Mechanical Engineering Doctoral Defense

Understanding the Role of Rheology in Binder-based Metal Additive Manufacturing of Solid and Nanoporous Metals

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Abstract

This dissertation is focused on the rheology scaling of metal particle reinforced polymer matrix composite (PMC) made of (i) solid and (ii) nanoporous metal powders to enable their continuous 3D printing at high (>60vol%) metal content. There remained a specific knowledge gap on how to predict successful extrusion with densely packed metals by utilizing their suspension melt rheological properties. In our first project, the scaling of the dynamic viscosity of melt-extruded PMC filaments made of PLA and gas-atomized solid Ni-Cu powders was studied as a function of the metal's volumetric packing and feedstock pre-mixing strategies and correlated to its extrudability performance, which fitted well with the Krieger-Dougherty analytical model. 63.4 vol.% Filaments were produced by employing solution-mixing strategy to reduce sintered part porosity and shrinkage. After sintering, the linear shrinkage dropped by 76% compared to the physical mixing. By characterizing PMC feedstock via flow-sweep rheology, a distinct extension of shear-thinning towards high shear rates (i.e. 100 s-1) was observed at high metal content – a result that was attributed to the improved wall adhesion of PMCs. In comparison, physically-mixed filament failed to sustain more than 10s-1 shear rate proving that they were prone to wall slippage at a higher shear rate, giving us an insight into the onset of extrusion jamming. In our subsequent study, nanoporous copper made out of electroless chemical dealloying was utilized as fillers, because of their unique physiochemical properties. The role of capillary imbibition of polymers into metal nanopores was investigated to understand their effect on density, zero-shear viscosity, and shear thinning. It was observed that, although the polymeric fluid's transient concentration regulates its wettability, the polymer chain length ultimately dictates its melt rheology, which consequentially facilitates densification of pores during vacuum annealing. Finally, it was demonstrated that higher imbibition into nanopores leads to extrusion failure due to a combined effect of volumetric packing increase and nanoconfinement, giving us a deterministic materials design tool to enable continuous PMC printing. The outcome of this study might enable us to integrate nanoporous metals into binder-based 3D printing technology to fabricate interdigitated battery electrodes and multifunctional 3D printed electronics.

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