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RESEARCH ARTICLE

Modeling & optimization of Ti6Al4V turning for sustainable shearing considering rake angle

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Abstract: Titanium alloys, such as Ti6Al4V, have become increasingly prevalent in aerospace and biomedical industries owing to their exceptional mechanical properties and corrosion resistance. However, the machining of these alloys presents significant challenges including high tool wear, poor surface finish, and low productivity. This study focused on enhancing the machinability of Ti6Al4V during CNC turning using the Taguchi optimization method. This approach aims to identify the optimal cutting parameters that minimize the surface roughness, flank wear, and crater wear, thereby improving the overall machining performance. This study systematically investigated the influence of various cutting parameters on machining outcomes. The experimental results demonstrate that the Taguchi method effectively determines the optimal process parameters, leading to a significant reduction in surface roughness and tool wear. These findings highlight the potential of the Taguchi optimization technique for achieving improved machinability and sustainability in the machining of Ti6Al4V.

Keywords: Ti6Al4V, Taguchi optimization, rake angle, machinability

1 Introduction

Titanium alloys have emerged as indispensable materials in a wide array of industries because of their exceptional strength-to-weight ratio, remarkable corrosion resistance, and excellent biocompatibility. Among these alloys, Ti6Al4V, characterized by its superior mechanical properties and widespread availability, is a preferred choice for demanding applications in the aerospace, biomedical, and chemical processing sectors [1, 2]. Its high strength, even at elevated temperatures, coupled with its resistance to fatigue and creep, make it particularly suitable for components subjected to extreme conditions [3–5]. Despite its numerous advantages, Ti6Al4V presents significant machining challenges owing to its inherent properties. Its low thermal conductivity hinders efficient heat dissipation during machining, leading to elevated temperatures at the tool-workpiece interface [6, 7]. This localized heat buildup accelerates tool wear, compromising surface integrity and overall machining efficiency [8–10]. Moreover, the high chemical reactivity of titanium promotes adhesion and diffusion between the tool and workpiece materials, further exacerbating tool wear and resulting in poor surface finish. The formation of a hard and brittle surface layer, often referred to as the white layer, adds another layer of complexity to the machining process [11–13].

The challenges associated with machining Ti6Al4V necessitate careful consideration and optimization of various cutting parameters to achieve the desired machining outcomes. Traditional machining optimization methods, which often rely on trial-and-error approaches, are time consuming, costly, and often yield suboptimal results [14–16]. To address these limitations, the Taguchi method, a statistical experimental design technique, has gained significant traction in the optimization of manufacturing processes. Developed by Genichi Taguchi, the Taguchi method emphasizes a systematic and efficient approach to experimental design, enabling engineers to evaluate the influence of multiple parameters and their interactions with a reduced number of experimental runs. Unlike traditional full-factorial experiments, which require a large number of experiments, the Taguchi method employs orthogonal arrays, thereby significantly reducing the experimental burden without compromising the statistical significance of the results [17–20].

The Taguchi method revolves around the concept of signal-to-noise (S/N) ratio, a measure of robustness that quantifies the desired output characteristics relative to the noise factors. By maximizing the S/N ratio, the process becomes less sensitive to uncontrollable variations, leading to improved quality and consistency [19,21,22]. The Taguchi method also incorporates analysis of variance, a statistical technique used to determine the relative significance of each parameter on the output response. In the context of CNC turning of Ti6Al4V, the Taguchi method can be effectively employed to optimize cutting parameters, such as cutting speed, feed rate, depth of cut, and rake angle [19,23]. These parameters significantly influence machining performance, thereby affecting surface roughness, tool wear, and tool life. By systematically varying these parameters and analyzing their impact on the desired output characteristics, the Taguchi method enables the identification of optimal cutting conditions that minimize surface roughness, reduce tool wear, and maximize tool life [24,25].

This study focuses on leveraging the Taguchi method to optimize the CNC turning process of Ti6Al4V to achieve improved surface integrity, reduced tool wear, and enhanced machining efficiency. This study investigates the influence of cutting speed, feed rate, depth of cut, and rake angle on surface roughness, flank wear, crater wear, and tool life. By employing orthogonal arrays, S/N ratio analysis, and ANOVA, this study aims to determine the optimal cutting parameters that yield the most favorable machining outcomes. The findings of this study will provide valuable insights for optimizing the CNC turning process of Ti6Al4V, contributing to enhanced machining efficiency, improved surface quality, reduced tool wear, and ultimately, more sustainable manufacturing practices. The optimized cutting parameters derived in this study can be readily implemented in industrial settings, leading to cost savings, reduced material waste, and improved product quality.

2 Material and methods

This study employed a systematic approach to optimize the CNC turning parameters of Ti6Al4V using the Taguchi method. This methodology encompasses material selection, parameter identification, experimental design, machining experiments, performance measurement, data analysis, and validation.

2.1 Material selection

The workpiece material used in this study was Ti6Al4V with dimensions of Ø 40 mm × 80 mm. Widely used Ti alloys are known for their exceptional mechanical properties and machinability. The chemical composition of the Ti6Al4V alloy used in this study is presented in Table 1.

Table 1 Chemical properties of Ti-6Al-4V

Contents	C	Fe	N	O	Al	V	H	Ti
wt. %	0.08	0.25	0.05	0.20	5.50-6.75	3.5-4.5	0.01	Balance

2.2 Parameter Identification

Four crucial cutting parameters with their levels were selected for optimization based on their significant influence on the machining performance of Ti6Al4V, as shown in Table 2.

Table 2 Process parameters with their levels

Sr. No.	Cutting Speed (Vc) (m/min)	Feed Rate (f) (mm/rev.)	Depth of Cut (d) (mm)	Rake Angle (α) (degree)
1	80	0.12	0.6	10
2	100	0.18	0.12	14
3	120	0.24	0.18	16
4	140	0.30	0.24	18
5	160	0.32	0.30	20

2.3 Experimental Design

An L25 orthogonal array, a statistical design matrix, was employed to efficiently evaluate the influence of the selected parameters on machining performance. This array allowed for the investigation of four factors, each at four levels, with only twenty-five experimental runs, significantly reducing the experimental burden compared to a full-factorial design. Table 3 presents the selected levels for each parameter and the corresponding L25 orthogonal array.

Table 3 L25 orthogonal array

Trial No.	Vc (m/min)	f (mm/rev.)	d (mm)	α (degree)
1	80	0.12	0.6	10
2	80	0.18	0.12	14
3	80	0.24	0.18	16
4	80	0.30	0.24	18
5	80	0.32	0.30	20
6	100	0.12	0.12	16
7	100	0.18	0.18	18
8	100	0.24	0.24	20
9	100	0.30	0.30	10
10	100	0.32	0.60	14
11	120	0.12	0.18	20
12	120	0.18	0.24	10
13	120	0.24	0.30	14
14	120	0.30	0.60	16
15	120	0.32	0.12	18
16	140	0.12	0.24	14
17	140	0.18	0.30	16
18	140	0.24	0.60	18
19	140	0.30	0.12	20
20	140	0.32	0.18	10
21	160	0.12	0.30	18
22	160	0.18	0.60	20
23	160	0.24	0.12	10
24	160	0.30	0.18	14
25	160	0.32	0.24	16

2.4 Machining Experiments

CNC turning experiments were conducted on an MTAB CNC 2-Axis lathe machine using DNMG110408 MP3 Walter-Tiger inserts. The experimental setup is shown in Figure 1. Each experimental run adhered to the predefined cutting parameters outlined in the L25 orthogonal array with a 15% concentrated water-miscible coolant. During each run, the following machining performance characteristics were meticulously measured, as listed in Table 4.

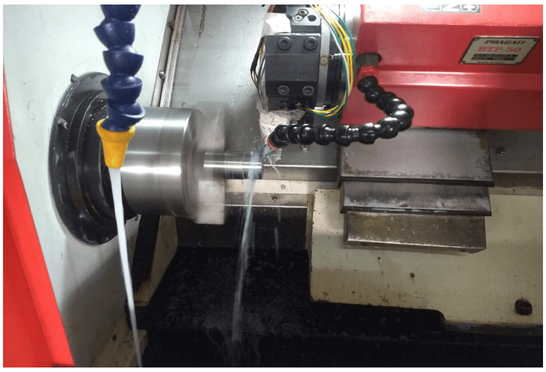

Figure 1 Experimental set up

2.5 Performance Measurements

Following each experimental run, the surface roughness of the machined workpiece was measured at three different locations and the average value was recorded. Tool-wear measurements, including flank wear and crater wear, were conducted using a toolmaker microscope equipped with a calibrated reticle.

3 Results and Discussion

3.1 Data analysis

The collected experimental data were systematically analyzed using the Taguchi method. The signal-to-noise (S/N) ratio, a measure of robustness, was calculated for each response characteristic (surface roughness, flank wear, and crater wear) using appropriate S/N ratio

Table 4 Performance of experimental trials

Trial No.	Flank Wear (μm)	Crater Wear (μm)	Ra (μm)
1	740	25.1	0.535
2	214	16.4	0.716
3	129	22.2	1.542
4	266	16.4	1.02
5	253	18	4.918
6	286	23.2	1.162
7	187	17.9	1.137
8	568	27.8	3.171
9	173	16	0.327
10	283	22.5	0.494
11	108	17	0.957
12	205	15.1	0.523
13	88.1	16.4	0.59
14	253	20.7	0.91
15	508	25.2	0.671
16	198	26.1	0.789
17	171	15.1	0.636
18	333	15.5	0.787
19	752	23.4	2.962
20	113	14	1.707
21	487	14	0.915
22	70.4	16	2.045
23	60.3	11.9	0.494
24	67.5	18.7	0.563
25	284	15.9	0.74

formulas, depending on the desired output characteristic (smaller-the-better). (refer Table 5).

Table 5 S to N ratios of experimental results

Trial No.	Flank Wear	Crater Wear	Ra
1	-57.3846	-27.9935	5.4329
2	-46.6083	-24.2969	2.9017
3	-42.2118	-26.9271	-3.7617
4	-48.4976	-24.2969	-0.1720
5	-48.0624	-25.1055	-13.8358
6	-49.1273	-27.3098	-1.3041
7	-45.4368	-25.0571	-1.1152
8	-55.0870	-28.8809	-10.0239
9	-44.7609	-24.0824	9.7090
10	-49.0357	-27.0437	6.1255
11	-40.6685	-24.6090	0.3818
12	-46.2351	-23.5795	5.6300
13	-38.8995	-24.2969	4.5830
14	-48.0624	-26.3194	0.8192
15	-54.1173	-28.0280	3.4655
16	-45.9333	-28.3328	2.0585
17	-44.6599	-23.5795	3.9309
18	-50.4489	-23.8066	2.0805
19	-57.5244	-27.3843	-9.4317
20	-41.0616	-22.9226	-4.6447
21	-53.7506	-22.9226	0.7716
22	-36.9515	-24.0824	-6.2139
23	-35.6063	-21.5109	6.1255
24	-36.5861	-25.4368	4.9898
25	-49.0664	-24.0279	2.6154

3.2 Flank wear optimization

Table 6 presents the mean signal-to-noise (S/N) ratio response for flank wear obtained from Taguchi L25 orthogonal array experiments. A higher S/N ratio indicates a more desirable outcome, representing minimal deviation from the desired low-flank wear.

Figure 2 generated using Minitab 17 software, visually depicts the mean S/N ratios for flank wear across different levels of each control factor. The graph highlights the optimal parameter

Table 6 Mean S to N ratio response table for Flank wear

Process Parameters	Mean SN ratios					
	L 1	L 2	L 3	L 4	L 5	Rank
Vc (m/min)	-48.55	-48.69	-45.60	-47.93	-42.39	3
f (mm/rev.)	-49.37	-43.98	-44.45	-47.09	-48.27	4
d (mm)	-48.60	-41.19	-48.96	-46.03	-48.38	1
α (degree)	-45.01	-43.41	-46.63	-50.45	-47.66	2

combination that yielded the highest mean S/N ratio.

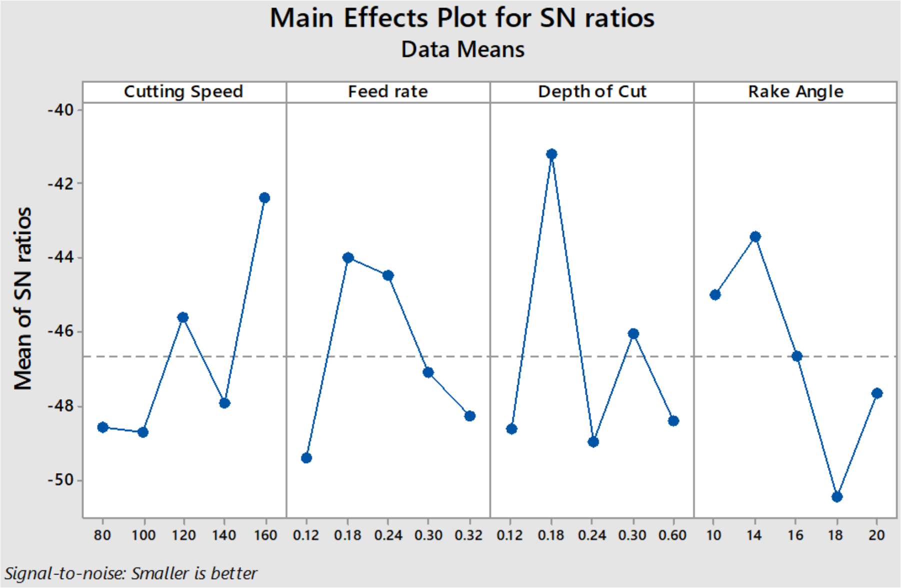

Figure 2 Mean S/N ratios for Flank wear

As is evident from Figure 2, the optimal parameter settings for minimizing flank wear are as follows:

(1) Cutting speed (Vc) = 160 m/min;
(2) (f): 0.18 mm/rev;
(3) Depth of cut (d): 0.18 mm;
(4) Rake angle (α): 14°.

These settings correspond to the highest point on the graph, indicating the most robust condition for minimizing flank wear. Furthermore, Table 6 reveals that the depth of cut exhibited the most significant influence on flank wear, achieving rank 1 across all levels. This ranking indicates that among the four investigated parameters, the DOC exerts the most substantial impact on flank wear. Consequently, maintaining a low DOC is crucial for minimizing flank wear during the CNC turning of Ti6Al4V.

3.3 Crater wear optimization

Table 7 Signal-to-noise ratio response plot of crater wear using Taguchi L25 orthogonal array experiments. Similar to the flank wear analysis, a higher S/N ratio indicated better results, indicating less deviation from crater wear in the area. Figure 3 shows that the mean S/N ratios for crater wear with different levels of each control factor are represented visually in the bar chart generated by the Minitab software. The chart shows the best parameter combination with respect to the highest mean S/N ratio.

As shown in Figure 2, the optimal parameter settings for minimizing crater wear are as follows:

(1) Cutting speed (Vc) = 160 m/min;
(2) (f): 0.18 mm/rev;
(3) Depth of cut (d): 0.3 mm;
(4) Rake angle (α) = 10 °.

The peak locations in our graph are the strongest conditions for minimal crater wear. Sub-

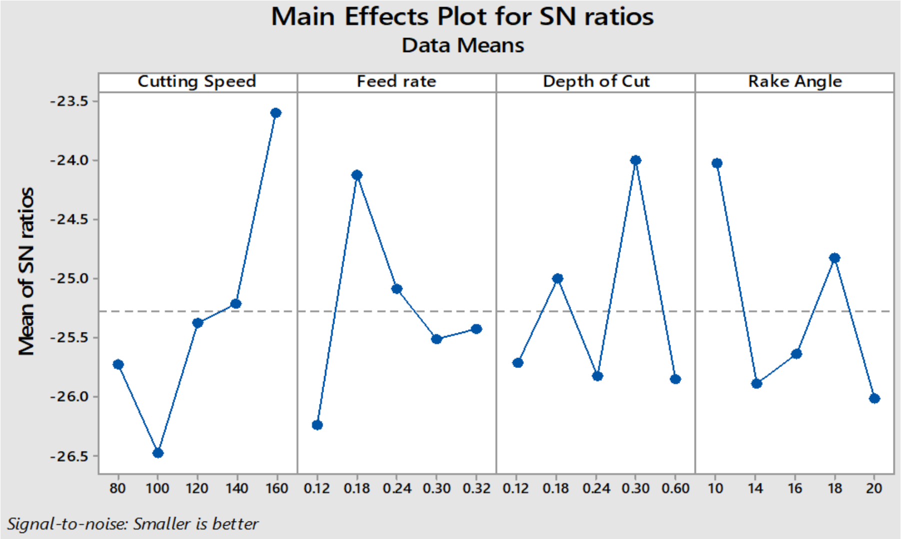

Figure 3 Mean S/N ratios for Crater wear

Table 7 Mean S to N ratio response table for Crater wear

Process Parameters	Mean SN ratios					
	L 1	L 2	L 1	L 4	L 1	Rank
Vc (m/min)	-25.72	-26.47	-25.37	-25.21	-23.60	1
f (mm/rev.)	-26.23	-24.12	-25.08	-25.50	-25.43	2
d (mm)	-25.71	-24.99	-25.82	-24.00	-25.85	4
α (degree)	-24.02	-25.88	-25.63	-24.82	-26.01	3

sequent analysis of Table 7 reveals that cutting speed is the dominant factor in crater wear, performing number one at all replication levels. This shows that of the four parameters examined, the cutting speed was by far and away, exerting a significant influence on crater wear. Consequently, the optimal cutting speed is key to minimizing crater wear in the CNC turning of Ti6Al4V.

3.4 Average Surface roughness value optimization

The resulting response table for the surface finish is presented for the obtained S to N ratio in Table 8.

Table 8 Mean S to N ratio response table for Ra

Process Parameters	Mean SN ratios					
	L 1	L 2	L 1	L 4	L 1	Rank
Vc (m/min)	-1.88696	0.67825	2.97588	-1.20131	1.65767	2
f (mm/rev.)	1.46812	1.02670	-0.19934	1.18287	-1.25481	3
d (mm)	0.35139	-0.82999	0.02157	1.03173	1.64884	4
α (degree)	4.45055	4.13169	0.45992	1.00608	-7.82470	1

From the observations in Figure 4, the rake angle is highly effective for the surface quality during the turning of Ti6Al4V. As shown in Figure 4, the optimal parameter settings for minimizing the average surface roughness values areas follows:

(1) Cutting speed (Vc): 120 m/min;
(2) (f): 0.3 mm/rev;
(3) Depth of cut (d): 0.6 mm;
(4) Rake angle (α) = 10 °.

As shown in Table 8, Rake angle 100 has a rank of 1 at all process parameter levels. Among the four process parameters, the rake angle affected the surface finish the most. Therefore, a lower value of the rake angle leads to a Better Surface finish; hence, it is subtractive.

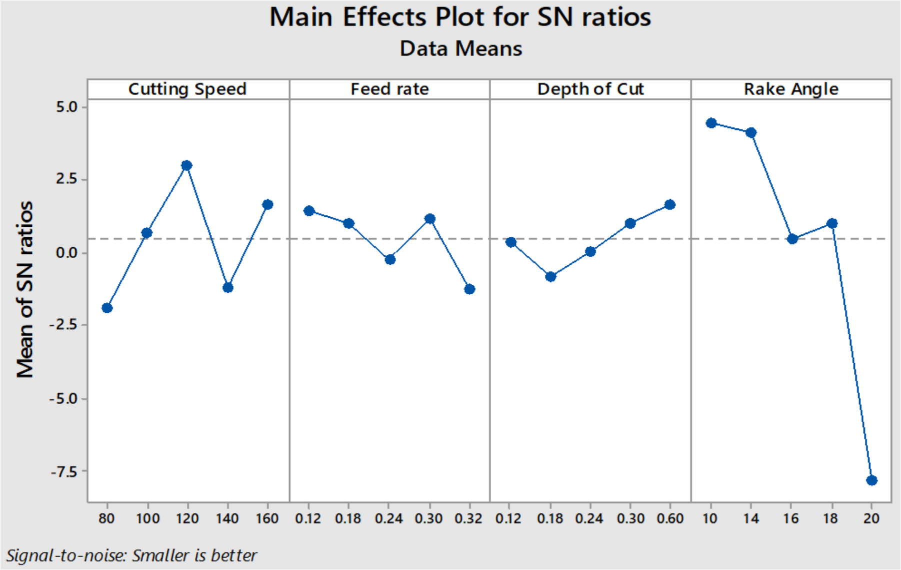

Figure 4 Mean S/N ratios for Ra

3.5 Validation

Confirmation experiments were conducted using the optimal cutting parameters predicted by the Taguchi method to validate its effectiveness in enhancing the machinability of a Ti alloy (Ti6Al4V). The results for the Surface Roughness, Flank wear, and crater wear are presented in Table 9, 10, and 11, respectively.

Table 9 Test result for surface roughness

	Initial process parameter	Optimal process parameters	
		Prediction	Experiment
Level	Vc1-f4-d4-α4	Vc2-f3-d3-α3	Vc2-f5-d1-α2
Surface roughness (μm)	1.02		0.494
S to N ratio (dB)	33.6969	26.015	29.3898
Improvement in S to N ratio (dB)		4.3071	
Percentage reduction of surface roughness		51.56%	

Table 10 Test result for Flank wear

	Initial process parameter	Optimal process parameters	
		Prediction	Experiment
Level	Vc1-f4-d4-α4	Vc5-f2-d2-α2	Vc5-f3-d2-α1
Flank wear (μm)	266		60.3
S to N ratio (dB)	-48.4976	19.0526	-35.6063
Improvement in S to N ratio (dB)		12.8913	
Percentage reduction in Flank wear		77.33%	

The confirmation experiments demonstrated a significant improvement in all three performance characteristics compared with the initial parameter settings. Specifically:

(1) ***Surface Roughness:*** A notable improvement in the surface finish was observed with an S/N ratio improvement of 4.3071 dB, corresponding to a 51.56% reduction in Ra compared to the initial value;

(2) ***Flank Wear:*** The Taguchi-predicted parameters led to a substantial reduction in flank wear, achieving a 12.8913 dB improvement in the S/N ratio and a remarkable 77.33% reduction in wear compared to the initial setting;

(3) ***Crater Wear:*** Crater wear also exhibited a considerable decrease, with an S/N ratio improvement of 2.786 dB and a 27.44% reduction in wear compared to the initial value.

These findings strongly support the effectiveness of the Taguchi optimization technique in significantly enhancing the machinability of Ti6Al4V under specified process settings. Confirmation experiments confirm that the predicted optimal cutting conditions outperform the initial

Table 11 Test result for Crater wear

	Initial process parameter	Optimal process parameters	
		Prediction	Experiment
Level	Vc1-f4-d4-α4	Vc5-f2-d4-α1	Vc5-f3-d2-α1
Crater wear (μm)	16.4		11.9
S to N ratio (dB)	-24.2969	19.0529	-21.5109
Improvement in S to N ratio (dB)		2.786	
Percentage reduction in Crater wears		27.44%	

parameter values, leading to reduced surface roughness, flank wear, and crater wear.

To validate the effectiveness of the optimized cutting parameters obtained from Taguchi analysis, confirmatory experiments were conducted using the predicted optimal parameter settings. The results obtained from the confirmatory experiments were then compared with the predicted values to assess the accuracy and reliability of the optimization process. (see Table 12).

Table 12 Experimental results, predicted results, and residuals

Trial No.	Experimental Results			Predicted Results			Residuals		
	Flank Wear (μm)	Crater Wear (μm)	Ra (μm)	Flank Wear (μm)	Crater Wear (μm)	Ra (μm)	Flank Wear (μm)	Crater Wear (μm)	Ra (μm)
1	740	25.1	0.535	296.18	20.13	0.04	443.82	4.97	0.49
2	214	16.4	0.716	279.67	20.60	1.16	-65.67	-4.20	-0.44
3	129	22.2	1.542	309.87	21.06	1.66	-180.87	1.14	-0.11
4	266	16.4	1.02	340.06	21.52	2.15	-74.06	-5.12	-1.13
5	253	18	4.918	372.79	22.09	2.52	-119.79	-4.09	2.40
6	286	23.2	1.162	285.50	20.18	1.15	0.50	3.02	0.01
7	187	17.9	1.137	315.69	20.64	1.65	-128.69	-2.74	-0.51
8	568	27.8	3.171	345.89	21.10	2.15	222.11	6.70	1.02
9	173	16	0.327	220.50	18.23	0.63	-47.50	-2.23	-0.31
10	283	22.5	0.494	311.44	19.60	1.21	-28.44	2.90	-0.72
11	108	17	0.957	321.51	20.22	1.65	-213.51	-3.22	-0.69
12	205	15.1	0.523	196.13	17.35	0.13	8.87	-2.25	0.39
13	88.1	16.4	0.59	252.26	18.37	0.96	-164.16	-1.97	-0.37
14	253	20.7	0.91	314.73	19.08	1.33	-61.73	1.62	-0.42
15	508	25.2	0.671	274.83	19.09	1.99	233.17	6.11	-1.32
16	198	26.1	0.789	227.88	17.48	0.46	-29.88	8.62	0.33
17	171	15.1	0.636	258.08	17.95	0.96	-87.08	-2.85	-0.32
18	333	15.5	0.787	320.55	18.65	1.33	12.45	-3.15	-0.54
19	752	23.4	2.962	278.12	18.57	2.11	473.88	4.83	0.85
20	113	14	1.707	155.27	15.80	0.47	-42.27	-1.80	1.24
21	487	14	0.915	263.90	17.53	0.95	223.10	-3.53	-0.04
22	70.4	16	2.045	326.37	18.23	1.32	-255.97	-2.23	0.72
23	60.3	11.9	0.494	128.36	14.81	0.09	-68.06	-2.91	0.40
24	67.5	18.7	0.563	184.49	15.83	0.93	-116.99	2.87	-0.36
25	284	15.9	0.74	217.22	16.40	1.29	66.78	-0.50	-0.55

3.6 ANOVA

Analysis of variance was employed to determine the influence of each process parameter on the performance attributes. Table 13, 14, and 15 summarize the ANOVA results for the flank wear, crater wear, and surface roughness, respectively.

Table 13 ANOVA for Flank wear

Process parameters	Degree of Freedom	S of Sq	Mean of Sq	% Contribution
Vc (m/min)	4	221.6	45.66	23.99
f (mm/rev.)	4	189.7	37.6	20.52
d (mm)	4	291.2	62.71	31.50
α (degree)	4	221.6	45.64	23.99
Total	16	924.1		100

The analysis revealed the following:

(1) Flank wear was primarily influenced by the depth of cut (31.50%), followed by the cutting

Table 14 ANOVA for Crater wear

Process parameters	Degree of Freedom	S of Sq	Mean of Sq	% Contribution
Vc (m/min)	4	30.58	6.611	32.60
f (mm/rev.)	4	20.04	3.978	21.36
d (mm)	4	20.86	4.182	22.23
α (degree)	4	22.34	4.551	23.81
Total	16	93.82		100

Table 15 ANOVA for Surface roughness

Process parameters	Degree of Freedom	S of Sq	Mean of Sq	% Contribution
Vc (m/min)	4	121.91	25.27	15.56
f (mm/rev.)	4	67.69	11.72	8.7
d (mm)	4	59.56	9.689	7.6
α (degree)	4	533.22	128.104	68.14
Total	16	782.35		100

speed (23.99%), rake angle (23.99%), and feed rate (20.52%);

(2) Crater wear: The cutting speed was the most significant factor (32.60%), followed by the rake angle (23.81%), DOC (22.23%), and feed rate (21.36%);

(3) Surface roughness: The rake angle exhibited the most substantial impact (68.14%), followed by the cutting speed (15.5%), feed rate (8.7%), and DOC (7.6%).

As a result, both the cutting speed and depth of cut significantly impact the tool health and crater wear. Conversely, the rake angle was the most influential factor for surface roughness.

4 Conclusions

This study investigated the optimization of process parameters in the CNC turning of Ti6Al4V titanium alloy, with the aim of enhancing machinability by minimizing surface roughness, flank wear, crater wear, and maximizing tool life. The Taguchi method coupled with ANOVA proved to be a robust approach for determining the optimal cutting conditions and understanding the influence of individual parameters on performance characteristics. The Taguchi L25 orthogonal array was employed to design experiments and investigate the effects of the cutting speed, feed rate, depth of cut, and rake angle on the desired output variables. Signal-to-noise (S/N) ratio analysis, utilizing the ”smaller-the-better” approach, identified the parameter settings that yielded the most desirable outcomes for each performance characteristic. Confirmation experiments conducted using the Taguchi-predicted optimal parameters validated the effectiveness of the optimization process. Significant improvements were observed in all performance characteristics compared with the initial settings. The surface roughness exhibited a remarkable reduction of 51.56 %, whereas the flank wear and crater wear were minimized by 77.33 % and 27.44 %, respectively. These findings highlight the efficacy of the Taguchi method in achieving substantial enhancement in the machinability of Ti6Al4V.

Furthermore, the ANOVA analysis provided valuable insights into the relative influence of each process parameter on the output variables. The depth of cut emerged as the most significant factor affecting flank wear, whereas the cutting speed influenced both crater wear and tool life. Notably, the rake angle had the most substantial impact on the surface roughness.

This study successfully demonstrated the efficacy of the Taguchi method in optimizing the CNC turning parameters to improve the machinability of the Ti6Al4V alloy. The optimization results obtained through the Taguchi method not only improved the machinability of Ti6Al4V, but also provided a comprehensive understanding of the complex relationships between the process parameters and output variables. These insights can be invaluable to engineers and manufacturers seeking to enhance their machining processes for titanium alloys. Moreover, the successful application of the Taguchi method in this study opens up possibilities for its implementation in optimizing machining parameters for other challenging materials in aerospace and biomedical industries. The identified optimal cutting conditions, validated through confirmation experiments, can be directly implemented in industrial settings to enhance the machining efficiency and product quality. Moreover, the insights gained from ANOVA provide valuable guidance for process planning and control, enabling manufacturers to make informed decisions regarding parameter selection to achieve the desired machining outcomes.

This study investigated the optimization of CNC turning parameters for Ti6Al4V using the

Taguchi method, leading to the following conclusions:

(1) Depth of Cut: Most influential factor for flank wear (31.50% contribution according to ANOVA);

(2) Cutting Speed: Dominant factors for crater wear (32.60%) and tool life (79.78%);

(3) Rake Angle: Most significant parameter for surface roughness (68.14% contribution);

(4) Reduced Average Surface Roughness value: A 51.56% reduction in surface roughness was achieved with a 4.3071 dB improvement in the S/N ratio;

(5) Minimized Flank Wear: Resulted in a 77.31% reduction in flank wear, with a 12.8913 dB improvement in the S/N ratio;

(6) Decreased Crater Wear: Led to 27.44% reduction in crater wear, with a 2.786 dB improvement in the S/N ratio.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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