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Developing process parameters through CFD simulations

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Abstract

Laser-material interaction is complex, and to accurately simulate it requires implementing the physics models that are relevant at these temporal and spatial scales. Process parameters such as laser power, scanning velocity, geometric scanning path, pre-heating temperature and powder size distribution influence the melt pool dynamics, which play a role in the stability of the additive manufacturing process. In this presentation, we will look at underlying mechanisms behind the formation of defects such as balling, porosity and spatter using computational thermal-fluid dynamics models built in FLOW-3D AM. While low energy densities can lead to lack of fusion defects, high energy densities result in strong recoil pressure and unstable keyholes that can lead to the formation of porosity and spatter. In addition to helping with process parameter development for both LPBF and DED processes, such models also output thermal gradient and cooling rate data that can be used to predict microstructure evolution.

Keywords: CFD simulations; laser powder bed fusion process; FLOW-3D; melt pool dynamics; direct energy deposition

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1. Introduction

Although AM has been generating significant interest, challenges remain towards a more widespread adoption of this technology. These challenges include defect formation such as porosity and spatially non-uniform material properties that occur because of insufficient knowledge of process control. Computational fluid dynamics (CFD) modelling can help researchers understand the effects of process parameters on underlying physical phenomena such as melt pool dynamics, phase change and solidification. With experimental studies successfully capturing melt pool data such as molten metal velocities and temperatures, it is possible to calibrate numerical models using experimental data. These numerical models,

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which are based on a rigorous solution of the conservation equations, can provide further insights such as fluid convection in the melt pool, temperature gradients and solidification rates.

In this paper, case studies from industry and academia highlighting the use of CFD and numerical models in understanding powder bed fusion processes are discussed. Process parameter optimization in controlling porosity formation and balling defects for the IN718 alloy are studied in detail. On the one hand, slower laser scan speeds and higher angles of inclination in laser welding can lead to an unstable keyhole configuration, which typically results in porosity. On the other hand, faster scan speeds result in longer melt pools, and Rayleigh instabilities can cause the elongated melt pool to break down into tiny islands of molten metal resulting in balling defects. Additionally, effects of powder packing density, laser power and particle size distribution on the formation of balling defects are explored. It is also seen that recoil pressure and material evaporation play important roles in determining the melt pool dynamics and surface morphology. Finally, melt pool data from the numerical models is used to study and predict the solidification morphology for the IN718 alloy. Based on temperature gradients and solidification rates, which can be obtained through CFD models, it is possible to determine the resulting microstructure evolution and primary dendrite arm spacing resulting from the powder bed fusion processes. These results are compared to experimental data wherever available.

1.1. Case Study 1: Effects of random powder distribution and material evaporation on melt pool dynamics[1]

A three-dimensional numerical model that incorporates a randomly-distributed powder bed and material evaporation is developed using FLOW-3D to investigate melt pool dynamics with keyhole formation by an Nd-YAG laser. The discrete element method (DEM) was employed to simulate powder packing, which accounts for the motion of a large number of particles including particle/particle and particle/wall interactions. The model was validated by measuring the particle size distributions in specific areas and ensuring that no powder size segregation occurs. Next the flow behaviour of the melt pool is characterized by calibrating parameters in the numerical model to achieve good agreement with the experimental results. The importance of including material evaporation in the numerical model is demonstrated by measuring the melt pool dimensions, which turn out to be narrower and deeper than when evaporation effects are not considered. Moreover, a keyholing effect is observed due to the recoil pressure resulting from evaporation, which affects surface morphology and surface temperatures of the melt pool. As illustrated in Figure 1, the contours of the cross-sections of the melt region including the dimensions and surface morphology compare very well between the simulations and experiments, justifying the importance of including evaporation effects.

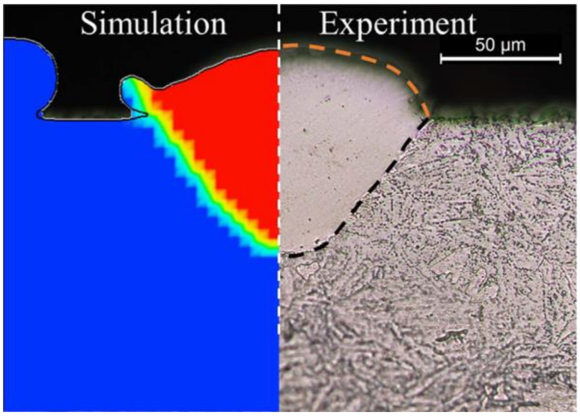

Fig. 1. Validation of the melt-pool dimensions (black-dashed line) and the surface morphology

In addition, we can extract the following outputs from CFD simulations:

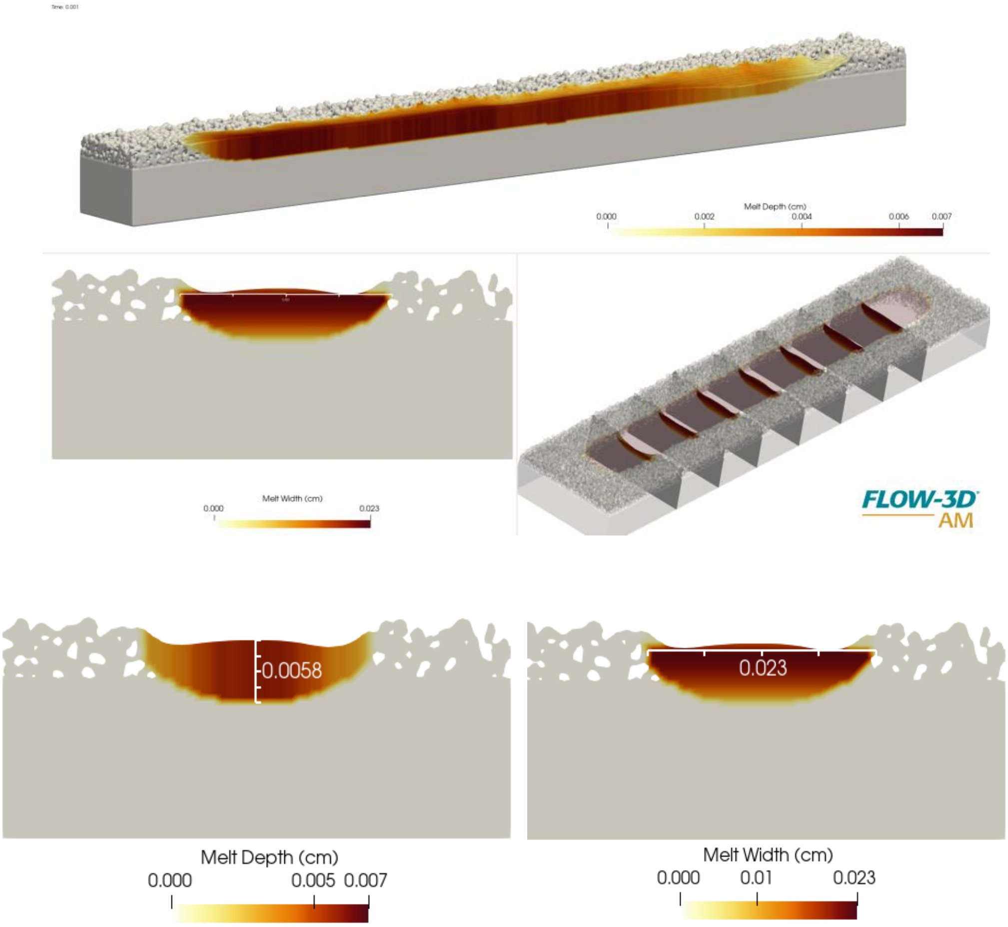

Fig. 2. Relevant melt pool dimensions can now be automatically extracted for every simulation

Additionally, LPBF simulations have a number of parameters that need to be optimized. They include

- Laser power, spot size and power distribution
- Scan path
- Laser speed
- Hatch spacing
- Powder size distribution
- Pre-heat temperature
- Atmospheric conditions

By running a parametric sweep of simulations, it becomes possible to understand the influence of each of these parameters on outputs of a melt pool simulation such as melt pool dimensions, porosity size and location, surface roughness and cooling rates and thermal gradients. For this study we have developed a way to run parametric sweep of directed energy deposition simulations to understand the influence of laser power and scan speed on melt pool dimensions. This study paves the way for additional process parameter developments.

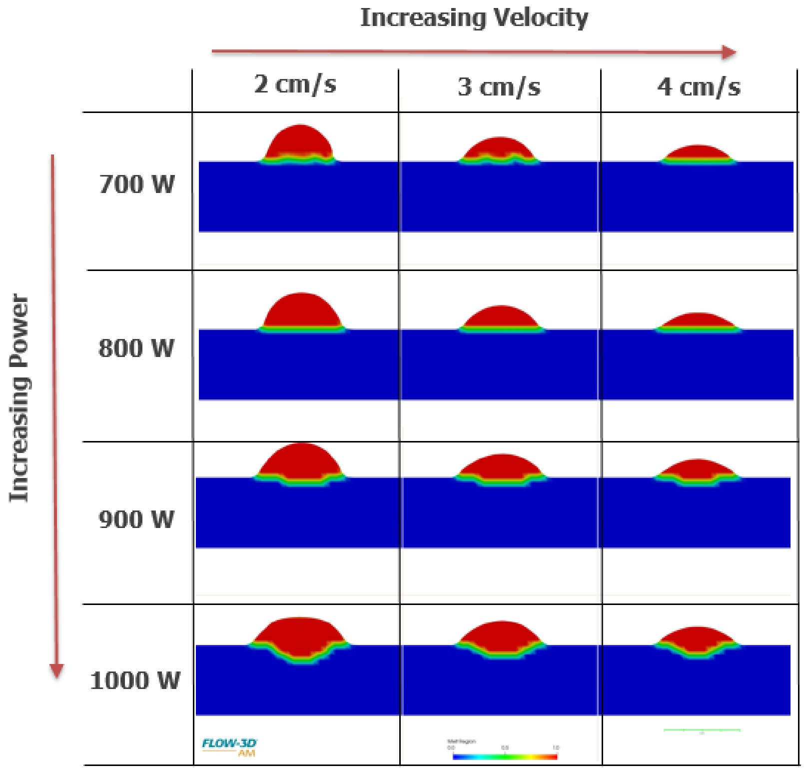

Fig. 4: Melt pool dimensions for various process parameters in a directed energy deposition process

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