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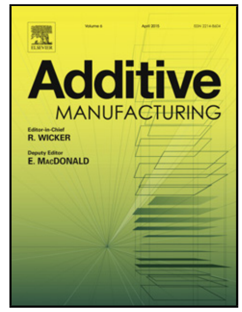

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Towards additive manufacturing of compressor impellers: 3D modeling of multilayer laser solid freeform fabrication of nickel alloy 625 powder mixed with nano-CeO_2 on AISI 4140

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Abstract

Gas turbine blades, turbine shafts and centrifugal compressor impellers are often damaged by erosion and/or corrosion. By laser cladding technique, a coating layer can be deposited on the base material in order to rebuild, repair and improve anti-erosion or anti-corrosion properties of the sensitive machine parts. In this paper, a three-dimensional finite element modeling of the laser solid freeform fabrication (LSFF) process for nickel alloy 625 powder mixed with nano-CeO_2 on AISI 4140 steel is extensively studied. Using Comsol Multiphysics software and the finite element method (FEM), the heat transfer equation, moving mesh equation and stress tensor are numerically solved. The dynamic geometry of the molten zone is studied by a 3D moving mesh based on Arbitrary Lagrangian-Eulerian (ALE) module. Clad shape, temperature distribution and stress fields are obtained. The effects of preheating as well as addition of nano-CeO_2 are investigated. Dependence of the clad height on the scanning velocity of the laser is also studied.

Keywords: Laser cladding; Powder injection; Nano-CeO_2; Moving mesh;

1. Introduction

Recently, additive manufacturing (AM) has received tremendous interest from both academic and industrial centers as a state-of-the-art and cost-effective technique to fabricate flexible machinery parts. Laser solid freeform fabrication (LSFF) [1, 2] can be considered as a useful process that combines advantages of the laser technology and additive manufacturing together that results in precise and reliable production of materials with specific surface properties and considerably reduced amount of material waste. The LSFF technique allows one-step fabrication of a complex object directly from its digital model by adding metallic materials into the design domain through sequential deposition tracks [3]. In contrast to the conventional methods, the process is accurate, fast, and provides better bonding between materials, smaller heat-affected zones, minimal dilution and direct deposition which can eliminate many of the limitations and challenges of the existing metal manufacturing technologies. Successfully applied, laser solid freeform fabrication process can be regarded as a smart solution with enhanced controllability for a wide range of novel applications including wear of diesel engine exhaust valves [4], corrosion of gas turbine blades [5], reparation of mold steels [6], wear of tools made of high-speed steel [7], and many others in which the conventional methods fail. Pertaining to the wider implications of the LSFF, any attempt to improve accuracy of the process can be considered as an important prerequisite for the process optimization.

This present work falls within the scope of adding nano-CeO_2 in the additive powder on alloy-based substrates which covers a wide range of applications **and results in improved surface properties** [8–11]. The materials considered in this study were chosen based on their existing applicability in key components of the oil and gas industry such as centrifugal compressor impellers [12]. This work represents the first theoretical study of the process for the desired materials (to the author's best knowledge). In addition to the specific material selection, another key objective of this paper is to implement a moving mesh approach for developing a 3-D transient finite element model of the laser cladding process by powder injection as an expansion upon our earlier work [13].

The theoretical model and governing equations for laser solid freeform fabrication are presented in Sec. 2. We then present and discuss the results obtained from the simulations in Sect. 3 of this paper. We have carefully studied and theoretically analyzed the effects of preheating and addition of nano-CeO_2 in the additive powder, on the clad geometry and crack formations. In an effort to thoroughly investigate the process, temporal behaviors of the characteristic features of the model such as maximum temperature, maximum stress, and their corresponding ratio associated with the first, second and third layers were computed and studied. Furthermore, by performing a series of simulations, clad heights were measured for different scanning velocities of the laser in range 1.5 - 4.0 (mm/s) and a decreasing trend was found associated with all the three deposited layers. The obtained qualitative understanding of the process was quantitatively supported by numerical results of the three-dimensional finite-element model presented in this work. Finally, we summarize our results and explain the key develop-

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