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LASSER CUTTING PROCESS – INFLUENCE OF ASSITING GAS PRESSURE ON SURFACE ROUGHNESS AT MILD STEEL CUTTING

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Abstract: *The paper presents the optimization of assisting gas pressure for a Laser Cutting System Mazak Super Turbo-X 48 MkII. The study was made using 3mm, 6mm and 10mm mild Steel. The laser parameters: feed rate v, power P, frequency F and efficiency R were maintained constant while the gas pressure p was varied and the roughness Rz was measured according to DIN EN ISO 9013. Was analyze the influence of gas pressure on surface roughness to obtain a complex relationship of roughness Rz variation according to the gas pressure variation. The goal of experiment is to minimize the Rz and the gas pressure. The settings for input parameters were chosen based on the manufacturer and laser operators indication. For each thickness of material a mathematical model of roughness variation with the gas pressure was find. It was find that the surface roughness increases with increasing of gas pressure and material thickness.*
Keywords: *experimental test, surface roughness, CurveExpert software*

1. INTRODUCTION

The laser cutting is one of the most common industrial applications of laser. About 80% of the industrial lasers in Japan are used in this technology. Besides the laser fascination which is seldom a leading force in investments in the heavy industry the most reasonable motive is probably the fact that it replaces a classical process that became obsolete and often the cutting speed and the surface quality are better than in competitive processes [1].
The laser cutting is a process in which an infusion of energy brought in the cutting zone melts the material in this area and the melted material is blown from this zone by a cutting gas flow and it leaves the area and the cutting gap is resulting. The energy sources in the case of O_2 laser cutting are the focused laser beam, the exothermal oxidation reaction and the mechanical force of oxygen flow. This combination and the action time on a certain surface are controlled by the following laser cutting process parameters: feed rate, v; gas pressure, p frequency, F; power P, W; efficiency R [2].
These parameters must have values which allow a constant removal of the material from the cutting zone. If a bigger quantity of energy is necessary in the cutting zone that could be provided by decreasing the feed rate, increasing of the laser power or oxygen flow. Only appropriate combinations ensure a perfect cut. Besides the three parameters (power, pressure and feed rate) the operator has two more parameters that can be modified directly in the machine menu. They are the frequency of the beam, F and laser efficiency rate, R. Those five parameters are the input parameters of the cutting process and they can be modified usually by the laser operator in order to improve the cutting process and the surface quality obtained. For the experiments we take into consideration the following parameters: purity of the cutting gas, ambient temperature humidity and the quality of the machined steel.

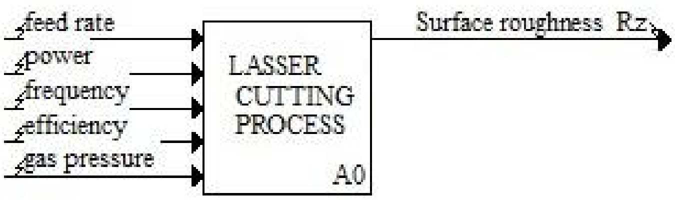


Figure 1. Monitored parameters of laser cutting process

2. THE INFLUENCE OF THE CUTTING GAS PRESSURE

The first step for realizing the mathematical model of the laser cutting process is the design of the experimental model. The gas pressure is an important factor of the laser cutting process because the increase of the pressure leads to higher costs of laser hour, reducing the economic efficiency. In the production environment a lower pressure is usually utilized but the limit is imposed by the surface quality imposed. On the laser cutting process, feed rate is also one of the most important parameter in terms of productivity (a higher feed rate means a higher economic efficiency) [5,6].

The other parameters of the laser cutting machine were kept constant and their values were set according to recommendations of the machine programming guide and laser operators. Taking into consideration that one of imposed condition on the part design is the surface roughness size, a special attention was dedicated to this parameter. For analyzing the influence of the cutting gas pressure on the surface roughness a mathematical model was created. The experimental tests were performed on:

- Mazak Super Turbo-X 48 MkII [9];
- Steel sheet from OL37 3 mm thickness, OL 52 6mm thickness and respectively 10 mm thickness;
- Surtronic 3+ , roughness meter [10];

The equipment for roughness measurement is presented in figure 2.

Figure 2. Surface roughness measurement

A series of experiments were performed (table 1-3) in order to obtain the influence of the cutting gas pressure on the surface roughness and we try to obtain a complex relation to give the roughness variation versus this parameter. Each value of the roughness is the simple average of four passes of the equipment pick-up.

Table 1. OL37 3mm

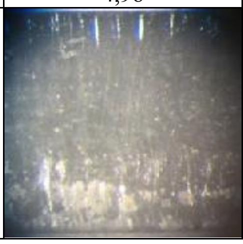
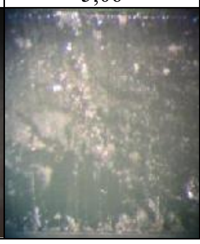
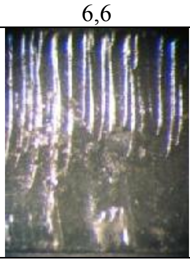
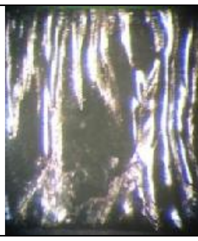
No.	62	78	75	76	77
p [bar]	0,6	1	2	5	8
Rz [µm]	4,98	5,06	6,6	35.7	m.top
picture					

Table 2. OL52 6mm

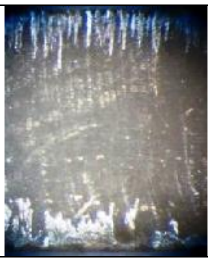
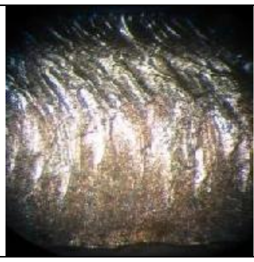
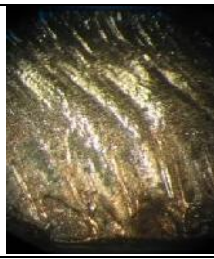
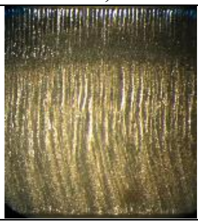
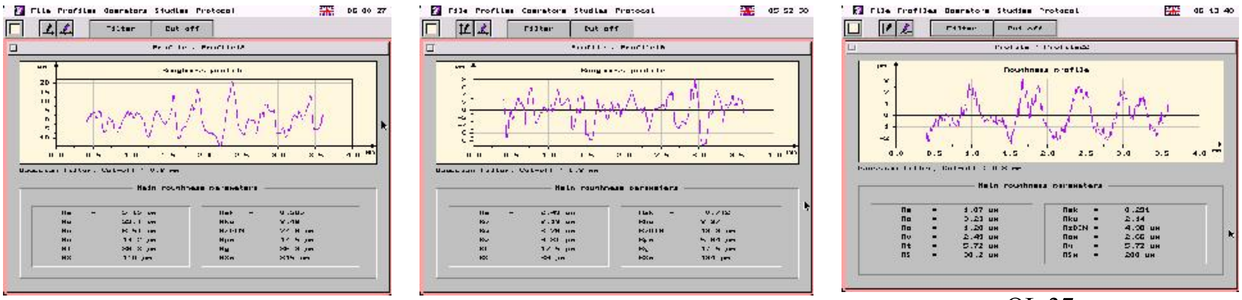
No.	31	37	38	39	40
p [bar]	0,6	1,2	2,5	4,5	6
Rz [µm]	12,7	14,3	15,8	rebut	rebut
picture					

Table 3. OL52 10mm

No.	1.3	26	27	29
p [bar]	0,6	1,2	2,5	6
Rz [µm]	23,42	28,2	29,8	30,9
picture				

For a better understanding in the following figures are presented the most representatives profiles of surface.



OL 52 10 mm | OL 52 6 mm | OL 37

Figure 3. Surface roughness graphs

For the parameters witch remain constants, it was chosen the following values:

- ✓ nozzle size: 1,2 [mm];
- ✓ nozzle focus NF=-1 [mm];
- ✓ gap offset NW=1[mm];
- ✓ feed rate v=3000 [mm/min];
- ✓ laser power P=1400 [W];
- ✓ laser frequency F=600 [Hz];
- ✓ laser duty R=100[%].

In table 1 it is shown the roughness value by cutting mild steel, OL37, with thickness 3mm for different gas pressure. Using the CurveExpert Professional 1.5.0 software [8] with input data from table 1 was find some regression functions witch approximate the roughness, Rz [µm] variation by gas pressure p[bar]. From the proposed functions was selected the regression function with the bigger score (997 points) and witch approximate better the roughness, Rz [µm] variation by gas pressure, p[bar]. The regression function is the *Reciprocal model*, figure 4.

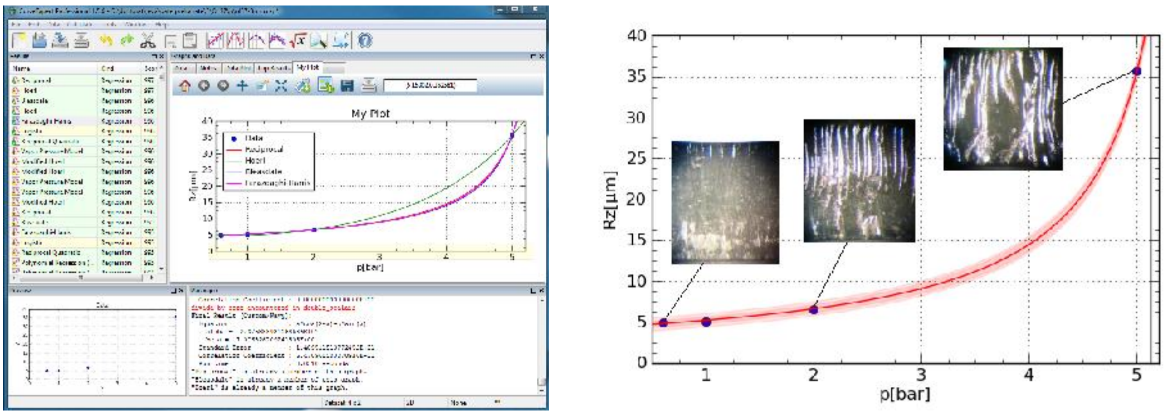


Figure 4. Regression function for OL 37 in CurveExpert Software

Regression function definition for a confidence interval of 95%, it is presented in equation 1:

$$y = \frac{1}{(a + b \cdot x)} \tag{1}$$

where:
a = 2.33079992476583E-01
b = -4.10136784330064E-02
The obtained function can be used to calculate the roughness value for a specified gas pressure or calculate the required gas pressure to achieve a certain surface roughness.
The laser system manufacturer gives no indication of surface quality achieved and also gives no indication how the cutting parameters should be modified to achieve a surface roughness imposed by the design or by standard classes.
From the experimental data and the plot of the equation (1) we conclude that the surface roughness increases with the pressure increase. In accordance with standard EN ISO 9013:2002 for quality class 1 the maximum roughness has to be Rz=10+0,6*3=11,8 [µm], and for quality class 2 it is Rz=40+0,8*3=42,4 [µm]. Using equation (1) to compute the cutting gas pressure for quality class 1 or 2 we obtain:

- For a roughness Rz=11,8 [µm] the pressure is 3.617 [bar], meaning that the working pressure must be lower than this value for class 1;
- For a roughness Rz=42,4 [µm] the calculated pressure is 5.108 [bar], resulting that the pressure must be in the limits of the interval 3.617 to 5.108 [bar]) for class 2.

From the experiments one can see that the minimum value of the surface roughness is Rz=4,98 [µm] obtained at a gas pressure p=0,6[bar]. A lower pressure cannot be obtained due to the technological limitations, a lower pressure leading to the deterioration of the focus lens of the laser beam. A higher pressure shell increase the surface roughness and also to the increase of gas consume and laser hour cost. As none of these effects are desirable the conclusion is that the optimal gas pressure in the case of OL 37 steel with 3 mm thickness is p=0,6[bar].
For cutting mild steel OL52 6mm, the parameters kept constant ware chosen at the following values:

- ✓ nozzle size: 1,5 [mm];
- ✓ nozzle focus NF=-1 [mm];
- ✓ gap offset NW=1,5[mm];
- ✓ feed rate v=2100 [mm/min];
- ✓ laser power P=1800 [W];
- ✓ laser frequency F=600 [Hz];
- ✓ laser duty R=100[%].

In table 2 is shown the roughness value by cutting 6mm mild steel, OL52, with thickness 3mm for different gas pressure.
Using the CurveExpert Professional 1.5.0 software, with input data from table 2 was find some regression functions witch approximate the roughness *Rz*[µm] variation by gas pressure *p*[bar]. From the proposed functions was selected the regression function with the bigger score (986 points) and witch approximate better the roughness *Rz*[µm] variation by gas pressure *p*[bar]. The chosen model was the *Natural Logarithm* Model, figure 5.

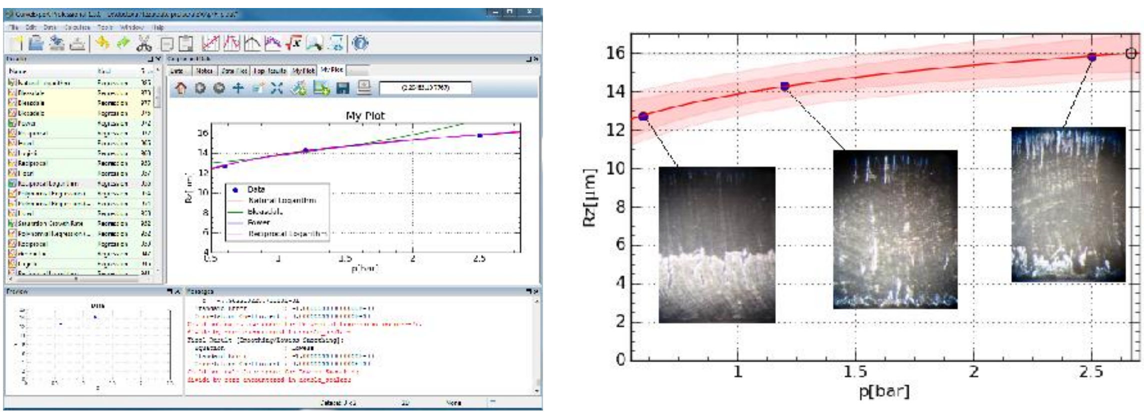


Figure 5. Regression function for OL 52, 3 mm

Regression function definition for a confidence interval of 95%, it is shown below:

$$y = a + b \cdot \ln(x) \tag{2}$$

where:
a = 1.38413143995260E+01
b = 2.17095228187007E+00
The obtained function can be used to calculate the roughness value for a specified gas pressure or calculate the required gas pressure to achieve a certain surface roughness.
From the experimental data presented in table 2, a similar behavior of the roughness with the pressure increase is relieved and at a pressure, p=4,5 [bar] the part became non conform and the roughness cannot be measured due

to the deformations in the cutting zone. In accordance with the quality standard the roughness for class 1 has to be Rz=10+0,6*6 =13,6 [µm] and for class 2, Rz=40+0,8*6=44,8 [µm].
Using equation (2) to compute the gas pressure in the both cases results:

- ✓ For quality class 1 the maximal gas pressure must be p=0,895 [bar];
- ✓ For quality class 2 the maximal gas pressure must be p=1,56 [bar]. Usually for the quality class 2 the roughness is reached practically for any pressure in the interval 0,6 to 4 [bar].

For cutting mild steel OL52 10mm, the parameters witch remain constant was chosen the following values:

- ✓ nozzle size: 2 [mm];
- ✓ nozzle focus NF=-3 [mm];
- ✓ gap offset NW=2[mm];
- ✓ feed rate v=1330 [mm/min];
- ✓ laser power P=1800 [W];
- ✓ laser frequency F=600 [Hz];
- ✓ laser duty R=100[%].

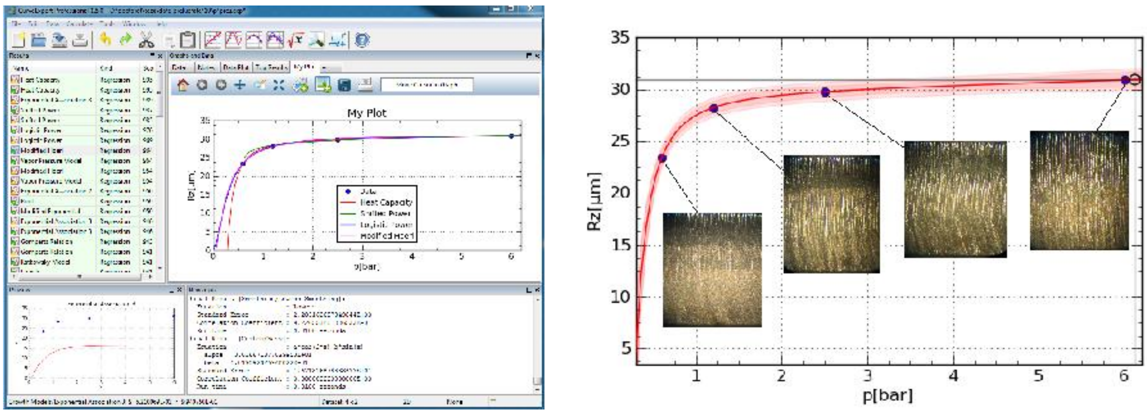


Figure 6. Regression function for OL 52, 10 mm

In table 3 is shown the roughness value by cutting 10mm mild steel, OL52, for different gas pressure.
Using the CurveExpert Professional 1.5.0 software, with input data from table 3 was find some regression functions witch approximate the roughness Rz[µm] variation by gas pressure p[bar]. From the proposed functions was selected the regression function with the bigger score (995 points) and witch approximate better the roughness Rz[µm] variation by gas pressure p[bar]. The chosen model was the *Heat Capacity* function model, presented in figure 6.
Regression function definition for a confidence interval of 95%, it is shown below:

$$y = a + b \cdot x + \frac{c}{x^2} \tag{3}$$

where:
a = 2.95058573925408E+01
b = 2.44510350790789E-01
c = -2.24641698997497E+00
The obtained function can be used to calculate the roughness value for a specified gas pressure or calculate the required gas pressure to achieve a certain surface roughness.
As in the previous cases the roughness is increasing with the cutting gas pressure. Also the minimum pressure of p=0,6 [bar] must be taken into consideration. In conformity with the quality standard mentioned above the limits for roughness are: for class 1, Rz=16 16 [µm] and for class 2, Rz = 48 16 [µm]. Computing the gas pressure with equation (3) the following values are delivered:

- ✓ for class 1 the value of the surface roughness, Rz=16 [µm] cannot be reached and the parts will not be in quality class 1;
- ✓ for quality class 2 any value of the pressure lower than p= 75.63 [bar] is suitable to reach the limit value of the roughness for this class;

3. CONCLUSIONS

The main conclusions drawn from the paper are:

- ✓ The mathematical model derived from the experiment is significant and has a degree of reliability P=95%;

✓ The increase of the cutting assisting gas produce extra costs and also a non controlled oxidation of the cut reducing the quality of the process. The gas pressure is the second most important factor of the laser cutting process due to the purchasing costs which are significant and the increase of pressure leads to the increase of the work cost per hour for laser cutting.

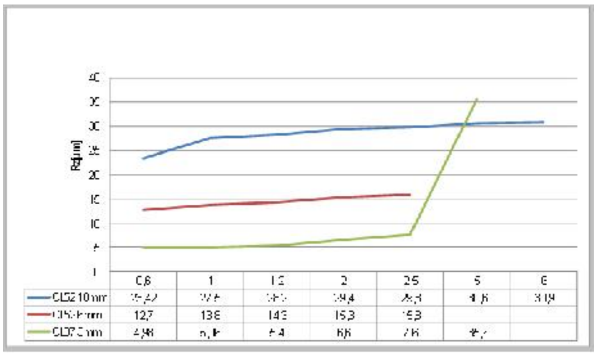


Figure 7. Roughness variation with gas pressure and material thickness

In figure 7 a plot of the surface roughness variation versus cutting gas pressure and work piece thickness is presented. One can observe that the surface roughness increases with the increase of the gas pressure and the work piece thickness in all the studied cases.
Following the experimental researches, mathematical models were derived for each particular case and the surface roughness is shown with the variation of cutting gas pressure.
Because the influence of the gas pressure on the surface roughness is poor and the side effects in cost increase are significant the conclusion is that for all the studied cases of laser cutting of mild steel the pressure can be maintained at a practical and optimal pressure, p=0,6 [bar].

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