

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

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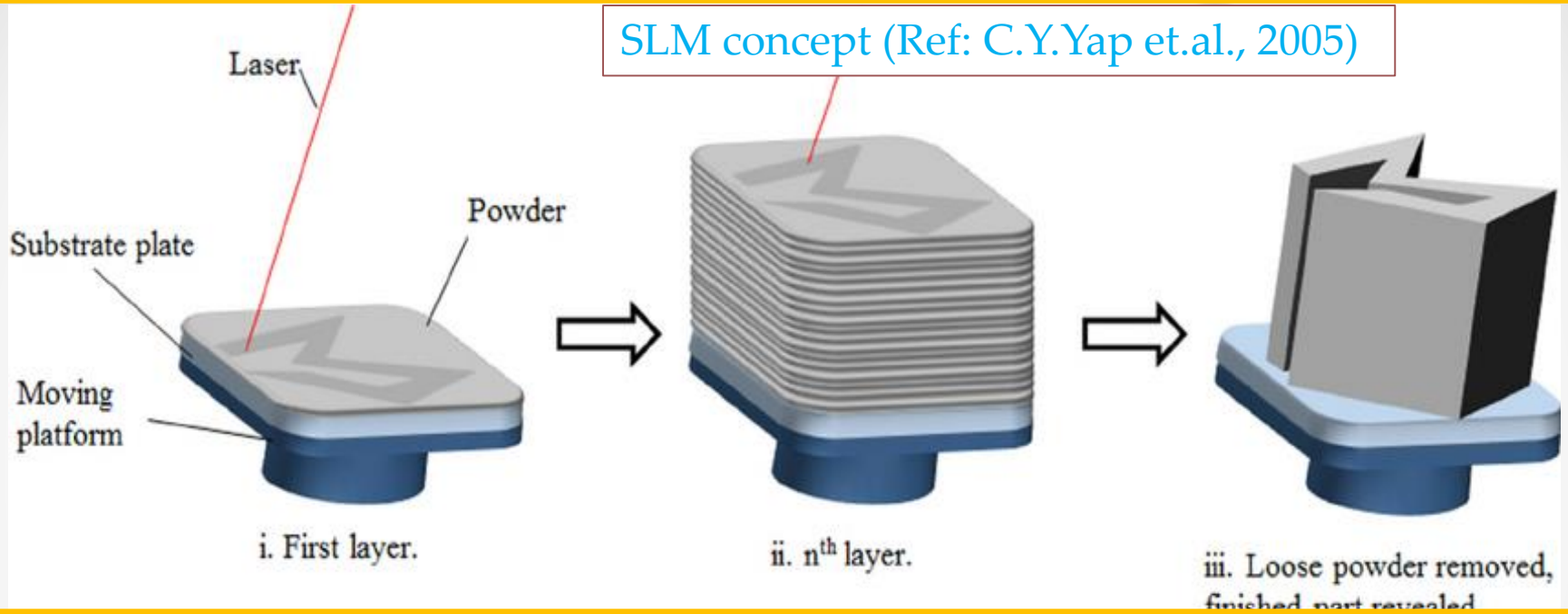
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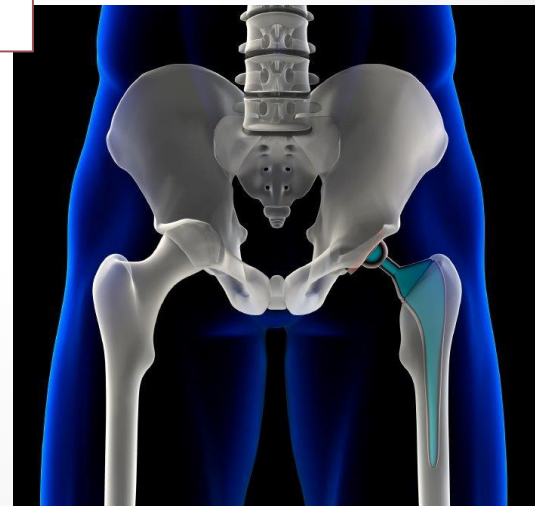
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Introduction to SLM process

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

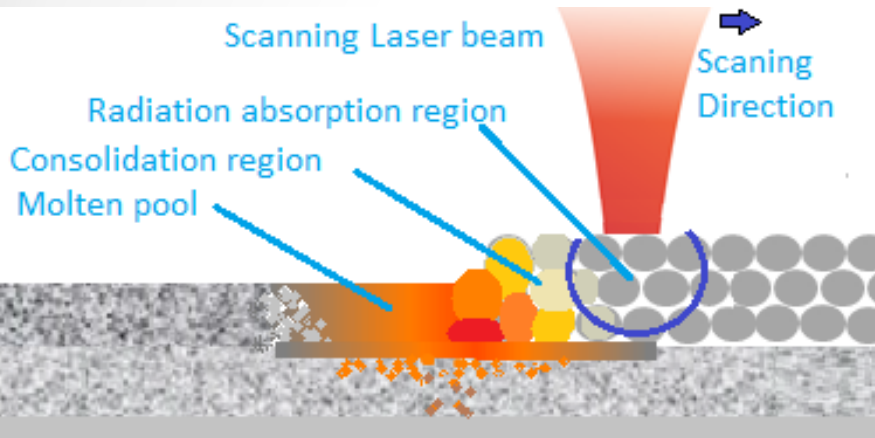


SLM applications ...flexibility in design

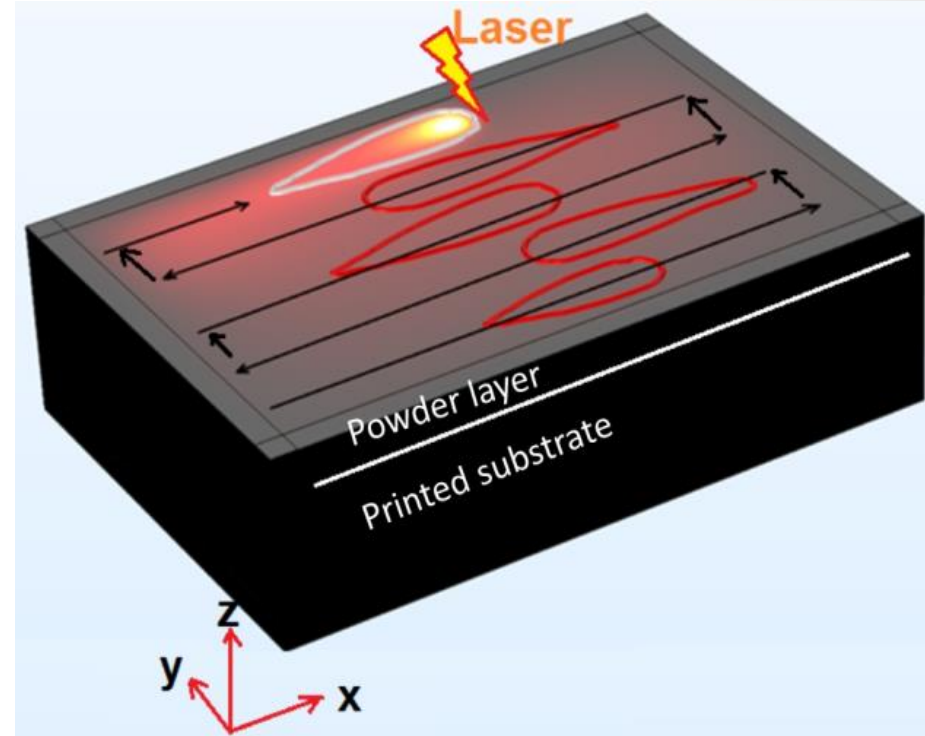


SLM simulation (introduction)

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

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

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

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

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

- Volumetric laser energy deposition

Heat transfer

- Main equation
- Convection and thermal radiation
- Initial condition

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

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

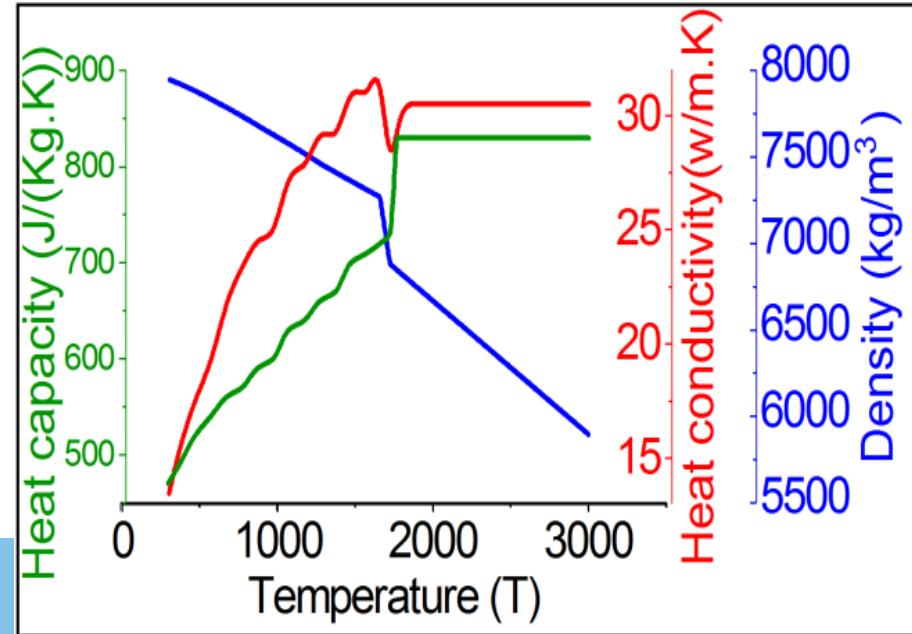
Laminar flow

- Energy equation
- Conservation equation

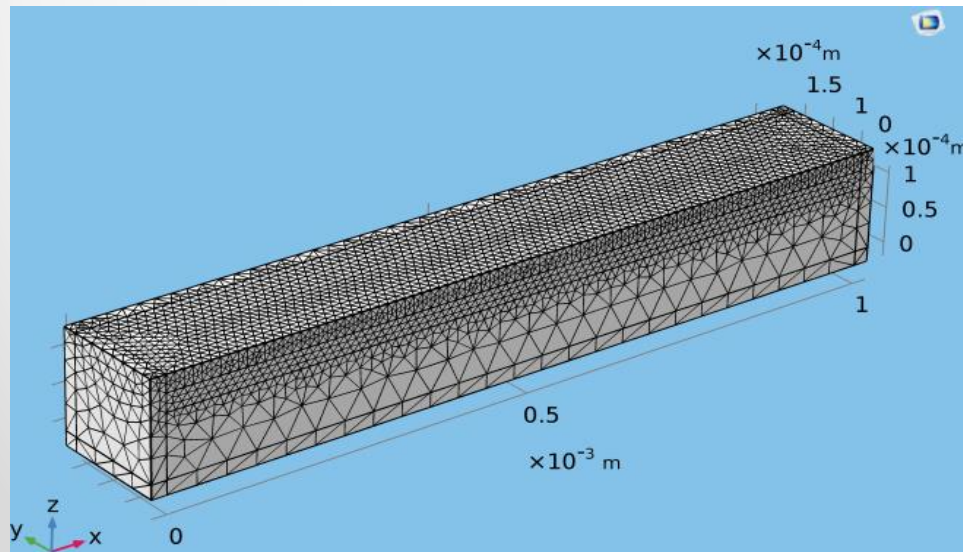
$$F^{Marangoni} = \nabla_s \gamma, \quad \gamma = \gamma_0 + \frac{d\gamma}{dT} (T - T_{ref})$$

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 (T_m) | 1450+273[K] |
| Solidus Temperature (T_s) | 1385+273 [K] |
| Powder porosity (ϕ) | 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

The image displays the Comsol Multiphysics Model Builder interface for a model named "marangoni_final 6_simple Q -deeper penetration_low A_long.mph (ro)". The interface is divided into three main panels: Global Definitions, Component 1 (comp1), and Results.

Global Definitions: Lists parameters such as laser heat flux (hf), heat capacity of bulk (c_{bulk}), density of bulk (ρ_{bulk}), thermo conductivity of bulk (k_{bulk}), heat capacity of powder (c_{powder}), density of powder (ρ_{powder}), thermo conductivity of powder (k_{powder}), and viscosity (μ).

Component 1 (comp1): Shows the following physics interfaces and settings:

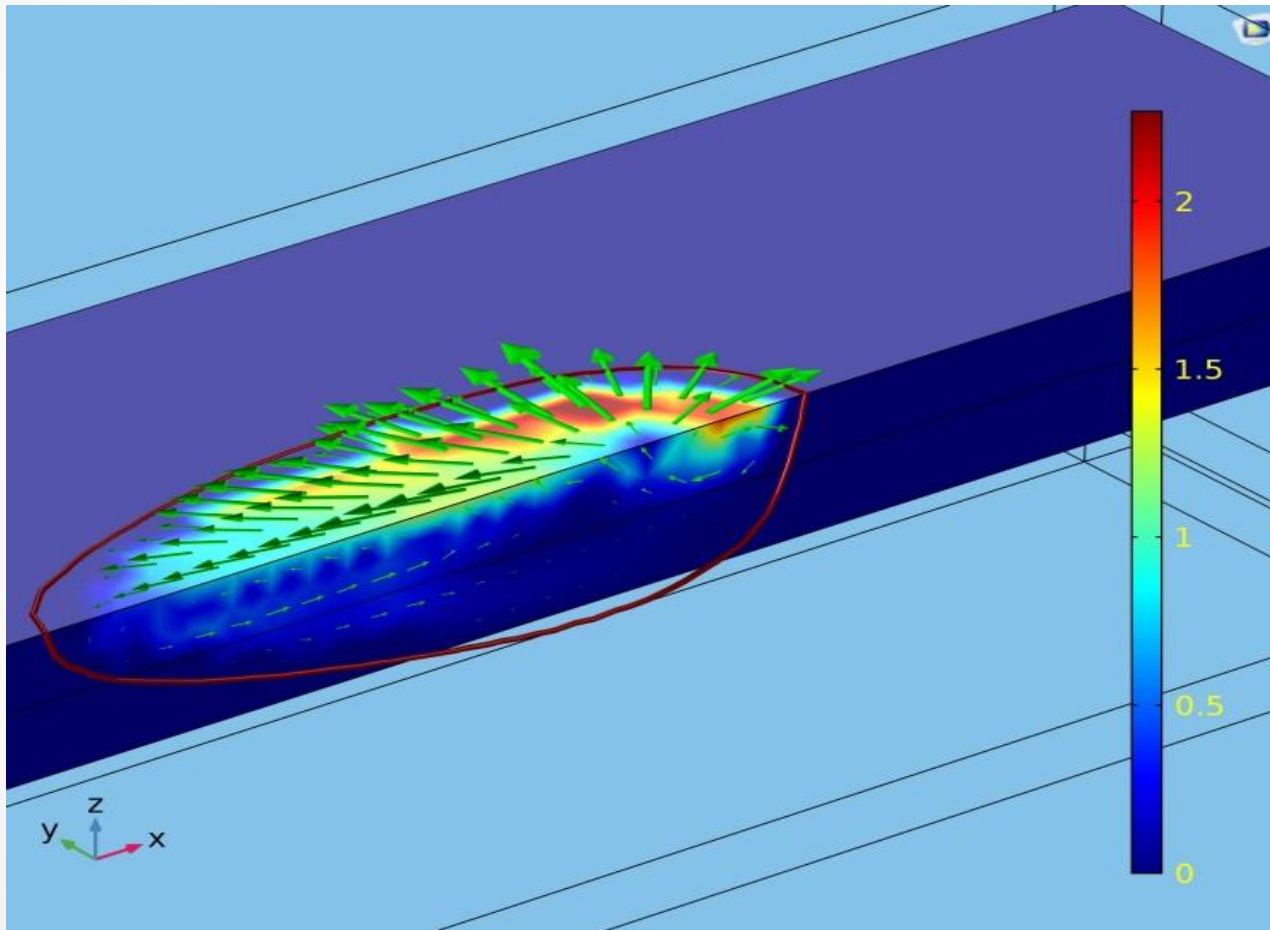
- Heat Transfer (ht):** Includes Solid 1, Initial Values 1, Thermal Insulation 1, Temperature 1, Symmetry 1, Diffuse Surface 1, convection, Laser heat source, and Phase Change Material 1.
- Laminar Flow (spf):** Includes Fluid Properties 1, Initial Values 1, Wall 1, Gravity 1, Symmetry 1, Pressure Point Constraint 1, and Wall 2.
- Domain ODEs and DAEs (dode):** Includes Distributed ODE 1 and Initial Values 1.
- Multiphysics:** Includes Nonisothermal Flow 1 (nitf1) and Marangoni Effect 1 (me1).

Results: Shows the following data sets and views:

- Temperature (ht):** Includes Surface, Arrow Surface 1, and Contour 1.
- Velocity (spf):** Includes Surface 1, Arrow Surface 1, and Contour 1.
- Pressure (spf):** Includes Arrow Surface 1 and Contour 1.
- Export and Reports:** Includes Export and Reports options.

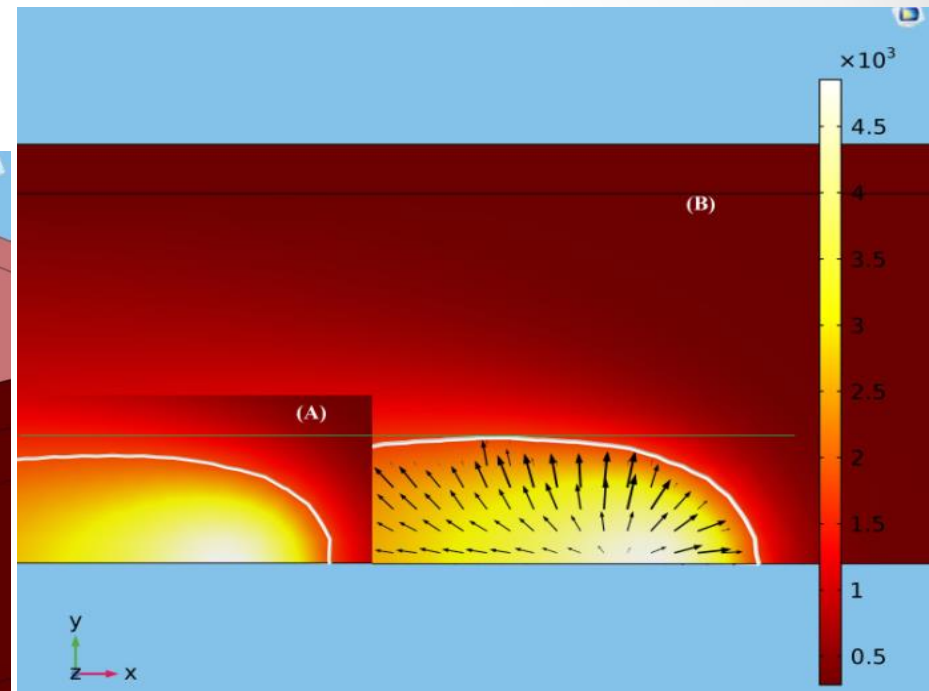
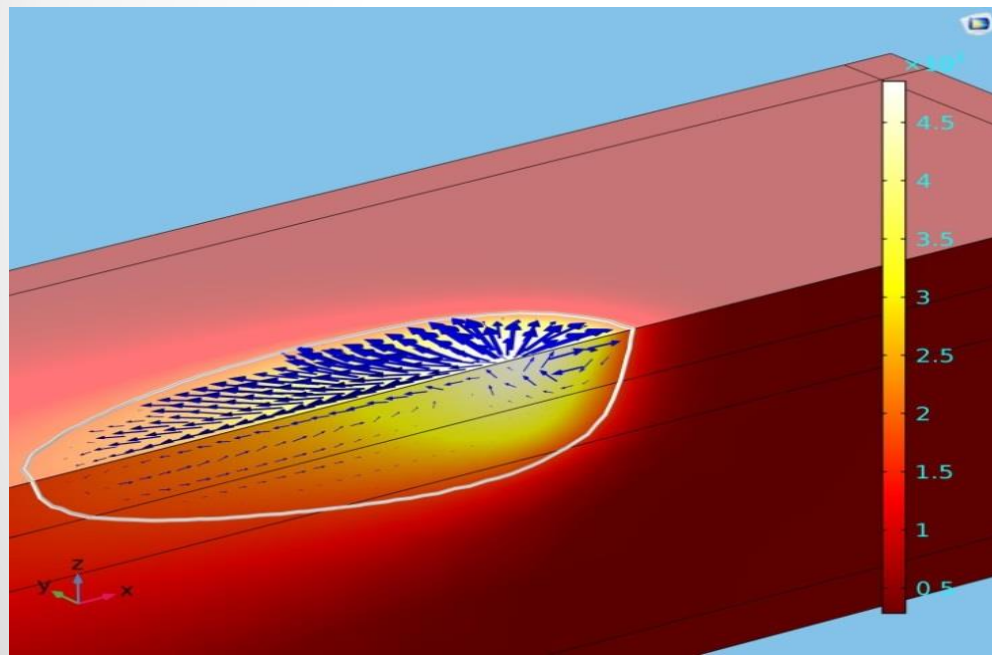
Red boxes highlight "Solid 1", "Laser heat source", and "Phase Change Material 1" in the Heat Transfer interface. A blue box highlights "Domain ODEs and DAEs (dode)" and its sub-items. Another blue box highlights "Marangoni Effect 1 (me1)" in the Multiphysics interface. A large blue box on the right highlights the "Temperature (ht)" and "Velocity (spf)" results sections.

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