Laser Cutting optimization of titanium alloy

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Abstract

The laser material processing of metals has fulfilled the industrial requirements covering a wide scope of application and consequently gains prosperity in a diversity of industries, including the automotive, the aerospace and the medical industries. There is a noticeable lack of knowledge between real processing applications and all experimental and theoretical investigation. In this study pulsed Nd:YAG laser cutting of titanium alloy sheet and its influences on laser cut quality factors are investigated according to design of experiments technique. An attempt of achieving an optimized laser cutting process a factorial arrangement regarding the several combinations of six different processing factors was performed and the influence of these specific parameters, which were evaluated. Results indicate the complexity of the interactions between this diversity of parameters.

Keywords: laser cutting optimization, laser Nd: YAG, titanium, design of experiments

1 Introduction

Titanium and its alloys find extensive use in many areas like aerospace and medical applications, and its cutting is one of the primary requirements in the fabrication of most of the components. Today, laser has been widely used for cutting sheets of these materials, mainly due to its exceptional precision and high intensity giving several advantages over conventional cutting methods. Among them there are the narrow kerf width, low roughness of cut surfaces, low heat affected zone and high productivity. The nature of interaction of laser radiation with metal surface depends upon physical and metallurgical properties of the metal and all the process parameters involved. This means that to each kind of material, including its thickness and surface finishing, there will be a different ensemble of process parameters that will optimize a determined feature of the cutting product.

The aim of this work is to optimize laser cutting of alloy Ti-6Al-4V (grade 5) sheets, by the use of a pulsed Nd:YAG laser. This alloy was chosen because it is today's most widely used in implants. Utilizing this type of laser as machining tools is also one of the most interesting alternative methods when conventional ones cannot fulfill some production requirements.

2 Materials & Methods

The cutting process is performed over a homemade laser coupled to a CNC milling machine. Among many different features of cutting surface, dross is our concern because it is the main reason for rework and absolutely intolerable in medical applications. Processing parameters are related to laser beam, assist gas, material's type, relative speed and position between laser beam focus and workpiece surface. Many of these process and independent variable can be identified [1] and the most sensitive ones chosen for an optimization. We selected six process parameters to be varied with the intension of identify and determine the regions of critical process control factors leading to minimum dross formation in cutting 1 mm thick sheets of Ti-6Al-4V alloy.

As optimization tool a two level factorial design of experiment [2,3] was applied for these six variable factors. The values for fixed and variable parameters used are listed in **Tab. 1**. Right after choosing the six factors, which were considered the most significant parameters over the cutting process it was necessary to set the minimal and maximum of the main process variables. In order to achieve the experimental design of laser cutting the follow steps were conducted. First of all a sequence of single shots coupled with the lens focal position variation was performed and so resulting as a surface depression. The higher intensity spot define thus the focal point over the titanium surface. From this, the maximum process speed could be established according to the Equation 1:

$$\mathbf{Vmax} = \varnothing . f \qquad (1)$$

Where the maximum process speed (v_{max} ≡ $mm.s^{-1}$) is proportional to the hole diameter (∅ ≡ mm) and the pulsing frequency (f ≡ Hz).

Tab. 1: *Fixed and Variable parameters.*

Fixed parameters	
Light polarization	Non-polarized
Nozzle design	conical shape, Ø= 0.7 mm
Nozzle-workpiece distance	*wz* = 0.6 mm
Cut geometry	Straight lines
Type of gas	Argon
Transversal mode	Multimode
Variables parameters	
Laser pulse energy	setup by the system; variation: dozens of millijoules to Joules;
Laser pulse length	Scale variation: from 0.2 to 10 ms;
Gas pressure	Controlled by the injection system valves; limit: 14 bar;
Cutting speed	Control by CNC; from 150 to 400 mm/min;
Lens focal length	Two type of lens used: 50 and 100 mm.
Lens focal position	Scale variation: from 0,5 to 10 mm

The next step was determining the range of energy per pulse as being capable of accomplishing a homogeneous hole on the material and keeping bellow of a maximum permitted value by the supply system. Besides that, the set up should maintain a constant average power for the laser lamp and consequently have a constant thermal lens in the laser medium assuring the best quality of the beam.

The gas jet plays an important role by removing melted material from the cutting edge and can cause influence over the superficial finishing surface. Due to this fact and the concern about the cost over the process a range of gas pressure was chosen.

Two type of focusing lens were picked from the most used in market, one with focal length of 50 and other from 100 millimeters, an attempt to verify which type of lens provide the most adequate machining conditions.

The intensity of the laser beam on the surface of the part is one of the most important between others parameters related to the dynamics of formation of molten material in the cut region. Thus, beyond the energy and the diameter, the laser pulse length is of basic importance in the process. In principle, the shorter is this pulse, greater are the evaporation rates and minor the amount of molten material, however, due to complexity of the interactions between these diversity of parameters, it is not proper to make such affirmation.

Moreover, an attempting to reach the maximum cutting speed of process and avoid a introduction of one more uncontrollable factor as the variation of the spatial mode distribution of the laser beam it should maintain the average power as constant and greater as possible. Based in all this concepts in addition of previous experience the value around 0.5 ms of the laser pulse length was varied.

Compare to this configuration, a very lower pulse length could generate insufficient energy per pulse to obtain a homogeneous puncture in all the thickness of the material. In the order hand a bigger pulse length could cause unnecessary losses, reduction over the repetition rates and consequence reduction of the process speed.

3 Results and discussion

Besides the influence of all complex interaction among fixed and variable the cutting process is firstly limited by the effective power of the equipment and the gas supply.

To maximize the amount of knowledge about laser processing, the design of experiment (DOE) was conducted on a design matrix set of a ¼ fractional factorial of 6 factors each at 2 levels -Resolution: IV with two replicates. Thirty-two samples were cut according with a combination of parameters listed in **Tab. 2** for the verification of the main influence of each factor and their interactions.

Tab. 2: *A $2^{(6-2)}$ Design for the Laser Cutting optimization of titanium alloy Experiment.*

Fractional Factorial Design									
Runs	**Factors**							**Responses**	
		(A)	(B)	(C)	(D)	(E)	(F)		
		Laser pulse energy	**Laser pulse length**	**Gas pressure**	**Cutting speed**	**Lens focal length**	**Lens focal position**		
		[J]	[ms]	[psi]	[mm/min]	[mm]	[mm]		
	Level (1) high	1.15	0.8	120	360	100	surface		
	Level (-1) low	0.64	0.6	70	180	50	0.5 below surface		
		Basic Design							
		A	**B**	**C**	**D**	**E = ABC**	**F = BCD**	Replicates	
1		-1	-1	-1	-1	-1	-1	Y1 (1)	Y1 (2)
		0.64	0.6	70	180	100	surface		
...	...	...	...	...	...	...	...	...	...
16		+1	+1	+1	+1	+1	+1	Y16 (1)	Y16 (2)
		1.15	0.8	120	360	50	(-)0.5		

An irregular edge formation was revealed after performing the laser cutting and elected as important indicator of surface quality. The **Fig. 1** shows the irregular surface in reason of the dross that was not fully ejected from the kerf. The image of the cutting area was captured as digital images format what allowed measuring the dross areas and used for analyzing the variation of each processing parameter [4].

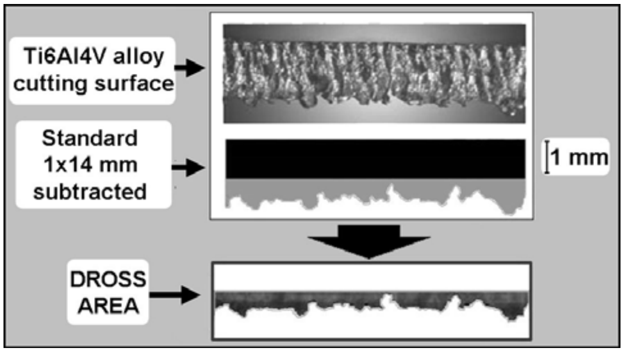

Fig.1: *Digital picture of the cut edge (top) and treated photo image (bottom). Note the thickness of titanium thin sheet is subtracted (black box) and the gray area highlighting the dross.*

After performing the DOE with these values it was possible to plot the graphic of main effects and interactions in response of dross.

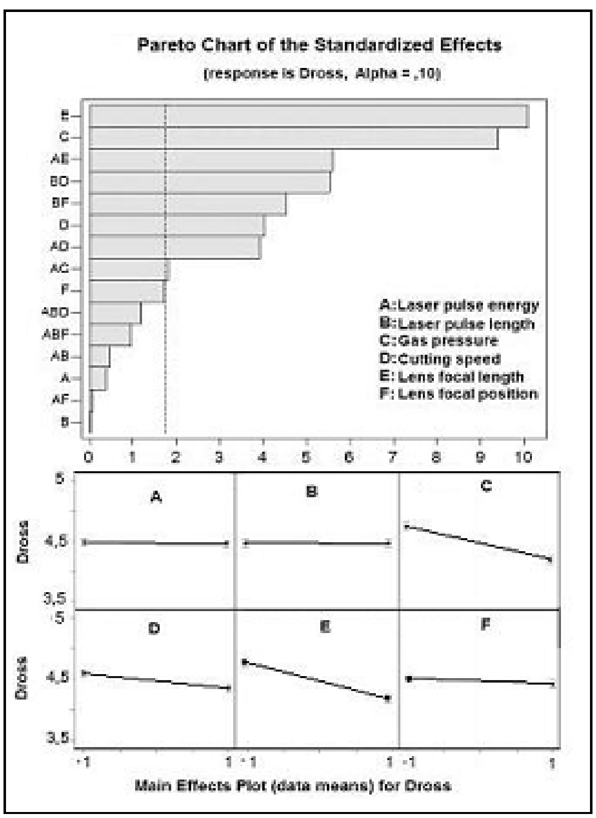

Fig. 2: *The main effects and interactions of laser cutting parameters.*

The **Fig. 2** permits us to observe that the lens focal length and gas pressure were the two most important factors. However there were some interactions as laser pulse energy with lens focal length and cutting speed with laser pulse length that should be considered.

In general increasing the gas pressure and the cutting speed as choosing the 100 mm focal lens, decreases the amount of dross. This setting may allow to a quality enhancement, on the other hand, the cost will be higher caused by a higher flow of gas. There is a maximum speed of the laser beam displacement, which should be chosen. Consequently, a higher speed would become impossible to accomplish the cutting. The cutting region by using the 100 mm lens could be larger as compared with the kerf from the 50 mm lens.

4 Conclusions

Regarding the parameters chosen for the experiment design, the lens focal length and gas pressure were highly influential to the process. In opposition of laser beam interaction regards, the lens focal position had showed less meaningful then the laser pulse length. However, the lens focal position could interfere over the intensity of the beam by modifying the size of focal spot. By this, smaller beam diameter combined with the focus on surface implies in a higher intensity that could decrease the dross formation.

As expectation a minimal width of kerf should demand a raise on the gas pressure to expel the molten material from this narrower groove. Probably, the minor dross formation by reason of higher speed as showed in the **Fig. 2** was resulted from lower overlapping rate, which leads a smaller thermal propagation and consequently smaller melt pool dimension.

Evidently, all these considerations are very simplistic and together on the application of DOE on this study should be more explored generating a better evaluation of all these several parameters. So this way to establish an accurate “optimized” set that will enable to obtain a cut surface characterized by less irregular edges, low roughness and free rework.

The particular application must be evaluated for the best parameters choice since the enhancement of one of the cut characteristics (dross or roughness) leads probably to failure of the other characteristic.

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