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Investigation of Effect of Machining Process Parameters on Surface Quality

M. Şafak BARAN^{*1}, Osman H. METE¹

Abstract

Machining method is the most commonly used manufacturing method in the industry. The product, which is chipped on the raw material with the help of a cutting tool, is finalized. The manufactured product must be within the dimensional and geometric tolerances determined by the designer in order to discharge its functionality. In addition to these tolerances, surface quality is expected. In this study, the effect of the process parameters on the surface quality of the milling operation, which is the most commonly used machining method, was investigated as experimentally. Experimental design was carried out by using Taguchi L₁₈ orthogonal array and the effect of four process parameters on the surface quality was investigated. ANOVA was carried out in order to investigate the effect of process parameters on experiment results and their statistical significance. The validity of experimental model was investigated by comparing the actual experimental results with the estimated results obtained by Minitab 19. According to Taguchi results; conventional cutting direction, 282 m/min. cutting speed, 0.15 mm/rev. feed rate and 0.5 mm cutting depth were found optimum levels of parameters. P value was found 0.00014 in ANOVA for feed rate parameter and it was found the most important parameter on the experiment results. R² of experiment model was found % 91.4 according to comparison result.

Keywords: Machining, process parameters, surface quality, Taguchi

1. INTRODUCTION

Machining is the process of removing unwanted material from a work piece in the form of chips [1]. With this method, it is possible to obtain products with micron level precision by using latest technology CNC machines. In the milling process, the surface roughness is one of the important properties indicating work piece quality [2]. Correct process parameters, correct machine and cutting tools selection, determination of the

correct machining methods are critic on product quality and tolerances. Surface quality is a product feature, which increases the fatigue strength and provides the sealing. The designer determines correct surface quality, especially for the surfaces, which work in constant contact with another surface, and lets this required value know the manufacturer with the help of technical drawing. Therefore, manufacturer must understand correctly required surface

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quality and define the parameters according to required values.

In this study, machining process parameters were focused. Usually these parameters, during machining operations according to cutting tool catalog data or experience of operators were selected. In this experimental study, for cutting direction two levels, for another parameters three levels were selected and totally eighteen experiments were carried out.

The purpose of this study is having knowledge based on experimental data and to determine optimum process parameters values for mass production conditions. For this purpose, using design of experiment method, both the optimum levels were determined and relationship between the parameters were examined on the surface quality.

2. MATERIAL AND METHOD

In this section, materials used in the experimental study and test method were informed. GG25/EN- GJL -250 cast iron raw material was used in the experiments. The chemical components and mechanical properties of the material are given in table 1 and in table 2.

Table 1 Chemical components of GG25 [3]

C	Fe	Mn	P	Si	S
%2.95	%92.63	%0.55	%0.10	%2.1	%0.040
%3.45	%94.26	%0.75	%0.20	%2.9	%0.070

Table 2 Mechanical properties of GG25 [4]

Density (gr/cm ³)	Hardness (HB)	Tensile strength (Mpa)
7.30	180	155

4 axes Doosan HP 5550 horizontal CNC machining center was used in the experiments. It can be seen in Figure 1. Properties of machining center are given in table 3.



Figure 1 CNC machining center

Table 3 Properties of machining center [5]

Number of controlled axes	4
Table sizes	60x60
Number of tables	2
Maximum load on table	800 kg
X axis travel	800
Y axis travel	700
Z axis travel	750
B axis rotation travel	360 degree
Maximum spindle rotation speed	10.000 rpm
Spindle power	22 kW
Number of tools	60

In rough milling operation, the cutting tool which has 63 mm cutting diameter and 6 flutes was used while in finish operation, the cutting tool which has 50 mm cutting diameter and 6 flutes was used. Rough operation cutting tool is seen in figure 2. Dimensional properties for this tool are given in table 4.

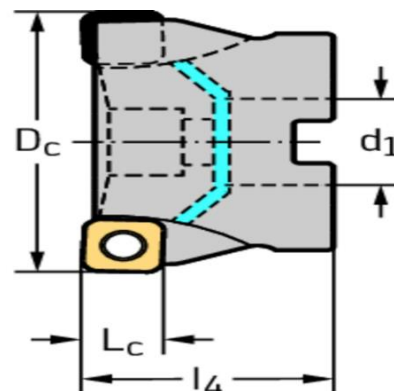


Figure 2 Rough cutting tool [6]

Table 4 Properties of rough cutting tool [7]

Cutting diameter (D_c)	63
Shank diameter (d_1)	27
Functional length (l_4)	50
Cutting length (L_c)	10
Number of inserts	6
Maximum rotation speed	15.000 rpm

Finish operation cutting tool is seen in Figure 3. Dimensional properties for this tool are given in table 5.

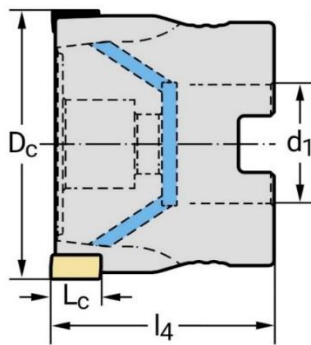


Figure 3 Finish cutting tool [8]

Table 5 Properties of finish cutting tool [9]

Cutting diameter (D_c)	50
Shank diameter (d_1)	22
Functional length (l_4)	40
Cutting length (L_c)	12
Number of inserts	6
Maximum rotation speed	20.200 rpm

In rough milling operation, SNMX 120520-D27 WKK25S coded square cutting inserts, while in finish milling operation, LNHU 130608R-55T WKK 25S coded rectangle cutting inserts were used. Rough operation cutting insert is seen in Figure 4. Dimensional properties for this insert are given in table 6.

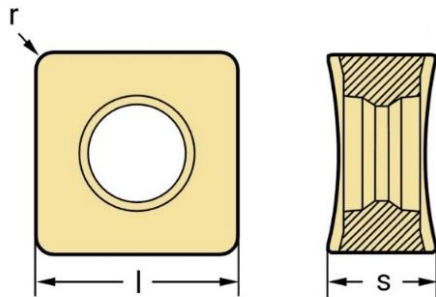


Figure 4 Rough cutting insert [10]

Table 6 Properties of rough cutting inserts [11]

Number of cutting edges	8
Cutting edge length (l)	12.7
Insert thickness (s)	5.55
Corner radius (r)	2
Insert angle	90 degree

Finish operation cutting insert is seen in Figure 5. Dimensional properties for this insert are given in table 7.

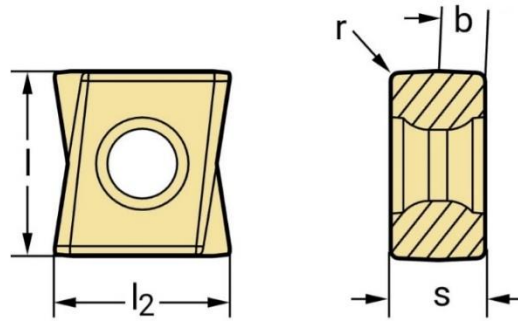


Figure 5 Finish cutting insert [12]

Table 7 Properties of finish cutting insert [13]

Number of cutting edges	4
Cutting edge length (l)	13
Insert width (l_2)	12
Insert thickness (s)	6.8
Wiper edge length (b)	2.2
Corner radius (r)	0.8
Insert angle	90 degree

Mitutoyo SJ-400 surface roughness measuring device was used to measure test samples. Sampling value (N) as 5, sampling length as 2.5 mm and evaluation length as 12.5 mm were chosen. Measuring speed is 1 mm/s. In Figure 6, surface roughness measuring device is seen.



Figure 6 Surface roughness measuring device

2.1. Design of Experiment

Design of experiment is a series of experiment performed by changing in the levels of experiment parameters in order to provide optimum results in a process. Experimental studies in engineering, product and process development play an important role [14]. In this study, in order to optimize the levels of each parameter, Taguchi method, which is one of the designs of experiment method, was

used. Taguchi experimental design is a fully accepted method which further enables to perform analysis and optimization for minimum number of minimum number of experiments [15]. In table 8, L₁₈ orthogonal array based on Taguchi design is given. For smaller is better function, formula is shown in the following.

$$\frac{S}{N} = -10 \log \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) \quad (1)$$

Table 8 Taguchi based experimental design

Experiment No	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

3. EXPERIMENTAL STUDIES

Surface roughness stands one of the important characteristics of a component produced [16]. In machining processes, this characteristic depends on some parameters. For this reason, machining parameters should be considered well. As mentioned in the previous section, by using Taguchi L₁₈ orthogonal array, experimental studies were carried out. For rough milling operation, fixedly 1.500 rpm and 0.8 mm/rev were chosen as cutting conditions. Since finish milling is the last operation, experimental studies were carried out by changing machining parameters of Ø50 cutting tool. Experiment parts were machined both in rough milling operations and in finish milling operations under dry condition. As

parameters, cutting direction, cutting speed, feed rate and cutting depth were selected. For cutting direction, climb milling and conventional milling, for cutting speed; 282 m/min, 314 m/min and 345 m/min, for feed rate; 0.15 mm/rev, 0.40 mm/rev and 0.65 mm/rev for cutting depth; 0.2 mm, 0.5 mm and 0.8 mm were selected. After determined orthogonal array and selected levels of every parameter, recorded experimental results and converted to S/N ratios. In table 9, experiment results are given.

Table 9 Experiment results and S/N ratios

Experiment No	Cutting direction	Cutting speed (Vc) m/min.	Feed rate (f) mm/rev.	Cutting depth (ap) mm	Surface roughness (Ra) μ	S/N
1	Climbing	282	0.15	0.2	0.439	7.151
2	Climbing	282	0.40	0.5	0.666	3.531
3	Climbing	282	0.65	0.8	1.075	-0.628
4	Climbing	314	0.15	0.2	0.450	6.936
5	Climbing	314	0.40	0.5	0.651	3.728
6	Climbing	314	0.65	0.8	1.316	-2.385
7	Climbing	345	0.15	0.5	0.415	7.639
8	Climbing	345	0.40	0.8	0.779	2.169
9	Climbing	345	0.65	0.2	0.934	0.593
10	Conventional	282	0.15	0.8	0.413	7.681
11	Conventional	282	0.40	0.2	0.450	6.936
12	Conventional	282	0.65	0.5	0.441	7.111
13	Conventional	314	0.15	0.5	0.336	9.473
14	Conventional	314	0.40	0.8	0.631	3.999
15	Conventional	314	0.65	0.2	0.976	0.211
16	Conventional	345	0.15	0.8	0.577	4.776
17	Conventional	345	0.40	0.2	0.592	4.554
18	Conventional	345	0.65	0.5	0.656	3.662

3.1. Optimization of Parameters

Taguchi method aims to achieve the best levels of every parameter and considers S/N ratio in order to find optimum levels. For all level, mean values are calculated afterward,

the greatest mean value is subtracted from the smallest value. Thus, the most important parameter is found on experiment results. For optimization, the greatest calculated mean S/N ratios are chosen. Table 10 shows mean S/N ratios and rank of every parameter.

Table 10 Response for signal to noise ratios

Level	Cutting direction	Cutting speed (Vc)	Feed rate (f)	Cutting depth (ap)
1	3.193	5.297	7.276	4.397
2	5.378	3.660	4.153	5.287
3		3.899	1.427	2.602
Delta	2.186	1.636	5.849	3.255
Rank	3	4	1	2

Minitab 19 provided the graphs obtained from the experiment results. According to graphs; conventional milling, 282 m/min cutting speed, 0.15 mm/rev feed rate and 0.5 mm

cutting depth were determined as optimum levels. Optimization results are seen in Figure 7.

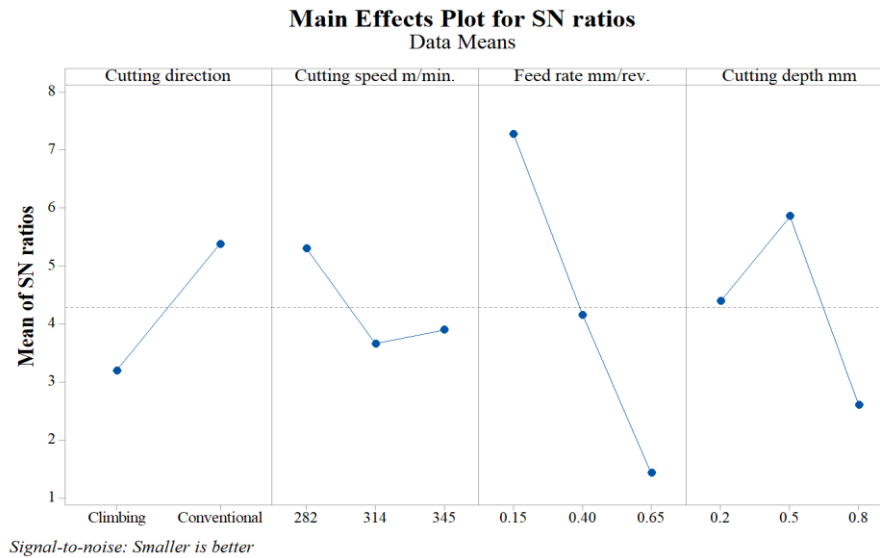


Figure 7 Optimization results

3.2. Analysis of Variance

Analysis of variance (ANOVA) is performed in order to determine the individual interactions and effects of all control factors in an experimental design [17]. On the other hand, statistical significance of procured results is tested. For this purpose, firstly SS_T value, which shows total variance of signal to noise ratio, is calculated.

$$SS_T = \sum_{i=1}^n (y_i - y_m)^2 \quad (2)$$

SS_T value is separately sum of squares of each factor and plus sum of square of error. Sum of square of each factor is calculated.

$$SS_A = \sum_{i=1}^{k_A} [y_{Ai}(y_A - y_m)^2] \quad (3)$$

Afterwards, F test is carried out. For each parameter, mean sum of square is divided to mean error value and thus, F value is calculated. According to the degree of freedom of parameters and error, critic value is seen on the F table. After that, this critic value is compared with the calculated F value. By comparing these values, it is decided that whether this parameter is statistical significance or not.

In addition, contributions of parameters on experiment results can be seen in ANOVA. Table 11 shows the ANOVA results.

Table 11 ANOVA of experiment results

Factors	DF	SS	Contribution	MSS	F	P
Cutting direction	1	0.15180	%12.50	0.15180	11.56	0.00678
Cutting speed	2	0.06405	%5.27	0.03203	2.44	0.13724
Feed rate	2	0.64515	%53.11	0.32258	24.56	0.00014
Cutting depth	2	0.22241	%18.31	0.11120	8.47	0.00706
Error	10	0.13135	%10.81	0.01314		
Total	17	1.21477	%100			

3.3. Regression Equations

Regression analysis is the analysis method used to measure the relationship between two or more variables [18]. Because of the different parameters in the study, regression analysis can be performed for surface

roughness [19]. Depending on the cutting direction, two surface roughness equations were found. For climbing milling direction equation 4, for conventional milling equation 5 can be used.

$$Ra = -0.149 + 0.00126V_c + 0.923f + 0.264a_p \quad (4)$$

$$Ra = -0.332 + 0.00126V_c + 0.923f + 0.264a_p \quad (5)$$

3.4. Comparison Actual Results with Predict Results

In this section of study, actual experiment results were compared with predicted results calculated by Minitab 19. The comparison was made at %95 confidence interval and R^2 of experiment model was found as %91.4. In table 12, predicted experiment results are shown. Quadratic regression model and comparison actual results with predicted results are seen in Figure 8.

Table 12 Predicted surface roughness results

Experiment no	Cutting direction	Cutting speed (V_c) mm/min.	Feed rate (f) mm/rev.	Cutting depth (a_p) mm	Predicted surface roughness (R_a) μ
1	Climbing	282	0.15	0.2	0.440
2	Climbing	282	0.40	0.5	0.517
3	Climbing	282	0.65	0.8	1.060
4	Climbing	314	0.15	0.2	0.586
5	Climbing	314	0.40	0.5	0.663
6	Climbing	314	0.65	0.8	1.206
7	Climbing	345	0.15	0.5	0.406
8	Climbing	345	0.40	0.8	0.867
9	Climbing	345	0.65	0.2	0.980
10	Conventional	282	0.15	0.8	0.415
11	Conventional	282	0.40	0.2	0.446
12	Conventional	282	0.65	0.5	0.605
13	Conventional	314	0.15	0.5	0.290
14	Conventional	314	0.40	0.8	0.751
15	Conventional	314	0.65	0.2	0.864
16	Conventional	345	0.15	0.8	0.493
17	Conventional	345	0.40	0.2	0.525
18	Conventional	345	0.65	0.5	0.683

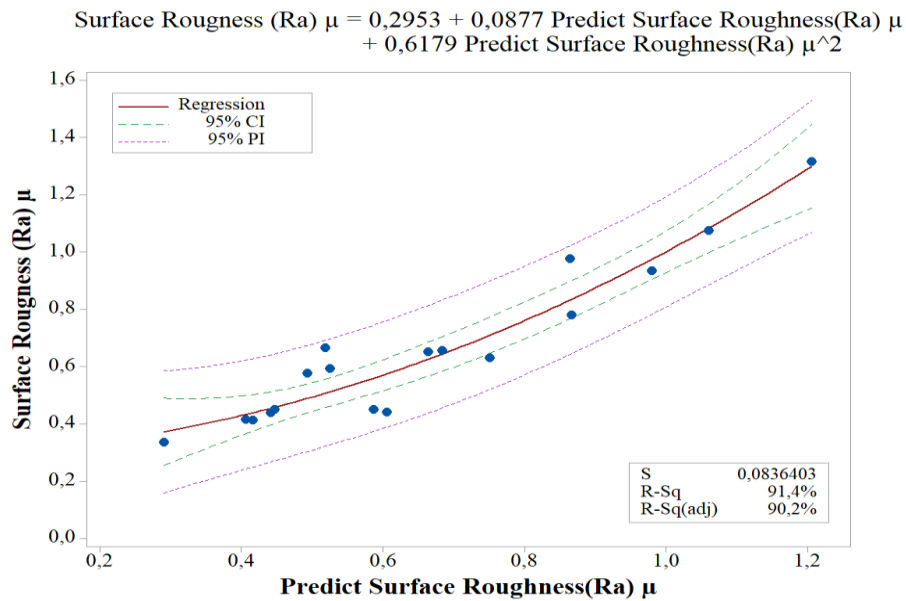


Figure 8 Quadratic regression model and comparison results

3.5. Verification Tests

The final step of optimization of process is to test the validity of the optimization. In this context, it is necessary to determine the confidence interval for the accuracy of the optimum machining process parameters determined by Taguchi [20]. Therefore, according to optimum levels of each parameter, ten experiments were carried out. Optimum levels are seen in table 13 and verification test results are seen in table 14.

Table 13 Optimum parameters and levels

Parameters	Levels
Cutting direction	Conventional
Cutting speed (Vc)	282 m/min.
Feed rate (f)	0.15 mm/rev
Cutting depth (ap)	0.5 mm

Table 14 Results of verification tests

Experiment no	Experiment results (Ra) μ
1	0.335
2	0.272
3	0.245
4	0.247
5	0.209
6	0.227
7	0.288
8	0.215
9	0.244
10	0.261

Average of verification results was found as 0.254 micron. Afterwards, the confidence interval was calculated by using equations (6) and (7) which are shown in the following.

$$C.I = \sqrt{F_{0,05}(1, v_e) V_e \left(\frac{1}{n_{eff}} + \frac{1}{r} \right)} \quad (6)$$

$$n_{eff} = \frac{N}{1+V_T} \quad (7)$$

$F_{0,05}(1, v_e)$ means the F value at %95, V_e means the error variance, N means the total number of experiments, V_T means the total main factor degrees of freedom and r means the number of replications for the confirmation experiments.

$F_{0,05}(1,10)=4.965$ (from F table), $V_e=0.0134$,

$$N=18, V_T=7, r=10, n_{eff}=2.25.$$

According to the equations (6) and (7), CI was calculated as 0.188. For optimum levels, prediction mean surface roughness was found as 0.144 micron by Minitab 19.

The following equation was used to determine whether the optimization study with Taguchi method is valid at %95 significance level or not.

$$Ra_{opt} - C.I < Ra_{mean} < Ra_{opt} + C.I \quad (8)$$

$$0.144-0.188<0.254<0.144+0.188$$

$$-0.044<0.254<0.332$$

Since Ra_{mean} is determined within the limit according to equation 8, the optimization process can be admitted successfully.

4. CONCLUSIONS

In this study, GG25 cast iron was machined under dry conditions. Milling process is intrinsically an interrupted machining method. The temperature variations are exacerbated when the cutting edge goes into and out of cut. The hotter the cutting zone is, the more unsuitable the use of cutting fluid becomes [21]. Due to the high temperatures, milling operations were performed without using cutting fluid.

Totally, four process parameters were investigated and found their optimum levels. The experiment levels, for cutting speed, feed rate and cutting depth were determined from the cutting tool catalog. By converting, experiment results to S/N ratios, optimum levels were found.

4.1. Evaluation of Conclusions

According to the mean S/N values shown in table 10, the surface roughness value obtained with the conventional cutting method is %40 lower than the surface roughness value obtained with the climbing cutting method.

When the cutting speed was increased from 282 m/min to 314 m/min, the surface roughness value increased by %30. When the cutting speed was increased from 314 m/min to 345 m/min, the surface roughness value decreased by %6.

When the feed rate was increased from 0.15 mm/rev to 0.40 mm/rev, the surface roughness value increased by %50. It was observed that, the surface roughness value increased by %34, when the feed rate was increased from 0.40 mm/rev to 0.65 mm/rev.

When the cutting depth was increased from 0.2 mm to 0.5 mm, the surface roughness value decreased by %25. When the cutting depth was increased from 0.5 mm to 0.8 mm, it was observed that, the surface roughness value increased by %55.

According to the ANOVA results, the most important parameters on surface roughness were determined feed rate, cutting depth, cutting direction and cutting speed respectively. When the P values were examined, all experiment parameters except of the cutting speed were found statistically significant.

Experiments were carried out with the optimum levels obtained according to the Taguchi design. The validity of the experimental model was admitted by comparing the mean of the verification test results with the mean optimum test result calculated by Minitab 19.

As in similar studies, in this study feed rate was found the most important parameter on the surface quality. In addition, it was observed that the relation between tool radius and cutting depth affects on the surface quality. Unlike similar studies, cutting speed is not statistical significance. As an additional parameter, the effect of cutting tool direction was investigated on the surface quality.

4.2. Discussions

As work piece in this study, GG25 cast iron was used and with conventional milling, surface roughness value was found lower. In climbing milling, the cutting tool is feed with the direction of rotation. Chip thickness decreases from the start of cut and gradually reaches zero at the end of cut. In conventional milling, the cutting tool is feed with the opposite direction of rotation. Chip thickness starts at zero and increases toward the end of the cut. Normally lower surface roughness value is expected in climbing direction.

Due to hard layer of casting material, maximum chip thickness at the entrance of the cutting tool to the work piece causes chatter and affects surface quality adversely. In order to demonstrate, same study can be performed with different materials such as steel, stainless steel, aluminum and can be investigated effect of cutting direction on surface roughness.

Surface roughness was found lowest with the lowest cutting speed. However, as cutting speed increased, the surface roughness value decreased again. Additionally since P value was found bigger than 0.05, this parameter was not admitted statistically significant on the surface roughness.

Experiment results show that, the most important parameter on the surface roughness is feed rate. As feed rate value decreases, lower surface roughness values are found. The reason is that when the feed rate increases, the cutting tool removes more chips on the material. However, low feed rate value causes more wear on cutting inserts because inserts contact the work piece longer time, which means that, cost of cutting insert and machining time increase. Therefore, in order to determine process parameters for serial conditions, technical drawings must be analyzed well.

Increasing the cutting depth to 0.5 mm decreased the surface roughness, while increasing the cutting depth from 0.5 mm to

0.8 mm increased the surface roughness. Lower cutting depth with higher cutting insert radius causes vibration on the raw material and this affects surface quality adversely. When the cutting depth and cutting insert radius edge are used same, a more balanced cutting is expected, while the surface roughness value was found higher. The reason is that increasing cutting depth increases the temperature and the friction between work piece and cutting tool. Result of this study is recommended that, in order to achieve a lower surface roughness cutting insert radius should be considered when determining cutting depth.

In addition to cutting direction, cutting speed, feed rate and cutting depth some parameters such as entrance angle of tool, depending on the work piece geometry and tool diameter radial cutting depth, number of cutting inserts on cutting tool can be investigated on surface roughness.

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

We declare that we comply with the scientific, ethical and citation rules of SAUJS in all processes of the article and that we do not falsify the collected data. In addition, we declare that Sakarya University Journal of Science and its editorial board have no

responsibility for ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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