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COMBIND EFFECT OF MACHINING PARAMETERS WITH NOSE RADIUS OF THE CUSTTING TOOL ON SURFACE ROUGHNESS OF 304-AUSTENITIC STAINLESS STEEL ALLOY PRODUCED BY CNC-TURNING MACHIN

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ABSTRACT

It is well known that machining parameters have strong effect on the properties of surface roughness. Many investigations have done on this area. This work studies of combining effect of turning process parameters (cutting speed, feed rate, and depth of cut) with on surface roughness. Where, nose radius of the tool and machining parameters have taken as input variables and the surface roughness (Ra) as response or output. Three experiments were conducted; they were used to investigate the surface roughness resulted by tool corner radiuses of the values: 0.4mm, 0.8mm, and 1.2mm Response surface methodology (R.S.M) is applied as a tool to show the cause and effect of output (response) and input control and relationship between them as a two or three dimensional hyper surface. A three factor with five level central composite rotatable factors design was used. The results showed that R.S.M is a strong tool and capability tool to predict the effect of machining parameters on surface roughness. Results improved that the five level factorial designs can be employed for developing statistical models to predict surface roughness by controllable machining parameters. Results showed that the combined effect of cutting speed at its higher level, feed rate and depth of cut at their lower values, and large nose radius can result in better surface roughness.

Keywords: CNC turning machine, Cutting speed, Feed rate, Depeth of cut, Nose radius of the cutting tool, Surface roughness, Response surface methodology.

Contribution/ Originality

This study is one of very few studies which have investigated effecting of four parameters (as input) on one response (surface roughness). To accomplish this, a three factor with five level central composite rotatable factors design was used.

This study originates new formula of combining effect of turning process parameters (cutting speed, feed rate, and depth of cut) with on surface roughness. Where, nose radius of the tool and machining parameters have taken as input variables and the surface roughness (Ra) as response or

output. This study documents that R.S.M is a strong tool and capability tool to predict the effect of machining parameters on surface roughness.

1. INTRODUCTION

The surface geometry plays a very important role in the performance characteristics of a machined part. It has an influence on mechanical properties such as wear resistance, fatigue strength, and corrosion resistance [1]. The accuracy requirements for machined parts have continuously increased and tend to be especially critical in modern industry [2].

A surface machined by conventional machining processes such as milling and turning consist of inherent irregularities produced by the cutter or a finer structure due to tearing of the metal during machining. Traditional finishing processes such as grinding, polishing lapping, and honing are commonly used to improve the surface finish. A good surface finish is reflective not only of good work main top, but it has effect on the life and function of component and is an essential requirement in the molding industry [3].

The machined surface topography affects the characteristics of the work piece. The quality of surface finish and the accuracy of geometric shape of rotating and sliding components have a great deal to do with how long these items would last .They have a marked influence on the functional properties of machined parts: such as, fatigue strength, and corrosion resistance [4].

The present work concerns with the optimization of the machining parameters in CNC-Turning machine, and study their effects on the surface roughness of stainless steel work piece. Predicting of some statistical model to select the optimum combination effect of machining variables such as cutting speed, feed rate, depth of cut, and nose radius of the tool as the input, and the surface roughness as response.

The development model was designed by using experimental design technique combined with regression and variance of analysis supporting by response surface methodology. The significance of the regression coefficients was testing and verifying by the development model. The effect of these interaction effects of the significant coefficients on the response will be representing in three dimensional graphs.

Response surface methodology applying three factors with five levels of center composite rotatable factorial design was used to design and develop the mathematical models. These models will be useful not only to predict the good surface but also to select the process parameters that are achieving a good response (surface roughness).

2. R.S.M APPLICATIONS

The main problem in getting a good surface finish by turning process is in the selection of the optimum combination of input variables, which can be solved by the development of mathematical models. The goal of the resent work is to use RSM to develop statistical models capable of accurate prediction of surface roughness. CNC-Turning machine was used to prevent any error in the input data (Independent variable) and output data (dependent data). The independent variables are, cutting speed (*v*), feed rate (*f*), and depth of cut (*d*), and nose radius (r_ε).

The working rang of the process variables and their decided levels of the parameters and their notation are given in Table1.The upper and lower limits*i* of the factor for experimental surface roughness was coded as +1.682 and -1,682 respectively [5-7] . The coded value of intermediate value was codes as 0. The five levels of the three variables coded values were calculated from the following relationship:

$$Xi = \frac{2\,[\,2X - (Xmax + Xmin)}{(Xmax - Xmin)} \ldots\ldots\ldots\ldots (1)$$

Where, X_i is the required coded value of a variable *X*. And *X* is any value of variable from X_{min} *to* X_{max}.Where; X_{min} and X_{max} are lower and the upper level of the variable respectively.

Table-1. Working range and control limit of machining parameters.

Processes control (Parameters	Working rang		Limits of surface roughness				
	Min.	Max	-1.682	-1	0	1	1.682
Cutting speed v[m/min]	160	200	160	170	180	190	200
Depth cut d[mm]	0.4	2.0	0.4	0.8	1.2	1.6	2.0
Feed rate f[mm/rev]	0.04	0.2	0.04	0.08	0.12	0.16	0.20

The selected experimental matrix is a 2^k full factorial central rotatable fixed levels design. The total number (*N*) of the experimental runs (treatment combinations) for these factors is given by [7, 8] as:

$$\alpha = (2)^{k/4} \qquad k < 5 \ldots\ldots\ldots\ldots (2)$$

$$\alpha = (2)^{(k-1)/4} \qquad k \geq 5 \ldots\ldots\ldots\ldots (3)$$

For the present investigation, where, k = 3 , there will be 8 corner, 6 stars , and 6 center runs yielding total number of points, N=20 with star arm, α= 1.682. These runs and their combination sets are listed in what is called "Experimental design matrix". Table 2 gives this design matrix with central composite rotatable, fixed levels. The complete design matrix consists of 20 sets of coded treatment combinations. It comprises a full replication of 23=8 factorial design plus 6 center and 6 start points respectively. All machining variables at the intermediate level (0) constitute the center points and combinations of each of machining variables at either its lowest (-1.682) level or its highest level (+1.682) with the two variables at the intermediate levels constitute at the star points [8]. Thus 20 experimental runs were allowed in the estimation of the linear quadratic, and two-way interactive effects the process parameters.

3. EXPERIMENTAL & MATHEMATICAL MODEL

The response function representing any of machining parameters (v, *f*, d) can be expressed as [9]:

$$Y = fun.\ (X_1, X_2, X_3) \ldots\ldots\ldots\ldots (4)$$

Where:

Y is the response or yield and,

X's are the coded levels of the k quantitative factors.

The statistical models F1, F2, and F3 for each of responses will be designed as Y1, Y2, and Y3 for surface roughness at r_ε =1.2, 0.8, and 0.4 mm respectively. The relationship which was selected is a second degree response surface expressed as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \ldots\ldots\ldots\ldots\ldots (5)$$

The 20 run experimental treatment combinations (run) were conducted as designed by the experimental matrix shown in Table 2, also the results obtained are shown in Table 2.

Table 2 Experimental design matrix and observed values of surface roughness at different nose radius (r_ε) = 1.2, 0.8 and 0.4mm.

Run. No.	Experimental design			Surface roughness (Ra)		
	$x_1\,(v)$	$x_2\,(f)$	$x_3\,(d)$	$(r\varepsilon)$=1.2mm	$(r\varepsilon)$=0.8mm	$(r\varepsilon)$=0.4mm
1	-1	-1	-1	0.28	0.36	0.4
2	-1	-1	+1	0.32	0.40	0.5
3	-1	+1	1-	0.40	0.48	0.6
4	+1	-1	-1	0.23	0.32	0.4
5	-1	+1	+1	0.44	0.52	0.6
6	+1	-1	+1	0.24	0.31	0.4
7	+1	+1	-1	0.26	0.35	0.4
8	+1	+1	+1	0.29	0.38	0.5
9	-1.682	0	0	0.37	0.46	0.5
10	+1.682	0	0	0.20	0.29	0.4
11	0	-1.682	0	0.22	0.30	0.4
12	0	+1.682	0	0.46	0.54	0.5
13	0	0	-1.682	0.24	0.32	0.4
14	0	0	+1.682	0.32	0.40	0.5
15	0	0	0	0.27	0.35	0.4
16	0	0	0	0.26	0.34	0.4
17	0	0	0	0.26	0.34	0.4
18	0	0	0	0.28	0.36	0.4
19	0	0	0	0.27	0.35	0.4
20	0	0	0	0.29	0.37	0.4

The second order polynomial (regression) can be expressed by equation number 6 or:

$$Y = b_0 + b_1 v + b_2 f + b_3 d + b_{11} v^2 + b_{22} f^2 + b_{33} d^2 + b_{12} v f + b_{13} v d + b_{23} f d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where: Y: is the response (surface roughness).

Let F1 , F2 and F3 representing the response surface roughness at corner (r_ε) equal 0.4, 0.8, and 1.2mm respectively. Using computer software statistical program (S.P.S) to the estimated values of the regression coefficients for each model, the following results given in table 3 were obtained for the regression coefficients for model I (F1) at corner radius 1.2 mm.

Table-3. Estimated values of regression coefficients at nose radius (r_{ϵ} =1.2mm).

NO.	Regression	Value	T(10)	P-level	Parameter
1	$b0$	0.272	32.072	0.0024	
2	b_1	-0.052	-9.202	0.002	v^*
3	b_2	0.0529	9.432	0.0019	f^*
4	b_3	0.0186	3.318	0.0078	d^*
5	b_{11}	0.006	1.017	0.333	v^2
6	b_{22}	0.025	4.573	0.001	f^{2^*}
7	b_{33}	0.004	0.694	0.504	d^2
8	b_{12}	-0.02	-2.725	0.0214	vf^*
9	b_{13}	-0.05	-0.681	0.5112	vd
10	b_{23}	0.003	0.341	0.7404	fd

Note: * Non-significance

T-test [10] was achieved to test the significance of the coefficient of the three models at significant level of ($\alpha = 0.05$) for all the models. For example: the coefficient in the model F_1 is significant, became P-level of this coefficient less than 0.05(P - level) of coefficient $b_1 = 0.0021 < \alpha = 0.05$. This means, that the coefficient b_1 has effect on the response of model F_1, on the other hand, the (P-level) of coefficient b_{11} in model F_1 is more than 0.05 (P-level) of coefficient $b_{11} = 0.333 > \alpha = 0.05$ .This means that, it has no effect on the response of model F_1 and so on for all other coefficients.

The adequacy of the model was tested by using ANOVA technique at confidence level of 95%. It was found that all models are adequate since (P-level) (0.00001) is less than the significant level (0.05) which means that the model has a significant meaning [5]. Table 4 shows the ANOVA analysis for the model and the other two models were done by same way.

Table-4. ANOVA analysis for the model

Effect	**Sum of squares**	**Degree of freedom**	**Mean squares**	***F* - level**	***P*- level**
Regression	0.09219	9	0.01024	23.7705	0.00001
Residual	0.00431	10	0.00043		
Total	0.09650				

After dropping out the non-significant terms from table 4, the equations for the models can be written as follow:

* Model F_1 (Surface Roughness at (r_{ε}) = 1.2 mm):

$$F_1 = 0.722 - 0.052\ X_1 + 0.0529\ X_2 + 0.0186 X_3 + 0.025 X_2^2 - 0.02\ X_1\ X_2 \qquad (7)$$

* Model F_2 (Surface Roughness at (r_{ε}) = 0.8 mm):

$F_2 = 0.352 - 0.05\ X_1 + 0.055\ X_2 + 0.0172\ X_3 + 0.025\ X_2^2 - 0.018\ X_1\ X_2$……………………………(8)

* Model F_3 (Surface Roughness at (r_ε) = 0.4 mm):

$F_3 = 0.461 - 0.053\ X_1 + 0.043\ X_2 + 0.018\ X_3 + 0.017\ X_1^2 + 0.13\ X_2^2 - 0.016\ X_1\ X_2$………………(9)

4. RESULTS AND DISCUSSIONS

The validity of the obtained final models can be judged from their coefficients of correlation (r) which are found as 0.95, 0.96, and 0.96 for models F_1, F_2, and F_3 respectively. This validity can also be judged from Figs. 1, 2, and 3 respectively which show the relationship between the measured and computed values of surface roughness. These graphs indicate that the above equations 5, 6 and 7 express very close relation between the measured (observed) and computed (calculated) values of surface roughness and the relationship and correlation between the dependent variables (response or surface roughness), And independent variables (machining Parameters $v, f,$ and d) are found 0.97, 0.98 and 0.98 for F_1, F_2, and F_3 respectively.

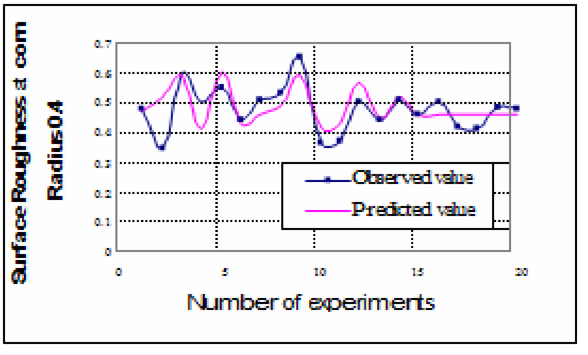

Fig-1. Effecting of cutting speed on surface roughness at (r_ε) = 0.4 mm.

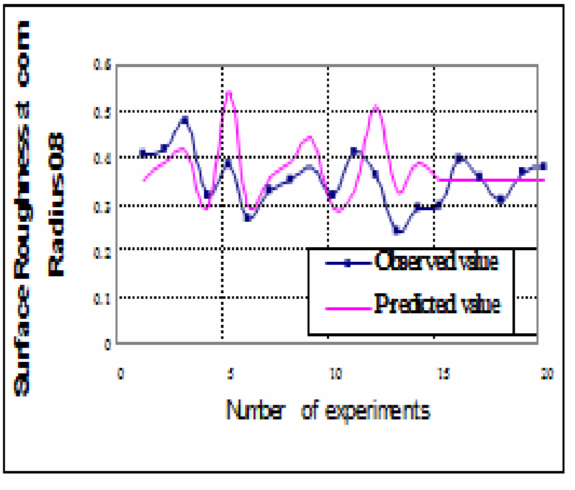

Fig-2. Effecting of cutting speed on surface roughness at (r_ε) = 0.8 mm.

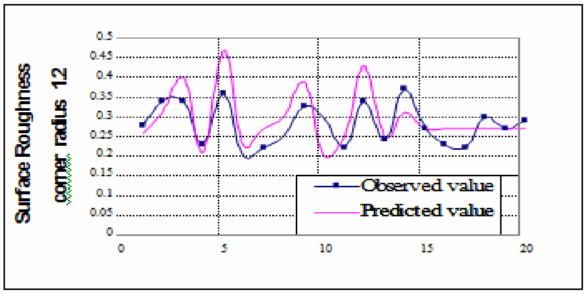

Fig-3. Effecting of cutting speed on surface roughness at (r_{ε}) = 1.2 mm.

From Fig. 4 improvement in surface roughness can be reported as the cutting speed increases, wherefore the minimum of surface roughness will be found at maximum level of cutting speed (200 m/min).

This can be referred to law value of interfacing period between the tool and machining surface. This in turn generates a small amount of machining heat leading to a small plastic deformation, which means smooth machined surface. In other words, in case of increased cutting speed the, cutting forces (F_c) decreases that lead to decrease machining temperature. In addition to that, when the cutting speed increase this means that the reported friction between the tool and the machining surface is low, leading to better surface roughness.

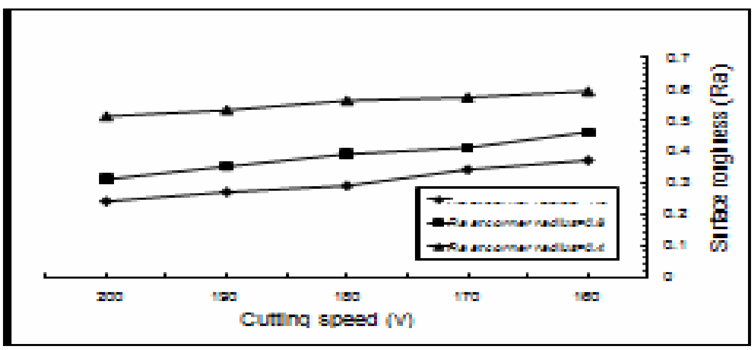

Fig-4. Effecting of cutting speed on surface roughness at corner radius 0.4, 0.8, and 1.2mm.

When the tool corner radius (r_{ε}) increases, it means that the interfacing area between the cutting tool and machined surface will increase at same feed rate. This lead to decreasing in surface roughness, it can be noted that at the maximum value of corner radius.

From Fig. 5, it can be observed that as the feed rate increases the surface roughness increases too. The optimum value of surface roughness can be registered at smallest feed rate (0.04mm). This interprets that when the feed rate increases, the cutting tool travel from point to another on the machined surface is with higher rate leading to high hardness of the chip and machined surface., Forcing a large amount of removed metal in a short time results high deformed chip with high temperature and causing the metal to be removed by the rupture action in addition to the cutting forces. These actions lead to the increase in the cutting forces (the tangential and vertical forces) resulting in rough surface.

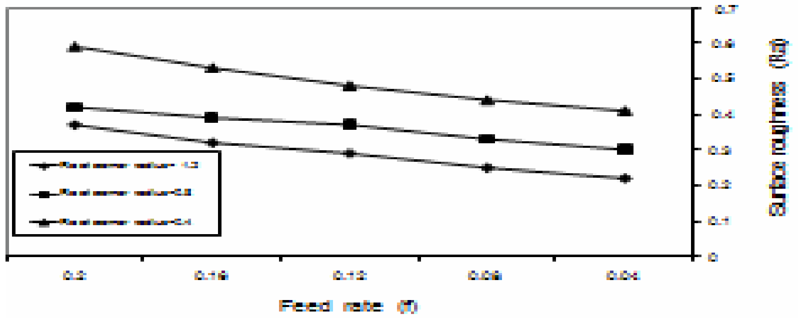

Fig-5. Effecting of feed rate on surface roughness at corner radius 0.4, 0.8, and 1.2mm.

From the same figure, it can be concluded that as the corner radius of the cutting tool (r_ε) increases the surface roughness decreases, and the maximum values would be recorded when (r_ε) = 0.4mm, according to the previous discussed reasons.

In fig. 6 one can observe that as the depth of cut increases the surface roughness increases, and it will be highest value at maximum value of depth of cut (2mm). This may be referred to that the increase in depth of cut means that the depth of removed metal is increased in addition to that the tool cutting edge will have large interfaced length with the metal to be removed. This leads to an increasing in the cutting forces which in turn increase the generated heat and resulting in surface roughness.

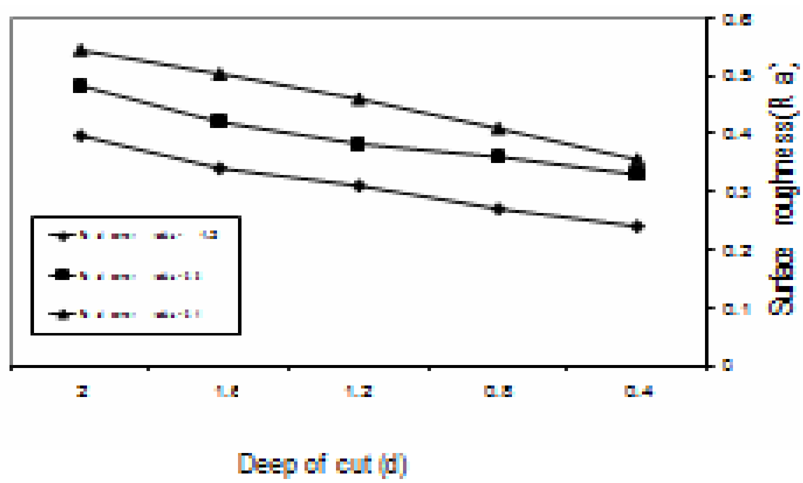

Fig-6. Effecting of depth of cut on surface roughness at corner radius 0.4, 0.8, and 1.2mm.

According to the cutting tool corner radius, the surface roughness would be improved as the (r_ε) decreased. It can be noted that the minimum value will be at (r_ε) = 1.2mm. In other words, the removed metal at the surface of the cutting tool will be low plus that the low generated heat resulting in better improvement in the surface roughness.

Inspecting Figs. 7, 8, 9 one can observe that, the surface roughness reaches its maximum value as the levels of feed rate and cutting speed are kept at their highest and lowest levels, namely at (0.20mm) and (160 m/min)) levels respectively. The observation could be referred to as large amount of removed material, which in turn increases the cutting temperature. In addition to this, low cutting speed gives a chance to spend more machining time which also leads to an increase in the temperature at the machined surface and the later will cause plastic deformation then increase in surface roughness.

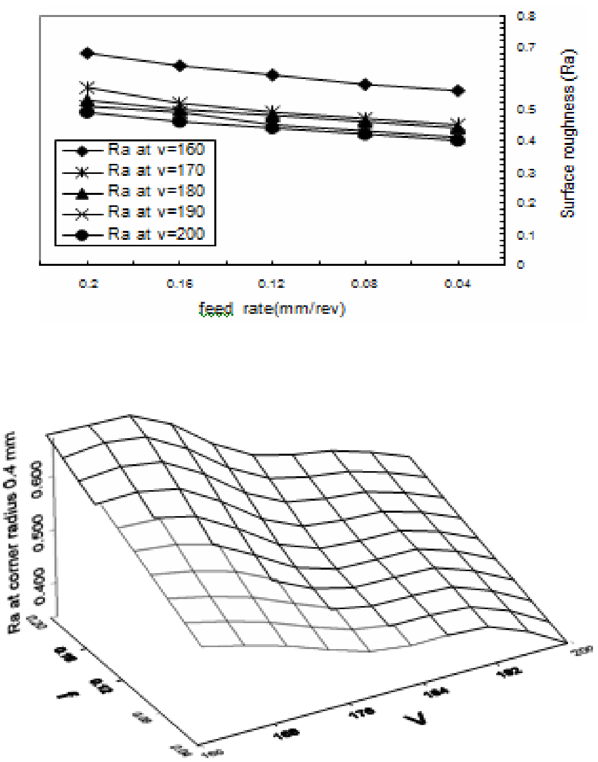

Fig-7. Interaction effect of cutting speed and feed rate on surface roughness (Ra) at corner radius = 0.4mm.

In addition to that, the increase of feed rate means that the tool tip will speed up its movement which in turn results greater cutting forces. But, since lower cutting speed increases the cutting forces, this will result the cut-off of the deformed, in other words, the surface roughness increases.

Also, one can observe that the surface roughness decreases, as the corner radius it increased. This means that the combined effect of the three mentioned variables (feed rate, cutting speed, and the corner radius, with value levels of (0.20mm, 160 m/min, and 0.4 respectively), will result in maximum surface roughness, according to the previous discussed reasons.

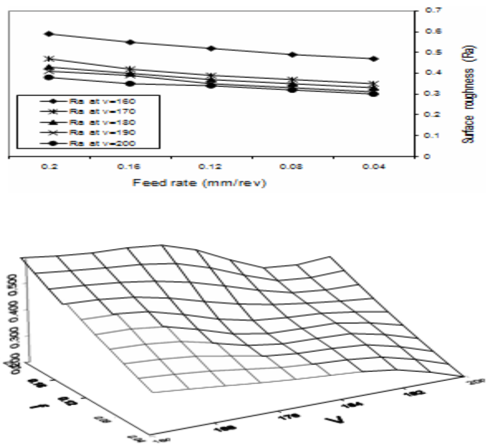

Fig-8. Interaction effect of cutting speed and feed rate on surface roughness (Ra) at corner radius = 0.8mm.

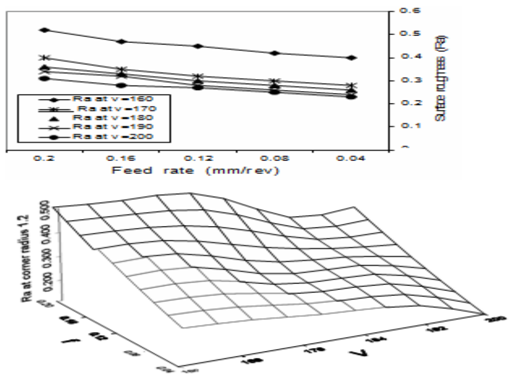

Fig-9. Interaction effect of cutting speed and feed rate on surface roughness (Ra) at corner radius = 1.2mm.

5. CONCLUSIONS

From the results obtained and discussion, the following facts were concluded:

1- Good surface roughness at high cutting speed (200 m/min) and large corner radius (1.2 mm).

2- Rough surface roughness at high feed rate (0.2 mm/rev) and small corner radius (0.4 mm).

3- Surface roughness was better at small depth of cut (0.4 mm) and large corner radius (1.2 mm).

4- There is no significant interaction effect between cutting speed and depth of cut on surface roughness at this range of machining parameters [160-200 m/min and 0.4-2.0 mm] of Austenitic Stainless Steel 304.

5- No significant effect between feed rate and depth of cut on surface roughness at this range of machining parameters [0.04-0.20 mm/rev and 0.4-2.0 mm] of Austenitic Stainless Steel 304.

6- The interaction effect between cutting speed and feed rate on surface roughness is reported easily, so, surface is rough at high level of feed rate [0.20 mm/rev], but it is better when increasing in cutting speed [200 m/min].

REFERENCES

[1] P. F. Ostwald and J. Munos, *Manufacturing processes and system*. New York: John Wiley and Sons, Inc, 1997.

[2] M. P. Groover, *Fundamentals of modern manufacturing*. USA: Prentice-Hall. Inc, 1996.

[3] A. Bhattacharyya and I. Ham, *Design of cutting tools use of metal cutting theory*. First. Dearborn, MI: American Society of Tool and Manufacturing Engineers, 1969.

[4] G. Boothroyd, *Fundamentals of metal machining and machine tool*. New York, USA: McGraw-hill, 1995.

[5] C. R. Hicks, *Fundamental concepts in the design of experiments*. New York: Holt, Rinehert & Winston Inc, 1973.

[6] W. E. Biles and J. S. James, *Optimization and industrial experimentation*. New York: John Wiley & Sons, 1980.

[7] G. E. Box and J. S. Hunter, "Multi-factor experiment design for exploring response surface, Annuals of Mathematical Statistics, vol. 28, Institute of Mathematical Statistics is Collaborating with JSTOR to Digitize, Preserve, and Extend Access to The Annals of Mathematical Statistics," *Annuals of Mathematical Statistics*, vol. 28, pp. 195-241, 1957.

[8] W. G. Cochran Gertruda and M. Cox, *Experimental designs*, 2nd ed. New York: John Wiley & Sons, 1957.

[9] D. C. Montgomery, *Design and analysis of experiments*. New York: John Wiley & Sons, 1976.

[10] N. R. Drapar and H. Smith, *Applied regression analysis*, 2nd ed. New York: John Wiley & Sons, 1990.

BIBLIOGRAPHY

[1] V. L. Anderson and R. A. Mclean, *Design of experiment*. New York: Marcel Dekker, Inc, 1974.

[2] N. H. Loh, "Effects of ball burnishing parameters on surface finish- Alitertrue survey and discussion," *Precision Engibeering October 1088, No. 4*, vol. 10.