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An Approach to the Influence of Fluid Viscosity and the Cutting Parameters in Turning a Carbon Steel using Surface Methodology

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ABSTRACT

This experimental study focuses on the effect of viscosity on the surface condition of machined part during turning. The tests are carried out on C45 steel, using metal carbide cutting tools. The objective is to optimize the cutting parameters as well as the analysis of the surface roughness (Ra), using the surface response method, which allows to present the mathematical models of the roughness. The effect of the interactions on the roughness criterion was studied using a statistical analysis based on analysis of variance (ANOVA). The results recorded show that the cutting speed has the most significant effect on the surface condition. This optimization deduces that the best surface roughness of the non-alloy steel parts C45 is obtained when the cutting speed is 286 m / min, the feed rate is 0,15 mm / rev, the viscosity is 22,5 Pas and the depth of cut is 1,1 mm.

Keywords: *Turning; Viscosity; Roughness; Cutting conditions; ANOVA; Optimization.*

1.0 Introduction

Machining is economically important in the industry. This is one of the most common processes for obtaining pieces of different shapes. As such, the mastery of turning processes is a major challenge for industries. To determine the quality of a turning operation, it is possible to use statistical methods to predict surface roughness, tool wear, cutting forces as a function of cutting conditions. Research is conducted to bring into play the influence of cutting parameters on the surface condition of a machined workpiece. The determination of this relationship remains an open field of research, primarily due to advances in machining technology and available materials and modeling techniques [1]. Million D.S and sentil. P [2] predicted the roughness of the C45 steel turning surface with the parameters, spindle speed, feed rate, depth of cut and nose radius. They found that the optimal values of the cutting parameters which give a Ra = 0.2433µm, are: (N = 2200 rpm, f = 0.1 mm / rev, dc = 0.1 mm and r = 1.2 mm). Tadeusz .L [3] showed the significant influence of the cooling and lubrication method on the topography of C45 steel. Lakhdar. B et al [4] used analysis of variance (ANOVA) to determine the effect of cutting speed, feed rate and depth of cut on the surface condition and cutting forces during turning of AISI 420 steel. Basim A et al. [5] developed two mathematical models respectively for roughness and temperature for AISI 1020 steel using the surface response methodology. Khaider B et al. And Mohamed W et al. [6,7] studied the response surface methodology to find the optimal values of the cutting parameters of AISI 52100 steel machining. Lakhdar B et al. [8] analyzed the effects of cutting speed, feed and depth of cut on surface roughness and material removal rate when turning the X20Cr13 steel by the Taguchi design method and also by the ANOVA analysis of variance method. M. Y. Nourdin et al. [9] studied the performance of a multilayered Tungestene carbon tool using the Surface Response

Methodology (RSM) when turning AISI 1045 steel. They found that the feed rate and the most important factor which influences roughness and tangential cutting force. Ashok K. S and Bidydhar [10] concluded that the developed Response Surface Model (RSM) can be used effectively to predict the surface roughness of D2 steel. Zeenat .F et al. **[**11] used three types of cutting fluid to examine its effects when turning AISI 1008 mild steel. Emel K et al.

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[12] Show that the choice of cutting fluid type (vegetable base) has a remarkable influence on the specific energy, the surface roughness and the service life of the tool when turning AISI 304 steel. Onyemachi .J et al. [13] used three cutting fluids with different characteristics (Ph, corrosion resistance, etc.) to study its effects on the surface condition of AISI 1330 alloy steel in turning. The results obtained show that the optimal parameters to obtain a better roughness Ra were obtained with a cutting fluid based on peanut oil. The regression method was used by B. Fnides et al. [14] on 50 HRC treated X38CrMoV5-1 grade steel machined using a mixed ceramic tool. The result revealed that the lap feed and the cutting speed are significant on the surface roughness in contrast to the non-significant depth of cut. The objective of the Rishi S study [15] is to know the optimal cutting parameters and the best lubrication conditions namely: dry machining, wet and solid lubrication for turning operations for AISI4340 steel with hardness 60 HRC. The evaluation of plant-based cutting fluids for the machining of 304 L austenitic steel and AISI 316 L steel is the goal of the Kuram .E et al. [16, 17].

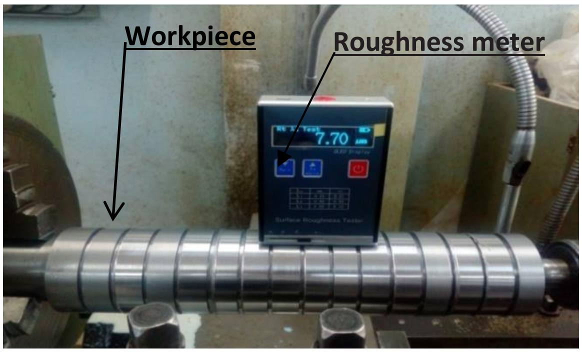
The studies of Anthony X and Adithan M [18] on the effect of Coconut Oil in reducing tool wear and roughness show that coconut oil best result is compared with two other cutting fluids namely an emulsion oil and pure cutting oil. In this context, the objective of the present work is to predict the influence of the viscosity of the cutting fluid (commercial fluid) and consequently the percentage of water in the oil and the cutting parameters during turning C45 carbon steel using a coated carbide tool. The response surface methodology and the ANOVA variance analysis are used to define the relationship between these parameters and the surface condition.

2.0 Experimental Procedure

2.1 Equipment and materials

In the present study, the workpiece material is a C45 steel bar with a diameter of 65 mm and a length of 260 mm. This steel, like all medium carbon steels, is used in mechanical engineering after normalization, improvement and surface hardening. Good oil hardenability, good overload resistance in the treated state. It is steel very used in mechanics, for parts of medium to strong sections: camshafts, racks, crankshafts, connecting rods, gears. Its chemical composition (in wt%) is given as follows: 0.50% C; 0.014% Cr; 0.002% Mo; 0.29% Si; 0.65% Mn; 0.01% S; 0.006% P; 0.003% Ti; 0.006% Ni; 0.016% Cu; 0.008% Ae; 0.002% Sn and the rest is Fe. The machining experiments were performed using a conventional lathe-type I11MT with 6.6 kW spindle power. The measurements of surface roughness (Ra) for each cutting condition were obtained from KR-100 roughness meter. The length examined is 6 mm with a basic span of 0.25 mm. The measurements were repeated at three equally spaced locations around the circumference of the workpieces and the result is an average of these values for a given machining pass [7].

Figure 1: Experimental Setup for Roughness Measurements



2.2 Planning of experiments

To study the impact of the cutting conditions (Vc, f, ap) and the viscosity (ε) of the cutting fluid, we used the Box-Behnken plan (27 tests) with 4 factors and 3 levels. These plans are easy to implement and have the property of sequentiality. The study of the first k factors can be undertaken with the possibility of adding new ones without losing the results of the tests already carried out [20]. Three levels are considered for each of the identified factors as shown in Table 1.

Table 1: Factors and Levels Used in the Experimental Plan

Factors	Symbol		Levels		
			Level 1	Level 2	Level 3
			-1	0	1
Cutting speed (m/min)	Vc	A	145	204	286
Feed rate (mm/rev)	f	B	0 .15	0.20	0.25
Depth of cut (mm)	ap	C	0.5	1	1.5
Viscosity of cutting fluid (Pa.s)	ε	D	12.81	21.28	30.27

Cutting parameters are selected based on the hardness of workpiece material, chemical composition and cutting tool manufacturer guidelines. Analysis of variance or 'ANOVA' is an analytical tool used to determine the significance of factors in an experiment by looking at the relationship between a response variable and a factor [19]. In this work, the RSM-based second-order mathematical model is selected:

$$\mathrm{Y} = \mathrm{b_0} + \sum_{\mathrm{i=0}}^{\mathrm{k}} \mathrm{b_i X_i} + \sum_{\mathrm{ij}}^{\mathrm{k}} \mathrm{b_{ij} X_i X_{j_{ij}}} + \sum_{\mathrm{i=1}}^{\mathrm{k}} \mathrm{b_{ii} X_i}^2 + \varepsilon_{\mathrm{ij}} \quad \ldots(1)$$

where b_0 is the free term of the regression equation, the coefficients b_1, b_2, ..., b_k and b_{11}, b_{22}, b_{kk} are the linear and the quadratic terms, respectively, while b_{12}, b_{13}, bk_{21} are the interacting terms. X_i represents the input parameters (Vc, f, ap, ε) and ε_{ij} represents the error of fit for the regression model [8].

3.0 Results and Discussions

The experimental results obtained are presented in Table 2.

Table 2: Experimental Data for C45 Steel

Runs	Coded Factors				Response
	A	B	C	D	**Ra(µm)**
1	0	0	-1	-1	1.13
2	0	0	-1	1	0.50
3	-1	0	1	0	1.04
4	-1	0	0	1	1.50
5	0	-1	1	0	0.96
6	-1	1	0	0	1.24
7	-1	-1	0	1	1.87
8	1	0	0	-1	0.43
9	0	1	-1	0	0.79
10	0	0	0	0	0.62
11	1	1	0	0	0.38
12	0	1	0	0	0.98
13	-1	0	-1	0	2.09
14	0	1	0	-1	0.82
15	0	0	1	1	1.04
16	0	-1	0	-1	1.54
17	0	1	0	1	0.85
18	1	-1	0	0	0.59
19	0	-1	-1	0	0.71
20	0	0	1	-1	1.09
21	1	0	0	1	0.52
22	0	0	0	0	0.68
23	1	0	1	0	0.51
24	1	0	-1	0	0.50
25	0	-1	0	1	1.73
26	0	0	0	0	0.53
27	-1	0	0	-1	1.96

These results will be used to determine the mathematical models that express the relationship between the input parameters (Vc, f, ap, ε) and the output parameter (Ra). The numerical and graphical results presented in this article are obtained using the Minitab 17.0 software. Tables 3 illustrate ANOVA results for Ra, for the 95 % confidence level (the level significance is 5 %).

Table 3: Analysis of Variance for Ra

Source	**DF**	**SS**	**MS**	**F**	**PC %**
Vc	1	3,61869	3,52381	37,82	55,49
ap	1	0,45630	0,36432	3,91	7,00
f	1	0,00083	0,00400	0,04	0,01
ε	1	0,02760	0,04381	0,47	0 ,42
Vc2	1	0,31232	0,54980	5,90	4,79
ap2	1	0,10966	0,23437	2,52	1,68
ε2	1	0,00306	0,03196	0,34	0,05
f2	1	0,47426	0,44595	4,79	7,27
vc×ap	1	0,01260	0,02376	0,25	0,19
vc× ε	1	0,19711	0,19754	2,12	3,02
vc×f	1	0,09921	0,10088	1,08	1,52
ap× ε	1	0,00090	0,00090	0,01	0,01
ap×f	1	0,00187	0,00187	0,02	0,03
ε ×f	1	0,08914	0,08914	0,96	1,37
Erreur	12	1,11810	0,09317		
Total	26	6,53167			100

DF: degree of freedom; SS: sum of squares; Ms: adjusted mean squares

3.1 ANOVA results

The analysis of the variance of roughness Ra is presented in Tables 3. The analysis was performed using non-coded data. This table include the values of the degrees of freedom (DL), the sum of the squared deviations (Seq SS), the average squares (M_s adjusted), the statistical property (F) and the percentage contribution (PC %) of each factor and different interactions.

The contribution percentage is calculated as:

$$PC\% = \frac{SS}{SS_{total}} \mathrm{X}\,100 \quad \ldots (2)$$

$$Ms = \frac{SS}{DF} \quad \ldots (3)$$

$$F = \frac{Ms}{Mse} \quad \ldots (4)$$

(With M_{se} is the average square of errors)

The results of the "PC%" clearly indicate that the cutting speed is the most significant factor affecting the roughness (Ra) with a contribution of 55.49% and that the depth of cut is the second significant factor with a contribution of 7.00% followed by the cutting fluid viscosity with a contribution of 0.42% and finally the feed rate with a contribution of 0.01%. Figure 2 shows the residual distribution of roughness Ra which follows a normal line that can be said to be significant. Figure 3 illustrates the average effects of the input parameters on the roughness Ra. From this figure, it can be seen that the cutting speed has a significant effect on the roughness. It can also be seen that as the viscosity increases from 21.28 Pa.s to 30.27 the roughness increases. However, the feed rate does not have a significant effect on surface roughness. Figure 5 shows the interaction effect of (cutting speed (Vc) – feed rate (f)), (cutting speed (Vc) – cutting fluid viscosity (ε)),(cutting speed (Vc) –depth of cut(ap)) (feed rate (f) – depth of cut(ap)), (feed rate (f) – cutting fluid viscosity (ε)) and (depth of cut(ap) – cutting fluid viscosity (ε)) on the roughness (Ra).

Figure 5 b) shows the influence of the combination of the cutting speed and the feed rate on the roughness. It appears that the higher cutting speed at the lowest feed rate gives the minimum roughness. It can be seen in figure.5 c) that the higher cutting speeds and the average cutting fluid viscosity values give the minimum values of roughness Ra. Also in Figure 5 (a), the higher cutting speeds and the average depth of cut values give the minimum values of roughness Ra. The interactions between the depth of cut and the viscosity of the cutting fluid show that the minimum values of the roughness (Ra) are obtained with maximum depth values and average viscosity values. In figure 5 f), it can be observed that the minimum values of roughness (Ra) are obtained with minimum values of feed rate and mean viscosity values. The interaction (Vc x ε) has significance on the roughness (Ra). The interactions (Vc x ap, Vc x f, f x ap, f x ε and ap x ε) have no significant effect (figure 4).

3.2 Regression analysis of the Ra

The regression analysis of the roughness (Ra) as a function of the cutting parameters (Vc, f, ap) and the cutting fluid viscosity (ε) give the complete model equation (5). Equation (5) expresses the linear model with interaction of surface roughness Ra:

$$Ra = 15{,}13 - 0{,}0563\, Vc - 2{,}28\, ap - 32{,}4\, f - 0{,}287\, \varepsilon + 66.10^{-6} V_c.V_c + 0{,}827\, ap.ap + 31{,}3\, f.f + 0{,}0038\, \varepsilon.\varepsilon + 0{,}00229\, V_c.ap + 0{,}0625\, V_c.f + 246.10^{-6} V_c.\varepsilon - 0{,}6\, ap.f - 0{,}0047\, ap.\varepsilon + 0{,}342\, f.\varepsilon \quad \ldots(5)$$

From Figure 6, the experimental values and predicted values are very close with a 95% confidence interval. It appears that the model based on the Surface Response Methodology (MSR) gives satisfactory results.

Figure 2: Normal Probability Plot (Ra)

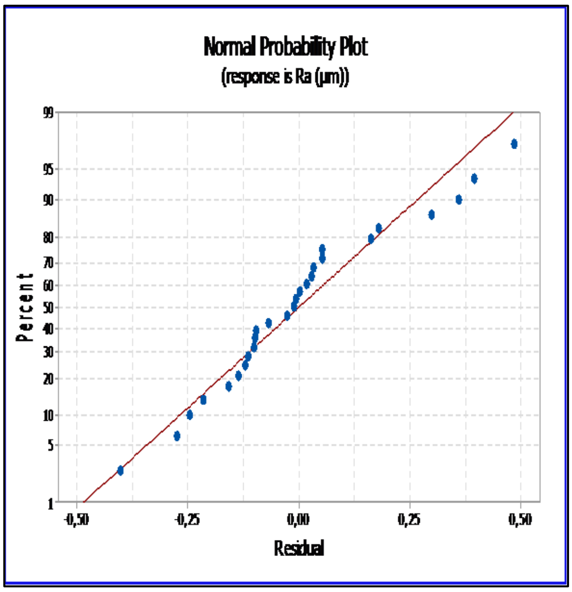


Figure 3: Graphs of Main Effects for Ra

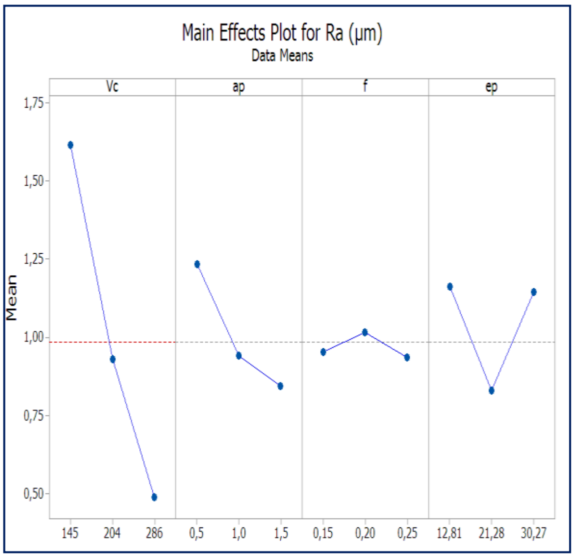


Figure 4: Interaction Plot for Surface Roughness (Ra)

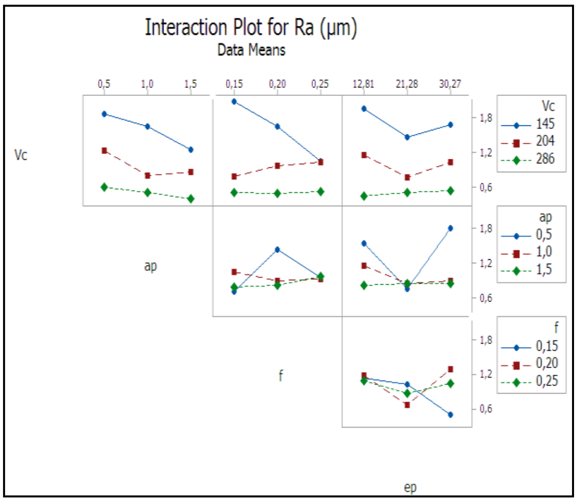
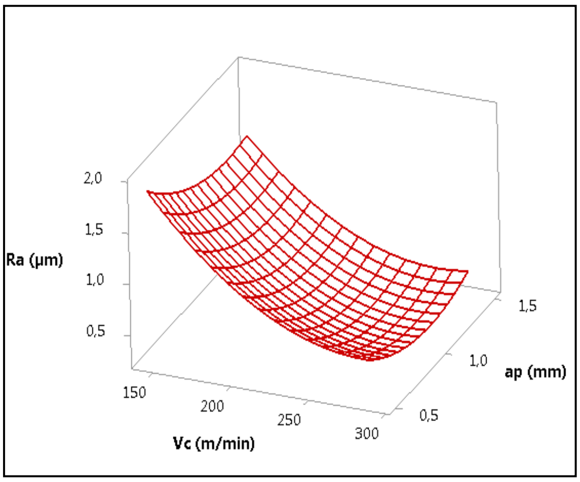
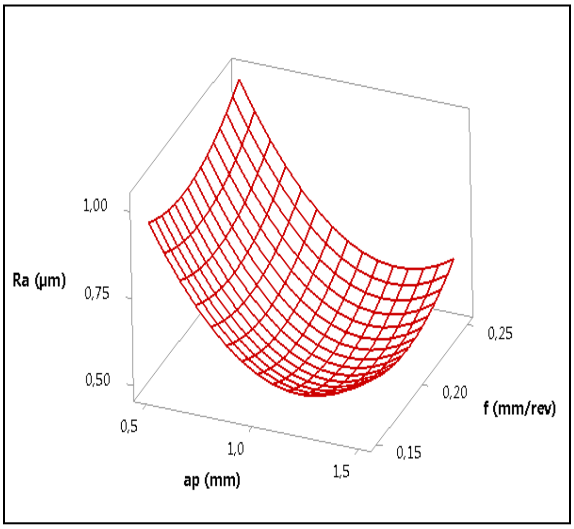


Figure 5: 3D Plots for Surface Roughness (Ra)

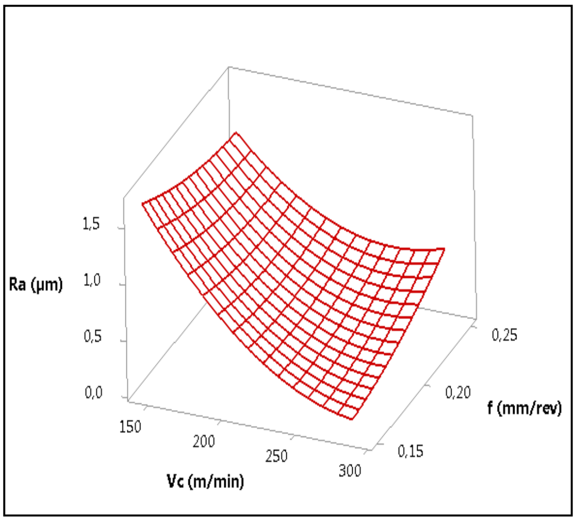
(a)



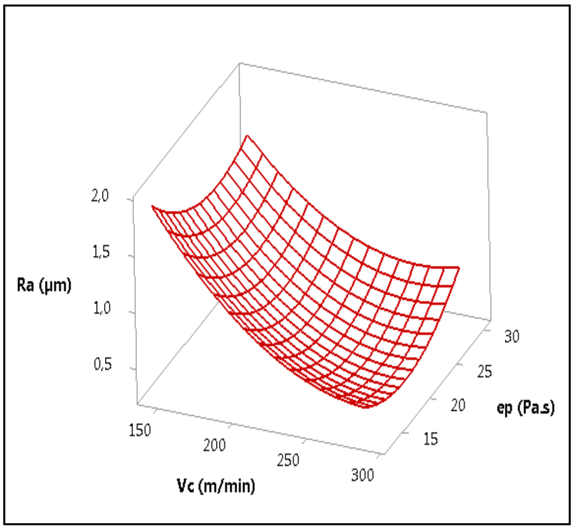
(b)



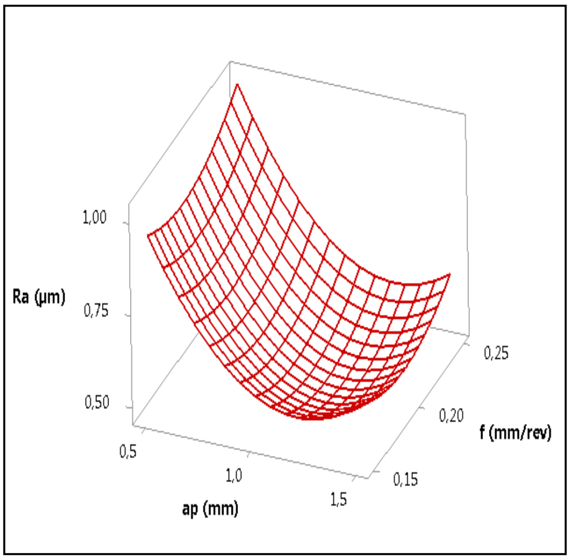
(c)



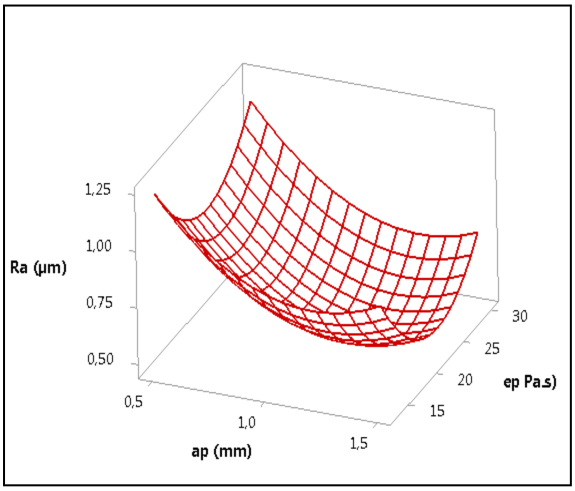
(d)



(e)



(f)



(g)

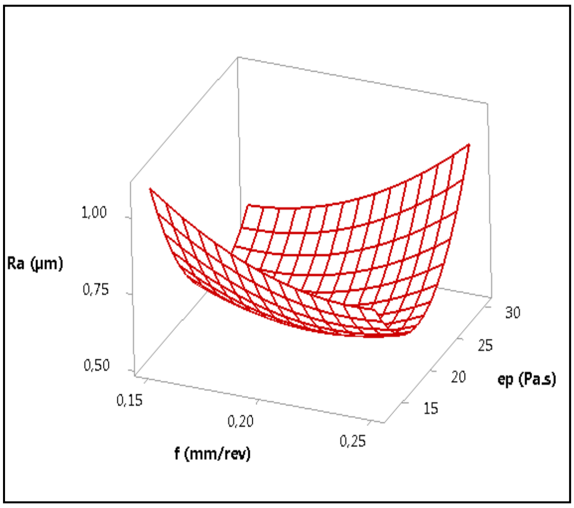
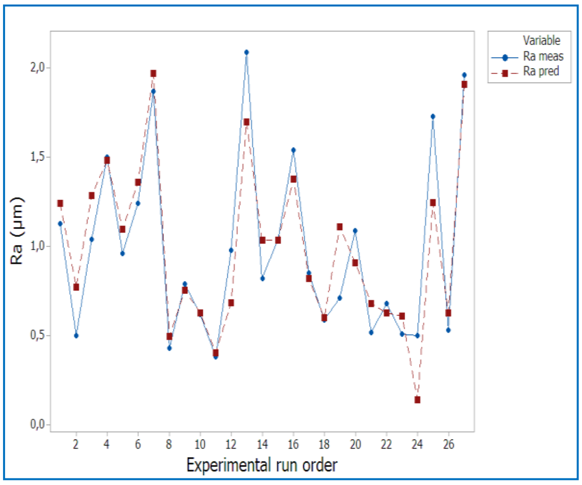


Figure 6: Comparison Between the Predicted and Measured Values for the Surface Roughness (Ra)



3.3 Optimization of response

The objective of the optimization process is to find optimal values of the cutting parameters (Vc, f, ap andε) in order to obtain a minimum surface roughness. Table 4 shows the conditions for optimizing input parameters when turning C45 steel with a carbide tool for surface roughness.

Table 4: Constraints for Optimization of Machining Parameters

Condition	Goal	Lower limit	Upper limit
Vc (m/min)	In range	145	286
f(mm/rev)	In range	0.15	0 .25
ap (mm)	In range	0 .5	1.5
ε(pa.s)	In range	12.81	30.27
Ra(µm)	Minimize	0.38	2.09

The optimal cutting parameters obtained are: the cutting speed is equal to 286 m / min, the feed rate: 0.15 mm / rev, the depth of cut: 1.1 mm and the fluid viscosity cut: 22.5 Pa.s which give a value of minimum roughness Ra = 0.126µm (Table 5).

Table 5: Response Optimization for Surface Roughness

Vc (m/min)	f(mm/rev)	ap (mm)	ε(pa.s)	Ra(µm)
286	0.15	1.1	22.5	0.126

4.0 Conclusions

The application of the MSR surface response methodology in turning non-alloy steel C45 with metal carbide tools allowed to obtain a mathematical model for the surface roughness criterion (Ra) as a function of the machining parameters. The study carried out leads to the following conclusions:

- The cutting speed has a greater influence on the surface roughness (55.49%). Then comes the depth of cut (7%) and the viscosity at a contribution equal to 0.42%.
- The best surface roughnesses were obtained for the large values of cutting speeds and average values of depth of cut and viscosity.
- Comparing the experimental and predicted values of the roughness criterion, we note that they are in good correlation.
- Optimization by MSR of the most suitable cutting conditions for a surface roughness Ra = 0.126 µm, gave us: Vc = 286 m / min, f = 0.15 mm / rev, ε = 22.5 (pa.s) and ap = 1.1 mm.

- The best roughness is obtained for a percentage of water of about 60% and 40% of oil which gives a viscosity of 22.5 Pa.s

5.0 Acknowledgment

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