CUTTING PERFORMANCE OF DIFFERENT COATINGS DURING MINIMUM QUANTITY LUBRICANT MILLING OF AA6061T6

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Report submitted in partial fulfillment of requirements
for award of the Degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

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SESI PENGAJIAN: 2012/2013

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Dedicated to my father, Khairolazar Kamarulzaman, my beloved mother, Rahimah bt. Yaakop, my family and my fellow friends.

ACKNOWLEDGEMENTS

I would like to show my highest gratitude to the almighty for blessing me in finishing the project. I am grateful and would like to express my sincere gratitude to my supervisor Assoc. Professor Dr. Md. Mustafizur Rahman his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to Madam Najiha for her excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I offer my regards and blessings to all of those who supported me especially my family and friends in any respect during the completion of the project. All of their help are very significant to the success of this project. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This report presents an experimental investigation on the effects of output parameters which are surface roughness, tool wear and material removal rate during machining aluminum alloy 6061-T6 using minimum quantity lubricant (MQL) technique. The minimum quantity of lubrication technique was becoming increasingly more popular due to the safety of environment. The cutting speed, depth of cut, feed rate and MQL flow rate were selected input parameters in this study. This experiment was conducted based on central composite design (CCD) method. To develop a model of process optimization based on the response surface method. MQL parameters include nozzle direction in relation to feed direction, nozzle elevation angle, distance from the nozzle tip to the cutting zone, lubricant flow rate and air pressure. To achieve a maximum output parameters based on the optimized process parameters for coated carbide cutting tools (CTP 2235). The surface roughness was increased with decrease of cutting speed. The optimum cutting condition for MQL and flooded are obtained. For MQL, the feed rate, depth of cut, cutting speed and MQL flow rate are 379 (mm/tooth), 2 (mm), 5548.258 (rpm) and 0.333 (ml/min) respectively. For flooded, the feed rate, depth of cut, cutting speed and MQL flow rate are 379 (mm/tooth), 2 (mm) and 5563.299 (rpm) respectively. It was seen that a majority of coated carbide inserts had a long tool wear when exposed to high cutting speed, and feed rate leading to breakage of the inserts.

ABSTRAK

Laporan ini membentangkan siasatan ujikaji mengenai kesan parameter pengeluar iaitu kekasaran permukaan, pemakaian alat dan kadar penyingkiran bahan semasa pemesinan aloi aluminium 6061-T6 menggunakan minimum kuantiti pelincir (MQL) teknik. Teknik minimum kuantiti pelinciran menjadi semakin popular kerana keselamatan alam sekitar. Kelajuan pemotongan, kedalaman pemotongan, '*feed rate*' dan kadar aliran MQL dipilih menjadi parameter kemasukan dalam kajian ini. Eksperimen ini telah dijalankan berdasarkan reka bentuk komposit pusat (CCD) kaedah. Untuk membentuk model pengoptimuman berdasarkan kaedah gerak balas permukaan. Parameter MQL termasuk arah muncung berhubung dengan makanan haiwan arah, sudut ketinggian jarak muncung dari hujung muncung ke zon pemotongan, kadar aliran pelincir dan tekanan udara. Untuk mencapai parameter pengeluar maksimum berdasarkan proses parameter dioptimumkan untuk bersalut alat pemotong karbida (CTP 2235). Kekasaran permukaan telah meningkat dengan penurunan kelajuan pemotongan. Keadaan pemotongan optimum untuk MQL dan '*flooded*' diperolehi. Untuk MQL, '*feed rate*', kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 (mm / gigi), 2 (mm), 5548,258 (rpm) dan 0.333 (ml / min) masing-masing. Untuk '*flooded*', '*feed rate*', kedalaman potongan, kelajuan pemotongan dan kadar aliran MQL adalah 379 (mm / gigi), 2 (mm) dan 5563,299 (rpm) masing-masing. Ia dilihat bahawa majoriti '*insert*' bersalut karbida mempunyai pemakaian alat yang lama apabila terdedah kepada kelajuan pemotongan yang tinggi, dan '*feed rate*' yang membawa kepada kerosakan kepada '*inserts*'.

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LIST OF SYMBOLS

RPM	Revolution per minute
v_c	cutting speed
f_r	feed rate in mm/rev
f_t	Feed rate in mm/tooth
n	Number of the teeth of cutter
R_a	Average surface roughness
L	Sampling length
CS	Cutting speed
mm^3/min	Millimetre cubic per minute
mm	Millimetre
μm	Micrometre
N	RPM of Cutter
W	Width of cut (may be full cutter or partial cutter)
t	Depth of cut
L	Length of pass or cut
f_m	Table (machine) Feed
D	Cutter Diameter in mm

LIST OF ABBREVIATIONS

MQL	Minimum quantity lubrication
RSM	Response surface method
CNC	Computer numerical control
TiC	Titanium carbide
TiCN	Titanium carbon nitride
TiN	Titanium nitride
PVD	Physical vapour deposition
CVD	Chemical vapor deposition
WOC	Width of cut
DOE	Design of Experiment
RPM	Revolution per minute
WC	Tungsten carbide
Ra	Average roughness
MRR	Material Removal Rate

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Manufacturing in general term is the use of machine, tools and labor to produce things for sale. In this field of expertise, the competition is indeed fierce and manufacturer have to produce new products in a very short time and with reduced costs, whereas customers require more and more quality and flexibility, as explained by Kebrat et al. (2010). Manufacturing usually occur in large scale that involve mass of production. Beside the manufacturers in the competitive marketplace because of the manufacturing environment, low costs, goals of high rates of production, and high quality. The minimization of cutting fluid also leads to economic benefits by way of saving lubricant costs and workpiece/tool/machine cleaning cycle time (Dhar et al., 2006). In order to improve the traditional manufacturing, many technologies are developed and it's cause many machine are created as well as tool itself. There are many types of machine and tool that are used to process the material in manufacturing process. Some of them may involve high cost to operate the process such as cost of machine, cost of maintained, energy consumption, labor and so on. Therefore, in mass production, there is important to consider the economic aspect due to make the industry profitable and growth. Many traditional techniques and hybrid methodologies are developed to make the manufacturing process more effective by many ways such as directly assess the machining performance (Jawahir et al., 2003).

An ultimate machine required ultimate tool to operate at full of performance. We can use high quality of material to created better tool for example by using TiN-coated carbide cutting tool as it can stand at high temperature, high cutting-speed and it was prove that can improve the tool life. The coated tools are used more than 40% in industry and perform more than 80% to all machining use (Cselle and Barimani, 1995). However, the performance of that cutting tool is depending on many variable of cutting condition.

This project focused the technique of minimum quantity lubrication performed for machining of AA6061T6 using coated carbide tool and CNC end milling machine. The mechanical properties for AA6061T6 depends on the greatly on the temper, or heat treatment, of the material. The aluminum offers advantages over other materials because of its relatively low density, high recyclability, design flexibility in mass production and economic benefit (Chu and Xu, 2004). Besides that, the aluminum with increasing concern of fuel economy and stringent government emission regulations, light weight materials, specifically aluminum, are being extensively adopted by design engineers for structural components. Surface finish is essential factor in evaluating the quality of products and surface roughness (R_a) most used index to determine the surface finish. The response surface method (RSM) as a statistical method that been used to optimize the surface responses. The RSM quantifies the relationship between response surfaces and input parameters. Fuh and Hwang (1997) constructed a model that can predict the milling force in end milling operations by using RSM method. They measured the speed of spindle rotation, feed per tooth and axial and radial depth of cut as the three major factors that affect in milling operation. The authors had made a comparison between the experimental data and the values predicted by this prediction model showed the model's accuracy to be as high as 95%. In this experiment focuses on best usage of machining AA6061T6 and coated carbide in respect to the cutting force, tool life and surface roughness using the RSM approaches in the CNC milling machine as explained by Fuh and Hwang (1997).

1.2 PROBLEM STATEMENT

Performance of milling machine almost depending in how fast the machine can cut the work piece, meaning that even a slight change in machining element such as implementing a suitable coating on the cutting tool could improve the machinability of a material (Chattopadhyay et al., 2009). High productivity needed high rate of metal removal, so it will reduce manufacturing cost and operation time. The large amount of the cutting fluid contain potentially damaging or environmentally harmful possibly damaging chemical elements that can expose skin and lung disease to the operators plus air pollution (Sreejith (2008) . The minimal quantity lubrication (MQL) will be used in our experiment compare another cutting fluid. MQL in an end-milling process is very much effective regarding (Lopez de Lacalle et al., 2001) and they mentioned that MQL can reach the tool face more easily in milling operations compared with other cutting operations. AA6061-T6 is more suitable choice due to its cost-efficient element (MacMaster et al., 2000) and economical aspect has always been important when it came to mass production while there is more material such as aluminum alloy AA 6069 (Chu and Xu, 2004). Ghani et al (2004) investigated that the coating typically reduced the coefficient of friction between the cutting tool and reduce the tool wear. Eventually, sudden failure of cutting tools lead to loss of productivity, rejection of parts and consequential economic losses. The coated carbide tool is to be considered in this study to evaluate the performance of a machining process depends on tool wear or tool life.

1.3 OBJECTIVES OF THE PROJECT

The objectives of this project are as follows:

i. To experimentally investigate the machining characteristics of aluminum alloy in end mill processes for MQL techniques.
ii. To investigate of coated carbide cutting tool performance on surface finish by using MQL method.
iii. To study the tool wear and the material removal rate regarding the MQL technique.

1.4 SCOPE OF THE STUDY

i. Using CNC milling machine to operate the end milling on AA6061T6 by coated carbide using MQL.

ii. Determine optimum performance of coated carbide cutting tools in milling operation by vary machining parameter which is cutting speed, feed and depth of cut.
iii. Design of experiments and optimization model is prepared using MiniTab software.
iv. Mathematical model using Response Surface Method (RSM).

1.5 ORGANIZATION OF REPORT

There are five chapters including introduction chapter in this study. Chapter 2 presents the literature review of previous studies includes the end milling, process parameters, response parameters, prediction modelling. Meanwhile, Chapter 3 discusses the design of experiment, preparation of experimentation, mathematical modeling techniques and statistical methods. In Chapter 4, the important findings are presented in this chapter. Chapter 5 concludes the outcomes of this study and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to milling process, CNC milling machine, cutting parameters in milling machine, and cutting tools. This chapter also involves a review some research studies like the statistical method and artificial neural network which are related to the mathematical modelling the present study. Substantial literature has been studied on machinability of aluminum alloys which is covers on surface roughness, tool life, tool wear cutting force and chip formation. This review has been well elaborate to cover different dimensions about the current content of the literature, the scope and the direction of current research. This study has been made in order to help identify proper parameters involved for this experiment. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 END MILLING

Milling is the most common form of machining process used in the production of moulds/dies, due to the high tolerances and surface finishes by cutting away the unwanted material. A serious attention is given to accuracy and surface roughness of the product by the industry these days (Nagallapati et al., 2011). Surface finish has been one of the important considerations in determining the machinability of materials. In end milling process, the end-milling cutter are discretized into limited number of elements, and the forces exerted by each element regarded as oblique cutting are calculated (Wang et al., 2004) By summing up the cutting forces generated by elemental edges, the instantaneous cutting forces of end milling can be determined. Wang et al. (2004) also stated that the end-milling operation is an oblique cutting process. There have been a lot of important factors to predict machining performances of any machining operation, such as surface roughness and dimensional accuracy. Ibraheem et al. (2008) investigated the effect of cutting speed, feed, axial and radial depth of cut on cutting force in machining of modified AISI P20 tool steel in end milling process. They concluded that, higher the feed rates, larger the cutting forces. They also developed the genetic network model to predict the cutting forces. Abou-El-Hossein et al. (2007) developed the model for predicting the cutting forces in an end milling operation of modified AISI P20 tool steel using the response surface methodology. End milling has been the most versatile form of milling for quite and the fact that it can be used to machine slots, shoulders, die cavities, contours, and profiles is indeed magnificent. It is one of the most common processes in product manufacturing and is very commonly employed in a lot of machines (Li and Li, 2004). However numerical control machines are the kind of machine that had been employed for material removal operations. Li and Li (2004) later also added that the prediction of cutting forces in milling is of fundamental importance in order to establish optimization of the cutting processes. There were many force models developed for milling processes. However, despite the increased sophistication and usefulness of the models developed in recent years, the predictive capability of the force and surface error predictions rely on the empirically established milling force component coefficients for each cutter design. Usually there are a lot of other limitations can be prevented by modeling a milling force in a more scientific nature. Based on the research carried out by Wang et al. (2004), the precise metal cutting has become more and more important for productivity and reliability requirement for modern industry. There are a lot of sources when it comes to the causes the vibration in cutting process. Dynamic change in cutting force is one of the major sources causing the vibration in cutting process. The result of this phenomenon is that the machining accuracy will be deteriorated. Thus, accurate modeling of cutting forces is necessitated for the prediction of machining performance and to determine the mechanisms and machining parameters that affects the stability of machining operations. Referring to all the facts including the difficulty of measuring the length of shear line and to represent it as a function of measurable variables, the linear force model that is proportional to undeformed chip thickness has been widely used in analysis and simulation (Wang et al., 2004).

Figure 2.1 shows cutting force coefficients and cutting force models (Dang et al. 2010). Cutting force coefficients are determined directly from milling tests, using a specific cutter / work piece combination in this direct calibration method. The cutting forces were presumed to be directly proportional to the uncut chip thickness, which somehow explained that in other words, the cutting force coefficients were constants. The non-linear connection exists between the cutting forces coefficients and the prompt uncut chip thicknesses. The cutting force coefficient has the tendency to increase quickly as the instantaneous uncut chip thickness becomes smaller. This is the so-called size effect, which to put it simply is vice-versa, where the cutting force would be much weaker when the chip thickness where to be larger in size. The designated feed per tooth is large enough and the employed radial depth of cut is identical, the total cutting forces will be roughly in quantity to the flank instantaneous uncut chip thickness under the condition that only the first disc element of any edge is in cut at the prime phase of each tooth period. Sun et al. (2009) explained that the ball-end milling is widely used in machining parts with curved geometries such as die, mould, propellers and turbine blades. There are bound to be challenges and difficulties in whatever the system that has to work with and with that, regardless of the emergence of many advanced CAM systems, machining of complicated surfaces is still acknowledged as a challenge. All these little elements had no doubt contributes to high demand for tolerance, roughness and more often than not, it affects the machinability of difficult-to-cut materials. The cutting force modeling has become an essential step to understand the behavior of cutting process and it can serve as a stepping stone to further ensure the stability of machining system and the optimization of process parameters.

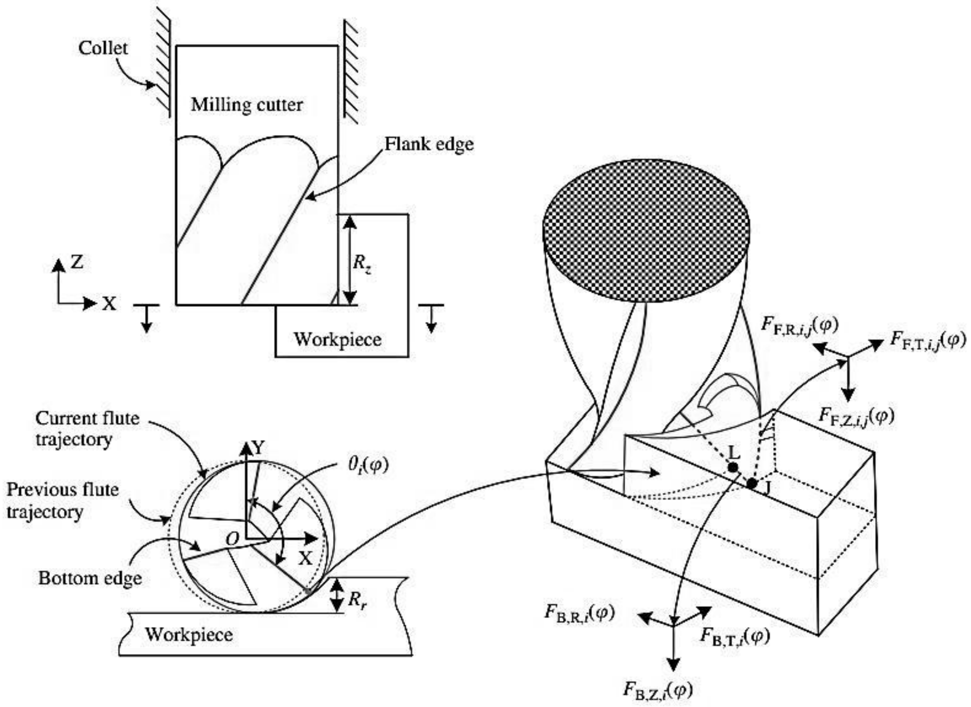


Figure 2.1: Modeling of flat end milling

Source: Dang et al. (2010)

Figure 2.2 shows a chip load distribution model in end milling where another investigation to reveal the relationship between the cutting force and cutting depth, the change of cutting force at the instant when a flute passes point *p* was examined. There are supposedly a lot of things to be considered in this issue. However, in this case, seven engagement cases were established within the range of cutting depths being considered. The behavior of chip loads for these cases were examined in a similar manner as described above. Based on this study, the initial conclusion is that the cutting force at the instant when a flute passes point *p* is at a maximum for most cutting conditions. Generally speaking, there are many factors and causes that may affect CNC machining result many aspects including the form error. The final deviation is the combined result of errors in CNC machine tool elements (geometry, orientation, and relative motion), errors in control (servo and NC program), errors from structural compliance (tool, machine tool, and fixture), and environmental effects (temperature). The form of error in ball milling has been dominated by tool deflection, particularly in the precision milling machining process. Li and Li (2004) also experimenting about the predictive force model for which oblique cutting can be established by using a machining theory in which the cutting forces can be calculated from the input data of workpiece material properties, tool geometry and cutting conditions. The study and analysis of the stress distribution and tool chip interface had always been the basis of the theory. The shear plane and the tool chip interface are estimated to be a direction of maximum shear stress and maximum shear strain rate. The end milling process where it’s consists of a cylindrical cutter that has multiple cutting edges on both its periphery and tip, permitting end cutting and peripheral cutting. These cutting edges or flutes are usually made helical to reduce the impact that occurs when each flute engages the work piece.

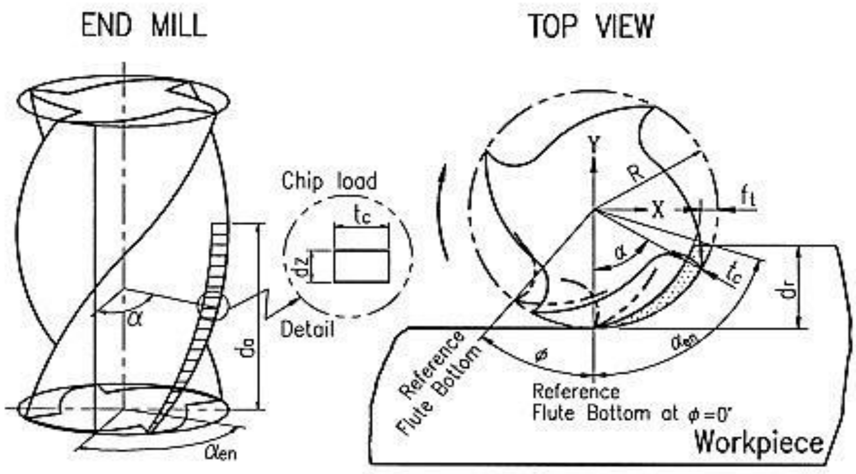


Figure 2.2: Chip load distribution model in end milling.

2.3 RESPONSE SURFACE METHOD

Many researchers have conducted studies on predicting cutting forces produced in machining operations using theoretical and analytical approaches. The response surface method is a powerful reliability method that approximates the limit state function with a polynomial expression using the values of the function at specific points, explained Allaix and Carbone 2011. The difficulties with these methods are that they are grounded on a big number of estimations that are not included in the analysis. This may reduce the reliability of the calculated cutting force values found by these methods. In addition, these approaches may be successfully applicable only for certain ranges of cutting conditions (Kadirgama et al. 2008). The authors had describe in detail regarding the present study regarding the effect of simultaneous variations of four cutting parameters (cutting speed, feed rate, radial depth of cut and axial depth of cut) on the behavior of cutting forces. The response surface methodology (RSM) is utilized. RSM is statistical techniques that are useful for modeling the relationship between the input parameters (cutting conditions) and the output variables, as elaborated by Kadirgama et al. (2008). RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. RSM has been extensively used in the prediction of responses such as tool life, surface roughness and cutting forces. As we all know, The RSM is used to build the relationship between the input parameters and output responses, and used as the fitness function to measure the fitness value of the genetic algorithm (GA) approach. The GA is later applied to find the optimal parameters for a milling process. The experimental results show that the integrated approach does indeed find the optimal parameters that result in very good output responses (Hou et al., 2007).

2.4 INPUT PARAMETERS

There are many input cutting parameters that need to be considered in end milling process such as nose radius, cutting speed, depth of cut, federate and many more. The range of these input parameters need to be carefully determine as it will directly affect the output parameters later on the experiment.

2.4.1 Cutting Force

According to Li and Liang (2006), the know-how of cutting forces is a requirement to cutting temperature estimation, tool life prediction, cutting process planning, and chatters analysis. Many researchers have conducted studies on predicting cutting forces produced in machining operations using theoretical and analytical approaches (Abou-El-Hossein et al., 2007). Cutting force is the acknowledged factor that influences the most on the milling operation performance. Thus, prediction of cutting forces before real machining can provide key guidelines to the planning and optimization of cutting process (Wei et al., 2011). It is crucial to create a set of predictive thermo-mechanical models in order to predicting the cutting forces as functions of near dry lubrication parameters and cutting conditions. The most documented studies on near dry machining were empirical and qualitative. Despite the fact that the evaporative heat transfer model is created for near dry machining, there is no experimental evidence was presented whatsoever. Since Yang and Park first developed a cutting force model for ball end milling, many contributions to modeling and/or predicting of the cutting force for ball end milling have been develop (Yang and Park, 1991). The shear angle and chip thickness do not vary considerably with tool wear. The cutting forces can also be calculated as the summation of the forces attributed to the sharp tool and the forces attributed to the tool flank wear. In near dry machining, in order to achieve the cooling effect, a moving heat source method is pursued to quantify the primary-zone shear deformation heating, the secondary-zone friction heating, and flank face air–oil mixture cooling (Li and Liang, 2006). There are a lot of other effects to be considered but these two had been specifically used to estimate cutting forces under the condition of sharp tools. The predicted variables of flow stress, contact length, and shear angle obtained from the model are used to predict the cutting forces due to the tool flank wear effect.

2.4.2 Depth of Cut

Depth of cut (DOC) is an input parameter to determine the values of cutting range on which the material wish to be cut. There are multiple types of depth of cut, radial and axial depth of cut, on which both are equally important in most cases. Azeem et al. (2004) had addressed his idea regarding depth of cut parameters where describe that the CNC machines have radically changed the machining operations, especially those having high variety and moderate batch sizes. For machining process, there are multiple input cutting parameters to be acknowledge including cutting speed (v), feed rate (f_r), radial depth of cut (d_r) and axial depth of cut. After the proper machine sequence and operation had been chosen, the cutting tools and the parameters for each of the operations have to be determined. The parameters will later then have a substantial impact on the cycle time, the tool life and the material removal rate as well as low surface roughness average and dimensional accuracy (Toussaint and Cheng, 2006). Abou-El-Hossein et al. (2006) were investigated that the significance of input parameters in the improvement of the output parameters such as surface roughness and tool life. It is due to the fact that it has been observed that the improvement in the output variables, such as tool life, cutting forces and surface roughness through the optimization of input parameters, such as feed rate, cutting speed and depth of cut, may result in a considerable economic performance of machining operations. The authors also addressed that one of these output variables that may have either direct or indirect indications on the performance of other variables such as tool wear rate, machined surface characteristics and machining cost, is cutting forces.

2.4.3 Feed Rate

Feed rate is an important aspect. By selecting a fixed feed rate based upon maximum force, which is obtained during full length of machining, the tool is saved but very often these results in extra machining time, which reduces productivity. By optimizing the feed rate, both the objectives of saving the tool (and hence more tool life) and also reducing machining time thereby increasing productivity are achieved (Salami et al., 2007). Feed rate is measured in the units of mm/rev. Sun and Wright (2005) focused on ball end milling presents strategies and algorithms for selecting cutting parameters such as width of cut (WOC) and spindle speed. However, the authors decided to pin point their research towards feed rate. When it came to algorithms and strategies of milling process, there are a lot of goals and objectives to be considered. One of the major goals is to minimize the overall machining time, but it was done within the constraints of the cutting tool limitations (such as the CNC machine tool capability and the tool strength) and the design specifications of the part being machined (such as the allowable surface finish, the accuracy of machined dimensions of prismatic pockets, and the faithfulness between the CAD specified free-form contours and the as machined free-form contours--usually referred to as allowable form error). This is a multiple-variable and multiple constraint optimization problems (Sun and Wright, 2005).

Figure 2.3 shows the constraint of WOC-Feed space. In ball end milling, the form error can generally be defined as the deviation of the machined surface from the desired surface (as specified by the original designers in the CAD file) in the surface-normal direction. There are multiple experiments that had been done regarding the feed rate and it can be initially conclude that the optimum feed rate of the experiment 0.15 mm/rev to get the good surface finish. In the research to determine whether or not the MQL technique does give advantages to tool wear, Attanasio et al. (2006) had decided to choose the range of feed rate to be in between 0.20 mm/rev and 0.26 mm/rev. On the other hand, Arumugam et al. 2004 use the range feed rate between 0.2 mm/rev and 0.4 mm/rev in their experiment using dry machining of aluminum–silicon alloy coated cutting tools insert. The result of this experiment had demonstrated a good outcome especially in terms of its output parameters such as surface roughness, the higher feed rate and depth of cut. On the same note, Itoigawa et al. (2006) had also conducted an experiment on which the maximum value of the feed rate is 0.2 mm/rev and the minimum is set to be 0.05 mm/rev. Ghani et al. (2004) however, were to analyzed the performance of P10 TiN coated carbide in milling and recommended that the range of the feed rate should be in between 0.1 mm/tooth and 0.25 mm/tooth. The feed rate value increase results in higher cutting force and requires more power consumption to remove the material and accordingly more heat produced at the tool edge.

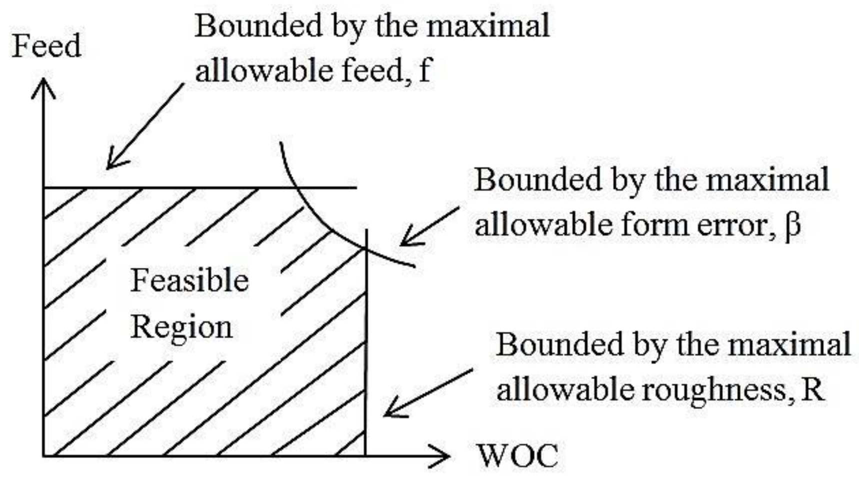


Figure 2.3: Constraint WOC-Feed Space

Source: Sun and Wright (2005)

2.5 OUTPUT PARAMETERS

In this part, the output machining parameters is discussed. It involves the surface roughness, material removal rate (MRR), tool wear and chip formation. These parameters are crucial because it is one on the ways to compare the cutting performance at the end of the experiment. Lower surface roughness, higher MRR, minimum tool wear and smaller chip formation are one of the many the indications that the cutting performance had been done in an effective manner.

2.5.1 Surface Roughness

Surface roughness is one of the most important requirements in machining process. The surface roughness value is a result of the tool wear. When tool wear increase, the surface roughness also increases. The determination of the sufficient cutting parameters is a very important process obtained by means of both minimum surface roughness values and long tool life. Ozcelik and Bayramoglu (2005) had conducted an experiment to analyze the statistical modeling of surface roughness in high-speed flat end milling. In this study, spindle speed, feed rate, depth of cut and step over has been selected as machining parameters and a statistical model was develop using these cutting parameters.

Topal (2009) suggested that the surface roughness is a criterion of the product quality of machined parts and a factor that greatly influences tribological characteristics of a part. Several factors influence the final surface roughness in a CNC end milling operation such as cutting speed, depth of cut, feed rate, step over ratio and many more. The research of the surface roughness prediction is to determine the optimum cutting conditions for minimum surface roughness for the sake of saving time and money. Wang and Chang (2004), said that the manufactured part qualities are determined by their form errors and surface finishes produced by the manufacturing processes. The surface roughness generally plays important role in wear resistance, ductility, tensile, and fatigue strength for machined parts and cannot be neglected in design. A machined surface also is a result of geometric and kinematics reproduction of the tool point shape and trajectory.

2.5.2 Material Removal Rate

In most studies, the MRR is fixed because of the expensive of observation of the control. However, through a computer interface for programmable speed and feed rate on modern numerical machines, the MRR is capable of being controlled dynamically (Yeh and Lan, 2002). Material removal rate (MRR) and surface quality in copper-chemical mechanical planarization (Cu-CMP) process are highly sensitive to slurry chemistry parameters, namely, pH, and concentrations of complexing, corrosion inhibiting, and oxidizing agents. It was found that principal component regression models relating these features to MRR are significantly more accurate than the conventional statistical regression models that use process parameters (slurry chemistry settings) only to estimate MRR (Phatak et al., 2009). MRR is one of the important output parameters that need to be considered in machining. In order to determine the cutting performance in end milling process, the output parameters such as material removal rate (MRR), tool wear, tool life and surface roughness need to be measured and compared. Dhar et al. (2005) had studied the effect of MQL on tool wear specializing in high production machining steel. This kind of machining has the tendency to generate high cutting zone temperature due to its nature. Such high temperature causes dimensional deviation and premature failure of cutting tools. The result of such phenomenon are the impair of the surface integrity of the product by the process of inducing tensile residual stresses and surface and subsurface micro cracks in addition to rapid oxidation and corrosion. In high speed machining, conventional cutting fluid application fails to penetrate the chip–tool interface, and thus cannot remove heat effectively. There are several MQL systems, which are appropriate for use with a wide range of equipment types in order to create a competent, individually optimized solution. They extensively allow the conversion of manufacturing processes (Fratila, 2009). However, high-pressure jet of soluble oil, when applied at the chip tool interface, have a chance of reducing cutting temperature and improve tool life to some extent. (Dhar et al., 2009). The authors conducted multiple experiments and concluded that the cutting performance of MQL machining is better than that of dry and conventional machining with flood cutting fluid supply because MQL simply provides the benefits mainly by reducing the cutting temperature, on which later on will enhance the chip tool interaction and upholds the sharpness of the cutting edges. Looking onto another perspective, surface finishes improved mainly due to reduction of wear and damage at the tool tip by the application of MQL. Such reduction in tool wear would either improvement in tool life or enhancement of productivity allowing higher cutting velocity and feed (Dhar et al., 2009). Therefore, MQL jet provided reduced tool wear, improved tool life and better surface finish as compared to dry and wet machining of steel. Gu et al. (1999) stated that cutting tool wear is the result of load, friction, and high temperature between the cutting edge and the work piece. There are a lot of outcomes that may happen when it came to cases like these including several wear mechanisms such as adhesive wear, abrasive wear, diffusion wear and oxidation.

2.5.3 Tool Wear

The term tool wear can be describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools. There are a lot of types of tool wear and it can be pretty much sums in into two major kinds, which is flank wear and crater wear. Flank wear is the portion of the tool in contact with the finished part erodes, while crater wear is the associated with the eroded rake face due to in contact with the chip (Jindal, 2012). Lin and Lin (1996) conducted a research to monitor tool wear in face milling online. The authors stressed that this is important in order to prevent tool breakage and to realize a fully automated system. However, most of the tool wear monitoring techniques developed are for single-point cutting process such as turning. The results are not to be used for the multi-tooth face milling process directly. The authors later on concluded their research by stating that tool wear can also be properly estimated by knowing the average chip thickness, tooth number, and the average normal force coefficients or frictional force coefficient. Wang et al. (2008) also agrees and added that the tool machining is the radical process of friction and wear. Tool wear during cutting not only decreases the service life of cutting tools, but also leads to increased roughness of cutting surfaces of work pieces. An optimal machining process is one where the maximum material removal rate is obtained with the minimal amount of tool wear. This can be attained through the appropriate choice of machining conditions. The wear mechanism map is a good means of selecting suitable machining conditions to the machinist, which can reflect wear rates and wear mechanisms under different operating conditions in one map, and shows the transformation relation of one dominant wear mechanism to another. It is the most forceful implement to wear resistant design at present.

Figure 2.4 shows the flank wear measurement of HSS drill tools. The position for the flank wear measurement is compliment to the stereoscopic microscope was later used to observe the chip and the drilled tools. The authors also added that it is the optimal machining parameter in the safety zone with an acceptable wear rate. The periphery of the safety zone is a region with higher wear rate range of −7.3 to −7.6 and is called the lower-wear region. This region has bigger scope than the safety zone and is also optional machining range. When the tools have been used numerous times, there are tend to be a build-up edge (BUE). This is where at the edge of the tool somehow build-up with cuts material and forming a shape.

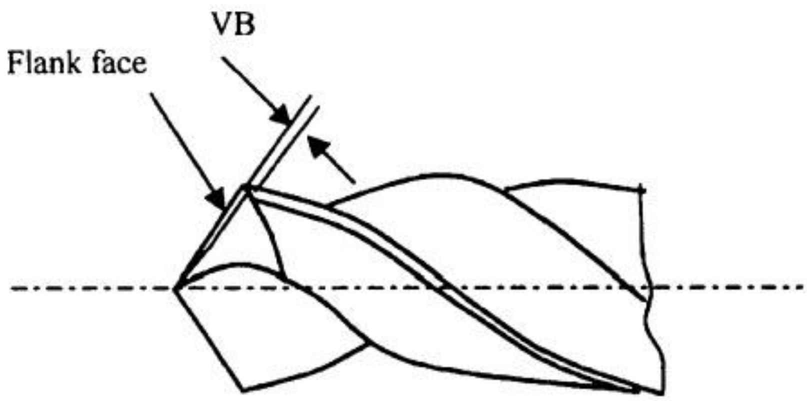


Figure 2.4: Method to measure the flank wear of HSS tool.

Figure 2.5 shows the plot of the tool life in the cutting length. When cutting speed is low, BUE is a common occurrence. The BUE grows on the tip of the cutting tool. One important thing to remember is that when the BUE reaches a certain size, it breaks away from the insert and part of it smears on the surface of work-piece. In the absence of BUE, workpiece surface is clean and shiny, and categorized by regular grooves, Regarding the feed rates above 0.315 mm/tooth, the insert did displayed some micro-chipping on the cutting edge, on which later on rapidly developed into macro chipping and successive tool failure

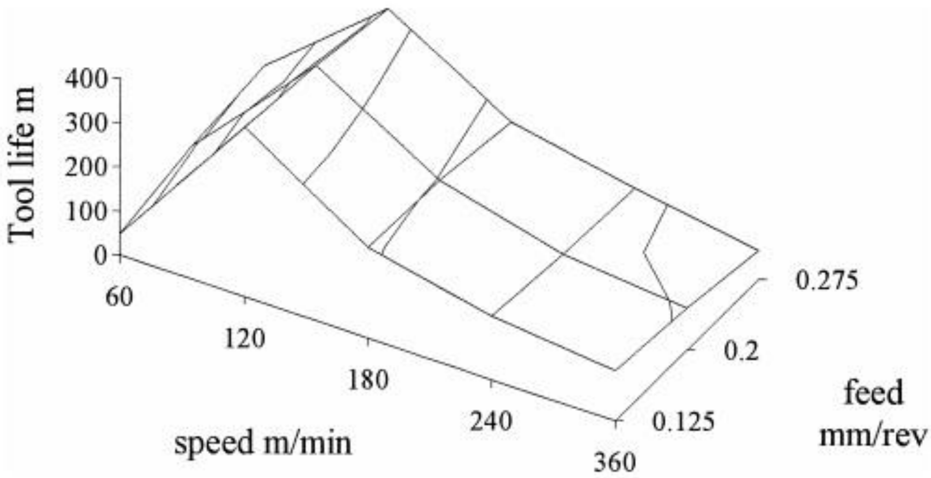


Figure 2.5: Plot of tool life in cutting length.

From Figure 2.5, the tool life is more sensitive to cutting speed than to feed rate. Based on the observation, the optimum cutting condition is a speed of 120 m/min, and a feed of 0.125 mm. The authors later made a finalized statement about the tool life being found to depend more on cutting speed than on feed rate. Tool life was observed to be highest at a moderate cutting speed of 120 m/min. At lower cutting speeds wear rate increased due to the development of BUE edge and at higher cutting speed wear rate increased due to increased temperature in the cutting zone.

2.5.4 Chip Formation

Chip formation is part of the process of cutting materials using tools. It is one of the most important aspects in end milling process in order to determining the cutting performance. Wang et al. (2008) conducted an experiment with uncoated HSS tools during drilling die-cast magnesium alloy on which they later on observed the chip formation after the machining. Figure 2.6 shows the chip formation of a HSS machining with the cutting speed of 5000 rpm and feed rate of 0.2 mm/rev. The chip generated in this region is a massive chip owing to extrusion. The massive chip sometimes accumulates at the flute, and not beneficial to chip removal, elaborated by Wang et al. 2008. They also observed the chip formation and acoustic emission in machining Ti-6Al-4V alloy. The mechanism of saw-tooth chip formation in machining titanium and its alloys is generally accepted to be based on the occurrence of a thermoplastic instability within, what may be considered as the primary shear zone.

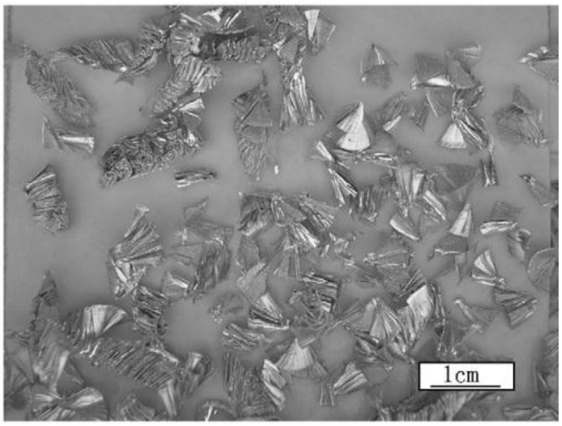


Figure 2.6: Shape of chip generated by HSS machining.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of this study. This includes the selection and properties of the workpiece material, cutting inserts and tools used. The performance and cutting limits are included within the machining performances. A thorough explanation regarding the design of experiment (DOE), machines equipment, workpiece preparation and experiment set up are also provided. Then, detailed descriptions concerning the mathematical model along with a few analyses are presented.

3.2 WORKPIECE MATERIALS

AA6061-T6 aluminium alloy (Al–Mg–Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring high strength-to-weight ratio and good corrosion resistance (Rajakumar et al., 2011). The chemical compositions in mass% of base metals (BMs) AA6061-T6 is 0.92Mg, 0.68Si, 0.43Cu, 0.33Fe, 0.013Mn, 0.01Ti, 0.01Zn, Al balance (Xu et al., 2012). According to Sivarao et al. 2010), Al 6061 is widely used in numerous engineering applications including transport and construction where, superior mechanical properties such as tensile strength and hardness are essentially required. There are a lot of instances to be taken when it came to this kind of aluminum. It can be used for a variety of interior parts in cars, in railway carriages, pipelines, furniture or in trucks. The inherent corrosion resistance of these alloys and their filler metals are also excellent. The AA6061-T6 alloys can be welded with ER4043 (Al-Si5%) or ER5356 (Al-Mg5%) filler alloys dependent on weld performance requirements. The usual difficulties and trouble regarding aluminum alloy welding process are often associated with their properties. There are high thermal conductivity, high chemical reactivity with oxygen, and high hydrogen solubility at high temperature are among the important ones. The crucial consideration is to sufficiently dilute the Mg_2Si percentage in the base material with sufficient filler alloy for the sake of reducing the weld metal crack sensitivity.

Table 3.1 shows the chemical composition of aluminum alloy AA6061-T6. As can be seen, the aluminum mostly consists of magnesium which is 4.98 percent, besides the main component which is the base metal, 6061. The element of silicon also present in this aluminum. This is quite an advantage situation because when these two elements combined together, it underwent precipitation reaction and forms a strengthening precipitate of Mg_2Si. The outcome of this chemical reaction is a fine and uniform distribution of these precipitates throughout the aluminum matrix provides on which will later provide higher strength to these alloys. Figure 3.1 shows the aluminum alloys workpiece.

Table 3.1: Chemical compositions (wt%) of AA6061-T6

Base Metal 6061	Si	Fe	Cu	Mn	Mg	Cr	Zn	Sn
93.44	0.10	0.27	0.07	0.82	4.98	0.06	0.17	0.03

Source: Xu et al. (2012)

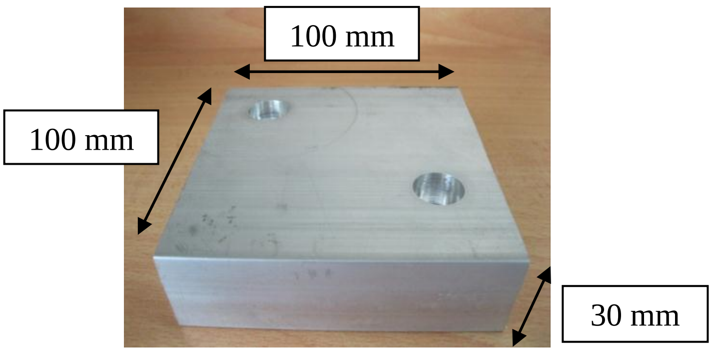


Figure 3.1: Workpiece aluminium alloy 6061-T6

3.3 CUTTING TOOL MATERIALS

The cutting tools used for this experiment are coated carbide and uncoated carbide cutting tool. Tool machining is the radical process of friction and wear. Tool wear during cutting not only decreases the service life of cutting tools, but also leads to increased roughness of cutting surfaces of work pieces (Zhang et al. 2001). According to Ghani et al. (2004), coated carbide is suitable for machining because it is possible to employ the carbide and nitride based tool materials at cutting speeds that are so low that mechanical wear predominates. In addition to that, these tool materials are limited by chemical stability, where the tool material dissolves into the flowing chip. Table 3.2 shows the composition of the coated and uncoated carbide inserts. It can be observed that there is, although small, a significant difference in grain size between coated and uncoated carbide inserts. However, the composition between the two is almost similar except on the slight difference in the quantity of tungsten carbide (WC) in the inserts.

Table 3.2: Composition of the coated and uncoated carbide inserts

Type of carbide	Code name	Composition	Coating	Grain size
Coated carbide	CTW 4615	6 % of Co, 4 % carbide,90 % WC	PVD TiA1N, TiN	4µm
Uncoated carbide	CTP 1235	6 % Co, 94 % WC	-	1 µm

3.4 MACHINING PARAMETERS

The parameters of the machine can be sorted in two types; input parameters and output parameters. Table 3.3 shows the input and output parameters for machining on end milling.

Table 3.3: Input and output parameters

Input Parameters	Output Parameters
Spindle speed	Surface roughness
Depth of cut	Material removal rate (MRR)
Feed rate	Tool wear
Cutting flow	

3.4.1 Spindle Speed

Cutting speed also known as spindle speed is the speed difference (relative velocity) between the cutting tool and the surface of the workpiece it is operating on. It is expressed in units of distance along the workpiece surface per unit of time, which in meters per minute (m/min). In conventional machining at low cutting speeds, the friction mechanism is mostly effective at the tool rake face (Ozel and Altan 2000). Hence, it is crucial for us to determine the optimum value of spindle speed especially in aluminium alloy machining. This can be done by comparing and analysing the data in end milling process. Table 3.4 shows the range of values of cutting speed based on a number of experiments had had been done by numerous researchers. Based on Table 3.4, the initial conclusion that can be state is that the cutting speed is low for most of the machining sets of experiment.

Table 3.4: Cutting speed

Exp. No.	Minimum	Maximum	Reference
1	75	95	Nagallapati et al. (2011).
2	480	690	Arumugam et al. (2004).
3	40	250	Amin et al. (2007).
4	100	300	Aslantas et al. (2012).
5	200	500	Itoigawa et al. (2006).
6	150	250	Liao et al. (2007).
7	-	300	Attanasio et al. (2006).
8	-	12000 rpm	Kang et al. (2008).
9	224	355	Ghani et al. (2004).
10	94.2	219.8	Yan et al. (2012).

3.4.2 Feed Rate

Feed rate can be defined as the speed at which the cutting tool of a lathe moves along the length of a workpiece. Therefore, it is no doubt an important aspect of the machining. Some machining require high feed rate and some do not depending on the material used, cutting speed and many other aspects to be considered. Feed rate is measured in the units of mm/rev. Feed rate is also an important input parameter because of its direct influence on the surface roughness and the chips formation. Table 3.5 shows the feed rate used in multiple experiments by a number of researchers.

Table 3.5: Feed Rate

Exp. No.	Minimum	Maximum	Reference
1	0.2	0.4	Arumugam et al. (2004).
2	0.07	0.14	Aslantas et al. (2012).
3	0.05	0.2	Itoigawa et al. (2006).
4	0.1	0.2	Liao et al. (2007).
5	0.2	0.26	Attanasio et al. (2006).
6	-	0.01	Kang et al. (2008).
7	-	550	Ghani et al. (2004).
8	-	0.075	Yan et al. (2012).
9	-	0.075	Yuan et al. (2011).
10	0.125	0.315	Gu et al. (1999).

3.3.3 Depth of Cut

Depth of cut is an input parameter that determines the values of cutting range on which the material wish to be cut. There are multiple types of depth of cut including radial and axial depth of cut, on which both are equally important in most cases. Depth of cut is no doubt important in maximizing the material removal rate of a workpiece because the higher depth of cut, the more material can be removed. Therefore, it is crucial for us to determine the optimum depth of cut in machining experiment. Table 3.6 shows the range of depth of cut selected for experiments done by the researchers.

Table 3.6: Depth of cut

Exp. No.	Minimum	Maximum	Reference
1	0.3	0.7	Nagallapati et al. (2011)
2	0.5	1.0	Arumugam et al. (2004)
3	0.5	0.5	Aslantas et al. (2012)
4	-	5	Liao et al. (2007)
5	-	1	Attanasio et al. (2006)
6	-	2	Kang et al. (2008)
7	0.3	0.8	Ghani et al. (2004)
8	0.25	0.8	Yan et al. (2012)
9	-	1.0	Yuan et al. (2011)
10	-	0.5	Ravi and Kumar (2011)

3.5 EXPERIMENTAL SETUP

For the experimental setup, the machine used in HAAS TM-2 A wet cutting condition is made to test the effectiveness of the result of the CNC milling machine, HAAS TM-2, as shown in Figure 3.2. This machine is equipped with 5.6 KW motor drive, 400 rpm spindle speed and 5.1 m/min feed rate. The detailed specification would later be shown in Table 3.7. This particular machine is very delicate. Hence it requires the cutting tool to be of high quality. Therefore, coated carbide and uncoated carbide are very suitable to be used as cutting tool. For each different set of experiments, a new set of cutting tool is used every time to make sure that the data is reliable.

Figure 3.2: CNC milling machine model HAAS TM-2

3.6 DESIGN OF EXPERIMENTS

In the machining, the range of values in spindle speed, feed rate, depth of cut (DOC) and flow rate need to be determined in order to proceed with the experiment. Analysing the previous literature and machine specification and limitation, the following range of parameters had been determined. Table 3.8 shows the range of parameters that has been chosen for the machining. Along with the dynamometer, a workpiece block is fastened on the table of CNC milling. It is also a crucial aspect to figure out that the dynamometer is used to measure the force of cutting a thing with the machine. For the next step, after the work piece had been properly clamped to the machine table, the edge finder is placed onto the machine in order to set the origin of the x and y axis. Figure 3.3 shows the edge finder that was used to determine the origin of the axis before machining starts. The workpiece needs to be properly clamped before the process of setting the origin can begin. Next, after taken into account that the diameter of the tool is 10 mm, the origin would later be offset at the value of 5 mm. The tool offset measure panel would be set up. After the proper value had been keyed-in and the flow rate had been set up, the experiment can be started.

Table 3.7: The specification of the CNC milling machine HAAS TM2

Part	**Specification**
X- axis	40"
Y- axis	16"
Z- axis	16"
Table surface to spindle nose	4" to 20"
Column to spindle centre	22.05"
Table working surface	57.75" x 10.5"
Table load capacity	1000 lb
Spindle speed RPM	4000 to 6000 rpm
Spindle taper size	40 Taper
Drive system	Direct speed, belt drive
Maximum torque	33 ft-lb@ 1200 rpm
Maximum thrust rating	2000 lb
Cutting feed	200 to 400 rpm
Tool storage capacity	20 Tools
Max tool diameter with adjacent tools	5.31"
Max tool weight	12 lb
Tool-to-Tool (avg)	5.7 sec
Spindle drive	5.7 sec

Table 3.8: Range of parameters for chosen machining

	No. of Exp.	Cutting speed (m/s)	Feed rate (mm/rev)	Depth of Cut (mm)	Flow rate
Work	1	1142	145	1	0.0275
Piece A	2	1037	120	2	0.02175
	3	932	95	3	0.0275
	4	932	95	1	0.016
Work	5	1037	157.0645	2	0.02175
Piece B	6	1142	145	3	0.016
	7	1142	95	3	0.016
	8	1142	95	1	0.016
Work	9	932	95	3	0.016
Piece C	10	932	95	1	0.0275
	11	1037	120	2	0.013225
	12	1037	120	1	0.02175
Work	13	932	145	3	0.016
Piece D	14	1037	120	2	0.030275
	15	932	145	3	0.0275
	16	1142	95	1	0.0275
Work	17	1142	95	3	0.0275
Piece E	18	1142	145	3	0.0275
	19	1037	82.93554	2	0.02175
	20	932	145	1	0.0275
Work	21	1037	120	2	0.02175
Piece F	22	1142	145	1	0.016
	23	881.3293	120	2	0.02175
	24	1192.671	120	2	0.02175
Work	25	1037	120	3.482579	0.02175
Piece G	26	932	145	1	0.016

3.7 MEASUREMENT OF SURFACE ROUGHNESS

After the experiment had been done, one of the output parameters that need to be measured is surface roughness. The test of surface roughness was checked by using portable roughness tester (Perthometer). Perthometer is a device with high sensitivity that is able to find a very small difference in surface roughness. Figure 3.4 shows the Mahr Perthometer. Prior to the time for the measurement to be taken, the workpiece is to be properly clean from any sorts of impurities so that the data would be pure and accurate. Once the material is placed on a horizontal surface, the Perthometer can be use to measure the surface roughness.

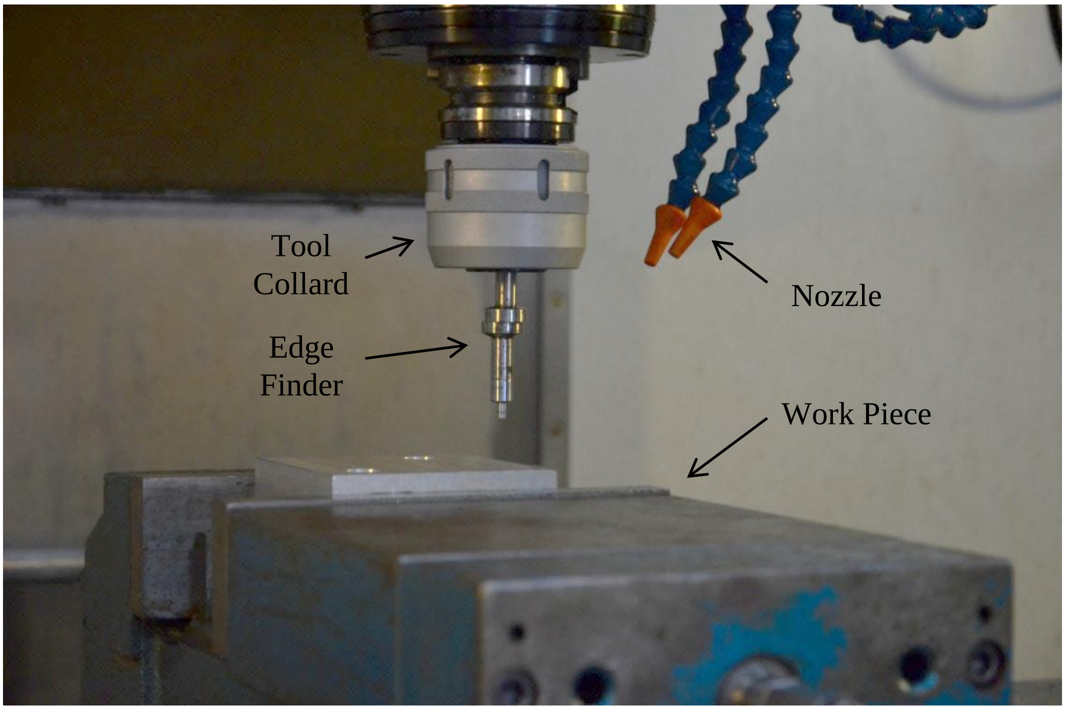


Figure 3.3: Edge Finder

3.8 MEASUREMENT OF TOOL WEAR

One of the response parameters that need to be taken into account is tool wear. When it can to milling machining, the most common wear in cutting tools is flank wear. The flank wear can be measured using the optical video measuring system, where the dimension would be recorded as label to show the flank wear. The images of this flank wear are saved as data in computer so that it can be used as comparison for the next tool wear evaluation for another cut. Figure 3.5 shows the optical video measuring system model SOV-2010 (N/A) used in this experiment to measure the tool wear. On the other hand, Figure 3.6 shows the one of the dimensions on which the images was saved into the computer in order to make a comparison for our next cutting. The tool needs to be properly clean in order to avoid confusion between a flank wear with just a form of impurities on the tool surface.

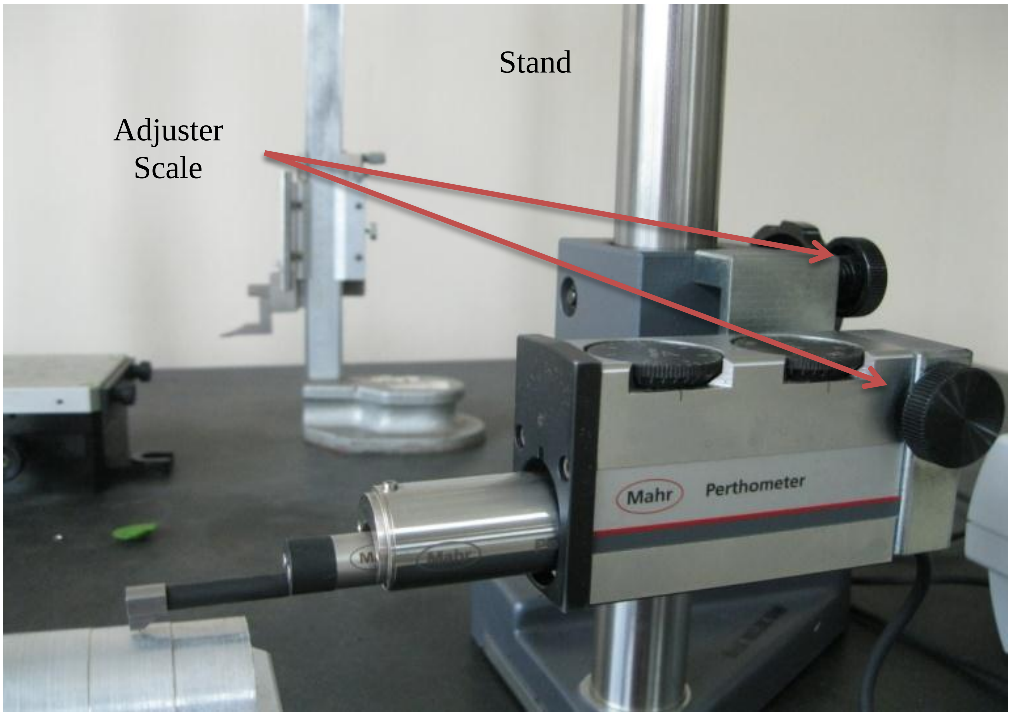


Figure 3.4: Surface roughness measuring device model Mahr Perthometer SE500

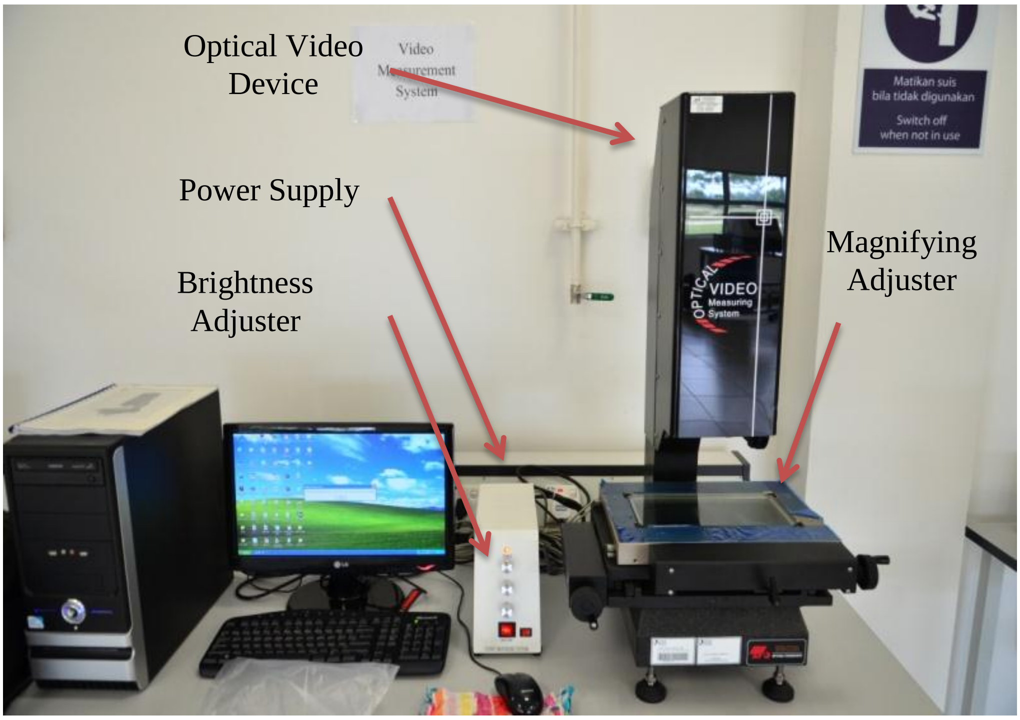


Figure 3.5: Optical video measuring system model Swift-Duo

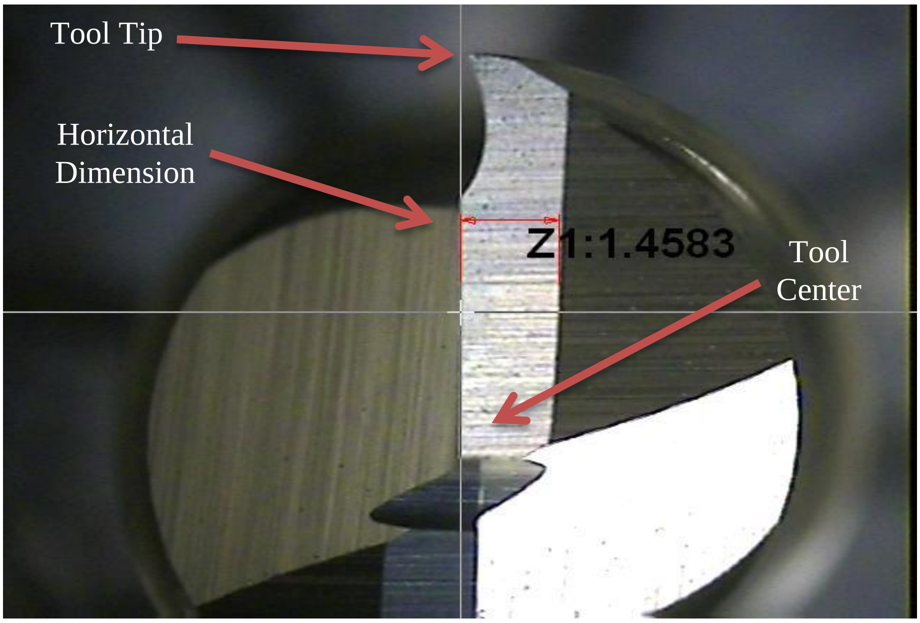


Figure 3.6: Tool dimension measurement of cutting tool

3.9 CUTTING FLUID

For this project, the experiment had been done with minimum quantity lubricant and flooded. MQL was said to be a good choice in milling operation. Dhar et al. (2006) conducted multiple experiments and concluded that the cutting performance of MQL machining is better than that of dry and conventional machining with flood cutting fluid supply because MQL simply provides the benefits mainly by reducing the cutting temperature, on which later on will enhance the chip tool interaction and upholds the sharpness of the cutting edges. Besides, surface finishes also improved mainly due to reduction of wear and damage at the tool tip by the application of MQL. In this experiment, MQL was delivered to the machining by using UNIST Coolube where the MQL was delivered to the experiment. Figure 3.7 shows the UNIST Coolube. Figure 3.8 shows the layout for the setting of the nozzles for the MQL experiment. Horizontally, the nozzles were 120 degrees apart from each other on the horizontal distance to the cutting tool is 6mm. The vertical distance from the nozzles to the surface of the workpiece is 4 mm.

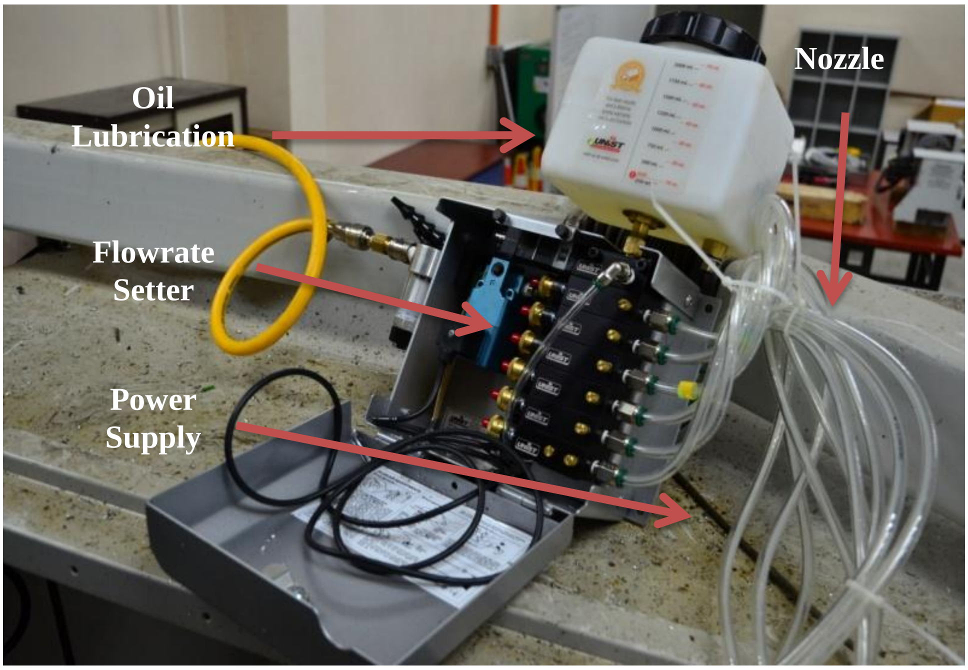


Figure 3.7: Lubrication supply model UNIST Coolube

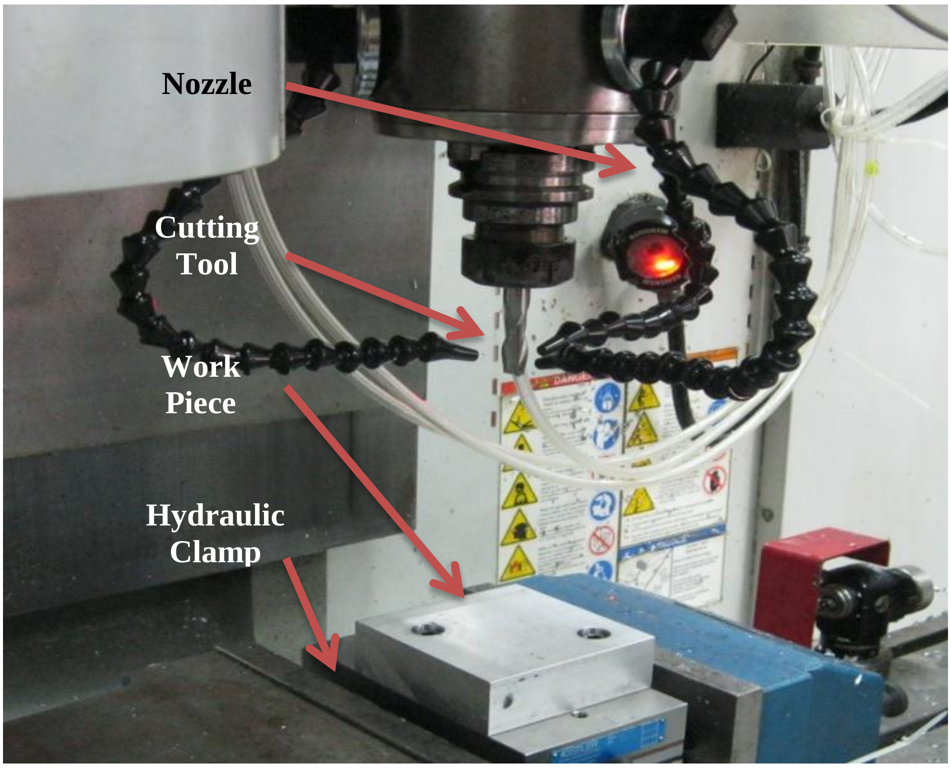


Figure 3.8: Nozzle configuration around the tool

The flowchart of the study is shown in Figure 3.9.

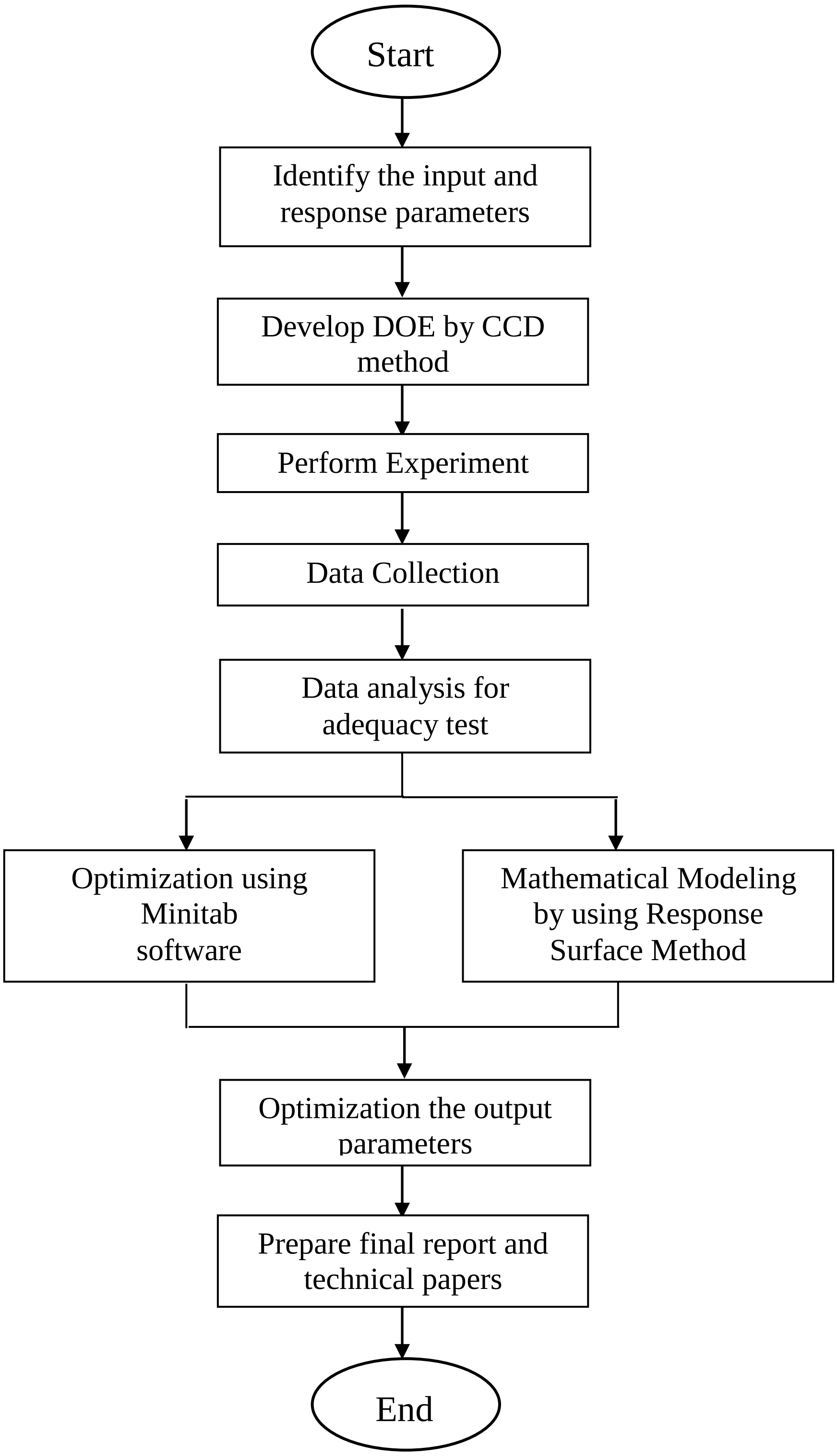


Figure 3.9: Flowchart of Study

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The purpose of this report is to develop a mathematical model by making use of the response surface method. The process would take place when machining HAAS TM-2 using coated and uncoated carbide in the end milling processes. The mathematical model would help to establish a relationship between the input variable like feed rate, axial depth, and cutting speed with the cutting responses which are the surface roughness, tool life and cutting force. Regression models have been used to carry out the optimization of the machine characteristics and the prediction of these characteristics is done by the artificial neural network (ANN). In order to extract efficient results it is essential to use the hidden layers, neuron number, training algorithm and activation functions. To make sure the best performance is achieved, the ANN and RSM are compared to the most appropriate models. The chip formation and tool wear mechanism have also been stated as part of the report.

4.2 EXPERIMENTAL STUDY

Table 4.1 and 4.2 shows the design of experiment for coated insert CTP 2235 and CTP 1235. Along with the design of experiment, we can see the response parameters data of surface roughness for the inserts that has been obtained from the experiments. There are three response parameters that had been investigated with its respective units. The unit for surface roughness is millimetre, the unit for MRR is mm^3/min and the unit for tool wear is micrometre. All of the experiments that had been done on both coated carbide were done with minimum quantity lubricant. A total of three nozzles were used for this experiment. Each of those nozzles generates a particular number of strokes per minute. The nozzle can be set by turning the valve in a number of turns. The flowrate specifications are shown in Table 4.3. The total number of turns used in this experiment is 6. For each turn, the oil lubrication will flow at a specific amount as indicates by Table 4.3. The minimum number of valve turn is 2.4 and the maximum number of valve turn is 6. If the valve is turned 6 times, the number of strokes per minutes is 0.9 and the flowrate is 0.03 ml/min.

Table 4.1: Design of experiment for coated CTP 2235

Spindle Speed, rpm	Feed rate, mm/min	Depth of Cut, mm	MQL, ml/min	Surface roughness, mm	Material Removal Rate	Tool Wear, µm
3	5500	318	0.48	0.819	9885.313	82.1628
1	5300	440	0.825	0.516	5092.795	61.28
1	5300	318	0.48	0.845	3522.957	66.60538
2	5400	379	0.9	0.803	8773.496	69.95
2	5400	469.4373	0.6525	1.132	10711.79	62.96
3	5300	440	0.48	1.175	15642.16	49.99504
3	5500	318	0.825	1.098	10779.2	92.03204
1	5300	318	0.825	0.486	1577.444	76.47462
2	5548.258	379	0.6525	0.816	9713.514	47.83
2	5400	288.5627	0.6525	1.033	6679.957	84.53336
2	5400	379	0.39	1.505	8460.157	57.3183
3	5500	440	0.825	0.906	14187.07	78.55767
2	5251.742	379	0.6525	0.562	9086.835	21.55972
2	5400	379	0.6525	0.971	8773.496	64.48
1	5500	440	0.825	0.606	4365.253	81.69365
3	5300	318	0.825	0.875	10621.45	71.6
3.482579	5400	379	0.6525	0.745	14601.6	93.04
3	5300	318	0.48	1.034	11042.1	63.4694
1	5500	318	0.825	0.623	2891.98	97.44
0.517421	5400	379	0.6525	0.212	626.6783	98.37539
1	5500	440	0.48	1.346	5092.795	71.8244
1	5300	440	0.48	1.017	5456.566	53.13101
1	5500	318	0.48	0.749	3680.702	82.29877
3	5500	440	0.48	1.496	14550.84	69.19
2	5400	379	0.6525	1.091	8710.828	61.67899
3	5300	440	0.825	0.563	1351.14	59.86428

Table 4.2: Design of experiment for coated CTP 1235

Spindle Speed, rpm	Feed rate, mm/min	Depth of Cut, mm	MQL, ml/min	Surface roughness, mm	Material Removal Rate	Tool Wear, µm
5300	318	1	0.48	0.202	9573.793	46.534
5500	440	1	0.48	0.876	4529.979	27.85736
5300	440	1	0.48	0.222	3472.36	46.26001
5500	318	1	0.48	0.442	8631.607	26.15573
5300	440	1	0.825	0.309	10984.2	41
5300	318	1	0.825	0.464	14756.75	53.87771
5500	440	1	0.825	0.707	9673.003	76.98
5500	318	1	0.825	0.524	3631.096	52.17608
5400	469.4373	2	0.6525	0.717	8625.695	70.57873
5548.258	379	2	0.6525	0.765	6549.419	47.23072
5400	288.5627	2	0.6525	0.617	8406.949	50.35707
5251.742	379	2	0.6525	0.532	15305.84	56.75528
5500	318	3	0.48	0.629	8944.946	69.95
5300	440	3	0.48	0.69	8791.232	64.15606
5300	318	3	0.48	0.58	4886.887	79.9
5500	440	3	0.48	0.908	9821.818	44.84
5500	318	3	0.825	0.575	13775.1	82.64
5500	440	3	0.825	0.608	9176.951	52.40377
5300	318	3	0.825	0.853	3526.926	67.21
5300	440	3	0.825	0.558	2104.693	50.70214
5400	379	2	0.6525	0.756	4941.795	77.37
5400	379	2	0.6525	0.772	5147.704	78.42412
5400	379	2	0.39	0.804	3472.36	96.82677
5400	379	2	0.9	0.695	15305.84	77.76
5400	379	3.482579	0.6525	1.047	8767.584	95.12514
5400	379	0.517421	0.6525	0.35	15305.84	80.11

Table 4.3: MQL flowrate specification

No. of valve turns	MQL flowrate, ml/min/nozzle	No. of strokes per minute
2.4	0.013	0.39
3	0.016	0.48
4	0.022	0.66
5	0.0275	0.825
6	0.03	0.9

4.3 SURFACE ROUGHNESS

Topal (2009) suggested that the surface roughness is a criterion of the product quality of machined parts and a factor that greatly influences tribological characteristics of a part. Several factors influence the final surface roughness in a CNC end milling operation such as cutting speed, depth of cut, feed rate, step over ratio and many more.

4.3.1 Development of Mathematical Model

The quality of a product is scrutinised by its surface roughness because it is a fundamental quality feature of end-milled product. If a higher surface roughness is required it is essential that before the process starts the setting of cutting parameters is done properly (Lou et al., 1999). The mechanical properties of work pieces that has to machined ,the rotational speed of the cutter, velocity of traverse and feed rate are all factors that yield the final surface however the machining process is responsible for the development of surface roughness (Benardos and Vosniakos, 2003). RSM has been used to develop the mathematical modelling and to optimize the machining parameters when machining HAAS TM-2 by using coated carbide (CTP 2235) and coated carbide (CTP 1235). First order and second order of RSM model has been developed based on surface roughness results. Using the RSM model it is possible to find those factors which have the ability to influence the surface roughness. This is basically done to enhance the efficiency levels of the response surface which is found to be influenced by the different parameters. The RSM also provides a quantifiable relationship with the response surfaces and the input parameters (Kwak, 2005). Equation (4.3) is a linear model which consists of independent variables and responses correlation in order to perform the task.

$$y = a \times \text{Feed rate} + b \times \text{Axial depth} + c \times \text{Cutting speed} + d \tag{4.1}$$

where *a, b, c* and *d* are the constants and *y* is the response.

Equation (4.1) can also be written as Eq. (4.2):

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \tag{4.2}$$

where, y is the response, x_0 = 1(dummy variable), x_1=feed rate, x_2 =axial depth, and x_3 = cutting speed. β_0 = D and β_1, β_2, and β_3, are the model parameters.

Equation (4.3) is the presentation of the second-order model:

$$\begin{aligned} y'' = {} & \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x^2{}_1 + \beta_{22} x^2{}_2 + \beta_{33} x^2{}_3 \\ & + \beta_{11} x_1 x_2 + \beta_{12} x_1 x_3 + \beta_{13} x_2 x_3 \end{aligned} \tag{4.3}$$

The surface roughness for the CTP 2235 (TiAIN) coated inserts for MQL is represented by y whereas:

$$\begin{aligned} y = {} & 234.6914195 + 0.1822751 x_1 + 0.0923969 x_2 - 0.0653677 x_3 \\ & - 11.0299521 x_4 - 0.1855936 x_1 x_1 - 8.9824840\mathrm{E\text{-}06} x_2 x_2 \\ & + 0.0000239 x_3 x_3 + 4.0447846 x_4 x_4 + 0.0001324 x_1 x_2 \\ & - 0.0004795 x_1 x_3 + 0.2333333 x_1 x_4 + 0.0000105 x_2 x_3 \\ & + 0.0016449 x_2 x_4 - 0.0123425 x_3 x_4 \end{aligned} \tag{4.4}$$

The surface roughness for the CTP 1235 (TiN) coated inserts for MQL is represented by y whereas:

$$\begin{aligned} y = {} & 218.6262294 + 5.0167402 x_1 + 0.0793285 x_2 - 0.0503158 x_3 \\ & + 22.1167190 x_4 - 0.0508520 x_1 x_1 - 7.3597305\mathrm{E\text{-}06} x_2 x_2 \\ & - 0.0000175 x_3 x_3 - 0.8950102 x_4 x_4 - 0.0008206 x_1 x_2 \\ & - 0.0003637 x_1 x_3 - 0.1721014 x_1 x_4 + 0.0000127 x_2 x_3 \\ & - 0.0033731 x_2 x_4 - 0.0063970 x_3 x_4 \end{aligned} \tag{4.5}$$

where;

x_1 = depth of cut, mm $\quad$ x_2 = spindle speed, rpm

x_3 = feed rate, mm/min $\quad$ x_4 = MQL flow rate, ml/min

4.3.2 Analysis of Surface Roughness

Figure 4.1 shows the surface roughness versus spindle speed for coated carbide 2235. It started with minor increase and then followed by a uniform decrement as the spindle speed for MQL. The maximum surface roughness is 0.965 mm. For coated carbide 1235, the same pattern can be observed except the increment and decrement is smaller in value. The maximum surface roughness recorded is 0.84 mm. Figure 4.2 shows the graphs that illustrates the relationship between surface roughness and depth of cut. For coated carbide 2235 with MQL, we can see that as the depth of cut increase, there is a major increment of surface roughness at the beginning followed by a uniform decrement at the end. The maximum surface roughness is 0.97 mm. For coated carbide 1235 however, a significant increase of surface roughness can be observed as the depth of cut increases. The maximum surface roughness recorded is 0.88 mm.

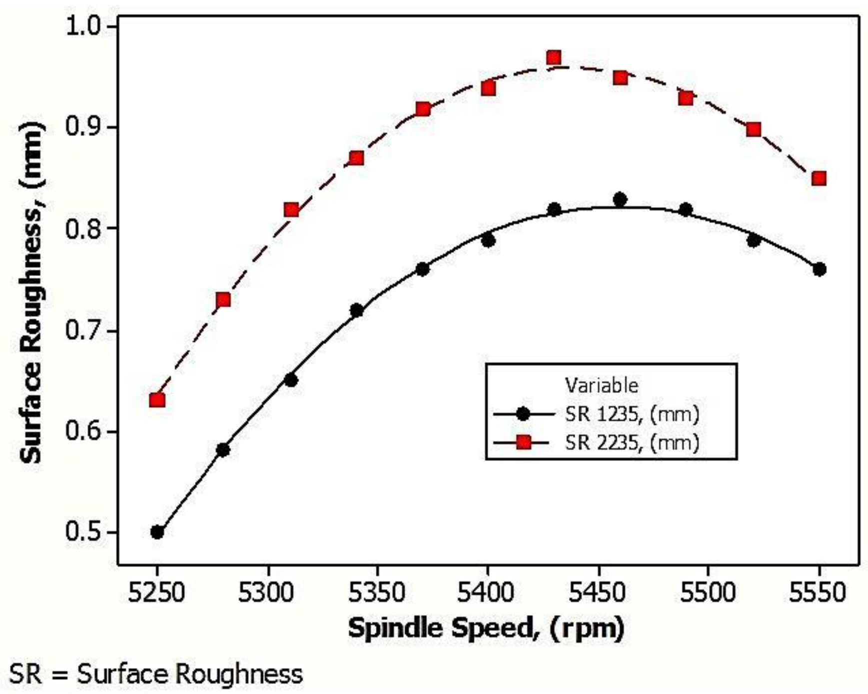


Figure 4.1: Effects of surface roughness on coated inserts with different spindle speed

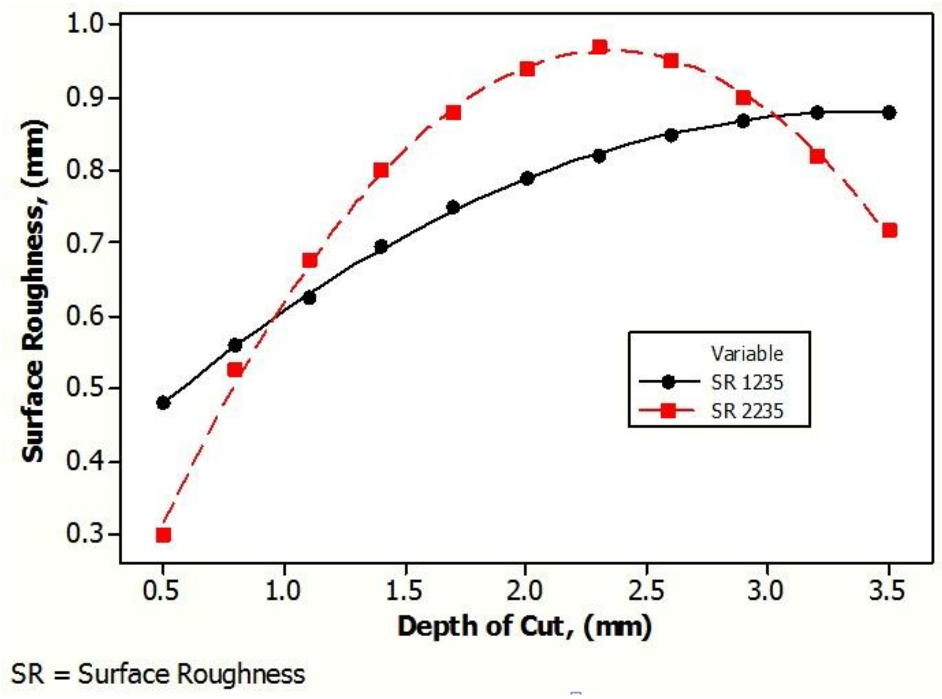


Figure 4.2: Effects of surface roughness on coated inserts with different depth of cut

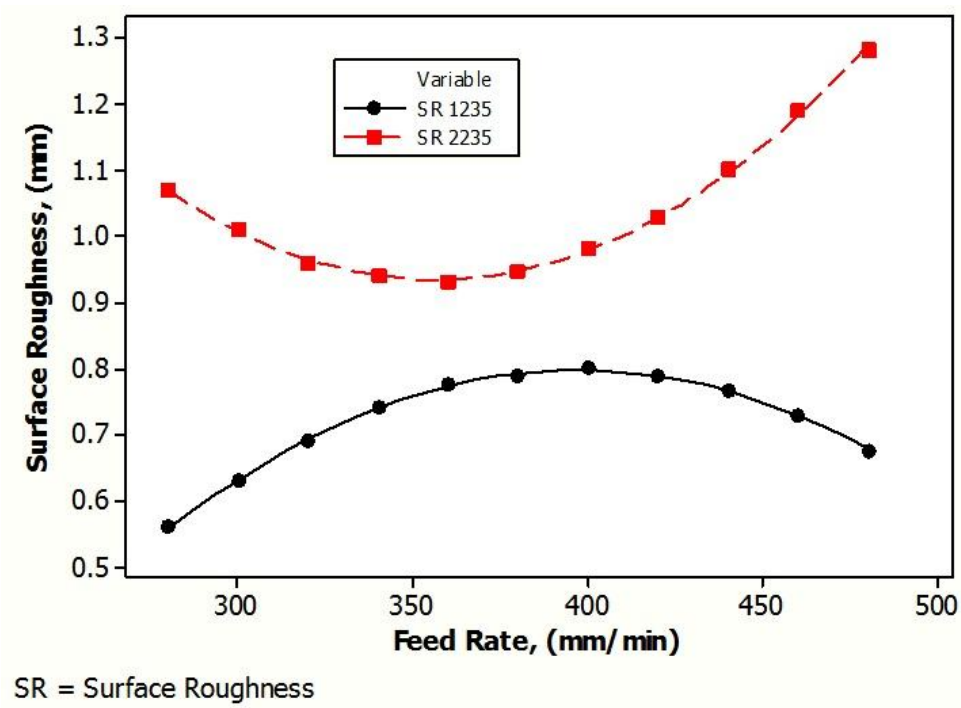


Figure 4.3: Effects of surface roughness on coated inserts with different feed rate

Figure 4.3 shows the graph that illustrates the relationship between surface roughness and feed rate. For coated carbide 2235 with MQL, we can see that it started with a minor decrease and then followed by an increasing value of surface roughness as the feed rate increase. The maximum value of feed rate is 1.13 mm. On the other hand for coated carbide 1235, the opposite pattern can be observed as it started with increment of surface roughness as the feed rate value increase followed by a uniform decrement. The maximum surface roughness is 0.8 mm. Figure 4.4 shows the graph that illustrates the relationship between surface roughness and MQL flow rate. For coated carbide 2235, as the flow rate increase, we can see that the surface roughness is significantly decreasing but towards the end, it undergoes a minor increase. The maximum surface roughness recorded is 1.82 mm. For coated carbide 1235, we can see the graph stated with a uniform increment and followed by an almost similar rate of uniform decrement. The maximum surface roughness measured is 0.794 mm. Table 4.3 shows the maximum surface roughness that has been analyze in terms of its individual input parameters which is depth of cut, spindle speed, feed rate and MQL flowrate. It can be observed that overall, coated carbide CTP 1235 showed a better result compared to CTP 2235. The resulting surface roughness generated on the workpiece is significantly less with coated carbide 1235 compared to CTP 2235.

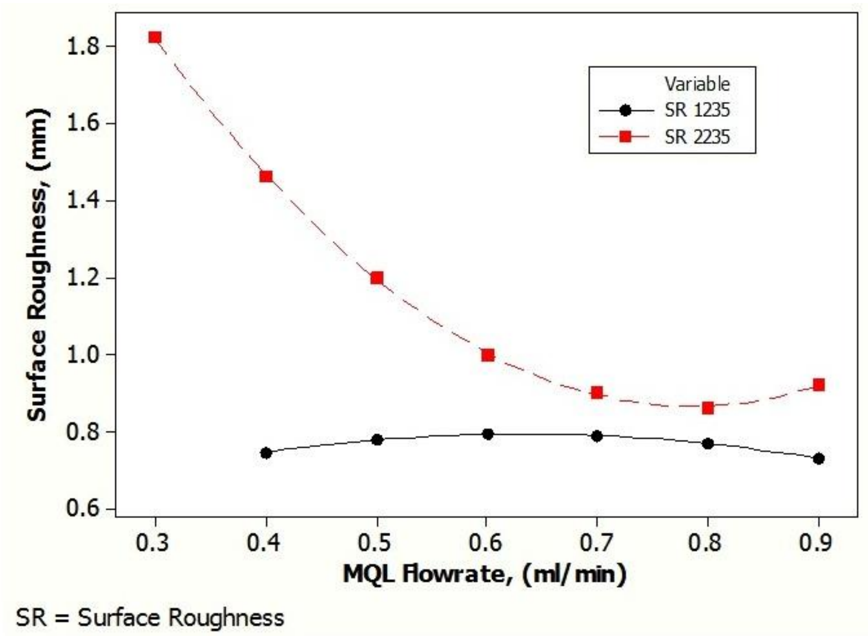


Figure 4.4: Effects of surface roughness on coated inserts with different MQL flow rate

Table 4.4: Summary of maximum surface roughness on CTP 1235 and CTP 2235

Surface Roughness Vs.	**Surface Roughness, mm**	
	CTP 2235	**CTP 1235**
Spindle Speed	0.965	0.84
Depth of Cut	0.97	0.88
Feed Rate	1.13	0.8
MQL Flowrate	1.82	0.74

4.3.3 Microstructure Analysis

The Figure 4.5 shows the microstructure from the experiments of coated carbide 2235 with flooded condition. As you can see, the surfaces are marked with what appear to be linear lines. For the workpiece A with MQL condition, the surface seems to be a bit rough compared to the one with flooded condition. It is to be understood that the greater strength of nickel based alloys is due to elevated temperature, high ductility, high tendency to work hardening, etc. that is why heat treatment strengthens them further because of their sensitivity to microstructure change (Dudzinski et al., 2004). As you can see, the surfaces of workpiece with MQL are marked with what appear to be spotty whilst maintaining the linear pattern. For the flooded condition, the pattern seems to be more uniformly linear-lined compared to the workpiece with MQL condition. Ginting and Nouari (2009) stated that materials and cutting conditions and the depth of cut cannot influence the surface roughness. The reported thermal and mechanical cycling, microstructural transformations, and mechanical and thermal deformations during machining processes all cause these impacts (Axinte and Dewes, 2002). The functional characteristic of products including their fatigue, friction, wearing, light reflection, heat transmission, and lubrication are all will effects the surface roughness (Ibraheem et al., 2008). When the product is exposed to extensive machining we may observe slight differences in surface roughness because of the on-going wear produced at the coated carbide cutting edge and the temperature reduction at the cutting by the coolant active all through machining Inconel 718 (Ezugwu et al., 2004). Hence, we can see the significance of lubrication end milling machining.

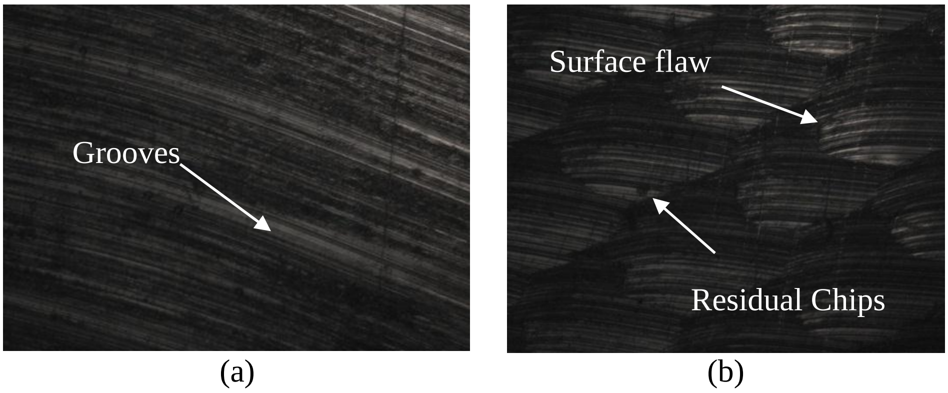


Figure 4.5: Microstructure of coated carbide 2235 with W/P A (a) Flooded Condition (b) MQL condition

4.3.4 Regression Analysis

Table 4.5: Estimated regression coefficients of CTP 2235 for surface roughness

Source	Degree of Freedom	Coefficient	p − value	f − value	Significance, α=0.05
Regression	14	-	0.000	10.63	yes
Linear	4	-	0.072	21.27	no
Square	4	-	0.001	10.29	yes
Interaction	6	-	0.018	4.30	yes
Constant	-	-234.693	0.069	-	no
Depth of Cut	1	0.182	0.916	20.63	no
Spindle Speed	1	0.092	0.054	7.08	no
Feed Rate	1	-0.065	0.043	5.93	yes
MQL	1	-11.030	0.288	51.45	no
DOC x DOC	1	-0.186	0.001	21.88	yes
SS x SS	1	-0.000	0.045	5.13	yes
FR x FR	1	0.000	0.046	5.06	yes
MQL x MQL	1	4.045	0.012	9.17	yes
DOC x SS	1	0.000	0.676	0.18	no
DOC x FR	1	-0.000	0.363	0.90	no
DOC x MQL	1	0.233	0.218	1.70	no
SS x FR	1	0.000	0.060	4.39	no
SS x MQL	1	0.002	0.377	0.85	no
FR x MQL	1	-0.012	0.001	17.75	yes
Lack of Fit	10	-	0.482	2.22	-
R-Square			95.12%		

DOC = Depth of Cut, FR = Feed Rate, SS = Spindle Speed, MQL = Flowrate

Table 4.5 and 4.6 show the estimated regression coefficients of CTP 2235 and CTP 1235 for surface roughness. The probability value should be less than 0.05 in order for it to be significant while for lack of fit value, it needs to be more than 0.05 for it to be significant. According the Table 4.5, both models have *P*-values of linear source which are more than the α-value (0.05) and the square source is less than α-value stating that they are significant. The lack of fit values for CTP 2235 and CTP 1235 of 0.482 and 0.097 respectively have been found to be unfit and insignificant since they are higher than the α-level. The interaction effects in the model show also significance. R square of this experiment states that the model explains nearly 95.12 % of the variation in the data of surface roughness using CTP 2235 coated carbide while for CTP 1235, the R-square explains nearly 95.68 %.

Table 4.6: Estimated regression coefficients of CTP 1235 for surface roughness

Source	**Degree of Freedom**	**Coefficient**	**p − value**	**f − value**	**Significance, α=0.05**
Regression	14	-	0.000	9.69	yes
Linear	4	-	0.001	18.45	yes
Square	4	-	0.026	4.21	yes
Interaction	6	-	0.002	7.92	yes
Constant	-	-218.631	0.021	-	yes
Depth of Cut	1	5.017	0.001	48.39	yes
Spindle Speed	1	0.079	0.023	20.99	yes
Feed Rate	1	-0.050	0.029	4.38	yes
MQL	1	22.117	0.008	0.04	yes
DOC x DOC	1	-0.051	0.094	3.35	no
SS x SS	1	-0.000	0.023	7.03	yes
FR x FR	1	-0.000	0.039	5.51	yes
MQL x MQL	1	-0.895	0.359	0.92	no
DOC x SS	1	-0.001	0.003	14.47	yes
DOC x FR	1	-0.000	0.326	1.06	no
DOC x MQL	1	-0.172	0.196	1.89	no
SS x FR	1	0.000	0.004	13.09	yes
SS x MQL	1	-0.003	0.021	7.27	yes
FR x MQL	1	-0.006	0.010	9.73	yes
Lack of Fit	10	-	0.097	63.91	-
R-Square			95.68%		

DOC = Depth of Cut, FR = Feed Rate, SS = Spindle Speed, MQL = Flowrate

4.4 TOOL WEAR

The cutting tool is subjected to stress at the tool tip and this is how the tool wear is actually classified. The term tool wear can be describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools. There are a lot of types of tool wear and it can be pretty much sums in into two major kinds, which is flank wear and crater wear. Flank wear is the portion of the tool in contact with the finished part erodes, while crater wear is the associated with the eroded rake face due to in contact with the chip resulting in catastrophic failure (Jindal, 2012). Lin and Lin (1996) conducted a research to monitor tool wear in face milling online. The authors stressed that this is important in order to prevent tool breakage and to realize a fully automated system. However, most of the tool wear monitoring techniques developed are for single-point cutting process such as turning. The results are not to be used for the multi-tooth face milling process directly. The authors later on concluded their research by stating that tool wear can also be properly estimated by knowing the average chip thickness, tooth number, and the average normal force coefficients or frictional force coefficient. Wang et al. (2008) also agrees and added that the tool machining is the radical process of friction and wear. Tool wear during cutting not only decreases the service life of cutting tools, but also leads to increased roughness of cutting surfaces of work pieces. An optimal machining process is one where the maximum material removal rate is obtained with the minimal amount of tool wear. This can be attained through the appropriate choice of machining conditions. The wear mechanism map is a good means of selecting suitable machining conditions to the machinist, which can reflect wear rates and wear mechanisms under different operating conditions in one map, and shows the transformation relation of one dominant wear mechanism to another. The result and discussion part for the tool wear is mainly divided into five parts. The first four parts explained about the relationship between tool wear and spindle speed, feed rate, depth of cut and MQL flow rate. The last part is regarding the surface roughness of the work piece.

4.4.2 Design of Experiment

Table 4.7 and 4.8 show the design of experiment for coated carbide 1235 and coated carbide 2235 that used to measure the tool wear.

Table 4.7: Design of experiment of coated carbide 1235.

Depth of Cut, mm	Spindle Speed, rpm	Feed Rate, mm/min	MQL, ml/min	Tool Wear, µm
1	5300	440	0.825	41
2	5400	379	0.9	79.9
2	5400	469	0.6525	44.84
2	5548	379	0.6525	82.64
2	5400	379	0.6525	69.95
3	5300	318	0.825	67.21
3.5	5400	379	0.6525	80.11
1	5500	318	0.825	76.98
3	5500	440	0.48	77.76
3	5300	440	0.825	77.37

Table 4.8: Design of experiment of coated carbide 2235.

Depth of Cut, mm	Spindle Speed, rpm	Feed Rate, mm/min	MQL, ml/min	Tool Wear, µm
1	5300	440	0.825	61.28
2	5400	379	0.9	69.95
2	5400	469	0.6525	62.96
2	5548	379	0.6525	47.83
2	5400	379	0.6525	64.48
3	5300	318	0.825	71.6
3.5	5400	379	0.6525	93.04
1	5500	318	0.825	97.44
3	5500	440	0.48	69.19
3	5300	440	0.825	63.86

4.4.1 Development of Mathematical Modelling

The surface roughness for the CTP 2235 (TiAIN) coated inserts for MQL is represented by y whereas:

$$y = -34948.97167 - 64.11780x_1 + 12.99725x_2 - 1.30283x_3$$
$$- 31.02270x_4 + 15.63745x_1x_1 - 0.00119x_2x_2 + 0.00157x_3x_3 \qquad (4.6)$$
$$+ 45.69285x_4x_4$$

The surface roughness for the CTP 1235 (TiN) coated inserts for MQL is represented by y whereas:

$$y = 218.6262294 + 5.0167402x_1 + 0.0793285x_2$$
$$- 0.0503158x_3 + 22.1167190x_4 - 1.8973x_1x_1 \qquad (4.7)$$
$$+ 3.9917E\text{-}4x_2x_2 - 0.0012x_3x_3 - 34.1023x_4x_4$$

Where; $x_1 = depth\ of\ cut, mm$ $\quad x_2 = spindle\ speed, rpm$

$x_3 = feed\ rate, mm/min$ $\quad x_4 = MQL\ flow\ rate, ml/min$

4.4.3 Analysis of Tool Wear

Figure 4.6 shows the relationship between tool wear and spindle speed. For coated carbide 2235 with MQL, we can see that the tool wear is uniformly increased as the spindle speed increase and towards the end, a minor uniform decreased can be observed. Meanwhile for coated carbide 1135, we can observe it started with the constant decrement and then follows by a uniform increase of tool wear as the spindle increase. The maximum tool wear for CTP 2235 is 63 µm and for CTP 1235 is 41 µm. Figure 4.7 shows the relationship between tool wear and depth of cut. For coated carbide 2235 with MQL, we can see that the tool wear is uniformly decreased as at first and then uniformly increased forming a U-shaped graph. Meanwhile for coated carbide 1235, we can observe it started with the constant decrement and then follows by a uniform increase of tool wear as the depth of cut increase. The maximum tool wear for CTP 2235 is 98 µm and for CTP 1235 is 31.8 µm. Figure 4.8 shows the relationship between tool wear and feed rate. For coated carbide 2235 with MQL, we can see that the tool wear is uniformly decreased as the feed rate increase and then had a minor increased at the end. The maximum tool wear for CTP 2235 is 87.5 µm and for CTP 1235 is 33 µm.

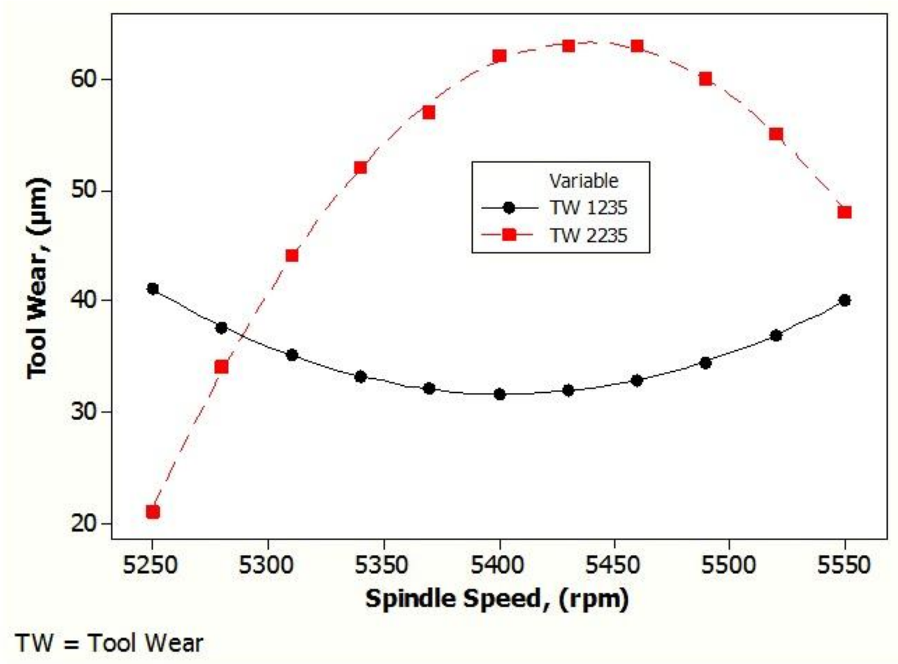


Figure 4.6: Effects of tool wear on coated inserts with different spindle speed

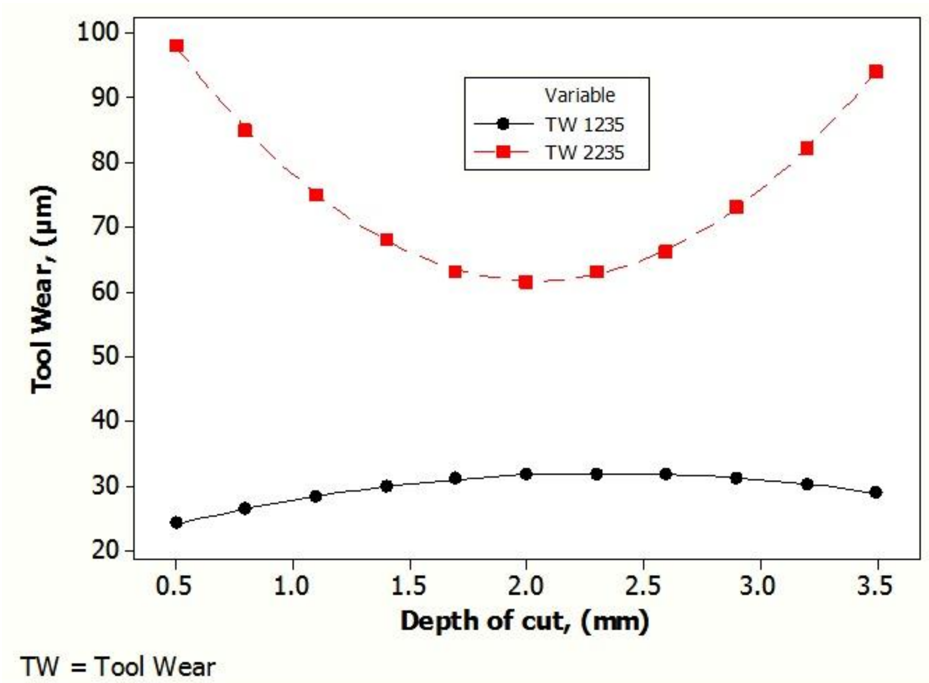


Figure 4.7: Effects of tool wear on coated inserts with different depth of cut

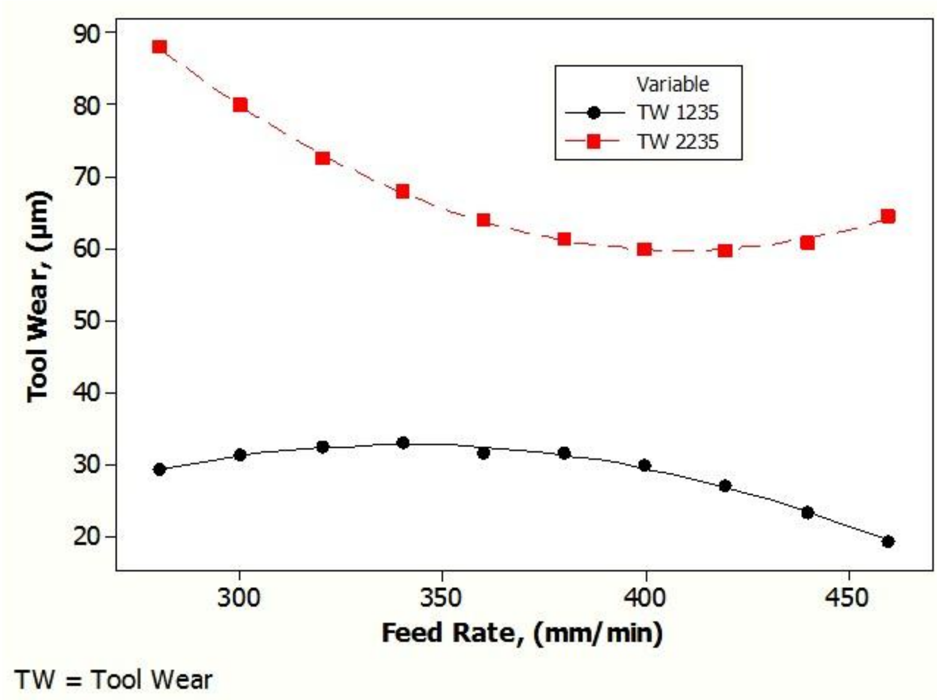


Figure 4.8: Effects of tool wear on coated inserts with different feed rate

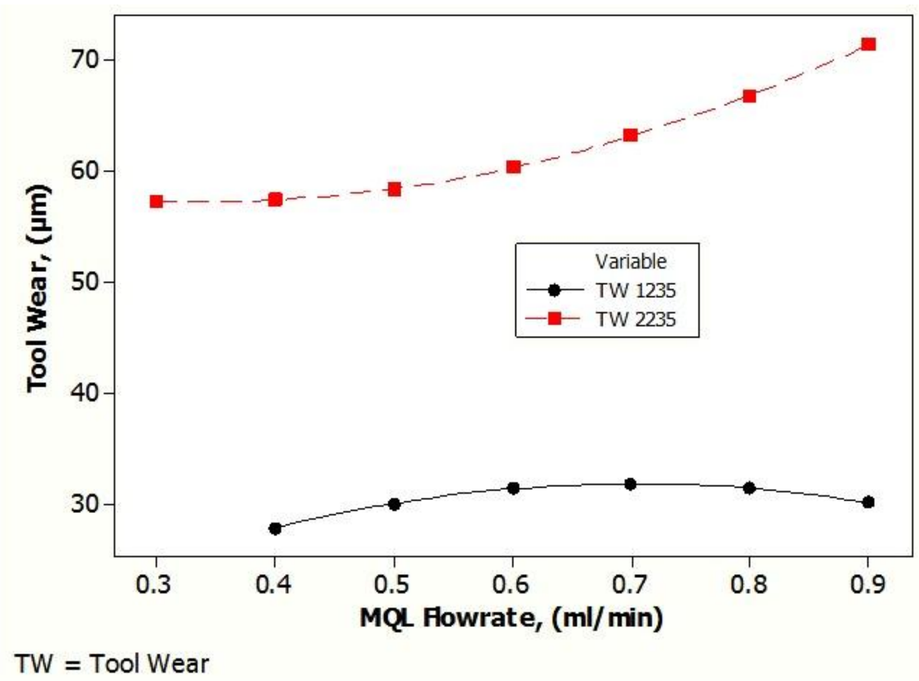
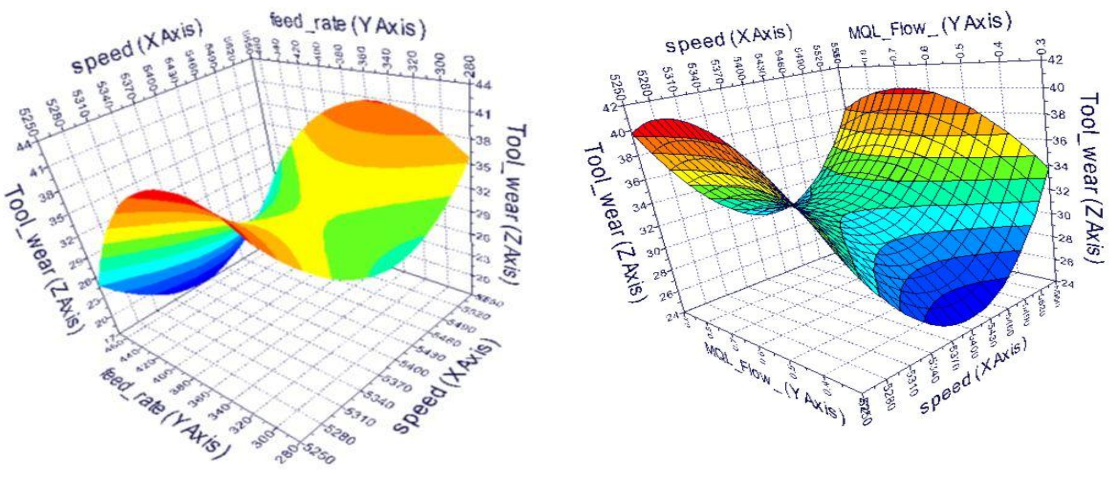


Figure 4.9: Effects of tool wear on coated inserts with different MQL flow rate

Figure 4.9 shows the relationship between tool wear and MQL flow rate. For coated carbide 2235 with MQL, we can see that throughout the graph, the tool wear is uniformly increased as the flow rate increase. Meanwhile for coated carbide 1235, we can observe it started with the constant decrement and then follows by a uniform increase of tool wear as the MQL flow rate increase. The maximum tool wear for CTP 2235 is 71.5 µm and for CTP 1235 is 31.8 µm. Figure 4.10 shows the relationship between tool wear and multiple input parameters such as depth of cut, federate and spindle speed of coated carbide 1235. Based on the first graph, it can be observed that minimum tool wear is achieved when the feed rate value is at the lowest and the spindle speed is at the average of the highest and the lowest value. However, maximum tool wear is observed when the value of feed rate is at the average of highest and lowest. On the other hand for spindle speed, both the lowest and the highest value of spindle speed had clearly contributed to the generation of tool wear. For the second graph, minimum tool wear is achieved when the MQL flowrate value is at the lowest and the spindle speed is at the average of the highest and the lowest value. The maximum tool wear is generated when the value of spindle speed both highest and lowest while the value of MQL flowrate is the average of the highest and the lowest value. These results are acceptable as it did exceed the limit range of 0.3 mm (Kalidass et al., 2012).



(a) (b)

Figure 4.10: The CTP 1235 (TiN); (a) Tool wear versus speed and feedrate, and (b) Tool wear versus speed and MQL flowrate

Table 4.9 shows the maximum tool wear that has been analyze in terms of its individual input parameters which is depth of cut, spindle speed, feed rate and MQL flowrate. It can be observed that overall, coated carbide CTP 1235 showed a better result compared to CTP 2235. The resulting tool wear generated on the cutting tools are significantly less with coated carbide 1235 compared to CTP 2235.

Table 4.9: Summary of maximum tool wear on CTP 1235 and CTP 2235

Tool Wear Vs.	Tool Wear, µm	
	CTP 2235	**CTP 1235**
Spindle Speed	63	41
Depth of Cut	98	31.8
Feed Rate	87.5	33
MQL Flowrate	71.5	31.8

4.5 MATERIAL REMOVAL RATE

MRR is one of the important output parameters that need to be considered in machining. In order to determine the cutting performance in end milling process, the output parameters such as material removal rate, tool wear, tool life and surface roughness need to be measured and compared. Dhar et al. (2005) had studied the effect of MQL on tool wear specializing in high production machining steel. This kind of machining has the tendency to generate high cutting zone temperature due to its nature. Such high temperature causes dimensional deviation and premature failure of cutting tools. However, through a computer interface for programmable speed and feed rate on modern numerical machines, the MRR is capable of being controlled dynamically (Yeh and Lan 2002).

4.5.1 Development of Mathematical Modeling

The material removal rate for the CTP 2235 (TiAIN) coated inserts for MQL is represented by y whereas:

$$y = 703017.7163 + 14530.8632x_1 - 275.9462x_2 + 226.9092x_3 \\ - 40117.4125x_4 - 544.4231x_1x_1 + 0.0268x_2x_2 - 0.0140x_3x_3 \\ - 3463.7573x_4x_4 - 2.2721x_1x_2 + 9.2917x_1x_3 + 1320.3260x_1x_4 \\ - 0.0391x_2x_3 + 7.3735x_2x_4 + 3.0583x_3x_4 \tag{4.8}$$

The material removal rate for the CTP 1235 (TiN) coated inserts for MQL is represented by y whereas:

$$y = 21339.1659 - 3988.4602x_1 - 6.8096x_2 - 33.1204x_3 \\ + 19011.0889x_4 - 379.6171x_1x_1 + 0.00049x_2x_2 - 0.00091x_3x_3 \\ - 3896.7046x_4x_4 + 0.4688x_1x_2 + 17.4436x_1x_3 + 634.9275x_1x_4 \\ + 0.00569x_2x_3 - 2.3043x_2x_4 - 6.41957x_3x_4 \tag{4.9}$$

Where;

x_1 = depth of cut, mm $\quad$ x_2 = spindle speed, rpm

x_3 = feed rate, mm/min $\quad$ x_4 = MQL flow rate, ml/min

4.5.2 Analysis of Material Removal Rate

Figure 4.11 shows the relationship between material removal rate and depth of cut. For coated carbide 2235 with MQL, we can see that throughout the graph, the tool wear is uniformly increased as the flow rate increase. For coated carbide 1235, we can also observe the same pattern of increment. The maximum MRR for CTP 2235 is 14200 mm^3/min and for CTP 1235 is 14000 mm^3/min. Figure 4.12 shows the relationship between material removal rate and depth of cut. For coated carbide 2235 with MQL, we can see that throughout the graph, the tool wear is uniformly increased as the feed rate increase. For coated carbide 1235, we can also observe the same pattern of increment. The maximum MRR for CTP 2235 is 11000 mm^3/min and for CTP 1235 is 11200 mm^3/min. Table 4.10 shows the maximum material removal rate that has been analyzes in terms of its individual input parameters which is depth of cut, spindle speed, feed rate and MQL flowrate. It can be observed that overall, the MRR of coated carbide CTP 1235 is significantly greater compared to coated carbide CTP 2235. Table 4.11 shows the optimization of data. The table indicates that for both coated carbide CTP 2235 and CTP 1235 that the optimize sequence is ninth and tenth experiment.

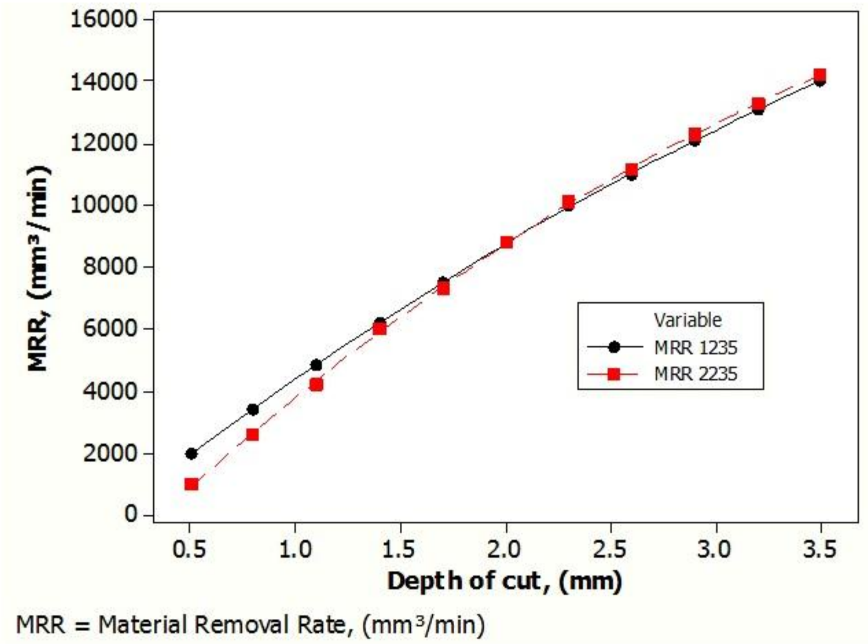


Figure 4.11: Effects of MRR on coated inserts with different depth of cut

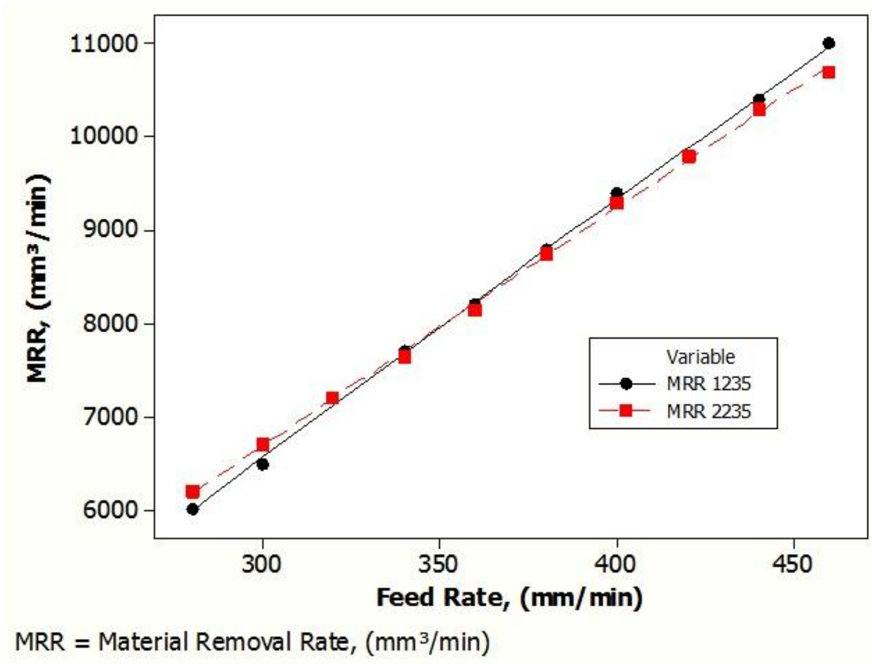


Figure 4.12: Effects of MRR on coated inserts with different feed rate

Table 4.10: Summary of maximum MRR on CTP 1235 and CTP 2235

Tool Wear Vs.	**Material Removal Rate, mm^3/min**	
	CTP 2235	**CTP 1235**
Depth of Cut	11000	11200
Feed Rate	10000	10100

Table 4.11: Optimization of Data

Optimize Data		**Depth of Cut, mm**	**Spindle Speed, rpm**	**Feed Rate mm/min**	**MQL flowrate, ml/min**	**Sequence No. in DOE**
Surface Roughness	CTP 2235	2.0	5548.26	379.0	0.6525	9
	CTP 1235	2.0	5548.26	379.0	0.6525	10
Tool Wear	CTP 2235	2.0	5548.26	379.0	0.6525	9
	CTP 1235	2.0	5548.26	379.0	0.6525	10
MRR	CTP 2235	2.0	5548.26	379.0	0.6525	9
	CTP 1235	2.0	5548.26	379.0	0.6525	10

4.6 SUMMARY

The objective of the project is to experimental investigate the machining characteristics of aluminium alloy in end mill processes for MQL techniques, to investigate different coated carbides cutting tool performance on surface finish by using MQL method and to study the tool wear and the material removal rate regarding the MQL technique. After all the experiments had been done, along with the designs of experiment, the output parameters had been measured and organized. After that, the mathematical models were developed. The equations then were later used in order to generate the graphs necessary for analysis. Data optimizations were made in order to know the optimum cutting parameters. With that a conclusion can be made.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

All the aforementioned objectives of the thesis had been accomplished. Optimum cutting performance requires low tool wear and surface roughness along with high material removal rate. Hence, it can be concluded that the cutting performance of coated carbide CTP 1235 is superior compared to CTP 2235.

i. The machining characteristics such as the spindle speed, depth of cut, feed rate and MQL flowrate in end milling operation were all investigated and the optimum design of experiment had been obtained. The optimum value for spindle speed, depth of cut, feed rate and MQL flowrate were 5548.26 rpm, 2.0 mm, 379.0 mm/min, and 0.6525 ml/min respectively.

ii. The performance of coated carbide cutting tool had been evaluated by its surface finish using MQL method. Experiments with MQL using coated carbide CTP 2235 produced more surface roughness on the workpiece compared to the coated carbide CTP 1235. The value of estimated regression coefficients of R-square for CTP 2235 and CTP 1235 were both 95.12% and 97.68%.

iii. The response parameters such as tool wear and material removal rate with MQL technique had also been analysed. Experiments with MQL using coated carbide CTP 2235 generated more tool wear compared to the coated carbide CTP 1235. The resulting tool wear generated on the cutting tools of CTP 2235 is 39.86% greater than CTP 1235. Material removal rate for experiments using coated carbide CTP 1235 is higher compared to CTP 2235. The maximum MRR for CTP 2235 is 14200 mm^3/min and for CTP 1235 is 14000 mm^3/min.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

This study presents a wider scope in making the model more reliable and useful and to display an improved understanding of the end milling processes. Several fields of research are described in this section.

i. Research on the cutting temperature must be emphasized upon since it is one of the main factors of tool failure.
ii. The minimum quantity lubricant and nano-fluids coolant should be use more widely in conventional machining.
iii. The experiment must be carried out in higher feed rate, depth of cut and cutting speed so that greater variety of results can be obtained.

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