

Selection of Appropriate Cutting Parameters to Achive Optimum Surface Roughness with Taguchi

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Abstract

In this study, AISI 1040 steel, which has a hardness of 41 HRc which is frequently used in the field of automotive industry, has been turned with a CNC lathe. The test list was made by creating L9 orthogonal array in the cutting speed, cutting depth and feed parameters with Taguchi method. The work pieces are machined on CNC lathes using Ti+Al2O3+TiN coated carbide inserts. The experiments were done with dry conditions without any coolant. According to the results of the experiments, the surface roughness values (Ra) were examined. With this method signal/noise (S/N) ratio is determined and the results of the experiments in the three parameters of the surface roughness of the most significant effect is reached from the results of feed. Finally, Taguchi control experiments were applied. The obtained results show that the Taguchi estimate is about 90% accurate. In the analysis of variance, the confidence level of progress was 95%.

Keywords: AISI 1040, Surface roughness, Turning, Taguchi method

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1. Introduction

The main aim in production is to reduce production cost and to obtain better quality products. It is also aimed to minimize production time [1]. Automation is used for this aim to ensure the mass production [2]. Computerized (CNC) machines are preferred to ensure good surface for producing in short time and at low cost [3].

Turning is used to reduce the work piece's diameter and get a nice surface [4]. Machining strategies, cutting tool's type, work pieces material, physical, chemical, thermal factors, cooling fluid, mechanical movements between machining and cutting parameters affecting the quality of surface [5]. The high quality surface ensures major improvements in wear resistance, friction and life. Taguchi method is widely used to estimate surface roughness [6].

The goal of the researchers is to determine the optimal cutting condition in design, manufacturing field. For this purpose, statistical and mathematical models are commonly preferred to determine the optimal conditions in studies [7]. Artificial neural networks, regression, Taguchi and surface response methods help researchers in making the right decision [8]. The Taguchi technique is a problem-solving process that has a low cost development cycle and can improve product performance in system and process design. This process relates experimental and analytical notions that determine more effective parameters on results for significant improvements in overall performance [9]. Recently, optimizing cutting parameters has attracted researchers to improve quality and reduce costs. Research is going on, to find the direct and interaction effects of cutting parameters on the surface roughness [10].

Asilturk and Neseli [11] optimized surface finish and verified the results. After optimization, the feed was the most dominant factor. Also, Asiltürk and Akkuş [7] examined the effect of cutting factors affecting surface roughness with different optimization systems. They examined the cutting forces and They have determined the cutting conditions at which it achieves the lowest surface roughness. Yang and Tarng [12] have worked to find the best cutting parameters for the parameters that affect the cutting performance in turning. Thamizhmanii et al. [13] machined the SCM 440 steel and tried to determine the optimum cutting parameters for the smallest surface roughness. They used Taguchi method in their studies. In their study, they have determined that the most important parameter for the low roughness of the surface is the cutting depth. Then the feed and cutting speed are coming. The lowest effect is the cutting speed.

In this study, the turning process with the test list designed using the Taguchi method, the optimal parameters for average surface roughness (Ra) values were determined. The results were showed similar features to the previous studies.

2. Experimental Design

AISI 1040 steel is widely used in engines and automotive, gear and shaft manufacturing, mold components, machines and apparatus. Therefore, this material was used in the experiments. Table 1 shows the chemical content of the material used in the experiment.

Table 1. Chemical content of AISI 1040 manufacturing steel.

(Element)	(%)
C	0.40 – 0.50
Si	0,25 - 0.35
Mn	0.60 - 0.90
P	≤ 0.04
S	≤ 0.05

The test material was subjected to heat treatment to reach the desired hardness. In the heat treatment, the material was heated at a temperature of about 1000°C for a period of time and air cooled. In this way, normalization annealing is performed. To harden the material, it was heated to 800°C and allowed to cool in water for one hour. The hardness of the product obtained at the end of these processes was measured as 41 HRc. In our experiments, 60 mm diameter and 200 mm long cylindrical parts were processed. 80 mm length processing was done on the part. Distortions on the material surface, crusts were removed by turning before starting experiments.

Our experiments were carried out on ACE brand CNC machine which can make two axis cutting as lathe. No coolant was used during processing. SANDVIK brand tool holder and SANDVIK brand Ti+Al2O3+TiN coated carbide cutting insert have been used in the experiments. Cutting insert has the ability to cut from four corners due to the shape. For cutting operations, cutting edges are used only once. The turning of the samples on the CNC machine and the dimensions of the tool holder and cutting tool are given in Figure 1.

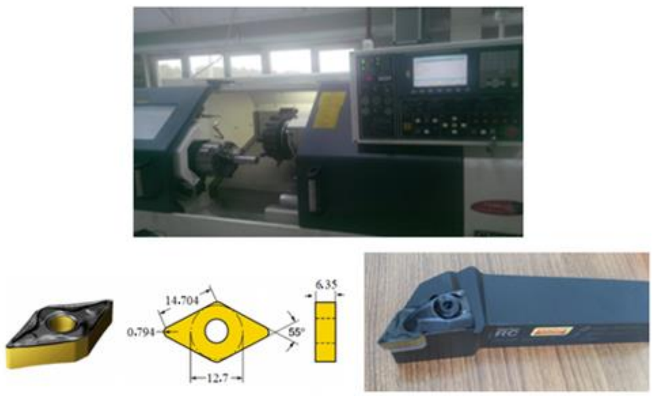

Figure1. Machining of samples on the machine, tool holder and cutting tool.

Cutting parameters are determined within the limits specified in the catalog of the cutting machine manufacturer. Three different values have been determined for the parameters from the cutting speed, cutting depth and feed parameters. The selected parameter values are given in Table 2.

Table 2. Parameters with three different levels.

Symbol	Cutting Parameters	Levels		
		1	2	3
A	Cutting speed (m/min.)	275	345	415
B	Feed (mm/rev.)	0.15	0.30	0.45
C	Cutting depth (mm)	1	3	5

Taguchi method was used to reduce cost and time in production. L9 array was created by the determined cutting parameters and experiments were performed. At the end of experiments, the surface roughnesses of the workpiece surface were measured by measuring the Mitutoyo brand roughness value device as shown in Figure 2.

Figure 2: Offline measurement of surface roughness.

The surface roughness values were measured from different locations on the machined cylindrical part and the measured values were averaged. The measurements were made offline. Figure 2 shows the surface roughness measurement. L9 experimental list and the found surface roughness values are given in Table 3.

3. Evaluation with Taguchi Method

In this study using Taguchi method, the S/N equation, which is the smallest is best for the lowest surface roughness value, is used. Thus, the most suitable cutting parameters have been determined. It is generally used in the problems that are desired to reduce the average and change as much as possible. The obtained S/N values are given in Table 3.

Table 3. Test list and measured surface roughness values.

Number of Experiment	A	B	C	Ra (μm)	S/N
1	275	0.15	1	1.80	-5.105
2	275	0.30	3	9.64	-19.681
3	275	0.45	5	15.84	-23.995
4	345	0.15	3	3.24	-10.210
5	345	0.30	5	9.70	-19.735
6	345	0.45	1	11.72	-21.378
7	415	0.15	5	4.94	-13.874
8	415	0.30	1	8.80	-18.889
9	415	0.45	3	13.06	-22.318

In this study, S/N ratios should be the highest to determine the best parameters in the Taguchi method. Considering all this, the optimal cutting condition in the L9 test list was found to be -5.105 S/N for the average surface roughness (Table 3). A1B1C1 array, which is the first experiment in list, was the most appropriate experiment with the lowest surface roughness. That is, the cutting speed is 275 m/min., the feed is 0.15 mm/rev. and the cutting depth is 1 mm levels are optimum cutting parameters (Figure 3). It also appears to be the largest S/N ratio in the first experiment. Table 4 shows that the effect rates of the factors on Ra are first feed, second cutting depth and third cutting speed, respectively.

Table 4. S/N value response table of average surface roughness of cutting factors.

Level	A	B	C
1	-16.261	-9.730	-15.125
2	-17.108	-19.436	-17.404
3	-18.361	-22.564	-19.202
Delta	2.100	12.834	4.077
Rank	3	1	2

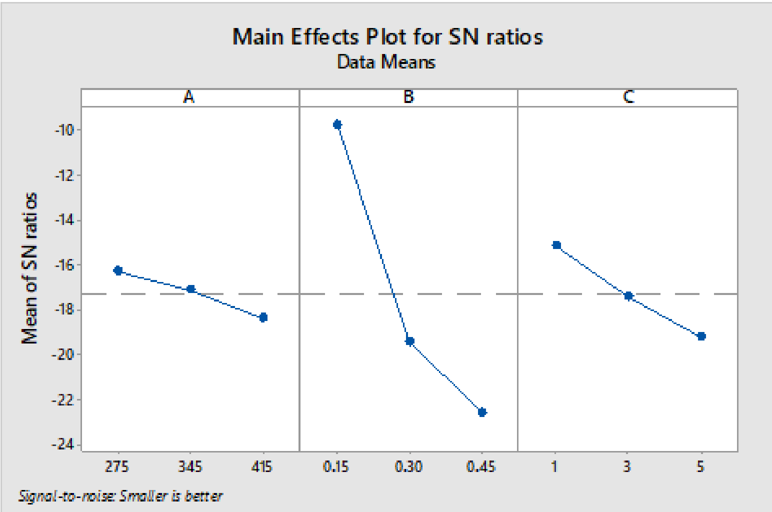

Figure 3. The S/N ratio of factor levels according to the best Ra graph.

In figure 4, the surface roughness increased when the feed increased. If the cutting speed increases, the surface roughness should be reduced [10]. As clearly seen in Figure 4, surface roughness decreased when cutting speed increased from 275 m/min to 345 m/min. However, when the cutting speed increased to 415 m/min, the surface roughness increased again due to the increase of feed. In general, the increase of feed increased the surface roughness, and the increase of the cutting speed decreased the surface roughness.

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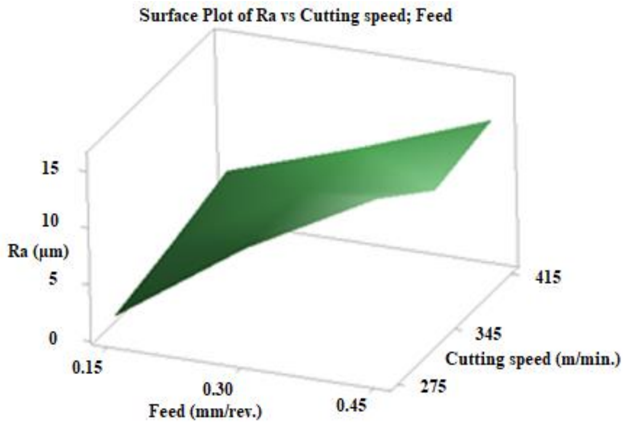

Figure 4. Cutting speed-feed effects on surface roughness.

It is clearly seen in Figure 5. The surface roughness increased as the depth of the cut increased. The highest surface roughness was seen at the values with the highest cutting depth and feed (the feed was 0.45 mm/dev. and cutting depth was 5 mm). Surface roughness increased as the cutting depth increased.

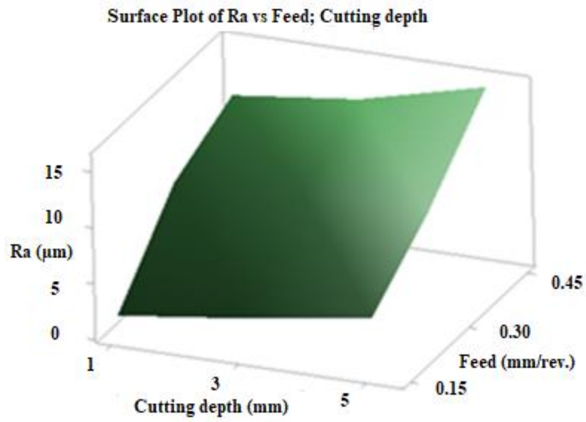

Figure 5. Feed-cutting depth effects on surface roughness.

The surface roughness should decrease as the cutting speed increases. As the surface depth and cutting speed are inverse effect on surface roughness, a wavy surface area graph is formed. Because, the cutting depth and cutting speed are inversely proportional to the surface roughness, a wavy surface area graph is formed in Figure 6.

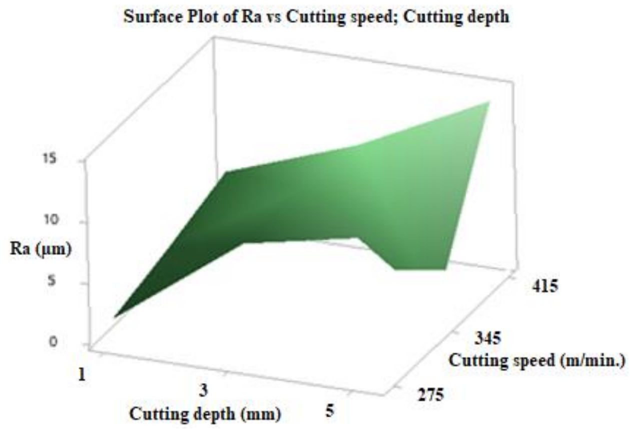

Figure 6. Cutting speed-cutting depth effects on surface roughness.

3.1. Control Experiments for Taguchi Estimations

In the last stage of the Taguchi analysis, two different control experiments were performed with the levels not found in the combination in the L9 experiment design. These levels were given in Table 5. Also, in Table 5, the result of Taguchi estimation, the result of the experiment and the error between these results are given in percent. These results show that the Taguchi estimate is about 90% accurate.

Table 5. Differences between Taguchi estimation and test results.

Prediction Experiments			Experimental Ra (µm)	Taguchi Estimation Ra (µm)	Absolute Difference	% Absolute Error	Accuracy Rate
A	B	C					
275	0.15	3	3.96	3.56	0.40	0.10	% 90
345	0.45	5	16.71	14.42	2.29	0.14	% 86

Table 6. The relationship between factors and S/N ratios.

Factors	SD	KT	KO	F	P
A	2	0.248	0.124	0.99	0.502
B	2	41.066	25.533	202.83	0.005
C	2	2.283	1.141	9.07	0.098
Error	2	0.251	0.125		
Total	8	43.8503			

While the most suitable processing conditions were found by Taguchi method, it was determined by variance analysis in the relations between factors. The data of S/N ratios obtained with ANOVA are shown in Table 6. $P < 0.01$ or $P < 0.05$ significance in ANOVA is required. According to the data obtained, it is seen that the significance values are in progress, the depth of the cut, the cutting speed. While the confidence level of progress was 95%, the depth of cut and the cutting speed did not exceed this confidence level. These results confirm the importance of the factors given in Table 5.

4. Conclusions

In this study, Taguchi method was used to find the lowest average surface roughness (Ra) and optimization of the cutting parameters was made. The results of study are given below.

Firstly, L9 experiment list was generated by the Taguchi method as 3 different levels of the cutting factors. Then, the samples were turned on the CNC lathe. As a result of the experiments, S/N values of average surface roughness were determined. S/N values were found to be the highest values with the smallest-best rule. The highest S/N value shows the optimum machining conditions. The minimum Ra value was 1.80 µm in the first experiment. This is the smallest surface roughness value among the experiments. The optimum machining condition with a maximum of -5.1055 S/N for the minimum Ra value in the experiment, the cutting speed is 275 m/min, the feed is 0.15 mm/rev. and the cutting depth is 1 mm. This result occurred in the A1B1C1 array. As seen in Table 4, the significance ratio of the parameters was as BCA, respectively. In other words, while the feed was the most efficient parameter, the cutting speed was the most ineffective parameter. In generally, when the feed increased, the surface roughness increased and when the cutting speed increased, surface roughness decreased. Also, the surface roughness increased as the depth of the cut increased.

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