Modelling of Powder Bed Fusion (PBF) Process

Gowthaman Parivendhan, Philip Cardiff, Alojz Ivankovic

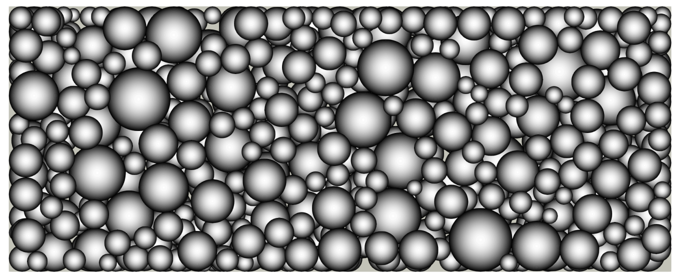
Introduction

Powder Bed Fusion using Laser Beam (PBF-LB) is highly complex and some of the mechanisms are difficult to observe using experiments. Numerical models can aid experimental studies in providing a better understanding of the process. In the current study, Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) are coupled to model the PBF process at mesoscale. However these models are computationally expensive. To provide realtime predictions, several emulators were developed based on the training data provided by the simulations.

Methods

Powder Bed Generation

Particles with similar grain distribution of raw powder are generated at the top of the domain and allowed to settle on the build plate [1]. After equilibrium, particles above the desired layer thickness are removed.



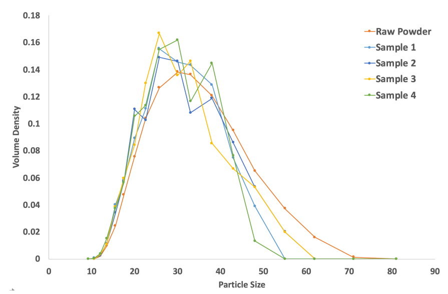


Figure 1: Top view of Powder Bed sample using DEM (left). Grain size distribution of raw sample and DEM models (right).

The position and size of each particles is then transferred to the Finite Volume mesh in OpenFOAM by assigning material volume fraction in each cell as shown in Figure 2.

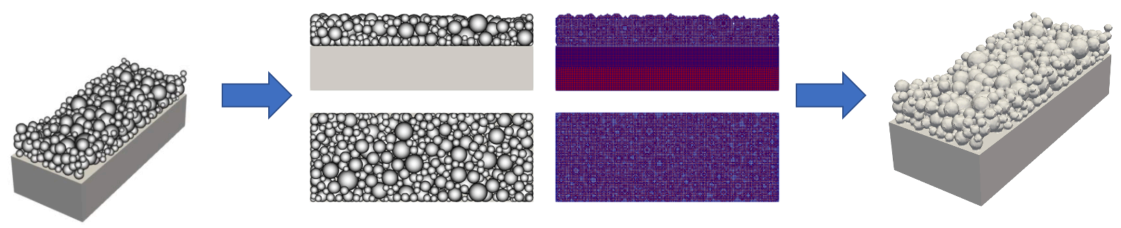


Figure 2: Representation of powder data transfer from LIGGGHTS (DEM) to Finite Volume mesh in OpenFOAM (CFD).

Melt pool Hydrodynamics

The material flow during the Laser processing includes several complex physical phenomena. In this study, we assume the material to be incompressible. Thus the continuity equation is:

$$\frac{\partial \bar{\rho}}{\partial t} + \nabla \cdot \left(\bar{\rho}\mathbf{u}\right) = 0$$

Volume of Fluid(VoF) method is used for the simulation of multiphase interaction. The properties of each cell in the mesh is averaged based on the volume fraction of the phases in the corresponding cell. The mixture velocity is calculated using the modified Navier-Stokes Equation given below [2]:

$$\frac{\partial \bar{\rho}\mathbf{u}}{\partial t} + \nabla \cdot \left(\bar{\rho}\mathbf{u} \otimes \mathbf{u}\right) = -\nabla p + \nabla \cdot (\bar{\mu} \nabla \mathbf{u})$$
$$+\bar{\rho}\mathbf{g}\beta\left(T - T_l\right) + \mathbf{F_s} - \alpha_m C\left[\frac{(1-g_l)^2}{g_l^3 + q}\right]\mathbf{u}$$

The flow equation includes the effects of Buoyancy driven flow and surface forces such as Capillary flow, Marangoni Convection and recoil pressure. The last term in the N-S equation is a momentum sink that drives the velocities of solid cells to zero. The temperature in the domain is calculated using the classic heat equation. The melting/solidification of the metal is modelled using the Voller method. The laser heat source and heat sinks such as radiation and convection loss, and heat loss due to vaporisation are included at the metal/gas interface. The laser is included only at the top surface of the powder using an approach similar to [3]. Fresnel absorption and reflections of laser beam are not considered.

$$\frac{\partial \bar{\rho}\bar{C}_pT}{\partial t} + \nabla \cdot (\mathbf{u}\bar{\rho}\bar{C}_pT) = -\frac{\partial \bar{\rho}L}{\partial t} - \nabla \cdot (\bar{\rho}\mathbf{u}L) + \nabla \cdot (\bar{k}\nabla T)$$
$$+Q_{laser} - Q_{loss}$$

Web Platform

At present, the influence of process parameters such as Laser Power, Scanning speed, Layer thickness on the melt pool dimensions is studied. The OpenFOAM simulation predictions are validated with the experimental data for different combinations of these process parameters.

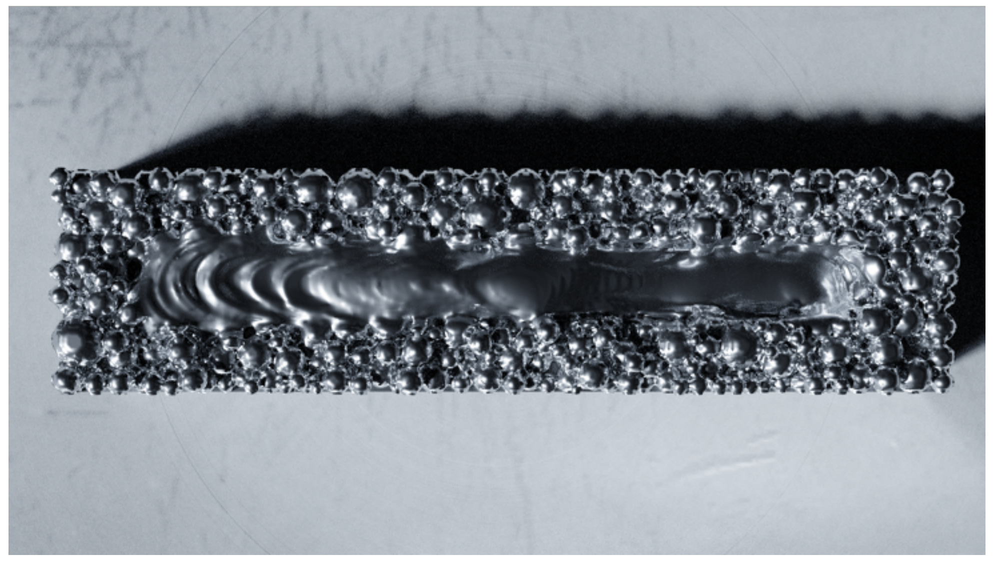


Figure 3: Melt Pool topology predicted by the OpenFOAM model. The results are render. Using Blender 2.8 for visualisation.

Each OpenFOAM model requires 48-72 hours based on the scanning speed and 80 cores to simulate the PBF process. Although these provide a provide a lot of data that cannot be observed experimentally, it is not suitable for real time predictions required by industries. Thus, Gaussian Process based emulators are developed using the simulation data for training and testing. The cross-validated emulators are light and easy to use. These models are linked to a web platform to provide average melt pool dimensions, porosity etc based on the values given by the user. Currently, all the models are developed for SS316L material used by Aconity MINI printer.

References

(1) Zhang, Y.; Zhang, J. Modeling of solidification microstructure evolution in laser powder bed fusion fabricated 316L stainless steel using combined computational fluid dynamics and cellular automata. *Additive Manufacturing* **2019**, *28*, 750–765.

(2) Panwisawas, Chinnapat, et al. "Mesoscale modelling of selective laser melting: Thermal fluid dynamics and microstructural evolution." *Computational Materials Science* 126 (2017): 479-490.

(3) Tan, J. L., C. Tang, and C. H. Wong. "Study and modeling of melt pool evolution in selective laser melting process of SS316L." *MRS Communications* 8.3 (2018): 1178-1183.

Ireland's European Structural and Investment Funds Programmes 2014-2020
Co-funded by the Irish Government and the European Union

European Union
European Regional Development Fund

I-Form is an SFI Research Centre funded under the Science Foundation Ireland Research Centres Programme and co-funded under the European Regional Development Fund.