COST MODELS FOR COMPARING ROOM TEMPERATURE AND PREHEATED END-MILLING OF AISI D2 TOOL STEEL

BY

MOHAMED ELHADIE ELAMIN ABBAS

A dissertation submitted in partial fulfilment of the requirements for the degree of Master in Manufacturing Engineering

Kulliyyah of Engineering
International Islamic University
Malaysia

FEBRUARY 2011

ABSTRACT

Preheated machining was found to yield improvements in the machinability of the AISI D2 tool steel, such as longer tool life and lower surface roughness. For preheated machining to be more preferred than room temperature machining, it has to be economically more attractive –besides being better in the context of machinability–. In this research, a thorough investigation was conducted to determine the conditions under which; preheated machining would yield lower machining cost. The conditions under which; room temperature machining would yield lower machining cost were determined as well. User-friendly and accurate mathematical models to estimate the cost of machining in terms of the machining parameters were developed. Initially, the components of machining cost were identified, followed by establishment of equations to evaluate their contributions to the cost of machining. All the required data were made available and the bottom-up approach was adopted for evaluating the cost of end-milling the AISI D2 tool steel. The cost of machining corresponding to each of fifteen experimental runs in each of the two machining methods was evaluated; this was done for two types of cutting tool insert: TiAlN coated carbide inserts and polycrystalline cubic boron nitride inserts, and four levels of utilization: 15%, 25%, 80%, and 90%. Machining costs in room temperature machining were compared with the corresponding ones in preheated machining to determine the conditions under which; preheated machining would yield lower machining cost, and those under which; room temperature machining would yield lower machining cost. The results indicated that when 15% utilization and TiAlN coated carbide inserts are considered, preheated machining would yield lower machining cost in two out of nine experimental runs. The number of experimental runs in which preheated machining would yield lower machining cost increases as the level of utilization is increased. At 90% utilization, preheated machining would yield lower machining cost in eight experimental runs. When PCBN inserts were used, preheated machining yielded lower machining cost in all the nine experimental runs irrespective of the utilization level. Increasing the utilization was found to significantly reduce the cost of machining. The Response Surface Methodology was used to develop the models for both the machining methods considering the two types of inserts, and the four levels of utilization, based on this, sixteen models were developed. The statistical adequacy at 95% confidence interval of the developed models was checked using ANOVA tables. All the developed models were found to be very adequate.

ملخص البحث

لقد ثبت أن القطع الحار لمادة ال"AISI D2 tool steel" يؤدي إلى نتائج قطع أفضل مقارنة بالنتائج التي يؤدي إليها القطع المعتاد (قطع المادة و هي في درجة حرارة الغرفة). لكي يكون القطع الحار مفضلا على القطع المعتاد، يجب أن تكون تكلفة القطع الحار أقل من تكلفة القطع المعتاد. في هذا البحث أجري تحليل عميق لتحديد الحالات التي تكون فيها تكلفة القطع الحار أقل، و كذلك الحالات التي تكون فيها تكلفة القطع المعتاد أقل. بالإضافة إلى هذا، يتضمن هذا البحث بناء نماذج رياضية سهلة الإستعمال و دقيقة النتائج لتقدير تكلفة القطع إعتمادا على عوامل القطع. إبتداءا، تم التعرف على مكونات تكلفة القطع، و بناء معادلة لكل مكون لحساب القيمة التي يساهم بها في تكلفة القطع. جميع البيانات التي يحتاج إليها لحساب تكلفة القطع تم إيجادها، ثم استخدمت تقنية ال"bottom-up" لحساب تكلفة القطع. حسبت تكلفة القطع لكل من القطع الحار و القطع المعتاد، أستخدم في كل منهما قاطعين مختلفين: TiAlN coated carbide and PCBN inserts و اعتبرت لكل منهما أربعة مستويات إستفادة: 15%، 25%، 80%، و 90%. تم مقارنة قيم تكلفة القطع الحار بقيم تكلفة القطع المعتاد و ذلك لتحديد الحالات التي تكون فيها تكلفة القطع الحار أقل، و كذلك الحالات التي تكون فيها تكلفة القطع المعتاد أقل. أثبتت النتائج أن القطع الحار عند استخدام القاطع الأول و اعتبار مستوى إستفادة يساوي 15% يؤدي إلى تكلفة قطع أقل في حالتين من تسع حالات. أما عند اعتبار مستوى إستفادة يساوي 90%، القطع الحار يؤدي إلى تكلفة قطع أقل في ثمانية حالات من تسع. أما عند إستخدام القاطع الثاني، فإن القطع الحار يؤدي إلى تكلفة قطع أقل في جميع التسع حالات بغض النظر عن مستوى الإستفادة. تم إستخدام طريقة ال"RSM" لبناء النماذج الرياضية. أثبتت جداول ال"ANOVA" أن جميع النماذج الرياضية التي تم بناءها ذات جودة عالية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Manufacturing Engineering.

…..……..…………………………
A.N. Mustafizul Karim
Supervisor

I certify that I have read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Manufacturing Engineering.

…..……….………………………
Erry Yulian Triblas Adesta
Examiner

I certify that I have read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Manufacturing Engineering.

………….………………………
Awaluddin Mohamed Shaharoun
External Examiner

This dissertation was submitted to the Department of Manufacturing and Materials Engineering and is accepted as a partial fulfillment of the requirements for the degree of Master of Manufacturing Engineering.

……………..………..……………
Erry Yulian Triblas Adesta
Head, MME Department

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as a partial fulfillment of the requirements for the degree of Master of Manufacturing Engineering.

...……………..……..……………
Amir Akramin Shafie
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Mohamed Elhadie Elamin Abbas

Signature………………………. Date………………………..

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

COST MODELS FOR COMPARING ROOM TEMPERATURE AND PREHEATED END-MILLING OF AISI D2 TOOL STEEL

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

Affirmed by Mohamed Elhadie Elamin Abbas.

…………………………	…………………….
Signature	Date

ACKNOWLEDGEMENTS

In the name of Allah, most gracious, most merciful

Alhamdulillah, with the help and blessing of Almighty Allah, I have been able to complete this research study successfully.

I would like to express my sincere appreciation and gratitude to my supervisor Dr. A.N. Mustafizul Karim for his guidance, encouragement, constructive suggestions, and valuable time for correction in the course of preparing this dissertation.

I also would like to extend my sincere thanks to my co-supervisor Prof. A.K.M. Nurul Amin for his valuable inputs, advices, and suggestions in various phases of this research.

I must acknowledge that without their support and co-operation, it would not have been possible to complete this dissertation in the current form.

Special thanks are directed to Dr. M. A. Lajis; from whom I got the experimental data that I used in this research; this is a big contribution from Dr. M. A. Lajis.

I also would like to thank Br. Zakaria who had assisted me in some of the laboratory work, and those in charge in Kulliyyah Postgraduate Office and Centre for Postgraduate Studies.

These acknowledgements will not be complete without expressing my deep gratitude and thanks to my parents for their support and guidance.

Finally, I thank all those who have contributed directly or indirectly in the successful completion of this research study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

C_M	Machining cost
RTM	Room temperature machining
PHM	Preheated machining
CC	TiAlN Coated carbide cutting tool insert
PCBN	Polycrystalline cubic boron nitride cutting tool insert

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Nowadays, the increasing competition among manufacturers is exerting much pressure on them to become more innovative in producing parts with optimal characteristics and manufacturing costs. With the advancement of technology, the problems of cost estimation, cost analysis and cost control have assumed great dominance in economic and engineering decisions. These factors are highly critical for the continued success of a manufacturing enterprise. Without accurate cost estimates and costing of a company's output, it is difficult to secure business and remain competitive in the global market (Eric M. M., 1984; Roy R., Allen D. and Zamora O., 2004).

There are four basic outputs or areas of work in which cost estimates and cost accounts are very important. These areas of work are: products, processes, projects and services (R. D. Stewart, 1991). Cost estimates are obtained before production; they are predictions. Whereas, cost accounts are obtained after the production; they are the actual cost.

Some of the significant uses to which cost estimates are put are the following:

a) To provide information to be used in establishing the selling prices.

b) To determine the most economical process for manufacturing a product.

c) To be used as a basis for a cost-reduction program.

d) They are used in cost control.

e) To provide input concerning the profitability of a new process/product.

Hardened steel is one of the difficult-to-cut materials. During the last few years, numerous studies have been conducted to improve the machinability of this kind of materials and to explore and develop new techniques to minimize machining costs while maintaining the quality requirements of the machined parts. The benefits of direct manufacture of components from hardened steel are expected to be substantial especially in the context of machining costs and lead times compared to the traditional route of machining in the annealed state followed by heat treatment, finishing operations such as grinding or electrical discharge machining (EDM), polishing, etc.

Advances in machine tool and cutting tools have allowed machining of hardened steels to become widespread in manufacturing processes, and to become a realistic replacement for many grinding operations. AISI D2 hardened steel group is extensively used in making molds and dies for fabrication of automotive and aerospace components.

Experimental work has been conducted (M. A. Lajis, 2009) to investigate the effect of preheating the AISI D2 hardened steel work-piece on its machinability during end-milling operations. It has been found that preheating does improve the machinability of the AISI D2 hardened steel. For instance, longer tool life and lower surface roughness were obtained.

Now, the problem of poor machinability of the AISI D2 tool steel is solved or reduced by preheating, however, a very significant question arises: "Is preheated machining of this material economically more attractive than room temperature machining?". A detailed machining cost evaluation is required to be able to answer this question correctly. This is because the cost of machining involves numerous conflicting factors to be taken into account.

Besides this, development of reliable mathematical models to estimate the cost of room temperature and preheated end-milling of the AISI D2 tool steel would be a useful endeavor. A cost model can enable determining which cost elements contribute the most to the overall cost and consequently helps in identifying the prominent cost drivers. With a cost model, it is possible to determine the conditions that minimize the cost (cost optimization). Another important use for cost models is to aid in the decision process in R&D studies.

Furthermore, in this study, using perturbation plots, response surfaces, and contour plots, the variation of machining cost relative to the machining parameters is discussed. This would widen and deepen the understanding of machining cost scenario in end-milling of the AISI D2 hardened steel using TiAlN coated carbide and polycrystalline boron nitride cutting tool inserts, and would help the practitioners to choose correct input values of process parameters and secure superior process performance.

1.1.1 Benefits and Drawbacks in Preheated Machining

In the context of machinability, preheating yields several positive outcomes, such as longer tool life, lower surface roughness, and reduced chatter and vibration (M. A. Lajis, 2009). These positive outcomes of preheating are coupled with an increment in the cost of machining. This increment is due to the cost of the heating device and its installation, the cost of operating it, and the cost of its maintenance. For preheated machining to be economically more preferable than room temperature machining, the yielded positive outcomes must offset the cost of incorporating the preheating mechanism.

At a first glance, one might think that the inclusion of the heating device in preheated machining always makes it costlier than room temperature machining. This may not be true, because there are several factors that affect the difference in machining cost between room temperature and preheated machining in a conflicting manner. These factors include tool life, material removal rate, power consumption, level of utilization, setup time, etc. Some of these factors make the cost of room temperature machining higher, in the same time, others make it lower. For instance, tool life tends to make preheated machining more economical than room temperature machining. However, in preheated machining, the setup time is longer (due to the heating device), and consequently, for the same span of time, less material is removed compared with room temperature machining. This makes the cost of removing a unit volume of material higher in preheated machining. Thus, it is difficult to make a judgment on the economic worthiness of one machining method over the other without a detailed cost evaluation.

1.1.2 Modeling of Machining Cost

In this research, the cost of removing a unit volume of material (RM per cm^3) under room temperature and preheated end-milling of the AISI D2 tool steel using TiAlN coated carbide and PCBN tool inserts has been evaluated. The bottom-up costing technique was adopted for this purpose. This was followed by developing parametric cost models in terms of the machining parameters (cutting speed, feed per tooth, depth of cut/preheating temperature). Thus, the bottom-up and the parametric techniques are merged; a method to eliminate the limitations of both the techniques and develop a technique that inherits the advantages of the two.

The bottom-up and parametric cost estimation techniques are the most common in practice. They are the two main techniques from which several other techniques branch out (Rajkumar Roy, 2003; Charles A. Toth, 2006; William G.S., James A.B., and Elin M.W., 2000).

With the bottom-up technique, cost of a product (or an operation) is estimated by estimating the cost of work elements at the lower levels of the work structure which are then added together to obtain the total cost of the product. With the parametric technique, the cost is estimated using Cost Estimating Relationships (CERs) that tie the cost to one or more independent variables (cost drivers). These CERs are developed based on historical data and statistical techniques.

Each of these two techniques has limitations and advantages. Accuracy is the main advantage of the bottom-up technique. In this technique, every activity is accounted for and thus, determination of a very accurate cost estimate is possible. However, it is not user-friendly and the estimation process is slow. On the other hand, the parametric cost estimation technique is generally less accurate. It uses key attributes or parameters that describe a part in a general way. Minimizing the number of attributes is the goal of the parametric technique. This makes it less accurate, but it becomes more user-friendly and faster (Charles A. Toth, 2006).

Merging the bottom-up and the parametric techniques is a way through which the limitations of the two are eliminated while their advantages are maintained. Merging these two techniques, results in the development of user-friendly and accurate parametric cost models.

Several parametric machining cost models have been proposed by previous researchers, however, they tend to be either user-friendly but not accurate, or accurate but not user-friendly.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Preheated machining was found to yield improvements in the machinability of the AISI D2 tool steel, such as longer tool life, lower surface roughness, reduced chatter and vibration, etc. On the other hand, preheated machining incorporates the cost of the heating device, its operation and maintenance. Detailed analysis is required to determine whether those improvements in machinability offset the cost of incorporating the heating device.

Due to the important role played by cost estimation in the success of manufacturing enterprises, there is an apparent need for having a technique that enables estimating the cost of room temperature and preheated machining of the AISI D2 tool steel when end-milled with TiAlN coated carbide and PCBN inserts. The relevant literature includes several techniques that can be used for this purpose; however, each has some limitations. In this research, two leading cost estimation techniques: the bottom-up and the parametric techniques are merged to develop a fairly new technique that is free from the limitations of the parent techniques and inherits their advantages.

The parametric machining cost models found in the literature have some limitations; firstly, the cost is given in terms of many input parameters for which; the user has to find data, furthermore, data for some of these input parameters are not easily obtainable. This makes the past models to be less user-friendly. Secondly, these models do not combine user-friendliness and accuracy; they tend to be either user-friendly or accurate. These limitations were overcome by the models developed in this research; they are user-friendly and accurate machining cost models. In addition to this, these models link between tool life, surface roughness, and machining cost, thus, they can answer some important questions.

1.3 RESEARCH OBJECTIVES

The objectives of this research study are as follows:

1) To examine the effect of preheating on machining cost.

2) To develop user-friendly and accurate models for estimating the cost of room temperature and preheated end-milling of the AISI D2 tool steel.

1.4 RESEARCH METHODOLOGY

The methodology of this research can be outlined as follows:

a) The relevant literature was explored to identify the cost components that make up the cost of machining.

b) Equations were established for the considered cost components to evaluate their contribution to the cost of machining.

c) The required experimental and non-experimental data were collected. Some were obtained from previous researches, some from mathematical calculations, and some were realistically assumed or estimated.

d) Machining cost was evaluated for both the machining methods considering two types of cutting tool inserts and four levels of utilization.

e) Machining costs in room temperature machining were compared with the corresponding ones in preheated machining.

f) The RSM was used to model the costs of machining in room temperature and preheated machining. The adequacy of the developed models was checked using ANOVA output.

g) Perturbation plots, response surfaces, and contour plots were used to examine the variation of machining cost relative to the machining parameters.

1.5 RESEARCH SCOPE

This research study has the following scope of work:

1) Evaluation of machining cost for both of room temperature and preheated machining considering two types of cutting tool inserts: CC and PCBN, and four levels of utilization: 15%, 25%, 80%, and 90%.
2) Comparison in machining cost between room temperature and preheated machining.
3) Use of the Response Surface Methodology (RSM) to model the cost of machining by utilizing the software Design-Expert 6.0.8.
4) Drawing of perturbation plots, response surfaces, and contour plots for the cost of machining relative to the machining parameters to examine the effect of these parameters on the cost of machining.

1.6 ORGANIZATION OF THE DISSERTATION

Chapter 1 presents the background of this research and introduces the problem and its significance. This chapter also presents the objectives and scope of this research, and gives a brief description for the methodology that was followed to accomplish the objectives of this research.

Chapter 2 gives a review of the relevant literature. It starts by presenting some of the past machining cost models; which is followed by discussing their limitations. The past techniques that are used for cost estimation and costing are briefly described in this chapter. Due to the fact that the models developed in this research can be used to build cost estimation software, the importance of computers in the field of cost estimation, and a short description for some of the commercially available cost estimation software have been included in this chapter.

In chapter 3, equations to evaluate the cost of machining are established and explained. Furthermore, the experimental and non-experimental data that were used to evaluate the cost of machining are presented.

In chapter 4, machining cost was evaluated for each of the fifteen experimental runs found in both of room temperature and preheated machining. Machining cost was evaluated for two types of cutting tool inserts and four levels of utilization. This is followed by comparing and discussing the cost of machining in both of room temperature and preheated machining. Finally, this chapter presents an analysis for the sensitivity of machining cost relative to change in the values of some of the input factors that contribute to the cost of machining.

In chapter 5, user-friendly and accurate mathematical models to estimate the cost of machining in both of room temperature and preheated machining are developed. Furthermore, perturbation plots, response surfaces, and contour plots are produced to examine the variation of machining cost relative to the machining parameters.

Chapter 6 includes the conclusions derived from this research, as well as recommendations and scope for future work.