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Investigation of effect of process parameters on multilayer builds by direct metal deposition

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HIGHLIGHTS

- Direct laser deposition DLD.
- Microstructure of stainless steel 316L.
- Thermocouples measurement.
- 3D finite element modeling.

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ABSTRACT

Multilayer direct laser deposition (DLD) is a fabrication process through which parts are fabricated by creating a molten pool into which metal powder is injected as. During fabrication, complex thermal activity occurs in different regions of the build; for example, newly deposited layers will reheat previously deposited layers. The objective of this study was to provide insight into the thermal activity that occurs during the DLD process. This work focused on the effect of the deposition parameters of deposited layers on the microstructure and mechanical properties of the previously deposited layers. It is important to characterize these effects in order to provide information for proper parameter selection in future DLD fabrication. Varying the parameters was shown to produce different effects on the microstructure morphology and property values, presumably resulting from in-situ quench and tempering of the steels. In general, the microstructure was secondary dendrite arm spacing. Typically, both the travel speed and laser power significantly affect the microstructure and hardness. A commercial ABAQUS/CAE software was used to model this process by developing a thermo-mechanical 3D finite element model. This work presents a 3D heat transfer model that considers the continuous addition of mass in front of a moving laser beam using ABAQUS/CAE software. The model assumes the deposit geometry appropriate to each experimental condition and calculates the temperature distribution, cooling rates and re-melted layer depth, which can affect the final microstructure. Model simulations were qualitatively compared with experimental results acquired in situ using a K-type thermocouple.

1. Introduction

In the direct laser deposition (DLD) process, the material in a single deposited layer typically is not enough to create a part. Several layers must be deposited sequentially to achieve a fully built part. With each subsequent deposited layer, the previously deposited layers are reheated. This is but one simple example of how multiple temperature gradients can be created during the additive layering process, which could influence the material being deposited. These gradients, resulting from the repeated non-uniform heating and cooling process not only affects the mechanical performance and the post-machining precision of the fabricated component, but also results in fabricated component distortion, and possibly even cracking.

The complex thermal behavior that occurs during the DLD process results in a complex microstructure evolution. Mostly attributable to its stepwise additive nature, the thermal cycles associated with the DLD process can involve several reheating cycles. However, in building complex geometries adjacent deposition tracks, junctions, and interrupted deposition all could add further

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reheating steps to a reference volume. Thus, the goal of any assessment of microstructural evolution is to determine the response of the deposited alloy to these cycles [1].

The microstructure of the material formed from the molten pool is most strongly related to the cooling rate during the solidification process. Further microstructural evolution takes place in the solid state depending on the subsequent temperature field and profiles developed within the samples as the laser is traversed during the build operation. Thus, it is important to control the temperature profiles during the DLD process so that an ideal microstructure can be achieved in the fabricated component. The most important DLD parameters include the laser power (W), travel speed (mm/min) and powder feed rate (g/min), which all significantly affect the microstructure of the formed parts [2].

There have been a number of studies looking at deposition parameters on the resulting properties and structure. Zhang carried out some experiments depositing 316 SS to determine the influence of processing parameters on dilution ratio in laser clad layer. The results showed that the influence degree of scanning speed is most significant, while that of laser power is relative slight [3]. Wu studied the effects of processing conditions, such as laser power, scan speed, powder feed rate on the microstructure of Ti–6Al–4V. They concluded that the microstructure of deposited Ti–6Al–4V is influenced by laser power, scan speed or powder feed rate, but the effects of each parameter are not straightforward [4]. Rasheedat investigated the influence of the scanning velocity on the evolving physical properties, the microstructure, the microhardness and the wear resistance behavior of Ti6Al4V/TiC composite. Ti6Al4V. The deposit was successfully at various scanning velocities between 0.015 and 0.105 m/s at an interval of 0.01 m/s. As the scanning velocity was increased, the microhardness also increased. Also, the wear resistance performance of the samples increased as the scanning velocity was increased [5].

Much fundamental research on the thermal behavior has concentrated on investigating the temperature distribution and cooling rate during the solidification process. However, the DLD process is more complicated than a series of successive solidifications of molten pools. As already stated, during laser deposition, the previously deposited layers reheat when a new layer is deposited on top of them. The temperature of the sample varies from one location to another and from one point in time to another. So far, however, there has been limited research on the effect of the reheating process which accompanies a multilayer build. In order to understand the evolution of the microstructure and control the microstructure, it is important to understand the thermal history of the deposited component during the DLD process.

There has been some work on the modeling of the thermal history of deposited metals. However, most of this work has been limited to modeling a single layer and has ignored the effects of subsequent deposition on the already deposited material. Finite element modeling studies have been reported for the application of some materials including stainless steel alloys, titanium alloys, nickel-based alloys, tool steel and other specialty materials, as well as composite and functionally graded material deposition using simultaneous feed of powder and wire in DLD processing for a single layer.

Fu, developed a model to simulate the temperature distribution and residual stresses in the single-pass powder laser deposition process, the results showed that less difference of thermal conductivity and thermal expansion coefficient between powder material and substrate material produces lower residual stress; higher laser power, laser scanning speed and smaller laser beam diameter can lead higher peak temperature and higher residual stress [6]. Giuliani, developed a model to predict the powder temperature distribution for a laser with top-hat and Gaussian intensity distribution, as well as the temperature profile for a single-track laser The results showed that a more vertical position of powder delivery nozzle will lead to a higher and more uniform particle temperature distribution, in particular for the top-hat intensity distribution case [7]. Vahid et al. developed a model to simulate the shape and geometries of the real-time melt-pool and to predict the local solidification condition along the solid/liquid interface for a single-track laser the temperature gradient and interface velocity can be accurately evaluated along the predicted solid/liquid interface [8]. Pinkerton and Li developed a simple thermal model to analyze the temperature distribution and estimate the molten pool size in laser cladding [9]. Liu and Li established a model to investigate the effects of process parameters on laser direct formation of thin wall [10]. Jendrzejewski et al. developed a two-dimensional thermal model to understand the temperature distribution in laser multi-layer cladding [11].

In this work, a transient thermal model for a thin wall build by succeeding multiple layers was developed to reveal the heating and reheating cycles during the DLD process. The model assumes certain geometries appropriate to process parameter combinations and was used to predict the temperature distribution, thermal gradient, remelted layer depths, peak temperatures and cooling rate as a function of process parameters, such as laser travel speed (mm/min) and laser power (W), which can affect the final microstructure and elemental distribution in the part as well as the mechanical properties of deposited material.

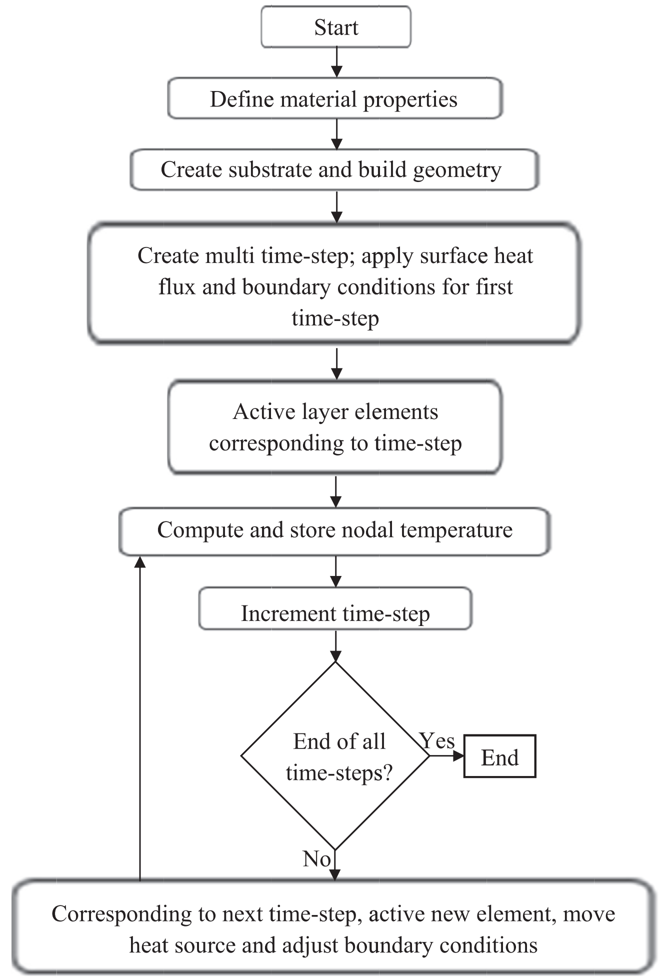

Fig. 1. Flow chart showing various steps involved in the temperature distribution model.