Finite elements modelling and simulation tools to investigate Selective Laser Melting process and materials 3D-printed.
Introduction to SLM process

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

SLM applications ...flexibility in design
Introduction to SLM process

- Difficult / impossible to measure accurately some process parameters with currently available technologies
- Expensive experiment: try-and-error method is not favored
- Simulation is an important tool

Model of laser absorption
Model of T-profile estimation
Model of mass transfer

The use of the simulation model in real engineering situation
Introduction: Different levels of approximation

Approximate the granular nature of powder:
- High computation cost/time
- Differ from real powder bed
- Particular case
- Good for studying porosity or roughness of printed parts

Deformed geometry-moving mesh:
- High computation cost/time
- Generalized study
- Good for studying roughness of printed parts

Indirect modelling of volume shrinkage and mass transfer without geometry change:
- Low computation cost/time
- Generalized printing quality
- Melt pool size, cooling curve, scanning patterns, multiple layers...
- Adjust the size of powder layer and printed layer

Simulated temperature-profile is comparable in the 3 approximations
1. Laser absorption: Ray-tracing
Comparison of total absorption obtained by RT, 1D-RTE and experiment: High resolution SEM image of commercial powder used in SLM reveals non-mirror-like surface of powder particles justifying the deviation from specular reflection.
2. Model of T-profile estimation

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

Note: Immediate coupling of ray-tracing

\[ k \left[ \frac{\partial T}{\partial z} \right]_{z=H} = \varepsilon \sigma (T_0^4 - T^4(x, y, H, t)) + h(T_0 - T(x, y, H, t)) \]

\[ T(x, y, z, t)|_{t=0} = T_0 \]

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

Laser energy source from Ray-tracing and distribution

\[ Q = \left( \frac{\alpha_d}{\pi \alpha_r} \right)^2 \frac{2P}{\tau} \exp \left( \frac{2[(x-p_1(t))^2+(y-p_2(t))^2]}{\alpha_r^2} \right) \times u(z) \]

Note: Immediate coupling of ray-tracing

- \( F^{Marangoni} = \nabla_s \gamma \), \( \gamma = \gamma_0 + \frac{d\gamma}{dT} (T - T_{ref}) \)
- Recoil pressure during vaporization
3. COMSOL setting

Options includes:
- Heat Transfer in Solids
- Heat Transfer in Solids 1
- Translational Motion 1
- Initial Values 1
- Thermal Insulation 1
- Convection
- Diffuse Surface 1
- Heat Transfer with Phase Change in bulk
  - Laser volume source
  - Temperature 1
  - Symmetry 1
- Heat Transfer with Phase Change in powder
  - Temperature 1
- Laminar Flow
  - (spf)
- Domain ODEs and DAEs (docd)
- Multiphysics
- Meshes
- Study 1
- Results
  - Data Sets
  - Views
  - Derived Values
  - Tables
  - Temperature (ht)
  - Velocity field
- 1D Plot Group 8_depth
  - 1D Plot Group 9_Top_scanning lines
  - 1D Plot Group 9_substrate_lines
  - 1D Plot Group 9_substrate_lines 1
  - U_comparison

Graph with axes:
- Time (s)
- Temperature (°C)

Axis limits:
- x minimum: -1.22263E-4
- x maximum: 0.00776
- y minimum: 151.59997
- y maximum: 1016.23428

Grid settings:
- Show grid
- Manual spacing
  - x spacing: 1
  - y spacing: 1
316L-Alumina composite: control of grain size

3. Some examples using SLM simulation
4. COMSOL App – Multiple scanning lines
Note: Melt pool size usually increases a bit from 1 to 2nd line due to heat accumulation but it normally stabilizes at the 3rd line. One should know this while using this single scan model.
Summary

- Compared to experimental measurements of laser absorption in commercial powders used in SLM, ray-tracing diffuse mode gives the best approximation.

- The results of T-profile simulation (overlapping of molten truck, molten pool size, cooling information) agree with experiment.

- SLM being a relatively complex process, COMSOL Apps is useful for users without strong background in modelling.