geometric resolution of the junctions was reduced (Figure 3, right) in order to simulate a large scale storage. Effective thermal properties were based on the weight composition of each and every part .

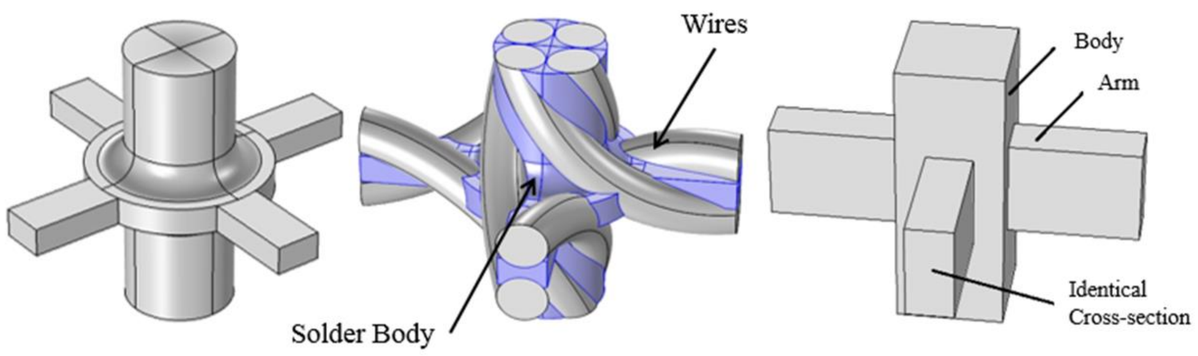

Figure 3. Solder Body (left), Body combined with wires in a crossroad (mid) and the simplified model (right)

Methods and Modelling: For validation purposes, the eutectic mixture of 33 wt.-% LiNO3 – KNO3 with a melting temperature of 406 K was simulated. Simulations start at 396 K and the heat source has a temperature of 431 K. Wire material C50 and Cu were investigated with Ni/Cu and Ag as solder, respectively.

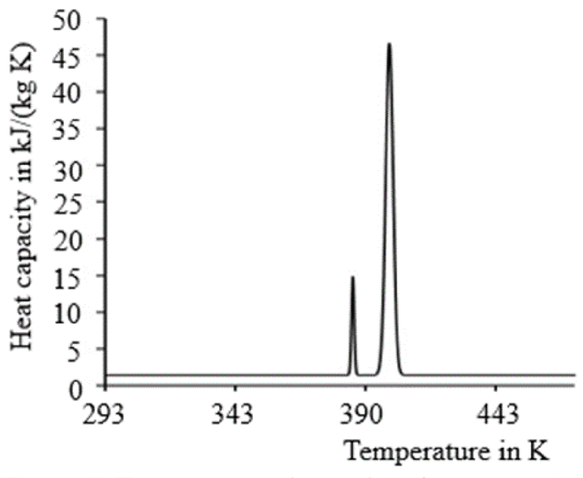

Figure 4. Temperature dependent heat capacity of the used PCM including both phase changes.

The used PCM has two separate phase changes within the simulated temperature range [1]. The first phase change is considered as a solid-solid change at a about (388 ± 1.5) K with an enthalpy of about 18 kJ/kg. The second phase change is the actual melting at about (406 ± 4) K with a heat of fusion of 160 kJ/kg. Both phase changes are represented by peaks within the heat capacity function as shown in Figure 4.

Results and Discussion: Figure 5 shows isothermal surfaces throughout the unit cell after 100 minutes of heating for a non-brazed and brazed C50 wire structure. The dark red isothermal surface represents the position of the melting front at 406 K.

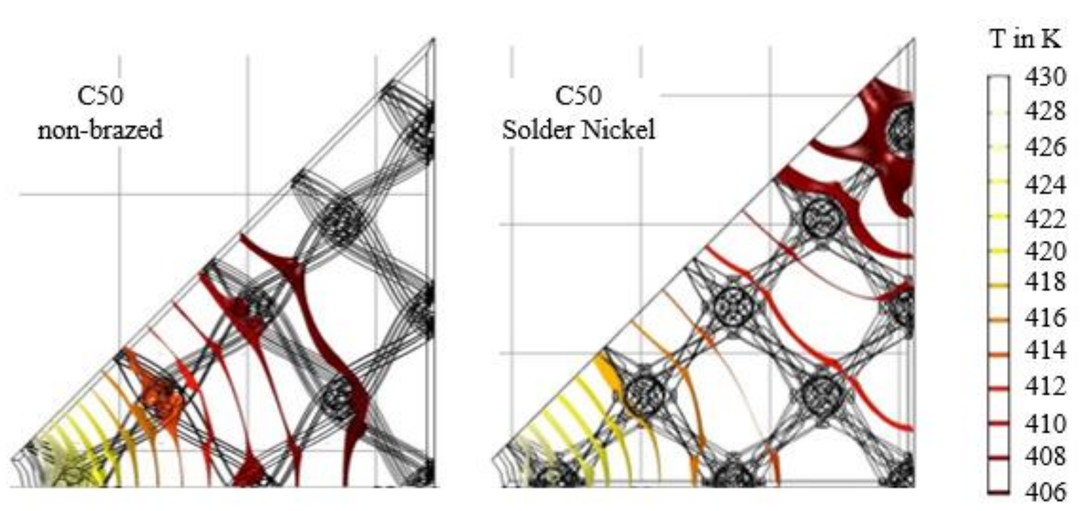

Figure 5. Temperature distribution within the unit cell at a time of 100 minutes.

The melting front is slightly more advanced in the vicinity of the wires. As expected, the brazed structure results in a faster melting of the PCM and, therefore, the melt front has almost reached the end of the unit cell by the given time. Hence brazed wire structures will result in considerably higher storage power.
Similar simulations were conducted for the given wire and solder materials and the time needed to fully melt the unit cell was compared. The results are shown in Figure 6.

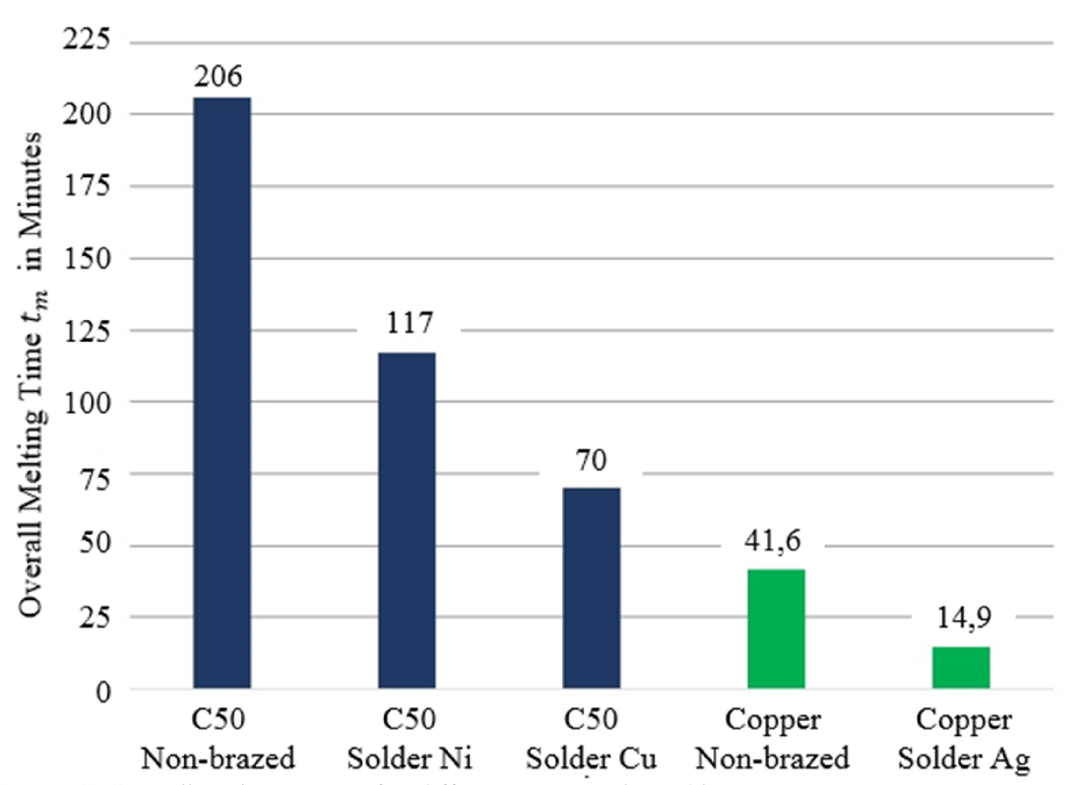

Figure 6. Overall melting times for different materials and brazes.

As expected, high conductive wire materials and brazing the structure lead to significantly lower melting times and, therefore, higher storage power. By changing the wire structure's mesh size it is possible to design tailored storage systems for a wide range of applications.

Conclusions: The transient behavior of the phase change within a latent heat storage with 3D wire structures was simulated. The detailed model for a unit cell was validated with experimental measurements. To allow simulations of entire storages, a simplified model was developed and validated. Both developed models can be used to investigate different wire and solder materials and alternative PCM. Therefore, it is possible to design a tailored latent heat storage in terms of power and capacity for any given application.

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References:

1. Tamme, R.; Bauer, T.; Buschle, J.; Laing, D.; Müller-Steinhagen, H.;Steinmann, W.-D.: Latent heat storage above 120 °C for applications in the industrial process heat sector and solar power generation. In: International Journal of Energy Research, 32 (2008), 3: 264–271. DOI: 10.1002/er.1346.