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Experimental research and multi-response multi-parameter optimization of laser cladding Fe313

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ABSTRACT

As an advanced additive manufacturing technology, laser cladding has become a research hotspot in the field of material surface modification and green remanufacturing. The quality of the cladding layer directly depends on the choice of process parameters. This paper optimized the process parameters by Taguchi-grey correlation method. The orthogonal experiment of 25 groups was designed by Taguchi method, the cladding width, cladding height and dilution rate were selected as the response targets. Contour plot, surface plot and the analysis of variance (ANOVA) for signal to noise ratio (SNR) of the response targets can obtain the influence trend and magnitude of the process parameters on the geometric characteristics, combined with the grey relational theory, three response targets were transformed into single grey relational grade (GRG) value, which was quantified to optimize the process parameters for maximum cladding width, minimum cladding height and proper dilution rate. Then validation experiment was conducted to verify the improvement of the response targets. Finally, it was found that the three response targets were improved as expectation, and the optimized cladding layer has obvious advantages over those of other cladding layers in morphology and microstructure, which verified the feasibility of Taguchi-grey relational method.

1. Introduction

Laser cladding is known as a type of surface modification technology, it forms a metallurgical bonding coating on the base surface by adding material to the surface of a part's surface and using high energy laser beam to fuse the powder together with the thin layer of the substrate surface [1–3]. It has become a hot topic in the material surface modification due to the metallurgical combination with the substrate, and it is widely used in fields of aerospace, automobile industry, petroleum and chemical industry etc.

It is one of the most important and common technologies to realize remanufacturing of surface repair, it has outstanding advantages in the surface repair of parts [4–6], which can make the cladding layer of components with better performance, make it more wear resistance, high temperature resistance and corrosion resistance. Nowadays, the growing popularity of laser cladding technology provides an effective solution for the remanufacturing of machine tool parts, which can effectively solve the problem of high energy consumption, serious environmental pollution and low repair rate of parts. Based on the remanufacturing of linear guide of CNC machine tool [7], it not only avoids waste but also saves manufacturing costs.

The purpose of laser cladding is to improve the performance of the substrate, and the quality of the cladding layer is affected by the selection of process parameters directly. At present, there are many methods to optimize the process parameters, such as Taguchi method, response surface methodology, mathematical statistics, artificial neural network and so on [8–11]. Peng et al. [12] compared the wear resistance of 316 stainless steel powder after adding the same mass fraction of TiC, WC and TiN powder by gas shielded welding, the process parameter combination to hardness maximization was obtained through the ANOVA of SNR of single response target (coating hardness). Riquelme et al. [13] cladded composite coating on aluminum alloy matrix in order to maximize the cladding width and height, minimize the penetration depth, it was found that the process parameters that affect geometrical features were different by means of SNR analysis, and the optimum parameters combination was obtained with the optimization conditions of the maximum aspect ratio, and minimum

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defect rate finally. So it is very easy to optimize the single response target by using ANOVA, but it is difficult to use the Taguchi method to optimize the multi-objective parameters [14], some scholars have realized the multi-response and multi-parameter by combining Taguchi method with grey relational analysis method. Shi et al. [15] improved the roughness and hardness in the dry-milling magnesium alloy, the ANOVA was used to find the parameters which played a major role in response target, the grey correlation analysis was used to obtain the best milling process to meet targets response, the experimental results of optimal parameters showed that there was a considerable improvement in surface roughness and micro-hardness. Dhas & Satheesh [16] used the Taguchi-Grey correlation analysis method for obtaining the best welding parameters for the pressure vessel, the influence of parameters on the geometrical characteristics of welding was studied by 27 orthogonal experiments, and the optimum parameters combination was obtained through the response plot of grey relational grade. Farahmand et al. [17] used the central composite design (CCD) to design the experiment, used the response surface method to optimize the laser cladding process parameters with multi-parameter and multi-response. However, the disadvantage of this method is that the surface plot will appear to be climbing all the time if the initial parameter selection is irrational, it will be regarded as failure in this parameter selection and another retest is required. Erfanmanesh et al. [18] used empirical data statistical methods to optimize the laser cladding process parameters, each response target was represented by a regression mathematical model in the same graph, and the optimal parameters were selected by the range interval. The disadvantage of this method is that the error of the fitted curve is large if the data is irregular, or it cannot even be represented in the same coordinate system. Gao et al. [9] used Kriging model and genetic algorithm (GA) to optimize the parameters after design of experimental (DOE) in order to obtain the parameters of hybrid laser-arc welding. However, this method uses a large amount of data for training and a few data for verification, and requires repeated calculation. The disadvantage of this method is that there are large errors when the number of experimental groups is small. In contrast, the Taguchi-grey correlation method can be used to optimize the required relatively reliable process parameters at one time.

In this study, the optimal parameter combination of laser cladding was optimized based on Taguchi-grey correlation analysis, and multi-parameter optimization under multi- response was realized. The common material of linear guide (S55) was used as the substrate, Fe313 was chosen as the cladding powder. The cladding width, cladding height and dilution rate were selected as the response targets, the SNR of three response targets was analyzed by ANOVA. The influence trend and order of each factor on the response target were analyzed respectively. The Taguchi method combined with grey relational analysis can transform multi-response targets into a single grey correlation degree to find the optimal combination of process parameters for the maximum cladding width, minimum cladding height and proper dilution rate. Finally, final experiment was used to verify the prediction of the grey correlation degree and the improvement of the response targets.

2. Material and methods

2.1. Experiment condition

The laser cladding device that used for experiment is composed of the laser head, 6-axis KUKA robot, powder feeder, laser generator, water cooler, robot control system, and laser control cabinet. The rated power of Germany IPG YLR-500 fiber laser with a wavelength of 1070 nm is 500 W, and the laser head adopts coaxial nozzle, the schematic view of laser cladding experiment device is shown in Fig. 1.

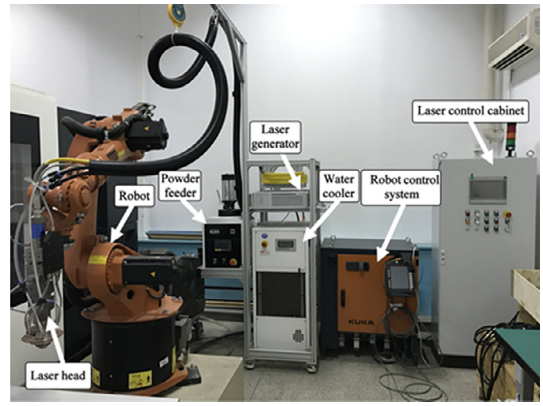

Fig. 1. Laser cladding system experimental device.

2.2. Material and procedure

Quality carbon steel S55C was selected as substrate with a dimension of $120 \times 80 \times 12\ mm^3$. The powder was iron-based self-fluxing powder Fe313 [19,20] whose shape is nearly sphere with a size of 100–270 screen mesh, as shown in Fig. 2. Their chemical compositions are shown in Table 1. The upper surface of the substrates was ground on grinding machine, and then wiped clean with absolute ethanol. The powders were dried at 100 °C for 4 h.

After programming through offline programming software Robot Art, the single-track experiment of laser cladding was deposited on the already prepared substrate, each track is 40 mm in length and the distance between each other is 4.5 mm, the plate was cut into pieces on the wire cut electrical discharge machining, then they were ground with different types of sandpaper from coarse to fine in turn and polished through diamond paste, corroded with 4% nitric acid alcohol solution, and then measured the geometry with a laser scanning confocal microscopy.

2.3. Design of experiment

Taguchi method provides an effective method to design the experiment, it can help minimize the number of it [15,21], three main factors that primarily influence the heat and mass transfer, cladding geometry characteristics, microstructure were considered. The laser spot diameter (D) is 1.045 mm, the three

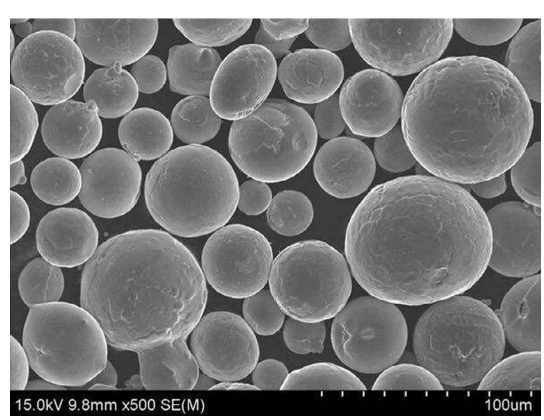

Fig. 2. The morphology of the powder Fe313.