PERFORMANCE EVALUATION OF ELECTRICAL DISCHARGE MACHINE ON TITANIUM ALLOY USING COPPER IMPREGNATED GRAPHITE ELECTRODE

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A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Mechanical - Advance Manufacturing Technology)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MAY 2010

First of all, all the praises and thanks be to Allah S.W.T for His Love,

This thesis is dedicated to my family,

To my beloved parent,

Maimunah Hj Abdullah,

My supportive wife,

Amizah Abdul

My wonderful brothers and sisters,

Hamnah Mohd Isa, Mohd Helmi Mohd Isa, Huda Mohd Isa

Norhana Mohd Isa

And last but not least to all my relatives and my close friends

Thank you very much for your unstinting help and encouragement

May Allah bless all people that I love and it's my honor to share this happiness with my love ones.

Sorry if I forgot to mention any name.

ACKNOWLEDGEMENTS

I would like to thank Allah Almighty for blessing me and giving me strength to accomplish this thesis. A special thanks and deep gratitude to my supervisor, Professor Dr. Safian Sharif who greatly helped in guiding and assisting me in every way throughout this entire project.

Many thank to all of the technicians and staff from KKTM Balik Pulau especially Mr Faiezem Ibrahim, Mr Asmar Suid, Mr. Ridwan Ramli, person in charge in Metrology Laboratory, Mr. Ashamudin Technician in Material Failure Testing and Mr. Mohzani lecturer from Department of Mechanical Engineering, USM and other technical staff for their cooperation and assistance me in the various laboratory tasks.

Lastly, I would also like to express my special thanks to my wife and my family members for their trust in me and continuously supporting me throughout this project. Less but not least, I would like to thank those who have contributed directly or indirectly towards the success of this study.

ABSTRACT

Electrical discharge machining (EDM) which is very prominent amongst the non conventional machining methods is expected to be used quite extensively in machining titanium alloys due to the favorable features and advantages that it offers. This thesis presents the EDMing of titanium alloy (Ti-6246) using copper impregnanted graphite electrode with diameter of 8 mm. The main purpose of this study was to investigate the influenced of various parameters involved in EDM on the machining characteristics, namely, material removal rate (MRR), electrode wear ratio (EWR), surface roughness (Ra) and overcut.

In this investigation, the machining trials were performed using a Sodick linear motor EDM sinker series AM3L The experimental plan for the processes were conducted according to the design of experimental (DOE) and the results were statistically evaluated using analysis of variance (ANOVA). Results showed that current was the most significant parameter that influenced the machining responses on EDM of Ti-6246.

Confirmation tests were also conducted for the selected conditions for each machining characteristics in order to verify and compare the results from the theoretical prediction using Design Expert software and experimental confirmation tests. Overall, the results from the confirmation tests showed that the percentage of performance was acceptable due to all results obtained were within the allowable values which was less than 15% of marginal error.

ABSTRAK

Proses pemesinan nyahcas elektrik (EDM) yang agak dominan di antara proses pemesinan bukan konvensional dijangkakan akan bertambah meluas penggunaannya disebabkan sifat-sifat dan kelebihan yang dihasilkan keatas bendakerja. Kajian yang dijalankan ini adalah mengenai pemesinan EDM *sinker* terhadap bahan aloi titanium (Ti-6246) dengan menggunakan *copper impregnanted graphites* yang berdiameter 8 mm sebagai elektrod. Tujuan utama kajian ini adalah untuk mengkaji kesan beberapa parameter yang terlibat dalam EDM proses terhadap kriteria pemesinan seperti kadar pembuangan bahan (MRR), nisbah kehausan elektrod (EWR), kekasaran permukaan (Ra) dan '*overcut*'.

Dalam kajian ini, pemesinan yang dijalankan ke atas titanium dilakukan menggunakan *Sodick linear motor EDM series AM3L*. Ujian pemesinan untuk kedua-dua proses telah dinilai secara statistik menggunakan analisa variasi (ANOVA). Keputusan menunjukkan arus lektrik merupakan parameter yang paling signifikan yang mempengaruhi tindak balas pemesinan EDM ke atas Ti-6246.

Ujikaji pengesahan juga telah dijalankan bagi tujuan pengesahan dan perbandingan keputusan di antara nilai ramalan teori menggunakan perisian *Design Expert* dengan nilai yang diperolehi dari ujikaji. Secara keseluruhan, keputusan pengesahan ujikaji menunjukkan bahawa kesemua peratusan ralat perbezaan yang diperolehi berada di dalam lingkungan nilai yang dibenarkan iaitu peratus ralat kurang daripada 15%.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	-	Analysis of variance
CCD	-	Central composite design
CMM	-	Coordinate measuring machine
EDM	-	Electro discharge machining
EWR	-	Electrode wear rate
EWW	-	Weight of electrode used
MRR	-	Material/metal removal rate
RSM	-	Response surface methodology
SR	-	Surface Roughness
Tm	-	Machining times
Wa	-	Weight of workpiece after machining
Wb	-	Weight of workpiece before machining
WRW	-	Weight of workpiece used
x1,x2, x3,…,xk	-	Input variables
α	-	Alpha phase
β	-	Beta phase

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CHAPTER 1

INTRODUCTION

1.1 Overview

The use of light, thin and compact mechanical elements has recently become a global trend. The search for new, lightweight material with greater strength and toughness has led to the development of new generation of materials such as titanium and nickel alloys, although their properties may create major challenges during machining operations. Having greater hardness and reinforcement strength, these materials are difficult to machine by the traditional methods. Although these materials can be machined conventionally, sub surface damages such as metallurgical alterations, work hardening, delimitation and microcracks and others can occur under certain circumstances which cause a detrimental effect on the performance of the machined component. Since the cost of using conventional machining is generally prohibitive, non-conventional machining such as electric discharge machining (EDM) and laser machining probably amongst the ideal technique in dealing with these materials.

Most titanium alloys and component design characteristics make them expensive to be machined and historically, titanium has been perceived as a material that is difficult to machine (Ezugwu, E.O and Wang, Z.M. 1997). Due to titanium's

growing acceptance in many industries, along with the experience gained by progressive fabricators, a broad base of titanium machining knowledge is now exist. It was reported that commercially pure grades of titanium [ASTM B, Grades 1, 2, 3, 4] (ASM International, 1988) can be machined much easier than aircraft alloys.

Although titanium alloys is tough it can experienced sub-surface damaged during machining operations. Damage appears in the form of microcracks, built up edge, plastic deformation, heat affected zones and tensile residual stresses **(**Sharif, 1999; and Hong *et al*., 2001**)**. In service, these can lead to degraded fatigue strength and stress concentration.

Non-traditional machining of metal removal such as EDM expected to be used extensively years to come, because it's favorable results. It is particularly useful for rapid removal of metal of free form surface or complex shaped parts, thin sections, and from large areas down to shallow depths. This process has less damaging effect on the mechanical properties of the metal (Rival, 2005).

1.2 Background of Research

EDM is a non-traditional concept of machining which has been widely used to produce dies and molds. It is also used for finishing parts for aerospace and automotive industry and surgical components. This technique has been developed in the late 1940s (Norliana Mohd Abbas *et al*., 2006).where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid (Norliana Mohd Abbas *et al*., 2006).

This process is finding an increasing demand owing to its ability to produce geometrical complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. EDM has proved its

capability especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys (Rival, 2005). The process variables include not only the electrical but also non-electrical parameters, which have received quite a substantial amount of research interest.

Optimum selection of process parameters is very much essential, as this is a costly process to increase production rate considerably by reducing the machining time. Several researchers carried out various investigations for improving the process performance. As EDM is a very complex and stochastic process, it is very difficult to determine optimal parameters for best machining performance, i.e., productivity and accuracy (T. A. El-Taweel, 2009). Material removal rate, tool wear, surface finish and also overcut are most important output parameters, which influence the cutting performance. But these performance parameters are conflicting in nature. The higher the MRR, the better, whereas the lower the tool wear, the better. In a single objective optimization, there exists only one solution. But in the case of multiple objectives, there may not exist one solution, which is the best with respect to all objectives. In EDM process, it is difficult to find a single optimal combination of process parameters for the performances parameters, as the process parameters influence them differently. Hence, there is a need for a multi-objective optimization method to arrive at the solutions to this problem.

The published literature indicates that few studies have been reported for the optimization of process parameters in EDM. Therefore, this study is aims at investigating the best performance of various input process parameters in EDM die-sinking process of Ti-6246. Further, no technology tables or charts are available for EDM of titanium alloy (Ti-6246) using copper graphite electrode. Therefore, it is imperative to develop a suitable technology guideline for appropriate machining of Ti-6246. Electrodes with copper graphite, peak current, servo voltage, pulse on time and pulse off time are considered as input EDM machining parameters. The process performance such as material removal rate (MRR), surface roughness (SR), overcut and electrode wear rate (EWR) were evaluated.

1.3 Statement of the research problem

How does a new developed electrode performed when EDM alpha beta titanium alloy Ti-6246 with respect to material removal, electrode wear, dimensional hole accuracy and surface finish.

1.4 Research Question

a. What are the machining parameters that influence the EDMing of Ti-6246 using copper impregnanted graphite electrode.
b. What are the significant parameters that influence to the responce during EDM of Ti-6246.
c. What correlations exist among the parameters and machining responses and also how to quantify.
d. What mathematical model is suitable to represent the performance evaluation of EDMing Ti-6246.

1.5 Objectives

The objectives of the study are:

a) To evaluate the performance of copper Impregnated graphite electrode when Electro-Discharge Machining Ti-6246 with respect to various machining responses.

b) To determine the significant parameters that influences the machining responses during Electro-Discharge Machining of Ti-6246.
c) To establish mathematical model for the MRR, EWR and surface finish during EDM of Ti-6246 using DOE approach.

1.6 Scope of study

a) Machining responses to be investigated are material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR) and overcut.
b) Electro-Discharge Machining (Die sinking) AM3L SODICK will be employed.
c) Alpha-beta alloy, Ti 6Al 2Sn 4Zr 6Mo (Ti-6246) will be selected as workpiece material.
d) Copper impregnated graphite will be used as the EDM electrode.
e) Kerosene will be used as the dielectric fluid.

SOFTWARE DEVELOPMENT OF CONCURRENT DESIGN FOR MANUFACTURING PROCESS SELECTION OF PLASTIC MATERIALS

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical – Advanced Manufacturing Technology)

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MAY 2010

To my beloved family Mohd Yunus Bin Ibrahim, Selamah Binti Hasan and my wife Noor Jihan Binti Harun. Thanks for all your support.

ACKNOWLEDGEMENT

Alhamdullilah, thank to Allah, because of Him we are still here, breathing His air, pleasuring His entire gift in this world. And most of all, for giving me opportunities to learn His knowledge.

This work was supervised by Dr. Ariffin B. Abdul Razak from Universiti Teknologi Malaysia. I greatly appreciate all his helps and guidances.

I am indebted to my parents, Mohd Yunus B. Ibrahim and Selamah Bt. Hasan and my wife Noor Jihan Bt. Harun, without whose help, encouragement and patience I would never have gotten this thesis completed and who made it all worthwhile. Thanks to all classmates on your sincere and solid support also to management part of Kolej Kemahiran Tinggi MARA Balik Pulau.

Finally, thank you to all the other people who have supported me during the course of this work.

ABSTRACT

For plastic products, one of the most critical decisions made during the early design stage is the selection of an appropriate manufacturing process. Designers or engineers must concurrently select the suitable plastic materials and its processing method while they develop the part geometry. It is thus meaningful to develop such a system for helping the engineers at preliminary design stages. This project proposes a system of selecting suitable manufacturing processes and materials in concurrent design for manufacturing environment. The prototype system called PROSEP, use Boothroyd-Dewhurst DFM methodology in evaluating and selecting suitable manufacturing process/material. Visual Basic computer programming language is used as a tool for system development. Three major factors are considered; shape attributes of part, material requirements and production characteristics. The working of the prototype system is demonstrated using prismatic and rotational parts case study.

ABSTRAK

Untuk produk plastik, satu daripada keputusan paling kritikal dibuat semasa permulaan peringkat reka bentuk adalah pemilihan satu proses pembuatan yang sesuai. Para jurutera mesti serentak memilih bahan-bahan plastik yang sesuai dan cara pembuatannya manakala mereka membangunkan bahagian geometri. Oleh itu adalah amat bermakna bagi membangunkan satu sistem yang boleh membantu jurutera-jurutera pada permulaan fasa reka bentuk. Projek ini mencadangkan satu sistem untuk memilih proses-proses pembuatan dan bahan-bahan yang bersesuaian dalam reka bentuk serentak untuk bidang pembuatan. Sistem yang dinamakan PROSEP, menggunakan kaedah Boothroyd-Dewhurst DFM dalam menilai dan memilih proses pembuatan atau bahan yang munasabah. Bahasa pengaturcaraan Visual Basic digunakan untuk pembangunan sistem. Tiga faktor utama diambil kira; sifat-sifat bentuk bahagian, syarat-syarat bahan dan ciri-ciri pengeluaran. Penggunaan sistem prototaip ini ditunjukkan menggunakan kajian kes komponen prismatik dan putaran.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to the Problem

Plastic materials have become an essential necessity in all aspect of today's recent life. Plastics are replacing most of the materials today due to good mechanical, chemical and thermal properties. Plastics are found on various products ranging from housing appliances, telecommunication equipment, electronics product, clothing and commercial market. One of the reasons for the great popularity of plastics in a wide variety of industrial applications is the great range of properties exhibited by plastics and their ease of processing (Harper, 2006).

Plastic properties can be modified to meet particular needs by changing the atomic composition of the repeat structure, by changing molecular weight and molecular weight distribution. The flexibility can also be varied through the existence of side chain branching, via the lengths and polarities of the side chains. Figure 1.1 shows the example of plastic products that very common used in modern life.

Figure 1.1: Typical plastic products

The importance of process and materials selection in designing plastic products has increased in recent years. The adoption of concurrent design methods and Design for Manufacturing has brought design engineers into the design process at an earlier stage. The selection of plastics material and an appropriate manufacturing process for a specific application is always a challenging task. Wrong process and material selection lead to product failure. In this situation, one of the most important tasks for engineers or designers is process and material selection at the early stages.

Some plastic processes can readily produce certain classes of shape attributes, but it may be very costly, or even impractical, to realize other classes of shape attributes. Furthermore, some processes may be totally unsuited with certain materials. As a result, together with the selection of materials, process selection becomes a very important decision before designers continue to the design of detailed geometry.

As a design engineers, they requires general knowledge of the part design, process limitations, advantages and disadvantages, success and failure affect with a collective practical significance of design and manufacturing process. Plastic product

can be manufactured by employing a wide variety of manufacturing processes such as blow moulding, structural foam moulding, injection moulding, rotational moulding, and thermoforming. Each plastic manufacturing process has individual advantages and disadvantages. The manufacturing process also affects productivity, cost, and quality of the part.

By tradition, the decision to choose an appropriate manufacturing process is delegated to an expert who employs a complex reasoning process based on empirical knowledge and previous experience. This selection procedure may result in inconsistent or poor choices if the decision is made by a novice who fails to map correctly the product characteristics with the manufacturing efficiency of various manufacturing processes (Raviwongse *et al.,* 2000).

In order to select the most suitable material and process, a lot of methods and techniques has developed, but only a few work has been done in developing a computer-aided software that accommodates information about different plastics processes, evaluates the appropriateness of each process with the design engineer's needs, and assist in selecting the most appropriate process. As a result this project has tried to contribute on this issue to help an engineer at the early design stage.

1.2 Objective of Study

The main objective of this project is to develop the prototype system for concurrently selecting the plastic materials and its processing method while attributes of the part are considered.

1.3 Scopes of Study

The scope of work is clearly defined the specific field of the research and ensure that the entire content of this project is confined the scope. Scopes of this project are limited to:

i. Concentrate on plastic materials in term of process selection of material properties for thermoplastics, thermosets and elastomers.
ii. Use Boothroyd-Dewhurst DFM methodology to do the process selection.
iii. Use Visual Basic computer programming language for system development.

1.4 Methodology of Study

The methodology of study begins with literature review on existing materials selection and manufacturing processes procedures. The next step is review on manufacturing processes capabilities and plastic material properties. At this stage all the advantages, disadvantages and limitations of processes and materials are analysed. The analysis or selection of processes and materials are done using Boothroyd-Dewhurst DFM methodology.

Visual Basic computer programming software is used as a tool for prototype system development. This stage is the critical part of the study that involved with develops the graphical user interface and writes the program coding. Finally, the verification of the prototype software will be done by doing the case studies of prismatic and rotational parts. It can be described in terms of flowchart as the following Figure 1.2

while Gantt charts as shown in Appendix A show the detail of the works of the project that had been implemented in the first and second semesters.

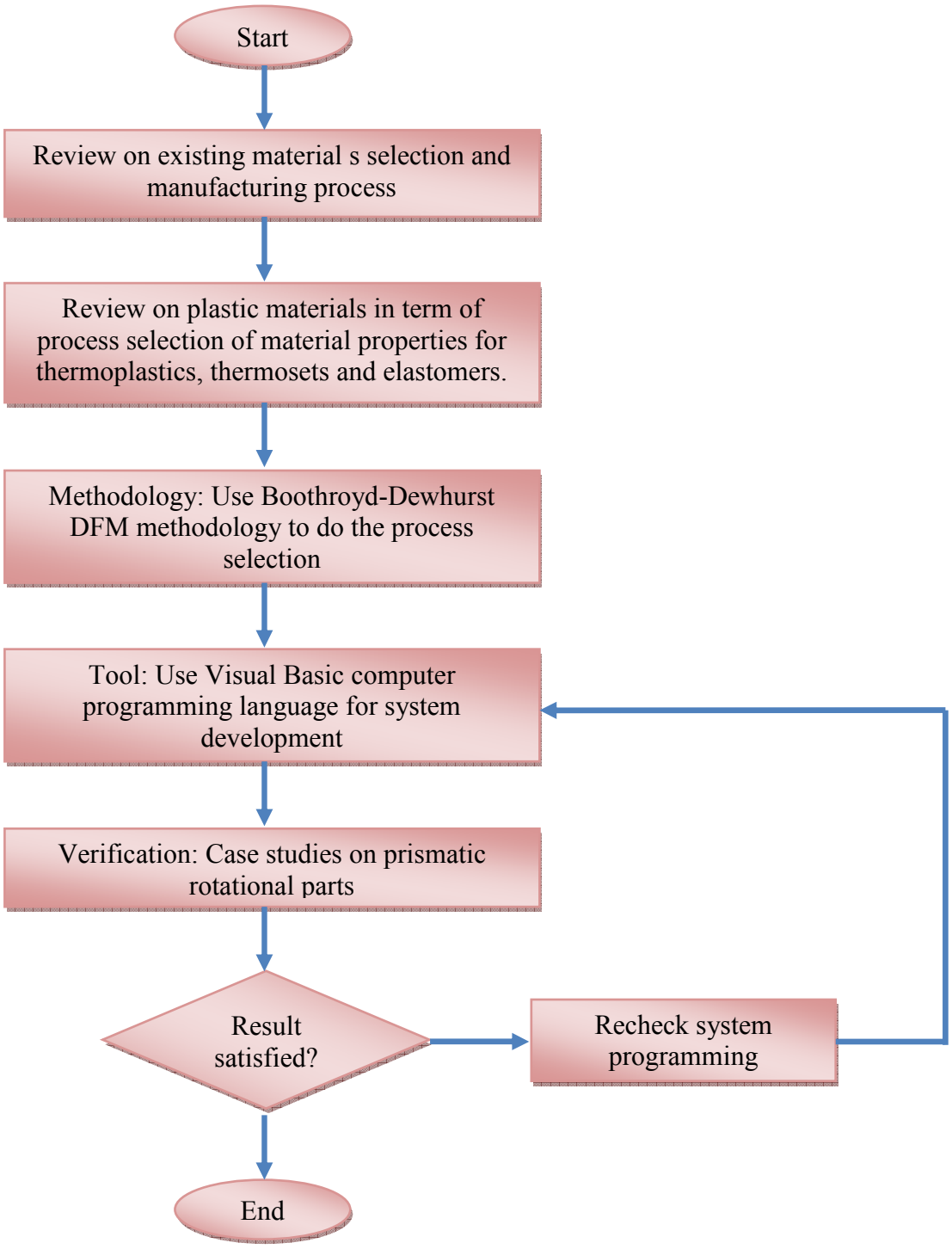

Figure 1.2: Flowchart represents the methodology of study

1.5 Significant of Study

The use of prototype software, PROSEP (Process Selection of Plastic Materials) should help the designers or engineers to select a manufacturing process for engineering plastics effectively. On the other hand, this prototype software can also be used as a teaching tool or as guidance to the inexperienced designer or student in manufacturing processes and plastic materials selection. The design of a part is often iterative in environment, but by using PROSEP software, major design drivers can be identified early in the design stages, and improvement can be simply and economically made.

1.6 Thesis Structure

The thesis presents the software development for concurrent design for manufacturing process selection of plastic materials. This thesis consists eight chapters. In first chapter, it discusses generally an introduction to the problem, objective, scopes and significant of this project as long as summary of works.

Chapter 2 focuses on the literature review, which introduces the overview on Design for Manufacturing and Assembly. Then the detail discussion and explanation on manufacturing process capabilities for plastic materials are covered. The discussion covers six processes namely injection moulding, blow moulding, structural foam moulding, rotational moulding, thermoforming and machining. Besides, the types of plastic materials; thermoplastics, thermosets and elastomers and related properties also discussed in details. This chapter is then described by related researches on existing software or procedures which are found to be related and facilitate to this project.

Chapter 3 provides the Boothroyd-Dewhurst DFM methodology. It well discusses about the technique on process and material selection refers to Boothroyd-Dewhurst DFM methodology. It also discusses on factors that are considered in process and material selection. Chapter 4 deals with the tool that is used to develop the prototype software. It discusses about Visual Basic software. In Chapter 5, it provides the methodology that is used through out the work of this project. It covers the software development methodology in terms of prototype software structure and graphical user interface.

Chapter 6 will focuses on verification of prototype software. The case studies on prismatic and rotational parts will discuss on this chapter. On the other hand, the software capabilities also are explained. The result of case studies and discussions on that result will be presented in Chapter 7. Last but not least, Chapter 8 presents the conclusions of the project as well as some constructive suggestions for further development of this project. The project outcomes are concluded in this chapter.

1.7 Summary

In this chapter, the background of the project, objective, scopes, methodology of study and significant of study were discussed. The structure of the thesis also was presented in general overview of the contents for each of chapters.