University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

**Journal of Engineering**
journal homepage: www.joe.uobaghdad.edu.iq
Number 10 Volume 25 October 2019

***Mechanical and Energy Engineering***

# Effect of laser process an inclined surface cutting of mild steel then analysis data statistically by RSM

**Dr. Kamil Jawad Kadhim***
Lecture
Al-Mussaib Technical Institute / Al-Furat Al-Awsat Technical University, 51009 Babylon, Iraq
E-mail: kamil_jawad35@yahoo.com

## ABSTRACT

The regression analysis process is used to study and predicate the surface response by using the design of experiment (DOE) as well as roughness calculation through developing a mathematical model. In this study; response surface methodology and the particular solution technique are used. Design of experiment used a series of the structured statistical analytic approach to investigate the relationship between some parameters and their responses. Surface roughness is one of the important parameters which play an important role. Also, its found that the cutting speed can result in small effects on surface roughness. This work is focusing on all considerations to make interaction between the parameters (position of influence) because laser power directly depends on cutting speed with high gas pressure and vice versa to obtain a less surface roughness. Data analysis showed that the lower value for roughness was (0.68) µm and the high roughness was (8.56) µm. The model values for considered fit are suggested to be as ($R^2$) = 51.76%. The selected coefficient is referred to the amount of model variation in the response. The adjusted value of ($R^2$) = 8.34% will calculate the number of forecasting model and is normally useful for comparing models with different numbers of predictions. The (F) test is used to determine whether interaction and major effects are significant. The **p-value** is the probability of obtaining a statistic test which is considered as the extreme of actual calculated values if the null hypothesis is true. A commonly cut-off value that used for the **p-value is (0.05)**. This value is used to be the active contribution to investigate the correlation between laser machining parameter with the surface roughness. Also the goal of this research highlights the experimental control parameters of mild steel laser processing with their responses.

**Keyword:** RSM, Design of experiment, mild steel, Statistical Approach roughness optimization.

# تحليل البيانات احصائيا لنهج خشونة السطح المثلى عن طريق القطع بالليزر للفولاذ الطري

**كامل جواد كاظم**
مدرس
المعهد التقني المسيب / جامعة الفرات الاوسط التقنية في الكوفة

## الخلاصة

باستخدام منهجية التصميم التجريبية (DOE) تم تطوير نموذج رياضي بشكل أساسي من خلال تحليل الانحدار لدراسة التنبؤ بالاستجابة . ثم تم تصميم التجربة باستخدام طريقة متسلسلة من المنهج التحليلي الاحصائي المنظم لدراسة العلاقة بين المدخلات والمخرجات .علما ان تقنية الحل الخاصة المستخدمة في هذة الدراسة هي منهجية سطح الاستجابة (RSM) وكانت نتائج خشونة السطح متباينة ولذلك لعبت دورا هاما ، لابد من ايجاد الحلول المناسبة لها . وتبين ان سرعة القطع يمكن ان تؤدي الى خشونة

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2019.10.09

Article received: 21/2/2018
Article accepted: 17/7/2018

اقل . في كل تطبيق تم التركيز على التفاعل بين العوامل ،عندما كانت قوة الليزر تعتمد مباشرة على سرعة القطع حيث ارتفاع ضغط الغاز ، والعكس بالعكس للحصول على أقل خشونة للسطح . وجرى تحقيق الربط بين هذه العوامل وعملية القطع بالليزر مع خشونة السطح الناتج موضح بشكل تفصيلي في المخططات التحليلية . وكانت اقل خشونة تم الحصول عليها من قياس ثلاث مناطق من العينة بعد اخذ المعدل هي 0.68 ، 8.56 مايكرون على التوالي. وكذلك تبين $R^2$ (R-sq) معامل التحديد يشير إلى مقدار التباين في الاستجابة الموضح بالنموذج. كلما زادت نسبة $R^2$ ، كلما كان النموذج أفضل للبيانات الخاصة بالتجربة. Adjusted $R^2$ (R-sq Adj) حسابات لعدد المتنبئين في النموذج الخاص بالتجربة ومفيد لمقارنة النماذج مع أعداد مختلفة من تنبؤات. P-value إن القيمة (p) هي احتمال الحصول على إحصائية اختبار تكون متطرفة على الأقل كالقيمة المحسوبة الفعلية إذا كانت فرضية الخطأ صحيحة. قيمة القطع المستخدمة بشكل شائع لقيمة p هي 0.05 ، إذا كانت قيمة p المحسوبة لإحصائية اختبار أقل من 0.05 . (F ) اختبار لتحديد ما إذا كان التفاعل والآثار الرئيسية كبيرة. كما يسلط بحثنا الضوءعلى عوامل السيطرة التجريبية من الليزرالمثالي المصحح و معالجة الليزر مع المخرجات المثالية .

# 1. INTRODUCTION

## 1.1 Response Surface Methodology (RSM).

RSM is a set of a statistical and mathematical method useful for modeling and optimization many engineering problems. The basic idea of RSM is to use a designed experiment sequence for getting the optimal responses that are affected by different input process parameters **Wander, 2010; Sivero, and Ammar, 2010.** Analysis by RSM can help for quantify the relationship between the input parameters and the responses. Compared with the traditional cutting method; the laser beam cutting has good features regarding the quality of the product surface finish. **Chaudhry and Shirley 2010 and Baskoro, et al., 2011.** Many investigations have been performed about a series of mechanical input parameters, such as oxygen pressure, pulse width, pulse frequency, and cutting speed and two output parameters such as average kerf taper and average surface roughness **Rivera, et al., 2011.** The results revealed that the average roughness is significantly influenced by oxygen pressure, cutting speed and interaction effects of oxygen pressure and cutting speed. On the other hand, average surface roughness is significantly influenced by oxygen pressure, pulse frequency, cutting speed, the interaction effect of pulse width and cutting speed, and interaction effects of pulse frequency and cutting speed. **Syn, et al., 2011. Sharma and Yadava 2012,** used pulsed Nd: YAG laser for cutting thin (Al) alloy sheet for curved profile, and they modeled and optimized the cutting quality during the cutting process by using Taguchi methodology and response surface methodology (RSM).

Many process input parameters have been investigated such as arc radius of curve profile, oxygen pressure, pulse width, pulse frequency and cutting speed, and the output parameters are an average kerf taper and average kerf deviation. The results are used to identify a specific central processing unit and the value of pulse frequency which most of the desire finding at the lower average of the kerf deviation. It is desirable to model and control the overcome of average deviation during cutting. It’s found that oxygen pressure is the most significant factor for minimization of average kerf deviation. It has been approved that the minimum values of the pulse width are the most desirable to achieve the average reduction of the kerf taper. **Sivarao, et al., 2012 and Deepak, 2012.** The outcome of many researches has been shown that scientific proceeding for response surface methodology is the latest optimization techniques have been applied successfully in industrial applications for optimal selection of process variables in the area of machining.

## 1.2 Statistical Approach

DOE is used to emphasize the basic experimental study based modeling. It is used to refer to the designed experimental approach which is far superior to an unplanned approach whereby a systematic way will be used to plan the experiment, collect the data and analyze the data **Madić, et al., 2012 and Radonjic, et al., 2012**. The design and analysis of the experiment are usually used to statistically prove the relationship between the parameters and the results. Design experiments are widely applied in the technology factories for the purpose of obtaining accurate results with high quality and tests validity. The application of conventional machines is restricted for normal cutting, and due to the sophisticated shape and unusual volume with high demands, the need for smart design, its become very essential for the appearance and advanced engineering in materials cutting. Thus, the need for unconventional methods in manufacturing becomes an urgent demand for the emergence of advanced manufacturing processes (AMP) **Chowdhury and Shirley 2010; Madi and Radovanovi, 2012 and Madik, et al., 2013.**

## 2. INITIAL DESIGN

The mathematical model was developed to investigate the selected parameters that affect the represented responses by kerf with an appearance of response surface roughness. This experiment is the actual application by using RSM program of Minitab 16, which shows the relationship between the inputs and their impact on the segment. As well as, using a matrix of (20) reading of inputs and outputs with central composite design (CCD) method to perform a full analysis by using a graphics to define the importance of each parameter of the response and select the best results.

## 3. WORKPIECE MATERIAL

### 3.1 Experimental details

Mild steel **(ASME SA 36)** is an important material having wide application in the industry due to soft and ductile properties, easy to cut and machined with good welding practice. The main reasons for these properties are the low carbon content, which varies between 0.15% and 0.3%. Some of the uses of mild steel are ship hulls, garden gates, girders, general structures. Also, ASME SA 36 Mild Steel Plates are used in heavy machinery, industrial boilers, wagon tippers, feeders, stackers, crushers, loaders, cranes, and supporting frames for equipment used in metallurgical and other heavy industries. The chemical compositions of this type of steel are given in **Table 1.** The sheet dimensions were 250 x 155 mm with a thickness of 6 mm.

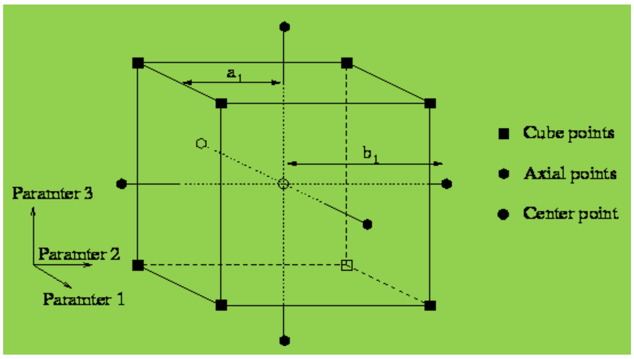
**Table 1.** A36 Mild Steel Plates Chemical Compositions.

| Grade | | C | CU | Fe | Mn | p | Si | S |
|---|---|---|---|---|---|---|---|---|
| A36 | min | 0.25 | - | - | - | - | - | - |
| | max | 0.290 | 0.20 | 98.0 | 1.03 | 0.040 | 0.280 | 0.050 |

## 4. CUTTING PARAMETERS

The main aspect of our study is that the experiment factors (cutting speed, power supply, and gas pressure) are focusing on investigating systematically and observing the effect of these factors on the roughness of the cutting surface of the kerf width without considering the kerf width. In addition, it also focuses on the outputs of the cutting operations (roughness) by using a different set of pieces to choose the best factors for the purpose of adoption and recommendation. Determining the upper and lower value of the roughness as well as the factors involved with

comparison between them to choose the less roughness among them, as shown in **Fig. 1 (a, and b)**. The remaining values and results are shown in **Table 3.**




| | |
|---|---|
| | Factors: 3 Replicates: 1<br>Base runs: 20 Total runs: 20<br>Base blocks:1 Total blocks: 1<br>Two-level factorial: Full factorial<br>Cube points: 8<br>Center points in cube: 6<br>Axial points: 6<br>Center points in axial: 0<br>Alpha: 1.68179 |
| **(a)** | **(b)** |

**Figure 1**. RSM Central Composite Design for 3 factors at two levels.

The experiment is based on the values of inputs parameters specified previously, and these values are then corrected with the determinants of the selected factors, as well from the results of the reasonable matrix values after correction. After entering the upper roughness values, an entire analysis can be performed using RSM to define each parameter that affects on the response. The first procedure in RSM is to find an appropriate approximation for the true relationship between Y and the independent variables. Usually, a low-order polynomial in some region of the independent variables is employed. If the response is well modelled by a linear function of the independent variables, the approximating function is the first-order model, such as a regression equation for a model with multiple predictors, as in equation below:

$$\mathbf{Y = \beta 0 + \beta 1x1 + \beta 2\ x2 + \beta k\ xk + e} \quad \textbf{(1)}$$

A linear function of these factors are considering a first-order model: Where Y= response, X1, X2= factors, β1, β2, βk = regression coefficients, β0= regression estimates, e = error term ~ N (0, 1) with a normal distribution, mean of 0, and standard deviation of б. If there is curvature in the system, a polynomial of the higher degree must be used. The second-order model is quadratic (equation 2):

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_{i}x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum \beta_{ij}\, x_i x_j + e \quad (2)$$

Many of RSM problems usually use one or both of these approximating polynomials. The input parameters for experience should be identified, high peak points and the low peak values of the experiment depend on the used materials. The machine model (LVD 2513) laser cutting was used with maximum power of 4000 watts, (6-10) micrometers of wavelength and (100) plus. Oxygen and carbon dioxide are used according to the type of metal to conduct laser cutting with an auxiliary agent of inert gasses such as nitrogen. So nitrogen gas maintains the properties of the harvested metal and isolates the other lanes from the surface of the cut metal. Carbon dioxide was used in this experiment in soft steel cutting. **Fig. 2**, shows the details of the position of the laser pieces.

**Figure 2**. A laser cutting machine LVD Model 2513 with a maximum output power of 4000 Watt, 6301 µm wavelength, available in University technical Malaysia (UTeM).

**4.1 INTERPRETATION OF RESULTS**

The degree of accuracy in this experiment can be increased by using scientific experimental design techniques. The design of experiment (DOE) approach is excellent outperforms for unplanned approach because it is a systematic and scientific method, testing data collection and analysis, with limited use of available resources.

In the central **composite design (CCD)** method**,** three factors can run in one block. This design is rotatable and orthogonal, as shown in **Fig. 1, Table 2** and **Table 3**. Minitab programming can display the conditions or experimental settings for each design point. In these experiments, we can use the order values to determine the conditions for each run, such as, in the first round of experiment, Laser Power can set to (A) in 2500 (watt) (1 = high), cutting speed (B) at 1000 (mm/min) (1 = high) and gas pressure at 6 (psi) (1= High). These values will sets and design in Minitab by default. The p-value is used in hypothesis tests to determine whether it will reject or fail to reject the null of hypothesis. The value (p) is the probability of obtaining a statistic test that at least as extreme as the actual calculated value when the null hypothesis is correct. The value of pieces commonly used for the p-value of 0.05. Also, if the calculated p-value for a test statistic is less than 0.05, zero hypotheses will be rejected. Therefore, this research is focusing on finding a method or formula for superior-excellent to solve all the problems in the analysis of the critical cutting area. Many of the RSM problems are normally use one or both of these approximating polynomials. The input parameters for experience should be identified as the high and low value depends on the type of the used material. The range of these parameters values is shown in **Table 2**.

**Table 2.** Parameters Range.

| **Parameter** | **Low** | | **High** |
|---|---|---|---|
| Laser Power (watt) | 1250 | - | 2500 |
| Cutting Speed (mm/min) | 500 | - | 1000 |
| Gas Pressure (psi) | 2 | - | 6 |

**Table 3.** Experimental Run and Results of Surface Roughness Non-Linear Incline Cutting.

| Run | StdOrder | RunOrder | PtType | Blocks | power | speed | pressure | Roughness |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | -1 | 1 | 2500.00 | 750.00 | 4.00000 | 1.34 |
| 2 | 7 | 2 | 1 | 1 | 1503.37 | 898.65 | 5.18921 | 0.79 |
| 3 | 19 | 3 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 1.98 |
| 4 | 14 | 4 | -1 | 1 | 1875.00 | 750.00 | 6.00000 | 1.18 |
| 5 | 3 | 5 | 1 | 1 | 1503.37 | 898.65 | 2.81079 | 1.24 |
| 6 | 4 | 6 | 1 | 1 | 2246.63 | 898.65 | 2.81079 | 0.75 |
| 7 | 17 | 7 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 1.19 |
| 8 | 8 | 8 | 1 | 1 | 2246.63 | 898.65 | 5.18921 | 1.46 |
| 9 | 15 | 9 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 1.26 |
| 10 | 20 | 10 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 0.69 |
| 11 | 16 | 11 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 1.28 |
| 12 | 11 | 12 | -1 | 1 | 1875.00 | 500.00 | 4.00000 | 0.84 |
| 13 | 18 | 13 | 0 | 1 | 1875.00 | 750.00 | 4.00000 | 0.94 |
| 14 | 5 | 14 | 1 | 1 | 1503.37 | 601.35 | 5.18921 | 1.30 |
| 15 | 6 | 15 | 1 | 1 | 2246.63 | 601.35 | 5.18921 | 1.20 |
| 16 | 12 | 16 | -1 | 1 | 1875.00 | 1000.00 | 4.00000 | 1.16 |
| 17 | 9 | 17 | -1 | 1 | 1250.00 | 750.00 | 4.00000 | 1.08 |
| 18 | 1 | 18 | 1 | 1 | 1503.37 | 601.35 | 2.81079 | 0.83 |
| 19 | 2 | 19 | 1 | 1 | 2246.63 | 601.35 | 2.81079 | 1.54 |
| 20 | 13 | 20 | -1 | 1 | 1875.00 | 750.00 | 2.00000 | 8.56 |

## 5. RESULTS AND DISCUSSIONS

Three readings were calculated for each sample, and then the calculation of the average values of surface roughness for each sample is estimated. Each sample was analyzed by examination and decomposition device as in **Fig.5** to obtain the roughness data by the laser cutting for the mild steel as shown in **Table 3**, and the main aim is to estimate the effects of regression coefficients for roughness on the surface as shown in **Table 4.**

For necessary action, it's important to check the adequacy of the supplied model whether it was incorrect or unspecified model which can lead to misleading conclusions. By checking the suitability of the linear form (first-order), the model can be checked f it is specified or not. The small p-value ($p = 0.000$) indicates that there is no appropriate test to indicate that the linear model does not fit the response surface appropriately. Because of not adequately, the linear model of unfit surface response, therefore fitting it as quadratic (second-order) model is needed.

Linear comparison of each effect in the linear case was done independently so that the linear terms are the same when they fit only as a linear model with quadratic model and fits as square terms when the rest design is taken to use as an orthogonal design. The error interval, S = 1.61129, is small because the variability accounted by this error is reduced. The applications of this operational method is a linear ordinary differential equation with variable coefficients as shown in upper tables. For versus fits, a quantity remaining after other things have been subtracted or allowed for the residuals, these to be randomly scattered about zero. In this case, one may want to try to include higher-order terms of the predictor and see whether one can get a better fit. This model is shown in **Table 3** as R-Sq = 51.76% R-Sq (pred) = 0.00% R-Sq (adj) = 8.34% through suggesting that the model value for this case is considered fit.

Minitab shows the experimental conditions or settings for each factor in any design point. The central composite design is shown in **Fig 1, and Table 2 to Table 3**. Therefore, the summary of resolution and tables design will appear according to choice RSM method. Performing the experiment by using the specific order is important to determine the conditions for each run, as discussed above. The regression equation details of the catalytic reaction data for surface roughness (Ra) is:

**Ra= 1.18692 + 0.07892 * pressure – 0.01724* power - 0.90223 * speed (3)**

This work focused on three separate models in the form of multi-boundary equations and implementing each experiment separately to select the best product and then adopted them in the specific design. The next step is to take the values of the best input parameters to insert them as an operations data for the laser cutting machine (oxygen pressure, cutting speed and power supply) to find the best results as shown in **Fig 5: (a, b, c, and d).** Sur test SJ-310 machine contact stylus profiler by MITUTOYO, of the limited track are using in measuring the roughness. **Table 4** shows the details of the linear and quadratic processes and the interaction between them. It's essential to observe the four conditions obtained from the interactions mentioned in **Table 4** where p = 0.994 for small and quadratic interactions was p=0.165 (few). The value of the pressure was p = 0.836 small through the reaction of velocity, the square pressure p= 0.489, and the power supply p= 0.726. All these values of statistical are significance to the effects of interaction among them. The micro-geometry is a precise configuration of the shape of the surface parts that appear when looking at the surface under the microscope, where it normally appears in the form of fine curls or roughness of a groove or ducts that exist no matter how strong the speed of the laser, pressure or power supply. Analysis of variance for surface roughness is shown in **Table 4.** It is too early to predict a result or predict the responses for new design points by using model of roughness. This model was suggested through various roughness rates as a top-order are more than important to model the response surface to fit the full quadratic model. For the full quadratic model, the p-value for lack of fit is (0.000), and it will be suggested that this model is adequately addressed to fit the data in Table 4, and the schematic of straight-line method characterizes the nature of model remnants. This method of defining a residual as a difference between the observed value Y and it's fitted $\hat{Y}$. As shown in the first plot of **Fig. 4 (C),** which represents the residuals versus the fitted values used to exam the sufficiency of functional part of the model. In the second plot **Fig. 4 (D),** shows the residual versus order, which was used to check for any drift in the process, where each residual is plotted against an index of observation orders of data. As discussed earlier and described in **Fig. 4 (C) and (D**), the remaining graph analysis indicated that there was no clear pattern, implying that the remains of the models are randomly distributed, as described in probability plot data in **Fig. 4 (A).**

**Table 4.**Estimated Regression Coefficients for Roughness.

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.18692 | 0.6572 | 1.806 | 0.101 |
| Pressure | 0.07895 | 0.4360 | 0.181 | 0.860 |
| Power | -0.10724 | 0.4360 | -0.246 | 0.811 |
| Speed | -0.90223 | 0.4360 | -2.069 | 0.065 |
| Pressure*Pressure | -0.30510 | 0.4244 | -0.719 | 0.489 |
| Power*Power | -0.15308 | 0.4244 | -0.361 | 0.726 |
| Speed*Speed | 0.96062 | 0.4244 | 2.263 | 0.047 |
| Pressure*Power | 0.02375 | 0.5697 | 0.042 | 0.968 |

| | | | | |
|---|---|---|---|---|
| Pressure*Speed | -0.12125 | 0.5697 | -0.213 | 0.836 |
| Power*Speed | -0.09875 | 0.5697 | -0.173 | 0.866 |

S = 1.61129 PRESS = 194.375

R-Sq = 51.76% R-Sq (pred) = 0.00% R-Sq (adj) = 8.34%.

## 6. INTERPRETING THE RESULTS AND DISCUSSION

It is already explained in the analysis of the first-degree equation that it did not fit the required model in production, so a model of the second degree is needed to fit with the required design and develop it to reduce the roughness of the required surface. By working on the second-order (quadratic model), the value of p = (0.000) indicates that the model appropriately fits the desired design as in **Table 5**. Creating a histogram is possible before or together with the analysis to confirm the assumptions and guide further analysis. The probability plot is shown in **Fig. 4 (B),** and these data are plotted as a straight line. The **p-value** is more **than 0.05,** the roughness is low, and it can be concluded that the data is taken from a naturally distributed group. Besides, the log-transformed quadratic model appears to provide a good fit to the data. The contour plot of catalytic reaction data in **Fig 5** shows the reaction power is plotted on the X-axis and reaction speed is plotted on the Y-axis. The contour areas represent constant responses, which correspond to yields **of 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8.** The contour with the dark purple colour in the lower right corner indicates the contour where Yield is the highest **(1.8).** It's observed that the surface roughness increased when moving away from the lower right to the lower right corner of the plot. Thus, the surface roughness is reduced simultaneously by reducing the power and increasing speed. This plot suggests that it is possible to minimize roughness at a cutting speed of slightly more than **560 (mm/min)** and a power less than **220 Watts**. The contours suggest that the response surface indicate a lower roughness. As shown in the diagram analysis in **Fig.6**, the surface contour indicates that the less roughness value on the surface is obtained at low power supply levels and when the cutting speed is high, and this observed in the right corner below the plot. In addition, the shape of the response surface can be plotted and get a general idea of yield at various settings of laser power and cutting speed with four residual plots by using Minitab software. The remaining quantity after the other values have been subtracted or allowed for (residual plots) do not indicate any problems with the pattern. Residual plot choices can discern visually for technical assistance in interpreting residual plots, as a one representing contour for roughness schemes of this response surface. The contour plots as shown in **Fig. 5**, show the quadratic effect of the surface plot in both laser power and cutting speed. That is, the response surface changes exhibiting the curvature is with variable shape as a rising ridge while the other holding area is constant. The surface plot in **Fig. 6** shows that the high power supply during laser cutting with low oxygen pressure according to the matrix in **Table 3** giving excellent advantages of the product. This feature appears in the upper left corner of the chart in **Fig. 5**. For more suitable increment, it's possible to see the shape of the response surface and get a general idea of the full magnitude of yield at various settings of pressure and power.

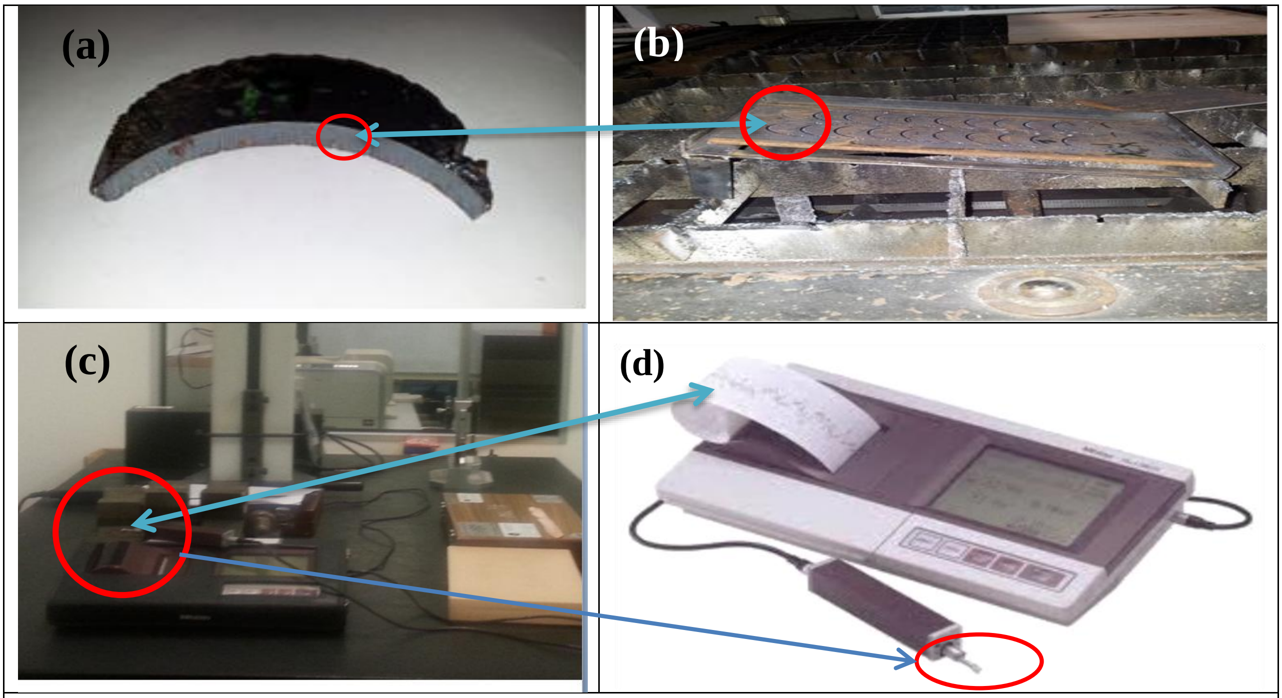



**Figure 3.** Laser cutting process and inspection device the surface roughness as applied to hard cutting such as (a, b, c, and d).

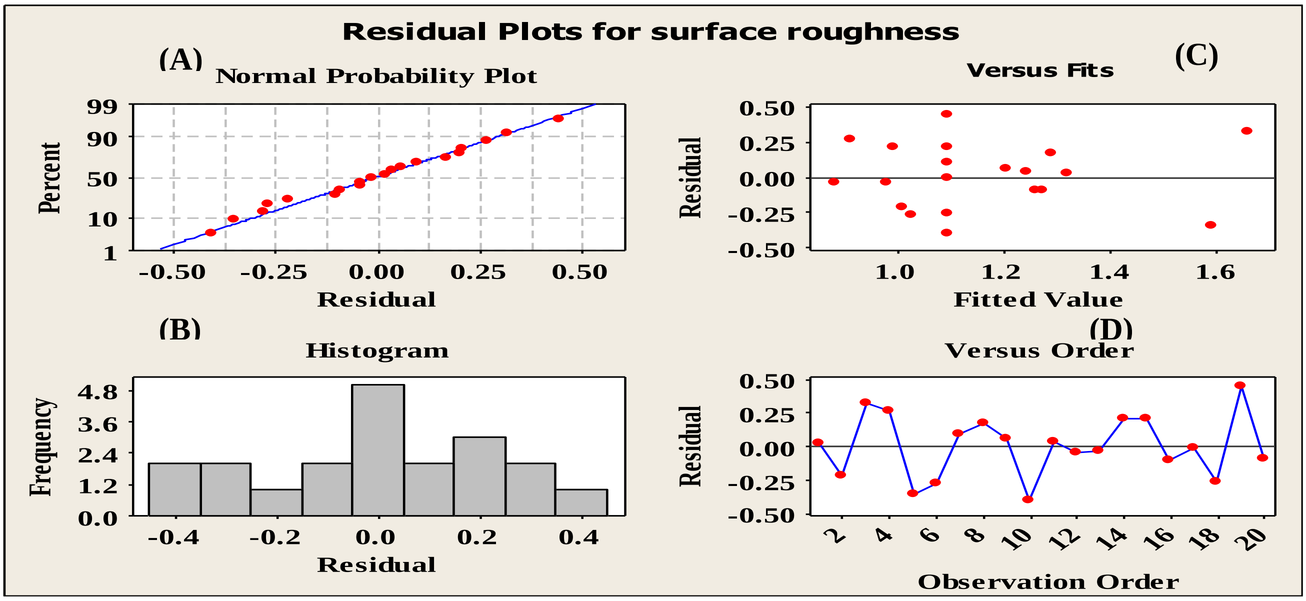



**Figure 4.** Residual Plots for Roughness.

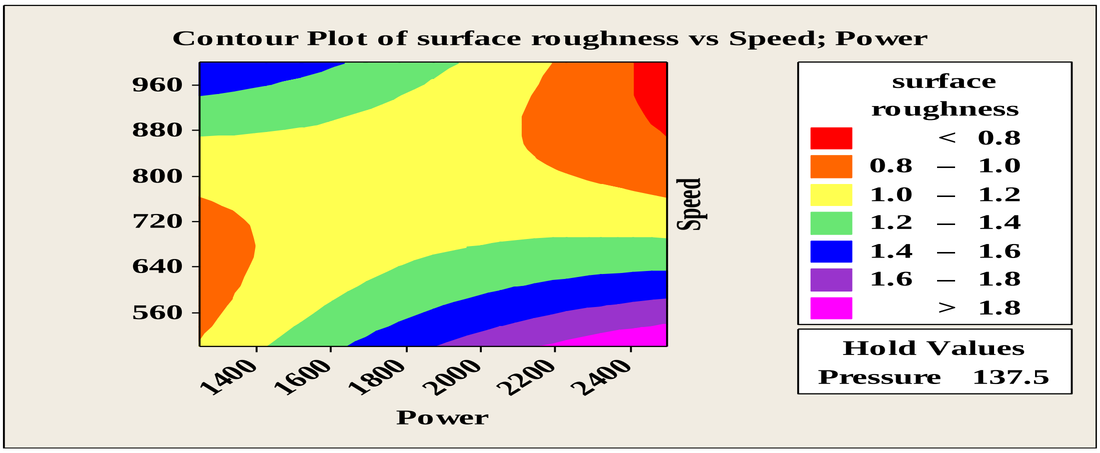



**Figure 5.** Contour Plot .

**Table 5.** Analysis of Variance for Roughness.

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 9 | 27.8535 | 27.8535 | 3.0948 | 1.19 | 0.392 |
| Linear | 3 | 11.3591 | 11.3591 | 3.7864 | 1.46 | 0.284 |
| Pressure | 1 | 0.0851 | 0.0851 | 0.0851 | 0.03 | 0.860 |
| Power | 1 | 0.1571 | 0.1571 | 0.1571 | 0.06 | 0.811 |
| Speed | 1 | 11.1170 | 11.1170 | 11.1170 | 4.28 | 0.065 |
| Square | 3 | 16.2943 | 16.2943 | 5.4314 | 2.09 | 0.165 |
| Pressure*Pressure | 1 | 2.0973 | 1.3415 | 1.3415 | 0.52 | 0.489 |
| Power*Power | 1 | 0.8985 | 0.3377 | 0.3377 | 0.13 | 0.726 |
| Speed*Speed | 1 | 13.2985 | 13.2985 | 13.2985 | 5.12 | 0.047 |
| Interaction | 3 | 0.2001 | 0.2001 | 0.0667 | 0.03 | 0.994 |
| Pressure*Power | 1 | 0.0045 | 0.0045 | 0.0045 | 0.00 | 0.968 |
| Pressure*Speed | 1 | 0.1176 | 0.1176 | 0.1176 | 0.05 | 0.836 |
| Power*Speed | 1 | 0.0780 | 0.0780 | 0.0780 | 0.03 | 0.866 |
| Residual Error | 10 | 25.9625 | 25.9625 | 2.5962 | | |
| Lack-of-Fit | 5 | 25.5618 | 25.5618 | 5.1124 | 63.80 | 0.000 |
| Pure Error | 5 | 0.4007 | 0.4007 | 0.0801 | | |
| Total | 19 | 53.8160 | | | | |

## 7. RESPONSE OPTIMIZATION

The results of disproportions and roughness were obvious on the surface. **Table 6** shows these results and optimization values**.** The cutting process was implemented at the following factors: (pressure 2, power 1250 and speed 500). Therefore the data of results validation of cutting roughness model should be based on the typical global solution in order to typify that the ideal parameters are (Pressure = 5.95960, Power = 1464.65 and Speed = 505.118). In addition, the expected response was as follows: (Roughness = 4.61986, desirability = 0.999964 and Composite Desirability = 0.999964). These results represent the validated data of cutting roughness model is in this range. **Fig. 7** shows distinct quality is desirable for both of two cases. The amount of surface roughness is 0.099996 is the numerical value considered being desirable in design. The ideal factors for the real design and machine operation of the as follows: pressure value (5.9596), the

power value of (1464.6465), and the speed become (505.1178). The necessary hypothesis is desire to possess and adjust the factors, and settings of initial solution. By using the plot. It is easy to move the vertical bars to change the factor settings and see how the separate desirability of the responses and the composite desirability change. In **Fig. 7**, the shape can be changed as the designer wants to reduce the cost of the product and meet the specifications of optimal production. **Fig. 8:** Summarize the cutting operations according to the experimental conditions of four samples to illustrate the course of the RSM method according to the matrix in **Table 3**.

**Table 6**. Surface Roughness Optimization.

| Roughness | Goal | Lower | Target | Upper | Weight | Import |
|---|---|---|---|---|---|---|
| | Target | 0.68 | 4.62 | 8.56 | 1 | 1 |

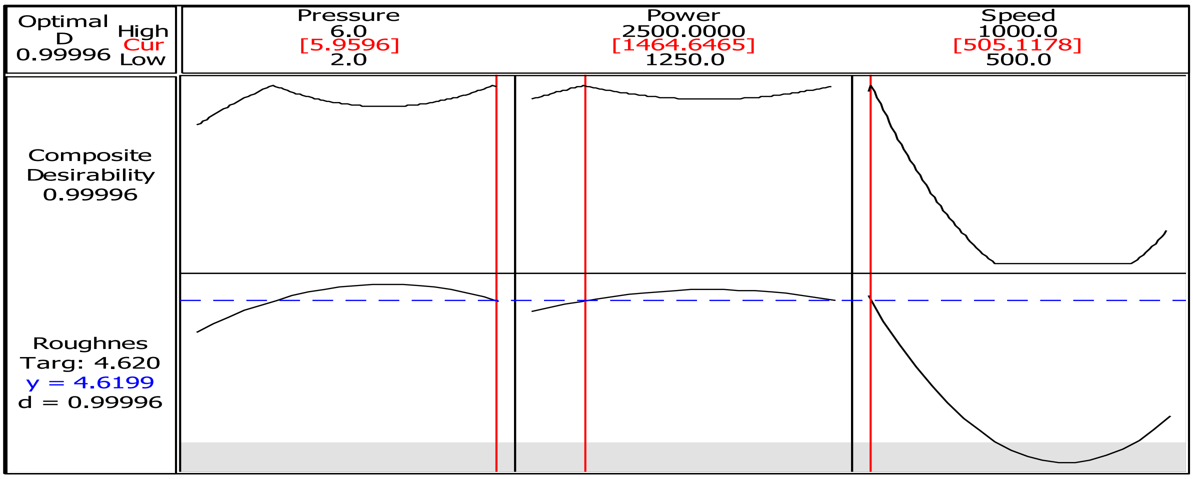



**Figure 7**. Surface Roughness Optimization.

Run 1

**1-Cutting Parameters**

A- Laser Power (watt) : 2500.00

B- Cutting Speed (mm/min) : 750.00

C-Gas Pressure (psi) : 4.000.00

**2- Surface roughness** : 1.34

Run 2

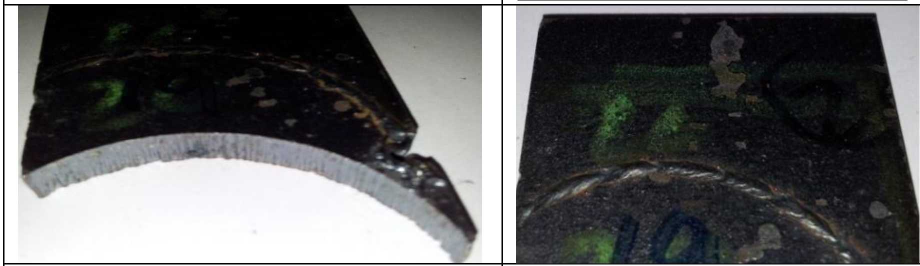
**1-Cutting Parameters**

A-- Laser Power (watt) : 1503.37

B- Cutting Speed (mm/min) : 898.65

C-Gas Pressure (psi) : 5.18921

**2- Surface roughness** : 0.79



Run 19

**1-Cutting Parameters**

A- Laser Power (watt) : 2246.64

B- Cutting Speed (mm/min): 601.35

C-Gas essure (psi) : 2.81079

**2- Surface roughness**: 1.54

Run 20

**1-Cutting Parameters**

A- Laser Power (watt) : 1875.00

B- Cutting Speed (mm/min): 750.00

C-Gas Pressure (psi) : 2.00000

**2- Surface roughness**: 8.56

**Figure 8.** Summary of cutting operations with the working conditions of four samples to illustrate the course of the method according to the matrix in Table 4.

## 8. CONCLUSIONS

The RSM method and the results obtained from the numerical and practical analysis on the laser cutting machine of the experiment model indicate that such programs should be used to assist the researcher in the investigation and results comparing. The three inputs in the cutting machine (oxygen pressure, cutting speed, power supply) and output responses (roughness) reactivity for the purpose of obtaining an ideal product depend on the development of continuous laser cutting process for the aforementioned metal. The polynomial equations were successfully related to the relationships between machine laser input process parameters. The roughness, outputs of the runs of modeling validation were within the (95) % prediction interval of the developed models and their residual errors, compared to the predicted values, were less than 5%. The investigation of the research validity results for the (model) and in comparison with practitioners research in this field through the published research, showed the reduction of surface roughness was approved based on the change of factors mentioned above. These factors were determined from the analysis of ANOVA during the models development and the equations mentioned above, especially the equation of the second degree. This research work focused on the relationship between the effect of oxygen and the power supply that cannot be ignored during cutting operations and which has not been mentioned in previous research. Also, this work has focused largely on the interaction of oxygen pressure and power, which has an excellent effect on reducing roughness as oxygen pressure is increased during laser cutting operations and unevenly. In general, it’s noted that the linear equations did not meet the purpose at of this research, so the equations of the second degree

are included in the results to ensure the little roughness. The correlation study between cutting characteristics and the non-linear inclined suggested that the cutting performance correlated most significantly to the surface roughness with nozzle type assessment. Therefore, an obligation to ensure the roughness values that meet successively for each cutting magnitude.

## REFERENCES


- Baskoro, A. S., Herwandi, K. G. S., Siswanta, A., & Kiswanto, G. 2011. *Analysis of Cutting Process of Materials Using Low Power Laser Diode and CO2*. International Journal of Mechanical & Mechatronics Engineering IJMME IJENS Vol: 11 No: 06.

- Choudhury, I. A., & Shirley, S. 2010. *Laser cutting of polymeric materials: An experimental investigation*. Optics & Laser Technology, 42(3), 503-

- Madić, M., Radovanović, M., & Nedić, B. 2012. *Correlation between Surface Roughness Characteristics in CO2 Laser Cutting of Mild Steel.* Tribology in Industry vol. 34, No. 4

- H.A. Eltawahni, M. Hagino, K.Y. Benyounis, T. Inoue, and A.G. Olabi. 2012. Effect of CO2 laser cutting process parameters on edge quality and operating cost of AISI316L, Optics & Laser Technology 44 (2012) 1068–1082 Contents

- Deepak, S. S. K. 2012. Applications of Different Optimization Methods for Metal Cutting Operation–A Review. Research Journal of Engineering Sciences . Vol. 1(3), 52-58

- A. Sharma, V. Yadava. 2012. Modelling and optimization of cut quality during pulsed Nd:YAG laser cutting of thin Al-alloy sheet for straight profile. Optics & Laser Technology 44 (2012) 159–168

- Madić, M., Radovanović, M., & Slatineanu, L. 2013. *Surface Roughness Optimization In* $Co_2$ *Laser Cutting By Using Taguchi Method.* U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 1,
- Milo J. MADI and Miroslav R. RADOVANOVI. (2012). *Analysis of the Heat Affected Zone in Co2 Laser Cutting of Stainless Steel*. Thermal Science, Year 2012, Vol. 16, Suppl. 2, pp. S363-S373.
-
- Radonjić, P. D. S., Save, S., Čačak, S., Kovač, P. D. P., & Sad, N. 2012. *Defining New Processing Parameters in Laser Cutting*. 16th International Research/Expert Conference. Dubai, UAE

- Radovanovic, M., & Madic, C. 2011. *Experimental investigations of* $CO_2$ *laser cut quality*: a review. Nonconventional Technologies Review, 4, 35-42

- Riveiro, A., Quintero, F., Lusquiños, F., Comesaña, R., & Pou, J. 2011. *Study of melt flow dynamics and influence on quality for* $CO_2$ *laser fusion cutting.* Journal of Physics D: Applied Physics, 44(13), 135501

- Sharma, A., & Yadava, V. 2013. *Modelling and optimization of cut quality during pulsed Nd: YAG laser cutting of thin Al-alloy sheet for curved profile*. Optics and Lasers in Engineering, 51 77–88

- Sivarao, S., Sivakumar, D. M., Yuhazri, Y., Tan, C., & Haeryip, S. 2012. *An Exploratory Study-Critical Laser Processing of Composite Materials*. International Journal of Engineering Research & Technology, 1(10), 1-8

- Sivarao, T. J. S., & Ammar, S 2010. *RSM Based Modeling for Surface Roughness Prediction in Laser Machining*. International Journal of Engineering & Technology IJET-IJENS Vol: 10 No: 04

- Syn, C. Z., Mokhtar, M., Feng, C. J., & Manurung, Y. H. 2011. *Approach to prediction of laser cutting quality by employing fuzzy expert system*. Expert Systems with Applications, 38(6), 7558-7568

- Wandera, C. 2010. *Performance of high power fibre laser cutting of thick section steel and medium section aluminium*. Ph.D. thesis. Lappeenranta University of Technology, Finland.