INVESTIGATION AND MODELLING PREDICTION ON SURFACE ROUGHNESS OF TITANIUM IN DRY TURNING OPERATION

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ABSTRACT

Surface roughness basically known as Ra is one of the best important requirements in machining process. Titanium generally used for part requiring greatest reliability, therefore surface integrity must be maintained. The proper setting of cutting parameter is crucial before process take place in order to get the better surface finish. This research presents the development of mathematical model for surface roughness prediction before turning process in order to evaluate the fitness of machining parameters; spindle speed, feed rate and depth of cut. 9 samples were run in this study by using CNC lathe Machine with non-coolant cutting condition. Multiple Regression Methods used to determine the correlation between the criterion variable and the combination of predictor variables. It was established that the surface roughness is most influenced by the feed rate. By using multiple regression method, the average percentage deviation of the Non-Adding Interaction term model was 22.594% which shows the statistical model for Non-Adding Interaction term model could predict 74.406% accuracy. The Adding Interaction term model shows improvement in accuracy of the statistical model. It shows the statistical model could predict 86.57% accuracy for surface roughness which means 13.43% was the percentage deviation on model of surface roughness. Analysis of Variance (ANOVA) shows at least one of the population regression coefficients was not equal to zero for Non-Adding interaction Term model and the population regression coefficient didn't significantly differ from zero for Adding Interaction term model.

ABSTRAK

Kekasaran permukaan pada dasarnya dikenali sabagai Ra merupakan keperluan yang paling penting bagi penggunaan mesin. Lazimnya,Titanium digunakan pada benda yang memerlukan kekuatan yang tinggi, oleh itu, interity permukaannya perlu di kawal. Bagi mendapatkan kekasaran permukaan yang baik, parameter mesin yang sesuai adalah sangat penting sebelum menjalankan sebarang proses. Tujuan kajian ini adalah untuk menghasilkan satu persamaan matematik yang dapat meramalkan kekasaran permukaan sebelum proses penggilingan. Kelajuan mata alat, kadar dan kedalaman pemotongan bahan merupakan pembolehubah dalam kajian ini. 9 sample telah dijalankan dalam kajian ini menggunakan CNC Lathe Machine tanpa menggunakan bahan penyejuk. Kaedah regresi berganda digunakan untuk menentukan hubung kait diantara satu pembolehubah dengan kombinasi pembolehubah yang lain. Kaedah tersebut telah menunjukkan bahawa kadar pemotongan adalah pembolehubah yang paling mempengaruhi kekasaran permukaan. Daripada persamaan yang dihasilkan oleh kaedah regresi berganda, purata peratusan ketidak tepatan untuk model yang tidak ditambahkan istilah interaksinya adalah 22.594%, dimana model ini dapat meramal 74.406% ketepatan untuk kekasaran permukaannya. Model yang ditambahkan istilah interaksinya menunjukan pertambah baikkan dalam ketepatannya. Model statistik ini dapat meramal sebanyak 86.57% ketepatan kekasaran permukaan bermaksud 13.43% adalah purata peratusan ketidaktepatan untuk model kekasaran permukaan ini. Analisis Variance menunjukan sekurang-kurangnya salah satu daripada populasi pembolehubah regresi(kemunduran) adalah tidak bersamaan dengan sifar untuk model yang tidak ditambah istilah interaksinya dan untuk model yang diambil kira istilah interaksinya menunjukkan populasi pembolehubah regresi tidak berbeza daripada sifar.

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Y_i	Surface Roughness (Ra): micro millimeter (μmm)
X_{1i}	Spindle Speed (S): revolutions per minute (rpm)
$X_{2i} =$	Feed Rate (F): millimeter per minute (mm/min)
$X3i$	Depth of cut (D): millimeter (mm)
ϕ	Percentage deviation of single sample data
$\bar{\phi}$	Average percentage deviation of all sample data

LIST OF ABBREVIATIONS

DC	Depth of cut
C.N.C	Computer Numerical Control
TiN	Titanium Nitride
VB	flank wear

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION OF RESEARCH

Measuring in machining and an effective parameter is one of the most common performances in the surface roughness. This is because surface roughness representing the quality of machined surface. Surface roughness is influenced by controlled machining parameters such as feed rate, cutting speed and depth of cut. Surface finish is important factor in evaluating the quality of products. Surface roughness is mostly used as an index to determine the surface finish in machining process.

The surface parameter that used to evaluate surface roughness in this study is the roughness average (*Ra*). The roughness average is the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the evaluation length. There are a great number of factors influencing the surface roughness.

This research investigates the surface integrity which focusing on the surface roughness. Therefore, three parameters had been selected which is spindle speed, feed rate, and depth of cut.

1.2 PROBLEM STATEMENT

Quality and productivity of product is the focus of the manufacturing industry today. This related to the economic consideration that always being a topic in industrial research. Machining waste has to be controlled because it is effect to the common thought of people which is cost production of the product.

Titanium is the high strength-to-weight ratio material and its corrosion resistance at room and elevated temperature. Beside that, titanium generally used for a material for parts requiring the greatest reliability, and therefore the surface integrity must be maintained. This characteristics or the properties of titanium makes it attractive for many applications such as in industrial but, the properties of the titanium also makes the price of titanium is one of the expensive materials in the industry. Hence, Specific studies on surface integrity parameters (microstructures hardness, surface roughness and residual stress) have been carried out.

Coolant took high responsibility in turning operation and also to the surface finish of the product. This was due to the coolant function which is to dissipate heat generated at the tool point and thus keep workpiece temperature down, to reduce friction and tool wear by lubrication, and to facilitate chips disposal (Gan Sin yi, 2009). Hence, to meet the appropriate parameter for dry cut machining for titanium 6Al4V, an appropriate research should be done.

In order to solve the problem, develop one surface prediction technique which is termed the multiple regression prediction models to optimize the cutting conditions. This method can find the best conditions required for the machining independent variables such as speed, feed and depth of cut that would result in the best machining response. Thus, manufacturers can improve the quality and productivity of the product with minimum cost and time.

1.3 OBJECTIVE

The objective of this study is to:

(i). Determine the parameter in turning process.
(ii). Evaluate the surface roughness of the titanium.
(iii). Modeling the prediction surface roughness of the titanium.
(iv). Find the optimum parameter in order to get best surface finish.

1.4 PROJECT SCOPE

In this study, turning operation with dry machining or non-coolant machining will be used in order to observe their effect on the surface finish at the titanium 6Al4V as part of product. In turning operation, there are 2 type of variable exist which is independent variable and the dependent variable. Basically, independent variable means the factor that influences the cutting process. As a handler, this variable is the most important things to be consider or controlled to get the best product. Dependent variable is the variable that influenced by changed the independent variable. Those two variables are described as below:

1.4.1 Independent variable

- Turning material, coatings, and the tools condition.
- Tool shape, surface finish, and sharpness.
- Work piece material, condition, and temperature.
- Cutting parameter, such as speed, feed, and depth of cut.
- Cutting fluid.

1.4.2 Dependent variable

- Type of chip produced.
- Force and energy dissipated in the cutting process.
- Temperature rise in the workpiece, the chip, and the tool.
- Wear and failure of the tool.

- Surface finish produced on the workpiece after machining.

Some factor have to be controlled which influences the surface finish of the material used which is cutting speed, depth of cut, feed rate, and cutting fluid.

Hence, to achieve the project objective, multiple regression method will be used for statistical method. The workpiece tested is titanium round bar with diameter is 100mm and length testing is 300mm. Three parameter with three level for each variable which is high, middle, and low had been selected. For spindle speed, N 55 m/min, 75m/min, and 95 m/min, for feed rate is 0.15m/rev, 0.25m/rev, 0.35m/rev, and for depth of cut is 0.10mm, 0.15mm and 0.20mm.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide the information of the past research related to the surface roughness in turning operation. Beside that, this chapter will be includes the related information and explanation of the surface integrity, tuning operation and the dry cut machining, and titanium alloy.

2.2 TURNING PROCESS

Turning mean the part is rotating while it is being machining. Turning process is the process whereby a centre lathe is used to produce "solids of revolution". It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not. This type of machine tool is referred to as having computer numerical control, better known as C.N.C. and is commonly used with many other types of machine tool besides the lathe.

When turning, a piece of material (wood, metal, plastic even stone) is rotated and a cutting tool is traversed along 2 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. Although now quite rare, early lathes could even be used to produce complex geometric figures, even the platonic solids; although until the advent of C.N.C it had become unusual to use one for this purpose for the last three quarters of the twentieth century. It is said that the lathe is the only machine tool that can reproduce itself.

Facing is part of the turning process. It involves moving the cutting tool across the face (or end) of the work piece and is performed by the operation of the cross-slide, if one is fitted, as distinct from the longitudinal feed (turning). It is frequently the first operation performed in the production of the work piece, and often the last- hence the phrase "ending up". The bits of waste metal from turning operations are known as chips (North America), or swarf in Britain. In some locales they may be known as turnings.

2.2.1 CNC Lathe Machine

Figure 2.2 below shows the example of CNC lathe machine which is CNC lathe DMG machine(NEF 400 GILDEMEISTER).

FIGURE 2.1: *NEF 400 LATHE MACHINE*

Source: Mechanical laboratory UMP

Computer numerical control (CNC) is a computer "controller" that reads G-code instructions and drives a machine tool, a powered mechanical device typically used to fabricate components by the selective removal of material. CNC does numerically directed interpolation of a cutting tool in the work envelope of a machine.

2.3 SURFACE INTEGRITY

Surface integrity is concern to the definition, specification, and the control surface layer of a material which is commonly in metal. Surface integrity is includes of the surface texture as well as the altered layer beneath. Surface integrity is the sum of all of the elements that describe all the conditions existing on or at the surface of a piece of finished hardware. Surface integrity has two aspects. The first is *surface topography* which describes the roughness, lay or texture of the outermost layer of the workpiece; i.e., its interface with the environment. The second is *surface metallurgy* which describes the nature of the altered layers below the surface with respect to the base or matrix material. It is the assessment of the impact of manufacturing processes on the properties of the workpiece material.

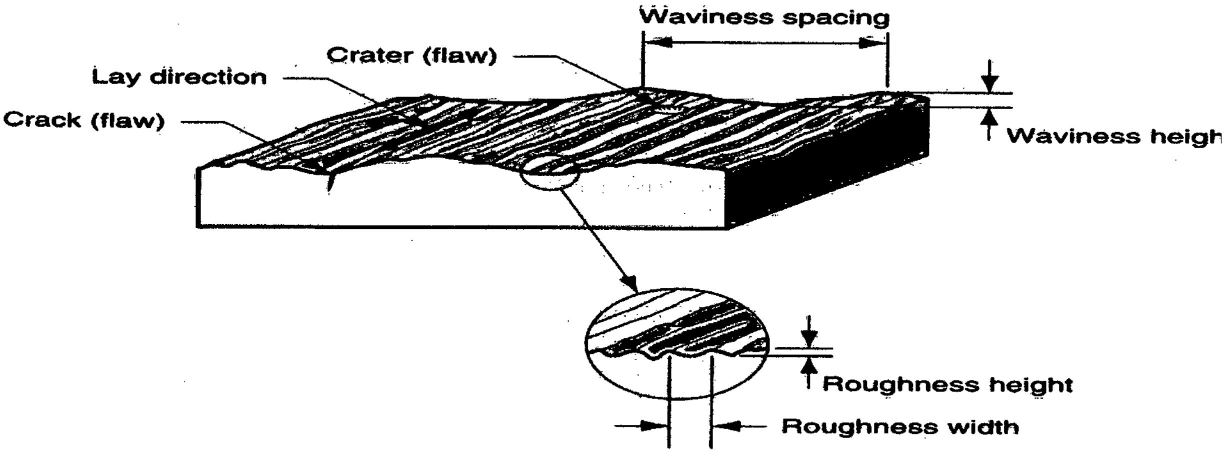

Figure 2.2: *Roughness, waviness, lay, and flaws.*

Surface texture is a repetitive or random deviation from the nominal surface of an object. In 1947, the American Standard B46.1-1947, “Surface Texture”, defined many of the concepts of surface metrology and terminology which overshadowed previous standards (Brosheer,1948; Hommel,1988; Olivo, 1987; ASME, 1988).

Surface texture divided into four elements which is roughness, waviness, lay, and flaws as shown in the figure above. In this observation, surface roughness will be main focus to find the optimum parameter in surface finish.

2.3.1 Surface Roughness

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Surface finish is important factor in evaluating the quality of products. Surface roughness is mostly used as an index to determine the surface finish in machining process. Modeling techniques for prediction performance measure of surface roughness generally can be classified into four groups: machining theory based approaches, experimental investigation approaches, designed experiments approaches, and Artificial Intelligent (AI) approaches (Gokkayah & Nalbant, 2006).

The average roughness (Ra) is the area between the roughness profile and its center line, or the integral of the absolute value of the roughness profile height over the evaluation length (Figure 1). Therefore, the Ra is specified by the following equation:

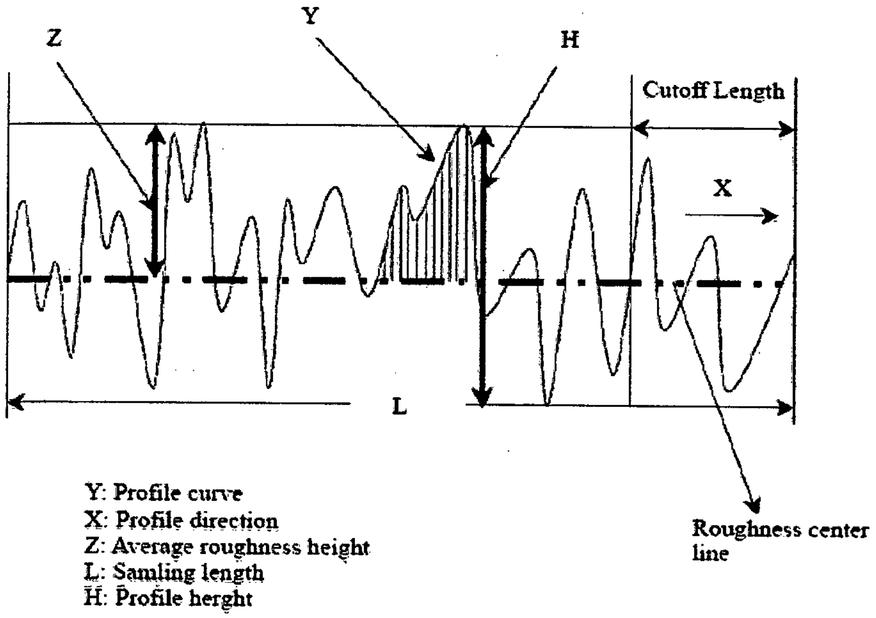

Figure 2.3: *Surface Roughness Profile* [G¨O KKAYA, NALBANT(2006)]

Surface Roughness, Ra basically calculated by using,

$$\mathrm{Ra} = \frac{1}{L}\int_0^L |Y(x)|\, dx \qquad (2.1)$$

When evaluated from digital data, the integral is normally approximated by the trapezoidal rule:

$$\mathrm{Ra} = \frac{1}{n}\sum_{i=1}^{n} |Yi| \qquad (2.2)$$

Where,

Ra is the arithmetic average deviation from the mean line, *L* is sampling length and *Y* represents the ordinate of the profile curve

2.3.2 Importance of Modeling Process

Surface roughness, which is used to determine and evaluate the quality of a product, is one of the majors quality attributes of an end-milled product. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process take place (Dr. Mike S.Lou et al., 1999). Importance of modeling process is to improve the quality, increase productivity, reducing time and machining cost. From the modeling process, the machining parameters can be determined.

Multiple regressions used to determine the correlation between a criterion variable and a combination of predictor variables. It can be used to analyze data from any of the major quantitative research designs such as correctional, experimental, and causal-comparative. Beside, multiple regression method is also able to handle interval, ordinal, or categorical data and provide estimates both of the magnitude and statistical significance of the relationships between variables (Gall, M et al. 1996). This method can predict the surface roughness of a product before milling in order to evaluate the fitness of machining parameters such as feed rate, spindle speed or depth of cut for keeping a desired surface roughness and increasing product quality.

2.3.3 Importance of Predict Surface Roughness

Surface roughness of a machined product could affect several of the product's functional attributes, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue. Surface roughness is an important measure of the technological quality of product and a great factor that influences manufacturing cost (Julie Z.Zhang et al., 2006).

This good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life (Huynh, V.M. and Fan, Y., 1992). Thus, it is necessary to know how to control the machining parameters to produce a fine surface quality for these parts. The control factors for the machining parameters are spindle speed, feed rate and depth of cut and the uncontrollable factors such as tool diameter, tool chip and tool wear (Julie Z.Zhang et al., 2006).

Characterization of surface topography is important in applications involving friction, lubrication, and wear. In general, it has been found that friction increases with average roughness. Therefore, surface roughness has to be carefully considered in many applications such as automobile brake linings, floor surface, and tires. For example, the performance of ships is affected by roughness in the form of skin friction, which can account for 80-90% of the total flow resistance. In addition, the power consumption can increase as much as 40% during the service life of a ship as a result of increased surface roughness caused by paint cracking, hull corrosion and fouling. Surface roughness is also a topic of interest in fluid dynamics. The roughness of the interior surface of pipes affects flow parameters, such as the Reynolds number, which is used to evaluate the flow regime (i.e., laminar or turbulent) (Kuang-Hua Fuh and Chih-Fu Wu, 1994).

2.4 TITANIUM

Titanium is the material of the workpiece used in this project. Titanium (Ti) named after the giant Greek God titan was discover in 1971 but it was not produced commercially until 1950s. Titanium is high strength to weight ratio and its corrosion resistance at room and elevated temperature which is two of the expensive material. These properties of titanium make it attractive for many applications.

The properties and manufacturing characteristics of titanium alloy are extremely sensitive to small variation in both alloying and residual element. Control of composition and processing are therefore important especially the prevention of the surface contamination by hydrogen, oxygen, or nitrogen during process.

Titanium and its alloys are used extensively in aerospace because of their excellent combination of hi~ specific strength (strength-to-weight ratio) which is maintained at elevated temperature, their fracture resistant characteristics , and their exceptional resistance to corrosion. They are also being used increasingly (or being considered for use) in other industrial and commercial applications, such as petroleum refining, chemical processing, surgical implantation, pulp and paper, pollution control, nuclear waste storage, food processing, electrochemical (including cathodic protection and extractive metallurgy) and marine applications (J.R. Myers et al 1984). They have become established engineering materials available in a range of alloys and in all the wrought forms, such as billet, bar, plate, sheet, strip, hollows, extrusions, wire, etc.

Despite the increased usage and production of titanium and its alloys, they are expensive when compared to many other metals because of the complexity of the extraction process, difficulty of melting, and problems during fabrication and machining (H.B. Bomberger et al, 1984). Near net-shape methods such as castings, isothermal forging, and powder metallurgy have been introduced to reduce the cost of titanium components (H. van Kann, 1983). However, most titanium parts are still manufactured by conventional machining methods. Virtually all types of machining operations, such as turning, milling, drilling, reaming, tapping, sawing, and grinding, are employed in producing aerospace components (J.F. Kahles et al, 1985). For the manufacture of gas turbine engines, turning and drilling are the major machining operations, whilst in airframe production, end milling and drilling are amongst the most important machining operations.

The machinability of titanium and its alloys is generally considered to be poor owing to several inherent properties of the materials. Titanium is very chemically reactive and, therefore, has a tendency to weld to the cutting tool during machining, thus leading to chipping and premature tool failure. Its low thermal conductivity increases the temperature at the tool/workpiece interface, which affects the tool life adversely. Additionally, its high strength maintained at elevated temperatureand its low modulus of elasticity further impairs its machinability (H. Hong et al, 1994).

Workpiece material	Cutting tools	General purpose starting condition			Range for roughing and finishing		
		Depth of cut (mm)	Feed Mm/rev	Cutting speed m/min	Depth of cut (mm)	Feed mm/rev	Cutting speed m/min
Titanium alloy	Uncoated carbide	1.0-3.8	0.15	35-60	0.25-6.3	0.1-0.4	10-75
	TiN-coated carbide	1.0- 3.8	0.15	30-60	0.25-6.3	0.1-0.4	10-100

Table 2.1: General Recommendation for Turning operation.

Source: The general recommendation for turning operation

2.5 PREVIOUS RESEARCH DUE TO SURFACE ROUGHNESS

The first study on surface roughness was performed in Germany in 1931 (Bayrak, 2002). As a result of this study, the surface qualities were arranged as the standard DIN 140. Surfaces are expressed as "machined or not machined surfaces" . In all machined pieces, the examinations performed by hand and eye are taken into consideration. The surfaces are classified according to tactile feeling and the naked eye. Surface qualities are designated in 4 different forms: coarse, rough, medium and fine.

Kopac and Bahor (1999), who studied the changes in surface roughness depending on the process conditions in tempered AISI 1060 and 4140 G¨O KKAYA, NALBANT steels, found speed to be the most dominant factor if the operating parameters were chosen randomly. They also reported that, for both steel types, the cutting tools with greater radius cause smaller surface roughness values. Similar studies were published by Yuan et al. (1996) and Eriksin and ¨Ozses (2002).

G¨okkaya et al. (2004) investigated the effect of cutting tool coating material, cutting speed and feed rate speed on the surface roughness of AISI 1040 steel. In their study, the lowest average surface roughness was obtained using cutting tool with coated TiN. A 176% improvement in surface roughness was provided by reducing feed rate by 80% and a 13% improvement in surface roughness was provided by increasing the cutting speed by 200%.

Lin and Lee (2001) formulized the experimental results of surface roughness and cutting forces by regression analysis, and modeled the effects of them using S55C steel. Similar investigations were conducted by Risbood and Dixit (2003), Ghani and Choudhury (2002), Petropoulos et al. (2003), Feng and Wang (2002), Sekulic (2002) and Gadelmavla and Koura (2002).