Through-process microstructure prediction of Ti-6Al-4V in laser powder bed fusion process

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Introduction

Laser powder bed fusion (LPBF) is a rapid prototyping method to fabricate objects layer-by-layer from 3D numerical models that can fit the further challenge in implant component fabrication to manufacture complex structures. Complex heat transfer during the LPBF process has a significant effect on thermal gradient and solidification rates, which in turn strongly influences the solidification morphology, grain size and growth direction. At the same time, the complex thermal history directly influences the kinetics of microstructure formation during solid-state phase transformation. For Ti-6Al-4V, the typical high cooling rate during the LPBF process will result in a diffusionless transformation, leading to the formation of martensitic microstructures.

Objective

To develop a systematic through-process method to predict microstructure during LPBF of Ti-6Al-4V, focusing on solidification morphology, phase fraction and a lath width.

Method for simulating thermal process

Due to the very rapid thermal transients during LPBF, it is extremely difficult to measure thermal gradients. Hence, a transient heat transfer simulation of the LPBF process is developed here using the finite element (FE) software Abaqus, to quantify the evolution of key thermal phenomenon of the process. A physically-based layer build-up approach with a surface moving heat flux is developed via a user subroutine. In contrast with previous work, we have included the temperature-dependent powder absorptivity.

Temperature-dependent thermal properties of Ti-6Al-4V:

- Specific heat
- Conductivity
- Powder absorptivity

Conclusion

A systematic through-process method is developed to predict microstructure of Ti-6Al-4V in LPBF process, from thermal process to solidification, and hence the solid-state phase transformation.

- The thermal gradient in the depth direction is significantly higher than in the width and laser scanning directions, due to lower thermal conductivity of the pre-deposited powder layers.
- The higher laser power and faster scan speed in LPBF process tends to form equiaxed crystals, due to more uniform solidification.
- Evolution of solid-state phase transformation is presented with the thermal history. LPBF process leads to a high fraction of martensite α phase due to the high cooling rates.
- The α lath width slightly decreases during the cooling process, and a thermal cycle with a peak temperature below the β transus point has no effect on it.

Method for predicting solidification morphology

In order to predict solidification morphology here, a hunt map approach (2), adopted for Ti-6Al-4V (3), as shown in Fig. 3, can be employed with FE-predicted cooling rates and thermal gradients.

Method for predicting solid-state phase transformation

The classical phase transformation kinetics JMAK model is modified for diffusion-controlled α and β phase transformation and discretized for the non-isothermal process of LPBF (4, 5).

Temperature-time transformation (TTT) curves for the different α phases (grain boundary α, Widmanstätten α) are used to determine the associated kinetic parameters.

Microstructure prediction for LPBF of Ti-6Al-4V

Through-process predicted results are presented here for the combined simulation of (i) LPBF thermal process, (ii) solidification morphology and (iii) phase transformation.

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