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Stereo vision based hybrid manufacturing process for precision metal parts

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ABSTRACT

This paper presents the research and development of an automatic hybrid manufacturing process which based on stereo vision and laser scanning technology to produce fully dense metal parts with CNC level precision. High performance metals, such as titanium alloys, nickel superalloys, tool steel, stainless steels, etc, can benefit from this process. Coupling the additive and the subtractive processes into a single workstation, the hybrid process, can produce metal parts with accuracy. The surface quality of the final product is similar to the industrial milling capability. It will certainly impact the future rapid manufacturing industry. To achieve such a system, issues, including the modeling of the metal deposition process, the automated path planning and accurate surface scanning of the hybrid manufacturing process, are summarized.

1. Introduction

The Directed Energy Deposition (DED) process referred here is a metal additive manufacturing process in which metal is added to the part or product, layer by layer, to rapidly manufacture or form the part or product to a predetermined shape. It is a technique that can produce fully dense functional metal parts or tools directly from a CAD system and eliminate the need for intermediate steps. An example of DED process discussed in this paper is shown in Fig. 1.

A DED process is especially beneficial for high performance metals, such as fully dense titanium alloys, Inconel, and tool steel, which are difficult for traditional CNC machines or rapid prototyping (RP) machines to fabricate. For example, titanium and its alloys have proven to be technically superior and cost-effective materials for a wide variety of aerospace, industrial, marine, medical, and commercial applications. Parts or products cast and/or machined from these high performance metals are very expensive, partly due to the processing difficulties and complexities during machining and casting. DED processes however have been found to be very cost effective because they can produce near-net shape parts from these high performance metals with little or no machining. However, as DED processes cannot build support materials, multi-axis capability is critical in metal deposition technologies. The hybrid manufacturing process here combines laser deposition and machining processes to develop a rapid manufacturing process to build functional metal parts. This paper summarizes the research and development of such a hybrid process, including modeling and understanding of the direct laser deposition process for distortion, and automated process planning of the hybrid process.

2. Deposition process modeling

The basis of DED process is a sound microstructure which is dominated by the created melt pool during deposition. Melt pool formed during laser deposition is a critical factor and melt pool geometry is a crucial factor in determining deposition quality. To optimize process parameters, a deep understanding of the underlying mechanisms is beneficial. A mathematical model, as shown in Fig. 2, was developed to simulate the coaxial laser cladding process with powder injection, which includes laser-substrate, laser-powder and powder-substrate interactions [1]. The model considers most of the associated phenomena, such as melting, solidification, evaporation, evolution of the free surface and powder injection. The fluid flow in the melt pool, which is mainly driven by Marangoni shear stress as well as particle impinging, together with the energy balances at the liquid–vapor and the solid–liquid interfaces are investigated. Powder heating and laser power attenuation due to the powder cloud are incorporated into the model in the calculation of the temperature distribution. The influences of the powder injection on the melt pool shape, penetration, and flow pattern are predicted by comparison between cases with powder injection and without powder injection. Dynamic behavior of the

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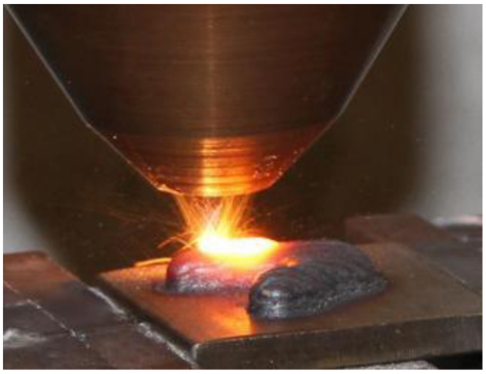

Fig. 1. A blown powder metal deposition process is depositing a steel part.

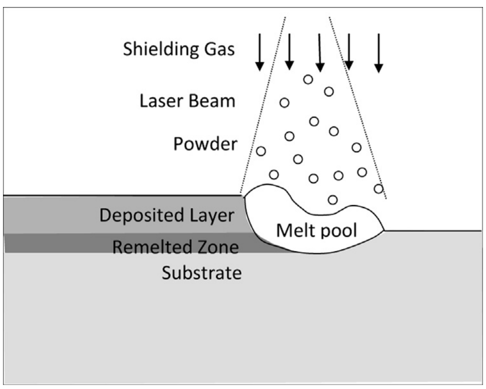

Fig. 2. Schematic diagram of the calculation domain for laser deposition process.

melt pool and the formation of the clad are simulated. The effects of the process parameters on the melt pool dimension and peak temperature are further investigated based on the validated model.

3. Distortion analysis

Highly localized heating and cooling during DMD process produces nonuniform thermal expansion and contraction, resulting in complicated distribution of residual stresses in the heat affect zone and unexpected distortion in the whole structures. The residual stresses may promote fracture and fatigue and induce unpredictable buckling during the service of deposited parts and the distortion is often detrimental to the dimensional accuracies of structures. Therefore, it is vital to predict the behavior of materials after DMD process and optimize the design/manufacturing parameters to control the residual stresses and distortion.

During DED process, the substrate will continuously experience expansion and shrinkage and finally keep a deformed shape. Deformation in *y* direction, shown in Fig. 3, is the main deformation under consideration and is observed by both experiments and simulations shown in Fig. 4.

The distortion analysis tool allows the planning of an effective hybrid manufacturing process so that the distortion effect could be minimized through the machining process.

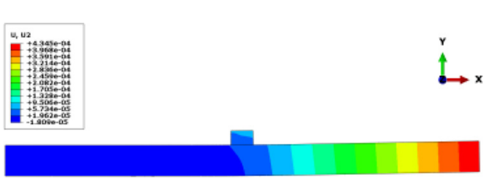

Fig. 3. Deformation of substrate in *y* direction.

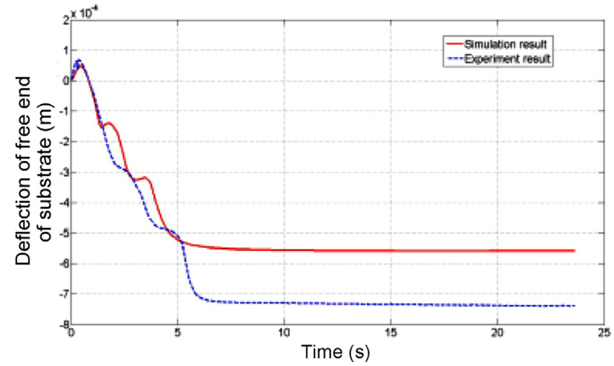

Fig. 4. Simulation and experiment results of deflection of substrate.

4. Hybrid manufacturing system

In order to expand the applications of DED processes, multi-axis capability is needed. A multi-axis rapid manufacturing system can be hardware-wise configured by adding extra degrees of mobility to a deposition system or by mounting a laser deposition device on a multi-axis robot. The configuration could also be a hybrid system in which a laser deposition system is mounted on a multi-axis CNC machine. With the addition of extra rotations, the support structures may not be necessary for the deposition process in order to build a complicated shape. Due to the nature of the deposition process, it is driven by a so-called “slicing” procedure, which uses a set of parallel planes to cut the object to obtain a series of slicing layers. So far, the slicing software on the market is only able to handle 2.5D slicing in which the building/slicing direction is kept unchanged and it lacks the capability of changing directions to fully explore the capability of multiple degrees of freedom.

This process uses laser deposition for material deposition and CNC milling for material removal. As shown in Fig. 5, it includes two major systems: a laser deposition system and a CNC milling machine system.

The laser deposition system and CNC milling machine work in shifts in a five-axis motion mode. The laser deposition system consists of a laser and a powder feeder. In a conventional 2.5-D laser deposition process to create three-dimensional parts, overhang and top surfaces of hollow parts must be supported. Often support materials for functional metal parts are not feasible. Moreover, it increases the build time of the part and necessitates a time-consuming post-processing. Additionally use of support increases the build time of the part and necessitates a time-consuming

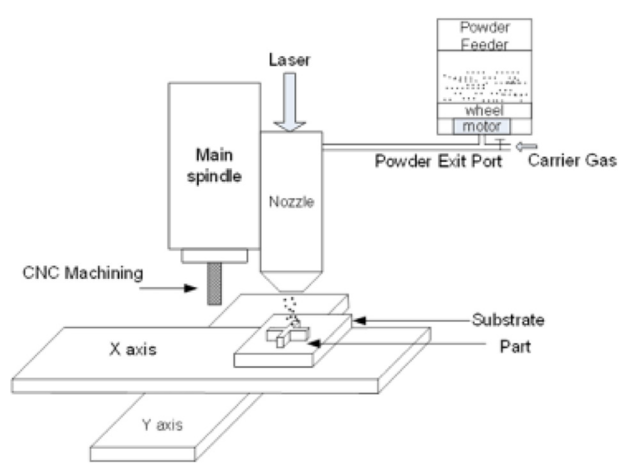

Fig. 5. A hybrid manufacturing system: laser deposition for material deposition and CNC milling for material removal.