Temperature field simulation of the Bridgman process as a basis for microstructure simulations

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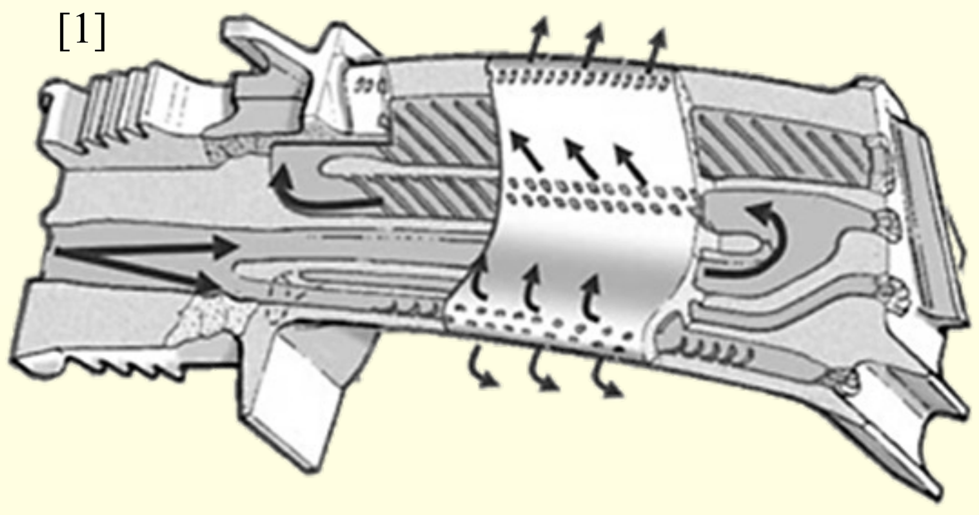
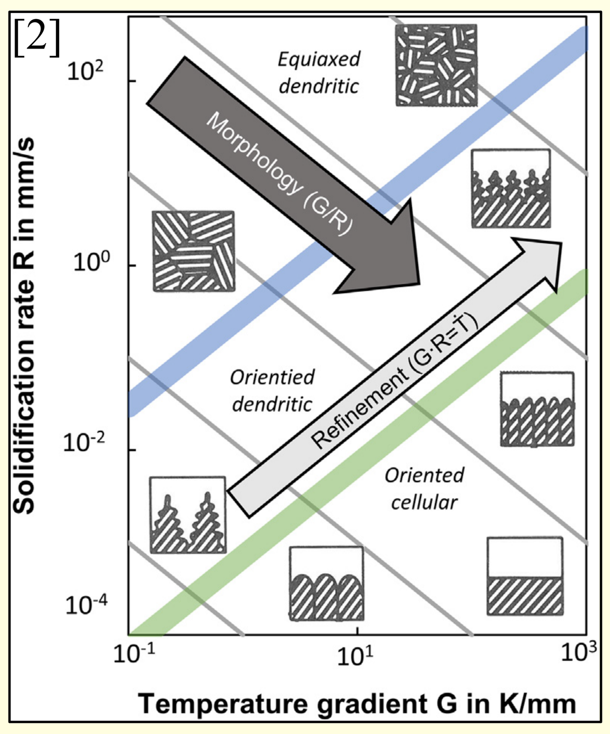
Motivation

[1]

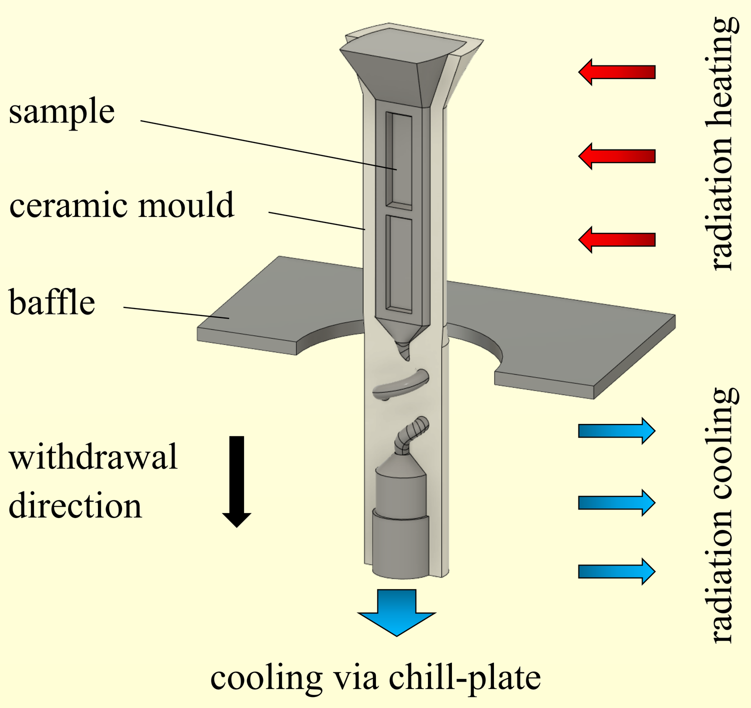


- Thin-walled blades are prerequisite for highly efficient turbine engines
- The hollow thin-walled blades are cast from high temperature alloys using the Bridgman process
- Temperature gradient and solidification rate determine the formation of the microstructure and therefore the material properties
- Aim: Determine the influence of process parameters and geometry on solidification conditions to predict the microstructures

[2]



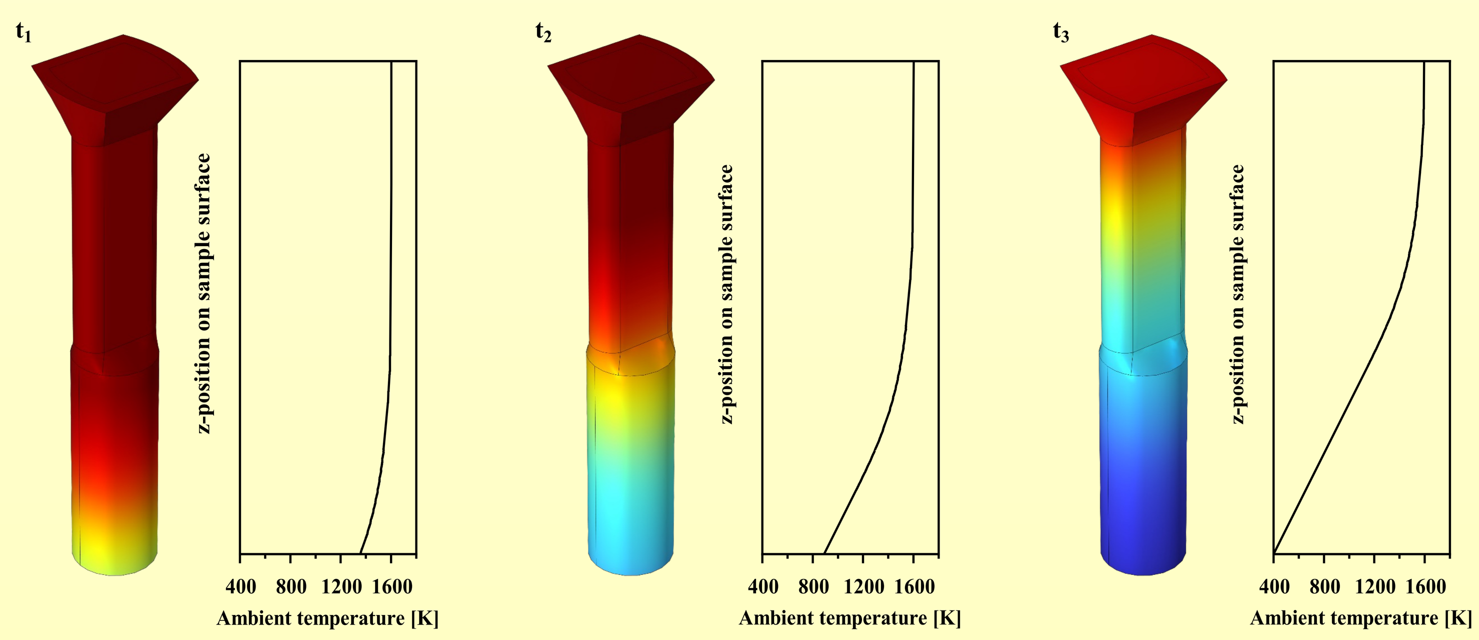
Simulation setup



- Simplified model is used to determine influence of wall thickness
- Heat transfer on sample surface is by radiation only (vacuum process)
- Heat transfer in solids (conduction) was used for the shell mould and heat transfer in liquids (conduction and convection) was used for the sample
- A volumetric force was used to prevent convection in the solidified areas of the sample
- CMSX4 and CM186LC were used for the sample [3], Al_2O_3 for the mould [4]

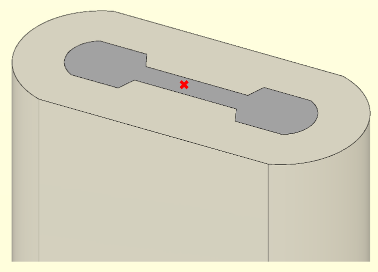
A time dependent variation of an externally applied temperature field is used to simulate the withdrawal process

$$T(z,t) = T_{dist.}(z - v * t)$$

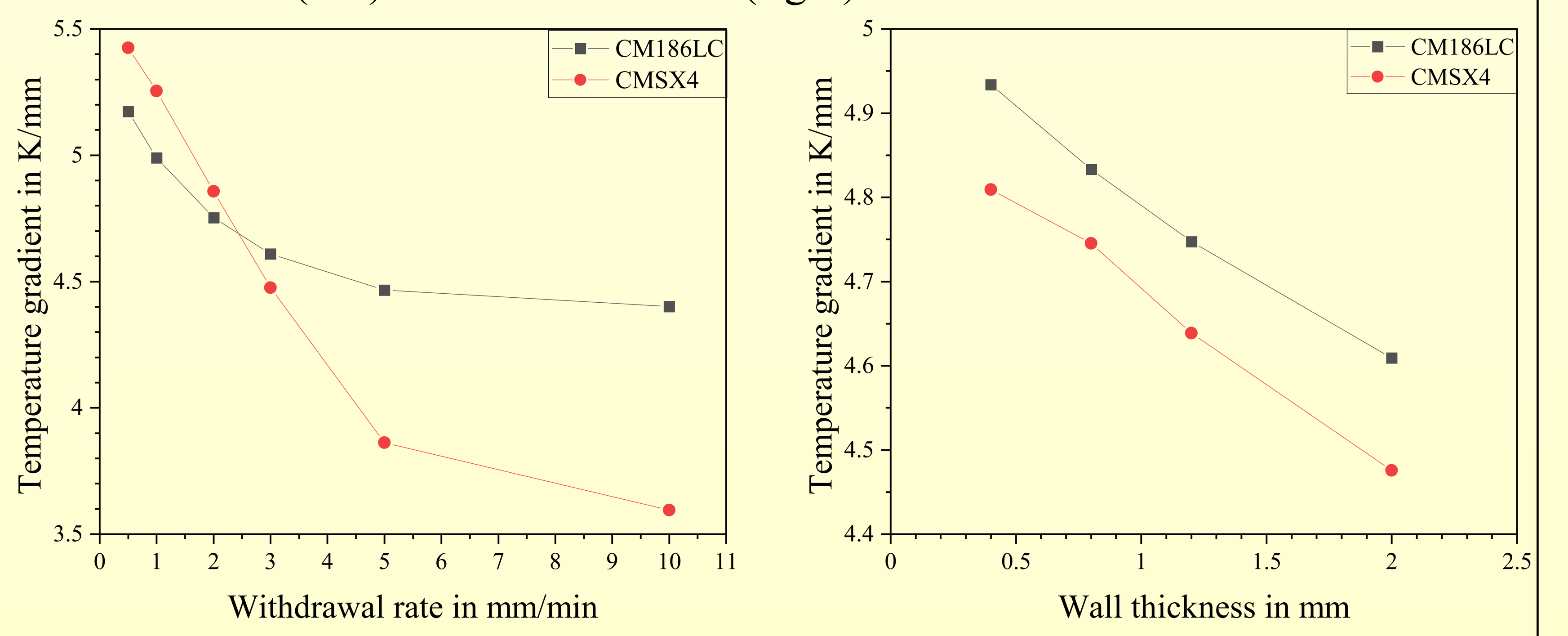


varied parameter	wall thickness in mm	withdrawal rate in mm/min
withdrawal rate	2.0	0.5, 1.0, 2.0, 3.0, 5.0, 10.0
wall thickness	0.4, 0.8, 1.2, 2.0	3.0

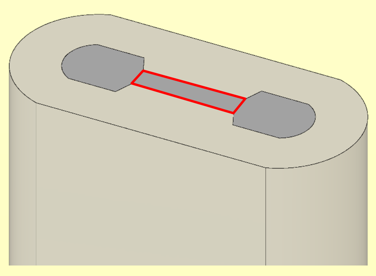
Results



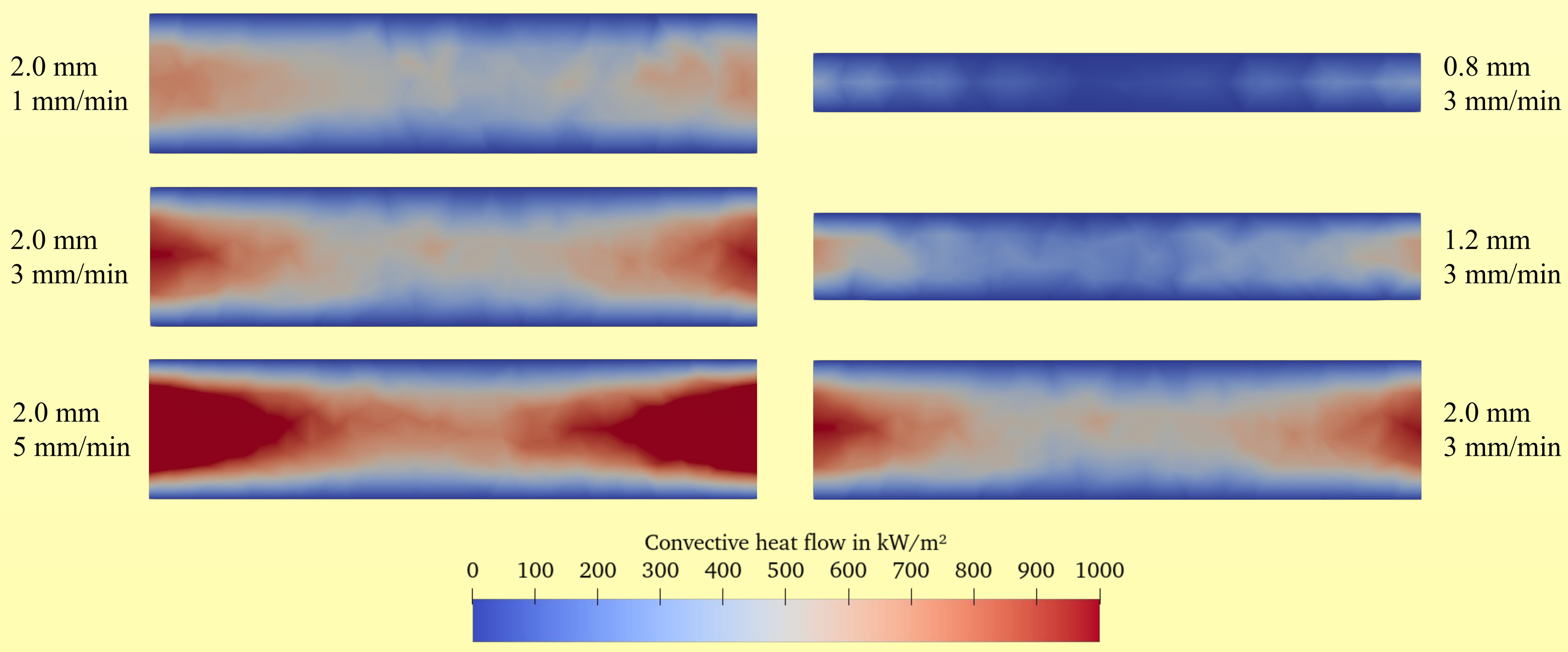
Temperature gradient in the center of the thin-walled structure as a function of withdrawal rate (left) and wall thickness (right)



- Temperature gradient decreases from 5.4 K/mm to 3.6 K/mm (CMSX4) and from 5.2 K/mm to 4.4 K/mm (CM186LC) as withdrawal rate increases from 0.5 mm/min to 10.0 mm/min
- Temperature gradient decreases from 4.8 K/mm to 4.5 K/mm (CMSX4) and from 4.9 K/mm to 4.6 K/mm (CM186LC) as wall thickness increases from 0.4 mm to 2.0 mm



Convective heat flow in the thin-walled area for different withdrawal rates (left) and different wall thicknesses (right) of CMSX4



The increase in convective heat flow with increasing withdrawal rate and wall thickness allows better heat exchange within the sample, resulting in a reduction in the temperature gradient.

References

[1] R.C. Reed, *Cambridge Univ. Press*, 2006
[2] C. Hagenlocher et. al, Mat. & Design, 2019
[3] P.N. Quested et. al., *Mat. Science & Technology*, *2009*
[4] C.H. Konrad et. al., *Mat. Processing & Technology*, *2011*
[5] D. Goldschmidt, *Mat.-Wiss & Werkstofftechnik*, *1994*

Acknowledgements

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Summary

- Both withdrawal rate and geometry affect the solidification conditions in the Bridgman process, although the influence of the withdrawal rate is greater
- The reason for the decrease in the temperature gradient is an increase in convection with an increase in the withdrawal rate and wall thickness
- CMSX4 and CM186LC show similar behavior when the parameters are varied

Outlook

Using the simulated temperature fields, it is possible to predict the microstructure formed during solidification.

[5]

$$\lambda_P = K * v^{-0.25} * G^{-0.5}$$