2D FE Modeling of the Thermal History of the Heat Affected Zone in AlSi10Mg LPBF

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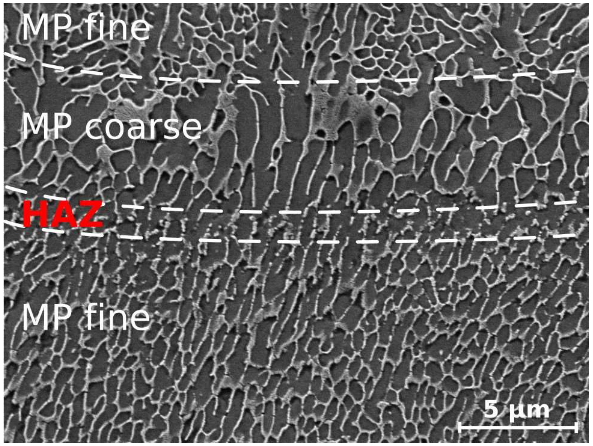
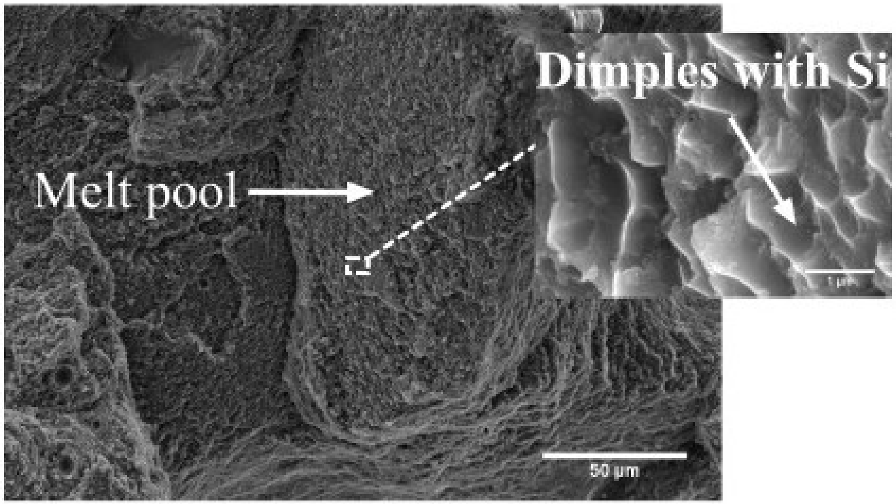
Motivation



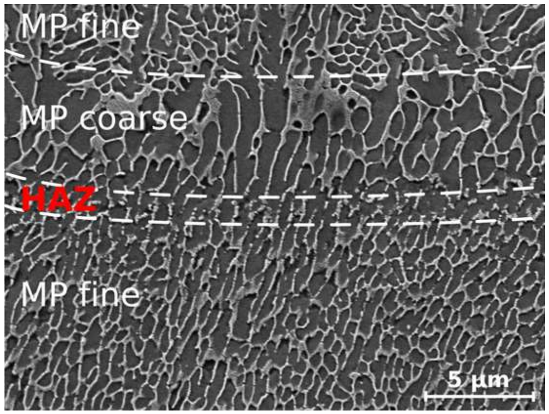
So far, AlSi10Mg is the most studied Al alloy in LPBF due to its ease of processing (good weldability, high melt fluidity...)

Microstructural heterogeneity at melt pool scale brings a **loss in ductility** in AlSi10Mg LPBF

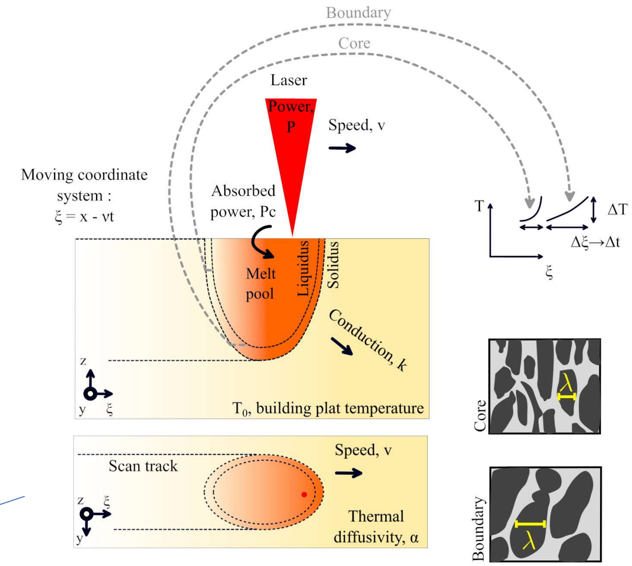
Melt pool boundary, Heat affected Zone (HAZ) in particular, act as preferred site for damage initiation and fracture
[Delahaye et al., Acta Mater. (2019)]



Motivation

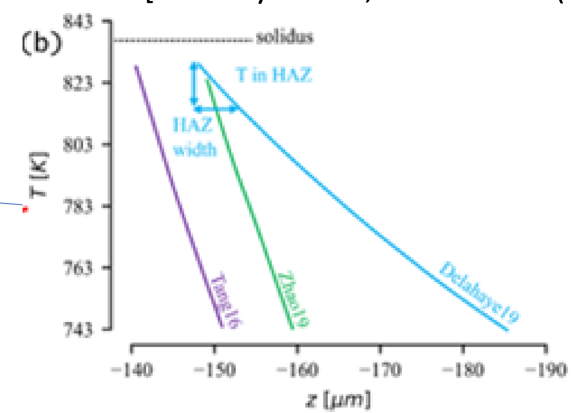


⇒ 2 possible solutions to reduce the heterogeneity:
(1) post-treatments (at expense of a loss of strength) or
(2) optimizing the processing parameters



[Delahaye et al., Acta Mater. (2019)]

- Cell size determined by cooling rate during solidification
- HAZ thickness determined by the maximum temperature and residence time during re-heating



[Mertens et al., Proc. Manuf. (2021)]

Here: Development and calibration of a 2D FE model to guide the optimisation of the processing parameters

Finite Element model

- FE model using the FE code LAGAMINE (developed in-house at ULiège)
- Element birth and death technique is used to switch between desactivated elements, unfused powder and bulk material
- Temperature evolution (non-linear equation for isotropic material):

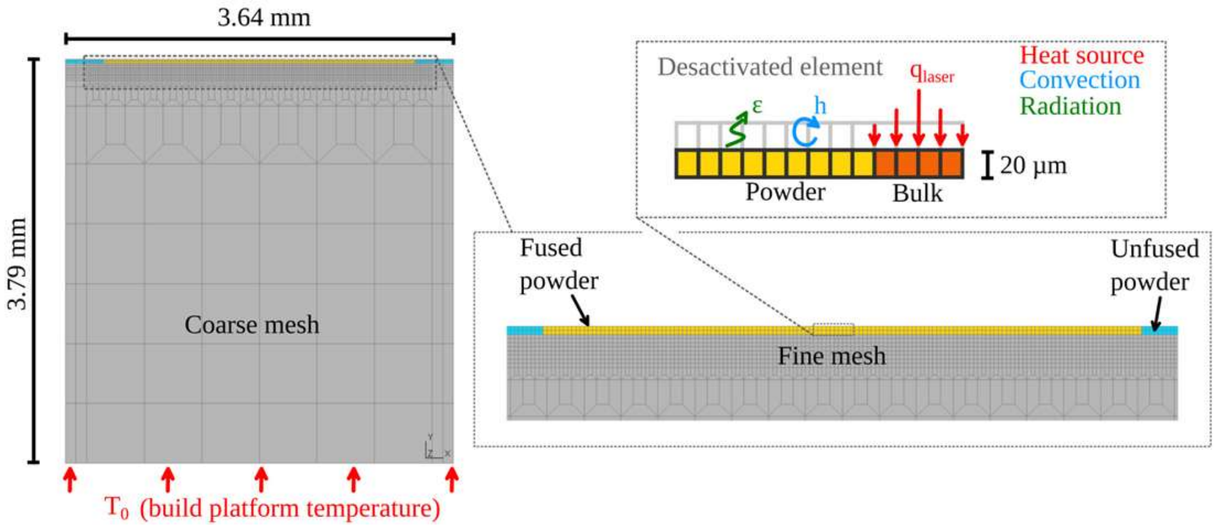
$$\nabla . k \nabla T + Q = \rho c_p \frac{\partial T}{\partial t}$$

(see Delahaye et al., Esaform 2023 Conf. Proc. for details)

- Thermo-physical properties are considered temperature-dependent, determined experimentally at ULiège (DSC, Laser Flash Diffusivimetry)
  [J. Delahaye, PhD Thesis (ULiège, 2022)]

Finite Element model

- Boundary condition: $-k\nabla T.n = q_{laser} - h(T - T_{amb}) - \mathcal{E}\sigma\left(T^4 - {T_{amb}}^4\right)$
- Laser = gaussian heat source: $q_{laser} = \frac{2AP}{\pi R^2} exp\left(\frac{2r^2}{R^2}\right)$



A: laser absorptivity in 3D
Used as tuning parameter in 2D model

(see Delahaye et al., Esaform 2023 Conf. Proc. for details)

Materials and methods

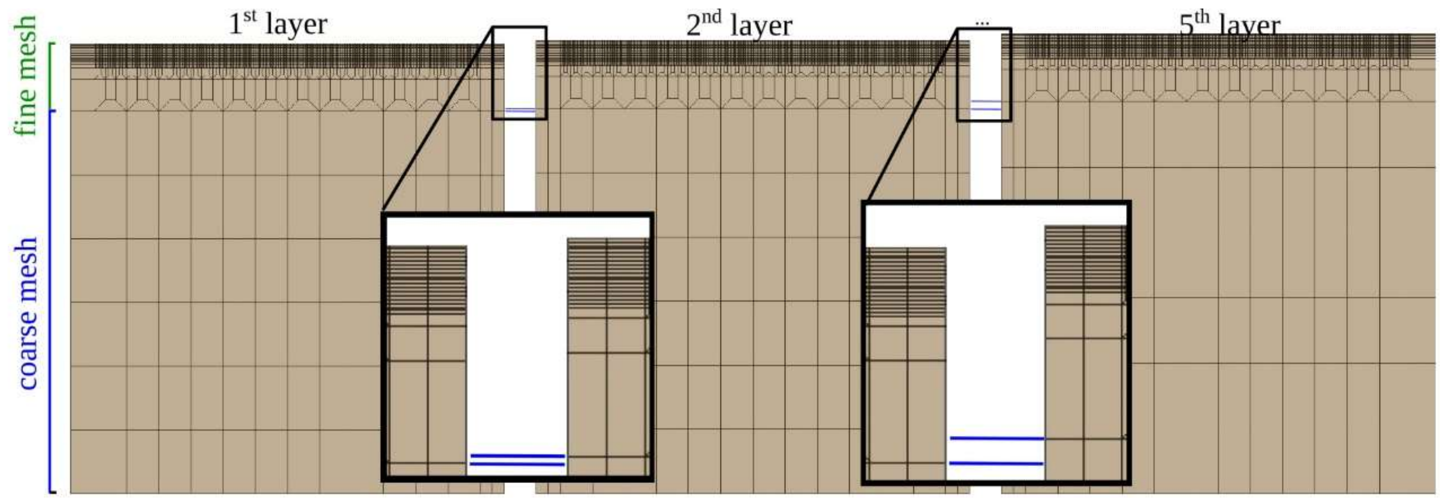
- Calibration and validation of the FE model against two sets of samples, to vary the HAZ thickness: set A is expected to enlarge the HAZ

	Printer	Laser power [W]	Scan speed [mm/s]	Layer thickness [µm]	Build platform temperature [°C]
Set A (Sirris)	MTT SLM 250	175	195	60	200
Set B (Anyshape)	EOS SLM	370	1300	40	35

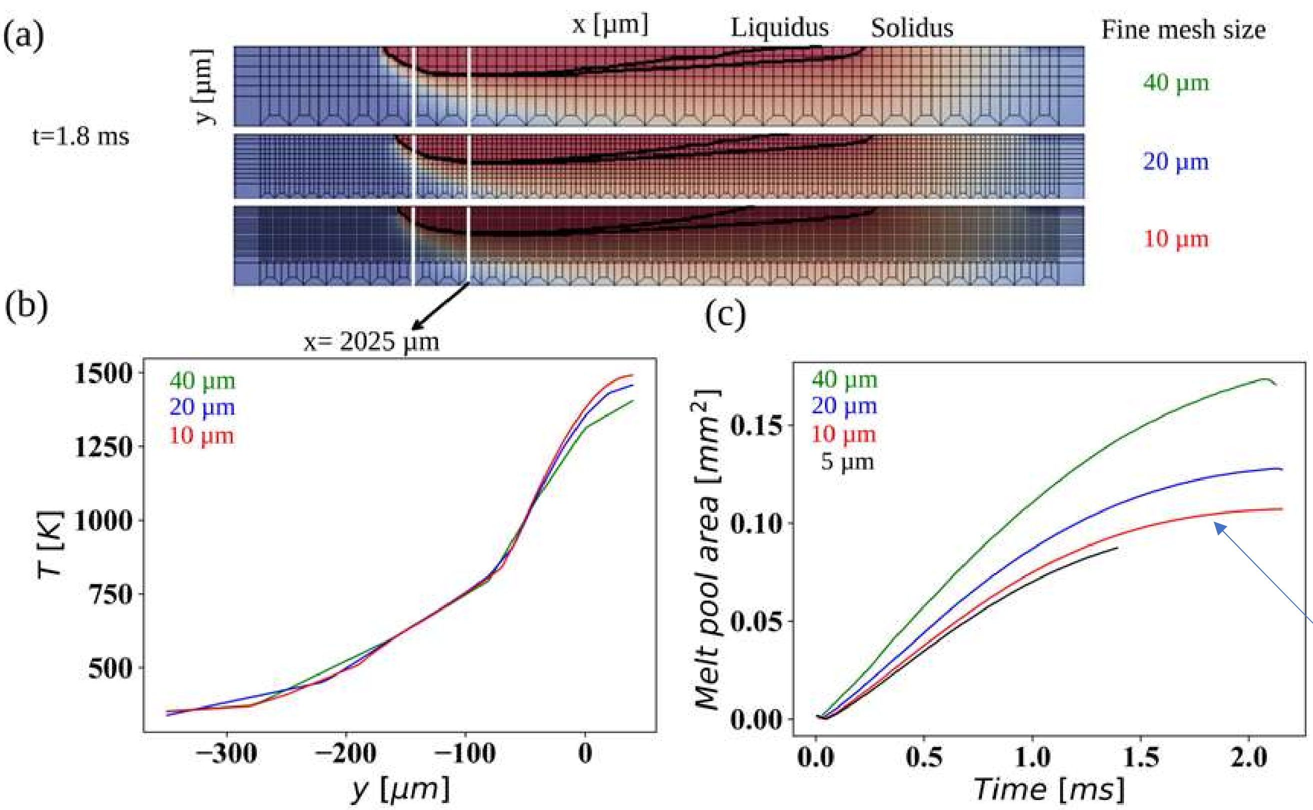
- Characterization by SEM after polishing and etching with Keller's reagent
- Calibration of the FE model performed by 2 methods:
  - Using the cell size
  - Using the melt pool height (last layer)

Computational costs – Remeshing strategy

To allow for multi-layer simulation, the number of nodes is kept constant independently of the number of layers.
Practically, the temperature field for the layer n°1 is taken as initial nodal condition for layer n°2, then the process is repeated...



Sensitivity to mesh size

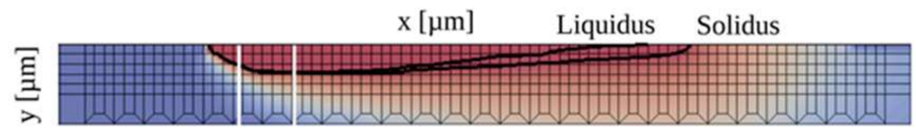


Convergency was tested for mesh size ranging from 40 to 5 µm

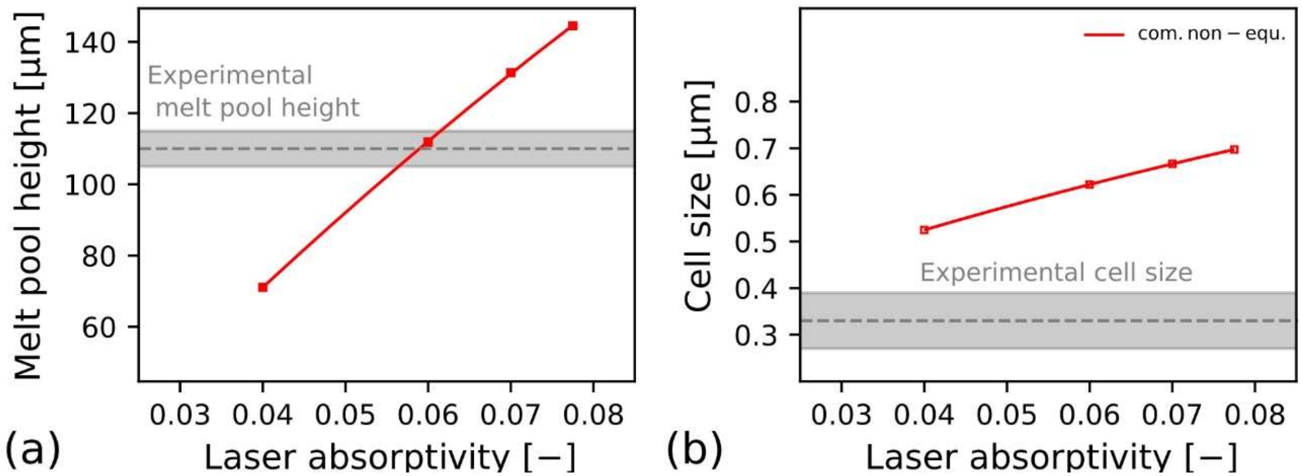
A mesh size of 10 µm offers a good compromise between accuracy and computation time.

Steady state is reached after ~1,8 ms

Calibration



Laser absorptivity (A) as tuning parameter, against samples from set B



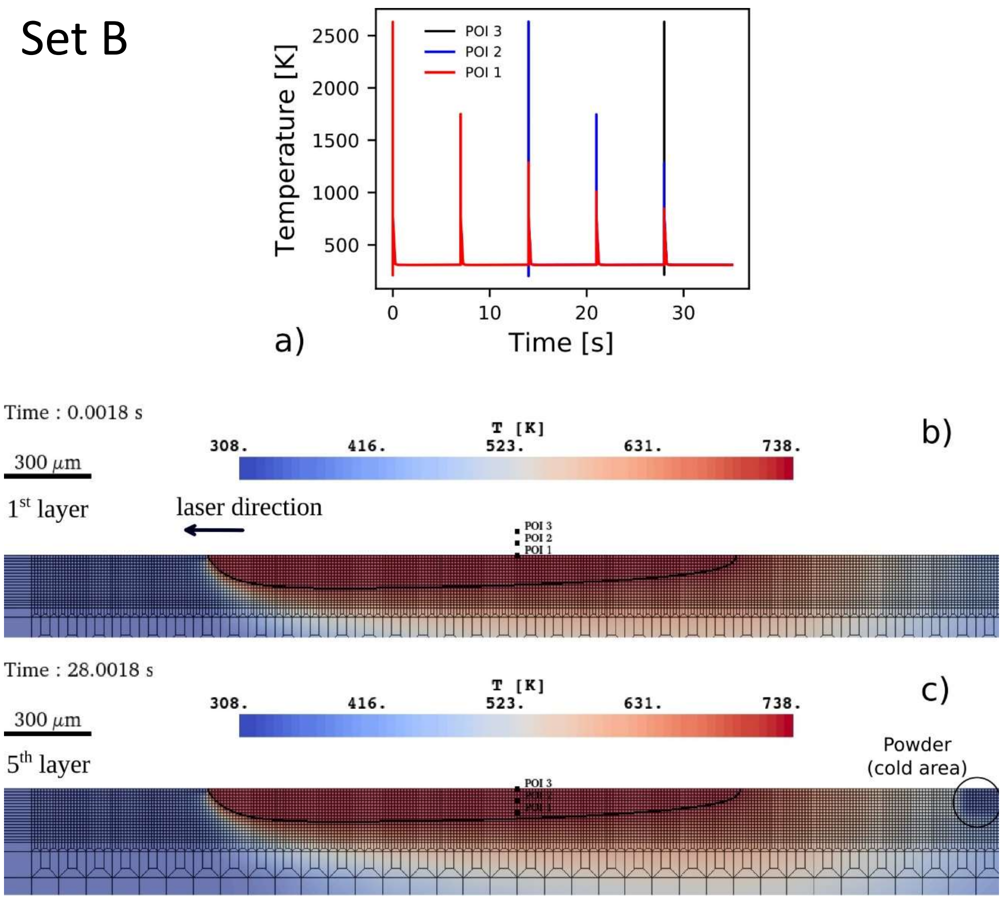
Model can only be calibrated against melt pool height (measured on the last layer)

Predicted cell size are systematically larger than the experimental value
$\Rightarrow$ Not suitable for calibration

Error inherent to 2D approximation?

Effect of the number of layers

Set B



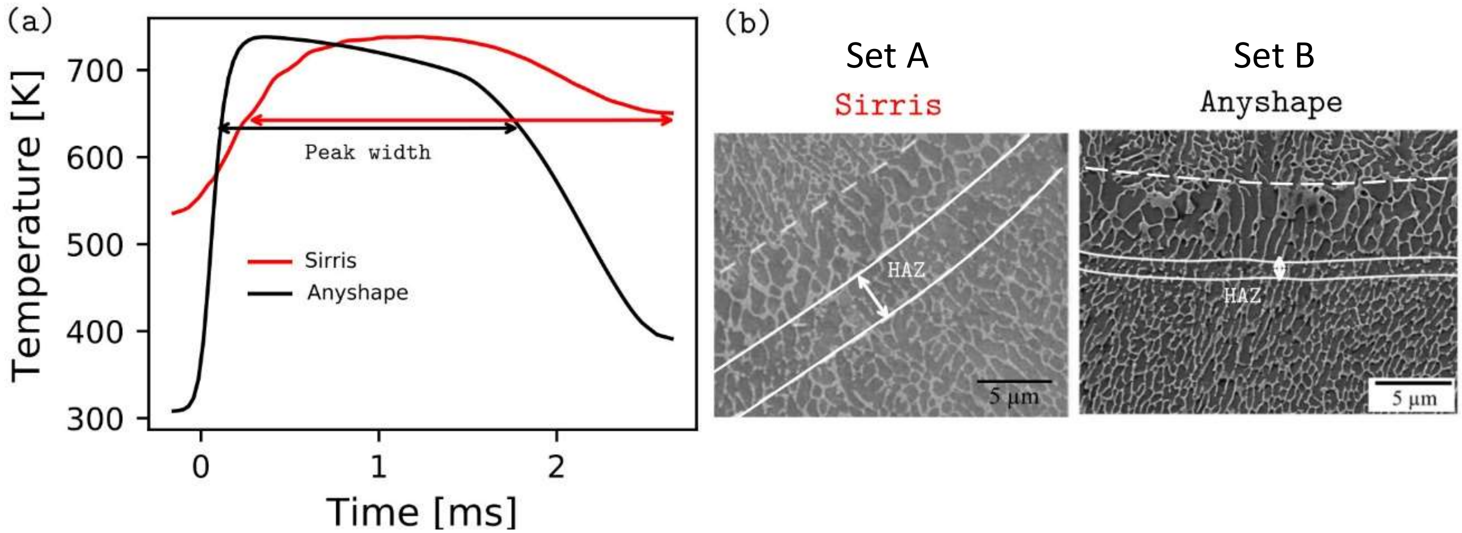
- Comparison of the thermal history for 3 points of interest
  - POI1: layer 1
  - POI2: layer 3
  - POI3: layer 5
- The 3 POIs experience the same peak temperature, with a shift in time

⇒ Heat accumulation remains negligible

This may be due to the very high thermal conductivity of AlSi10Mg

⇒ Possibility to study the HAZ through a single-layer 2D FE model

Influence of Processing Parameters



Higher energy input for set A (~921 J*m^{-2}) compared to set B (~284 J*m^{-2}) results in a larger temperature peak, and thus in a thicker HAZ.
The higher build platform temperature (200°C for set A) also plays a role, leading to smaller thermal gradient, and thus to a decrease in heat conduction.

Conclusions

- A 2D FE model for the thermal history of LPBF AlSi10Mg is developed and calibrated against the melt pool height
- A remeshing procedure is implemented (keeping constant number of nodes)
- For AlSi10Mg (high thermal conductivity) under "average" processing conditions (energy input), heat accumulation is found negligible
  $\Rightarrow$ Influence of processing parameters on HAZ thickness can be studied through single-layer model
- 2D FE model can be used to guide and accelerate the optimisation of processing parameters towards enhanced microstructure homogeneity

Prospects

Temperature field and thermal history obtained through the FE model can be used

1. to feed a model for prediction of microstructure evolution
   E.g. Phase field approach to predict Si precipitates dissolution / growth (paper under preparation)
2. to feed a model for prediction of mechanical properties (Master thesis under progress)

Thanks for your attention

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