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Direct laser fabrication of nickel alloy samples

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Abstract

Direct laser fabrication (DLF) is an advanced manufacturing technology which can build full density metal components directly from CAD files without using any modules or tools. An open-loop controlled hardware system and associated control software for the DLF process of nickel alloy samples was constructed in our work. The hardware system is consisted of a CO_2 laser, a 4-axis CNC table, a coaxial powder nozzle and a powder recycler. In order to achieve the maximum flexibility and extensibility for the fabrication of metal parts, path plug-ins was introduced into the control software. The effect of the specific energy on the cross-section shape of nickel alloy cladding was studied by a single-track cladding experiment with different laser processing parameters. The comprehensive effect of the optimized laser processing parameters was also studied by an orthogonal experiment. The experimental results showed that the specific energy for laser processing is the most important factor, which controls the component qualities. There is an appropriate range for the specific energy in which the nickel alloy samples can be fabricated layer by layer with a uniform height. If the specific energy is too low, the inner height of a sample is lower than its contour height. Banding structure can be observed in the microstructure of nickel alloy samples. The gain size in the light zones of the bandings is much smaller than those in the dark zones.

Keywords: Laser; Nickel alloy; Direct Laser Fabrication (DLF); Specific energy

1. Introduction

Direct Laser Fabrication (DLF) is an advanced manufacturing technology which can build full density metal components directly from CAD files without using any modules or tools [1,2]. With one step manufacturing ability, DLF technology can greatly reduce the lead-time and investment cost for modules and dies design, hard or rare metal components fabrication, components repair, etc. Laser Engineering Net Shaping (LENS), Directed Light Fabrication (DLF) [3], Direct Metal Deposition (DMD) [4], Shape Deposition Manufacturing (SDM) [5], etc. are all successful examples of DLF technology.

The principle of DLF technology is based on the Rapid Prototyping (RP) and laser cladding. First the CAD model of component is sliced into a series of parallel layers with a certain build-height. Then, the solid areas in a layer are filled by well-designed fill path (or named 'tool path') which are translated into CNC instructions such as G-codes. Controlled by the instructions, a focused laser beam moves on a metal deposition substrate in x–y plane to create a molten pool into which metal powder or wire is simultaneously transported to deposit a layer along with the pool solidification. And then, an assembly of lens and nozzle raise a build-height alone z-axis to repeat the process again. Finally, the metal component with desired geometry can be fabricated layer by layer.

As a particular application, DLF is a very attractive processing technique to the aerospace industry because a great amount of aerospace components with complex shape are made of metals such as titanium, nickel alloys, which are very difficult to process for conventional methods. Nickel alloy provides high wear and corrosion resistance at ambient and high temperature environment. Some researches on the DLF process of titanium alloy such as Ti–6Al–4V were

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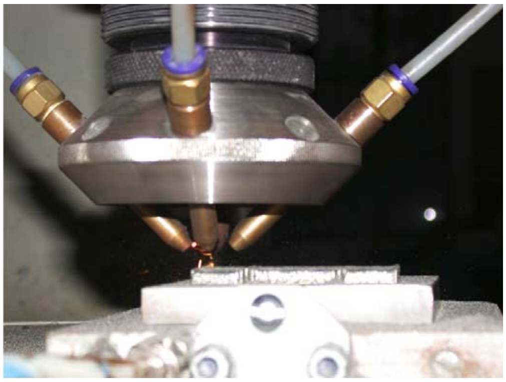

Fig. 1. Coaxial powder nozzle designed for DLF process.

reported [3,6,7], however, there was very little literature published on the DLF process research of nickel alloy samples. The present work describes our researches on this subject.

2. Experimental procedure

2.1. Hardware description

The hardware system for our DLF process consists of a 5 kW ROFIN TR050 CO_2 laser, a CNC system, a powder feeder, a powder nozzle and a powder recycler. The laser is a DC-excited, fast axial flow laser which low TEM mode and excellent stability are very suitable for the requirements of DLF process. The CNC system is a 4-axis HNC-1 CNC unit and stage. The powder feeder is a HGL-III Powder Feeder made from Huazhong University of Science and Technology (HUST) for general purpose such as laser cladding, laser welding, laser repairs, etc. During the fabrication process, the Ni alloy powder was injected into the molten pool through the nozzle to deposit a layer along with the pool solidification. A coaxial powder nozzle with four tubes shown in Fig. 1 was taken in this experiment. The unmelted powder can be recycled by a powder recycler for later use. The CNC unit is the core device in the hardware system because it controls the start/stop of the laser, powder feeder, powder recycler and the movements of the powder nozzle.

2.2. Control software description

The control software of DLF process can be divided into several rudimentary tasks such as CAD model loading and viewing, model slicing, fill path generation and path-to-instruction translation among which the fill path design is the most important task of the whole software development. Because of the influence of thermal stress and surface tension, the fill path design of the DLF process is more complicated than the traditional RP processes such as SL, LOM, etc., especially if the process is open-loop controlled. An excellent path design can not only improve the qualities of final components but also increase the manufacturing efficiency of the process. During the development of fill path module, the effects of component shape on the path scheme should be considered very carefully. For most normal metal parts, the raster fill is a simple and efficient method because the solid areas in each layer are much wider than the laser spot diameter. For parts with thin-walled structures, however, the width of solid areas in each layer is nearly same as the diameter of the laser spot, and in these situations the contour-offset method maybe a good choice to fabricate nice thin-walled structures. Furthermore, engineers sometimes need to adjust and optimize the fill path once and once again for some special parts. In order to achieve the maximum flexibility and extensibility for the fabrication of metal components with various shapes, a control software named HGL-RP was developed in this work and path pattern plug-ins were introduced with which engineers can choose a suitable fill pattern for a certain component. Moreover, engineers can even design particular path by programming a customized plug-in, as described in Fig. 2. Three fill patterns for a hexagon with seven holes by using different plug-ins are exhibited in Fig. 3. The optimization of the process parameters and the fabrication of sample components are all instructed under the G-code translated from the fill path by HGL-RP.

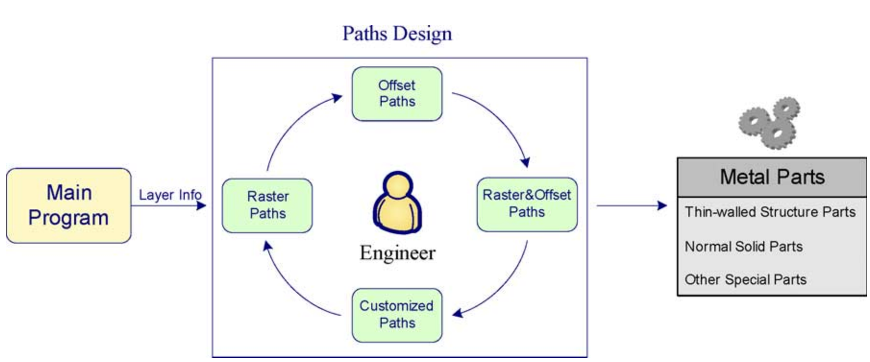

Fig. 2. Engineers can choose an appropriate path scheme via path plug-ins.