E. A Coupled Thermal and Microstructure Model for Laser Processing of Ti-6Al-4V

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Introduction

The current challenge in laser processing of titanium alloys using methods such as Laser Metal Deposition (LMD) is in understanding the complex microstructure evolution during deposition of multiple layers of material. The current work focuses on the thermal and microstructure modeling of multilayered Ti-6Al-4V deposits. Prior work with LMD-Ti-6Al-4V has shown that a complex microstructure evolves consisting of a two-phase alpha+beta structure that is measurably different across the deposit. A thermal model has been developed to predict the thermal history of the LMD process1, the results of which are used as input to a microstructure model based on phase transformation kinetics.

Experimental Procedure

The thermal model utilizes the implicit finite differencing scheme to numerically solve the two-dimensional transient heat conduction equation with temperature-dependent properties. Laser heating is modeled using an elliptical volumetric distribution of the laser power.2 In the current work involving Ti-6Al-4V, the following process conditions are modeled: a laser power of 13kW, a laser scan speed of 2.54 mm/s, and a corresponding interpass time of 98.4 seconds, and an eight layer deposit. Further details of the processing parameters used in the thermal model may be found in Kelly, et al.3 The phase fraction of the alpha phase may be tracked using the thermal cycle as input to a microstructure model. The current model assumes the phase fraction on heating is based on the equilibrium phase diagram, while upon cooling, phase transformation kinetics for Ti-6Al-4V are used.4

Results and Discussion

The thermal cycles in Figure 1 are for a fixed position within the deposit and show the heating and cooling through the two (a+b) and single (b) phase fields, which contributes to the complex microstructure that evolves. In particular, the thermal cycles due to the addition of the n+3 layer to layer n are responsible for the greatest change in microstructure due to a narrow region near the top of layer n experiencing heating above the beta transus, while the underlying material experiences heating into the two phase field. This variation in peak temperature and associated cooling rates leads to an inhomogeneous microstructure.

Figure 2 shows the results of the current microstructure model plotted as alpha-phase fraction as a function of time for the first deposited layer. For the first three passes of the laser, the entire layer is heated above the beta transus (fa=0) and upon cooling, the alpha fraction returns rapidly to the room temperature equilibrium value (fa=0.9). Upon the addition of a third layer to layer 1, the top of the layer again is heated above the beta transus, however, the underlying alpha phase is dissolved to alpha fractions ranging from 90 to 10%. Additional layers have no effect on the alpha fraction because the peak temperatures are too low. Thus, the initial results of the microstructure model are in agreement with the hypothesis that the greatest microstructure change will occur during the deposition of layer n+3.

Shortcomings of the current microstructure model lie within the kinetic parameters available in the literature, which predict an ever increasing driving force for the b->a+b transformation, that is, if a time-temperature-transformation diagram were plotted using the available kinetic data, a “C” curve would not be observed, contrary to typical TTT diagrams. This is manifested in Figure 2 when the alpha fraction always attains the room temperature equilibrium value, regardless of cooling rate. In addition the results shown above assume equilibrium values upon heating which is not accurate under elevated heating rates. It is known that the completion of the alpha dissolution reaction may occur above the equilibrium beta transus.5-8 Future efforts will focus on obtaining better kinetic data for alpha precipitation and dissolution reactions.

Conclusions

A framework to model microstructure evolution during laser processing has been developed. The results from a process thermal model have been used to predict the layer deposition responsible for the greatest microstructure variation in Ti-6Al-4V laser metal deposition builds. The microstructure model also predicts that the deposition of layer n+3 onto layer n will lead to the greatest variation in phase fraction. The two models that have been developed could be equally applied to other processes whereby multiple layers of material are added using a heat source.

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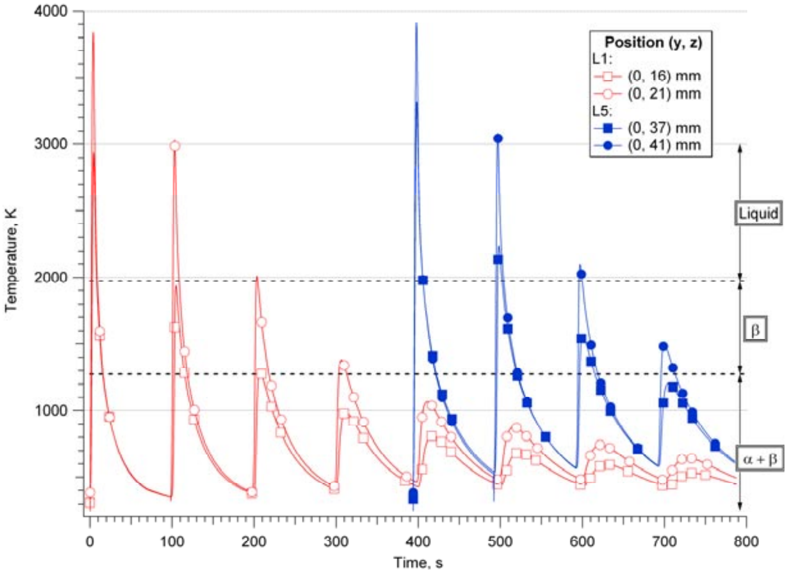

Figure 1: Calculated thermal cycles for the first (L1) and fifth (L8) deposited layers in an eight layer deposit. Positions at the bottom and top each layer along the centerline (y=0) of the deposit are shown.

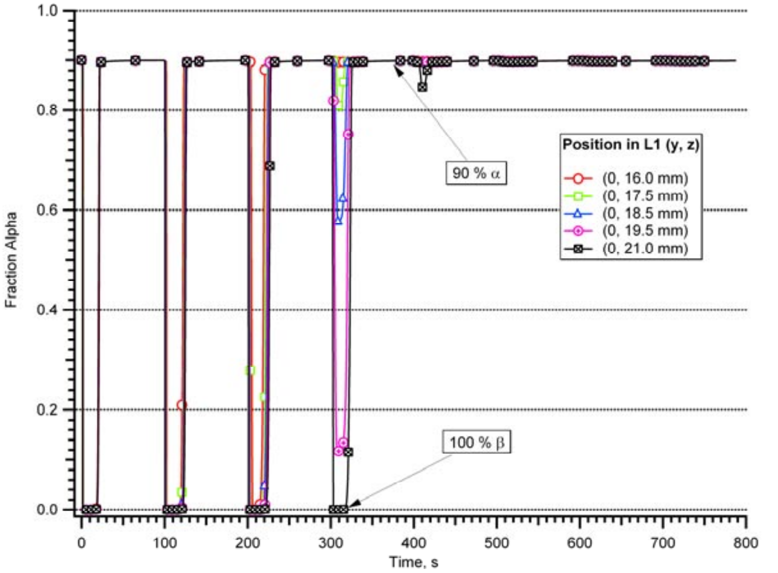

Figure 2: Fraction alpha as a function of time calculated for the thermal cycles shown in Figure 1