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RESEARCH ARTICLE

EFFECTS OF CUTTING PARAMETERS ON SURFACE ROUGHNESS DURING PRECISION TURNING OF TI-6AL-4V ALLOY

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ABSTRACT

The main objective of this thesis work is to optimize the machining performance in precision turning operations. In finishing operations, surface roughness is a major concern. Hence, to quantify the machining performance in precision turning operations, 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. By finding optimal depth of cut and feed in each segment through the profile, the machining performance in precision turning can be improved. In precision turning, the machining surface can be divided into small segments according. The optimal cutting condition would be different in each segment due to the various effective parameters.

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. 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.[7] 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 they are 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. [8] 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. In the metal cutting process, during which chips are formed, the work piece material is compressed and subjected to plastic deformation. Previous studies proved the significant impact of DOC, machining speed, and rake angles on surface roughness. The few studies that have studied boring bar length that effect of cutting

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stability or vibration during boring operation. But very few researchers have studied the interaction effect of boring bar length and bar diameter. [9]The combination of both of these factors suggests a significant weight in the relationship. All the previous studies on predicting surface roughness have not included diameter as a major factor that affects surface roughness.

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. 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.

Historical Background

Ti6Al4V is an alpha beta alloy; the alpha phase proportion usually varies from 60 to 90%. The alpha phase in pure titanium is characterized by a hexagonal close-packed crystalline structure that remains stable from room temperature to approximately 1,620°F The beta phase in pure titanium has a body-centered cubic structure, and is stable from approximately 1,620°F to the melting point of about 3,040°F. Adding alloying elements to titanium provides a wide range of physical and mechanical properties. Certain alloying additions, notably aluminum, tend to stabilize the alpha phase; that is, they raise the temperature at which the alloy will be transformed completely to the beta phase. This temperature is known as the betatransus temperature. Alloying additions such as chromium, copper, iron, manganese, molybdenum, and vanadium stabilize the beta phase by lowering the temperature of transformation from alpha to beta. The typical microstructure is equaled (the same dimension in all directions), or elongated alpha grains in a transformed beta matrix.

Table 1. Physical Properties of Ti6Al4V

Property	Typical Value
Density g/cm^3 (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)

Table 2. 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 3. 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

Properties and Uses of Titanium Alloys

Besides the high toughness to mass ratio of titanium alloys, they have excellent resistance to corrosion. This is due to the presence of a protective strongly adherent titanium oxide film on the surface. This film is usually transparent and titanium has the ability of healing and reproducing this film instantly in any environment with a presence of oxygen and moisture. Titanium alloys are considered to be very stable and can be attacked by few substances mostly hydrofluoric acid. They are unique in their ability to handle specific chemicals such as chlorine, chlorine chemicals, and chlorides. Also, titanium alloys are biocompatible and they are non-toxic and resistant to body fluids corrosion. Such properties made titanium alloys suitable to be used in body implants, such as hip and knee prostheses, bone plates, screws and nails for fractures, pacemaker housing and heart valves. The combination of high strength to weight ratio and the ability to operate at elevated temperatures made titanium alloys attractive to be used in aerospace and aircraft industry.

Design of experiments and observations

Design of Experiments is a highly resourceful and effective method of optimizing process parameters, where several parameters are implicated. 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 consider for the experiment. The cost of machining a Ti6Al4V sample is very high and a highly time uncontrollable 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 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. 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.

Figure 1. Experiments on precision training

Table 2 and 3shows the machining parameters and observation for each trail of experiment. Figure1 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. Figure 2

Figure 2. Mitutoyo SJ-301 surface roughness testers

Surface roughness formation in precision turning

Surface measurement synonymous with surface metrology determines surface topography, which is essential for confirming a surface's suitability for its function. Surface measurement conceptually includes surface shape, surface finish, surface profile roughness (Ra), or in surface area roughness (Sa), surface texture, asperity and structural characterization. For manufacturing and design purposes, measurement is critical to ensure that the finished material meets the design specification. A microscopic surface is measured in three dimensions using an interference microscope. Surface roughness also known as surface profile Ra is a measurement of surface finish it is topography at a scale that might be considered "texture" on the surface.

Surface roughness is a quantitative calculation of the relative roughness of a linear profile or area, expressed as a single numeric parameter (Ra). In three dimensional optical profilometry, roughness is usually expressed as surface area roughness (Sa). Profile roughness (Ra) can be extracted as a line through an area. Interestingly, Sa is also able to report average Ra through a surface by averaging several profiles. Simulation is widely used in the study of manufacturing processes. It is found to be a powerful tool for evaluating the process capabilities without the need for conducting costly trial and error Experiments. Examples are found in the development of simulators for use in casting, milling, turning, etc. However, relatively few research works have been reported for the simulation of the precision turning process. Precision turning is widely used in the manufacturing of high precision components with a surface roughness of a few nanometers and with a tolerance which is in sub micro meter range. Figure 2

Effect of cutting parameters on cutting forces

The results presented in Fig. 1 show the evolution of the cutting forces for a given feed rate. If the feed rate increases, the section of sheared chip increases because the metal resists the rupture more and requires larger efforts for chip removal.

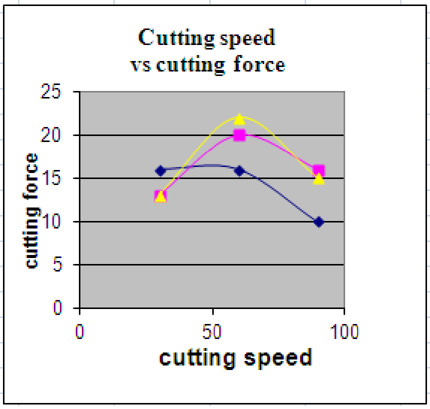

Fig. 1 Cutting forces vs. cutting speed

Fig. 2 shows that an increase in cutting speed generally leads to a reduction in the components of cutting forces. This is due to the rise in the temperature in the cutting zone which makes the metal machined more plastic and consequently the efforts necessary for machining decrease.

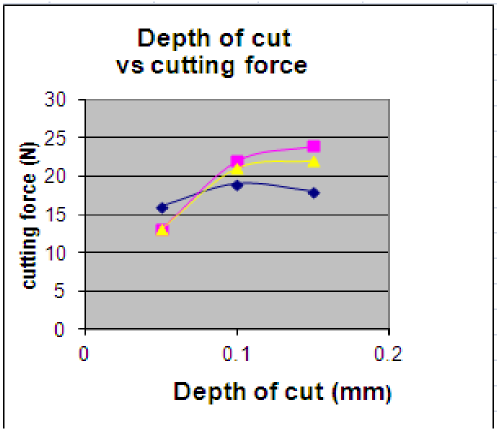

Fig. 2 Cutting forces vs. depth of cut

Fig. 3 illustrates the evolution of cutting forces for variation in depth of cut. With its increase, chip thickness becomes significant which causes the growth of the volume of deformed metal and that requires enormous cutting forces to cut the chip. For the cut depth of 0.01 to 0.1, 0.15mm, an increase in the components of the cutting forces F_x, F_y and F_z was recorded.

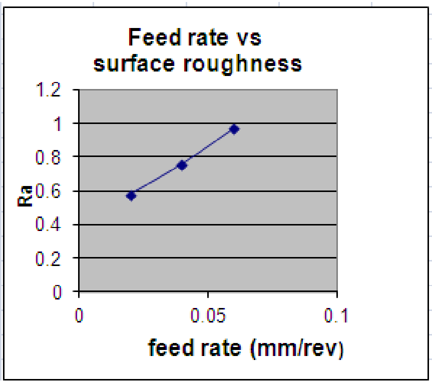

Fig. 3 Surface roughness vs. feed rate

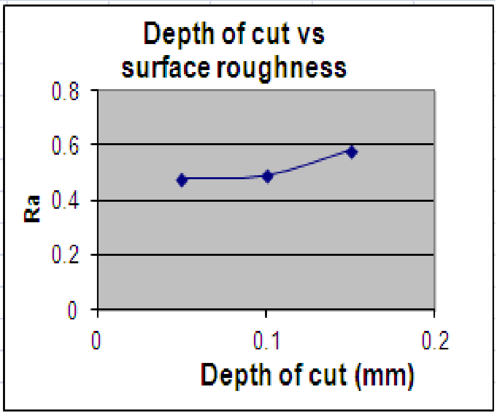

Fig.4 Depth of cut vs Surface roughness

The analysis of the effect of feed rate on surface roughness (Fig. 4) shows that this parameter has a very significant influence, because its increase generates uniform ploguing effect on the surface of the workpiece which, results in narrow cavities These cavities are deeper and broader as the feed rate increases. In practice, the consequences of the influence of the feed rate on surface roughness are as follows: the increase in the feed rate from 0.02, 0.04 to 0.06 mm/rev correspondingly increases the criteria of roughness Ra, Fig 5 shows the plot between cutting speed and surface roughness.

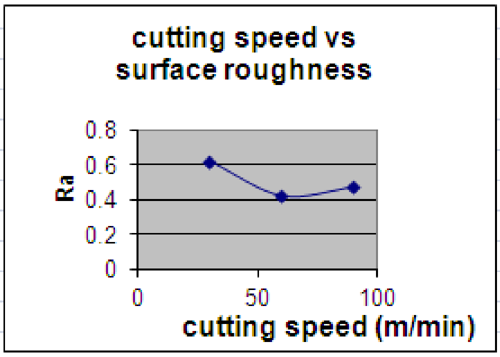

Fig. 5 Cutting forces vs. Surface roughness

From the graph it is understood that for a low cutting speed the surface roughness is more and as the cutting speed is increased the surface roughness value decreases. But beyond 60m/min of cutting speed there is an increased trend in the surface roughness. This shows that surface roughness will be minimum only for an optimum range of cutting speed between 50to 65m/min.

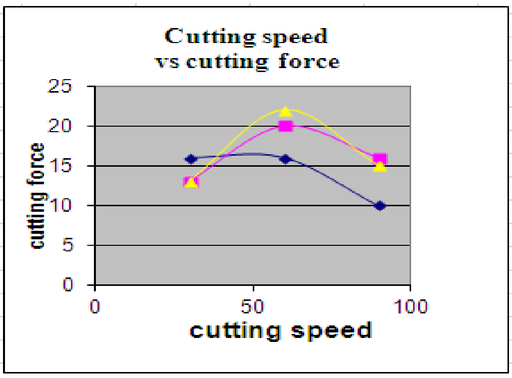

Fig. 6 Cutting forces vs. cutting speed

The effect of depth of cut on cutting force in shown in Fig .6. From this figure it is understood that for an increase in depth of cut there is a slight increase in surface roughness which indicates that depth of cut is not influencing as feed rate.

Cutting temperature measurement on thermocouple

A thermocouple is a device consisting of two different conductors (usually metal alloys) that produce a voltage, proportional to a temperature difference, between either end of the two conductors. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert a temperature gradient into electricity. They are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy and system errors of less than one degree Celsius (C) can be difficult to achieve. Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

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 experimental and recorded. Analyzes of Variance was minitab software and it was found that feed rate have more authority 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. Opportunity work can be focused on the dimensional accuracy experimental on the work specimen as the consequence of precision machining

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