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Optimal design of process parameters during Direct Metal Deposition of multi-material parts

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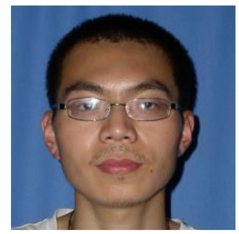

Biography

Mr. Yan is a Ph.D. candidate in Department of Mechanical Engineering, Clemson University. He got his bachelor degree in Sichuan University, China, in 2010. He got his master degree in Clemson University in 2013. He has been doing 3D printing related research since 2010. At present, his research focuses on design and optimization of the Direct Metal Deposition process, which is a metal based 3D printing technique. He is a student ASME member since 2014.

Overview:

The need for functionally graded material (FGM) parts, composite parts, or parts made of multi-materials has surfaced with the development of material science and additive manufacturing techniques. Direct Metal Deposition (DMD) process, a metal based additive manufacturing technique, can locally deposit dissimilar metal powders to produce FGM parts as needed. The manufacturing accuracy as well as the thermal/mechanical properties of parts requires the design, optimization, and tailoring of the process parameters. This research proposes a design method that links the process parameters to the desired composition of the part based on mathematical models and simulations. The outcome of this research includes the shape design of powder injection nozzles, the design of the powder delivering system (e.g., the injection angle, the injection speed, the feed rate, and the composition ratio for the two powders), and the design of the laser parameters including the laser power and the laser scanning speed.

Motivation

During manufacturing of multi-material parts using DMD process, one of the critical issues is the waste of building powder. The powder usage in literature was not ideal and can only achieve around 70% [1-3]. This can be not only due to the combination of process parameters, but also the geometry of the injection nozzles. Redesign the injection nozzles has the potential of approaching perfection, saving powders as well as energy, reducing the manufacturing cost. Another issue that exists in the process is that the dilution and overlapping effects between adjacent layers/tracks have not been considered when manufacturing multi-material parts. Inappropriate mixing ratio of materials without considering these effects as well as the variation of material properties can result in inaccurate material composition in the fabricated parts when compared to the desired compositions. The inaccuracy of material composition can also lead to inappropriate mechanical/thermal properties of the parts made. Under these context, the proposed research aims at reducing the material waste, reducing the energy usage, and reducing the composition deviation between the manufactured parts and the desired parts.

State of the Art

A review of coaxial nozzles design in present laser cladding can be seen in [4]. For example, Lin compared the powder distribution for both an inward position nozzle and an outward position nozzle through FLUENT simulation, and he found that the peak powder concentration of an inward position nozzle is about 50% of that of outward position nozzle [5]. Yet, present studies do not investigate the geometrical details of injection nozzles. These research focus more on the effects of external configuration of nozzles instead of their interior geometry, and a systematically shape design for injection nozzles is missing.

Previous studies have shown that DMD and similar processes have the potential for fabricating FGM parts, and some of the research work has been well summarized by Qi et al. [6]. However, in these papers, the deposition was uniform throughout each circular or straight track, allowing a composition change only at the next track/layer. To our knowledge, the investigation of composition change point by point has not been researched or published.

Intellectual Merit

The intellectual merit of this proposed work is in the development of the science needed to be able to: (1) Represent engineered heterogeneous components, optimize their shape and material composition, and take into consideration manufacturing constraints to generate machine instructions to build such artifacts; (2) Understand the process of melting dissimilar materials and injecting them in the melt pool in the proportions defined by the design where and when needed in an additive manufacturing paradigm defining manufacturing constraints for the design and (3) Identify the critical parameters that will enable the control of the stochastic aspects and of the homogeneous mixing of the materials in the melt pool further defining manufacturing constraints for the design. Beside the ability to create engineered materials, a methodology to address the design of engineered heterogeneous components will be made available to practitioners and educators.

Broader Impact

In terms of broad impacts, the ability to design and manufacture truly heterogeneous engineered components where the materials are strategically placed where needed and in the correct proportion, will revolutionize design, manufacturing, and education. It will lead to leapfrog improvements in functionalities and possibly in weight reduction. The study of the performance of such components will be more complicated and necessitate novel analytical methods since traditional approaches valid for homogeneous materials will not be adequate. This will affect the education of engineers. The potential game changing benefits will therefore be very significant.

Research Approach

The research approach include artificial neural network (ANN), genetic algorithm, simulation for two phase flow, heat transfer with phase change, mathematical modeling, and other model/design methods. The tools for this research are: computation software Matlab, simulation software COMSOL Multiphysics, and optimization software modeFRONTIER.

Findings to Date

The research study include three parts: (1) with the methodology proposed, the injection nozzle can be designed to maximize the process efficiency. It is found that the bottom section of the nozzle has little effect on the laser energy efficiency, and a large slope angle is preferred. It is also found that the powder catchment efficiency decreases with the bottom section of the nozzle, and a small slope angle is preferred. A couple of feasible designs exist. If other manufacturing constraints are not considered, one of the design can be: L_1 = 0 mm, L_2 = 6 mm, d = 1.5 mm, and D = 4.5 mm. Some prescribed constants include: a 10 mm gap distance from nozzle tip to the substrate, a 20 mm length for the top section (L_3) of the injection nozzle, a 1 m/s inlet gas mean velocity, and a powder feed rate of 1.5 g/min.

(2) The proposed pre-process optimization approach has its merits in improving the print quality, and the DMD system should be able to memorize and/or even learn from the previous calculation results, which would greatly reduce the calculation time and be useful for potential real-time control. This study provides an approach to optimize the process parameters in the pre-process stage of multi-materials DMD. This approach can be easily generalized to any materials other than Inconel 718 and Ti-6Al-4V.

(3) This study proposes a design method that links the process parameters to the desired composition of the part based on mathematical models. The proposed scheme is illustrated through a case study of fabricating a copper-nickel FGM part with three-dimensional composition variation. Using the proposed method, the process parameters can be planned prior to the manufacturing process, and the material distribution deviation from the desired one can be reduced.

Conclusions

The research provides a design methodology to design and plan the process parameters to meet the design/manufacturing requirements. The most significant potential of this research is that it can link the design to manufacturing. In the future, designers can design the composition of a desired part made of multi-materials, based on mechanical and/or thermal analysis, or even aesthetic consideration. The requirements then generate a series of manufacturing file format through computer/code written based on our method. The files will be considered as operating file that can be directly read by the manufacturing equipment.

References

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