SURFACE ROUGHNESS ANALYSIS VERSUS DEPTH OF CUT IN CNC MILLING

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Design) with Honours.

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) with Honours. The member of the supervisory committee is as follow:

Ir. Sivarao Subramonian

ABSTRACT

This work focuses on the study of the effects of depth of cut using CNC milling to investigate mechanical forces impacting the outcome of surface quality on 6061-T6511 Aluminum Alloy steel using TiALN coated carbide 4 flute end-mills. This work also looks into the cutting forces brought upon by the horsepower required at the spindle acting upon the workpiece, more specifically tangential forces exerted by the depth of cut acting upon the 6061-T6511 Aluminum Alloy workpiece and the resultant surface quality. Tangential forces generated by the horsepower required to move the spindle at a predetermined cutting depth has been found to be one of the contributing factors in the deterioration the surface quality as elaborated further in this work. Furthermore, this work will delve into the relationship the depth of cut has to the surface roughness quality and the foreseeable outcome which is dissimilar hardness of solids in contact gives rise to penetration of the harder asperities into the surface of the softer body. The deformation of the harder body is substantially smaller than that of the softer body and can be neglected. The surface roughness of the softer body should be taken into account.

ABSTRAK

Laporan ini menumpu kepada kesan kedalaman pemotongan menggunakan mesin *CNC milling* untuk mengkaji impak daya mekanikal luaran terhadap kualiti kelicinan permukaan Aluminium Alloy 6061-T6511 yang dimesin menggunakan alat pemotong "end-mill" carbide bersalut TiALN. Laporan ini juga akan mengkaji daya pemotongan yang di jana oleh kuasa kuda mesin bertindak terhadap bahan kerja, secara lebih spesifik daya tangen yang dikenakan ke atas bahan kerja dan kesan kedalaman pemotongan dalam pengurangan kualiti permukaan seperti yang akan dibincang dalam laporan ini. Daya tangen yang dijana oleh kuasa kuda untuk menggerakkan gelendong akan mengurangkan kualiti permukaan seperti yang telah dihuraikan dalam laporan ini. Selain itu, kajian ini juga akan menyingkap kaitan di antara kedalaman pemotongan dan kualiti kelicinan permukaan bahan kerja Alloy Aluminium 6061-T6511 yang telah dimesin dan jangakaan akhir yang dapat diringkaskan iaitu perbezaan diantara kekerasan dua jasad yang bertembung akan membenarkan jasad yang lebih keras menembusi jasad yang lebih lembut. Deformasi jasad yang lebih keras adalah lebih kecil berbanding jasad yang lembut dan boleh diabaikan. Oleh itu, kelicinan permukaan yang lebih lembut perlu diambil kira.

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LIST OF ABBREVIATIONS

°C	-	Degrees Celsius
µm	-	Micrometer / Microns
AISI	-	American Iron and Steel Institute
Al_2O_3	-	Aluminium Oxide
ANN	-	Artificial Neural Network
ANSI	-	American National Standard Institute
ASME	-	American Society of Mechanical Engineers
Bhn	-	Brinell Hardness Number
BUE	-	Built-Up Edge
CEL	-	Cutting Edge Length
CNC	-	Computer Numerical Control
Co	-	Cobalt
Dia.	-	Diameter
DOC	-	Depth of Cut
ECT	-	Equivalent Chip Thickness
F	-	Feed Rate
FPM	-	Feet Per Minute
F_t	-	Feed Per Tooth
Ft/min	-	Feet Per Minute
GA	-	Genetic Algorithm
Hp	-	Horsepower
HRC	-	Rockwell Hardness
HSS	-	High Speed Steel
ISO	-	International Standard Organization
JIS	-	Japanese International Standard
kV	-	Kilo-volt
mA	-	Milli-ampere
Manganese	-	Manganese
Mg	-	Magnesium
Min	-	Minute

Mm	-	Millimeter
MPa	-	Mega Pascal
MRR	-	Material Removal Rate
N	-	Newton
N_f	-	Number of Flutes
PSM	-	Projek Sarjana Muda
R_a	-	Arithmetic Mean Value / Arithmetical Mean Deviation
Revs/min	-	Revolutions Per Minute
RPM	-	Revolutions Per Minute
R_q	-	Root Mean Square
RSM	-	Response Surface Methodology
SEM	-	Scanning Electron Microscopy
Sfpm / spm	-	surface feet per minute
Si	-	Silicone
S_m	-	Mean Peak Spacing
TiALN	-	Titanium Aluminium Nitrate
TiC	-	Titanium Carbide
TiN	-	Titanium Nitrate
V_c	-	Cutting Speed
XRD	-	X-ray Diffraction

CHAPTER 1

INTRODUCTION

Surface roughness plays an important part in the functional performance of many engineering components. To illustrate the impact of this criterion, surface roughness or texture quality plays a vital role in the corrosion rate of materials, residual stress, heat resistance, friction capabilities, surface reflectability as well as aesthetic value. In addition, surface roughness is often used as the fingerprint of the process used in the production which therefore correlates to both dependent and independent variables in the machining process. Using the correlation between the machining parameters and the surface roughness, the machining parameters could well be adjusted to meet the desired surface finish.

1.1 Background

Surface finish, as described by Bhushan (2001), is the allowable deviation from a perfectly flat surface that is made by a manufacturing process. Whenever any process is used to manufacture a part, there will be some roughness on the surface. This roughness can be caused by a cutting tool making tiny grooves on the surface or by the individual grains of the grinding wheel each cutting its own groove on the surface. It is affected by the cutting parameters, cutting tool geometry, tool properties, environmental conditions, chip formations, heat distribution, mechanical and chemical properties of the work material. Whitehouse (1994) stated that solid surfaces, irrespective of their method of formation (casting, hot forming, drawing, etc…) contains irregularities or deviations from the prescribed geometrical form. The surfaces contain irregularities of various orders ranging from shape deviations to irregularities of the order of inter atomic distances. No machining method, however precise, can produce a molecularly flat surface on conventional materials as clarified by Whitehouse (1994). Surface finish as described in the ASME International Handbook Vol. 16 (1999) is concerned with only the geometric irregularities of surfaces of solid materials and the characteristics of instruments for measuring roughness. Surface texture is defined in terms of roughness, waviness, lay and flaws as illustrated in Figure 1:

- Surface roughness consists of fine irregularities in the surface texture, usually including those resulting from inherent action of the production process such as feed marks produced during machining as stated by Whitehouse (1994).
- ASME Vol. 16 (1999) defines waviness is a more widely spaced component of surface texture and may result from such factors as machine or work deflections, vibration or chatter.
- Lay is the direction of the predominant surface pattern.
- Flaws are unintentional, unexpected and unwanted interruptions in the surface – for example cracks, nicks, scratches and ridges.

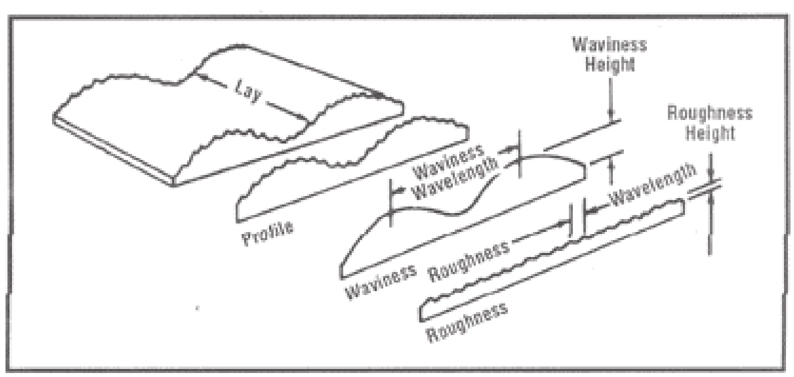


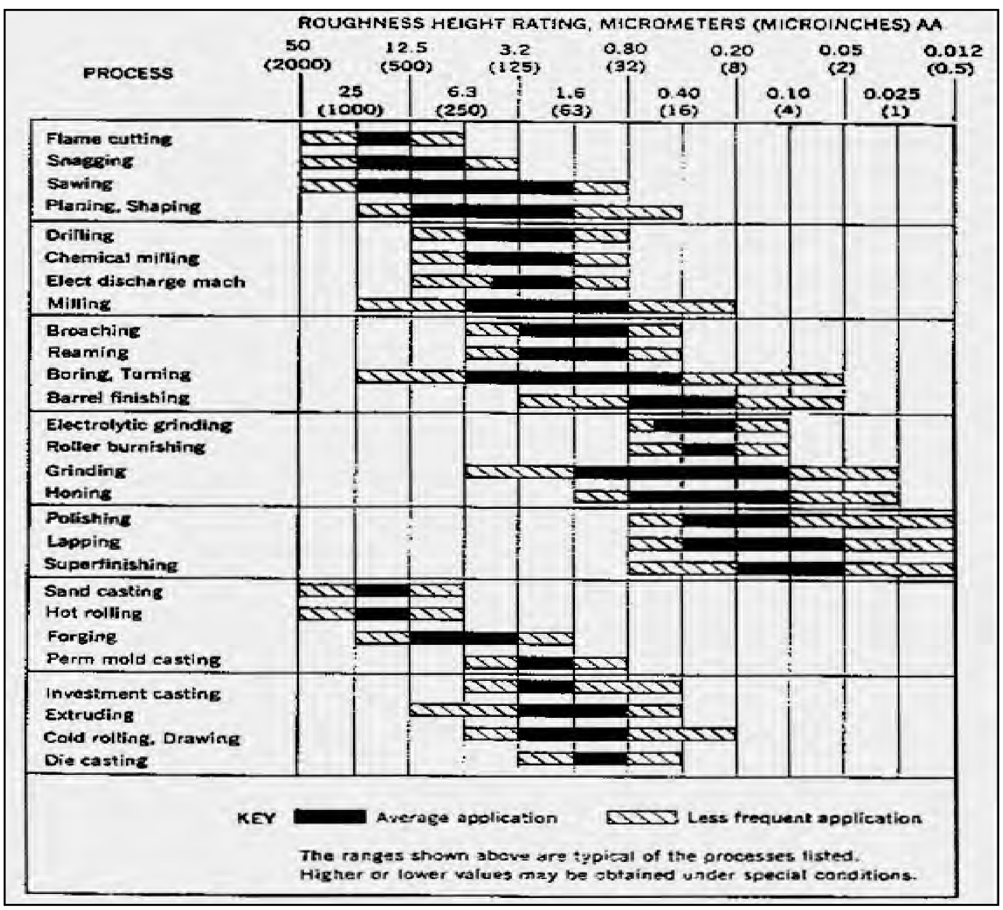
Figure 1: Illustration of surface texture from Bhushan (2001)

The specification of unimpaired or enhanced surfaces require an understanding of the interrelationship among metallurgy, machinability, and mechanical testing. To point out here that the main purpose of this study is to distinguish the effects of increasing depth of cut on the quality of the surface finish. According to the ASME Vol. 16 (1999) to satisfy such requirement, an encompassing discipline known as surface integrity was introduced, and it has since gained worldwide acceptance. Surface integrity technology describes and controls the many possible alterations produced in a surface layer during manufacture, including their effects on material properties and the performance of the surface in service. Simplified, surface integrity technology is a discipline of the study of various metallurgical, characteristic and machining parameters and its effects on surface quality. Surface integrity is achieved by the selection and control of manufacturing processes, estimating their effects on the significant engineering properties of work materials, ASME Vol. 16 (1999). Surface integrity involves the study and control of both surface roughness or surface topography, and surface metallurgy. Surface roughness is closely tied to the accuracy or tolerance of a machine component as shown in Table 1 below. According to Table 1 adapted from ANSI B46.1-1962, milling would most likely produce R_a values of between 0.2 – 25µm in which the most permissible and applicable values are between 0.8 – 6.3µm. However, this figure is merely a summation or estimation of the R_a values obtained through milling as milling as we know, has many facets to it. A close-tolerance dimension requires a very fine finish, and the finishing of a component to a very low roughness value may require multiple machining operations. For example when dynamic loading is a principal factor in a design, useful strength is frequently limited by the fatigue characteristics of materials. Fatigue failure and stress points almost always nucleate or permeate at or near the surface of a component; similarly stress corrosion, a structural phenomenon, is also likely to occur. Therefore, the nature of surface from a metallurgical point of view is important in the design and manufacture of critical parts or hardware.

As pointed out in the beginning of this chapter, the importance of surface integrity is further heightened when high stresses occur in the presence of extreme environments. Heat-resistant, corrosion resistant, and high-strength alloys are used in a wide variety of such applications. According to Oberg et al. (2008) typical alloys used in these applications include alloy steels with the hardness of 50 to over 600 HRC and heat-treated alloys with strength levels as high as 2070 MPa (300 ksi). Additional materials include stainless steels, titanium alloys, and high-temperature and corrosion-resistant applications.

Unfortunately, according to the ASME Vol. 18 (1998) the alloys for high-strength applications are frequently difficult to machine. The hard steels and high-temperature alloys for example, must be turned or milled at low speeds, which tend to produce built-up edge and poor surface finish. The machining of these alloys tends to produce undesirable metallurgical surface altercations, which have been found to reduce fatigue strength. However workpiece material composition and chemical properties of this research will be discussed further in chapter 3.

Table 1: Surface Roughness (R_a) Produced by Common Production Methods (adapted from ANSI B46.1-1962, R1971)



To conclude, this study focuses on the effect of depth of cut (DOC) on the surface roughness quality and as an added advantage to study the effects of tool wear in an effort to understand the needs in optimization of surface integrity.

1.2 Problem Statements

In metal cutting operations, one of the most important aspects is the process of establishing operating conditions such as depth of cut, feed rate, and surface speed. Operating conditions control tool life, productivity, and manufacturing cost. Take for example, if operating conditions are changed to increase the material removal rate (MRR), machining time is reduced at the cost of tool life which decreases as well as the quality of the surface roughness. To address this matter further, a few issues are identified that would underline the foundation of this research such as:

i. Nature of the correlation between surface roughness and the level of dependency on depth on cut – adversely or in adverse.
ii. The permissible tangential forces exerted by the DOC under pre-determined cutting conditions to obtain surface finish within the ANSI B46.1-1962 standards.
iii. Cutting profiles and the effects on surface finish – if any.
iv. Overall relationship between depth of cut, cutting horsepower, tangential forces, and R_a.

To point out, the above statements provide a niche or a trend in directing this study by providing a guideline in drawing out the objectives of this research.

1.3 Research Objectives

This paper is a study on machining conditions using computer numerical control (CNC) milling, namely depth of cut and its tribological effects upon a work surface. Findings upon which will be quantified into surface roughness measurement parameters or more accurately the arithmetical mean deviation (R_a). Furthermore, the impact of depth of cut will also be catalogued in the tool wear as well as chip morphology to corroborate the impact of these factors on overall surface integrity. Variations in cutting profiles ideally will also be studied. In a summary, objectives of this research are:

i. To isolate and study the depth of cut as a separate entity and its tribological impact on surface roughness using CNC milling.
ii. To determine correlations between tool wear and depth of cut, as well as the effect of tool wear on overall surface texture.
iii. Formulation of material removal rate, *MRR* based on the variations in depths of cut to determine correlation to surface roughness.
iv. Design and execution of an experiment setup to meet the abovementioned objectives.

1.4 Scope of Research

The focus of the study is on the quality of the surface roughness respective to varying depth of cut given other parameters (spindle speed, feed rate, surface speed, tool rake angle and cutting speed) are constant. The study will be conducted by performing an experiment with a constant set of parameters (i.e. feed rate and cutting speed) with one variable (depth of cut) in order to explore different of result on the workpiece surface. The characteristic of the surface roughness will be analyzed in order to determine the relationship between the cutting parameter with the resulting milled surface.

CHAPTER 2

LITERATURE REVIEW

The term "surface texture" refers to the fine irregularities (peaks and valleys) produced on a surface by a forming or material removal process. By convention, the texture comprises of two components: roughness and waviness. Avallone et al. (1997**)** stated that roughness consists of the finer irregularities characteristic of the process itself such as the teeth spacing in a milling cutter or the feed of a single-point tool. Waviness on the other hand, according to Whitehouse (1994) consists of the more widely spaced irregularities that are often produced by vibration in the machining process. Yet the ASME Handbook Vol. 18 (1998) defines the terms "surface texture" and "roughness" are used interchangeably, because roughness is specified and measured more often than waviness.

At this point the need arises to conjugate past literatures to the current study. However to fully understand what is being studied in this research, the surface parameters used in this study would first need to be highlighted.

2.1 Surface Parameters

There are a great variety of surface parameters, many of which have been developed to characterize the function of engineering surfaces for particular applications. ASME Vol. 18 (1998) stated that about 50 to 100 parameters have been defined for industrial use, and many of these appear in national standard as well. Nevertheless, surface parameters can generally be classified as height parameters, wavelength parameters, shape parameters, and combinations of these known as hybrid parameters. This research however studies the basis of height parameters exclusively when regarding surface roughness as height parameters is sufficient enough in measuring roughness as clarified by Bhushan (2001**).**

2.1.1 Height Parameters

The most common statistical descriptors of surface height are the roughness average or the arithmetic mean average, R_a, and the Root Mean Square (RMS) roughness, R_q. These are closely related and are given by the following formulas, as shown in Bhushan (2001) in integral and digitized form:

$$R_a = \frac{1}{L}\int_0^L |y(x)|dx = \frac{1}{N}\sum_{i=1}^{N}|y_i| \qquad \text{(Eq. 1)}$$

$$R_q = \left[\frac{1}{L}\int_0^L y^2(x)dx\right]^{\frac{1}{2}} = \left[\frac{1}{N}\sum_{i=1}^{N} y_i^2\right]^{\frac{1}{2}} \qquad \text{(Eq. 2)}$$

where y(x) is the surface profile, sampled by the N set points over y_i over the length, L, as shown in Figure 2.1. The parameters R_a and R_q are useful estimators of the average heights and depths of surface profiles. The RMS roughness is commonly specified for the surfaces of optical components. In Drozda and Wick (1983), the lower RMS roughness of an optical component, the less stray scattered light and thus the higher the quality of the component.

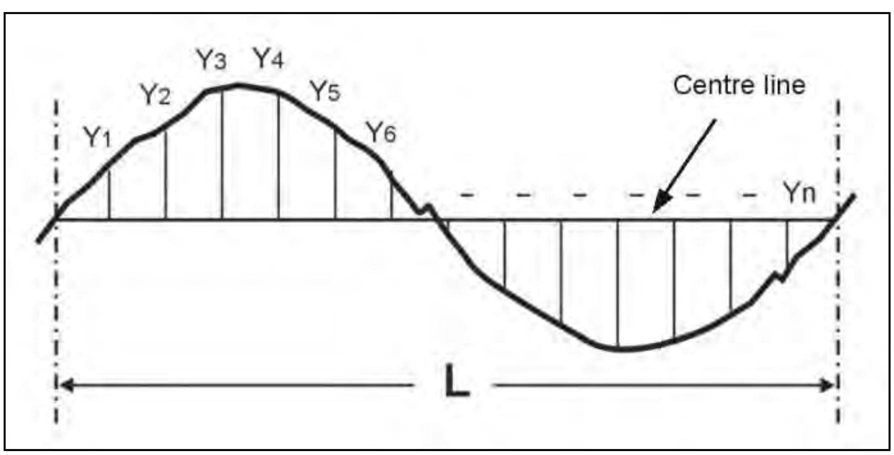


Figure 2.1: R_a = Average absolute deviation of profile y(x) from the mean line = total shaded area (L)

Roughness average (R_a) is used in the automotive and other metalworking industries to specify the surface finish of many types of components, ranging from cylinder bores to brake drums. In addition to these two averaging height parameters, an assortment of other height parameters has been defined for various applications, including several for characterizing peak-to-valley height according to Bhushan (1999).

2.1.2 Wavelength Parameters

Wavelength parameters are used to characterize the spacings of the peaks and valleys of the surface. The spacings or wavelength are often characteristic of the process that forms the surface, such as the grit size of a grinding wheel, or the feed of a tool. A typical wavelength parameter, as recognized as standard by the International Organization for Standardization (ISO) in Figure 2.2, is the mean peak spacing S_m, defined for a surface profile, as the average spacing between two successive negative crossings of the mean line given in the equation below:

$$s_m = \frac{1}{n}\sum_{i=1}^{n} S_{ni} \qquad \text{(Eq. 3)}$$

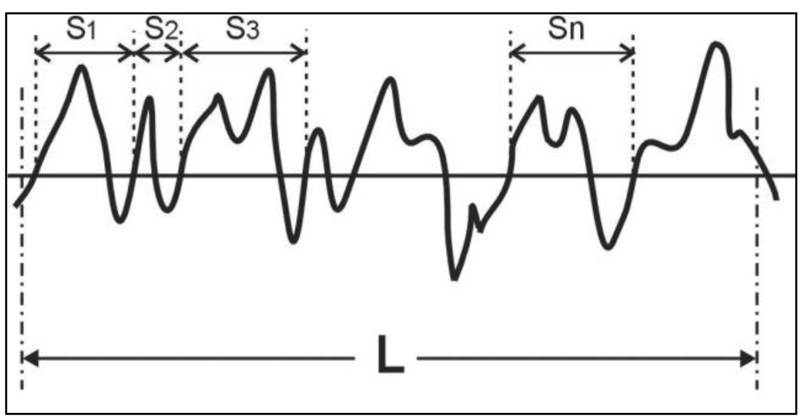


Figure 2.2: Surface profile showing the ISO definition for the peak spacing parameter, S_m.