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Simulations on beam shaping in laser powder bed fusion

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Abstract

To enable wider adoption, LPBF processes require manufacturing features with varying levels of detail at high production speeds. This becomes challenging when working with single mode lasers that operate exclusively in either the Gaussian or top hat modes. By varying spot sizes and beam shapes, new laser technologies can switch real time between different heat flux distributions that enable faster builds with higher detail.

In this presentation we discuss how CFD models built in FLOW-3D AM are used to analyze different heat flux distributions for single mode and ring beam modes that affect the melt pool dynamics. Gaussian distributions have higher localized temperatures resulting in high rates of vaporization compared to ring beam modes that distribute heat fluxes evenly over a larger area. Such CFD models also help generate process windows that utilize higher scan speeds for the various ring beam modes, ensuring higher productivity rates while maintaining process stability.

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

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, which are based on a rigorous solution of the conservation equations, can provide further insights such as

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fluid convection in the melt pool, temperature gradients and solidification rates.

High laser powers and beam qualities enable keyhole welding, which is advantageous in improving productivity, minimizing porosity, and creating a narrow fusion zone, resulting in a minimal heat affected zone. Additionally, in conduction mode, it is possible to create a larger spot size, helping with aesthetic builds and minimal post-processing. Switching between these modes can thus be beneficial depending on the geometry of the part being manufactured.

Beam shaping can help with modifying the melt pool behavior and gaining full control over the building process. According to the energy distribution, the temperature gradients and cooling rates can also be influenced. In the image below, implementations of different beam distributions can be seen in FLOW-3D AM and their effects on melt pool dynamics can be studied.

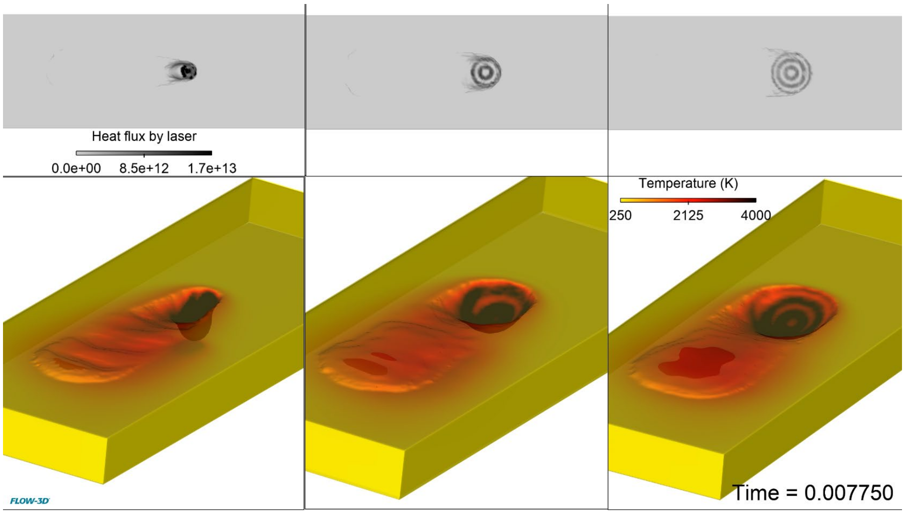

Fig. 1. Melt pool dynamics for different laser beam shapes

Additionally, in FLOW-3D AM, we can implement appropriate heat flux distributions such as the following:

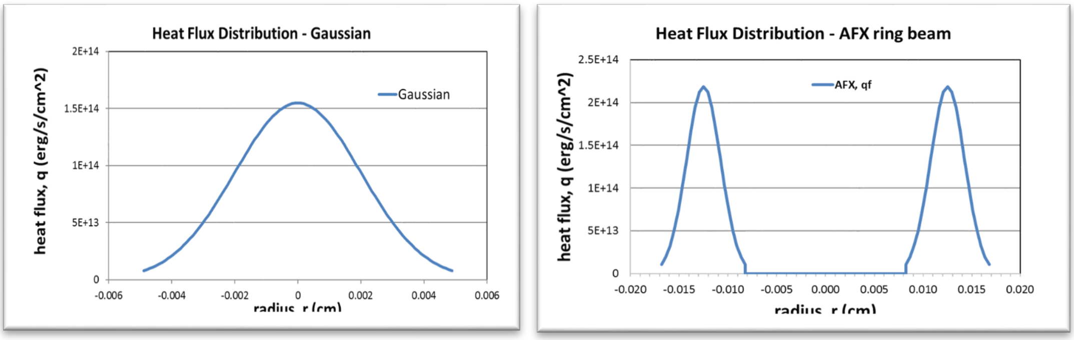

Fig. 2. Heat flux profile distributions for a Gaussian and a ring beam

Lastly, relevant outputs from melt pool models can be extracted such as velocities and mass flux due to phase change to predict the possibility of spatter ejection in melt pool dynamics.

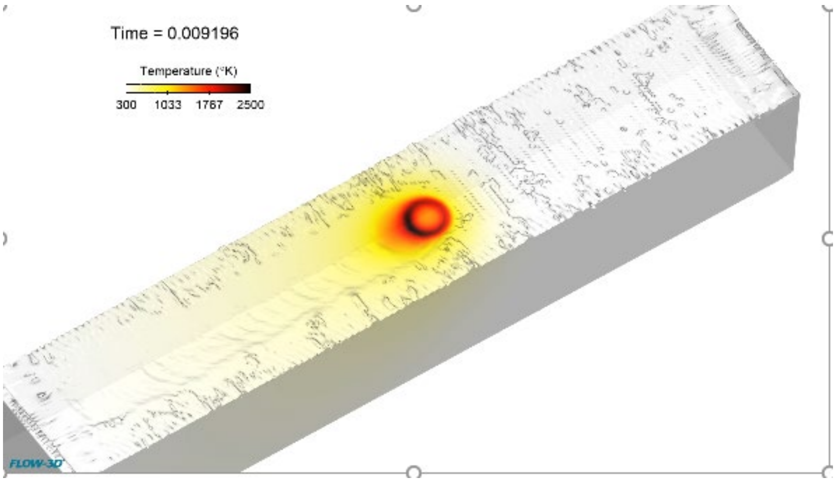

Fig. 3. A melt pool simulation showing temperature profiles in a ring beam simulation

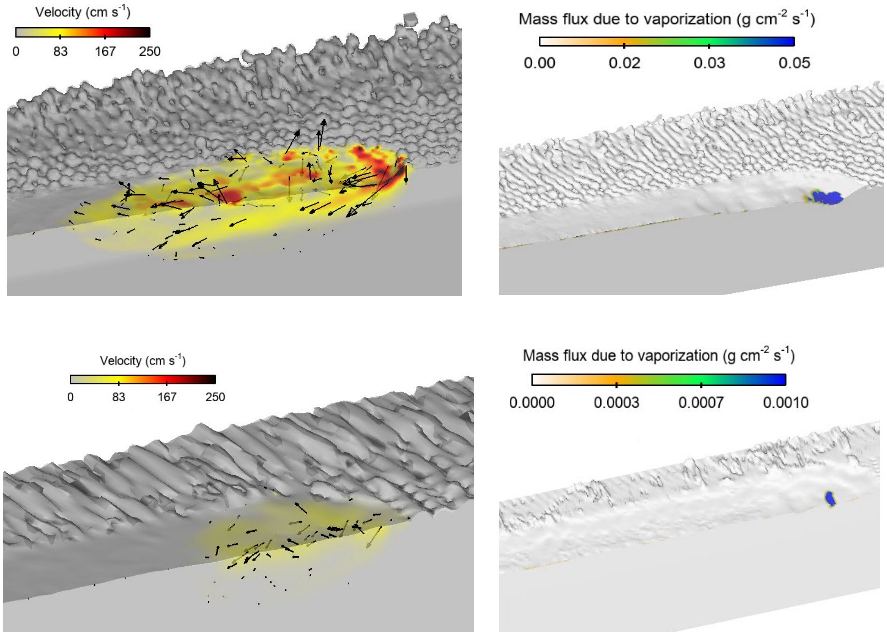

Fig. 4. Melt pool velocities and mass flux due to phase change (Gaussian – top and Ring beam – bottom)

In Figure 3, it can be seen that there are high velocities in the melt pool and a heat mass flux due to phase change in the melt pool of the Gaussian, indicating a higher probability of spatter compared to the ring beam simulation.

Such CFD simulations can help with process parameter development while using different beam shapes.

References

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