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A MATHEMATICAL MODEL FOR DETERMINING THE ROUGHNESS OF LASER-MACHINED SURFACES

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Abstract.*The paper aims to determine the influence of input parameters on surface roughness in CO_2 laser cutting. The material used is Hardox 450 steel in the form of plates with a thickness of 12 mm. Adjustment parameters that ensure cutting, laser power (3700,3900) W, pressure (0.55,0.75) bar, and cutting speed (1250,1650) mm/min were identified through trial tests.Based on the current state of research in the field, a mathematical model is proposed to describe the relationship between roughness and input parameters. The designed model is validated with statistical methods. The results show that the pressure of the assistant gas is the most influential factor with regard to surface roughness. The laser surface treatment of manganese steel is a promising technique for increasing roughness if the pressure is used at the minimum input level of 0.55 bar. For low production costs, the combination of 3700 W power, 1250 mm/min speed, and 0.55 bar pressure is recommended for cutting Hardox 450 steel.*

Key words:*Hardox 450, Roughness, Laser cutting, Model, Assist gas pressure, Speed, Power*

1. INTRODUCTION

The trends in the global markets to increase the quality of processed surfaces, the yield of different processing processes, the reduction of energy consumption, and the ecological character of technologies determine the increase in concerns regarding the research of technological processes. One of the non-conventional technologies is laser processing that allows processing such as: cutting, welding, drilling, engraving, directed energy deposition, and others. Such technology is present in several industries, such as extractive, manufacturing, automotive, aerospace, and others [1].Laser beam machining is a process that can be applied to almost all metallic or non-metallic materials. Cutting

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metal with laser technology consists of bombarding a small surface with high-energy photons. The process occurs when the laser melts the material and the assist gas removes the molten metal.

Hardox 450 steel is chosen for the determination of the experimental tests due to its physical, chemical and mechanical properties. Steel is characterised by high corrosion and wear resistance, high strength-to-weight ratio, resistance to impact loads, good weldability, good cold plastic deformation properties, and is not intended for additional heat treatment [2-4]. These properties have determined the use of steel for different applications that combine abrasion resistance with impact and good cold bending properties. Currently, high-strength steels are widely used in engineering structures because they have high strength and hardness with sufficient properties of ductility and toughness [5,6].

The use of classical technologies for the processing of Hardox 450 steel involves rapid tool wear, long processing times and an average roughness of the obtained surfaces [7]. As a result, laser processing is emerging as an alternative technology. However, other problems arise during processing due to melt viscosity, melt reflectivity, high melting point of steel and low viscosity of formed oxides [8]. Such difficulties have an effect on the cutting width, quality and hardness of the cut surfaces [9]. Reducing the roughness of a cut surface is an important practical task, since roughness parameters have a significant effect on the operational properties of functional surfaces [10].

The objective of the paper is to determine the influence of main cutting parameters on surface roughness. For this purpose, a mathematical model is developed that determines the individual and group influence of the parameters on the quality of the surface. The proposed mathematical model is verified with statistical methods.

The work is structured in sections. The following section contains a synthesis of the subject in literature. The thirdsection contains an overview of the material used and the methods used. The fourth section describes the research results and the discussions related to the results obtained. The fifth section includes research conclusions, limitations, and future research directions.

2. LITERATURE

A synthesis of studies in the field was carried out with the aim of identifying the latest results obtained in the laser cutting of steelswith regard to surface roughness. Meško et al. (2018) showed the effect of selected parameters (speed, pressure, and focal position) on the surface roughness generated during laser cutting of S235JR steel[11]. According to the authors the strongest influence was determined by increasing the cutting speed from 1 to 6 m/min which caused the reduction of R_a by 47.5% and the reduction of R_z by 51%. Jadhav and Kumar (2019) investigated the laser cutting of AISI 304 stainless steel [1]. The authors studied the influence of the process parameters (laser power, cutting speed, and gas pressure) on surface roughness. The authors concluded that roughness decreases with increasing laser power and gas pressure. The same steel was studied by Senthilkumar and Jayaprakash, (2017) in CO_2 laser cutting [12]. The authors measured the influence of a large number of process parameters (laser power, gas pressure, cutting speed, and focal length) on surface roughness, hardness and cut dimensions, and developed a mathematical model that contributes to the determination of surface hardness and quality. When fiber laser cutting ASTM 304 stainless steel with a thickness of 3 mm, Kotadiya et al. (2018) determined that laser power had a greater influence compared to gas pressure and cutting speed [4].According to Rajesh et al. (2019), kerf and surface roughness R_a were influenced by process parameters such as cutting speed, assist gas pressure and laser power [13]. The authors performed CO_2 laser cutting experiments on SS-304 stainless steel using nitrogen as an auxiliary gas. Ružbarský (2023) determined the feed speed of the cutting head to achieve the roughness imposed by the customer [14]. Using two materials, S235JRG1 steel and AW 5754 aluminum alloy, the study provided information on the effectiveness of cutting head feed rates in achieving the target roughness levels. Patel and Bhavsar (2021) determined the effect of process parameters such as cutting speed, laser power, frequency, duty cycle, and gas pressure [15]. A hard steel (EN-31, 10 mm thick) was investigated to determine the impact on taper, roughness and heat affected zone. The authors concluded that a better surface roughness is obtained at average values of all studied parameters.

Achieving low machining costs at the same time as high yields of cutting facilities, dimensional accuracy, and superior quality of cut surfaces drives the need to formulate and solve laser cutting optimization problems. It is a non-linear process with different parameters, which are the main challenges in the optimization process. Laser cutting is decisively influenced by material composition and process parameters. The variability of these elements implies changes in the values of the cutting parameters. The vast majority of studies on this topic have been conducted using CO_2 lasers. Madić et al. (2020) compiled a mathematical optimization model for CO_2 laser cutting of mild steel [16]. The goal was to determine the values of the laser cutting parameters so as to maximize the material removal rate.

Anghel et al. (2020) studied CO_2 laser cutting of 304 stainless steel miniature gears [17]. The effects of power, cutting speed, focal position, and gas pressure on the roughness R_a were analyzedby the authors. The optimization of the cutting parameters led to the best values of R_a= 0.43 μm at laser power 2407 W, cutting speed 1.25 m/min, focal position - 2.4 mm, and gas pressure 12.5 bar. Rao et al. (2024) studied the multiple effect determined by power, frequency, speed and nozzle tip distance on surface roughness, cut width, heat affected zone, and metal removal rate in laser cutting of AISI 304 stainless steel [18]. According to the authors, laser power, and cutting speed have a significant effect on these responses. The purpose of the study carried out by Cao et al. (2020) was to optimize the processing conditions of laser-processed 13-8 stainless steel [19]. Three factors have a significant effect on the machining characteristic feed rate, spindle speed, and depth of cut. The objective of the study conducted by Lazov et al. (2018) was to determine the optimal laser cutting parameters for minimizing the average surface roughness [20]. Three cutting parameters were used in the investigation: cutting speed, laser power, and assist gas pressure. The authors found that it is necessary to integrate all parameters to obtain a minimum roughness. Obeidi et al. (2019) examined the effect of roughness on laser absorption to determine how laser parameters should be adjusted when working with a different roughness [21]. Materials used were 316L stainless steel and aluminum. Bohdal and Schmidtke (2020) conducted experimental research on laser cutting of stainless steel RVS 1.4301 [22]. The authors determined the influence of selected parameters and cutting conditions on the quality of the obtained product. Laser power and cutting speed had a significant influence on fiber and CO_2 laser cutting output factors. For cutting material with a thickness of 3 mm with a CO_2 laser, the highest quality of the cut edge was obtained using the power values (4200-4300) W and the cutting speed of 2100 mm/min. For the thickness of 6 mm, the speed values should be set approximately in the range of (1600-1800) mm/min, and the power should be selected in the range of (3700-4200) W.

The research carried out by Magdum et al. (2022) found that the interaction of power with speed and speed with gas pressure has a substantial impact on surface roughness in laser cutting of 304 stainless steels [23]. Surface roughness and energy consumption were the parameters tracked by Venkatesan (2018) in cutting Inconel steel 718, a difficult material to process [24]. The input parameters were laser beam angle, laser power, cutting speed, and feed rate. The author was able to present combinations of parameters to optimize the objectives. Jarosz et al. (2016) evaluated the effects of cutting speed on the heat-affected zone and roughness during laser cutting of AISI316L stainless steel [25]. The authors demonstrated that using the highest cutting speeds considered (16.5 mm/s) produces cut surfaces with good roughness and negligible HAZ, while low cutting speed values have no practical content. A comprehensive evaluation of the microgeometry and microstructure of the surface during laser cutting of a 9M4K8 steel, deposited on the 30KhGS structural steel identified at Izmailov et al. (2021) [10]. The authors traced the relationship between the cutting speed and the power of the laser radiation on the roughness, phase composition, and microhardness of the cut surface layers. According to the authors, the roughness height parameters depend significantly on the cutting modes.Based on the literature, the input parameters used in the experiment were chosen.

An important physical quantity in laser cutting processes is the intensity of laser radiation. This is obtained in the laser tube following the transition of an excited electron from level 4 to the lower level 3 in the case of the CO_2 laser. We apply Heisenberg's uncertainty relation for the energy variation between the two levels and the time for the electron to make the transition resulting in the stimulated photon:

$$\Delta E \times \Delta\tau = \frac{h}{2\pi}, \tag{1}$$

where E is the energy, h is the quantum action constant and τ is the transition time of the electron.

If we accurately determine the energy, there is a large imprecision of the duration. As a result, for the photon it follows:

$$\Delta(E_4\text{-}E_3) \times \Delta\tau = h\Delta\vartheta \times \Delta\tau = \frac{h}{2\pi} \tag{2}$$

We calculate the bandwidth $\Delta\vartheta = \frac{1}{2\pi\Delta\tau}$, where Δτ is the coherence duration. Laser intensity can be expressed by the relation [26]:

$$I = \frac{I_0}{1+\left[\frac{\delta\vartheta}{\frac{\Delta\vartheta}{2}}\right]^2} = \frac{I_0}{1+\Delta\tau\frac{e}{m}gB} \tag{3}$$

Laser intensity depends on the durations between transitions 4 and 3, the specific charge e of the electron, the Lande factor g and the magnetic induction B. The frequency difference δϑ was taken into account in the determination. In the presence of the magnetic field, an energy level splits into sublevels through the Zemann effect. The laser emission is between two narrow band sublevels in a gaseous mixture. The intensity of the laser radiation has a Gaussian distribution, with a maximum I_o in the centre.

2. EXPERIMENTAL PROCEDURE

The cutting plan was designed according to a reduced factorial plan containing 5 multiplications (Figure 1). The BySoft 7 software was used to process the 45 pieces. The design of experiments (DOE) describes the fractional factorial plan that can provide relevant information about the variation of the cutting process to improve the working parameters. The experiment was designed to vary two input parameters. Mathematical modelling of independent parameters that give a high quality of the cutting surface was pursued.

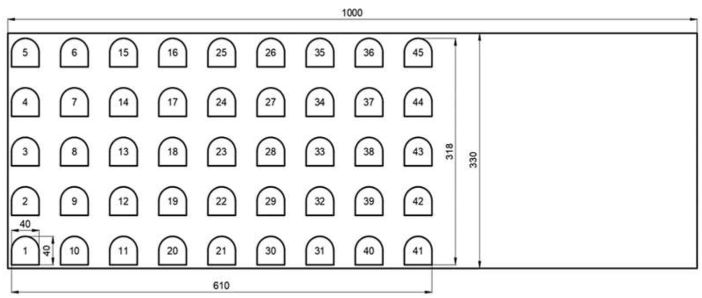

Fig. 1 Cutting plan

The piece had the dimensions of X=40 mm and Y=40 mm. The cutting plane had the dimensions of X = 610 mm, Y = 318 mm, while the steel sheet had the dimensions of X=1000 mm, Y=330 mm and 12 mm in thickness.

Hardox 450 is a special steel whose cut surface, when treated with a laser, loses its hardness. The explanation emerges relatively easily after the cutting experiment. It is found that the laser beam has a stronger intensity, the accumulation of local heat increases, the interatomic distances between the constituents increase, resulting in a decrease in hardness. On the surface of the metal, there is a rough spot that has low penetration power. Heat dissipates more easily towards the extremities than in the depth of the material. Through the melt, the heat is transmitted through thermal convection, and through the plate through thermal conduction. Hardox 450 is a material that diffuses heat quickly, so the board changes its temperature permanently with each cut. This result imposes restrictions in the successive cutting of the parts because at a certain temperature the parts cannot be completely cut.

The chemical composition of steel is shown in Table 1. It was checked that the work surface was clean, without asperities or bumps that could scatter the light. It is a hard material that undergoes significant changes when laser processing.

Table 1 Chemical composition Hardox 450 [27]

Alloying element	C	Si	Mn	P	Cr	Ni	Mo	S
% max	0.26	0.70	1.60	0.025	1.40	1.50	0.60	0.010

Through trial tests, the levels of input parameters were identified (Table 2).The focus position was f=+3.8 mm. To avoid overheating the Hardox 450 plate, parts were not cut consecutively. The choice of the main parameter generated certain problems when setting up the experiment. As a result of the local heat accumulated by the energy supplied by the laser and the energy released by oxidation, the sheet became excessively hot. This heat was transmitted through the board, which in some cases negatively influenced cutting. Thus, a 23-levelvariable design was chosen to find the most influential parameter and the hierarchy of factors. This reduced design can improve the control of cutting parameters.

Table 2 Parameter values

Parameter	Minimum level	Maximum level
Laser power (P)	3700 W	3900 W
Cutting speed (v)	1250 mm/min	1650 mm/min
Gas pressure (p)	0.55 bar	0.75 bar

The board cut was designed for 3 predictors at extreme levels. The design of the cutting plan was assisted by computer graphics using cutting plant software. The measurement of roughness R_a samples was performed with a Mytutoyo SJ-201 roughness meter. The infrastructure used is the Bystronic ByAutonom 3015 laser cutting machine with a working surface of 3000 x 1500 mm and a divergence of the laser beam < 2 mrad (Fig. 2).

Fig. 2 Bystronic ByAutonom 3015 installation

The construction of the model is based on the influence of threeinput parameters systematically run to obtain experimental roughness data. The interaction is presented through the levels of the input parameters and the roughness points placed symmetrically on the faces of a cube (Fig. 3).The geometric interpretation of the effects is described with the help of a cube in which the eight experimental values of the roughness R_a are placed at the corners. The sides show the differences between the measured experimental points. The (+) sign shows an increase and (-) a decrease in the roughness R_a under the influence of the input parameters. The minimum values of $R_a$were obtained under the conditions of setting the predictors to the minimum. The maximum values of the pressure of the working gas O_2 had the effect of increasing the roughness.

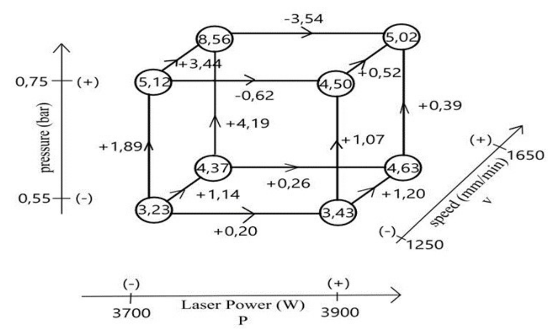

Fig. 3 Cube of experimental points

The first face of the cube shows significant changes in the surface roughness R_a when the pressure of the assistant gas changes. Increasing the laser power from minimum to maximum does not influence R_a. In fact, the gas pressure has the role of protecting the laser light, initiating the oxidation reaction, and pushing the melt deeper. The increase in pressure will produce viscosity in the melt, so its sliding on the walls will produce friction with the effect of increasing R_a. The values on the face behind the cube are increased compared to the initial one, and it follows that factors have intervened that change the cutting conditions. A prime factoris temperature, called by Taguchi the noise factor. The rise in temperature of the semifinished product will lead to a loss in the quality of the parts. There are other factors, the surface tension coefficient of the melt, the Stokes force in the melt, the local heat. The cube is a predictive model for evaluating R_a. It is recommended that the board is cooled with a local agent, so the cut can be improved if we use ice or other protection. The generation of an incandescent focus, an intense flow of sparks, can affect the research team. Protective equipment is mandatory to avoid radiation produced by the photoelectric effect, Compton effect, and thermochemical combustion reaction.

3. RESULTS AND DISCUSSION

When cutting steels, the input parameters frequently used in the literature are laser power, assist gas pressure, and cutting speed. These predictors are contained in the reduced factorial cutting plan. Table 3 shows the variation of the process parameters and the response variable - roughness R_a.

In order to determine the effect of each input parameter, a matrix containing individual coded values is created. For the maximum value of a parameter, +1 is associated, and for the minimum value -1. This results in an orthogonal matrix with coded values that will be combined with the responses of roughness R_a resulting from the experimental measurements (Table 4).

Table 3 Roughness values

Trial	Power (W)	Speed (mm/min)	Pressure (bar)	Roughness (μm)
1.	3700	1250	0.55	3.23
2.	3900	1250	0.55	3.43
3.	3700	1650	0.55	4.37
4.	3900	1650	0.55	4.63
5.	3700	1250	0.75	5.12
6.	3900	1250	0.75	4.5
7.	3700	1650	0.75	8.56
8.	3900	1650	0.75	5.02

Table 4 Coded experimental design

Trial	Design factors of interaction						Roughness (μm)
	P	v	p	P·v	P·p	v·p	
1.	-1	-1	-1	-1	-1	-1	3.23
2.	1	-1	-1	1	-1	-1	3.43
3.	-1	1	-1	-1	1	-1	4.37
4.	1	1	-1	1	1	-1	4.63
5.	-1	-1	1	-1	-1	1	5.12
6.	1	-1	1	1	-1	1	4.5
7.	-1	1	1	-1	1	1	8.56
8.	1	1	1	1	1	1	5.02

The effect of each input parameter is calculated as a function of the coded value and the R_a response. To determine the effect of two input parameters, the columns in Table 4 will be multiplied by each other resulting in a new column of values that combine with roughness R_a.The response parameter R_a has a different value for each independent experiment. The matrix of the factorial experiment contains 8 independent observations, sufficient to estimate the effect of each parameter and the interaction between them. Thus, the effect generated by the laser power will be:

$$Effect\ P=\frac{-3.23+3.43-4.37+4.63-5.12+4.5-8.56+5.02}{4}=-0{,}925\ \mu m \qquad (4)$$

Similarly, the effects due to each parameter and the interactions between them are obtained (Table 5).Table 5 shows that the assist gas pressure has the greatest effect on roughness R_a. The second parameter that exerts a strong influence on this roughness is the cutting speed. A high cutting speed ensures a lower amount of laser energy delivered to the material and a shorter interaction time. The interaction between laser power and gas pressure has a significant effect on improving roughness. Based on the results in Table 5 we can conclude that the effects of the independent parameters are stronger compared to the interactions between the parameters.

Table 5 Parameter effects

Parameter	Parameter effect	Regression coefficient	Coefficient value
P	-0.925	β_1	-0.4625
v	1.575	β_2	0.7875
p	1.885	β_3	0.9425
P·v	-0.715	β_{12}	-0.3575
P·p	-1.155	β_{13}	-0.5775
v·p	0.405	β_{23}	0.2025

The effect of the interaction between laser power and assistant gas pressure has the following value:

$$Effect\ P\cdot p=\frac{3.23-3.43+4.37-4.63-5.12+4.5-8.56+5.02}{4}=-1.155\,\mu m \qquad (5)$$

Subsequently, two replications of the experiments were performed and the arithmetic mean of the 16 R_a responses was calculated. Therefore, the coefficient of the model β_0= 4.8575 was obtained. The main effect is described by a cube face containing 4 roughness points and the main parameter. The interaction effects between two factors contains 8 roughness points of the cube, two intersecting interior surfaces that have as elements two diagonals of the cube faces.

The regression equation that expresses the roughness is obtained from the coefficient of the model to which the beta coefficients determined inTable 5 are added. Coefficients express the intensity of a factor or the interaction between 2 factors. The regression equation that expresses the relationship between R_a and the selected parameters P, p, v, has the following form:

$$R_a=4.8575-0.4625\cdot P+0.7875\cdot v+0.9425\cdot p-0.3575\cdot P\cdot v-0.5775\cdot P\cdot p+0.2025\cdot v\cdot p \qquad (6)$$

Linear graphs were made showing the linear dependence between roughness and each input parameter in Fig. 4. The plot length and slope estimate the relationship between R_a and an input parameter.

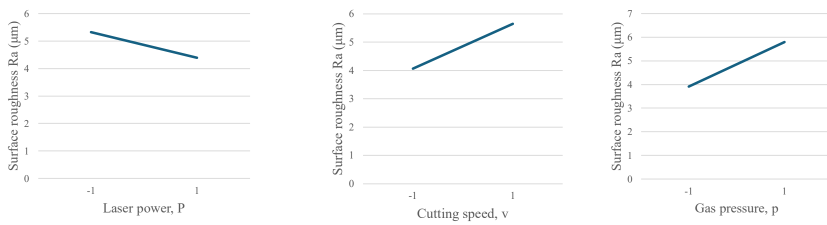

Fig. 4 Main effect of the parameters on the roughness

When the laser power is adjusted to higher values, a decrease in roughness is observed. On the other hand, if the cutting speed increases, roughness increases. The pressure graph has the longest length, the highest slope; it follows that this parameter compared to the laser power and cutting speed becomes the most significant. At low pressure firing is more suitable and low roughness values are obtained, and at high pressure R_a reaches 6 µm. The minimum R_a is obtained at the maximum power at the same time as the minimum speed and pressure.

The interaction diagrams showing the simultaneous action of two input parameters on the roughness are shown in Fig.5.

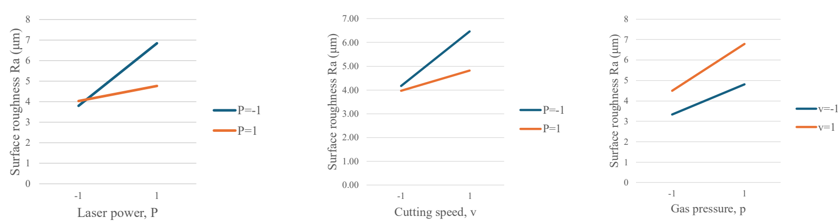

Fig. 5 Main effects of twointeraction parameters on the roughness

The minimum roughness is obtained when the gas pressure and the cutting speed are selectedsimultaneously at minimum values. Such a combination determines a roughness value below 4 µm. The effect of interactions between 2 factors causes a greater reduction in roughness than the individual effects. Both variants indicate pressure as the most influential parameter.

The effects produced by the pressure of the cutting gas are to intensify the thermoenergetic reaction, to push the melt toward the lower edge, and to cool the cut surfaces after themelt disappears between the walls of the slot. From a thermodynamic point of view, pressure is a factor that can reduce the viscosity of the droplet with the direct effect of reforming the surface layer. It is possible that this input parameter creates conditions of Marangoni heat transfer from the melt to the walls with a stable flow that can improve the quality of the cut. From the average analysis of R_a as a function of the input parameters, it is found that the cut surface has minimised R_a under conditions of maximum power setting at the same time as the minimum pressure and speed.

After a few cuts, the material heats up strongly and the temperature in the work area rises, resulting in the deterioration of the quality of the cut surface. The cutting width is influenced by the thermal fusion between the energy absorbed from the laser radiation and the heat developed by the oxidation reaction. It is found that with an increase in the thickness of the material, a widened cut result. The absorption of laser radiation occurs at very small angles of incidence. The consequences of this result lead to an increased laser energy absorptivity in the Hardox 450 steel, which will locally produce melts of larger sizes. These droplets inside the slit do not have a high cutting capacity, but only a widening, causing high local heat. Such effects produce a weaker roughness by increasing the friction between the melt and the superficial surface. In the melt, the viscosity coefficient increases by decreasing the thermal convection between the layers of atoms. In order to evacuate the melt from the slot, higher pressures of the assist gas jet are required, thus affecting roughness.

In the case of the experiments carried out, it is found that the best R_a is in piece 1 when the plate was at ambient temperature. As the first pieces are being processed, the sheet heats up strongly due to the heat accumulated from the laser, and some pieces are not perforated to the bottom edge. The temperature of the blank is an uncontrollable factor that will affect cutting. Increasing the hardness of the steel has the effect of increasing the resistance to melting. Thicker steel plates become more difficult to cut due to local heat build-up.

Table 6 Estimated effects and coefficients for surface roughness R_a

Term	Effect	Coef.	SE Coef.	T	P
P		4.8575	0.3725	13.04	0.049
v	-0.9250	-0.4625	0.3725	-1.24	0.432
p	1.5750	0.7875	0.3725	2.11	0.281
P·v	1.8850	0.9425	0.3725	2.53	0.240
P·p	-0.7150	-0.3575	0.3725	-0.96	0.513
v·p	-1.1550	-0.5775	0.3725	-1.55	0.365
R-Sq. = 94.13%, R-Sq. (Adj.) = 58.90%, R-Sq. (Pred.) = 0.00%, S = 1.05359					

Table 7 Analysis of variance for surface roughness R_a

Source	DF	SS (Seq.)	SS (Adj.)	MS (Adj.)	F
Main effects	3	13.779	13.779	4.593	4.14
2-way interactions	3	4.019	4.019	1.340	1.21
Residual error	1	1.110	1.110	1.110	
Total	7	18.908			

In our study, two models (mathematical,statistical) were used to determine and verify the surface roughness of R_a. The first model identified the mathematical relationship that precisely determines R_a. The second model confirms the influencing factor that has an important connection with R_a.

In the statistical evaluation of the experiment, emphasis is placed on the dispersion of the R_a data. The standard deviation calculated based on the data in Table 6 is S=1.05359. With the help of the standard deviation, the confidence interval of the roughness can be estimated. The standard error SE was determined using the standard deviation and the square root of the number of experiments$SE=\frac{S}{\sqrt{N}}=\frac{1.05359}{\sqrt{8}}=0.3725$. Analysing the statistics of the cutting gas pressure, the sum of the squares of the regression SS=17.798, and $S=\sqrt{\frac{17.798}{16}}=1.05359$. Student's test is not relevant because the probability $p>0.05$.The difference between the measured values and the estimated values represents residual errors (Table 7). The sum of squared residual errors is SSE=1.110. Depending on SS and SSE, the mean MS and MSE were calculated, which establish the Fischer test (F). Because the probability $p>0.05$ results in the fact that there is no strong connection between roughness and pressure. The coefficient of determination of the R^2 model was established as follows$R^2=\frac{SS}{SST}=\frac{17.798}{18.908}=0.9413$.Even if the statistic does not decide the main factor, it is useful in demonstrating that the obtained experimental data are reliable. We used two models to identify the most influential input parameter. These are sufficient to demonstrate that when laser cutting, the Hardox 450 steel gas pressure is the main factor for roughness. The regression equation can be used in production to obtain parts with a controlled roughness.

4. CONCLUSIONS

The object of the research was to determine the influence of three input parameters (laser power, assist gas pressure, and speed) on the roughness of the surfaces processed by CO_2 laser cutting of Hardox 450 steel. For this purpose, a mathematical model was proposed that established the connection between roughness and the main cutting parameters. The influence of input parameters on surface roughness R_a in CO_2 laser cutting is a significant factor affecting energy absorption when scanned with laser radiation. It is a robust variable that affects the cost of laser cutting and the appropriate levels for process parameters.

Having conducted the study, the following conclusions can be drawn:

- the time to identify the working parameters was significantly reduced by determining the effect of each input parameter, the combination of which analytically determined roughnessR_a;
- the analytically established mathematical relationship is based on two factors of influence, pressure and speed, which, when properly set, provide the roughness appreciated by the manufacturers;
- laser cutting of thick plates is difficult due to the accumulation of heat generated by the laser and the combustion reaction;
- the mathematical model developed in the paper is based on two influencing factors, while the third one is kept constant;
- a preset roughness value can be obtained by setting the assistant gas pressure and the cutting speed accordingly, an aspect followed in the production activity;
- assist gas pressure is the most influential factor on roughness;
- for low production costs, the combination of 3700 W power, 1250 mm/min speed and 0.55 bar pressure is recommended when cutting Hardox 450 steel.

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