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OPTIMIZATION OF MACHINING PARAMETERS IN MILLING OF Ti-6Al-4V ALLOY USING TAGUCHI METHOD

ABSTRACT

This paper presents optimizing and effect of machining parameters on the cutting forces and surface roughness during face milling of Ti-6Al-4V alloy with carbide tools under dry conditions. Experimental setup was determined by using Taguchi design method. The optimum machining parameter combination was acquired by using signal-to-noise (S/N) ratio analysis. According to experimental results, resultant cutting forces and surface roughness increased with an increase in feed rate, whereas decreased with increase in cutting speed. Optimum machining conditions for the both resultant cutting forces (F_R) and surface roughness (R_a) were obtained at cutting speed of 180 m/min and feed rate of 250 mm/min.
Keywords: Ti-6Al-4V Alloy, Face Milling, Surface Roughness, Cutting Forces, Taguchi Method

Ti-6Al-4V ALAŞIMININ FREZELENMESİNDE İŞLEME PARAMETRELERİNİN TAGUCHI METODU KULLANARAK OPTİMİZASYONU

ÖZET

Bu çalışma Ti-6Al-4V alaşımının karbür takımlarla kuru şartlarda yüzey frezelenmesinde işleme parametrelerinin kesme kuvvetleri ve yüzey pürüzlülüğü üzerindeki etkilerini ve optimizasyonunu göstermektedir. Deneysel düzen Taguchi metodu kullanılarak belirlenmiştir. Optimum işleme parametreleri kombinasyonu sinyal-gürültü oranı analizi kullanılarak elde edilmiştir. Deney sonuçlarına göre, bileşke kesme kuvveti ve yüzey pürüzlülüğü ilerlemenin artmasıyla artarken kesme hızının artmasıyla azalmıştır. Hem bileşke kesme kuvveti (F_R) hemde yüzey pürüzlülüğü (R_a) için optimum kesme şartları 180 m/dak kesme hızında ve 250 mm/dak ilerlemede elde edilmiştir.
Anahtar Kelimeler: Ti-6Al-4V Alaşımı, Yüzey Frezeleme, Yüzey Pürüzlülüğü, Kesme Kuvvetleri, Taguchi Metodu

1. INTRODUCTION (GİRİŞ)

Titanium and its alloys find a wide application in the aerospace, biomedical and automotive industries because of their good strength-to weight ratio and high corrosion resistance [1]. Along with its corrosion resistance properties, titanium is used to reduce the weight in aircraft without loss of strength needed in critical areas. Titanium is also expensive to machine compared to aluminium or magnesium, for several reasons, such as low thermal conductivity, high chemical reactivity, and the high cutting forces needed for milling [2].

Issue to deal with is the titanium's tendency to built-up edge (BUE) during machining, which leads to chipping and premature tool failure. The tendency to form catastrophic shear bands produces fluctuations in cutting force and causes vibration, which is also related with surface cracking and undulations in the cutting surface [3]. According to the theoretical models, the cutting force depends on the area of the chip (feed rate and depth of cut), the tool path (width of cut), the material, cutting tool properties and some experimentally determined constants. High cutting forces cause tool failure in roughing and semi-finishing operations, and because of this reason usually very small feed rates are used to reduce cutting forces. High cutting forces also cause significant tool deflections which may violate dimensional tolerances, and cause small feed rates to be used in finishing operations, as well [4].

In a machining operation, tool life, metal removal rate, force components and power consumption, surface finish generated and surface integrity of the machined component as well as the chip morphology can all be used in the evaluation of machinability [5]. Diniz and Filho were investigated effects of the machining conditions on machinability for milling. In that study, cutting tests were carried out under dry conditions using uncoated inserts. As cutting forces are directly related to the increase in cutting speed, cutting speed is directly affects the tool life. They showed that from the machinability point of view, asymmetric milling is better than symmetric milling [6]. Ginting and Nouari carried out a study on the strength of the alloyed carbide tool in ball end mill configuration for machining the aerospace material Ti-6242S under dry cutting condition. The results demonstrated that the higher cutting speed is better for the surface quality [7]. Furthermore, in order to extend tool life and use it efficiently, cutting tool diameter should be wider than milling width in face milling [8 and 9].

It is well known that temperature rise in metal cutting process is caused by two principle heat sources—first source is resulting from plastic deformation developing at the primary shear plane (the shear zone heat source) and the second is due to the friction at the tool–chip interface (the frictional heat source) [8 and 10]. Hence, the strategy of titanium machining is to use tools which show less reactivity, has higher thermal conductivity (in order to increase the chip–tool contact length and effectively take away the generated heat) and use tougher and harder tools grades which could withstand the dynamic action of the cutting force. Straight tungsten carbide (WC–Co) tools are reported to have superiority in machining Ti alloys in interrupted cutting[1]. Furthermore, a higher cutting speed also results in rapid crater wear and/or plastic deformation of the cutting edge. This is due to the temperature generated at the cutting edge closer to the nose of the inserts. The heat affected zone is very small while cutting titanium alloys. The shorter chip/tool contact length, the smaller the heat affected area is produced. It is mainly for this reason that the cutting speeds are limited to about 45 m/min when using straight tungsten carbides [11 and 12]. The rapid tool failure and chipping at the cutting edge led to poor surface finish of the machined surface. It was not only because of the higher surface roughness values but also because of the higher micro-hardness values and severe microstructure alteration [13]. On the other hand, the heat sources diffuse either into the work piece, in the substrate or into the chip body. Indeed, the quantification of the heat sources remains unclear for both uncoated and coated cutting tools. Moreover, the influence of coating on the level of heat created by these heat sources is unknown [14].

Taguchi which was developed by Genichi Taguchi is a methodology for the application of designed experiments [15]. The advantage of Taguchi design is that multiple factors can be considered directly. By means of the Taguchi techniques, industries are able to very much reduce product development cycle time for design and production, therefore decreasing costs and increasing profit. Besides, Taguchi design allows inspect the variability cause to by noise factors, which are usually passed over in the traditional design of experiment approach [16]. Taguchi method recommends the use of the loss function to measure the performance characteristic diverge from the value of desired. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio (η,dB) [17]. S/N is defined as the ratio of the wanted signal to undesirable random noise and, it represents quality characteristics for the observed data [18]. Rely on the experimental purpose categories of the S/N ratio are nominal-the better, larger-the-better, smaller-the-better. No matter what the category of S/N ratio, the larger S/N ratio point out to the better performance characteristic. And so, the optimum level of the process parameters is the level with the highest S/N ratio. Also, analysis of variance (ANOVA) is conducted to determine which process parameters are statistically significant. With the S/N and ANOVA, the optimum combination of the process parameters can be predicted. After the analysis, a confirmation experiment is performed to verify the optimal process parameters acquired from the parameter design [17 and 19].

The effects of cutting parameters on surface roughness in turning using a L_{27} orthogonal array were investigated by Davim [20]. By vay of the regression analysis, two types of surface roughness were modelled with the correlation coefficients of 78% and 76%. The results predicted by the model were compared with the confirmation test results. Manna and Bhattacharyya investigated the optimization of two types of surface roughness in turning operation of composite material. The optimum factor levels were specified using ANOVA and the plots of main effects and interactions [21]. Aslan et al., studied the optimization of tool life and the surface roughness quality characteristics in turning by means of the ANOVA and the regression analyses. The correlation coefficients of the obtained models are 69% and 47%, respectively [22]. Basavarajappa et al., discussed the dry sliding wear behaviour of the metal matrix composites by way of Taguchi method. The effects of process parameters on quality characteristics were determined by L_{27} orthogonal array and ANOVA [23]. An experimental investigation was carried out by Davim and Figueira [24], using ceramic cutting tools, in surface finish operations on cold work tool steel D2 (AISI) heat treated to a hardness of 60 HRC. An integrated technique using orthogonal array and analysis of variance (ANOVA) was employed to investigate the machinability of cold work tool steel.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

In this study, optimization of the machining parameters using the Taguchi design method by asymmetric milling of Ti–6Al–4V under dry cutting condition with TiN coated cemented carbide tools was investigated. Signal-to-noise ratio (S/N) analysis, analysis of variance (ANOVA) and regression analysis were carried out to determine the effects of each machining parameters on the cutting forces and surface roughness and optimal factor settings. Finally, confirmation tests verified that Taguchi method achieved optimization of machining parameters performance with sufficient accuracy.

3. EXPERIMENTAL CONDITIONS AND PROCEDURE (DENEYSEL ŞARTLAR VE YÖNTEM)

In the machining test, an alpha-beta titanium alloy Ti−6Al−4V was used as the workpiece material, which has a hardness of 40 HRC and dimensions of 50x70x50 mm. The chemical composition of the alloy is given in Table 1. The tool holder and indexible inserts used in the machining test were produced by Safety. The tool holder, insert used and machining configuration were selected according to ISO standards and shown in Fig. 1. The recommended cutting speed of this insert in titanium machining is 40-150 m/min, and feed rate is 0.03-0.15 mm/tooth. Experimental conditions were chosen based on this recommendation, and listed as follows: V_c =100-140-180 m/min, f= 250-500-750 mm/min, axial depth of cut a_p= 0.5mm, radial depth of cut a_e = 15 mm, and number of teeth n = 3. Radial depth of cut (a_e) and axial depth of cut (a_p) values used in asymetric face milling were selected from the recommended ISO face milling standard values. The radial dept of cut was selected as 60% of tool holder diameter in asymmetric face milling according to ISO 8688-1 [25].

Table 1. Nominal chemical composition of the Ti-6Al-4V alloy
(Tablo 1. Ti-6Al-4V alaşımının kimyasal bileşimi)

Chemical composition (wt.%)						
V	Al	N	O	H	C	Fe
4	6	0.05	0.2	0.0125	0.1	0.3

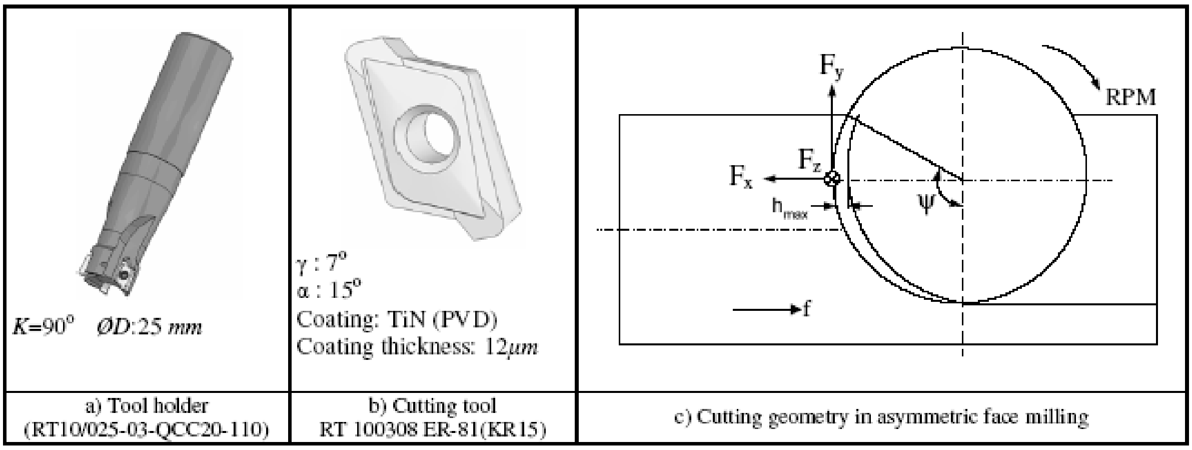

Figure 1. a) Tool holder,
b) Cutting tool,
c) Cutting geometry in asymmetric face milling
(Şekil 1. a) Takım tutucu,
b) Kesici takım,
c) Asimetrik yüzey frezelemede kesme geometrisi)

The oblique machining theory was extended to three-dimensional machining cases. Traditionally, this theory predicts cutting forces from cutting conditions and work material properties. The oblique cutting force data may be used in the computation of cutting forces acting on the tool [8 and 26]. Cutting force components acting on one tooth of the face milling cutter are shown in Fig. 1. In this figure, the table system of cutting forces is: F_x_instantaneous feed component (the projection of resultant cutting force in the X direction); F_y_instantaneous normal component (the projection of resultant cutting force in the Y direction); F_z_instantaneous vertical component (the projection of resultant force in the Z direction); and F_R_instantaneous resultant cutting force acting on the workpiece. F_x, F_y and F_z are the instantaneous cutting forces on an individual tooth per cut in the X, Y and Z directions respectively, ψ is the instantaneous (cutting) angle of the cutter [27]. The resultant cutting force F_R was calculated by using Eq. (1) [8].

$$F_R = \sqrt{\left((F_x)^2 + (F_y)^2 + (F_z)^2\right)} \qquad (1)$$

Machining tests were carried out on 3-axis CNC vertical machining centre of Johnford which has a 5.5 kW main power with a continuously variable spindle speed. Cutting force measurements were performed in a dry cutting condition. Cutting force measurements were carried out using a Kistler three component piezoelectric dynamometer type 9257B. This dynamometer was connected to a series of multi-channel charge amplifier type Kistler 5070A. Cutting force data were examined by using Dynoware Software. The cutting force values were acquired from the dynamometer on the point which has maximum chip thickness (h_{max}) and F_R was calculated using Eq. (1). Surface roughness (R_a) was measured by using Mahr Perthometer M1 surface profilometer with a cut-off length 0.8 mm and evaluation length of 5.6 mm. Each measurement was repeated three times at different positions on the surface and an arithmetical mean was taken into consideration.

Table 2. Factors and levels
(Tablo2. Faktörler ve seviyeleri)

Symbol	Machining parameters	Level 1	Level 2	Level 3
A	Cutting Speed, V_c (m/min)	100	140	180
B	Feed rate, f (mm/min)	250	500	750

Table 3. L_9 orthogonal array with factors and responses
(Tablo 3. L_9 ortogonal dizide faktörler ve sonuçlar)

Experiment no.	A (m/min)	B (mm/min)	F_x (N)	F_y (N)	F_z (N)	F_R (N)	R_a (µm)
1	100	250	65.48	16.05	95.4	116.82	0.64
2	100	500	92.97	43.47	110.92	151.12	1.20
3	100	750	122.52	78.4	138.65	200.95	1.30
4	140	250	57.4	17.8	62.1	86.42	0.42
5	140	500	76.38	38.44	105.68	135.94	0.83
6	140	750	110.81	59.7	136.15	185.42	0.93
7	180	250	41.5	6.87	44.71	61.39	0.40
8	180	500	67.78	32.84	107.6	131.34	0.80
9	180	750	79.71	39.12	100.64	134.21	0.85

In this study, two machining parameters were used as control factors and each parameter was designed to have three levels, marked as 1, 2 and 3 (Table 2). In accordance with the Taguchi design method, a L_9 orthogonal arrays table with 9 rows (corresponding to the number of experiments) was selected for the experiments (Table 3).

Statistical analyses were performed by using MINITAB R14 software. The statistical treatment of the data was performed in three phases. The first one interested in the signal-to-noise (S/N) ratio analysis. The second one concerned with the analysis of variance (ANOVA) and the third one allowed the correlation between the parameters to be acquired. Subsequently, the results were obtained through confirmation tests. Statistical analyses of the datum are performed for a confidence level of 95%, i.e., for a significance level of 0.05. Taguchi method uses an S/N ratio to measure the present variation. The meaning of S/N ratio differs according to an objective function, i.e., a characteristic value. There are three kinds of characteristic value of S/N ratio: nominal-the better, larger-the-better and smaller-the-better. The-smaller the-better quality characteristic for surface roughness and resultant cutting force were adopted to the optimal cutting performance. S/N ratio η is defined as follows:

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

Where; y is the data and n is the number of observations. The unit of S/N ratio is decibel. All F-tests are based on the residual mean square error. The ANOVA table decomposes the variability of eigenvalues into contributions due to design parameters. The P-coefficient tests the statistical significance of each of these parameters. Since the P-coefficient of the parameters in the ANOVA table is less than 0.05, this factor has a statistically significant effect on force components at the 95% confidence level [28].

4. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

4.1. Evaluation of Cutting Forces (Kesme Kuvvetlerinin Değerlendirilmesi)

It is shown in Table 3 that cutting forces increased with an increase in feed rate for all the cutting force components. Increase in F_x and F_y cutting force components are more than F_z cutting force components. As can also be seen in Table 3, the lowest values of cutting force components are obtained at 180 m/min cutting speed. When Table 4 is closely examined, it can be seen that F_z force is higher than the others. This can be explained that force vector directions are close to the z-direction in reply to each tooth during the instantaneous (cutting) angle of the cutter (see Fig. 2). Because of the axial depth of cut lower than tool nose radius, end milling process look like ball-end milling. The material flow and associated shearing occurring at the clearance face lead to ploughing force which can be added in the model by introducing edge coefficients as in mechanistic approaches, but in this case, the level of prediction decreases. The ploughing force component grows up when cutting speed and undeformed chip thickness tends to go to zero. These critical conditions appear mainly around the tool tip (especially for ball-end mills). The direction of this ploughing force is close to the Z-direction in this region and the F_z component is then more influenced by this phenomenon. The squeezing effect on tool tip result in a higher value of F_z cutting force [4].

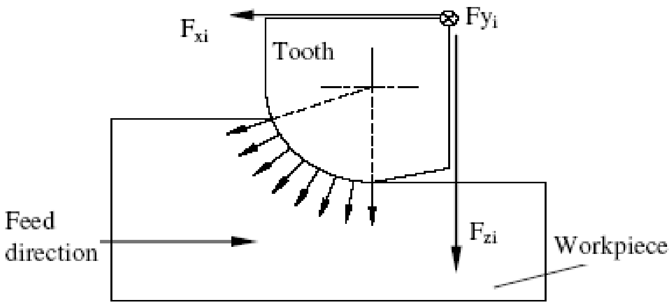

Figure 2. Distribution of vectors of cutting forces on x-z plane
(Şekil 2. Kesme kuvveti vektörlerinin x-z düzlemindeki dağılımı)

Effect of cutting speed (V_c) and feed rate (f) on resultant cutting force (F_R) is shown in Figure 3. In this figure, the resultant cutting force was increased because of increasing chip cross-section with feed rate. Besides, resultant cutting force decreases with increasing cutting speed. The main reasons of the case explained in Ref. [29] are because of the increase in cutting temperature in the shear zone that consequently results in the reduction of the yield strength of the workpiece material, chip thickness and tool-chip contact length. It can be seen from Table 3 that when cutting speed increases to 180 m/min from 100 m/min and at 250 mm/min feed rate, the resultant cutting force decreases by 53%. Also, when the feed rate is increased to the highest value (750 mm/min) and cutting speed is increased to 180 m/min from 100 m/min, the resultant cutting force decreases by 67%. This drop in the resultant cutting force is partially caused by a decrease in contact area and partially by a drop in shear strength in the flow-zone as its temperature rises with increasing speed [29]. Hence, it was concluded that effect ratio of cutting speed on the resultant cutting force is affected by low feed rates more than high feed rates. It can be also seen from Table 3 that, when feed rate is increased to 750 mm/min from 250 mm/min and at 100 m/min cutting speed, the resultant cutting force increases by 72%. Also, when cutting speed is increased to the highest value (180 m/min) and feed rate is increased to 750 mm/min from 250 mm/min, the resultant cutting force increases by 118%. Budak and Kops asserted that the cutting force depends on the chip cross-sectional area (feed rate and depth of cut), the tool path (width of cut), the material and cutting tool properties and some experimentally determined constants [4]. Effect of feed rate on cutting force components is concerned about this case.

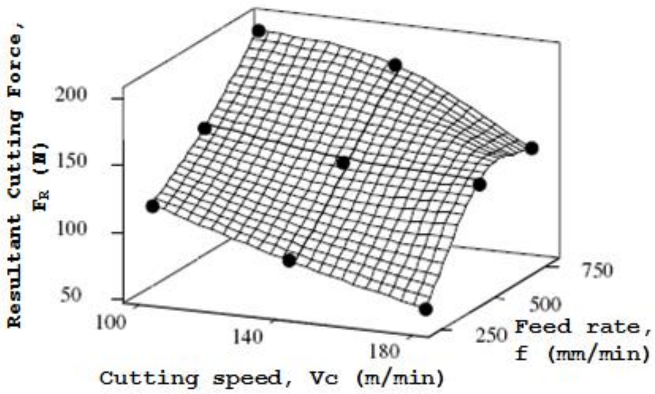

Figure 3. Effect of cutting parameters on resultant cutting force
(Şekil 3. Kesme parametrelerinin bileşke kesme kuvveti üzerine etkisi)

4.2. Signal-to-noise (S/N) Ratio Analysis for F_R
(F_R için Sinyal-gürültü (S/N)oranının analizi)

By applying the Eq. (2) S/N ratios of F_R are given in Table 4. Regardless of category of the performance characteristics, a greater η value corresponds to a better performance. Therefore, the optimum level of the machining parameters is the level with the greatest η value. The mean S/N ratios of F_R for each level of the machining parameters are given in Table 5. Based on S/N ratio analysis (Fig. 4 and Table 5), the optimum cutting performance for the F_R was obtained for the cutting speed of 180 m/min (Level 3), 250 mm/min feed rate (Level 1) settings.

Table 4. S/N ratio of F_R, (η)
(Tablo 4. F_R'nin S/N oranı (η))

Experiment no.	A (m/min)	B (mm/min)	F_R Measured (N)	F_R S/N (dB)
1	100	250	116.82	-41.3503
2	100	500	151.12	-43.5864
3	100	750	200.95	-46.0618
4	140	250	86.42	-38.7323
5	140	500	135.94	-42.6669
6	140	750	185.42	-45.3631
7	180	250	61.39	-35.7620
8	180	500	131.34	-42.3679
9	180	750	134.21	-42.5557

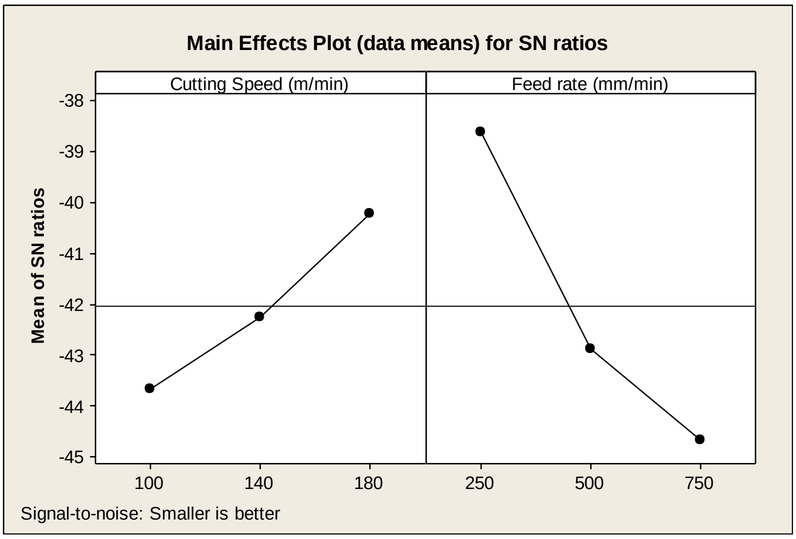

Figure 4. Main effect plot for S/N ratio of F_R
(Şekil 4. F_R'nin S/N oranı için ana etki grafiği)

Table 5. Response table mean S/N ratio (η) for F_R
(Tablo 5. $F_R$için ortalama S/N (η)oranı sonuç tablosu)

Parameters	Mean S/N ratio, η Level 1	Level 2	Level 3	Max-min
A	-43.67	-42.25	-40.23	3.44
B	-38.61	-42.87	-44.66	6.05

ANOVA results performed on the F_R show that feed rate are statistically the most significant parameter with a PCR value of 57.97% (Table 7). This was followed by cutting speed with a PCR value of 8.75%. The relationship between the factors (cutting speed and feed rate) and resultant cutting force (F_R) were acquired by multiple linear regressions. The regression equation of F_R was as follows:

$$F_R = 131 - 0.591\ V_c + 0.171\ f \qquad (3)$$

R^2=0.94

It is clear that statistical model can predict the surface roughness with accuracy depending on the obtained correlation coefficients R^2=0.94.

Table 6. ANOVA results for S/N ratios of F_R
(Tablo 6. F_R'nin S/N oranı için ANOVA sonuçları)

Source	Degrees of freedom (DoF)	Sequential sum of squares (SS)	Mean sum of squares (MS)	F-test	P-coefficient	PCR (%)
A (m/min)	2	17.914	8.957	6.62	0.054	8.75
B (mm/min)	2	57.876	28.938	21.37	0.007	57.97
Residual error	4	5.415	1.354			33.28
Total	8	81.215				100

4.3. Evaluation of Surface Roughness (Yüzey Pürüzlülüğünün Değerlendirilmesi)

Machined surface roughness depends on several factors, such as cutting speed, feed rate, tool nose radius, flank wear, chatter, work-tool material properties, etc. [1]. In this study, the effect of cutting speed (V_c) and feed rate (f) on average surface roughness (R_a) were investigated. Surface roughness variations measured on machined surface according to the cutting speed and feed rate are shown in Fig. 5.

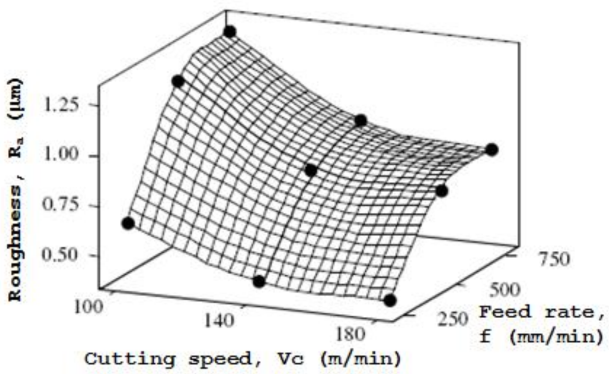

Figure 5. Effect of cutting parameters on surface roughness
(Şekil 5. Kesme parametrelerinin yüzey pürüzlülüğü üzerine etkisi)

The first trend which can be seen in Figure 5 is the decreasing trend on surface roughness with increasing cutting speed. This situation is an expected indicator of the positive effect of the increase in cutting speed on surface roughness. Together with increasing cutting speed, increasing heat in the cutting zone provides continuity in chip flow and also facilitates it. As a result, surface roughness values display a decreasing trend [7 and 29]. It can be seen from Fig. 5 that when cutting speed is increased to 180 m/min from 100 m/min at the feed rate of 250 mm/min, the average surface roughness decreased by 37.5%. At the same conditions with 750 mm/min feed rate the R_a decreased by 34.6%. It can also be seen from Fig. 5, when feed rate is increased to 750 mm/min from 250 mm/min at 100 m/min cutting speed, the R_a increased by 103%. In this situation, theoretic calculations used in real surface roughness predictions affirm that the increase in surface roughness is directly proportional with the increase in the feed rate [13].

At the highest value (180 m/min) of the cutting speed the Ra increased by 112% while increasing the feed rate from 250 mm/min to 750 mm/min. Minimum value of R_a was obtained at cutting speed of 180 m/min and feed rate of 250 mm/min. Amin et al. [1] used WC-Co inserts for milling of titanium alloy—Ti-6Al-4V, and found that the surface roughness was increased due to diffusion and superficial plastic deformation occurred in the inserts with increasing cutting speed. However, results of this study showed that the surface roughness decreases with increasing cutting speed. This can be explained that TiN (PVD-12 μm thick) coating exhibits the best tribological improvements compared to uncoated tools: important decrease of the tool-chip contact area, decrease of the thickness of the secondary shear zone and of the temperature at this interface, which leads to a decrease of the heat flux transmitted to the cutting tool substrate [14].

4.4. Signal-to-Noise (S/N) Ratio Analysis for R_a (R_a için Sinyal-Gürültü (S/N) Oranının Analizi)

S/N ratios of R_a calculated by using experimental results are given in Table 7. Based on S/N ratio analysis (Table 8 and Fig. 6), the optimal machining performance for the R_a was obtained for the cutting speed of 180 m/min (Level 3) and 250 mm/min feed rate (Level 1) settings. From the outcome in Table 9, it can be seen that the feed rate factor (PCR= 74.92%) has statistical significance on the surface roughness (R_a). That is to say, R_a is more sensible to the changes in the feed rate than the other processes parameter.

Table 7. S/N ratio of R_a (η)
(Tablo 7. R_a'nın S/N oranı (η))

Experiment no.	A (m/min)	B (mm/min)	R_a	
			Measured (μm)	S/N (dB)
1	100	250	0.64	3.87640
2	100	500	1.20	-1.58362
3	100	750	1.30	-2.27887
4	140	250	0.42	7.53501
5	140	500	0.83	1.61844
6	140	750	0.93	0.63034
7	180	250	0.40	7.95880
8	180	500	0.80	1.93820
9	180	750	0.85	1.41162

Table 8. Response table mean S/N ratio (η) for R_a
(Tablo 8. $R_a$için ortalama S/N (η)oranı sonuç tablosu)

Parameters	Mean S/N ratio, η			
	Level 1	Level 2	Level 3	Max-min
A	0.00464	3.26126	3.76954	3.76490
B	6.445674	0.65767	-0.07897	6.53571

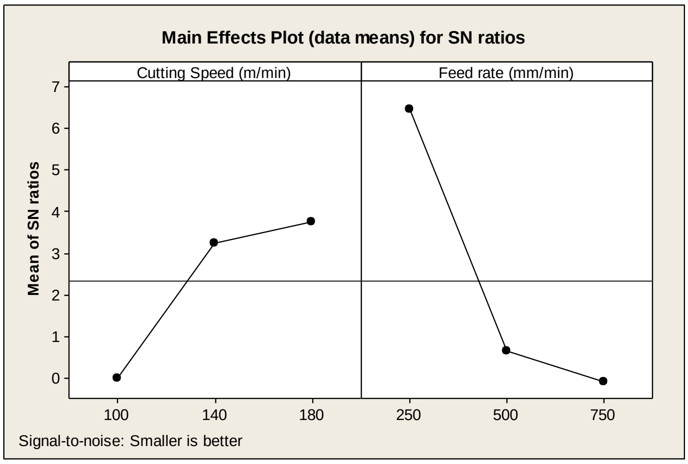

Figure 6. Main effect plot for S/N ratio of R_a
(Şekil 6. R_a'nın S/N oranı için ana etki grafiği)

Table 9. ANOVA results for S/N ratios of R_a
(Tablo 9. R_a 'nın S/N oranı için ANOVA sonuçları)

Source	Degrees of freedom (DoF)	Sequential sum of squares (SS)	Mean sum of squares (MS)	F-test	P-coefficient	PCR (%)
A (m/min)	2	25.038	12.5192	264.53	0.000	24.15
B (mm/min)	2	76.887	38.4436	812.38	0.000	74.92
Residual error	4	0.189	0.0473			0.93
Total	8	102.115				100

The relationship between the factors (cutting speed and feed rate) and surface roughness (R_a) were acquired by multiple linear regressions. The regression equation of R_a was as follows:

$$Ra = Ra = 0,915 - 0.00454\ V_c + 0.00108\ f \qquad (4)$$
$$R^2=0.84$$

It is clear that statistical model can predict the surface roughness with accuracy depending on the obtained correlation coefficients R^2=0.84.

4.5. Confirmation Tests (Doğrulama Deneyleri)

After the optimal level of the design parameters has been determined, the final step is to predict and verify the improvement of the performance characteristic using the optimal level of the process parameters in Taguchi method [30].

The results of the confirmation experiment using the optimal machining parameters of resultant cutting force and surface roughness are given in Table 10 and Table 11, respectively. In this place, there is a good compatibility between the predicted and real cutting performance. The confirmation tests results showed that prediction error became 1.0328 for the F_R and 0.07767 for the Ra.

Table 10. Results of confirmation tests for F_R
(Tablo 10. F_R için doğrulama deneylerinin sonuçları)

	Initial cutting parameters	Optimum cutting parameters	
		Prediction	Experimental
Level	A2B2	A3B1	A3B1
F_R (N)	135.94	63.4556	61.39
S/N ratio (dB)	-42.6669	-36.7938	-35.761
Improvement of S/N ratio	6.9059 dB		
Prediction error (dB)	1.0328		

Table 11. Results of confirmation tests for R_a
(Tablo 11. R_a için doğrulama deneylerinin sonuçları)

	Initial cutting parameters	Optimum cutting parameters	
		Prediction	Experimental
Level	A2B2	A3B1	A3B1
R_a (μm)	0.83	0.35111	0.4
S/N ratio (dB)	1.61844	7.88113	7.95880
Improvement of S/N ratio	6.34036 dB		
Prediction error (dB)	0.07767		

5. CONCLUSIONS (SONUÇLAR)

In this paper, the effects and optimization of the machining parameters on resultant cutting force and surface roughness when asymmetric face milling of Ti-6Al-4V under dry cutting condition were investigated by using Taguchi method. The following specific conclusions are achieved based on the results:

- Resultant cutting forces were found to increase with an increase in feed rate, whereas resultant cutting force decreased with an increase in cutting speed.
- Average surface roughness decreased with increasing cutting speed during machining using TiN coating WC-Co inserts. This was attributed to the low friction coefficient of TiN coating.
- According to results of S/N ratio, the optimal experimental condition for F_R and R_a were obtained on the third level of cutting speed (180 m/min) and first level of feed rate (250 mm/min).
- The effects of factors and their two-way interactions on response were modelled by using regression and correlation analysis with values of R^2 for the R_a and the F_c were 94% and 84%, respectively.
- The confirmation experiments including optimum experimental conditions were conducted and the results of the predicted and confirmation test results were compared. For the both surface roughness (R_a) and resultant cutting force (F_R), the calculated value of the prediction error was found to be within the confidence limit at 95% confidence level.

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