

## Investigations on the Machinability of Titanium Alloy During Precision Turning

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**Abstract:** This research work focuses on precision turning of Ti6Al4V material to investigate the machinability of the material. Precision turning is a type of machining where, very low feed rate and depth of cut is being used to machine using a cutting insert with a lower nose radius. The cutting parameters considered for the experiments include the cutting speed, feed rate, depth of cut and nose radius. PVD coated carbide cutting inserts with different nose radius and constant rake and clearance angle are being considered for experimentation. The experimentation was designed based on Taguchi's L 27 orthogonal array. Three different levels of cutting parameters were being considered for the experimentation. The turning experiments were carried out on a conventional variable speed motor lathe under dry working conditions. Based upon the experimental values, Analysis of Variance (ANOVA) was conducted to understand the influence of various cutting parameters on cutting force, surface roughness and cutting tool temperatures during precision turning of titanium alloy.

**Key word:** Titanium alloys • Precision machining • Cutting tool temperature • Surface roughness • Cutting force • ANOVA.

### INTRODUCTION

Titanium and its alloys has played a significant role in the field of aerospace, energy, chemical and bio medics due to its high strength to weight ratio and exceptional mechanical and chemical properties. Machining of titanium alloys are a major concern because of its low thermal conductivity that prevents dissipation of heat easily from the tool chip interface, which in turn heats up the tool due to increasing temperature resulting in lower tool life. Titanium forms alloys easily due to high chemical reactivity that causes weld and smear formation along with rapid cutting tool destruction. Titanium has comparatively low elasticity modulus than steel. Therefore work piece has a tendency to move away from the cutting tool unless proper backup is used. Also thin parts may deflect under tool pressures, causing chatter, tool wear and tolerance problems. [1] Selection of cutting conditions, tool material and its coating and cutting edge geometry is important not only to increase the productivity of machining operation but also to obtain a desirable surface integrity (i.e. residual stresses

roughness, etc.) of the finished machined part. Hence, comprehensive reviews on machinability of titanium alloys are provided [2, 3].

Roughness plays a primary role in the interaction of a material with its surroundings. Rough surfaces deteriorate quickly and have greater coefficient of friction than smooth surfaces. Roughness often predicts the performance of a mechanical component, as defects in the surface may result in the formation of nucleation sites for cracks or corrosion [4]. Measurement of surface roughness of a finished component is critical in order to meet design standards for manufacturing processes. Selection of machining condition/parameter is tedious and difficult and depends mainly on the experience and capabilities of the operators and also the machining parameters catalogue provided by the builder for the finished product. So, the optimization of operating parameters is of primary importance where the cost and quality of a machined product are concerned. In precision machining operation, the quality of surface finish is an important requirement of many bored work pieces and parameter in precision manufacturing engineering. It is

characteristic that could influence the performance of precision mechanical parts and the production cost. Various failure, some time catastrophic, leading to high cost, have been attribute to the surface finish of the component in question. [5] For these reasons there have been research developments with the objective of optimizing the cutting condition to obtain a surface finish. During a precision turning operation, the cutting tool and the work piece subjected to a prescribed deformation as a result of the relative motion between the tool and work piece both in the cutting speed direction and feed direction. [6] As a response to the prescribed deformation, the tool is subjected to traction and thermal loads on those faces that have interfacial contact with the work piece or chip. The cost of machining a Ti6Al4V sample is very high and highly time consuming process. The machining of titanium alloys is a major production problem and often the cutting speed is low. Titanium and titanium alloys have low thermal conductivity and high chemical reactivity with many cutting tool materials. Hence, on machining, the cutting tools wear very rapidly due to the high cutting temperature and strong adhesion at the tool chip interface and tool work piece material interface. Many researchers have studied the machinability of titanium alloys in the past [7].

The tool life was influenced significantly by the temperature generated and the forces exerted at or near the cutting edge of the tools. Therefore, changes in cutting speeds and feed rates will directly influence the cutting forces and temperature generated, especially during dry cutting and hence the tool life. [8] For a 4 factor 3 level experiment more than 80 experiment have to be carried out leading to a very huge expenditure and waste of time. Taguchi [9] designed certain standard orthogonal arrays by which the instantaneous and independent evaluation of two or more parameters for their ability to affect the variability of a particular product or process distinctiveness can be done in a minimum number of tests.

**Experimental Procedure:** The target material used for the experimentation is Ti-6Al-4V. Gedee Weiler MLZ 250V variable speed adjusting capstan lathe is used for the experiment. And the experimental setup is shows in Fig 1. PVD coated carbide tool with 98 HRC hardness, nose radius of 0.1 0.2 and 0.4 were used for the turning operation. Surface roughness was measured using mitutotyo surfstest SJ-301 portable surface roughness tester with a sampling length of 4 mm. The cutting



Fig. 1: Experimental setup

temperature was measured using a thermocouple. The cutting parameters were so selected after comparison with different literature surveyed. The design of experiments and analysis of variance was done using Minitab 15 software.

#### **Tool Specifications of Ccgt09t301f Coated Carbide**

**Insert:** The tool is comprehensively used in manufacturing of the aerospace components because of the combination of high strength-to-weight ratio, excellent tool specifications, rupture Strength and average density. Tool specifications of CCGT09T301F coated carbide insert are given in Table 1

**Typical physical properties for Ti6Al4V:** This alloy is expansively used in manufacturing of the high density, melting range, volume electrical resistivity ohm, thermal conductivity, mean co efficient of thermal expansion and melting range. Typical physical properties for Ti6Al4V is given in Table 2

**Design of Experiments and Observation:** Design of Experiments is a highly efficient and effective method of optimizing process parameters, where multiple parameters are involved. The design of experiments using Taguchi approach was adopted to reduce the number of trials. The time and cost for doing an experiment is very high, therefore it is necessary to select an orthogonal array with minimum number of trials. In this research work L27 orthogonal array is chosen which a multilevel experiment is where feed rate, depth of cut, cutting speed and nose radius are the four factors considered for the experiment. Table 3 shows the machining parameters and their levels considered for experimentation.

Table 1: Tool specifications of CCGT09T301F Coated carbide insert.

Composition	Grain Size	Rupture Strength	Average density	Young's Modulus	Hardness	Coefficient of Thermal expansion
80% Al <sub>2</sub> O <sub>3</sub> and 20%TiC	3.0 µm	551-786 MPa	3.90-3.99 g/cm <sup>3</sup>	641 GPa	91-94 HRA	Good

Table 2 Typical physical properties for Ti6Al4V.

Density g/cm <sup>3</sup> (lb/ cu in)	4.42 (0.159)
Melting Range °C±15°C (°F)	1649 (3000)
Specific Heat J/kg.°C (BTU/lb.°F)	560 (0.134)
Volume Electrical Resistivity ohm.cm (ohm.in)	170 (67)
Thermal Conductivity W/m.K (BTU/ft.h.°F)	7.2 (67)
Mean Co Efficient of Thermal Expansion 0-100°C /°C (0-212°F /°F)	8.6x10 <sup>-6</sup> (4.8)
Mean Co-Efficient of Thermal Expansion 0-300°C /°C (0-572°F /°F)	9.2x10 <sup>-6</sup> (5.1)
Beta Transus °C±15°C (°F)	999 (1830)

Table 3: Machining parameters and their level

Cutting parameter	Level 1	Level 2	Level 3
Feed (mm/rev)	0.02	0.04	0.06
Depth of cut (mm)	0.05	0.10	0.15
Cutting speed (m/min)	30	60	90
Nose radius (mm)	0.1	0.2	0.4

Table 4: Experimental observations

SL NO.	Feed mm/min	Depth of cut mm	Cutting speed m/min	Nose radius mm	Surface roughness	Cutting tool temp (T)	Cutting Force (N)
1	0.02	0.05	30	0.1	0.45	47	25
2	0.02	0.05	60	0.2	0.42	49	34
3	0.02	0.05	90	0.4	0.47	54	24
4	0.02	0.1	30	0.2	0.47	59	36
5	0.02	0.1	60	0.4	0.42	64	38
6	0.02	0.1	90	0.1	0.65	59	26
7	0.02	0.15	30	0.4	0.58	63	33
8	0.02	0.15	60	0.1	0.64	64	32
9	0.02	0.15	90	0.2	0.43	49	37
10	0.04	0.05	30	0.1	0.76	51	32
11	0.04	0.05	60	0.2	0.67	53	38
12	0.04	0.05	90	0.4	0.6	52	27
13	0.04	0.1	30	0.2	0.69	62	26
14	0.04	0.1	60	0.4	0.61	59	22
15	0.04	0.1	90	0.1	0.79	69	33
16	0.04	0.15	30	0.4	0.57	76	24
17	0.04	0.15	60	0.1	0.81	72	38
18	0.04	0.15	90	0.2	0.71	52	27
19	0.06	0.05	30	0.1	0.97	57	30
20	0.06	0.05	60	0.2	0.82	63	25
21	0.06	0.05	90	0.4	0.68	68	27
22	0.06	0.1	30	0.2	0.87	69	30
23	0.06	0.1	60	0.4	0.57	77	21
24	0.06	0.1	90	0.1	1.12	76	34
25	0.06	0.15	30	0.4	0.69	83	27
26	0.06	0.15	60	0.1	1.19	82	35
27	0.06	0.15	90	0.2	0.89	48	33

The proposed work is to perform machining under the selected levels of conditions and parameters and to estimate the, cutting force, cutting temperature and surface roughness generated as the result of the machining process. Table 4 shows the machining parameters and observation for each trail of experiment.

## RESULT AND DISCUSSION

From the series of machining experiments conducted with PVD coated carbide tool to study the individual effects of various parameters on the surface roughness, cutting force and cutting temperature, several important relationships were established.

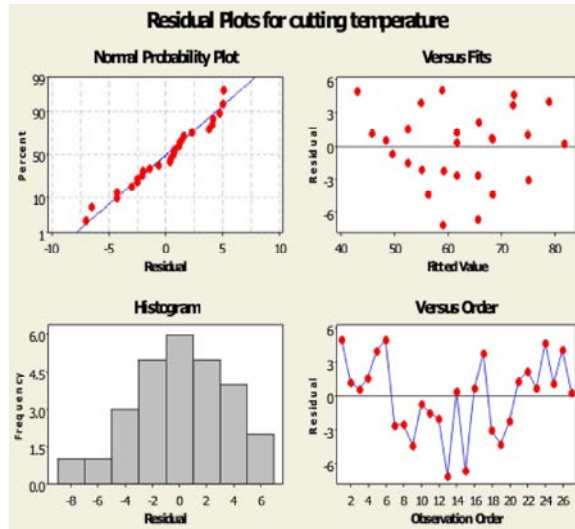


Fig. 2: Shows the residual plots for Cutting temperature

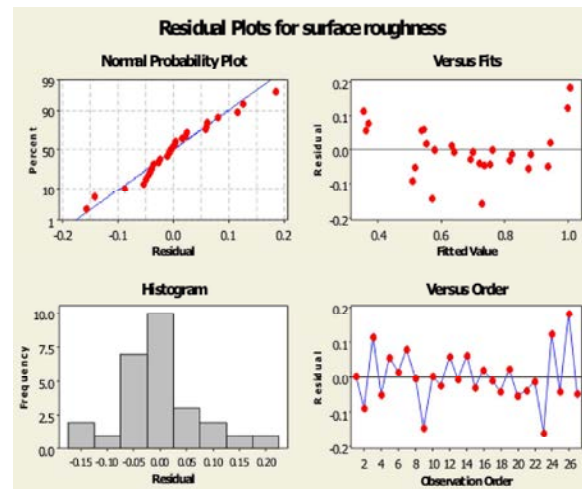


Fig. 3: Shows the residual plots for Surface roughness

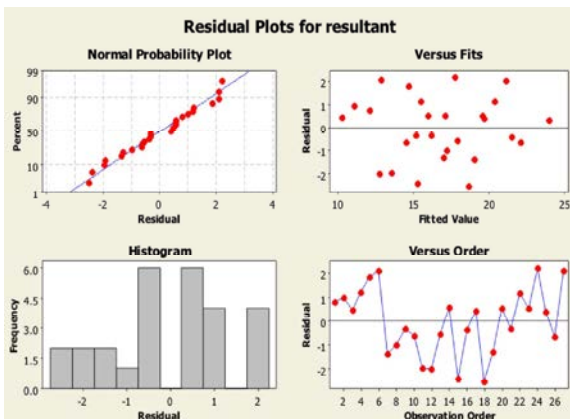


Fig. 4: Shows the residual plots for Cutting force

Fig 2, 3 and 4 shows the residual plots for cutting temperature, surface roughness and cutting force respectively.

#### ANOVA for Cutting Tool Temperature

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed	1	800.00	800.00	800.00	58.74	0.000
depth of cut	1	1701.39	1701.39	1701.39	27.97	0.000
cutting speed	1	184.22	184.22	184.22	13.79	0.002
nose radius	1	3.43	3.43	3.43	0.25	0.621
Error	22	299.63	299.63	13.62		
Total	26	2978.67				

S = 3.69045 R-Sq = 89.94% R-Sq (adj) = 88.11%

#### Expected Mean Squares, Using Adjusted SS

Square for	Source Each Term
1 Feed	(5) + Q [1]
2 Depth of cut	(5) + Q [2]
3 Cutting speed	(5) + Q [3]
4 Nose radius	(5) + Q [4]
5 Error	(5)

#### Error Terms for Tests, Using Adjusted SS

Synthesis			
Source	Error DF	Error MS	Error MS
1 Feed	22.00	13.62	(5)
2 Depth of cut	22.00	13.62	(5)
3 Cutting speed	22.00	13.62	(5)
4 Nose radius	22.00	13.62	(5)

#### Anova for Surface Roughness:

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed	1	0.60134	0.60134	0.60134	88.88	0.000
Depth of cut	1	0.00980	0.00980	0.00980	1.45	0.242
Cutting speed	1	0.00436	0.00436	0.00436	0.64	0.431
Nose radius	1	0.30156	0.30156	0.30156	44.57	0.000
Error	22	0.14884	0.14884	0.00677		
Total	26	1.06590				

S = 0.0822527 R-Sq = 86.04% R-Sq(adj) = 83.50%

#### Expected Mean Squares, Using Adjusted SS

Expected Mean	Square for
Source Each	Term
1 Feed	(5) + Q [1]
2 Depth of cut	(5) + Q [2]
3 Cutting speed	(5) + Q [3]
4 Nose radius	(5) + Q [4]
5 Error	(5)

#### Error Terms for Tests, Using Adjusted SS

Synthesis			
Source	Error DF	Error MS	Error MS
1 Feed	22.00	0.00677	(5)
2 Depth of cut	22.00	0.00677	(5)
3 Cutting speed	22.00	0.00677	(5)
4 Nose radius	22.00	0.00677	(5)

**ANOVA for Cutting Force**  
**Analysis of Variance for resultant, using Adjusted SS for Tests**

Source	DF	Seq	SS	Adj SS	Adj MS	F	P
Feed	1	108.108	108.108	108.108	48.90	56.8	0.000
Depth of cut	1	183.659	183.659	183.659	82.72	31.2	0.000
Cutting speed	1	27.502	27.502	27.502	11.89	12.8	0.002
Nose radius	1	1.789	1.789	1.789	0.83	0.27	0.378
Error	22	49.636	49.636	2.221			
Total	26	366.704					

S = 1.48685 R-Sq = 86.70% R-Sq (adj) = 84.28%

**Expected Mean Squares, Using Adjusted SS**

Expected Mean Square for Source	Each Term
1 Feed	(5) + Q [1]
2 Depth of cut	(5) + Q [2]
3 Cutting speed	(5) + Q [3]
4 Nose radius	(5) + Q [4]
5 Error	(5)

**Error Terms for Tests, Using Adjusted SS**

Synthesis Source	Error DF	Error MS of	Error MS
1 Feed	22.00	2.211	(5)
2 Depth of cut	22.00	2.211	(5)
3 Cutting speed	2.00	2.211	(5)
4 Nose radius	22.00	2.211	(5)

Percentage influence of each cutting parameter on output parameter

Table 5: Percentage influence of cutting parameter

Cutting parameters	Cutting temperature	Surface roughness	Cutting Force
Feed	19.82%	52.32%	29.55%
Depth of cut	36.54%	24.36%	49.39%
Cutting speed	25.51%	8.6%	7.2%
Nose radius	0.56%	0.25%	0.49%
Error	15.57%	14.47%	13.2%
Total	100%	100%	100%

Table 5 shows the Percentage influence of all cutting parameters on each of the output parameters. It was found that depth of cut have more influence on cutting force and cutting temperature. Feed rate have more influence on surface roughness followed by depth of cut and cutting speed.

## CONCLUSION

Precision turning experiments were conducted on Ti-6Al-4V material to investigate its machinability in terms of cutting force, cutting zone temperature and surface roughness. Taguchi's L 27 orthogonal array was

used to design and conduct the experiments in a efficient manner. Based on the experimental results ANOVA was performed and residual plots are drawn using MINITAB software. The percentage influences of all cutting parameters on the output parameter were determined and the results found were in line with published research. The residual plots shows a good understanding on the relationship between various cutting and output parameters. Future work can be focused on the dimensional accuracy observed on the work specimen as the result of precision machining.

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