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MATHEMATICAL MODELLING OF SURFACE ROUGHNESS FOR EVALUATING THE EFFECTS OF CUTTING PARAMETERS IN DRILLING PROCESS

Fatlume Zhujani, Nexhat Qehaja, Fitore Abdullahu* & Mirlind Bruçi

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Abstract

The optimization of surface integrity in drilling process using response surface method (RSM) is presented. This paper investigates the machining parameters affecting the roughness of surfaces produced in dry drilling process. Three parameters were selected for study: cutting speed, feed rate and drill diameter. In this study developed a model of surface roughness based on the response surface method, logarithmic linearized approach for determining the processing parameters in drilling process of steel EN 1.0038, using HSS coated TiN drill tools. The experiment has been designed and carried out on the basis of a three level factorial design. Obtained results are in good accordance with the experimentally obtained data, confirming the effectiveness of regression analysis in modeling of surface roughness in the dry drilling process. The established predictive model shows that the surface roughness increases with the increase of feed rate and depth of cut but decreases with cutting speed increase.

Keywords: Machining; cutting process; drilling; roughness; tool

1. Introduction

Drilling is one of the most important machining processes. Approximately 75% of all metal cutting process involves drilling operation [1]. In automotive engine production, costing of drilling hole is among the highest [2].

Therefore, surface integrity is an important parameter in manufacturing engineering. It is because, surface integrity can influence the performance of final parts and it's quality [3]. In order to study the relationship between drilling process parameters and surface integrity, a systematically approach, the design of experiments (DOE); response surface method (RSM) can be used effectively [4].

In the manufacturing industries, various machining processes (turning, milling, drilling etc.) are adopted for removing the material from the workpiece to obtain finished product. Among the various metal removing processes, drilling is the one of most important metal removing process as compared to other traditional machining processes. Drilling is use for making the hole in the workpieces. Hole making is a most important machining process in manufacturing. During the drilling, the drill rotates and feed into the work Different drilling tools and hole making methods are used for drilling. The selection of different tools and methods depends on the type of workpiece, size of the hole, the quantity of holes, and the quantity of the holes in given time periods.[5].

The surface quality is one of the most specified customer requirements and the major indicator of surface quality on machined parts is surface roughness. The surface roughness is mainly a result of various controllable or uncontrollable process parameters and it is harder to attain and track than physical dimensions are. A considerable number of studies have researched the effects of the cutting speed, feed, depth of cut, nose radius and other factors on the surface roughness. In recent studies the effects of some factors on surface roughness has been evaluated and models has been developed.

A central task in science and engineering practice is to develop models that give a satisfactory description of physical systems being observed. The goal of this study is to obtain a mathematical model that relates the surface roughness to three cutting parameters in face milling, precisely to the cutting speed, feed rate and depth of cut. [17],[12].

Although metal cutting methods have improved in the manufacturing industry, conventional drilling process still remains one of the most common processes. Drilling can be applied to various workpiece materials. The surface quality is important for the functional behavior of the mechanical parts [6],[. The most obvious factors influencing the accuracy of drilled holes are cutting speed and feed rate [9]. Cutting speed and feed rate significantly affect the surface roughness of the machined surface whereby high cutting speed and low feed rate resulted in the better surface finish [3]. In material removal processes, an improper selection of cutting conditions will result in rough surfaces and dimensional errors. Therefore, it is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling.[10]

Metal cutting is one of the most significant manufacturing processes in the area of material removal. Black [14] defined metal cutting as the removal of metal chips from a workpiece in order to obtain a finished product with desired attributes of size, shape, and surface roughness [15]. One important parameter in the qualification of cut surfaces is their roughness, and its indexes. The roughness has great significance primarily at mating, sliding surfaces. This has been one more reason for the researchers' increased interest for a long time to predict these indexes for a given process within the specified cutting conditions. Several modeling procedures and techniques were worked-out, which essentially can be classified into four groups: l) analytical models, 2) experimental methods, 3) DoE (Design of Experiment)-based methods and 4) AI (Artificial Intelligence)-based methods.

Experiment aim is to define adequate mathematical model that is used to determine the influence of independent factors and cutting data, at surface roughness. The following independent factors are selected: cutting speed (*v*), drill diameter (*d*), and feed rate (*f*). For a concrete case, that means determination of criteria:

– surface roughness: $R_a = f(v,f,d)$

2. Nomenclature

R_a the average surface roughness
P power
n RPM
f feed rate
d tool drill diameter
L lenth
B width
H hight
N factorial design
K number of factors
N_0 number of additional tests
v cutting speed
c_0, c_1, c_2,c_3 constants
y logarithmic value of the measured surface roughness
β_0, β_1, β_2, β_3 regression coefficients
x_0 unit vector
x_1, x_2, x_3 logarithmic values of cutting speed, feed rate, cut of depth

3. Experimental conditions

Machine tool: Universal milling machine *GKA-3,* 8 kw spindle power, spindle speed range: 250 - 1400 rpm, feed rate range: 0,02 - 2,0 mm/rev, working are: X/Y/Z 400x2000x300 mm, max. tool diameter: 80 mm, max. tool length: 200 mm. Workpiece was made of forgings steel EN 1.0038 (EN 10250-2), vith dimensions; BxLxH=100x100x10 mm. Its chemical composition is as follows: (0.16-0.178)% C; (1.35-1.45)% Mn; 0.032% S; 0.034% P, (0.52-0.56) Cu, (0,34-0,36)CE. Tensile strength is (380-510) MPa, and hardness 240-250 N/mm2.. Cutting tool: HSS-TiN coated jobber drills DIN 338, A1211TiN, with data in table 1. To guarantee the initial conditions of each test, a new drill tool is used in each experiment.

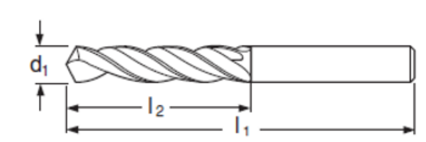
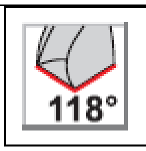
			
DIN 338	d_1 [mm] h8	l_1[mm]	l_2 [mm]
1	8	117	75
2	10	133	87
3	12	151	101

Table 1. Cutting tool data

The measurement of surface roughness was made by; HADRON, SRT-6210. The measurement of chemical composition was made by; Spectrometer Metorex Arcmet 930 and hardness by; meter Krautkramermic.10.DL.

4. Experimental setup

Experimental design: This work is an experimental study focused on the effect of cutting and geometrical parameters on surface roughness, developing a correlation between them. The experimental design involves variation of three factors at three levels (low, medium and high), including cutting speed (v), feed rate (f) and drill tool diameter (d) as indicated in Table 2.

A design matrix was constructed on the basis of the selected factors and factor levels as shown on the table 2. The selected design matrix was a full factorial design N=2k+N0 (k=3 - number of factors, N0=4 – number of additional tests for three factors) consisting of 12 rows of coded/natural factors, corresponding to the number of trials. This design provides a uniform distribution of experimental points within the selected experimental hyper-space and the experiment with high resolution [7[, [8].

The factor ranges were chosen with different criteria for each factor, aiming at the widest possible range of values, in order to have a better utilization of the proposed models. At the same time, the possibility of the mechanical system and manufacturer's recommendations are taken into account.

Machining conditions used in the experiment also are shown in Table 2 [9], [10], [11]. All of the trials have been conducted on the same machine tool, with the same tool type and the same cutting conditions.

Measured values of surface roughness, as the results of testing twelve experimental points defined by experiment plan matrix, are shown in Table 3. The mentioned values of surface roughness are input data for mathematical modeling of results, which was made by multiple regression analysis.

Input factors	Coded values of input factors		
	Low level	*Midlle level*	*High level*
	-1	0	+1
$x_1 = v$ [m/min]	15	20	25
$x_2 = f$ [mm/rew]	0.1	0.175	0.3
x_3 = d [mm]	8	10	12

Table 2. Experimental setup at three level factors.

a. *Regression based modeling*

The main task for regression analysis is to show relationship between the roughness and machining independent variables. Many authors suggested linear and exponential empirical models for surface roughness as functions of machining parameters [13], [14], [15], [16], by the following:

$$R_a = c_0 \cdot v^{c_2} \cdot f^{c_1} \cdot d^{c_3} \qquad (1)$$

Three parameters: cutting speed (v),feed rate (f), and drill tool diameter (d). Ra is the surface roughness in µm, f - feed rate in mm/rev, d-drill tool diameter, and respectively c_0, c_1, c_2, and c_3 are constants.

Test No.	Coded factors				Performance measures	
	X_0	X_1	X_2	X_3	Ra	Y = ln R a
1	+1	+1	-1	+1	2.425	0.885831524
2	+1	-1	+1	+1	4.232	1.442674695
3	+1	+1	+1	-1	3.241	1.175881924

4	+1	-1	-1	-1	3.564	1.27088351
5	+1	0	0	0	3.582	1.275921304
6	+1	0	0	0	3.322	1.200567011
7	+1	-1	-1	+1	5.826	1.762330659
8	+1	+1	-1	-1	2.542	0.932951173
9	+1	+1	+1	+1	7.321	1.990746931
10	+1	-1	+1	-1	8.824	2.177475282
11	+1	0	0	0	3.501	1.253048642
12	+1	0	0	0	3.614	1.284815192

Table 3. Experimental results.

Multiple linear regression models for surface roughness can be obtained by applying a logarithmic transformation that converts non-linear form of eq. (1) into following linear mathematical form:

$$ln\ R_a = ln\ c_0 + c_1\ ln\ f + c_2\ ln\ f + c_3\ ln\ d \quad (2)$$

The linear model of eq. (3) in term of the estimated response can be written as:

$$y= \beta_0+ \beta_1 x_1+ \beta_2 x_2+ \beta_3 x+\varepsilon \quad (3)$$

where y is the logarithmic value of the measured surface roughness, β_0, β_1, β_2, β_3 are regression coefficients to be estimated, x_0 is the unit vector, x_1, x_2, x_3 are the logarithmic values of cutting speed, feed rate, cut of depth and ε is the random error.

The above equation in matrix form becomes:

$$y=X\beta+ \varepsilon \quad (4)$$

Thus, the least squares estimator of β is

$$\beta = (X'X)^{-1}X'y \quad (5)$$

The fitted regression model is

$$\acute{Y}=X\,\beta \quad (6)$$

The difference between the experimentally measured and the fitted values of response is:

$$e=y- \dot{y} \quad (7)$$

The regression analysis technique using least squares estimation was applied to compute the coefficients of exponential model. The following empirical exponential model for surface roughness was determined and is given, respectively: Final mathematical model of surface roughness R_a is obtained:

$$R_a = 46.566 \cdot v^{-0.816} \cdot f^{0.44} \cdot d^{0.323} \quad (8)$$

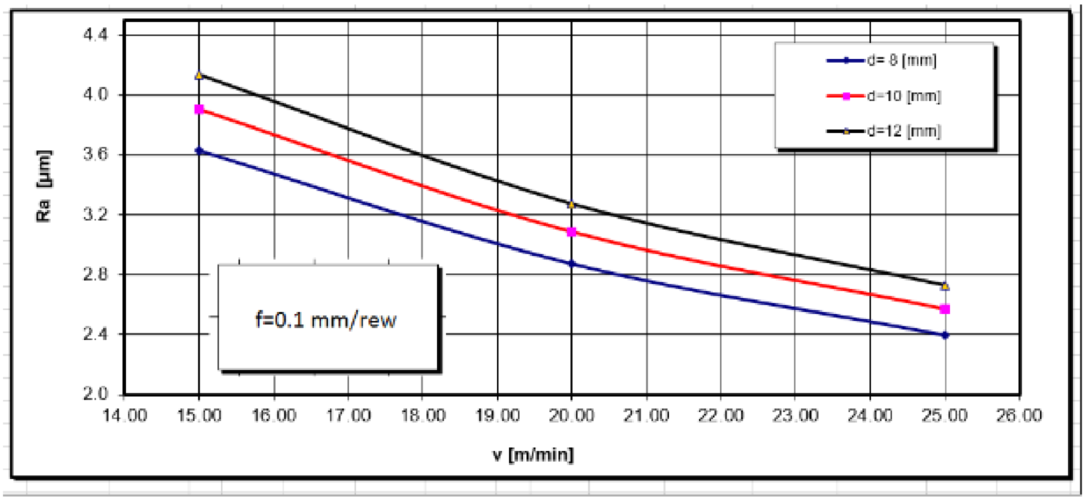
5. Results and discussion

Table 3 presents experimental results of surface roughness criteria R_a for various combinations of cutting speed, feed rate and drill tool diameter to full factorial design. Minimal value of surface roughness criteria R_a was obtained at V=25 m/min, f = 0,1 mm/rev, d=12 mm, (test No. 1). That means increasing of cutting speed and drill tool diameter with the lowest feed rate lead to decreasing of surface roughness.

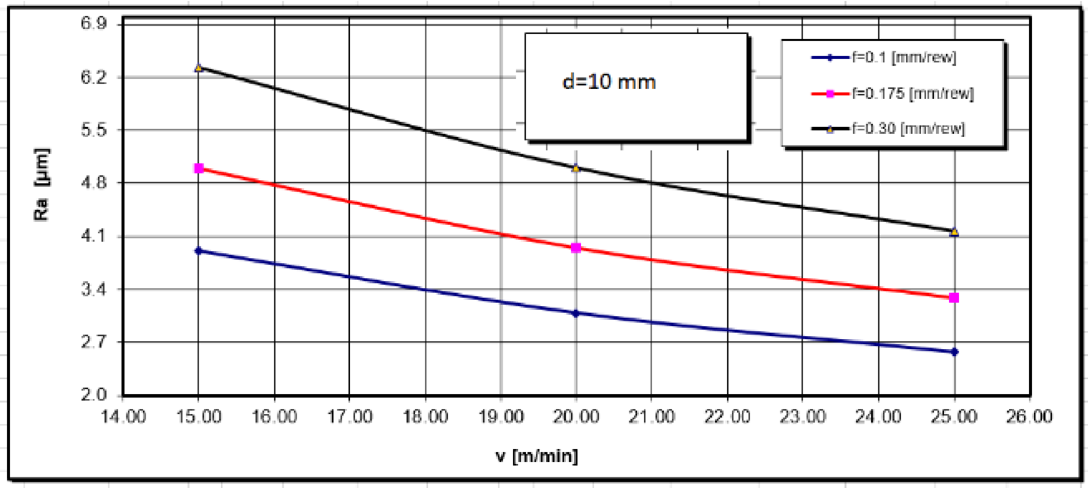
It is found that cutting speed has the most significant effect on surface roughness, followed by feed rate and drill tool diameter.

Maximal value of surface roughness criteria R_a was registered at V = 15 m/min, f = 0.3 mm/rev, d=8 mm, (test No. 10). In order to achieve better surface finish, the highest level of cutting speed, and the lowest level of feed rate and drill tool diameter, should be recommended.

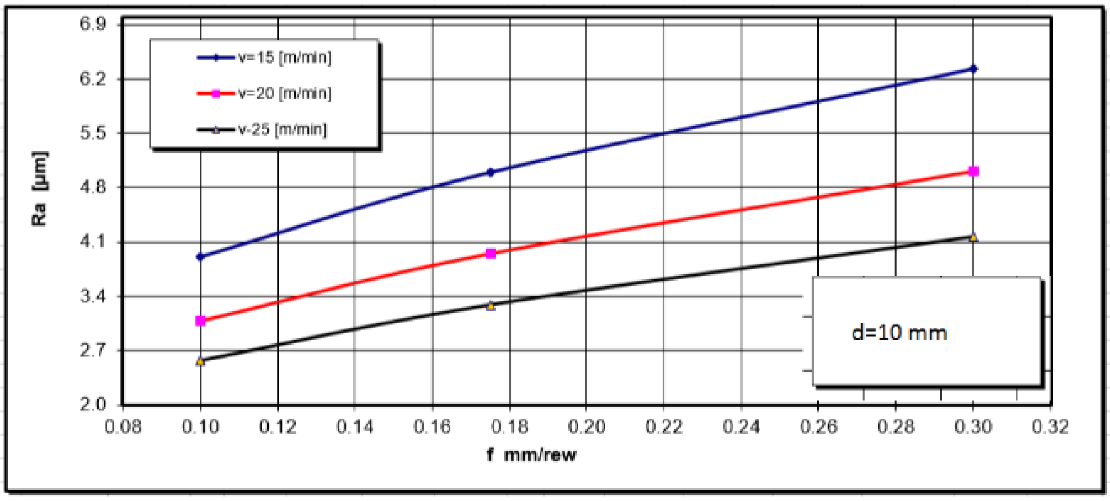
Fig. 1 which highlights the main factor plots for Ra appears to be an almost linear decreasing function of cutting speed and an increasing function of feed rate (f) and drill tool diameter (d). Figs. 2 a, b, c and d illustrate 3D surface plots of Ra according to the predictive exponential empirical model (9).



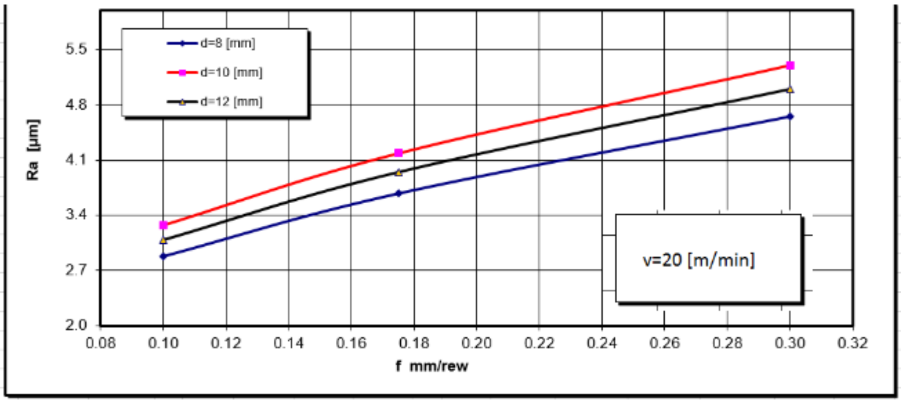
a)



b)

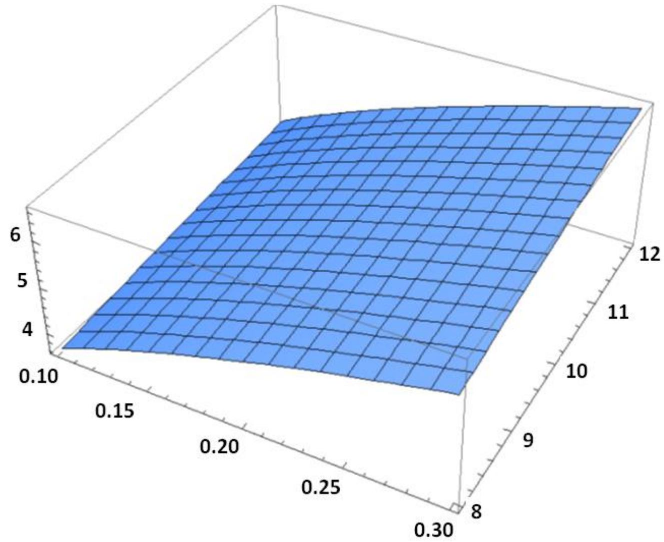


c)

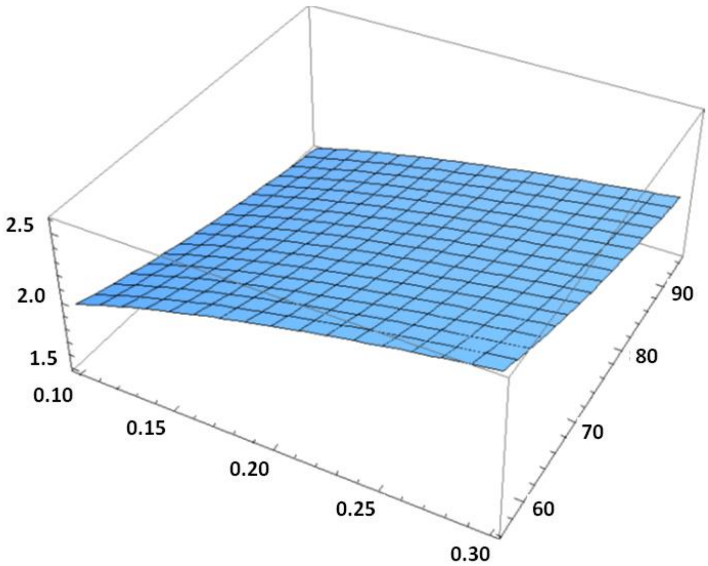


d)

Fig. 1. The dependence of surface roughness on: a) cutting speed and various values of tool diameter, b) cutting speed and various values of feed rate, c) feed rate and various values of cutting speed, d) feed rate and various values of tool diameter



a)



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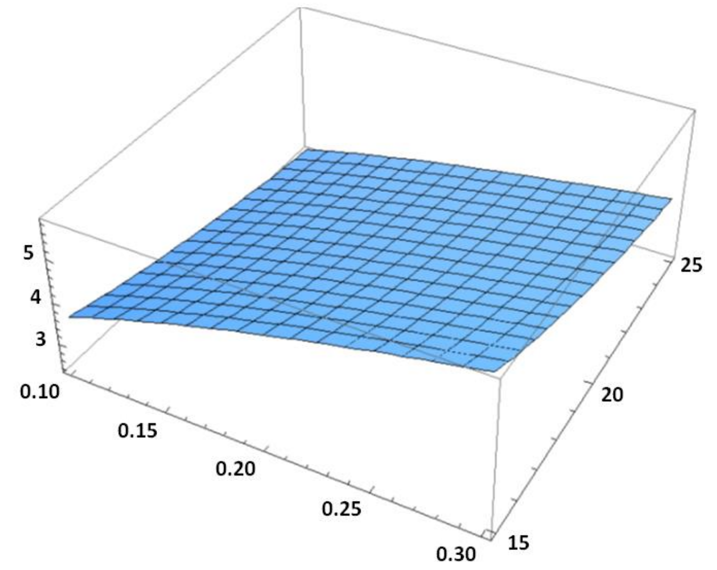

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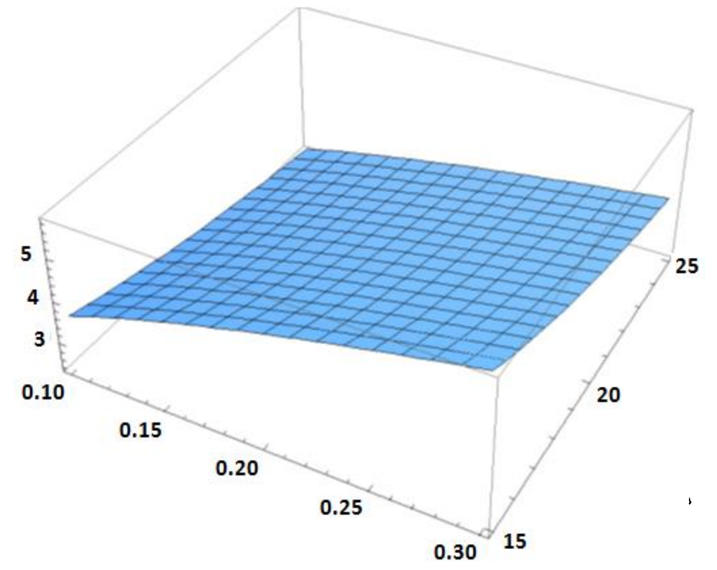

d)

Fig.2. 3D surface plots: $\mathbf{3PlotD}[\mathbf{46.567} * (\mathbf{12\hat{}0.32}) * (\boldsymbol{f}\mathbf{\hat{}0.44}) * (\boldsymbol{v}\hat{} - \mathbf{0.816}), \{\boldsymbol{f}, \mathbf{0.1}, \mathbf{0.3}\}, \{\boldsymbol{v}, \mathbf{15}, \mathbf{25}\}]$

6. Conclusions

This paper presents research of various cutting parameters affecting the surface roughness in dry drilling of forgings steel EN 1.0038 using HSS coated TiN drill tools.
The investigations of this study indicate that the cutting parameters like cutting speed and feed rate are the primary influencing factors, which affect surface roughness.
Statistical models deduction defined the degree of influence of each cutting parameter element on surface roughness criteria.
The results revealed that cutting speed seems to influence surface roughness (0.816) more significantly than feed rate (0.44). However, drill tool diameter is less significant (0.323).
With the regression equation generated, the best combination of design independent variables for achieving the optimization of cutting processes.
The predicted developed mathematical model can be used by the manufacturer while selecting the machining parameters.
The predicted results are in good agreement with the measured ones. These relationships are applicable within the range of tested parameters.

7. References

[1] M. A. Amrana,*, S. Salmah, N.I.S. Hussein, R. Izamshah, M. Hadzley, Sivaraos, M.S. Kasimb, M.A. Sulaiman, Effects of machine parameters on surface roughness using response surface method in drilling process, The Malaysian International Tribology Conference 2013, MITC2013, Procedia Engineering 68 (2013) 24 – 29, Available online at www.sciencedirect.com

[2] Kalpakjian, S., Chmid, S., 2006. Manufacturing Engineering and Technology, Singapore, Pearson

[3] S. Garg, R. k. Goyal, A Study of Surface Roughness in Drilling of AISI H11 Die Steel using Face Centered Design , IJIRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 12 | May 2015 ISSN (online): 2349-6010 All rights reserved by www.ijirst.org 464

[4] S. Thamizhmanii, S. Saparudin and S. Hasan; Analyses of Surface Roughness by Turning Process Using Taguchi Method, Journal of Achievements in Materials and Manufacturing Engineering, Volume 20 Issues 1-2 January-February 2007

[5] J. Jurko, Study of Changes in a Machined Stainless Steels Surface during Drilling, Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, 20-23rd October 2010, Zadar, Croatia, ISSN 1726-9679, ISBN 978-3-901509-73-5, Katalinic, B. (Ed.), pp. 0051-0052, Published by DAAAM International Vienna, Vienna

[6] A. Z. Sultana, Safian Sharifb,*, Denni Kurniawanb, Effect of Machining Parameters on Tool Wear and Hole Quality of AISI 316L Stainless Steel in Conventional Drilling, Procedia Manufacturing 2 (2015) 202 – 207 Available online www.sciencedirect.com, 2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015,4-6 February 2015, Bali Indonesia.

[7] N. Qehaja, H. Zeqiri, A. Salihu, H. Osmani, F. Zeqiri, Machinability of Matals, Methods, and Practical Application, Annals of DAAAM & Proceedings 2012, The 23RD World Symposium, 24-27th October 2012, University of Zadar, Croatia, URL: http:\\www.daaam.com, Vienna University of Technology, Karlsplatz 13/311, A-1040 Wien, Austria, Europe

[8] A. Salihu, H. Zeqiri, A. Bunjaku, N. Qehaja, F. Zeqiri, Research of Surface Roughness Average of Steel C45 During Turning, Anals of DAAAM for 2010 & Procedings of the 21st International DAAAM symposium, Volume 21, PP. 0185÷0186, ISBN 978-3-901509-73-5. No 1. ISSN 1726-9679. Vienna University of Technology, Karlsplatz 13/311, A-1040 Wien, Austria, Europe

[9] L. Huang and C. Chen, A Multiple Regression Model to Predict In-process Surface Roughness in Turning, Journal of Industrial Technology • Volume 17, Nr. 2 • February 2001 to April 2001.

[10] N. Qehaja, A. Bunjaku, J. Kacani. A.Salihu, H. Zeqiri, H. Osmani, Mathematical models of flank wear curve during the turning of steel C60E4, The 20thInternational DAAAM SYMPOSIUM “Intelligent Manufacturing & Automation: Focus on Next Generation of Intelligent Systems and Solutions” 22-25th October Vienna, Austria,2009

[11] N. Qehaja, M. Bruçi, H. Zeqiri, A. Salihu and A Gjelaj; Tool Life Prediction of Tungsten Carbide Cutting Tools in Turning Process, International Conference on Innovative Technologies In-Tech2014, p.271-275, Budapest, Hungary

[12] H. Zeqiri, N. Qehaja, F. Zeqiri, A. Salihu, H. Osmani, Research of Flank Wear in Turning of Steel Ck 60, Annals of DAAAM & Proceedings 2012, The 23rd DAAAM World Symposium, 2012

[13] A. Salihu, H. Zeqiri, A. Bunjaku, N. Qehaja, H. Osmani, A. Kyçyky, Research of the horizontal parameters of the roughness machined surface by turning, The 20th International DAAAM Symposium “Intelligent Manufacturing & Automation: Focus on Next Generation of Intelligent Systems and Solution”, 2009

[14] M. Durairaja, S. Gowri, Parametric Optimization for Improved Tool Life and Surface Finish in Micro Turning using Genetic Algorithm, International Conference On DESIGN AND MANUFACTURING, IConDM 2013, Procedia Engineering 64 (2013) 878 – 887

[15] C.G. Onwubolo, S. Kumar, Response Surface Methodology Based Approach To CNC Drilling Operation, Journal of Materials rocessing Technology 171, pp. 41-47. 2006.

[16] N. Qehaja, K. Jakupi, A. Bunjaku, M. Bruçi, H. Osmani, Effect of machining parameters and machining time on surface roughness in dry turning process. Procedia Eng 100:135–140, 2015

[17] S. Tangjitsitcharoen, A. Senjuntichai, In- Process monitoring and prediction of surface roughness in ball-end milling process, Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679 ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010