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Optimization of titanium cutting by factorial analysis of the pulsed Nd: YAG laser parameters

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Abstract

The need to establish the laser processed parts that satisfy all functional requirements of the application as an uniform surface finish, low roughness and the conservation of their metallurgic properties was the main motivation in the accomplishment of this study. Besides the versatility and advantages, as well as the industrial sector global trend, became important factors in the lasers use as machining tools. The scope of present study was to investigate the effects of laser processing on the quality and formation of phases in the cut surface. The cutting process was performed on commercially pure (CP) titanium (grade 2) and alloy Ti–6Al–4V (grade 5) sheets. The obtained samples were analyzed through optical microscopy (OM) in order to determine the edge roughness formations. An increase on the superficial hardness on the cut region and the formation of nitrogen precipitates under a thin layer of a melted zone were verified. A factorial arrangement regarding the several combinations of different processing factors was built and the influence of these specific parameters, which were statistically significant for the process, was evaluated by the analysis of variance statistical test.

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Keywords: Laser machining; Nd:YAG laser; Titanium; Analysis of variance

1. Introduction

Every industry inserted in the production chain aims a continuum enhancement on their processes control and also on their products development. The factors such as quality, reliability and costs reduction are important motivations for the operational excellence achievement serving also to generate competitive items in the global scenario.

Consequently, these factors may be the basis of choosing the laser processing [1] replacing the conventional methods. This procedure includes several segments in different areas where the laser is focused by the main industrial applications [2] such as cutting, drilling, welding, thermal treatment and marking.

The applications for the laser material processing involves mechanisms on which it becomes necessary to adequate the type of material and its geometrical shape to the laser type (which is determined by the wavelength and the continuous or pulsed operation mode). From this selection it is also necessary to choose and set the various process parameters that influence on the final result quality, cost and speed, among others factors [3,4].

This technology stimulates major interest due to the fact that it joins various advantages such as: non contact process and no tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on the beam delivering, simplicity in fixation, easy automation, small heat affected zone, high speed, excellent edge quality.

The fabrication of components from titanium alloys [5–7] and commercially pure titanium (Ti-CP) appears associated with the development of machining technology. After the 1950s decade this material aroused a great interest in several engineering applications mainly because its metallurgical and mechanical characteristics such as relatively low density ($4.5\,\mathrm{g\,cm^{-3}}$), medium elasticity module (105 GPa) and high values of the mechanical resistance associated with some alloying elements.

The metallurgical titanium classification [8,9] according to the American Society of Testing Materials (ASTM) is determined by different grades of Ti-CP (also denominated as unalloyed) [10] and its alloys into three categories: alpha, alpha–beta and beta alloys which define the predominance of the phases present in the microstructure.

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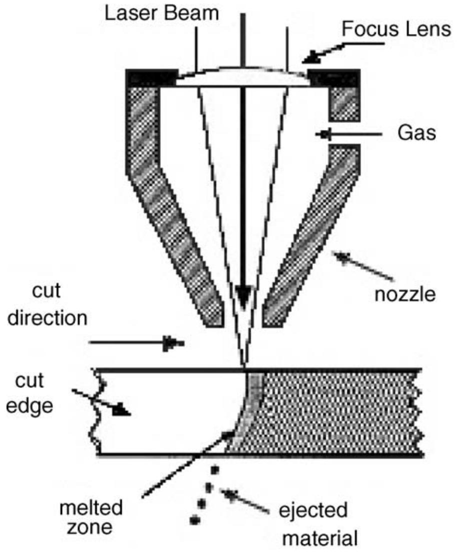

Fig. 1. A schematic of the laser beam interaction with the material (for the cutting process).

Table 1
Fixed and variable parameters

Fixed parameters	
Light polarization	Non-polarized
Nozzle design	Simple conical shape, Ø = 0.7 mm
Nozzle-workpiece distance	$w_z = 0.6$ mm
Lens focal length	100 mm
Cut geometry	Straight lines
Type of gas	N_2
Transversal mode	Multimode
Variables parameters	
Power density	Controlled by the incident beam diameter relation with the pulse peak power
Laser pulse energy	Given by the system; variation: dozens of millijoules to Joules
Laser pulse length	Scale variation from 0.2 to 10 ms
Process speed	Continuous control by CNC; variation: hundreds of mm/min
Gas flow	Controlled by the injection system valves
Pressure	Controlled by the injection system valves; limit: 14 bar

The allotropic behavior of titanium allows diverse changes in crystalline structures by variations of the temperature. Titanium can exist in the low-temperature a hexagonal close-packed (HCP – alpha phase), or above 890 °C a body-centered cubic (BCC – beta phase). These phases are directly related to the microstructure formation and present different metallurgical and mechanical properties.

Titanium has many desirable properties, most notably its outstanding mechanical strength and high corrosion resistance at room temperature. However, titanium and its alloys suffer from serious disadvantages of poor tribological properties. An attempt to improve such properties surface engineering may cause some difficulties to the conventional machined methods such as: high tool wear, processing time and operational costs. These factors enable the development of titanium laser processing and its alloys as an alternative process.

The present study joins the current laser processing technology to relatively new material, titanium, aiming optimized the process of pulsed laser cutting of thin sheets.

As the processing aims the highest quality excellence, one must obey an optimized combination of parameters [11] as follows: power density; transversal laser beam mode; light polarization; process speed; material characteristics; geometry and diameter; workpiece-focus distance; lens focal length; gas type, pressure, flux and purity; laser pulse energy and temporal length; wavelength; focal point distribution energy distribution among others. Fig. 1 shows the laser cutting procedure and evidences some of the study parameters.

The laser parameters described above lead to a complex interactive relations. Therefore the beginning of the study intends to present the most influent parameters during the cutting procedure and the possible interaction among them. Table 1 shows the fixed parameters and those chosen to be variable.

The parameter classification of Table 1 was elected according to previous acquired knowledge at the laboratories of the Center for Laser and Applications (CLA/IPEN, São Paulo, Brazil, University of São Paulo) and also regarding to easily monitoring process.

The energy per pulse and the pulse overlapping were considered the most significant parameters on the cutting procedure and consequently became the main process variables.

Thus, the minimal energy per pulse was chosen as being capable of accomplish a homogeneous hole on the material. From this, the laser repetition rate can be determined due to the fact that it maintains a constant average power for the laser lamp supply. The importance of keeping it constant is related to its function to determine the thermal lens in the laser medium and by its influence on the laser beam quality (and consequently on the focal diameter). This way, the relation described below (Eq. (1)) was kept constant and with a maximum permitted value by the supply system.

$$P_m = Ef \tag{1}$$

P_m was defined as being the real laser average power output, E as being the energy of each laser pulse and f as the pulse repetition rate (i.e. the number of pulses per second).

An attempt to verify which parameters for the process gives the most adequate machining conditions as well as to establish the best parameters combination the analysis of variance was conducted.

Many experiments involve the analysis of effects of one or more factors in a system being studied. According to Montgomery [12], the method of varying one of the factors at a time and keep the others fixed is not adequate when there is a possibility of the influence of one factor over the other. In this case, the most appropriate is the use of factorial shapes where all the possible combinations of the factors are investigated in a complete run of experiments.

This paper presents an approach to determine the effects of the laser conditions and of the assistant gas on the surface finishing quality, roughness, edges quality, and formation of phases on the cut surface, as well as to establish a set of parameters,

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