Process-structure-properties modeling of selective laser melted tool steel using phase field method and crystal plasticity

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Abstract

A major challenges in additive manufacturing is understanding and predicting its unique microstructure, which occurs through rapid solidification. These rapid solidification microstructures can be explored with a phase field model coupled to a larger scale heat transfer model. Here we investigate the selective laser melting of a tool steel. Based on the process parameters, the large scale heat transfer model predicts the overall temperature distribution, which in turn provides temperature data for phase-field modeling, specifically thermal gradients and cooling rates. Major segregating elements are identified, and the solidification patterns are modeled using the phase-field method. The subsequent martensitic transformation is simulated with crystal plasticity model. Finally the mechanical responses of various solidification microstructures are compared, using a micromechanical finite element method with crystal plasticity modeling.

Main text

Additive manufacturing of tool steels present significant challenges. This is mainly due to the complex solid-state transformations that occur during the printing and the potential post heat treatment.

In additive manufacturing of high strength steels, one of the major challenges is understanding and controlling the martensitic transformations, which can lead to detrimental embrittlement, and high heterogeneous residual stresses due to high thermal gradients. This often leads to cracking and thereby failed builds.

As maraging steels are metallurgically rather complicated and not much studied in the literature, we investigate the additive manufacturing of H13 tool steel, which we predict will present similar challenges as maraging steel. The presented modeling procedure and main parts of the results are expected to generalize to additive manufacturing of maraging steels.

As majority of tool steels are metallurgically rather complicated and their additive manufacturing is not thoroughly reported, we investigate the additive manufacturing of H13 tool steel, which will likely present similar printing challenges as other tool steels. The presented modeling procedure and main parts of the results are expected to generalize to additive manufacturing to other tool steels with stronger alloying.

This work demonstrates a computational framework for integrated computational materials engineering (ICME) style design of tool steels. First the potential phases and the rapid solidification microsegregation pattern is investigated using computational thermodynamics. Typical thermal environments are used to simulate the formation of rapid solidification microstructures using phase field method. The resulting microstructures are analysed with a crystal plasticity model. Martensite transformation related crystal plasticity effects are demonstrated.

Methods

The computational thermodynamics analyses are conducted using Thermo-Calc with the appropriate steel databases for Gibb's free energies (TCFE9) and mobilities (MOBFE4). The assumed H13 tool steel composition are shown in Table 1.