ME – PhD Thesis Colloquium

Coupled transport phenomena and microstructure evolution in laser-DED based additive manufacturing

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ABSTRACT

A multi-phase three-dimensional Computational Fluid Dynamic (CFD) model is developed to study the deposition of Inconel 718 (IN718) powder on a 316L Stainless Steel (SS316L) substrate by Laser-Direct Energy Deposition (L-DED) process. The model resolves the transport phenomena associated with laser-induced melting, powder feed and its diffusive and convective mixing with substrate, and solute partitioning associated with the solidification of Ni-Cr-Fe alloy within the melt pool. The model uses the enthalpy technique for simulating phase change. It incorporates the progressive melting effect of laser beam in producing a deeper melt-pool, while also including element specific vaporization. It utilizes the Volume of Fluid method to simulate the free surface deformation and predict the resultant bead formation. These processes are governed by the combined effect of continuous powder deposition and the surface tension operating at the continuously evolving interface between the molten pool free surface and surrounding gas. The inclusion of individual element-specific species distribution in the molten pool, along with the solute fractioning at the solidification interface, incorporates macro-segregation effects in the developed CFD model while estimating the solute concentration at the solidification front. This serves as the initial liquid composition for microstructure evolution simulations. The simulated results with respect to temperature distribution and dimensions of bead and dilution zones are validated against corresponding experimental findings. Thereafter, the temperature gradient and cooling-rate obtained from the CFD model, along with species concentration are taken up as inputs towards a meso-scale microstructure evolution model. The Phase Field (PF) technique employed minimizes a free energy functional consisting of a grand potential term, a potential energy term, and a gradient energy term, with the thermal gradient, cooling rate and species concentration values driving the interface between the phases. The PF simulated microstructures obtained for the identified locations on the bead are then compared with corresponding FESEM micrographs of the deposited samples. A qualitative agreement in the grain morphology and quantitative consistency in primary dendritic arm spacing validates the meso-scale model, and by extension, confirms the reliability of the inputs derived from macro-scale CFD simulations. This two-tier validation establishes the predictive capability of the coupled CFD-PF approach as a comprehensive modelling tool for L-DED process.

ABOUT THE SPEAKER

Abhik Deb is a PhD student in the Department of Mechanical Engineering at the Indian Institute of Science (IISc), Bangalore, working under the supervision of Prof. Pradip Dutta. He completed his BTech in Mechanical Engineering from National Institute of Technology, Silchar, and his MTech in Mechanical Engineering from Indian Institute of Technology (ISM) Dhanbad. His research interests include heat transfer and additive manufacturing, with a particular focus on modelling strategies for Laser based Direct Energy Deposition and microstructure evolution.