Optimization of discrete coaxial nozzles for laser metal deposition

Characterization of powder flow from discrete coaxial nozzles via Eulerian-Lagrangian approach

***R. Groll, A. Haghshenas**, Center of Applied Space Technology and Microgravity, University Bremen.*

In Short

- We aim to increase the powder utilization degree and improve the precision in near net shape.
- We study dependence of the powder flow on control parameters such as the flow rate of the gas and powder and the size distribution of powder.
- We study the adaptive position of three nozzles to each other, to the laser beam, and to the substrate.
- We study the powder-laser interaction, the formation and the structure of the melt pool.

Laser metal deposition (LMD) is an innovative, additive manufacturing process, which is becoming increasingly important in the field of production technology due to its broad application for coating, repair, and manufacturing of complete components [1]. In this process, a laser beam forms a melt pool on a substrate, into which powder is simultaneously deposited using a gas flow issuing from discrete coaxial nozzles. Advantages of the LMD process over traditional manufacturing processes include high build rates, near net shape, easy material change, reduced material waste, and the relatively low applied heat. Nonetheless, the LMD process has not become a mainstream production technology mainly because of the high cost of specialised powder flowstock and laser equipment and the low build resolution, such that secondary processing like machining or aqua blasting is often required. In addition, the large number of process parameters that affect the quality of the deposited components results in the lack of robustness and reproducibility in the LMD process. These limitations motivate this work. The main objective of this project is therefore to enhance the degree of the powder utilization and improve the precision in near-net-shape additive manufacturing.

Despite extensive numerical and experimental research on the LMD process, process-structure-property relationships are still far from being fully understood. In this respect, a particular emphasis needs to be placed on characterization of the dependence of the track geometry on relevant parameters such as powder flow properties (i.e. powder particle size, shape, distribution, and velocity), laser properties (i.e. laser beam diameter, power, and power distribution), and laser-powder interaction. Such a characterization enables us to pin down the optimal selection of process parameters required for high-quality manufacturing. To systematically approach this goal, we divide this project into three phases. In the first phase, we investigate the dependence of the powder flow issuing from a single vertically-aligned nozzle on the control parameters, such as the mass flow rates of the carrier gas and the powder and the size distribution of powder. In the second phase, we study the adaptive positioning of three powder nozzles to each other, to the laser beam, and to the substrate surface. In the last phase, we scrutinize the powder-laser interaction, the formation and the structure of the melt pool.

A precise numerical simulation of the laser metal deposition is required to achieve the aforementioned objective of this project, even though the experimental methods are more accurate when the measurement error is limited. This lies in the fact that investigation of the LMD process using experiments requires a lot of expensive and technically difficult experimental trials. In general, the computational fluid dynamics method has been progressively becoming popular tool to study such problems owing to its lower cost and faster solution. In addition, numerical simulation of the LDM process allows us to isolatedly investigate the relevance of each control parameters and provides us a full, three-dimensional set of variables over the entire parameter space.

We employ an Eulerian-Lagrangian approach (the so-called computational fluid dynamics-discrete element method approach) to simulate the powder flow. As a novelty to previous numerical simulations in the field of laser metal deposition, we take both fluid-particle and particle-particle interactions into account [2]. We use the open-source C++ software OpenFOAM to make the computations. In addition, we employ the dimensional analysis to systematically define a set of numerical simulations for the monodisperse and polydisperse particle-laden jet flows, covering a wide range of the parameter space corresponding to the LMD process. Numerical results are validated using experimental data acquired at the Bremen Institute for Applied Beam Technology. In the following, preliminary results for the first phase of this project are presented and shortly discussed.

As a representative of the powder flow in the LMD process, we consider a particle-laden turbulent jet flow issuing from a round, aerodynamically smooth pipe nozzle. The nozzle is vertical and both phases flow in the same direction as the gravitational force. Dimensional analysis indicates that five

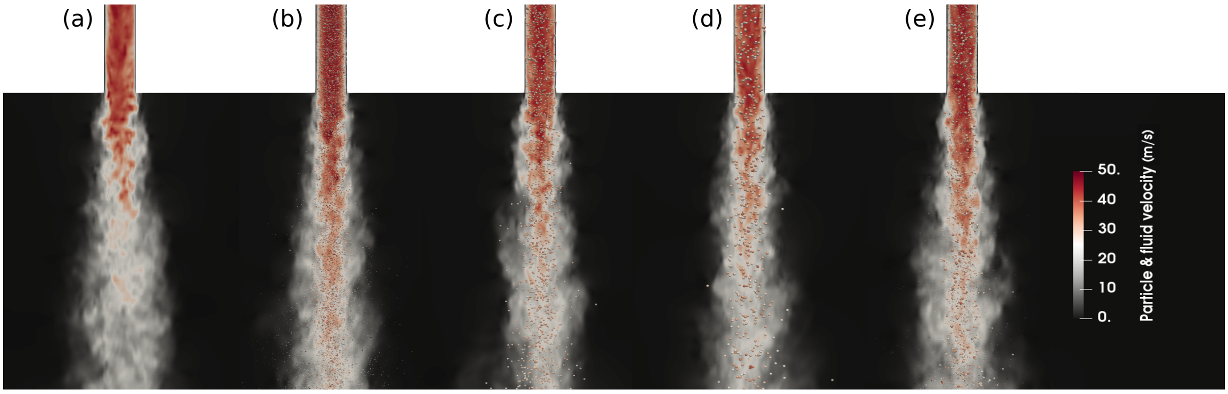

***Figure 1:** Instantaneous snapshots of the fluid velocity on the vertical plane together with the particle position and the particle velocity for the considered cases. (a) Unladen case; (b) monodisperse with $St = 28$; (c) monodisperse with $St = 111$; (d) monodisperse with St =250; (e) polydisperse case. (Images only show a small part of the nozzle, and the particles are enlarged for better visualization.)*

non-dimensional parameters are sufficient to characterize the system. These parameters are the bulk Reynolds number Re_b, the particle volume fraction Φ_v, the mass loading Φ_m, the bulk particle Stokes number St_b, and the particle Froude number Fr_p (Definitions are provided in the project description). To start with the first phase of this project, we focus on effects of the particle size, i.e. the Stokes number, on fluid and particle properties. Hence, we fix the mass flow rate of the gas and particles, corresponding to fixed $Re_b = 4726$, $\Phi_m = 0.84$, and $\Phi_v = 5.5 \times 10^{-4}$. We consider three classes of spherical particles with different sizes, namely $d_p = 15, 30, 45$ μm, corresponding to the bulk Stokes number, $St_b = 28, 111, 250$, respectively. In addition, we set up one polydisperse case, in which Re_b, Φ_m, and Φ_v are the same as in the monodisperse cases, but we consider particles from three aforementioned classes with equal mass loading from each particle size class.

Figure 1 depicts the instantaneous snapshots of the fluid velocity on the vertical plane together with the position and the velocity of particles for the different cases considered in the present work. It is evident that particles with small Stokes numbers, i.e. $St = 28$, strongly suppress the fluid turbulence inside the nozzle, while particles with larger Stokes number appear to have less effects on turbulent structures. However, the fluid turbulence in the case with $St = 28$ recovers immediately after the nozzle exit. The spreading rate of the fluid is reduced by adding particles. Although small inertial particles qualitatively seem to have larger spreading rate, a quantitative examination contradicts this qualitative observation. We note that much larger number of particles in the case with $St = 28$ is in this respect misleading. Larger particle scattering in the high Stokes-number simulation can be attributed to the fact that the dynamics of the high Stokes-number particles is predominantly controlled by particle-wall interaction, while the dynamics of the small Stokes-number particles is largely governed by particle-fluid interaction. In addition, we find that the small inertial particles accumulate in the nozzle center, a feature that is retained in the region far away from the nozzle exit. These two aspects of particle-laden turbulent jet are of considerable relevance for the laser metal deposition process, as limited scattering of small inertial particles as well as accumulation of these particles in the jet center could lead to the enhancement of the particle utilization degree. As the next step, we should thoroughly analyse the obtained data and complement the first phase of this research by extending the considered parameter space, mainly by changing the mass flow rate of the particles and the volume flow rate of the fluid.

WWW

https://www.zarm.uni-bremen.de/en/research/space-science/thermofluid-dynamics/projects/aulapro.html

More Information

[1] M. Schmidt, M. Merklein, D. Bourell, D. Dimitrov, T. Hausotte, K. Wegener, L. Overmeyer, F. Vollertsen, and G. N. Levy. *CIRP Annals*, **66**(2):561-583, doi:10.1016/j.cirp.2017.05.011, (2017).

[2] B. Zhang and C. Coddet. *Journal of Manufacturing Processes*, **23**:54-60, doi: 10.1016/j.jmapro.2016.05.019, (2016).

Project Partners

Bremen Institute for Applied Beam Technology

Funding

DFG project number: GR2720/09-01