Analyses of hydrodynamic instabilities in the melt pool in SLM

Work environment

This project is funded within the framework of SOFIA project leaded by AddUp. It will be held in Ecole Polytechnique within Solid Mechanics Laboratory (LMS) and LadHyX, with frequent interaction with different partners in the SOFIA project.

Supervision

- **Daniel Weisz Patrault** (daniel.weisz-patrault@polytechnique.edu, LMS)
- **Eric Charkaluk** (eric.charkaluk@polytechnique.edu, LMS)
- **Christophe Josserand** (christophe.josserand@ladhyx.polytechnique.fr, LadHyX)

Context

The additive manufacturing process by selective laser melting (SLM) consists in scanning a bed of metallic powder with a laser (i.e., energy source), which leads to a localized fusion. This kind of fabrication process enables us to build parts with very complicated geometries using layer by layer strategies. To gain in productivity and quality, it is useful to map the zone without major defects in the space of process parameters. It is common for a set of fixed parameters (laser spot size, thickness of layers etc.) to consider the laser power vs laser speed plan.

Within this framework, we are interested in determining by numerical simulation the boundaries that define a zone without defects. Defects are in general of four different kinds. 1) The **keyhole** is due to an excess of metal vaporization responsible for the formation of a capillary leading to high porosity. 2) The **humping** is a turbulent movement associated to a speed difference between the surrounding gas and the liquid metal. 3) The **balling** is a segregation of the melt pool in various drops associated to the Plateau-Rayleigh instability due to slight variations of curvature of the melt pool associated with variations of surface tension. 4) The **lack-of-fusion** is an incomplete fusion of the powder due to insufficient power with respect to the laser speed.

These phenomena have been studied with simplified approaches so that analytical formulas defining the boundaries between the free from defect zone and instabilities are available. However, these analyses rely on assumptions on the melt pool shape and temperature that are very questionable. These approaches enable us to have an order of magnitude for the boundaries but remain inaccurate with respect to experimental results. In addition, some important parameters are not taken into account, and defect severity is not characterized. There also exist extremely detailed approaches, but whose computation time forbid parametric studies.

Work to do

That is why in this work we propose a hybrid approach associating simplified calculation and detailed computations, in order to obtain a model sufficiently fast to investigate melt pool instabilities in the space of process parameters, and to characterize resulting defects.

To do so, a simplified and fast code of thermal conduction (relying on finite difference discretization) is available. This code neglects hydrodynamics contributions in the heat equation, but enables us to compute the melt pool geometry and temperature in the conduction zone (i.e., in the zone without instability). One can therefore estimate the residual porosity and productivity by overlapping the melt pool geometry for the different layers. The validity of such a model being very limited in the melt pool for various process parameters, we propose a coupling between this simplified model and another existing model including fluid dynamics and the computation of instabilities. This second model called BASILISK relies on embedded boundaries and volume of fluid discretization.

1. **Couple and extend existing models**
   The idea of this post-doctoral work is to extend and couple these existing numerical simulation tools in order to develop an analysis of melt pool instabilities. For each set of process parameters, we will use the simplified code to determine whether a more comprehensive computation with BASILISK is necessary. In this case we will use the temperature computed sufficiently far from the melt pool as boundary conditions for BASILISK.

2. **Map the boundaries of instabilities in the power-speed diagram**
   This strategy enables us to avoid a large number of detailed computations when they are not necessary, and to focus on the determination of instabilities by exploiting information obtained from the fast code to reduce the size of the comprehensive problem solved with BASILISK. Furthermore, computation time can be reduced by using BASILISK in 2D. The coupled model should be sufficiently fast to enable a large amount of computations with various process parameters so that we can map the instabilities in the laser power vs laser speed plan.

3. **Propose new strategies to increase productivity under quality constraints**
   On the basis of the obtained results, one can consider to propose some ideas to push the limits of productivity without major defects, especially the porosity. For instance, if the resulting porosity is acceptable, one can consider to willingly fix the process parameters so that the melt pool is in an instability zone.

Applicant

The applicant should have obtained a PhD degree, and his or her area of expertise should be centered on fluid mechanics and especially theoretical and numerical aspects. The gross monthly salary is around 3000€ for an applicant who defended his or her PhD less than two year before the post-doctoral contract, and around 3800€ for an applicant with 2 to 4 years of experience after the PhD.

Contact: Daniel Weisz-Patrault (daniel.weisz-patrault@polytechnique.edu)