ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 4, Issue, 11, pp.177-180, November, 2012

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

DETERMINING THE EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN PRECISION TURNING USING THE TAGUCHI METHOD

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ARTICLE INFO

Article History:
Received 28th August, 2012
Received in revised form
11thSeptember, 2012
Accepted 30th October, 2012
Published online 23th November, 2012

Key words:
Titanium alloys;
Precision machining;
Cutting temperature; s
Urface roughness; ANOVA;

ABSTRACT

The quality of a machined surface is becoming further and more significant 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 by means of conventional lathe on Ti6Al4V under dry working conditions. Various parameters that impinge on 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]

Technology is advancing, demand of the hour is increasing and to face that engineers are also ready. Maintaining the economic production with optimal use of resources is of prime concern for the engineers. Metal machining is one of them. In machining process, there are various parameters involved. Some challenges that the engineers come across are to find out the optimal parameters for the desired product quality and to maximize the performance of manufacturing using the available resources. In today's manufacturing industry, special attention is given to dimensional accuracy and surface finish. The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Surface roughness is used as the critical quality indicator for the machined surface. Formation of a rough surface is a complicated mechanism involving many parameters. The quality of the work piece (either roughness or dimension) are greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, work piece material, tool wear and vibration during cutting [1]. Extensive effort has been done to observe the critical parameters which affect the surface roughness.

This work aims at one such Taguchi optimization study of process parameters for surface roughness as the response. On surfaces produced by machining and abrasive operations, the irregularities produced by the cutting action of tool edges and abrasive grains and by the feed of the machine tools are called surface roughness. It is the irregularity of primary texture. Roughness may be considered as being superposed on a wavy surface. 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

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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.

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.

Chemical Composition Of Titanium Alloy (Grade 5)

Table 1. Chemical composition of titanium alloy

Alloy	Al	V	Fe	C	Ti
Ti-6Al-4V	6.40%	3.89%	0.16%	0.002%	Balance

These treatments Ti-6al-4v is an example of β alloys. Alpha + Beta alloys contain compositions which support a mixture of α and β phases. These alloys may contain from 10 to 50 % of β phase at room temperature.

Mechanical Properties of Ti-6Al-4V

Table 2. Mechanical Properties of Ti-6Al-4V

Hardness (HRA)	Hardness (HRA)	Hardness (HRA)	Hardness (HRA)	Hardness (HRA)	Hardness (HRA)	Hardness (HRA)
70	363	950Mpa	14%	0.342	113Gpa	4.43g/cm3

These treatments Ti-6al-4v is an example of β alloys. Alpha + Beta alloys contain compositions which support a mixture of α and β phases. These alloys may contain from 10 to 50 % of phase at room temperature.

Typical physical properties for Ti6Al4V

Table3. Typical physical properties for Ti6Al4V

Density g/cm³ (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)	$8.6x10^{-6}$ (4.8)
Mean Co-Efficient of Thermal Expansion 0-300°C /°C (0-572°F /°F)	$9.2x10^{-6}$ (5.1)
Beta Transus °C±15°C (°F)	999 (1830)

Ti-6Al-4V is considered to be the most common α+β alloy. Heat treatment can be used to control the properties of these alloys; it is used to adjust the amounts and types of β phase present. Alpha + Beta alloys generally have good formability; except for Ti-6Al-4V in particular has poor formability. Table 3

Tool specifications of CCGT09T301F coated carbide insert

Table 4. Tool specifications of CCGT09T301F Coated carbide insert

Composition	80% Al2O3 and 20% TiC
Grain Size	3.0 µm
Transverse Rupture Strength	551-786 MPa
Average density	3.90-3.99 g/cm3
Youngs Modulus	641 GPa
Hardness	91-94 HRA
Coefficient of Thermal expansion	Good

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 6 shows the machining parameters and observation for each trail of experiment.

Table 6. Machining parameters and trail 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

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

Surface roughness

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

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Feed	1	0.66074	0.66074	0.66074	98.55	0.000
Depth of cut	1	0.02226	0.02226	0.02226	3.32	0.082
Cutting speed	1	0.00611	0.00611	0.00611	0.91	0.350
Nose radius	1	0.31807	0.31807	0.31807	47.44	0.000
Error	22	0.14750	0.14750	0.00670		
Total	26	1.15469				

S = 0.0818826 R-Sq = 87.23% R-Sq (adj) = 84.90%

Expected Mean Squares, using Adjusted SS

	Expected Mean Source	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	0.00670	(5)
2 Depth of cut	22.00	0.00670	(5)
3 Cutting speed	22.00	0.00670	(5)
4 Nose radius	22.00	0.00670	(5)

Variance Components, using Adjusted SS

Source	Estimated Value
Error	0.00670

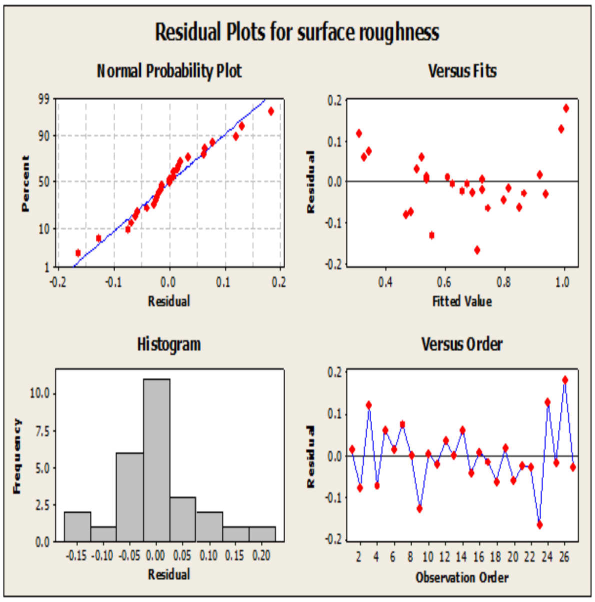

Fig 1. shows Residue plots for surface roughness

Temperature

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

Source	DF	Seq	SS	Adj SS	Adj MS	F	P
Feed	1	660.06	660.06	660.06	62.67 0.000		
Depth of cut	1	1605.56	1605.56	1605.56	152.45 0.000		
Cutting speed	1	220.50	220.50	220.50	20.94 0.000		
Nose radius	1	2.71	2.71	2.71	0.26 0.617		
Error	22	231.70	231.70	10.53			
Total	26	2720.52					

S = 3.24527 R-Sq = 91.48% R-Sq(adj) = 89.93%

Expected Mean Squares, using Adjusted SS

Expected Mean Source	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	10.53	(5)
2 Depth of cut	22.00	10.53	(5)
3 Cutting speed	22.00	10.53	(5)
4 Nose radius	22.00	10.53	(5)

Variance Components, using Adjusted SS

Source	Estimated Value
Error	10.53

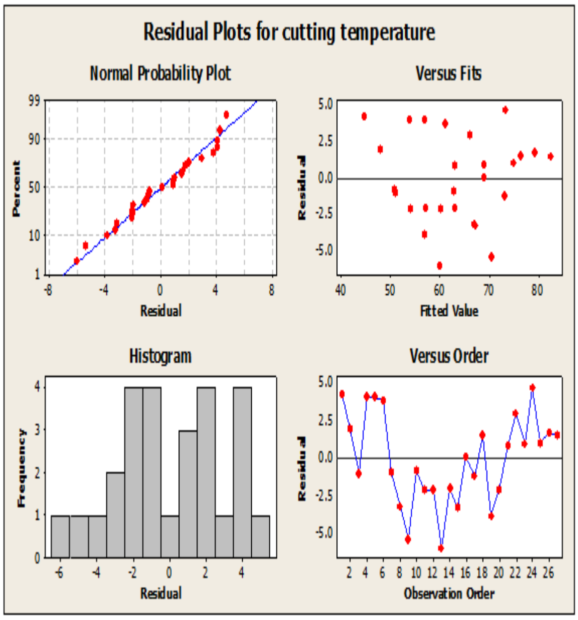

Fig 2. shows Residue plots for surface roughness

Table 6. Machining parameters and trail level

SL.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

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 having 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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