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Modelling Thermal Capillary Effects and Flow in the Molten Pool during Selective Laser Melting

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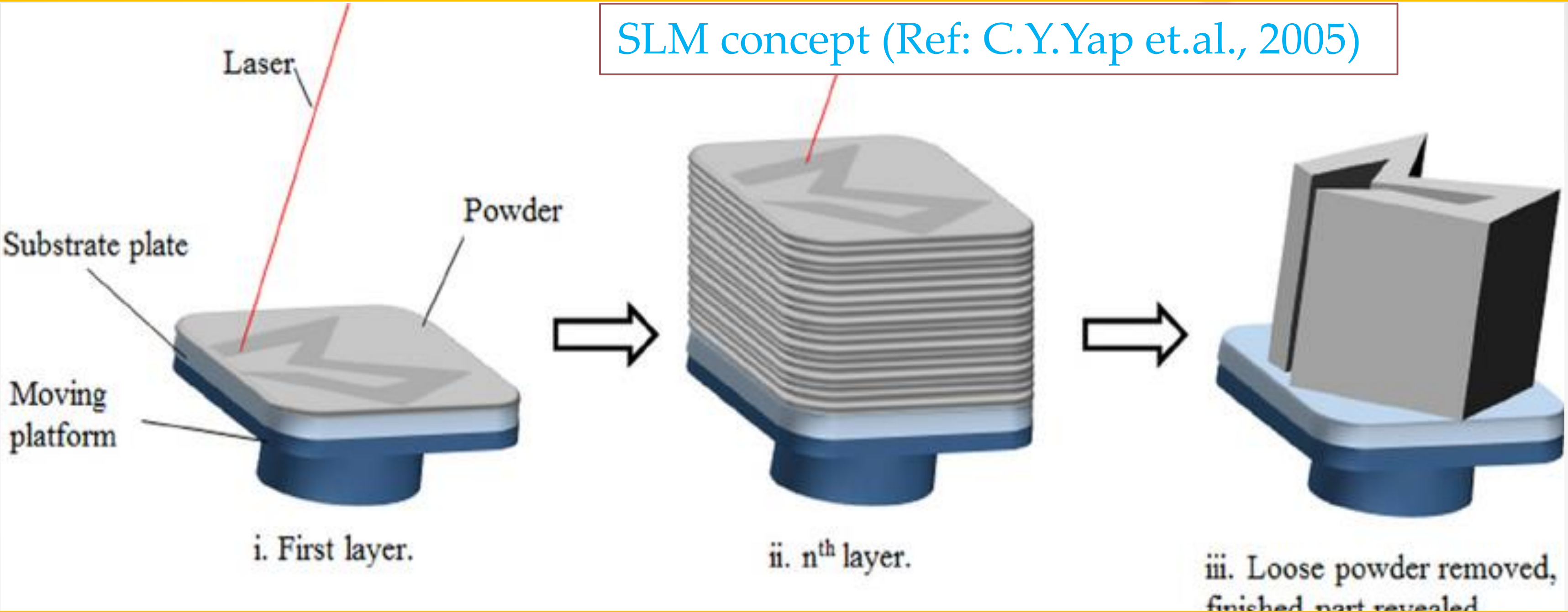
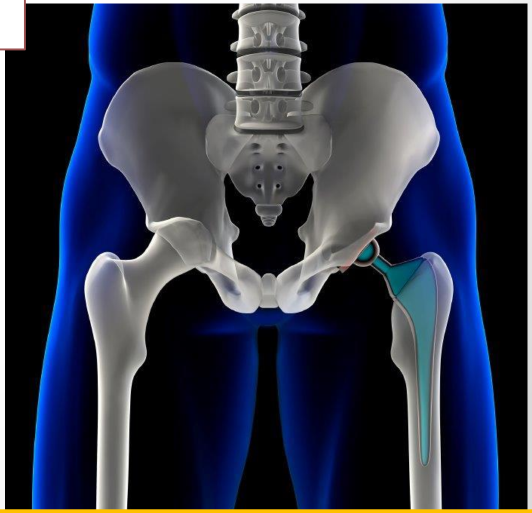
Introduction to SLM process

SLM concept (Ref: C.Y.Yap et.al., 2005)

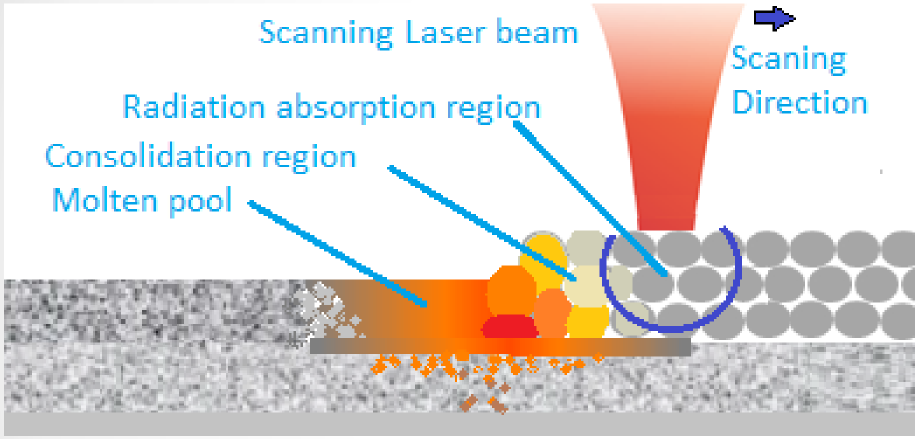


SLM applications …flexibility in design

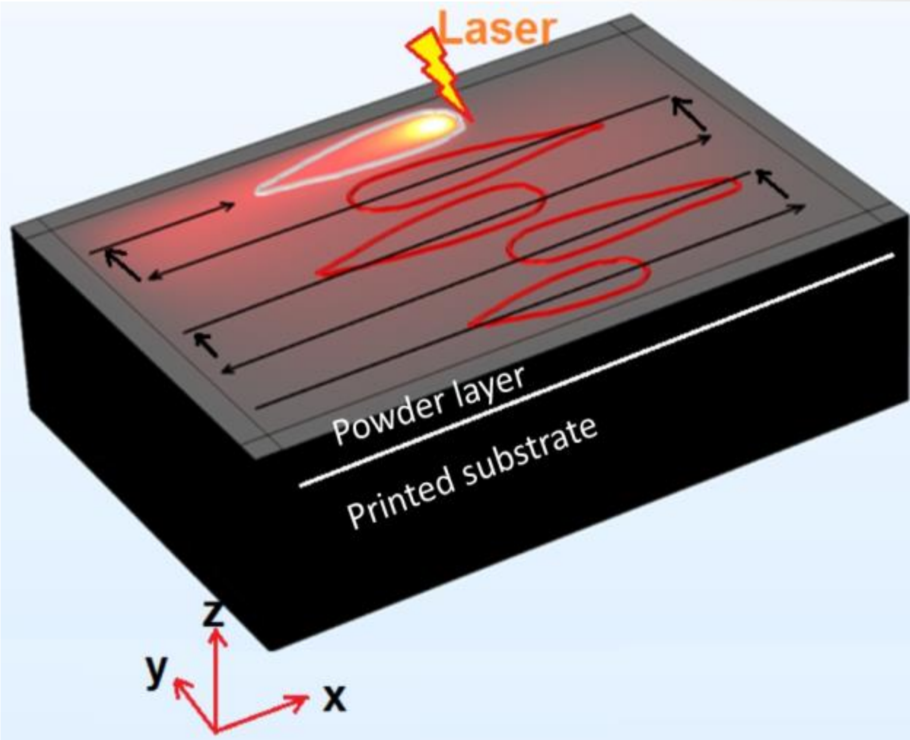


SLM simulation (introduction)

SLM Process



Simulation



- Many phenomena
- Single layer
- Single or multiple scan:

✓ Quality of melting:
(size and geometry of the molten pool)

✓ T-profile: cooling rate, T-gradient

Mathematical model

$$Q = \frac{2AP}{\pi r^2 \delta} \exp\left\{\frac{2[(x-vt)^2+y^2]}{r^2}\right\} \exp\left(\frac{-|z|}{\delta}\right)$$

- Volumetric laser energy deposition

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

$$k\left[\frac{\partial T}{\partial z}\right] = \varepsilon\sigma\left(T_o^4 - T^4(x,y,H,t)\right) + h(T_o - T(x,y,H,t))$$

$$T(x, y, z, t)|_{t=0} = T_0$$

Heat transfer

- Main equation
- Convection and thermal radiation
- Initial condition

Flow in the MP (Ignored in SLM Simulations with COMSOL in literature)

$$\begin{cases} \rho \frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla\left[-P\boldsymbol{I} + \mu\left(\left(\nabla u + (\nabla u)^T\right)\right)\right] + \rho g + \boldsymbol{F}, \\ \rho\nabla.(u) = 0. \end{cases}$$

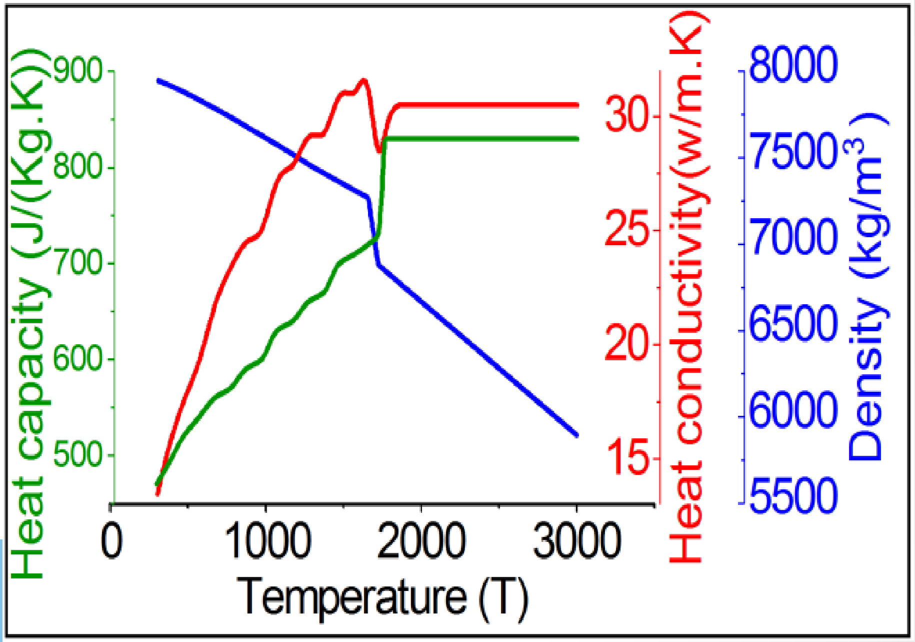
Laminar flow

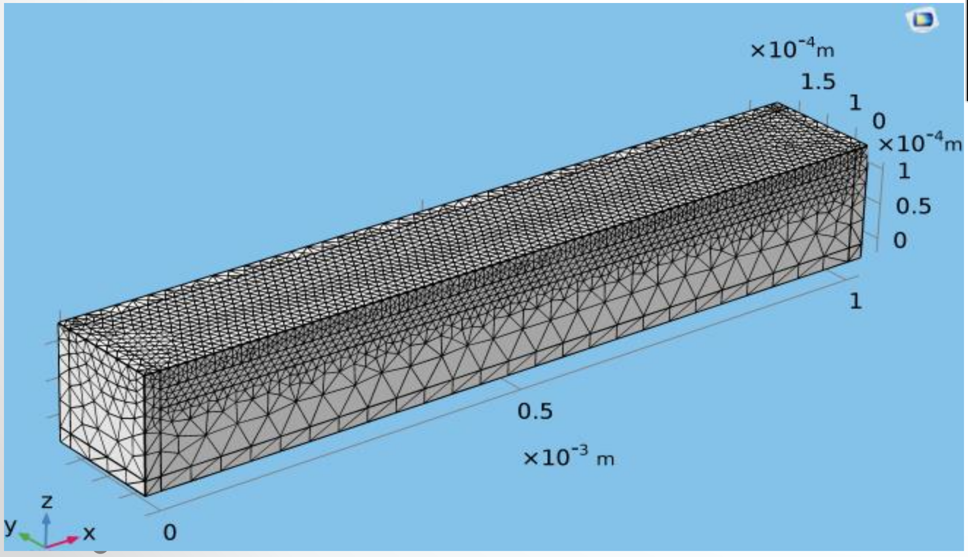
- Energy equation
- Conservation equation

$$F^{Marangoni} = \nabla_s \gamma\ , \quad \gamma = \gamma_0 + \frac{d\gamma}{dT}(T - T_{ref})$$

Material and Geometry

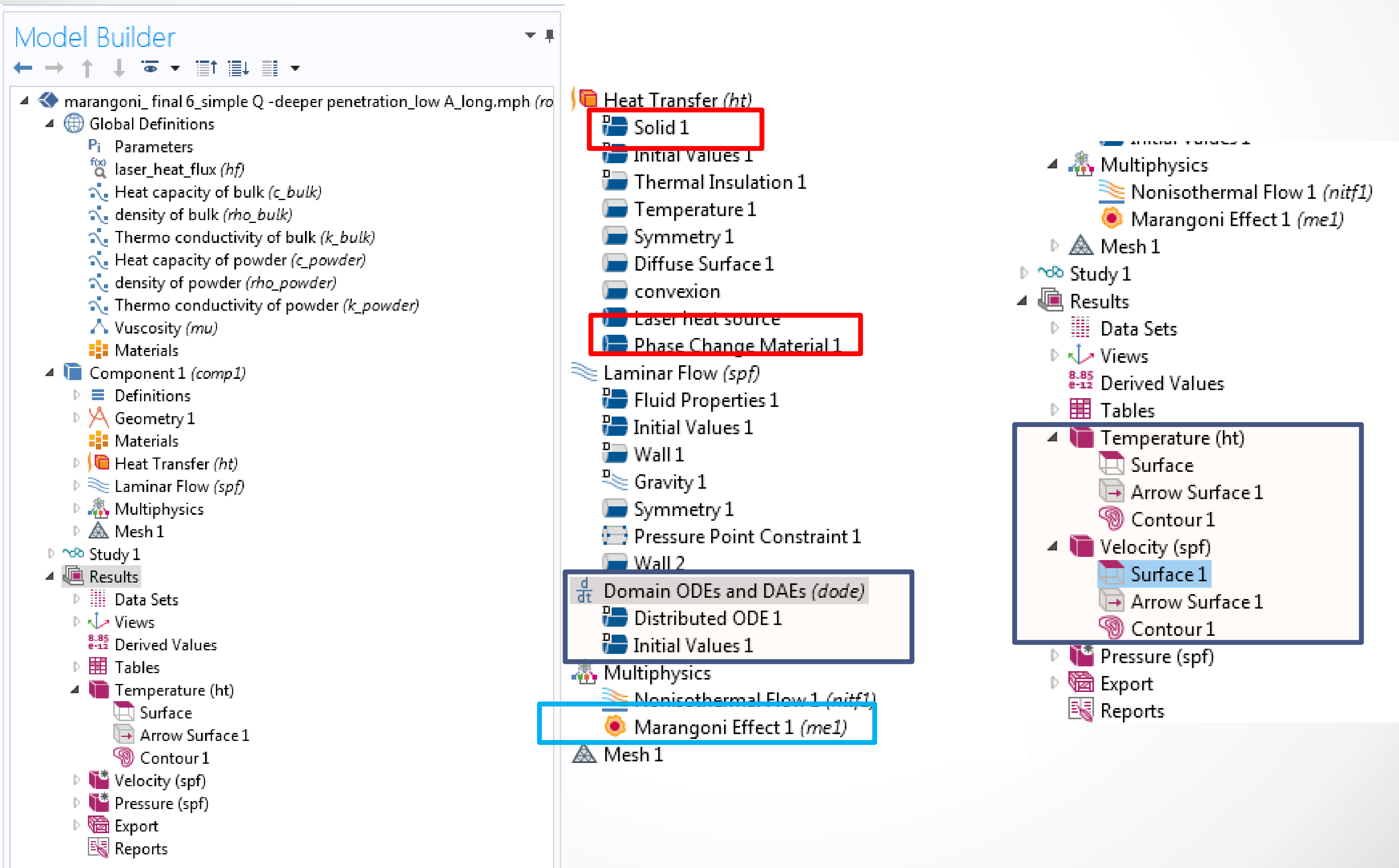
Parameter (Symbol)	Values [Unity]
Length (L)	1000[μm]
Width (W)	150[μm]
Height (H)	150[μm]
Powder layer Thickness (l)	60[μm]
Scanning speed (v)	750[mm/s]
Spot radius (r)	40[μm]
Surface emissivity (ε)	0.8
Laser power (P)	175[W]
Melting temperature (Tm)	1450+273[K]
Solidus Temperature (Ts)	1385+273 [K]
Powder porosity (∅)	0.48
Latent heat of fusion (Lf)	260[J/g]
Dynamic viscosity	0.0028[kg/(m s)]
Temperature derivative of the surface tension	-0.04685[m N/(m K)]
Total absorptivity of powder bed (A)	0.63



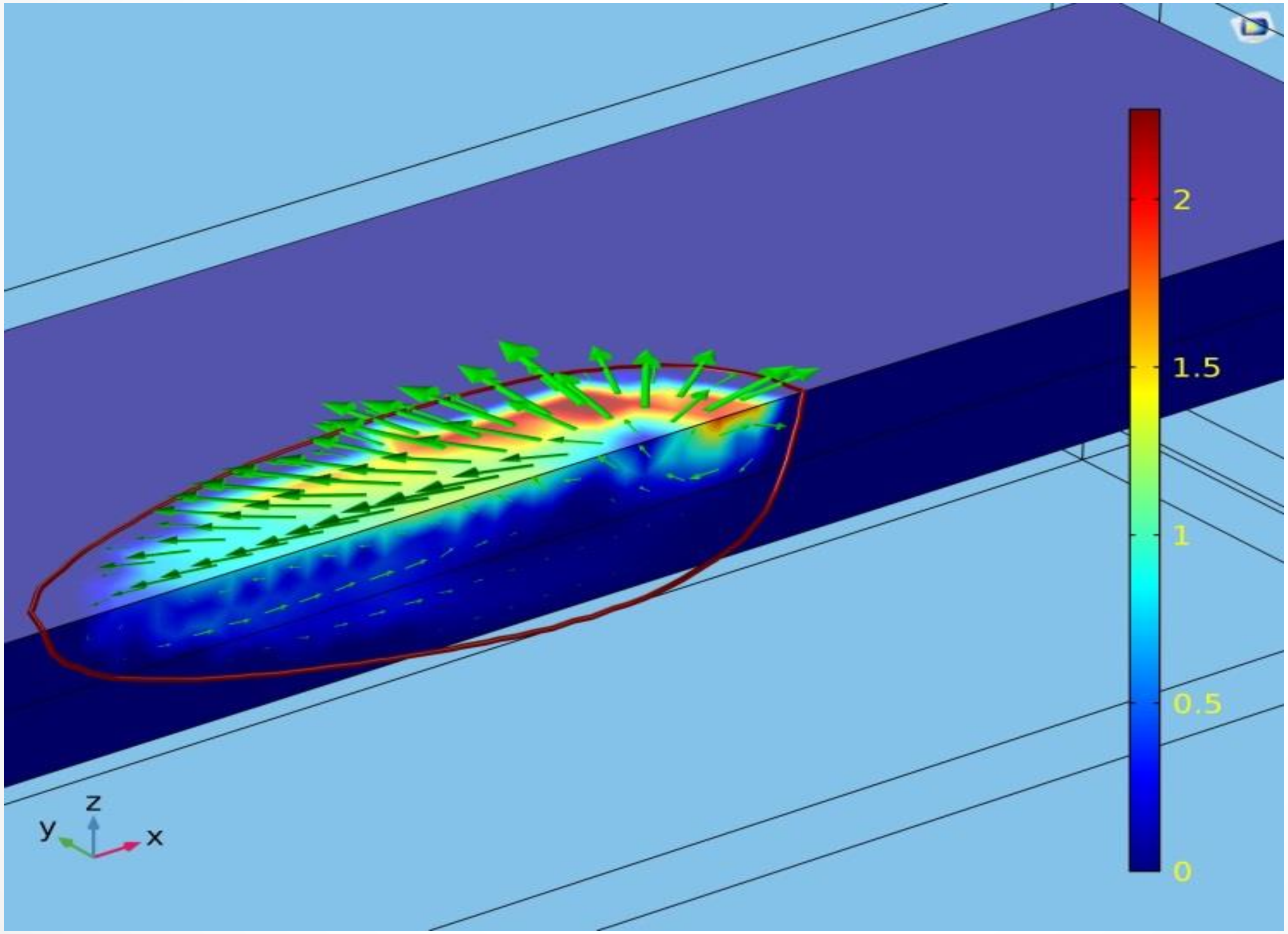


316 Stainless steel

Implementation in Comsol

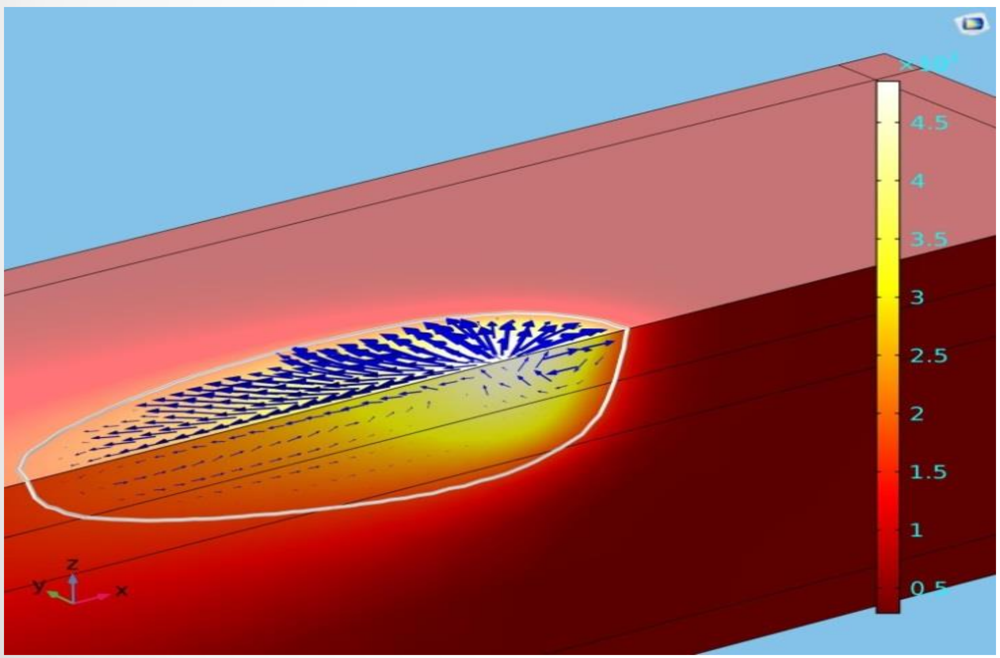


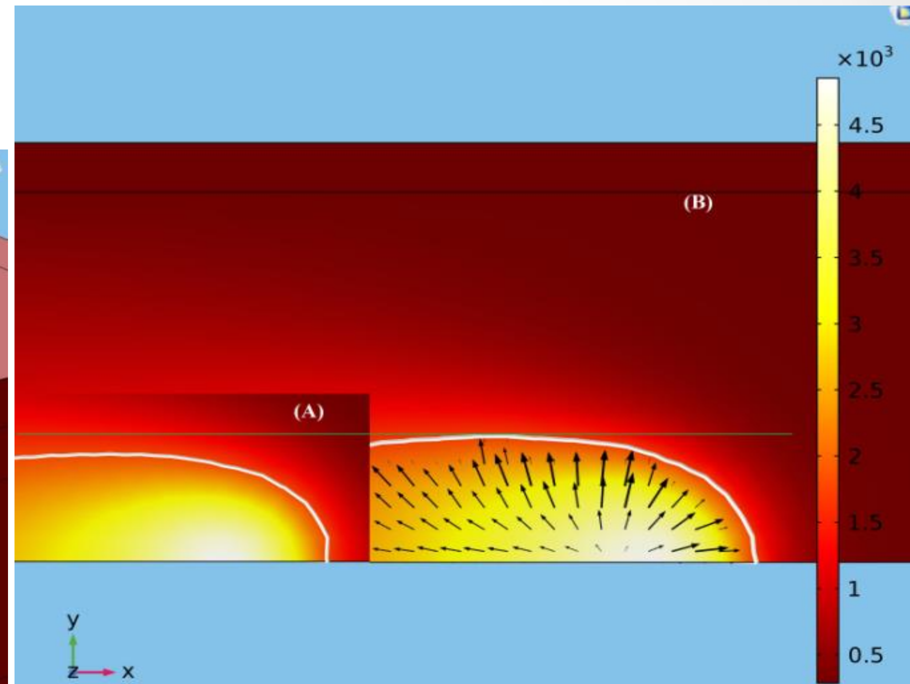
Velocity magnitude



(in m/s).

Velocity field , size of molten pool





Conclusions

- Due to gradient in surface tension, a shear thermal capillary force acts on the molten fluid and generates movements from region of highest temperature gradient towards the solidification front.
- The velocity magnitude is of the order of 2 m/s and cause enlargement of the molten pool as compared to the assumption of a molten pool with no melt flow.

QUESTIONS & COMPLEMENTS