THE ROUGHNESS OF THE HARDOX400 STEEL CUT PIECES WITH CO2 LASER

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Abstract: *The study on the roughness of Hardox cut laser parts is exploited in this article ranging from input parameters (laser power, pressure, cutting speed) to a Taguchi reduced to 9 references and then replicated under the same conditions 4 times. For the experiment, a fractional factorial plan L339 was chosen for three experimental parameters (P, v, p), each varied at 3 distinct levels. The blank used was HARDOX400 steel sheet with a thickness of 10 mm. This thickness is suitable for the study of several parameters that characterize the quality of laser cut parts: slot width, taperedness, flange roughness, dimensional precision. With the help of Statistica 7, the prediction and correlation formula of the influence factors were highlighted. DOE and SSM were used to obtain roughness while maintaining a constant parameter - laser power and simultaneously varying the pressure and cutting speed. It is found that pressure is a dominant influence factor.*

Keywords: surface roughness, laser cutting, statistical processing, parameters laser cutting

1. INTRODUCTION

Laser cutting is the most widely used advanced steel cutting method for applications in aeronautics, automotive, mining, construction, and so on. Steels are materials having Fe and C components and, depending on% C, are classified in soft, hard and ultra-hard steels with interesting and remarkable corrosion properties, tear strength, shear strength, durability, elasticity, lower coefficient of reflection. To increase production yields, it is important to determine the cutting width at the top and bottom of the parts to achieve dimensional accuracy, surface quality, low roughness, reduced melt material loss.

The CO2 laser is used to cut 0,6 to 25mm thick steel plates / sheets at 85% speed, power between 1800 and 6000W and pressures between 0.4-5bar. The minimum cutting width ensures low cost in production and short processing times at the right profile or circular profile optimizing Taguchi input parameters for HARDOX400 steel sheets.

In the countries of the world, advanced research is ongoing to optimize these parameters using CO2 laser and laser lasers by Jetro Pocorni et al., Petring et al., Rodriguens et al., Tamilarosan et al., Yilbas et al., J. Powell et al. and others, E.H. Amara et al ..

In order to deepen the study of the roughness of steel surfaces, recent research on CO2 laser cutting was carried out by: Adelmanna used a FALCOA algorithm of rapid cutting to provide information on the influence of individual parameters: laser power, speed, nozzle distance, gas pressure, focal position [1].

Power shows the determination of the specific point energy (SPE), the power density q to find out the penetration depth.

Thombansen defines that the roughness of a steel material surface is made up of a set of irregularities (pores, striations, craters) describing the relief of a laser cut surface where the

S-step is small compared to the depth Rz [9].

Power, 2015, shows in his own work that the C and Mn contents influence the quality of the cut surface when cutting materials, so if the concentration of C and Mn increases the exothermic Mn-O reaction decreases.

Yan-Liang Zhang introduces the Model (ANFIS) that predicts laser cutting roughness according to model input parameters: ash gas pressure, power, speed, Kerf, roughness [10]. Lutey AHA shows that for laser cut sheet steel thicknesses of 1 to 4mm, the best roughness of the cutting surface is at cutting average power and reduced speed, resulting in improved laser cutting quality and study [2].

The objective of the paper is to analyze the roughness with the help of the Mytutoyo rugosimeter to increase the industrial productivity of HARDOX400 steel sheets, table 1.

Thus, the qualities of the steel sheet have been taken into account: very good machinability, very good wear resistance, drilling, threading, welding, weldability etc. but also its applications: armor crushers, military bunkers, military components, knives, chisels, etc.

Table 1. Chemical composition H400

Material nr.	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**S**	**EW**	**C14**
118154	0.19	0.50	1.25	0.011	0.001	0.70	0.07	0.038	0.001	0.55	0.354

The equivalent of carbon C93 –C99:

$$CEV\ (EW) = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \quad (1)$$

$$C14 = CET = C + (Mn+Mo)/10 + (Cr+Cu)/20 + Ni/40 \quad (2)$$

Hardox is known in the form of 400HB hardness tables. Due to the very good resistance to wear, the best sheet is used in construction, gravel, mining, quarrying, mining, the cement manufacturing industry at thermal power stations. Under laser treatment of H400 the chemical composition of the surface is not changed by X-ray spectrometer analysis, and the hardness decreases to 300HB, so the plate is subjected to a thermal quenching phenomenon that gives us a solid, hard and ductile plate. Due to the hardness of the sheet, a much longer operating time results from OL, OLC, soft steel, etc. Table features: expansion - 16% elongation, the modulus of elasticity is $E = 10^6 \frac{daN}{cm^2}$, the resistance - the unitary effort is $\sigma = 10^5 \frac{daN}{cm^2}$.

Over 250-300 $^{\circ}C$ HARDOX 400 steel changes its mechanical properties and strength.

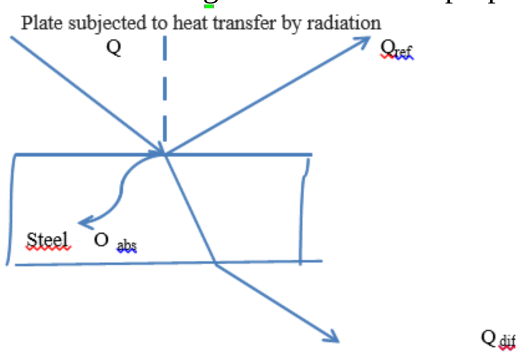


Fig. 1 Steel plate subjected to heat transfer Q

Steel plate fig. 1 is subjected to thermal transfer by laser radiation, thus the heat Q received by the plate is subdivided into heat absorbed Qabs, part in Qref reflected heat, and part in heat dissipated Qdif, passing through the metal, the steel has an important property of to carry the heat (heat):

$$Q = Q_{abs} + Q_{ref} + Q_{dif} \tag{3}$$

Since the oxygen ignites at 1200 $^\circ C$, the oxidation reaction of Fe with O_2 begins, Fe melts at 1538 degrees Celsius, and 3000 $^\circ C$ vaporises, resulting in the heat due to this process being calculated taking into account heat specific *c* to the material and the heat latent vaporization:

$$Q = m \cdot c \cdot (T_m - T_0) + m\lambda_l + m \cdot \overline{c} \cdot (T_v - T_m) + m\lambda_v \tag{4}$$

with the physical significance of the intervening sizes: m - melt mass (g), T_0 - steel ignition temperature ($^\circ C$), T_m - steel melting temperature ($^\circ C$), T_v - steel vaporization temperature $^\circ C$, λv - latent vaporization heat (KJ / kg), λ_l - latent heat of melting (KJ / kg).
With the help of the paper [14] we can calculate the heat received from the CO_2 laser:

$$Q_{laser} = \alpha(\lambda) \cdot A(\theta) \cdot I_0 \cos\theta \cdot e^{\alpha \cdot z} \tag{5}$$

with the physical significance of the intervening sizes: α- extinction coefficient, β – thermal diffusion (cm^2/s), A – Absorption coefficient, I_0 - Intensity of the incident beam W/cm^2, Θ - The angle between the incident beam and the flat surface of the cutting surface, z – melting depth, were $\alpha = \frac{4\pi \cdot \beta}{\lambda}$, I chose β=14,6$cm^2$/s thermal diffusion, λ=10,6μm, A=0,3.
By heating the laser cut surfaces change the roughness, which results in the parts obtained being used in the mining, construction and machinery industries. We define roughness Ra is defined as the mean arithmetic deviation of roughness.

$$R_a = \frac{\sum_{i=1}^{k} |y_i|}{k} \tag{6}$$

Roughness Rz is the average depth of 10 points of roughness, the arithmetic mean of the difference of the highest and lowest order

$$R_z = \frac{(R_1 - R_2) + (R_3 - R_4) + (R_5 - R_6) + (R_7 - R_8) + (R_9 - R_{10})}{5} \tag{7}$$

The maximum roughness Rm is the total roughness depth or the distance between the maximum ordinate and the minimum ordinate on the Oy axis, or between the outer e and lower profile lines i:

$$R_m = y_M - y_m \tag{8}$$

Roughness Rq is equal to the average square root value of parameter Ra.

2. EXPERIMENT

A recent study on the cutting of the hard steel using the Bystronic CO2 laser was made on a HARDOX steel plate of 470x270mm thickness g = 10mm where 45 reference / samples were shown. 2. The experiment was designed and planned for an OLH 400 plate to measure the roughness of cut pieces. Cutting of the steel was performed with a 7.5 inch lens, with a defocusing of -0.5 mm inside the material. The 45 pieces were obtained after a continuous CW cutting after an experimental cutting plan containing 9 pieces at certain parameters varied after a Taguchi pattern that had been replicated at the same values 4 times. The steel plate is cut with laser by a thermal processing process. The pieces were cut according to a model containing 3 sides with straight cutting profiles and one side with a circular profile fig. 3.

Fig. 2 Cutting head Splitter - Model By speed 3015

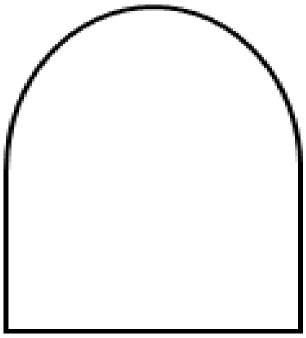


Fig. 3 The Steel Piece Hardox 400

The laser beam is generated by the mirror system in the optical resonator and amplified by multiple reflections on the exterior mirrors that direct the laser light onto a lens with different focal lengths of a few inches through a nozzle Fig. 4, speed and increases when it requires a higher heat transfer over a faster time interval.

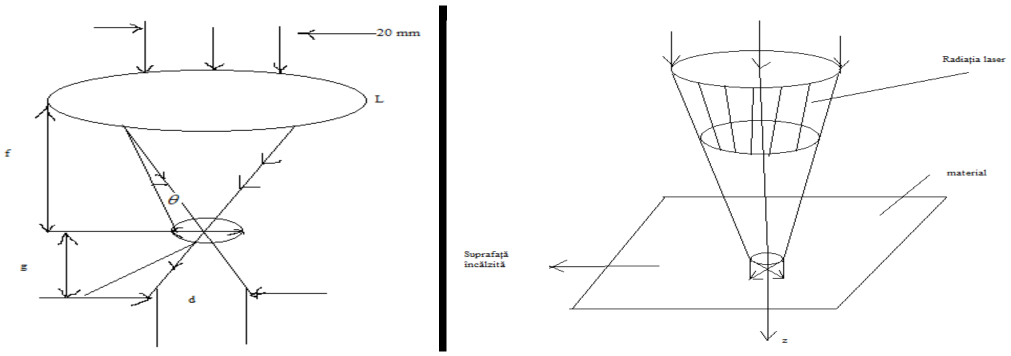


Fig. 4. Drawing of the laser beam penetration drawing into the lens and focusing the material.

The melt is so hot due to the heat absorbed by the laser and the burning of oxygen in a smaller amount of time. It is interesting to examine the melt / solid interaction in the Kerf area.

Fig. 5 Laser installation By speed 3015

We chose to choose as a subject of study a material about which no relevant information was found in the literature, which has special physico-mechanical characteristics, but which is widely used in the construction of machines: HARDOX 400 debited with the plant in FIG. 5.

The blank used was the sheet of this material having a thickness of 10 mm. This thickness is considered to be suitable for the study of several parameters that characterize the quality of the laser cut parts: kerf width, taper (flank angle) of the parts, flange roughness, dimensional accuracy, table 2. This thickness also allows the study microstructure of the cut surface and provide suitable conditions for the measurements that were provided (hardness, roughness). The laser was cut with 45 pieces resulting from the variation of the input parameters fig. 6.

Fig. 6. Piece Hardox 1 and 9 cut out of the HARDOX 400 sheet **.**

Tabel 2. Parameters used for cutting. Work parameters

Group	steels
Abbreviation of the Group	STW 22
Nr. material	10332
Thickness	10mm
Focal length of the lens	7.5 inch
Diameter of nozzle	1.5mm
Type of nozzle	NK1515
Type of gas	O_2
Gas pressure in stanbay	1.2
The power of the laser type	4400W
Time piersing	0.5s
The nose-piece distance in the piercing	3mm
Laser power in piercing	4000W
Nozzle-piece distance in cutting	0.8mm
The power of laser cutting	4300W
Focal position at cutting	-0.5mm
Gas pressure	0.45bar

3. OPTIMIZATION METHOD TAGUCHI:

Genichi Taguchi proposes a method of calculating the effects of factors and interactions:

• It is the most effective method of planning experiments.
• Several restrictive conditions must be observed in the study of a phenomenon.
• Modeling with fewer experiments.
• Enter the quality loss function and the signal / noise function.
• The parts are executed within tolerances.
• The design of the experiments is done according to the input parameters table 2, the disturbing factors (uncontrollable signal / noise-variables), the response variables.
• The interaction is between the input parameters - the disturbing factors where an optimal

point and the imposed limit are obtained.
• For the use of the method, 4 replicas were made to obtain 45 pieces under the same conditions.
• Power was varied between 4100 and 4300W, from 100W to 100W.
• The pressure was changed between 0.35 bar and 0.55 bar, from 0.10 bar to 0.10 bar.
• Speed varied between 1200mm / min and 1400mm / min, increased by 100mm / min, Table 3.

4. RESULTS

On the walls a rib structure is formed due to the Humping phenomenon. These striations occur due to small expulsions of molten steel acting on the side walls of the slit under the action of the gas jet that pushes the material and as a result scratch the wall giving rise to roughness. When reducing the purity of the O2? 99.8% ash gas results in a decrease in the intensity of the combustion and oxidation reaction resulting in a more rusty surface of the slit and the formation of slag inside the slit. If the speed increases, we have a cutting process without sufficient optimal energy, where the melts flow on the side edges of the slit. So the slag formation is born with the increase of the cutting advance. At a normal cut the width of the Kerf is higher at the lower than the upper, Kerf = 0.50-0.72mm for the H400. Measurements of Ra, Rz were made on a straight contour by means of a touch probe on one of the lateral sides cut by laser.

Tabel 3. Reply nr. 1

Nr. Piece	Power [W]	Pressure [bar]	Speed [mm/min]	**R_a [µm]**	**R_z [µm]**
9	4100	0.35	1200	3.81	18.81
10	4100	0.45	1400	2.60	12.69
11	4100	0.55	1600	3.12	14.00
12	4200	0.35	1400	3.73	16.42
13	4200	0.45	1600	3.57	15.51
14	4200	0.55	1200	5.79	24.09
15	4300	0.35	1600	3.23	18.49
16	4300	0.45	1200	4,14	18.75
17	4300	0.55	1400	3.36	17.41

In Table 3 are recorded the roughness values Ra and Rz for hardox pieces that were measured in the laboratory of Constantin Brâncuşi University with a rugosimeter. It is noted for the reply no. 1 Ra has a single value of less than 3 µm, which is obtained at the lowest 4100W power and the average pressure values of 0.45bar and the speed of 1400mm / min. The high Ra value over 4 µm is at 14 and 16. The Ra result of 5.79 µm is obtained at mean power and at a maximum pressure of 0.55 bar and minimum speed.

Tabel 4. Analysis of cut pieces

Cutting quality	**Reply cutting**	**(1) No melt**	**(2) Lower melt**	**(3) With melt at the bottom continuously deposited**
Nr. piece	**I**	1, 2, 3, 6, 8	5, 7, 9	4
	II	10, 12, 15, 18	11, 14, 17	13, 16
	III	20, 21, 24, 26, 27	19, 23	22, 25
	IV	30, 32, 33, 35, 36	29	28, 31, 34
	V	42, 45	37, 38, 39, 41, 44	40, 43
Total	**45**	**21**	**14**	**10**

By analyzing the surfaces that make up the slit and cutting edges on the Hardox 400 plate, we can classify the cutting quality as follows: (1) No melt; (2) Lower melt; (3) With the bottomless melt deposited continuously.

After inspection of the cutting slit to the right profile it is easy to notice that 21 cuts have a very good cutting quality after 4 replicas due to the power input, pressure, speed table 4. Thus the first two replicas have 4 very good cuts, Replica III and IV have 5 very clean slots, and Replica V, only 2, is the plate temperature, but also the oxygen pressure of 0.55 bar (max in the experiment).

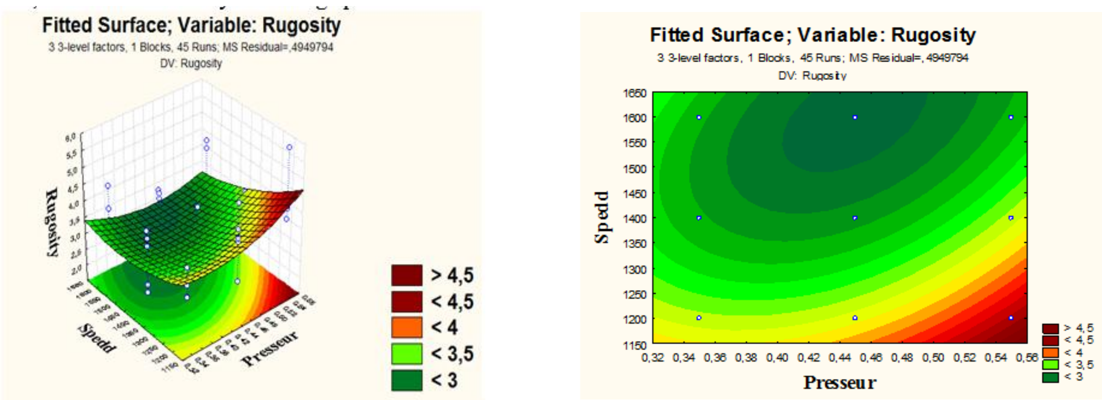
-The view of observing a small melt on the lower edge of the straight slit cut is found in 14 pieces. One reason for sure is the high cutting speed at high power.

-13 cuts have a continuous melt on the bottom edge, and one of the causes is the low pressure of 0.35 bar that does not burn and melts the material.

5. INTERPRETATION OF RESULTS

Prediction varies: pressure and speed, and power is constant, for surface plot (fitted response) fig 7.

The 3D graph shows that at the high velocity values and the average values of the pressure we obtain the lowest values of roughness Ra <3µm and the highest values of Ra> 4.5µm are obtained when the speed values are small and those of the pressure are large, eg. v = 1150mm / s and p = 0.56bar. From the measured values that are presented in the quadricular graph few are below 3.0µm, and most often are higher than this value, but the operator can claim what value he wants to obtain for a certain Ra depending on pressure and speed, maintaining the constant power at average value. Ra is readily predicted between O2 gas pressure values of 0.40 and 0.45 bar, and simultaneously at cutting speeds between 1500-1600mm / min.



a b

Figure 7: a. for surface plot (fitted response), b. for contour plot (fitted response)

When the speed is small eg. 1160-1200mm / min laser lies more in the material, heats the material more heavily, and therefore the surface roughness is affected. When the pressure increases, Ra rises because the oxidation reaction melts more material, so the mass of the melt in the channel is larger, being eliminated by the lower part of the piece.

The formula of the roughness correlation Ra according to the simultaneous influence factors (velocity, pressure) is linear regression type fig.8:

$$Ra = 4,4011 + 2,0433 * X - 0,0014Y \qquad (9)$$

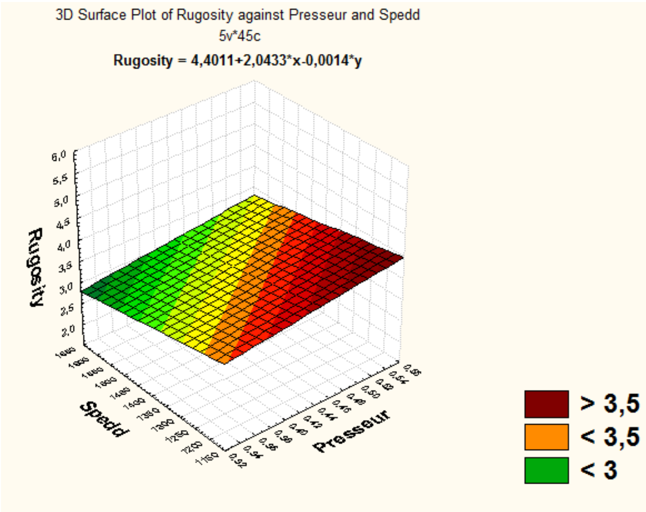


Fig. 8 Linear regression formula and corresponding graph

Shows the value of the constant of the model is 4,4011, the linear coefficient of pressure is 2,0433 which is much higher than the velocity, -0014, which implies the correlation relation of the influence factors that the pressure is in this case more influential than the speed , the coefficient of the pressure influence coefficient increases and the velocity decreases. The linear regression of Ra shows the linear transformation of the spectrum of colors from green to dark red. Ra increases from green (low pressure and high speed) to (high pressure, low speed).

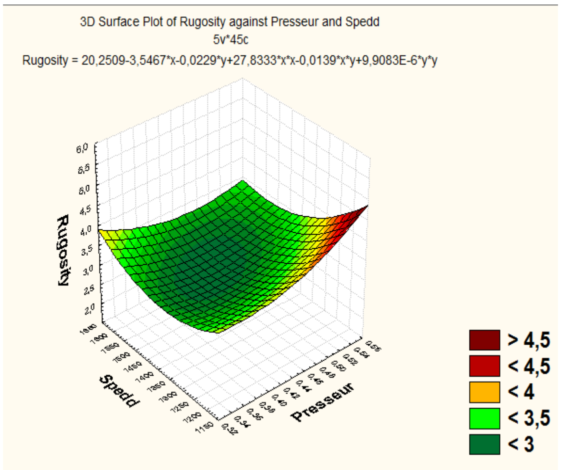


Fig. 9 Correlation graph quadric

The correlation formula of Ra is given by the relationship:

$$Ra = 20,2509 - 3,5467 * X - 0,0229Y + 27,8733X * X - 0,0139X * Y + 9,9083E - 6Y * Y \quad (10)$$

The linear influence factor is pressure and the quadric / quadric is 27.8733 is all the pressure and the highest, which shows us that this parameter is the main influence between pressure and velocity when the pressure is constant fig.9.

6. CONCLUSIONS

Predictions indicate the transformation of the color spectrum by a Gaussian pressure curve according to the cutting speed, which will simultaneously describe the roughness value through a regression of the quadric model.

In the linear correlation formula of Ra according to pressure and velocity, Ra is influenced by the influence influence factor called pressure.

The quadratic formula indicates the values of the influence coefficients of the model constant at 20.2509, the quadratic term of the pressure is 27.8733, the term of each interaction with each is -0.0139 which indicates a decrease, the exponential term of simultaneous variation of the pressure with velocity, -6 the quadratic coefficient of velocity that decreases, which tells us that even in the case of the quadratic correlation formula the pressure is the most influential factor.

The results of the experimental measurements coincide with those given by the prediction and correlation formula.

A layer of oxides is deposited by the reactive oxygen reaction with Fe on the cut surfaces.

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