Optik 127 (2016) 4031–4038

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Analysis of laser powder deposition parameters: ANFIS modeling and ICA optimization

Hamed Sohrabpoor*

Advanced Processing Technology Research Centre, School of Mechanical and Manufacturing Engineering, Dublin City University, Dublin, Ireland

ARTICLE INFO

Article history:
Received 13 November 2015
Accepted 10 January 2016

Keywords:
Laser powder deposition
Adaptive neuro-fuzzy inference systems
Imperialist competitive algorithm

ABSTRACT

The newly developed laser powder deposition technique requires the optimization of various coating parameters. The optimized parameters will lead to a greater coating performance. We present an adaptive neuro-fuzzy inference system, ANFIS, to model the response of deposition parameters based on experimental data of Laser powder deposition of Fe-based alloy on ASTM 36 mild steel substrate. A series of systematic experiments has been conducted using central composite design (CCD) taking into account the response of laser power (LP), powder feeding rate (PF), carrier-gas flow rate (CG) and stand-off distance (SD) as processing parameters and catchment efficiency (CE), clad height (CH) and clad width (CW). Moreover, in order to simultaneously maximize these parameters, the ANFIS models of responses were associated with imperialist competitive algorithm (ICA). Results indicated that ANFIS structures with 2 2 2 2 Triangular membership function ensure lowest values of prediction error for catchment efficiency and clad width, while for clad height 2 2 2 2 structure with Generalized-bell, the membership function has highest prediction accuracy. Also, ICA optimization show that setting LP = 3.199 kW, PF = 43.237 g/min, CF = 19.583 SCFH, and SD = 8.632 mm leads to maximum responses in CE = 0.5417, CH = 1.3470 mm and CW = 12.3048 mm. The modeling results are in agreement with the experimental data.

1. Introduction

Laser deposition or cladding by lateral powder injections, is a surface coating that can enhance the metrological surface of component. This process recently is used for repairing and coating of some critical components in industry. In this process, the powder is deposited laterally or coaxially on molten pool which is produced via laser beam with a Gaussian energy intensity [1]. Where, the substrate surface was coated with overlapped clads to cover large area. The width to height aspect ratio is a critical factor during laser deposition process that should be more that 5:1 to achieve desirable cladding quality characteristics [2]. However, in Gaussian beam laser cladding the formed clad has convex shape that significantly reduces the aspect ratio. Also dilution is another critical factor that should be minimized during laser cladding process [3].

In comparison with other high laser power (CO_2 or Nd:YAG laser), high-power diode laser (HDPL) is tightly packed with more efficiency from aspect of zone deposition, electricity and operation expenditure. HDPL has widely used in repairing and producing molds and motor components [4]. For achieving large-area cladding with a smooth surface, HPDL supplies a wide rectangular laser spot. Also, top flat-top beam causes to minimization of dilution to less than 3%. Because of these privileges, many surface cladding have been accomplished by HPDL. By acquiring minimum dilution, maximum quality of bonded clads and preferable deposited clad makes HPDL superior [5].

Recently, numbers of works have been carried out to study the impact of processing factors of laser deposition. The most investigations have focused on impact of one or various factors on the coating microstructure, clad depth and mechanical features. Fu et al. [6] studied the impact of laser cladding of Fe-based alloy on microstructure and wear feature of wheel materials. They found out that coating with Fe-based material can be efficiently utilized to increase the wear life and hardness of wheal and rail materials. Also, when lanthanum oxide has been added into laser cladding coating, the wear and surface damage microstructure of wheel/rail rollers would be considerably reduced. Huang et al. [7] studied effect of powder feeding rate on the laser intensity distribution and particle temperatures in laser deposition coating. The theoretical model was applied for calculate the laser intensity distribution and the particle temperatures at different sites of the workpiece. They inferred that the maximum value of the laser beam reduces

* Tel.: +353894563673.
E-mail address: h.sohrab@outlook.com

http://dx.doi.org/10.1016/j.ijleo.2016.01.070
0030-4026/

when the injection angle increases. There are many experiments have been done by changing factors at a time with a trial-and-error method. Anyway, in this type of method, because of costly, low accuracy and time consuming, acquired results would not be efficient and reliable. Xu et al. [9] investigated about effect of process parameters and powders on bonding shear strength and micro hardness in laser coating. The type of alloy powders, laser power and scanning speed were inputs and bonding shear strength and micro hardness of the clad layer were chosen as responses. All of output were tested and analyzed by scanning electron microscope (SEM) image. The experimental results revealed that excellent metallurgical bond is formed among the deposited layer and substrate.

However, there are some complex correlation among the process predominant factors like stand-off distance and carrier-gas flow rate on the clad results such as clad height or width and powder catchment efficiency. In order to have desirable coating performance an apprehensive knowledge about interaction between process factors and responses is necessary. Therefore, numerical approach like finite element modeling (FEM), statistical method such as response surface methodology (RSM) and intelligent computation like artificial neural network (ANN) and adaptive neuro-fuzzy inferred systems (ANFIS) should be used for modeling of the laser cladding process.

Shuang and Kovacevic [8] investigated statistical and optimization of processing parameters in high direct diode laser cladding. The used quadratic regression model via RSM and the relationship between inputs and outputs were analyzed by ANOVA. Also, they found out that laser power has biggest effect on laser cladding process. Hao and Sun [10] applied a 3D thermal finite element model (EFM) for simulation of temperature field in the laser cladding of Ti6Al4V alloy by ANSYS software. This model was proposed by the numerical and experimental results. They found that it has potential to be applied in the thermal simulation of laser coating with varying process parameters considering the changing of the characteristic dimensions of deposition molten pool and the heat source. The majority of recent studious regarding to laser deposition are reported only one or two process conditions such as laser power and/or powder feed rate, therefore it is hard to find a good parametric combination under the premise of keeping other parameters constant. However, the intelligent modeling method is a successful alternative to investigate the relations between cladding characteristics and its input parameters. Aminian and Teimouri [11] studied on modeling and analysis of material removal rate and taper in laser machining and welding process by using RSM, ANFIS and ANN. The impact of each process's factors on its performance measures was analyzed. Results revealed that for both typed of laser manufacturing process, the ANFIS method predicted more accurate results. Alimardani and Toyserkani [12] used neuro-fuzzy method of laser solid freeform for predicting clad height. In this paper laser pulse energy, laser pulse frequency and traverse speed assigned for input parameters. A neuro-fuzzy model is used to predict the clad height (coating thickness) as a function of laser pulse energy, laser pulse frequency, and traverse speed as a response. The comparison between the experimental data and the model output shows promising results. The model can predict the process with an absolute error as low as 0.07%. Although, the intelligent modeling was successfully used on laser manufacturing process like laser welding [13–15], laser hardening [16] and laser cutting [17–19], there is still lack of the application of intelligent modeling method on laser cladding process.

In this paper, series of artificial intelligence modeling were applied to laser deposition process to find optimal combination of powder feeding rate, laser power, carried-gas flow rate and stand-off distance that maximizes powder catchment efficient, clad height and clad width, simultaneously. To reach this purpose, firstly 30 experiments were carried out by central composite design (CCD). Then, an adaptive neuro-fuzzy inference system has been applied for generating estimation models based on experimental observation. After that, the effect of process factors on laser catchment efficiency, clad height and width have been studied through plots which were derived by developed ANFIS models. Finally, ANFIS models of responses were associated with imperialist competitive optimization algorithm simultaneously maximize catchment efficiency, clad height and clad width.

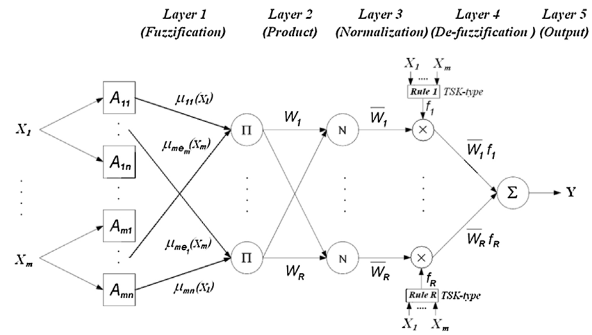

Fig. 1. Basic structure of an ANFIS model.

2. Methodologies

2.1. Adaptive neuro-fuzzy inference system (ANFIS)

For create planning connection among inputs and responses, an adaptive neuro-fuzzy inference system is a mixed predictive pattern that utilize both of artificial neural network (ANN) and fuzzy logic [20]. ANFIS consists of five layers that each layer is made by some nodes. Each layer of ANFIS is created by previous layer nodes, like ANN. ANFIS structure is presented in Fig. 1. It is seen from the figure that the network consists of m inputs ($X_1 \ldots X_m$), that each one includes of n membership functions (MFs). In addition, output layer and R fuzzy rules layer, are added to creation of this network. For obtaining the number of nodes, it can be easily computed with response of m as number of inputs and n as number of membership function ($N = m \cdot n$). Number of fuzzy rules (R) is depended on number of nodes in other layers (layers 2–4).

The ANFIS structure is categorized as follows. Also, further details about each layer are found in references [20,21].

- First layer (fuzzification layer)
- Second layer (product layer)
- Third layer (normalized layer)
- Fourth layer (defuzzification layer)
- Fifth layer (output layer)

To check the adequacy of developed model, the root means square error (RMSE) is defined as error function that is calculated but use of following equitation:

$$\mathrm{RMSE} = \sqrt{\frac{1}{M}\sum_{z=1}^{M}(S_z - Y_z)^2} \quad (1)$$

where S_z is the real output value, M is the overall number of training sample and the ANFIS output value in training is Y_z.