

# PREDICTIBILITY OF PROCESS PARAMETERS FOR OXYGEN ASSISTED LASER CUTTING OF STEELS IN INDUSTRIAL APPLICATIONS

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**ABSTRACT:** Oxygen assisted laser cutting is a technological process which is achieved by reaching physical conditions which allow penetration of the steel plate by melting, stabilizing a cutting front and its propagation in the material in the feed direction. Parameters achieve a certain cutting process depends on technological laser system used. The paper presents models showing face to face some of the cutting process parameters with the end result of the process, which is the cut. The main concern is for parameters that control irradiation. This is to achieve predictability of the laser cutting process applicable under industrial conditions.

**KEY WORDS:** laser oxygen cutting, spot overlap ratio, peak power, cut width, regression functions.

## 1. INTRODUCTION

Oxygen assisted laser cutting is a widely applied machining process. Oxygen-assisted laser cutting has been the subject of many studies. Chen 1997 [3] investigated the effect of oxygen pressure on 3 mm thick middle steel pieces. An experimental region was identified in which quality cuts were made, around a pressure of 2 bar and a speed of 40 mm / s. O'Neill 2000 [4] studied the possibility of increasing the cut thickness for medium steel and carbon steel up to 50 mm. The process is called LASOX. It is achieved by a larger diameter of the laser beam at the surface of the piece than the diameter of the gas jet. The laser has the role of heating the material, the important energy input being given by the oxidation reaction. Lamikiz 2004 [5] studied laser cutting of high strength steels. Sheets with thickness of 0.7 mm and 0.8 mm were cut. Good cuts were obtained on a range between 2000 and 7000 mm / min of cutting speed. The power of 200 W allowed cutting speeds up to 4000 mm / min. In the paper Karatas [6] laser cutting for alloy steel HSLA-Steel is being studied. The thicknesses of the cut plates were 1.5 mm and 3.5 mm. The minimum diameter of the laser beam and its position relative to the piece surface were controlled by the focal length of the lens. The interest was for the study of the striations at cuts surfaces. Cutting was carried out at a speed of 300 mm / min, power of 1500 W, pulses frequency of 100 Hz, 25% pulse cycle and the oxygen pressure of 100 kPa. By comparing the results of this work with our results, we appreciate that the presence of striations is due to the reduced pulses frequency. The ratio *spo* (spot overlap) for these experiments is estimated at 0.75. Heidenreich 1995 [7] studied the instability of the laser cutting process for steel

used in shipbuilding. It has been shown that the layer of molten material at the cut surface increases with the thickness of the piece. This molten metal layer with high-viscosity is non-removable and forms the striations. Pieces with thickness between 6 mm and 16 mm were cut. It shows that cutting of thick pieces requires a decrease in oxygen pressure. The problem of uncontrolled burns during the cutting process is related to the diffusion of oxygen in the molten metal layer at the cut surface. In Christophe's work [8] is investigated the form of nozzles to bring oxygen to the piece surface. These are convergent, divergent and convergent-divergent. The problem of subsonic or supersonic has been shown, studying the flow of oxygen at the piece surface. In the Wetzig's paper [9] it is shown the 2D laser cutting of sheets of the electrical steel and high strength steel, less than 1 mm thick. The laser beam was transmitted directly to the piece or through optical fiber. Two laser technological systems were used. There is a correlation between the cutting speed and the thickness of the material at various power values. In the Boulbene's paper [10] is shown the laser cutting of 6 mm thick low carbon steel S235 pieces. The roughness of the surfaces is studied. An experimental model is obtained to link roughness to power and cutting speed. Adequacy of the model is achieved by the ANOVA statistical analysis method. The Karthikeyan's paper [11] presents laser cutting experiments on mild steel plates. An experimental plan is used that varies cutting speed, power and oxygen pressure on three levels. The cut width was measured. Gray relational analysis is used to interpret the results. The experimental results have shown that the optimal cutting parameters were high power 1 kW, lower speed 4.3 m/min and gas

pressure 0.15 bar. In the Parthiban's paper [12], laser cutting was performed on 2.5 mm thick 304 stainless steel plates. The power, cutting speed and oxygen pressure varied. For these, three levels were considered. The cut width at the top and bottom of piece were measured. The analysis of the results was done by the ANOVA method integrated into the genetic algorithm. In the Rodrigues' work [13], the optical aspect of the radiation transmission to the workpiece surface related to surface temperature is modeled for laser cutting. Issues related to laser beam polarization and absorption are modeled. Ozaki presented observations in X-ray of cutting front evolution in real-time [14]. Pocorni presented a modeling of the cutting front in which he considered the melt dynamics [15]. Jae Sung Shin using a 6kW power laser cut stainless steel plates with 50 mm thickness [16]. Riveiro analyzed the gas flow at the cutting front [17].

In recent years, the number of laser technological systems that cut 2D steel plates has increased. Many of these technological systems have particular adjustments to parameters that are not reproducible on other systems. Although there is a large number of studies on cutting similar materials, translating their results into decision to making choices for parameters for a machining process on a particular technological system and a material of certain thickness becomes difficult.

In this paper we propose a study of the laser cutting process from a technological perspective based on experimental results accepted in the hypothesis of a partial knowledge of varied and fixed parameters.

This occurs when it is desired to interpret data obtained under industrial conditions when the processing did not follow an appropriate experimental plan.

It also occurs when we want to synthesize studies or reinterpret some studies with samples made under different experimental conditions.

Experimental conditions that are difficult to reproduce or correlate are those related to laser beam focusing and the intensity distribution at the piece surface.

The method proposed in the paper is to analyze:

- Sizes that generally describe the process, for example linear energy and the spot overlap ratio;
- Independent sizes describing laser beam irradiation;
- Arbitrary functions that include all parameters that have been varied.

Cuts made are characterized by the cut width measured at the top of the piece and at the bottom of the piece.

The single cut width cannot characterize the quality of the inner surfaces of the cut.

However, roughness and striations may be assumed as a function of the cut width respectively fraction from the cut width.

The cut width can show if the laser cutting process is in a critical situation. This happens when the bottom cut width approaches to the diameter of the laser beam.

The cut width variation was modeled using regression functions. Data obtained under different experimental conditions will have as a consequence the small values of correlation coefficients. The proposed model wanted to obtain the best correlation coefficient for predefined variations. More important than the obtained regression function is that it can be applied for both top cut width and bottom cut width in the same correlation conditions. The paper also presents arbitrary functions that adequately describe the laser cutting.

## 2. EVALUATION OF IRRADIATION CONDITIONS

A study is presented on the cutting of OL 37 plates with a thickness of 3 mm by Glod [1]. Cutting was done using a MAZAC CO<sub>2</sub> laser technological system with a maximum power of 1500 W. The diameter of the laser beam at the piece surface was estimated at  $D = 0.2$  mm. Irradiation was in pulsed wave. Irradiation is characterized by linear energy, defined as the ratio of average power to cutting speed:

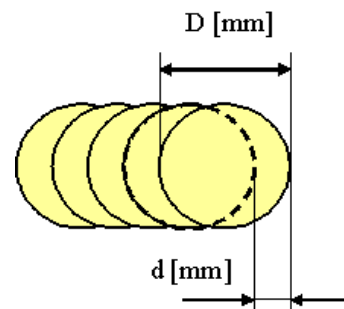
$$E_l = \frac{P}{v} \left[ \frac{J}{cm} \right] \quad (1)$$

where:

$P$  - average power [W]

$v$  - cutting speed [mm/min]

and the ratio spot overlap,  $spo$ . It is defined based on figure 1.



**Figure 1.** Spot coverage for laser beam irradiation of the piece

$$spo = \frac{D-d}{D} [-] \quad (2)$$

The ratio  $spo$  is given by the relation:

$$1 - spo = \frac{v}{D \cdot f} \quad (3)$$

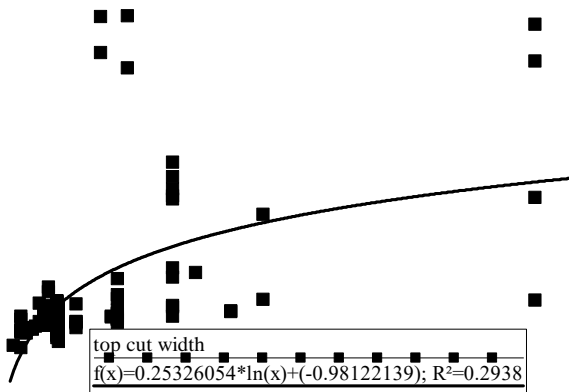
where:

$v$  - cutting speed [mm/min]

$D$  - laser beam diameter [mm]

$f$  - pulses frequency [Hz]

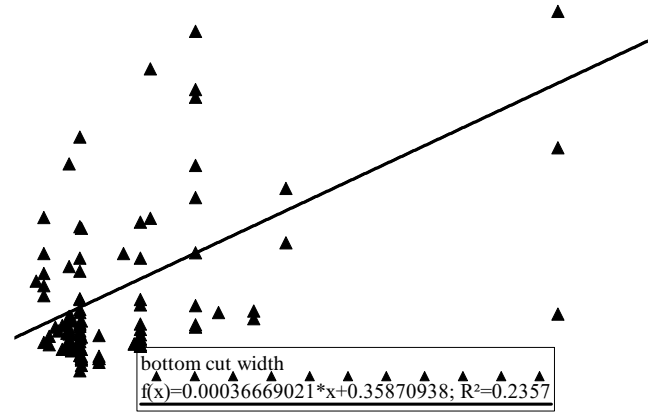
Linear energy is the energy transmitted by the laser beam to the material at a certain irradiated length which may be a segment or curve arc. The ratio  $spo$  is dimensionless size that may be subunit or negative. The ratio  $spo$  was used in paper [2] to characterize the experimental conditions. The cut was characterized by the cut width  $w$  [mm] at the top and bottom of piece. For the made cuts, the pulses frequency, the pulse time, the distance between the nozzle and the piece and the oxygen pressure were varied. Their variation is not considered in the following data processing.



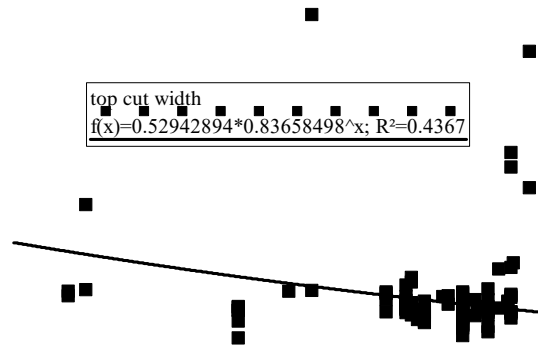
**Figure 2.** Variation of top cut width with linear energy

Figure 2 shows that although the cuts are made under different experimental conditions there are a relatively well correlated logarithmic increase trend taking into account the instability of the melting process. Figure 3 shows that the bottom cut width increases with linear energy. Importantly, the correlation type and correlation coefficient is close to the one for top cut width. This match is explained by the fact that a thin sheet has been cut. The bottom cut width of the piece is more difficult to correlate with the linear energy than the top cut width. It has been confirmed that for ratio  $spo$  may be more difficult to correlate it with the bottom cut width. Both variations, Figures 4 and 5, show that

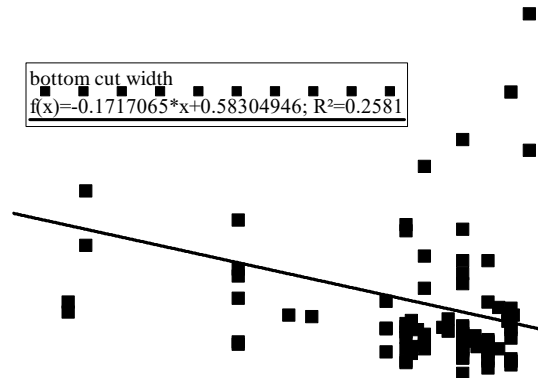
with the increase of the ratio  $spo$  the cut width decreases. This means an increase in evaporation. For the oxidation reaction, it is expected to be stable even with minimal irradiation.



**Figure 3.** Variation of bottom cut width with linear energy



**Figure 4.** Variation of top cut width with ratio  $spo$



**Figure 5.** Variation of bottom cut width with ratio  $spo$

It can be noted that we can express irradiation by a function independent of cutting speed.

$$E_l (1 - spo) = \frac{P}{D \cdot f} [\text{J/cm}] \quad (4)$$

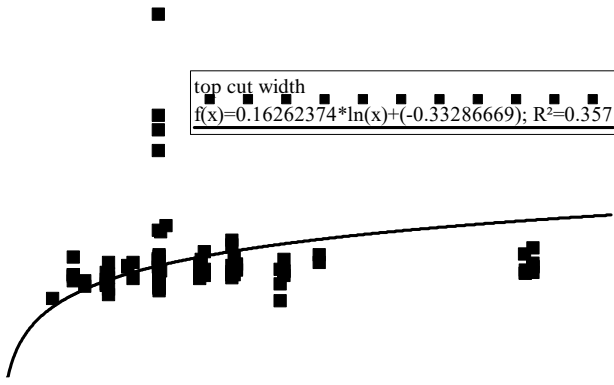


Figure 6. Variation of top cut width with  $E_l(1-spo)$

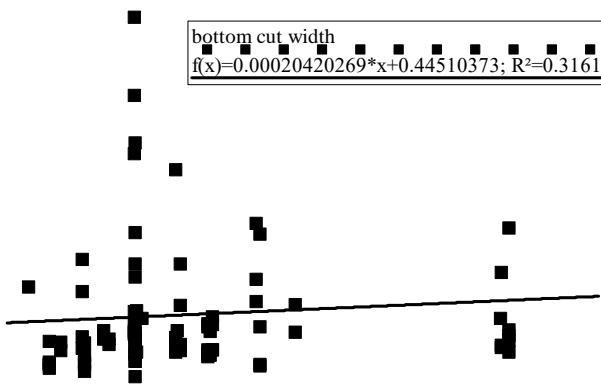


Figure 7. Variation of bottom cut width with  $E_l(1-spo)$

Figures 6 and 7 show that the cut width varies linearly with size of  $E_l(1-spo)$ . It can be seen that the cut width correlates better with size of  $E_l(1-spo)$  than with linear energy.

### 3. IRRADIATION CONDITIONS BY INDEPENDENT PARAMETERS

The technological laser system used allowed variation of average power,  $P$  [W], cycle [%], pulses frequency,  $f$  [Hz] and cutting speed  $v$ , [mm/min].

The cycle is given by:

$$\eta = \frac{t_p}{t_p + t_{off}} = t_p f \quad [\%] \quad (6)$$

where:

$t_p$  [s] - pulse time

$t_{off}$  [s]- the time that irradiation is stopped

By adjusting the cycle and the frequency, the pulse time  $t_p$  is determined. Another size that is defined by cycle is the peak power:

$$P_c = \frac{P}{\eta} \quad [\text{W}] \quad (5)$$

The ratio of the peak power to the surface of the spot (at the surface of the piece) will give the laser beam the intensity. Based on this, the thermal phenomena in the material can be estimated. It is noted that for laser cutting the average power and cutting speed are independent parameters. But they are not the only parameters that control irradiation, the frequency and the cycle appear. It is noted that peak power  $P_c$  and ratio  $spo$  are two independent parameters that include all varied parameters:

- peak power - power and cycle;
- ratio  $spo$  - cutting speed and frequency.

The independent expression of process parameters is considered to group parameters and simultaneously evaluate their effect.

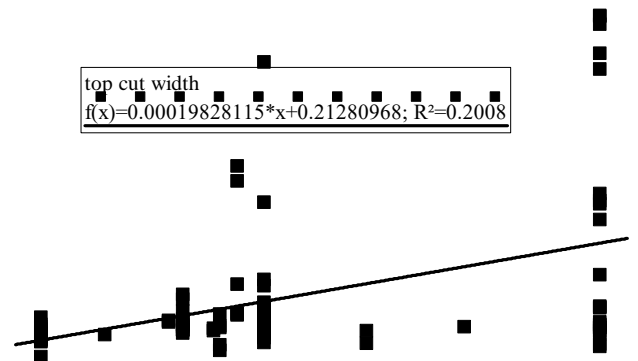


Figure 8. Variation of top cut width with peak power

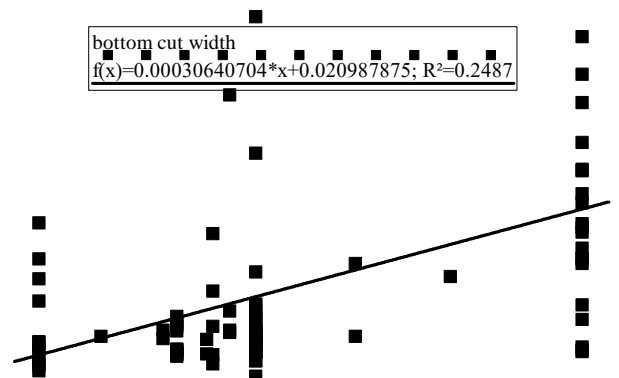


Figure 9. Variation of bottom cut width with peak power

Figures 8 and 9 show that there is a linear increase in cutting width with peak power for both top cut width and bottom cut width. This means that the intensity of the laser beam has a determined role in all the thermal phenomena that take place.

An arbitrary function that combines independent parameters peak power  $P_c$  and  $spo$  ratio is defined by the relation:

$$i = \frac{P_c}{1-spo} = \frac{E_l \cdot D}{t_p} [\text{W}] \quad (7)$$

It is independent by pulse frequency.

Figures 10 and 11 show the variation of the cut width with arbitrary function  $i$ . For this, a polynomial model was chosen that had a correlation coefficient  $R^2 = 0.4$ . This was achieved both for top cut width and for bottom cut width.

This function shows that at the center of the experimental field, narrow cuts with stability can be obtained.

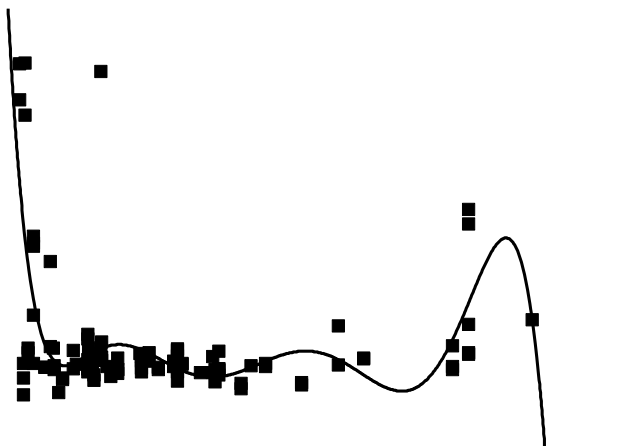


Figure 10. Variation of top cut width with function  $i$

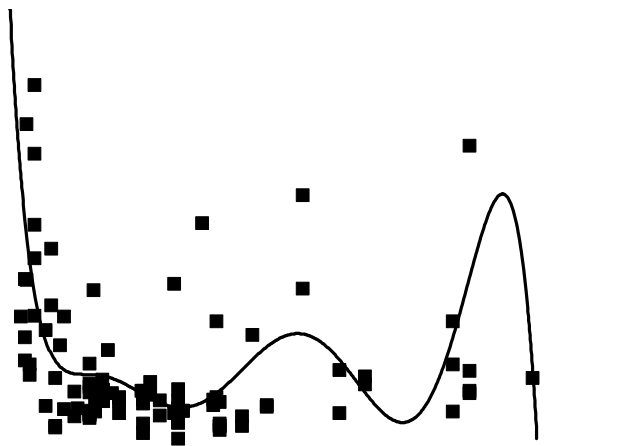


Figure 11. Variation of bottom cut width with function  $i$

## 4. CONCLUSIONS

The paper presents methods for the processing of experimental data related to oxygen assisted laser cutting. Among the parameters characterizing the laser cutting process were the parameters that characterize laser irradiation.

Cuts were characterized by the cut width. It was desired to obtain patterns that show the variation of a parameter under the condition that other parameters vary using regression functions. It has been shown that this type of analysis can yield results if we keep a certain type of regression function. For the correlation coefficient we make the condition to be a few tenths of the unit.

The proposed method can be applied to the processing of data obtained under industrial conditions where samples have not been made after classical experimental series or factorial experimental design. In the analysis, the concept of significant sizes for irradiation has been developed, linear energy and the ratio  $spo$ . Also irradiation was presented by independent sizes, ratio  $spo$  and peak power. Independent sizes can be used to define abstract functions. Their variation modeled within the limits of a sufficient correlation includes a large number of experimental data. By analyzing these variations, comparisons can be made between different researches or different industrial processes. This type of analysis is useful for developing an overview of laser cutting.

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