Realtime Measurement of Temperature Field during Direct Laser Deposition Shaping

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Abstract. Direct laser deposition shaping is a state-of-the-art rapid prototyping technology. It can directly fabricate metal parts layer-by-layer without any die, mold, fixture and intermediate, just driven by the laminated CAD model. Accordingly, how to improve the quality of as-formed parts becomes an urgent issue in this research field. It is well known that as for the hot working, the heat history can generate enormous influence on the microstructure and mechanical properties of the parts. Due to the large quantity of heat introduced by laser fabrication process, it is necessary to build a temperature measuring platform to realtime monitor and control the temperature field in the laser fabrication process. As a result, such platform was created to communicate with computer by the temperature data collecting module and interface standard converting module, and achieved the temperature acquisition in the serial communication process through the Microsoft programming software. The experimental result proves the validity of the platform, which can provide effective boundary condition and experimental verification for the numerical simulation. In addition, the desirable temperature distribution can be obtained through the realtime process monitoring and effective parameter adjusting.

Introduction

Direct laser deposition shaping is a kind of laser hot working process. High-energy laser beam focuses on the surface of metal substrate, and then the stable molten pool is formed so as to simultaneously melt the metal powder spayed by coaxial nozzle. Subsequently, the molten metal substrate and powder solidify into new cladding layer. During the fabrication process, the numerical control system is adopted to control the worktable scanning back and forth according to the given path of sliced CAD model. Consequently, the free-form metal part can be obtained by the multi-layer cladding deposition on the substrate [1-3]. The whole forming process is performed on the high-temperature condition, so the heat transfer traverses the layer-by-layer deposition from beginning to end. As a result, during this process the distribution of temperature field plays an important role on the metallic solidification, thus determining the microstructure features of as-deposited parts, and even remarkably changing the mechanical properties of them. Accordingly, it is very important to understand and control the temperature distribution of as-formed parts for the whole laser deposition shaping process [4]. Only grasping the distribution rule of temperature field and fulfilling effective realtime monitoring and feedback control through corresponding technical means, can the quality, precision, microstructure and properties of the as-fabricated parts be ensured. In addition, the temperature field has a remarkable effect on the distribution of thermal stress field in the parts, thus determining the occurrence probability of defects, such as cracks and holes [5,6]. Consequently, the measure and control of temperature field during laser deposition have become the very important research field of direct laser deposition shaping technology.
Recently, the rapid development of information technology makes it possible to numerically simulate the heat history of multi-layer accumulation during laser deposition. However, it is necessary to verify the accuracy of numerical model through the relative experiment. Considering the practical case, this research presents a contact measure method that the thermocouples are embedded in the substrate to measure and study the temperature field during laser fabrication.

Experimental Setup and Method

Experimental Setup. In order to monitor the variety of temperature during laser deposition shaping, the temperature-measuring system needs to be built. This paper chooses serial communication technology as the information exchange channel between computer and temperature collection module. The system building and hardware composition of temperature measuring and collecting platform are introduced as follows.

According to the practical requirements of temperature measuring and collecting platform, the Advantech ADAM-4520 and ADAM-4018 are taken as serial communication interface converting module and thermocouple input module (Seeing Fig. 1). Besides, the signal transport protocols adopt ASCII command/response protocols. The computer realizes the conversion between RS232 and RS485 interface standard by ADAM-4520 module. Moreover, the front-end equipment employs ADAM-4018 thermocouple temperature data collecting module, which converts the analog signals to the digital signals.

The system building and hardware composition of temperature measuring and collecting platform are illustrated in Fig. 2. The reason why the ADAM-4520 is selected to fulfill the conversion of interface standard from RS232 to RS485 is that there are many drawbacks with RS232 interface provided by common computers, while RS485 interface can just overcome them. The parameter indexes of temperature-measuring system are listed in Table 1.

![Fig. 1](image1.png) Schematic showing the real link between ADAM-4018: temperature data collecting module (left) and ADAM-4520: interface standard converting module (right)

![Fig. 2](image2.png) Sketch map illustrating the connection between the temperature testing and the temperature collecting system

| Types of indexes                        | Parameter values           |
|----------------------------------------|-----------------------------|
| Type of thermocouples                  | special armoured K-type     |
| Number of temperature probes           | 8 points                    |
| Range of temperature measurement       | 0 °C~1300 °C                |
| Precision of temperature measurement   | ±0.5 °C                     |
| Sampling rate of system                | 8 channels / 1 second       |

Experimental Method. The temperature-measuring platform applies the software programming to drive the hardware module, thus realizing the serial communication of temperature measurement and collection.
First, the Advantech ADAM-4520 and ADAM-4018 are selected as interface standard converting module and temperature data collecting module for serial communication. Then, the host computer can provide friendly human-machine interface, which makes the realtime monitoring and acquisition more visual, easy and convenient. Through the serial communication technology, it can control and manage the base hardware modules which take the single-chip microcomputer as control core. The computer is connected to the ADAM-4520 by using its RS232 standard serial interface, which achieves the conversion from RS232 to RS485 interface standard. The front-end equipment employs the ADAM-4018 with RS485 interface standard as the thermocouple temperature collecting module, which transforms the analog signals into digital ones. This system will be applied to realize the realtime measurement, acquisition and monitoring of temperature data during laser depositing fabrication. Subsequently, the obtained data can be further processed with save and analysis. Consequently, based on the serial communication ActiveX, a kind of serial communication programming technology is realized between personal computer and temperature data collecting module, thus completing the temperature acquisition and supervision of laser deposition process. Accordingly, the temperature collecting and monitoring system of laser direct deposition shaping process is successfully developed.

Experimental Realization and Result

Programming Realization. By using the serial communication ActiveX, the programming technology is developed to achieve serial communication and realtime temperature data acquisition through the RS232 standard serial port of computer.

The flow chart representing the fundamental realization of temperature acquisition serial programming is showed in Fig. 3. This serial port program is mainly divided into two modules:

Program main-control module: responsible for realizing the program logic and main interface, and calling the serial parameters to set the port exposed in the module.

Serial parameters setting module: answering for achieving the setting and modification of serial communication parameters.

![Fig. 3 Flowchart regarding concept design of temperature collecting serial programming](image)

Limited to the space, only the realization of program main-control module is briefly introduced. The implementation steps of program main-control module are described as follows.
Create project;
Insert communication ActiveX controls;
Add other controls and their control variables;
Add member variable;
Add program initializing treatment;
Add member function, and open serial port;
Create processing function responded to MSComm event, and catch serial port event;
Add other response functions of serial port events.
The design of program main interface is illustrated in Fig. 4.

![Fig. 4 On-site main interface of temperature collecting and monitoring program for laser metal deposition shaping system](image1)

**Experimental Process.** Based on the established temperature measurement platform and compiled serial communication program, the temperature evolution is measured by pre-burying thermocouples in the substrate, which is employed during laser direct fabrication. The operating manufacturing process is displayed in Fig. 5. A kind of nickel-based alloy powder is selected to perform this laser rapid manufacturing experiment. The powder size is 200 mesh, and the substrate is A3 steel plate with the dimension of 60 mm × 60 mm × 10 mm. The processing parameters are laser power 600 W, scanning speed 4 mm/s, powder feeding rate 8 g/min and spot diameter 2 mm, and the experiment is performed by the single-pass and eight-layer cladding on the substrate. The thermocouples on the substrate are distributed as described in Fig. 6. First, several equal interval holes are drilled to the diagonal plane at the middle of substrate along the depth direction, and then the thermocouples are put into the drilled holes. When the laser fabricates the metal parts on the substrate, the thermocouples can fulfill the serial communication temperature acquisition through the interface standard converting module and temperature data collecting module.

![Fig. 5 Photograph showing the operating manufacturing process](image2)

**Experimental Result.** The experimental result is illustrated in Fig. 4. It can be seen from it that in a cladding circulation, namely laser beam reciprocating once, due to the laminated manufacturing, the
temperature distribution represents the definite feature and regularity: the temperature at every point undergoes a cycle from low to high, and then to low again. Because of the different time when the laser beam goes through every point, the peak and valley values of temperature, varying with time, of each point in the curve appear at the different places. As seen in Fig. 4, the peak and valley of temperature curve both exhibit the gradually increased tendency. The reason is that with the function of high-energy laser beam, the heat continuously transfers to the substrate through the cladding layer, and the accumulated heat makes the temperature of substrate gradually rise. The periodic fluctuation of substrate temperature proves the tempering effect during laser rapid manufacturing [7]. By recording the temperature values of every point at different time, the measured data can be introduced to the boundary condition of numerical simulation in the way of polynomial interpolation, thus making the temperature variation of model boundary in accordance with the fact. In addition, the measured varied temperature of specific points can verify the validity and authenticity of numerical simulation result.

Summary

The temperature field distribution during direct laser deposition shaping has a remarkable influence on the microstructure and mechanical properties of as-formed metal parts, so it is necessary to grasp the temperature variation rule in the process of laser rapid manufacturing by building the temperature measuring platform. Accordingly, the method that the thermocouples are pre-buried in the substrate is adopted to measure the temperature distribution variation in the laser fabrication process. The temperature measuring platform communicates with computer by the temperature data collecting module and interface standard converting module, and achieves the temperature acquisition in the serial communication process through the Microsoft programming software. This platform has been successfully applied into the temperature data realtime measurement, acquisition and monitoring system on the laser fabrication site, and obtains the favorable monitoring and control effect. The related experiment and practical operation have proved the feasibility of temperature measuring platform for the field application. The experimental measuring result can provide effective boundary condition and experimental verification for the numerical simulation. Meanwhile, the desirable temperature distribution can be attained by realtime process monitoring and effective parameter adjusting.

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