Advanced Materials Research *Online: 2012-12-27*
ISSN: 1662-8985, Vols. 622-623, pp 399-403
doi:10.4028/www.scientific.net/AMR.622-623.399
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Investigation on Precision Turning of Titanium Alloys

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Keywords: Titanium alloys, precision machining, cutting temperature, surface roughness, ANOVA

Abstract. The quality of a machined surface is becoming more and more important to satisfy the increasing demands of sophisticated component performance, longevity, and reliability. The objective of this paper is to analyze the performance of precision turning using conventional lathe on Ti6Al4V under dry working conditions. Various parameters that affect the machining processes were identified and a consensus was reached regarding its values. The proposed work is to perform machining under the selected levels of conditions and parameters and to estimate the, cutting temperature and surface roughness generated as the result of the machining process. ANOVA is used to find the percentage contribution of each parameter to the surface roughness and cutting temperature.

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 1) 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. 2) Titanium forms alloys easily due to high chemical reactivity that causes weld and smear formation along with rapid cutting tool destruction. 3) 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 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 – 5]

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 [6]. Measurement of surface roughness of a finished component is critical in order to meet design standards for manufacturing processes. Turning is a fundamental machining process for the finishing of machined parts. To choose a proper machining 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.

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Experimental procedure

The target material used for the experimentation is Ti-6Al-4V. The high toughness to mass ratio of titanium alloys and excellent resistance to corrosion has made this titanium alloy a very suitable component in the industry [7]. Gedee Weiler MLZ 250V variable speed adjusting capstan lathe is used for the experiment. PVD coated carbide tool with 98 HRC hardness, nose radius of 0.1 0.2 and 0.4 are used for the turning operation. Surface roughness was measured using mitutotyo surftest SJ-301 portable surface roughness tester with a sampling length of 4 mm. The cutting temperature is 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.

Design of experiments and observations

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 is a multilevel experiment Feed, depth of cut, cutting speed, nose radius are the. Feed four factors considered for the experiment.

The cost of machining a Ti6Al4V sample is very high and a highly time consuming process. 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 [8] designed certain standard orthogonal arrays by which the simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a particular product or process characteristics can be done in a minimum number of tests. Taguchi's method of experimental design provides a simple, efficient, and systematic approach for the optimization of experimental designs for performance quality and cost. Table 1 shows the machining parameter and their levels. Table 2 shows the machining parameters and observation for each trail of experiment.

Table 1 Machining parameters and trail levels

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 2 Experimental observations

NO.	Feed	Depth of cut	cutting speed	Nose radius	Cutting tool temp	Surface roughness
1	0.02	0.05	30	0.1	48	0.58
2	0.02	0.05	60	0.2	47	0.42
3	0.02	0.05	90	0.4	49	0.47
4	0.02	0.1	30	0.2	54	0.47
5	0.02	0.1	60	0.4	59	0.42
6	0.02	0.1	90	0.1	64	0.65
7	0.02	0.15	30	0.4	59	0.45
8	0.02	0.15	60	0.1	63	0.64
9	0.02	0.15	90	0.2	64	0.43
10	0.04	0.05	30	0.1	49	0.76
11	0.04	0.05	60	0.2	51	0.67
12	0.04	0.05	90	0.4	53	0.60
13	0.04	0.1	30	0.2	52	0.69
14	0.04	0.1	60	0.4	62	0.61
15	0.04	0.1	90	0.1	59	0.79
16	0.04	0.15	30	0.4	69	0.57
17	0.04	0.15	60	0.1	76	0.81
18	0.04	0.15	90	0.2	72	0.71
19	0.06	0.05	30	0.1	52	0.97
20	0.06	0.05	60	0.2	57	0.82
21	0.06	0.05	90	0.4	63	0.68
22	0.06	0.1	30	0.2	68	0.87
23	0.06	0.1	60	0.4	69	0.57
24	0.06	0.1	90	0.1	77	1.12
25	0.06	0.15	30	0.4	76	0.69
26	0.06	0.15	60	0.1	83	1.19
27	0.06	0.15	90	0.2	82	0.89

Results 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 and cutting temperature several important relationships were established. Fig 1 shows the residual plots for cutting temperature and Fig 2 shows the residual plots for surface roughness.

ANOVA Results

Analysis of Variance for cutting temperature, using Adjusted SS for Tests

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	124.92	0.000
cutting speed	1	174.22	174.22	174.22	12.79	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

Source	Expected Mean Square for 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

Source	Error DF	Error MS	Synthesis of 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)

Analysis of Variance for surface roughness, using Adjusted SS for Tests

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				

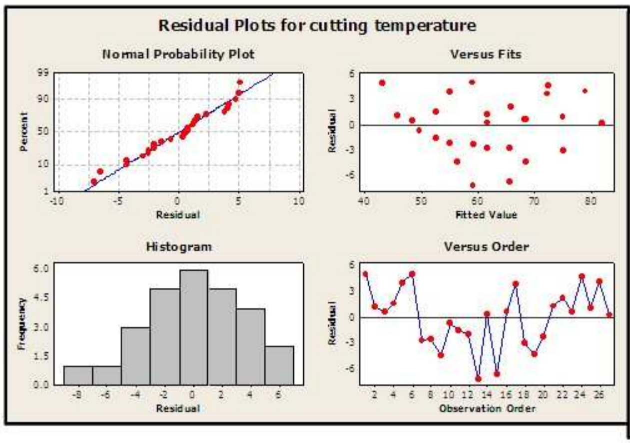
S = 0.0822527 R-Sq = 86.04% R-Sq(adj) = 83.50%

Expected Mean Squares, using Adjusted SS

Source	Expected Mean Square for 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

Source	Error DF	Error MS	Synthesis of 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)



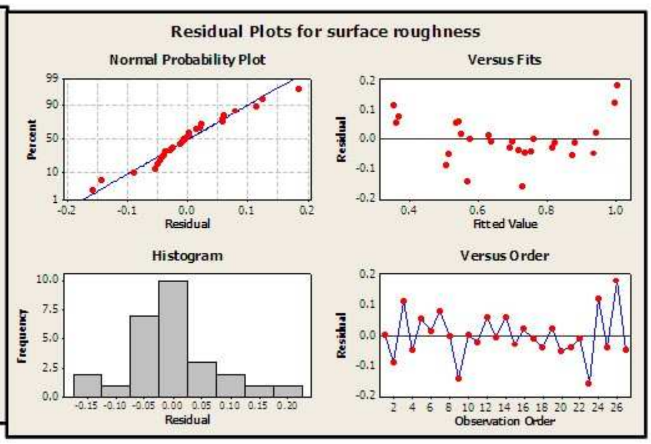


Fig 1 Shows the residual plots for cutting temperature

Fig 2 Shows the residual plots for surface roughness

Conclusions

Experiments were conducted on titanium alloy materials using a set of cutting parameters as per L27 orthogonal array. Cutting zone temperature and surface roughness on the workpiece after precision turning was observed and recorded. Analyzes of Variance was minitab software and it was found that feed rate have more influence on surface roughness followed by the nose radius. Like were depths of cut have more influence on cutting zone temperature followed by feed rate and cutting speed. Future work can be focused on the dimensional accuracy observed on the work specimen as the result of precision machining

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