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A simulation model for the fabrication of components made from multiphase perfect materials

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Abstract

A component, which has an optimized combination of different materials (including homogeneous materials and different types of heterogeneous materials) in its different portions for a specific application, is considered as the component made of a multiphase perfect material. To manufacture such components, a hybrid layered manufacturing technology was proposed. Since it would be risky and very expensive to make such a physical machine without further study and optimization, manufacturing simulation is adopted to do further research so as to provide the reliable foundation for future practical manufacturing. This paper describes its virtual manufacturing technologies and modeling of the component virtually manufactured. Such a model can be used to evaluate the errors of the virtual manufacturing. Finally, an example of simulating manufacturing process and generating the model of the component virtually manufactured is introduced in more detail.

Keywords: Simulation; Virtual manufacturing; Virtual component; Layered manufacturing; Multiphase perfect materials

1. Introduction

With the rapid development of high technology in various fields, there appear more special functions of the mechanical components or products, which may require component to possess some special properties. Since homogeneous materials cannot satisfy these requirements, attention has been paid to heterogeneous materials, including composite materials (CMs), functionally graded materials (FGMs) and materials with a periodic microstructure (MPMs). However, components made of one heterogeneous material may not meet all special requirements in its different portions. To satisfy all the requirements, it would be necessary to use components made of different materials, including homogenous materials and the three types of heterogeneous materials, thus satisfying all special requirements in different portions and also making the best use of different materials. Such components can be compared to certain natural organisms (e.g. bamboo, tooth and bone). A component, which has an optimized combination of different materials (including homogeneous materials and different types of heterogeneous materials) in its different portions for a specific application, is thus considered as the component made of a multiphase perfect material (CMMPM).

To design and represent such components according to requirements from high-tech applications, a corresponding computer-aided design method [1] (including both geometric and material design) and a corresponding CAD modeling method [2–3] (containing both geometric and material information) have been successfully developed. Currently the researches about how to fabricate such components are rarely reported in the published literature. Shin et al. [4] proposed to apply layered manufacturing technology to fabricate heterogeneous objects. However, the existing layered manufacturing methods of heterogeneous objects have some limitations and cannot satisfy the requirement for manufacturing CMMPMs. For example, in the process of direct metal deposition [4], the voids of microstructures on previous layers will be deformed due to high temperature of laser when laser micro-cladding adds

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materials on the current layer. Shape deposition manufacturing [5] cannot create very small and precise voids for periodic microstructures (down to less than 0.1 mm) because it is difficult to fabricate the milling cutter with such small sizes (down to less than 0.1 mm). Three-dimensional printing [6] cannot add different materials with variational volume fractions simultaneously for every point according to the specified material constituent composition function. Therefore, a new hybrid layered manufacturing technology for fabricating such components was developed [7,8].

Since it would be risky and expensive to make such a physical machine, virtual manufacturing technology is adopted to do further research so as to provide the reliable foundation for future practical manufacturing. The component/product made by a virtual manufacturing system is not physical one but is virtual one which is represented by a model and can be used to evaluate the errors of the virtual manufacturing. This paper first introduces the hybrid manufacturing process of CMMPMs in Section 2, discusses the manufacturing sequence for layered manufacturing in Section 3, describes virtual manufacturing technologies in Section 4 and the model of the component virtually manufactured in Section 5, and finally, takes an example to show the simulation of manufacturing process and the model of a virtual component.

2. Hybrid process for fabricating CMMPMs

After previous study [7,8], a hybrid process can be developed and its scheme is shown in Fig. 1. The process includes the following steps:

(1) If there are adjoining material regions which are higher than the layer to be spread, remove the superfluous material from the layer by an end mill to obtain precise boundary of the layer since the spraying area of a jet is much larger than a point so that the practical area of obtained layer is larger than the required area, and, at the same time, suck out the formed chips by vacuum.
(2) Spread a material layer with the required thickness (layer thickness plus a rough grinding allowance and a finish grinding allowance for the material region of periodic microstructures) and constituent composition (for all material regions) and, at the mean time, spray the inclusion with the required distribution and quantity to stick in the layer (only for CM region) for every point.
(3) Grind the top surface of added material layer by the annular end face of a cup grinding wheel to obtain a required thickness of material layer (layer thickness plus a finish grinding allowance for the material region of periodic microstructures), since metal cladding is not flat enough and the thickness of the added layer is not accurate enough, and, at the mean time, suck out the formed chips or sludge by vacuum; If the layer being fabricated is not the material region of periodic microstructures go to Step (1).
(4) Engrave or sculpt the layer to create very small and precise voids for periodic microstructures with a required depth (layer thickness plus a finish grinding allowance), and, at the mean time, suck out formed chips or sludge by vacuum.
(5) Fill the voids with a softer material to avoid the refilling of the material spread for next layer (The softer material is a kind of material that has lower Young's Modulus than that the previous material has. These materials can be found according to the previous material used. The soft material is also required to be filled into voids for avoiding singularity in the stiffness matrix of the structure [9]).
(6) Grind the top surface of the material layer again to remove superfluous softer material and the burrs formed in Step (4). This will ensure that the required thickness and flatness of the material layer is produced.
(7) Return to Step (1) to repeat the procedure until the component is completely fabricated. The component so formed will have the required constituent composition, inclusions and their distribution, and/or periodic microstructures with softer materials in the voids. The softer material in the voids will not affect the function of the component and can protect the component from erosion.

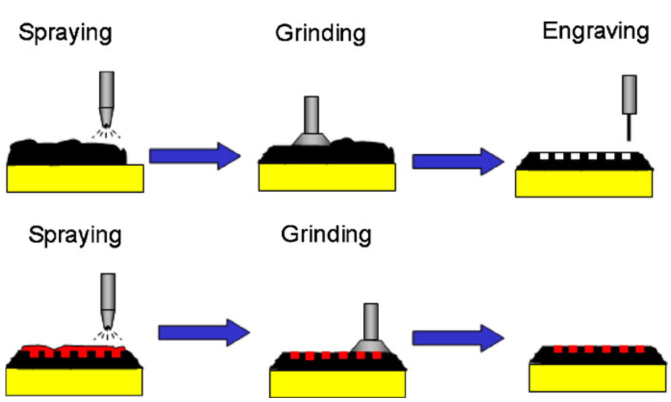

Fig. 1. Scheme of the hybrid manufacturing process.

The machine designed for implementing the hybrid layered manufacturing [8] has three working stations for spreading, grinding/milling, and engraving, respectively, as shown in Fig. 2. The workpiece is fixed on the platform that can be moved vertically (in Z direction), transversely (in X direction), and laterally (in Y direction).

3. Determination of manufacturing sequence of layers

Since CMMPMs are made of different types of materials and the optimal spraying thickness for different material regions are different, the layers to be sprayed in different material regions are at different heights. Thus, a reasonable manufacturing sequence is needed to be built, so that the top surface of the sprayed layer can be ground by a cup