

IT TAKES TWO (FLUIDS) TO MAKE A KEYHOLE: ASSESSING ONE- AND TWO-FLUID APPROACHES FOR LASER MELT POOL AND VAPORIZATION MODELING

Constantin Zenz^{*,†}, Peter S. Cook[‡], Laszlo Vörös[†], Tobias Florian[†], Michele Buttazzoni[†] and Andreas Otto[†]

[†] Institute for Production Engineering and Photonic Technologies, TU Wien
Getreidemarkt 9, 1060 Wien, Austria
e-mail: constantin.zenz@tuwien.ac.at, andreas.otto@tuwien.ac.at

[‡] CSIRO Manufacturing
Private Bag 10, Clayton, VIC 3169, Australia
e-mail: peter.cook@csiro.au

ABSTRACT

Most multiphysical simulation models of laser-based Additive Manufacturing (AM) employ a simple, calibrated one-fluid approach to account for liquid-vapor interactions, where constant and uniform vapor-sided conditions are assumed. In practice, AM-relevant conditions usually feature a recoil-induced vapor depression, and its evolution and stability is closely linked to local laser irradiation conditions and coupled with evaporation dynamics. Building on our recent comprehensive comparison between one- and two-fluid modeling approaches for laser-based AM [1] we assess the impact of model choice on predictive capabilities and limitations, and the associated computational costs. Main areas of difference between one- and two-fluid models are identified in the evaporation mass flux and resulting evaporative recoil pressure, as well in surface tension forces at the three-phase line. We deduct potential calibration methods for one-fluid models and outline multi-fidelity modeling approaches. Using the high-fidelity, two-fluid model of [2], we expand the scope towards application-oriented scenarios by adding realistic powder particle distributions and analyzing the influence of non-Gaussian spatial laser intensity distributions on evaporation and keyhole dynamics through its local coupling with the vapor-sided pressure distribution. Thus, we shed light on the possibilities of beam shaping in process design and the implications on computational modeling, where the advent of beam shaping challenges long standing phenomenological models of evaporation-induced recoil and requires highly predictive models without the need for process-specific calibration.

REFERENCES

- [1] C. Zenz, P. S. Cook, L. Vörös, A. Otto, *A critical comparison of one- and two-fluid approaches for the simulation of laser-induced melt pool formation and vaporisation*, Discover Materials, Vol. 5, Art. No. 266, 2025.
- [2] C. Zenz, M. Buttazzoni, T. Florian, K. E. Crepsio Armijos, R. Gómez Vázquez, G. Liedl, A. Otto, *A compressible multiphase mass-of-fluid model for the simulation of laser-based manufacturing processes*, Computers & Fluids, Vol. 268, Art. No. 106109, 2024.