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SOME MODELING AND COMPUTATIONAL CHALLENGES IN METAL 3D PRINTING

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Abstract. How to construct and trust a model for Selective Laser Melting (SLM)? SLM is the process of printing a 3D geometry by depositing and selectively melting regions of a layer of a powder bed. In this process, the range of temperatures and strains, the number of potential material deformation mechanisms involved, and the difficulties in experimentally isolating individual physical phenomena, cast a shadow of uncertainty over the use of computational models to inform and enrich the understanding of inelastic processes active during printing. In this talk I will illustrate the issues we found while doing this for 17-4 PH SS. First, we examine the question of how reliable thermal histories computed from a model that reproduces melt pool traces are. To this end, we perform experiments in which one of two different laser beams moves with constant velocity and power over a substrate of 17-4PH SS or Ti-6Al-4V, with low enough power to avoid generating a keyhole. We find that many different models that reproduce melt pool traces can give rise to different thermal histories. However, thermal histories appear to be reliably computed provided that (a) the power density distribution of the laser beam over the substrate is well characterized, and (b) convective heat transport effects are accounted for. Second, we examine the question of how to calibrate a phenomenological model for the mechanical response of 17-4 PH SS in SLM: what are the important mechanisms? Which of the mechanisms can we validate with the experiments we propose, and which are those for which we do not have enough information to tell? To this end, we designed deflection experiments of metallic beams monitored by a high-speed camera, which offer the benefit of the substrate's simple thermal and mechanical history. By reproducing the deflection experiments with a material model that includes both heat conduction and elasto-viscoplasticity, we conclude that the solid-state phase transformation plays an indispensable role in the evolution of residual stresses of 17-4PH SS. We also highlight the necessity of monitoring time evolution instead of the end state when evaluating models for residual stress of alloys with volume change during phase transformation. Finally, I will illustrate one particularly interesting computational challenge: How do we optimize the path of the heating source, e.g. a laser, to obtain a desired thermal history? This is a complex combinatorial problem. I will show a way in which we reformulated this problem as a Traveling Salesperson Problem (TSP), for which a number of heuristics are available to perform the optimization.