Numerical Simulation of Solidification Microstructure of Nickel Base Superalloy Considering Non-spherical Particles in Laser-powder Bed Fusion

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Abstract

Metal powder particles used for additive manufacturing, commonly produced by gas atomization, tend to have spherical shapes but with important non-sphericities such as satellites and joined particles. Currently, the quantitative understanding of the effect of non-sphericities on melt pool temperature distribution and ensuing solidification microstructure is limited. This study extended existing particle-scale models for laser-powder bed fusion of Nickel Alloy 718 to consider non-spherical particles. Specifically, satellites and joined particles were modeled by "attaching" several spherical particles together to form clumps. The packing of mixed spherical and non-spherical particles on powder bed was simulated using discrete element method. The calculated packing information was then mapped into a powder-scale heat transfer and fluid flow model, which took into account various important phenomena including interactions between laser beam and individual particles, Marangoni shear stress, free surface evolution, keyhole dynamics, and laser multiple reflections. The calculated melt pool geometry was compared with that determined from the transverse and longitudinal cross sections of the laser melted tracks.

For modeling of solidification microstructure, the cooling rate computed from the melt pool model was inputted into an analytical expression based on the work by Kurz and Fisher to calculate the primary dendrite arm spacing (PDAS). Placing dendrite cells in a hexagonal arrangement, which was used by Bhadeshia and Svensson for weld metal solidification, the spatial micro-segregation profile was predicted from the results obtained using the Scheil model. The predicted compositional profile of key alloying elements (e.g., Niobium) as a distance from dendrite core to inter-dendritic region was compared with experimental data measured by transmission electron microcopy. The effect of non-spherical particles on the formation of porosity defects as well as solidification microstructure (i.e., PDAS and micro-segregation) was discussed for additively manufactured Nickel Alloy 718.

Keywords: Powder bed packing, Particle sphericities, Melt pool heat transfer and fluid flow, Non-equilibrium solidification, Nickel base superalloy