Journal of Materials Processing Technology 191 (2007) 220–223

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Experimental analysis of the laser milling process parameters

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Abstract

The process of laser milling, or laser ablation as it is also known, was developed over the last decade. In conventional milling techniques material is physically removed by a milling tool. In laser milling the material is removed by a laser beam through the layer by layer ablation mechanism.

The aim of this paper was to find out the parameters setting for manufacturing 3D structures with a good surface finishing through the laser milling technology using a laser marker machine equipped with a pulsed Nd:YVO_4 laser having a wavelength of 1064 nm. The material investigated was an aluminium–magnesium alloy.

The design of experiment methodology was used to evaluate the influence of the parameters involved in the process (laser power, frequency, overlapping, pulse width, scanning speed of the laser source, scanning modality used to fill the single manufactured layers) on the success of the ablation process in terms of depth of removed material (DP) and surface roughness (SR).

Keywords: Laser milling; Micromachining; Ablation; Optimization

1. Introduction

The aim of milling is to shape a workpiece into a well defined geometry by removal of material. To perform milling several conventional and no conventional technologies are available: mechanical milling, ultrasonic machining, electro discharge machining, electro chemical machining, laser milling (LM) [1,2].

Laser micromachining provides a new method of producing parts in a wide range of materials directly from CAD data. The process consists in an ablation operation causing vaporization of material as a result of interaction between a laser beam and the work piece being machined. Particularly, in LM technology the material is removed by a laser beam through the layer by layer ablation mechanism. This process offers several advantaged compared to the other processes: the capability to machine difficult-to-machine materials such as ceramics, graphite and cemented carbides, the totally absence of tool wear, surface finish, aspect ratio, dimensional accuracy and minimum feature size [3–5].

The value of the depth of removed material determines the accuracy of parts produced through a layer manufacturing technology. Unlike the traditional technologies, as mechanical milling, mechanical incision, etc., in which the depth of the single removed layer is chosen at the beginning as input parameter of the process, in laser milling the ablated depth depends from the process parameters such as laser power, scan speed, pulse duration, frequency overlapping, scanning speed of the laser source, scanning modality used to fill the single manufactured layers.

The aim of this paper was to evaluate the influence of the main parameters involved in the process on the success of the ablation process in terms of depth of removed material (DP) and surface roughness (SR). The best parameters combination leading to the contemporary maximization of the DP and the minimization of the SR was found. All tests were conducted on aluminium–magnesium alloy specimens using a laser marker machine (the Trumark VMc5 from Trumpf) equipped with a pulsed Nd:YVO_4 laser having a wavelength of 1064 nm and an average laser power of 30 W.

2. Laser milling process

2.1. Process parameters

In laser milling several parameters can be controlled and varied in order to get complex parts with optimised quality [3,6,7].

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doi:10.1016/j.jmatprotec.2007.03.005

Table 1
Parameters of the Trumark VMc5

Parameters	Range
Scan speed	100–5000 mm/s
Average power	30 W
Peak power	10–40 KW
Frequency	1–100 kHz
Pulse width	5 ns
Focus diameter	40 μm

In particular, on the Vmc5 machine (Table 1) it was possible to change the peak power (PP), the pulsing frequency (F_p), scan speed (V), overlapping (O), pulse width (PW), where:

- peak power is the laser instantaneous output power during the laser pulse;
- pulsing frequency or repetition rate is defined as the number of pulses per second from the laser;
- scan speed is the velocity by which the laser beam moves over the material surface;
- pulse width or pulse duration is the time duration of the pulse;
- average power is the average output power over a time base of several seconds. The laser pulse energy multiplied by pulse frequency determines the average power output of the laser;
- overlapping is defined as the distance between two consecutive spot diameters and it is related to F_p and V by means of the following equation:

$$O = \frac{V}{F_p} \quad (1)$$

3. Evaluating contributions of process parameters

3.1. Experimental design

Full factorial designs were planned for the simultaneous study of the effects of the involved parameters on the success of the ablation process in terms of depth of removed material and surface roughness.

Two different analyses were conducted for the output parameters DP and SR. Preliminary tests showed that meaningful results could be reached only setting the peak power to the maximum value and the pulse width to 5 ns. Setting the PP to the maximum value allowed to get available always during the process an average power of 30 W; it allowed obtaining a more energetic impulse and a bigger amount of absorbed energy on the manufactured material. Setting the PW to the minimum value of 5 ns allowed obtaining a bigger peak power of that available in normal pulse mode: this is due to the way of working of the laser that in this case operates in Q-switch modality; in fact, bigger values of the pulse width reduce notably the energy of the single impulse so that, despite the increasing of the peak power, a lower amount of energy is transferred to the material and this quantity is often not enough for ablation [8]. The operation in Q-switch modality in not suitable when a uniform removal of material is desired; in this case it is convenient operate with low values of pulse width.

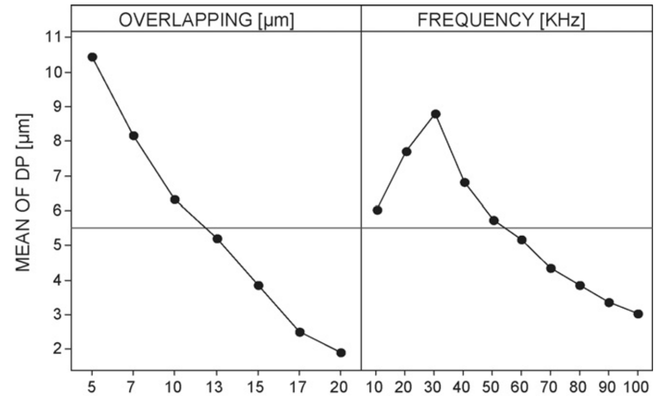

Fig. 1. Main effects plot for DP vs. O and F_p.

3.2. Analysis of results for DP

The effect of the input factors overlapping and frequency on DP was evaluated in this study. The two factors were changed, respectively, on 7 and 10 levels with the result of 70 parameters combinations.

In order to evaluate the influence of the considered process factors on the quality of the parts, the Analysis of Variance (ANOVA) was performed. The General Linear Model was used for ANOVA and the probability value α was set to 0.01. Fig. 1 shows main effects plot for DP versus O and F_p. Two observations can be done: both the two factors affect the ablated depth DP; a peak of DP is present around the value F_p = 30 KHz. This is due to the interaction between the two factors as shown in Fig. 2. The interaction is higher for low values of overlapping where a greater departing from being parallel is present. The maximum DP for a single layer is obtained for the minimum overlapping O = 5 μm and F_p = 30 kHz.

3.3. Analysis of results for SR

The evaluation of the surface roughness required the analysis of an other input factor, the scanning strategy (SS). Four different types of scanning strategy were considered:

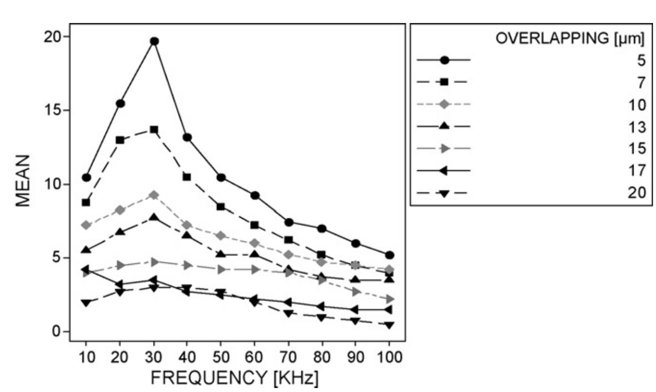

Fig. 2. Interaction plot for DP vs. O and F_p.