

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

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Background

- Welding of nickel-based superalloys

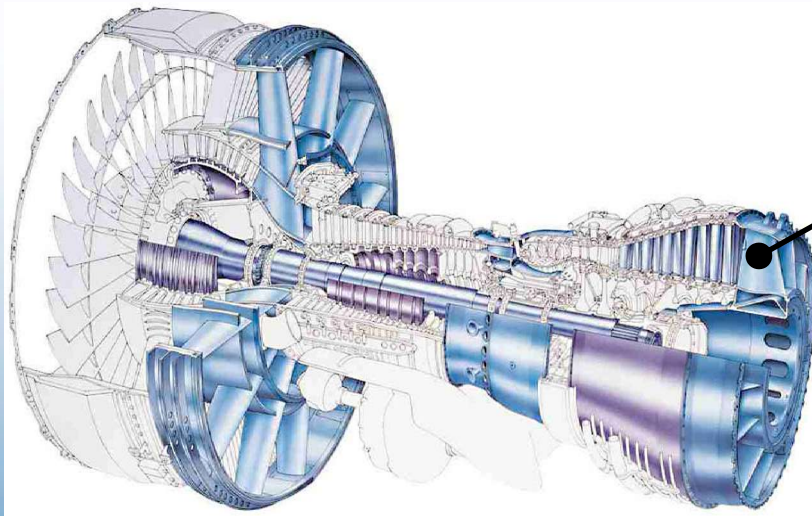


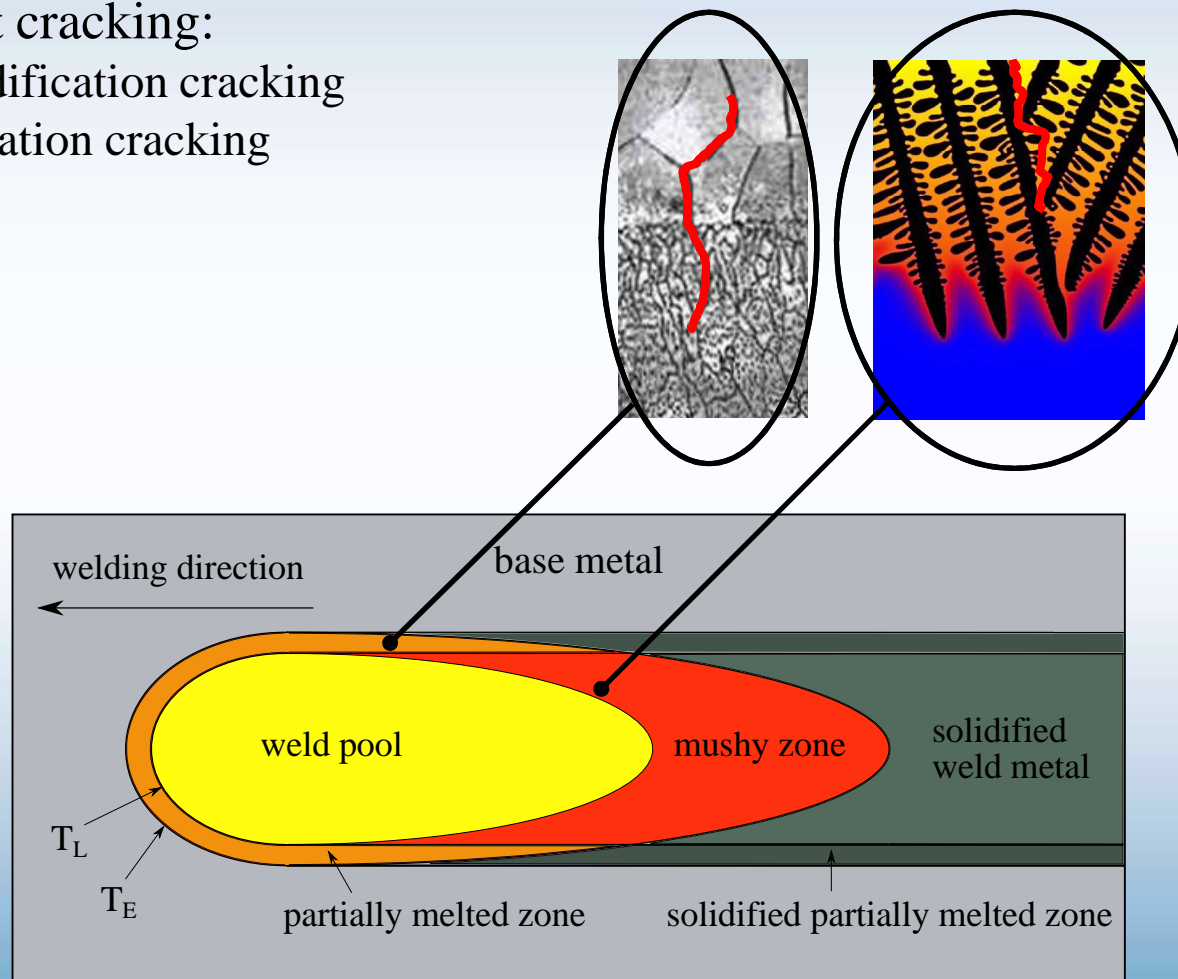
Image courtesy of GKN Aerospace



Turbine structure

Weld Hot Cracking

- Weld hot cracking:
 - Solidification cracking
 - Liquation cracking



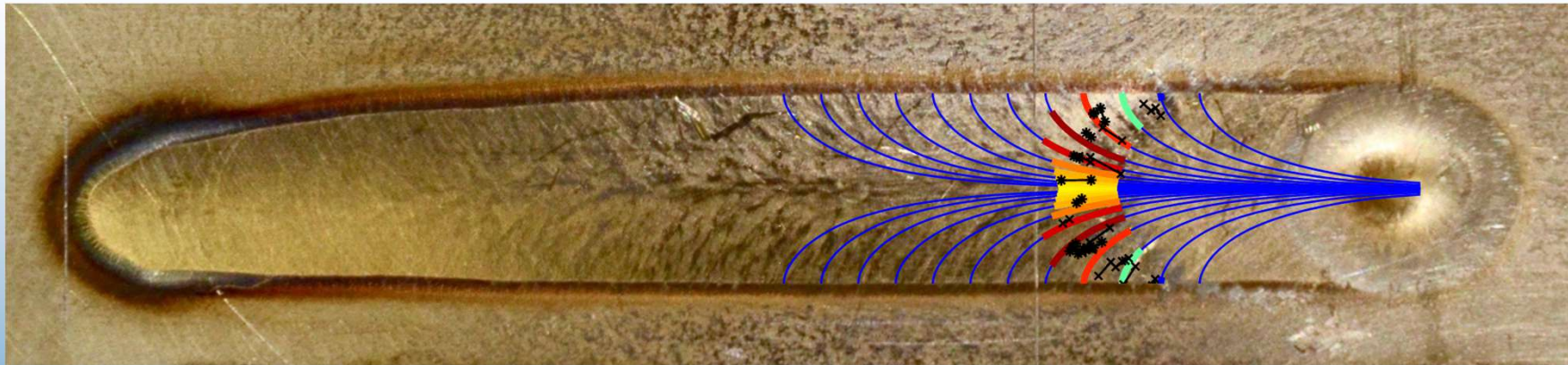
T_L = liquidus isotherm

T_E = eutectic isotherm

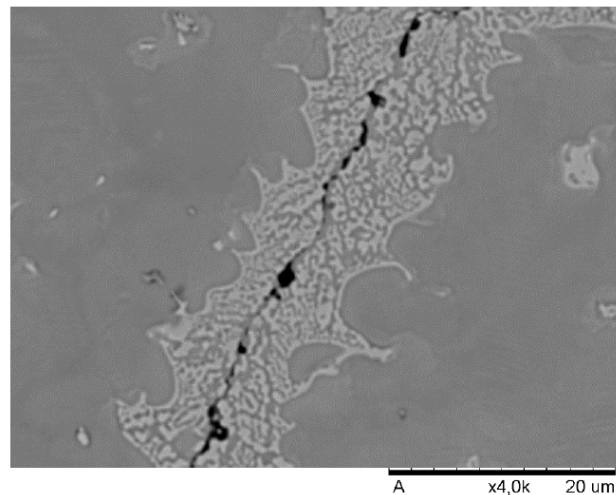
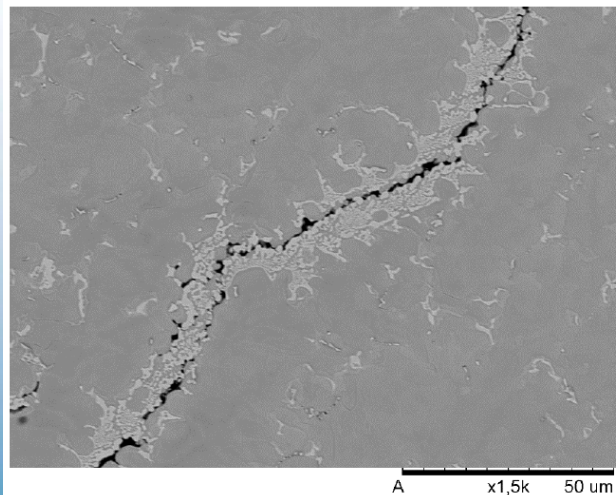
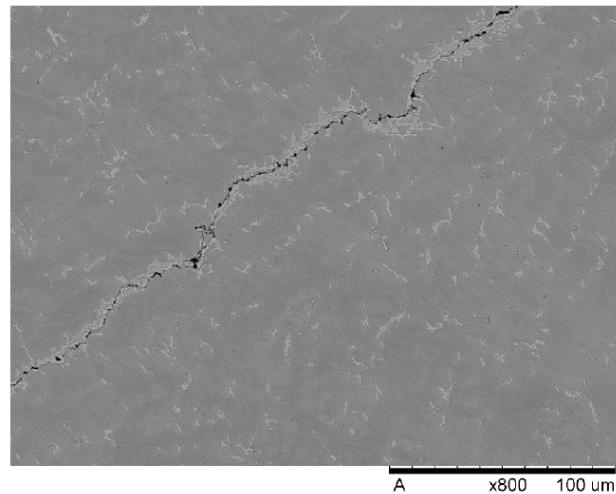
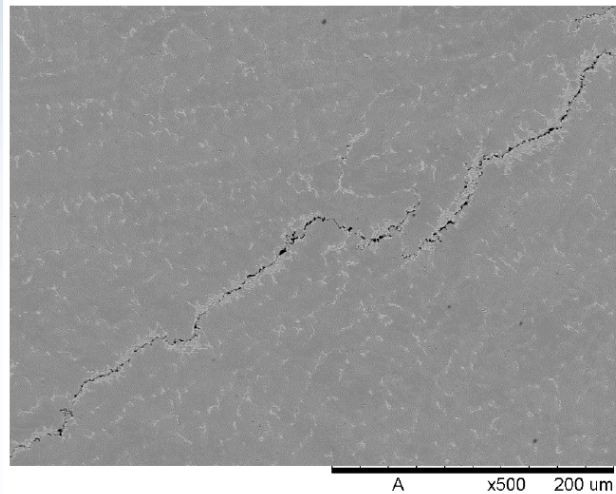
Objective

Development of a numerical model for hot cracking

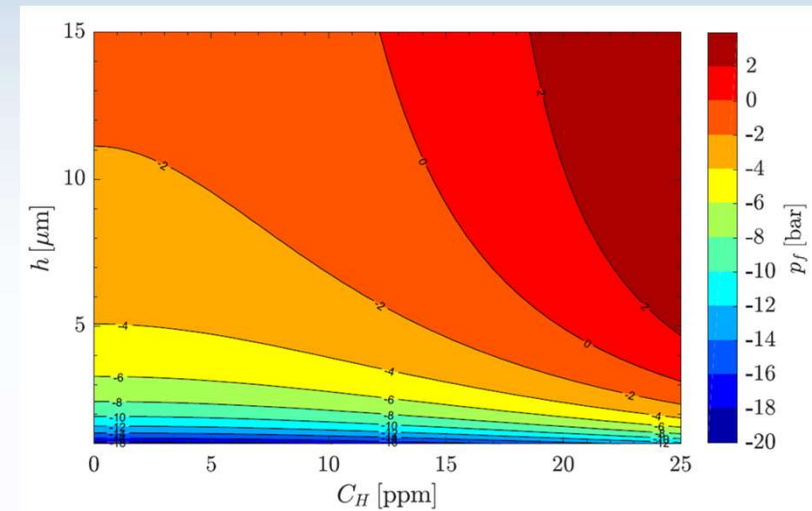
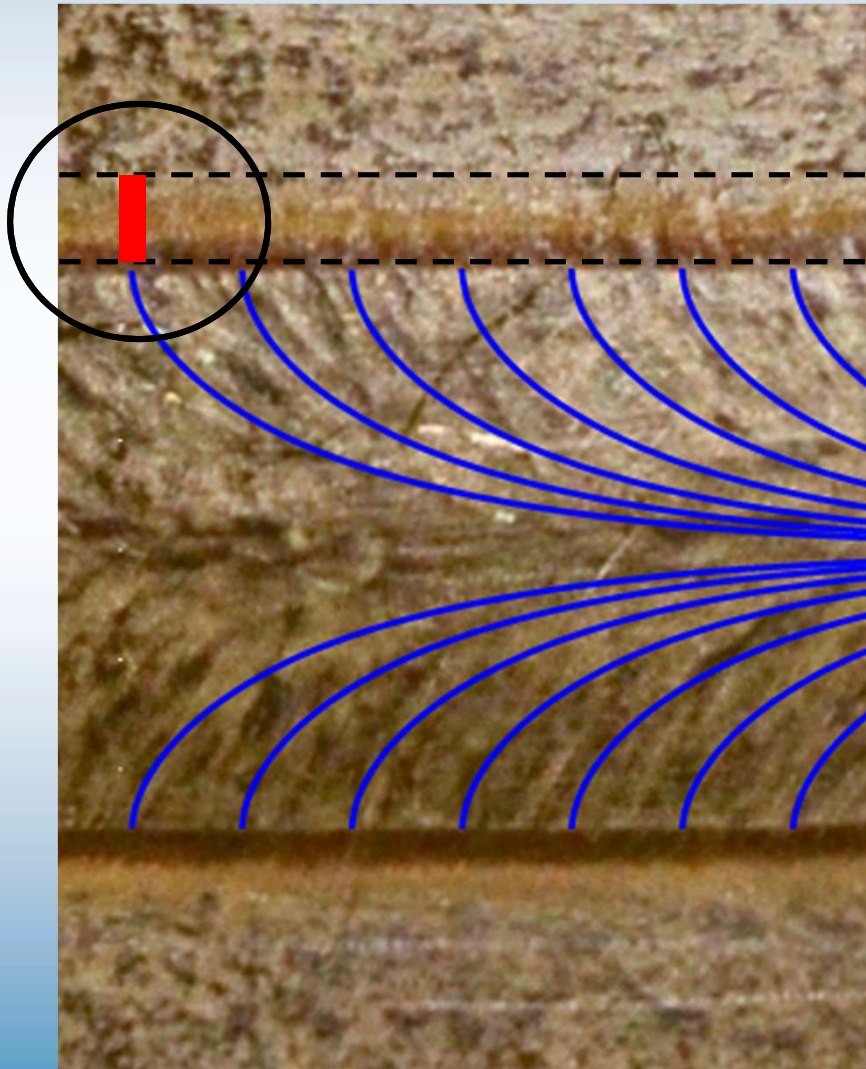
- Physically based crack criterion
 - Grain boundary liquid pressure model
 - Material model



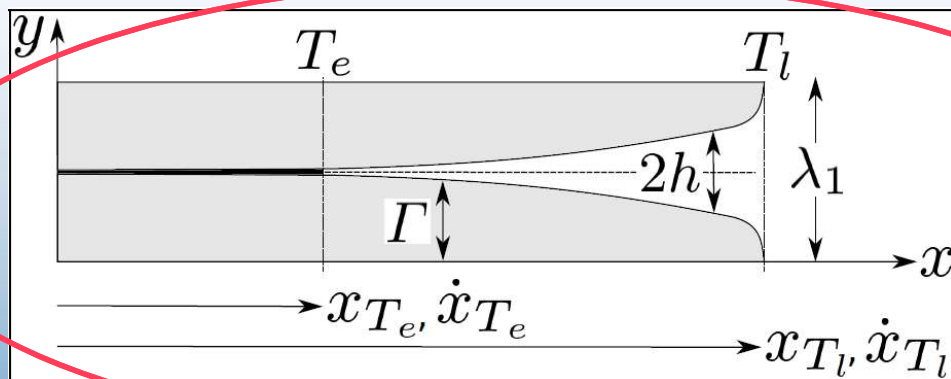
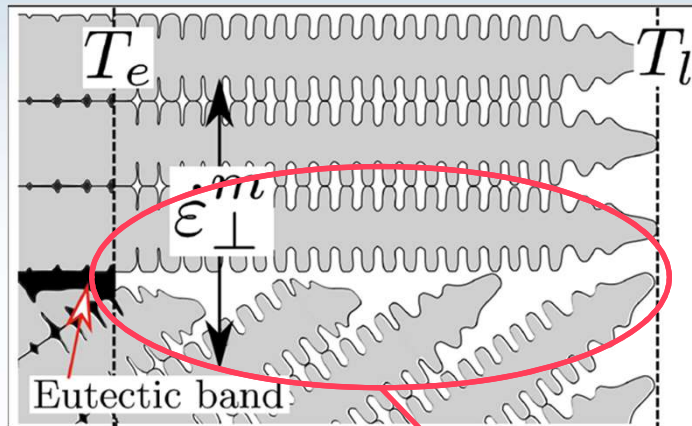
HAZ Liquation Cracking in Alloy 718 from Gamma/Laves Eutectic Bands



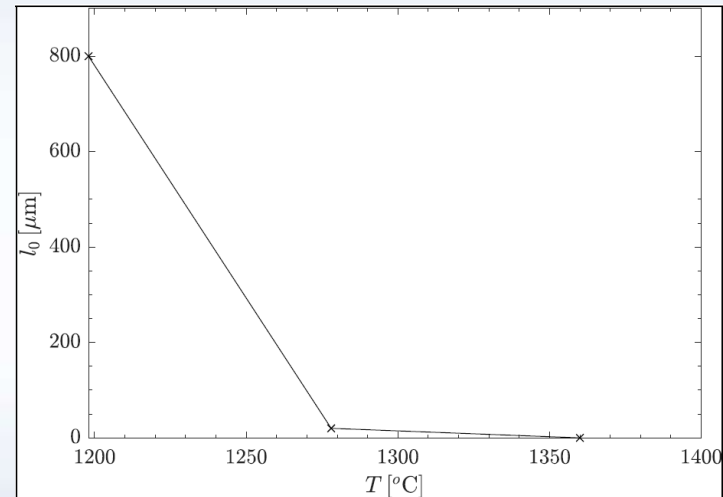
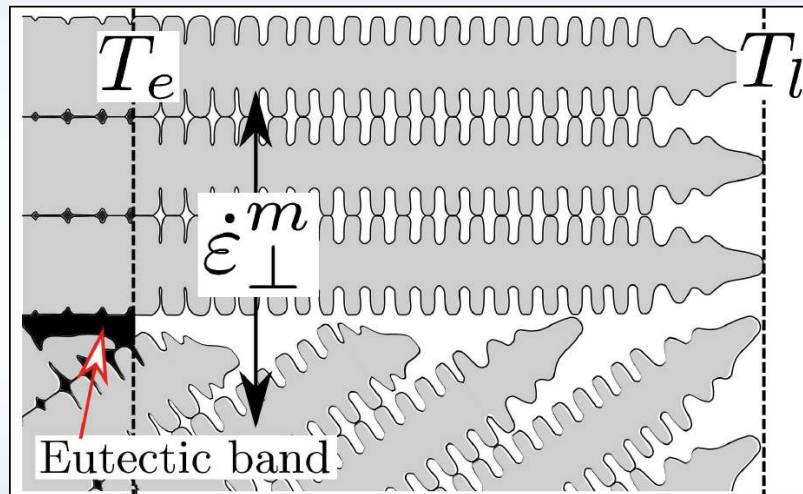
HAZ Liquation Cracking from Eutectic Bands



Modeling Approach



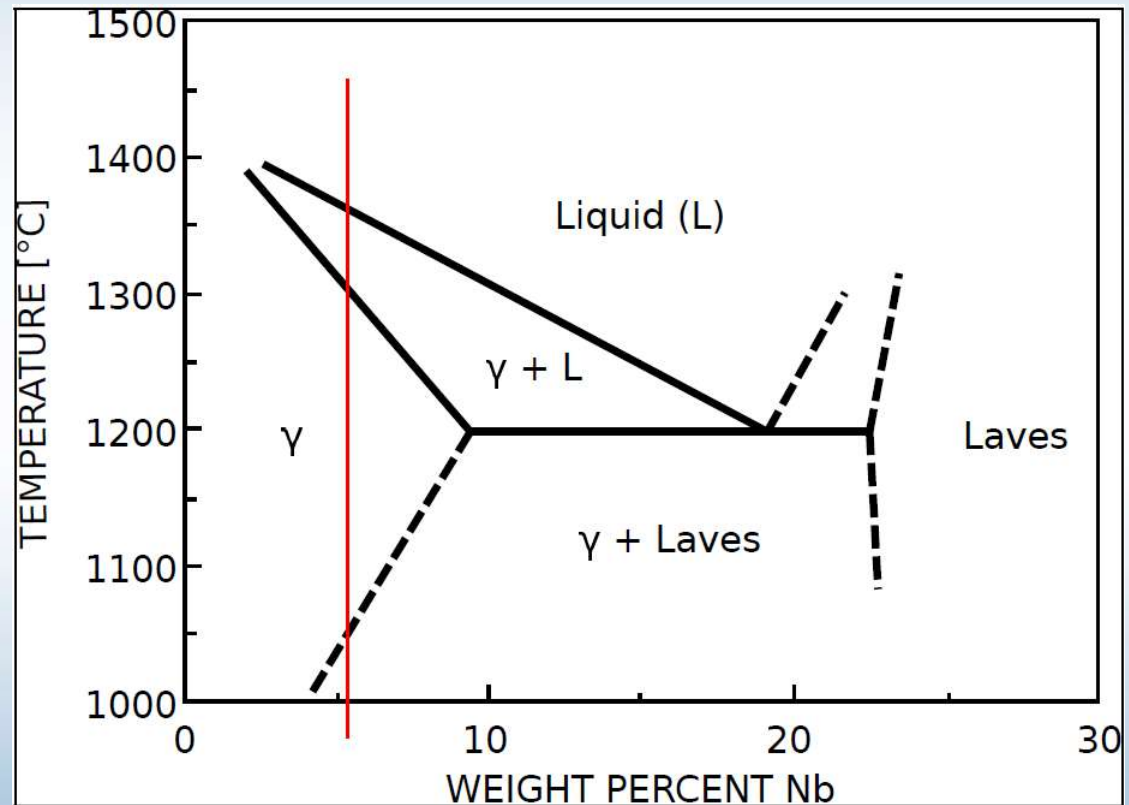
Strain Localization



Interface Equilibrium

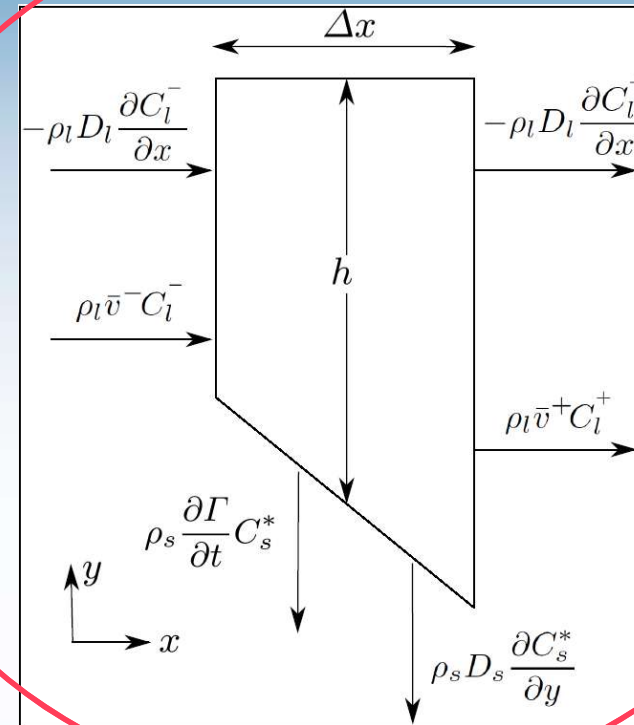
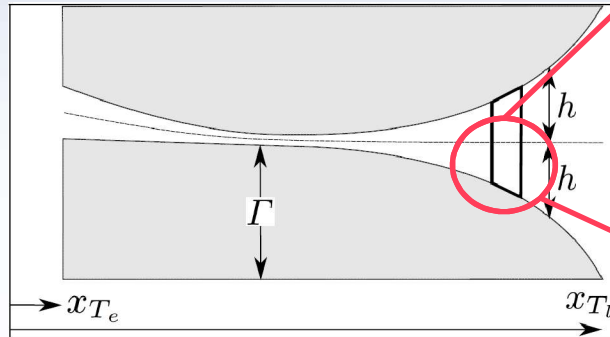
$$C_l = \frac{T - T_l}{m} + C_0$$

$$C_s^* = kC_l$$



(Knorovsky et al, 1989)

Solute Balance



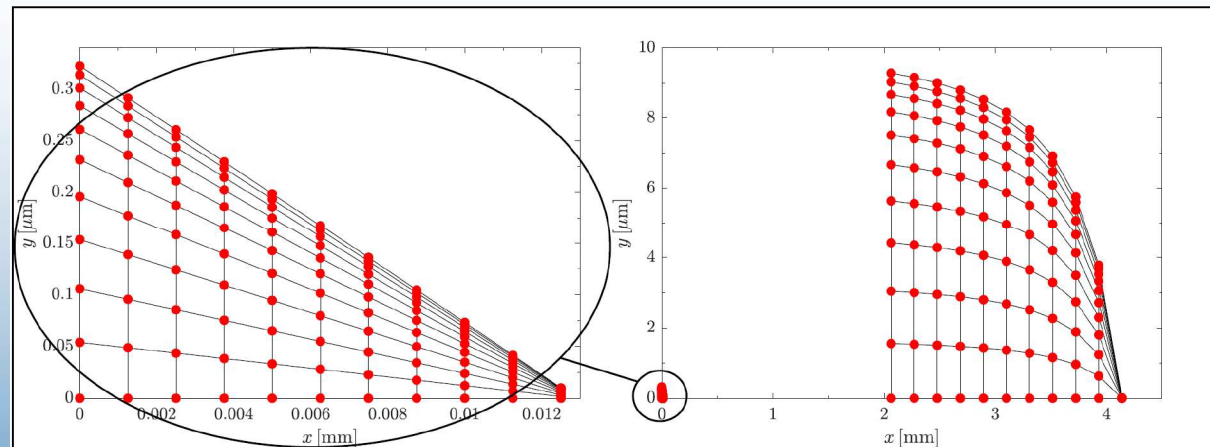
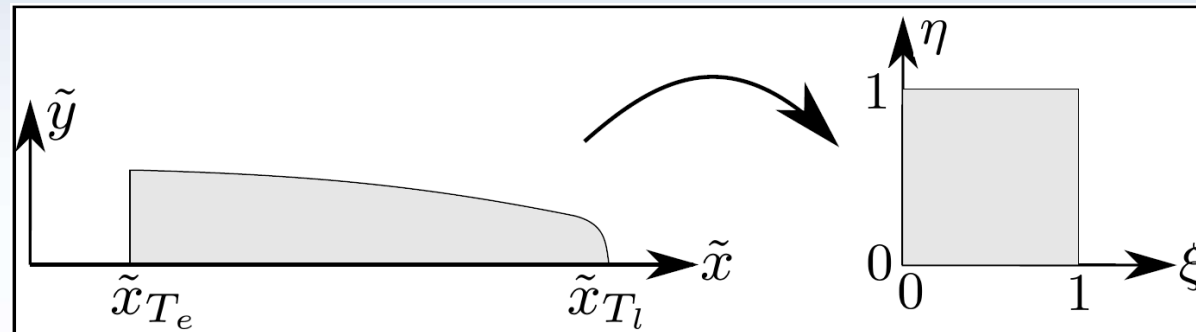
$$\rho_l \frac{\partial(C_l h)}{\partial t} + \rho_l \frac{\partial}{\partial x}(C_l \bar{v} h) - \rho_l D_l \frac{\partial}{\partial x} \left(\frac{\partial C_l}{\partial x} h \right) + \rho_s C_s^* \frac{\partial \Gamma}{\partial t} + \rho_s D_s \frac{\partial C_s^*}{\partial y} = 0$$

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

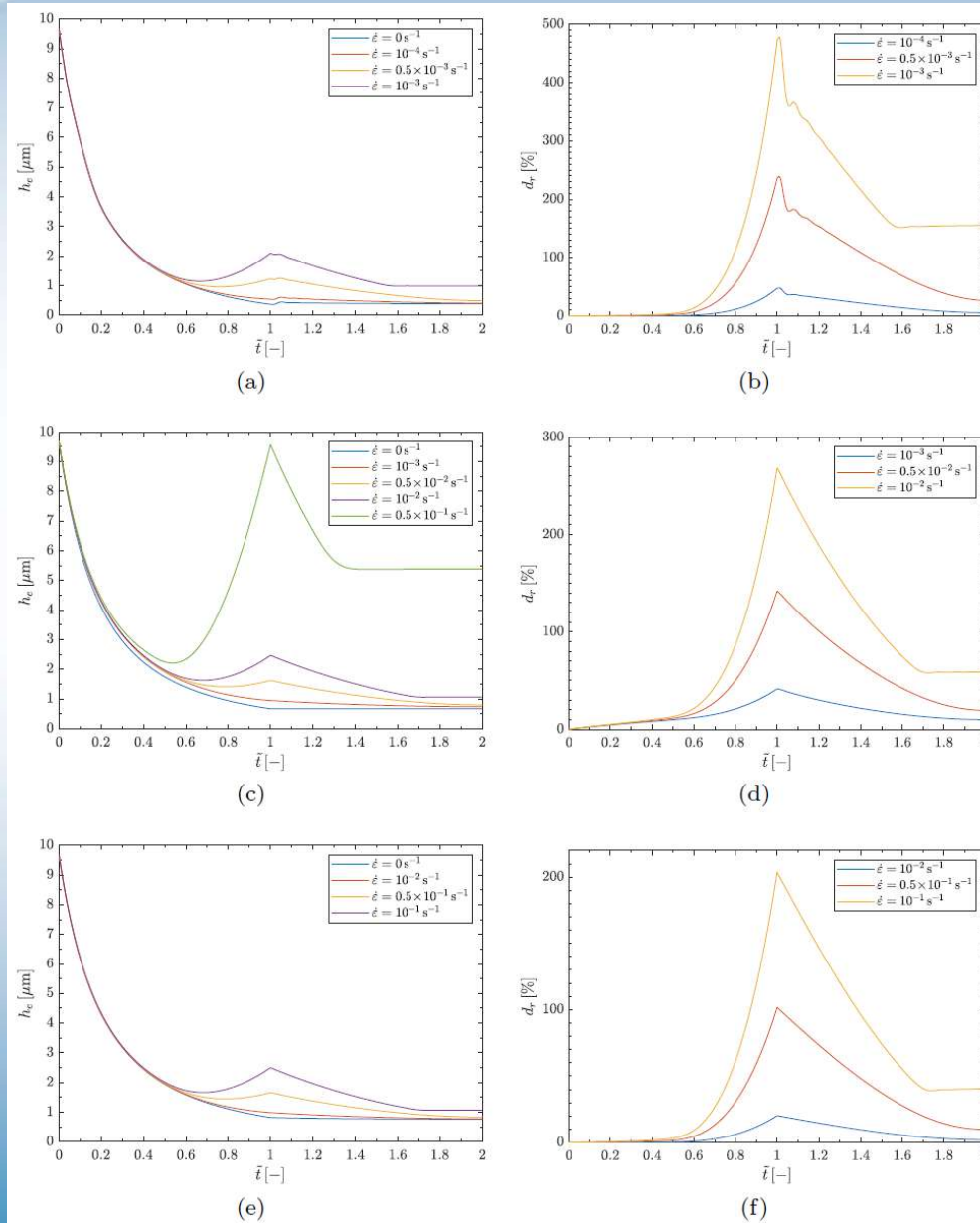
$$\frac{\partial(\bar{v} h)}{\partial x} = -(1 + \beta) \frac{\partial \Gamma}{\partial t} - \frac{\partial h}{\partial t}$$

Back Diffusion

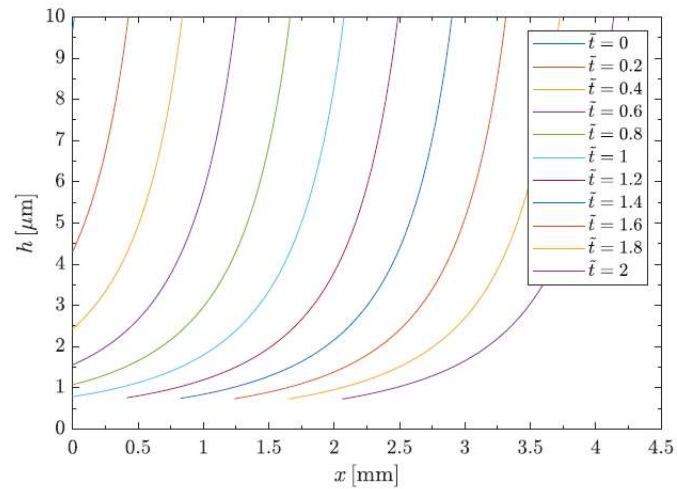
$$\left\{ \begin{array}{l} \frac{\partial \tilde{C}_s}{\partial \tilde{t}} - \tilde{D}_s \frac{\partial^2 \tilde{C}_s}{\partial \tilde{y}^2} = 0 \\ \tilde{C}_s(\tilde{y} = \tilde{\Gamma}) = k\tilde{C}_l \\ \frac{\partial \tilde{C}_s(\tilde{x} = \tilde{x}_{T_e})}{\partial \tilde{x}} = 0 \\ \frac{\partial \tilde{C}_s(\tilde{y} = 0)}{\partial \tilde{y}} = 0 \end{array} \right.$$



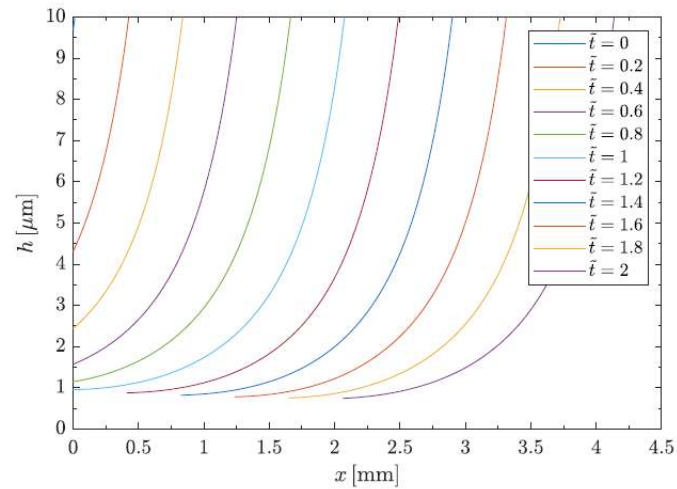
Results: Eutectic Band Thickness



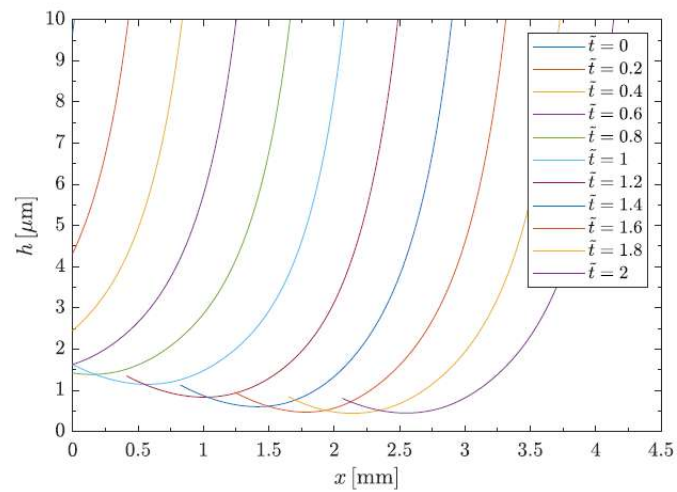
Results: Liquid Film Thickness



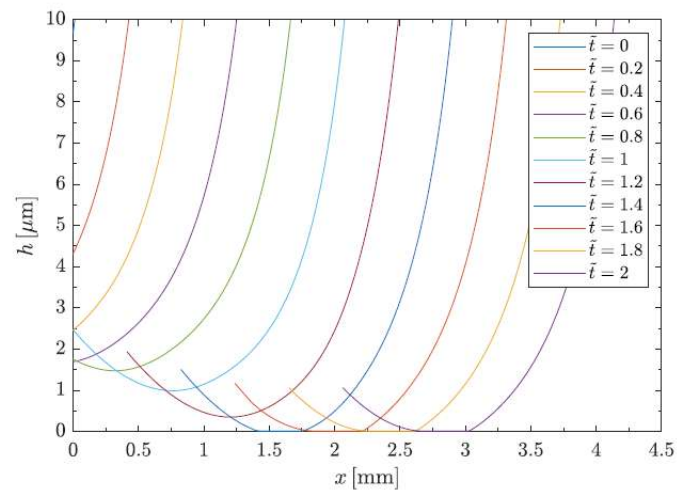
(a)



(b)

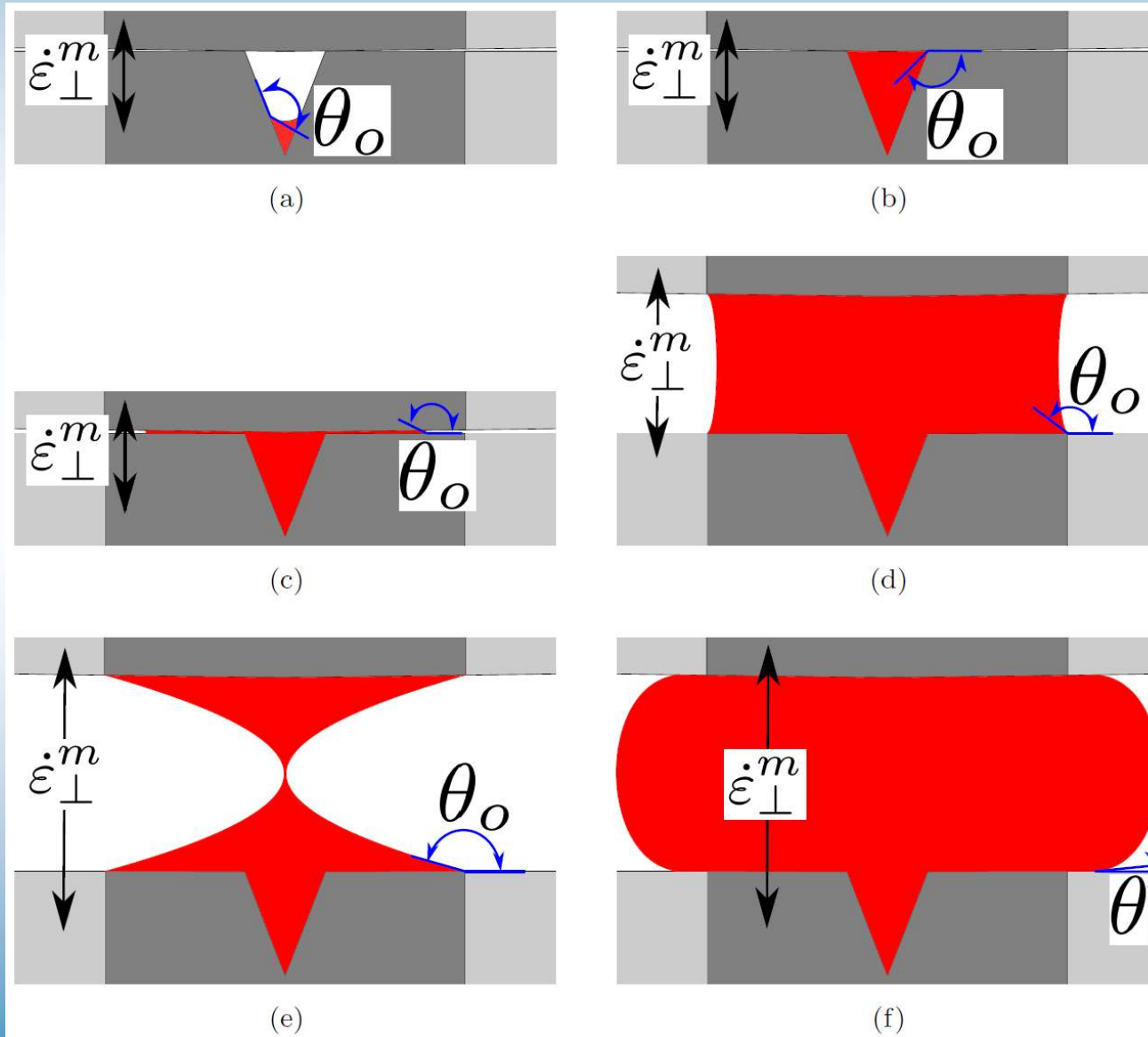


(c)

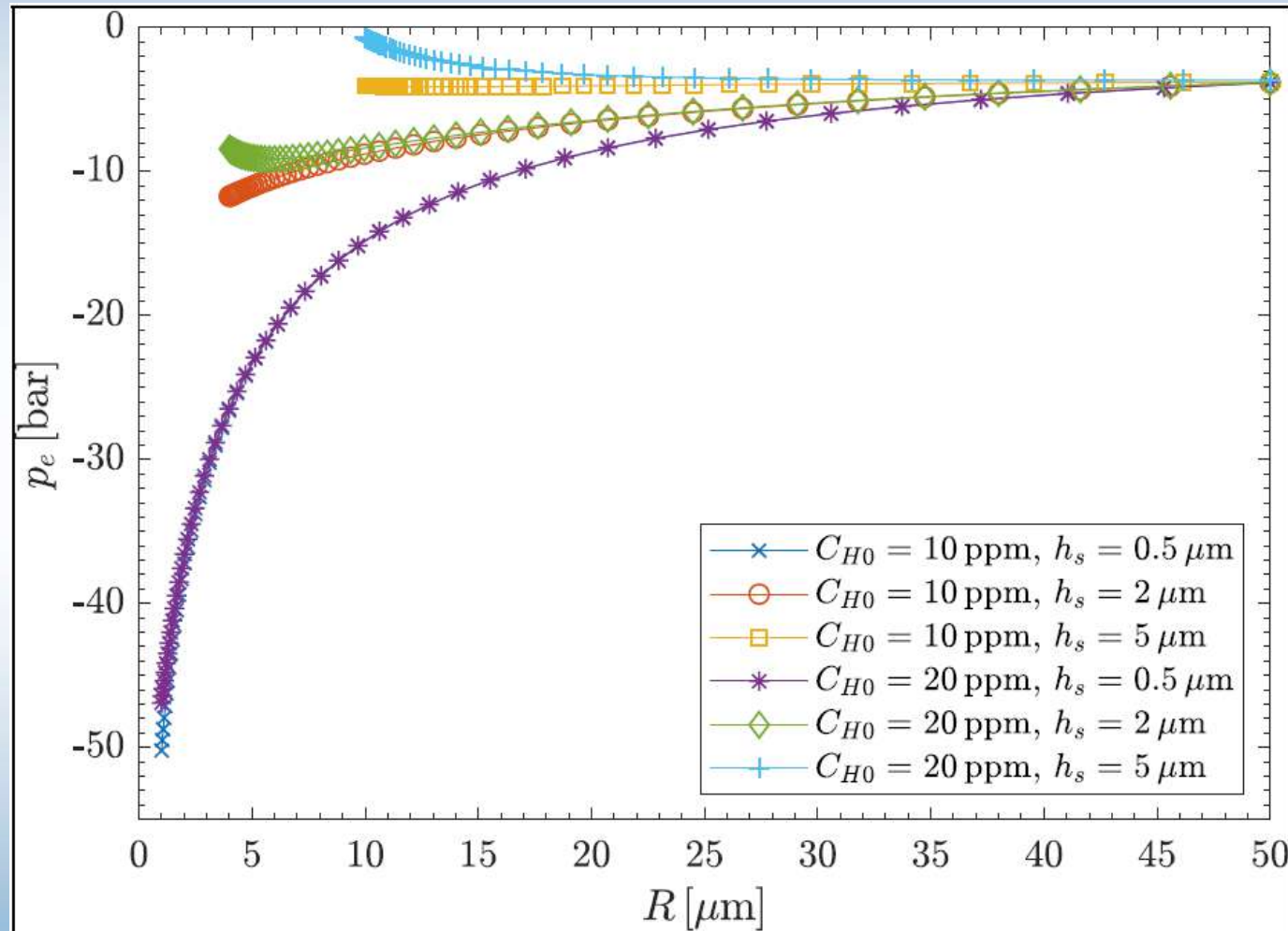


(d)

Results: Pore Nucleation Mechanism



Results: Pore Nucleation Mechanism



L

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.

A circular micrograph showing a dark, irregular crack or inclusion in a light-colored, textured material. The crack runs diagonally from the upper left towards the lower right. Several small, rectangular labels with numerical values are placed along the crack, indicating measurements. The values are: 9.79 µm, 12.44 µm, 11.76 µm, 10.75 µm, 14.00 µm, 14.58 µm, 10.60 µm, 12.08 µm, 15.31 µm, 17.01 µm, 16.24 µm, 6.54 µm, 10.20 µm, 10.00 µm, 4.56 µm, and 13.29 µm. The background material has a fine, fibrous or granular texture.