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Full length article

Prediction of temperature and HAZ in thermal-based processes with Gaussian heat source by a hybrid GA-ANN model

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ABSTRACT

Thermal-based processes with Gaussian heat source often produce excessive temperature which can impose thermally-affected layers in specimens. Therefore, the temperature distribution and Heat Affected Zone (HAZ) of materials are two critical factors which are influenced by different process parameters. Measurement of the HAZ thickness and temperature distribution within the processes are not only difficult but also expensive. This research aims at finding a valuable knowledge on these factors by prediction of the process through a novel combinatory model. In this study, an integrated Artificial Neural Network (ANN) and genetic algorithm (GA) was used to predict the HAZ and temperature distribution of the specimens. To end this, a series of full factorial design of experiments were conducted by applying a Gaussian heat flux on Ti-6Al-4 V at first, then the temperature of the specimen was measured by Infrared thermography. The HAZ width of each sample was investigated through measuring the microhardness. Secondly, the experimental data was used to create a GA-ANN model. The efficiency of GA in design and optimization of the architecture of ANN was investigated. The GA was used to determine the optimal number of neurons in hidden layer, learning rate and momentum coefficient of both output and hidden layers of ANN. Finally, the reliability of models was assessed according to the experimental results and statistical indicators. The results demonstrated that the combinatory model predicted the HAZ and temperature more effective than a trial-and-error ANN model.

1. Introduction

Some thermal-based methods such as Electro Discharge Machining (EDM), surface treatment, welding, etc. load a Gaussian-type heat source on the workpieces, and influence the metallurgical and mechanical properties of materials. The very common problem in thermal-based manufacturing processes is lack of certain information on HAZ and temperature distribution. The HAZ left behind by thermal process mostly contains residual stress and micro-cracks; it is usually softer than the parent material [1]. It can also weaken the functional properties of material, and cause the material to propagate the cracks and stress fractures which may lead to malfunction of the material. Additionally, the temperature history of the workpiece within thermal processes plays a crucial role in determination of the residual thermal stress, phase transformation and surface integrity as well as the HAZ boundary [2]. Therefore, it seems to be imperative to predict the HAZ and temperature distribution by using different possible approaches. Many attempts have been made to model these kinds of processes; models can be divided into three main categories: theoretical, numerical and experimental investigations. Due to the complexity and uncertainty of processes, running experiments for investigating different aspects of process is time-consuming and costly. Besides, the development of an analytical equation for the HAZ geometry and temperature distribution requires many assumptions which not only simplify the models but also predict the results based on unrealistic approximation. In case of EDM, in order to achieve more accurate prediction of heat input, investigators like Patel [3], Gadalla [4], Singh [5] and Joshi [6] have used Gaussian distribution for heat flux in the EDM process to predict temperature fields. But solving heat conduction equations in these processes basically does not bring out the real temperature distribution [7]. This is due to the fact that theoretical models are not able to consider whole aspects of the thermal process modelling such as variable thermo-physical properties, but use a series of simplifying assumptions.

In case of surface treatment processes, comprehensive thermal models which are capable of predicting the temperature

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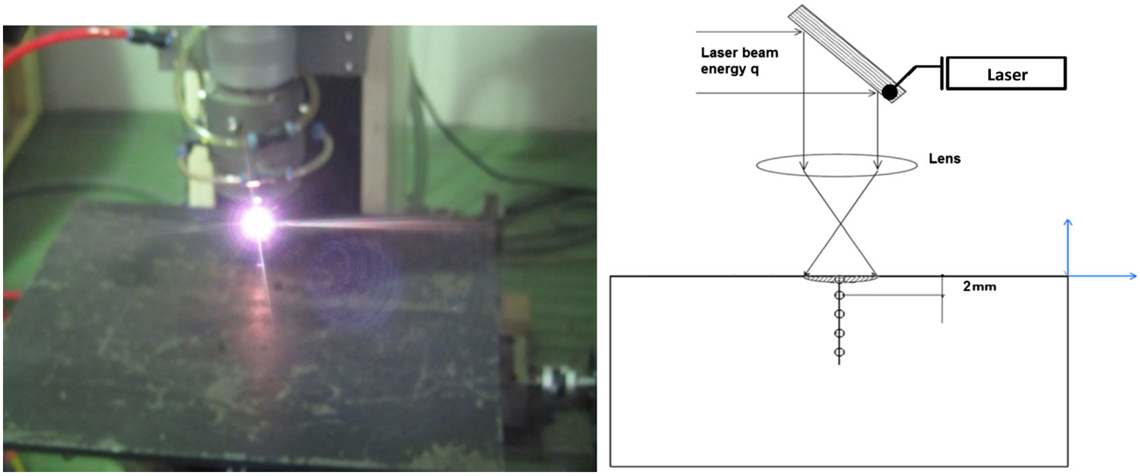

Fig. 1. A schematic view of experimental setup for laser surface processing.

Table 1
Range of laser process parameters.

Factor	Laser power (W)	Focal point diameter (mm)	Irradiation time (s)
Range	50–500	3–10	4–10

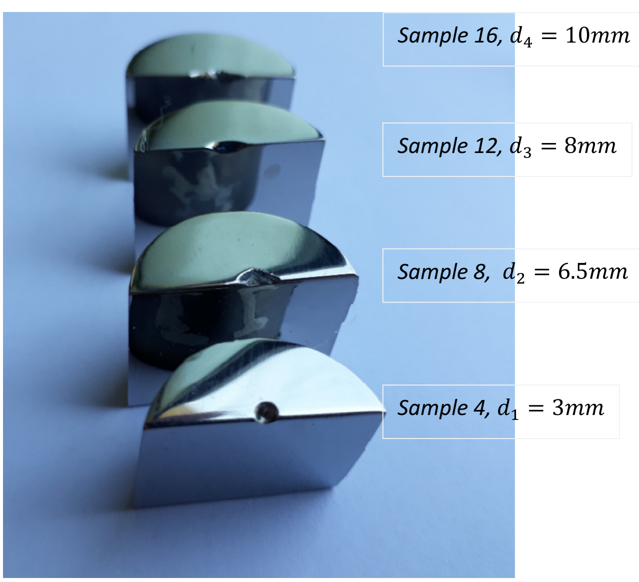

Fig. 2. Four cut-polished specimens relating to four laser beam diameters.

Table 2
Experimental design, three factors and four levels.

Symbol	A	B	C
Factor	Laser power (W)	Focal point diameter (mm)	Irradiation time (s)
Level 1	50	3	4
Level 2	200	6.5	6
Level 3	350	8	8
Level 4	500	10	10

distributions accurately in workpieces are rarely available. These processes are mainly categorized into laser hardening, laser cladding and laser alloying [8], and only there are a few analytical studies to investigate the temperature distribution in the workpiece. For example, Ashby and Eastering have developed a theoretical model to approximate the temperature by considering a Gaussian heat source in laser hardening process [9].

With regard to this fact that a number of manufacturing processes benefit from Gaussian heat source, it is worth-investigating, and necessary to characterize different factors of such processes. Laser processing of alloys has particularly attracted investigators' interests as it offers excellent non-contact surface modifications and desirable surface properties. On the other hand, due to difficulties of temperature measurements, the experimental data on the temperature distribution as well as HAZ are still inadequate especially for some materials like Titanium alloys, Inconel, etc. [10]. Researchers who intend to analyse the thermal processes largely have serious problems in the area of exactly determination of thermal stress. This is largely because of this fact that already-proposed models, neither analytical nor numerical, can predict the real amount of temperature distribution. Therefore, forecasting the parameters of laser-treated materials is complex.

In earlier literatures, laser processes were extensively scrutinized by different researchers. The majority of them have focused on optimizing the process parameters such as laser power, scanning speed, etc. [11–13]. It lies at the root of this fact that the parameters of laser process are numerous and hard to be considered in investigations. Ciurana et al. have modelled the pulsed laser micromachining process by Artificial Neural Network (ANN), and optimized operational parameters by multi-objective particle swarm optimization (PSO) to minimize the surface roughness and volume error [14]. Pan et al. have used the Taguchi analytical methodology to optimize the welding parameters governing the laser beam in butt welding [15]. Pandey and Dubey have developed the Genetic Algorithm (GA) to optimize the quality characteristics (surface roughness and kerf taper) of laser cutting of Titanium alloy sheet based on developed regression models as objective functions [16]. Khan et al. have utilized the response surface methodology (RSM) for developing the mathematical modelling of the laser welding of stainless steels. Maximum weld resistance length and shearing force, and minimum radial penetration were of the quality criteria of their study with consideration of laser power, welding speed, and incident angle as process parameters [17]. Among various process parameters, focal point diameter and irradiation time were rarely investigated previously [18,19] and therefore a need for finding out the effects of such parameters is felt.

This study implemented the laser technology to study the effects of Gaussian-type heat sources on temperature fields and HAZ. The GA-ANN model was applied to predict both temperature