UNIVERSITI PUTRA MALAYSIA

CUTTING PARAMETER OPTIMISATION FOR ALUMINIUM LM6 COMPOSITE USING EXPERIMENTAL DESIGN

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

July 2013

DEDICATED TO

My father, Teungku Abdullah
My mother, Halimah
My wife, Agustinawati
and
My children, Ryan Naufal
Rais Zaky
also
My Brothers, Muhammad Nur
Habibi
Muhammad Yunus
My Sisters, Husna
Husni Junidar
Sri Wahyuni

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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MUHAMMAD YUSUF

July 2013

Chairman : Assoc. Prof. Mohd Khairol Anuar Mohd Ariffin, PhD

Faculty : Engineering

The purpose of metal cutting operations such as a machining process is to produce a part of the required shape and dimensions with the specified quality and surface finish. A comprehensive understanding of the cutting process is required to determine optimum cutting conditions which enable the machining of new generation materials such as alloys and metal matrix composites, which are often more difficult to machine due to the pursuit of improved product properties and improved dimensional accuracy of machined products. The Machinability of a material is should always be considered in conjunction with the machining method, the cutting tool, and the machining parameters. The materials have excellent machinability required little power to cut, longer tool life and good surface finish. Machinability can be difficult to predict because machining has so many

variables. Optimisation of cutting parameters is the most common strategy to improve the machinability of the materials. Therefore, selection of cutting parameters such as cutting speed, feed rate and depth of cut are important for optimum machining performance. The inappropriate selection of combination cutting parameter will lead to bad cutting condition e.g. vibration that affects the surface finish. Different workpiece material with different property and microstructure give different effect to the surface condition and the cutting tool performance. This research intended to optimisation cutting condition with three principal cutting parameters which are cutting speed, feed rate and depth of cut based on the surface roughness, tool wear and chip formation during turning process under wet and dry cutting conditions. The cutting parameters are selected based on design of experiment method. Results show that there are various differences in surface roughness between wet and dry cutting process with the applied similar cutting parameter model during machining of mild steel material. Surface roughness values of AA7050 aluminium alloy is found to be lower as compared to surface roughness values of LM6 alloy in the similar of cutting condition model. Surface roughness values of titanium carbide particles reinforced LM6 aluminium composite are higher as compared to LM6 aluminium alloy at similar cutting condition. This indicates that the machined surface quality is depending on the structures and constituents of the workpiece materials. The chip forms produced during turning of aluminium alloys and aluminium-titanium carbide composite at similar of cutting condition is found the different of shape. The chip characteristics of these materials are found continuous and noncontinuous shape. This is due to the chip forms depending on the constituent and the properties of the workpiece materials. Turning operation at high cutting speed of 250 m min^{-1} produced faster tool wear as compared to low cutting speed of 175 m min^{-1} and 100 m min^{-1} during cutting of 2 wt.% titanium carbide particles reinforced LM6 aluminium using uncoated carbide tool. The flank wear progression increases rapidly at high depth of cut and feed rate, 1.5 mm and 0.2 mm rev^{-1}, respectively.

Abstrak tesis dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN PARAMETER PEMOTONGAN UNTUK ALUMINIUM LM6 COMPOSIT MENGGUNAKAN REKA BENTUK EKSPERIMEN

Oleh

MUHAMMAD YUSUF

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Tujuan operasi pemotongan logam seperti proses pemesinan ialah untuk menghasilkan satu komponen daripada bentuk dan dimensi yang diperlukan dengan kualiti dan kemasan permukaan yang dinyatakan. Satu pemahaman yang menyeluruh daripada proses pemotongan diperlukan untuk menentukan keadaan pemotongan optimum yang membolehkan pemesinan generasi bahan baru seperti aloi-aloi dan logam matriks komposit, yang sering lebih sukar untuk dimesinkan disebabkan mengejar ciri produk yang lebih baik dan ketepatan dimensi yang lebih baik daripada produk dimesin. Keupayaan mesin daripada bahan mesti sentiasa dianggap

bersempena dengan kaedah pemesinan, perkakas pemotong, dan parameter-parameter pemesinan. Bahan-bahan yang cemerlang keupayaan mesin diperlukan kuasa sedikit untuk memotong, hayat perkakas pemotong lebih lama dan kemasan permukaan yang baik. Keupayaan mesin menjadi sukar untuk diramalkan kerana pemesinan mempunyai begitu banyak pembolehubah. Pengoptimuman parameter-parameter pemotongan adalah strategi yang paling biasa untuk memperbaiki keupayaan mesin daripada bahan-bahan. Oleh itu, pemilihan parameter-parameter pemotong seperti kelajuan pemotongan, kadar suapan, dan kedalaman pemotongan adalah penting untuk prestasi pemesinan yang optimum. Pemilihan gabungan parameter pemotongan yang tidak sesuai akan berlaku keadaan pemotongan yang buruk contohnya getaran yang kesan kepada buruk kemasan permukaan. Bahan bahan kerja yang berbeza dengan ciri dan mikrostruktur yang berlainan memberi kesan yang berbeza kepada keadaan permukaan dan prestasi perkakas pemotong. Penyelidikan ini bertujuan untuk pengoptimuman keadaan pemotongan dengan tiga parameter pemotongan utama seperti kelajuan pemotongan, kadar suapan dan kedalaman pemotongan berdasarkan kepada kekasaran permukaan, haus perkakas pemotong, dan pembentukan sepihan semasa proses pelarikan dengan kondisi pemotongan basah dan kering. Parameter pemotongan dipilih berdasarkan kaedah reka bentuk eksperimen. Hasil kajian menunjukkan bahawa terdapat perbezaan dalam kekasaran permukaan antara proses memotong basah dan kering dengan model parameter pemotongan serupa yang digunakan semasa pemesinan bahan keluli lembut. Nilai kekasaran permukaan aloi AA7050 aluminium didapati lebih rendah berbanding dengan nilai kekasaran aloi LM6 aluminium pada model keadaan pemotongan serupa. Nilai kekasaran permukaan zarah titanium karbida diperkukuh dalam LM6 aluminium komposit lebih tinggi berbanding aloi LM6 aluminium pada keadaan pemotongan yang serupa. Ini menunjukkan bahawa kualiti permukaan dimesin adalah bergantung kepada struktur dan constituen bahan kerja. Bentuk serpihan yang dihasilkan semasa melarik aluminium aloi dan aluminium-titanium karbida komposit pada keadaan pemotongan serupa ditemui bentuk yang berbeza. Ciri-ciri serpihan daripada bahan-bahan ini telah ditemui bentuk berterusan dan bukan berterusan. Ini adalah disebabkan juga bahawa bentuk serpihan bergantung kepada juzuk dan ciri bahan kerja. Pelarikan pada laju pemotongan yang tinggi 250 m min^{-1} menghasilkan haus perkakas lebih cepat berbanding dengan laju pemotongan rendah 175 m min^{-1} dan 100 m min^{-1} semasa pemotongan daripada 2 wt.% zarah titanium karbida diperkukuh dalam aluminium LM6 menggunakan perkakas karbida tidak bersalut. Perkembangan haus rusuk perkakas pemotong meningkat dengan pesat pada kedalaman pemotongan dan kadar suapan yang tinggi, 1.5 mm dan 0.2 mm rev^{-1}.

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APPROVAL

I certify that a Thesis Examination Committee has met on 22 July 2013 to conduct the final examination of Muhammad Yusuf on his thesis entitled "Cutting parameter optimisation for aluminium LM6 composite using experimental design" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MUHAMMAD YUSUF

Date: 22 July 2013

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LIST OF ABBREVIATIONS

AA	- Aluminium association
AISI	- American Iron and Steel Institute
Al	- Aluminum
a_p	- Depth of cut
ASME	- American Society of Mechanical Engineers
ASTM	- American Society for Testing and Materials
BBD	- Box Behnken design
BUE	- Built-up edge
BS	- British Standard
C	- Carbon
CCD	- Central composite design
CMCs	- Ceramic matrix composites
cot	- Cotangent
Cr	- Chromium
Cu	- Copper
CVD	- Chemical vapor deposition
D	- Initial workpiece diameter
d	- Final workpiece diameter
DIN	- Deutsches Institut für Normung/ German industrial standard
DOE	- Design of experiment
EDM	- Electro Discharge Machining
f	- Feed
Fe	- Iron
HB	- Hard Brinell
HRC	- Hard Rockwell C
ISO	- International organisation for standardisation
JIS	- Japanese industrial standard
K_{re}	- Major cutting edge angle
K'_{re}	- Minor cutting edge angle
KT	- Crater depth
l	- Length of cut

Lm	- Specified surface length
LM6	- Type of aluminium alloy
MMCs	- Metal matrix composites
Mg	- Magnesium
Mn	- Manganese
n	- Spindle speed
Ni	- Nickel
P	- Phosphorus
Pb	- Lead
PCD	- Poly crystalline diamond
PMCs	- Polymer matrix composites
PCBN	- Poly-crystalline cubic boron nitride
Q	- Material removal rate
r	- Tool nose/corner radius
Ra	- Average surface roughness
Rmax	- Maximum surface roughness
RSM	- Response surface methodology
S	- Sulfur
Si	- Silicon
SiC	- Silicon Carbide
T	- Cutting time
Ti	- Titanium
TiC	- Titanium Carbide
v	- Cutting speed
VB	- Flank wear
Vf	- Speed of the cutting tool
y	- Vertical deviation from nominal surface
Zn	- Zinc

CHAPTER 1

INTRODUCTION

1.1 Background

Metal cutting process has become a very large segment in manufacturing industries. The industrial revolution and the growth of economical based manufacturing of the world can be traced largely by the development of the various machining operations for making parts of different shapes and contours to fulfil industry's need for mass production at low cost and high precision (Stephenson and Agapiou, 2006; Groover, 2010). In view of its economical significance, the technique of metal cutting process was developed continuously by researchers to fulfil the manufacturing company necessaries which highly depend on that. Without the sophisticated knowledge, it is impossible to develop new cutting equipment or determine the optimum cutting conditions. A comprehensive understanding of the metal cutting process also enables the machining of new generation materials, which are often more difficult to machine due to the pursuit of improved product properties and improved dimensional accuracy of machined products.

In general, the purpose of any material cutting operation is to produce a part of the required shape and dimensions with the specified quality and surface finish. The metal cutting process is accompanied by deformation in form of compression, tension and shear as well as heat generation (Gorczyca, 1987; Davim, 2007). According to Boothroyd (1981) and Astakhove (2007), in machining process, friction between workpiece-cutting tool and cutting tool-chip interfaces generates heats which affect the shorter tool life, higher surface roughness and lowers the dimensional sensitiveness of the workpiece.

In contrary, cutting fluids are used in machining process to remove the heat, reducing fiction, reduce cutting force and power requirements, improve surface finish longer tool life (Avila and Abrao, 2001; Cakir, 2007). Meanwhile, the used of cutting fluids can be dangerous to health workers and the environment (Adler, 2007). Machining without used of cutting fluids (dry cutting) is becoming increasingly important due to concern regarding safety and environmental legislation. However, dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which generates higher temperatures, higher wear rates, and consequently shorter tool life (Abhang and Hameedullah, 2010).

Machinability of a particular material have evaluated by assessing any one of the following parameters: tool life or wear, surface finish, cutting force, power consumption, and cutting temperature (Stephenson and Agapiou, 2006). The excellent machinability materials required a little power to cut, longer tool life and good surface finish. Machinability can be difficult to predict because machining has so many variables. Optimisation of cutting parameters is an essential element to determine the machinability of material. Therefore, in the investigation of machinability, selection of cutting parameters such as cutting speed, feed, and depth of cut are important for optimum machining performance (Boothroyd and Knight, 2006; Stephenson and Agapiou, 2006). There are numbers of studies have been done to investigate the machinability of material based on the selection of cutting parameters.

Che Haron et al. (2001) investigated the wear of coated and uncoated cutting tool in turning of tool steel (ISO: 95MnCrW1). Machining test was performed under wet and dry cutting conditions at various cutting speeds and constant feed and depth of cut. It was found that the coated carbide tools were superior compared to the uncoated carbide tools. Wet cutting is better than dry cutting for coated carbide tools. The used of oil-based coolant can increase the tool life of coated carbide tools since the coolant is actively supporting the effect of coatings (TiN, Al_2O_3, TiCN), particularly in reducing friction and heat.

Sreejith (2008) conducted machining experiment for 6061 aluminium alloy using diamond-coated carbide cutting tool with different lubricant environments; dry cutting, minimum quantity of lubricant (MQL) and flooded coolant conditions. The results show that, the tool wear cutting force and increases with cutting speed at all cutting environments. The resultant cutting force was the highest under dry cutting conditions. For improving the quality of workpiece surface, coolant is necessary.

Bhushan et al. (2010) investigated the influence of cutting speed, feed, and depth of cut on surface roughness and tool wear during turning of 7075 aluminium alloy and 7075 Aluminium alloy with 10 wt.% SiC particulate metal matrix composite. The experiment was carried out using tungsten carbide and polycrystalline diamond (PCD) cutting tools with dry cutting condition. The results were found that, surface roughness of 7075 Al alloy is less as compared to 7075 Al composite during turning by carbide as well as PCD cutting tool. Wear of carbide and PCD cutting tool is less during turning of 7075 Al alloy as compared to 7075 Al composite. Wear of PCD cutting tool is less compared to wear of carbide cutting tool during turning of 7075 Al composite.

In machining investigation, design of experiments (DOE) is used very extensively. DOE is powerful analysis tool for modeling and analyzing of the process effect. The application design of experiment is able to reduce the experiment expenses. DOE method is an effective approach to optimize the various cutting parameters on machining processes. There are some methods in the design of experiment including factorial design, response surface methodology, mixture design and Taguchi method applied in experimental studies (Myers and Montgomery, 2002).

Bartarya and Choudhury (2012), DOE factorial design was used to predict cutting force and surface roughness during finish machining of EN31 steel. Palanikumar et al. (2008) has used DOE response surface methodology to optimise the surface roughness in machining of Al/SiC composites.

1.2 Problem statement

Metal cutting processes to produce a part of the required shape and dimensions and with the specified quality and surface finish. The surface finish of machined parts must always be considered in conjunction with the machining method, the cutting tool, and the cutting parameters (Boothroyd and Knight, 1989; Stephenson and Agapiou, 2006).

The determination of cutting parameter is the most common strategy to improve the tool life, the product surface finish and the dimension accuracy (Stephenson and Agapiou, 2006). The inappropriate selection of combination cutting parameter will lead to bad cutting condition e.g. vibration that effect the poor surface finish. Different workpiece material with different property and microstructure give different effect to the surface condition and the cutting tool performance (Bhushan, 2010; Kaladhar, 2010; Doja and Singh, 2012).

Machinability of metal matrix composites has received considerable attention because the high tool wear and lower surface finish quality. Hard ceramic reinforcing components in metal matrix composites make these materials difficult to machine (El-Gallab and Sklad, 1998; Li and Seah, 2001 Kannan and Kishawy, 2006; Bhushan, 2010; Muthukrishnan and Davim, 2011). During machining of metal matrix composites, reinforcement particles are fractured and pulled out of the matrix which leads to the deterioration of the product surface quality and rapid tool wear. Moreover, rapid failure of the cutting tool affecting on the workpiece surface roughness and the leads to recurrent tool changes which increases machining operation time and cost. Hence, choosing right cutting tools and cutting parameters to minimize the machining cost is a critical issue.

1.3 Research objectives

The main objective of this research to evaluate the effect of cutting speed, feed and depth of cut parameters on the workpiece surface roughness, the tool wear and the chip formation in turning operations for some of materials include mild steel, aluminium alloy and aluminium composite. Design of experiment (DOE) is used to optimize cutting parameters on machining process.

The objectives this research are follow:

1. To analyse the optimum cutting conditions based on three principal cutting parameters such as cutting speed, feed and depth of cut to get lowest surface roughness value on turning of mild steel under wet and dry cutting.
2. To indentify influence of cutting parameters on surface roughness for turning of aluminium alloy AA7050 in dry cutting using Response Surface Methodology.
3. To validate the surface roughness and chip formation when turning of LM6 and AA7050 aluminium alloys. Machining results are compared with those under the same cutting conditions.
4. To optimise of cutting parameters base on surface roughness and the tool wear during turning of LM6 aluminium reinforced TiC composite in dry cutting. Effect of cutting parameters on the surface roughness, chip formation and tool wear will be studied.

1.4 Scope and limitation

The research has been conducted on the following scopes:

1. Study focused only for turning process, using conventional and CNC lathe machines. The conventional lathe machine used only for turning of mild steel material since this experiment using low speed machining. The CNC lathe machine is used for turning of aluminium alloy and MMCs materials with using high speed machining.

2. Coated and uncoated carbide cutting tool was used when conducting the experiment. Based on the cutting tool manual, coated carbide tool was used only for turning of mild steel and uncoated carbide tool used for turning of aluminium alloys and aluminium composites.
3. The materials of mild steel S45C, aluminium alloys (LM6, AA7050), and LM6 reinforced with 2 wt.% TiC particles were used as the workpiece of machining experiments. All the workpieces were prepared in the round bar form.
4. The cutting parameters such us cutting speed, feed and depth of cut were used as the process factors. The cutting parameter levels were selected based on the references, machine and cutting tool manuals.
5. Machining experiments conducted under wet and dry cutting conditions. Wet cutting condition used only for turning of mild steel material.
6. Design of experiments (DOE) method was used for the experiments set up. Factorial design and Box-Behnken response surface methodology used for design of cutting models. Factorial design was used only for experiment set up of mild steel material.
7. Surface roughness, chip formation and initial tool wear will be investigated. Tool wear and surface roughness was investigated only for machining of composite material. For the experiment efficiency, the tool wear on others materials (mild steel and aluminium alloys)

can be found based on relationship between surface toughness-tool wear refer to the references.

1.5 Thesis layout

This thesis is divided into 9 chapters. Chapter 1 will provide introduction and objectives of the project. Literature reviews of related topic to guide the study towards achieving the objective are presented in Chapter 2. The experimental set up and techniques are explained in Chapter 3. Chapter 4 presents the influence of cutting parameters on surface roughness under wet and dry cutting conditions in turning of mild steel material. Optimization of cutting parameters on turning process based on surface roughness using Response Surface Methodology is described in Chapter 5. Chapter 6 presents the chip formation and surface roughness in dry machining of aluminium alloys. Surface quality and chip formation in turning of LM6 aluminium alloy and particulate reinforced metal matrix composite are presented in Chapter 7. Chapter 8 presents the experimental investigation on surface roughness and tool wear in dry machining of TiC reinforced aluminium LM6 composite. Chapter 9 provides a conclusion of the experiment accomplished, and recommends some important issues to be addressed in future research.

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