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Additive Manufacturing/Diagnostics via the High Frequency Induction Heating of Metal Powders: The Determination of the Power Transfer Factor for Fine Metallic Spheres

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ORNL Manufacturing Demonstration Facility
Technical Collaboration **Final Report**

Additive Manufacturing/Diagnostics via the High Frequency Induction Heating of Metal Powders: The Determination of the Power Transfer Factor for Fine Metallic Spheres[1]

Grid Logic, Inc.

Project ID: MDF-UP-2013-034
Start Date: 02/07/14
Completion Date: 05/31/14
Company Size: US owned small business

Summary

Grid Logic Inc. is developing a method for sintering and melting fine metallic powders for additive manufacturing using spatially-compact, high-frequency magnetic fields called Micro-Induction Sintering (MIS). One of the challenges in advancing MIS technology for additive manufacturing is in understanding the power transfer to the particles in a powder bed. This knowledge is important to achieving efficient power transfer, control, and selective particle heating during the MIS process needed for commercialization of the technology. The project's work provided a rigorous physics-based model for induction heating of fine spherical particles as a function of frequency and particle size. This simulation improved upon Grid Logic's earlier models and provides guidance that will make the MIS technology more effective. The project model was successful and will be incorporated into Grid Logic's power control circuit of the MIS 3D printer product and its diagnostics technology to optimize the sintering process for part quality and energy efficiency.

Background

Grid Logic is developing an innovative 3D printing technology for the direct writing of both metal and ceramic/metal matrix composite components that circumvents many of the inherent limitations that hinder wide implementation of metal additive manufacturing. This additive manufacturing method is similar to Selective Laser Sintering/Melting (SLS/SLM) and electron beam melting (EBM) additive manufacturing methods with the exception that the high power laser, or electron beam, is replaced with a small-scale high-frequency induction heating transducer. This transducer consists of a radio frequency (VHF/UHF) power source and an innovative magnetic flux concentrator (FC)

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that applies a spatially compact, very high frequency magnetic field to a dense powder bed with a Computer Numerical Control (CNC) translation stage. Three-dimensional, structurally sound metallic parts can be manufactured with this system through the layer-by-layer induction sintering of a dense metallic powder bed. This additive manufacturing method is called Micro-Induction Sintering (MIS). Unlike traditional additive manufacturing methods, MIS is a versatile technology that is compatible with a wide range of material compositions and powder morphologies. The interaction between the transducer and powder are a strong function of the specific electrical properties of the powder bed and particle size and therefore requires an accurate understanding of these interactions. The ability to predict and model the transient energy transfer dynamics will enable the rapid tuning of processing parameters for a wide range of material systems in an economically viable way.

The MIS process offers unique capabilities not possible with laser- or electron beam-based additive machining methods. Specifically, the MIS additive manufacturing process:

- **Tightly couples the manufacturing method to powder morphology and composition**
  In the MIS process, the characteristics of the metal powder (e.g. resistivity, magnetic permeability, particle size, etc.) are critical to the efficiency of the induction heating and subsequent sintering of the particles. Unlike SLS or EB additive manufacturing methods that indiscriminately heat the metal powder, MIS system parameters are specific to the metallic powder. In essence, the metal powder and the MIS system form a tightly integrated additive manufacturing tool that allows for the development of robust material-specific MIS additive manufacturing “recipes”.
- **Allows for selective processing of materials**
  Laser- and electron beam-based additive manufacturing methods provide local, indiscriminant heating of a material, which is used to sinter the metallic powder into a dense form. Grid Logic’s MIS additive manufacturing method provides local heating of the metal particles, but also is capable of selectively heating specific materials (based on particle size or composition) or sections of the part being manufactured by varying the frequency of the applied magnetic field.
- **Is low cost**
  Grid Logic’s MIS manufacturing method uses conventional RF power supplies and low cost electronic materials to concentrate a high frequency magnetic field on a metallic powder. The MIS system is anticipated to be significantly less expensive than other AM systems as it does not require expensive heating mechanisms, such as lasers or electron beam sources, and does not require stringent atmosphere control capabilities such as the inert atmosphere for laser-based AM systems or the high vacuum requirements for electron beam AM systems.

Figure 1a shows a sample slide of γ-TiAl powder in the flux concentration point of a MIS-FC print head. Figure 1b shows the same slide less than one tenth of a second after energizing the MIS-FC, illustrating the highly localized induction heating and the effectiveness of MIS-based power transfer to metallic powdered material.

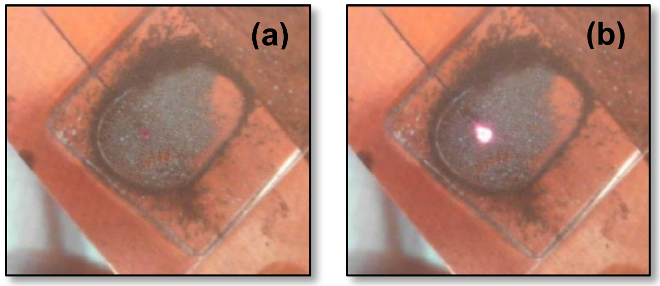

Figure 3: MIS-FC Tests on γ-TiAl Powder.

Technical Results

The objective of the modeling was to calculate the spatial distribution of the induced field in a spherical particle, the power transferred to a spherical particle and the effective power transfer factor for a spherical particle as a function of the applied frequency and particle diameter. The calculations were performed using known solutions to Maxwell's equations for a conducting sphere placed in an alternating magnetic field. The effective power consumed by the spherical particle was calculated using an expression for the induced emf in a primary coil that is used to create the axial magnetic field in which the particle is situated.

The results of this modelling provided a rigorous physics-based model for induction heating of fine spherical particles as a function of frequency and particle size. The fundamental model developed here can be incorporated into commercial or proprietary finite element analysis software packages to assist in the prediction and understanding of complex processes such as melting and consolidation. The simulation agreed with empirical results and with Grid Logic's earlier modeling.

Impacts

The ORNL-Grid Logic model will guide development of the power control circuit of the MIS 3D printer product and its diagnostics technology. The simulation ability will help to address heating issues relating to powder morphology and will help to optimize part quality and energy efficiency. Grid Logic continues to work toward commercial deployment of MIS technology for additive manufacturing.

Conclusions

This project to determine the power transfer factor for fine metallic spheres met its objectives. The model created for the induction heating of fine spherical particles as a function of frequency and particle size provided the necessary understanding of how power is transferred from a high-frequency magnetic field to the metallic particles in the powder bed. The simulation agreed with empirical results and with Grid Logic's earlier modeling work. The developed model also provided a more robust framework for predicting particle heating that is critical to the operation of the MIS system.

The ORNL-Grid Logic model will guide development of the power control circuit of the MIS 3D printer product and its diagnostics technology. The simulation ability will help to address heating issues relating to powder morphology and will help to optimize part quality and energy efficiency. Grid Logic would like to build on this work to include the effects of particle morphology and particle size distribution on the power transfer to the powder bed. The models were tested against experiments performed at Grid Logic and validated.

About the Company

Grid Logic develops manufacturing solutions for processing advanced materials and for manufacturing high performance components used in defense, energy and other industrial applications. The company has developed proprietary superconducting composite materials, component fabrication techniques, and an additive manufacturing technique using very high frequency magnetic fields to consolidate fine powders. This novel additive manufacturing technique shows promise for fabricating parts using high performance materials that other methods are unable to process.

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