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Influence of Cutting Parameters in Machining of Titanium Alloy

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Abstract

Objective: The influence of input parameters, to improve the surface finish of the machined part and to reduce the tool wear rate in turning titanium alloy (Ti-6Al-4V) using coated carbide inserts. **Method/Analysis:** Turning experiments are conducted on all geared lathe. The machining parameters used for the turning experiment include cutting speed, feed and depth of cut. Taguchi's orthogonal array is used for conducting the experiments. Surface roughness of the work piece after each turning is evaluated. Here, the optimal cutting parameter for better surface finish is determined using S/N ratio. Analysis of variance is used to study the influence of parameters. **Finding:** The present work considers the surface roughness in machining of titanium alloy. From the results, it has been found that the feed rate is the most influencing factor having 41.69% contribution followed by cutting speed and depth of cut. The optimal parameters are found to be: high cutting speed, lower feed rate and low depth of cut. Also, the tool is investigated for general wear pattern. Low cutting speeds leads to the adhesion of work piece material on to the tool after a certain period of time. **Conclusion:** The optimal machining parameters are studied. Feed rate is the dominant parameter for surface roughness followed by cutting speed and depth of cut.

Keywords: Cutting Parameters, Machining, SEM Studies Titanium Alloy: Coated Carbide Inserts, Surface Roughness

1. Introduction

Titanium and its alloy are considered as important engineering materials for industrial applications because of good strength to weight ratio, superior corrosion resistance and high temperature applicability. Titanium alloys have been widely used in the aerospace and aircraft industry are due to their ability to maintain their high strength at elevated temperature, and high resistance for corrosion. They are also being used increasingly in chemical process, automotive, biomedical and nuclear industry[1,2]. Titanium grade 5 has outstanding resistance to corrosion in most natural and much industrial process environmental. When machining titanium alloy with conventional tools, the tool wear rate progress rapidly. Some type of tool material including cemented carbide, ceramics are highly reactive with titanium alloy at high temperature[3]. Norihiko Narutaki and Akio Murakoshhi[4] studied and they found that the quality of surface machined with the coated carbide cutting inserts was better than that with the other tools. Fadare[5] have observed the surface roughness tended to increase with increase in feed rate and depth of cut, while it decreased with increase in cutting speed good surface quality can be achieved in high speed turning of Ti-6Al-4V alloy at low feed rate and depth of cut with high cutting speed. Palanikumar et al has observed that surface roughness is known to play an important role in many areas and is a factor of great importance in the

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evolution of dimensional accuracy of a machining component could affect several of the components[6]. Recently, Ahmet Hascalik and Ulascaydas[7] have studied the surface roughness tool life during machining of titanium alloy and they have stated that the tool life is mainly dependent on cutting speed. From the above literature, it has been revealed that there is no comprehensive study on modeling and analysis in machining of titanium alloy. In this study the effectiveness of coated carbide cutting inserts in machining of titanium alloy is carried out. With the evolution of a number of new cutting tools, advanced tool materials such as Cubic Boron Nitrite (CBN), Poly Crystalline Diamond (PCD) and coated carbide cutting inserts are being considered to achieve high speed machining of titanium alloy[8,9]. Zoya and Krishnamurthy have carried out specific cutting pressure study for a titanium alloy in high speed machining, and they found that specific cutting pressure increase with increase of cutting speed[10]. Colafemina[11] he has done experiments on Ti-6Al-4V alloy. They have observed an increase in surface roughness with increase in feed rate. They have not found any systematic relationships between depth of cut and roughness value. Deng jianxin[12] they have carried out different modes of tool failure including abrasive wear, adhesive wear, and diffusion wear, were observed when machining titanium alloy with WC/Co carbide tools in this study. The diffusion of elements from the titanium alloy to the WC/Co carbide tool through the tool-chip interface in machining processes lead to a composition change of the tool substrate, which may accelerate the tool wear. Machining is an important Manufacturing process because it is almost always involved, if precision is required and is the most effective process for small volume production. The selection of optimal cutting parameters, like feed rate, cutting speed and depth of cut, is very important issue for every machining process[13,14]. Turning is a commonly used machining operation in the industry producing a variety of components, meeting high accuracy and reliability requirements. From the survey of number of literatures, it has been revealed that optimization of cutting parameters is usually difficult work where the following aspects are required knowledge of machining empirical equations relating the tool life, cutting forces, surface roughness, and electrical power consumption. Surface roughness is known to play an important role in many areas and is a factor of great importance in the evolution of dimensional accuracy of machining components[15–20]. Ozel et. al they have been conducted turning experiment with coated and uncoated carbide tools and cutting performance of these coatings are evaluated. Tool wear zone measurements and predictions show that coated inserts depict smaller wear zone. Consequently, CBN coating may lead to reduction in tool wear dry machining of titanium alloy[18]. Krishna Sastry et al[21] have studied the machining of carbon fiber reinforced composite materials. In [22] studied the influence of cutting parameters in machining of wood composite panels. Danial Ghodsiyeh et al.[23] have investigated the wire electrical discharge machining of titanium alloy using response surface methodology. In [24] investigated the effect of parameters on drilling of glass fiber reinforced plastic composites. From these studies, it has been asserted that machining of materials like titanium is an important problem. In the present investigation, turning of titanium alloy is carried out. The influence of cutting parameters on turning of titanium alloy is studied in detail and presented in this study.

2. Experimental Details

2.1 Work Material and Cutting Tool

Alloys of Titanium (Ti-6Al-4V) material of 60mm diameter and 600mm length were used for all the experiments. In this present work the experiments were conducted on all geared lathe. The different sets of dry turning experiment are performed using a lathe machine. The cutting tool used for turning carbide cutting inserts, (CNMP120408 WS 25 PT) and the nose radius of 0.8mm in the experiments[11].

2.2 Experimental Procedure

The cutting parameter used for these experiments were cutting speed, feed, and depth of cut. The level of input variables used in the experiment is given in Table 1. The experimental design was planned as per Taguchi's method for the optimization of cutting parameters by following orthogonal array L09 (Table 3)[3,4,12]. The lower-the-better category is always preferred to calculate the S/N ratio for the smaller-the better characteristic is chosen .The analysis was made using MINITAB Software. The level of each design parameter has been identified and an analysis of the influence of the machining parameters on the surface roughness has been performed using the response table for the S/N ratios, which indicates the response at

Table 1. The levels and input parameters used in the experiment

PARAMETERS	UNITS	SYMBOLS	LEVELS		
			1	2	3
Cutting Speed	m/min	*v*	75	125	175
Feed	mm/rev	*f*	0.05	0.102	0.159
Depth of cut	mm	*d*	0.5	1.0	1.5

Table 2. L_{09} Orthogonal array used for the experimentation

Sl.no	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness (Ra) µm	S/N values
1	1	1	1	1.62	-4.1903
2	1	2	2	2.24	-7.0050
3	1	3	3	3.44	-10.7312
4	2	1	2	1.88	-5.4832
5	2	2	3	1.98	-5.9333
6	2	3	1	2.22	-6.9271
7	3	1	3	1.42	-3.0458
8	3	2	1	1.40	-2.9226
9	3	3	2	1.92	-5.6660

each level of the control factors. In addition, a statistical analysis of variance (ANOVA) was performed to find the process parameter that significantly affects the response (Ra)[19]. The experimental condition and the observations are presented in Table 2.

The surface roughness measured was the commonly used and most popularly known parameter, the average surface roughness (Ra) .The machined surface is measured at three different positions and the average values are taken using a surface testing machine. Surface finish is important parameters in manufacturing engineering. It is a characteristic that can influence the performance of mechanical parts and production costs. For these reason there have been research development with the objective of optimizing the cutting conditions to obtain a good surface finish[19-21]. The surface roughness of the machined surface of titanium alloy was measured by using Taylor Hobson – Surface tester (Figure 1). The surface roughness is evaluated after every step of turning operations.

3. Results and Discussion

3.1 Surface Roughness

The evaluations of the surface roughness of titanium alloy when it is machined, discontinuous chips are produced, resulting different conditions. The optimization of cutting parameters in machining of titanium alloy is done by SIGNAL -to- NOISE ratio also called as S-N ratio method which is very attractive and effective method to deal with responses influenced by number of variables following 'smaller the better" value. The response table and the mean surface roughness for each level are also determined as shown in Table 3. The table reveals the optimal cutting parameters and it is found that feed rate is the most influencing parameter then followed by cutting speed lesser surface roughness. The depth of cut showed only minimal effect[7,11,12]. From the results of tables 3, the optimum cutting conditions are determined as: v = 175 m/min, f = 0. 05 mm/rev and d = 0.5mm. The plots for S/N ratio and the mean of Ra had shown in Figures 2&3. The three dimensional Surface plot (Figure 4) are drawn to show the surface texture. The analysis of variance (ANOVA) is one of the most popularly used statistical methods for validation of multiple response results. For the conducted experimental data ANOVA is carried out (Table 4).

The percentages of contribution for all cutting parameters for the surface roughness are determined[12–15]. It is found that the feed is having a maximum contribution as 41.69%. As the percentage of error is 8.31% which is lesser than 15% (permissible limit of error) it may be stated that the design, conduction, observation and analysis are in the correct direction.

Table 3. Response table for S-N ratio for surface roughness

Levels	S/N ratio for surface roughness, dB			Average surface roughness (Ra), µm		
	Cutting Speed(*v*) m/min	Feed rate(*f*) mm/rev	Depth of Cut(*d*) mm	Cutting Speed(*v*) m/min	Feed rate(*f*) mm/rev	Depth of Cut(*d*) mm
1	-7.309	-4.240	-4.680	2.433	1.640	1.747
2	-6.115	-5.287	-6.051	2.027	1.873	2.013
3	-3.878	-7.775	-6.570	1.580	2.527	2.280
Δ	3.431	3.535	1.890	0.853	0.887	0.533
Rank	2	1	3	2	1	3
Optimal Parameters	175	0.05	0.5	175	0.05	0.5

Table 4. Analysis of Variance for Surface roughness

Source	DoF	Sum of squares	Mean variance	F-value	Percentage of contribution
v	2	1.0931	0.5465	4.32	**35.95%**
f	2	1.2675	0.6337	5.01	**41.69%**
d	2	0.4267	0.2133	1.69	**14.00%**
error	2	0.2528	0.1264	-	**8.31%**
Total	8	-	-	-	-

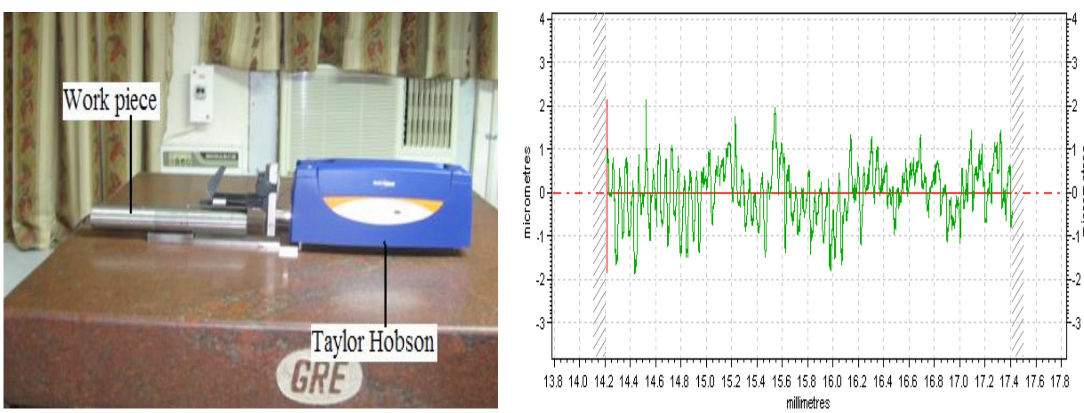

Figure 1. Surface roughness tester used for the Measurement of surface roughness.

3.2 Tool Wear

Tool was investigated for general types of wear patterns namely flank, crater, and nose using a SEM image. In this present studies, best machining parameter was determined as cutting speed 175 m/min, feed rate 0.05 mm/rev, and depth of cut 0.5mm Now setting this cutting condition as a constant parameter and machined

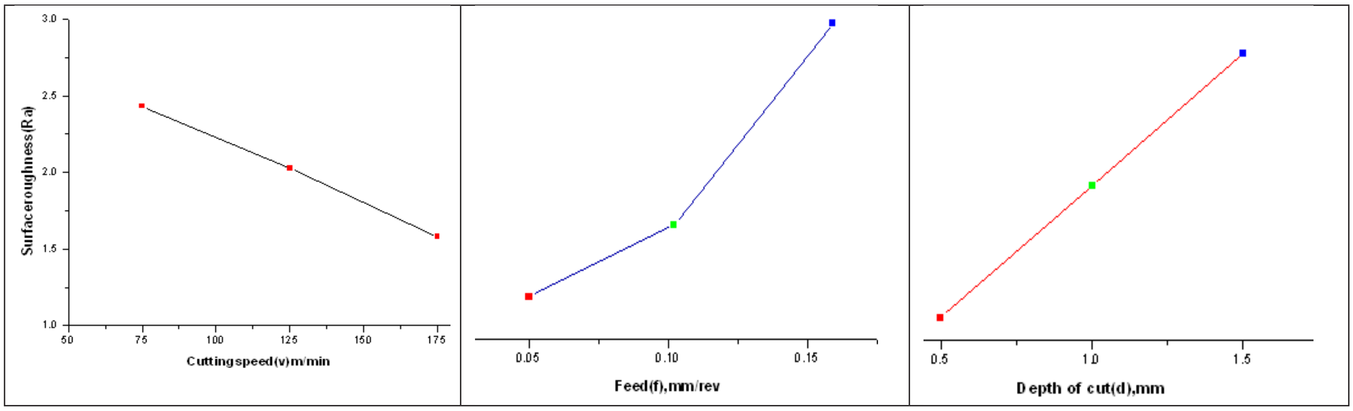

Figure 2. Main effect plot for S-N ratio w. r. t. Ra vs v ,f, d.

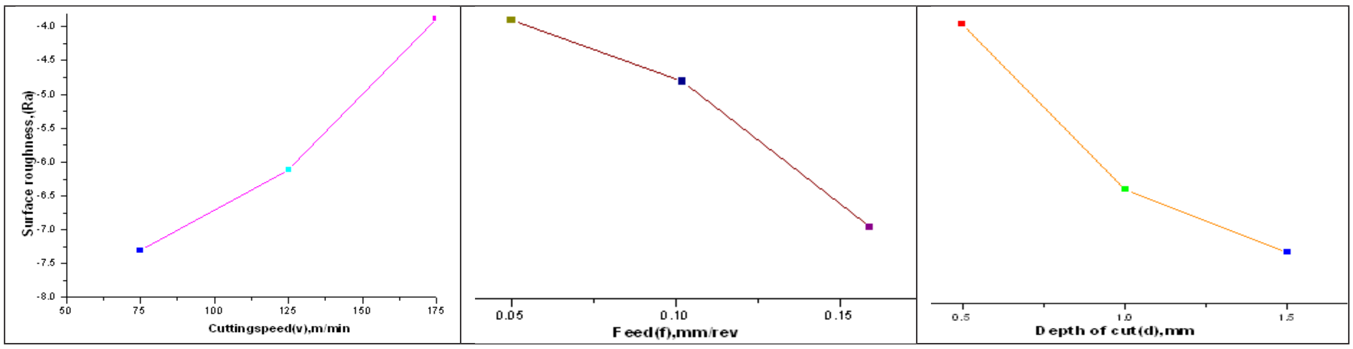

Figure 3. Main effect plot for Means w. r. t. Ra vs v ,f, d.

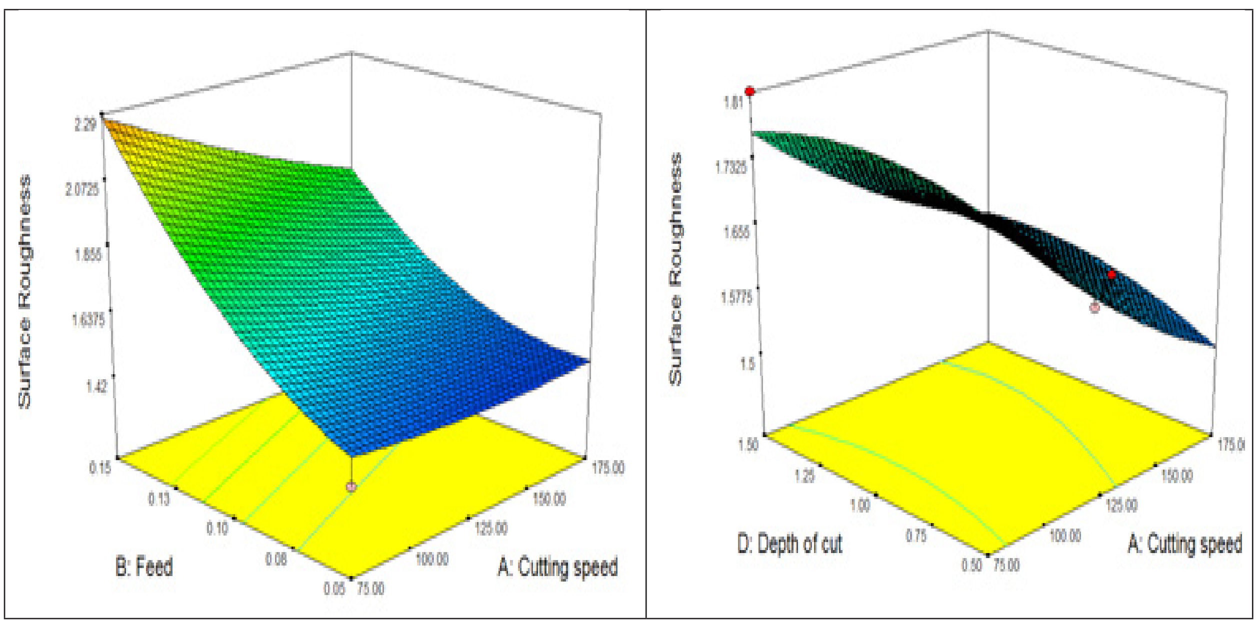

Figure 4. Surface plot of Ra with varying parameters

the samples for a time duration 30 min the tool flank wear study was carried out. From the Figure 5 it is clearly understood that, the tool flank wear is increasing linearly and reaches approximately 0.24mm after 30 min duration. At low cutting speed, worn flank encourages the adhesion of work piece material on the tool insert and formed BUE[13,14,17] it was observed that uniform diffusion/adhesive wear is existing in the flank portion for the first 10 min duration, After that, it was noticed that, sudden increase in the wear, this is happened due to shock loading associated with the machine and micro chipping of the insert was found at the nose region. Figure 7 shown the rake and flank portion of insert and built up edges is seen on the flank portion of the insert. It was also one of the reasons for tool wear. When machining with coated carbide insert, there was as increase in the hardness of the surface of titanium alloy. This hardness may also believe to increase the adhesive wear. Figure 8 shows image of coated carbide tool after machining the titanium material for 30 min duration. It is proved that work piece have higher hardness than coated carbide cutting tool. It is observed that the tool life of cutting insert is performing well in the chosen cutting condition.

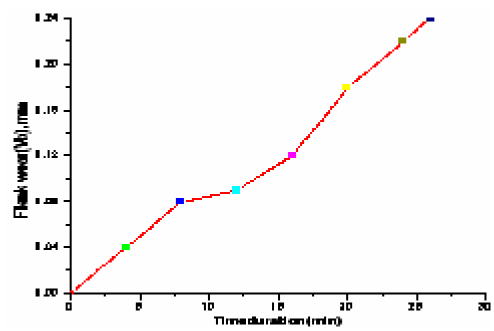

Figure 5. Time vs Tool wear (30min duration).

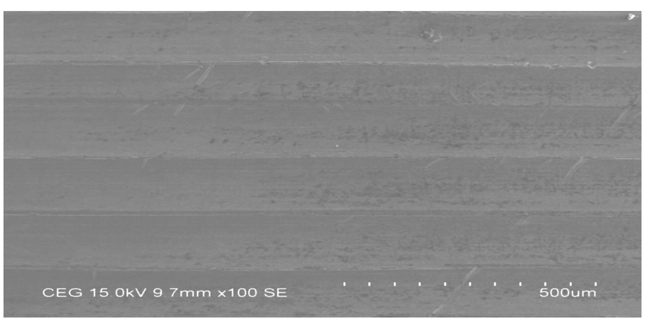

Figure 6. SEM surface profile observed at minimal surface condition.

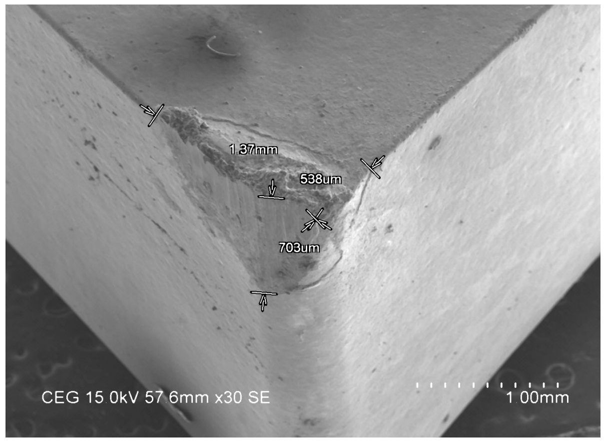

Figure 7. SEM image of worn out insert (machining after 10 min).

Figure 8. SEM image of worn out insert (machining after 30min).

4. Conclusion

Using coated carbide cutting inserts on turning of titanium alloy under different cutting parameters been investigated using Taguchi's orthogonal array (L_{09}).

1. The feed rate is the dominant parameter for surface roughness followed by the cutting speed, and compared to other parameters the depth of cut shown minimal effect on surface roughness.
2. Minimal surface roughness could be obtained significantly for titanium alloy turning operation through the specified machining parameters. Cutting speed (v) = 175 m/min, Feed rate (f) = 0.05 mm/rev, Depth of cut (d) = 0.5 mm.
3. The plots and graphs for Mean Ra and S-N ratio are also represented. Diffusion- adhesive wear is in the flank portion which was dominating tool wear for nano coated carbide insert. The SEM observation of the worn

out inserts indicate the presence of stable built up edge. The beginning of the flank and crater wear also observed.

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