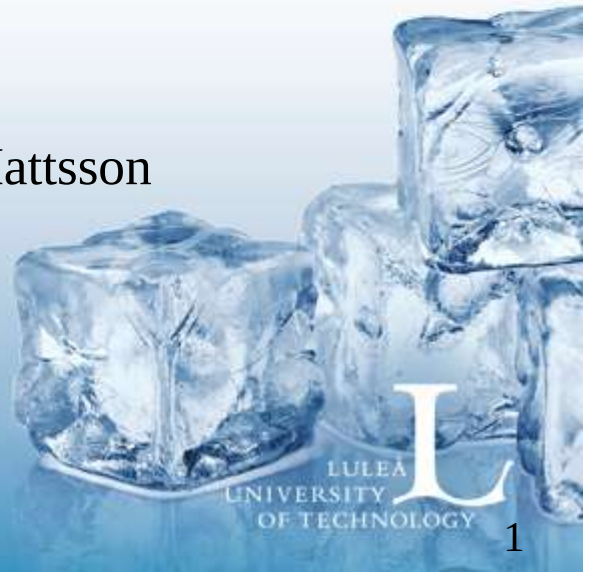
Modeling and Simulation of Heat Affected Zone Liquation Cracking in Alloy 718

Joar Draxler

Supervisor: Lars-Erik Lindgren
Co-supervisor: Jonas Edberg
Project leader: Jesper Liljemark-Mattsson



Background

- Welding of nickel-based superalloys

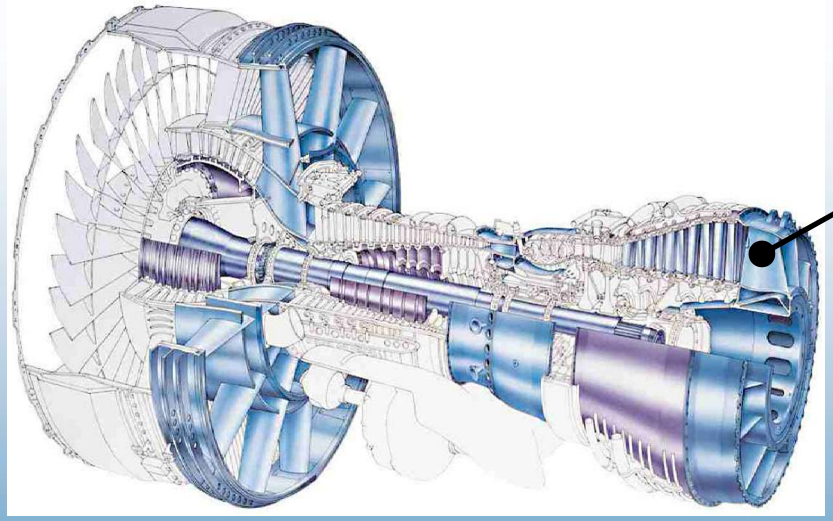
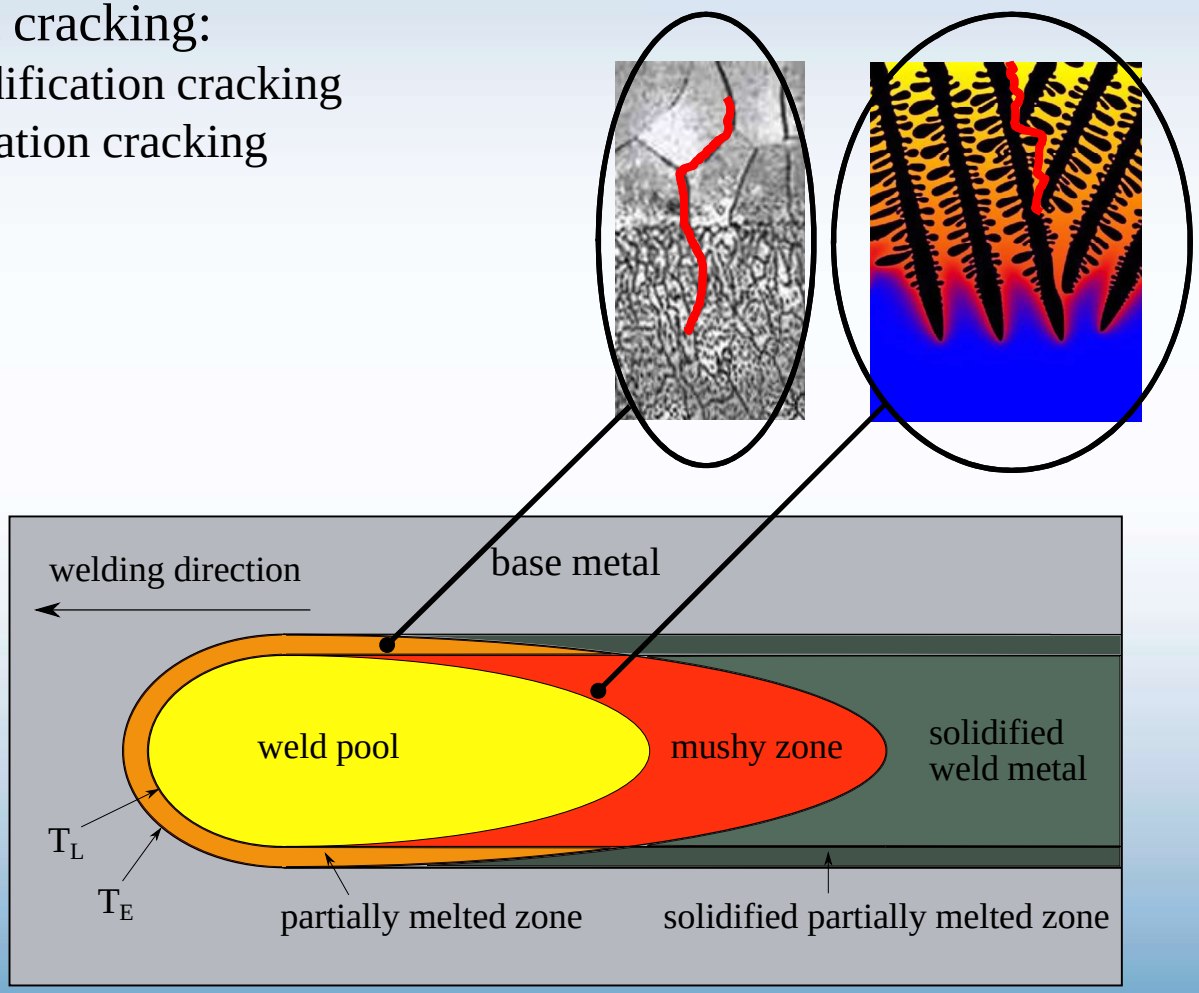


Image courtesy of GKN Aerospace

Turbine structure

Weld Hot Cracking

- Weld hot cracking:
  - Solidification cracking
  - Liquation cracking

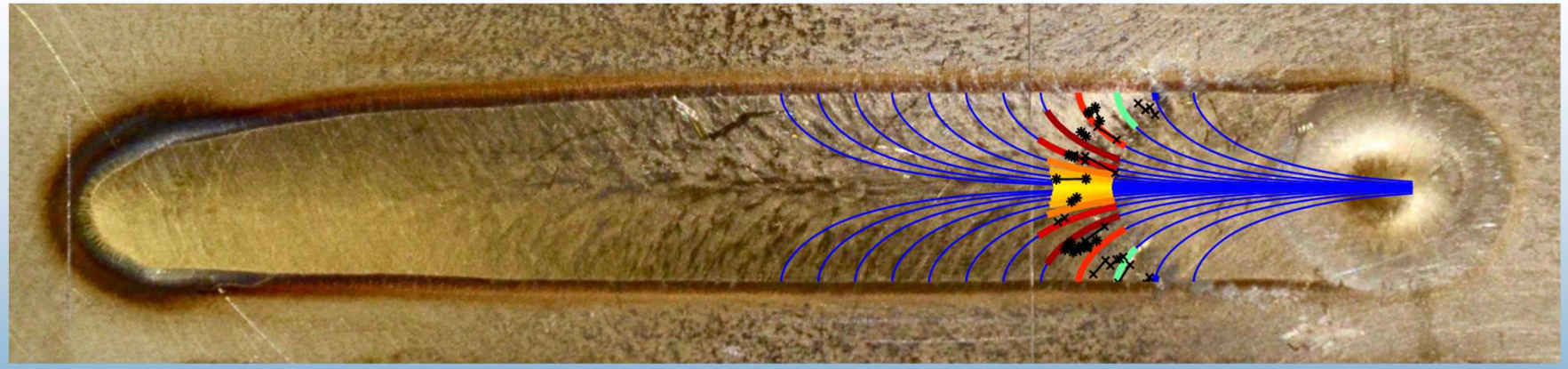


T_L = liquidus isotherm
T_E = eutectic isotherm

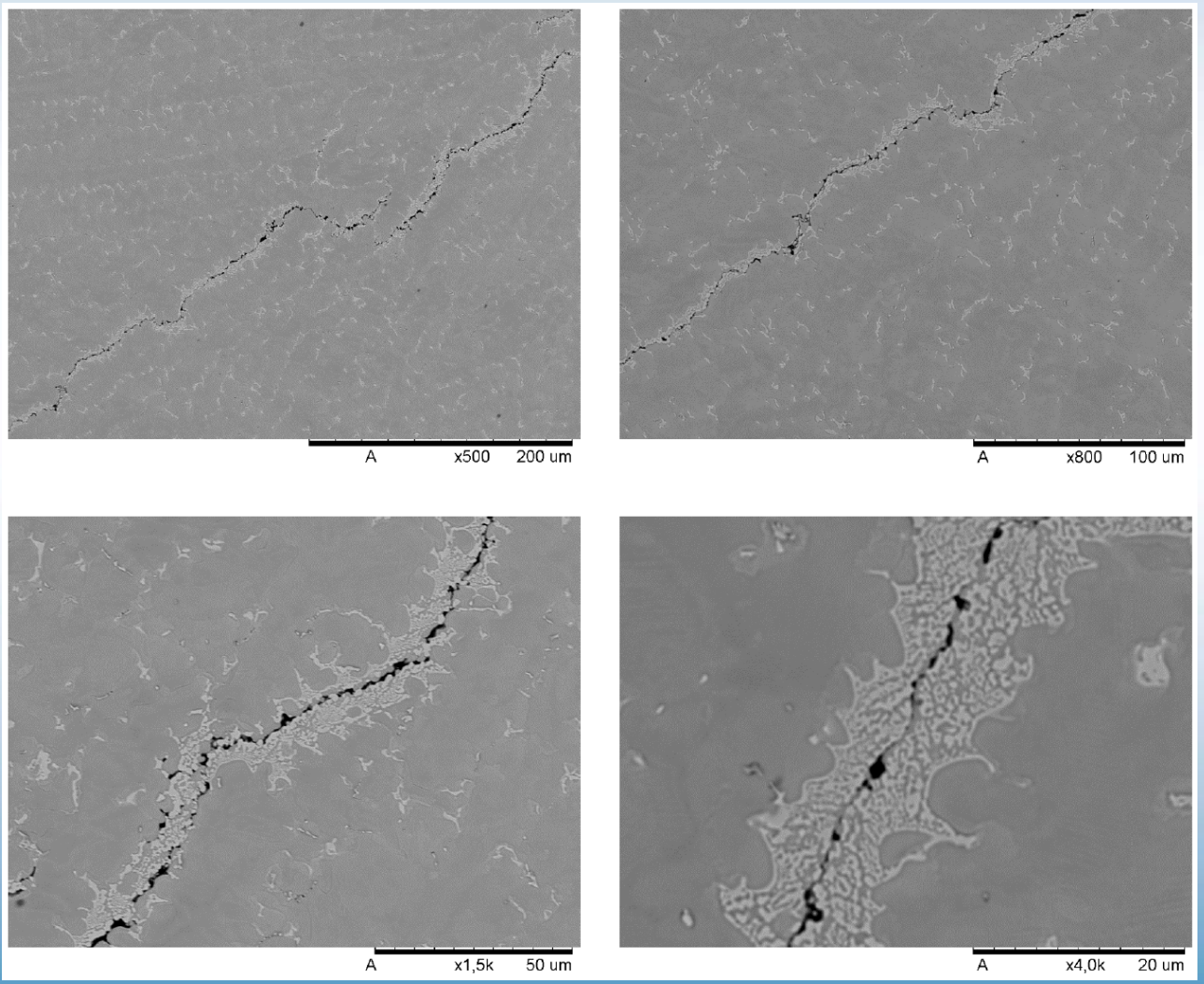
Objective

Development of a numerical model for hot cracking

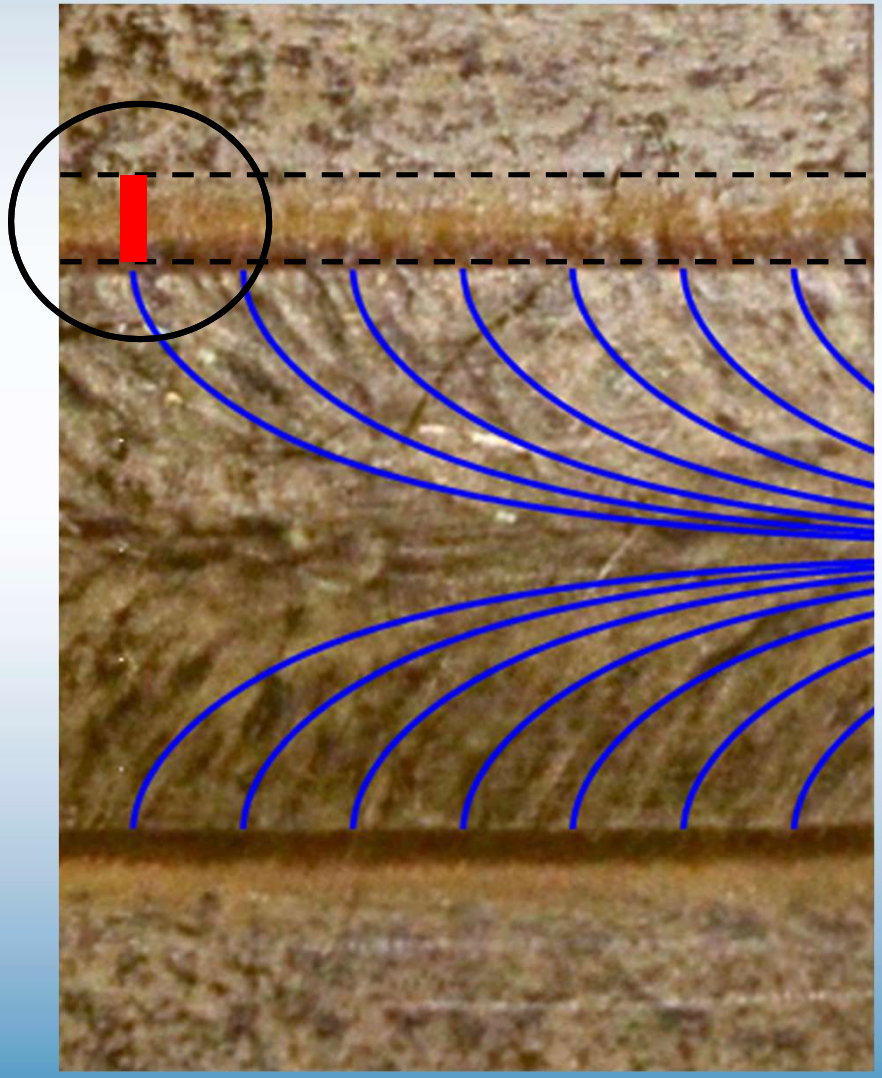
- Physically based crack criterion
  - Grain boundary liquid pressure model
    - Material model

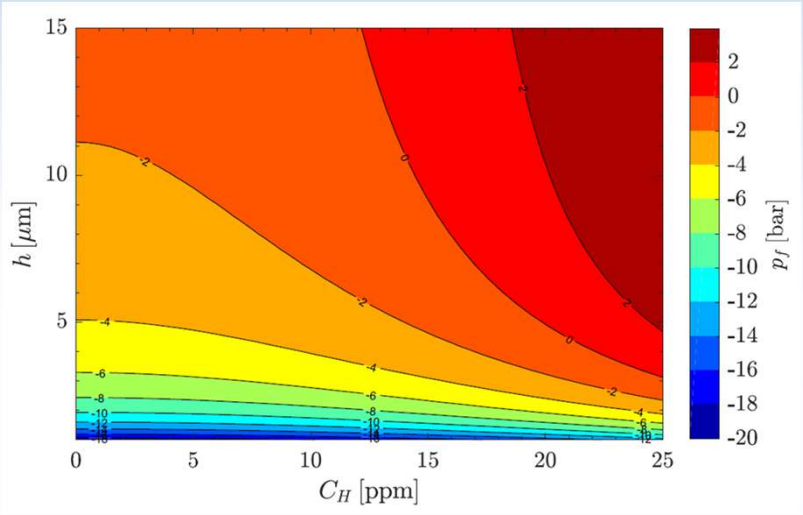


HAZ Liquation Cracking in Alloy 718 from Gamma/Laves Eutectic Bands

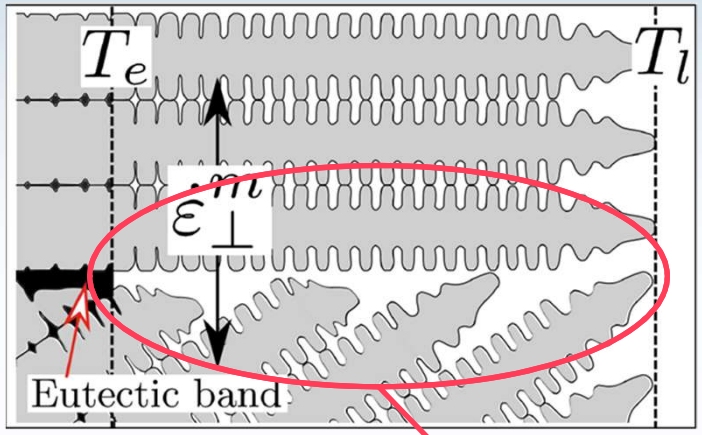


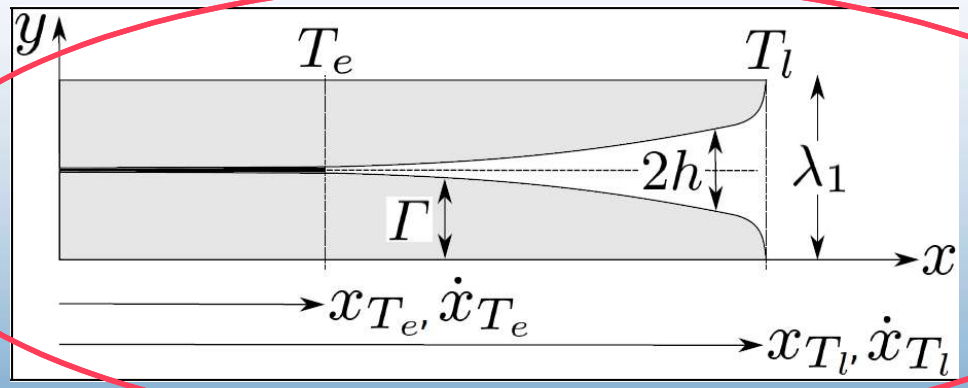
HAZ Liquation Cracking from Eutectic Bands



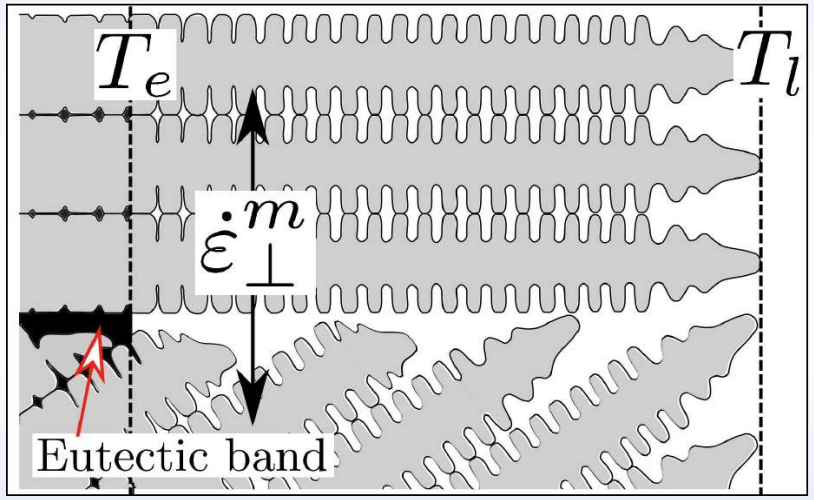


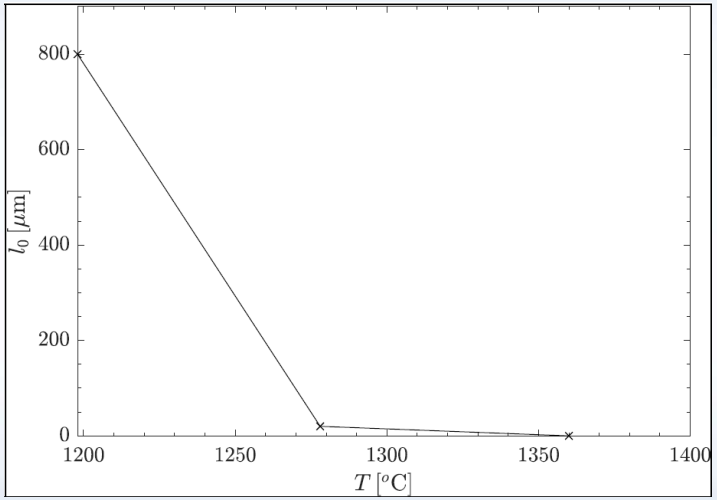
Modeling Approach





Strain Localization

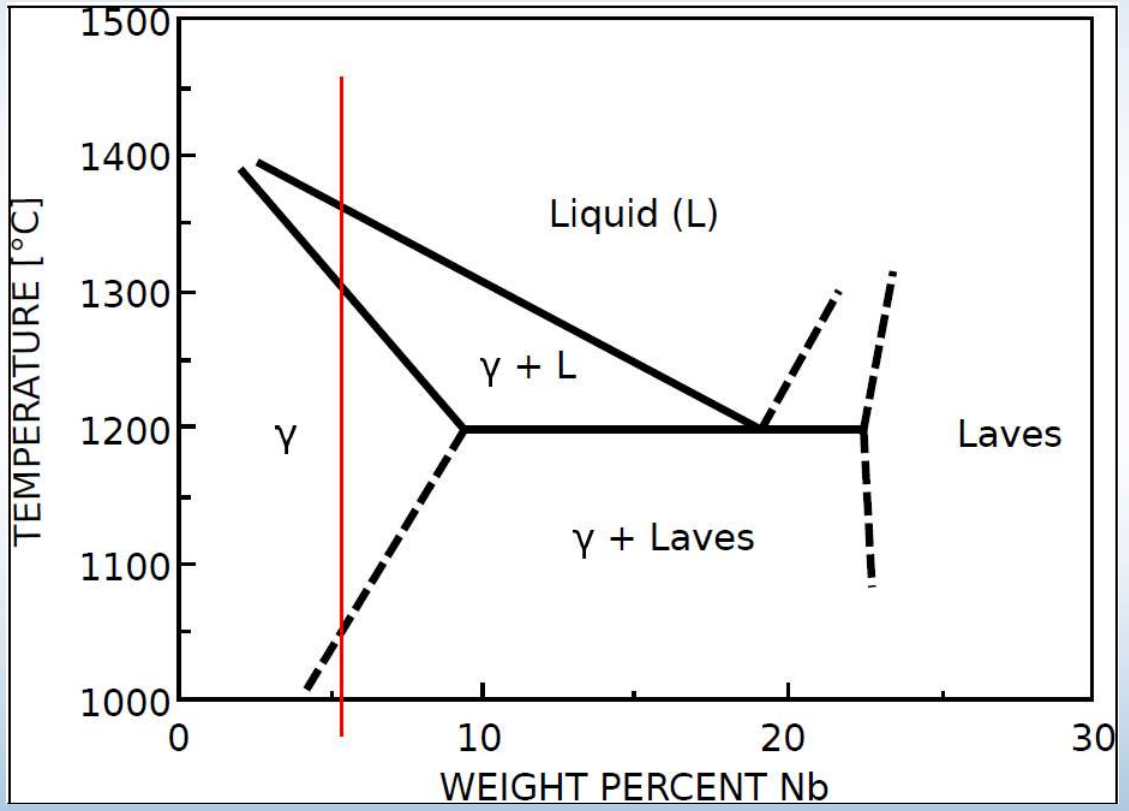




Interface Equilibrium

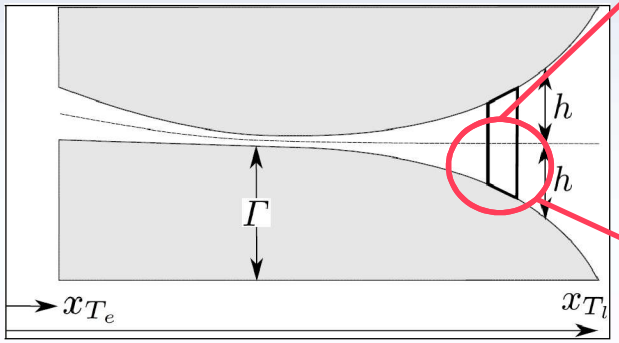
$$C_l = \frac{T - T_l}{m} + C_0$$

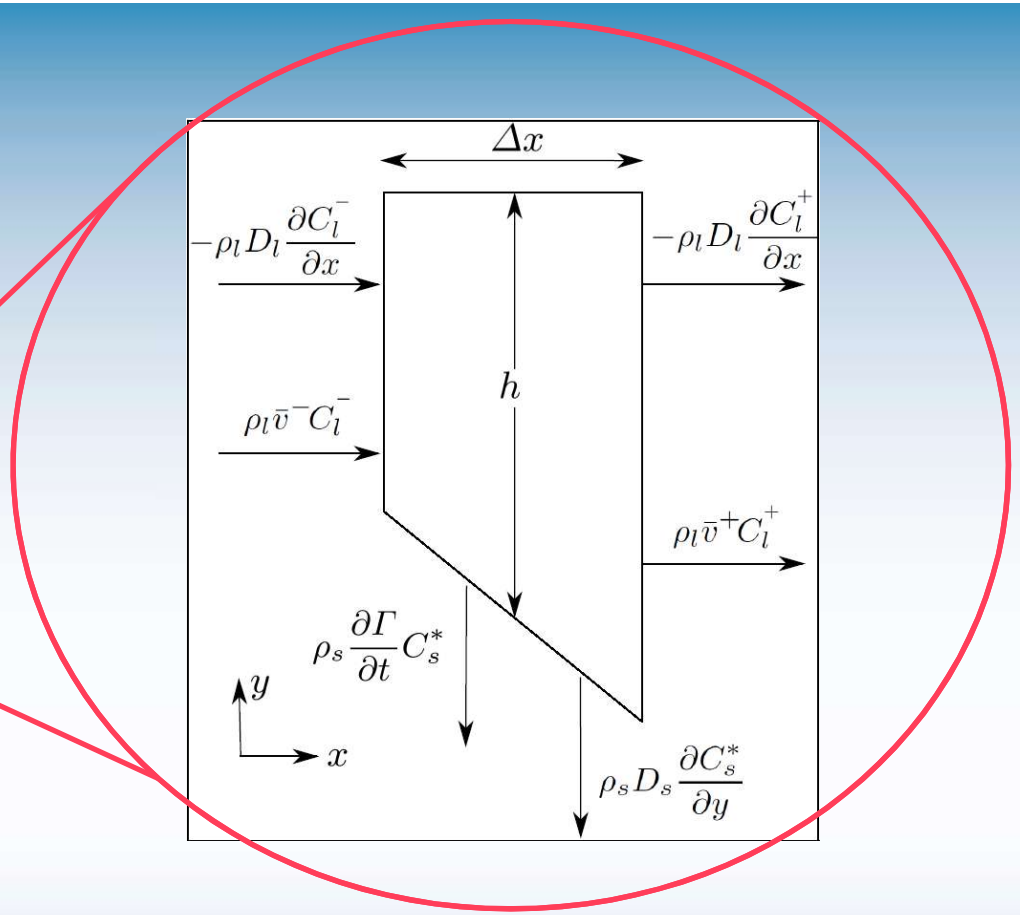
$$C_s^* = kC_l$$



(Knorovsky et al, 1989)

Solute Balance





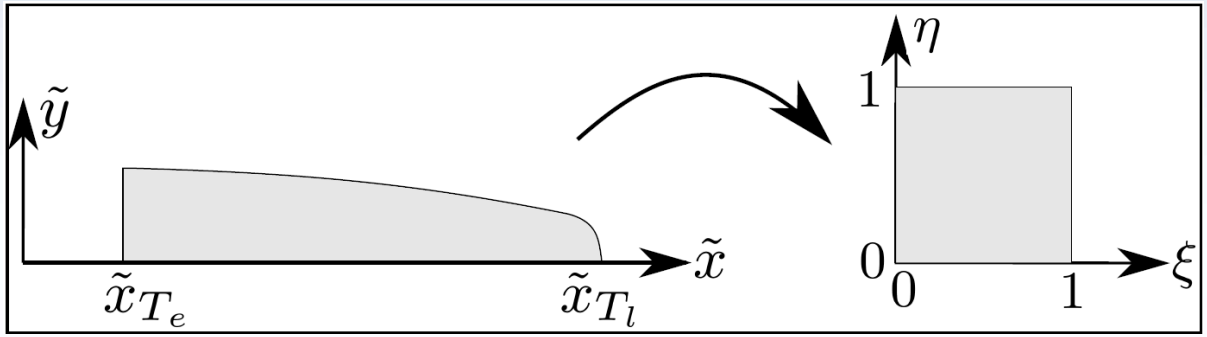
$$\rho_l \frac{\partial (C_l h)}{\partial t} + \rho_l \frac{\partial}{\partial x}(C_l \bar{v} h) - \rho_l D_l \frac{\partial}{\partial x}\left(\frac{\partial C_l}{\partial x} h\right) + \rho_s C_s^* \frac{\partial \Gamma}{\partial t} + \rho_s D_s \frac{\partial C_s^*}{\partial y} = 0$$

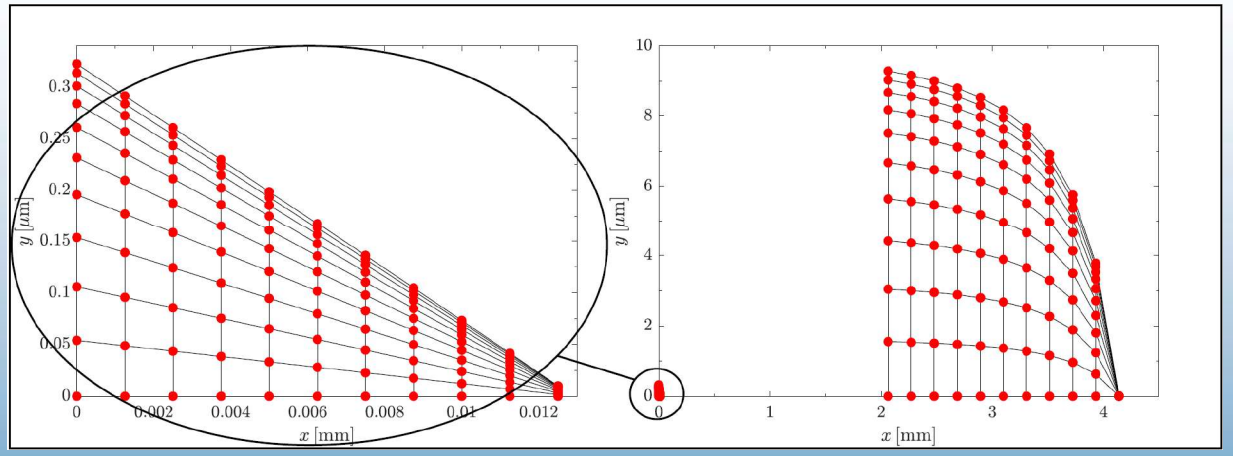
$$\frac{\partial h}{\partial t} = \left(h + \frac{l_0}{2}\right) \dot{\varepsilon}_\perp^m - \frac{\partial \Gamma}{\partial t}$$

$$\frac{\partial (\bar{v} h)}{\partial x} = -(1+\beta) \frac{\partial \Gamma}{\partial t} - \frac{\partial h}{\partial t}$$

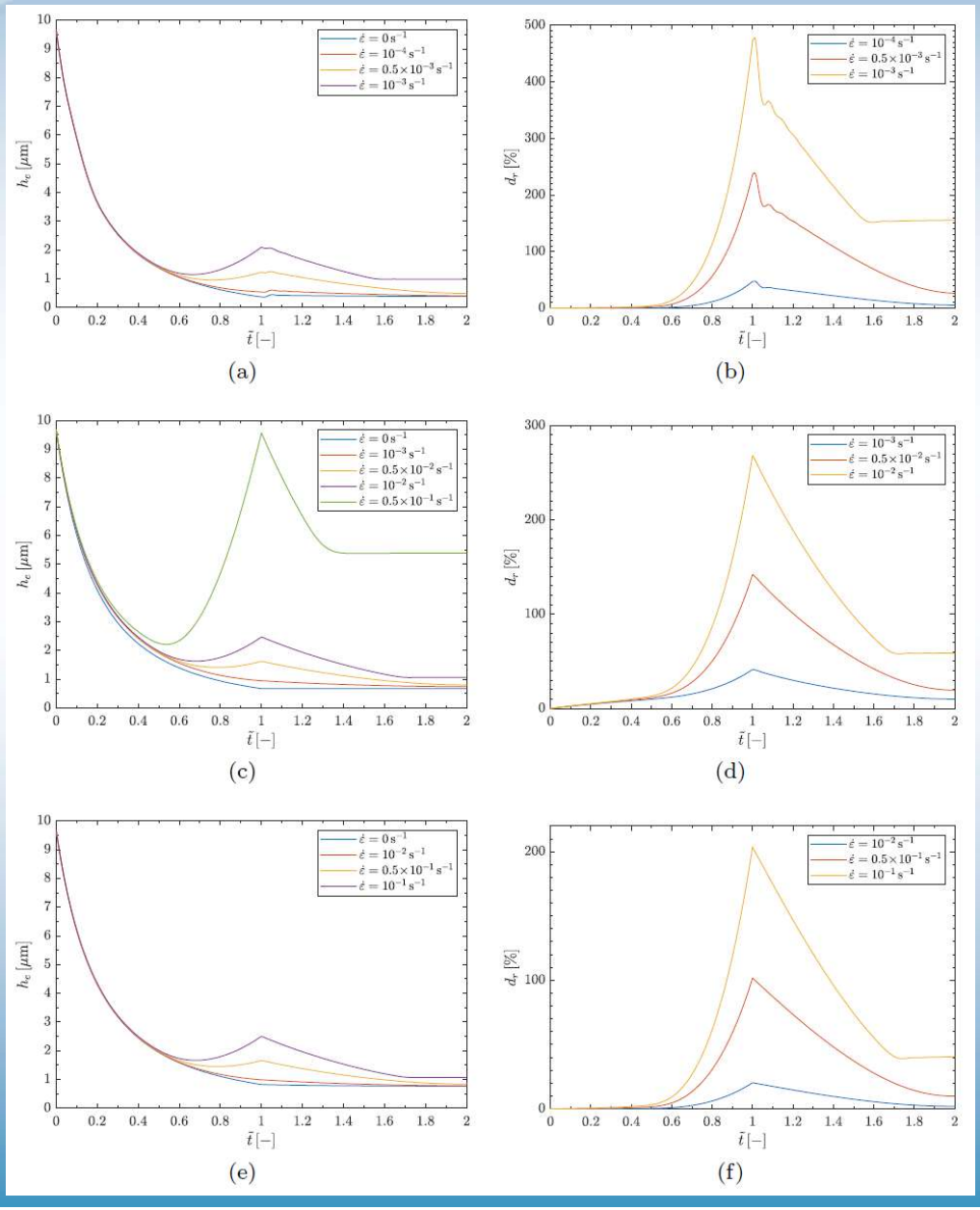
Back Diffusion

$$
\begin{cases}
\dfrac{\partial \tilde{C}_s}{\partial \tilde{t}} - \tilde{D}_s \dfrac{\partial^2 \tilde{C}_s}{\partial \tilde{y}^2} = 0 \\
\tilde{C}_s(\tilde{y} = \tilde{\Gamma}) = k\tilde{C}_l \\
\dfrac{\partial \tilde{C}_s(\tilde{x} = \tilde{x}_{T_e})}{\partial \tilde{x}} = 0 \\
\dfrac{\partial \tilde{C}_s(\tilde{y} = 0)}{\partial \tilde{y}} = 0
\end{cases}
$$

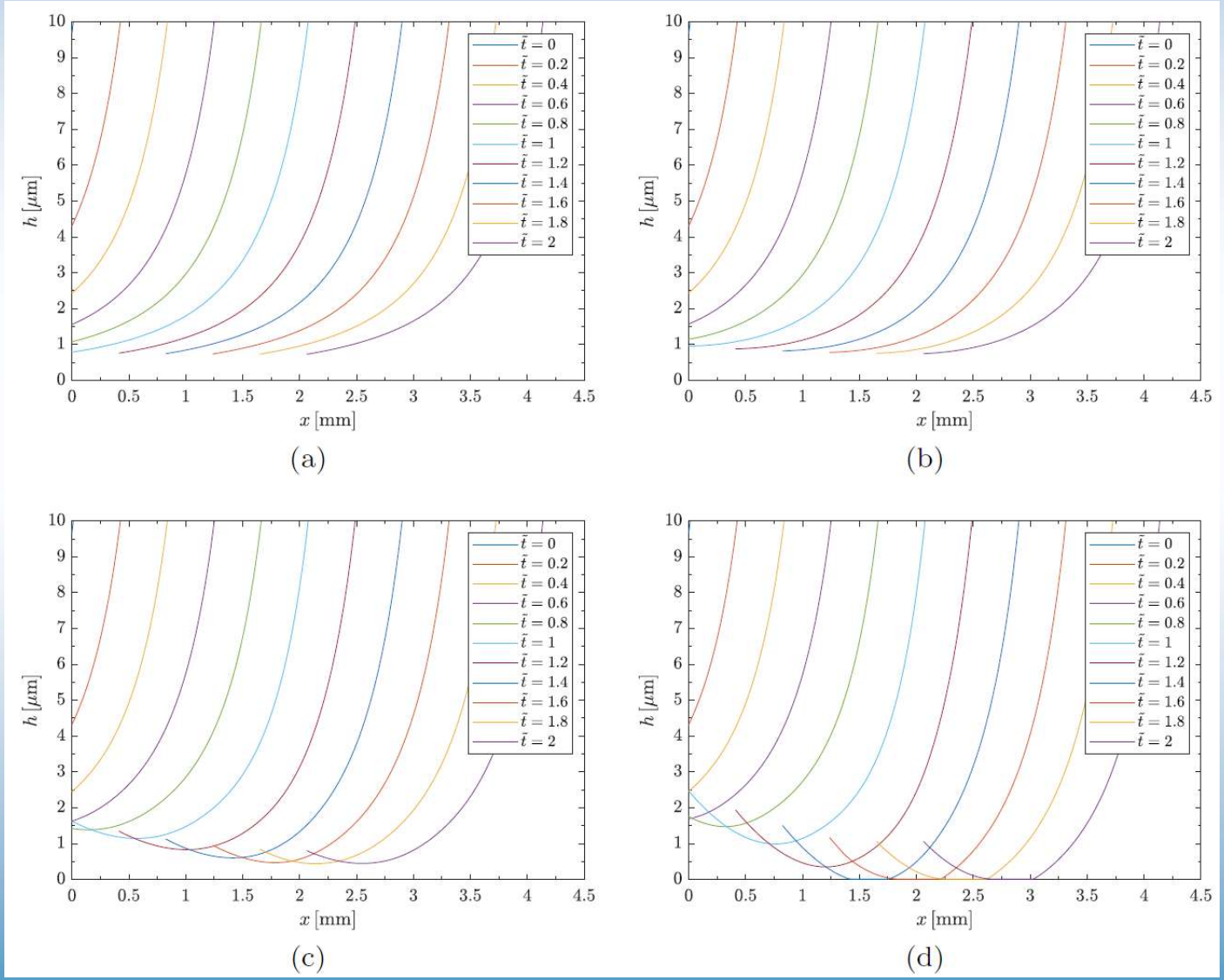




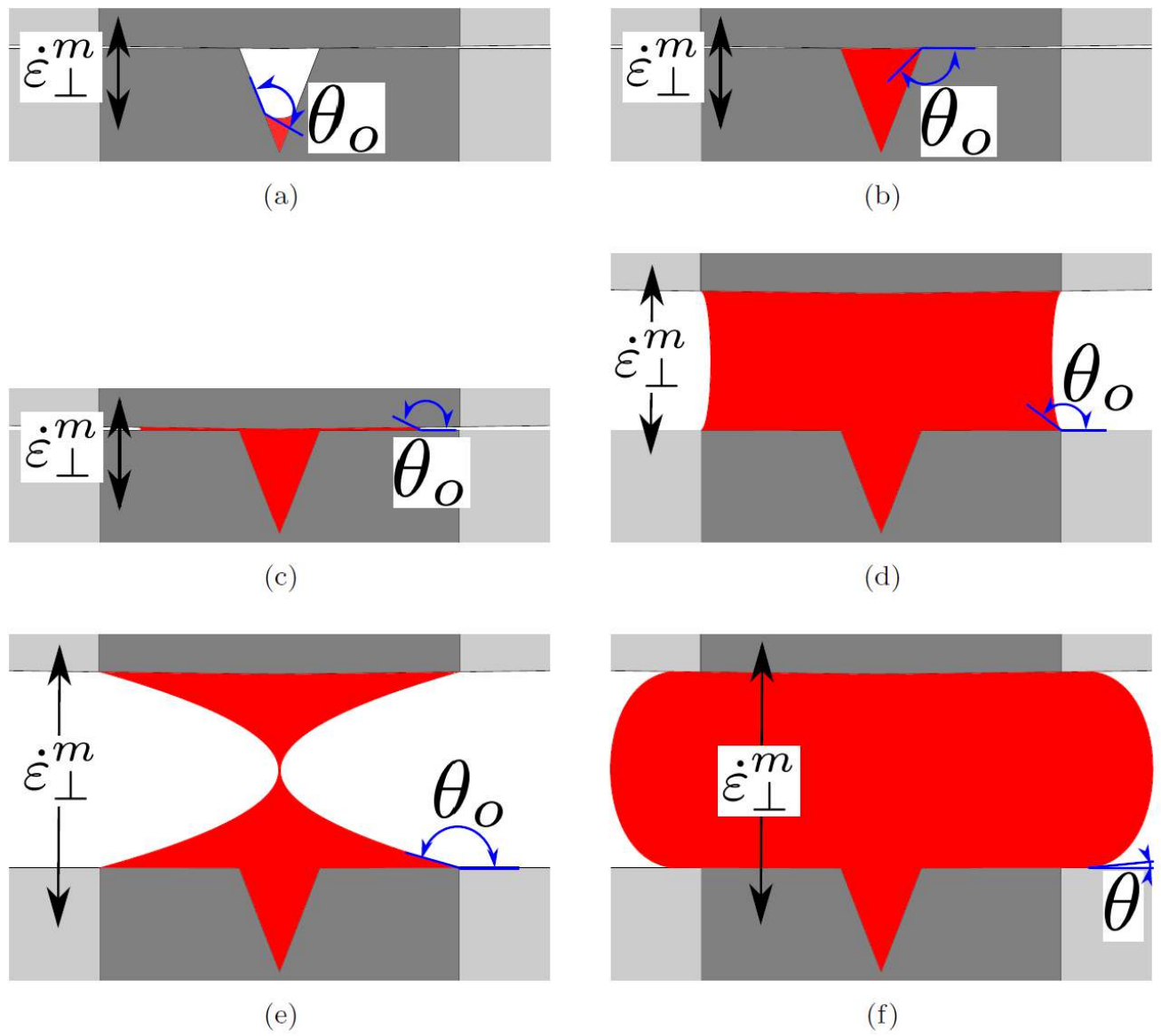
Results: Eutectic Band Thickness



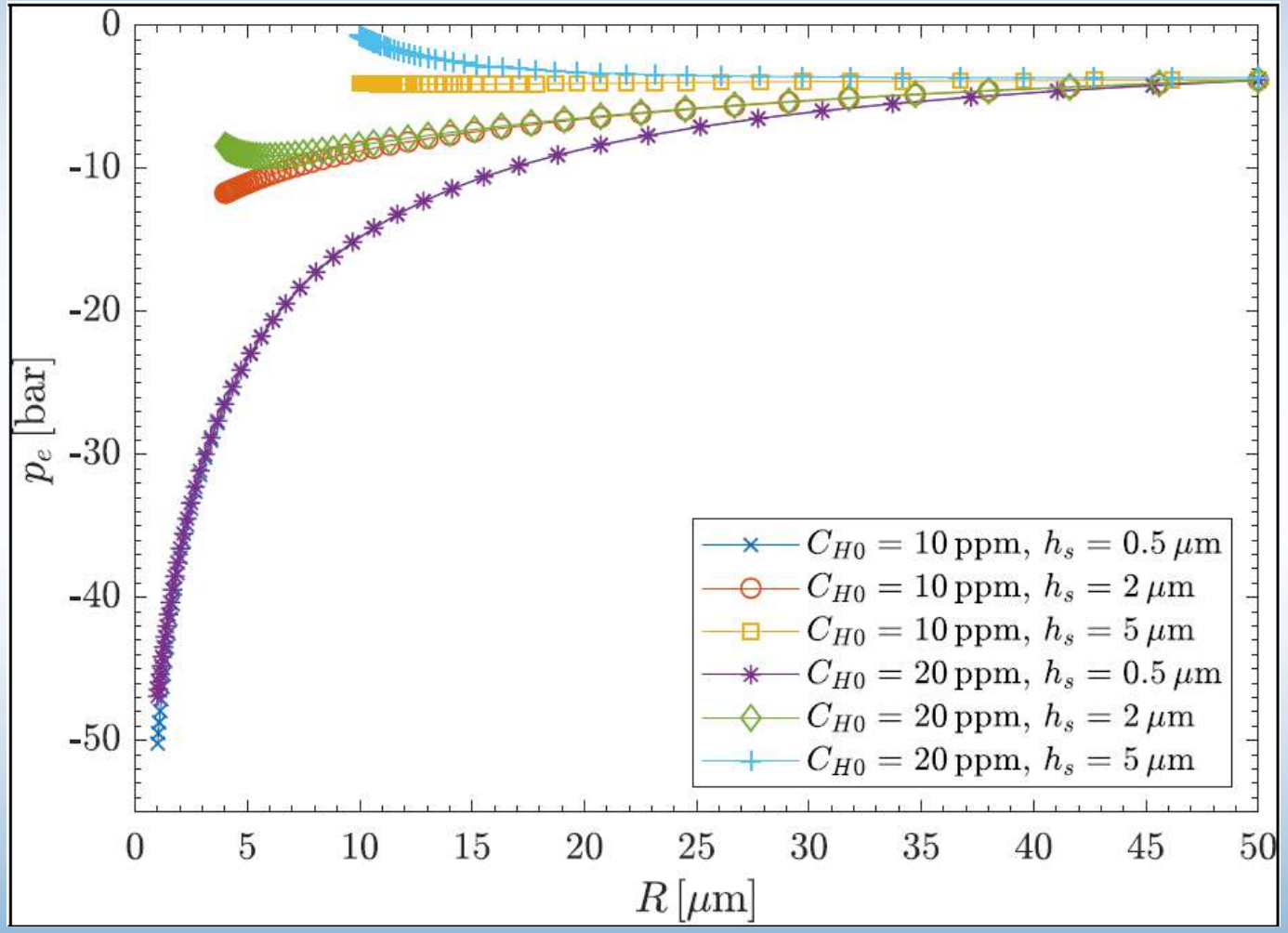
Results: Liquid Film Thickness



Results: Pore Nucleation Mechanism



Results: Pore Nucleation Mechanism



Conclusions

- A numerical model for simulating the effect of strain rate on eutectic band thickness in Alloy 718 has been developed.
- Relations between eutectic band thickness, solidification velocity and mechanical strain rate has been studied.
- The counterintuitive phenomenon that an increase in strain rate can lead to a decreased in permeability has been discovered.
- A new heterogenous pore nucleation mechanism has been proposed.

Thank you very much for your attention!