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# Estimation of the most influential factors on the laser cutting process heat affected zone (HAZ) by adaptive neuro-fuzzy technique

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## HIGHLIGHTS

- Heat affected zone (HAZ) of the laser cutting process.
- HAZ forecasting based on the different laser cutting parameters.
- To analyze the influence of three inputs on the HAZ.
- Cutting speed has the highest influence on the HAZ forecasting.

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## ABSTRACT

Heat affected zone (HAZ) of the laser cutting process may be developed on the basis on combination of different factors. In this investigation was analyzed the HAZ forecasting based on the different laser cutting parameters. The main aim in this article was to analyze the influence of three inputs on the HAZ of the laser cutting process. The method of ANFIS (adaptive neuro fuzzy inference system) was applied to the data in order to select the most influential factors for HAZ forecasting. Three inputs are considered: laser power, cutting speed and gas pressure. According the results the cutting speed has the highest influence on the HAZ forecasting (RMSE: 0.0553). Gas pressure has the smallest influence on the HAZ forecasting (RMSE: 0.0801). The results can be used in order to simplify HAZ prediction and analyzing.

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## 1. Introduction

Composite materials gains increasing use in aeronautic, aerospace, automotive and marine industries due to their superior properties. There is a drastic increase in research in the field of laser cutting of composites because laser machining offers an attractive alternate among all nonconventional machining due to improved end product quality, low cost, short processing time, smoothness and precise cuts, narrow width and small heat affected zone (HAZ) [1]. By controlling the different process parameters of laser, precision cuts can be made for different geometry and complex shape [2]. Laser cutting is a non-contact, abrasion less technique eliminates tool wear, machine-tool deflections, vibrations and cutting forces and can be used for almost all type of materials [3–5].

The interest of manufacturers using laser cutting is the optimization of the productivity and the subsequent quality of components made by the laser cutting process. Both aspects are governed by the selection of appropriate laser process parameters, which are unique for each material and thickness. These parameters include laser power, cutting speed and assist gas parameter [6]. These parameters are usually adjusted and tuned to provide the quality of cut desired, but this consumes exhaustive amounts of time and effort and still good quality cutting conditions may not be found. Laser cut quality cannot be easily predicted. This is due to the dynamic nature of the laser cutting process, and it is particularly clear when cutting ferrous alloys using oxygen as an assisting gas. There are several investigations of the HAZ during the laser cutting process.

In study [7] was aimed at introducing the laser induced thermal-crack propagation (LITP) technology to solve the silicon-glass double layer wafer dicing problems in the packaging procedure of silicon-glass device packaged, investigating the feasibility of this idea, and studying the crack propagation process of LITP cutting double layer wafer. The analysis of experimental results and numerical simulation results shows that dual laser beam revision the separation path technology can effectively revise the deviation

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of the separation path in asymmetry linear cutting glass with LITP [8]. In order to develop a detailed map of cracks and understand the root cause of cracking, a comprehensive microstructural and numerical analysis was performed in article [9]. In article [10] was shown that the absorbed power melts a part of the material and preheats the part that would be manufactured during the following interaction time. The numerical predictions of the mechanical properties in the HAZ was shown that there are large variations both in yield stress and work hardening depending on the distance from the weld line [11]. In article [12] was found that the HAZ did not appear to have an adverse effect on the high-cycle fatigue behavior. The predicted temperature distribution is correlated with the HAZ and a critical temperature range corresponding to the maximum depth of the HAZ is identified using a combination of metallography, hardness testing, and thermal modeling [13]. Parametric studies showed that the depth and width of the heat affected zone increased with an increase in the laser power and decreased with an increase of the laser spot size and the laser scan speed [14]. The thermal model can be used to determine the laser parameters for a given cut geometry that will yield no residual heat affected zone in the material after cutting.

Even though a number of new mathematical functions have been proposed for modeling of the HAZ, in this investigation the main aim is to overcome high nonlinearity by applying the soft computing method. ANN can be used as alternative to analytical approach as ANN offers advantages such as no required knowledge of internal system parameters, compact solution for multi-variable problems.

The main aim in this article was to analyze the influence of three inputs on the HAZ of the laser cutting process. In this study laser cutting of Glass Fibre Reinforced Plastic Composites has been carried out to find the influence of laser cutting parameters on cut quality parameter HAZ. Three input parameters: laser power, cutting speed and gas pressure were taken under experimental investigation to find the effect and consequently models have been developed to predict the HAZ in context of cutting parameters. Adaptive neuro-fuzzy inference system (ANFIS) [15], which is a specific type of the ANN family, was used to select the most influential parameters of the HAZ. ANFIS shows very good learning and forecasting capabilities, which makes it an efficient tool to deal with encountered uncertainties in any system. ANFIS, as a hybrid intelligent system that enhances the ability to automatically learn and adapt, was used by researchers in various engineering systems [16–19]. So far, there are many studies of the application of ANFIS for estimation and real-time identification of many different systems [20–26].

## 2. Methodology

### 2.1. Heat affected zone

The experimental specimen was made of Glass Fibre Reinforced Plastic Composite. The size of the material was 400 mm × 300 mm × 5 mm. The laser beam was focused using a 135 mm focal length lens, the nozzle diameter was 1.3 mm and the nozzle tip distance was 1.3 mm. All parameters were precisely controlled as the machine is equipped with PLC controller. The machine was capable of using nitrogen and oxygen as an assist gas at right angle and coaxially to the laser beam. By trial experiments it was decided to use nitrogen as inert gas.

For measurement of HAZ, straight cuts of about 50 mm in length were made on sheet and they were measured. In experiments, number of fixed and independent parameters were involved. The fixed parameters were focal length, nozzle diameter, nozzle tip distance and material thickness and the values are as mention above whereas the variable parameters were laser power, cutting speed and gas pressure. Table 1 shows input and output parameters which are used in this investigation.

### 2.2. ANFIS methodology

Fuzzy inference system in MATLAB software is employed in the whole process of the ANFIS training and evaluation. An ANFIS network for 2 input variables is depicted in Fig. 1.

The fuzzy IF-THEN rules of Takagi and Sugeno's class and two inputs for the first-order Sugeno is employed for the purposes of this study:

$$\textit{if } x \textit{ is } A \textit{ and } y \textit{ is } C \textit{ then } f_1 = p_1x + q_1y + r_1 \quad (1)$$

Bell-shaped membership functions having the maximum value (1.0) and the minimum value (0.0) are selected, such as,

$$\mu(x) = bell(x; a_i, b_i, c_i, d_i) = \frac{1}{1 + \left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}} \quad (2)$$

where $\{a_i, b_i, c_i, d_i\}$ is the set of parameters set. The parameters of this layer are designated as premise parameters.

The final layer is known as the output layer. It adds up all the receiving inputs from the preceding layer. Thereafter, it converts the fuzzy classification outcomes into a binary (crisp). The single node of the 5th layer is considered non-adaptive. This node calculates the total output as the whole sum of all receiving signals,

$$O_i^5 = \sum_i w_i^* x f = \frac{\sum_i w_i f}{\sum_i w_i} \quad (3)$$

In the process of identification of variables in the ANFIS architectures, the hybrid learning algorithms were applied. The functional signals progress until the 4th layer whereby the hybrid learning algorithm passes.

**Table 1**
Input and output parameters.

| Inputs | Parameters description |
|---|---|
| Input 1 | Laser power (Watt) |
| Input 2 | Cutting speed (mm/min) |
| Input 3 | Gas pressure (Bar) |
| Output | Heat affected zone (HAZ) (mm) |

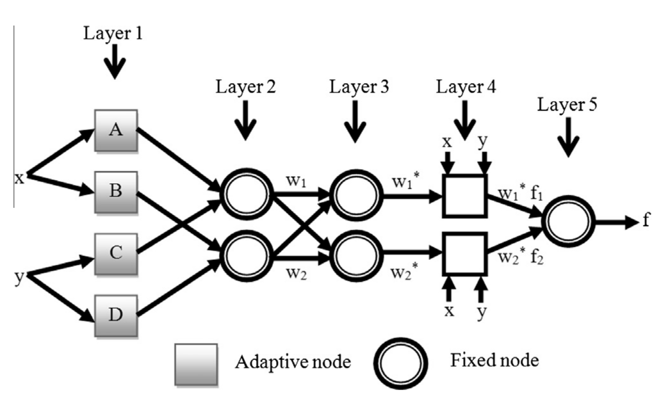


**Fig. 1.** ANFIS structure.

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