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Research Article

CREATING THE MATHEMATICAL MODEL FOR THE SURFACE ROUGHNESS VALUES OCCURRING DURING THE TURNING OF THE AISI 1040 STEEL

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ABSTRACT

In this research, AISI 1040 steel whose hardness is 46 HRc was processed in CNC lathe. Taguchi L_{16} experiment design was created based on cutting speed, feed rate and depth of cut of which is consisted of four levels. As a result of these experiments, average surface roughness (Ra) values were measured. Multiple regression models for measured Ra values were created by using MINITAB 14 program. The closest results to the experiment results in regression models created for Ra were obtained with the quadratic regression model with the 99.8% coefficient of determination. With the regression models created, it was determined that the most effective parameters are the feed rate parameters. From mathematical equations created in the result of the experiments carried out, it was determined that the quadratic regression equation is approximately 90% correct.
Keywords: AISI 1040, turning, surface roughness, the multiple regression model.

1. INTRODUCTION

One of the modern industry trends is manufacturing high quality products with low cost and in a short time [1]. Automation and manufacturing systems can be used for this purpose [2]. While manufacturing in short time with low cost, CNC lathes are used to ensure the surface quality [3,4].

Turning process is carried out to decrease the diameter of the workpiece and to obtain a smooth surface [5]. Processing method, the type of the cutter, processed material, physical factors, chemical factors, coolant, mechanical action between the cutter and the object are the parameters affecting the surface quality [6,7]. A properly processed surface supplies important enhancements to the surface fatigue strength, corrosion resistance and friction working life. Regression equations are widely used to estimate the surface roughness [8].

The most frequently used materials in turning process are notably steel and aluminum and magnesium alloys [9]. Choosing the proper cutting parameter according to the material machined:

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it is important for the high accuracy and the efficient machining [10]. The aim of the researchers is that to find the ideal values for manufacturing and maintenance. Therefore, mathematical programming methods are widely used to find the optimal value in the researches [11]. Methods like Taguchi, regression models, respond surface methodology, artificial neural nets, fuzzy logic and ant colony help the researchers at the decision making stage [12-15].

Regression analysis is an analysis method to measure the relation between the two or more variables [16]. If an analysis is made using only one variable, it can me named as one-variable regression; if more than one variable are used it can be named as multiple-variable regression analysis. The information is obtained about whether there is a relation between the regression analysis and variables and about the force of this relation [17]. The number of the experiments is high in machining and this causes some problems in terms of time and cost. For example, the information can be obtained about the effect on the variable in different parameters thanks to a regression equation created by measuring the surface roughness depending on the certain cutting speed, feed rate and cutting depth [18]. This returns profit in terms of time and cost.

In this study, the approximate surface roughness values occurring after the turning process on the AISI 1040 steel were measured experimentally. Taguchi L_{16} design was used as the experiment design. For the surface roughness values obtained, first order, quadratic and logarithmic regression models were created with multiple regression. The most effective parameters affecting the regression equations were determined. The calculations of the regression equations according to the experiment parameters were made and they were compared with the experiment results. As the last stage of our study, repetition experiments were carried out and the % of the absolute error values were calculated.

2. MATERIALS AND METHODS

In this study, AISI 1040 work tool steel used in engines, machine and apparatus production, middle-forced parts, gears, transmission shafts and mold sets was used as workpiece material. The chemical composition of AISI 1040 steel is shown in Table 1.

Table 1. The chemical composition of AISI 1040 steel.

Element	Percent (%)
Mn (Magnesium)	0,6-0,9
C (Carbon)	0,37-0,44
Si (Silicium)	0,15-0,35
S (Sulfur)	≤0,05
P (Phosphor)	≤0,04

It is desirable that the steel parts used in some applications have high abrasion resistance and high impact strength. To this end, the surfaces of the parts must be rigid, their centers as soft as possible. To achieve this, the shredding surface is applied. The surfaces of steel parts can be hardened by cementation, nitriding, flame and Induction current. Before heat treatment, oxide layers on the experiment material were removed. As heat treatment, the material was heated at 950 ^{o}C and then normalisation tempering was applied to the material by cooling the material in the air. For the hardening process, the material was heated up to 850 ^{o}C and then cooled in the water 30 minutes. After the heat treatment, the hardness value of the material was measured averagely as 46 HRc with BMS Digirok RSR hardness measurement device. Before the hardness measurement, the device was calibrated with calibre disk.

Ø80x135 mm-sized steel material was used. The dimension differences occurred after the heat treatment, oxide layers and oscillations were removed with CNC lathe.

In the experiments, ACE Micromatic Designers LT-20C CNC lathe was used. No coolant (liquid or gas) was used in the experiments, turning process was carried out under the dry cutting conditions. In the experiments, Teknik DDJNR 2525M15 was used as tool holder, DNMG 150608 diamond cutting insert was used as cutting tool. Machining distance is 50 mm. In the Figure 1, the connection of the sample on the turning lathe, cutting insert and tool holder can be seen.

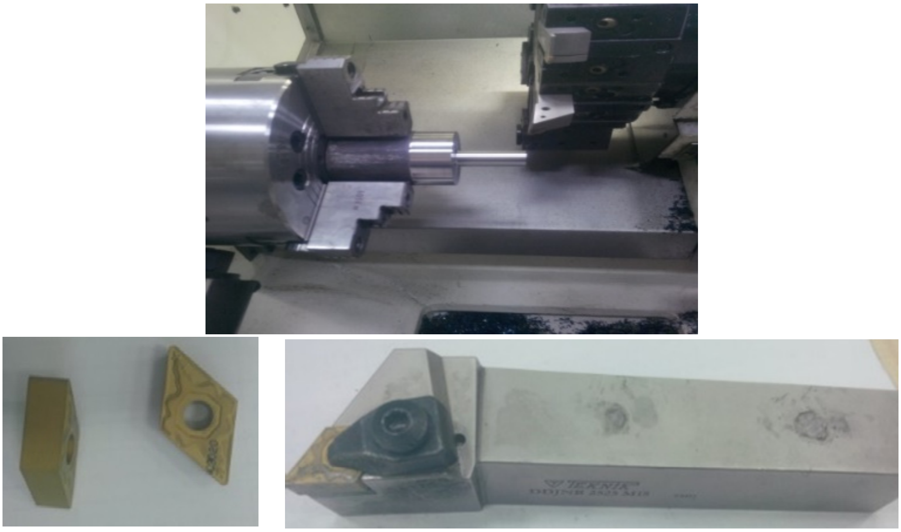

Figure 1. The test sample, inserts and tool holders.

Cutting parameters, in accordance with the manufacturer company catalogue, were determined as four different cutting speed (V), four different feed rate (f) and four different depth of cut (a). These cutting parameters are shown in the Table 2.

Table 2. Cutting parameters and level values.

Cutting parameters	Units	Level 1	Level 2	Level 3	Level 4
Cutting speed	m/min	200	225	250	275
Feed rate	mm/rev	0,15	0,25	0,35	0,45
Depth of cut	mm	1,5	2,5	3,5	4,5

3. EXPERIMENTAL RESULTS

Since carrying out 64 experiments in total with full factorial design will cause time and cost loss, in order to eliminate these problems L_{16} orthogonal array was created with Taguchi method. After the cutting parameters given in the Table 2 were applied, Ra values coming into existence were measured with Mitutoyo Surftest SJ-210 surface roughness measurement device. Before the measurement, surface roughness device was calibrated.

Experiments were repeated five times and average value of the measurement was taken. Concerning the chosen cutting edge type, four process are made with one edge in this experiment. Different cutting edge was used for every experiment. Experiment list and average Ra values obtained are shown in Table 3.

4. MULTIPLE REGRESSION EQUATIONS, RESULTS AND EVALUATION

In the regression equation coefficient; Coef: The coefficient of the values, Coef SE: Standard errors in coefficients, T: The result of the test statistics, P: Signifies whether the regression analysis is significant or not. If P<0.05 the conclusion that independent variable affects the dependent variable in regression equation is drawn[19-20].

Table 3. L_{16} orthogonal array created using the experimental design and experimental results.

Experimental number	V (m/min)	f (mm/rev)	a (mm)	Experimental Ra (µm)
1	200	0,15	1,5	1,13
2	200	0,25	2,5	2,71
3	200	0,35	3,5	4,94
4	200	0,45	4,5	7,70
5	225	0,15	2,5	1,32
6	225	0,25	1,5	2,66
7	225	0,35	4,5	5,18
8	225	0,45	3,5	7,44
9	250	0,15	3,5	0,94
10	250	0,25	4,5	2,68
11	250	0,35	1,5	4,75
12	250	0,45	2,5	7,25
13	275	0,15	4,5	1,49
14	275	0,25	3,5	2,74
15	275	0,35	2,5	4,72
16	275	0,45	1,5	7,05

The regression equation of the first order for Ra

First order regression equations obtained for the Ra values are given in the equation (1). First order regression coefficients for Ra were given in Table 4.

$$Ra = - 1,90 - 0,00242 *V + 20,6 *f + 0,111 *a \quad (1)$$

Table 4. First-degree coefficients of the regression equation for Ra.

Predictor	Coef	SE Coef	T	P
Constant	-1,90	0,75	-2,54	0,03
V	0,00	0,00	-0,84	0,42
f	20,62	0,72	28,79	0,00
a	0,11	0,07	1,55	0,15

The coefficient of determination (R^2) in the regression equation is 98.6% for Ra. Since it is close to 1, it can be said that there is a strong relation between the variables. The 98.6% of the change in the dependent variables can be explained with independent variables. Since P<0.5 is the most effective independent variable affecting the Ra variable in the first order equation, it is feed rate.

The regression equation for in the second degree Ra

Quadratic regression equation obtained for the Ra values is given in the equation (2). Quadratic equation coefficients for Ra were given in Table 5.

$$Ra = 0,83 - 0,0090*V + 9,45*f - 0,394*a + 0,000026*v^2 + 24,6*f^2 + 0,0362*a^2 - 0,0196*V*f + 0,00053*V*a + 0,393*f*a \quad (2)$$

Table 5. Second degree regression equation coefficients for Ra.

Predictor	Coef	SE Coef	T	P
Constant	0,83	4,68	0,18	0,87
V	-0,01	0,04	-0,25	0,81
f	9,45	6,74	1,40	0,21
a	-0,39	0,67	-0,58	0,58
V^2	0,000026	0,00007289	0,36	0,734
f^2	24,63	4,56	5,41	0,00
a^2	0,04	0,05	0,80	0,46
V*f	-0,02	0,02	-0,80	0,46
v*a	0,00	0,00	0,21	0,84
f*a	0,3932	0,6143	0,64	0,546

The coefficient of determination (R^2) in the regression equation is 99.8% for Ra. Since it is close to 1, it can be said that there is a strong relation between the variables. The 99.8% of the change in the dependent variables can be explained with independent variables. Since $P<0.5$ is the most effective independent variable affecting the Ra variable in the quadratic equation, it is feed rate.

Logarithmic regression equation for Ra

Logarithmic regression equation obtained for the Ra values are given in the equation (3). Logarithmic regression equation coefficients for Ra were given in Table 6.

$$Ra = 13,9 - 1,32*Log(V) + 12,5*Log(f) + 0,66*Log(a) \quad (3)$$

Table 6. Logarithmic regression equation coefficients for Ra.

Predictor	Coef	SE Coef	T	P
Constant	13,86	8,38	1,65	0,12
Log(V)	-1,32	3,52	-0,38	0,71
Log(f)	12,51	1,02	12,33	0,00
Log(a)	0,66	1,02	0,65	0,53

The coefficient of determination in the logarithmic regression equation is 92.7% for Ra. Since it is close to 1, it can be said that there is a strong relation between the variables. The 92.7% of the change in the dependent variables can be explained with independent variables. Since $P<0.5$ is the most effective independent variable affecting the Ra variable in the logarithmic equation, it is feed rate.

Comparison of the results for Ra

The calculations made after the first order, quadratic and logarithmic regression equations for Ra were given in the Table 7. The obtained results are shown in Figure 2 as bar chart. When Table 7 and Figure 2 is assessed, it can be seen that the obtained coefficients of determination are closer to the experiment results of the quadratic regression equation.

Table 7. The results obtained for Ra.

Case number	Experimental Ra(µm)	I. degree Ra(µm)	II. degree Ra(µm)	Logarithmic Ra(µm)
1	1,13	0,87	1,19	0,68
2	2,71	3,04	2,74	3,60
3	4,94	5,21	4,94	5,52
4	7,70	7,39	7,77	6,96
5	1,32	0,92	1,12	0,76
6	2,66	2,87	2,74	3,39
7	5,18	5,27	5,01	5,53
8	7,44	7,21	7,47	6,82
9	0,94	0,97	1,18	0,79
10	2,68	3,14	2,88	3,64
11	4,75	4,87	4,71	5,15
12	7,25	7,04	7,25	6,66
13	1,49	1,02	1,36	0,81
14	2,74	2,97	2,79	3,51
15	4,72	4,92	4,71	5,24
16	7,05	6,87	7,10	6,46

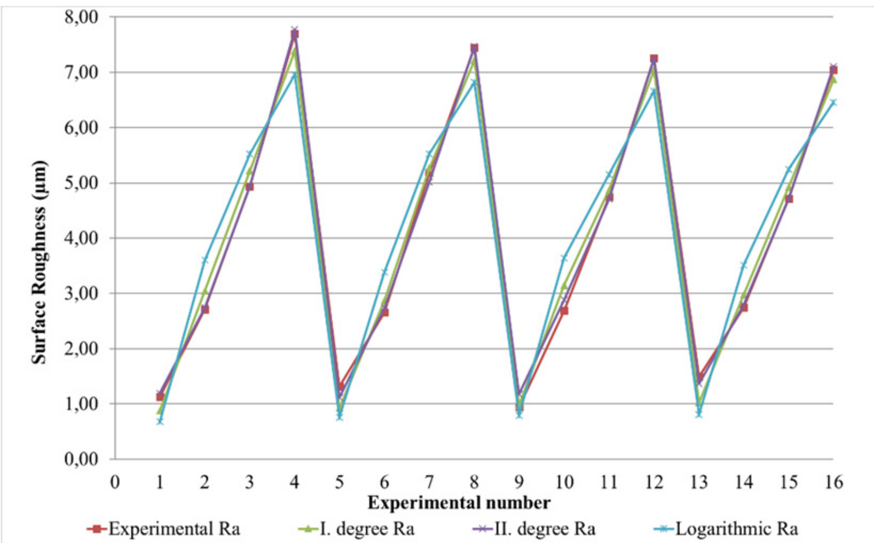

Figure 2. Comparison of the experimental results and regression for Ra.

In this study, differently from our another study, we carried out three estimation experiment. The experiment parameters, the surface roughness values obtained according to the experiment parameters, calculated results with the multiple regression models and the % error between these results can be seen in Table 8. In the direction of these experiments, it can be seen that quadratic regression equation is approximately 90% correct. The reason why the quadratic regression equation is reliable is that it includes the relations of the parameters with each other.

Table 8. Prediction parameters and results.

Control experiments parameters			Experimental results				Absolute error(%)		
V (m/min)	f (mm/rev)	a (mm)	Experimental Ra(μm)	I. degree Ra(μm)	II. degree Ra(μm)	Logarithmic Ra(μm)	I. degree	II. degree	Logarithmic
200	0,15	4,5	1,28	1,21	1,16	0,99	5,62	9,55	22,11
250	0,25	2,5	2,57	2,92	2,70	3,47	13,54	4,82	34,87
225	0,35	1,5	4,63	4,93	4,77	5,21	6,45	3,04	12,49

5. CONCLUSIONS

In this study, the approximate surface roughness values occurring after the turning process on the AISI 1040 steel were measured experimentally. The results obtained show that as the cutting speed increases, the surface roughness decreases and as the progress and chip depth increase, the surface roughness increases. Taguchi L_{16} design was used as the experiment design. For the surface roughness values, the estimation model was created with the multiple regression. With the regression model created, it can be said that with the 99.88% coefficient of determination the quadratic regression equation is the best regression equation for Ra. It was determined that the most effective independent variable affecting the Ra variable in the quadratic equation is feed rate. From mathematical equations created in the result of the experiments carried out, it was determined that the quadratic regression equation is approximately 90% correct.

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