Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

THE INFLUENCE OF LASER MILLING PROCESS PARAMETERS ON DEPTH OF CUT AND SURFACE ROUGHNESS

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Abstract: *Laser beam machining (LBM) is one of the lately most used nonconventional machining processes. It is based on melting and evaporation of processed material. It can be applied to almost a whole range of materials. Lately, it has been increasingly used for mark-engraving materials, as well as for milling less demanding 3D shapes. This paper presents the results of research on the possibility of laser milling of plexiglass. The influence of the cutting speed, laser power and the radial step on the machined surface roughness and depth of the cut was analyzed. It was concluded that increase in radial step and cutting speed causes lover values of the depth of cut. Laser milling with higher laser pover leads to higher values of depth of cut. Influence of mentioned laser machining parameters on surface roughness of machined surface is obvious, but it is necessary to realize more detail investigation on this subject.*

Keywords: *laser milling, depth of cut, surface roughness.*

1. INTRODUCTION

Unconventional processing methods have been developed to enable the machining of new materials, high strength and hardness and resistant to high temperatures. Some of these materials can not be machined by conventional machining methods at all, due to the appearance of very high processing forces and high stresses in the cutting zone. Laser machining is a good solution in these cases. The possibility of laser machining a certain material, depends primarily on material characteristics such as: thermal conductivity, specific heat and melting and boiling temperatures.

Laser cutting and engraving is nowadays very often applied machining in most manufacturing industries. With laser of various characteristics, almost all metal and non-metallic materials can be cut, welded, surface treated. Laser beam machining is now beeing increasingly used for engraving and milling of nonmetalic materials. Smaller power lasers are sufficient for this kind of machining. The nonmetalic materials have low thermal condustivity and thermal diffusion coefficients, but most of these materials have high absorptivity for the 10.6µm wavelenght radiation of CO_2 laser [1].

2. LASER BEAM MACHINING

Laser is the abbreviation of light amplification by stimulated emission of radiation [2]. Highly collimated, monochromatic and coherent light beam is generated and focused on a small spot on machined surface, resulting in very high power density (oko 10^6W/mm^2). A large number of laser machines, with different characteristics, are available today. Table 1 gives general types of the laser.

Table 1. Laser types

Laser type		Wavelenght, nm	Typical performance
Solid	Ruby	694	Pulsed, 5 W
	Nd-YAG	1064	Pulsed, CW, 1÷800 W
	Nd glass	1064	Pulsed, CW, 2 mW
Semiconductor	GaAs	800÷900	Pulsed, CW, 2÷10 mW
Molecular	CO_2	10.6µm	Pulsed, CW, <15 KW
Ion	Ar^+	330÷530	Pulsed, CW, 1W÷5 KW
	Excimer	200÷500	Pulsed
Neutral gas	He-Ne	633	CW, 20 mW

CO_2 laser is a molecular gas laser. Figure 1 shows CO_2 laser schematic.

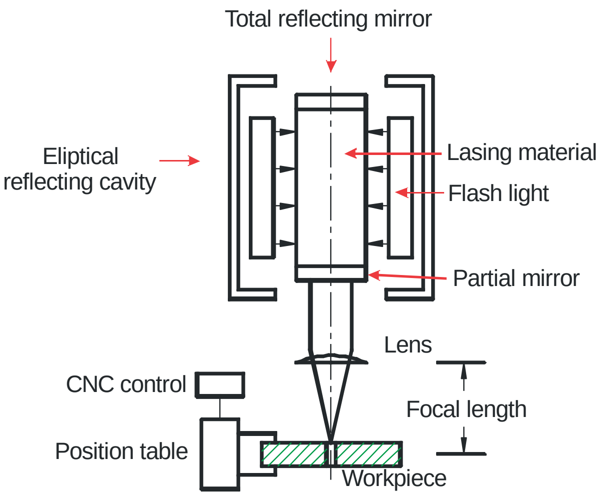

Figure 1. Laser beam mashining schematic

The laser tube is about 1000 mm long and a few tens of millimeters in diameter. A 10.6 µm wavelength laser beam passes through a partial mirror and then through a lens that focuses the laser beam on a small spot on the machined surface. Such a focused laser beam on the small spot on the surface of the machined object leads to the creation of an enormous amount of light and thermal energy, which leads to the melting and evaporation of any material, of any characteristic, and only in the laser beam action zone.

Laser milling is a new technology suitable for machining a wide range of materials (metals, glass, ceramics and plastics) by removing material in a layer-by-layer [3]. This technique involves the heating and melting of a material and material removal. This process depends on temperature developed on machined surface. It means that problems like micro cracks can commonly appear at heat affected zones.

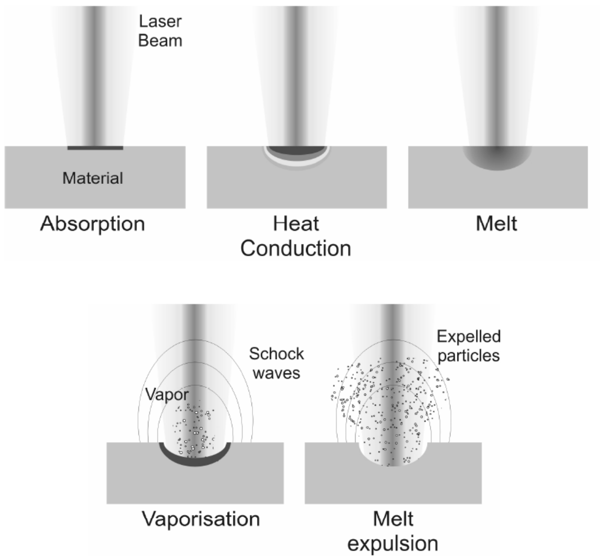

Figure 2. Laser milling phenomena [3]

When machining metals, the laser beam is heating, melting and evaporating the metal (metal sublimation), while in polymers the process is based on the rupturing of molecular chains (laser ablation), as shown in Figure 2.

The major disadvantage of the laser milling process is difficult achievement of vertical walls on shapes made by laser milling. Side walls that initially were meant to be vertical might end with a draft angle of 10° to 15°, depending on the size of the work area [4].

Laser milling is the removal of material from the top surface down to a specified depth. CO_2 lasers with 10.6 µm wavelength are primarily used for removal of non-metallic materials. The material type and laser power level determine the maximum depth of cut and speed of milling. Shallow milling-engraving is a faster process than deep milling. Also, lower density materials are faster engraved than higher density materials. Increasing laser power level increases laser milling speed. The non-metallic materials have low thermal conductivity and thermal diffusion coefficients, but most of these materials have high absorptive for the 10.6 µm wavelength radiation of CO_2 laser.

3. EXPERIMENTAL SETUP

Today, laser milling is mainly used to remove one layer of material, that is, it is used for engraving of the low depth contours. Machined material is in this case removed in one passage of the laser cutting head. There is very little research that investigates the laser machining parameters influence on the depth of cut in laser milling and roughness of the surface machined with laser milling. The aim of this study was to investigate the influence of cutting speed, laser power and radial step (step between two cutting laser head passes), on the depth of cut and surface roughness of machined surface with laser milling.

Experiments were performed on Laser Cut-1208 Laser CNC Machine, laser engraving machine. It is primarily intended for engraving and cutting of sheet non-metalic materials. The maximum laser power for this machine is 80 W.

The square shapes, 10x10 mm, were machined in 8 mm thick **PMMA** (polymethyl methacrylate - PLEXIGLASS), with laser milling. In the first part of the experiment, for each machined square, cutting speed and laser beam power were varied. The squares were made with several passes of the laser head in one layer. Cutting speed and laser power were varied during experiment. The radial step s_r between two passages of the laser head was constant and it was 0.02 mm. Depth of cut and surface roughness were measured. The appearance of the machined samples is given in Table 2.

In the second part of the experiment, the laser power was constant and amounted to 16 KW, while the cutting speed and the radial step were varied. The depth of cut and the roughness of the treated surface were also measured for thus obtained quadratic samples. The appearance of the samples obtained with these parameters of the laser milling process is given in Table 3.

Table 2. Machined samples-I

Radial step s_r = 0.02 mm				
V , mm/s	P, KW			
	16	24	32	40
100				
200				
300				

Table 3. Machined samples-II

Laser power P = 16 KW				
V , mm/s	s_r , mm			
	0.02	0.05	0.01	0.02
100				
150				
200				
250				
300				

4. THE RESULTS OF EXPERIMENTAL RESEARCH

As already mentioned, for samples obtained in both parts of the experiment, the depth of the cut and the roughness of the treated surface were measured. The depth of the cut was measured with a coordinate measuring machine with a measuring tap at several places. Surface roughness was also measured in several places, transverse with respect to the movement of the laser head. The mean values of the measured depth of cut and surface roughness are given in Table 4 and 5 respectively.

Table 4. Depth of cut and surface roughness in laser milling - I

Radial step s_r = 0.02 mm								
V [mm/s]	P , KW							
	16		24		32		40	
	h, mm	Ra, µm	h, mm	Ra, µm	h, mm	Ra, µm	h, mm	Ra, µm
100	0.59	18.4	1.453	8.9	4.109	/	5.977	/
200	0.24	15.1	0.24	26.3	0.24	42.7	0.24	40
300	0.121	11.7	0.121	13.3	0.121	22.9	0.121	42.5

Table 5. Depth of cut and surface roughness in laser milling - II

Laser power P = 16 , KW								
V [mm/s]	s_r , mm							
	0.02		0.05		0.1		0.2	
	h ,mm	Ra, µm	h, mm	Ra, µm	h, mm	Ra, µm	h, mm	Ra, µm
100	0.59	18.4	0.257	16.6	0.096	12.4	0.022	9.5
150	0.415	19.4	0.145	17.2	0.071	11.3	0.001	13.8
200	0.24	15.1	0.136	12.6	0.054	8.8	0.001	19.2
250	0.185	13.9	0.103	6.9	0.035	8.6	0.004	18.9
300	0.121	11.7	0.07	3.85	0.023	7.2	0.005	10.75

Based on the measured values for the depth of cut in laser milling - h, the following expressions were obtained:

$$h = 0.08 \cdot V^{-0.95} \cdot P^{2.37} , \quad (1)$$

and

$$h = 3.06 \cdot V^{-1,24} \cdot s_r^{-1.05} . \quad (2)$$

The dependence of the depth of cut - h on the cutting speed and the laser power has a correlation coefficient of 0.99 while the dependence of the depth of cut - h on the cutting speed and radial step has a coefficient of correlation of 0.988. This shows that the models represented by formulas (1) and (2) describe very well the dependence of the depth of cut on the parameters of the laser milling process. Unlike the cut depth, surface roughness could not be described satisfactorily by some simpler model.

The results shown in Tables 4 and 5 are shown graphically in the diagrams, Figures 3, 4, 5 and 6.

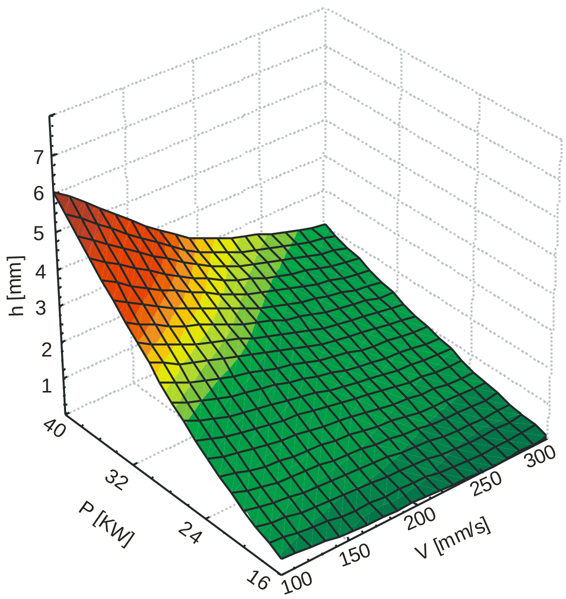

Figure 3. The laser power and cutting speed influence on the depth of cut

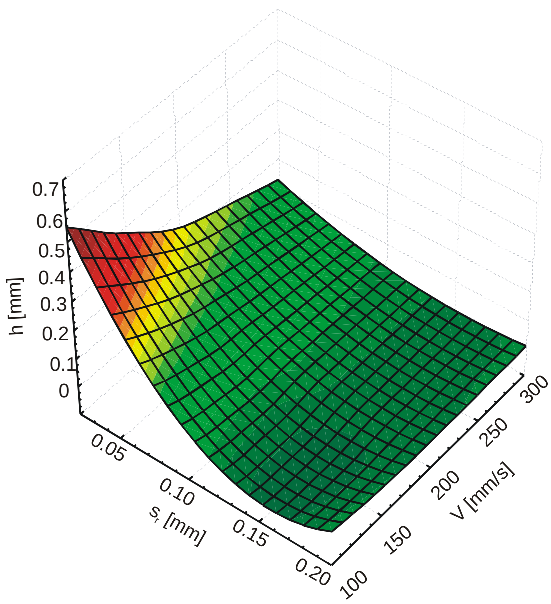

Figure 4. The radial step and cutting speed influence on the depth of cut

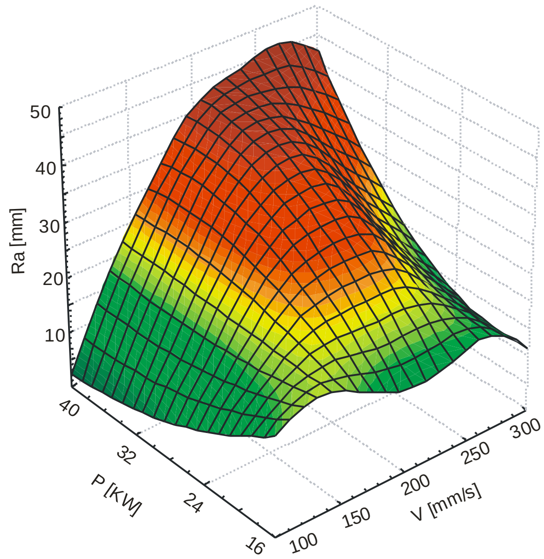

Figure 5. The laser power and cutting speed influence on the machined surface roughness

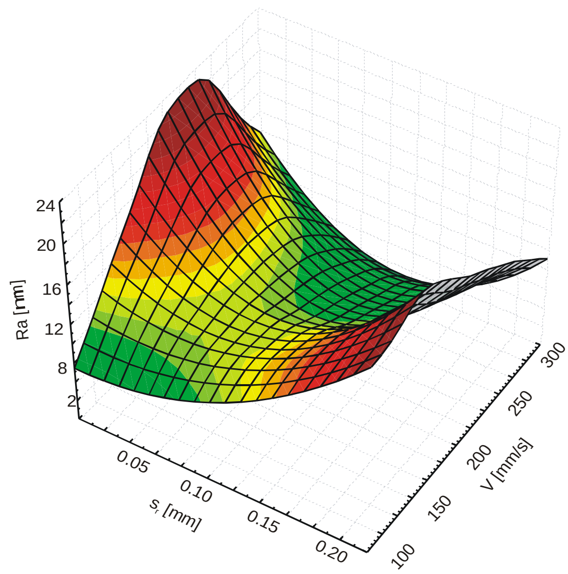

Figure 6. The radial step and cutting speed influence on the machined surface roughness

5. CONCLUSION

After measuring the depth of the cut and the roughness of the treated surface of the samples obtained in both parts of the experiment, it can be concluded that the selected parameters of the laser milling process have a significant influence on the depth of the cut and the roughness of the machined surface. In the laser milling with higher cutting speeds, a smaller depth of cut is achieved. The higher the laser beam's power, the greater the depth of the cut can be achieved. As the radial step increases, the cut depth decreases. These phenomena can be explained by the fact that with the increase in the energy of the laser beam, reduction of the cutting speed and the radial step, the amount of energy transferred to the unit of the machined material increases, which expedite the process of heating and melting of the material, and therefore the depth of the cut is higher.

The influence of machining parameters of laser milling on the surface roughness cannot be described by simple models. To define this addiction, more detailed research is needed.

ACKNOWLEDGEMENT

This paper is part of project TR35034, funded by the Ministry of Education, Science and Technological Development of Serbia.

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