Experimental Investigation of Machinability of Chromium-Nickel Based Steels by Milling Method

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Abstract:- Today, it has become very important to determine the cutting parameters in the machining process. In order to produce at the desired quality, it is necessary to determine the processing parameters according to the type of material. Because cutting insert selection should be made according to the hardness of the material so that both the cutting insert service life is longer and the desired surface quality can be achieved in the material to be processed. In the literature, the main factors affecting surface roughness are feed rate, cutting speed, depth of cut, coolant, etc. In this context, 1.2316 steel, which is one of the chromium nickel-based materials, was preferred, and a study was conducted to evaluate the effects of steel on surface roughness with the processes performed under cutting speed, feed rate, depth of cut and wet/dry cutting conditions. Using the Taguchi optimization method, the interaction between the determined levels of the processing parameters was examined and the optimum values were tried to be determined. Within the scope of the study, nine different experiments were carried out using Taguchi's L9 orthogonal sequence and the surface roughness data obtained as a result of each experiment were recorded. According to the results of the analysis, the feed rate with an effect rate of 35.2 % was the parameter that affected the surface roughness the most. Progress was followed by aqueous and dry cutting conditions with an effect rate of 29.09 % The effect of the depth of cut was 22.18 % while the cutting speed was 3.54%, very little. As a result of the experimental studies, the experimental study, in which the surface roughness was the best, that is, the Ra value was the lowest, was conducted under the conditions of cutting speed of 100 m/min, feed rate of 400 mm/min, depth of cut of 1.5 mm and aqueous cutting. These findings may be useful in the processing of groups of stainless materials to be used in the production of equipment that will be resistant to corrosion.

Keywords:- *Chrome Nickel-based Steels, Milling, Machinability, Taguchi, Test Design, Surface Roughness.*

I. INTRODUCTION

With the development of today's industry, the usage areas and processing methods of steels are gradually increasing. In particular, a large number of steel types are used in the production of storage tanks, food,stainless pipes and pressure vessels used in the petrochemical, chemical, pharmaceutical industry and in aircraft defense industry projects. Chrome and nickel-based steels are mainly preferred because they have good corrosion resistance. After the interaction of chromium with oxygen, a thin protective layer of chromium oxide is formed on the material surface, which protects the steel against corrosion. Examples of application areas are shown in Figure 1[1]. Machinability determines how successful a material is in its machining processes and how easy or difficult these processes are. Therefore, a detailed study of the machinability characteristics of chromium nickel-based steels can increase the efficiency of production processes and reduce costs.

The aim of this study is to experimentally examine the machinability of chromium nickel-based steels by milling method, to contribute to parameters such as the surface quality of the material in the projects to be produced in the manufacturing industry, the selection of cutting tools to be used in the machining process and tool life.

Fig 1 Some Application Areas of Chromium-Nickel based Steels [1]

II. LITERATURE REVIEW

Ay et al. [2] conducted experimental studies to determine the factors affecting the surface roughness in the milling process of Ç1050, Ç1040 and Ç1045 materials. They measured the forces and vibration that occurred during the cutting process. When the test studies are completed, as a result, the surface roughness value increases by increasing the depth of cut, that is, the surface deteriorates and the cutting forces increase in the same way.

Lin [3] conducted experimental studies on the processing of stainless steel at high speeds in his study. He investigated surface roughness, tool life, burr formation, and tool wear by performing high-speed drilling with a TiN-coated carbide cutting tool. As a result of the experimental studies, the cutting speed, which is the most ideal in terms of burr height and surface roughness, was determined. It has been stated that the most prominent wear in the drill is outer corner wear and wear in the helical channels.

Boy and his colleagues [4] carried out experimental studies to investigate the effects of cutting parameters on surface roughness value by turning Vanadis10 steel, which is one of the cold work tool steels. The experiments were carried out at a constant chip depth with five different feed rates and eight different cutting rates using two types of cutting tools made of CVD-coated cementite carbide. When the experimental studies were completed, they stated that the average surface roughness value decreased with increasing the cutting speed, that is, the surface quality improved, but they also stated that the surface roughness values increased at high values of the cutting speed due to the material loss caused by the wear on the tool.

Uzbek et al. [5] used the Taguchi L9 experimental design to determine the optimal cutting parameters with CVD coated tungsten carbide tools in the process of turning hardened AISI 420 stainless steel. In the study conducted to reach the lowest side surface wear values, 0.08 mm/rev feed rate, 0.6 mm cutting depth and 170 m/min cutting speed were determined as the most appropriate parameters. ANOVA analysis showed that feed rate has the greatest effect on side surface wear (47.04%). Cutting speed (36.28%) and depth of cut (4.10%) are other important factors.

In their study, Gennari and his colleagues [6] conducted experimental studies to compare the effects of processing AISI 316 steel, one of the stainless steels, with the coolant to be used during the turning process. In this method, almost dry processing (60ml/hour) method and traditional liquid application (150lt/hour) are compared. As a result of the experimental studies, they stated that the traditional liquid application provides better tool life under different heavy thermal conditions, and in most of the conditions examined, it performs better in terms of providing lubrication on the chip interface with the tool and performing sufficient cooling process in the liquid application by spraying, and most importantly, it makes a great improvement in tool life.

Akasawa and his colleagues [7] conducted experimental studies to determine the effects of additives on the workability of austenic stainless steels. They used SUS303Cu, SUS316, SUS303 as experimental materials and changed the composition of the materials with additives such as Bi, S and Ca. Akasawa and his colleagues carried out the experiments with the carbide cutting tool and the cutting fluid in the CNC lathe machine. They used a cutting speed of 12.5 100 m/min and a feed rate of 0.05 0.1 mm/rev as the cutting parameter. They made martensitic transformation measurements and microhardness measurements based on stress from the machined surface.

Altınkaya and Güllü [8] examined the cutting parameters of AISI 316 stainless steel during the milling process and the effect of cutting tool geometry on the surface quality of the machined surfaces and the wear on the cutting tool and evaluated the results. In their experiments, 270 m/min, 225 m/min, 180 m/min were taken as the cutting speed with fixed chip depth and three cutting tools with different chipbreaking forms were used using variable parameters. In the experimental studies, they shared that it is necessary to work with the team that provides the most appropriate surface roughness and shows the wear behavior well.

In the study conducted by Ranganathan and his colleagues [9], they developed the mathematical modeling method to examine the effects of cutting parameters in the hard turning process of AISI 316 steel, one of the stainless steels, with WC inserts. In this modeling method, they used ANOVA analysis and regression analysis to estimate the surface roughness with tool wear. Ranganathan processed AISI 316 steel under variable machining conditions with the help of tungsten carbide cutting tool and determined the interactions of cutting parameters.

In the study conducted by Safa Bodur [10], the effects of sawdust amount, cutting speed and feed rate at different levels in terms of power consumption and surface roughness under the conditions where coolant is used in the turning process of AISI 304 stainless steel, which has a wide application area, were examined by using statistical analyzes and at the same time, mathematical models were created and the results were compared with experimental data. When the results were examined, the amount of feed had effects on power consumption at the rates of 19%, the cutting speed at the rate of 24%, and the amount of pass at the rate of 44%. The most appropriate parameters in terms of average surface roughness were determined as 1 mm of the pass amount, 125 m/min of the cutting speed, and 0.12 mm/rev. of the feed. The parameters where the cutting speed was 100 m/min, the feed was 0.12 mm/rev, and the pass amount was 1 mm were the most appropriate parameters in terms of power consumption. As a result of the studies, it has been emphasized that AISI 304 stainless steels should be worked at low surface roughness value in the turning process and small pass amount, low feed rate and low cutting speeds for low power consumption.

Kara and Öztürk [11] determined the appropriate cutting conditions in the turning process. Using Taguchi experiments and regression analysis, it was determined that TiAlN coated tools performed best and PVD coated carbide tools gave the most appropriate results.

III. METHODOLOGY

- *Material Selection and Properties*

In the literature, machinery, equipment, etc. according to working conditions. The properties of the materials to be used are very important. Chromium-nickel based steels are generally used in applications requiring corrosion resistance. In the experimental study, 1.2316 steel, which is chrome-nickel based, was preferred. This type of steel is available in thicknesses between 6.00 and 40.00 mm and its hardness in air and oil is 50-52 HRC. The yield strength of 1.2316 steel is maximum 550 N/mm^2 and the tensile strength is maximum 950 N/mm^2 [12].

Table 1 1.2316 chemical composition compound [12].

Chemical Composition (%)	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**
% Mean	0,36	≤1,00	≤1,50	16	1,1	≤1,00
DIN Analysis	0,33-0,45	0,1-1,00	0,1-1,5	15,5-17,5	0,8-1,30	0,01-1,00

- *Test Samples and Cutting Tools*

The test samples were prepared by laser cutting the 20 mm thick sheet plates measuring 235x135x20 mm. 9 plates were prepared for the experimental work to be carried out, and before starting the processing, the surfaces were cleaned and made ready for the experiments by milling the raw surfaces of the plates. Figure 2 shows that the raw material to be used in the experiments was prepared by clamping it in a vise.

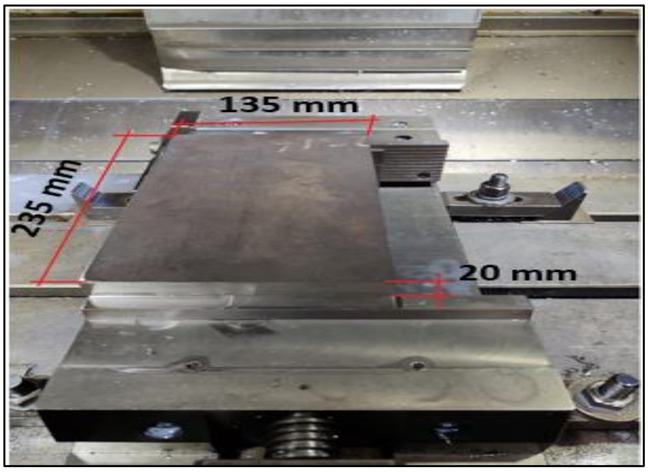

Fig 2 Raw Material to be Processed

In the study, a Tungaloy brand diamond tip with code ONGU0507ANEN-MJ AH3135 – 6735445 with 16 corners was used. The cutting edge was selected considering the hardness value of the 1.2316 steel to be processed. Dimensional dimensions of the cutting tip used are shown in Figure 3, and dimensional dimensions of the scanning head used are shown in Figure 4.

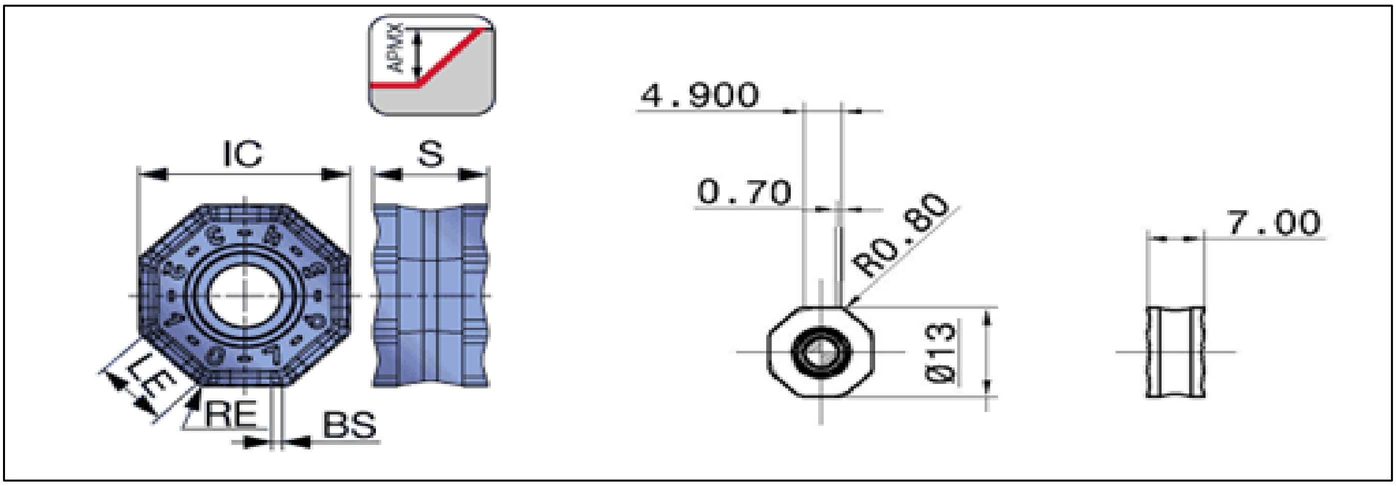

Fig 3 Dimensional Dimensions of the Cutting Tool

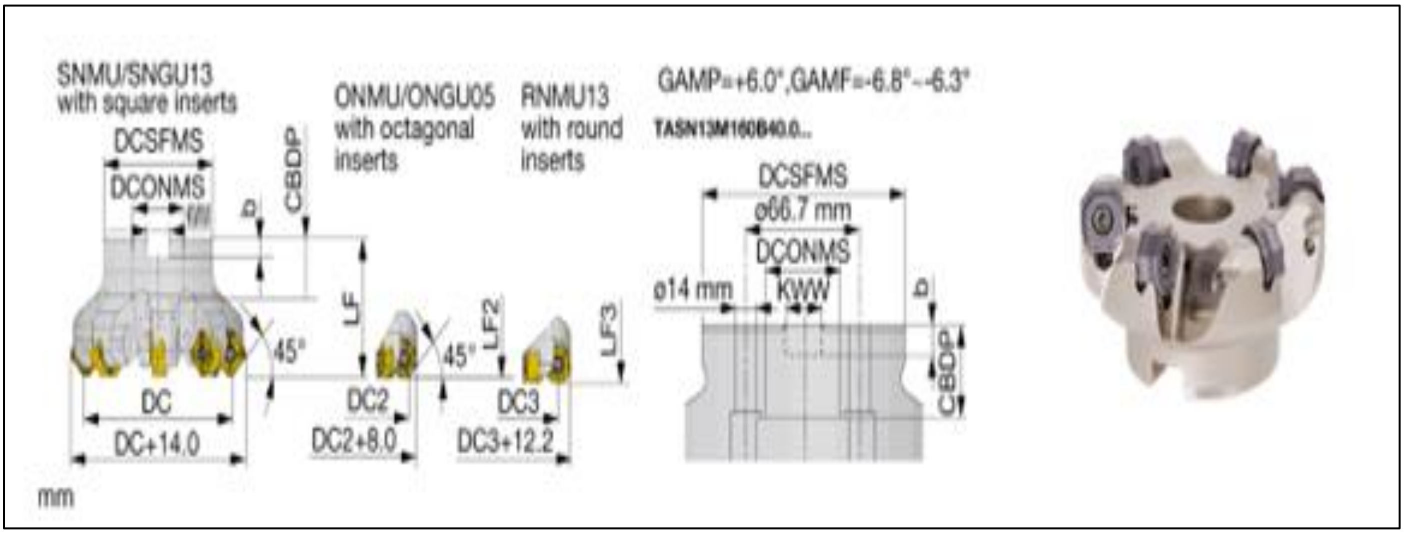

Fig 4 Dimensional Dimensions of the Milling Head

In Figure 5, it is shown that the CNC milling machine was started by assembling the cutting tip with the scanning head and tool holder, and the surface milling process was carried out from the raw material surface.

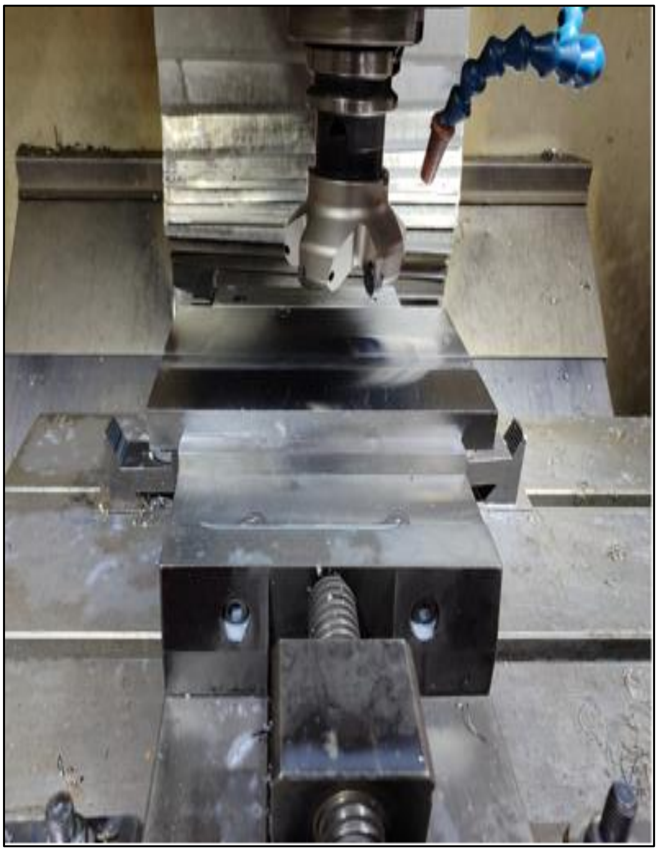

Fig 5 Test Sample Surface Milling Process

- *Selection and Execution of Experimental Parameters*

In machining processes, there are many parameters that affect surface roughness. Material properties of the workpiece, type of cutting tool, cutting speed, feed rate, depth of cut, heat generated, use of coolant and structural features of the machine are just a few of these factors. Changing any of these factors can cause changes in surface roughness. Variable parameters and level values selected for the Taguchi experimental design method are shown in Table 2.

Table 2 Experimental Design Variable Parameters and Level Values

Parameters	**Level 1**	**Level 2**	**Level 3**
Spindle speed (m/min),A	100	150	200
Feed rate (mm/min),B	400	600	800
Depth of cut (mm),C	1,5	1	0,7
Wet / Dry Processing,D	Wet	Dry	-

When the table is examined, the factors are mixed level since we have one 2-level factor and 3 3-level factors. Since our factors are mixed levels and the number of 3-stage factors is more than the number of 2-stage factors, 2-stage factors will be tried to be compared to 3-stage factors in the orthogonal series to be selected.

Because of this feature and since the total degree of freedom is 7, we will need to use the Dummy level technique in selecting the appropriate orthogonal array according to the Taguchi method. The dummy level method is a method used to integrate a two-level factor into a three-level orthogonal array system. In this case, the appropriate orthogonal array is the L9 (33 x 21) array, as seen in table 3.

Tablo 3 Dummy Level (Artificial Level) Method

Experiment No.	**Factors**			
	1	**2**	**3**	**4**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	1
4	2	1	2	1
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	1
9	3	3	2	1

Considering our variable factors according to the dummy level L9 orthogonal array, the experimental design shown in table 4 was created.

Tablo 4 Display of level values and experimental order according to the L9 orthogonal array

Trial	**A**	**B**	**C**	**D**
1	100	400	1,5	Wet
2	100	600	1	Dry
3	100	800	0,7	Wet
4	150	400	1	Wet
5	150	600	0,7	Wet
6	150	800	1,5	Dry
7	200	400	0,7	Dry
8	200	600	1,5	Wet
9	200	800	1	Wet

Surface roughness values occurring on the test samples that were surface milled with the specified levels and control factors. Surface roughness measurements of the "SURFTEST SJ-201P portable surface roughness tester" were carried out at the 10 mm distance at which the tool started to process and at the 10 mm distance before the tool exited the surface.

Experimental studies were carried out under wet and dry cutting conditions. In the dry cutting experiments, in order to examine the effect of temperature on the average surface roughness, measurements were made in the area where the temperature value was highest during the cutting process and the values were recorded with the MESTEK IR01A brand heat detector shown in Figure 6.

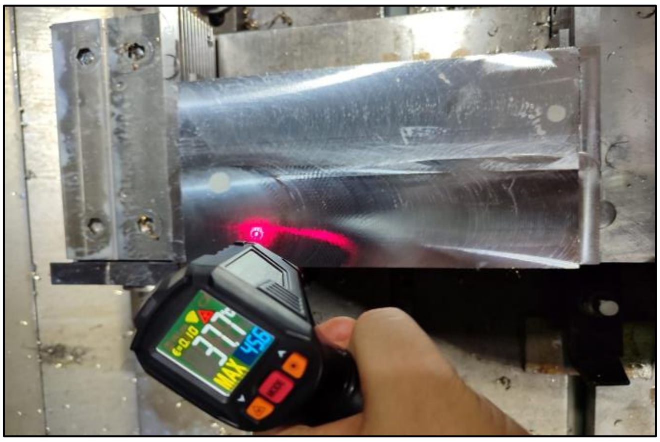

Fig 6 Surface Temperature Measurement with Heat Detector

After the experiments were completed, the flank wear on the cutting inserts and the chip types formed by wet and dry cutting were examined with the METKON PST - 901 brand microscope shown in Figure 7.

Fig 7 Examining the Cutting tip with a Microscope

The roughness values of the surfaces after the 9 experiments carried out and the temperature values when the cutting tool leaves the surface in operations carried out under dry cutting conditions are shown in table 5.

Table 5 Post-Process Measurement Results

Trial	**Control Factors**				**Surface Rouhgness Ra** (µm)	**Heat** (°C)
	A (Vc)	**B** (Vf)	**C** (ap)	**D** (W/D)		
1	100	400	1,5	Wet	0,7	*
2	100	600	1	Dry	1,26	26,8
3	100	800	0,7	Wet	1,5	*
4	150	400	1	Wet	0,8	*
5	150	600	0,7	Wet	0,95	*
6	150	800	1,5	Dry	1,29	37,7
7	200	400	0,7	Dry	1,23	55,1
8	200	600	1,5	Wet	0,89	*
9	200	800	1	Wet	0,92	*

When the cutting tip was examined under the microscope, it was observed that free surface wear occurred on the tip. Figure 8 shows the flank wear occurring on the cutting edge.

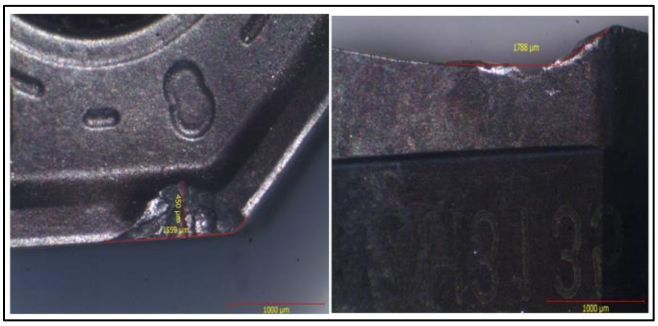

Fig 8 Flank wear on the Cutting insert

During the experimental studies carried out under wet and dry cutting conditions, the first experimental study was where the cutting speed was 100 m/min, the feed rate was 400 mm/min, the depth of cut was 1.5 mm and the chip removed from the material surface after the work carried out under wet cutting conditions is shown in Figure 9.a. Shown in . In our 6th experiment, the sawdust removed from the material surface after the cutting speed was 150 m/min, feed rate was 800 mm/min, depth of cut was 1.5 mm and dry cutting conditions were shown in figure 9.b.

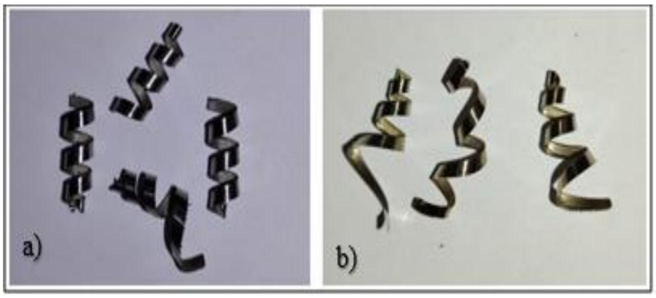

Fig 9 Chip Shapes Emerging after Wet and Dry Machining

IV. RESULTS AND DISCUSSIONS

By making analytical calculations of the experimental study results and using Minitab 18 statistical software, analysis of S/N (signal-to-noise) ratio, ANOVA analysis of variance and parameter interaction graphs were created. Analysis and interaction graphs of the measured surface roughness results were obtained.

- *Analysis of Signal-to-Noise Ratio*

Table 6 shows the experimental results of S/N ratios and Ra, surface roughness values obtained with the Taguchi L9 experimental design of machining chromium-nickel based 1.2316 steel by milling method.

The most effective control factors of cutting speed, feed rate, depth of cut and wet/dry machining method were determined by using the Taguchi-based response table to determine the most appropriate levels of Ra performance characteristics. Table 7 gives the S/N response chart and Table 8 gives the Ra significance and outcome chart. It was determined that the most effective parameter on Ra was the feed rate. The graphs in Figure 10 show the control factor effects on the S/N values for Ra of 1.2316 steel. The graphs in Figure 11 show the effects of the control factor on the surface roughness values of 1.2316 steel.

The experimental study in which the surface roughness was the best, that is, the Ra value was lowest, was carried out under cutting speed (Vc) of 100 m/min, feed rate (Vf) of 400 mm/min, depth of cut (ap) of 1.5 mm and wet cutting conditions. Of course, the coating on the cutting edge used also has an effect.

Tablo 6 S/N Ratios Obtained According to the L9 Orthogonal Array

Trial	**Control Factors**				**Surface Rouhgness Ra** (µm)	**S/N Ratio Ra** (db)
	A (Vc)	**B** (Vf)	**C** (ap)	**D** (Wet/Dry)		
1	100	400	1,5	Wet	0,7	3,09804
2	100	600	1	Dry	1,26	-2,00741
3	100	800	0,7	Wet	1,5	-3,52183
4	150	400	1	Wet	0,8	1,9382

5	150	600	0,7	Wet	0,95	0,44553
6	150	800	1,5	Dy	1,29	-2,21179
7	200	400	0,7	Dy	1,23	-1,7981
8	200	600	1,5	Wet	0,89	1,0122
9	200	800	1	Wet	0,92	0,72424

Table 7 S/N Severity and Consequence Chart

S/N (µm)				
Level	**Spindle speed (m/min)**	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Wet / Dry Processing**
1	-0,8104	1,07938	-1,6248	0,61606
2	0,05731	-0,18323	0,21834	-2,00577
3	-0,02055	-1,66979	0,63281	-
Delta	0,86771	2,74917	2,25761	2,62183
Rank	4	1	3	2

Table 8 Ra Severity and Consequence Chart

Ra (µm)				
Level	**Spindle speed (m/min)**	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Wet / Dry Processing**
1	1,1533	0,9100	1,2267	0,9600
2	1,0133	1,033	0,9933	1,2600
3	1,0133	1,1367	0,9600	-
Delta	0,1400	0,3267	0,2667	0,3
Rank	4	1	3	2

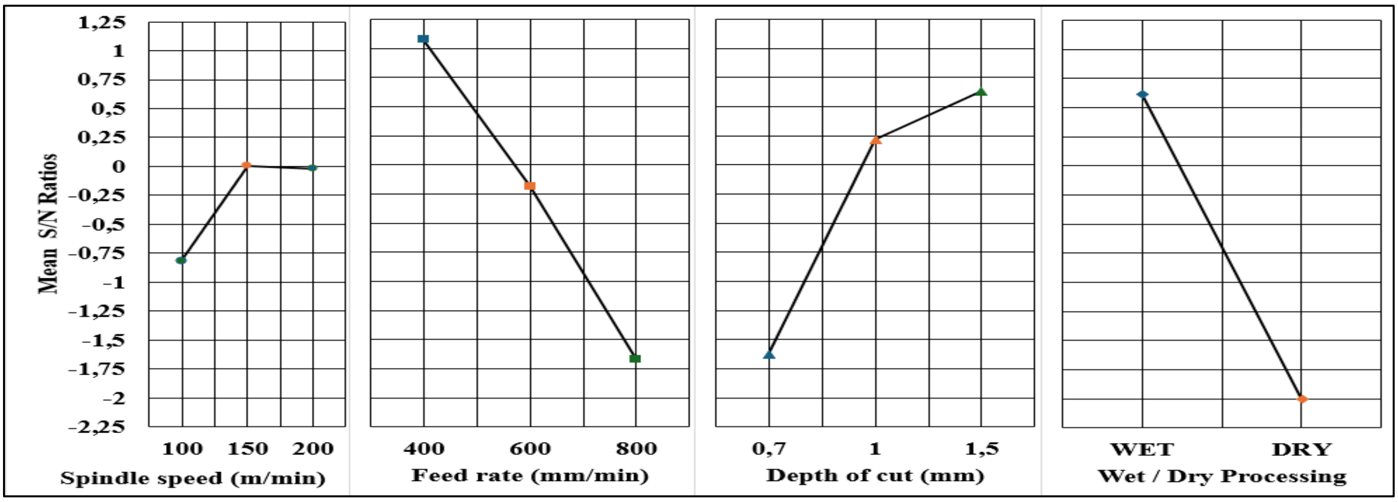

Fig 10 Effects of Process Parameters on S/N Ratio

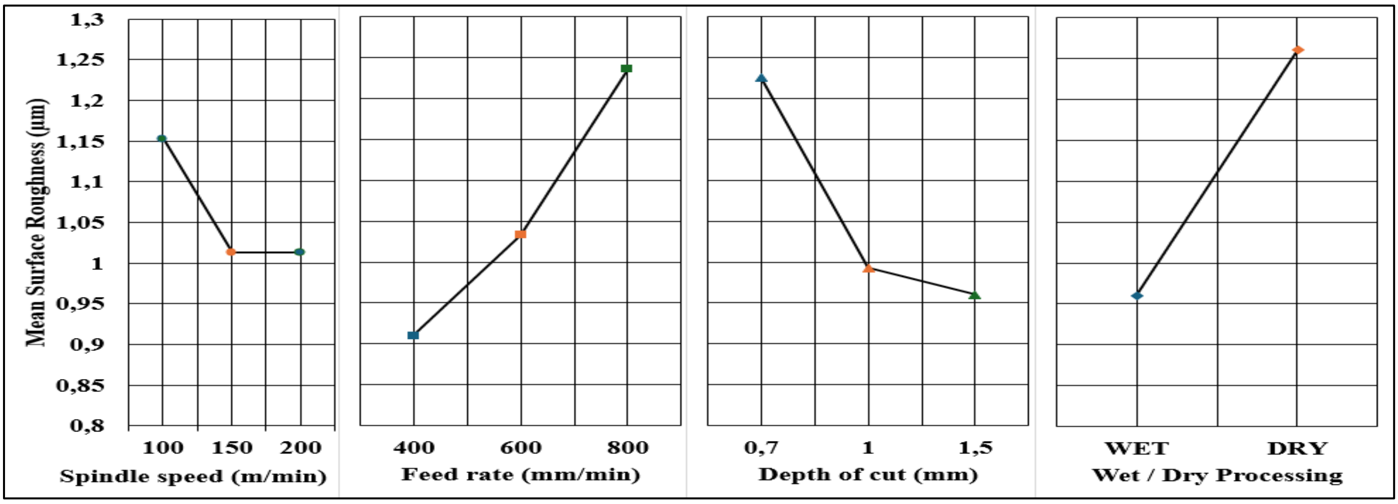

Fig 11 The Effects of Active Process Parameters on Surface Roughness

The effect of feed rate on the average surface roughness value is shown in Figure 12. As can be seen from the figure, as the feed rate increased, the surface roughness value also increased.

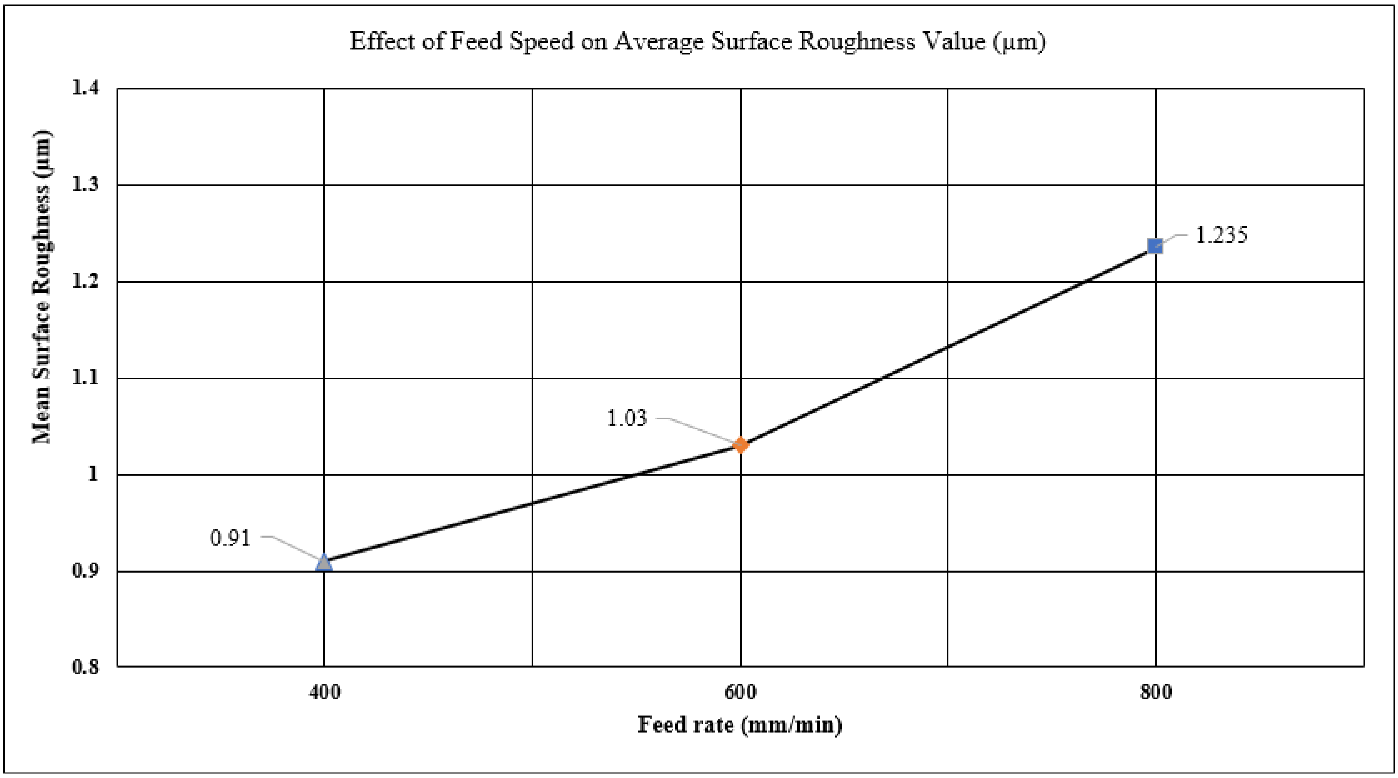

Fig 12 Effect of Feed Speed on Average Surface Roughness Value (µm)

Figure 13 shows the effect of feed rate on the surface roughness value under wet and dry cutting conditions. As can be seen in the figure, the average surface roughness values in wet cutting conditions are lower than the average surface roughness values in dry cutting conditions at all feed rates.

The effect of cutting speed on the surface roughness value is shown in figure 14, and the effect of depth of cut is shown in figure 15.

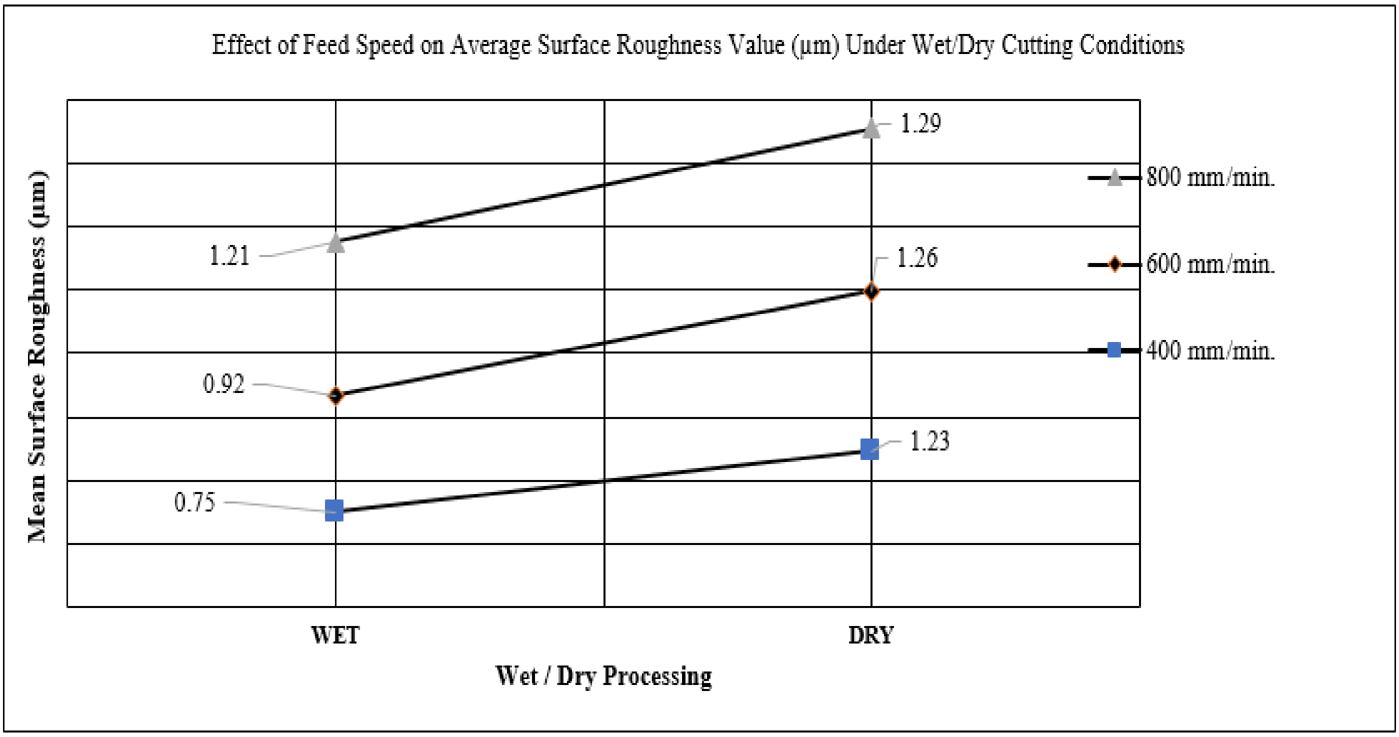

Fig 13 Effect of Feed Speed on Average Surface Roughness Value (µm) Under Wet/Dry Cutting Conditions

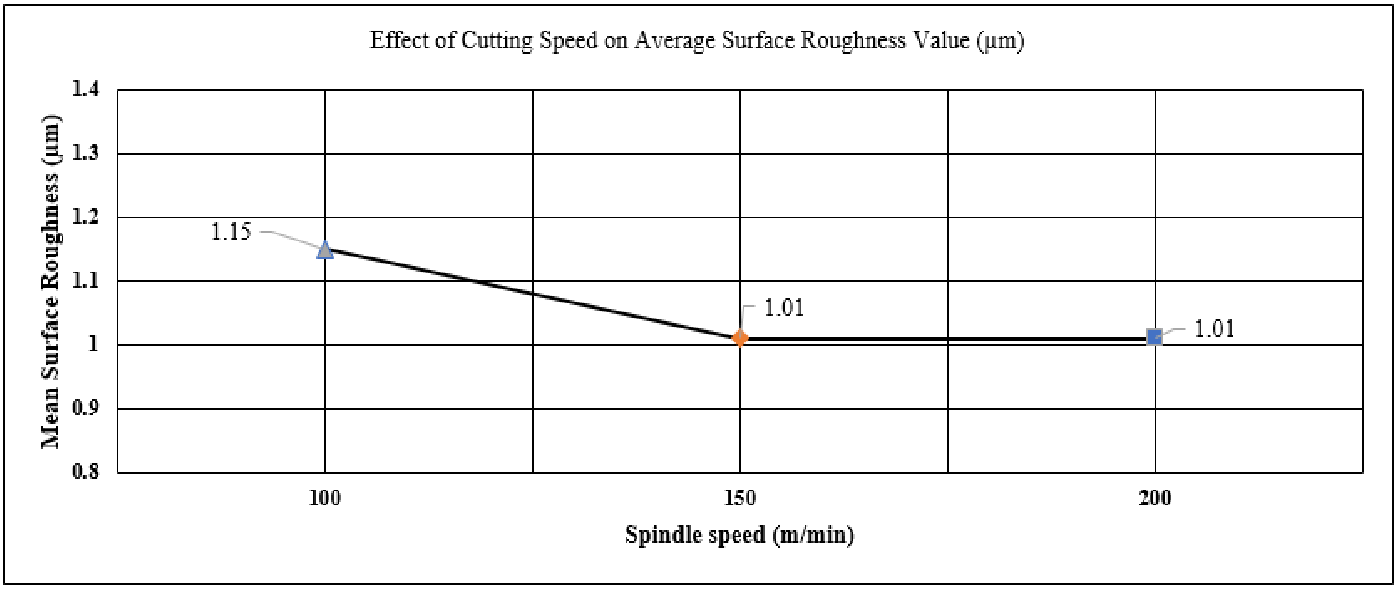

Fig 14 Effect of Cutting Speed on Average Surface Roughness Value (µm)

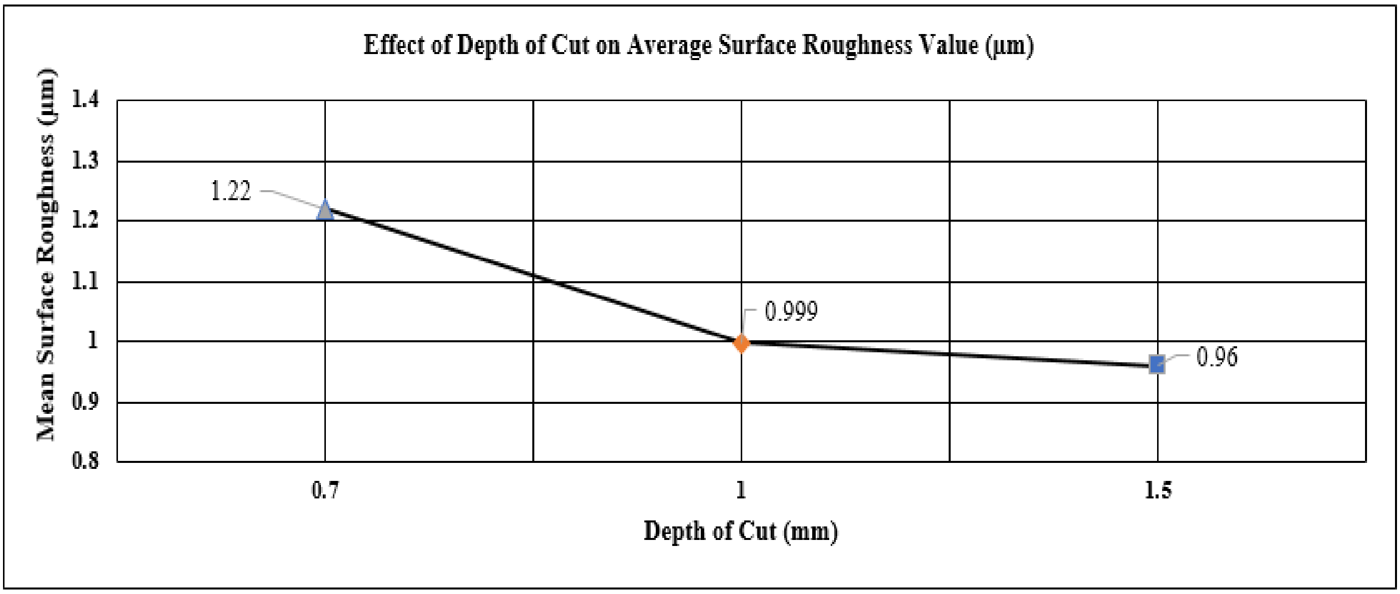

Fig 15 Effect of Depth of Cut on Average Surface Roughness Value (µm)

- *ANOVA Analysis*

Analysis of variance (ANOVA) is used to determine the individual interactions and effects of all control factors in an experimental design, and regression analysis is used to measure the relationship between two or more quantitative variables. Table 9 gives the ANOVA results, the effects of the control factors of feed rate, cutting speed, depth of cut and lateral pitch on surface roughness, Ra, with 90% confidence interval and 10% significance level. In this study, ANOVA results revealed that the most effective parameter on Ra was factor A (feed rate) with an effect rate of 35.2%. Factor D (wet / dry cutting) and factor C (depth of cut) are the most effective parameters with values of 29.09% and 22.18%, respectively. The effect of Factor B (cutting rate) was found to be insufficient compared to other parameters.

Table 9 ANOVA Results Table for Ra

Variance Source	**Degree of Freedom** (Dof)	**Sum of squares** (SS)	**Cont. Rate**	**Mean Square** (MS)	**F Ratio**	**P Ratio**
A (Vf)	2	1,3833	3,54%	0,69165	0,18	0,859
B (Vc)	2	11,362	35,20%	5,681	1,46	0,506
C (ap)	2	8,666	22,18%	4,333	1,11	0,557
D (S/K)	1	13,748	29,09%	13,748	3,52	0,312
Error	1	3,903	9,99%	3,903		
Total	8	25,189	100%			

V. CONCLUSION

In the milling process, the selection of different machining parameters is very important in terms of surface roughness quality and tool life. In this experimental study, the effect of different machining parameters on the surface roughness of 1.2316 steel in the milling process is analyzed. Nine different experimental studies were conducted based on the Taguchi optimization method for the selected parameters. Signal-to-Noise (S/N) ratio and analysis of variance (ANOVA) were applied to determine the optimum level and contribution percentage. The parameter that had the greatest impact on surface roughness was feed. After progress, the most effective parameter was dry/wet cutting conditions. Then comes the depth of cut and cutting speed. According to the results of the experiments, it was observed that the surface roughness value increased as the progress increased. Because as the feed rate increases, the amount of chip that the cutting edge must remove in one revolution will also increase. Thus, the roughness value on the surface also increased. After the advancement, the parameter that had the greatest impact on surface roughness was wet/dry cutting conditions. Looking at the results here, surface roughness values increased under dry cutting conditions. Because, after the high temperatures formed at the interface between the tool and the material, it became difficult to remove the chips from the material surface. As a result of this situation, surface defects occurred. Considering the results obtained after the experiments, it was seen that the cutting speed and depth of cut had little effect on the average surface roughness values. In the experimental study where the surface roughness was best, that is, the Ra value was lowest, the cutting speed was 100 m/min, The study was conducted under feed speed of 400 mm/min, depth of cut of 1.5 mm and wet cutting conditions. Of course, the coating on the cutting edge used also has an effect. The effect of wet cutting on surface roughness, tool wear and chip shapes formed during the process has been revealed in machining.

After this study, it was concluded that the desired surface roughness values can be easily achieved under wet cutting conditions with low feed rate, average cutting speed and depth of cut, and efficient working conditions can be created by increasing the cutting tool life.

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